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DOT-VNTSC-FAA-95-4

Final Report
April 1995

A cooperative effort between the U.S. Department of Transportation, Federal Aviation Administration, and the international and domestic aviation community in the interest of safety

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**Federal Aviation
Administration**

Memorandum

Subject: The Wake Turbulence Training Aid Report

Date: March 15, 1995

From: David Hinson

David Hinson

Reply to
Attn of:

To: Distribution

It is a pleasure to recommend this "Wake Turbulence Training Aid" for use throughout the aviation industry. This training tool is the culmination of an aggressive, painstaking effort on the part of an industry/government working group representing a broad spectrum of the aviation community.

Throughout 1994 the group has gathered information from many sources regarding wake turbulence. This group has advocated, based on their discussions and reviews of the material, a training aid aimed at both pilots and air traffic controllers. The consensus of this industry working group is that the widespread use of the material developed will enhance flight safety.

I urge the pilots and air traffic controllers to adopt this material for use in qualification and recurring training programs. I am convinced that adopting these materials will make genuine improvements in avoiding wake turbulence accidents and incidents.

My thanks to the members of the wake Turbulence working group. By working together industry and government can best promote safety and efficiency for all users while protecting the flying public.

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13. ABSTRACT *(Maximum 200 words)*

Wake-turbulence accidents and incidents have been, and continue to be, a significant contributor to worldwide safety statistics. The National Transportation Safety Board (NTSB), in a report on safety issues related to wake-vortex encounters, stated that between 1983 and 1993 there were at least 51 accidents and incidents in the United States that resulted from probable encounters with wake vortices.

The goal of the Wake Turbulence Training Aid is to reduce the number of wake-turbulence related accidents and incidents 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. The major three objectives of the Wake Turbulence Training Aid are: (1) to educate pilots and air traffic controllers on wake turbulence and avoidance of the phenomenon; (2) to increase the wake-turbulence situational awareness of pilots and air traffic controllers; and (3) to provide usable information to develop a ground training program.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 3.0 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)]°F = y°C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeters (mm) = 0.04 inch (in)
1 centimeters (cm) = 0.4 inch (in)
1 meter (m) = 2.2 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectares (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliters (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.06 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5)(y + 32)]°C = x°F

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INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

25, 40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C1310286.

Wake Turbulence Training Aid

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SECTION 1

1

Wake Turbulence Overview for Training Aid Users

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Wake Turbulence - Overview for Training Aid Users

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Wake Turbulence - Overview for Training Aid Users

1

1.0 Introduction

Airframe manufacturers, aircraft associations, airlines, pilot groups, air traffic controllers, government and regulatory agencies, and other organizations and individuals have developed this training resource dedicated to reducing the number of wake-turbulence accidents and incidents. The training package consists primarily of this document. A condensed version of this aid can be found in Section 3, Appendix 3-A, Pilot and Air Traffic Controller Guide - Pullout Section. Additionally, a companion video developed by the Wake Turbulence Training Aid Industry Team is also available.

Wake-turbulence accidents and incidents have been, and continue to be, a significant contributor to the worldwide safety statistics. The National Transportation Safety Board (NTSB), in a report on safety issues related to wake-vortex encounters, stated that data shows that between 1983 and 1993, there were at least 51 accidents and incidents in the United States that resulted from probable encounters with wake vortices. As a result of these encounters, 27 occupants were killed, 8 were seriously injured, and 40 aircraft were substantially damaged or destroyed. In this report, the NTSB raised concern over "the adequacy of air traffic control procedures" and "pilot knowledge related to the avoidance of wake vortices."

Key points raised by the NTSB recommendations and findings can be summarized as follows:

1) Current air traffic control procedures and pilot reactions can result in aircraft following too closely behind larger aircraft while on a visual approach to landing.

2) Pilots of arriving visual flight rules (VFR) aircraft and instrument flight rules (IFR) aircraft cleared for visual approach often do not have sufficient information to maintain adequate separation distances or to determine relative flightpaths.

3) Pilots are not provided adequate training related to the movement and avoidance of wake vortices or for determining relative flightpaths and separation distances.

4) Annual refresher training is needed for air traffic controllers regarding wake-turbulence separation and advisory criteria.

The Wake Turbulence Training Aid Industry Team unanimously concluded that the enhancement of pilot and air traffic controller awareness and knowledge via training offers the highest probability of significantly improving the wake turbulence safety record.

This training aid is intended to be a comprehensive training package which users can use in their training programs. It is structured in a manner which should allow either stand-alone use, incorporation into existing programs, or customizing by users to meet unique requirements. Whether users choose to adopt the Wake Turbulence Training Aid as the foundation of their training program or extract portions of the material into their existing training program, a significant and measurable benefit is expected.

It is anticipated that the cost of implementing this enhanced training will be minimal. A user who is already doing a credible job of training will find the implementation of this training aid to be principally a change in emphasis, not a replacement of existing training. In the final analysis, the individual pilot and air traffic controller actions are the last chance to prevent a wake-turbulence accident or incident. They must be aware and prepared to take those actions.

1.1 General Goal and Objectives

The goal of the Wake Turbulence Training Aid is to reduce the number of wake-turbulence related accidents and incidents 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.

The objectives of the Wake Turbulence Training Aid are to summarize and communicate key wake-turbulence related information to all pilots and air traffic controllers.

The Wake Turbulence Training Aid can be summarized by the following three objectives:

- Educate pilots and air traffic controllers on wake turbulence and avoidance of the phenomena.
- Increase the wake-turbulence situational awareness of pilots and air traffic controllers.
- Provide usable information to develop a ground training program.

1.2 Documentation Overview

In addition to this section, the package consists of the following:

Section 2	Pilot and Air Traffic Controller Guide to Wake Turbulence
Section 3	Example Pilot and Air Traffic Controller Wake Turbulence Training Program
Section 4	Wake Turbulence Training Aid - Background Data
Video	*Wake Turbulence Avoidance - A Pilot and Air Traffic Controller Briefing*

Section 2 - Pilot and Air Traffic Controller Guide to Wake Turbulence, is a comprehensive look at wake-turbulence history, accidents, characteristics, guidelines, responsibilities, and recommended procedures and techniques. The guide is a highly readable, concise treatment of pilot and air traffic controller issues, written by and for pilots and controllers. It is intended for self study or classroom use.

Section 3 - Example Pilot and Air Traffic Controller Wake Turbulence Training Program is a stand-alone resource designed to serve the needs of the individual pilot and air traffic controller or a training department. Appendix 3-A contains a Pilot and Air Traffic Controller Guide - Pullout Section which is a short and concise review of the information found in Section 2. Additionally, this section contains Appendix 3-B, Wake Turbulence Training Aid Examination containing a student examination, an instructor examination guide, and a summary of answers; Appendix 3-C is the Wake Turbulence Safety Briefing; Appendix 3-D is the Wake Turbulence Safety Training Aid - Video Script: *Wake Turbulence Avoidance—A Pilot and Air Traffic Controller Briefing* that supports the VHS video described below.

Section 4 - Wake Turbulence Training Aid - Background Data provides additional background data for instructors and training designers or interested readers regarding wake turbulence; Section 4 includes Appendices 4-A through 4-F. Appendix 4-A is the NTSB Report of Wake Turbulence, with appendices; Appendix 4-B is a 1991 Report of Where We Are Today in Wake Turbulence; Appendix 4-C is the Wake Turbulence Training Aid Guidelines and Issues offered and addressed by the Wake Turbulence Training Aid Industry Team; Appendix 4-D is the FAA Integrated Wake Vortex Program Plan; Appendix 4-E is a bibliography; and Appendix 4-F presents Wake Turbulence Take-Off Gross Weight Categories and IFR Separation Distances.

<u>VHS Video</u> - *Wake Turbulence Avoidance—A Pilot and Air Traffic Controller Briefing* is a stand-alone video for use in an academic program in conjunction with Section 2, the Pilot and Air Traffic Controller Guide to Wake Turbulence. Although the video is specifically designed to be used in a briefing scenario, it can also be used to heighten the awareness of all people who are involved in areas which are impacted by wake turbulence.

1.3 Resource Utilization

This document has been designed to be of maximum utility both in its current form and as a basis for pilots or air traffic controllers to modify current programs.

This academic training material should be employed as needed to achieve balanced and effective training. The training aid material specifically addresses the need for a shared understanding of how all parties involved in this issue need to work together to prevent wake-turbulence accidents and incidents. For some users, the adoption of the Wake Turbulence Training Aid will require little more than a shift in emphasis. For others, this training aid will readily provide the foundation for a thorough and efficient program.

The allocation of training time will vary from user to user. The pullout section (Appendix 3-A) provides an easy to read condensed version of this training material for the individual user. It consists of 30 pages. The entire document provides an extensive resource of information, question material, and review items for training managers and instructors to design training to the depth required. The 25-minute video provides a stand-alone overview of the material.

1.4 Summary

This document and the video are intended to assist air traffic controllers and pilots in developing an understanding and awareness of wake turbulence. Increased awareness and education will reduce wake-turbulence accidents and incidents. Training programs for pilots and air traffic controllers should include wake-turbulence training.

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SECTION 2

2

Pilot and Air Traffic Controller Guide to Wake Turbulence

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Pilot and Air Traffic Controller Guide to Wake Turbulence

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Pilot and Air Traffic Controller Guide to Wake Turbulence

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 recommended 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 Aviation 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.

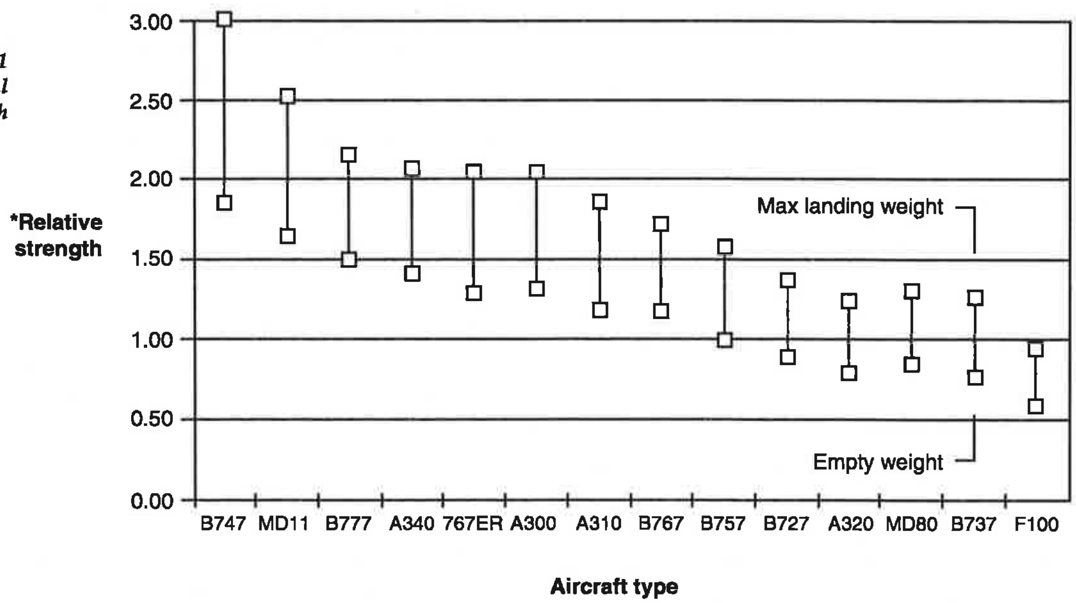
- The strength of the wake turbulence is governed by the weight, speed and wingspan of the generating aircraft.

- 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 "burble," 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 Gulfsteam 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 separation 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 requirement, 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.

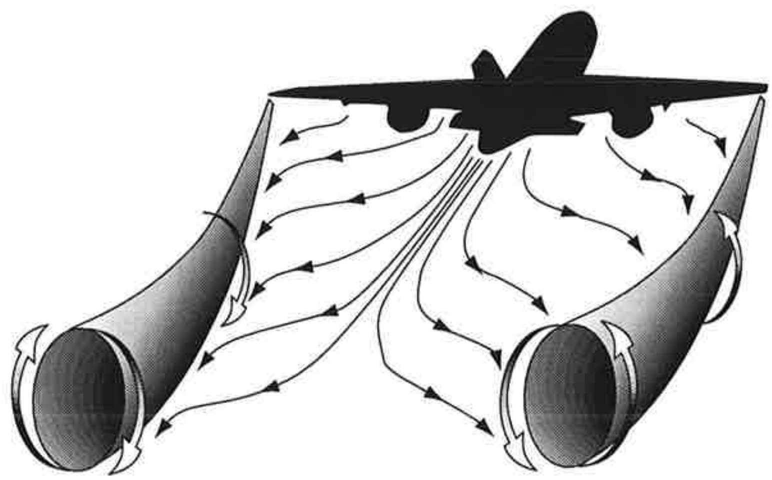
These cases are extreme wake-turbulence encounters. In all cases, it was possible to avoid the encounters if the pilots and air traffic controllers had sufficient knowledge of wake turbulence and applied proper avoidance procedures and techniques. Hopefully, this training aid will help prevent similar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

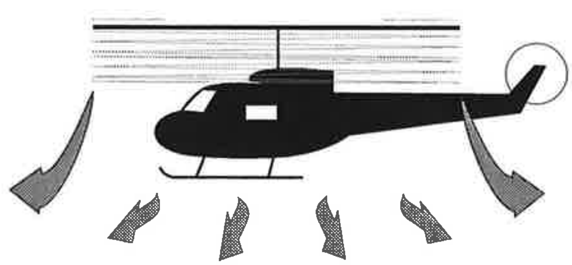
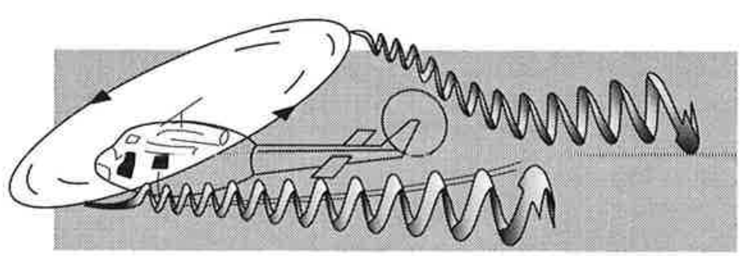


Figure 2.4-1B Formation of helicopter wake turbulence (forward flight)



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.

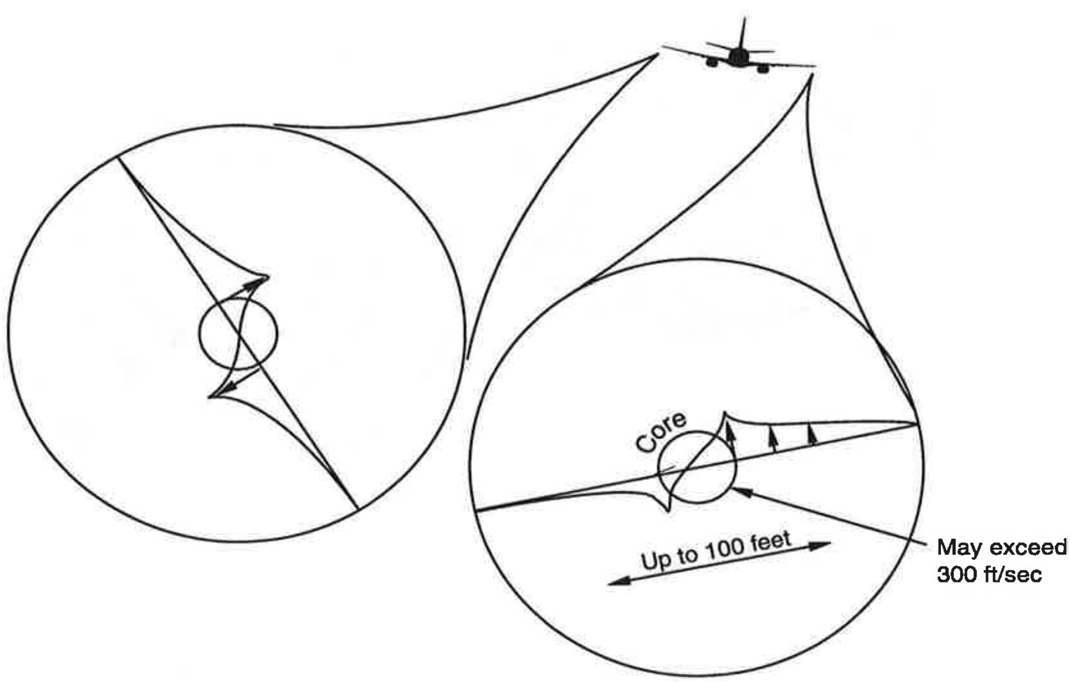


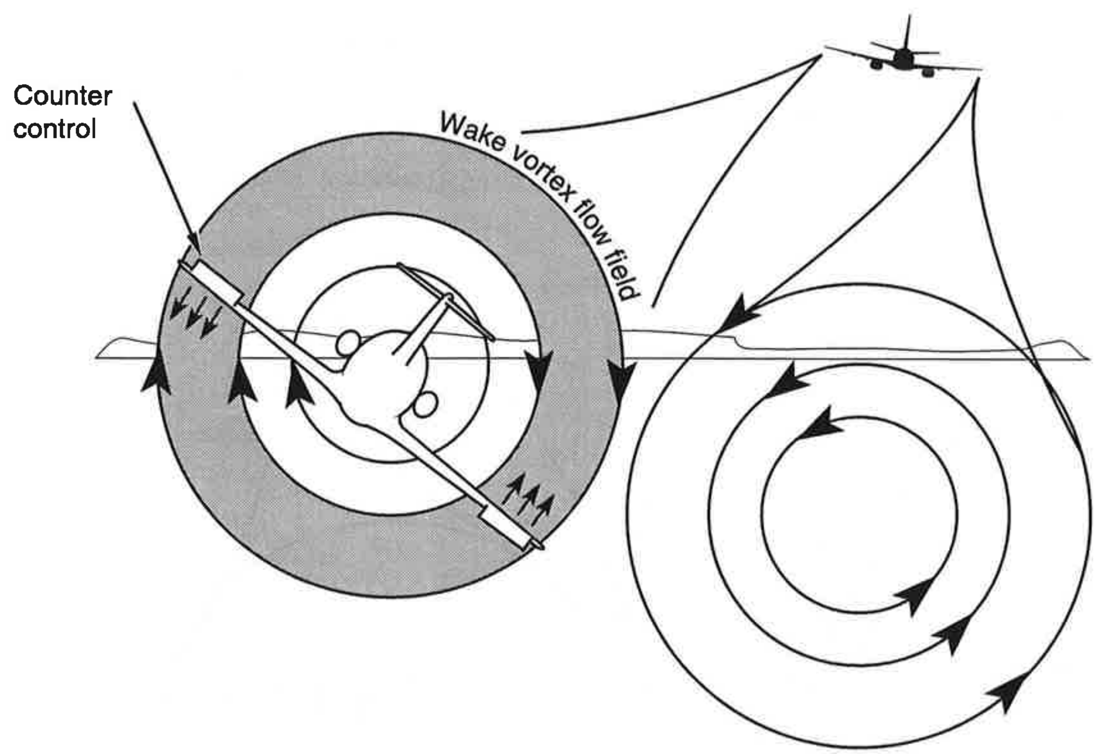
Figure 2.4-2
Velocity profile

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).

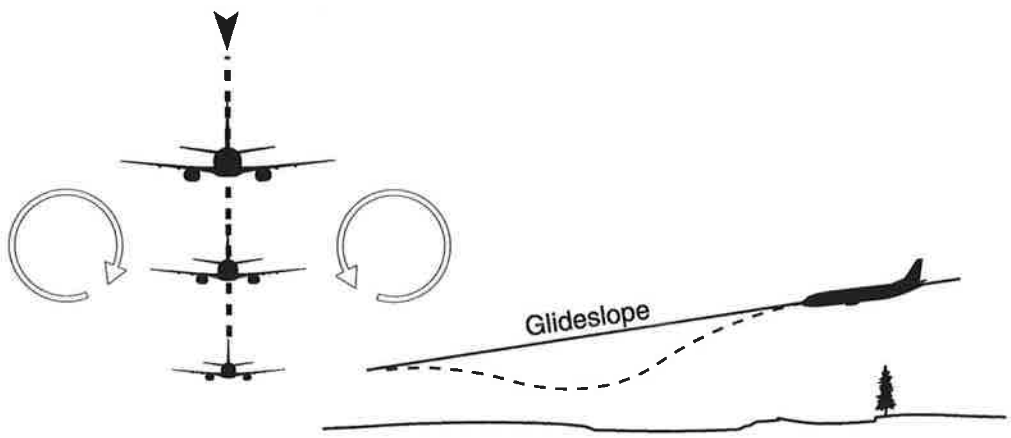


Figure 2.4-4
Aircraft reaction to wake-turbulence encounter, approach from above-center (rear view depiction)

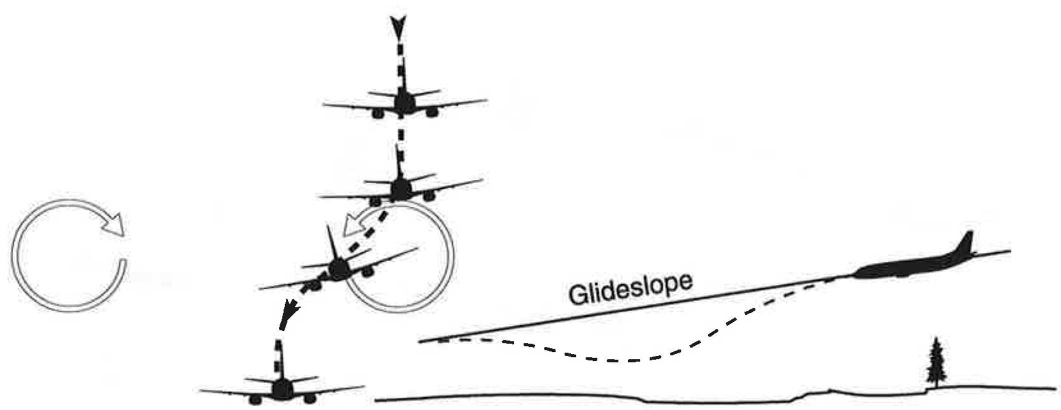


Figure 2.4-5
Aircraft reaction to wake-turbulence encounter, approach from above-right (rear view depiction)

Source for Figures 2.4-4 through 2.4-9: Goldburg, Arnold, John Olsen, and Milton Rogers, ed. Aircraft Wake Turbulence and Its Detection. Proceedings of a Symposium on Aircraft Wake Turbulence held in Seattle, September 1-3, 1970. New York: Plenum Press, 1971, pp. 473-508.

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)

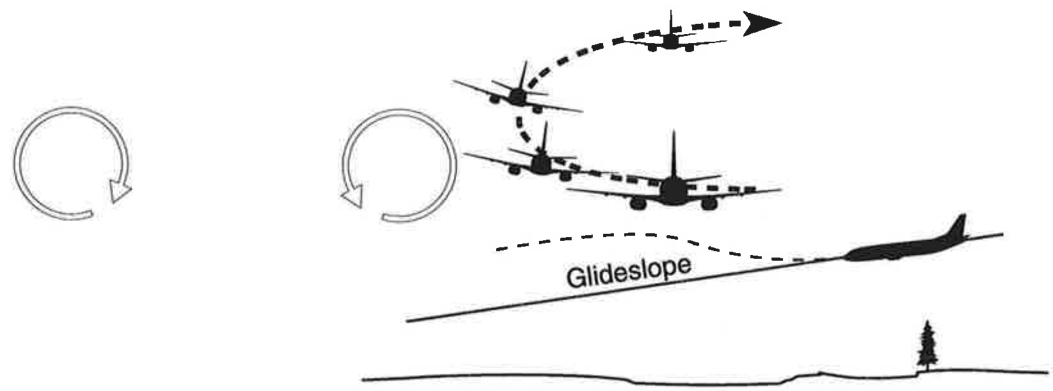
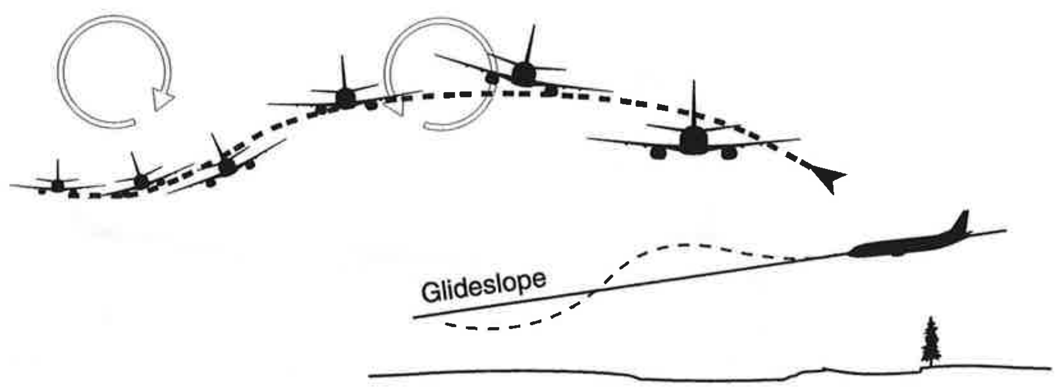


Figure 2.4-7
Aircraft reaction to wake turbulence encounter, rapid approach from the side (rear view depiction)



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).

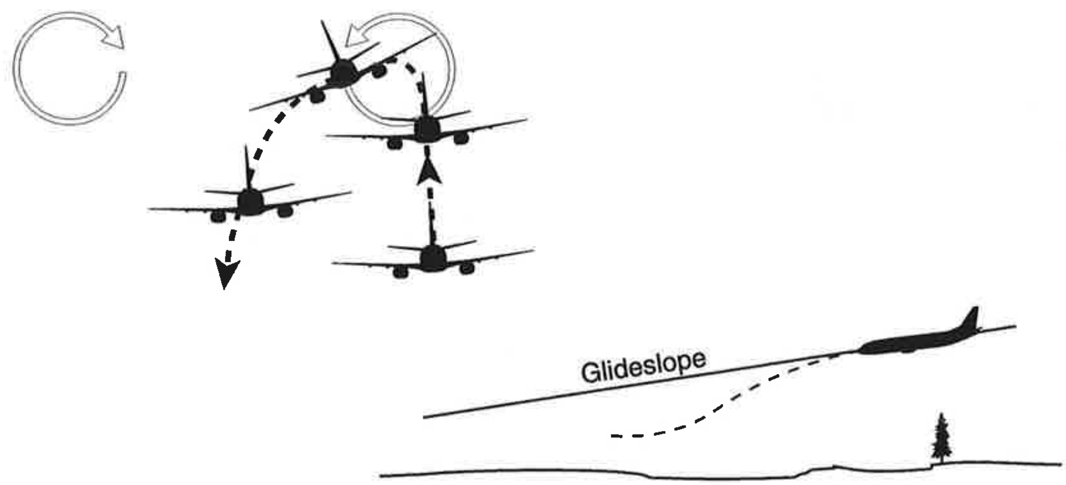


Figure 2.4-8
Aircraft reaction to wake-turbulence encounter, approach frome below right (rear view depiction)

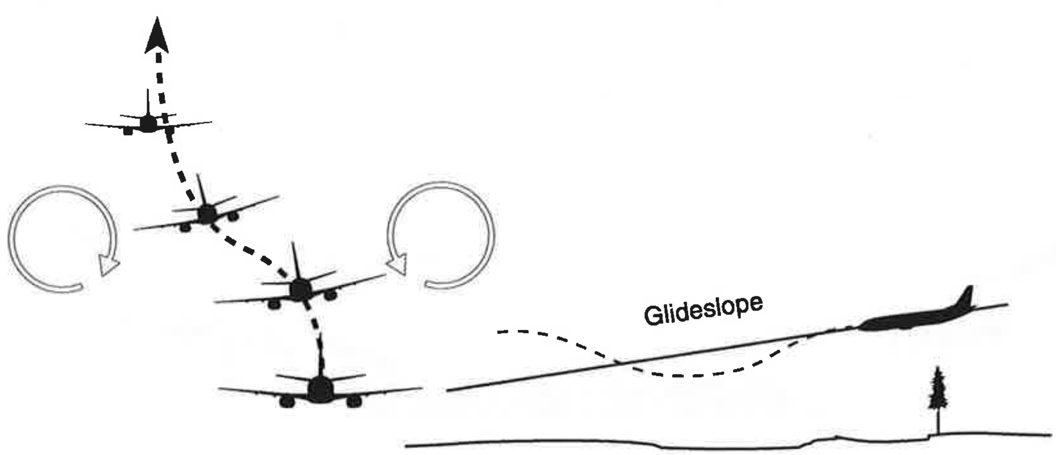
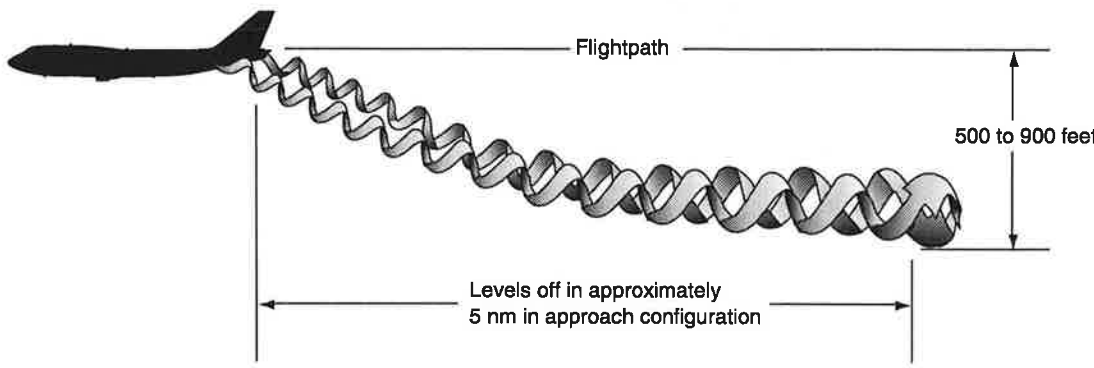


Figure 2.4-9
Aircraft reaction to wake-turbulence encounter, rapid approach from below (rear view depiction)

2.4.4 Vertical Motion of the Wake

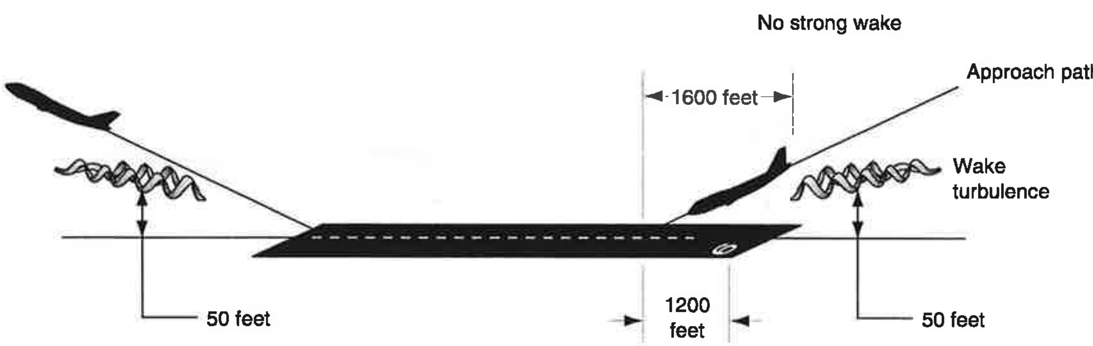
The wake of an aircraft has behavioral characteristics which can help the pilot visualize the wake location and thereby take avoidance precautions. The initial descent rate of the wake is adequately described by classical theory; the descent rate is determined by the weight, flight speed and wingspan 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. Below 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

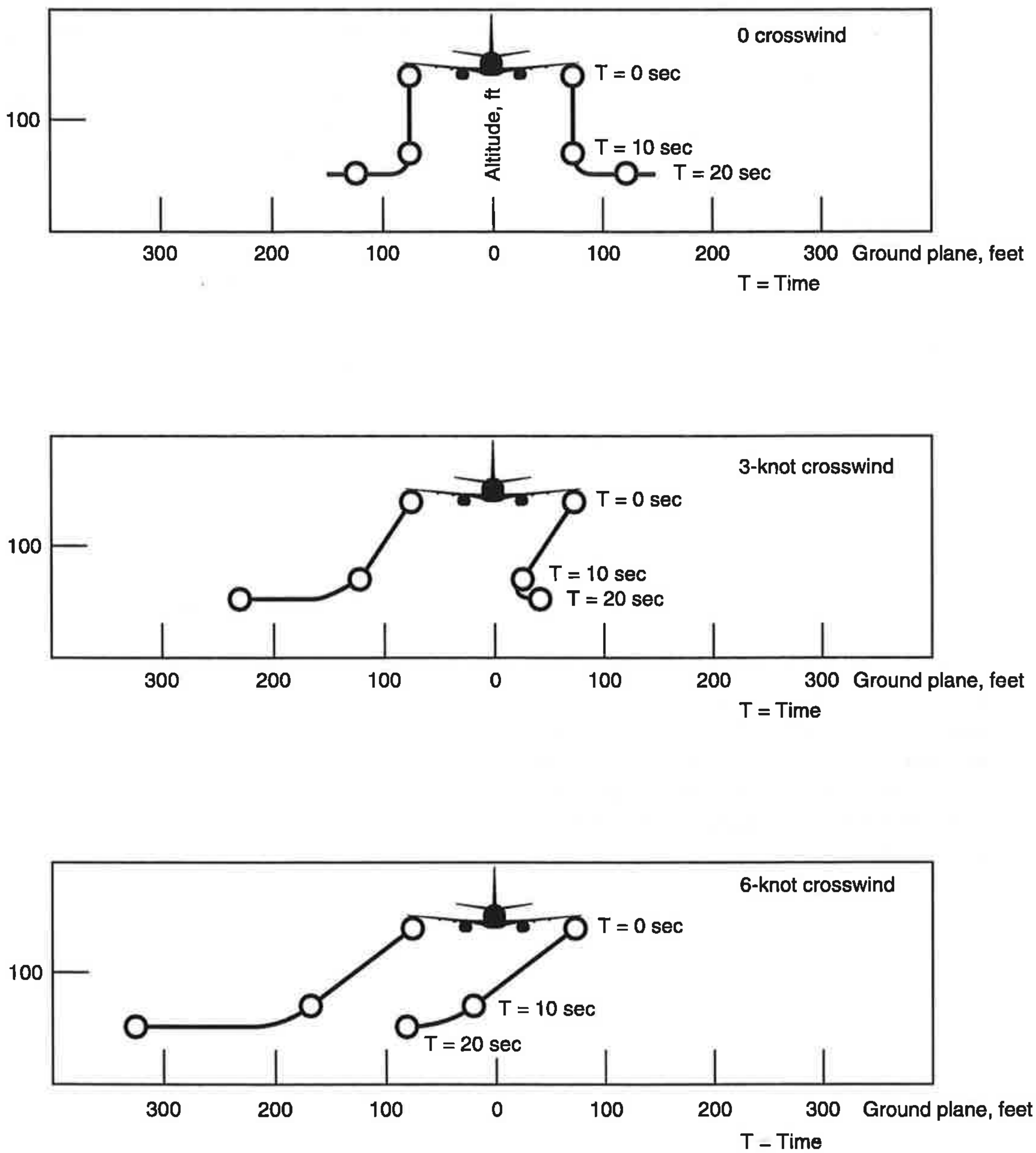


2.4.5 Horizontal Motion of the Wake

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. A light quartering tailwind requires maximum caution. However, a pilot does not have the tools to determine that a perfectly zero crosswind condition exists. 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.

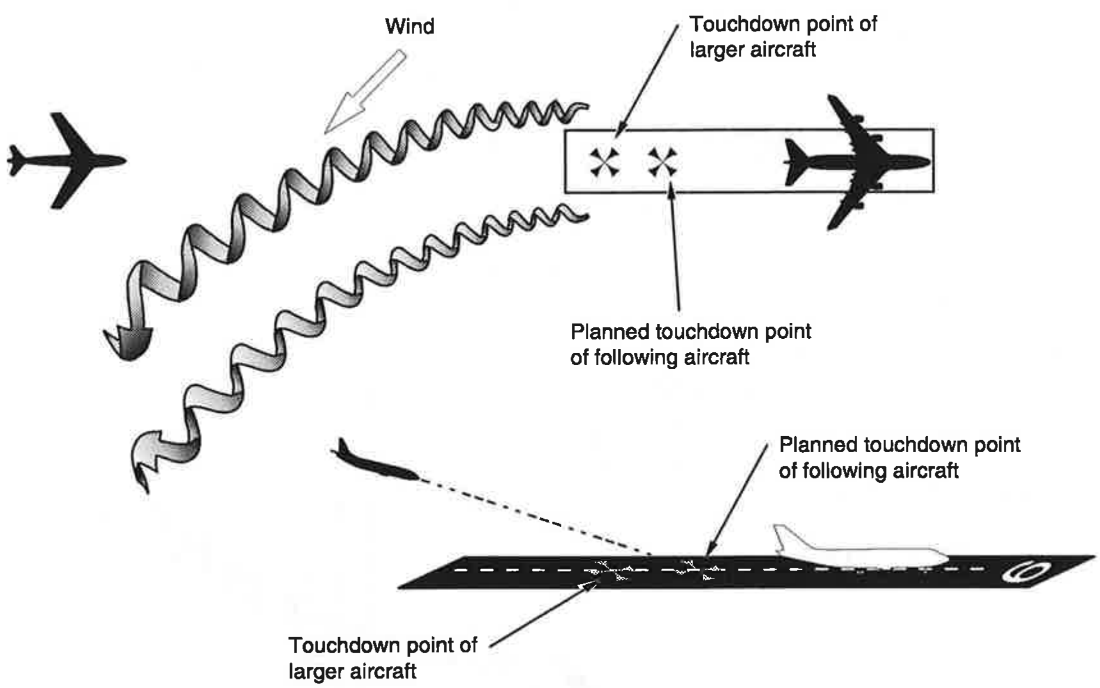


Figure 2.8-1 Landing behind a larger aircraft - same runway

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.

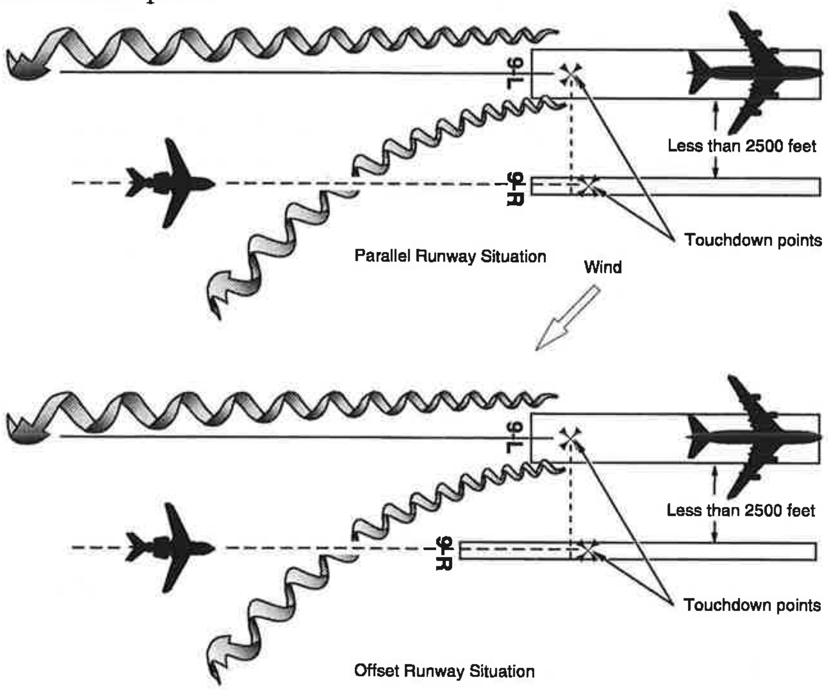


Figure 2.8-2 Landing behind a larger aircraft - parallel runway closer than 2500 feet

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.

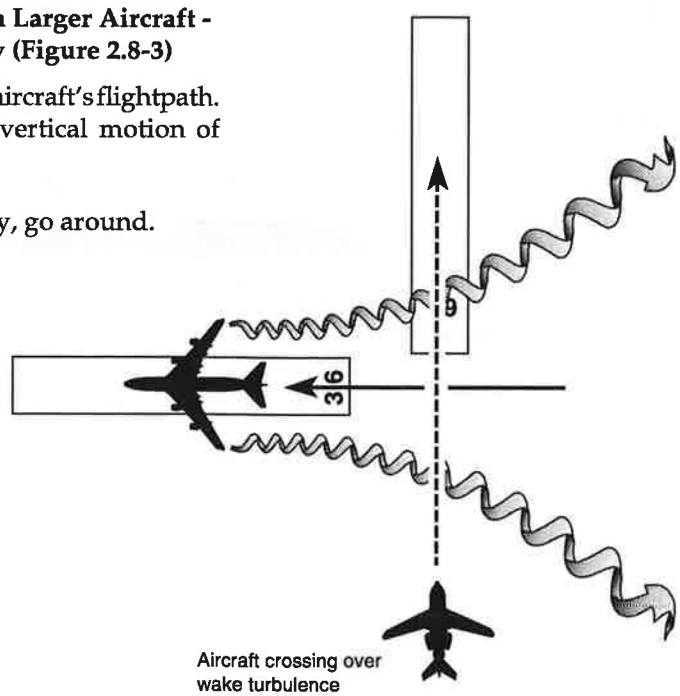


Figure 2.8-3 Landing behind a departing larger aircraft - crossing runway

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.

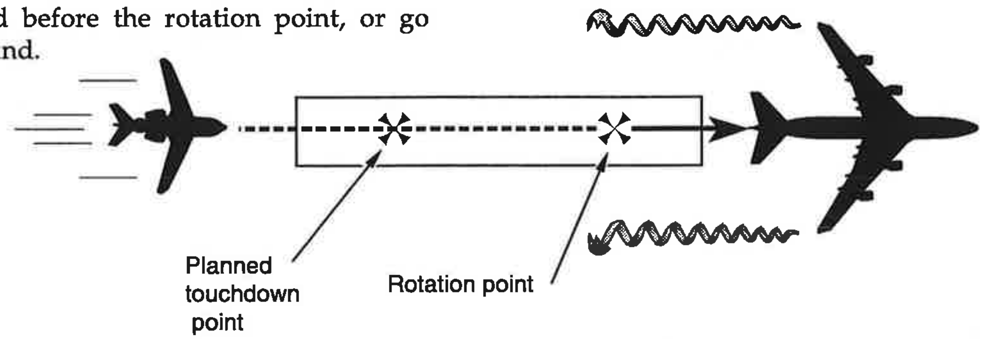


Figure 2.8-4
Landing behind a departing larger aircraft - same runway

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.

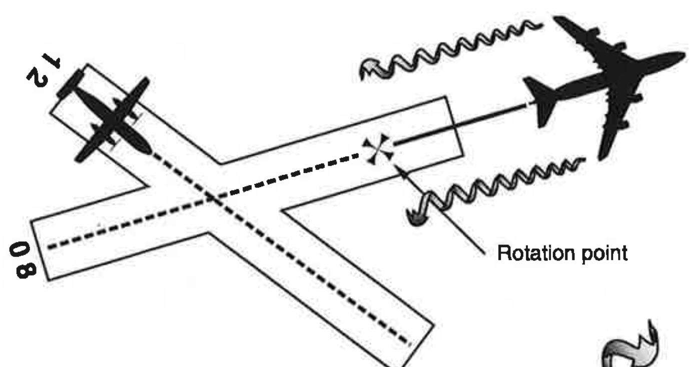


Figure 2.8-5
Landing behind a departing larger aircraft - crossing runway

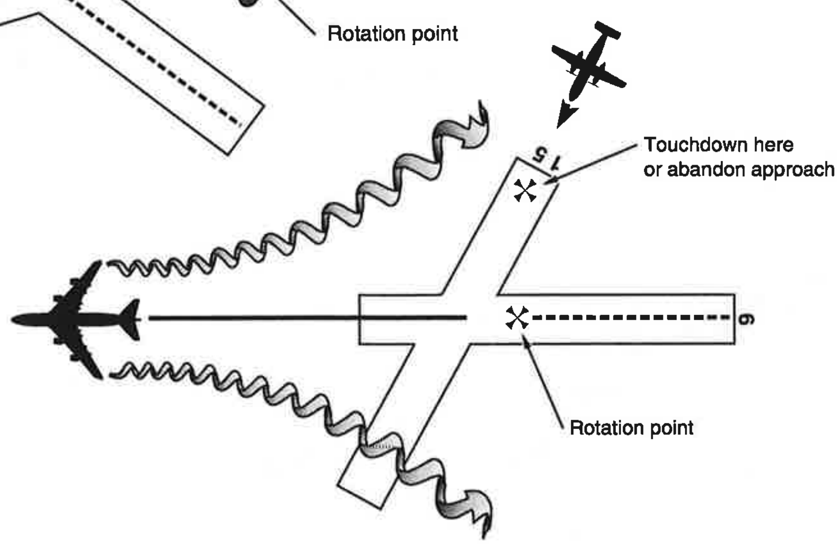


Figure 2.8-6
Landing behind a departing larger aircraft - crossing runway

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

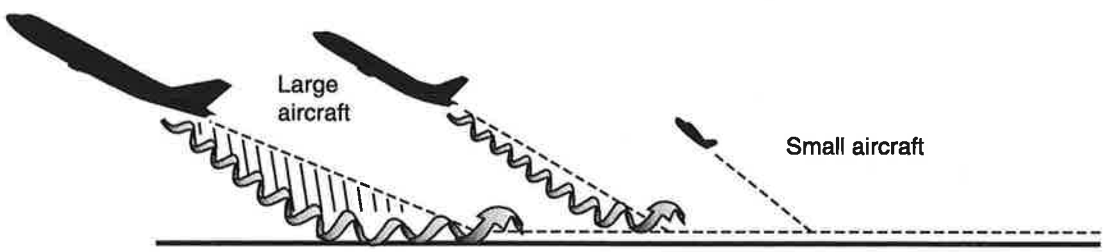


Figure 2.8-8
Departing behind a larger aircraft - crossing departure courses

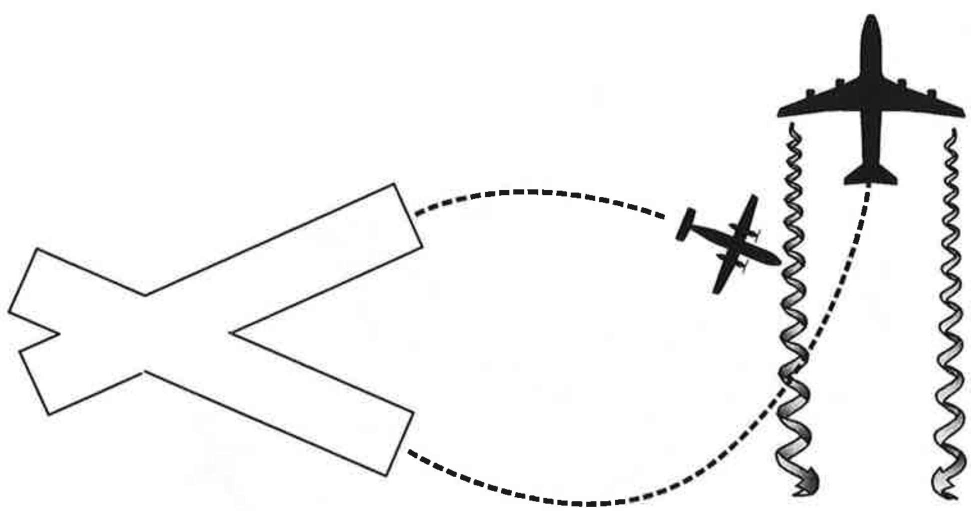
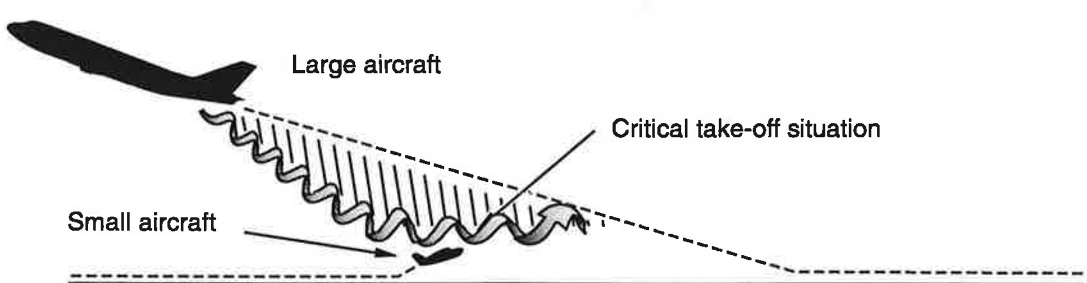


Figure 2.8-9
Departing behind a larger aircraft - opposite direction



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.

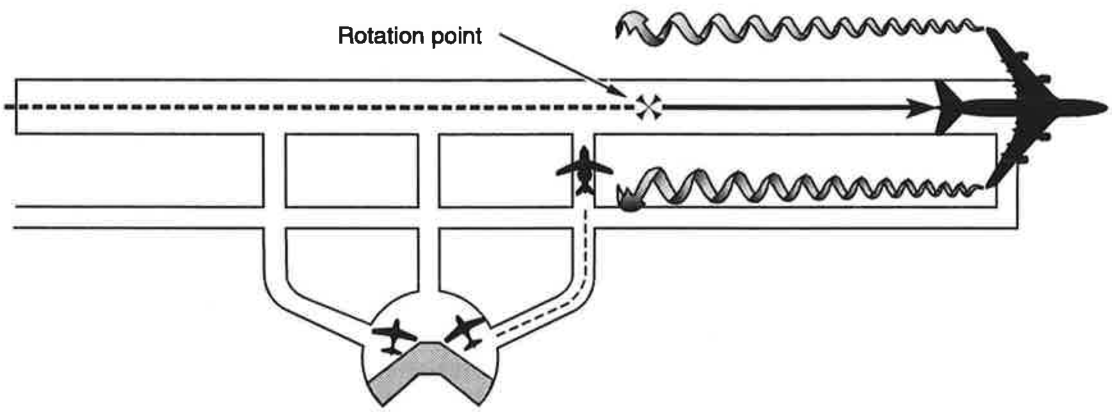


Figure 2.8-10
Intersection takeoffs - same runway

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.

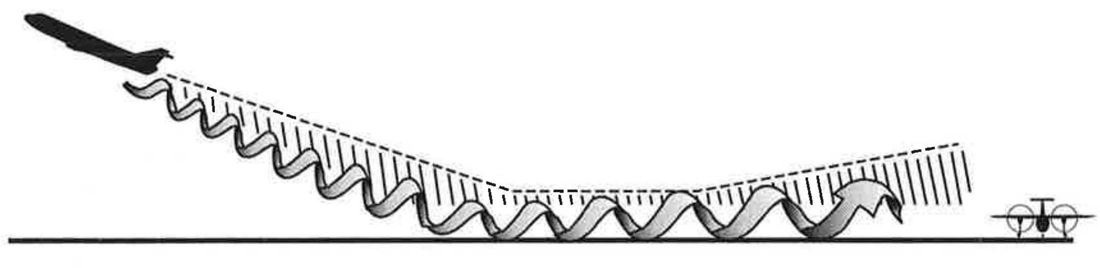


Figure 2.8-11 Departing or landing after a heavy aircraft executing a low approach, missed approach or touch-and-go landing

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.

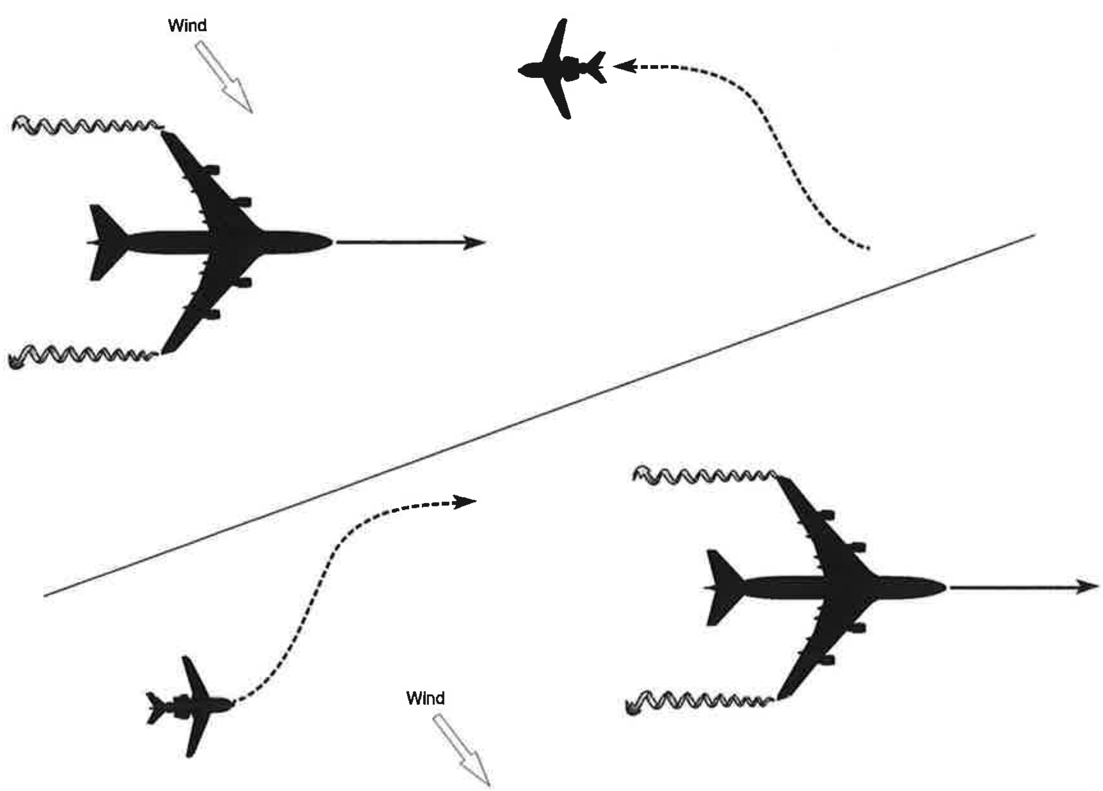


Figure 2.8-12 En route VFR (1000 foot altitude plus 500 feet)

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.

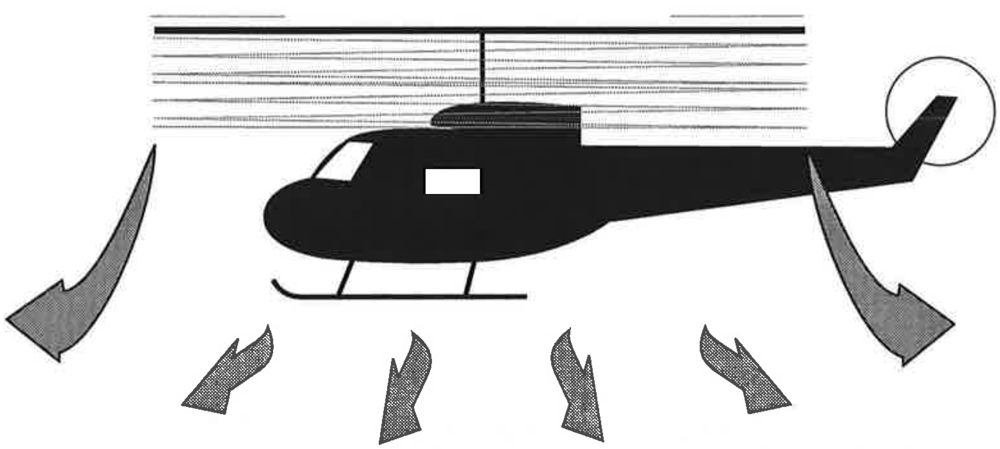


Figure 2.8-13 Helicopter hover-produced downwash

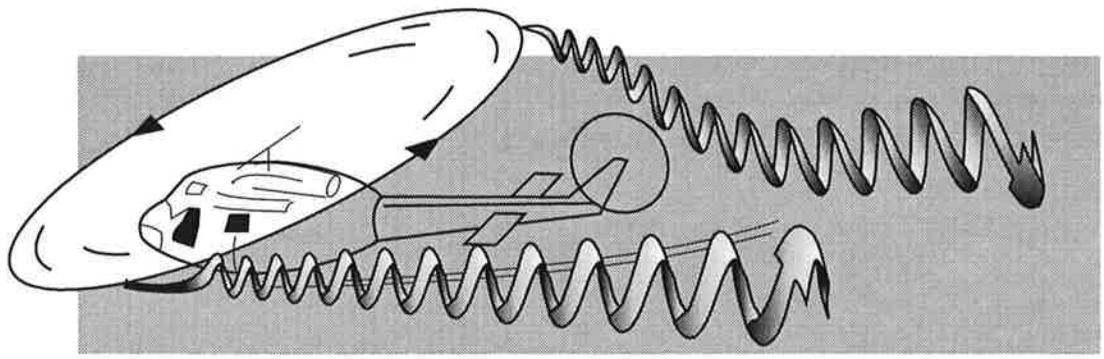


Figure 2.8-14 Helicopter forward-flight-produced wake turbulence

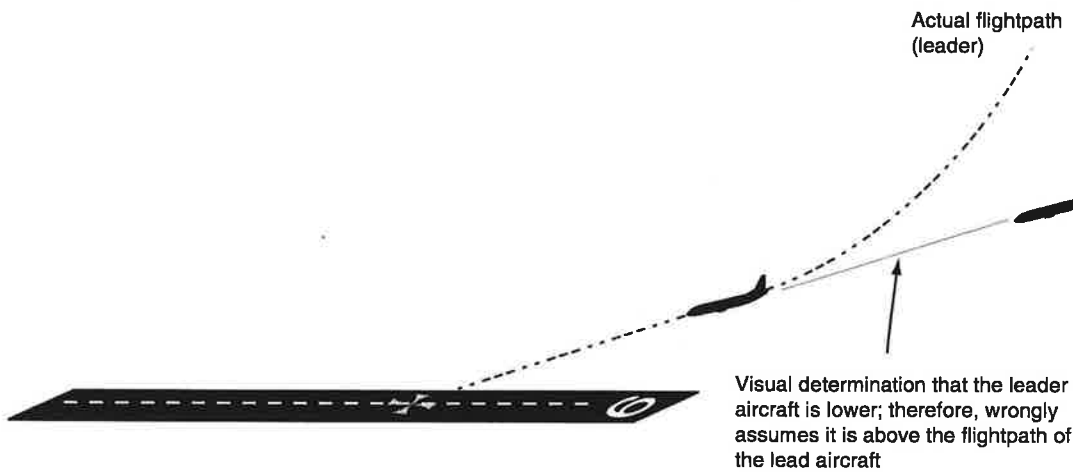
2.9 Pilot Difficulty in Visually Maintaining Separation

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.

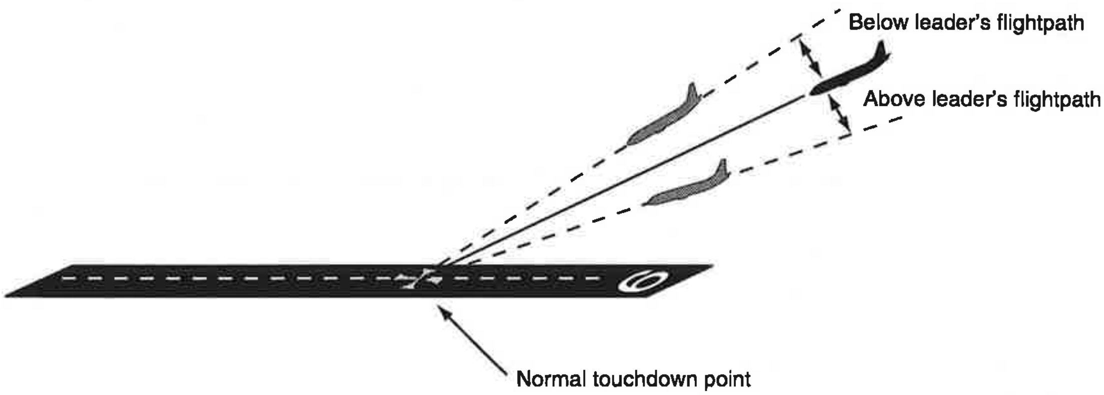
For pilots to be able to avoid wake turbulence by staying on or above the flightpath of the leader aircraft, trailing pilots must make some assumptions on where the leader has flown since there is no available visual reference. The use of visual glideslope indicators such as VASI or PAPI or instrument 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. <u>Air traffic controllers and pilots must understand that accomplishing a steep descent may have serious ramifications for trailing aircraft with regard to wake turbulence.</u>

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

2.10.2 Visual Cues for Estimating Leader's Flightpath

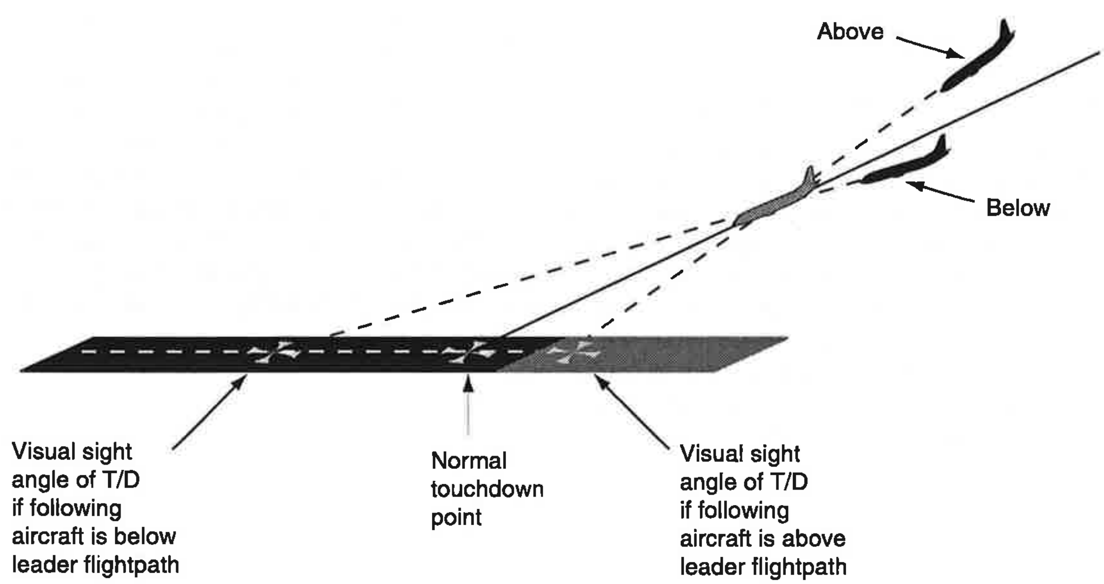
One way to determine the flightpath that the leader has flown is to extend an imaginary line from your position to the runway normal touchdown point (Figure 2.10-1A). If the leader aircraft is above this line, you are below its flightpath. Conversely, if the leader aircraft is on or below the imaginary 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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SECTION 3

3

Example Pilot and Air Traffic Controller Wake Turbulence Training Program

WAKE TURBULENCE

TRAINING AID

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Example Pilot and Air Traffic Controller Wake Turbulence Training Program

3

Table of Contents

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Example Pilot and Air Traffic Controller Wake Turbulence Training Program

3

3.0 Introduction

The Example Pilot and Air Traffic Controller Wake Turbulence Training Program is one part of the Wake Turbulence Training Aid. The other parts include Section 1, Wake Turbulence – Overview for Training Aid Users; Section 2, Pilot and Air Traffic Controller Guide to Wake Turbulence; and Section 4, Wake Turbulence Training Aid – Background Data, and a video.

3.0.1 The Goal of the Example Wake Turbulence Training Program

The overall goal of the Wake Turbulence Training Aid is to reduce the number of wake turbulence related accidents and incidents 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. The example training program's aim is to illustrate the type of training that should be conducted to meet the goal of the Wake Turbulence Training Aid.

3.0.2 Overview of the Example Training Program

Although structured to stand alone, the Example Pilot and Air Traffic Controller Wake Turbulence Training Program can be integrated with existing training and checking programs. This is a ground training program that describes and suggests a method for applying the academic training portions of the Wake Turbulence Training Aid. It suggests a comprehensive review of the subject by use of a pullout guide, Appendix 3-A, to supplement the knowledge learned from Section 2 of this Aid. Additionally, it contains an examination on wake turbulence information, a briefing guide for instructors, and an example briefing aimed at a classroom environment. Finally, it contains information regarding the video portion of the example training program.

3.1 Ground Training Program

The Ground Training Program focuses on improving knowledge and increasing awareness of wake turbulence.

3.1.1 Ground Training Objectives

The objectives of the Ground Training Program are to:

- 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); and
- provide usable information to develop an effective ground training program.

A suggested syllabus is provided in Section 3.1.3 with the knowledge that no single training format or curriculum is best for all users or training situations. The training materials have been designed to "stand alone." As a result, some redundancy of the subject material occurs. However, using these materials together in the suggested sequence will enhance overall training effectiveness.

3.1.2 Ground Training Modules

The following ground training modules are available to prepare an academic curriculum:

The Pilot and Air Traffic Controller Guide to Wake Turbulence (Section 2) is a comprehensive treatment of the wake turbulence information and guidance. The Guide is designed as a document that may be reviewed by an individual pilot or controller at any time prior to formal training.

The Pilot and Air Traffic Controller Guide – Pullout Section, Appendix 3-A, is intended to be a condensed version of the Pilot and Air Traffic Controller Guide to Wake Turbulence, Section 2, suitable for review on a recurring basis. It is designed for situations in which time, location, or recurrent training in this subject does not call for use of the other training sections.

The Pilot and Air Traffic Controller Examination, Appendix 3-B, is a set of questions based on the material contained in Section 2. These questions are designed to test the pilot's and air traffic controller's knowledge of each section of the Wake Turbulence Training Aid. In a wake turbulence training curriculum, these questions may be utilized in one of two ways:

1) As part of a pilot's or air traffic controller's review of Section 2, or
2) As an evaluation to determine the effectiveness of the pilot or air traffic controller's self study prior to ground training.

The Wake Turbulence Safety Briefing is a paper copy of view foils with descriptive words for each that can be used for a classroom presentation. The briefing supports a classroom discussion of Section 2.

Video: *Wake Turbulence Avoidance - A Pilot and Air Traffic Controller Briefing* presents the wake turbulence problem, procedures for avoiding wake turbulence, and the interaction of pilots and air traffic controllers necessary to prevent wake turbulence accidents and incidents. Appendix 3-D is a paper copy of the script.

3.1.3 Ground Training Syllabus

Combining all of the previous ground training modules into a comprehensive training syllabus results in the following suggested Ground Training Program:

Training Module	Method of Presentation
• Pilot and Air Traffic Controller Guide to Wake Turbulence (Section 2)	Self Study/Classroom
• Pilot and Air Traffic Controller Guide Pullout Section (Appendix 3-A)	Recurring Self Study
• Pilot and Air Traffic Controller Student Examination (Appendix 3-B)	Self Study/Evaluation
• Wake Turbulence Safety Briefing (Appendix 3-C)	Classroom
• Video: *Wake Turbulence Avoidance - A Pilot and Air Traffic Controller Briefing* (Appendix 3-D is the storyboard script of the video)	Classroom

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3.1.4 Additional Ground Training Resources

The Wake Turbulence Training Aid - Background Data, Section 4, is an excellent source of background information for an instructor needing a more detailed explanation of the material contained in the Pilot and Air Traffic Controllers Guide to Wake Turbulence or the video: *Wake Turbulence Avoidance - A Pilot and Air Traffic Controller Briefing.*

Pilot and Air Traffic Controller Guide - Pullout Section

The purpose of the Pilot and Air Traffic Controller Guide – Pullout Section is to provide a more convenient and concise source of wake-turbulence information for pilots and air traffic controllers. The intent is for this Guide to be extracted or reproduced so that pilots and air traffic controllers may have a readily available source of information regarding wake turbulence.

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3-A Wake Turbulence Considerations

Encounters with wake turbulence can be avoided when pilots and air traffic controllers employ various techniques and apply proper avoidance procedures. The following considerations capture most of the concepts associated with avoiding an encounter with wake turbulence. These considerations are not mandatory nor are they all derived from regulations or directives. They do capture some basic principles that, if correctly considered, can help aircraft avoid encounters with wake turbulence.

Consider the Positive Impact of:

1. During VFR traffic pattern operations, lighter aircraft intercepting final approach upwind of heavier aircraft.
2. Following aircraft flying at or above the flightpath of the leading aircraft during approach.
3. Pilots of following aircraft landing beyond the touchdown point of a preceding heavier aircraft.
4. Pilots of lighter aircraft taking off before the rotation point of a preceding heavier aircraft.

Consider the Negative Impact of:

1. A leading heavier aircraft executing a steeper approach than that of a following lighter aircraft.
2. A lighter aircraft flying within 1000 feet below the flightpath of a larger aircraft when intercepting the final approach.
3. A lighter aircraft landing or departing on the downwind runway when a heavier aircraft is using an upwind parallel runway that is within 2500 feet.
4. Visual approach clearances issued to a lighter aircraft that is rapidly overtaking and/or operating behind and below the flightpath of a heavier aircraft.
5. Flying or allowing aircraft in the area below the final approach corridor.

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3-A 1 Historical Examination of the Wake-Turbulence Hazard

3-A 1.1 Growing Concern

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 fleets.

3-A 1.2 Several Observations 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.

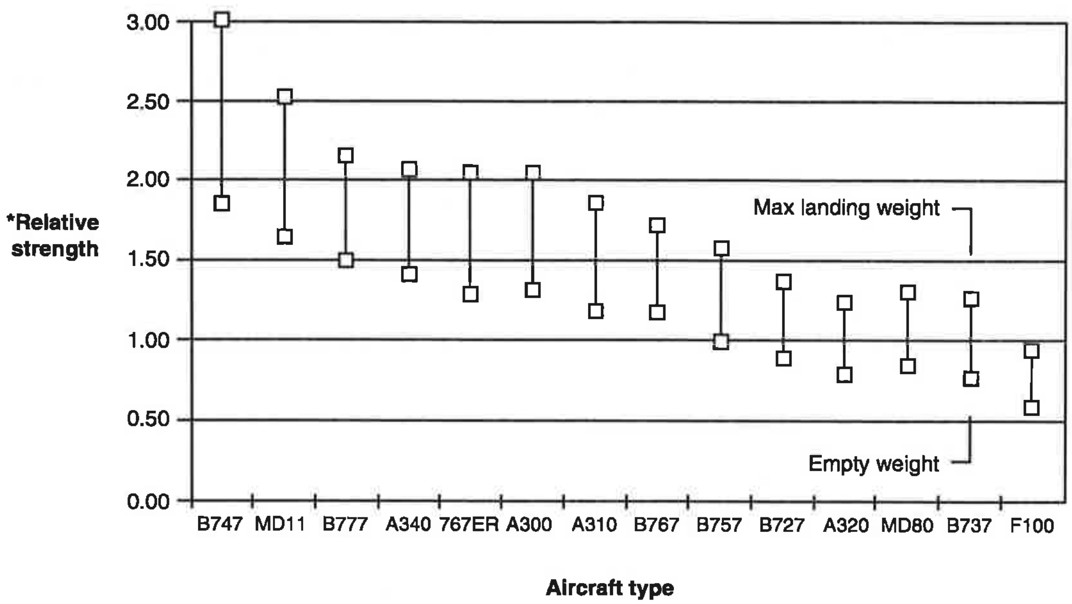
Initial flight tests produced sufficient information about the strength, duration and movement of wake turbulence to come to conclusions and recommendations on how to avoid it. The wake was observed to move down initially and then level off. It was never encountered at the same flight level as the generating 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 maximum gross certificated take-off weight of both the leading and following aircraft. Adjustments in separation distances were made as more information on wake-turbulence phenomena was gained during the 1970s, 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 3-A 1-1).

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.

Figure 3-A 1-1
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.

3-A 2 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. The following are accounts of real events.

1. A pilot of a medium transport began his take-off roll about 30 or 40 seconds behind, and just as a large transport rotated. The large transport went straight ahead and the pilot of the medium transport started a left turn at 300 feet with 15 degrees angle of bank. The bank angle violently increased to 30 degrees from the apparent wake turbulence of the large transport.

2. A Cessna Citation 550, on a visual approach, rapidly rolled left and contacted the ground while in a near-vertical dive.

The two crew members and six passengers were killed. 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.

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 an approach to runway 32. The wind was out of the south at 5 knots. The approach ends of runways 32 and 35 are about 560 feet apart. The Cessna was at an altitude of less than 100 feet above ground level (AGL) when it crossed above the flightpath of the B-757. The B-757 had passed the crossing position about 38 seconds prior to the Cessna 182. The pilot proceeded "direct to the numbers" of runway 32 and passed above and behind a "Boeing" that was on final approach to runway 35. The Cessna experienced a "burble," 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. As the aircraft began to respond the aircraft crashed short of the threshold of runway 32. The pilot and the two passengers suffered minor injuries, and the aircraft was destroyed.

4. A Gulfstream IV was descending. The weather was clear with unlimited visibility and smooth air. At approximately Flight Level 250, ATC advised the pilot of 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 passengers were jettisoned to the ceiling and slammed to the floor. The aircraft landed uneventfully.

5. A MD-88 was executing a visual approach while following a B-757. 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. 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.

6. A Westwind rolled and crashed while on a visual approach. The two crew members and three passengers were killed. The Westwind was about 1200 feet above mean sea level and 3.5 nautical miles from the runway and was about 2.1 nautical miles (60 seconds) behind a B-757. The 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.

Both aircraft were flying generally toward the east and would have to make right turns to land to the south. Data 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 separation 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 requirement, 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.

3-A 3 Description/Characteristics of the Wake-Turbulence Hazard

3-A 3.1 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 3-A 3-1. 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.

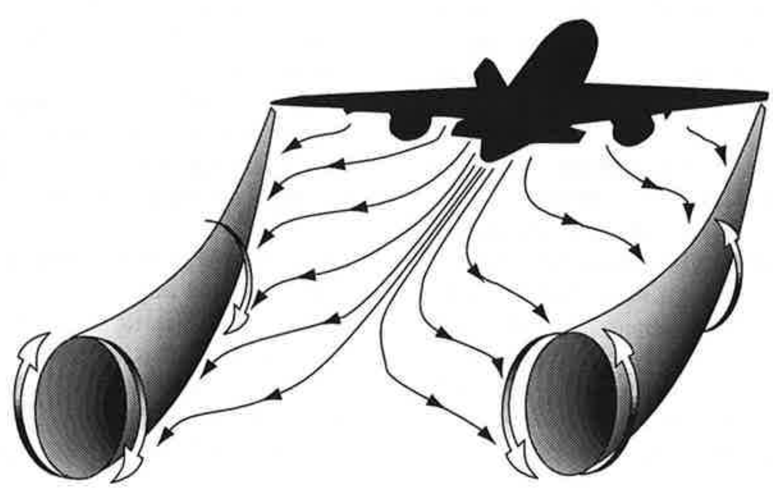


Figure 3-A 3-1 Wake turbulence formation

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 3-A 3-2. In forward flight a pair of downward spiraling vortices are thus shed from the rotor blades, as shown in Figure 3-A 3-3. This region of rotating air below the helicopter is where wake turbulence occurs.

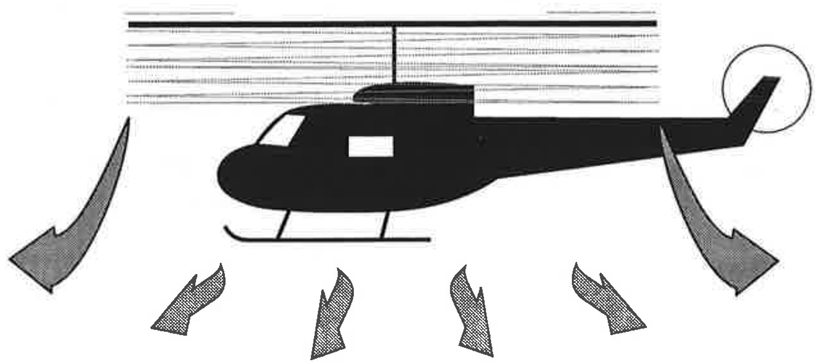


Figure 3-A 3-2 Formation of helicopter wake turbulence (hover)

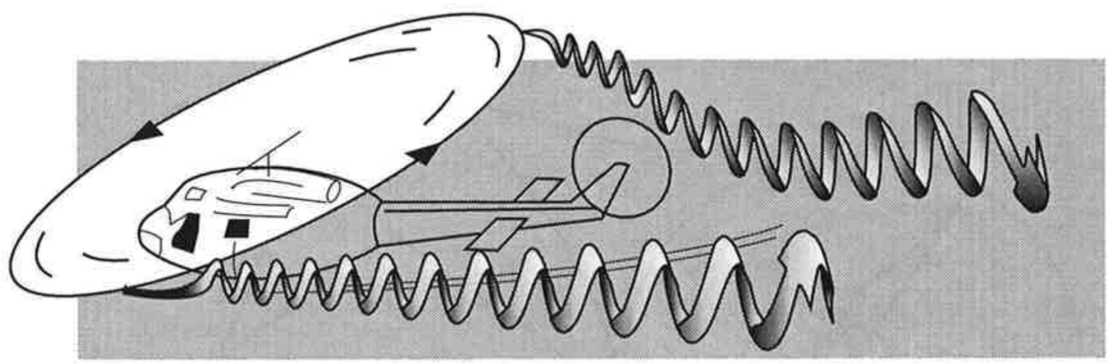


Figure 3-A 3-3 Formation of helicopter wake turbulence (forward flight)

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.

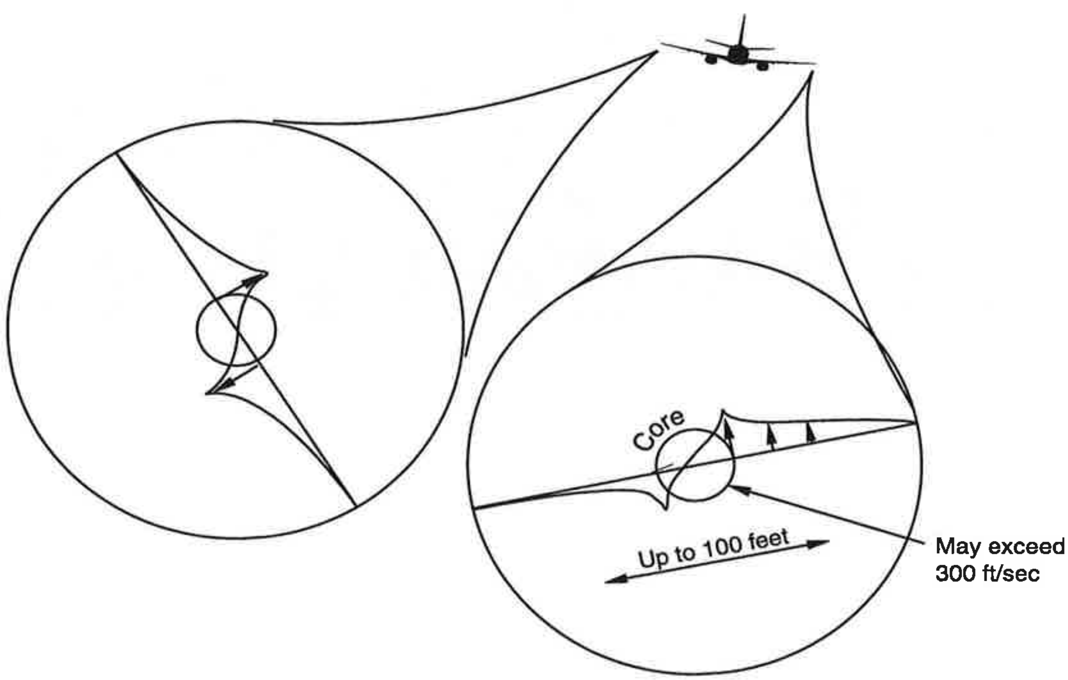
This section briefly summarizes the current knowledge of the behavior of wake vortices. Much has been learned about the characteristics of vortices, but there are still gaps in our understanding. The weight, wingspan and speed of the aircraft determine the initial strength and motion of the vortices; however, the ambient atmosphere (wind, stability, turbulence, etc.) eventually dictates the motion and decay rate of the vortices.

3-A 3.2 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 strength profile. As seen in Figure 3-A 3-4 this region may be as large as 100 feet in diameter.

Figure 3-A 3-4
Velocity profile



3-A 3.3 The Hazard (Figure 3-A 3-5)

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.

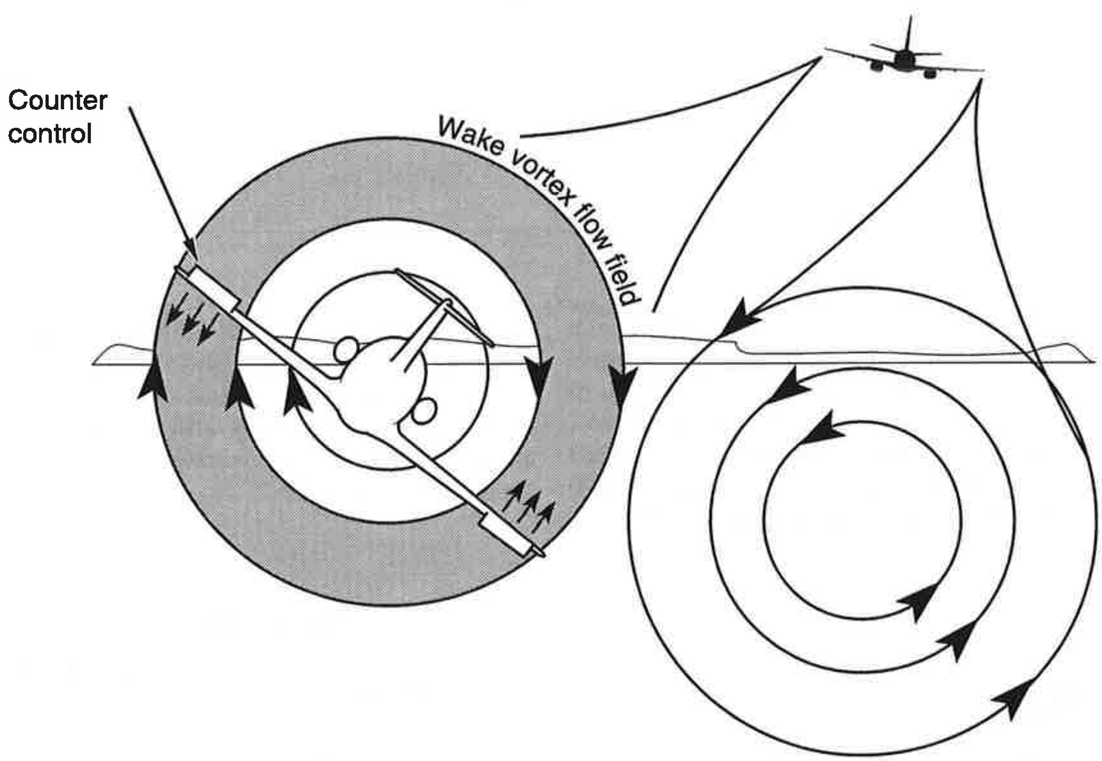


Figure 3-A 3-5
Induced roll

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.

3-A 3.4 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 3-A 3-6.

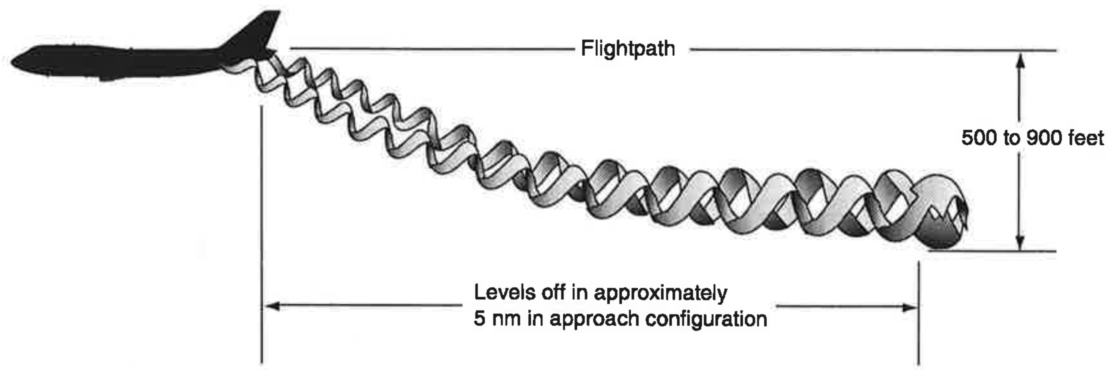


Figure 3-A 3-6 Vertical motion out of ground effect

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. Typically, the wake's descent will be arrested within approximately 1/2 wingspan (50-100 feet for the B-747) of the ground. Below this height the wake does not completely form into concentrated vortices and the turbulence in the wake is weaker. Thus, the turbulence level is reduced, but may still be a factor to aircraft in the touchdown areas. This is illustrated in Figure 3-A 3-7.

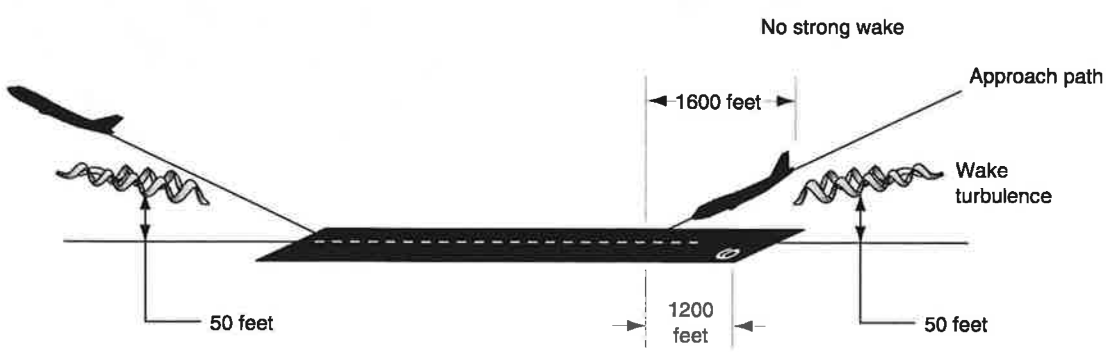


Figure 3-A 3-7 Vertical motion in ground effect

3-A 3.5 Horizontal Motion of the Wake

The horizontal motion of vortices is dictated by the ambient wind and the proximity of the vortex 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. A light quartering tailwind requires maximum caution. However, a pilot does not have the tools to determine that a perfectly zero crosswind condition exists. Crosswinds greater than 5 knots cause the vortices to move quickly across the flightpath and to break up. This is illustrated in Figure 3-A 3-8 below.

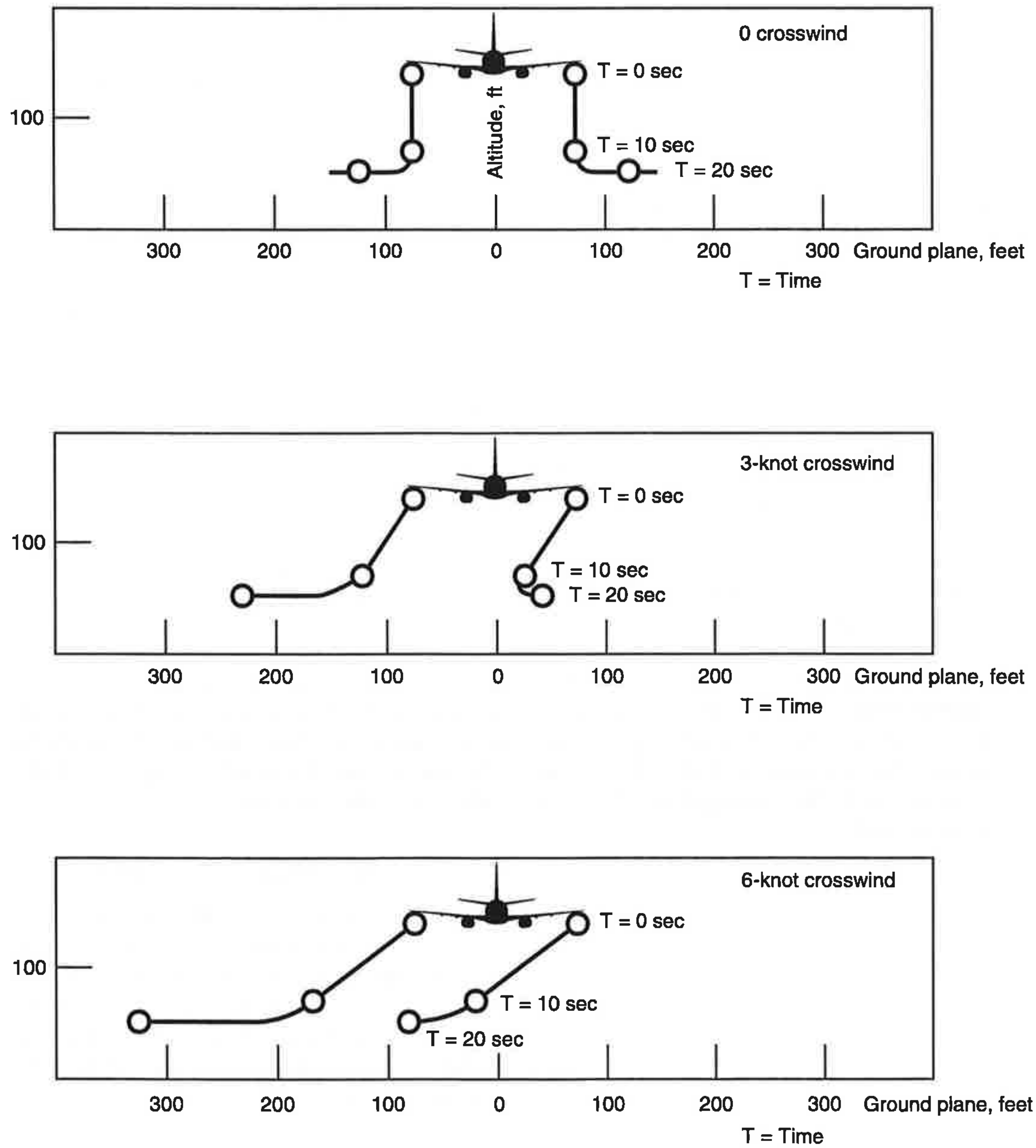


Figure 3-A 3-8
Horizontal motion

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).

3-A 3.6 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 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.

3-A 4 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 to VFR aircraft.

3-A 4.1 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 and VFR aircraft not being radar vectored, but which are behind heavy jets or B-757s.

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.

3-A 4.2 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.

*The information provided in Section 3-A 4 is compatible with FAA air traffic directives.

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.

3-A 4.3 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.

3-A 4.4 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.

3-A 4.5 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).

3-A 4.6 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.

3-A 4.7 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 about the other aircraft, including position, dircction 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.

3-A 4.8 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 3-A 4.6 for those procedures.

3-A 4.9 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.

3-A 5 Pilot Responsibilities for Maintaining Wake-turbulence Separation

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

3-A 5.1 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 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, and
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, take-off 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.

3-A 5.2 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.

3-A 6 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.

3-A 6.1 Specific Procedures

3-A 6.1.1 Landing Behind a Larger Aircraft - Same Runway (Figure 3-A 6-1)

- 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.

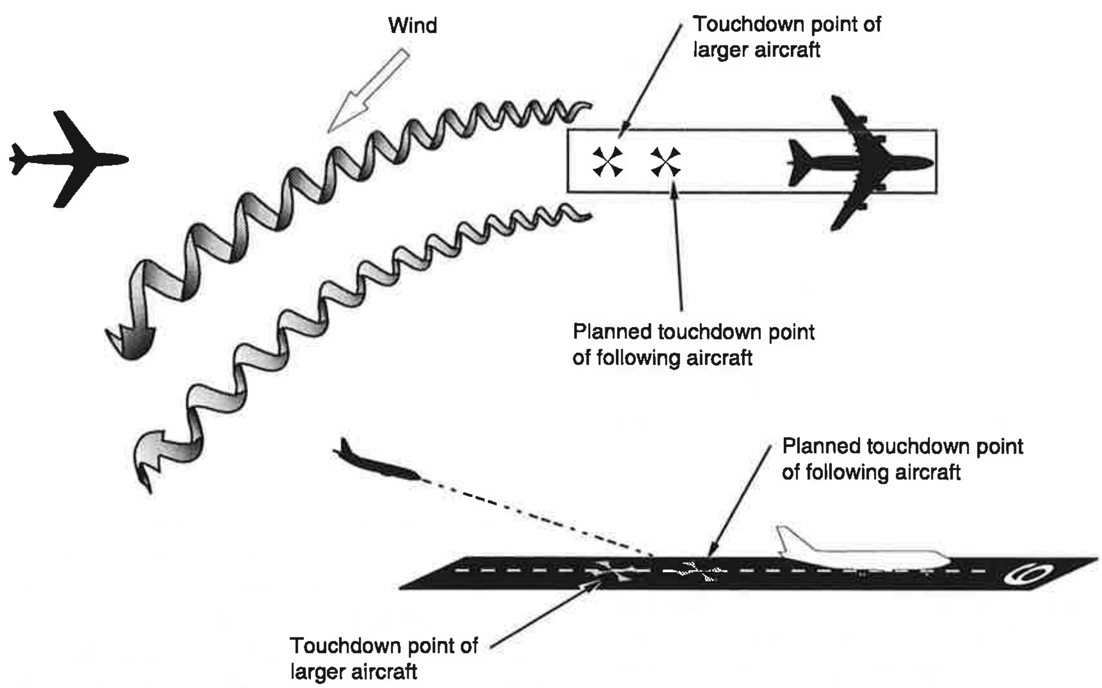


Figure 3-A 6-1 Landing behind a larger aircraft - same runway

3-A 6.1.2 Landing Behind a Larger Aircraft - Parallel Runway Closer Than 2500 Feet (Figure 3-A 6-2)

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

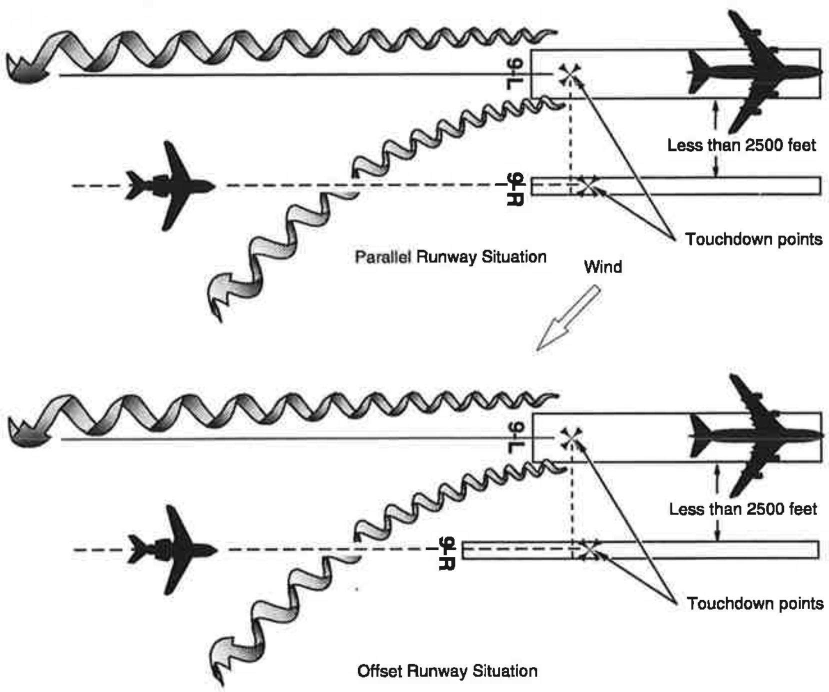


Figure 3-A 6-2 Landing behind a larger aircraft - parallel runway closer than 2500 feet

3-A 6.1.3 Landing Behind a Larger Aircraft - Crossing Runway (Figure 3-A 6-3)

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

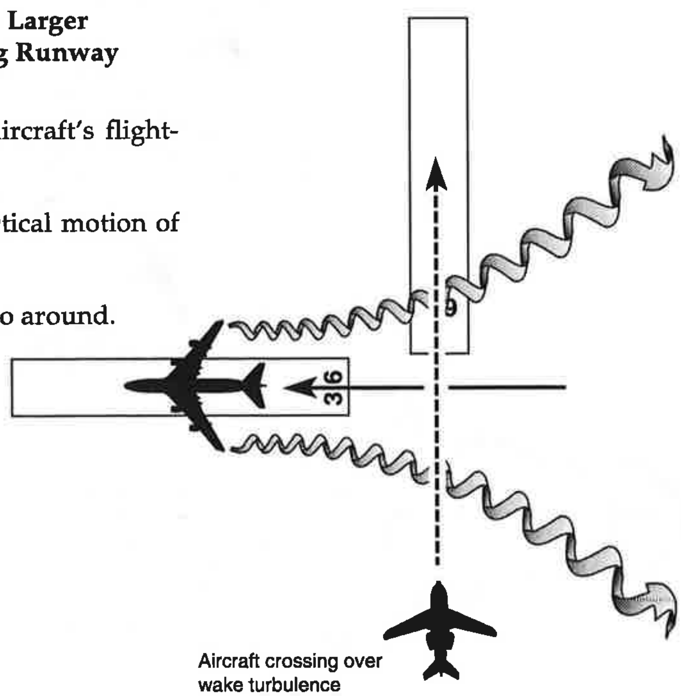


Figure 3-A 6-3 Landing behind a departing larger aircraft - crossing runway

3-A 6.1.4 Landing Behind a Departing Larger Aircraft - Same Runway (Figure 3-A 6-4)

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

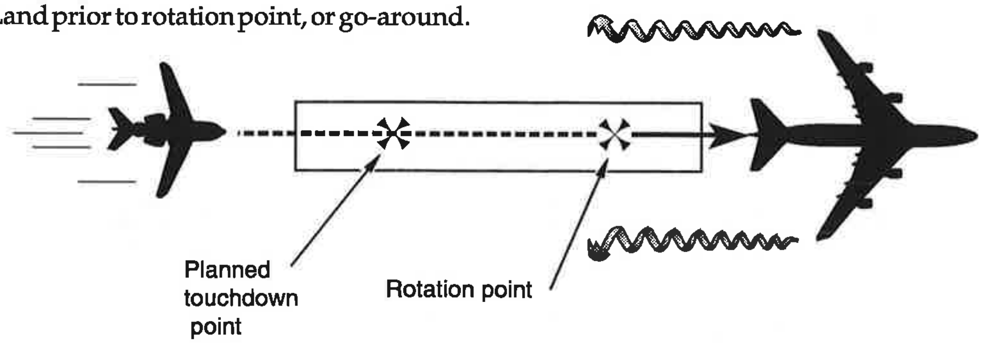


Figure 3-A 6-4 Landing behind a departing larger aircraft - same runway

3-A 6.1.5 Landing Behind a Departing Larger Aircraft - Crossing Runway (Figure 3-A 6-5,-6)

- Note the larger aircraft's rotation point. If past the intersection, continue the approach and land prior to 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.

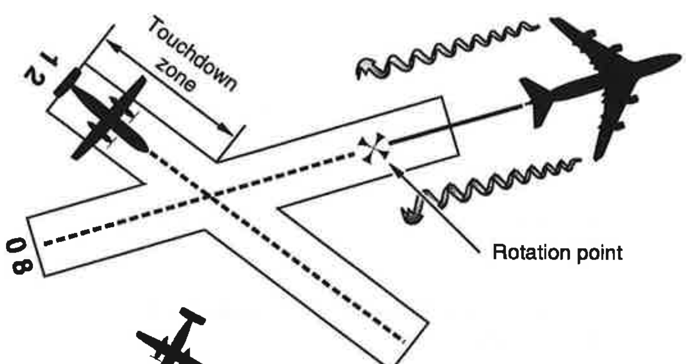


Figure 3-A 6-5 Landing behind a departing larger aircraft - crossing runway

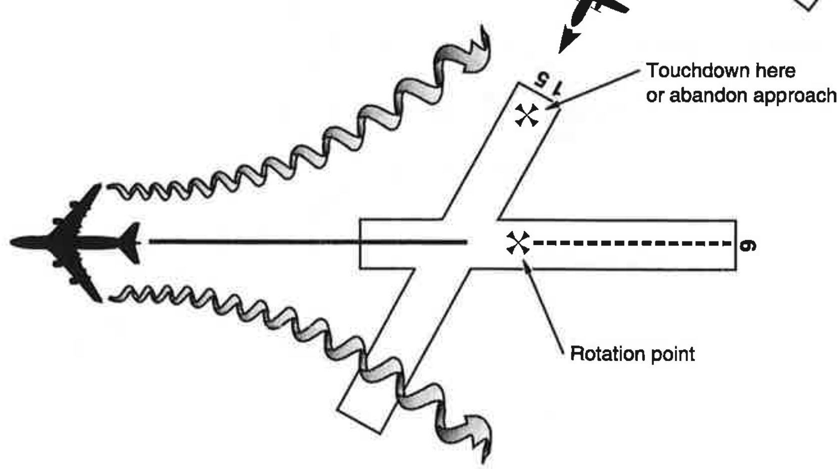


Figure 3-A 6-6 Landing behind a departing larger aircraft - crossing runway

3-A 6.1.6 Departing Behind a Larger Aircraft (Figure 3-A 6-7,-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.

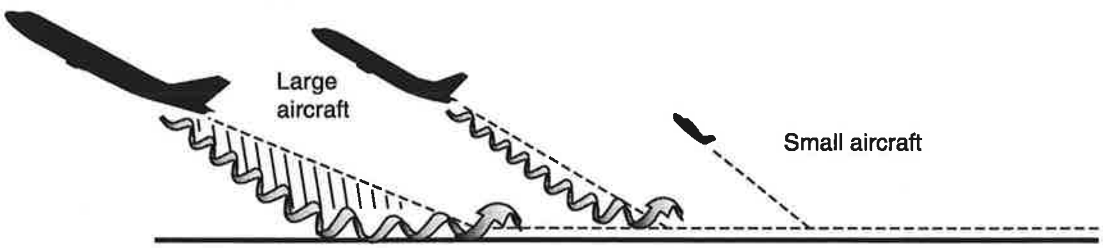


Figure 3-A 6-7
Departing behind a larger aircraft - same runway

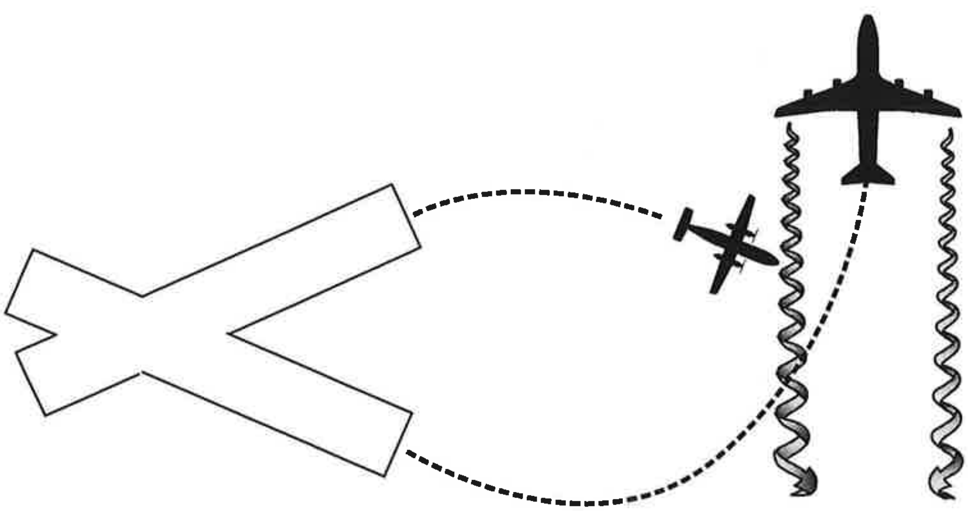


Figure 3-A 6-8
Departing behind a larger aircraft - crossing departure courses

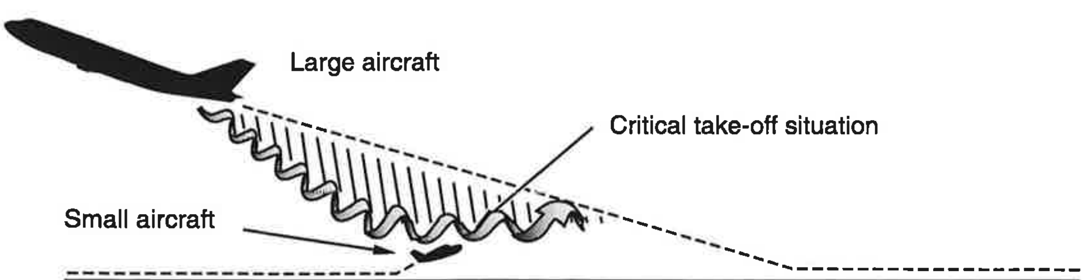


Figure 3-A 6-9
Departing behind a larger aircraft - opposite direction

3-A 6.1.7 Intersection Takeoffs - Same Runway (Figure 3-A 6-10)

- 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.

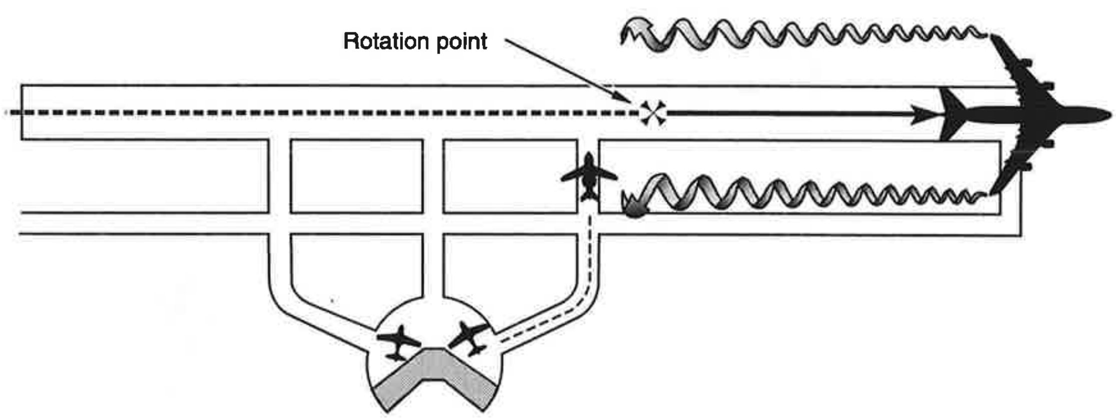


Figure 3-A 6-10 Intersection takeoffs - same runway

3-A 6.1.8 Departing or Landing After a Heavy Aircraft Executing a Low Approach, Missed Approach, or Touch-and-Go Landing (Figure 3-A 6-11)

- Ensure that an interval of at least 2 minutes has elapsed before your takeoff or landing.

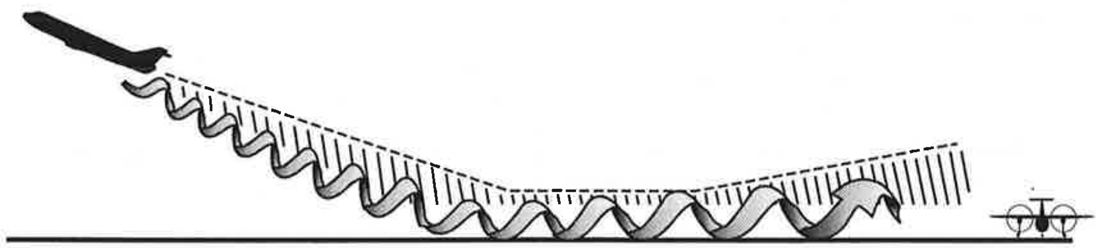


Figure 3-A 6-11 Departing or landing after a heavy aircraft executing a low approach, missed approach, or touch-and-go landing

3-A 6.1.9 En Route Within 1000 Feet Altitude of a Large Aircraft's Altitude (Figure 3-A 6-12)

- 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.

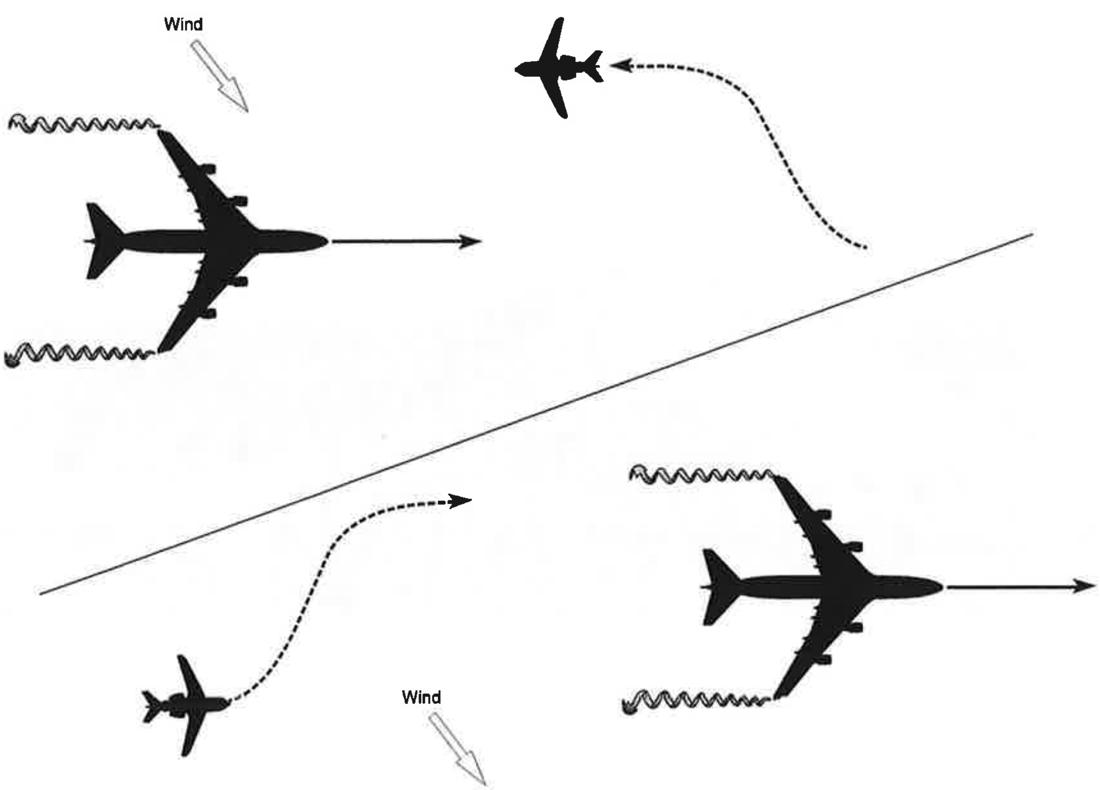


Figure 3-A 6-12 En route VFR (1000-foot altitude plus 500 feet)

3-A 6.2 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 3-A 6-13).

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 3-A 6-14) 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 3-A 6-13 Helicopter hover- produced downwash

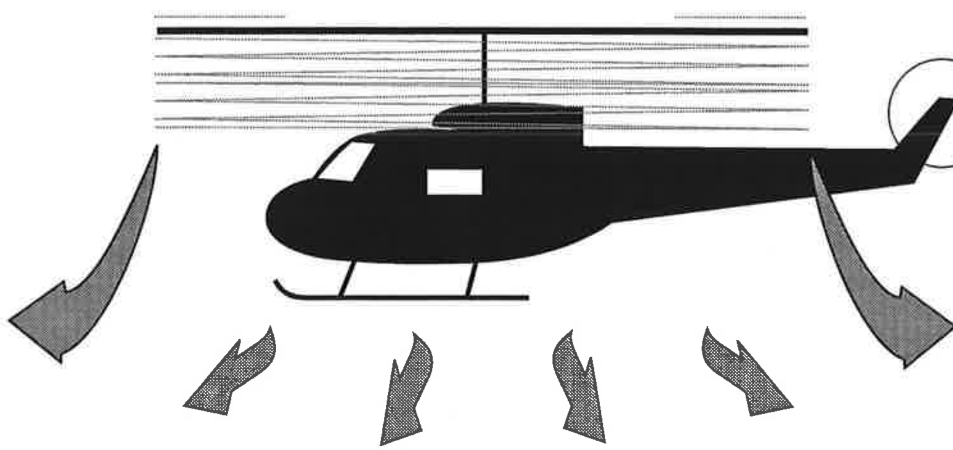
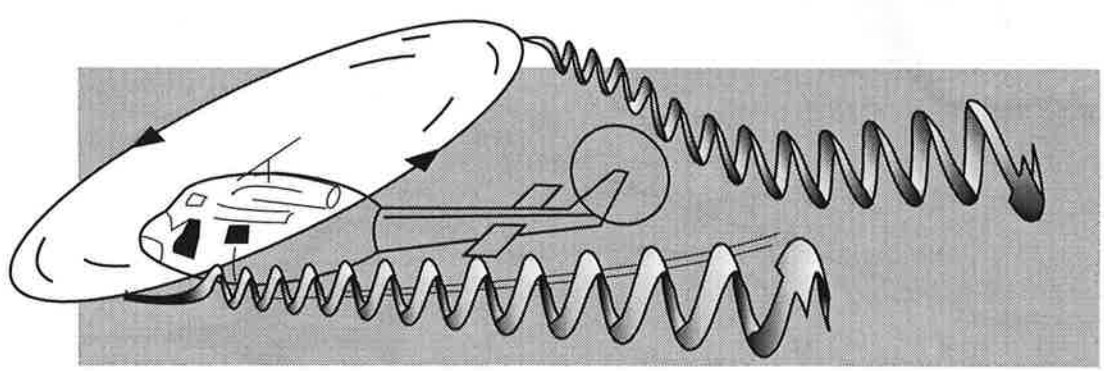


Figure 3-A 6-14 Helicopter forward flight-produced wake turbulence



3-A 7 Pilot Difficulty in Visually Maintaining Separation

3-A 7.1 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 3-A 7-1).

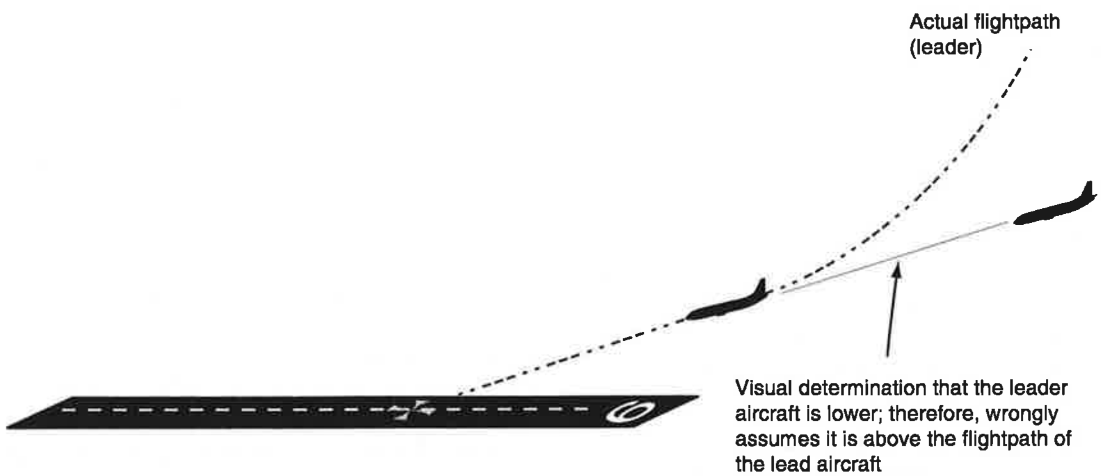


Figure 3-A 7-1
Steeper flightpath by leader aircraft

3-A 7.2 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.

3-A 7.3 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.

3-A 7.4 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.

3-A 7.5 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.

3-A 8 Pilot Techniques for Visually Maintaining Separation

3-A 8.1 General

The wake-turbulence avoidance procedures discussed in Section 3-A 6 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 3-A 3. 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. <u>Air traffic controllers and pilots must understand that accomplishing a steep descent may have serious ramifications for trailing aircraft with regard to wake turbulence.</u>

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

3-A 8.2 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 3-A 8-1). 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.

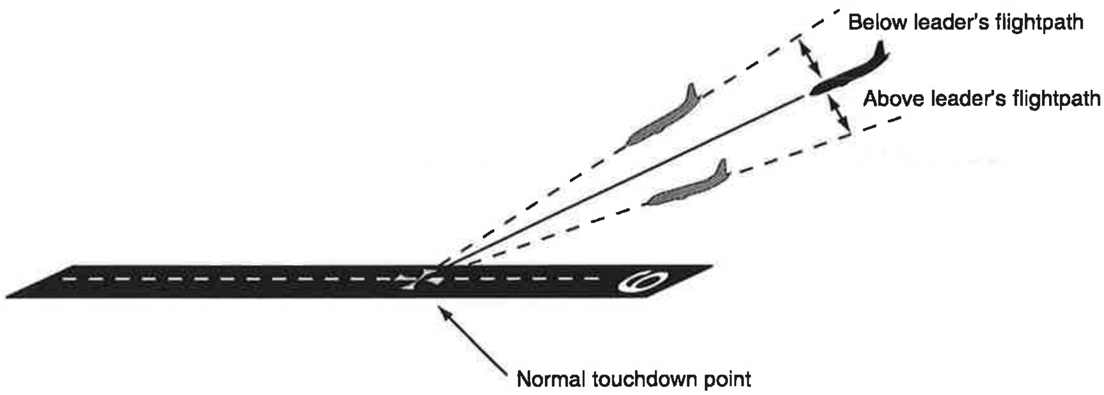

Figure 3-A 8-1
Determining flightpath of leader using imaginary-line-extension method

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 3-A 8-2). If it ends at a point down the runway, the trailing aircraft is probably below the leader's flightpath. 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.

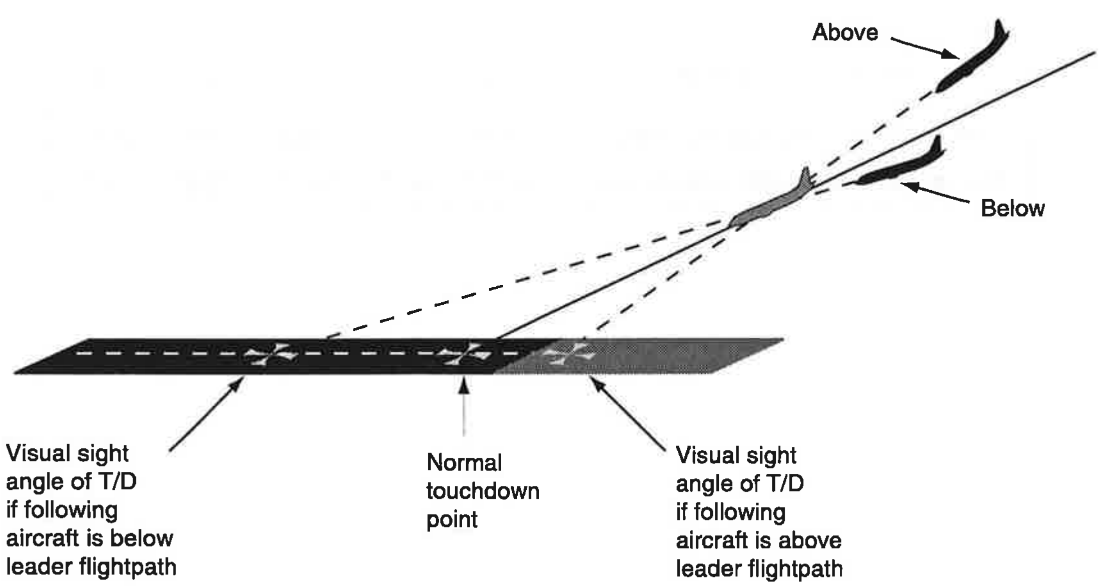

Figure 3-A 8-2
Determining if follower is above or below leader

3-A 8.3 Using ILS Glideslopes for Vertical Separation (Table 3-A 8-1)

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 3-A 8-1 provides distance in feet for degrees in deviation from the glideslope and illustrates position relative to the glideslope.

Table 3-A 8-1 Deviation from standard 3-degree 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'

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

3-A 8.4 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 3-A 8-2 can be used to determine offset distance in feet for degrees in deviation from the localizer course.

Table 3-A 8-2 Localizer deviation

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'

3-A 8.5 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.

3-A 8.5.1 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.

3-A 8.5.2 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 touch down on landing. Pilots of trailing aircraft, upon observing the smoke, can estimate their own position from touch down 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.

3-A 8.6 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 takeoff, 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.

3-A 8.7 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.

3-A 8.8 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.

3-A 9 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. 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.

3-A 10 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.

3-A 11 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.

APPENDIX

3-B

The Pilot and Air Traffic Controller Student Examination Instructor's Examination Guide Summary of Answers

This appendix to the Example Pilot and Air Traffic Controller Training Program contains a comprehensive examination covering all areas identified in Section 2. Appendix 3-B contains the student examination, an instructor's examination guide that contains the correct answers as well as the location by paragraph number of the information in Section 2 of the Wake Turbulence Training Aid, and a summary of answers.

Table of Contents

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Student Examination

Instructions

These questions are based on the material in the Wake Turbulence Training Aid. The answers to each question can be found in that document. The questions are all multiple choice. Circle the one answer to each question which is most correct.

Questions

1. Wake turbulence is a result of
    a. aircraft lift
    b. aircraft propwash or jet exhaust
    c. windshear
    d. aircraft wingspan
2. The strength of the wake turbulence is governed by aircraft
    a. speed
    b. weight
    c. wingspan
    d. all of the above
3. Pressure differential created by the flow of air around the wingtips results in swirling air masses which trail downstream of the wingtips and produce
    a. two counter rotating cylindrical vortices
    b. two clockwise rotating cylindrical vortices
    c. one large rotating cylindrical vortex
    d. none of the above
4. Aircraft wake turbulence IFR separation categories are determined by the aircraft
    a. speed
    b. weight
    c. aerodynamic wing shape
    d. both a and b above
5. The usual hazard associated with encountering wake turbulence is
    a. aircraft structural damage
    b. induced rolling moment which exceeds roll control
    c. inability to escape the wake core
    d. none of the above
6. Before the air traffic controller may clear a pilot to follow an aircraft and fly a visual approach, the pilot must
    a. have only the leading aircraft in sight
    b. have both the leading aircraft and the airport in sight
    c. cancel his or her IFR flight plan
    d. be within 3 nautical miles of the runway or the leading aircraft

7. The pilot is responsible for avoiding wake turbulence when flying VFR weather, maintaining visual aircraft separation, and when cleared for a visual approach.

   a. True
   b. False

8. IFR radar-controlled longitudinal separation is applied between aircraft to ensure that sufficient time is available for the wake turbulence to completely dissipate.

   a. True
   b. False

9. The most important factor in the wake turbulence decay process is

   a. atmospheric conditions
   b. aerodynamic shape of the aircraft wing
   c. aircraft approach speed
   d. a and b above

10. Wake vortices initially descend at what rate?

    a. 700 feet per minute
    b. 300 feet per minute
    c. 300 to 500 feet per minute
    d. 100 feet per minute

11. The capability of an aircraft to counteract the roll imposed by the vortex primarily depends on its

    a. control responsiveness
    b. wingspan
    c. wing sweep
    d. a and b above

12. Wake turbulence is a hazard to aircraft landing on parallel runways separated by more than 2500 feet.

    a. True
    b. False

13. Tower controllers provide visual wake turbulence separation to arriving and departing aircraft of different wake turbulence categories.

    a. True
    b. False

14. Air traffic controllers may issue a take-off clearance, and waive take-off wake turbulence time and distance intervals under what circumstances?

    a. A pilot specifically requests a waiver of the interval
    b. A pilot specifically requests a waiver of the interval and the traffic permits
    c. A pilot specifically requests a waiver of the interval, the traffic permits, and the pilot acknowledges separation responsibility
    d. A pilot specifically requests a waiver of the interval, the traffic permits, and the controller issues a wake turbulence cautionary advisory

15. When considering wake turbulence, pilots should stay at or above the
    a. ILS glideslope
    b. lead aircraft
    c. 3-degree descent path
    d. lead aircraft's flightpath

16. Which situation represents the most likely wake turbulence landing hazard?
    a. 3-knot quartering tailwind
    b. 6-knot headwind
    c. 12-knot crosswind
    d. 10-knot headwind

17. When you are 3 miles from touchdown and 1 dot high on ILS glideslope, how many feet are you above the glideslope?
    a. 325 feet
    b. 32 feet
    c. 78 feet
    d. 156 feet

18. When does an aircraft produce the strongest wake turbulence, if all other parameters are equal?
    a. At heavy weights
    b. At slow speeds
    c. In a clean-wing configuration
    d. All of the above

19. Wake turbulence separation is a limiting factor in airport capacity at some airports.
    a. True
    b. False

20. When air traffic is providing radar control during VFR weather conditions, the pilot is relieved of the responsibility for assuring that the flightpath will avoid an encounter with wake turbulence.
    a. True
    b. False

21. Which of the following statements about helicopter-produced wake turbulence is <u>false</u>?
    a. In forward flight, a helicopter produces a pair of trailing vortices like fixed-wing aircraft
    b. In forward flight, a helicopter produces a single vortex trailing from the blades as they rotate into the flight direction
    c. Vortex circulation in a hover is outward, upward, around and away from the main rotor(s) in all directions
    d. Pilots of small aircraft should avoid operating within three rotor diameters of the hovering or stationary helicopter

22. A nose-high pitch attitude is a good indicator of a steep flightpath of the lead aircraft?

    a. True
    b. False

23. When landing behind a larger aircraft that is taking off on a crossing runway, which of the following statements is true?

    a. Note the larger aircraft's rotation point and if it was before the intersection, continue the approach and land past the intersection
    b. Note the larger aircraft's rotation point and if it was past the intersection, continue the approach and land before the intersection
    c. It is not necessary to avoid flight below the larger aircraft's flightpath since it will not produce wake turbulence that close to the ground
    d. Assure that your landing is at least 1 minute after the larger aircraft has rotated for takeoff

24. When taking off after a heavy aircraft has executed a low approach, missed approach or touch-and-go landing, what minimum elapsed time interval should be applied before departing or landing on the same runway?

    a. 1 minute
    b. 2 minutes
    c. 3 minutes
    d. No delay is required

25. Pilots must always maintain the minimum longitudinal wake turbulence separation distance appropriate for their aircraft category until the landing is completed.

    a. True
    b. False

26. After turning on to final approach behind another aircraft, it is observed that the leading aircraft is at a lower altitude. In this situation, the trailing aircraft will not encounter wake turbulence.

    a. True
    b. False

Instructor's Examination Guide

Instructions

This guide contains questions based on the material in the Wake Turbulence Training Aid. The answers to each question can be found in that document. The questions are all multiple choice. There is one answer to each question which is most correct. The correct answer is listed after each question, along with the section in Section 2 where the correct answer may be found.

Questions

1. Wake turbulence is a result of

    a. aircraft lift
    b. aircraft propwash or jet exhaust
    c. windshear
    d. aircraft wingspan

    Answer: a. (Section 2.4.1)

2. The strength of the wake turbulence is governed by aircraft

    a. speed
    b. weight
    c. wingspan
    d. all of the above

    Answer: d. (Section 2.2)

3. Pressure differential created by the flow of air around the wingtips results in swirling air masses which trail downstream of the wingtips and produce

    a. two counter rotating cylindrical vortices
    b. two clockwise rotating cylindrical vortices
    c. one large rotating cylindrical vortex
    d. none of the above

    Answer a. (Section 2.4.1)

4. Aircraft wake turbulence IFR separation categories are determined by the aircraft

    a. speed
    b. weight
    c. aerodynamic wing shape
    d. both a and b above

    Answer: b. (Section 2.2)

5. The usual hazard associated with encountering wake turbulence is

    a. aircraft structural damage
    b. induced rolling moment which exceeds roll control
    c. inability to escape the wake core
    d. none of the above

    Answer: b. (Section 2.4.3)

6. Before the air traffic controller may clear a pilot to follow an aircraft and fly a visual approach, the pilot must

   a. have only the leading aircraft in sight
   b. have both the leading aircraft and the airport in sight
   c. cancel his or her IFR flight plan
   d. be within 3 nautical miles of the runway or the leading aircraft

   Answer: a. (Section 2.7.1)

7. The pilot is responsible for avoiding wake turbulence when flying VFR, maintaining visual aircraft separation, and when cleared for a visual approach.

   a. True
   b. False

   Answer: a. (Section 2.7.1)

8. IFR radar-controlled longitudinal separation between aircraft is applied to ensure that sufficient time is available for the wake turbulence to completely dissipate.

   a. True
   b. False

   Answer: b. (Section 2.7.1)

9. The most important factor in the wake turbulence decay process is

   a. atmospheric conditions
   b. aerodynamic shape of the aircraft wing
   c. aircraft approach speed
   d. a and b above

   Answer: a. (Section 2.4.6)

10. Wake vortices initially descend at what rate?

    a. 700 feet per minute
    b. 300 feet per minute
    c. 300 to 500 feet per minute
    d. 100 feet per minute

    Answer: c. (Section 2.4.4)

11. The capability of an aircraft to counteract the roll imposed by the vortex primarily depends on its

    a. control responsiveness
    b. wingspan
    c. wing sweep
    d. a and b above

    Answer: b. (Section 2.11)

12. Wake turbulence is a hazard to aircraft landing on parallel runways separated by more than 2500 feet.

    a. True
    b. False

    Answer: b. (Section 2.4.5)

13. Tower controllers provide visual wake turbulence separation to arriving and departing aircraft of different wake turbulence categories.

    a. True
    b. False

    Answer: b. (Section 2.6.3)

14. Air traffic controllers may issue a take-off clearance, and waive take-off wake turbulence time and distance intervals under what circumstances?

    a. A pilot specifically requests a waiver of the interval
    b. A pilot specifically requests a waiver of the interval and the traffic permits
    c. A pilot specifically requests a waiver of the interval, the traffic permits, and the pilot acknowledges separation responsibility
    d. A pilot specifically requests a waiver of the interval, the traffic permits, and the controller issues a wake turbulence cautionary advisory.

    Answer: d. (Section 2.7.1)

15. When considering wake turbulence, pilots should stay at or above the

    a. ILS glideslope
    b. lead aircraft
    c. 3-degree descent path
    d. lead aircraft's flightpath

    Answer: d. (Section 2.9.1)

16. Which situation represents the most likely wake turbulence landing hazard?

    a. 3-knot quartering tailwind
    b. 6-knot headwind
    c. 12-knot crosswind
    d. 10-knot headwind

    Answer: a. (Section 2.4.5)

17. When you are 3 miles from touchdown and 1 dot high on ILS glideslope, how many feet are you above the glideslope?

    a. 325 feet
    b. 32 feet
    c. 78 feet
    d. 156 feet

    Answer: c. (Section 2.10.3)

18. When does an aircraft produce the strongest wake turbulence, if all other parameters are equal?

    a. At heavy weights
    b. At slow speeds
    c. In a clean-wing configuration
    d. All of the above

    Answer: d. (Section 2.2)

19. Wake turbulence separation is a limiting factor in airport capacity at some airports.

    a. True
    b. False

    Answer: a. (Section 2.12)

20. When air traffic is providing radar control during VFR weather conditions, the pilot is relieved of the responsibility for assuring that the flightpath will avoid an encounter with wake turbulence.

    a. True
    b. False

    Answer: b. (Section 2.7.1)

21. Which of the following statements about helicopter-produced wake turbulence is false?

    a. In forward flight, a helicopter produces a pair of trailing vortices like fixed-wing aircraft
    b. In forward flight, a helicopter produces a single vortex trailing from the blades as they rotate into the flight direction
    c. Vortex circulation in a hover is outward, upward, around and away from the main rotor(s) in all directions
    d. Pilots of small aircraft should avoid operating within three rotor diameters of the hovering or stationary helicopter

    Answer: b. (Section 2.4.1)

22. A nose-high pitch attitude is a good indicator of a steep flightpath of the lead aircraft?

    a. True
    b. False

    Answer: b. (Section 2.10.3)

23. When landing behind a larger aircraft that is taking off on a crossing runway, which of the following statements is true?

    a. Note the larger aircraft's rotation point and if it was before the intersection, continue the approach and land past the intersection
    b. Note the larger aircraft's rotation point and if it was past the intersection, continue the approach and land before the intersection
    c. It is not necessary to avoid flight below the larger aircraft's flightpath since it will not produce wake turbulence that close to the ground
    d. Assure that your landing is at least 1 minute after the larger aircraft has rotated for takeoff

    Answer: b. (Section 2.8.1.5)

24. When taking off after a heavy aircraft has executed a low approach, missed approach or touch-and-go landing, what minimum elapsed time interval should be applied before departing or landing on the same runway?

    a. 1 minute
    b. 2 minutes
    c. 3 minutes
    d. No delay is required

    Answer: b. (Section 2.8.1.8)

25. Pilots must always maintain the minimum longitudinal wake turbulence separation distance appropriate for their aircraft category until the landing is completed.

    a. True
    b. False

    Answer: b. (Section 2.6.2)

26. After turning on to final approach behind another aircraft, it is observed that the leading aircraft is at a lower altitude. In this situation, the trailing aircraft will not encounter wake turbulence.

    a. True
    b. False

    Answer: b. (Section 2.9.1)

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Summary of Answers

1	A
2	D
3	A
4	B
5	B
6	A
7	A
8	B
9	A
10	C
11	B
12	B
13	B
14	D
15	D
16	A
17	C
18	D
19	A
20	B
21	B
22	B
23	B
24	B
25	B
26	B

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APPENDIX

3-C

Wake Turbulence Safety Briefing

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APPENDIX

3-C

Wake Turbulence Safety Briefing

This appendix contains a paper copy of view foils with descriptive words for each foil that can be used for a classroom presentation. The briefing supports a classroom discussion of the Pilot and Air Traffic Controller Guide and/or the video.

APPENDIX 3-C

WAKE TURBULENCE SAFETY BRIEFING

Wake-turbulence accidents continue to happen even though basic information about the hazard as well as avoidance procedures have been available for air traffic controllers and pilots for many years. National Transportation Safety Board (NTSB) 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. The Aviation Safety Reporting System (ASRS) had 447 incidents attributed to wake turbulence reported from January 1986 to March 1994.

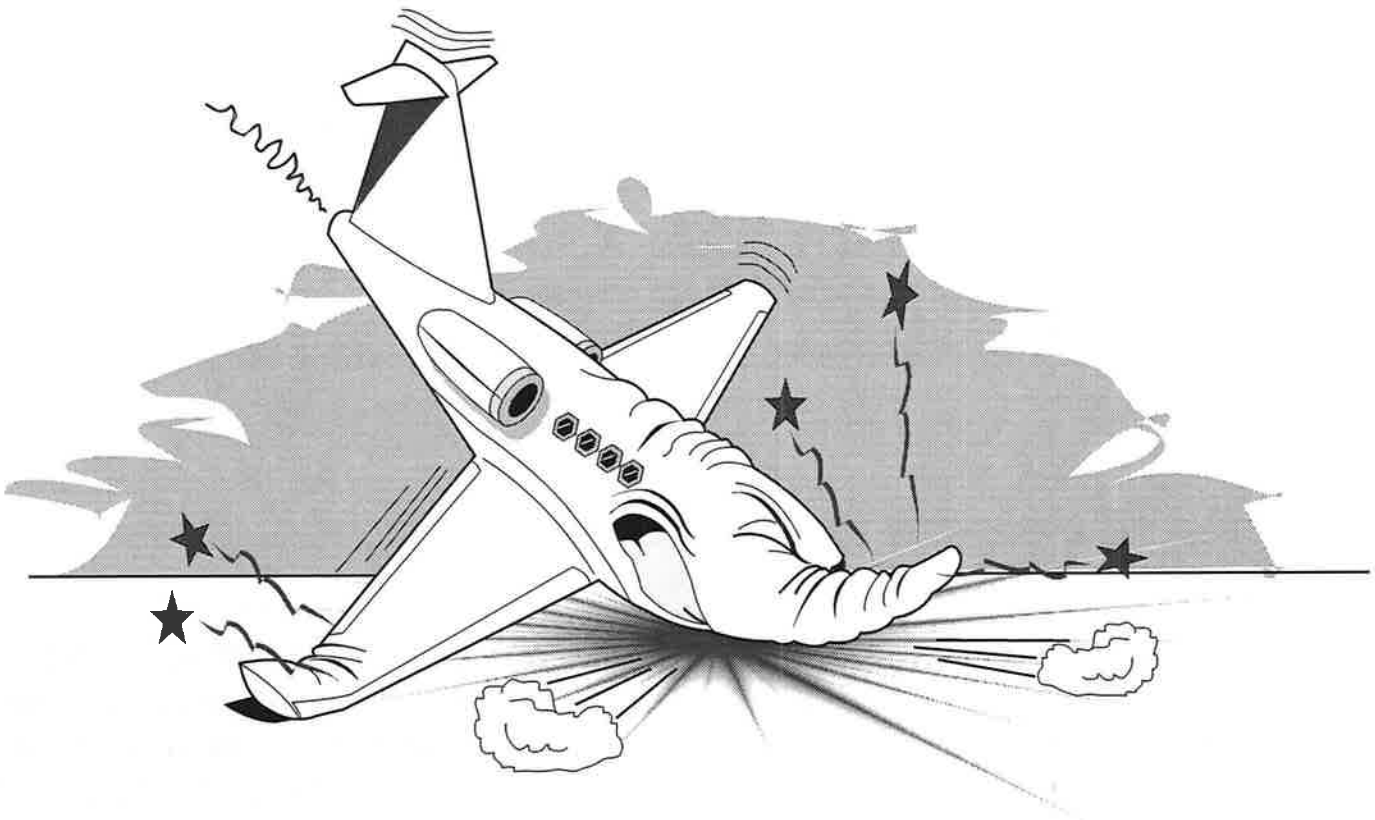


Figure 1

A Cessna Citation 550 crashed while on a visual approach. Two crewmembers 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. The Citation was about 2.78 nautical miles behind a Boeing 757.

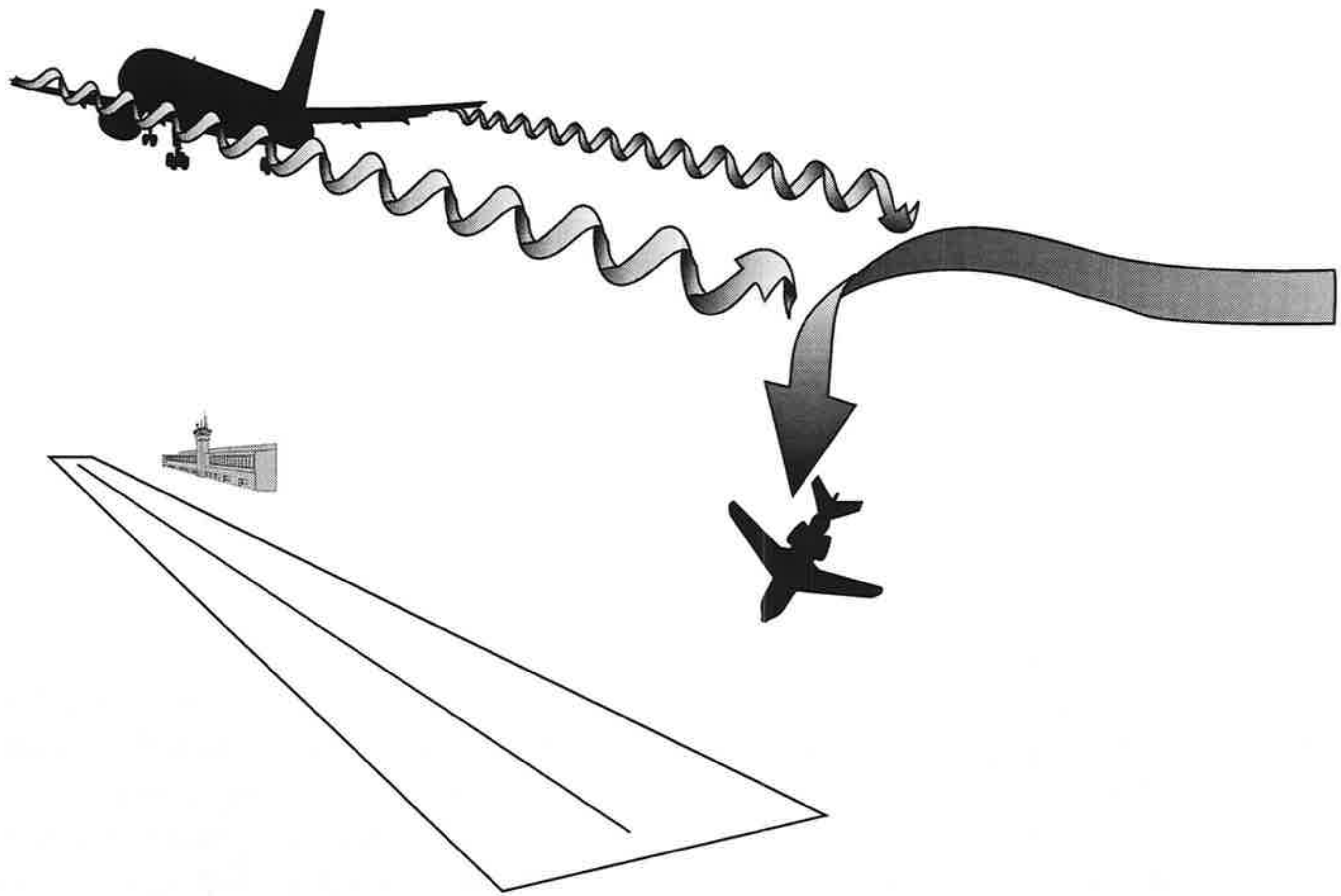


Figure 2

A Gulfstream IV departed on a routine night trip. 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 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."

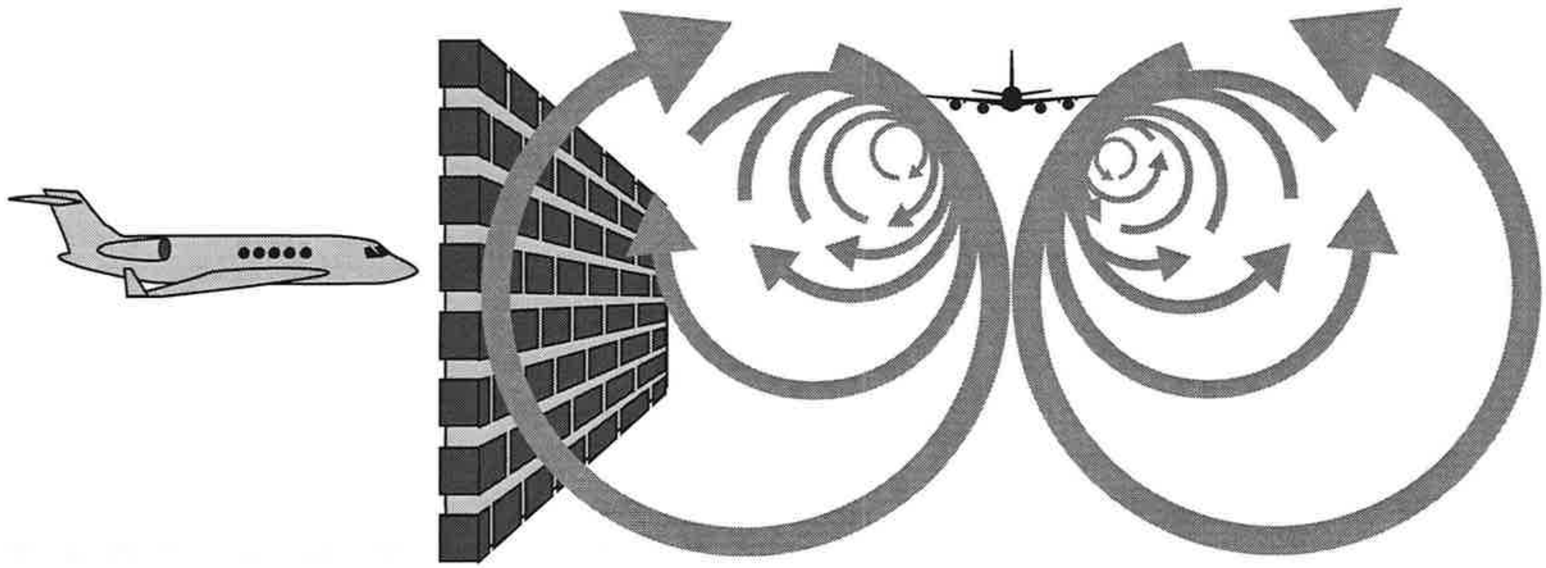


Figure 3

A medium size transport was told to expedite the takeoff behind a large transport. The medium transport began its take-off roll as the large transport rotated. The large transport departed straight ahead. The medium transport started a turn at 300 feet AGL using 15 degrees of bank angle. Suddenly and violently the bank angle increased to 30 degrees apparently from the wake turbulence created by the large transport.

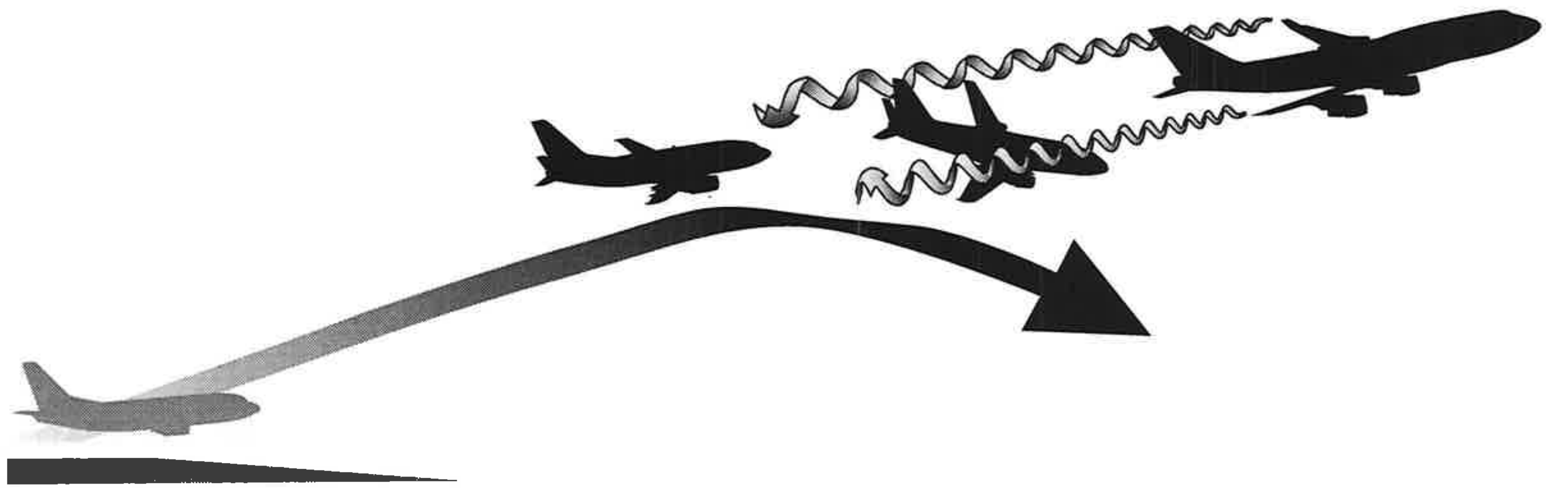


Figure 4

Investigation of the most recent accidents involving wake turbulence by the National Transportation Safety Board (NTSB) indicates, that, while the aviation and scientific communities have a comprehensive understanding of wake turbulence, there is still a need for more information. The NTSB also found that pilots are not sufficiently knowledgeable of wake-turbulence and avoidance procedures. Additionally, there are inadequacies in air traffic control procedures related to visual approaches and visual flight rules operations behind heavier aircraft.

NTSB:

"...Insufficient pilot knowledge and training related to the avoidance of wake vortices"

"...not provided adequate training related to the movement and avoidance of wake vortices..."

"...Current air traffic control procedures and pilot reactions can result in aircraft following too closely…while on a visual approach to landing"

Figure 5

In this presentation, we are going to look at what every pilot and air traffic controller should know to avoid wake turbulence encounters.

We'll look at:

- the description, formation and characteristics of wake turbulence
- air traffic controllers and pilot responsibilities for avoiding the hazard
- visual avoidance procedures
- the problems pilots face in visually maintaining separation from wake turbulence
- some pilot techniques for visually avoiding wake turbulence
- what pilots can expect during an inadvertent encounter with wake turbulence
- air traffic control considerations when applying separation standards

What pilots and air traffic controllers should know about wake turbulence:

- **What it is**
- **Who is responsible for avoidance and when**
- **Visual avoidance procedures**
- **Separation difficulties**
- **Avoidance techniques for pilots**
- **Effects of inadvertent encounters**
- **ATC considerations**

Figure 6

The phenomenon that creates wake turbulence results from the forces that lift the aircraft. High pressure air from the lower surface of the wing flows around the wingtips to the lower pressure region above the wings. This pressure differential triggers the roll-up of airflow aft of the wing resulting in counter-rotating air masses trailing downstream of the wingtips.

The wake turbulence associated with helicopters results from the high pressure air on the lower surface of the rotor blades flowing around the tips of the rotor blades to the lower pressure region above the rotor blades.

Since wake turbulence dissipates more rapidly in ground effect, the turbulence level is reduced, but still may be a factor in the touchdown areas.

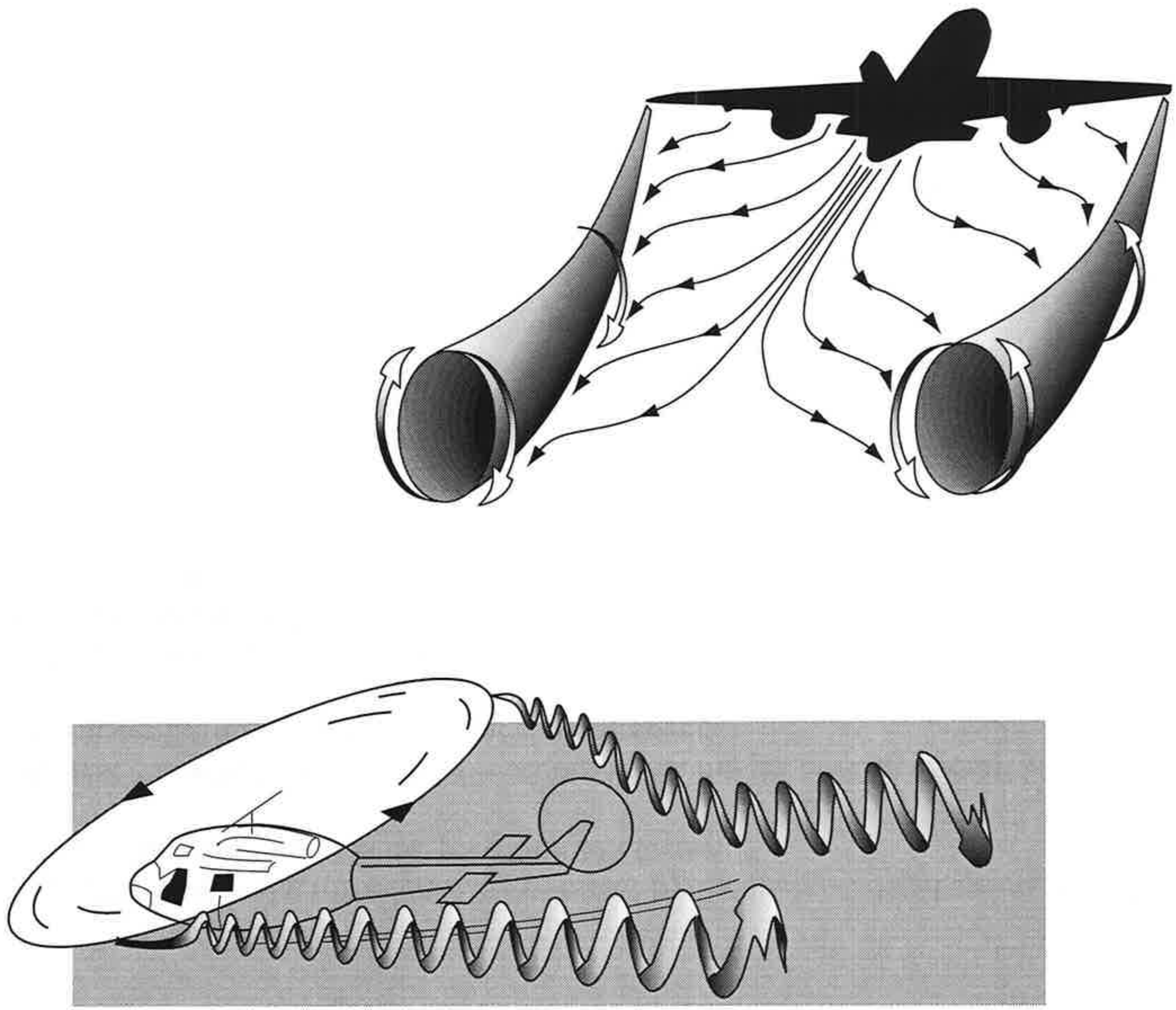


Figure 7

WAKE TURBULENCE SAFETY BRIEFING

The strength of the wake turbulence is governed by the weight, flight speed, and wingspan of the aircraft. Aircraft weight is the predominant factor.

The greatest wake turbulence strength occurs when the generating aircraft is heavy, in a clean-wing configuration, and flying at slow airspeed.

Aircraft are grouped into categories based upon gross weight. Longitudinal distance intervals between aircraft for each category are used to provide safe wake-turbulence separation criteria.

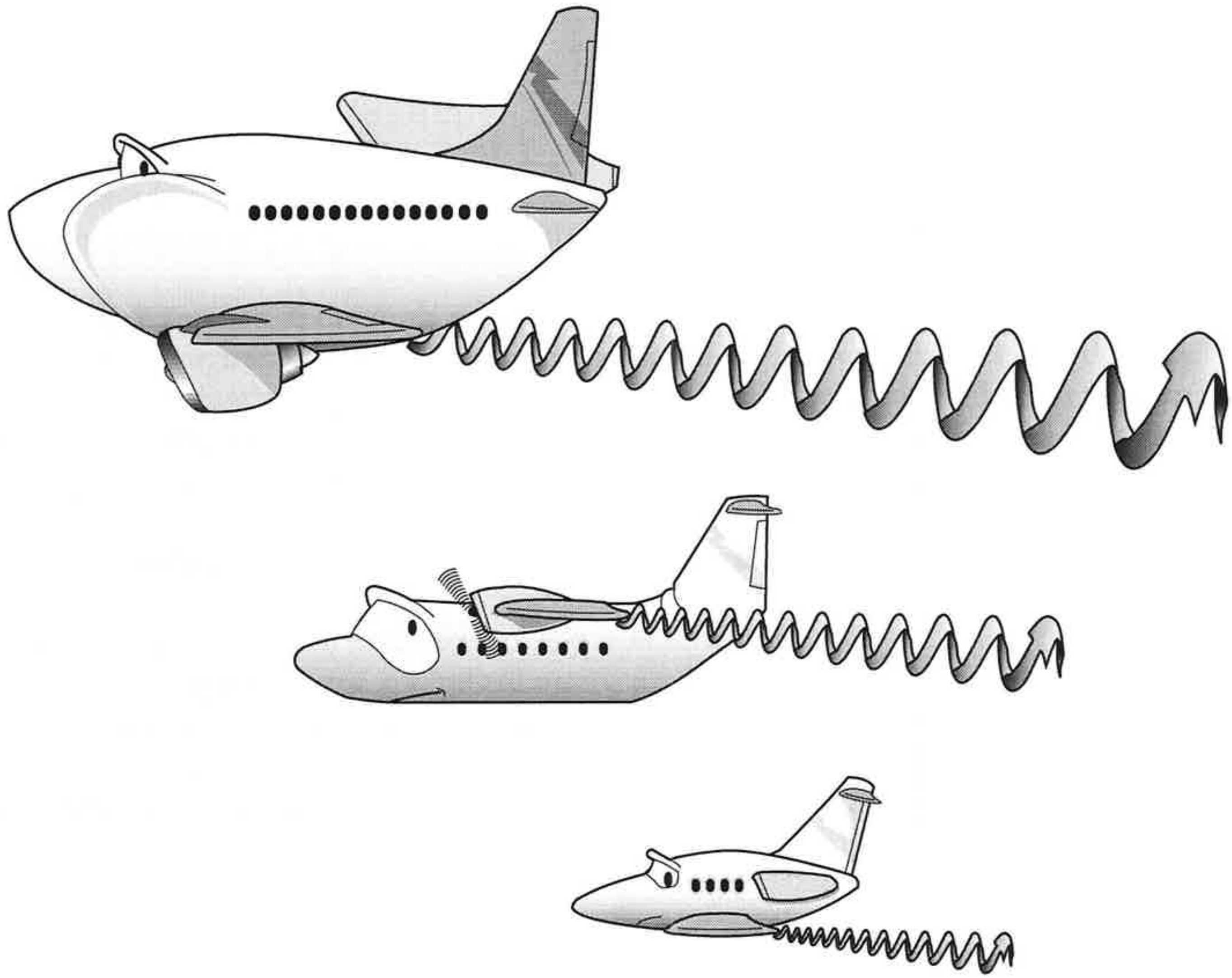


Figure 8

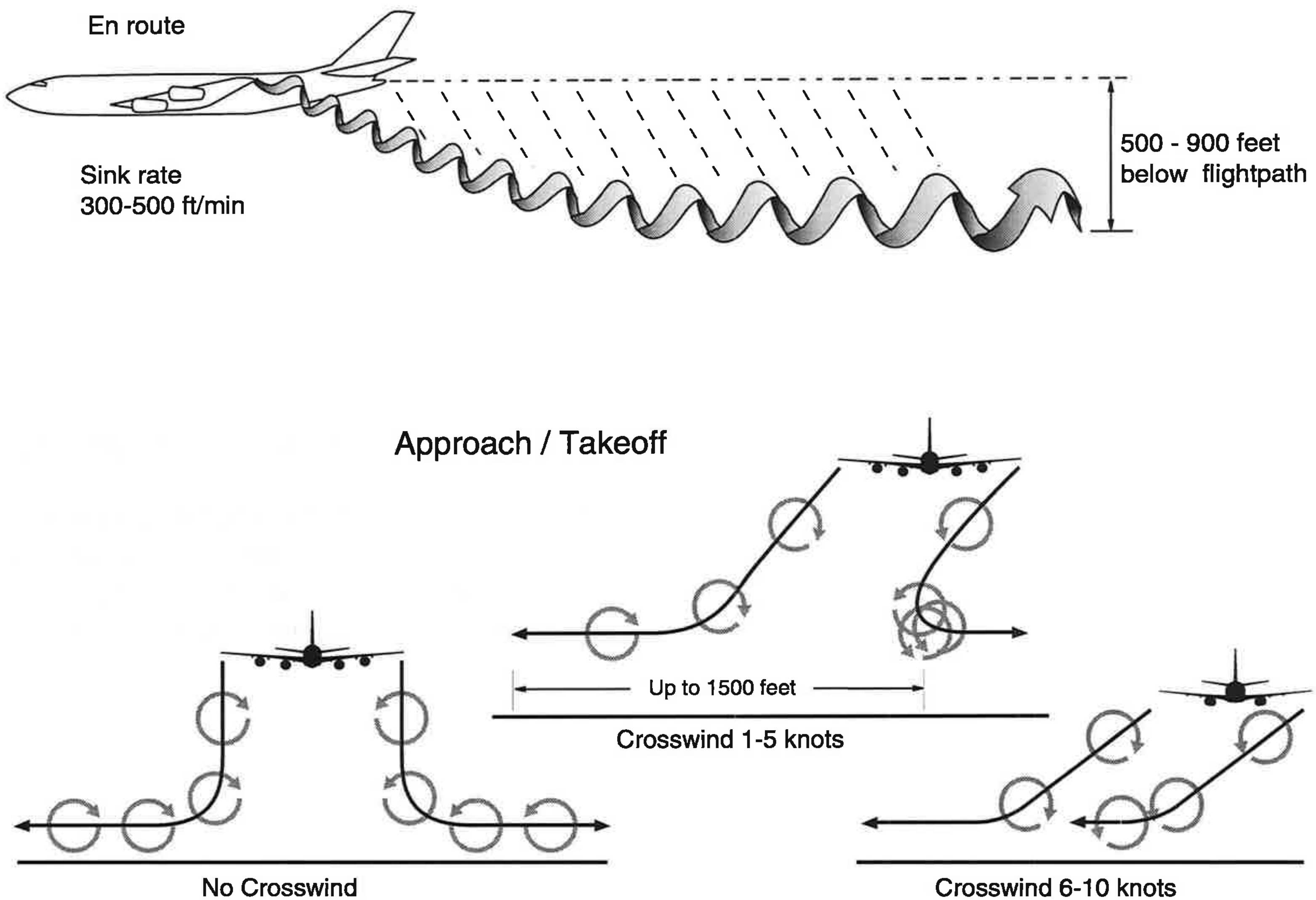
WAKE TURBULENCE SAFETY BRIEFING

Wake turbulence is generated from the moment aircraft leave the ground since it is a function of aircraft lift. At altitude, the two vortices begin to sink at a rate 300 to 500 hundred feet per minute for about 30 seconds. The rate then decreases and eventually approaches 0 at between 500 and 900 feet below the flightpath of the generating aircraft. Horizontal motion is dictated by the ambient wind and proximity to the ground.

At altitude, the wake's horizontal motion is determined by the velocity of the crosswind.

When the aircraft is near the ground on approach or takeoff, the wake descends below the flightpath until it enters ground effect. The two vortices then slow their downward descent and begin to move laterally. With no crosswind, the two vortices move apart at a height of about 60 feet AGL. Crosswinds greater than 6 knots cause the vortices to move quickly across the flightpath and to breakup rapidly.

Vortices have been found to move laterally in ground effect as much as 1500 feet under certain conditions.



En route
Sink rate
300-500 ft/min
500 - 900 feet
below flightpath
Approach / Takeoff
Up to 1500 feet
Crosswind 1-5 knots
No Crosswind
Crosswind 6-10 knots

Figure 9

The decay process of the wake is complex and is strongly influenced by atmospheric conditions. Normal turbulence and the internal circular motion of the vortex extracts energy. Sometimes, a small amount of turbulence in the atmosphere can also cause the two vortices to join which quickly dissipates their strength.

The wake will retain its strength longer in calm wind conditions.

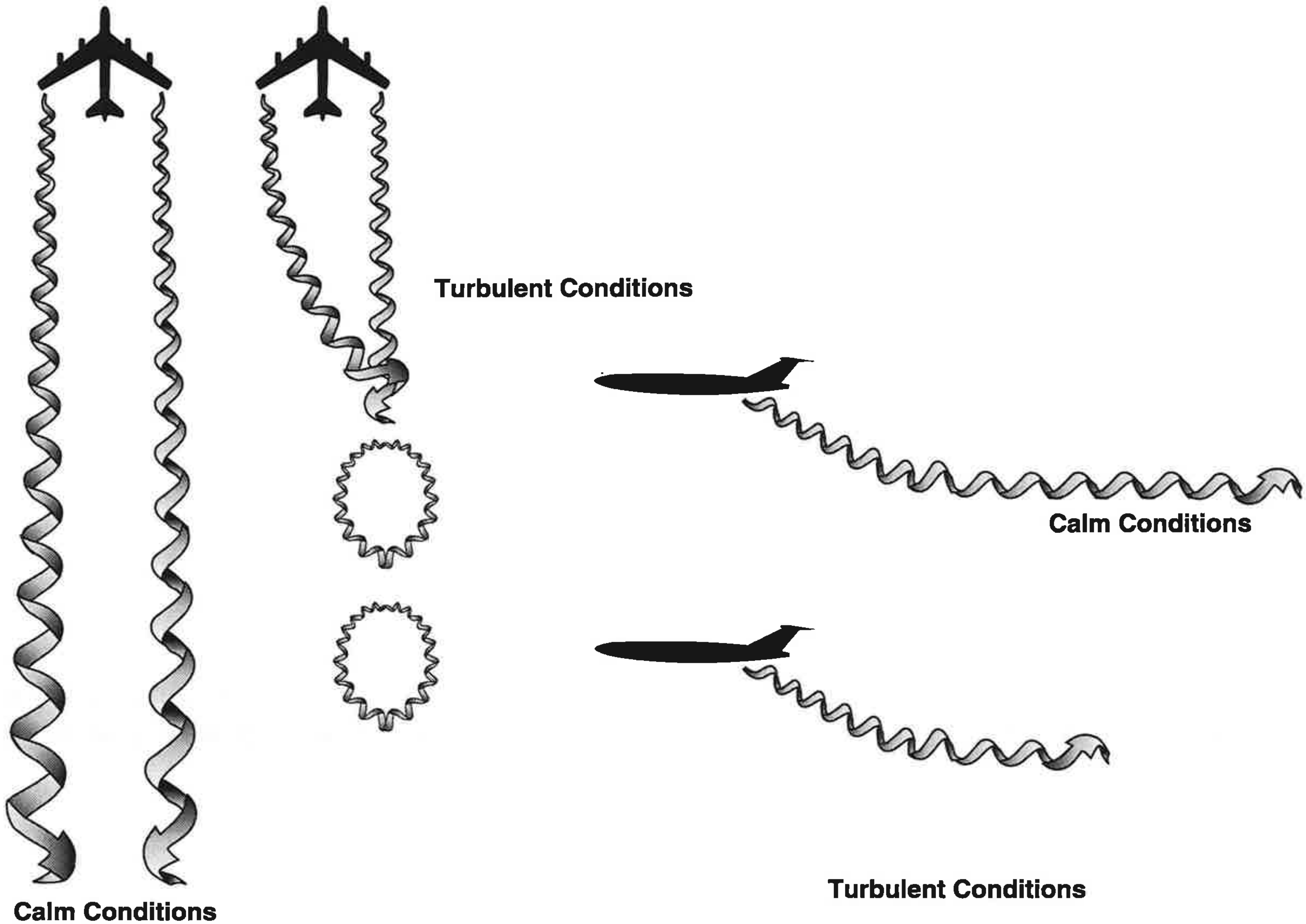

Turbulent Conditions
Calm Conditions
Calm Conditions
Turbulent Conditions

Figure 10

WAKE TURBULENCE SAFETY BRIEFING

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

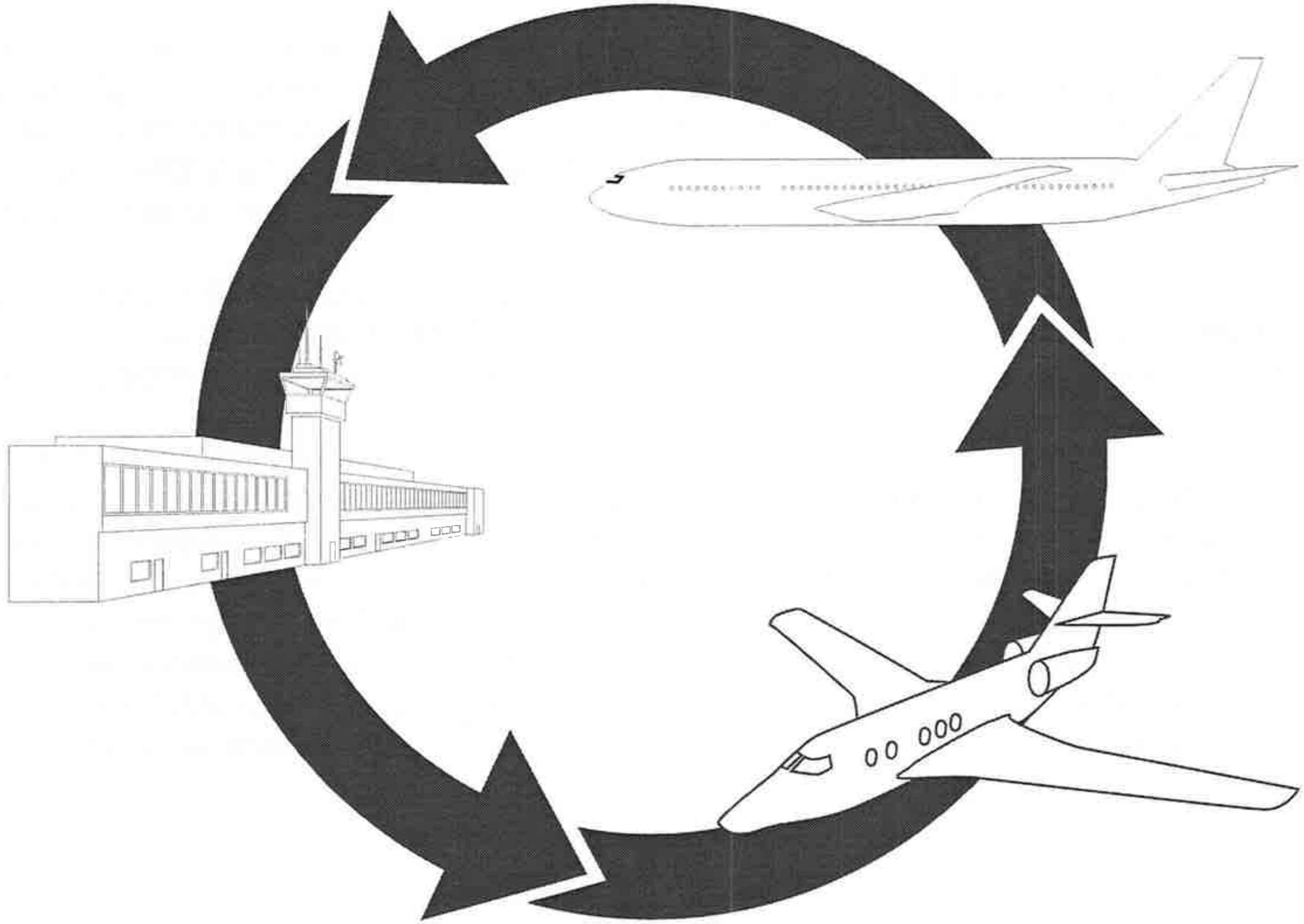


Figure 11

When providing radar service to the aircraft, air traffic controllers apply wake-turbulence longitudinal separation distances between IFR aircraft and to VFR aircraft in some terminal areas. The amount of distance between aircraft is dependent on the weights of the aircraft. This is because aircraft weight is a major factor in producing the strength of the wake turbulence. The distance between aircraft allows time for the wake turbulence to descend below the flightpath of the leader aircraft and begin to dissipate. Controllers are required to maintain this minimum radar controlled separation until the pilot accepts visual separation or a visual approach for landing.

Tower controllers are responsible for runway separation for arriving or departing the airport; however, tower controllers do not provide visual wake-turbulence separations to arrival aircraft. That is the pilot's responsibility.

Wake turbulence separation for departing aircraft is provided by the tower controller by applying takeoff time intervals between aircraft. The intervals are based upon aircraft weight categories and the runway situation. Distinctions are made for parallel runways separated less than 2500 feet, intersecting runways, or same runway and whether takeoffs are in the same, opposite, or intersecting direction.

Figure 12

ATC wake turbulence advisory:

- Air traffic controllers are required to provide a "Caution-Wake Turbulence" advisory when VFR aircraft are not being radar vectored and are behind heavy category jets or B-757s. The caution must also be issued to IFR aircraft that accept visual separation or a visual approach.

- Controllers may issue a caution anytime wake turbulence may have an adverse effect on an aircraft following another aircraft.

- 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.

"CAUTION - WAKE TURBULENCE"

Figure 13

Pilots are responsible for avoiding wake turbulence:

- when flying in visual flight rules and not being radar vectored
- when maintaining visual separation
- when cleared for a visual approach.

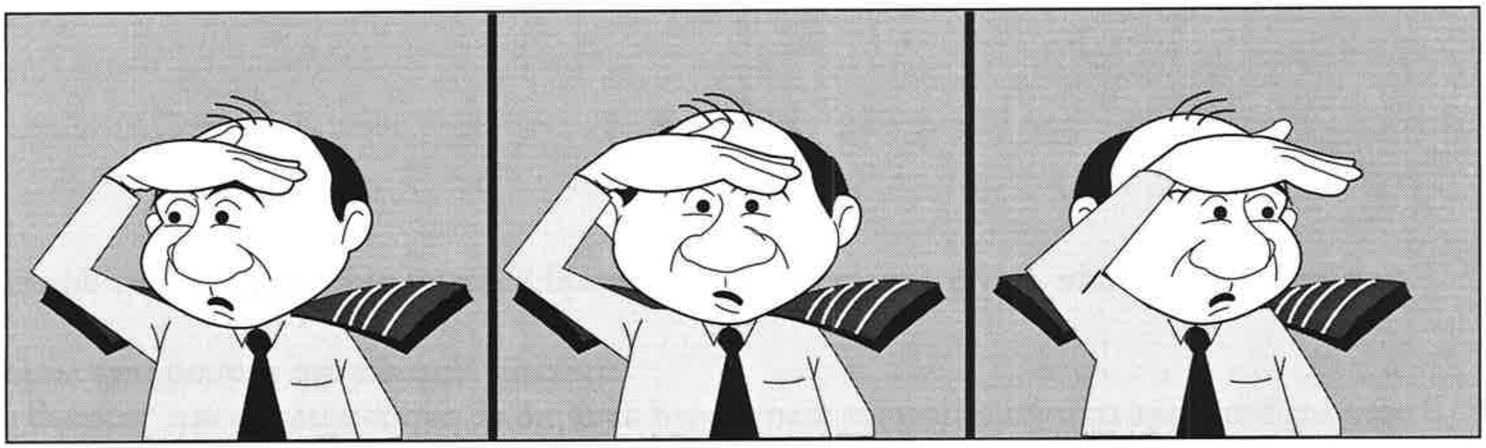
If VMC exist when ATC is providing IFR radar control, the pilot is not relieved of the responsibility for assuring his/her flightpath will avoid an encounter with wake turbulence.

When it is operationally beneficial, ATC may authorize the pilot to conduct a visual approach to an airport or to follow another aircraft in VMC. The pilot must have in sight, the airport or an aircraft identified by ATC as an aircraft to follow during the approach, before the clearance is issued. When the pilot is able to comply and accepts the clearance, he/she also assumes responsibility for avoiding wake turbulence.

The pilot may request a waiver to air-traffic-control imposed wake-turbulence timing separation requirements between takeoffs. If no other traffic conflict exists, the tower controller will then advise the pilot of potential wake turbulence and clear the aircraft for takeoff.

Pilots are also responsible for avoiding wake turbulence during cruise flight VFR, when altitude separation could be as little as 500 feet between IFR and VFR aircraft.

Some aircraft wake-turbulence weight categories require the pilot to identify the aircraft category (i.e., Heavy) when communicating the flight's call sign during radio transmissions.



Visual Flight Rules — Maintaining Visual Separation — Cleared for Visual Approach

Figure 14

Pilots must rely on their knowledge of the behavior and characteristics of wake turbulence to visualize its location so that it may be avoided. Avoidance procedures were developed for various situations. These procedures may require you to adjust your normal operations or flightpath. Make sure you consider your aircraft performance when using these procedures.

In general, the recommended avoidance procedures assist the pilot in avoiding the area below and behind the leading aircraft.

During the approach and landing phase, a go-around may be the appropriate solution.

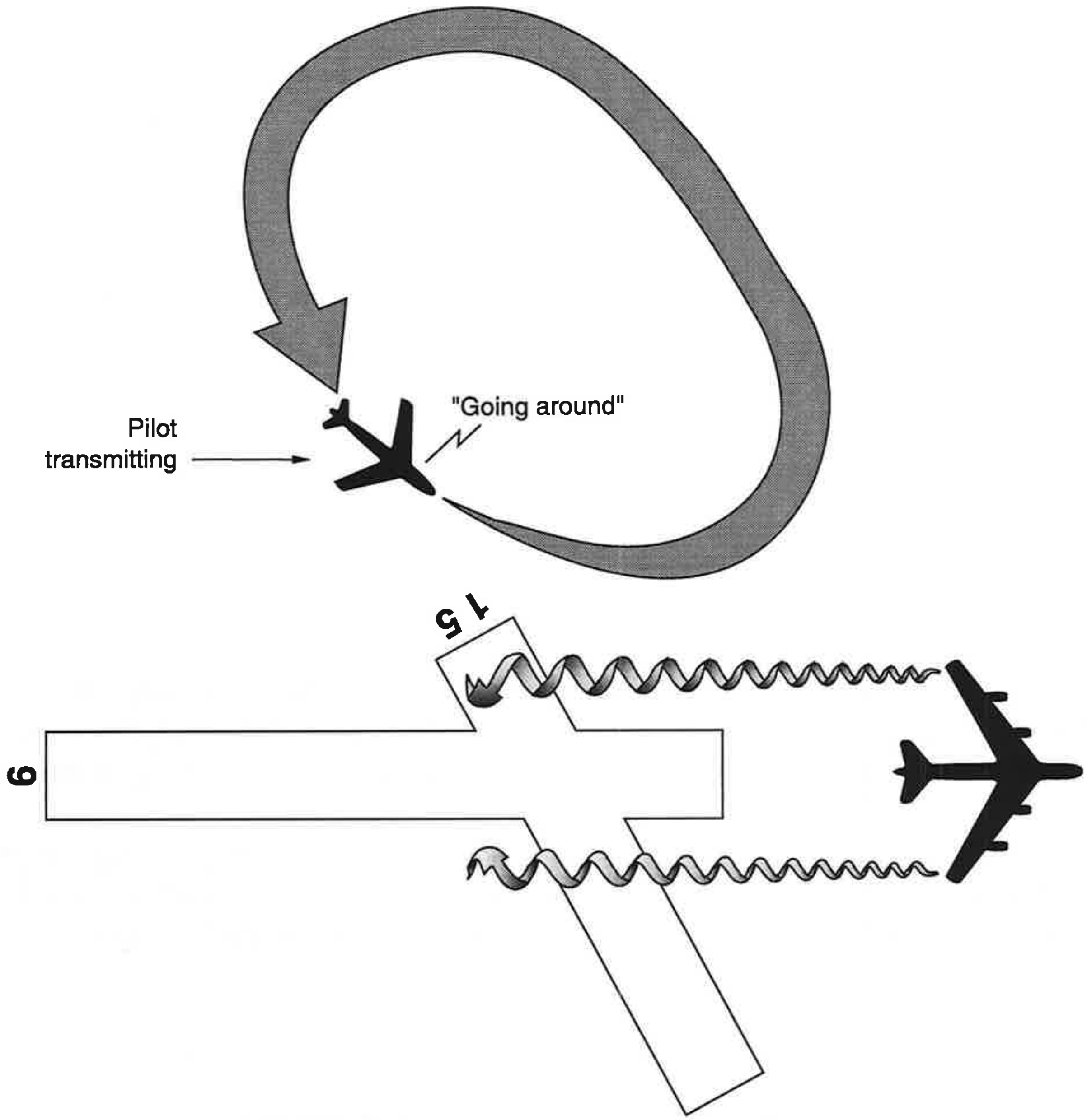
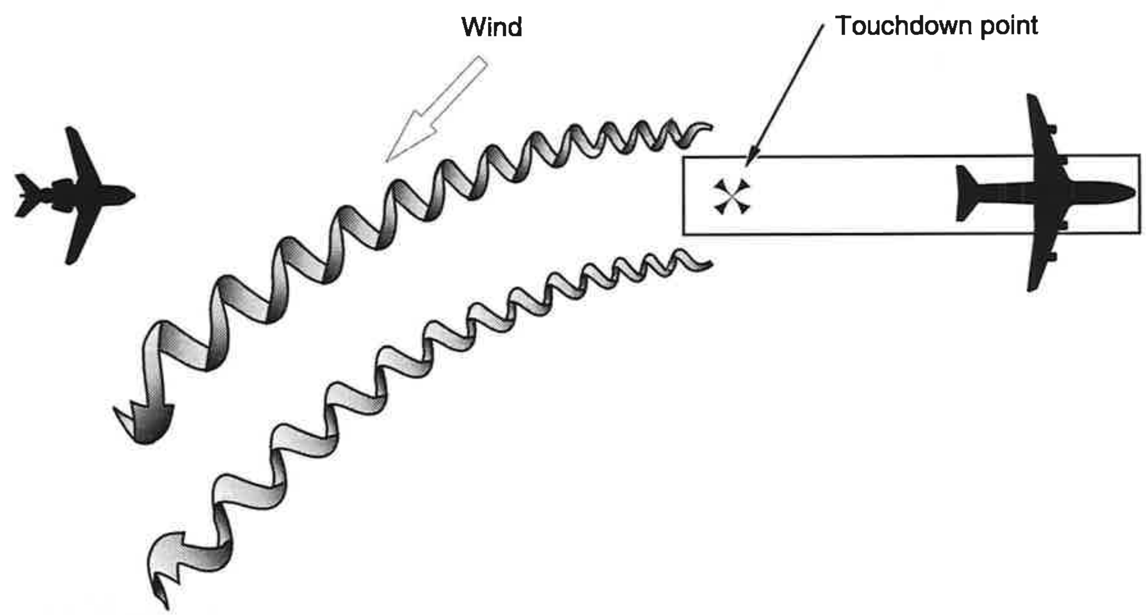


Figure 15

Now, let's review the recommended wake-turbulence avoidance procedures for several different flight situations. These procedures are also listed in the Airman's Information Manual and the FAA Advisory Circular on wake turbulence.

The first situation discussed is landing behind a larger aircraft landing on the same runway. Stay at or above the leading aircraft's flightpath and note its touchdown point and land beyond it. Assure that sufficient runway is available for your landing.

Avoidance Procedures: Landing



Same Runway:

Behind a larger aircraft that is using the same runway, fly at or above leader aircraft's final approach flightpath

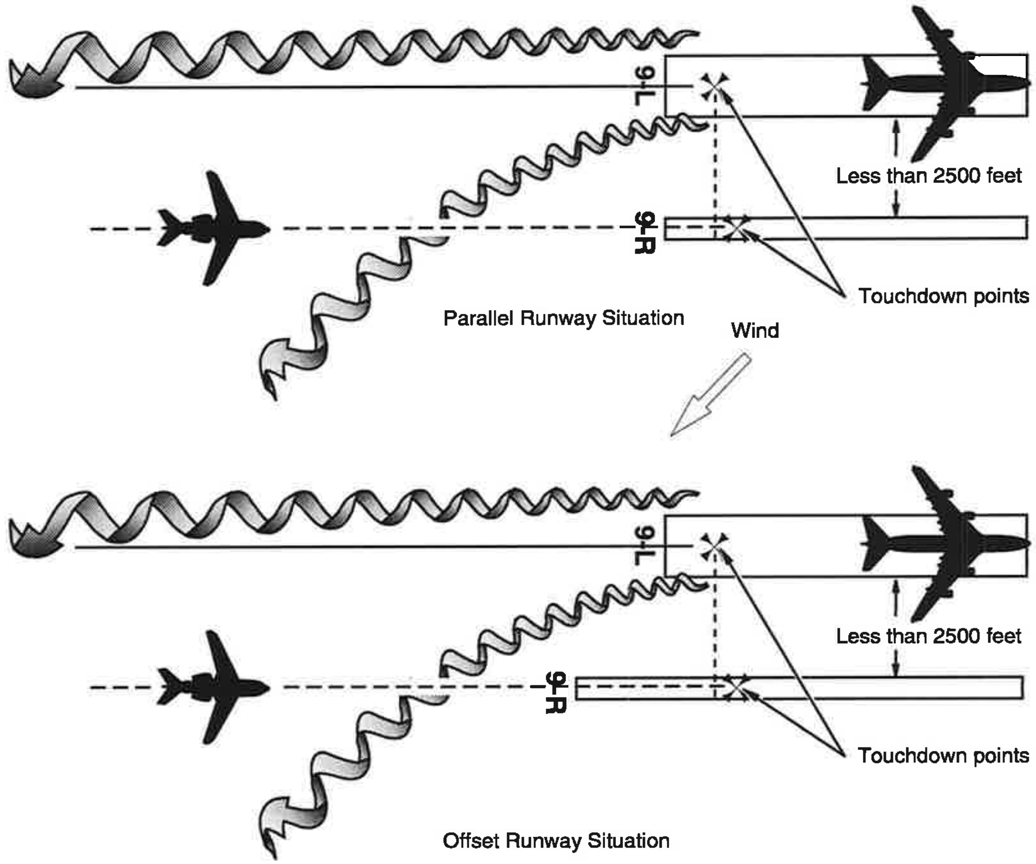
Note touchdown point

Land beyond the touchdown point if there is enough runway

Figure 16

When it is necessary to land behind a larger aircraft that is using a parallel runway located closer than 2500 feet, you should be alert for the possibility that its wake turbulence may drift over to your runway especially if the parallel runways have displaced thresholds. Note its touchdown point, and adjust your touchdown point if necessary. Wake turbulence from flight operations on parallel runways that are more than 2500 feet apart should not be a hazard to your approach and landing.

Avoidance Procedures: Landing



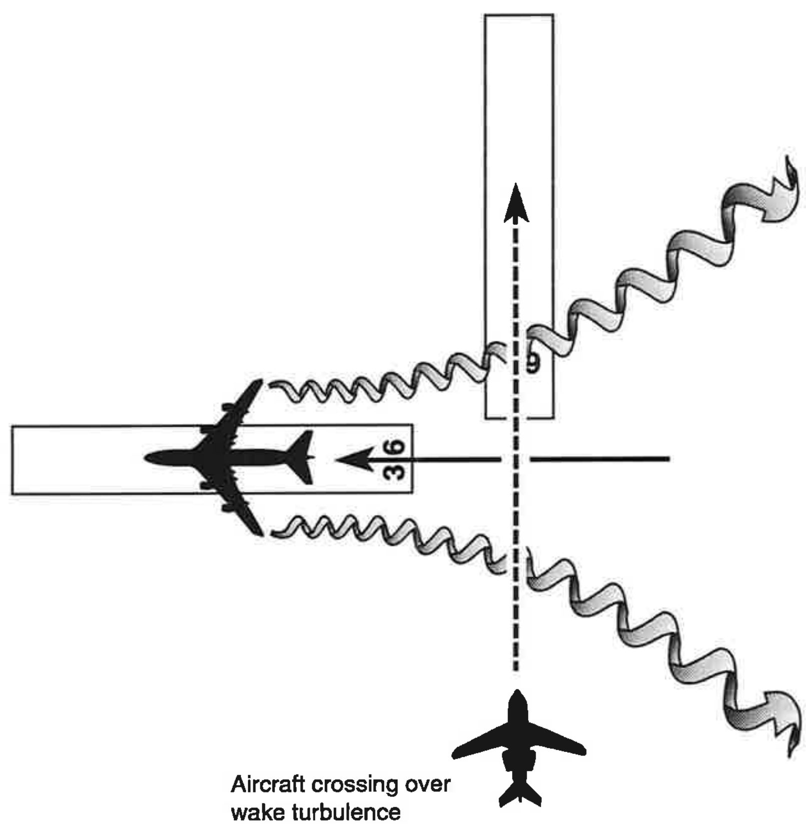
Parallel and Offset Runways Closer Than 2500 Feet:

Consider wake turbulence drift over to runway above flightpath
Note touchdown point

Figure 17

When landing behind a larger aircraft that is using a crossing runway, it is necessary to cross above its flightpath.

Avoidance Procedures: Landing



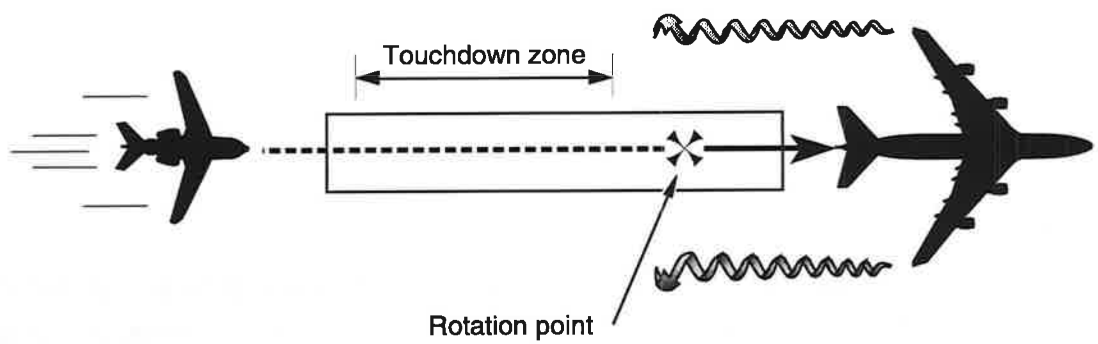
Crossing Runway:

Landing behind a larger aircraft that is using a crossing runway
Cross above the larger aircraft's flightpath

Figure 18

When you land on the same runway behind a departing larger aircraft, you should note its rotation point and land well before that point. This is because the departing aircraft will begin producing significant wake turbulence as it lifts off the runway.

Avoidance Procedures: Landing



Same Runway:

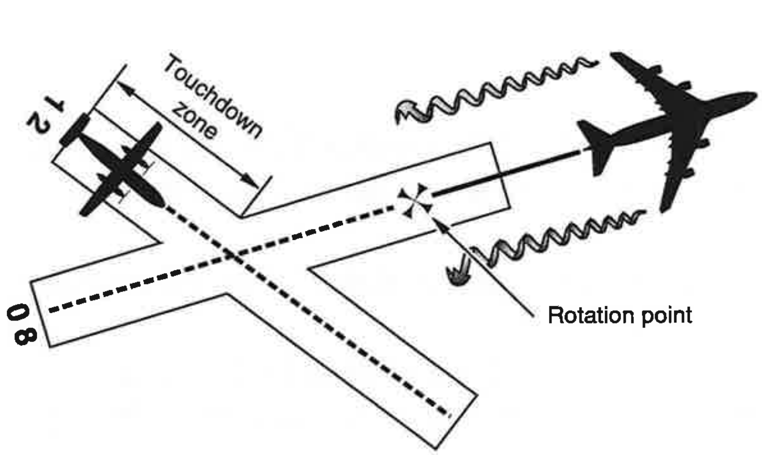
- **Landing behind departing aircraft that is using the same runway**
  - **Note rotation point**
  - **Land prior to rotation point**

Figure 19

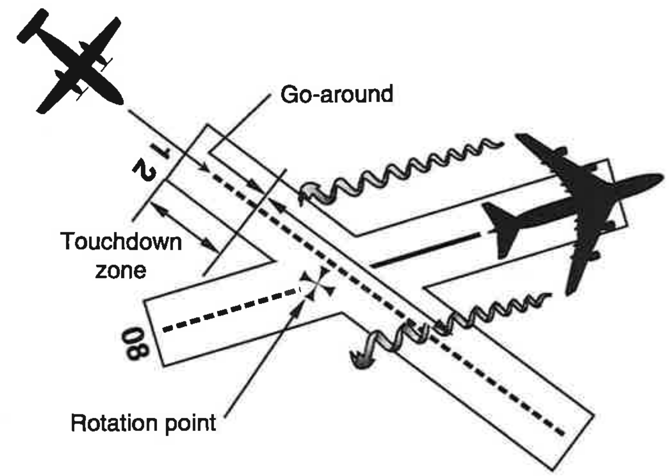
Making a landing behind a departing larger aircraft that is using a crossing runway is a more difficult situation. It is necessary to note the larger aircraft's rotation point and determine if it was past the intersection of the crossing runway. If it was past the intersection, continue your approach and make sure your landing is before that intersection. If the departing larger aircraft rotates before the intersection, avoid flight below its flightpath. Be alert for the possibility that the wake turbulence may drift over to your runway. Abandon your approach unless a landing is assured well before reaching the intersection.

Avoidance Procedures: Landing

Rotation past intersection



Rotation prior to intersection



Crossing Runway:

Landing behind a departing larger aircraft

Be alert for wake turbulence drift
Note larger aircraft's rotation point

Past the intersection??
- **Continue approach**
- **Land prior to intersection**

Prior to intersection??
- **Avoid flight below its flightpath**
- **Abandon approach unless landing well prior to intersection**

Figure 20

WAKE TURBULENCE SAFETY BRIEFING

There are some critical decisions necessary when you take off behind a larger aircraft. Your aircraft's performance can be a significant factor. Normally, the tower operator will apply appropriate time intervals between departing aircraft.

First, your should note the departing aircraft's rotation point and determine that your rotation will be before that point.

After your takeoff, climb upwind of the larger aircraft and continue to climb above its climb path until turning clear of its wake.

During your departure, be sure and avoid subsequent headings which will require you to cross below and behind the larger aircraft.

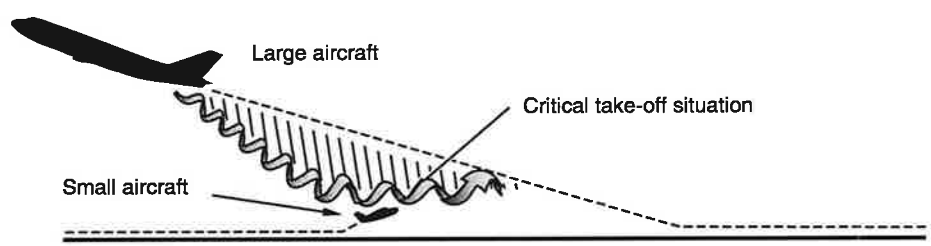
Be alert for any critical takeoff situation which could lead to a wake turbulence encounter.

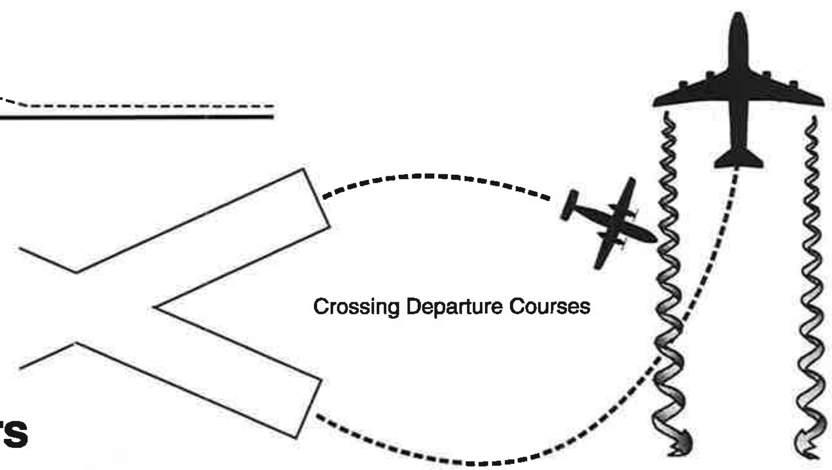
Delaying your takeoff to allow time for generated wake turbulence to dissipate or move away from the runway, should be your first choice in your decision making.

Avoidance Procedures: Takeoff

Same runway:

- **Departing behind a larger aircraft**
  - **Note rotation point and rotate before that point**
  - **Climb above previous aircraft's climb path before turning**
  - **Avoid a heading that will take you behind and below the larger aircraft's path**





Be alert of take-off encounters

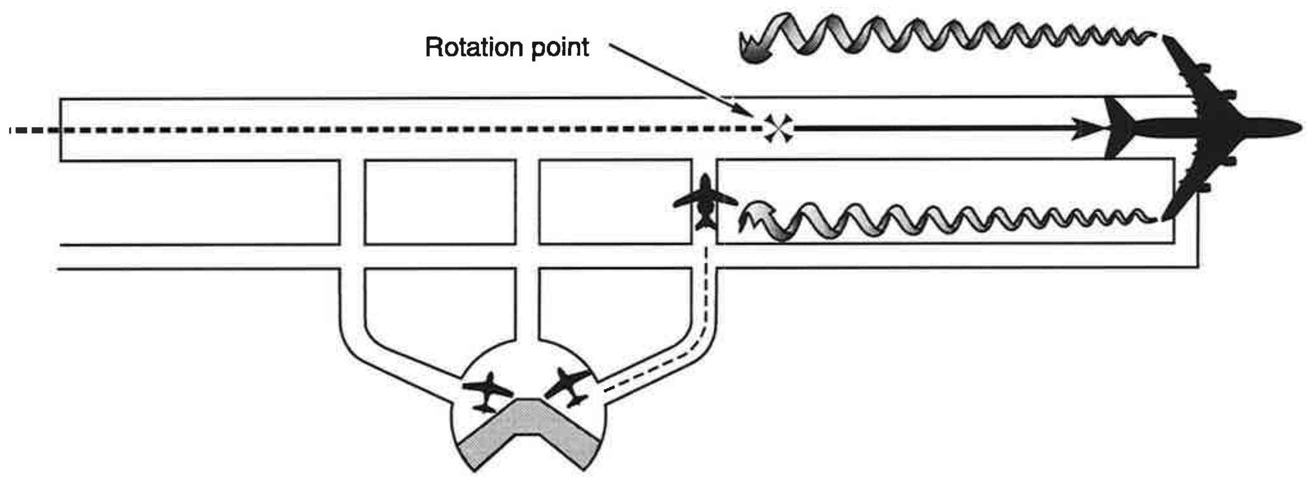
Figure 21

WAKE TURBULENCE SAFETY BRIEFING

Be alert to adjacent larger aircraft operations when you make a takeoff from a runway intersection, particularly those that are upwind of your take-off position.

After takeoff, plan to avoid any subsequent heading which will require you to cross below the larger aircraft's flightpath.

Avoidance Procedures: Takeoff



Intersection takeoff:

Be aware of operations upwind

Avoid headings that will take you below the lead aircraft's flightpath

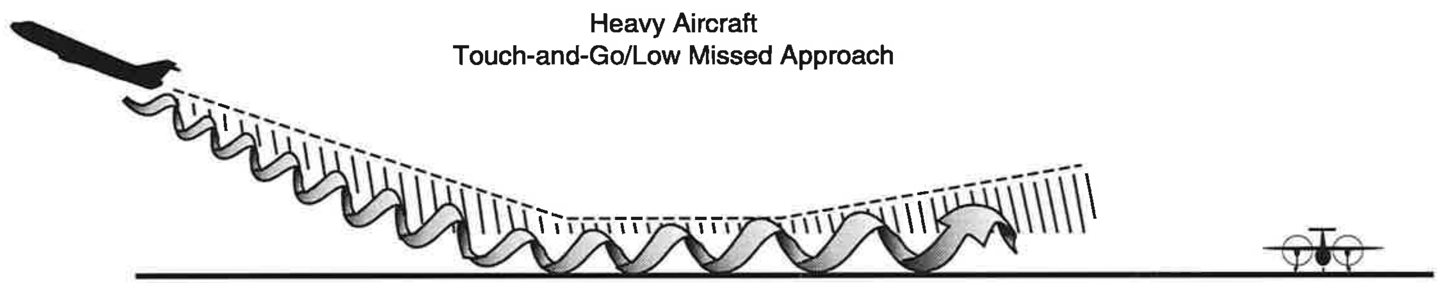
Figure 22

WAKE TURBULENCE SAFETY BRIEFING

Assure that an interval of at least 2 minutes has elapsed before taking off after a heavy aircraft has executed a low approach, missed approach, or touch-and-go landing. This is because the wake turbulence settles and moves laterally near the ground and may exist along the runway and in your flightpath. This is particularly true in light quartering tailwind conditions.

Avoidance Procedures: Takeoff

Wait 2 minutes



Departing takeoff:

Departing after a heavy aircraft's:

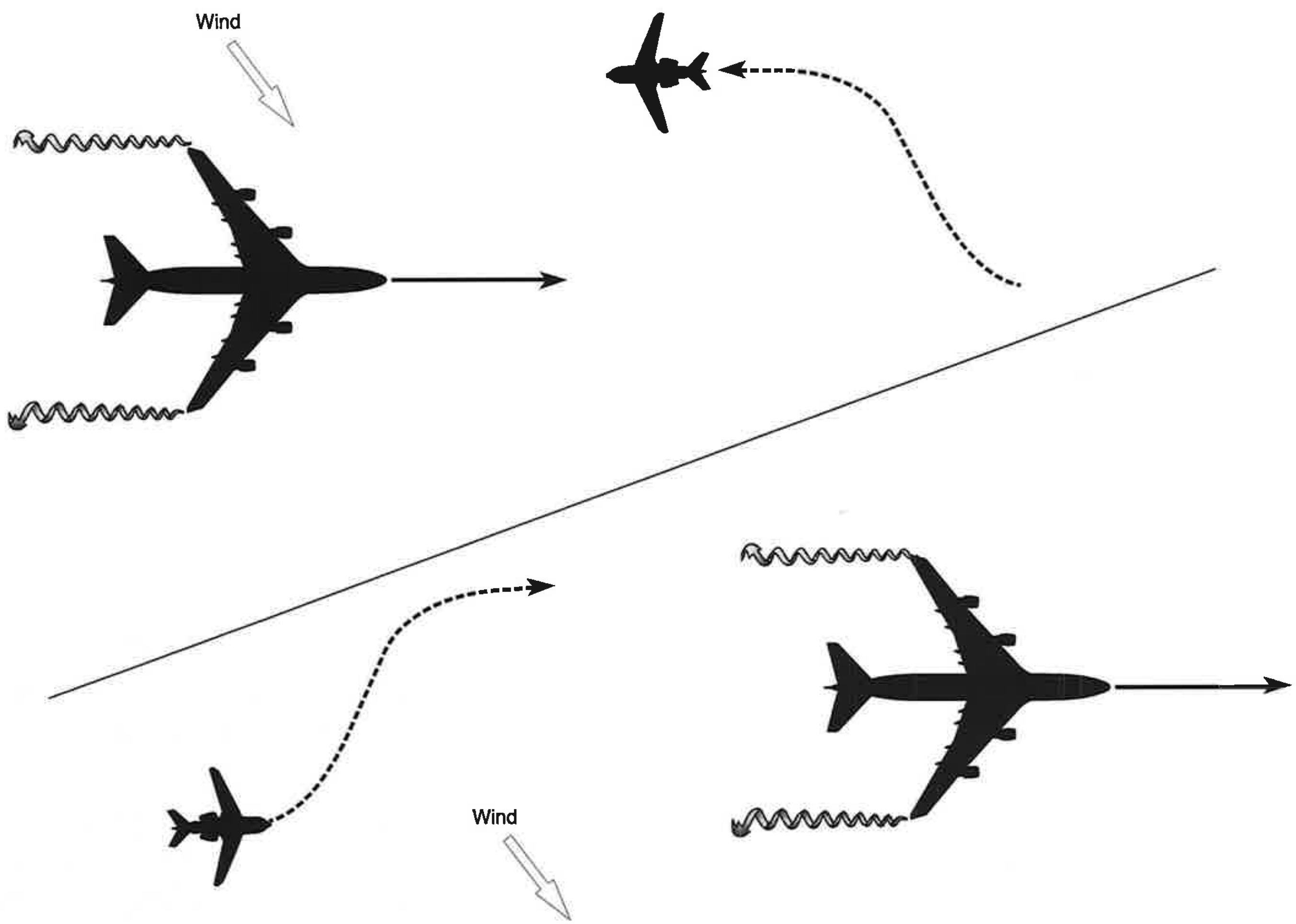
- **low approach**
- **missed approach**
- **touch-and-go**

Figure 23

For en route VFR situations where the cruise altitude is usually at 1000 foot plus 500 feet, normal logic prevails: Avoid flying behind and below a large aircraft's flightpath.

If you observe a larger aircraft above and on your same track (meeting or overtaking), adjust your position laterally, preferably to the upwind side.

Avoidance: En Route



Avoid path below larger aircraft
Adjust position upwind - if possible

Figure 24

WAKE TURBULENCE SAFETY BRIEFING

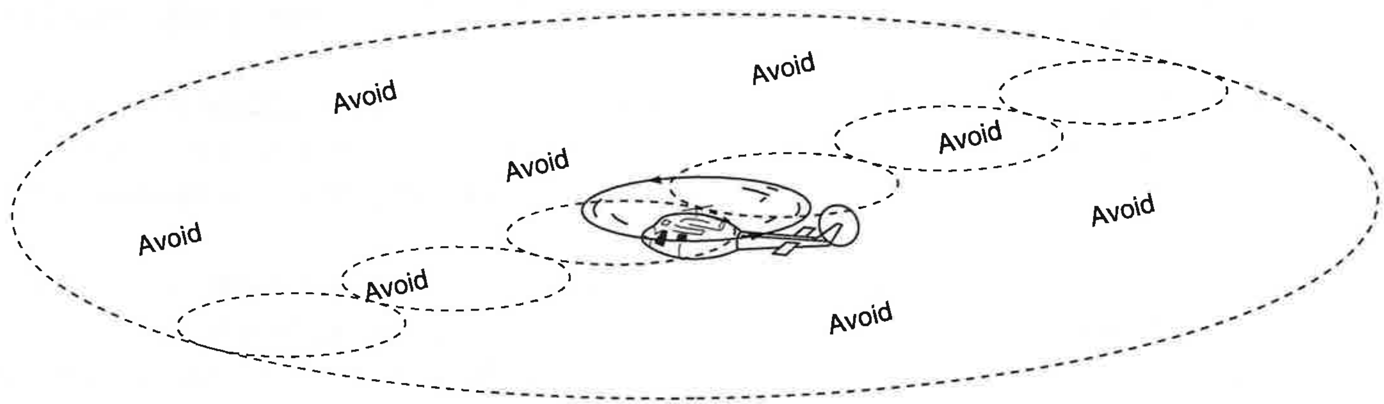
Hovering helicopters produce rotor downwash that turns into outwash when it contacts the surface and moves in all directions. Pilots of small aircraft should avoid operating within a distance equal to 3 times the helicopter rotor diameter.

When a helicopter is operating in forward flight, it produces wake turbulence similar to fixed-wing aircraft. Pilots of small aircraft should use caution when operating behind or crossing behind landing and departing helicopters.

Avoidance Procedures: Helicopter Wake Turbulence

Slow hover taxi or stationary hover

Avoid operations within distances of 3 times rotor diameter



Forward flight, landing and departing helicopters

Small aircraft, use caution behind/crossing behind

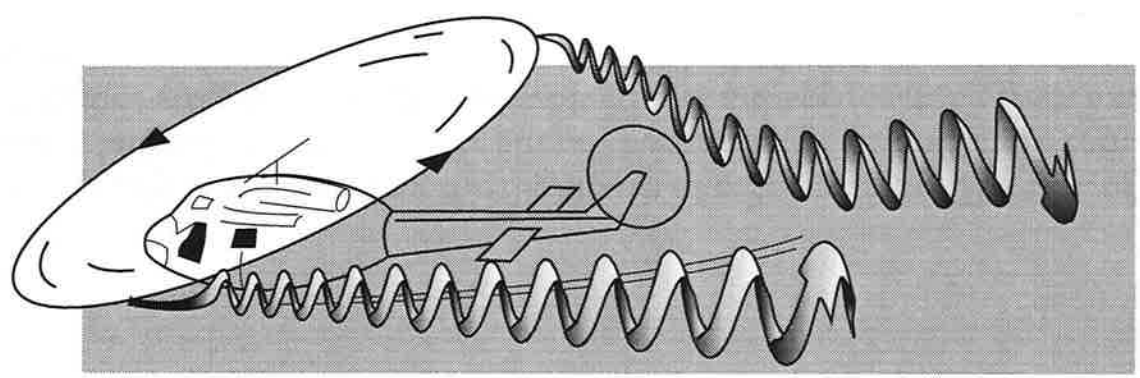


Figure 25

Pilots have difficulty in determining the flightpath of other aircraft. The task of maintaining proper visual relationship with a leader aircraft becomes greater and more complicated when aircraft of different sizes and speeds are involved and are approaching from various altitudes and directions.

Do not make an assumption that because a leader aircraft is below you that its flightpath is or was also below you. It is possible the leader aircraft varied its descent rate, especially during the initial portion of its approach.

An ILS glideslope can be a starting point for assistance in determining a leader aircraft's flightpath, but it is not foolproof. In fact, the leader aircraft may have flown above the glideslope for wake-turbulence avoidance or other reasons.

Pilots can experience visual illusions for several reasons:

Aircraft sizes can make it difficult in judging distances and rates of closure.

Changing aircraft body attitudes can be confused with a change in flightpath.

Depth perception is inhibited during darkness because you have only the other aircraft's lighting to determine its flightpath.

Reduced weather visibility also makes it difficult in determining another aircraft's flightpath.

Problems in Visually Maintaining Separation

Different aircraft
- Sizes
- Speeds
- Altitudes
- Approach directions

Changing descent rates
ILS glideslope adjustments
Visual Illusions
Darkness
Reduced visibility weather

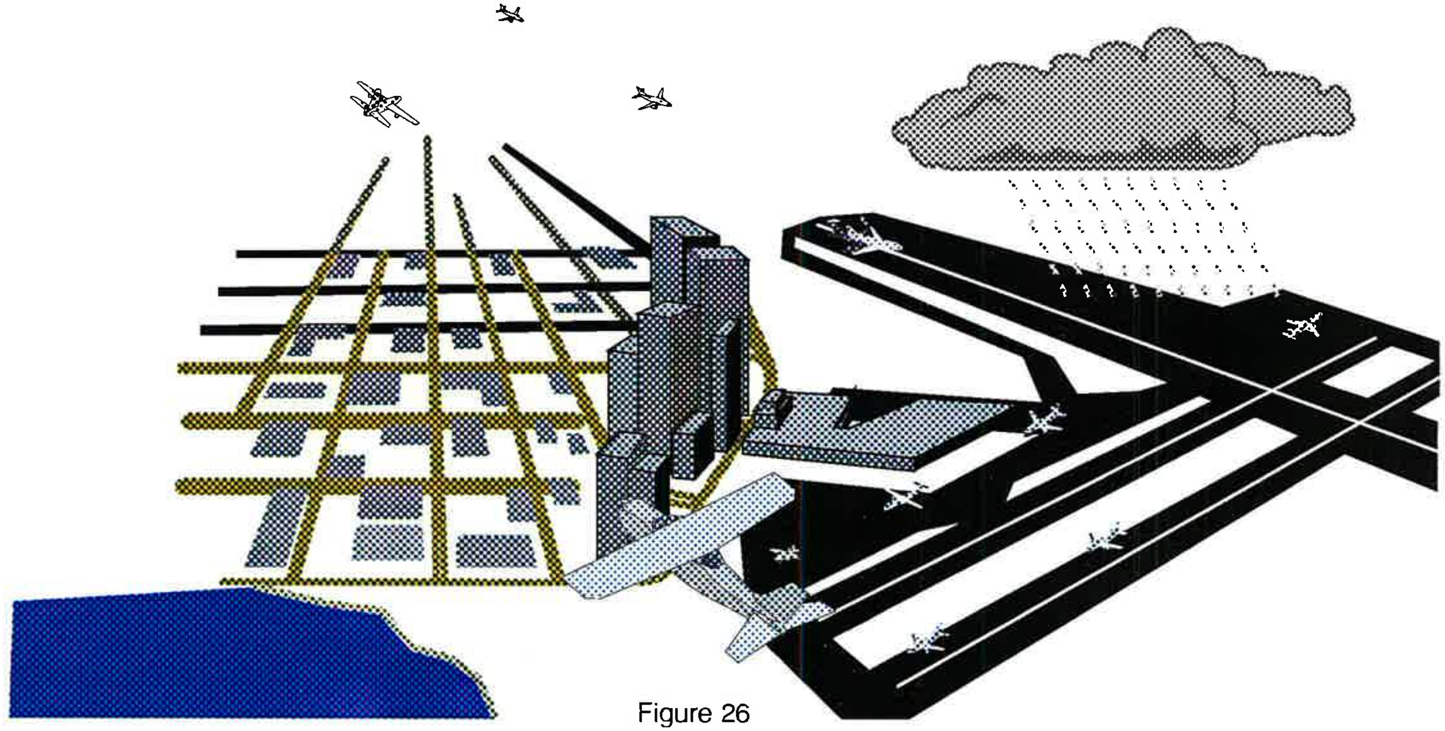


Figure 26

Now that we have reviewed the recommended wake-turbulence avoidance procedures, let's look at some techniques available to help you with visually maintaining separation. Remember, the pilot is responsible for maintaining separation from wake turbulence by positioning his / her aircraft vertically, laterally or longitudinally away from the turbulence.

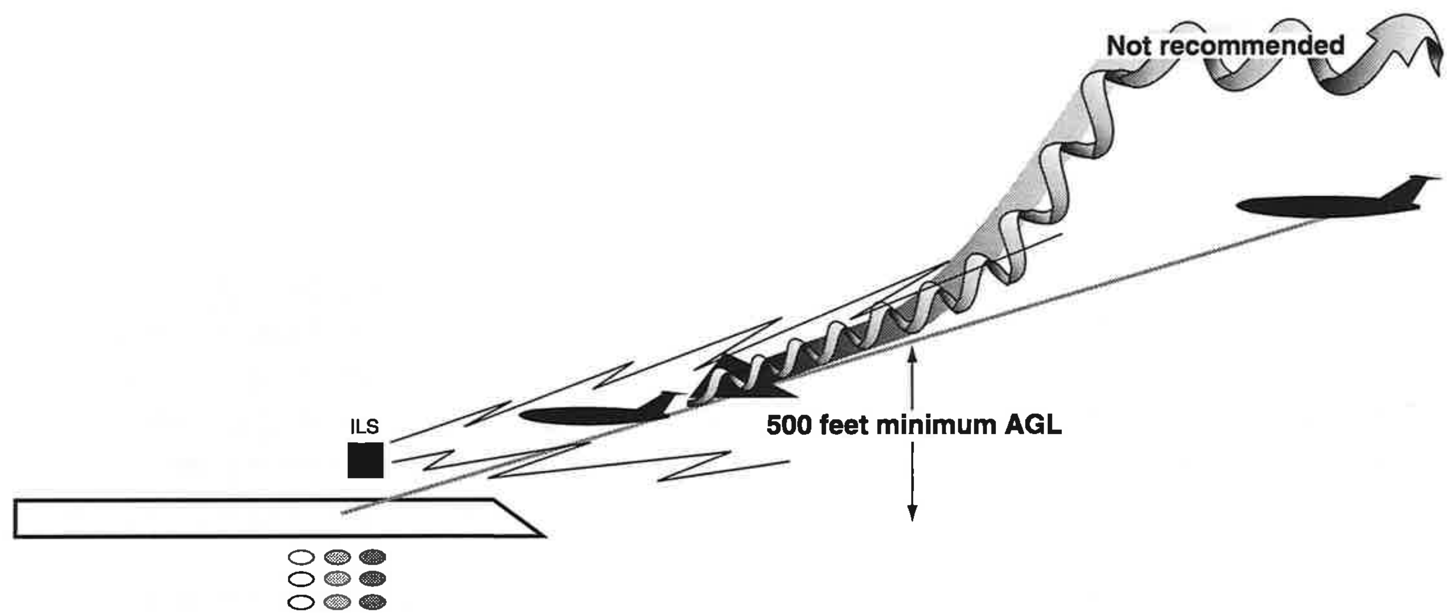
A key in employing many of the recommended visual avoidance procedures is to be aware of a leader aircraft's flightpath. Pilots must make some assumptions on where a leader aircraft has flown. If pilots fly a normal 3-degree flightpath during an approach, it will aid a trailing pilot in judging the flightpath.

Steep descents may have serious ramifications for trailing pilots with regard to wake turbulence.

The use of visual glideslope indicators such as VASI or PAPI or instrument precision approach aid will assist in flying a normal approach flightpath.

The aircraft should be stabilized on the flightpath not lower than 500 feet AGL.

Techniques for Visually Maintaining Separation



Fly normal flightpath:

- 3-degree flightpath
- Stabilize not lower than 500 feet AGL
- Use:
  - VASI
  - PAPI
  - Instrument precision approach aids

Figure 27

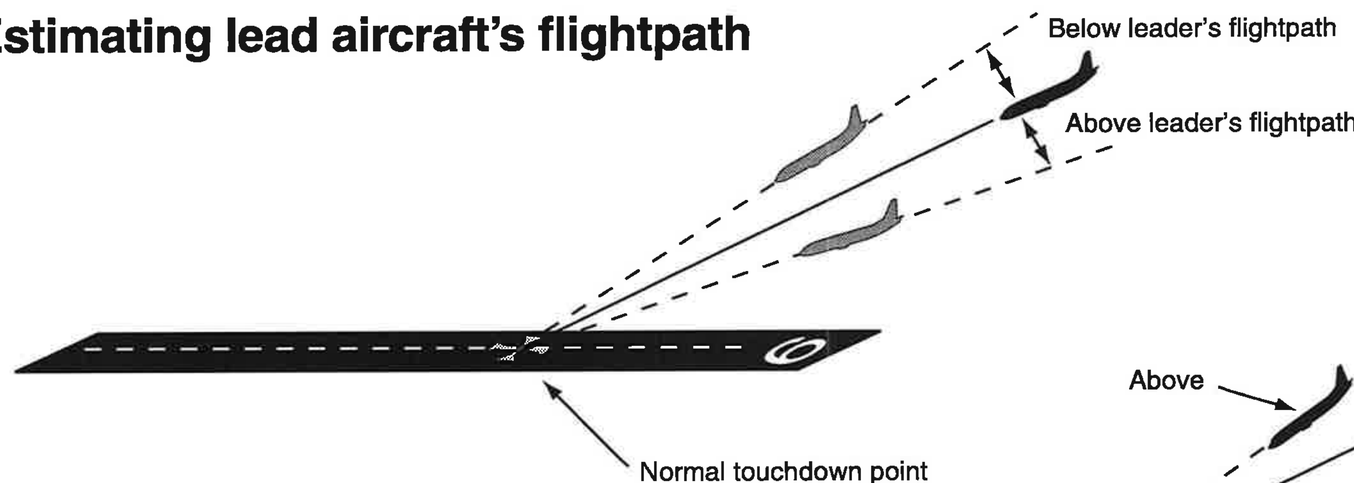
Visual cues are available to help pilots determine a leader aircraft's flightpath.

- Extend an imaginary line from your position to the runway normal touchdown point. 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 assumes the leader has flown a consistent flightpath and is using a normal runway touchdown point.

- While following an aircraft, extend an imaginary line from your aircraft through the lead aircraft to the runway. It should end at the normal runway touchdown point. If it ends at a point down the runway, the trailing aircraft is probably below the flightpath of the lead aircraft. If the imaginary line extension is before the touchdown point, e.g., in the overrun, the trailing aircraft is probably above the lead aircraft's flightpath.

Techniques for Visually Maintaining Separation

Estimating lead aircraft's flightpath



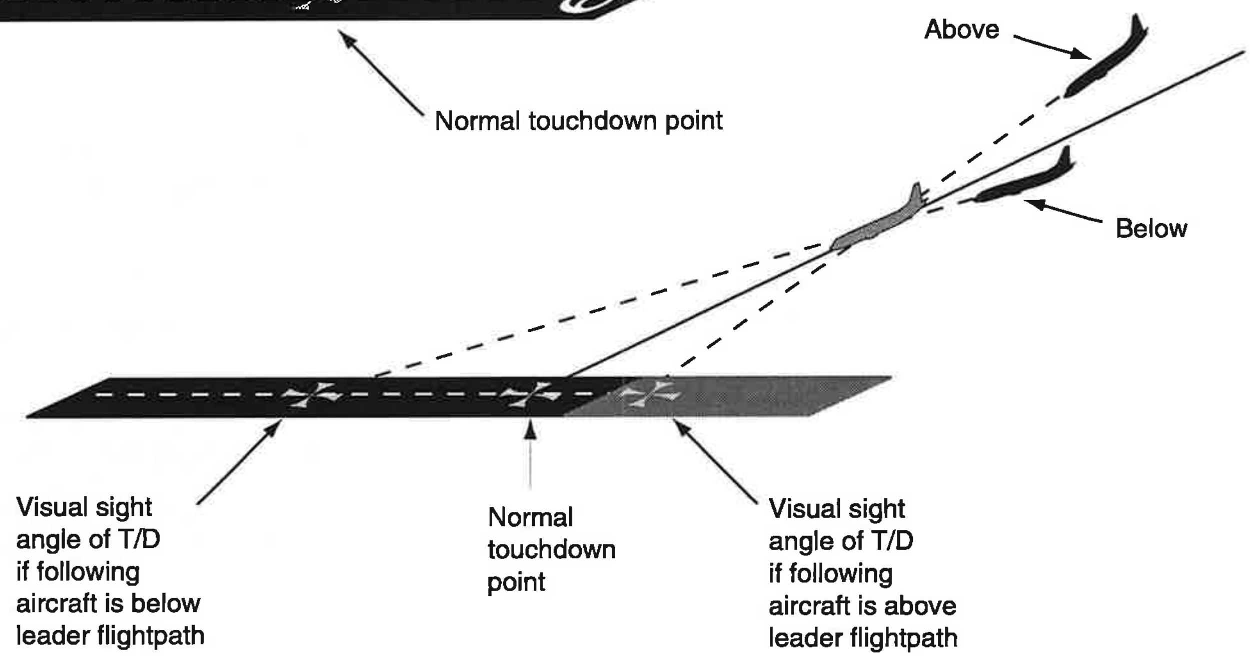


Figure 28

When ILS approaches are being used in VFR weather, consideration may be made by the pilot of the trailing aircraft to deviate from the normal glideslope and or localizer to avoid wake turbulence. This assumes that the lead aircraft is on localizer course and glideslope. Be alert! This is not always true.

- One-dot glideslope deviation is only 78 feet from the glideslope at 3 nautical miles. A two-dot deviation is only 156 feet at 3 nautical miles.

- Offsetting upwind one-dot localizer deviation is 573 feet at 3 nautical miles and 1,147 feet for a two-dot deviation.

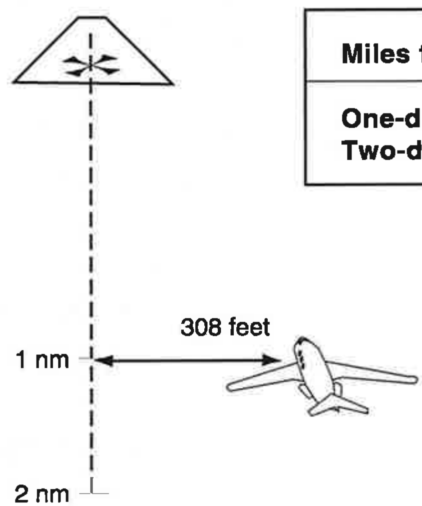
Techniques for Visually Maintaining Separation

Glidescope

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'

Localizer

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'



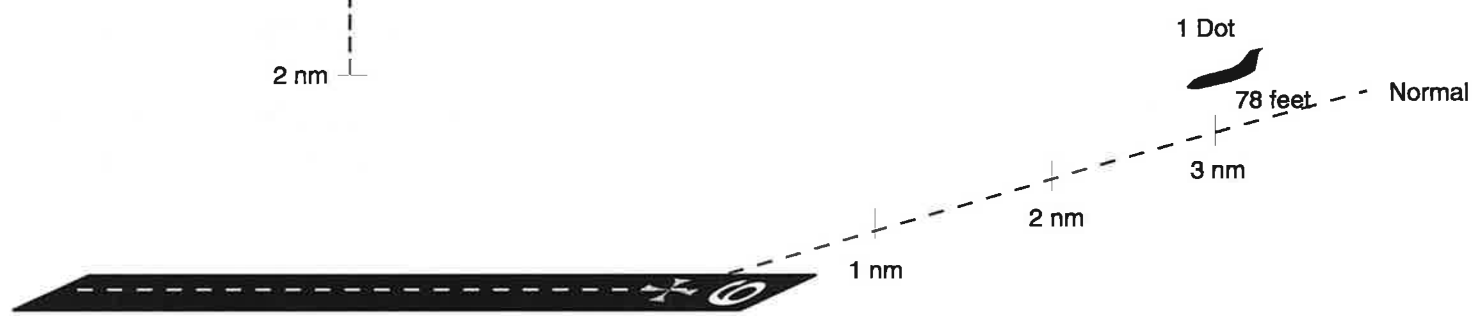


Figure 29

Pilots may establish longitudinal separation from aircraft to allow time for the wake turbulence to dissipate or move. Judging in-flight distances can be difficult.

- Air traffic control can assist with distances as well as airspeed differentials.

- Time and distance methods can also be used as aircraft pass over geographical or radio call points. It is helpful to know the distance from the runway to an instrument approach fix or an available landmark.

Several factors such as aircraft performance, in-flight visibility, other aircraft, etc., should be considered when increasing separation distances while established on final approach.

- Reduction of airspeed is usually the first choice for increasing distances. Pilots should not reduce airspeed below the aircraft's minimum safe operating speed. Be aware that recovery from an inadvertent wake-turbulence encounter is more difficult at slower airspeeds. Most transport aircraft final approach speeds are between 120 and 150 knots.

- Execute "S" turns or a 360 degree turn to increase separation.

- A go-around is always an alternative for avoiding wake turbulence.

Techniques for Visually Maintaining Separation

- Judging distances
    - ATC provided
    - Time and distance
- Achieving longitudinal separation
    - Speed reduction
    - "S" turns
    - 360s
- Go-around

Figure 30

Radio communications (not just those directed to you) can provide pilots with information which can improve wake-turbulence situational awareness. Prior to entering a traffic pattern or initiating an instrument approach, radio transmissions can alert pilots on where they may fit in the landing sequence or what type of aircraft they may follow. Take-off and landing clearances are useful for spacing considerations as well as anticipating the location of generated wake turbulence.

Basic surface wind indications can aid pilots with estimating the movement of wake turbulence. Blowing dust, smoke, and wakes on lakes and ponds are indicators of wind movement and can be applied to wake-turbulence movement. On-board avionics equipment, i.e., inertial reference, Doppler radar, and global positioning system (GPS) provide wind information. Observed aircraft drift angles will also give clues in determining wind direction.

Techniques for Maintaining Separation

Situational awareness:

- Radio transmissions
- Wake turbulence movement indicators

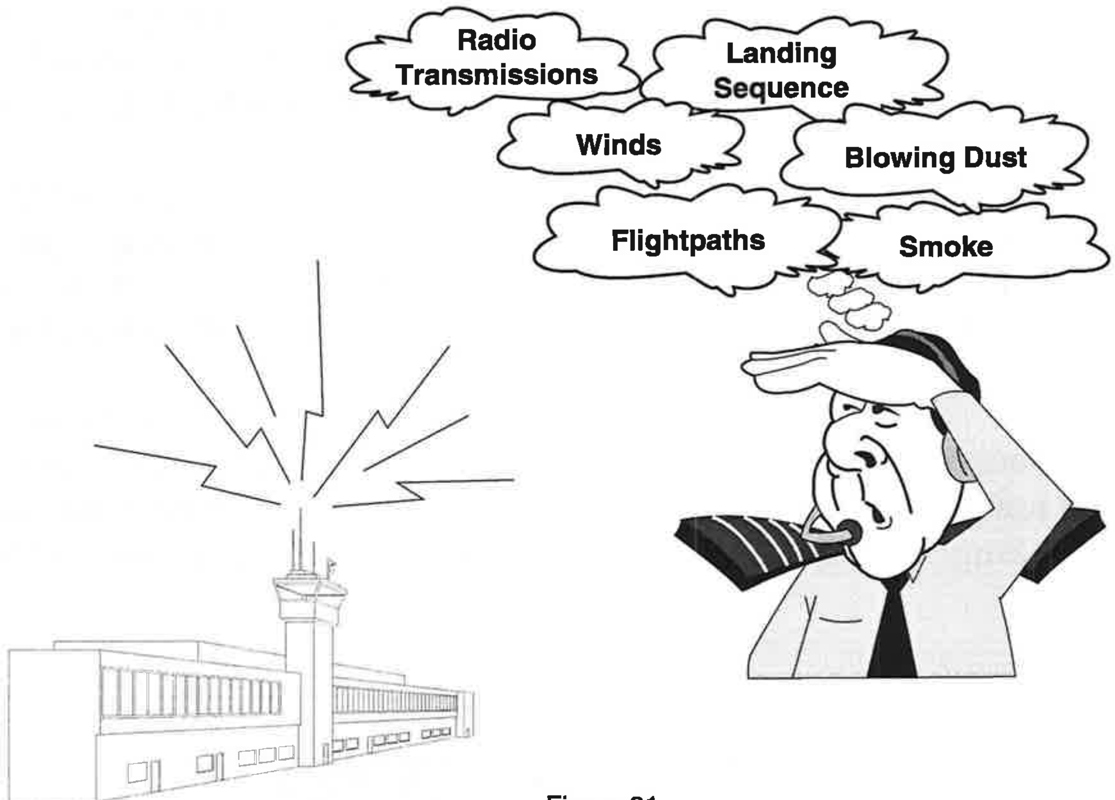


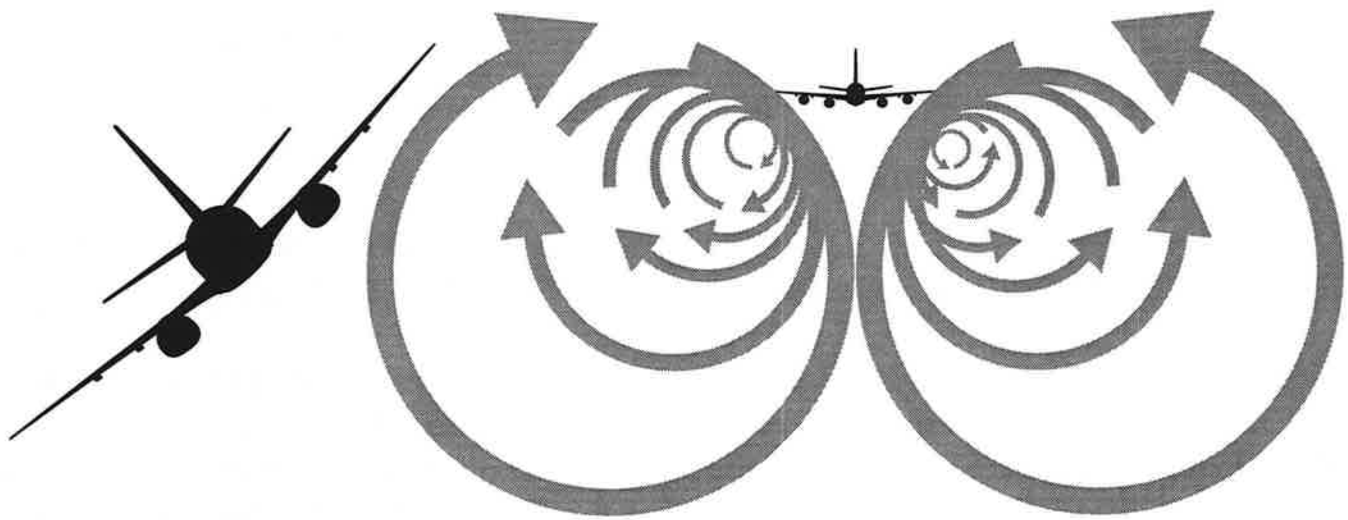
Figure 31

An encounter with wake turbulence usually results with induced rolling or pitch moments; however, in rare instances, an encounter could cause catastrophic in-flight structural aircraft damage. With all encounters, without a concerted effort by the pilot, the aircraft will be expelled from the wake.

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 wingspans (relative to the generating aircraft) to counter induced roll.

It may be difficult or impossible for pilots to differentiate between wake turbulence and turbulence generated from another source (like windshear). Pilots should analyze the conditions in which they encounter turbulence in order to determine if it was wake turbulence and apply appropriate procedures if wake turbulence is suspected to be present. An inadvertent encounter at low altitude is much more hazardous than an encounter at cruise altitude or early during the approach phase of flight.

Pilot Response If Wake Turbulence Encountered



- Short wingspan increases difficulty of countering induced roll
- Difficult to determine wake turbulence from windshear/normal turbulence
- Low-altitude encounter extremely hazardous

Figure 32

WAKE TURBULENCE SAFETY BRIEFING

Air Traffic Control is responsible for the safe, orderly, and expeditious flow of all aircraft in their area of responsibility. A controller's ability to do this is affected by several considerations in addition to wake turbulence.

Weather conditions determine separation considerations. Visual conditions provide advantages to better service.

More aircraft can land and take off if the weather is VFR and visual approaches are used. Separations will be approximately 1-1/2 miles between landing and arriving aircraft. Under IFR weather conditions, a minimum separation of 2-1/2 miles is required inside the final approach fix. If wake-turbulence separation is required, the separation can extend to 6 nautical miles. Visual conditions and visual separation allow controllers to handle more aircraft within the system. When a pilot takes responsibility for aircraft separation, the controllers can concentrate their efforts on the remaining IFR aircraft.

The following wake-turbulence factors should be considered (if appropriate) when clearing a pilot to maintain visual separation or approach:

Winds	Place smaller aircraft upwind of larger aircraft when possible
Relative airspeeds	Consider the impact of closure
Intersecting runways	Anticipate the effect on future flightpath situations
Aircraft departures	Consider the effect or a go-around of arriving aircraft
Relative flightpaths	Do not vector aircraft below leading aircraft
	Avoid steep aircraft descent situations

Air Traffic Control Considerations

Cleared for the visual!

- **Winds**
- **Relative airspeeds**
- **Intersecting runways**
- **Aircraft departures**
- **Relative flightpaths**

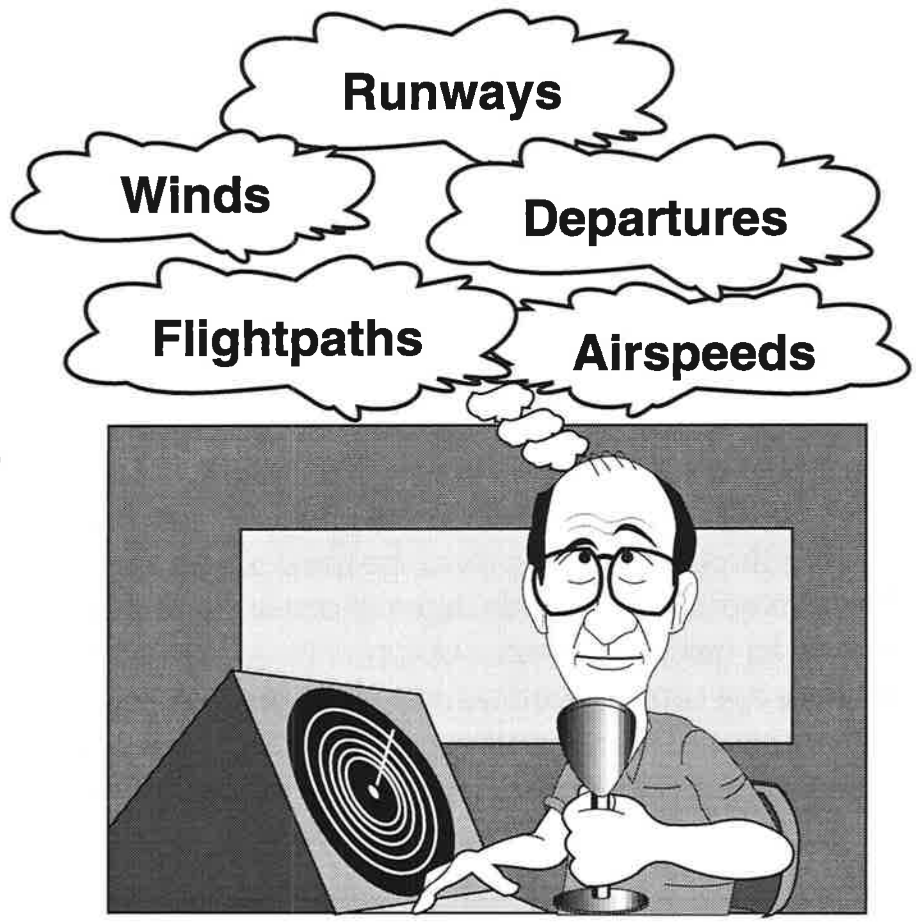


Figure 33

Since wake turbulence is formed when aircraft lift is produced, the potential for aircraft accidents and incidents will always be present. The potential doesn't have to become a reality if we understand what it is, what it does, and what our responsibilities are associated with in avoiding it. Wake turbulence is one of several aviation hazards that can be avoided by applying recommended procedures and using various techniques when implementing the procedures. It requires the effort by both air traffic controllers and pilots working together as a team to prevent wake-turbulence encounters.

Pilots and Air Traffic Controllers Can Prevent Wake-Turbulence Encounters by Working Together

Figure 34

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APPENDIX

3-D

Wake Turbulence Safety Training Aid - Video Script

Wake Turbulence Avoidance - A Pilot and Air Traffic Controller Briefing

The data in this appendix is provided for training purposes only and should not be used for any other purpose.

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WAKE TURBULENCE AVOIDANCE
TRT: 24:27

1. MS of flight deck of a (Large) aircraft. Pilot begins to request clearance to go VFR.	**"Washington approach, Pinnacle 452, we have the airport in sight."**
2. MS of controller granting VFR request.	**"Pinnacle 452, Washington approach cleared for a visual approach runway 34 right, contact Washington tower 1-1-9er.0"**
3. MS of flight deck large aircraft.	**"Pinnacle 452 cleared visual 34 right."**
4. MS of flight deck of a (Smaller) corporate jet. The pilot requests permission for VFR approach.	**"Washington approach, November 2-6-1-2-4 approaching the mall."**
5. MS of controller talking to (Smaller) aircraft.	**"Citation 2-6-1-2-4, Washington approach, traffic 1 O'clock, 5 miles westbound, Boeing 7-57 descending through 5000 for runway 3-4 right. "Do you have that traffic in sight?"**
6. MS of (Smaller) aircraft flight deck with pilots.	**"Did he say 7-5-7...?" "Yeah, there it is!" "Affirmative Washington, I have the 7-5-7 in sight."**

7. Over-shoulder of controller with radar screen 8. CU controller's face.	**"Citation 1-2-4, you are 4 miles behind the Boeing 7-57, caution wake turbulence. Follow that traffic. Cleared visual approach runway 3-4 right. Contact Washington tower 1-1-9er.0."**
9. MS of (Large) flight deck and pilots. Cut to a CU of the glideslope indicator which is indicating a 1.5 dots high. And the airspeed indicator showing 140 knots.	***Ambient sound of engines slowing down and communication between pilots and tower.***
10. MS of tower controller.	**"Pinnacle 452, can you accept 34L, following traffic 34 right."**
11. CU of glideslope indicator on glideslope.	**"Roger Washington, 3-4 left, no problem."**
12. CU airspeed indicator at 175 knots.	
13. MS flight deck smaller aircraft	

14. CU exterior of large aircraft landing.

Ambient sound of tires hitting pavement, reverse thrusters, flaps and gear.

15. CU of smaller flight deck and pilot. Suddenly, pilot is turning yoke back and forth to recover from uncontrolled roll.

"OH..."

16. CU glideslope indicater out of control

17. MS smaller aircraft flight deck with pilots struggling for control. Fade to black.

Dramatic stingers

18. CU of newspaper headlines: "Four Injured In Wake Turbulence Encounter"
Title over:
....too close
....below flightpath
....light winds.

19. Graphic of text comes up:

AVOID WAKE TURBULENCE. This takes cooperation and awareness among pilots and air traffic controllers.

20. Scenes of early 70's flights. Passengers in terminals, inside airlines, assortment of wide-body airplanes.	***Transitional Music*** **The introduction of wide-body airplanes in the 70s was instrumental in satisfying the public's desire for traveling. In order to safely avoid the wake turbulence associated with these aircraft, separation standards were developed that established aircraft weight categories and distances. At that time, aircraft were easily categorized: wide-bodies, B-727, B-737, DC-9, and others.**
21. Scenes of modern airports with mixed traffic.	**As the aircraft within the categories increased in number and size, the potential for wake-turbulence encounters increased as well.**
22. WS of modern wide-bodied aircraft.	**Today there is almost a continuum of aircraft sizes as manufacturers develop the "airplane family" concept of new transport and corporate aircraft.**
23. Small airport with mixed traffic.	**Airports of various sizes are handling increased air traffic that includes everything from heavy wide-bodies to small business and recreational aircraft. Along with this increased mix of aircraft comes an increased concern about wake turbulence.**
24. WS of wide-body jet in flight with wake turbulence smoke.	**Wake turbulence, being a natural by-product of powered flight, is generated by the lift created by the aircraft wings and helicopter rotor systems.**

25. Animation of vortex formation showing movement and direction of flow behind aircraft. Model rotates to show size of vortices.	**It develops when air rolls up off the wingtips forming 2 counter-rotating vortices.**
26. Wide-body aircraft approached vortex tower with smoke, turbulence develops. Title over: Size, weight, speed, wing configuration.	**The strength and effect of a trailing vortex is predominantly determined by the size, weight, speed, and wing configuration of the aircraft producing it. The strongest and potentially most dangerous wake turbulence is produced when the aircraft is heavy and flying slowly.**
27. Animation of aircraft approaching from left to right and illustrating rate of vortices diminishment.	**The vortices from larger aircraft sink initially at about 300 to 500 feet per minute to a maximum of 900 feet below the flightpath of the generating aircraft. Vortex strength diminishes with time and is affected by atmospheric conditions and contact with the ground.**
28. Animation illustrating vortices movement over ground.	**In calm wind, as the vortices sink close to the ground, they tend to move laterally over the ground at approximately 2 to 5 knots.**
29. Animation illustrating effect of ambient wind on vortices.	**The vortices are strongly influenced by ambient wind. A strong enough wind will dissipate the turbulence. A light crosswind will decrease the lateral movement of the upwind vortex and increase the movement of the downwind vortex.**

30. Animation illustrating effect of tailwinds on vortices.	**A tailwind condition can move the vortices forward into the touchdown area. One of the most hazardous situations is a light quartering tailwind.**
31. WS of active runway, aircraft landing.	**The location and strength of wake turbulence still remains fairly difficult to determine and usually invisible to both the pilot and controller.**
32. CU pilot in aircraft, title over: Wake Turbulence Avoidance Procedures.	**There are, however, some basic recommended procedures which can be used to assist pilots in avoiding the preceding aircraft's wake. Your aircraft's performance and capability should be considered when applying these procedures.**
33. Animation shows landing behind a larger aircraft on the same runway.	**When landing behind a larger aircraft on the same runway, stay at or above its flightpath, noting its touchdown point and landing beyond it.**
34. Animation shows a landing behind a larger aircraft on a parallel runway closer than 2500 feet with wind drifts.	**In the case of parallel runways closer than 2500 feet, landing behind a larger aircraft requires the pilots to be aware of possible wind drift towards their runway. Stay at or above the larger aircraft's flightpath and note its touchdown.**
35. Animation shows landing behind a larger aircraft on a crossing runway.	**If you are landing behind a larger aircraft on crossing runways, cross <u>above</u> the larger aircraft's flightpath.**
36. Animation shows landing behind a larger aircraft departing on the same runway.	**If the larger aircraft is departing on the same runway, note its rotation point and land well prior to that point.**

37. Animation shows landing behind a larger aircraft departing on a crossing runway. Larger aircraft rotates after intersection.

Here, the larger aircraft is departing on a crossing runway. Note the rotation point. If it is past the intersection, continue your approach and land prior to the intersection.

38. Animation shows landing behind a larger aircraft departing on a crossing runway, rotating before the intersection of two runways.

If it rotates prior to the intersection, avoid flying below the larger aircraft's flightpath. Abandon the approach unless you can land well before the intersection.

39. Long shot of aircraft waiting as other aircraft takes off.

Be alert for any critical take-off situation which could lead to a vortex encounter. In take-off situations, note the departing aircraft's rotation point and rotate prior to it. Be sure to evaluate aircraft performance and determine if it is possible. If necessary, or there is any doubt, delay the takeoff.

40. Animation shows departing behind a larger aircraft (departed) on a single runway. The lead aircraft's flightpath is visible.

After takeoff, continue your climb <u>above</u> and <u>upwind</u> of the larger aircraft's climb path until turning clear of its wake. Avoid any headings which will place you behind the preceding aircraft's path.

41. MS of flight deck with pilots.

42. Animation shows departing (Large) aircraft and its rotation point and another aircraft waiting for takeoff at intersection.

In the case of an intersection takeoff on the same runway or parallel runways, be alert to adjacent large aircraft, particularly upwind of your position. Avoid subsequent headings which will cause you to cross below a large aircraft's path.

43. WS aircraft in flight. 44. Animation shows a runway with a large aircraft making a low, missed approach. Wake turbulence is illustrated as it settles across the runway. Wind is illustrated as being light, quartering. Aircraft (Small) waits for takeoff.	**In the case of an aircraft making a low, missed approach or touch-and-go, wake turbulence may exist along the runway and in your flightpath, especially if a light quartering wind exists.** **Leave an interval of at least 2 minutes before executing a takeoff AFTER A HEAVY AIRCRAFT.**
45. Animation shows an aircraft (Small) being overtaken by an aircraft (Large). We then see the aircraft (Small) adjust its course.	**If you are en route VFR, and you observe a large aircraft above, on the same track, avoid the area below and behind its path by adjusting your position laterally, preferably upwind.**
46. LS aircraft on approach, zoom out to show CU of controller in tower. 47. CU radar screen with controller's reflection in screen.	**The other key player directly involved with avoiding wake turbulence is the air traffic controller. Air traffic controllers are required to provide radar and wake turbulence separation or visual separation until the pilot accepts visual separation or a visual approach.**
48. CG graphic over still frame of air traffic controller. Type of approaches available (IFR VFR). Mix of traffic (turbojet, propeller, helicopter). Traffic density. Wake turbulence separation. Noise abatement procedures.	**The primary considerations that affect the controller's ability to control traffic safely, orderly, and expeditiously are: the types of approaches available, (Instrument Flight Rules or Visual Flight Rules), the mix of traffic (jet, propeller, or helicopter), traffic density, wake-turbulence separation, and noise abatement requirements.**

49. Long shots of stacked aircraft on approach, takeoff, and taxiing.

Traffic density is the major factor in the amount of airplanes that can be safely, orderly, and expeditiously landed or departed. The busiest airports schedule takeoffs and landings based on weather conditions. Visual conditions and visual separation allow air traffic control to handle more aircraft within the traffic control system. Air traffic controllers can gain more flexibility in handling aircraft still under IFR control by clearing aircraft to maintain visual separation or a visual approach.

50. CU controllers and radar screen.

51. CU of radar screen. We hear the pilot and controller on the radio. The pilot is requesting VFR approach.

Title over: Air Traffic Considerations for Visual Separation or Visual Approach.

There are several factors a controller should consider before clearing an aircraft to maintain visual separation or for a visual approach when wake turbulence separation must be applied.

52. Animation of smaller aircraft upwind of a larger aircraft. Show crosswind and direction. Show small aircraft landing on parallel runway with large aircraft. Show the vortices of the large aircraft, wind direction, moving vortices, and the small aircraft.

An aircraft upwind from a larger aircraft is unlikely to encounter any wake turbulence. However, it is not always possible or practical to have a smaller aircraft follow a larger aircraft on the upwind side.

53. Animation of the large aircraft making a steep descent. Show a very suburban area in the background to convey a noise abatement situation. As the large aircraft descends, show a small aircraft descending at a normal rate and eventually ending up below the glidepath of the large aircraft. Show vortices rolling behind the large aircraft and slowly drifting toward the runway into the path of small aircraft.

Another consideration controllers need to make is the flightpath of the preceding aircraft compared to the flightpath of the following aircraft. A steep descent of larger aircraft could create a hazard for smaller aircraft following on a normal descent to the same runway. As you can see, at some time, the smaller aircraft would be below the flightpath of a larger jet. When practical, air traffic controllers should advise the following aircraft of the leader's steep descent.

54. Animation of a large aircraft on regular glidepath. Show a small, fast jet coming in behind the large aircraft. Show vortices from the large aircraft rolling off and eventually coming in front of the small aircraft's glidepath.

Faster aircraft following slower aircraft can create a serious wake-turbulence problem by easily getting too close. The separation distance provides time for the wake turbulence to dissipate as well as descend.

55. Animation of intersecting runways. Show a large jet aircraft taking off on and a small jet on approach to an intersecting runway. Rolling vortices are falling off of the large aircraft and descending to same flightpath as the small jet aircraft on approach.

Intersecting runways can also create a hazard when a small aircraft is cleared to land on a runway where the flightpath will take it through the flightpath of a larger aircraft that was landing or departing on a different runway.

56. Interior approach tower Seattle-Tacoma International Airport. On-camera is Tom Davidson, Air Traffic Manager.

Title Over: Tom Davidson
Air Traffic Manager

Slow zoom-in to CU of Davidson

The best method for avoiding wake turbulence is both pilot and controller awareness. Controllers must know where wake turbulence could occur and how it will affect other following aircraft. Crosswinds, steep descents, different airspeeds, and crossing runways are just some of the factors controllers should consider.

Pilots also have to be aware of where potential hazards exist. Sometimes giving a cautionary wake-turbulence advisory is not enough. The pilots need to know if the aircraft they are following is on a steeper than normal descent, is flying slower than they are, or if it is landing on another runway. If there is a potential for a wake-turbulence hazard, the controller needs to inform the pilots of it and allow the pilots to adjust their flightpath accordingly.

Conversely, it is the pilot's responsibility to keep air traffic controllers informed of flight profiles outside of the normal operation.

When it's operationally beneficial, air traffic control may authorize the pilot to conduct a visual approach to an airport or to follow another aircraft in VFR weather conditions. The pilot must have the airport or the preceding aircraft in sight before the clearance is granted.

57. MS of flight deck. Aircraft is VMC. 58. Color Graphic illustration of urban airport with variety of aircraft	**The pilot is solely responsible for avoiding wake turbulence. The task of maintaining proper visual relationship with the lead aircraft in order to remain at or above its flightpath becomes greater and more complicated when aircraft of different sizes and speeds, approaching from various altitudes and directions are involved.**
59. Shots of flight deck and pilot. Title over: Pilot Techniques for Visually Maintaining Separation	**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 determine the traffic situation and apply proper avoidance procedures.** **In order for pilots 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 to indicate this.**
60. Shot of runway while on approach. Title over: Normal VASI for Wide-Body Aircraft	**The use of visual glideslope indicators such as VASI or PAPI or instrument precision approach aids will assist in establishing and maintaining a normal approach flightpath.**

61. CU ILS glideslope. 62. Superimpose glideslope indicater with MS flight deck with pilots.	**When available to the pilot, the ILS glideslope can assist in determining the flightpath of a leader aircraft. However, it is not foolproof. In fact, the leader aircraft may have flown above the glideslope for wake-turbulence avoidance or other reasons.**
63. MS different flight deck (nighttime) 64. Color graphic showing 3-degree flight path equals 300 feet per nautical mile traveled. 65. CU pilot at controls.	**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 as early as possible, but not later than 500 feet above the ground.**
66. Animation showing leader aircraft with line drawn to runway touchdown point.	**One way to determine the flightpath the leader aircraft has flown is to line up the leader aircraft with the anticipated or normal runway touchdown point. Visualize an extension of the line between those two points. This technique assumes the leader has flown a consistent flightpath and is using a normal touchdown point.**
67. Animation of line running from following aircraft through the leader aircraft and to the runway end.	**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. If it ends at a point down the runway, the trailing aircraft is probably below the flightpath of the leader. If the line extension is prior to the touchdown point, as in an overrun, the trailing aircraft is probably above the leader flightpath.**

68. MS flight deck (nighttime) 69. CU of ILS glideslope indicator. 70. CU pilot	**When ILS approaches are being used in VMC, 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. However, this assumption is not always valid. Pilots should be cautious of leader aircraft intercepting the glideslope from above.**
71. Color graphic of different aircraft pitches.	**A nose-high pitch attitude of the leader aircraft should not be used as an indicator of flightpath because pitch attitudes vary among aircraft types and manufacturers.**
72. CU of pilot. CU of ILS localizer.	**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.**
73. WS of flight deck of following aircraft.	**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.**
74. MS of tower controller giving separation distances and airspeed differential. We hear the conversation between controller and pilot.	**Air traffic controllers are willing to provide separation distance information to pilots. They can also provide airspeed differential between aircraft, if applicable.**

75. MS flight deck. 76. Animation of leader aircraft passing a point; Indicate timing reference at point.	**One technique available is for the trailing pilot 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. After determining the amount of time it takes for the trailing aircraft to pass over the same point, convert that time into distance.**
77. LS of aircraft landing showing tire smoking and trailing aircraft visible in background.	**Most heavy and large aircraft produce some smoke from 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.**
78. MS inside flight deck. Title over: Aircraft Performance In-flight Visibility Coordination with ATC. Other Traffic in the Pattern	**There are multiple ways to increase separation distances while following an aircraft on final approach. Several factors should be considered, however, before implementing these techniques—aircraft performance, in-flight visibility, coordination with ATC, and other traffic in the pattern that are taking off or preparing to take off.**
79. MS on flight deck. 80. CU airspeed indicator decreasing.	**Airspeed reduction is an obvious choice of most pilots for increasing separation. But, it is usually limited to small changes because of aircraft performance or ATC restrictions.**
81. MS flight deck.	**Pilots must not reduce airspeed below the aircraft's minimum safe operating speed. Be aware that recovery from an inadvertent wake-turbulence encounter is more difficult at slower speeds.**

82. Interior of flight deck of plane performing a turn.	**Performing "S" turns is another way to gain separation. Flying a 360-degree turn will greatly increase the distance from the leader, but the impact on other aircraft may preclude its use.**
83. MS flight deck	**The decision to abort the approach or landing and go around is always an alternative for avoiding wake turbulence.**
84. WS interior flight deck, we hear radio communication between another aircraft and the ATC.	**Listening to all radio communications (not just those directed at you) can be helpful in providing information that can improve wake turbulence situational awareness. Prior to entering a visual pattern or initiating an instrument approach, radio communications between ATC and other airplanes can alert pilots on where they may fit in the landing sequence or what type aircraft they may follow.**
70. Continuation of visual.	**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. In other words, don't overlook any information that can aid your planning and flying an approach, takeoff, landing, or go-around.**

85. On camera; Paul Smith, Sr. Manager AT Services. Title over: NATIONAL BUSINESS AIRCRAFT ASSOCIATION, INC.	**The number of aircraft continues to increase each year for reasons that reach from the desire for greater recreational use to responding to commercial requirements. As this number has increased, so has the necessary support or infrastructure.**
86. WS airport activity	**We have evolved from few pilots to many pilots, from few air traffic controllers to many air traffic controllers. This situation, coupled with high air traffic density, creates an environment that requires pilots and air traffic controllers to cooperate in order 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 air traffic until the pilot enters visual conditions. This means initially that it may be difficult for us to visually detect whether we may be overtaking the leader aircraft or where we are relative to the leader's flightpath.**
87. CU Paul Smith.	**We as pilots can assist air traffic in several ways.**

88. Flight deck scenes	**One way is to understand that controllers are continually challenged in sequencing arrivals with departures, planning for different aircraft with different performance characteristics, and applying wake turbulence separation criteria.**
89. More of Paul Smith.	**If we initiate an unusual request or make a change in our flight operations from what is normally expected by air traffic, it will probably increase an already high workload for most controllers at major airports. Timely, precise, and disciplined radio communications with air traffic improves the flow of vital information.**
90. Return to original situation with a heavy aircraft being followed by small corporate jet. We hear the same communication between ATC and heavy aircraft and ATC and small aircraft.	**Now let's review the reenactment of the wake turbulence encounter you watched at the beginning of this video and see where increased awareness might have prevented the incident.**
91. Return to opening shot 757 (Large) flight deck. We hear some ambient noise, radio talk, etc. Then camera shows CU of glideslope/airspeed. Then picture freezes for teaching point.	**The leader aircraft is coming in high and slow because its descent was delayed. Although not typically a problem, it contributes to the situation which arises.**
92. Return to opening shot of (Smaller) flight deck. Title over: Below Leader's Overtaking Airspeed	**The "CITATION" should have been aware of the location of the 7-5-7's flightpath and that the CITATION'S current flightpath would be below the flightpath of the 7-5-7. The pilots lacked sufficient situational awareness of the possibilities.**

93. MS tower controller talking to 757. Title over: Smaller Aircraft Positioned to the Downwind Runway	**Putting the 7-5-7 on the left runway with a trailing CITATION on the right positioned the CITATION downwind from the 7-5-7. Light winds enabled the wake turbulence from the 7-5-7 to drift to the right.**
94. MS ATC. Title over: Insufficient Communication	**Additionally, if the controller had been aware that there was potential for reduced separation upon landing, and of the 7-5-7's higher approach path, he could have warned the CITATION of its closure with the 7-5-7. <u>And</u>, he could have given important information regarding the 7-5-7's flightpath by advising the following aircraft that the leader aircraft was higher. For example: "Your traffic departed the outer marker at 3000 feet."**
95. Montage of aircrafts landing, pilots flying, air traffic controllers controlling.	***Closing music***
96. Same montage of aircraft landing, pilots flying, air traffic controllers controlling	***Off camera narrator as music fades down.*** **Wake turbulence is one of many factors that pilots and air traffic controllers must overcome to fly safely. It takes cooperation, awareness, <u>AND</u> the understanding of each other's requirements to safely avoid wake turbulence.** ***Music up and out*** ***FADE TO BLACK*** ***FADE UP TO DISCLAIMER***

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4

Wake Turbulence Training Aid Background Data

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Wake Turbulence Training Aid - Background Data

Table of Contents

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Wake Turbulence Training Aid - Background Data

4.0 Introduction

The avoidance of wake-turbulence encounters will take the coordinated efforts of pilots of all sizes of aircraft and controllers throughout the ATC system. It is the goal of this Training Aid to reduce the number of accidents and incidents attributable to wake turbulence. This section, Wake Turbulence Training Aid - Background Data, is an excellent source of information for an instructor or user needing a more detailed explanation of the material contained in Section 2, the Pilot and Air Traffic Controller Guide to Wake Turbulence or the video, *Wake Turbulence Avoidance - A Pilot and Air Traffic Controller Briefing*. Additionally, this section contains charts and graphs in Appendix 4-A which could be utilized by an instructor to emphasize specific points. The material in this section is intended to be an additional resource for training and answering questions raised in the training process.

4.0.1 Goal of the Background Data Section

The goal of this section is to provide to users, particularly instructors, additional information and sources of information that can be utilized in instruction or understanding of wake turbulence. Periodically, this information will be updated as new information is gathered and additional reports, findings, and issues are addressed by the wake turbulence industry team.

4.0.2 Overview of the Contents

Appendix 4-A, the NTSB Special Report of Wake Turbulence, addresses specific incidents, wake turbulence issues, and makes recommendations regarding wake turbulence; Appendix 4-B, the 1991 Report of Where We Are Today in Wake Turbulence, gives an historical accounting of the efforts and history of research regarding wake turbulence; Appendix 4-C, Wake Turbulence Training Aid Guidelines and Issues, outlines some of the guidelines used in developing this training aid and addresses issues that were discussed at length by the industry team; Appendix 4-D, the FAA Integrated Wake Vortex Program Plan, outlines present and future efforts to assist pilots and controllers in avoiding wake turbulence encounters; Appendix 4-E is a bibliography of further research issues related to wake turbulence. Lastly, Appendix 4-F is added, as desired by the distributor of the aid, to inform pilots and controllers of the wake turbulence take-off weight categories and the latest IFR separation standards in effect that deal with wake turbulence. It is expected that these standards will change periodically.

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APPENDIX

4-A

NTSB Report of Wake Turbulence

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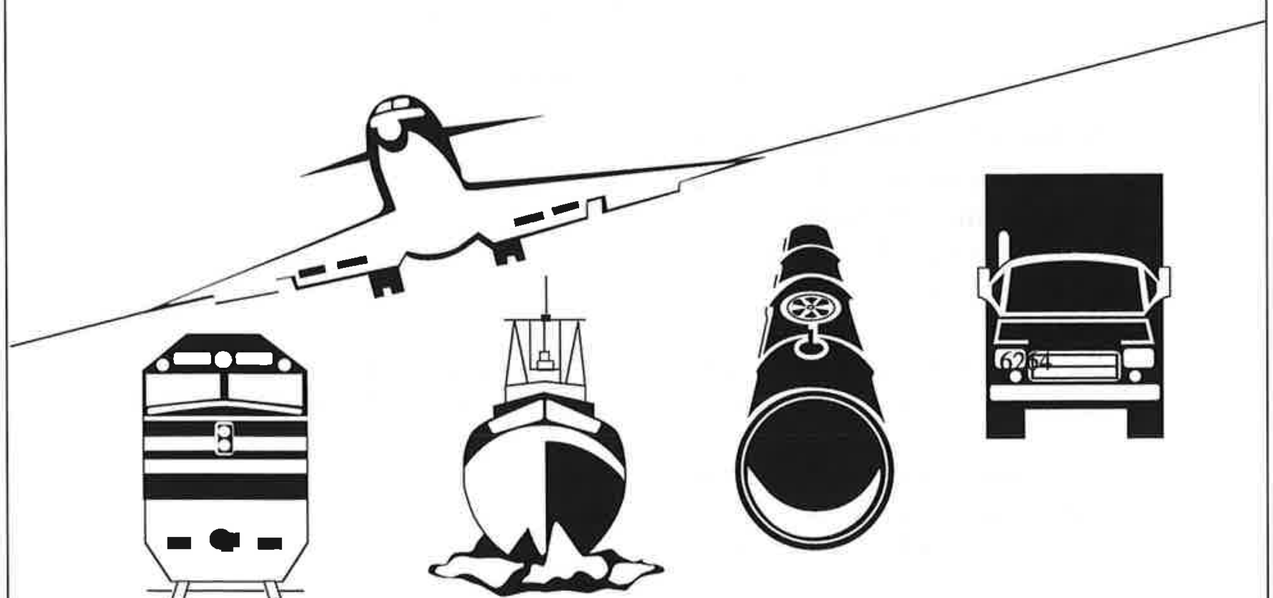
PB94-917002
NTSB/SIR-94/01

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SPECIAL INVESTIGATION REPORT

SAFETY ISSUES RELATED TO
WAKE VORTEX ENCOUNTERS
DURING VISUAL APPROACH
TO LANDING



National Transportation Safety Board. 1994. Safety issues related to wake vortex encounters during visual approach to landing. Special Investigation Report NTSB/SIR-94/01. Washington, DC.

The Safety Board conducted a special investigation to examine in detail the circumstances surrounding five recent accidents and incidents in which an airplane on approach to landing encountered the wake vortex of a preceding Boeing 757. Thirteen occupants died in two of the accidents. The encounters, which occurred during visual conditions, were severe enough to create an unrecoverable loss of control for a Cessna Citation, a Cessna 182, and an Israel Aircraft Industries Westwind. Additionally, there were significant but recoverable losses of control for a McDonnell Douglas MD-88 and Boeing 737 (both required immediate and aggressive flight control deflections by their flightcrews). The safety issues discussed in this special investigation report are: the adequacy of the current aircraft weight classification scheme to establish separation criteria to avoid wake vortex encounters, the adequacy of air traffic control procedures related to visual approaches and visual flight rules operations behind heavier airplanes, pilot knowledge related to the avoidance of wake vortices, and the lack of available data to analyze the history of wake vortex encounters in the United States. Recommendations concerning these issues were made to the Federal Aviation Administration.

The National Transportation Safety Board is an independent Federal agency dedicated to promoting aviation, railroad, highway, marine, pipeline, and hazardous materials safety. Established in 1967, the agency is mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable causes of the accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The Safety Board makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

Information about available publications may be obtained by contacting:

National Transportation Safety Board
Public Inquiries Section, RE-51
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594
(202)382-6735

Safety Board publications may be purchased, by individual copy or by subscription, from the National Technical Information Service. To purchase this publication, order report number **PB94-917002** from:

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SAFETY ISSUES RELATED TO WAKE VORTEX ENCOUNTERS DURING VISUAL APPROACH TO LANDING

Special Investigation Report

Special Investigation Report NTSB/SIR-94/01
Notation 6264

National Transportation
Safety Board

Washington, D.C.
February 1994

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Contents

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Executive Summary

Since December 1992, there have been five accidents and incidents in which an airplane on approach to landing encountered the wake vortex of a preceding Boeing 757 (B-757). Thirteen occupants died in two of the accidents. The encounters, which occurred during visual conditions, were severe enough to create an unrecoverable loss of control for a Cessna Citation, a Cessna 182, and an Israel Aircraft Industries Westwind. Additionally, there were significant but recoverable losses of control for a McDonnell Douglas MD-88 and a B-737 (both required immediate and aggressive flight control deflections by their flightcrews).

Safety Board data show that between 1983 and 1993, there were at least 51 accidents and incidents in the United States, including the 5 mentioned above, that resulted from probable encounters with wake vortices. In these 51 encounters, 27 occupants were killed, 8 were seriously injured, and 40 airplanes were substantially damaged or destroyed.

The Safety Board conducted a special investigation to examine in detail the circumstances surrounding the five recent accidents and incidents to determine what improvements may be needed in existing procedures to reduce the likelihood of wake vortex encounters.

The Safety Board's investigation initially focused on why the B-757 appeared to be involved in a disproportionate number of wake vortex encounters. Several reports indicated that the B-757 generated wake vortices that were more severe than would be expected for an airplane of its weight. However, as a result of a thorough study and analysis of the issue, the Safety Board found little technical evidence to support the notion that the wake vortex of a B-757 is significantly stronger than indicated by its weight.

The Safety Board's investigation, therefore, raised concerns about the following safety issues:

- the adequacy of the current aircraft weight classification scheme to establish separation criteria to avoid wake vortex encounters;

- the adequacy of air traffic control procedures related to visual approaches and visual flight rules operations behind heavier airplanes;

- pilot knowledge related to the avoidance of wake vortices; and
- the lack of available data to analyze the history of wake vortex encounters in the United States.

As a result of this special investigation, 19 recommendations were issued to the Federal Aviation Administration, U.S. Department of Transportation.

Introduction

Since December 1992, there have been five accidents and incidents in which an airplane on approach to landing encountered the wake vortex of a preceding Boeing 757 (B-757) (see table 1). Thirteen occupants died in two of the accidents. The encounters, which occurred during visual conditions, were severe enough to create an unrecoverable loss of control for a Cessna Citation, a Cessna 182, and an Israel Aircraft Industries Westwind. Additionally, there were significant, but recoverable losses of control for a McDonnell Douglas MD-88 and a B-737 (both required immediate and aggressive flight control deflections by their flightcrews).

Safety Board data show that between 1983 and 1993, there were at least 51 accidents and incidents in the United States, including the 5 mentioned above, that resulted from probable encounters with wake vortices (see appendix A). In these 51 encounters, 27 occupants were killed, 8 were seriously injured, and 40 airplanes were substantially damaged or destroyed.

In the last 20 years, the Safety Board has issued several safety recommendations to the Federal Aviation Administration (FAA) to address wake vortex issues. In 1972, following the crash of a Delta Air Line DC-9-14 at Fort Worth, Texas,[1] the Safety Board asked the FAA to "reevaluate wake turbulence separation criteria for aircraft operating behind heavy jet aircraft," and to "develop new ATC separation standards which consider the relative span loadings of the vortex-generating aircraft and the following aircraft under meteorological conditions conducive to the trailing vortices." The FAA responded that such actions were not necessary. (Appendix B contains details of the Board's past safety recommendations that address wake vortex issues.)

The Safety Board conducted a special investigation to examine in detail the circumstances surrounding the five recent accidents and incidents in which an airplane on approach to landing encountered the wake vortex of a preceding B-757. The purpose of the Safety Board's special investigation was to determine what improvements may be needed in existing procedures to reduce the likelihood of wake vortex encounters.

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[1] National Transportation Safety Board. 1973. Delta Air Lines, Inc., McDonnell Douglas DC9-14, N3305L, Greater Southwest International Airport, Fort Worth, Texas, May 30,1972. Aircraft Accident Report NTSB-AAR-73-3. Washington, DC.

Table 1—Five airplane encounters with the wake vortex of the preceding airplane on visual approach to landing since December 1992

Date	Location	Leading aircraft	Trailing aircraft	Comments
12/18/1992	Billings, MT	B-757	Cessna Citation 550	Cessna rapidly rolled left and contacted ground in a near vertical dive when about 2.8nm behind and about 300 feet below the flight path of leading aircraft.
3/1/1993	Orlando, FL	B-757	MD-88	At about 110 ft AGL,[a] MD-88 suddenly rolled right about 15°; crew regained control and approach continued.
4/24/1993	Denver, CO	B-757	B-737	About 1,000 ft AGL, B-737 rolled left violently, pitch decreased 5°, and the airplane lost 200 feet altitude; a go-around was initiated, and the airplane landed without further incident.
11/10/1993	Salt Lake City, UT	B-757	Cessna182	On final approach, airplane rolled 90° to the right; as pilot attempted to level airplane, it crashed short of runway.
12/15/1993	Santa Ana, CA	B-757	Westwind	About 2.1 nm behind and 400 feet below the flight path of leading airplane, Westwind rolled suddenly and contacted the ground with a 45° nose down pitch attitude.

[a] Above ground level.

Recent Encounters With Wake Vortices

Billings, Montana.—On December 18,1992, a Cessna Citation 550, N6887Y, operating under Part 91, Title 14 of the Code of Federal Regulations (14 CFR 91), crashed while on a visual approach[2] to runway 27R at the Billings Logan International Airport, Billings, Montana.[3] The two crewmembers and six passengers were killed. Witnesses reported that the airplane 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 (nm) (about 74 seconds) behind a B-757 and on a flight path that was about 300 feet below the flight path of the B-757 (see appendix C). The flight path angle of the Citation was 3°, and the flight path angle of the B-757 was 4.7°.

The B-757, at a takeoff weight of 255,000 pounds, and the Citation, at a takeoff weight of 13,000, are both classified as large airplanes.[4] Standard IFR separation (greater than 3 nm) was provided to the pilot of the Citation until the pilot requested and was cleared for a visual approach behind the B-757. The clearance was issued to the pilot

2 Air traffic controllers are required to provide lateral and vertical separation guidance between airplanes when the airplanes are operating under instrument flight rules (IFR) and receiving air traffic control (ATC) services. The separation criteria are intended to physically separate airplanes and to minimize the risk of wake vortex encounters. However, under prescribed conditions, the controller may issue a visual approach clearance to the pilot of the following airplane. Once the pilot accepts the visual approach clearance, the pilot is responsible for maintaining adequate wake turbulence separation and visual contact with the lead airplane and airport.

3 NTSB accident SEA 93-G-A041.

4 The FAA classifies airplanes as small, large, and heavy based on their maximum takeoff weight. Small airplanes may weigh up to 12,500 pounds. Large airplanes weigh between 12,500 and 300,000 pounds. Heavy airplanes weigh 300,000 pounds or greater. (Also see table 2.) These classifications were established in 1970 after the FAA conducted flight tests to determine the wake vortex characteristics of existing jet aircraft. These classifications were used to establish aircraft separation standards. For example, a large airplane is required to be separated from another large airplane by 3 nm while on an instrument approach to landing. Before 1970, radar operating limits and, to a lesser extent, runway occupancy restrictions dictated separation standards; there were no aircraft separations imposed because of wake vortices.

about 4.5 minutes prior to the accident while following the B-757 at a distance of 4.2 nm. 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 pilot of the Citation that the B-757 was slowing and advised the pilot that a right turn could be executed to increase separation. Although the pilot never asked the controller about his distance from the B-757, a statement recorded on the cockpit voice recorder (CVR) indicates that the pilot recognized the separation had decreased because he stated, "Almost ran over a seven fifty-seven," about 40 seconds prior to the upset.

The Citation's rapid and extreme departure from controlled flight occurred when the airplane was about 2.78 nm (about 74 seconds) behind the B-757. Calculations indicate that an additional 0.22 nm (about 6 seconds) would have provided the required 3 nm of longitudinal IFR separation had the pilot not requested the visual approach clearance. However, available data show that under the existing atmospheric conditions, a vortex would not likely have diminished an appreciable amount in the next 6 seconds. Consequently, this accident indicates that lighter weight airplanes in the large category, such as the Cessna Citation, require a separation distance greater than 3 nm when following heavier airplanes in the large category, such as a B-757.

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 flight path of the Citation was actually at least 300 feet below that of the B-757.

The only cue available to the Citation pilot to determine his flight path relative to the flight path of the B-757 would have been the Citation pilot's visual alignment of the B-757 and objects on the ground. For example, assuming that the B-757 was on a relatively constant flight path, the Citation flight path would have been similar to that of the B-757 if the Citation pilot had observed that the B-757 was aligned with the runway touchdown zone. If the B-757 were aligned with the far end of the runway, the flight path of the Citation would have been lower than the flight path of the B-757. If the B-757 were aligned with the approach lights, the flight path of the Citation would have been above the flight path of the B-757.

The failure of the Citation pilot to prevent the decrease in separation distance strongly suggests that the pilot failed to realize that he was placing the airplane in a dangerous position relative to the wake of the B-757. Although the Airman's Information Manual (AIM) suggests that the pilot of the following airplane should remain above the flight path of the preceding airplane, the Safety Board is not aware of existing training material that discusses techniques for determining the relative flight paths of airplanes on approach to landing.

Orlando, Florida.—On March 1, 1993, a Delta Airlines McDonnell Douglas MD-88, operating under 14 CFR 121, was executing a visual approach to runway 18R at Orlando International Airport, Orlando, Florida, while following a B-757 to the airport.[5] The crew of the MD-88 reported that the airplane suddenly rolled right about 15°, and the pilot rapidly deflected both the wheel and rudder pedal to correct the uncommanded roll. Data from the digital flight data recorder (DFDR) indicate that at about 110 feet above ground level (AGL), the roll angle reached 13° right wing down and the ailerons and rudder were deflected about one-half of full travel, 10° and 23°, 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 nm (65 seconds) behind a Delta B-757 while the flight path of the MD-88 was slightly below that of the B-757. The flight path angle of both airplanes was 3°.

The MD-88 flightcrew was issued a visual approach clearance when the airplane was 4.5 nm from the leading B-757. However, the separation quickly reduced to 2.5 nm. Had the MD-88 flightcrew not accepted the visual approach, the required IFR separation distance of 3 nm would have provided an additional 13 seconds of separation. The MD-88 flightcrew told investigators that they thought they had a 4 nm separation at the time of the encounter.

Denver, Colorado.—On April 24, 1993, the flightcrew of a United Airlines B-737 reported a wake vortex encounter while executing a visual approach to runway 26L at Stapleton International Airport, Denver, Colorado.[6] The flightcrew reported that about 1,000 feet AGL, the airplane rolled left violently with no yaw, the pitch decreased 5°, and the airplane lost 200 feet altitude. To correct the uncommanded roll, the pilot rapidly deflected the wheel and rudder about 60° and 7°, respectively, according to the DFDR. A go-around was initiated, and the airplane landed without further incident. The DFDR data also indicate that at the point of upset, the B-737 was about 900 feet AGL; in 2 seconds, its roll angle reached 230 left wing down. Recorded radar data show that at the point of upset, the flight path of the B-737 was about 100 feet below the flight path of a B-757 that was landing on runway 26R. The B-737 was about 32 seconds and 1.35

[5] NTSB incident DCA 93-I-A021.

[6] NTSB incident DEN 93-I-A044.

nm behind the B-757. The wind was from the north at about 10 knots gusting to 16 knots. The flight path angle of both airplanes was about 3°.

Runway 26L is parallel to, and displaced 900 feet south of runway 26R. The threshold of runway 26L is offset about 1,300 feet to the east of the threshold of runway 26R, resulting in a flight path to 26R that is about 70 feet higher than the flight path to 26L. Under the existing wind conditions, a wake vortex from the B-757 would descend and move to the south, toward a standard flight path to runway 26L.

Air traffic controllers are required to provide standard separation to IFR airplanes that are approaching 26L and 26R because the runways are separated by less than 2,500 feet. If the flightcrew of the B-737 had not accepted a visual approach, the controller would have been required to provide 3-nm separation. During the early portions of the approach, ATC provided vectors to the B-737 which resulted in S-turns for spacing (see appendix D). Subsequently, the B-737 and B-757 were on converging courses within 12 nm of the runway. Upon completion of the S-turns, the actual separation between the airplanes was about 4.6 nm. However, the separation was predominately lateral, not in-trail or longitudinal. The lateral component of the separation was about 4.55 nm, and the longitudinal component was only about 0.65 nm along the intended approach path. The B-757 was 1.6 nm to the right of its final approach path, and the B-737 was 2.8 nm to the left of its final approach path. The final approach paths were separated by 0.15 nm. Radar data show that the B-757 was on a 15° intercept from the right side to align for the approach to runway 26R. The B-737 was on an 8° intercept from the left side to align with the approach to runway 26L. Both airplanes converged to their respective runway alignments, which resulted in a 900-foot lateral (left-right) separation. The longitudinal component of the separation increased from about 0.65 nm to an in-trail separation of about 1.35 nm. The controller should have recognized that the relative spacing, in conjunction with the converging courses, would result in less than a 3-nm separation when the B-737 was in-trail behind the B-757. To maintain a 3-nm separation after the acceptance of a visual approach clearance, the pilot of the B-737 would have had to continue to execute S-turns.

Salt Lake City, Utah.—On November 10, 1993, the pilot of a Cessna 182, N9652X, operating under 14 CFR 91, was executing a visual flight rules (VFR) approach to runway 32 at Salt Lake City International Airport, Utah.[7] 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. There is no evidence to suggest that the pilot was advised that the airplane was a B-757.[8] The Cessna pilot reported that while on final approach, the airplane experienced a "burble," and then the nose pitched up and the airplane suddenly rolled 90° 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 airplane and to get the nose down. As the airplane 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 airplane crashed short of the threshold of runway 32, veered to the northeast, and came to rest on the approach end of runway 35. The pilot and the two passengers suffered minor injuries, and the airplane 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 AGL when it crossed the flight path of the B-757 (see appendix F). The B-757 had passed the crossing position about 38 seconds prior to the Cessna 182. Trends in the recorded radar data suggest that the flight path of the Cessna was slightly above the flight path of the B-757 at the point of crossing. The exact position of the upset has not been determined. However, wake vortices tend to remain above the ground while in ground effect and translate outward at a speed of 3 to 5 knots plus the wind component. In ground effect, the left vortex from the B-757 typically would have translated 200 to 300 feet to the west. The vortex core may have been located about 75 feet above the ground, although researchers have said the vortex has the potential to "bounce" twice as high as the steady state height. In addition, the diameter of the vortex's flow field is usually about equal to the wing span of the generating airplane. Thus, the Cessna 182 could have been affected by the vortex at any altitude between ground level and 200 feet AGL. Although the Cessna's flight path was above that of the B-757, the pilot did not adequately compensate for the height of the vortex.

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[7] NTSB accident SEA 94-G-A024.

[8] At the time of the accident, there was no requirement for such an advisory. On December 22, 1993, the FAA issued a General Notice (GENOT) requiring wake turbulence advisories to airplanes operating behind B-757 airplanes. The FAA also issued a pilot bulletin cautioning pilots about the possibility of wake vortex encounters, especially when following a B-757. (See appendix E.) However, the separation distances were not changed.

Santa Ana, California.—On December 15, 1993, an Israel Aircraft Industries Westwind, operating under 14 CFR 135 at night, crashed while on a visual approach to runway 19R at the John Wayne Airport, Santa Ana, California.[9] The two crewmembers and three passengers were killed. Witnesses reported that the airplane rolled, and CVR data indicate that the onset of the event was sudden. The airplane pitch attitude was about 45° nose down at ground contact. Recorded radar data show that at the point of upset, the Westwind was about 1,200 feet mean sea level (MSL) and 3.5 nm from the end of runway 19R. The Westwind was about 2.1 nm (60 seconds) behind a B-757 and on a flight path that was about 400 feet below the flight path of the B-757. The flight path angle of the Westwind was 3°, and the flight path angle of the B-757 was 5.6° (see appendix G, altitude profile). CVR data indicate that the Westwind pilots were aware they were close to a Boeing airplane and that the airplane appeared high. They anticipated encountering a little wake and intended to fly one dot high on the glide slope (about 3.1° instead of 3.0°). There is no evidence that the crew were advised specifically that they were following a B-757.

While receiving radar vectors to the airport, the crews of both airplanes 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 nm northeast of the B-757 when cleared for a visual approach (see appendix G, ground track). The Westwind started its right turn from a ground track of 120° while the B-757 ground track remained at about 90°. The resultant closure angles started at 30° 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 B-757 were about 200 and 150 knots, respectively. The Westwind was established on course 37 seconds prior to the B-757. Although the combination of the closure angle and the faster speed of the Westwind reduced the separation distance from about 3.8 nm to about 2.1 nm 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 nm required for IFR separation. To prevent compromise of the separation requirement, 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.

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[9] NTSB accident LAX 94-F-A073.

The investigation disclosed that the company for which the crew were flying had not provided specific training regarding wake vortex movement and avoidance techniques. According to Safety Board investigators, the company's director of operations stated that any such training would have been included in the required windshear training. However, wake vortex avoidance was not discussed in the company's windshear training. Further, the Safety Board is unaware of any such training for Part 121 and 135 pilots.

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Research and Data on Wake Vortices

Research on Wake Vortex Detection and Prediction

The National Aeronautics and Space Administration (NASA), in conjunction with the FAA, is conducting an aggressive wake vortex research program related to the Terminal Area Productivity Program. According to the director of the NASA program, the purpose of the program is to increase airport capacity by accurately predicting safe separation distances using real-time data of atmospheric conditions and data specific to the airplane model. NASA envisions that the system would be backed up by real-time monitoring of wake vortex movements. The structure of the program is to parallel the highly successful windshear research program conducted by NASA several years ago. The multidisciplined program will address training, risk characterization (of airplane pairs), defining atmospheric effects of wake transport and decay, and airborne or ground-based wake vortex detection systems. Once the positions of wake vortices can be accurately predicted and detected, NASA research reportedly will focus on developing systems for controllers that will enable airplanes to be safely spaced at smaller separation distances.

NASA has had recent success using a ground-based LIDAR radar to track wake vortices at Stapleton International Airport; NASA plans to continue the project, testing LIDAR radar at Memphis this summer. In addition, NASA plans to install LIDAR radar on its B-737 to study the feasibility of using the radar for airborne detection of wake vortices. A highly instrumented Ov10,[10] with variable roll inertia, will be flown in the wake of other airplanes. NASA has conducted wind tunnel tests using a model to create wake vortices and used another remote control model to fly in the test wake. NASA plans additional tests in the NASA Ames 80-foot by 120-foot wind tunnel, using a large size B-747 wind tunnel model. The Safety Board is encouraged that new technology being developed may find application in future airborne and ground-based systems to

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10 The Rockwell OV-10 is a twin-engine turboprop airplane with a 40-foot wing span and a 9,900-pound gross weight.

monitor wake vortex movements and believes that the FAA should continue funding research in these areas.

Data on Wake Vortex Encounters

Data are not available to analyze the wake vortex incident history in the United States because the FAA does not require pilots to report wake vortex encounters. The only existing U.S. data on wake vortex encounters of which the Safety Board is aware are the Board's own accident and incident reports and reports filed through the Aviation Safety Reporting System (ASRS). Despite the limitations of the ASRS data,[11] the report narratives provide insight into specific safety issues, such as wake vortex encounters. Appendix H contains incident reports derived from the ASRS data base. Although the airplane models are not identified in the ASRS data base, on the basis of ASRS reporting categories, it can be inferred that most pilot reports defining a large (LRG) airplane (150,000 to 300,000 pounds) were referring to a B-757.

Unlike the FAA, the Civil Aviation Authority of Great Britain (CAA), in 1972, established a voluntary reporting system to gather data on wake vortex encounters. In 1982, using data from the reporting system, the CAA changed from a three-group airplane weight category to a four-group weight category. (See table 2 for a comparison of the weight categories used by the CAA, the FAA, and the International Civil Aviation Organization (ICAO).) According to a paper presented at the FAA-sponsored international conference of aircraft wake vortices held in Washington, D.C., in October 1991, "The four group scheme (weight categories) introduced in 1982 was divided as a result of incident data gathered in earlier years, and was designed to provide extra protection for some types of aircraft found to suffer particularly severe disturbance behind heavy group aircraft."[12]

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[11] Because all ASRS reports are voluntarily submitted, they cannot be considered a measured random sample of the full population of like events. Moreover, not all pilots, controllers, air carriers, or other participants in the aviation system are equally aware of the ASRS or equally willing to report. Consequently, the data reflect reporting biases.

[12] Proceedings of the Aircraft Wake Vortices Conference, October 29, 1991, DOT/FAA/SD-92/1.1, p. 6.2.

Table 2—Aircraft categories and weight range of aircraft in categories used by the International Civil Aviation Organization (ICAO), United Kingdom (U.K.), and United States (U.S.) as the basis for current separation standards established to avoid wake vortex encounters[a]

In pounds

Category	ICAO	U.K.	U.S.
Heavy	>300,000	>300,000	>300,000
Large	NA	NA	<300,000
Medium	<300,000 to 15,000	<300,000 to 90,000	NA
Small	NA	<90,000 to 37,500	<12,500
Light	<15,000	<37,500	NA

NA = not applicable because category has not been designated.

[a] The weight categories are based on maximum takeoff weight of the aircraft.

The CAA continues to gather data on wake vortex encounters. An analysis of CAA wake vortex incidents reported between 1972 and 1990 found:

> ... the B-747 and B-757 airplanes appear to produce significantly higher incident rates than the other airplanes considered, indicating prima facie that they produce stronger and more persistent vortices than the other aircraft in their respective weight categories....The fact

> that the B-747 is by far the heaviest in the 'heavy' wake vortex class (maximum take-off weight 371,000 Kg) is a likely explanation for its higher incident rates. However, the cause of the higher B-757 incident rates is uncertain.[13]

The B-737 was cited as being most involved as the following airplane. Of note, the CAA requires a 3-nm separation when a B-737 is following a B-757, and the B-757 is the largest airplane in its category.

The CAA Wake Vortex Reporting Programme (WVRP) was transferred to the Air Traffic Control Evaluation Unit (ATCEU) in 1989.[14] The ATCEU collects data from various parties on each wake vortex encounter and enters the data into the wake vortex data base. The notification usually comes from the affected airplane crew or ATC. Formal procedures for the reporting of wake vortex incidents by ATC are in operation only at London City and Heathrow airports. Additional data are collected from the pilot of the airplane causing the vortices, the Meteorological Office, London Air Traffic Control Center (for recorded radar data provided to ATCEU by data link), and from the airlines (flight data recorder data). One airline has agreed to extract FDR data for all reported wake vortex incidents. The data are analyzed to determine if the cause of the reported incident is, in fact, an encounter with a wake vortex. A total of 86 incidents were reported in 1990, and 87 incidents were reported in 1991.[15]

The Safety Board believes that the FAA should also require reporting of wake vortex encounters and establish a system to collect and analyze pertinent information, such as recorded radar data (including wind and temperature data recorded on many of the newer airplanes), atmospheric data, and operational information, including selected flight data recorder data. The Safety Board acknowledges the difficulty in developing clearly usable definitions and suggests that the CAA program could be an excellent source in developing this reporting system. Because pilots may be reluctant to report wake vortex encounters as a result of concerns of enforcement actions, the FAA will need to address the issue of enforcement when developing the reporting procedures.

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13 Proceedings of the Aircraft Wake Vortices Conference, October 29, 1991, DOT/FAA/SD-92/1.1, p.8.2.

14 National Air Traffic Services. Civil Aviation Authority, ATCEU Memorandum No. 177.

15 ATCEU Memorandum No. 184.

Discussion

The Safety Board's investigations of the preceding cases initially focused on why the B-757 appeared to be involved in a disproportionate number of wake vortex encounters. Several reports indicated that the B-757 generated wake vortices that were more severe than would be expected for an airplane of its weight. However, as a result of a thorough study and analysis of the issue, the Safety Board found little technical evidence to support the notion that the wake vortex of a B-757 is significantly stronger than indicated by its weight. Figure 1 presents the calculated initial relative vortex strength of the B-757 and other airplanes. The calculated initial vortex strength is closely related to the weight of the airplane. Of note, the B-757 is the heaviest airplane in its weight category, and there are no other airplanes of similar weight.

The current aircraft weight classification scheme was established in 1970 based on FAA flight tests to determine the wake vortex characteristics of existing jet aircraft. Based on these classifications, aircraft separation standards were established in 1970, with some modifications made in 1975. However, many transport category turbojet airplanes have been introduced into service since the implementation of the aircraft separation requirements.

The Safety Board's investigations, therefore, raised concerns about the adequacy of: (1) the current aircraft weight classification scheme to establish separation criteria to avoid wake vortex encounters; (2) air traffic control procedures related to visual approaches and VFR operations behind heavier airplanes; and (3) pilot knowledge related to the avoidance of wake vortices. Resolution of these concerns would address any concerns that were believed to have been specific to the B-757.

Aircraft Separation Criteria Based on Weight

The wake vortex characteristics of transport category airplanes are not required to be determined at the time of airplane certification; airplane separation distances to avoid wake vortex encounters are based solely on weight. For example, not until 1992 did the National Oceanic and Atmospheric Administration (NOAA) and FAA conduct

Figure 1—Calculated initial vortex strength of aircraft types. (Courtesy of the National Aeronautics and Space Administration.)

tower fly-by tests to determine the characteristics of wake vortices produced by the B-757; yet the airplane entered service in 1982, and there are 574 airplanes now in service. The testing has shown that the B-757 generated the highest vortex tangential velocity,[16] 326 feet per second, of any tested airplane, including heavy category B-747, B-767, and C-5A airplanes.[17] The vortex core radius was about 3 inches. Various theories have been offered as to why the tangential velocity was higher than previously measured. Although not proven, a number of researchers and engineers believe that the B-757 wing flap design is an important factor. Most of the larger transport category airplanes have gaps between the trailing edge flaps that disrupt the uniform development of the vortex. The B-757 flaps are continuous from the fuselage to the ailerons, a design that is believed to be more conducive to uniform development of the wake vortex.

More importantly, however, the high core velocity (within the small core radius) is not considered the primary factor in defining the risk associated with encountering the vortex. Researchers and engineers generally believe that the vortex circulation[18] is a more significant factor in the risk of a wake vortex encounter. The circulation theory has been verified and accepted for many years. The initial strength of a vortex can be accurately calculated and the fly-by test results have shown that the circulation of the B-757's wake is typical for its weight. The B-757's circulation was greater than that of a B-727 and less than that of a B-767. In addition, the data to date suggest that the longevity of the B-757 vortices is consistent with its wing span.

The January 1993 NOAA report did not recommend an increase in the separation distances behind the B-757, citing insufficient testing to determine the persistence of a B-757 vortex. The report did recommend additional testing to determine the persistence of and the effects of atmospheric conditions on B-757 vortices. The Safety Board concurs in this recommendation. However, the Board also believes, as discussed in

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16 A vortex, a mass of rotating air, consists of a core and a flow field about the core. Lift is created by a pressure differential between the upper and lower surface of the wing. This pressure differential results in a rollup of the airflow aft of the wing, thus creating a vortex. The tangential velocities of the core are proportional to the distance from the center of the core whereas the tangential velocities in the flow field are generally inversely proportional to the square of the distance from the core.

17 National Oceanic and Atmospheric Administration Technical Memorandum ERL ARL-199, January 1993.

18 Circulation is a measure of the angular momentum of the air in the flow field and defines the strength of a vortex. The size and strength of the flow field determine the risk of upset posed to a following airplane.

more detail later in this report, that the accident at Billings, Montana, provides sufficient evidence to warrant increasing the separation distance behind the B-757.

The Safety Board is concerned that the design of future airplanes could result in wake vortices that are unusually strong or persistent for the weight of the airplane. Flight testing would provide data about the vortex decay, transport, residual strength, effects of atmospheric conditions, and unusual or unique characteristics of the airplane's vortex. Accordingly, the Board believes that the FAA should require manufacturers of turbojet, transport category airplanes to determine, by flight test or other suitable means, the characteristics of the airplanes' wake vortices during certification.

Until the FAA has developed the knowledge and systems that will permit a significant reduction in the probability of wake vortex encounters, there will be a need to visually determine adequate separation distances. Further, the five vortex encounters described earlier and the CAA data demonstrate the need to increase the IFR separation distances for small and large airplanes on approach and in-trail behind the B-757 and other airplanes of similar weight if they are introduced into service. The accident at Billings and the incident at Orlando show that an encounter with a B-757 vortex at 3 nm can be dangerous to most large airplanes. In addition, greater ATC separation standards may have reduced or prevented the excessive closures noted in the other three encounters.

The FAA requires less radar separation for wake vortex considerations for IFR airplanes under positive air traffic control than that recommended by the ICAO and required by the CAA (see table 3). A Citation or Westwind following an airplane such as a B-757 would require a 5-nm separation based on ICAO recommendations and a 6-nm separation based on CAA standards, rather than the 3-nm separation required by the FAA.

One method to achieve increased separation behind a B-757 would be to reclassify the B-757 as a heavy airplane.[19] Large airplanes would benefit from a 5-nm separation and small airplanes would benefit from a 6-nm separation when executing an instrument approach in-trail behind a B-757. However, the reclassification would reduce the required radar separation of a B-757 in-trail behind a B-747 (maximum gross weight of 820,000 pounds) from 5 nm to 4 nm, increasing the risk of a wake vortex upset for the B-757. The FAA and Boeing have expressed concern about increasing the risk of a wake vortex encounter if a B-757 followed a heavy airplane more closely.

19 Canada has reclassified the B-757 as a heavy airplane when it is the leading airplane.

Table 3—Separation distance between lead and following aircraft currently established by the International Civil Aviation Organization (ICAO), United Kingdom (U.K.), and United States (U.S.) to avoid wake vortex encounters.

Weight category[a] of-		Minimum separation distance, (nautical miles)		
Lead aircraft	Following aircraft	ICAO	U.K.	U.S.
Heavy	Heavy	4	4	4
Heavy	Large	NA	NA	5
Heavy	Medium	5	5	NA
Heavy	Small	NA	6	6
Heavy	Light	6	8	NA
Large	Large	NA	NA	3
Large	Small	NA	NA	4
Medium	Medium	3	3	NA
Medium	Small	NA	4	NA
Medium	Light	5	6	NA
Small	Light	NA	4	NA

NA = not applicable because category has not been designated.

a The weight categories are based on maximum takeoff weight of the aircraft.

The characteristics of certain airplane pairs were examined to determine the relative risks of upset by wake vortex encounters. The relative risk of wake vortex upsets is a function of the strength of a vortex generated by the leading airplane and the roll moment inertia of the trailing airplane. The vortex strength is generally defined as a function of weight divided by velocity and span. The roll moments of inertia are generally proportional to the weight of the airplane.[20]

20 Roskam, Jan. 1982. Airplane flight dynamics and automatic flight controls. Ottawa, KS: Roskam Aviation and Engineering Corporation. (p. 19).

Safety Board staff used the maximum landing weights to represent the roll inertia of B-757s and Citations. The vortex strengths of B-747s and B-757s were also calculated using maximum landing weights. The combination of the B-747 vortex strength and the B-757 landing weight was compared to the combination of the B-757 vortex strength and the Citation landing weight. The comparisons show that, at equal separation distances, the risk of loss of control when a Citation encounters the wake vortex of an airplane similar in weight to a B-757 is 8 times greater than the risk associated with a B-757 encountering the wake vortex of a B-747 (see appendix I for calculations). In practice, however, the B-757/B-747 pair would be separated by 4 nm if both were classified as heavy airplanes, thus lessening the risk for that pair (because 3 nm was used in the risk calculations). Therefore, the relative risk of the two pairs is greater than a factor of 8. In addition, the determination of the relative risk does not reflect the CAA data, which suggest that the wake vortex of a B-757 may last longer than would be expected for its weight. Clearly, therefore, if the risk associated with reclassifying the B- 757 as a heavy category airplane is unacceptable, the current risk to a Citation at 3 nm behind a B-757 is also unacceptable.

The Safety Board shares the concern of the FAA and Boeing about reclassifying airplanes such as the B-757 as heavy airplanes. The Safety Board believes it would be preferable to maintain the current separation distance of 5 nm when such airplanes are following a heavy airplane and to increase the separation distances for other airplanes when they are following a B-757 or other airplanes of similar weight. The accident in Billings, Montana, for example, clearly demonstrates that lighter weight airplanes in the large airplane category require a separation distance greater than 3 nm when following a B-757. Further, the CAA wake vortex incident data raise concern about airplanes of the size of B-737s following only 3 nm behind airplanes of the size of the B-757. Accordingly, the Board believes that the FAA should immediately establish the following interim wake vortex separation requirements for IFR airplanes following a Boeing 757 and other airplanes of similar weight: 4 nm for airplanes such as the B-737, MD-80, and DC-9; 5 nm for airplanes such as the Westwind or Citation; and 6 nm for small airplanes. The current separation requirement of 5 nm when a B-757 or other airplane of a similar weight is following a heavy category airplane should be maintained.

The relative risk comparisons also indicate that the lighter weight airplanes in the large airplane category are at high risk of upset from the vortices generated from airplanes in the heavy category. Consequently, the Safety Board is concerned that the current separation requirements for IFR airplanes such as the Westwind and Citation when following heavy category airplanes are also inadequate.

The most significant problem related to establishing adequate separation standards is the great range of weights (12,500 to 300,000 pounds) in the large airplane category. Because of the large weight differences between the high and low end of the large airplane category, lighter weight airplanes are at high risk of upset from the vortices generated by the heavier weight airplanes. One possible means to minimize the risk of wake vortex encounters is simply to divide the large airplane category into two separate categories (for example, 12,500 to 150,000 pounds and 150,000 to 300,000 pounds), accompanied with increased separations between the newly created categories. However, a preferable approach would be to create four weight categories in which the ratios of the high and low weights in each category would be similar. For example: heavy (greater than 300,000 pounds), large (between 100,000 and 300,000 pounds), medium (between 30,000 and 100,000 pounds), and small (less than 30,000 pounds). The maximum ratio of weights within each category is about 3.

Appropriate separation distances, based on such a revised weight classification scheme, consistent with the separation distances discussed above, could be the following: for airplanes following a heavy category airplane, the separation distance should be 4 nm (heavy), 5 nm (large), 6 nm (medium), and 7 nm (small). For airplanes following a large category airplane, the separation distances should be 4 nm (large), 5 nm (medium), and 6 nm (small). Current data suggest that a separation distance of 3 nm may be adequate for a medium category airplane following another medium category airplane and for all airplanes following a small airplane. Such an approach would provide more separation because of the increased number of categories and would also reduce the weight disparity of the high and low weights within each category. Therefore, the Safety Board believes that the FAA should revise the airplane weight classification scheme to reduce the weight disparity of high and low weights within each category and to establish separation distances between the various weight categories, consistent with the separation distances discussed above (for airplanes trailing airplanes such as the B-757).

Air Traffic Control Procedures Related to Visual Approaches and VFR Operations Behind Heavier Airplanes

The Safety Board believes that one common element to the five wake vortex encounters described earlier is that a combination of ATC procedures and pilot actions resulted in separation distances that were too small for the airplane trailing behind a B-757 while on a visual approach to landing. Currently, controllers are required to ensure that airplanes have the proper radar separation prior to the issuance of a visual approach clearance. However, the incident at Denver and the accident at Santa Ana illustrate that controllers sometimes issue visual approach clearances when the separation distance and closure rate preclude the pilot from maintaining a safe separation distance without excessive maneuvering. During peak traffic periods, controllers rely on the use of visual approaches to increase traffic capacity and to reduce delays. Pilots may try to accommodate the controller by accepting a visual approach even though they may be unable to maintain adequate separation from the preceding traffic without excessive maneuvering, excessive reconfiguration of the airplanes, or drastic reduction of their airspeed. When this situation occurs, a compression effect can be created, increasing the exposure of each successive arrival to a wake turbulence encounter.

The Safety Board believes that the FAA should amend 7110.65H, Air Traffic Control,[21] to prohibit controllers from issuing a visual approach clearance to an IFR airplane operating behind a heavier airplane (in the large or heavy airplane category) until the controller has determined that the in-trail airplane should not have to execute S-turns, make abrupt configuration changes, or make excessive speed changes while maintaining a separation distance that would be required for IFR approaches. If the airplane is in-trail or on a converging course at the time the visual clearance is issued, closure rate should be consistent with the required separation distance. That is, if the separation distance is slightly greater than the required separation distance, the closure rate should be minimal. However, if the separation distance is large, a greater closure rate may be tolerated. The controller should set up the in-trail situation in a manner in which both airplanes can continue the approach in a reasonable manner.

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[21] This document is the air traffic control handbook that prescribes air traffic control procedures and phraseology for use by personnel providing air traffic control services.

In addition, although controllers receive initial training in these areas, the Safety Board believes that controllers should be provided annual refresher training related to wake turbulence separation and advisory criteria. The training should emphasize the need for controllers to avoid using phrases or terminology that would encourage pilots of VFR or IFR airplanes to reduce separation to less than that required during IFR operation, thereby increasing the chance for a wake turbulence encounter when operating behind a turbojet airplane.[22]

The Safety Board is especially concerned that the GENOT and pilot bulletin issued on December 22, 1993, by the FAA are not likely to be effective in reducing wake turbulence encounters of pilots who accept a visual approach clearance or who follow closely behind a B-757 while on approach to the airport.[23] The GENOT and pilot bulletin, in essence, reiterate past practices. The only change is the requirement that wake turbulence cautionary advisories be issued to airplanes following a B-757. Pilots are not provided any additional guidance on how to adhere to the procedures defined in the AIM. Specifically, pilots are still not provided sufficient information to determine that adequate separation distances are being maintained or to determine that their flight path remains above the flight path of the preceding airplane.

Knowledge of the manufacturer and model would help the pilot determine a safe separation distance. For example, in the Salt Lake City and Santa Ana accidents, the pilots knew they would be operating behind a turbojet airplane. The controller, in each situation, had ample opportunity to advise the pilot, specifically, that he would be operating behind a Boeing 757. In addition, a pilot, if provided with a wake turbulence cautionary advisory and other information relevant to the avoidance of wake turbulence, such as separation distance and the existence of an overtaking situation, would be better able to maintain an adequate separation distance. Thus, the Safety Board believes that controllers should be required to provide this information, as a minimum, to pilots prior to allowing visual operations behind or in-trail of heavier, turbojet airplanes. Several of the 46 accidents and incidents from 1983 to 1993 that resulted from probable encounters

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22 A review of ATC transcripts from some of the accidents and incidents which resulted from probable encounters with wake vortices revealed terminology used by controllers that would encourage pilots to violate separation requirements, such "keep a tight pattern and follow the large airplane." In one instance, the controller requested a short approach but also cautioned about wake turbulence; in that instance the pilot encountered turbulence at 50 feet and crashed, sustaining serious injuries.

23 See appendix E for GENOT, pilot bulletin, and other related correspondence.

with wake vortices occurred during phases of operation other than the approach phase. Had the pilots involved in these accidents and incidents known the manufacturer and model of the other aircraft, they might have been able to maintain adequate separation distances. Therefore, the Safety Board believes that the FAA should amend handbook 7110.65H, Air Traffic Control, to require that controllers issue both the manufacturer and model of airplane when issuing information about air carrier traffic.

The Safety Board recognizes that the proposed changes will be an additional burden for air traffic controllers. However, until more reliable systems are in place to predict and detect wake vortices, these measures should further reduce the likelihood of wake vortex encounters.

Pilot Knowledge Related to the Avoidance of Wake Vortices

The accident and incident data suggest that a combination of pilots' lack of understanding of the hazards of wake vortices and the difficulty of knowing the movements of wake vortices are major contributors to wake vortex encounters. A pilot's visual estimate of range is not sufficiently accurate to ensure safe separation. It is especially difficult to estimate separation distances at night. In addition, Safety Board accident and incident data show that student pilots and pilots operating under 14 CFR 91 rules continue to encounter wake vortices at an unacceptable rate. The Safety Board notes that many pilots involved in accidents and incidents had instrument ratings, had been given wake vortex precautions, and yet continued on, either ignoring the caution, or mistakenly believing that they were above the vortex. To help pilots avoid wake vortex encounters, the Board urges the FAA to develop comprehensive training programs related to wake turbulence avoidance and to publish the information in the Airman's Information Manual[24] and other training materials. This information should include techniques for determining relative flight paths and separation distances. The accident at Billings, Montana, for example, clearly demonstrated the need for techniques to help pilots maintain a flight path that is higher than that of the leading airplane. In that accident, the flight path of the Citation was at least 300 feet below that of the B-757. Further, the information should define the vertical movement of wake vortices in ground effect. In the accident at Salt Lake City, Utah, the Cessna 182 could have been affected by the vortex of the B-757 at any altitude between ground level and 200 feet AGL.

24 The Airman's Information Manual provides information on wake vortices and instructs pilots to maintain a flight path that is higher than that of the leading airplane. The manual, however, does not provide guidance on how to avoid wake vortices or to maintain the proper flight path.

Although the Cessna's flight path was above that of the B-757, the pilot did not adequately compensate for the height of the vortex. Knowledge of or training specifically related to the height of wake vortices in ground effect likely would have prompted the Cessna pilot involved in the Salt Lake City accident to remain several hundred feet above the B-757 flight path. However, the Safety Board is not aware of any training related to wake vortex avoidance that is provided to pilots after they initially receive their pilot's license. Consequently, the Safety Board believes that the FAA should require 14 CFR 121 and 14 CFR 135 operators to implement training specifically related to the movement and avoidance of wake vortices and techniques to determine relative flight paths and separation distances. In addition, the FAA should revise the practical test standards for commercial, air transport pilot, and additional type ratings to place emphasis on wake turbulence avoidance.

Finally, the B-757 has the capability to fly steeper approaches at slower speeds than most other turbojet transport category airplanes at similar weights. The steeper approaches may be conducted for fuel conservation, noise abatement policies, or simply because the performance of the B-757 allows such approaches. As a result, smaller airplanes, while conducting a normal approach, may be faster and on lower flight paths than a B-757, thus increasing the risk of an encounter with the vortex of the B-757. The Safety Board believes that the FAA should establish air traffic control and operational procedures for the B-757 and other heavier large category airplanes or heavy category airplanes that would result in approaches being conducted in accordance with flight path guidance, when available, or on a standard flight path angle of about 3° when such airplanes are established on course to the runway and other airplanes are in-trail. In addition, the FAA should inform operators of the B-757 and other heavier large category airplanes or heavy category airplanes to instruct pilots of the importance (because of the potential for a strong wake) on approach to landing of maintaining a flight path in accordance with guidance, when available, or on a standard flight path angle of about 3°.

Use of Traffic Collision and Avoidance Systems

As discussed above, the investigations show that pilots typically do not possess the skills to accurately determine the flight paths of airplanes they are following nor can they accurately estimate the distance to those airplanes. The Safety Board believes that training can improve those skills but cannot eliminate the problem. One possible remedy would be to develop technology to help the pilots determine their position relative to a preceding airplane. Currently, ground-based radar is the only operational tool designed for that purpose. With radar, air traffic controllers can determine separation but cannot easily determine relative flight paths. However, radar separation requires the constant attention of the controller and the controller's communication with the following airplane.

Another possibility would be to use Traffic Collision and Avoidance Systems (TCAS) to provide range information to a pilot following another airplane. Although TCAS was designed only for warning of pending collisions, certain models provide position data of other airplanes. The Safety Board understands that some pilots are currently using the range information provided by TCAS to corroborate range information provided by ATC. In addition, the FAA and some airlines are currently evaluating the feasibility of using TCAS to provide separation information over the Atlantic Ocean when radar coverage is not available. According to the FAA, TCAS manufacturers have determined that the systems are sufficiently accurate for use over the Atlantic when the range is within 10 to 15 miles.

However, various concerns have been raised about the use of TCAS for separation during a visual operation in the terminal environment. Among these concerns are: that TCAS was not designed to provide separation information; the pilot's attention may be diverted into the cockpit; the pilot will have more tasks to perform; the display of some TCAS systems are not adequate for use as a separation aid; and the systems have had problems with reliability and false alarms. Also, the smaller general aviation and corporate airplanes that would benefit the most from accurate range information are less likely to have TCAS installed.

TCAS II is required to be installed on Part 121 airplanes and TCAS I will be required to be installed on Part 135 airplanes by February 1995, although the FAA estimates that the compliance date will be extended by 1 or 2 years. Currently, more than 1,000 corporate airplanes have TCAS II installed. TCAS is now being installed during the manufacture of some corporate airplanes such as the Grumman Gulfstream IV and the Cessna Citation.

The Safety Board believes that TCAS may have the potential of providing useful range information to the pilot who has accepted a visual approach clearance while in-trail behind another airplane. Therefore, the Safety Board believes that the FAA, in conjunction with industry, should determine whether TCAS is appropriate for providing pilots with the separation distance to the preceding airplane during visual landing approaches. If appropriate procedures can be developed, the use of TCAS for establishing safe separation should be encouraged for the pilot of airplanes so equipped.

Findings

1. The Safety Board's investigations of five recent accidents in which an airplane on approach to landing encountered the wake vortex of a preceding Boeing 757 indicated that the following factors were more important than any specific characteristic of the B-757 wake vortex: (1) inadequacies in the current airplane weight classification scheme to establish separation criteria, (2) inadequacies in air traffic control procedures related to visual approaches and visual flight rules operations behind heavier airplanes, and (3) insufficient pilot knowledge and training related to the avoidance of wake vortices.

2. Because of the large weight differences between the high and low end of the large airplane category, lighter weight airplanes are at high risk of upset from the vortices generated by the heavier weight airplanes.

3. Current air traffic control procedures and pilot reactions can result in airplanes following too closely behind larger airplanes while on a visual approach to landing.

4. Pilots of arriving visual flight rules airplanes and instrument flight rules airplanes cleared for visual approach often do not have sufficient information to maintain adequate separation distances or to determine relative flight paths.

5. Pilots are not provided adequate training related to the movement and avoidance of wake vortices or for determining relative flight paths and separation distances.

6. Data are not available to analyze the wake vortex incident history in the United States because the Federal Aviation Administration does not require pilots to report wake vortex encounters.

7. The wake vortex characteristics of transport category airplanes are not required to be determined at the time of airplane certification; airplane separation requirements to avoid wake vortex encounters are based solely on weight.

8. New technology being developed may find application in future airborne and ground-based systems to monitor wake vortex movements.

Recommendations

As a result of this special investigation, the National Transportation Safety Board made the following recommendations to the Federal Aviation Administration:

> Establish the following interim wake vortex separation requirements for instrument flight rules airplanes following a Boeing 757 and other airplanes of similar weight: 4 nautical miles (nm) for airplanes such as the B-737, MD-80, and DC-9; 5 nm for airplanes such as the Westwind and Citation; and 6 nm for small airplanes. Maintain the current separation requirement of 5 nm when a B-757 or other airplane of a similar weight is following a heavy category airplane. (Class I, Urgent Action) (A-94-42)

> Revise the airplane weight classification scheme to reduce the weight disparity of high and low weights within each category and to establish separation distances between the various weight categories, consistent with the interim separation distances outlined in Safety Recommendation A-94-42. (Class II, Priority Action) (A- 94-43)

> Establish air traffic control and operational procedures for the Boeing 757 (B-757) and other heavier large category airplanes or heavy category airplanes that would result in approaches being conducted in accordance with flight path guidance, when available, or on a standard flight path angle of about 3° when such airplanes are established on course to the runway and other airplanes are in-trail. (Class II, Priority Action) (A-94-44)

> Inform operators of the Boeing 757 (B-757) and other heavier large category airplanes or heavy category airplanes to instruct pilots of the importance (because of the potential for a strong wake) on approach to landing of maintaining a flight path in accordance with guidance, when available, or on a standard flight path angle of about 3° (Class II, Priority Action) (A-94-45)

Amend FAA Handbook 7110.65H, Air Traffic Control, to prohibit the issuance of a visual approach clearance to an instrument flight rules airplane operating behind a larger airplane (in the large or heavy airplane category) until the airplane is in-trail and the closure rate is such that the pilot can maintain the minimum instrument flight rules separation without excessive maneuvering. (Class II, Priority Action) (A-94-46)

Amend FAA Handbook 7110.65H, Air Traffic Control, to require that instrument flight rules airplanes cleared for a visual approach behind a heavier turbojet airplane be advised of the airplane manufacturer and model, be provided a wake turbulence cautionary advisory, and be provided other information relevant to the avoidance of wake turbulence, such as separation distance and the existence of an overtaking situation. (Class II, Priority Action) (A-94-47)

Amend FAA Handbook 7 110.65H, Air Traffic Control, to require that arriving visual flight rules airplanes that have been sequenced for approach behind a heavier turbojet airplane be advised of the airplane manufacturer and model, be provided a wake turbulence cautionary advisory, and be provided other information relevant to the avoidance of wake turbulence, such as separation distance and the existence of an overtaking situation. (Class II, Priority Action) (A-94-48)

Amend FAA Handbook 7110.65H, Air Traffic Control, to require that controllers issue both the manufacturer and model of airplane when issuing information about air carrier traffic. (Class II, Priority Action) (A-94-49)

Develop annual refresher training for air traffic controllers regarding wake turbulence separation and advisory criteria. The training should emphasize the need for controllers to avoid using phrases or terminology that would encourage pilots of visual flight rules or instrument flight rules (IFR) airplanes to reduce separation to less than that required during IFR operation, thereby increasing the chance for a wake turbulence encounter when operating behind a turbojet airplane. (Class II, Priority Action) (A-94-50)

Expand the current guidance in the Airman's Information Manual and develop other training material to help pilots to determine that their flight path remains above the flight path of the leading airplane and that their separation distance remains consistent with that required for instrument flight rules operations. (Class II, Priority Action) (A-94-51)

Expand the information in the Airman's Information Manual and other training material to define the vertical movement of wake vortices in ground effect, such as vortex core height, upper and lower limits of the vortex flow field, and the potential to "bounce" twice as high as the steady state height. (Class II, Priority Action) (A-94-52)

Require 14 CFR 121 and 14 CFR 135 operators to provide training specifically related to the movement and avoidance of wake vortices and techniques to determine relative flight paths and separation distances. (Class II, Priority Action) (A-94-53)

Revise the practical test standards for commercial, air transport pilot, and additional type ratings to place emphasis on wake turbulence avoidance. (Class II, Priority Action) (A-94-54)

Conduct additional tests of the Boeing 757 to determine the persistence and strength of its wake vortex and the effects of atmospheric conditions on B-757 vortices. (Class II, Priority Action) (A-94-55)

Require manufacturers of turbojet, transport category airplanes to determine, by flight test or other suitable means, the characteristics of the airplanes' wake vortices during certification. (Class III, Longer Term Action) (A-94-56)

Require reporting of wake vortex encounters and establish a system to collect and analyze pertinent information, such as recorded radar data, atmospheric data, and operational information, including selected flight data recorder data. (Class III, Longer Term Action) (A-94-57)

Continue to sponsor research and development projects that may lead to technological or procedural solutions to reduce the hazards posed by wake vortices. (Class III, Longer Term Action) (A-94-58)

Determine if the Traffic Collision and Avoidance System (TCAS) is appropriate for providing pilots with the separation distance to the preceding airplane during visual approaches to landing. If appropriate, develop procedures to allow the use of TCAS for that purpose. (Class II, Priority Action) (A-94-59)

Encourage operators of smaller general aviation and corporate airplanes to install and use the Traffic Collision and Avoidance System (TCAS), if procedures to allow the use of TCAS to confirm separation distances during visual approaches are developed. (Class II, Priority Action) (A-94-60)

By the National Transportation Safety Board

Carl W. Vogt
Chairman

Susan M. Coughlin
Vice Chairman

John H. Lauber
Member

John A Hammerschmidt
Member

James E. Hall
Member

Adopted: February 15, 1994

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Appendix A

Accidents and Incidents From 1983 To 1993 That Resulted From Probable Encounters With Wake Vortices

Table 4—Accidents and incidents investigated by the National Transportation Safety Board from 1983 to 1993 that resulted from probable encounters with wake vortices

Date	Location	Leading aircraft	Trailing aircraft	Phase of operation	File No.
02/06/83	Tucson, AZ	B-727	Beech H-35	Approach	1928
05/13/83	Boston, MA	Airbus A-300	Cessna 402C	Cruise	5107
01/10/84	Los Angeles, CAL	L-1011	DC-9	Approach	6010
03/19/84	Riverton, WY	Convair 580	Piper PA-12-115	Approach	0407
06/21/84	Middle Town, PA	3-30 aircraft	Cessna 50M	Descent	1729
06/30/84	Grenada, MS	UH-I helicopter	Cessna 172G	Approach	0899
10/04/84	Norfolk, VA	B-727	Cessna 172M	Descent	3297
10/13/84	Miles City, EL	Helicopter[a]	Piper J3C-65	Descent	2541
02/28/85	West Palm Beach, FL	Heavy jet[a]	Piper PA-32R	Cruise	1411
03/13/85	DEW Airport, TX	B-747	Beech A-36	Approach	5043
06/11/85	Belmar, NJ	Helicopter[a]	Cessna 152	Takeoff	0760
07/10/85	Rochester, MN	DC-9	Cessna 152	Landing	2305
12/19/85	Tucson, AZ	EC-130	Cessna 150L	Descent	2623
01/27/86	Reno, NV	B-737	Cessna TRl82RG	Descent	0074
03/31/86	Boise, ID	Transport aircraft[a]	Cessna T210C	Landing	0225
05/17/86	Van Nuys, CA	C- 130	Aerospatiale TB20	Approach	2687
10/29/86	England AFB, LA	Four jet fighters[a]	Cessna 182J	Landing	1204
10/31/86	Ft. Pierce, FL	USCG helicopter[a]	Piper PA-28-181	Landing	1449
11/06/86	Tampa, FL	L-1011	Cessna 421C	Approach	1668

Table 4—Accidents and incidents investigated by the National Transportation Safety Board from 1983 to 1993 that resulted from probable encounters with wake vortices (continued)

Date	Location	Leading aircraft	Trailing aircraft	Phase of operation	File No.
03/04/87	Miami, FL	B-737	Piper PA-34-200	Landing	0253
07/14/87	Raleigh, NC	B-727	Cessna 172M	Descent	1041
09/08/87	Monterey, CA	BAE-146	Beech 95	Descent	2519
12/09/87	Anchorage, AK	B-727	Cessna 402B	Approach	2213
01/09/88	Colorado Springs, CO	C-141	Rotorway Executive	Taxi	0043
01/26/88	El Toro, CA	C-130	Cessna 152	Landing	1722
11/08//88	Nashville, TN	B-727	Cessna 210D	Descent	1122
11/09/88	Gainesville, FL	Navy P-3	Cessna 152	Takeoff	1744
11/19/88	Van Nuys, CA	King Air	Piper PA-28R-201T	Landing	2067
12/31/88	Grand Rapids, MI	B-727	Cessna 152II	Landing	2404
05/23/89	Phoenix, AZ	B-737	Piper PA-32RT-300T	Descent	0667
06/14/89	Columbus, OH	B-737	Grumman American AA-5	Approach	1343
06/18/89	Port Huron, MI	Junker JU-52	Cessna 150	Approach	0846
09/06/89	Santa Ana, CA	B-737	Cessna 180	Landing	1615
09/14/89	Santa Paula, CA	UNK	Cessna 152	Approach	0802
09/26/89	Portland, OR	Large airplane[a]	Piper PA-32-260	Landing	1987
10/05/89	Palm Springs, CA	B-727	Piper PA-28RT-201T	Approach	1536
04/01/90	Westfield, MA	UNK	Walter Hudson Mustang 2	Takeoff	2344
05/31/90	Anchorage, AK	B-757	Cessna 195	Landing	0284
06/20/90	Rialto, CA	Bell Helicopter 412	Cessna 152II	Takeoff	1054

Table 4–Accidents and incidents investigated by the National Transportation Safety Board from 1983 to 1993 that resulted from probable encounters with wake vortices (continued)

Date	Location	Leading aircraft	Trailing aircraft	Phase of operation	File No.
01/21/91	Sacramento, CA	MD-80	Cessna 172P	Cruise	0270
02/04/91	Greensboro, NC	DC-9	Piper PA-28-180	Landing	1422
3/11/91	Santa Ana, CA	B-757	Cessna 152	Landing	0129
03/16/91	Pullman, WA	Swearingen	Cessna 140	Approach	0181
09/07/91	Marion, OH	Larger airplane[a]	5-7 Courier	Takeoff	2018
09/13/91	Prescott, AZ	Beech 1900	Cessna 172N	Takeoff	1901
11/20/91	Chicago, IL	Like aircraft[a]	Aerospatiale	Descent ATR42-300	5046
10/27/92	Saipan, PO	DC-10	Cessna 310R	Takeoff	2992

[a] The make and model of the aircraft were not identified in the Safety Board's brief of the accident.

Appendix B
Summary of Safety Board Recommendations Addressing Wake Vortex Issues

Safety Recommendation No.:	A-72-076
Date Issued:	June 30, 1972
Recipient:	Federal Aviation Administration
Status:	Closed–No Longer Applicable

Subject:

Reevaluate wake turbulence separation criteria for aircraft operating behind heavy jet aircraft.

Safety Recommendation No.:	A-72-077
Date Issued:	June 30, 1972
Recipient:	Federal Aviation Administration
Status:	Closed–Acceptable Action

Subject:

Issue alert notices to all pilots and aircraft operators that will stress the urgent need to maintain an adequate separation from heavy jet aircraft.

Safety Recommendation No.:	A-72-213
Date Issued:	December 20, 1972
Recipient:	Federal Aviation Administration
Status:	Closed–Acceptable Action

Subject:

Revise appropriate publications to assure that they describe more specifically the desirable avoidance techniques (e.g., following aircraft maintain approach path above VASI or ILS glide slope, extending downwind leg, etc.).

Safety Recommendation No.: A-72-214
Date Issued: December 20, 1972
Recipient: Federal Aviation Administration
Status: Closed–Acceptable Action

Subject:

Define and publish the meteorological parameters which cause trailing vortices to persist in the vicinity of the landing runway.

Safety Recommendation No.: A-72-215
Date Issued: December 20, 1972
Recipient: Federal Aviation Administration
Status: Closed–Unacceptable Action

Subject:

Include wake turbulence warnings on the ATIS broadcasts whenever the meteorological conditions identified in Recommendation A-72-214 indicate that vortices will pose an unusual hazard to other aircraft.

Safety Recommendation No.: A-88-140
Date Issued: November 3, 1988
Recipient: Federal Aviation Administration
Status: Closed–Acceptable Action

Subject:

Initiate a research project to acquire data from dedicated sensors to determine what consideration, if any, should be given to wake vortices in a parallel offset runway situation.

Safety Recommendation No.: A-90-076
Date Issued: June 4, 1990
Recipient: Federal Aviation Administration
Status: Closed–Unacceptable Action

Subject:

Amend the Air Traffic Control Handbook, 7110.65F, paragraph 3-106I, to require air traffic controllers to impose a 3-minute delay on the pilots of "small" category airplanes who intend to depart in the same direction from the same runway behind a "large" category airplane that is on takeoff or a low or missed approach, to separate the small airplane from wake turbulence.

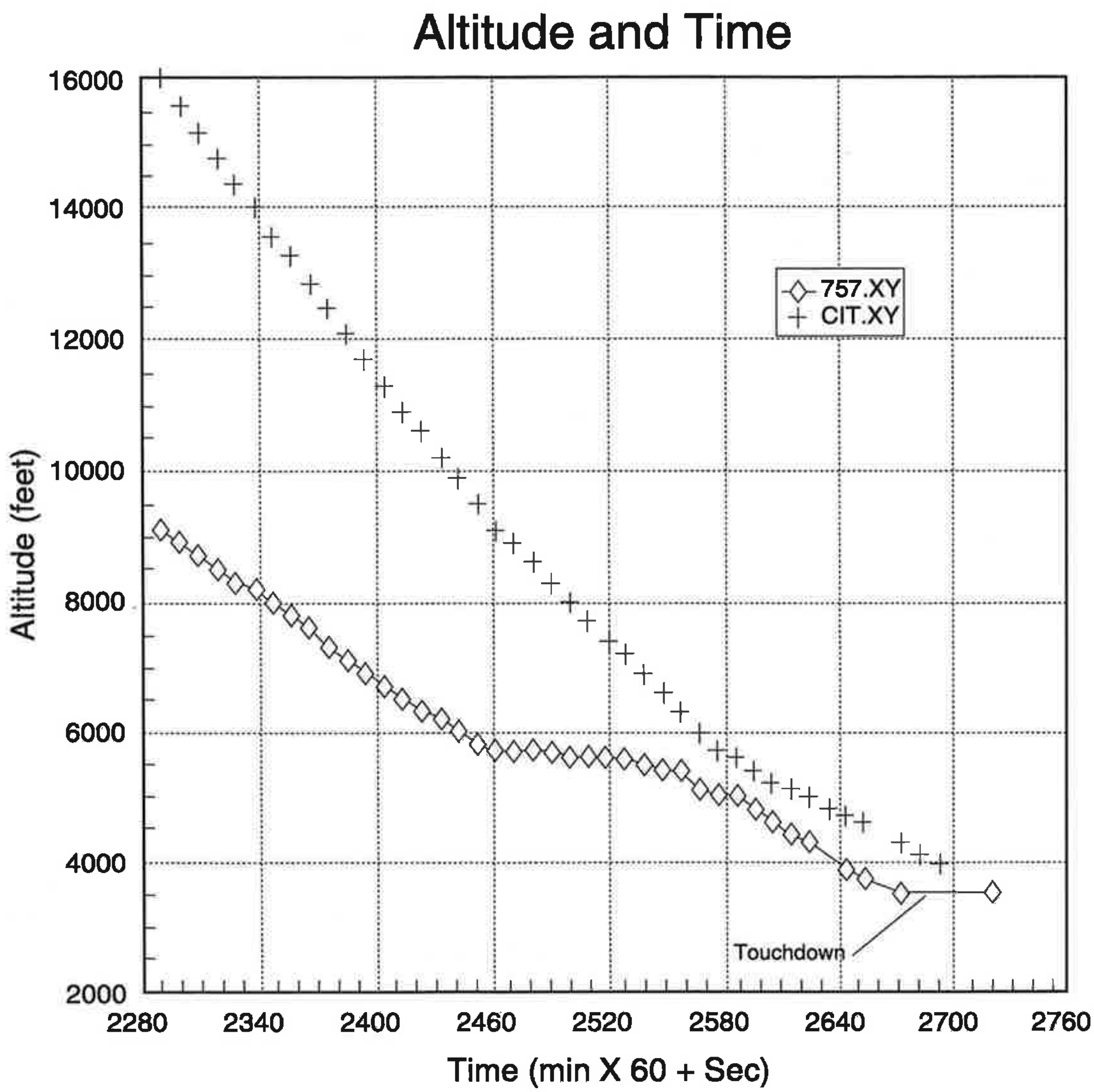
Safety Recommendation No.: A-90-077
Date Issued: June 4,1990
Recipient: Federal Aviation Administration
Status: Closed–Unacceptable Action

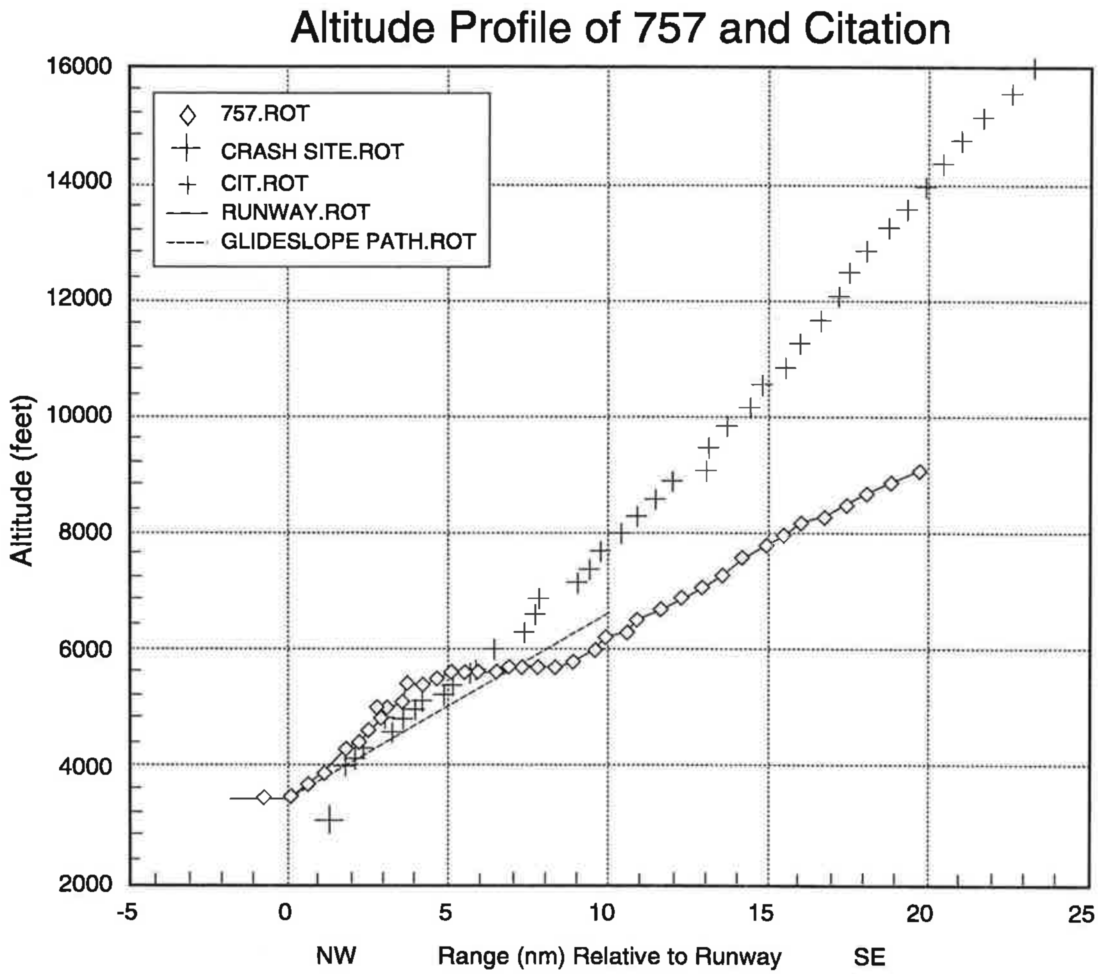
Subject:

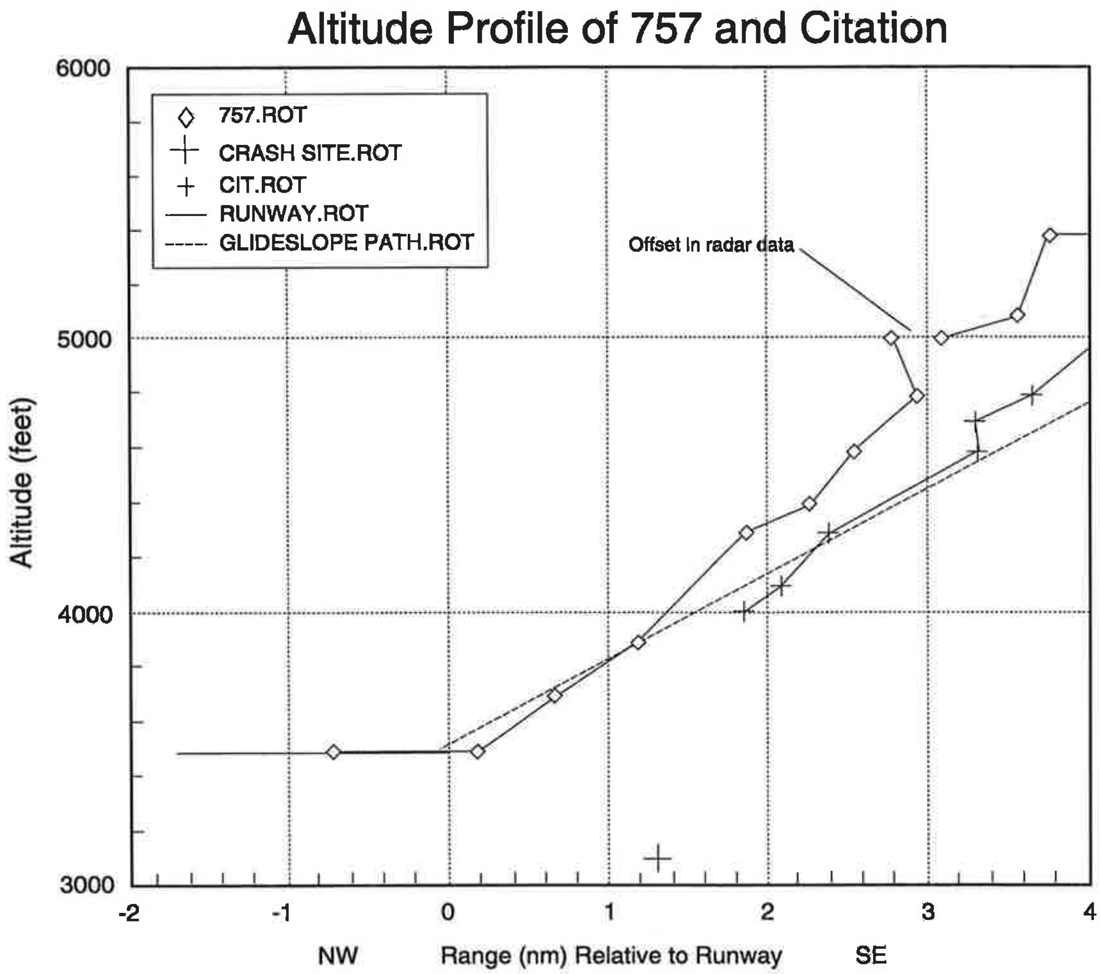
Amend the Purman's Information Manual, paragraph 545, and Advisory Circular 90-23D to inform pilots of "small" category aircraft that under certain circumstances involving takeoff behind "large" category aircraft, they can expect that a 3-minute delay will be imposed by air traffic controllers in order to allow for the dissipation of the wake turbulence.

Appendix C

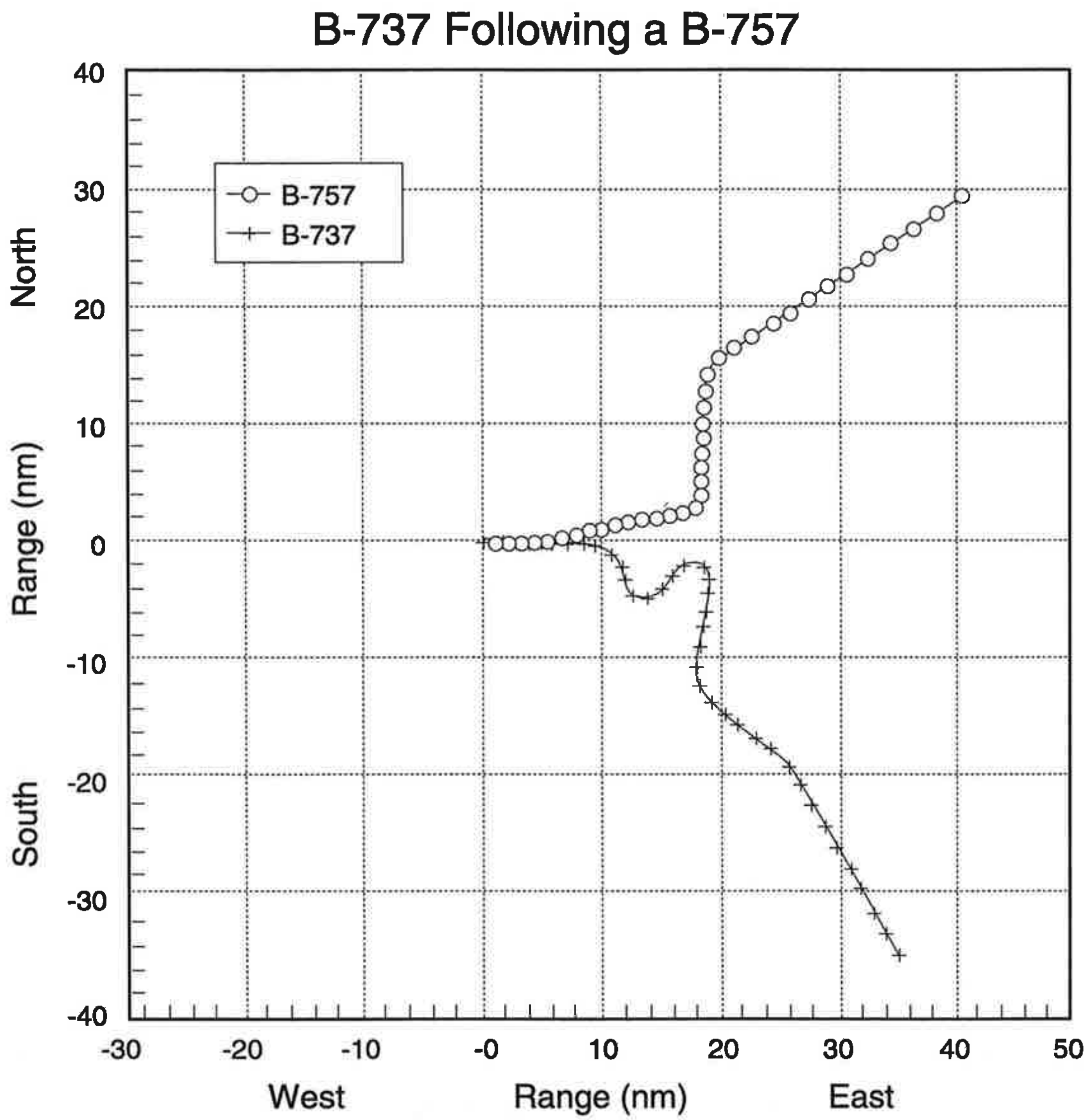
Altitude Profile of B-757 and Cessna Citation 550 at Billings, Montana, on December 18, 1992

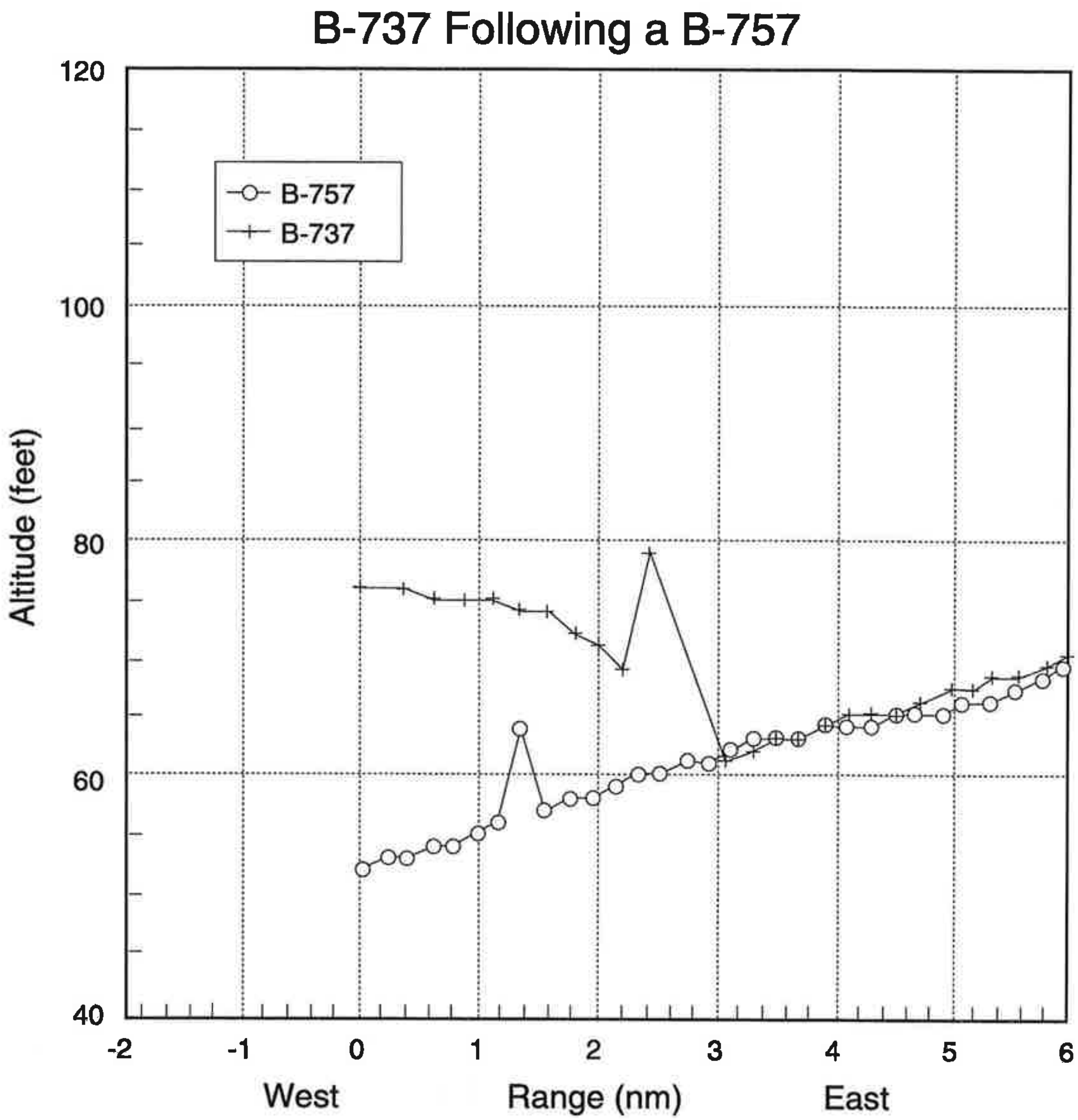

Altitude and Time
16000
14000
12000
10000
8000
6000
4000
2000
Altitude (feet)
2280
2340
2400
2460
2520
2580
2640
2700
2760
Time (min X 60 + Sec)
757.XY
CIT.XY
Touchdown


Altitude Profile of 757 and Citation
757.ROT
CRASH SITE.ROT
CIT.ROT
RUNWAY.ROT
GLIDESLOPE PATH.ROT
16000
14000
12000
10000
8000
6000
4000
2000
Altitude (feet)
-5
0
5
10
15
20
25
NW
Range (nm) Relative to Runway
SE


Altitude Profile of 757 and Citation
757.ROT
CRASH SITE.ROT
CIT.ROT
RUNWAY.ROT
GLIDESLOPE PATH.ROT
Offset in radar data
6000
5000
4000
3000
Altitude (feet)
-2
-1
0
1
2
3
4
NW
Range (nm) Relative to Runway
SE

Appendix D
Ground Track of B-757 and B-737 at Denver, Colorado, on April 24, 1993


B-737 Following a B-757
B-757
B-737
40
30
20
10
0
-10
-20
-30
-40
North
Range (nm)
South
-30
-20
-10
-0
10
20
30
40
50
West
Range (nm)
East


B-737 Following a B-757
B-757
B-737
Altitude (feet)
120
100
80
60
40
-2
-1
0
1
2
3
4
5
6
West
Range (nm)
East

Appendix E

FAA General Notice Issued on December 22, 1993, and Pilot Bulletin Regarding Wake Turbulence Advisories

TELEGRAPHIC MESSAGE

NAME OF AGENCY	PRECEDENCE	SECURITY CLASSIFICATION
FEDERAL AVIATION ADMINISTRATION 800 INDEPENDENCE AVE, SW WASHINGTON, DC 20591	PRIORITY	UNCLASSIFIED
ACCOUNTING CLASSIFICATION	DATE PREPARED	FILE
FOR INFORMATION CALL		
NAME PAUL EWING, ATF-121	PHONE NUMBER 267-8460	TYPE OF MESSAGE ☐ SINGLE ☐ BOOK ☐ MULTIPLE-ADDRESS

THIS SPACE FOR USE OF COMMUNICATION UNIT

MESSAGE TO BE TRANSMITTED *(Use double spacing and all capital letters)*

TO:

KRWA NOU S2 ______________

GENOT RWA ________________ SVC B

NOTICE N7110. ____________

GG ALRGNS 1/500 ALATFO AMA/1 ACT/1

SUBJECT: ORDER 7110.65H, AIR TRAFFIC CONTROL, PARAGRAPHS 2-20, WAKE TURBULENCE CAUTIONARY ADVISORIES; 3-122, SAME RUNWAY SEPARATION; AND 3-123, INTERSECTING RUNWAY SEPARATION. THIS GENOT APPLIES TO ALL AIR TRAFFIC CONTROL FACILITIES AND IS A MANDATORY BRIEFING ITEM.

CLN 12/1/94

CONTROLLERS ARE TO BE BRIEFED ON CHAPTER 7, SECTION 3, WAKE TURBULENCE OF THE AIRMAN'S INFORMATION MANUAL.

PAGE NO.	NO. OF PGS.	SECURITY CLASSIFICATION
1	5	

STANDARD FORM 14
REVISED 11-80
GSA FPMR (41 CFR) 101-35.306

Previous editions useable NSN 7540-00-634-3968 14-103

☆ U.S. GOVERNMENT PRINTING OFFICE: 1989-241-175/90066

TELEGRAPHIC MESSAGE

NAME OF AGENCY	PRECEDENCE	SECURITY CLASSIFICATION
ACCOUNTING CLASSIFICATION	DATE PREPARED	FILE
FOR INFORMATION CALL		
NAME	PHONE NUMBER	TYPE OF MESSAGE ☐ SINGLE ☐ BOOK ☐ MULTIPLE-ADDRESS
THIS SPACE FOR USE OF COMMUNICATION UNIT		

MESSAGE TO BE TRANSMITTED *(Use double spacing and all capital letters)*

TO:

ENSURE THESE BRIEFINGS ARE ENTERED IN ALL EMPLOYEES TRAINING AND PROFICIENCY RECORDS, 3120-1, WITHIN 30 DAYS OF RECEIPT. SEVERAL INCIDENTS INVOLVING AIRCRAFT FOLLOWING OR CROSSING THE FLIGHT PATH OF BOEING 757 (B-757) HAVE CREATED CONCERN FOR THE SAFETY OF AIRCRAFT IN CONNECTION WITH THE WAKE TURBULENCE CREATED BY THE B-757. ACCORDINGLY, TO ENSURE THAT PILOTS ARE AWARE OF THE POTENTIAL WAKE TURBULENCE HAZARD CREATED BY THE B-757, CONTROLLERS SHALL PROVIDE A WAKE TURBULENCE CAUTIONARY ADVISORY TO FOLLOWING AIRCRAFT.

PAGE NO.	NO. OF PGS.	SECURITY CLASSIFICATION
2	5	

STANDARD FORM 14
REVISED 11-80
GSA FPMR (41 CFR) 101-35.306

Previous editions useable NSN 7540-00-634-3966 14-103

☆ U.S. GOVERNMENT PRINTING OFFICE: 1989-241-175/90066

TELEGRAPHIC MESSAGE

NAME OF AGENCY	PRECEDENCE	SECURITY CLASSIFICATION
ACCOUNTING CLASSIFICATION	DATE PREPARED	FILE
FOR INFORMATION CALL		
NAME	PHONE NUMBER	TYPE OF MESSAGE ☐ SINGLE ☐ BOOK ☐ MULTIPLE-ADDRESS
THIS SPACE FOR USE OF COMMUNICATION UNIT		

MESSAGE TO BE TRANSMITTED *(Use double spacing and all capital letters)*

TO:

REPLACE ORDER 7110.65, PARAGRAPHS 2-20, 3-122,

AND 3-123 WITH THE FOLLOWING:

2-20 WAKE TURBULENCE CAUTIONARY ADVISORIES

A. ISSUE WAKE TURBULENCE CAUTIONARY

ADVISORIES AND THE POSITION, ALTITUDE IF

KNOWN, AND DIRECTIONS OF FLIGHT OF THE HEAVY

JETS OR B-757'S TO:

2-20A REFERENCE. NO CHANGE

1. TERMINAL: VFR AIRCRAFT NOT BEING

RADAR VECTORED BUT ARE BEHIND HEAVY JETS OR B-757'S.

(SEE FIGURE 2-20[1]).

2. NO CHANGE

3. NO CHANGE

PAGE NO.	NO. OF PGS.	SECURITY CLASSIFICATION
3	5	

STANDARD FORM 14
REVISED 11-80
GSA FPMR (41 CFR) 101-35.306

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TELEGRAPHIC MESSAGE

NAME OF AGENCY	PRECEDENCE	SECURITY CLASSIFICATION
ACCOUNTING CLASSIFICATION	DATE PREPARED	FILE
FOR INFORMATION CALL		
NAME	PHONE NUMBER	TYPE OF MESSAGE ☐ SINGLE ☐ BOOK ☐ MULTIPLE-ADDRESS
THIS SPACE FOR USE OF COMMUNICATION UNIT		

MESSAGE TO BE TRANSMITTED ***(Use double spacing and all capital letters)***

TO:

B. NO CHANGE

3-122 SAME RUNWAY SEPARATION

A. NO CHANGE

1. THRU 3. NO CHANGE.

B. ISSUE WAKE TURBULENCE CAUTIONARY ADVISORIES AND THE POSITION, ALTITUDE IF KNOWN, AND DIRECTION OF FLIGHT OF THE HEAVY JETS <u>OR B-757'S</u> TO AIRCRAFT LANDING BEHIND A DEPARTING/ARRIVING HEAVY JET <u>OR B-757'S</u> ON THE SAME OR PARALLEL RUNWAYS SEPARATED BY LESS THAN 2,500 FEET.

3-122B REFERENCE. NO CHANGE.

3-122B EXAMPLE 1. NO CHANGE.

3-122B EXAMPLE 2.-

"NUMBER TWO TO LAND, FOLLOWING A <u>BOEING 757</u> ON 2-MILE FINAL. CAUTION WAKE TURBULENCE."

PAGE NO.	NO. OF PGS.	SECURITY CLASSIFICATION
4	5	

STANDARD FORM 14
REVISED 11-80
GSA FPMR (41 CFR) 101-35.306

Previous editions useable NSN 7540-00-634-3968 14-103

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TELEGRAPHIC MESSAGE

NAME OF AGENCY	PRECEDENCE	SECURITY CLASSIFICATION
ACCOUNTING CLASSIFICATION	DATE PREPARED	FILE
FOR INFORMATION CALL		
NAME	PHONE NUMBER	TYPE OF MESSAGE ☐ SINGLE ☐ BOOK ☐ MULTIPLE-ADDRESS
THIS SPACE FOR USE OF COMMUNICATION UNIT		

MESSAGE TO BE TRANSMITTED ***(Use double spacing and all capital letters)***

TO:

3-122 REFERENCE. NO CHANGE.

3-123 INTERSECTING RUNWAY SEPARATION

A. THRU C. NO CHANGE.

D. ISSUE WAKE TURBULENCE CAUTIONARY ADVISORIES AND THE POSITION, ALTITUDE IF KNOWN, AND DIRECTION OF FLIGHT OF THE HEAVY JETS OR B-757'S TO:

1. THRU 2. NO CHANGE

3-123D1 EXAMPLE. NO CHANGE.

3-123D2 EXAMPLE.-

"RUNWAY NINER CLEARED TO LAND. CAUTION WAKE TURBULENCE, BOEING 757 LANDING RUNWAY THREE SIX."

3-123 REFERENCE. NO CHANGE.

Harold W Becker

for SPECK, ATP-1

SECURITY CLASSIFICATION	PAGE NO.	NO. OF PGS.
	5	5

STANDARD FORM 14
REVISED 11-80
GSA FPMR (41 CFR) 101-35.306

Previous editions useable NSN 7540-00-634-3968 14-103

☆ U.S. GOVERNMENT PRINTING OFFICE: 1989-241-175/90066

U.S. Department of Transportation
Federal Aviation Administration

Office of the Administrator

800 Independence Ave. S.W.
Washington, D.C. 20591

DEC 22 1993

Dec. 22, 1993

All Pilots

Dear Fellow Pilots:

Wake Turbulence accidents/incidents following B-757 aircraft.

In the past year, there have been four accidents or incidents involving aircraft following a Boeing 757 under visual flight rules. These include a Cessna Citation at Billings, Montana; a Boeing 737 incident at Denver where the aircraft experienced an uncommanded roll; a Cessna 182 at Salt Lake City, Utah; and the most recent accident, an Israeli Westwind corporate jet at Santa Anna, California. Although the NTSB is still investigating these accidents and incidents, it is possible that one or more of them may have been caused, in part, by an encounter with wake turbulence from the preceding Boeing 757.

To reduce the possibility of these types of occurrences, Air Traffic will now issue "Wake Turbulence Cautionary Advisories" to aircraft following the B-757 under Visual Flight Rules. I am also asking that you pay special attention to existing guidance related to the avoidance of wake turbulence such as the following procedures found in the Airman's Information Manual;

1. WHETHER OR NOT A WARNING HAS BEEN GIVEN. THE PILOT IS EXPECTED TO ADJUST HIS OR HER OPERATIONS AND FLIGHT PATH AS NECESSARY TO PRECLUDE SERIOUS WAKE ENCOUNTERS.

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

When Air Traffic is providing wake turbulence separations, controllers are required to apply no less that specified minimum separation for aircraft operating behind a heavy jet and, in certain instances, behind large **nonheavy** aircraft. When a small or large aircraft is operating directly behind a heavy jet at the same altitude or less that 1,000 feet below it, 5 or 6 miles separation is provided. Chapter 7, Section 3 of the Airman's Information Manual provides additional information regarding air traffic wake turbulence separation. All pilots should become familiar and utilize this information when anticipating conditions conducive to wake turbulence.

There is activity underway in the agency at this time to study the wake turbulence characteristics of the Boeing 757. It will be some time before any definitive results are available from this research effort. Until such time, all pilots should review and become familiar with wake turbulence avoidance. Avoid the area below and behind the generating aircraft, and be particularly alert in calm wind conditions and situations where the vortices could drift on to parallel or crossing runways. Finally, pilots should envision the location of the vortex wake generated by larger (transport category) aircraft and adjust their flight path accordingly.

In closing, I urge all of you to take the time to re-educate yourselves on wake vortex characteristics and avoidance procedures. With proper emphasis and education, these types of accidents/incidents can be avoided.

Sincerely,

David Hinson

David R. Hinson
Administrator

ORDER: 8400.10 and 8700.1

APPENDIX: 4

BULLETIN TYPE: Joint Publication of Flight Standards Information Bulletin (FSIB) for Air Transportation (FSAT) and General Aviation (FSGA)

BULLETIN NUMBER: FSAT 93-38 and FSGA 93-15

BULLETIN TITLE: Wake Turbulence Accident Prevention Program

EFFECTIVE DATE: 12-29-93

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1. PURPOSE. This Flight Standards Information Bulletin (FSIB) establishes an action program for Flight Standards Service to prevent Wake Turbulence Accidents. The bulletin contains information, direction, and guidance to inspectors and managers for completing this program.

2. BACKGROUND. In the past year there have been four accidents that were specifically related to Boeing 757 aircraft. These accidents occurred when the trailing aircraft were not being provided IFR traffic separation. The FAA is in the process of studying wake turbulence; however, it will be some time before the results will be known. To reduce the possibility of these types of occurrences, Air Traffic will now issue "Wake Turbulence Cautionary Advisories" to aircraft following B-757 aircraft under visual flight rules. Pilots of trailing aircraft at the same altitude or up to 1,000 feet below should maintain 5 to 6 miles separation.

A. Pilots and operators should review information, procedures, and guidance contained in the Airman's Information Manual (AIM), Chapter 7, Section 3. To date no known wake turbulence accident has occurred when pilots have been observing AIM recommended procedures. Also see Advisory Circular (AC) 90-23D, "Aircraft Wake Turbulence."

B. Wake turbulence is clearly not unique to the B-757. Pilots must avoid operating both behind and at or below the level of all heavier aircraft.

C. Pilots should attempt to visualize the location of the vortex wake generated by larger aircraft when operating in the terminal area. They should be particularly alert in calm wind conditions and in situations where the wake could drift onto parallel or crossing runways.

D. Pilots should be alert to the possibility that heavier aircraft may be using fuel conservation or noise abatement procedures and operating above the normal glideslope.

3. ACTION. The Administrator has directed that Flight Standards take immediate action to educate operators and the public to this hazard. On or before April 7, 1994, the following actions will be accomplished:

A. POI's. Each POI of a Part 121, 125, and 135 operator and Part 141 training school shall bring this bulletin to the attention of the operator. The material should be disseminated to flightcrews through bulletins or similar means. POI's shall ensure that wake turbulence awareness is included in operator training programs.

B. FSDO Managers. FSDO managers shall ensure that this bulletin is brought to the attention of Accident Prevention Program Managers (APPM) and the managers of non-certificated training centers operating under exemptions.

C. APPM's. APPM's shall disseminate this information to the aviation public.

4. INQUIRIES. This FSIB was developed by AFS-510. Any questions regarding this bulletin should be directed to AFS-510 at (703) 661-0333.

5. EXPIRATION. This FSIB will expire on June 30, 1994.

/s/ Edgar C. Fell

ORDER: 8400.10 and 8700.1

APPENDIX: 4

BULLETIN TYPE: Joint Flight Standards Information Bulletin (FSIB) for Air Transportation (FSAT) and General Aviation (FSGA)

BULLETIN NUMBER: FSAT 94-02 and FSGA 94-02

BULLETIN TITLE: Wake Turbulence Accident Prevention Program

EFFECTIVE DATE: 02-10-94

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1. PURPOSE. This FSIB establishes an action program for Flight Standards Service to prevent wake turbulence accidents. This FSIB provides information, direction, and guidance to be used by inspectors and managers for completing this program. This FSIB supersedes FSAT 93-38 and FSGA 93-15 of the same title.

2. BACKGROUND. There have been four accidents or incidents related to Boeing 757 wake turbulence. All of these events occurred when the trailing aircraft was not being provided instrument flight rules (IFR) traffic separation. To reduce the possibility of such occurrences, Air Traffic Control will now issue "Wake Turbulence Cautionary Advisories" to aircraft operating under visual flight rules (VFR) which are following B-757 aircraft. The FAA is presently studying wake turbulence to include pilot awareness, avoidance, and aircraft-specific procedures for a wake turbulence encounter.

A. Pilots and operators should review information, procedures, and guidance contained in Chapter 7, Section 3 of the Airman's Information Manual (AIM). We are not aware of any wake turbulence accidents occurring when pilots have observed AIM recommended procedures or utilized IFR traffic separation. Therefore, pilots may wish to apply the same separation to VFR operations as ATC applies to IFR traffic. This information is contained in paragraph 7-49 of the AIM. (Also see AC 90-23D, "Aircraft Wake Turbulence").

B. Wake turbulence is not unique to the B-757. All pilots should exercise caution when operating behind and/or below all heavier (or greater wing span) aircraft.

C. Pilots should attempt to visualize the location of the vortex wake generated by other aircraft when operating in the terminal area. They should be particularly alert for situations where the wake could remain over a runway or drift onto parallel/crossing runways.

D. We are not aware of any operator with "formal" procedures for steep approach profiles, but pilots should be alert to the implications of a heavier aircraft operating above the normal glideslope.

3. ACTION. The Administrator has directed that Flight Standards take immediate action to ensure that operators and the public are educated on this hazard. The following actions will be accomplished on or before April 7, 1994:

A. Principal Operations Inspectors (POI). Each POI for a Federal Aviation Regulations (FAR) Part 121, 125 or 135 operator, and each responsible inspector for a FAR Part 141 training school shall bring this FSIB to the attention of the operator. The material should be disseminated to flightcrews through bulletins or similar means. POI's shall ensure that wake turbulence awareness is included in operator training programs.

B. Flight Standards District Office (FSDO) Managers. FSDO managers shall ensure that this FSIB is brought to the attention of Accident Prevention Program Managers (APPM) and the managers of non-certificated training centers operating under exemptions.

C. APPM's. APPM's shall disseminate this information to the aviation public.

4. INQUIRIES. This FSIB was developed by AFS-510. Any questions regarding this FSIB should be directed to AFS-510 at (703) 661-0333.

5. EXPIRATION. This FSIB will expire on June 30, 1994.

/s/ Edgar C. Fell

ORDER: 8400.10

APPENDIX: 3

BULLETIN TYPE: Flight Standards Handbook Bulletin for Air Transportation (HBAT)

BULLETIN NUMBER: HBAT 94-17*

BULLETIN TITLE: Pilot Training in Heavy Wake Vortex Turbulence: Awareness and Containment

EFFECTIVE DATE: 12-29-94

TRACKING: NTSB RECOMMENDATION A-94-45

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1. PURPOSE. This bulletin meets a National Transportation Safety Board (NTSB) recommendation pertaining to training in wake vortex turbulence containment by pilots of aircraft that may produce heavy wake, including Boeing 757 aircraft.

2. BACKGROUND. The NTSB recently completed a special investigation of accidents involving wake vortex turbulence encountered during visual approaches. The Board's work raised questions about various issues, notably pilot knowledge related to the containment of heavy wake vortex turbulence. The Board found that pilots of heavy aircraft, heavier large aircraft, and specifically the B-757 aircraft (the heaviest type in its weight category), may be unaware of wake turbulence in two respects:

A. The consequences of the heavy wake produced by their aircraft in respect to lighter, following aircraft

B. Measures that they may take to contain wake turbulence for the benefit of lighter, following aircraft.

3. The following actions are strongly recommended. Pilots of heavy aircraft and heavier large aircraft that may produce strong wake, including the B-757, should use the following procedures during an approach to landing. These procedures should establish a dependable baseline from which pilots of in-trail, lighter aircraft may reasonably expect to make effective flightpath adjustments to avoid serious wake vortex turbulence.

A. Make every attempt to fly on the established glidepath, or if glidepath guidance is not available, to fly as closely as possible to a "3-to-1" glidepath.

EXAMPLE: At 10 miles from the runway, the aircraft should be at 3000' above the touchdown zone elevation (TDZE); at 5 miles the

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*HBAT 94-17 was not in the original report. It is included here to provide the reader with the most current information available at this time.

aircraft should be at 1500' above TDZE; at 4 miles, 1200'; at 3 miles, 900'; and so on, until a safe landing may be made. Techniques for deriving a "3-to-1" glidepath include using distance measuring equipment (DME), distance advisories provided by radar-equipped control towers, area navigation (RNAV) (exclusive of Omega navigation systems), global positioning system (GPS), and pilotage when familiar features on the approach course are visible to the pilot.

B. Fly as closely as possible to the approach course centerline, or to the extended centerline of the runway of intended landing, as appropriate to conditions.

C. Cross the runway threshold at a nominal height of 50' above TDZE.

D. Land within the touchdown zone.

4. POLICY. POI's are directed to ensure that initial, transition, and recurrent training programs for pilots of heavy category aircraft, heavier large category aircraft, and the Boeing 757 aircraft include discussion of the wake vortex turbulence hazard caused by such aircraft in respect to lighter, following aircraft. Those training programs also should include the wake vortex turbulence containment procedures recommended in this bulletin.

5. INQUIRIES. This FSIB was developed by AFS-210. Any questions may be directed to AFS-210 at (202) 267-3718.

6. LOCATION IN HANDBOOK. The material covered in this handbook bulletin will be incorporated by AFS-200 in volume 3, chapter 2, section 3, of FAA Order 8400.10, "Air Transportation Operations Inspector's Handbook." Until the handbook is updated, inspectors should make written reference to this bulletin in the margin of the indicated section.

/s/ David R. Harrington

NBAA*ALERT*BULLETIN

ROUTE TO:

AB #93-20
DECEMBER 22, 1993

SUBJECT: WAKE TURBULENCE

BACKGROUND

Last year, seven people were killed when a Cessna Citation crashed into an industrial section east of Billings, Montana after encountering wake turbulence from a Boeing 757.

Earlier this year, a Boeing 737 following a Boeing 757 into Denver apparently was turned on its side after encountering the wake of the larger jet. The aircraft landed safely.

Last week, an IAI Westwind crashed approximately two miles out from the Santa Ana Airport, killing all five aboard. It was on approach behind a Boeing 757.

Wake turbulence may have been a key factor in all of these incidents.

NATIONAL BUSINESS AIRCRAFT ASSOCIATION, INC.
1200 EIGHTEENTH ST., NW
SUITE 200
WASHINGTON, DC 20036-2598
(202)783-9000
FAX (202) 331-8364

THE ISSUE

As a party to the investigation of the Westwind accident, NBAA is prohibited from speculation as to the specific causal factors involved. However, the National Aeronautics and Space Administration (NASA), the Volpe National Transportation System Center (VNTSC), the British Civil Aviation Authority (CAA), and the Federal Aviation Administration (FAA) are currently examining data which may or may not require procedural changes for flight into areas prone to wake turbulence. The aviation industry is engaged in a joint program with the aforementioned agencies to improve our knowledge of wake vortex behavior and the potential of wake vortex hazards for all aircraft types.

MEMBERSHIP ACTION

The *Airman's Information Manual (AIM)* covers wake turbulence operational procedures in a clear and concise manner. A thorough review by all crew members of Chapter 7, Section 3 is strongly recommended. This contains information necessary to alert pilots to the hazard, as well as proper vortex avoidance procedures. Sections of the AIM are attached for your convenience. Please review them thoroughly.

For more information, please call Paul H. Smith, NBAA manager, air traffic services, at (202)783-9255

(REMEMBER THE NBAA BULLETIN BOARD (202) 331-7968)

Section 3. WAKE TURBULENCE

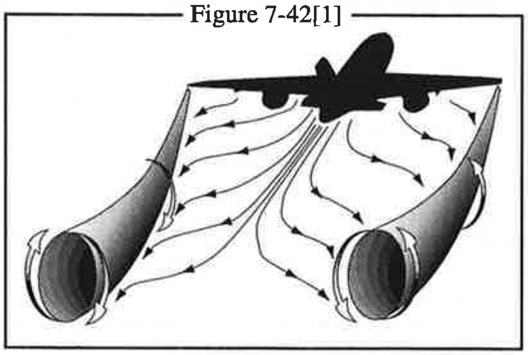
7-41. GENERAL

a. Every aircraft generates a wake while in flight. Initially, when pilots encountered this wake in flight, the disturbance was attributed to "prop wash." It is known, however, that this disturbance is caused by a pair of counter rotating vortices trailing from the wing tips. The vortices from larger aircraft pose problems to encountering aircraft. For instance, the wake of these aircraft can impose rolling moments exceeding the roll-control authority of the encountering 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 larger (transport category) aircraft and adjust the flight path accordingly.

b. During ground operations and during takeoff, jet engine blast (thrust stream turbulence) can cause damage and upsets if encountered at close range. Exhaust velocity versus distance studies at various thrust levels have shown a need for light aircraft to maintain an adequate separation behind large turbojet aircraft. Pilots of larger aircraft should be particularly careful to consider the effects of their "jet blast" on other aircraft, vehicles, and maintenance equipment during ground operations.

7-42. VORTEX GENERATION

Figure 7-42[1]



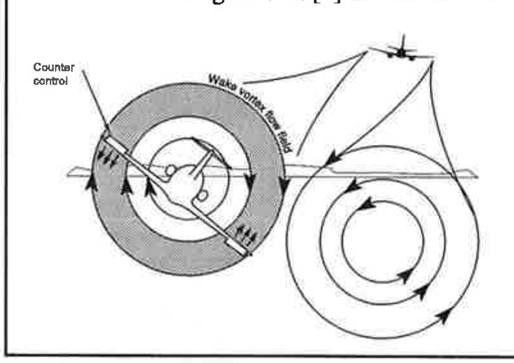
Lift is generated by the creation of a pressure differential over the wing surface. The lowest pressure occurs over the upper wing surface and the highest pressure under the wing. This pressure differential triggers the roll up of the airflow aft of the wing resulting in swirling air masses trailing downstream of the wing tips. After the roll up is completed, the wake consists of two counter rotating cylindrical vortices. (See Figure 7-42[1].) Most of the energy is within a few feet of the center of each vortex, but pilots should avoid a region within about 100 feet of the vortex core.

7-43. VORTEX STRENGTH

a. The strength of the vortex is governed by the weight, speed, and shape of the wing of the generating aircraft. The vortex characteristics of any given aircraft can also be changed by extension of flaps or other wing configuring devices as well as by change in speed. However, as the basic factor is weight, the vortex strength increases proportionately. Peak vortex tangential speeds exceeding 300 feet per second have been recorded. The greatest vortex strength occurs when the generating aircraft is HEAVY, CLEAN, and SLOW.

b. INDUCED ROLL

Figure 7-43[1]



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

2. Counter control is usually effective and induced roll minimal in cases where the wingspan and ailerons of the encountering aircraft extend beyond the rotational flow field of the vortex. It is more difficult for aircraft with short wingspan (relative to the generating aircraft) to counter the imposed roll induced by vortex flow. Pilots of short

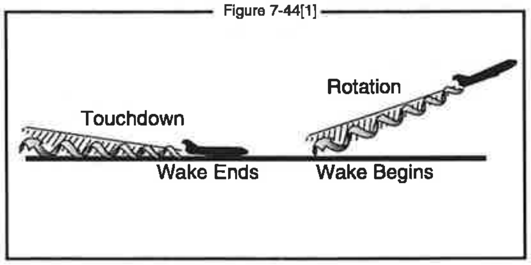
span aircraft, even of the high performance type, must be especially alert to vortex encounters. (See Figure 7-43[1].)

3. The wake of larger aircraft requires the respect of all pilots.

7-44. VORTEX BEHAVIOR

a. Trailing vortices have certain behavioral characteristics which can help a pilot visualize the wake location and thereby take avoidance precautions.

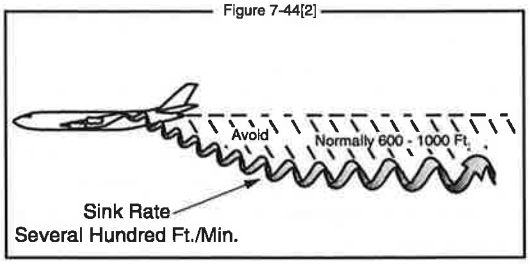
Figure 7-44[1]



1. Vortices are generated from the moment aircraft leave the ground, since trailing vortices are a by-product of wing lift. Prior to takeoff or touchdown, pilots should note the rotation or touchdown point of the preceding aircraft. (See Figure 7-44[1][Wake Begins/Ends].)

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

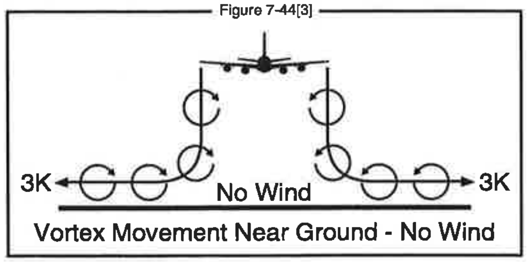
Figure 7-44[2]



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

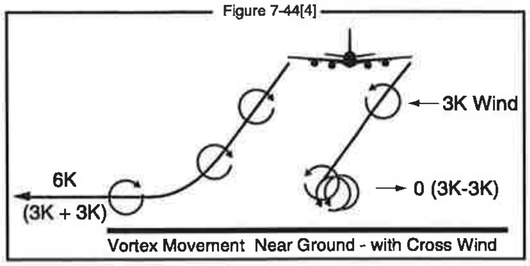
(See Figure 7-44[2][Vortex Flow Field].) However, vertical separation of 1,000 feet may be considered safe.

Figure 7-44[3]



4. When the vortices of larger aircraft sink close to the ground (within 100 to 200 feet), they tend to mover laterally over the ground at a speed of 2 or 3 knots. (See Figure 7-44[3][Vortex Sink Rate].)

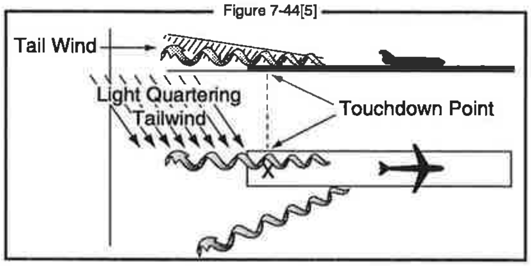
Figure 7-44[4]



b. A crosswind will decrease the lateral movement of the upwind vortex and increase the movement of the downwind vortex. Thus, a light wind with a cross runway component of 1 to 5 knots could result in the upwind vortex remaining in the touchdown zone for a period of time and hasten the drift of the downwind vortex toward another runway. (See Figure 7-44[4][Vortex Movement in Ground Effect (No Wind)].) Similarly, a tailwind condition can move the vortices of the preceding aircraft forward into the touchdown zone. THE LIGHT QUARTERING TAILWIND REQUIRES MAXIMUM CAUTION. Pilots should be alert to large aircraft upwind from their approach and takeoff flight paths. (See Figure 7-44[5][Vortex Movement in Ground Effect(Wind)].)

7-45. OPERATIONS PROBLEM AREAS

a. A wake encounter can be catastrophic. In 1972, at Fort Worth, a DC-9 got too close to a DC-10 (two miles back), rolled, caught a wingtip, and cartwheeled coming to a rest in an inverted position on the runway. All aboard were killed. Serious and



even fatal GA accidents induced by wake vortices are not uncommon. However, a wake encounter is not necessarily hazardous. It can be one or more jolts with varying severity depending upon the direction of the encounter, weight of the generating aircraft, size of the encountering aircraft, distance from the generating aircraft, and point of vortex encounter. The probability of induced roll increases when the encountering aircraft's heading is generally aligned with the flight path of the generating aircraft.

b. AVOID THE AREA BELOW AND BEHIND THE GENERATING AIRCRAFT, ESPECIALLY AT LOW ALTITUDE WHERE EVEN A MOMENTARY WAKE ENCOUNTER COULD BE HAZARDOUS. This is not easy to do. Some accidents have occurred even though the pilot of the trailing aircraft had carefully noted that the aircraft in front was at a considerably lower altitude. Unfortunately, this does not ensure that the flight path of the lead aircraft will be below that of the trailing aircraft.

c. Pilots should be particularly alert in calm wind conditions and situations where the vortices could:

1. Remain in the touchdown area.
2. Drift from aircraft operating on a nearby runway.
3. Sink into the takeoff or landing path from a crossing runway.
4. Sink into the traffic pattern from other airport operations.
5. Sink into the flight path of VFR aircraft operating on the hemispheric altitude 500 feet below.

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

7-46. VORTEX AVOIDANCE PROCEDURES.

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

b. The following vortex avoidance procedures are recommended for the various situations:

1. Landing behind a larger aircraft–same runway: Stay at or above the larger aircraft's final approach flight pat–-note its touchdown point-land beyond it.
2. Landing behind a larger aircraft-when parallel runway is closer than 2,500 feet: Consider possible drift to your runway. Stay at or above the larger aircraft's final approach flight path–note its touchdown point.
3. Landing behind a departing larger–crossing runway: Cross above the larger aircraft's flight path.
4. Landing behind a departing larger aircraft-same runway: Not the larger aircraft's rotation point–land well prior to rotation point.
5. Landing behind a departing larger aircraft–crossing runway: Note the larger aircraft's rotation point–if past the intersection–continue the approach–land prior to the intersection. If a larger aircraft rotates prior to the intersection, avoid flight below the larger aircraft's flight path. Abandon the approach unless a landing is ensured well before reaching the intersection.
6. Departing behind a larger aircraft: Note the larger aircraft's rotation point–rotate prior to larger aircraft's rotation point–continue climb above the larger aircraft's climb path until turning clear of his wake. Avoid subsequent heading which will cross below and behind a larger aircraft. Be alert for any critical takeoff situation which could lead to a vortex encounter.
7. Intersection takeoffs–same runway: Be alert to adjacent larger aircraft operations, particularly upwind of your runway. If intersection takeoff clearance is received, avoid subsequent heading which will cross below a larger aircraft's path.
8. Departing or landing after a larger aircraft executing a low approach, missed approach or touch-

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

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

7-47. HELICOPTERS

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 hits the surface, the resulting outwash vortices have behavioral characteristics similar to wing tip vortices produced by 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 in a slow hover taxi or stationary hover. In forward flight, departing or landing helicopter produce a pair of strong, high-speed trailing vortices similar to wing tip vortices of larger fixed wing aircraft. Pilots of small aircraft should use caution when operating behind or crossing behind landing and departing helicopters.

7-48 PILOT RESPONSIBILITY

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

b. Wake turbulence may be encountered by aircraft in flight as well as when operating on the airport movement area. (Reference-Pilot/Controller Glossary, Wake Turbulence).

c. Pilots are reminded that in operations conducted behind all aircraft, acceptance of instructions from ATC in the following situations is an acknowledgement that the pilot will ensure safe takeoff and landing intervals and accept the responsibility of providing his own wake turbulence separation.

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

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

7-49. AIR TRAFFIC WAKE TURBULENCE SEPARATIONS.

a. Because of the possible effects of wake turbulence, controllers are required to apply no less than specified minimum separation for aircraft operating behind a **heavy** jet and, in certain instances, behind large **nonheavy** aircraft.

1. Separation is applied to aircraft operating directly behind a **heavy** jet at the same altitude or less than 1,000 feet below:

(a) **Heavy** jet behind **heavy** jet–4 miles.

(b) **Small/large** aircraft behind **heavy** jet–5 miles.

2. Also, separation, measured at the time the preceding aircraft is over the landing threshold, is provided to small aircraft:

(a) Small aircraft landing behind **heavy** jet–6 miles.

(b) Small aircraft landing behind **large** aircraft–4 miles.

7-49a2b Note-34. See Pilot/Controller Glossary, Aircraft Classes.

3. Additionally, appropriate time or distance intervals are provided to departing aircraft:

(a) Two minutes or the appropriate 4- or 5-mile radar separation when takeoff behind a heavy jet will be:

–from the same threshold

–on a crossing runway and projected flight paths will cross

–from the threshold of a parallel runway when staggered ahead of that of the adjacent runway by less than 500 feet and when the runways are separated by less than 2,500 feet.

7-49a3a Note–Pilots, after considering possible wake-turbulence effects, may specifically request waiver of the 2-minute interval by stating, "request waiver of 2-minute interval" or a similar statement. Controllers may acknowledge this statement as pilot acceptance of responsibility for wake turbulence separation and, if traffic permits, issue takeoff clearance.

b. A 3-minute interval will be provided when a small aircraft will takeoff.

1. From an intersection on the same runway (same or opposite direction) behind a departing large aircraft.

2. In the opposite direction on the same runway behind a large aircraft takeoff or low/missed approach.

7-49b2 Note-This 3-minute interval may be waived upon specific pilot request.

c. A 3-minute interval will be provided for all aircraft taking off when the operations are as described in b(1) and (2) above, the preceding aircraft is a **heavy** jet, and the operations are on either the same runway or parallel runways separated by less than 2,500 feet. Controllers may not reduce or waive this interval.

d. Pilots may request additional separation i.e., 2 minutes instead of 4 or 5 miles for wake turbulence avoidance. This request should be made as soon as practical on ground control and at least before taxiing onto the runway.

7-49d Note-FAR 91.3(a) states: "The pilot in command of an aircraft is directly responsible for and is the final authority as to the operation of that aircraft."

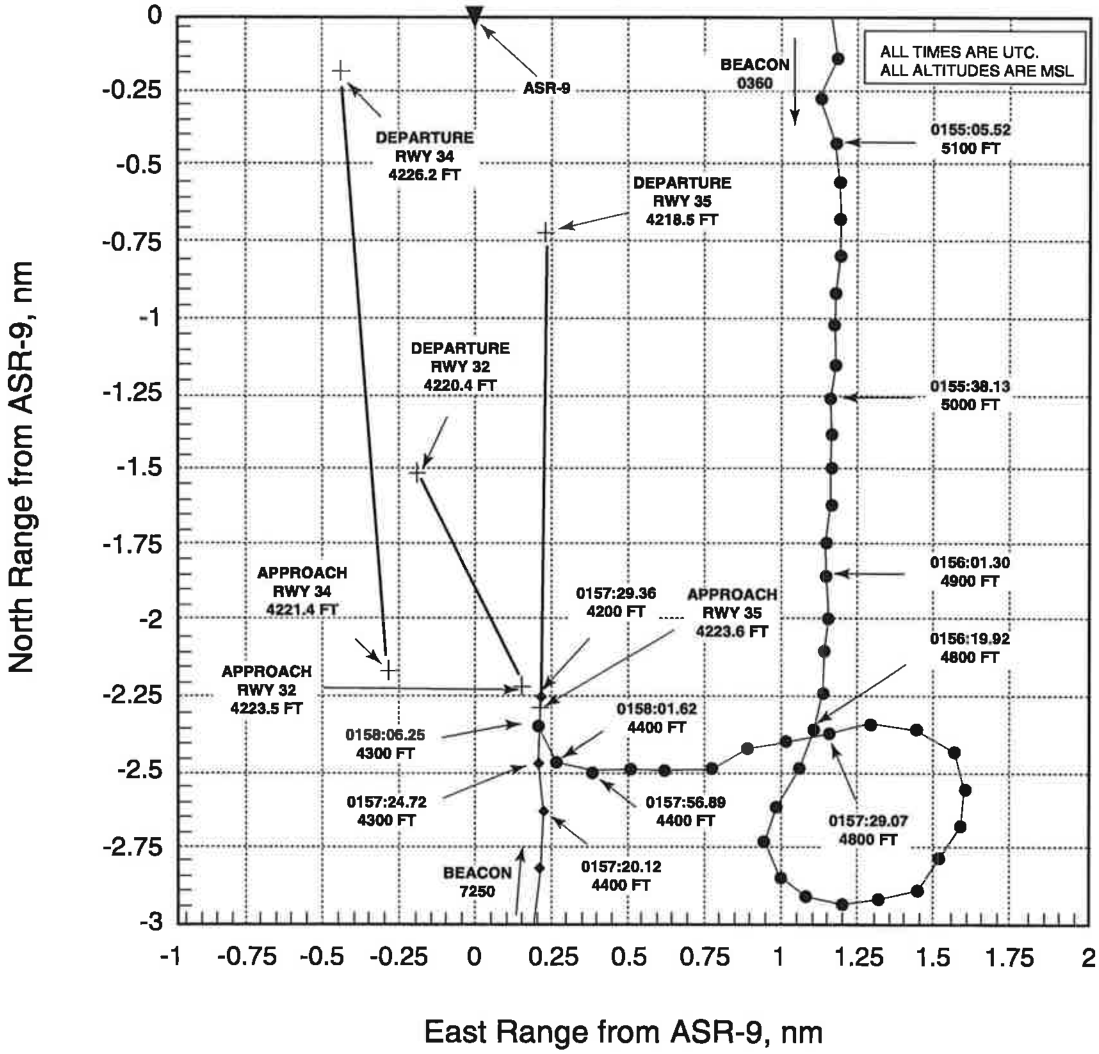
e. Controllers may anticipate separation and need not withhold a takeoff clearance for an aircraft departing behind a **large/heavy** aircraft if there is reasonable assurance the required separation will exist when the departing aircraft stats takeoff roll.

7-50 thur 7-60. RESERVED

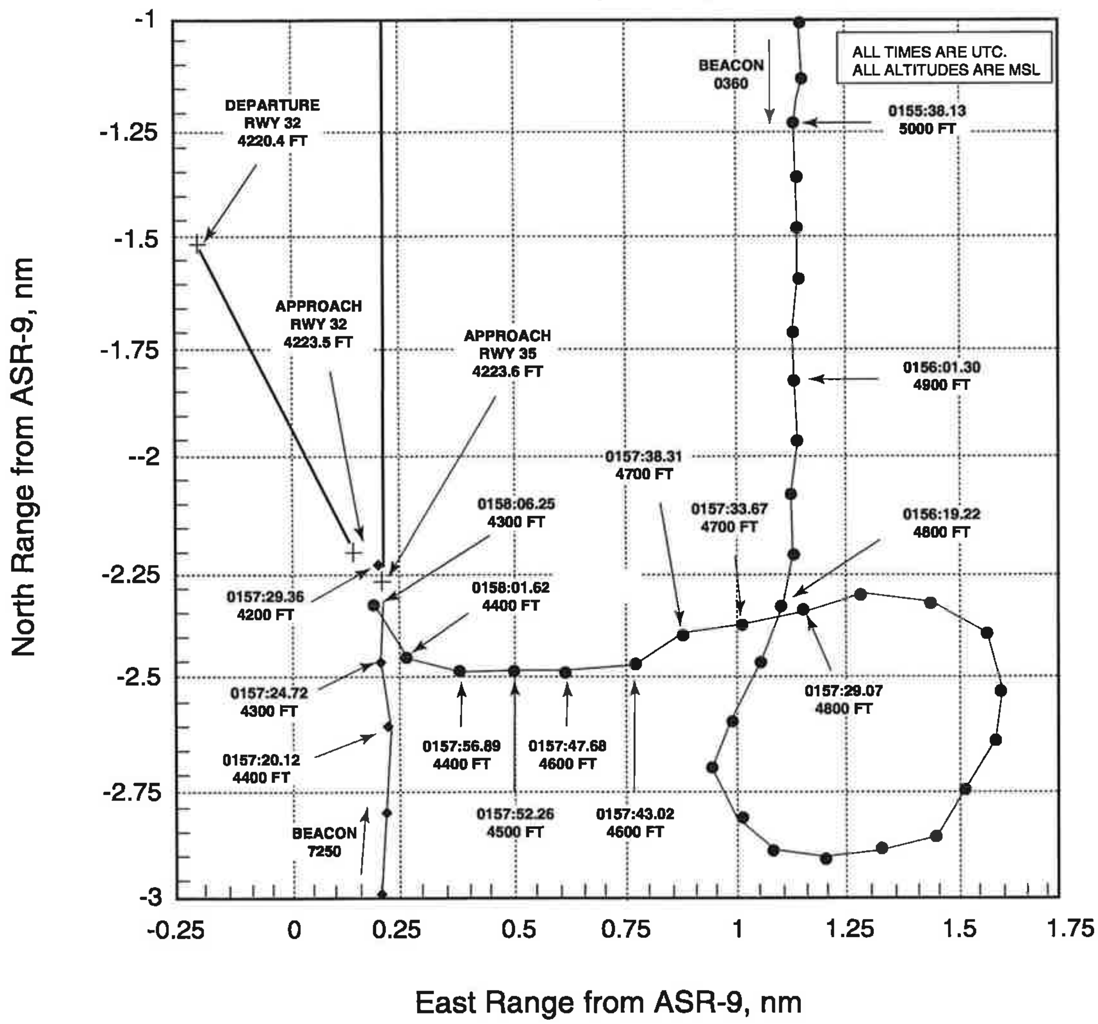
Appendix F

Ground Track of Cessna 182 and B-757 at Salt Lake City, Utah, on November 10, 1993

East Range vs. North Range
Cessna N9652X, Salt Lake City UTAH, 11/09/93, SEA94GA024

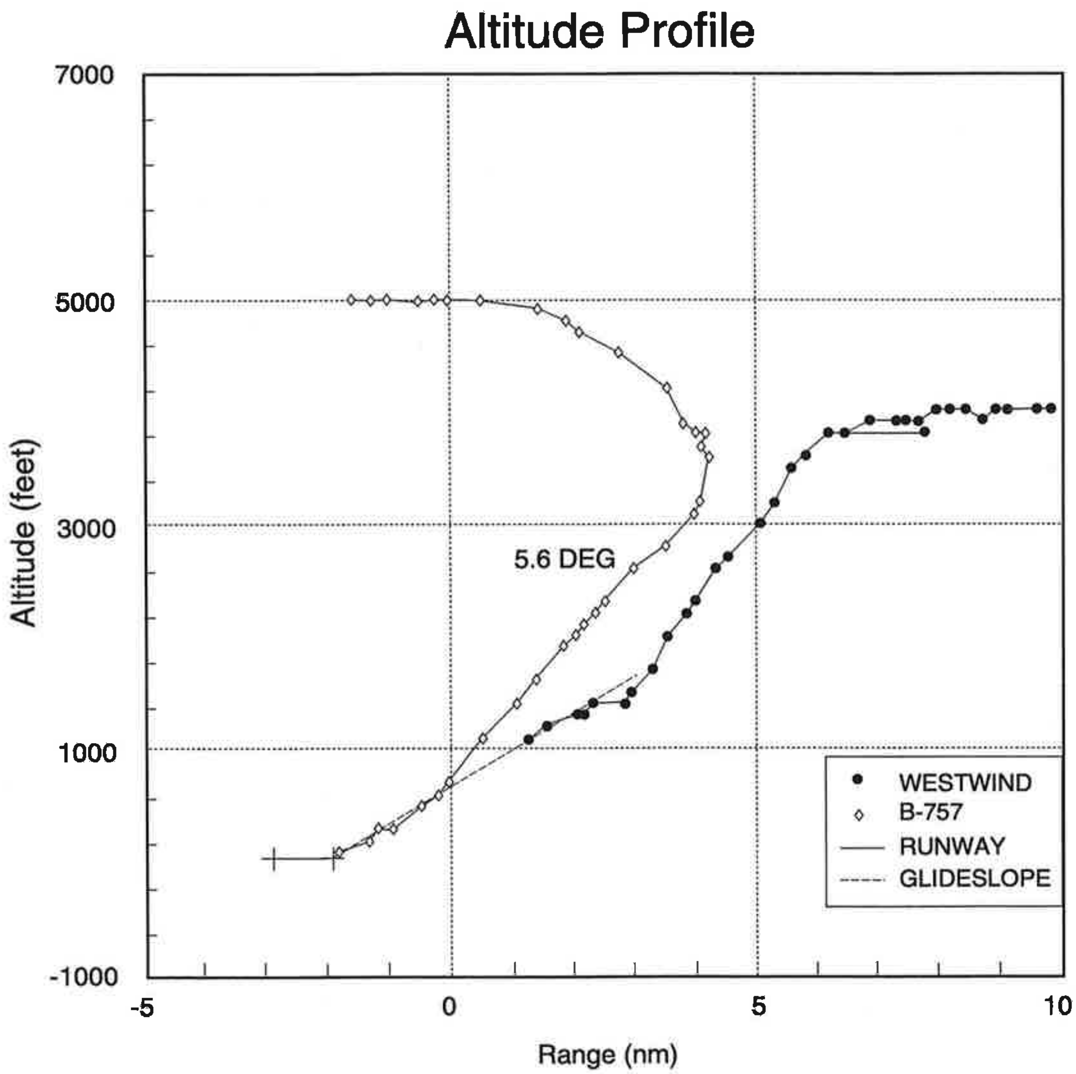


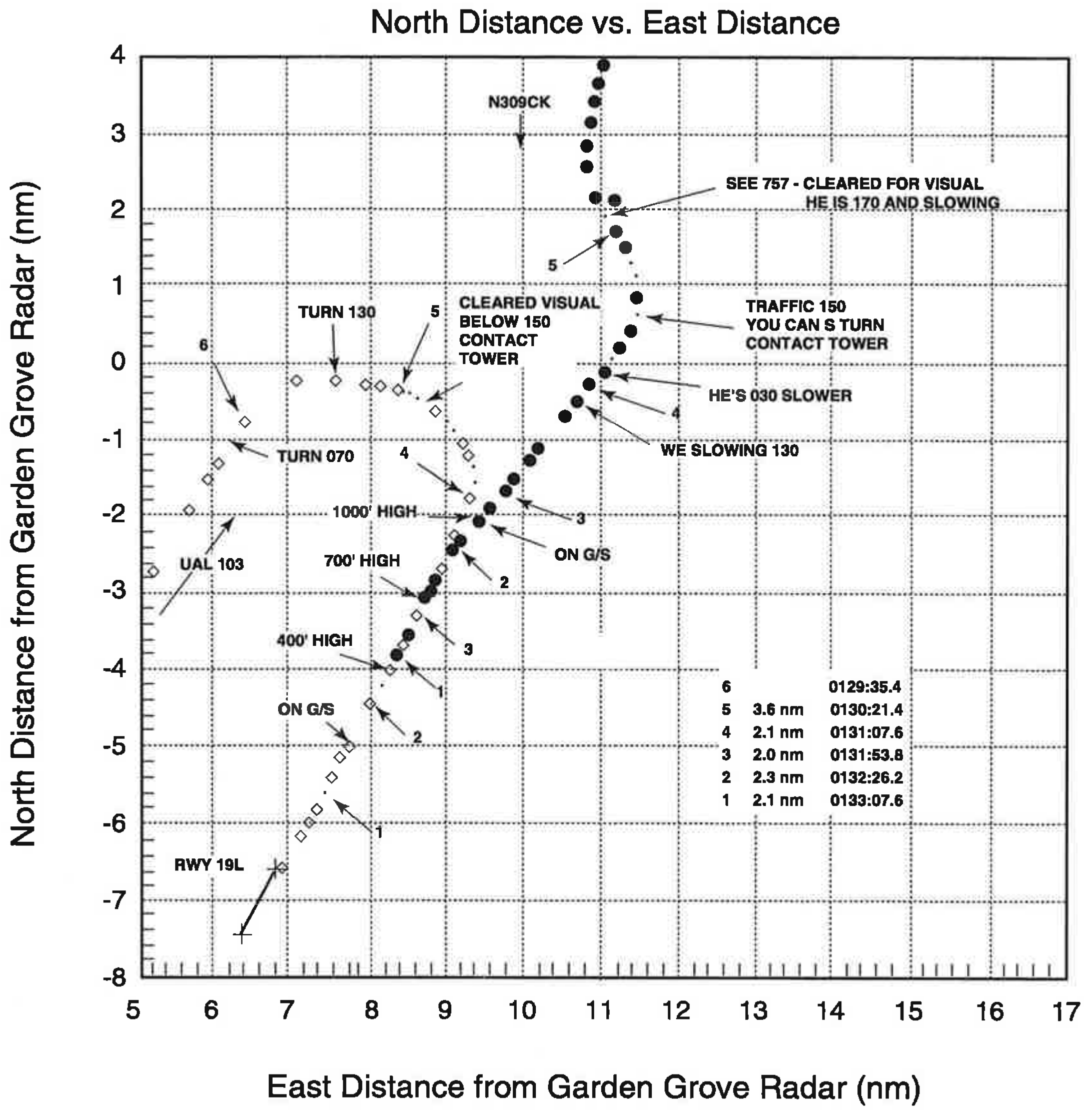
East Range vs. North Range
Cessna N9652X, Salt Lake City UTAH, 11/09/93, SEA94GA024



Appendix G

Ground Track and Altitude Profile of Westwind and B-757 at John Wayne Airport, Santa Ana, California, on December 15, 1993


Altitude Profile
7000
5000
3000
1000
-1000
Altitude (feet)
-5
0
5
10
Range (nm)
5.6 DEG
WESTWIND
B-757
RUNWAY
GLIDESLOPE


North Distance vs. East Distance
North Distance from Garden Grove Radar (nm)
East Distance from Garden Grove Radar (nm)
N309CK
SEE 757 - CLEARED FOR VISUAL
HE IS 170 AND SLOWING
TRAFFIC 150
YOU CAN S TURN
CONTACT TOWER
HE'S 030 SLOWER
WE SLOWING 130
TURN 130
CLEARED VISUAL
BELOW 150
CONTACT
TOWER
TURN 070
1000' HIGH
700' HIGH
400' HIGH
ON G/S
ON G/S
UAL 103
RWY 19L
6 0129:35.4
5 3.6 nm 0130:21.4
4 2.1 nm 0131:07.6
3 2.0 nm 0131:53.8
2 2.3 nm 0132:26.2
1 2.1 nm 0133:07.6

Appendix H
Aviation Safety Reporting System Reports of Wake Vortex Encounters

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, CA 94035-1000

Reply to attn of FL:262-1

MEMORANDUM FOR: Recipients of Aviation Safety Reporting System Data

SUBJECT: Data Derived from ASRS Reports

The attached material is furnished pursuant to a request for data from the NASA Aviation Safety Reporting System (ASRS). Recipients of this material are reminded of the following points which must be considered when evaluating these data.

ASRS reports are submitted voluntarily. The existence in the ASRS database of reports concerning a specific topic cannot, therefore, be used to infer the prevalence of that problem within the national aviation system.

Reports submitted to ASRS may be amplified by further contact with the individual who submitted them, but the information provided by the reporter is not investigated further. Such information may or may not be correct in any or all respects. At best, it represents the perception of a specific individual who may or may not understand all of the factors involved in a given issue or event.

After preliminary processing, all ASRS reports are deidentified. There is no way to identify the individual who submitted a report. All ASRS records systems are designed to prevent any possibility of identifying individuals submitting, or other names, in ASRS reports. There is, therefore, no way to verify information submitted in an ASRS report after it has been deidentified.

The National Aeronautics and Space Administration and its ASRS contractor, Battelle Memorial Institute, specifically disclaim any responsibility for any interpretation which may be made by others of any material or data furnished by NASA in response to queries of the ASRS database and related materials.

William Reynard, Director
Aviation Safety Reporting Systems

CAVEAT REGARDING STATISTICAL USE OF ASRS INFORMATION

Certain caveats apply to the use of ASRS statistical data. All ASRS reports are voluntarily submitted, and thus cannot be considered a measured random sample of the full population of like events. For example, we receive several thousand altitude deviation reports each year. This number may comprise over half of all the altitude deviations which occur, or it may be just a small fraction of total occurrences. We have no way of knowing which.

Moreover, not all pilots, controllers, air carriers, or other participants in the aviation system, are equally aware of the ASRS or equally willing to report to us. Thus, the data reflect **reporting biases**. These biases, which are not fully known or measurable, distort ASRS statistics. A safety problem such as near midair collisions (NMACS) may appear to be more highly concentrated in area "A" than area "B" simply because the airmen who operate in area "A" are more supportive of the ASRS program and more inclined to report to us should an NMAC occur.

Only one thing can be known for sure from ASRS statistics—they represent the **lower measure** of the true number of such events which are occurring. For example, if ASRS receives 300 reports of track deviations in 1993 (this number is purely hypothetical), then it can be known with certainty that at least 300 such events have occurred in 1993.

Because of these statistical limitations, we believe that the **real power** of ASRS lies in the **report narratives**. Here pilots, controllers, and others, tell us about aviation safety incidents and situations in detail. They explain what happened, and more importantly, **why** it happened. Using report narratives effectively requires an extra measure of study, the knowledge derived is well worth the added effort.

Your printout from the ASRS includes information on the following categories. Please note-each entry in a category is separated by a semicolon (e.g., two SMAs in one incident would be coded as "SMA;SMA;" in the Aircraft Type category.

Accession Number - a unique, sequential number assigned to each report.

Date of Occurrence - the date of the occurrence/situation in the form of a year and a month; e.g., 9304 represents April 1993.

Reported by - role of the person who reported the occurrence/situation. Codes used are: FLC-flight crew, PLT-pilot; CRM-crew member; CTLR-Air Traffic Controller; PAX-passenger; OBS-obvserver; AFC (or AIR)-Air Force; NVY-Navy; UNK-unknown.

Persons Functions - description of a person's function at the time of the occurrence. Codes used are:

FLC	PIC	- Pilot in command as determined by official designation, prior consensus, or actually controlling the aircraft			
	CAPT	- Captain role in a multi-person flight crew			
	FO	- First Officer/Copilot role in a multi-person flight crew.			
	SO	- Second Officer/Flight Engineer role in a multi-person flight crew			
	OTH	- Additional crew member (e.g., navigator) in a multi-person flight crew.			
	CKP	- Check pilot (essential flight crew member occupying a crew position/role)			
	ISTR	- Legally qualified flight instructor who is giving instruction at the time of the occurrence/situation			
	PLT	- Pilot in a single-person crew			
	TRNEE	- Flight crew member in training			
TWR	LC	- Local controller	COORD	-	Coordinator position
	GC	- Ground controller	CD	-	Clearance delivery
	FD	- Flight data position	SUPVR	-	Supervisor
	OTH	- Other	TRNEE	-	Trainee
TRACON	AC	- Approach controller	COORD	-	Coordinator position
	DC	- Departure controller	SUPVR	-	Supervisor
	RHO	- Radar hand-off position	OTH	-	Other
	FD	- Flight data position	TRNEE	-	Trainee
ARTCC	M	- Manual controller	COORD	-	Coordinator position
	R	- Radar controller	SUPVR	-	Supervisor
	H	- Hand-off position	OTH	-	Other
	D	- Assistant or data man	TRNEE	-	Trainee
MIL	PAR	- Precision approach radar	OTH	-	Other
	RSU	- Runway supervisory unit			
MISC	FSS	- Flt service station specialist	DISP	-	Dispatcher
	ACI	- Air Carrier inspector	CENR	-	Company enroute check personnel
	UNI	- Unicom operator			
	FBO	- Fixed base operator/employee	TADV	-	Tower advisory
	CAB	- Cabin attendant	AMGR	-	Airport manager
	VD	- Vehicle driver	OBS	-	Observer
	PAX	- Passenger	SUPVR	-	Supervisor
	CGP	- Company ground personal	OTH	-	Other

Flight Conditions - the weather environment at the time of the occurrence or situation in terms of the conventional definition for flight conditions. Codes used are: VMC-visual meteorological conditions; IMC-instrument meteorological conditions; MXD-mixed flight conditions (both VMC and IMC); MVI-marginal VFR; SVF-special VFR.

Reference Facility ID (or LOC ID) - the standard three-letter (or letter-number combination) location identifier associated with an airport or navigational facility as referenced in the FAA Order 7350.5Z series entitled "Location Identifiers."

Facility Identifier - the standard three-letter (or letter-number combination) location identifier associated with an ATC facility as referenced in the FAA Order 7350.5Z series entitled "Location Identifiers."

Aircraft Type - the aircraft type involved in the incident differentiated by arbitrary gross takeoff weight ranges (military aircraft type are differentiated by function). Codes used re:

SMA	-	small aircraft (less than 5000 lbs)
SMT	-	small transport (5001 - 14,500 lbs)
LTT	-	light transport (14,501 - 30,000 lbs)
MDT	-	medium transport (30,001 - 60,000 lbs)
MLG	-	medium large transport (60,001 - 150,000 lbs)
LRG	-	large transport (150,001 - 300,000 lbs)
HVT	-	large transport (over 300,000 lbs)
WDB	-	wide-body (over 30,000 lbs)
ULT	-	ultralight (including hang gliders)
SPB	-	sailplane/glider
SPC	-	special purpose
FGT	-	fighter
BMB	-	bomber
MLT	-	military transport
MTR	-	military trainer

Anomaly (Descriptions, Detector, Resolution, Consequences) - short summary of a standard chain of sub-events within a reported incident.

Situation Report Subjects - description(s) of a static hazard which creates a safety problem.

ANOMALY DEFINITIONS

ACFT EQUIPMENT PROBLEM/CRITICAL - Aircraft equipment problem that is vital to the safety of the flight.

ACFT EQUIPMENT PROBLEM/LESS SEVERE - Not qualifying as a critical aircraft equipment problem.

ALT DEVIATION - A departure from or failure to attain or failure to maintain an ATC assigned altitude. It does not include an injudicious or illegal altitude in VFR flight where no altitude has been assigned by ATC or specified in pertinent charts.

ALT DEV/OVERSHOOT - An aircraft climbs or descends through the assigned altitude.

ALT DEV/UNDERSHOOT ON CLD OR DES - An aircraft fails to reach an assigned altitude during climb or descent.

ALT DEV/EXCURSION FROM ASSIGNED - An aircraft departs from level flight at an assigned altitude.

ALT DEV/XING RESTRICTION NOT MET - Charted or assigned altitude crossing restriction is not met.

ALT-HDG RULE DEVIATION - Cruise flight contrary to the altitudes specified in FAR 91.159

CONFLICT/NMAC (NEAR MIDAIR COLLISION) - a conflict is defined as the existence of a perceived separation anomaly such that the pilot(s) of one or both aircraft take evasive action; or are advised by ATC to take evasive action; or experience doubt about assurance of continuing separation from the viewpoint of one or more of the pilots or controllers involved. A near midair collision is when the flight crew reports, either directly or as quoted by the controller, that the reported miss distance is less than 500 feet.

CONFLICT/AIRBORNE LESS SEVERE - a conflict not qualifying as a NMAC

CONFLICT/GROUND CRITICAL - A ground occurrence that involves (1) two or more aircraft, at least one of which is on the ground at the time of the occurrence, or (2) one or more aircraft conflicting with a ground vehicle. The flight crew reports, either directly or as quoted by a controller, that they took evasive action to avoid a collision (emergency action go-around, veering on runway or taxiway, takeoff abort, or emergency braking), and the balance of the report, including the narrative is judged consistent with a critical occurrence.

CONFLICT/GROUND LESS SEVERE - a ground conflict not qualifying as critical.

CONTROLLED FLT TOWARD TERRAIN - Flying at an altitude that would, if continued, result in contact with terrain.

ERRONEOUS PENETRATION OF OR EXIT FROM AIRSPACE - Self-explanatory.

IN-FLT ENCOUNTER/OTHER - In-flight encounter (e.g., bird strikes, weather balloons).

IN-FLT ENCOUNTER/WX - In-flight encounter with weather (e.g., wind shear, turbulence, clouds, high winds, storms).

LESS THAN LEGAL SEPARATION - Less than standard separation between two airborne aircraft (as standard separation is defined for the airspace involved).

LOSS OF ACFT CONTROL - Self-explanatory.

NON-ADHERENCE LEGAL RQMT/CLNC - Non-adherence to an ATC clearance.

NON-ADHERENCE LEGAL RQMT/FAR - Non-adherence to a Federal Aviation Regulation.

NON-ADHERENCE LEGAL RQMT/PUBLISHED PROC - Non-adherence to approach procedure, standard instrument departure, STAR, profile descent, or operational procedure as described in the AIM or ATC facility handbook.

NON-ADHERENCE LEGAL RQMT/OTHER - Non-adherence to SOPs for aircraft, company SOPs, etc.

RWY OR TXWY EXCURSION - An aircraft exits the runway or taxiway pavement.

RWY TRANSGRESS/OTHER - The erroneous or improper occupation of a runway or its immediate environs by an aircraft or other vehicle so as to pose a potential collision hazard to other aircraft using the runway, even if no such other aircraft were actually present.

RWY TRANSGRESS/UNAUTH LNDG - A runway transgression specifically involving landing without a landing clearance or landing on the wrong runway.

SPEED DEVIATION - Aircraft speed contrary to FARs or controller instruction.

TRACK OR HDG DEVIATION - Self-explanatory.

UNCTRL ARPT TRAFFIC PATTERN DEVIATION - Failure to fly the prescribed rectangular pattern or failure to enter on a 45 degree angle to the downwind leg.

VFR IN IMC - Flight conducted under Visual Flight Rules (VFR) into Instrument Meteorological Conditions (IMC) when not on an instrument flight plan and/or when not qualified to fly under Instrument Flight Rules (IFR).

ACCESSION NUMBER : 72048
DATE OF OCCURRENCE : 8707
REPORTED BY : FLC; ; ;
PERSONS FUNCTIONS : FLC,FO; FLC,PIC.CAPT; FLC,PIC.CAPT;TWR, LC;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : ATL
FACILITY STATE : GA
FACILITY TYPE : TWR; ARPT;
FACILITY IDENTIFIER : ATL; ATL;
AIRCRAFT TYPE : MLG; LRG;
ANOMALY DESCRIPTIONS : IN-FLT ENCOUNTER/OTHER; LOSS OF ACFT CONTROL;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : FLC EXECUTED GAR OR MAP; FLC REGAINED ACFT CONTROL; ACFT EXITED ADVERSE ENVIRONMENT;
ANOMALY CONSEQUENCES : NONE;
NARRATIVE : VECTORED FOR A VISUAL APCH AT 5000' 10 MI FROM ARPT. INSTRUCTED TO MAINTAIN 180 KTS TO MARKER AND FOLLOW AN LGT "20 KTS FASTER". THROTTLES WERE AT IDLE, FLAPS 15 DEG, AND GEAR DOWN. GLIDE SLOPE WAS SHOWING FULL DOWN INDICATION. JUST OUTSIDE OUTER MARKER, AS THROTTLES WERE RETURNED TO APPROX 1.15 EPR, WE BEGAN TO ENCOUNTER "LIGHT" WAKE TURB. NEAR OUTER MARKER AT APPROX 2000' AGL (STILL FULL DOWN DEFLECTION ON GLIDE SLOPE) ACFT BEGAN ROLL TO RIGHT, FULL OPPOSITE AILERON WAS APPLIED, WITH BOTH PLTS ON CONTROLS. ACFT CONTINUED TO ROLL TO A BANK ANGLE EXCEEDING 75 DEG OF BANK, STICK SHAKER AND GND PROX WARNING SYSTEM SOUNDED AND THROTTLES WERE ADVANCED TO FIREWALL THRUST. AIRSPEED AT THIS TIME WAS 170-180 KIAS. MISSED APCH WAS EXECUTED AND WE WERE VECTORED FOR A SECOND APCH AND UNEVENTFUL LNDG.
SYNOPSIS : MLG ENCOUNTERS WAKE TURBULENCE ON FINAL APCH BEHIND AN LGT.
REFERENCE FACILITY ID : ATL
FACILITY STATE : GA
AGL ALTITUDE : 5,,E
MSL ALTITUDE : 3000, 3000

ACCESSION NUMBER : 107506
DATE OF OCCURRENCE : 8812
REPORTED BY : FLC; ; ; ;
PERSONS FUNCTIONS : FLC,PIC.CAPT; FLC,FO; FLC,PIC.CAPT;FLC, FO;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : DFW
FACILITY STATE : TX
FACILITY TYPE : TWR; ARPT;
FACILITY IDENTIFIER : DFW; DFW;
AIRCRAFT TYPE : MLG; LRG;
ANOMALY DESCRIPTIONS : IN-FLT ENCOUNTER/OTHER; OTHER;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : NOT RESOLVED/ANOMALY ACCEPTED;
ANOMALY CONSEQUENCES : NONE;
SITUATION REPORT SUBJECTS : AN ACFT TYPE;
NARRATIVE : LGT WAS CLRED FOR TKOF. ONCE HE WAS AIRBORNE, WE WERE CLRED FOR TKOF. IMMEDIATELY AFTER TKOF WE ENCOUNTERED THE LGT WAKE TURB. IT TOOK ALMOST FULL AILERON INPUT TO KEEP FROM ROLLING PAST 45 DEGS. THE LGT IS NOT CONSIDERED A HVY CATEGORY ACFT. THE WAKE I ENCOUNTERED WAS CONSIDERABLY MORE THAN NORMAL. SUGGEST THERE BE AN INTERMEDIATE CATEGORY WITH SOME TIMING RESTRICTIONS, ESPECIALLY FOR LNDG. IF MORE INFO IS NEEDED, PLEASE CALL.
SYNOPSIS : MLG EXPERIENCED WAKE TURBULENCE FOLLOWING A NEW TYPE MLG NOT DESIGNED AS HVY.
REFERENCE FACILITY ID : DFW
FACILITY STATE : TX
AGL ALTITUDE : 0,350
MSL ALTITUDE : 100,100

ACCESSION NUMBER : 149927
DATE OF OCCURRENCE : 9006
REPORTED BY : FLC; ; ;
PERSONS FUNCTIONS : FLC,CAPT.PIC; FLC,FO; TWR,LC; FLC, PIC. CAPT;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : ORD
FACILITY STATE : IL
FACILITY TYPE : TWR; ARPT;
FACILITY IDENTIFIER : ORD; ORD;
AIRCRAFT TYPE : MLG; LRG;
ANOMALY DESCRIPTIONS : IN-FLT ENCOUNTER/OTHER; LOSS OF ACFT CONTROL;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : FLC REGAINED ACFT CONTROL
ANOMALY CONSEQUENCES : NONE;
SITUATION REPORT SUBJECTS : AN ACFT TYPE; PROC OR POLICY/FAA;
NARRATIVE : I AM CAPT OF AN MLG. TOLD TO EXPEDITE TKOF BEHIND LGT ON RWY 32L AT ORD. WE BEGAN TKOF ROLL AS LGT ROTATED. HE WENT STRAIGHT OUT[1] AND WE WERE TO TURN TO 180 DEGS. WE STARTED THE TURN AT 300' AGL WITH 15 DEGS ANGLE OF BANK. WE WERE VIOLENTLY INCREASED TO 30 DEGS ANGLE OF BANK FROM THE APPARENT WAKE TURB OF THE LGT. THE COPLT COVERED SMOOTHLY AND NO ONE WAS INJURED. I WONDERED IF THE FAA OR ACFT MFR HAD CONSIDERED INCREASED SEP BEHIND LGT ACFT BECAUSE OF WING DESIGN.
SYNOPSIS : FLT CREW OF MLG DEPARTING ORD ENCOUNTERS WHAT THEY BELIEVED TO BE THE WAKE TURBULENCE OF A LGT THAT DEPARTED JUST BEFORE THEM.
REFERENCE FACILITY ID : ORD
FACILITY STATE : IL
AGL ALTITUDE : 300,000

[1]Handwritten note: 40 - 50 sec.

ACCESSION NUMBER : 156250
DATE OF OCCURRENCE : 9008
REPORTED BY : FLC; ; ; ; ;
PERSONS FUNCTIONS : FLC,PIC.CAPT; FLC,FO; FLC, SO; FLC, PIC.CAPT; TWR,LC; TRACON,DC;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : LAX
FACILITY STATE : CA
FACILITY TYPE : ARPT; TWR; TRACON;
FACILITY IDENTIFIER : LAX; LAX; LAX;
AIRCRAFT TYPE : LRG; LRG;
ANOMALY DESCRIPTIONS : OTHER;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : FLC REGAINED ACFT CONTROL;
ANOMALY CONSEQUENCES : NONE;
SITUATION REPORT SUBJECTS : PROC OR POLICY/FAA; AN ACFT TYPE;
NARRATIVE : WE WERE CLRED ONTO RWY 25L AT LAX. THE SKY WAS CLR AND WINDS WERE 250 DEGS AT 9 KTS. AN LGT ADVANCED WAS ON ITS TKOF ROLL. WE WERE FLYING AN LGT WITH -15 ENGS AND RELATIVELY LIGHT AT ABOUT 140000#. AS THE LGT ADVC STARTED ITS ROTATION, WE WERE CLRED FOR TKOF. WE STARTED OUR TKOF ROLL RIGHT AFTER RECEIVING THE CLRNC, NOT MAKING ANY ALLOWANCES FOR THE LGT ADVNC. RIGHT AFTER LIFTOFF AT ABOUT 100' AGL, WE ENCOUNTERED THE WAKE VORTICES OF THE LGT ADVNC AND WE WERE IN THEM UNTIL ABOUT 2000' MSL. DURING THAT TIME WE EXPERIENCED VERY RAPID ROLL RATES, WITH THE ACFT ROLLING 45 DEGS LEFT AND RIGHT, AND FULL AILERON OFTEN REQUIRED TO KEEP THE ACFT RIGHT SIDE UP. WITH NO SEP REQUIREMENTS FOR THE LGT ADVNC MANDATED BY THE FAA AT THIS TIME, THIS PLT WILL BE REQUESTING ADDITIONAL SEP FROM LGT ADVNC ACFT AND STRONGLY SUGGESTS THE FAA CONSIDER TREATING THE LGT ADVNC AS A HVY FOR SEP REQUIREMENTS.
SYNOPSIS : FLT CREW OF LGT MAKING SHORT INTERVAL TKOF BEHIND ADVANCED LGT EXPERIENCED WAKE TURBULENCE FORM TKOF UP TO 2000' FOLLOWING THE ADVANCED LGT.
REFERENCE FACILITY ID : LAX
FACILITY STATE : CA
DISTANCE & BEARING FROM REF. : 3,250
AGL ALTITUDE : 0,2000

ACCESSION NUMBER : 167185
DATE OF OCCURRENCE : 9101
REPORTED BY : CTLR; ; ; ;
PERSONS FUNCTIONS : TWR,LC; FLC,PIC.CAPT; FLC,FO; FLC, PIC. CAPT;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : BOS
FACILITY STATE : MA
FACILITY TYPE : TWR;
FACILITY IDENTIFIER : BOS;
AIRCRAFT TYPE : LRG; LTT;
ANOMALY DESCRIPTIONS : OTHER; CONFLICT/AIRBORNE LESS SEVERE; LESS THAN LEGAL SEPARATION; NON ADHERENCE LEGAL RQMT/PUBLISHED PROC;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : CTLR ISSUED NEW CLNC; FLC EXECUTED GAR OR MAP; ACFT EXITED ADVERSE ENVIRONMENT;
ANOMALY CONSEQUENCES : NONE;
NARRATIVE : ACR X WAS ON FINAL (ILS/DME) TO RWY 33L AT BOS. ACR X SLOWED TO 120 KTS ON A 3 MI FINAL. LTT Y WAS ON APCH 3-4 MI IN TRAIL 170 KTS. (ALL SPDS ARE ARTS GENERATED IN THE DATA BLOCKS.) LTT Y WAS TOLD HE WAS INDICATING 50 KTS FASTER THAN ACR X. ACR X WAS TOLD THAT TFC WAS SPACED ON HIM. WITH ACR X LESS THAN A 1 MI FINAL AND LTT Y 2 1/2 MI IN TRAIL, LTT Y INFORMED ME HE WAS UNABLE TO FOLLOW ACR X AND WAS ABORTING THE APCH. WHEN I ASKED TO SAY AGAIN, THE PLT STATED HE WAS IN A RIGHT TURN. I ASKED THE PLT IF HE WAS ABLE RWY 27, AND HE STATED AFFIRMATIVE. THE PLT WAS ISSUED LNDG CLRNC FOR RWY 27. DURING THE SEQUENCE OF EVENTS, THE PLT OF LTT Y NEVER REDUCED HIS AIRSPD AND NEVER INFORMED ACR X (HE INFORMED THE GND CTLE OF THE WAKE TURB PROB). BOS TWR IS ALLOWED REDUCED SEP INSIDE THE OM (PER FAA HANDBOOK 7110.65, PARAGRAPH 5-72F) TO 2.5 MI. HVY ACFT CAN PARTICIPATE AS TRAILING ACFT ONLY. SINCE LTT Y RPTED ACR X IN SIGHT, I ASSUMED HE WAS PROVIDING HIS OWN VIS SEP (I HAD BOTH ACFT IN SIGHT). HAD I KNOWN THAT THE WAKE TURB FROM THE ACR CREATED SUCH A PROB FOR THE LTT, I WOULD HAVE TAKEN MORE POSITIVE ACTION (I.E., INSTRUCTED LTT Y TO REDUCE TO HIS FINAL APCH SPD, IF PRACTICAL) TO MAINTAIN AS MUCH SEP AS POSSIBLE.
SYNOPSIS : LTT Y HAD LESS THAN STANDARD SEPARATION FROM ACR X. SYSTEM ERROR.
REFERENCE FACILITY ID : BOS
FACILITY STATE : MA
DISTANCE & BEARING FROM REF. : 5,,NE
AGL ALTITUDE : 300,1100

ACCESSION NNBER : 190748
DATE OF OCCURRENCE : 9110
REPORTED BY : FLC; FLC; ; ;
PERSONS FUNCTIONS : FLC, FO; FLC,PIC.CAPT; TRACON,DC; TWR,LC;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : DFW
FACILITY STATE : TX
FACILITY TYPE : ARPT; TRACON;
FACILITY IDENTIFIER : DFW; DFW;
AIRCRAFT TYPE : MLG; LRG;
ANOMALY DESCRIPTIONS : IN-FLT ENCOUNTER/OTHER; LOSS OF ACFT CONTROL; TRACK OR HDG DEVIATION; NON ADHERENCE LEGAL RQMT/CLNC; NON ADHERENCE LEGAL RQMT/PUBLISHED PROC;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : NOT RESOLVED/ANOMALY ACCEPTED;
ANOMALY CONSEQUENCES : NONE;
NARRATIVE : AFTER TAKING OFF OF RWY 17R AT DFW AND PASSING 1200 FT MSL OUR MLG ENCOUNTERED SEVERE WAKE TURB CREATED BY A PREVIOUSLY DEPARTING LGT. THE PF WAS STRUGGLING TO RETAIN ACFT CTL, USING FULL FLT CTL INPUTS TO COUNTERACT THE ROLL RATE. THE WAKE TURB HAD CHANGED THE ACFT'S HDG TO APPROX 155 DEG FROM THE ASSIGNED 170 DEG RWY HDG. AS THE PNF I TOLD DEP CTL THAT WE WERE ENCOUNTERING SEVERE WAKE TURB AND TURNING L NOW TO GET OUT OF IT. DEP CTL RESPONDED 'NEGATIVE ON THE TURN.' I REINFORMED DEP THAT WE HAD NO CHOICE TO WHICH THEY INSTRUCTED THAT OUR TURN MUST BE LIMITED TO NO MORE THAN 10 DEG. STILL IN THE WAKE WE ADVANCED PWR TO MAX AND TOOK AN APPROX 140 DEG HDG AND ESCAPED THE TURB. WE WERE VISUALLY CLR OF ALL OBSTRUCTIONS AND TFC. IT SEEMS AS THOUGH THE TWR CTLR ISSUED TKOF CLRNC WITH LESS THAN NORMAL TIME SEPARATION. ADDITIONALLY, THE DEP CTLR, DESPITE OUR ADVISORY, GAVE INSTRUCTIONS THAT WOULD HAVE FURTHER ENDANGERED OUR FLT BY RESTRICTING OUR TURN. IT MAY BE THAT 1 OR BOTH OF THESE CTLRS WERE UNAWARE OF THE EFFECTS OF WAKE TURB OR FEEL THAT IT'S MORE IMPORTANT TO KEEP ACFT FROM OVERFLYING NOISE SENSITIVE AREAS THAN IT IS TO HAVE THEM OPERATE SAFELY. OUR CREW COULD HAVE ASKED FOR INCREASED SEPARATION FOR TKOF.
SYNOPSIS : ACR MLG WAKE TURB ENCOUNTER IN ICB OFF RWY 17R AT DFW.
REFERENCE FACILITY ID : DFW
FACILITY STATE : TX
DISTANCE & BEARING FROM REF. : ,,SO
MSL ALTITUDE : 1200,1200

ACCESSION NUMBER : 210179
DATE OF OCCURRENCE : 9205
REPORTED BY : FLC; ; ; ;
PERSONS FUNCTIONS : FLC,PIC.CAPT; FLC,FO; FLC,PIC,CAPT; TRACON,AC;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : ORD
FACILITY STATE : IL
FACILITY TYPE : TRACON; ARPT;
FACILITY IDENTIFIER : ORD; ORD;
AIRCRAFT TYPE : LTT; LRG;
ANOMALY DESCRIPTIONS : IN-FLT ENCOUNTER/OTHER; LOSS OF ACFT CONTROL;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : FLC REGAINED ACFT CONTROL;
ANOMALY CONSEQUENCES : NONE;
NARRATIVE : DURING A VECTOR FROM THE S, WE WERE SEQUENCED BEHIND AN ACR LGT Y. JUST AS FINAL WAS INTERCEPTED, THE WAKE WAS ENCOUNTERED. WE ROLLED UNCTLABLE INTO 80 DEG BANK. WE COULDN'T CTL FOR 2-3 SECONDS. THE LGT Y PUTS OUT MORE WAKE THAN ANY ACFT I HAVE EVER ENCOUNTERED.
SYNOPSIS : A COMMUTER ACFT ENCOUNTERS WAKE TURB WHEN SEQUENCED BEHIND AN ACR LGT ON FINAL AT ORD. REFERENCE FACILITY ID : ORD
FACILITY STATE : IL
DISTANCE & BEARING FROM REF. : 10,,SW
MSL ALTITUDE : 4000,4000

ACCESSION NUMBER : 218953
DATE OF OCCURRENCE : 9208
REPORTED BY : FLC; FLC; ; ; ;
PERSONS FUNCTIONS : FLC,PIC.CAPT; FLC,FO; FLC,PIC.CAPT; FLC,FO; TWR, LC;
FLIGHT CONDITIONS : MVF
REFERENCE FACILITY ID : ATL
FACILITY STATE : GA
FACILITY TYPE : ARPT; TWR; TRACON;
FACILITY IDENTIFIER : ATL; ATL; ATL;
AIRCRAFT TYPE : LTT; LRG;
ANOMALY DESCRIPTIONS : IN-FLT ENCOUNTER/OTHER; LOSS OF ACFT CONTROL; OTHER;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : FLC EXECUTED GAR OR MAP;
ANOMALY CONSEQUENCES : NONE;
SITUATION REPORT SUBJECTS : OTHER; PROC OR POLICY/ATC FACILITY; PROC OR POLICY/FAA;
NARRATIVE : WE HAD BEEN CLRED FOR AN ILS TO 27L IN ATL. WE JOINED THE FINAL AT 3500 FT AND, AS THE GS STARTED TO MOVE, WE GOT HIT BY WAKE TURB THAT BANKED THE ACFT ABOUT 45 DEGS TO THE R. WE RECOVERED AND CONTINUED. WE ASKED APCH FOR THE TYPE OF ACFT WE WERE FOLLOWING. HE STATED THAT WE WERE 3 1/2 MI BEHIND AN LGT. WE INTERCEPTED THE GS AND GOT HIT AGAIN BY WAKE TURB ALTHOUGH NOT AS BAD. WE HAD THE ARPT IN SIGHT AND DECIDED TO STAY ABOVE THE GS TO AVOID THE WAKE. WE WERE ABOUT 1 1/2 DOTS HIGH, ABOVE THE GS WHEN WE HIT EXTREME WAKE TURB, THE ACFT VIOLENTLY ROLLED INTO A 90 DEG BANK TO THE R, PITCHED 10 TO 12 DEGS DOWN, AND THE IAS WENT TO ZERO IN LESS THAN 5 SECONDS. IT TOOK BTWN 130-140 PERCENT TORQUE TO RECOVER AND START FLYING AGAIN. WE INITIATED A GAR AND ADVISED THE TWR. WE RETURNED FOR A NORMAL LNDG. AFTER LNDG, WE LEARNED FROM ANOTHER COMPANY PLT THAT, BEFORE WE SWITCHED TO THE TWR FREQ, THE LGT HAD RPTED TO THE TWR THAT HE WAS FULL DEFLECTION ABOVE THE GS BECAUSE OF WAKE TURB FROM A WDB. THE TWR CLRED THE LGT FOR A VISUAL APCH AFTER THE LGT SAID HE SAW THE ARPT. THE LGT MADE A QUICK DSCNT AND LANDED. BECAUSE OF THIS, OUR NORMAL PROC OF STAYING ABOVE THE GS TO STAY OUT OF HARM'S WAY DID NOT WORK. THE TWR SHOULD HAVE TOLD US THAT THE LGT WENT HIGH. I WOULD HAVE ABANDONED THE APCH. IN ATL, WE FOLLOW MANY DIFFERENT TYPES OF LARGE ACFT AND THE LGT HAS THE WORST WAKE TURB. I THINK THAT THE LGT SHOULD BE CLASSIFIED AS A HEAVY SO WE COULD GET HVY SEPARATION. 3 MI BEHIND AN LGT IS TOO CLOSE.
SYNOPSIS : AN LTT ACR HAD AN ENCOUNTER WITH SEVERE WAKE TURB REQUIRING A GAR.
REFERENCE FACILITY ID : ATL
FACILITY STATE : GA
DISTANCE & BEARING FROM REF. : 5,,E
MSL ALTITUDE : 2500,3500

ACCESSION NUMBER : 49847
DATE OF OCCURRENCE : 8601
REPORTED BY : FLC
PERSONS FUNCTIONS : FLC,PIC.CAPT; FLC, FO;FLC,SO;TWR,LC
FLIGHT CONDITIONS : VMC
AIRCRAFT TYPE : LRG
NARRATIVE : DURING TAXI OUT FOR TKOF ON 32R AT ORD WE HEARD THE TWR CLEAR AN ACFT FOR TKOF BEHIND A HEAVY JET. THE PLT OF THE ACFT CLRD FOR TKOF BEHIND THE HEAVY JET ASKED FOR ADDITIONAL TIME AS HE "DID NOT WANT TO TKOF SO CLOSE TO THE HEAVY JET." WE WERE ALSO IN LINE BEHIND A HEAVY JET AND CLRD INTO POSITION WHEN THE WDB WAS CLRD FOR TKOF. WE TIMED THE TKOF ROLL OF THE WDB AND AT 50 SECS AFTER BEGINNING OF THE WDB TKOF ROLL WE WERE CLRD FOR TKOF. THE REPORTED WIND WAS 290 DEG/6 KTS. WE ADVISED THE TWR THAT WE WANTED MORE SEPARATION BETWEEN US AND THE PRECEDING WDB. THE TWR ADVISED US WE HAD 5 MILES SEPARATION WITH THE WDB (WHICH WAS IMPOSSIBLE. THE WDB WAS JUST AIRBORNE AND THE RWY 32R IS 10,003' IN LENGTH. THE TWR THEN PROCEEDED TO TELL US THE NEXT TIME WE WANTED MORE SEPARATION BEHIND A HEAVY WE SHOULD ADVISE THEM BEFORE TAXIING INTO POSITION AND THEY WOULD SEQUENCE US ACCORDINGLY. THE TWR THEN ADVISED US TO TAXI DOWN THE RWY AND EXIT THE RWY AT THE 9L/27R PARALLEL. BY THE TIME THE TWR WAS THRU WITH THEIR ADVICE AND INSTRUCTIONS ENOUGH TIME HAD PASSED (APPROX 1 MIN 50 SECS) SO THAT WE FELT COMFORTABLE IN TKOF AND ADVISED THE TWR THAT WE WERE READY FOR TKOF. THE TWR THEN CLRD US FOR TKOF. AS WE STARTED THE TKOF ROLL THE TWR CANCELLED THE TKOF CLRNC DUE TO AN ACFT LNDG ON 27R. THIS WAS NO PROBLEM FOR US AS WE WERE JUST COMMENCING THE ROLL. AFTER THE ACFT LANDED ON 27R WE WERE RECLRD FOR TKOF BY THE TWR ALONG WITH THE ADVICE THAT IN THE FUTURE IF WE NEED MORE SEPARATION THAN THEY ALLOWED US IN THIS CASE WE SHOULD ADVISE THEM AND THEY WOULD SEQUENCE US ACCORDINGLY. AS WE ROLLED DOWN THE RWY WE HEARD OVER THE RADIO SOMEONE COMMENT TO THE TWR THAT "IT IS PRESSURING LIKE THAT THAT CAUSES ACCIDENTS". I GUESS THE TWR OPERATOR WAS TRYING TO DO HER JOB OF MOVING TFC, HOWEVER, IN NO WAY DID WE HAVE THE SEPARATION AS OUTLINED IN OUR FOM. EVERY SITUATION IS DIFFERENT AND BRINGS INTO PLAY THE JUDGEMENT FACTOR AND PAST EXPERIENCE AND IN THIS CASE (WIND 290/6, 50 SECS AFTER BEGINNING OF TKOF ROLL OF WDB WE WERE CLRD FOR TKOF, 2 MILES SEPARATION--NOT FIVE MILES SEPARATION) WE FELT IT WAS MORE PRUDENT TO DELAY TKOF UNTIL WE HAD ADDITIONAL SEPARATION. WE FELT THE TWR WAS APPLYING UNDUE PRESSURE AND DID NOT PROVIDE PROPER SEPARATION.
SYNOPSIS : ALLEGED IMPROPER WAKE TURB SEPARATION CRITERION FOR TKOF.
CALLBACK/COMMENTS : NONE
LOC ID (LOCATION IDENTIFIER) : ORD;ORD

ACCESSION NUMBER : 58754
DATE OF OCCURRENCE : 8610
REPORTED BY : FLC; ; ; ; ;
PERSONS FUNCTIONS : FLC,PIC.CAPT; FLC,FO; FLC,PIC.CAPT; TRACON,AC; TWR,LC;
FLIGHT CONDITIONS : MXD
REFERENCE FACILITY ID : ORD
FACILITY STATE : IL
FACILITY TYPE : TRACON; TWR; ARPT;
FACILITY IDENTIFIER : ORD; ORD; ORD;
AIRCRAFT TYPE : MLG; LRG;
ANOMALY DESCRIPTIONS : CONFLICT/AIRBORNE LESS SEVERE; LESS THAN LEGAL SEPARATION; SPEED DEVIATION; NON ADHERENCE LEGAL RQMT/ CLNC;
ANOMALY DETECTOR : ATC/CTLR;
ANOMALY RESOLUTION : CTLR INTERVENED; CTLR ISSUED NEW CLNC;
ANOMALY CONSEQUENCES : FLC/ATC REVIEW;
SITUATION REPORT SUBJECTS : PROC OR POLICY/ATC FACILITY; PROC OR POLICY/FAA;
NARRATIVE : THE SUPVR SAID "NO FURTHER ACTION WOULD BE TAKEN UNLESS SOMETHING ELSE WOULD COME UP". THESE HIGH ALT, 250 KT LOCALIZER INTERCEPTS AT LESS THAN 15 DMF FROM THE FIELD, WITH ONLY 5 DME ACFT SEPARATION, ARE NOT SAFE! THERE JUST IS NOT ENOUGH CUSHION FOR ACFT SLOWING CAPABILITIES, CREW REACTIONS AND DUTIES, WEATHER, AND OVERLOADED COMMUNICATIONS. AT ORD THERE IS LITTLE 2 WAY COMMUNICATIONS AS WE ARE GUILTY OF BEING INTIMIDATED BY APCH CONTROL INTO JUST LISTENING. THIS LETS THEM TALK CONTINUOUSLY AND CROWD MORE PLANES IN BY NOT TAKING THE TIME FOR QUESTIONS OR REPORTS FROM PLTS. THEY NORMALLY DO A GREAT JOB UNDER THE CIRCUMSTANCES, BUT LATELY THIS "JAMMING" TREND HAS STARTED AGAIN! ON FINAL APCH CONTROL, 90 DEG ABEAM FIELD, 7000', 250 KTS, 15 DME OUT, SOLID UNDERCAST, F/O FLYING, BEHIND HEAVY PLANE, FOR ILS 9R AT ORD. HEAVY TURNED IN, APPEARED TO BE SLOWING, WERE CONCERNED WITH CLOSURE RATE (5 DME SEPARATION), AND HE DESCENDED INTO CLOUDS. F/O STARTED SLOWING AND I AGREED BEING VERY CONCERNED WITH CLOSURE RATE, WAKE TURBULENCE, AND CTLR OVERLOAD. NON STOP TALKING BY CTLR PREVENTED ME INFORMING HIM OF OUR SLOWING. HE THEN ASKED OUR SPEED, 210 KTS REPORTED, AND HE YELLED FOR US TO PICK BACK UP TO 250 KTS AND WE DID. HEARD PLANE BEHIND US SLOW TO 180 KTS AND A RIGHT TURN. CTLR STARTED TURNING US IN, SLOW TO 180 KTS, NEXT BREATH THEN SLOW TO 160 KTS, AND WE OVERSHOT THE LOCALIZER. AT LOM CALLED TWR, INFORMED #2 FOR 9R, BROKE OUT OF CLOUDS, SAW HEAVY LANDING CONFIRMING MY LESS THAN 5 DME SEPARATION. TWR INFORMED THAT A LIGHT TWIN WAS 3 DME AHEAD OF US BETWEEN US AND THE HEAVY! RAPID FLAP DEPLOY NARROWLY PREVENTED US GOING AROUND BECAUSE OF LIGHT PLANE CLEAR 9R. GROUND CONTROL GAVE US A PHONE NUMBER TO CALL. APCH CONTROL SUPVR CHEWED ME OUT FOR NOT TELLING THEM OF OUR SLOWING AND CLAIMED THE LGT B BEHIND US CAME WITHIN 1 DME OF US. I TOLD HIM WE COULDN'T GET A WORD IN AND MY CONCERN FOR OUR CLOSURE ON THE HEAVY. THE LGT B CAPT CAME IN AND ALSO TALKED TO THE SUPVR AND TOLD HIM THERE WAS NO PROBLEM AS HE WAS VISUALLY WHAT WAS HAPPENING TO US. THIS CAPT TOLD ME APCH WAS DIVING HIM IN BEHIND US AT LESS THAN 5 DME, WHICH HAD HAPPENED TO ME THERE OFTEN.
SYNOPSIS : MLG FLT CREW CONCERNED OVER SPACING AND WAKE TURBULENCE SEPARATION BEHIND A HEAVY ACFT SLOWED FROM

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ACCESSION NUMBER               : 119921
DATE OF OCCURRENCE             : 8908
REPORTED BY                    : FLC;  ;  ;  ;
PERSONS  FUNCTIONS             : FLC,FO; FLC,PIC.CAPT; FLC,PIC.CAPT; TWR,
      LC;
FLIGHT CONDITIONS              : IMC
REFERENCE FACILITY ID          : CVG
FACILITY STATE                 : OH
FACILITY TYPE                  : TWR;
FACILITY IDENTIFIER            : CVG;
AIRCRAFT TYPE                  : MLG; MLG;
ANOMALY DESCRIPTIONS           : ALT DEV/EXCURSION FROM ASSIGNED; LOSS OF
      ACFT CONTROL; OTHER;
ANOMALY DETECTOR               : ATC/CTLR; COCKPIT/FLC;
ANOMALY RESOLUTION             : PLC REGAINED ACFT CONTROL;
ANOMALY CONSEQUENCES           :  NONE;
SITUATION REPORT SUBJECTS      : AN ACFT TYPE; PROC OR POLICY/FAA;
NARRATIVE                      : AT 250' AGL ON THE CAT II ILS RWY 36
      APCH TO CVG, WE ENCOUNTERED MOD WAKE TURBULENCE FROM A WDB THAT
      HAD LANDED IN FRONT OF US. ALTHOUGH WE HAD LEGAL IFR SEPARATION,
      A LARGE POWER INCREASE AND SIGNIFICANT CONTROL WHEEL INPUT WAS
      REQUIRED TO MAINTAIN A STABILIZED FLT PATH. IF THE RWY
      ENVIRONMENT HAD NOT BEEN IN SIGHT, A GO AROUND WOULD HAVE BEEN
      REQUIRED. THE TWR CTLR HAD WARNED US OF POSSIBLE WAKE TURBULENCE
      AT 1 NM ON THE APCH. THIS WARNING ALSO CONTRIBUTED TO A SAFE
      LNDG RATHER THAN A MISSED APCH. RECOMMEND INCREASING REQUIRED
      IFR SEPARATION BEHIND WDB ACFT TO 5 NM VICE THE PRESENT 3 NM TO
      PRECLUDE RECURRENCE OF THIS WAKE TURBULENCE HAZARD.
SYNOPSIS                       : MLG FOLLOWING A NEWER MLG TYPE
      ENCOUNTERED WAKE TURBULENCE.
REFERENCE FACILITY ID          : CVG
FACILITY STATE                 : OH
DISTANCE & BEARING FROM REF. : 1,180
AGL ALTITUDE                   : 250,250
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ACCESSION NUMBER : 188899
DATE OF OCCURRENCE : 9109
REPORTED BY : FLC; ; ;
PERSONS FUNCTIONS : FLC,PIC.CAPT; FLC,FO; TWR,LC;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : ORD
FACILITY STATE : IL
FACILITY TYPE : ARPT; TWR;
FACILITY IDENTIFIER : ORD; ORD;
AIRCRAFT TYPE : MLG; LRG;
ANOMALY DESCRIPTIONS : CONFLICT/AIRBORNE LESS SEVERE; IN-FLT ENCOUNTER/OTHER; LOSS OF ACFT CONTROL; OTHER;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : FLC AVOIDANCE-EVASIVE ACTION; FLC EXECUTED GAR OR MAP;
ANOMALY CONSEQUENCES : NONE;
NARRATIVE : AS CAPT AND PF I WAS VECTORED FOR PARALLEL VISUAL ORD USING 14L AND 14R. WAS CLRED FOR VISUAL. I WAS FLYING GS DOWN. EXPERIENCED MORE WAKE TURB FROM PRECEDING ACFT THAN WAS USUAL. TCASII SHOWED ABOUT 3.5 MI BEHIND. I ELECTED TO FLY ABOUT 1 DOT HIGH AND STAY OUT OF HIS WAKE AND TO LAND PAST HIS TOUCHDOWN POINT. AIR WAS FAIRLY SMOOTH AT 1 DOT HIGH. SAW MY INNER MARKER LIGHT FLASH AND THEN EXTINGUISH, WAS NOW 1/2 DOT HIGH. AT APPROX 50 FT AGL ACFT ROLLED RAPIDLY R THEN VIOLENTLY L. COUNTERED WITH FULL R AILERON. ACFT CONTINUED L ROLL. WENT TO MAX PWR THEN FIREWALL PWR. WE ACCELERATED THROUGH WAKE ZONE. ON GAR TWR ADVISED OF CONFLICTING TFC THAT HAD DEPARTED 22L. WE HAD A VISUAL ON HIM AND TCASII NEVER ISSUED ANY ADVISORY. I DID NOT CONSIDER HIM A THREAT AT HE WAS IN EXCESS OF 3 MI. NEVER IN 27 YRS HAVE I EXPERIENCED SUCH WAKE TURB. ACFT WE WERE FOLLOWING WAS LGT. WE ARE MLG. FOR A PERIOD OF A COUPLE SECONDS MY ACFT WAS OUT OF CTL DUE TO THE SEVERITY OF WAKE. NO RECOMMENDATIONS AS I SAID 3.5 IN TRAIL. WIND WAS 170 DEG/7.
SYNOPSIS : FLC OF MLG FOLLOWING AN LGT ON APCH FOR LNDG 3 PT 5 MI IN TRAIL, FLEW HIGH AS AWARE OF POSSIBLE WAKE TURB. 50 FT AGL ENCOUNTERED STRONG WAKE TURB. ACFT MOMENTARILY OUT OF CTL, FULL THRUST, FULL AILERON RECOVERY, GAR.
REFERENCE FACILITY ID : ORD
FACILITY STATE : IL
AGL ALTITUDE : 0,50

ACCESSION NUMBER : 195104
DATE OF OCCURRENCE : 9111
REPORTED BY : FLC; ; ;
PERSONS FUNCTIONS : FLC,PIC.CAPT; FLC,FO; FLC,PIC.CAPT; TRACON,AC;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : ORD
FACILITY STATE : IL
FACILITY TYPE : TRACON; ARPT;
FACILITY IDENTIFIER : ORD; ORD;
AIRCRAFT TYPE : MDT; LRG;
ANOMALY DESCRIPTIONS : OTHER;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLCTION : FLC REGAINED ACFT CONTROL;
ANOMALY CONSEQUENCES : NONE;
NARRATIVE : AFTER DEERE INTXN CLRED ORD VOR AT 7000 ENCOUNTERED WAKE FROM PRECEDING LGT AT SAME ALT APPROX VISUALLY APPEARED TO BE THE REQUIRED 3 MI SEPARATION BY ATC. ACFT STARTED ROLL TO THE L AND STARTED BUFFETING. AUTOPLT, YAW DAMPER AND ADU FAILED, NEGATIVE G'S WERE FELT AND COCKPIT AND CABIN ITEMS WERE DISLODGED AND A VERY ROUGH SHAKING WAS EXPERIENCED. FLT ATTENDANT WAS HURT, MINOR INJURIES. ACFT WAS INSPECTED FOR DAMAGE. THE ONLY DAMAGE I'M AWARE OF WAS INSIDE THE ACFT FROM THE FLT ATTENDANT BEING TOSSED AROUND AND BENT CURTAIN ROD. THE CONDITIONS OF FLT WERE SMOOTH AIR AND THE LEGAL SEPARATION DOES NOT APPEAR TO BE ADEQUATE UNDER SOME ATMOSPHERIC CONDITIONS SUCH AS SMOOTH AIR. AT THIS POINT IN TIME I UNDERSTAND THIS IS CLASSIFIED AS AN INCIDENT AND THE NTSB IS INVESTIGATING IT.
SYNOPSIS : MDT ENCOUNTERS WAKE TURB EVEN THOUGH PROPER 3 MI SPACING EXISTED.
REFERENCE FACILITY ID : ORD
FACILITY STATE : IL
DISTANCE & BEARING FROM REF. : 15,,NE
MSL ALTITUDE : 7000,7000

ACCESSION NUMBER : 227217
DATE OF OCCURRENCE : 9211
REPORTED BY : FLC; ; ;
PERSONS FUNCTIONS : FLC,PIC.CAPT; FLC,FO; FLC,PIC.CAPT;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : ATL
FACILITY STATE : GA
FACILITY TYPE : TRACON; ARPT;
FACILITY IDENTIFIER : ATL; ATL;
AIRCRAFT TYPE : LTT; LRG;
ANOMALY DESCRIPTIONS : IN-FLT ENCOUNTER/OTHER; OTHER;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : NOT RESOLVED/ANOMALY ACCEPTED;
ANOMALY CONSEQUENCES : NONE;
NARRATIVE : UPON TURNING ONTO THE LOC FOR THE VISUAL APCH TO ATL'S RWY 27L, APCH CTL ADVISED THAT WE WERE 4 MI BEHIND OUR TFC, AN LGT Y. WE THEN HIT 6 STRONG JOLTS OF WAKE TURB, AFTER WHICH OUR RIDE RETURNED TO SMOOTH. NO ONE WAS HURT. WAKE TURB IS A PROBLEM. IT IS SO COMMON IN THE ATL ARR AREA THAT WE TEND TO IGNORE IT, ACCEPTING IT AS A REGULAR PART OF FLYING. I HIT IT ON AN AVERAGE OF ONCE EVERY 10 APCHS TO ATL, OR ONCE EVERY 2 TO 3 'FLT DAYS.' USUALLY, BEHIND AN MLG OR LGT Y, IT IS 3 MEDIUM JOLTS IN WHICH NOTHING IN THE ACFT IS DISTURBED. BUT, BEHIND AN LGT Y, WAKE TURB IS ALWAYS STRONG -- MUCH STRONGER THAN OTHER 'NON HVY' ACFT. RECOMMENDATION: ASSIGN 'HVY' ACFT SEPARATION STANDARDS FOR LGT Y ACFT.
SYNOPSIS : LTT EXPERIENCES WAKE TURB WHEN 4 MI BEHIND LGT ON APCH.
REFERENCE FACILITY ID : ATL
FACILITY STATE : GA
DISTANCE & BEARING FROM REF. : 6,,E
MSL ALTITUDE : 3500,3500

ACCESSION NUMBER : 235192
DATE OF OCCURRENCE : 9303
REPORTED BY : FLC; FLC; ; ;
PERSONS FUNCTIONS : FLC,FO; FLC,PIC.CAPT; FLC,PIC.CAPT; TWR, LC;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : MCO
FACILITY STATE : FL
FACILITY TYPE : TWR; ARPT;
FACILITY IDENTIFIER : MCO; MCO;
AIRCRAFT TYPE : MLG; LRG;
ANOMALY DESCRIPTIONS : IN-FLT ENCOUNTER/OTHER;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : FLC RETURNED ACFT TO ORIGINAL CLNC OR INTENDED COURSE; ACFT EXITED ADVERSE ENVIRONMENT;
ANOMALY CONSEQUENCES : NONE;
NARRATIVE : LNDG BEHIND AN LGT. ON FINAL APCH AT APPROX 200 FT AGL, WE EXPERIENCED WAKE TURB FROM THE LGT WHO WAS ABOUT 4 MI AHEAD. OUR ACFT EXPERIENCED A ROLL TO THE R OF ABOUT 15 DEGS. IT WAS NOT AN ABRUPT OR TURBULENT ROLL, BUT A STEADY, SMOOTH ROLL. THE CAPT ADDED PWR AND ROLLED WINGS LEVEL AND OUR ACFT RECOVERED IMMEDIATELY. A GAR WAS NOT DEEMED NECESSARY DUE TO THE FACT THAT WE RECOVERED IMMEDIATELY AND WERE IN A SAFE POS TO LAND. THE REMAINDER OF THE LNDG AND ROLLOUT WAS UNEVENTFUL. UPON LNDG, WE ASKED TWR OUR SEPARATION ON THE LGT AND THEY CONFIRMED 4 MI. SUPPLEMENTAL INFO FROM ACN 235322: WHEN WE ENCOUNTERED THE WAKE TURB, I WAS SOMEWHAT SURPRISED, SINCE WE HAD SUCH GOOD SPACING BEHIND THE LGT. HOWEVER, ATIS WAS RPTING A WIND OF 340/4 KTS WHICH I'M SURE KEPT THE WAKE VORTEX RIGHT IN THE APCH PATH. BECAUSE OF OUR 'SLAM DUNK' APCH, WE WERE PREOCCUPIED WITH GETTING THE ACFT DOWN AND WERE DISTRACTED FROM THINKING ABOUT OR DISCUSSING THE POSSIBILITY OF WAKE TURB.
SYNOPSIS : MLG ENCOUNTERS WAKE TURB WHEN LNDG BEHIND AN LGT.
REFERENCE FACILITY ID : MCO
FACILITY STATE : FL
DISTANCE & BEARING FROM REF. : 1,,N
AGL ALTITUDE : 200,200

ACCESSION NUMBER : 238067
DATE OF OCCURRENCE : 9304
REPORTED BY : FLC; ; ; ; ;
PERSONS FUNCTIONS : FLC,PIC.CAPT; FLC,FO; FLC,~IC.CAPT; FLC, PIC.CAPT; TWR,LC;
FLIGHT CONDITIONS : VMC
REFERENCE FACILITY ID : DFW
FACILITY STATE : TX
FACILITY TYPE : ARPT; TWR;
FACILITY IDENTIFIER : DFW; DFW;
AIRCRAFT TYPE : LTT; MLG; LRG;
ANOMALY DESCRIPTIONS : IN-FLT ENCOUNTER/OTHER; LOSS OF ACFT CONTROL; OTHER;
ANOMALY DETECTOR : COCKPIT/FLC;
ANOMALY RESOLUTION : FLC EXECUTED GAR OR MAP; CTLR ISSUED NEW CLNC; FLC BECAME REORIENTED;
ANOMALY CONSEQUENCES : NONE;
SITUATION REPORT SUBJECTS : PROC OR POLICY/FAA; OTHER;
NARRATIVE : APCHING DFW FROM THE NW FOLLOWING MLG TFC WHEN CTLR SAW AN OPPORTUNITY TO ALLOW US TO LAND RWY 35R. WE WERE 3000 FT MSL AT 210 KIAS ASSIGNED AIRSPD WHEN TOLD TO FOLLOW LGT OVER LOM FOR RWY 35R. CROSSED BEHIND MLG ON FINAL FOR RWY 36L STILL AT 3000 FT AND INTERCEPTED LOC FOR RWY 35R. SWITCHED TO TWR FREQ AND WERE TOLD WE HAD A 70 KT OVERTAKE ON LGT AND BEGAN SLOWING. BEGAN DSCNT FROM 3000 FT NOTING WE WERE FULL DEFLECTION ABOVE GS. I JUDGED THIS TO BE PERFECTLY ACCEPTABLE KNOWING THE NASTY REPUTATION THE LGT HAS FOR GENERATING WAKE TURB AND, IN FACT, FULLY INTENDED TO REMAIN HIGH ON FINAL. TWR ADVISED 'CLRED TO LAND FOLLOWING TFC 2 1/2 AHEAD, CAUTION WAKE TURB.' I THOUGHT WE WOULD BE SAFELY ABOVE HIS WAKE. SHORTLY AFTER, MY ACFT (LTT) ROLLED TO THE R TO AN ANGLE OF APPROX 100 DEGS (MORE THAN 90 DEGS). FULL OPPOSITE CTL INPUT DID NOT HAVE ANY AFFECT IN STOPPING THIS ROLL. IAS BEGAN DROPPING AND THROTTLES WERE THEN FIREWALLED. AS WE ROLLED R, WE HAD ALSO TURNED SLIGHTLY IN THAT DIRECTION AND I ASSUME WE FLEW OUT OF THAT VORTEX AND WERE ABLE TO RIGHT THE ACFT. THEN WE HIT WHAT I ASSUME WAS HIS R WING VORTEX AND THE ACFT (MINE) BEGAN TO ROLL L. WE FLEW THROUGH THIS VORTEX FAIRLY QUICKLY, PROBABLY DUE TO OUR NEW (UNCOMMANDED) HDG, AND OUR BANK DID NOT EXCEED 60 DEGS. WE RECOVERED FROM THIS ROLL ON A HDG OF ABOUT 080 DEGS AND DECLARED A MISSED APCH. TWR ASKED IF WE COULD ENTER A BASE FOR RWY 31R AND LAND. WE DID, AND LANDED WITHOUT FURTHER INCIDENT. THE LGT HAD OBVIOUSLY BEEN VERY HIGH ON HIS APCH FOR SOME REASON, POSSIBLY AN EARLIER TCASII RESOLUTION. OUR ATTN HAD BEEN FOCUSED ON THE MLG WE WERE ORIGINALLY FOLLOWING, THUS I WAS UNAWARE OF THE LGT'S GLIDE PATH. I FEEL SOMEONE (CTLRS) SHOULD HAVE NOTICED THIS AND REALIZED A WAKE ENCOUNTER WAS INEVITABLE. SECONDLY, I FEEL THE LGT SHOULD BE CLASSIFIED AS A 'HVY' JET AND INCREASED SPACING SHOULD BE USED.
SYNOPSIS : AN LTT WAS NEARLY UPSET BY THE WAKE TURB OF AN LGT IN THE NIGHT TFC PATTERN.
REFERENCE FACILITY ID : DFW
FACILITY STATE : TX
DISTANCE & BEARING FROM REF. : 4,,SO
MSL ALTITUDE : 3000,3000

ACCESSION NO. : 261809
DATE OF OCCURRENCE : 9401
REPORTED BY : FLC
PERSONS FUNCTIONS : FLC,PIC.CAPT; FLC,FO; TWR,SUPVR;
FLIGHT CONDITIONS : IMC
REFERENCE FACILITY ID : DCA
FACILITY STATE : DC
FACILITY TYPE : TWR
FACILITY IDENTIFIER : DCA
AIRCRAFT TYPE : MDT, B757 OR A320
ANOMALY DESCRIPTIONS : LOSS OF ACFT CONTROL
ANOMALY DETECTOR : COCKPIT/FLC
ANOMALY RESOLUTION : FLC REGAINED ACFT CONTROL
ANOMALY CONSEQUENCES : NONE
NARRATIVE : AFTER AN OTHERWISE NORMAL ILS APCH, WE[*MDT*] EXPERIENCED RATHER SEVERE WAKE TURB AT APPROX 100 FT AGL. FULL AILERON DEFLECTION WAS NECESSARY TO CORRECT FOR THE ROLL AND GAR MANEUVER, [WHICH] WAS IMMEDIATELY EXECUTED. THE PRECEDING ACFT (TYPE UNKNOWN) WAS WELL CLR OF THE RWY AND THE APCH SPACING SEEMED ADEQUATE, BASED UPON TCAS II INDICATIONS. THE WX AT THE TIME WAS 400 FT CEILING, 2 MI VISIBILITY AND CALM WINDS. I SUBSEQUENTLY BECAME AWARE OF OTHER RPTS, AND EVEN ACCIDENTS, CAUSED BY B757 TYPE ACFT. PERHAPS THIS OCCURRENCE SHOULD BE ADDED TO THE LIST. (AFTER SPEAKING WITH THE DCA TWR SUPVR LATER THAT EVENING, HE SAID THAT THERE WAS NO WAY TO DETERMINE THE TYPE OF ACFT THAT WE FOLLOWED FROM AN OP EARLIER THAT DAY. HOWEVER, I DO RECALL SEEING A HVY TYPE ACFT (I.E., B757, A320, ETC.) ON DOWNWIND PRIOR TO STARTING THE APCH.)

[*MDT CLASSIFICATION – 2-ENGINE, TURBOJET, 43K WEIGHT CLASSIFICATION*]
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Appendix I
Risk Analysis of Airplane Pairs

A simplified approach for determining the relative risk of wake vortex upset for various airplane pairs is presented. It is assumed that the airplanes in each pair are separated by the same distance. A risk factor is calculated by dividing the circulation of the leading airplane by the weight of the trailing airplane. The calculated risk factors are then compared.

$$R_F = \frac{\Gamma_F \; leader}{W follower}$$

$$\Gamma_F = \frac{W}{Vb}$$

R_F = risk factor
Γ_F = circulation factor
W = landing weight (lbs)
V = velocity (knots)
b = wing span (ft)

Airplane	**W**	**b**	**V**	Γ_F	R_F **x 1000**
747	564,000	196	140	20.55	0.104[1]
757	198,000	125	140	11.31	0.838
Citation	13,500				

The risk of a wake vortex upset for Citation 3 nm behind a B-757 is 8.05 (0.838/ 0.104) times greater than the risk for a B-757 that is 3 nm behind a B-747.

[1] R_F x 1000 = (20.55/198,000) x 1,000 = 0.104.

*U.S. G.P.O.: 1994-300-644:80022

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APPENDIX

1991 Report of Where We Are Today in Wake Turbulence

4-B

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DOT/FAA/RD-90-29
DOT-VNTSC-FAA-90-6

Research and Development Service
Washington, D.C. 20591

Aircraft Wake Vortices: An Assessment of the Current Situation

J. N. Hallock

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe
National Transportation Systems Center
Cambridge, MA 02142

January 1991

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Federal Aviation Administration

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Technical Report Documentation Page

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16. Abstract

The state of knowledge about aircraft wake vortices in the summer of 1990 is summarized. With the advent of a new FAA wake vortex program, the current situation was assessed by answering five questions: (1) What do we know about wake vortices, (2) what don't we know about wake vortices, (3) what are the requirements and limitations for operational systems to solve the wake vortex problems, (4) where do we go from here, and 5) why do we need to collect more wake vortex data.

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PREFACE

After many years of dormancy, the Aircraft Wake Vortex Program in the United States has been reinstituted. The driving force is that commercial aviation has increased to the point that airports are or are becoming capacity limited. DOT's recent (February 1990) statement of national transportation policy ("Moving America, New Directions, New Opportunities") states that "21 primary airports each now experience more than 20,000 hours of annual flight delays at a yearly cost to airlines and U.S. businesses of at least $5 billion; by 1997, 33 airports are forecast to experience this level of delay."

In June 1981, the author published a Project Memorandum titled "Background Paper, Aircraft Wake Vortex Program," FA186-PM-81-38, which proposed alternative strategies for the wake vortex program based on the then current knowledge of wake vortices and the abortive attempt to introduce a simple vortex advisory system into the air traffic control system. The FAA elected at that time to terminate wake vortex research efforts. With flight delays ever increasing, the FAA has decided once again to establish a program to address wake vortex issues. The advent of the new wake vortex program inspired the preparation of this assessment of the situation. The current document used the 1981 memorandum as a starting point; the material herein is an update of the previous report bringing the reader to the Summer of 1990 by addressing the same four questions:

(1) What do we know about wake vortices?
(2) What don't we know about wake vortices?
(3) What are the requirements and limitations for operational systems to solve the wake vortex problem?
(4) Where do we go from here?

Extensive data was collected in the 1970's, so a natural additional question is:

(5) Why do we need to collect more wake vortex data?

It is the intent of this report to answer these questions by assessing the current state of wake vortex knowledge and the operational issues surrounding potential wake vortex systems.

It is a pleasure to acknowledge the helpful comments from Rick Page, Ed Spitzer, George Greene, Dave Burnham, and especially Robert Machol on various drafts of this assessment report.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 3.0 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)]°F = y°C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeters (mm) = 0.04 inch (in)
1 centimeters (cm) = 0.4 inch (in)
1 meter (m) = 2.2 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectares (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliters (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.06 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5)(y + 32)]°C = x°F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

25, 40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C1310286.

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LIST OF ACRONYMS

AIM	Airman's Information Manual
ALPA	Air Line Pilots Association
ATC	Air Traffic Control
CW	Continuous Wave
DAVSS	Doppler Acoustic Vortex Sensing System
DEN	Denver Stapleton International Airport
DOT	Department of Transportation
FAA	Federal Aviation Administration
FM	Frequency Modulated
GWVSS	Ground-Wind Vortex Sensing System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
JFK	John F. Kennedy International Airport
LAX	Los Angeles International Airport
LDV	Laser Doppler Velocimeter
MAVSS	Monostatic Acoustic Vortex Sensing System
MLS	Microwave Landing System
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
PANS	Procedures for Air Navigation Services
PAVSS	Pulsed Acoustic Vortex Sensing System
RVR	Runway Visual Range
SEA	Seattle-Tacoma International Airport
SFO	San Francisco International Airport
US	United States
VAS	Vortex Advisory System
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VNTSC	John A. Volpe National Transportation Systems Center

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1. INTRODUCTION

The growth of aviation has established a great demand for airport facilities to accommodate increased air traffic not only safely but efficiently. Optimum use of the facilities requires that every possible effort be expended to develop automation capabilities. The Federal Aviation Administration (FAA) is working toward the upgrading of its air traffic control system with the simultaneous goals of maintaining or improving safety, constraining or reducing operating costs, improving performance and productivity, and meeting energy conservation and environmental needs. Aircraft wake vortices represent an obstacle that must be confronted and overcome before many of the potential benefits of system improvements can be realized. Unless the adverse effects of wake vortices can be substantially reduced, air transportation's future growth potential will be seriously restricted.

The airport is the most critical element in the National Airspace System with respect to capacity limitations. Present and predicted demands being placed on airports cannot be met by indiscriminate construction of new runways and airports in the present ecologic, economic, and social environment. Capacity has actually been declining in recent years because of noise restrictions and wake-vortex separation requirements. The capacity loss coupled with increased traffic has resulted in significant increases in delays and delay-related fuel consumption.

The capacity of an airport to accommodate aircraft depends on such factors as the weather, the number and configuration of runways, the mix of aircraft types, and the spacing required between aircraft to ensure that safety is not compromised. Airports can achieve an increase in capacity with such improvements as dual-lane runways, the MLS, an improved beacon system, the automation of the terminal radar vector service, reduced separation between independent parallel runways, and reduced longitudinal separation on takeoff and final approach. The technology exists to develop the landing aids, but until the wake vortex problem has been mitigated, these improvements cannot be used to their full potential. Wake vortices and the associated separations required to avoid an aircraft upset tend to cancel out the potential gains from the major FAA efforts geared to increasing system capacity.

All aircraft generate trailing wake vortices as a direct consequence of the generation of lift. Although the phenomenon of aircraft wake vortices has been known since the beginning of powered flight, the introduction of the wide-bodied jets with their increased weight and hence stronger vortices rekindled the FAA's interest in the phenomenon.

Aircraft are classified for vortex purposes into three groups according to the maximum certificated gross takeoff weight:

Group	Max. Certificated Gross Takeoff Weight, W
Small	$W \leq 12{,}500$ lb
Large	$12{,}500 \text{ lb} < W < 300{,}000$ lb
Heavy	$300{,}000 \text{ lb} \leq W$

Before 1970, landing aircraft were required to maintain at least 3-nautical-mile separations under IFR conditions. The separation standard was based primarily on radar-operating limits and, to a lesser extent, on runway-occupancy limitations. There were no separation requirements imposed because of vortex considerations. With the introduction of the wide-body jets, the wake-vortex hazard potential increased significantly. Accordingly, the FAA in March 1970 increased the separation standards behind the Heavy jets. By 1973 the standards had evolved to 4 nautical miles for a following Heavy aircraft and to 5 nautical miles for a following non-Heavy aircraft. The international community followed the FAA lead and formally adopted the increased separations behind Heavy jets in 1978 with the approval of Amendment 10 to the ICAO Procedures for Navigation Services — Rules of the Air and Air Traffic Services (PANS-RAC, Document 4444). The U.S. standards were revised in November 1975 by requiring the addition of an extra nautical-mile separation at runway threshold for following Small aircraft. These increased separations obviously lead to additional delays and a decrease in the capacity and efficiency of the airport system, but the separations were imposed to preclude a hazardous vortex encounter. Recently, Air Traffic has permitted separations to be reduced to 2.5 nautical miles inside the final approach fix when the leading aircraft's weight group is the same or less than that of the trailing aircraft (e.g., a Large following a Large or Small), but there are a number of restrictions that must be met (e.g., Heavy aircraft and the B-757 are permitted to participate in the separation reduction as the trailing aircraft only).

The factor that now dominates the minimum allowable in-trail spacing between aircraft during landings and takeoffs is the hazard caused by the wake vortices shed by aircraft. These vortex wakes of aircraft persist long enough to force following aircraft to delay their arrival until the vortex wakes shed by previous aircraft have either descended below or been blown out of the flight corridor or have decayed to harmless levels. The current minimum separation distances are:

	Wake-generating aircraft		
Following aircraft	Small	Large	Heavy
Small	3 n.mi.	4 n.mi.	6 n.mi.
Large	3 n.mi.	3 n.mi.	5 n.mi.
Heavy	3 n.mi.	3 n.mi.	4 n.mi.

and are based primarily on observations of the lifetime and motion of wake vortices at airports.

Two major approaches have been pursued in the effort to reduce or eliminate the impediment on air traffic flow caused by wake vortices. One approach is to modify the generating aircraft so as to break up the vortices or alter their characteristics and thereby to decrease the potential hazard caused by them. The FAA has supported NASA in their efforts to disperse the vortex and accelerate its decay by modifications to the vortex-generating aircraft. The second approach is to develop a system which will predict and/or detect the presence of a vortex from a leading aircraft and thereby determine the minimum safe (vortexwise) separation for a following aircraft. In concept, the system will ensure that aircraft will avoid inadvertent encounters with hazardous vortices by tailoring aircraft spacings to be commensurate with the vortex hazard. The FAA has pursued this latter approach with the assistance of the John A. Volpe National Transportation Systems Center (VNTSC).

The wake vortex problem is complex because of the large number of variables. Setting aside the various operational scenarios, the problem involves the parameters introduced by the vortex-generating aircraft, by the vortex-encountering aircraft, and by the intervening atmosphere. The vortex is initially characterized by the parameters of the vortex-generating aircraft (weight, wingspan, speed, flap and spoiler settings, proximity to the ground, engine thrust, lift distribution, etc.). The encounter (safe or hazardous) is characterized by the parameters of the following aircraft (speed, wingspan, roll control authority, phase of flight, etc.). The meteorology (wind, crosswind, atmospheric stability, turbulence, etc.) plays a leading role in determining how long a vortex remains hazardous.

Much has been learned about aircraft wake vortices. During the 1970's, NASA conducted many tests of vortex alleviation techniques using wind tunnels and water channels and full-scale flight tests. The vortices from over 70,000 landing aircraft operations have been measured and analyzed with respect to the attendant meteorological conditions by VNTSC under the aegis of the FAA. During the 1980's, there was comparatively little aircraft wake-vortex research in the US. NASA's low-level program emphasized understanding the oftentimes perplexing alleviation test data and the development of vortex behavior models. The FAA's low-level program addressed helicopter vortices and further analysis of the 1970's data, but little was published due to fiscal constraints.

The purpose of this report is to address briefly five questions:

(1) What do we know about wake vortices?
(2) What don't we know about wake vortices?
(3) What are the operational requirements and limitations for systems to solve the wake vortex problem?
(4) Where do we go from here?
(5) Why do we need to collect more wake vortex data?

This report was prompted by the resurgence of the wake vortex program in the FAA. But, one must learn from history – there were a number of problems and constraints uncovered when operational implementation of a simple vortex avoidance system (the Vortex Advisory System) was attempted at Chicago O'Hare. Many of these problems and constraints will be confronted when any system is proposed for use in the air traffic control system. The report will also review our state of knowledge about wake vortex behavior as a guide to future data collection. (A detailed review of aircraft wake vortex knowledge is underway; it will be an update of the 1977 state-of-the-art review (Ref. 26).)

Sections 2, 3, and 4 address the present knowledge about vortex behavior; Section 5 examines the gaps in this knowledge; Sections 6 and 7 describe the various systems that have been considered and some of the problems faced; and Section 8 addresses various alternative paths that the vortex program could follow. Section 9 presents a recommended path for a wake-vortex program. This assessment report is a first step in developing an agency-integrated aircraft wake-vortex program.

2. HISTORICAL DEVELOPMENT OF VORTEX PROGRAM

The purpose of this section is to put the vortex program into its proper perspective. Beginning in 1970 the vortex problem was one of safety — what can one do to prevent a hazardous encounter? Flight tests by NASA and the FAA at altitude (Refs. 1 through 8) found significant vortex-imposed rolling motions 10 nautical miles behind Heavy jets. Does the vortex hazard persist for such distances when the aircraft are near the ground during approach, landing, and departure operations? In May 1972 a DC-9 crashed on final approach at Greater Southwest Airport; the cause was an encounter with a vortex from a DC-10 doing touch-and-goes, two nautical miles ahead of the DC-9 (Ref. 9). Most of the vortex-caused accidents occurred on final approach (Ref. 10), so the early effort was devoted to learning about the vortex phenomenon during landing operations; but first the tools for such work had to be developed. In early 1973 the FAA Air Traffic Service requested that the separation standards be reviewed, as the British had promulgated standards that included a 10-nautical-mile separation for a Small behind a Heavy. By late 1973 enough data were collected to demonstrate that the ATC separation standards for landing commercial airliners were indeed adequate for preventing hazardous vortex encounters. In 1975, at the instigation of the FAA Systems Engineering and Development Service, the landing separation standards were revised for Small following aircraft based on analysis of the vortex data (the addition of an extra nautical-mile separation at runway threshold). About this same time, the emphasis of the program shifted from safety to increasing capacity (without jeopardizing safety) as part of the Upgraded Third Generation Air Traffic Control System.

Of the approximately 68,000 aviation accidents that occurred in the United States during the 15-year period 1964-1978, wake vortices were cited by the NTSB as a cause or factor in 225 accidents. There were 116 landing accidents (26 fatal), 50 takeoff accidents (6 fatal), and 59 inflight accidents (6 fatal). Eliminating the 46 inflight cropduster accidents, an average of 12 accidents per year were listed as vortex related. Approximately two-thirds (116) of the accidents occurred while the victim aircraft was landing, and three-quarters (89) of these accidents occurred with the victim aircraft following another landing aircraft to the same runway. Most of the latter accidents occurred when the victim aircraft was between the middle marker and touchdown. The accident aircraft vary in size from a DC-8 (serious injuries behind an L-1011 descending through the same altitude) and a DC-9 (fatal, following a DC-10 doing touch-and-goes on the same runway, Greater Southwest Airport) to the Cessna 150s. General aviation aircraft weighing less than 12,500 pounds have been the primary victims of the vortex problem. Since the separation standards were increased for following Small aircraft in November 1975, the number of vortex-caused accidents has decreased.

The pre-1970 theories describing aircraft wake vortex characteristics were very simplistic. It was generally understood 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; and (3) the vortex motion was substantially affected by the ambient wind. However, the lack of field testing prior to 1970, especially of vortices near the ground, precluded an indepth understanding of vortex behavior, particularly decay. Some tests were conducted with a probe aircraft at relatively high altitudes and with aircraft flying past instrumented towers. However, these early tests were limited in scope and did not look at vortices from aircraft in an actual operational environment.

The first years of the wake vortex program at VNTSC saw the development of several sensor systems capable of detecting and tracking vortices near the ground (Refs. 11 through 18). This region was selected for study since this is the area where a vortex could stall in the approach path and thus pose a hazard to a following aircraft with little room to maneuver or recover. It was also the area in which most of the vortex-caused accidents occurred. Various sensing techniques were investigated, including acoustic (Refs. 11 through 12, 19 and 20), electromagnetic (Ref. 11), passive ground-wind measurements (Refs. 11 through 13), pressure (Refs. 12 and 21), and laser Doppler (Refs. 22 through 24). An extensive series of tests was performed in 1972 to test and calibrate the most promising sensors (Refs. 12 and 25).

The large-scale data collection phase of the program began with the installation of several sensor systems at the John F. Kennedy International Airport (JFK) in June 1973 to measure vortices from landing aircraft (Refs. 13 and 25 through 28). Additional newly developed sensors were also tested at JFK (Refs. 22, 29 and 30); the site was closed in January 1977. Other data collection sites were established at Stapleton International Airport (August through November 1973; Refs. 26 through 28), Heathrow International Airport (May 1974 through June 1975; Refs. 26 and 31 through 34), and O'Hare International Airport (July 1976 to August 1981; landing data collection terminated in September 1977; Refs. 26 and 35 through 37). A combined total of over 70,000 runs were obtained from these test sites; these runs examined the behavior of vortices from landing aircraft between the middle marker and the runway threshold. A test site was operated at Toronto International Airport between August 1976 and August 1977 for the study of vortices shed by departing aircraft (Ref. 38). Over 5000 runs were obtained. To expand the data base on takeoff vortices, a site was established at O'Hare and data collection commenced in December 1979. Over 15,000 runs were recorded, and the site was closed in November 1980.

Extensive analysis of thc landing data led to the concept of the Vortex Advisory System (VAS). The current landing separations were shown to be safe as they are oftentimes very conservative. Thus, opportunities exist to regain capacity by compressing the standards during those times when vortices do not pose a threat to a following aircraft. The VAS (Refs. 26 and 35 through 42) used measurements of the ambient winds in the middle marker region to indicate when vortices had either moved away from the approach path of a following aircraft or had dissipated to an innocuous level.

A demonstration VAS was designed, developed, and in 1977 was installed at O'Hare (Ref. 43 and 44). A detailed safety analysis was completed and published (Refs. 45 through 47), and a measurement program completed verifying the analytical model of the VAS which permits VAS utilization from the outer marker to touchdown (Ref. 35). When operational implementation of the VAS was attempted, problems and constraints were encountered. The problems were primarily procedural in nature. The imposed constraints never surfaced in the numerous interactions with the user community (e.g., Ref. 46) until the commencement of operational implementation. The VAS problems and constraints are discussed in Section 7. A reassessment of the direction of the vortex program is needed in light of the problems and constraints, as most of them will pertain to any solution to the vortex problem.

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3. VORTEX SENSORS

A number of different sensing systems have been developed for detecting and measuring wake vortices. This section will describe the ground-based sensors which were developed primarily as research tools for collecting vortex behavior data, and discuss airborne and ground-based sensors as they pertain to operational systems.

3.1 GROUND-BASED DATA COLLECTION SENSORS

The first measurements of wake vortex velocity profiles made use of towers instrumented with hot-wire anemometers (Refs. 48 through 52). Dedicated aircraft flew at low altitude past the tower on the up-wind side. Vortex decay was studied by varying the lateral offset of the aircraft and hence the age at which the vortex drifts through the tower. The instrumented-tower measurements suffered from sensitivity to the ambient wind and the effects of the tower on the wake; the technique also permitted only one measurement of a vortex for each aircraft passage.

Because of the impracticality of using dedicated flight tests to amass statistics on vortex transport and decay, subsequent data collection made use of remote sensors which could be deployed at airports during normal operations. The first sensors (Ground-Wind Vortex Sensing System (GWVSS), Pulsed Acoustic Vortex Sensing System, and an early version of the Laser Doppler Velocimeter (LDV)) could measure vortex position but not strength. The next generation of sensors (Monostatic Acoustic Vortex Sensing System (MAVSS) and Doppler Acoustic Vortex Sensing System (DAVSS)) could also measure strength. Eventually, techniques for deriving vortex strength from data collected by the LDV and GWVSS were developed.

The GWVSS consisted of an array of single-axis anemometers located on a baseline perpendicular to the flight path (Refs. 18, 26, and 53). They detect the presence of a wake vortex by the wind induced by the vortex near ground level. The positions of the most positive and most negative peaks in the crosswind velocity component give an accurate indication of the lateral positions of the two counterrotating vortices.

The success of the GWVSS in tracking wake vortices stems from the induced motion of a vortex pair. After generation, the vortices descend toward the ground. When they approach the ground, they separate (assuming no crosswind) and level off at a height equal to about one-half their initial spacing (initial spacing is about three-quarters of the wingspan). The GWVSS detection threshold for vortices at their equilibrium height and in light and relatively nonturbulent winds appears to be well below the hazard threshold; thus, any system based on GWVSS tracking is inherently conservative. However, vortices can rebound above the equilibrium height; the accuracy of the GWVSS in this situation (particularly when the winds are moderate to strong and turbulent) is in question. A technique was demonstrated for automatic tracking and for extracting vortex strength from GWVSS data (Ref. 53). Although only partially successful, such a technique could greatly extend the usefulness of the GWVSS.

The PAVSS detects the acoustic signal refracted by a vortex core (Refs. 18 through 20, 26, 29, and 54 through 56). Although the PAVSS gave accurate measurements of vortex height, the system was abandoned because it could not detect diffuse vortices from some aircraft types (B-707s and DC-8s) and because it gave no reliable information on strength or decay.

The LDV probes the atmosphere with a beam that can be scanned in range and angle (Refs. 18, 22 through 24, and 26). The radiation which is backscattered from aerosol particles in the focal region is spectrally analyzed to yield the velocity component along the beam. The LDV gives excellent angle resolution but poor range resolution. The original scan mode of the LDV could track vortices reasonably well, but gave only a vague indication of strength. After a new scan mode and a new data-processing procedure were developed (Refs. 18, 35, and 57), the LDV produced excellent vortex velocity profiles from which vortex strength can be calculated. The LDV produces its best measurements on vortices located about 600 feet overhead. Measurements on vortices at low elevation angles suffer from sensitivity to the ambient wind and mixing of the signals from the two vortices. The LDV is the only sensor currently used that can continuously track and measure a vortex until it decays.

The MAVSS consists of a vertically pointing acoustic beam in which pulses of acoustic energy are backscattered from temperature fluctuations in the atmosphere (Refs. 18, 26, 36, 58, and 59). Spectral analysis of the returns yields a vertical profile of the vertical velocity in the atmosphere. Since the ambient wind is horizontal near the ground, the MAVSS measurements of vortex velocities are not affected by the wind. The tangential velocity profile of the vortex is measured as the vortex drifts through an array of vertical beams. The MAVSS is operated with a range of 200 to 300 feet, and averages the velocity over a volume about 10 feet high and 6 feet in diameter. The MAVSS gives good measurements of the strength of moving vortices, but is much less useful for stalled vortices (a dense array of MAVSS units would be needed to deal with stalled vortices).

The DAVSS features a receiving antenna with multiple receiver beams in the form of a fan (Refs. 18, 26, 30, and 60). A variety of transmitter configurations using CW or pulsed signals was tested. The most useful configuration was a pulsed monostatic configuration (much like the MAVSS) with all antennas located near the runway centerline. This configuration showed promise for measuring stalled vortices, but was abandoned because of software problems and the cumbersome nature of the hardware.

3.2 OPERATIONAL AIRBORNE AND GROUND-BASED VORTEX SENSOR SYSTEMS

Potential airborne and ground-based sensors can be divided into three categories: a) remote sensors which measure velocity, b) remote sensors which detect some tracer in the wake which will dissipate when the vortices are no longer a hazard, and c) sensors which detect the proximity of some feature of the wake. The sensors which depend upon some tracer in the wake (such as infrared sensing of heat, ultraviolet sensing of nitric oxides, or radar sensing of refractive index fluctuations) are unlikely to be very useful because of the difficulties in relating hazard to sensor signatures. The local proximity sensors have similar problems as well as the problem of insufficient warning time. The proven velocity sensors (LDV and Doppler radar) are not practical for airborne applications because they measure the velocity component along the line of sight, whereas hazardous vortex velocities are transverse to the line of sight. However, novel techniques for measuring transverse velocities offer some promise.

Of all the ground-based velocity-measuring sensors developed to date, at this time only the GWVSS represents a sensor which would be useful as an operational vortex sensor. Reliable rapid processing could be based on available algorithms (Ref. 53). The system is simple, inexpensive, and easily installed everywhere except over the actual runway surface. The GWVSS is useful, however, only when the vortices are less than about 200 feet above the ground (between runway threshold and about a half mile from the threshold). The acoustic systems suffer from noise, rain, and snow problems and are far from having reliable real-time processing. The LDV has not yet been engineered for unattended operation, requires substantial human intervention in the data processing, and has limited utility in conditions with low ceilings or poor visibility.

Doppler radars can detect wake vortices if looking at them from the side. FM-CW monstatic radars (Refs. 61 and 62) and certain bistatic radars have shown promise. The observed signatures, however, are yet to be understood. The range capabilities of these sensors make them candidates for studying vortices at the outer marker and perhaps beyond. It may be possible to track both vortices off an incoming aircraft.

Sensor-based vortex avoidance systems rely to some extent on predicting vortex behavior rather than solely on direct measurement of wake vortices themselves. The lead time required to set up aircraft spacing on final approach requires prediction of vortex behavior; real-time measurements of the vortices from the preceding aircraft are not sufficient to ensure efficient traffic flow. To demonstrate that prediction is an inherent part of any system, consider the case of an ideal situation. Suppose that vortices somehow were visible until they no longer posed a hazard. A pilot could use this real-time vortex-tracking information to safely guide his aircraft only by predicting where the vortices will be when his aircraft reaches various positions ahead. The essential point is that, prediction is a component of any system used to avoid a hazardous condition (be it wake vortices or wind shear, downbursts, ground proximity, mid-air collisions, etc.). Either the pilot uses data to make a prediction directly or a sensor system assimilates data and predicts a potential hazardous condition and passes this information to the pilot for action.

4. STATUS OF CURRENT KNOWLEDGE OF VORTEX BEHAVIOR

Any finite lifting wing must leave behind it two counter-rotating trailing vortices, the direction of rotation being such that between these vortices the air moves downwards while outside of them the induced flow is upwards. Very simplistically, these vortices are formed because the pressure of the air above the wing is less than that of the air beneath the wing (hence the lift) and there is a tendency for the air to flow around the wingtip; air below the wing, as it streams backward moves outward, then upward past the wingtip, and finally inward when it gets above the wing. This motion sets up a swirl in the air and generates a vortex just inboard of each wingtip.

The wake vortex originates in the vorticity shed from the generating wing. The vorticity can be resolved into streamwise (oriented with the flight direction) and cross-stream (aligned perpendicular to the flight path) components (Ref. 26). The streamwise portion is the manifestation of the lift on the wing and forms the trailing vortices. The cross-stream component is associated with the viscous profile drag of the wing and represents the wake momentum deficit associated with the profile drag. This component causes an axial velocity to be imposed upon the vortex, and thereby contributes to vortex decay.

The generation and decay of the wake vortex system occurs in stages (Refs. 26 and 63). For simplicity, first consider the simplest case of a clean wing with no areas of abrupt change in lift or drag. The wing vorticity (both streamwise and cross-streamwise) is first shed in an approximately flat sheet of width roughly corresponding to the wing span. The sheet commences to form a self-induced scroll-like shape (Ref. 64). The rollup process continues until most of the wing vorticity is concentrated in two approximately circular vortex cores. Various interactions may occur in or between these cores creating instabilities which can cause the wake to break up rapidly. If catastrophic instabilities do not occur, final regular decay takes place. Here, under the influence of both atmospheric and aircraft-induced turbulence, theoretical considerations indicate that the cores expand to fill an approximately elliptical region of vorticity (Ref. 63). This simple picture of vortex decay has been used for many years; however, it is now in serious question as detailed measurements (Ref. 111) demonstrate that the vortices decay from the outside inward.

If the wing contains significant regions of concentrated streamwise or cross-stream perturbations (due to control surfaces, flaps, spoilers, landing gear, etc.), there may be more than one vortex pair, and the various stages may develop with different time scales compared to the clean-wing case. The various vortices interact and eventually combine into a single pair (sometimes into two pair as for the Concorde when flying subsonically). The different stages may be delayed or accelerated. This situation occurs for aircraft in the landing or takeoff configurations. There, strong disturbance effects occur induced by flaps, jet engine thrust, and landing gear (Ref. 65).

This section briefly summarizes the current knowledge of the behavior of wake vortices. Much has been learned about vortex behavior, but there is yet much to be learned. Aerodynamics dominates the rollup process, but the ambient atmosphere (wind, stability, turbulence, etc.) eventually dictates how the vortices behave. Vortex motion and decay are stochastic processes; i.e., the vagaries of the atmosphere and slight changes in aircraft characteristics can lead to different vortex behavior even though it seems that all the conditions are the same. Stochastic processes require extensive data collection to determine the envelope of behavior.

4.1 VELOCITY FLOW FIELD

The general flow field of a viscous vortex is a swirling flow having approximately circular streamlines. The tangential velocity along these streamlines varies from zero at the center to some maximum which may be as great as 50 percent of the flight speed, and then decreases approximately inversely with increase in radius (Ref. 26). The core radius is usually defined as the distance from the center at which the maximum tangential velocity occurs. Some vortices were found to have small cores and high tangential velocities; some had large cores and attendant lower velocities. Quantitative data on vortex flow fields were obtained in the early 1970's by FAA's National Aviation Facilities Experimental Center using an instrumented 140-foot tower and flying various aircraft upwind of the tower. Data were collected on B-707, B-727, B-747, DC-7, DC-8, DC-10, CV-880, L-1011, C-141, and C-5A aircraft (Refs. 48 through 52, and 66 through 73). Based on this extensive data, vortex flow field models were developed. Given the lift distribution on an aircraft wing, the expected flow fields can be calculated. Once the tangential velocity profile of a vortex is known, other useful characteristics of the vortex can be calculated such as the circulation profile and the average circulation up to a particular radius, which can be used in defining the vortex hazard.

4.2 LATERAL MOTION

The horizontal motion of vortices is dictated by the ambient wind. At altitude, the wind is the only influence; near the ground, the ground also has an influence. The lateral motion of vortices is dominated by the crosswind component of the ambient wind; at relatively high altitudes, the speed of the vortex lateral movement is equal to the crosswind. With no other external influence, these vortices would continue to move at this speed until they completely decayed. However, as the vortex pair descends to the proximity of the ground, the lateral motion is strongly affected by the boundary to a degree which is at least as important as the crosswind. With very calm winds (0 to 1 knots), the two vortices have a tendency to move in opposite directions away from the extended runway centerline with speeds of approximately 2 to 4 knots. At higher crosswinds (greater than 7 knots), both vortices move in the direction of the crosswind with the downwind vortex transporting at a speed slightly higher than the crosswind and the upwind vortex transporting at a speed slightly less than the crosswind. It is the region in between these values (3 to 5 knots) where the lateral motion of the upwind vortex becomes difficult to predict. The downwind vortex moves away from the extended centerline with a slight increase in speed, but the upwind vortex may either very slowly transport away or may stall near the runway centerline. If a vortex stalls near the centerline, the potential for a hazardous situation exists. The vortex motion in the latter case depends on many factors such as the generating aircraft type, vortex height above the ground, variability in the winds, etc.

The extensive data-collection tests at airports showed how vortices move as a function of wind near the ground. These tests led to a wind criterion that could indicate when the wind conditions were such that a vortex could not pose a threat to a following landing aircraft. Vortices were found to move laterally at least 1500 feet under certain conditions, but with seemingly weak strengths at the larger lateral distances. Recent measurements by the Germans at Frankfurt International Airport (Ref. 113) found B-747 vortices that moved laterally 1700 feet and still retained some strength. Motions of vortices were found to be affected by wind gradients and even "bounce" (i.e., descend toward the ground and later begin to rise up somewhat) at times.

4.3 VERTICAL MOTION

The initial descent rate of vortices seems to be adequately described by classical analysis; the rate is proportional to the weight of the aircraft and inversely proportional to the flight speed and to the square of the wingspan. Generally, vortices descend at the initial rate (about 4 knots for a DC-10) for about 30 seconds, and then the rate decreases and finally approaches zero (Ref. 74). The reduction in the descent rate is caused by entrainment of the outer flow into the top of the vortex cell along with a shedding of the cell vorticity in the wake, removing both vorticity and momentum from the cell (Ref. 63). Near the ground, the presence of the ground arrests the descent and the vortices level off at a height of approximatcly onc-half their initial separation.

Descent trajectories have been measured during various atmospheric conditions (Ref. 74). In stable atmospheres, the range of initial descent speeds are within 25 percent of the classical or theoretical rate. Slowing down occurs after about 30 seconds, with descent speeds at 60 seconds typically one-half to three-quarters of the initial values. Wakes in a neutrally stable atmosphere show a fairly rapid descent, with initial speeds often exceeding the theoretical rate. Wakes can rise in unstable atmospheres, probably because they are being carried upward by the considerable vertical currents which accompany instability. The high turbulence which naturally occurs in such an unstable atmosphere usually results in very brief lives for these wakes, however.

4.4 DECAY PROCESSES

After rollup is complete, the wake from high-aspect-ratio aircraft can be accurately described as a pair of coherent axially symmetric line vortices. These vortices ultimately decay into random turbulence through a variety of decay processes which depend upon atmospheric conditions. The basic vortex pair is subject to two types of instabilities: the sinuous or Crow instability (Refs. 63, 75 and 76) and core bursting (Refs. 77 through 79). The sinuous instability causes the spacing between the vortices to become modulated with a spatial wavelength of about eight times the wingspan (Ref. 75). Eventually, the cores of the two vortices link to form highly convoluted vortex rings. Core bursting is a poorly understood process where the vortex core suddenly expands. A burst is observed to travel axially along the core of a smoke-marked vortex. Even through a burst may disperse the smoke marking a vortex, it does not necessarily destroy the coherent circulation of the vortex. For weak turbulence with a large integral scale compared to the separation of the vortices, vortex linking is the dominant mode of vortex instability. However, as the turbulence intensity increases, vortex bursting begins to appear and eventually replaces linking as the dominant mode of instability (Ref. 114). Whether or not these instabilities occur, the final decay of the vortex into random turbulence is produced by turbulent diffusion effects (viscous decay is a much slower process). Vortex decay data often show a laminar vortex core which persists while the surrounding vorticity is dissipated by turbulent diffusion (e.g., Ref. 80).

Atmospheric effects play an important role in driving vortex decay processes. Atmospheric turbulence enhances vortex decay when it is stronger than the intrinsic turbulence of the vortex. The sinuous instability is particularly sensitive to ambient turbulence. There is considerable evidence that a very stable atmosphere (i.e., a temperature inversion) enhances vortex decay; vorticity and turbulence generated on the periphery of the vortex may be responsible (Ref. 80).

The airport tests and dedicated flight tests in cooperation with NASA led to the development of vortex decay models. It was found that many processes were taking place often at the same time (Crow linking, bursting, viscous decay, and "scrubbing" with the ground). Vortices were found usually to decay from the outside inward (Ref. 111), not from the core outward as most fluid-mechanic theories predict; thus, the picture of vortex decay is changing.

4.5 SAFETY CORRIDOR

Analysis of the data from thousands of vortex tracks necessitated that a reference zone be defined in which the mere presence of a vortex could be interpreted as a possible hazard to a following aircraft. The boundaries of this corridor were defined using two considerations. First, it was determined from photographic data recorded at Denver's Stapleton International Airport in 1973 that over 99 percent of landing aircraft in VMC are within 50 feet of the extended runway centerline in the region from middle marker to touchdown (Ref. 27). Second, simulations showed that if a vortex center was farther than 100 feet from the fuselage of the vortex-encountering aircraft, there would be no excessive disturbance to the aircraft (Refs. 81 and 82). Thus, a safety corridor was defined which extended 150 feet to either side of the extended centerline, was indefinite in height, and extended from the middle marker region to touchdown.

A vortex has the highest potential of becoming a hazard to a following aircraft when the ambient crosswind causes the upwind vortex to stall in the safety corridor for times approaching the interaircraft spacing with a height close to the aircraft flight path. It was determined in early tests (Ref. 27) that the vortices from aircraft at heights below about 50 feet tend to decay fairly rapidly, probably due to the rapid interaction of the newly forming vortex with the ground and incomplete rollup. The vortices from aircraft at heights greater than approximately 200 feet have only a small chance of becoming a hazard since they descend out of the flight path. It is the region in between where the stalled vortex can become a problem, and therefore most of the data were collected with sensor lines installed at a distance from runway threshold (typically 1500 feet) where the normal aircraft height would be in the range of 80 to 140 feet.

The vortex data were examined to determine the probability of finding a vortex stalled in the safety corridor. A time of 80 seconds was chosen as a reference as this translates to approximately a 3-nautical-mile spacing for typical aircraft approach speeds (135 knots). It was found that only 5 to 10 percent of the vortices from Heavy aircraft remained in the safety corridor for longer than 80 seconds (Refs. 26, 32, 37, and 83); thus 3-nautical-mile separations could theoretically be used most of the time. It must be pointed out that vortices observed remaining in the corridor may not represent a hazard since most of this data was obtained with the GWVSS, which yields no indication of vortex strength; detection of a vortex with this system does not necessarily imply a hazardous condition.

4.6 INFLUENCES OTHER THAN WIND

Tilting or banking of the vortex pair has been observed both at altitude and in ground effect. In tests with light aircraft (Refs. 74, 77, and 84), long segments of the wake were observed occasionally to roll past the vertical. It appears that asymmetries in the initial rollup and crosswind shear and/or the rate of dissipation of the background turbulence are responsible for this rolling tendency of vortex pairs (Refs. 74, 85, and 108). When the wake tilts in ground effect, the upper (generally downwind) vortex appears to break up well ahead of the other vortex, often leaving one vortex drifting alone for some time before it decays.

Vortex buoyancy (Refs. 26 and 63) is the aerostatic force imposed on the vortex by virtue of the difference in density between the air contained within the vortex and the surrounding ambient air. The sources of the density difference are static underpressure of the vortex, entrainment of hot exhaust gases from the engines, and descent through a nonadiabatic atmosphere. Overall, the effects of aerostatic forces on vertical wake motions may be of the same order as the dissipative mechanisms associated with turbulence.

The predominant effect of atmospheric stability (Refs. 26 and 84) appears to be the indirect one associated with the vertical air currents resulting from atmospheric mixing. In a stable atmosphere, this mixing is suppressed, resulting in reduced vertical air motions and reduced effects on vertical wake motions. In unstable conditions, vertical atmospheric activity and resulting wake motions are amplified and vortices decay rapidly, as discussed in Section 4.3. Under a strong inversion or a super stable atmosphere, vortices decay quickly. In neutral stability, the stability apparently kills the turbulence.

Near the ground, wake motions do not exhibit such extreme behavior. Under stable conditions and reduced thermal activity, the vortex pair undergoes more orderly motions, which are fairly well understood and can be approximated analytically (Refs. 26 and 109). These conditions are also the ones of greatest operational interest because these same factors are conducive to wake persistence and thus could pose a threat to an aircraft.

4.7 STRENGTH AND DECAY

A large MAVSS data base on the decay of vortex strength has been collected at O'Hare International Airport for landing aircraft (Ref. 36). One useful method of analyzing the data yields the probability of the vortex strength remaining above a hazard threshold as a function of vortex age. As one would expect, the hazard probabilities decay more slowly as the hazard threshold is decreased. In other words, the weaker a vortex needs to be to be still considered a hazard, the longer one needs to wait before the vortex decays sufficiently to be considered benign. The probability is observed to decay exponentially with the square of the vortex age. This rapid decay accounts for the observed safety of the IFR and vortex separation standards.

The MAVSS vortex decay data were disaggregated to determine the dependence of vortex decay on crosswind, wind speed, and other meteorological parameters. The most important factor is the crosswind. The downwind vortex decays more quickly than the upwind vortex. The latter is also the one which tends to stall near the extended runway centerline. Vortex decay is speeded up by higher ambient winds, presumably because of increased turbulence. The differences in the decay of vortices from landing Heavy and Large B-707s and DC-8s were examined and found to be minimal (Ref. 110), probably indicating that the actual weight of the vortex-generating aircraft is more important than the gross certificated takeoff weight.

4.8 VORTEX ENCOUNTERS

Wake vortex encounters have been studied by both aircraft probes (intentionally flying into a smoke-marked vortex; Refs. 1 through 8, 86, and 87) and by simulations (Refs. 26, 81, 82, and 88 through 93). The dominant vortex hazard appears to be the rolling moment induced on a directly following aircraft wing by the vortex motion. Vortex-induced deviations in roll attitude of greater than 10 degrees were found in simulations by NASA to be unacceptable near the ground (Refs. 92 and 94), although much more severe rolls have been encountered, and survived, at altitude. Computer simulations showed that a wake vortex causes no problems to an aircraft more than 100 feet away from the vortex axis (Refs. 26, 81, and 82). Complete six-degree-of-freedom simulations, as well as aircraft probes, show that the vortex tends to repel an encountering aircraft from a direct penetration of the vortex core. However, the pilot's response during an inadvertent vortex core encounter often exacerbates the effect of the vortex because the induced roll at the edge of the vortex is opposite in direction to that at the center of the vortex.

Because of the complexities of a vortex encounter, a simple parameter, the ratio of the maximum induced rolling moment to the maximum roll control authority of the aircraft, has generally been used to characterize the wake-vortex hazard (Refs. 45, 111, and 112). Flight-test pilots reported no problem flying at altitude in smoke-marked vortices with induced moments less than 50 percent of the roll control. An analysis of current separation standards in conjunction with preliminary vortex decay data led to a hazard threshold on induced roll of 40 percent of the roll control (Ref. 45). The analysis of wake vortex velocity profiles to yield vortex hazard has made use of a simple parameter: the average circulation over the wingspan of the encountering aircraft (Refs. 36 and 45). Calculations of induced rolling moments have shown that this procedure is justified (Ref. 112).

5. GAPS IN OUR KNOWLEDGE

The FAA wake vortex program has emphasized the collection of data on vortex behavior near the ground and the development of a system to reduce interarrival aircraft separations while maintaining or increasing the level of safety. Vortex behavior is a stochastic process, thus data collection projects necessarily must consider many aircraft (both in number and in type) and many meteorological conditions. Because data collection consumes a large portion of program resources, there are several areas of vortex behavior which have either not yet been addressed, or have too little data to permit definitive conclusions.

An often asked question is, why do we need to collect more data when the vortices from over 70,000 landing aircraft were studied in the 1970's? There are four answers to this question. First, vortex sensors had to be developed and tested at an airport. The testing revealed the suitability of the sensors for vortex data collection and pointed out their limitations. Some systems were tested and set aside (PAVSS, DAVSS, pressure, ultraviolet) because of hardware difficulties or because it was found that the sensor responded to a vortex characteristic that could not be directly related to hazard.

Second, much has been learned about how vortices move in the vicinity of a runway, but only limited data have been reported on vortex decay. The primary reason was the inordinate effort required to collect, reduce, and analyze the vortex strength data. New systems planned for airport tests will significantly simplify the data collection, reduction, and analysis.

Third, as noted above, much has been learned about how vortices move in the vicinity of a runway, but only limited data have been collected on time-of-day effects and how far and with what strength vortices can translate. Such information is paramount for setting vortex standards for parallel and intersecting runways.

Fourth, as vortex modeling improved, it was found that new and more complete meteorological data must be collected (turbulence, atmospheric stability, etc.). To verify the models, the vortex behavior data must be collected along with the more complete meteorological data.

The discussion below focuses on areas where more work is needed. The areas include vortex behavior under various meteorological conditions and quantifying the vortex hazard.

5.1 LONG-DISTANCE VORTEX TRANSPORT

The behavior of vortices transporting over long distances is an important consideration in the operation of parallel and intersecting runways. Many airports (LAX, DEN, SFO, SEA, etc.) have parallel runways separated by less than the minimum (2500 feet) now required for operation as independent VFR runways when considering the wake-vortex hazard. A relatively small amount of landing vortex data was collected at the JFK test site with anemometer baselines extending out to 2500 feet. Systems deployed at Toronto International Airport (Ref. 38) and O'Hare International Airport (takeoff vortices) utilized anemometer sensors out to 1600 and 2000 feet, respectively. A preliminary analysis of the landing data indicates that the current separation standard for runway independence may be reduced, and that guidelines can be formulated for the safe operation of closely spaced parallel runways with displaced thresholds. An increase in the size of the data base and further justification through analytic modeling are required before changes to the present operational procedures could be supported. The strength of the vortices that have transported over long distances near the ground must be measured; at O'Hare the strengths of vortices from landing aircraft were measured out to 1000 feet (unpublished), but more data and greater distances must be examined.

5.2 DEPARTURE VORTICES

The virtual assurance that vortices from a landing aircraft will descend out of the path of a following aircraft (at altitudes greater than about 200 feet) can not be assumed on takeoff —first because there is generally a headwind blowing the vortex pair back toward the following aircraft, and second because the lead aircraft may be climbing more steeply than the following aircraft. On the other hand, since both aircraft are less likely to be very close to the runway centerline, an encounter may be less probable.

Tests conducted at Toronto International Airport demonstrated the feasibility of detecting and tracking the vortices of aircraft taking off. However, these tests were limited in the volume and types of aircraft observed. The limited amount of data did show that vortices from departing aircraft appear to decay more slowly and to transport over longer distances than vortices from landing aircraft. A test facility for tracking vortices of departing aircraft was subsequently set up at Chicago's O'Hare International Airport. The strengths of takeoff vortices were measured out to 1300 feet. Two goals of these tests were to provide data to determine the necessity of the presently mandated 2-minute hold behind departing Heavy aircraft, and to develop the departure equivalent of the arrival VAS. The tests were completed in November 1980 and most of the data were analyzed, but the FAA vortex program was terminated before the analysis could be completed and the results published.

5.3 HIGH-ALTITUDE VORTEX BEHAVIOR

Vortex behavior has been studied extensively only in the realm of the planetary boundary layer, particularly when the vortices were in ground effect (less than 200 feet above the ground). This is because the sensors developed to collect vortex behavior data have limited range (about 800 feet). At the higher altitudes the data are sparse or nonexistent. The data consist of approximately 5000 LDV-tracked vortices when the aircraft were about 600 feet above the ground (Ref. 35), and the tracking of smoke-marked vortices during various NASA/FAA flight tests of vortex alleviation techniques (Refs. 86 and 96) and the two-segment approach (Ref. 97). But, such flight tests are usually limited in both quantity and quality of information that can be extracted because of the vagaries of atmospheric conditions. It has been shown (Ref. 109) that the stability of, and turbulence in, the atmosphere are responsible for some of the wide variation in the flight test results.

As noted earlier, vortex behavior is a stochastic process. Limited data can indicate trends in the behavior, but cannot delineate the extremes. The Airman's Information Manual notes that vortices tend to level off about 800 to 900 feet below the generating aircraft's flight path. The distances are known to be related to the atmospheric conditions, but the details have not been quantified. Similarly, the descent rates are known to start out at about 300 to 500 feet per minute, but the details of the slowing down of the descent rate are sketchy; the vertical motion is influenced by buoyancy, turbulence, vortex decay rate, and the continued random action of vertical air currents.

However, knowing vortex behavior in the region between the middle and outer markers and at the vectoring area altitudes can be important. Various traffic merging schemes for more efficient delivery of aircraft to the runway, as well as the multiple approach paths permitted by the MLS, are dependent on and can be affected by vortex motion. Vortices certainly translate with the wind; the descent distances and rates and the decay rates are the unknowns more than 1000 feet above the ground, but it is known that these parameters are directly related to the ambient meteorological conditions. Thus, vortex and meteorological data need to be collected at these higher altitudes (outside the middle marker).

5.4 QUANTITATIVE HAZARD DEFINITION

Our present understanding of the wake vortex hazard is not adequate to assess within a factor of two the strength of a vortex which can be encountered with acceptable consequences. Therefore, an improved understanding of what constitutes a hazard is required to allow the available data on vortex strength to be interpreted in terms of hazard exposure. The acceptable encounter strength depends upon the phase of flight (landing, takeoff, enroute), the type of encountering aircraft, the aircraft altitude, and the mode of piloting (autopilot, visual, instrument, etc.). Such information could be obtained from simulated encounters with real vortices using a full six-degree-of-freedom encounter simulation. Previous simulator work has suffered from poor definition of the final results desired. The desired results of the simulator program would be twofold: 1) the acceptable limits of a vortex encounter under the conditions listed above, and 2) the maximum strength vortex which will not lead to unacceptable encounters.

The use of maximum induced rolling moment as a vortex hazard criterion has not been totally justified. The rolling moment is dominated by the strength of a vortex and is little affected by the velocities in the vortex core. High core velocities may produce different hazards such as a rapid yaw when the rudder penetrates a core, flameout when a vortex is ingested into an engine, or structural damage.

Another way of looking at quantitative hazard definition is the assessment of how the wake-vortex hazard depends upon phase of flight, type of generating aircraft, aircraft parameters (weight, airspeed, etc.), and meteorological parameters (turbulence, stability, etc.). The additional contribution of wingspan, spanload distribution, and engine placement to hazard decay would be particularly useful to understand. The current classification of aircraft considers maximum certificated gross takeoff weight as the sole determinant of wake vortex hazard. Requisite data exist to assess the contributions of the various factors; detailed analyses might lead to a reclassification of aircraft for purposes of wake-vortex separation.

5.5 OTHER AIRCRAFT

As a consequence of deregulation, a rapid growth in the number of commuter/air-taxi aircraft has occurred. These aircraft are typically in the low-weight range of the Large category. Up to now, relatively few of these aircraft have operated into the high-density terminals. With the increase in number, the exposure of these aircraft to operations behind Heavy and especially behind high-weight Large aircraft is increased and could lead to potential vortex-related problems. Because of the extent of the Large category, the highest hazard probability under the current separation standards occurs with a low-weight Large aircraft (barely more than 12,500 pounds maximum certificated takeoff weight) behind a high-weight Large aircraft barely less than 300,000 pounds maximum certificated takeoff weight). The operational implication is a possible reclassification of the low-weight Large commuter/air-taxi aircraft for vortex purposes.

Through ICAO, many countries have adopted the separation criteria used by the FAA. There are a number of Heavy and Large aircraft for which little vortex behavior data exist (A-300, IL-62, Concorde, VC-10, Tridents, F-28, etc). Additionally, there are a number of new aircraft types for which no vortex data exists (B-747-400, B-757, B-767, A-310, A-320, IL-76, AN-225). Although some of these aircraft types are rare in the US, US flag carriers operate behind these aircraft throughout the world and the adequacy of the standards can only be inferred. Originally, Great Britain classified the A-300B as Large for wake vortex separation purposes, but in September 1977 it was moved into the Heavy group (the US has always classified the A-300B as a Heavy). Great Britian is considering moving the B-757 (a Large aircraft) into the Heavy group due to the number of vortex incidents recorded behind the B-757.

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6. VORTEX AVOIDANCE SYSTEMS

To formulate system concepts for wake-vortex avoidance, one begins by defining the system users, the user requirements, and the operational requirements. The users can be divided into three groups: airports, aircraft, and air traffic control. The user interests and needs are diverse. Airports require a decrease in delays with a possible increase in capacity, maintaining or increasing the safety of operations, minimization of system acquisition and operating costs, and site-independent system performance. For aircraft the needs are to maintain or improve safety of operations, operate during all weather conditions, cover all aircraft, have a low/no cost to acquire/use the system, and improve economics of operation. The ATC must maintain or improve safety of operations, optimize the use of airspace and runways (reduce delays), and have no excess demands on controllers or other factors which might interfere with or degrade other ATC functions.

Based on user needs, a wake-vortex avoidance system must meet the following set of requirements: replace fixed separation standards with adaptive separation standards to maximize traffic flow; detect presence (or guaranteed absence) of vortex hazard and generate information necessary to avoid the hazard (or take advantage of its absence); use a modular system design tailoring the system capabilities and cost to an airport's or aircraft's requirements; ensure uniform system performance independent of environmental or site constraints; design system for maximum independence from ATC systems; and minimize burden on air traffic controllers and pilots. A series of vortex avoidance systems of increasing complexity and cost can be envisioned, starting with the present IFR system using conservative and inviolate separation standards. Ground-based systems have been proposed varying from the simple VAS to a fully automated wake-vortex avoidance system. Airborne solutions to the vortex problem have been examined from the standpoint of using onboard sensors for vortex detection and avoidance, and from the goal of alleviating the vortex hazard via modifications to the vortex-generating aircraft.

6.1 SEPARATION STANDARDS

The FAA now operates two vortex-avoidance methodologies, one for VFR operations and one for IFR operations. During VFR operations the pilot assumes the responsibility for maintaining a safe separation. In normal operations, VFR pilots tend to use closer spacings than those mandated for IFR. Under VFR conditions the pilot apparently feels confident in reacting quickly to any problem which may develop, whether it be a problem on the runway or an encounter with a wake vortex. The VFR pilot also employs various vortex-avoidance procedures such as flying above the flight path and landing beyond the touchdown point of a preceding larger aircraft. VFR pilots experience occasional vortex encounters which apparently cause them little concern for safety. The observed safety of VFR operations at reduced separations (compared to IFR requirements) is a consequence of the conservatism of the separation standards, pilot training in vortex avoidance, and the improved pilot response to a limited encounter under VFR conditions.

During IFR operations the air traffic controller is responsible for the safe and expeditious flow of traffic and accomplishes this through the sequencing of traffic and ensuring that the appropriate interaircraft separations are maintained. Thus, an additional margin of safety is maintained by the air traffic controllers during IFR operations (to allow for communication delays and possible inaccuracies in assigning and maintaining radar separations).

6.2 GROUND-BASED VORTEX AVOIDANCE SYSTEMS

The VAS was proposed as a first step in a hierarchy of systems. The VAS indicates to controllers when the separation standards could be reduced to three nautical miles regardless of the leader or follower aircraft type. The concept evolved from the analysis of tens of thousands of vortex tracks and the correlation of vortex behavior with the ambient winds. It was noted that whenever the surface wind exceeded a defined criterion, IFR interarrival spacings could be safely reduced to the pre-1970 uniform 3 nautical miles; whenever the surface wind did not exceed the criterion, vortex behavior was unpredictable and the present separation standards should remain unchanged. The criterion is very conservative as it demands that no vortex, no matter how weak or strong (i.e., just GWVSS detectable), be within 150 feet of the extended runway centerline at or inside the middle marker location. The VAS consists of a meteorological tower emplaced near the middle marker of each ILS-equipped runway (precision approaches are required when using reduced separations); electronics and standard FAA cables to transmit the wind data to a central facility (control tower); a microprocessor to average the data, compare the data with the wind criterion, and detect equipment failures; and a display for the controllers. The display presents the averaged wind direction and magnitude and an indication (a green light) when decreased separations may be used.

A fundamental result of queuing theory is that, when a system is operating at or near capacity, a small increase in capacity, which would otherwise appear to be insignificant, can translate into a large decrease in delay. The VAS has been referred to at various times as either a capacity increasing system or as a delay reducing system. It is really both, but fundamentally should be considered as an interim technique to help minimize delays. One should not schedule more aircraft into O'Hare based on a successful VAS as one cannot always count on having meteorological conditions proper for using uniform three-nautical-mile spacings.

The next entry in the hierarchy of vortex systems (Ref. 26) incorporates real-time vortex tracking to monitor the critical approach region and to provide the pilot with information on corridor status (i.e., is the corridor clear of vortices). A vortex sensor or sensor system is used to monitor the corridor. Vortex position information could be displayed to the controller, or to a pilot via a data link or by lights installed near the runway threshold. A real-time vortex tracking system could be used alone or in combination with a VAS.

A Wake Vortex Warning System represents the ultimate system in the hierarchy of vortex systems and incorporates both the VAS and active real-time vortex tracking, but adds predictive capability to provide adaptive separations (Refs. 26 and 98). The Wake Vortex Warning System achieves greater utilization of the airport by the replacement of fixed, conservative separation standards with an adaptive standard permitting maximum traffic flow. This system might allow operations below 3 nautical miles (vortex behavior data indicate that 2-nautical-mile separations could be used about 90 percent of the time), providing the air traffic control system and the airport complex can handle the increased number of aircraft operations.

6.3 AIRCRAFT-BASED SYSTEMS

6.3.1 Alleviation

The goal of the vortex alleviation effort, conducted primarily by NASA, is to modify the generating aircraft in such a way that the wake vortex hazard is reduced or eliminated at normal aircraft separations. Since the wake vortex is a consequence of the lift generated by the wing, it is not possible to reduce the initial strength. Instead, the approach has been to redistribute the shed vorticity of the wing into the largest possible area and to enhance the decay of the vortex or to cause the two vortices to interact causing mutual momentum cancellation. A wide variety of devices and techniques have been tested in wind tunnels and in full-scale flight tests. The most successful static configurations have been able to reduce the induced-rolling moment from a jumbo-jet vortex to the roll-control level of a small aircraft at three nautical miles. One dynamic configuration (rapid roll inputs with spoilers deployed) showed a reduction of induced-rolling moment to half the roll control level. Unfortunately, the weight and drag penalties were excessive and passengers would find the ride uncomfortable. There is currently only modest detailed understanding about how the various alleviation configurations produce their results.

A successful alleviation system must satisfy three requirements. First, it must be proven to reduce the wake vortex hazard to safe limits at the desired minimum aircraft separation under all desired weather and flight conditions. Second, it must have some method of ensuring that the configuration is activated during actual operations. Third, the costs in weight, drag, and dollars of installing and operating the system must be commensurate with the benefits of the system. From a purely safety standpoint, the costs of such a system may be hard to rationalize inasmuch as the aircraft which bears the cost is not the aircraft which garners the benefits. (Under the hub concept, most aircraft are from the same airline, so there is some justification.) However, the capacity gains (delay minimizations) for commercial aircraft will be the touchstone for justifying any wake vortex system.

6.3.2 Airborne Vortex Sensors

An alternative to the ground-based predictive sensor system involves the aircraft and crew as active participants. The aircraft could be equipped with a real-time vortex sensor which could be either active or passive. If active, it could be monostatic (single sensor located on the aircraft) or bistatic (transmitter located on the ground with the receiver in the aircraft). If passive, it might measure lateral or angular displacement, velocity or acceleration, differential angle of attack, or other phenomena. The sensor would provide information about the vortex location and relative strength and the pilot would be responsible for avoiding the hazard.

As noted in Section 3.2, the airborne-sensor problem is not easy to solve inasmuch as radiation sensors would be looking predominantly along the vortex axis where there is little or no radial velocity component. The sensor system would either have to scan or have a wide field of view as vortices may drift into range from the side or from slightly above or below the flight path. Thus, an airborne sensor really operates only as a safety device to warn the pilot of a possible vortex encounter. Such sensor systems do not obviate the need for a predictive component to schedule reduced interaircraft separations. Use of an airborne vortex sensor system near the ground may be problematical due to ground clutter and the many activities that pilots must attend to during final approach and touchdown. Thus, a ground-based system would still be required to forecast periods when reduced separations may be used and so inform the air traffic controllers so they may sequence the aircraft with reduced separations.

The feasibility and development of an airborne sensor are highly dependent on defining a workable set of requirements (Refs. 99 and 100). The pilot wants to detect a hazardous vortex reliably, and quickly enough to respond, but not so far in advance as to see the wake of the preceding aircraft when it is not a hazard. He also does not want a high false-alarm rate due to detection of nonhazardous vortices or wind gusts. The hazard potential along the flight path may vary by such factors as phase of the flight, aircraft type, weather, etc.

There are two subtle problems with the airborne-sensor concept. First, the pilot may be provided with too much information which may not be fully understood. Presently, the pilot of the following aircraft knows that the jumbo jet in front of him has left a vortex in its wake. Unable to observe the vortex visually, the pilot realizes from experience that his aircraft should not intercept this vortex if he is maintaining the required safe separation distance and/or if he is above the track of the preceding aircraft. He does not know by how much, in time or space, he has missed the vortex, and he doesn't care. If, on the other hand, the actual vortex location were displayed to him, he might become reluctant to continue his flight toward what looks like an encounter. In the extremely busy final landing phase of the flight, the pilot should not be required to add an unnecessary monitoring task. Second, since any airborne sensor would probably be an expensive piece of equipment, the General Aviation aircraft that need it most probably would not be able to justify the cost.

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7. MAJOR ISSUES

A number of important issues surfaced during the operational implementation phase of the VAS at O'Hare. These issues imposed unanticipated requirements on the VAS, and these same requirements will likely be imposed on any vortex system.

7.1 BASIC SYSTEM REQUIREMENTS

During the vortex data-collection activities, an effort began to formulate the system concepts described in the preceding section. The fundamental system objectives based on user needs were obtained, but it was extremely difficult to get the users to define (either formally or informally) the operational requirements for a vortex system. What should the separation standard be in the absence of wake-vortex hazard: three, two and one-half, two nautical miles, or less? Should there be an interim system or should the work be directed toward the ultimate Warning System? Shall the system be operated in IFR only or will the system need to operate under both VMC and IMC conditions? What are the coverage requirements; that is, must the system monitor vortices in the vectoring area, etc? To identify these basic system requirements, a strawman system was proposed. The system would be very conservative, but would allow the vortex separation standards to return to the pre-1970 IFR standard of a uniform 3 nautical miles – the VAS. However, most of the needed operational requirements were unavailable until the strawman system was ready for commissioning as a demonstration system. During the final stages of the implementation phase, the basic requirements finally began to become clear as many of these operational requirements became constraints. Thus, it was the act of attempting to bring the VAS into the ATC system that elucidated the fundamental operational needs. The major issues confronted by the VAS were the coverage, the concern about missed approaches, the IFR/VFR question, and the inferential or predictive nature of the system.

7.2 VAS COVERAGE

Virtually all the vortex-tracking data have been recorded in the middle-marker-to-runway-threshold region. The VAS evolved from the study of these data; the VAS indicates when this region is clear of vortices. Although some gains may be realized if only this region is permitted to use the reduced separation standards, the utility of the VAS increases if the protected region is extended to the outer marker or beyond.

A detailed analysis was done of the relative safety of reduced separations out to the outer marker when the VAS indicated that reduced separations would be permitted near the runway (Ref. 45).

It was shown that the use of two guidelines maintained the level of risk with VAS-reduced spacings at, or below, the risk using the present separation standards. The two guidelines are: (1) reduced separations of 3 nautical miles are to be used only when the VAS indicates that conditions permit such separations, and (2) precision approaches are required (i.e., no short finals or VOR/localizer approaches). The FAA/TSC LDV was used to gather appropriate winds aloft and vortex behavior data in the middle-marker-to-outer-marker region; the data verified the detailed analysis (Ref. 35) to the effect that the VAS coverage extended from the runway to the outer-marker region. A limited flight test was conducted at O'Hare during which an FAA Gulfstream was intentionally vectored close behind landing Heavy aircraft. Approaches with separations as low as 2 nautical miles were safely flown. Two vortex encounters were experienced; however, they occurred when the guidelines above were not followed. The first encounter occurred with the Gulfstream 50 seconds behind an L-1011 approximately 6 miles from touchdown; however, the Gulfstream was more than 3 dots below the glideslope and less than 2 miles behind the L-1011. The second encounter occurred just inside the middle marker behind a B-747; however, the Gulfstream was 38 seconds or only about 1.5 nautical miles behind the B-747.

The uniform three-nautical-mile separations would be permitted using the VAS only after the lead aircraft is inside the outer marker location. In most situations the aircraft are in trail using the terminal area standards prior to crossing the outer marker. VAS-reduced separations will be due to the combination of the natural closing which takes place as the lead aircraft slows to its final landing speed (the accordion effect) and the lack of the need of an approximately 0.5-nautical-mile buffer now used by controllers to ensure that requisite separations are maintained at runway threshold. Although three nautical miles is claimed to be safe using the VAS, the interarrival separations behind Heavy aircraft will most likely initially be decreased by only the 0.5-nautical-mile buffer. To take full advantage of the capability of the VAS (3 nautical mile spacings), the terminal area separations would need to be reduced outside the Outer Marker (see Section 8.4).

7.3 MISSED APPROACHES

Proposed ATC procedures for the VAS required that an aircraft at VAS separations behind a Heavy aircraft must execute a go-around if the Heavy aircraft goes around (a rare situation) at, say, the middle marker. Concern was expressed that the double go-around would create an unsafe situation. However, analysis has shown that the flight profiles of the trailing aircraft can be maintained above the profiles of the lead aircraft as long as the trailing aircraft executes a go-around no closer than 1.25 nautical miles from the middle marker. This procedure avoids any vortex problems during the climbout.

7.4 IFR/VFR USAGE OF VAS

The VAS was conceived as an interim measure to minimize delays during IFR operations. If the conditions are such that VAS-reduced separations are not permitted, it has been posited that such information should be provided to the pilots during VFR operations — the implication otherwise being the withholding of safety information; if reduced separations cannot be used in IFR, the reduced separations inherent in VFR perhaps should not be accepted. When the VAS does not indicate that reduced separations are permitted, it does not mean that such separations are unsafe — it means that not enough information is available to say that it is absolutely safe. During high-wind conditions, data indicate that vortices are not a problem; during light-wind conditions, data are not conclusive but usually vortices are not a problem. In a sense, these low-wind conditions are when the "Caution Wake Turbulence" advisory has real meaning.

Chicago O'Hare exercises control over aircraft even during visual approaches. With such a high density of aircraft, it is imperative for the O'Hare controllers to follow the progress of all aircraft be it VMC or IMC. Thus, separations in VMC are not too different from separations in IMC at O'Hare (the difference being, perhaps, just the 0.5-nautical-mile buffer discussed in Section 7.2). Benefits from the VAS are derived in IFR, but one must consider the potential adverse implications of VAS on VFR operations. It should be noted that O'Hare achieves its greatest capacity increase in VMC by using triple approaches. A cost-benefit analysis of the VAS at O'Hare (Ref. 101) found that, given the present effectivity (percentage of the time the VAS indicates reduced separations are allowed) more than 40 percent of the pilots must request additional separation under VMC conditions when using two runways for approaches to drive the cost of the VAS operation above the IFR benefits. As will be discussed in the next section, one alternative would be to increase the effectivity of the VAS enough to offset any losses in VFR.

7.5 PREDICTIVE/INFERENTIAL NATURE OF VAS

Based on the study of vortex behavior from tens of thousands of aircraft, the VAS algorithm was developed. It was found that under certain wind conditions vortices posed no threat to any aircraft three nautical miles behind the vortex-generating aircraft. By measuring the wind in the vicinity of the runway, one can "predict" when separations can be set at a uniform three nautical miles. Since the vortices are not directly measured, the system is also inferential. Some section of the aviation community questioned the viability of predictive/inferential information in place of real-time measurements of the vortices.

Although it is generally true that a primary measurement of the phenomenon is desirable, there are precedents for predictive and/or inferential systems. The current vortex avoidance separation standards are accepted as a baseline safe system, but are essentially predictive in nature (no hazard when using 3, 4, 5, and 6 nautical miles; the VAS assumes no vortices/problems when using 3 nautical miles during certain wind conditions). Other aviation information also depend on prediction/inference. Winds measured sometimes a mile or two away from the landing runway are presumed to be valid on the runway. RVR is measured over a short horizontal path and is used to describe the slant visual range conditions that a pilot should expect.

The VAS and other sensor-based vortex avoidance systems rely to some extent on predicting vortex behavior on the basis of meteorological measurements, rather than just direct measurements of wake vortices themselves. The lead time required to set up aircraft spacing on final approach requires prediction of vortex behavior. The advantage of using meteorological parameters to predict vortex behavior is that they can always be measured.

8. OPTIONS/STRATEGIES

The preceding sections outlined what is and what is not known about aircraft wake vortices and some of the implementation problems/constraints that must be addressed. In this Section various alternative options or strategies are proffered. The alternatives, not necessarily mutually exclusive, include (1) halting all research and development on wake vortices, (2) resurrecting VAS and assessing total system operational requirements for acceptable vortex solutions, (3) substantially increasing the effectiveness of the VAS and thereby mitigating the VFR issue, (4) formulating the requirements for ground-based and airborne sensor systems thus moving toward systems more advanced than VAS, (5) continuing the search for effective alleviation of the vortex hazard, and (6) re-examining procedures in the light of vortex behavior to expedite traffic flow. Each option is briefly described along with its pros and cons, the risks and problems to be expected, and an outline of the work to be done. An effective wake vortex program should consist of some combination of these alternatives with proper emphasis consistent with FAA priorities and goals.

At this time there are six areas that appear to require further vortex research and development: parallel runways (including intersecting runways and staggered thresholds), reclassification and revised separation standards, further understanding of vortex behavior under various meteorological conditions, sensor development, hazard definition, and alleviation. Further data collection is warranted in these areas, but detailed planning is needed to demonstrate why more data are needed, how the results would be used, how the data should be collected, how many aircraft and types are required, etc.

8.1 HALT RESEARCH AND DEVELOPMENT ON WAKE VORTICES

One program option is to cease research and development on wake vortices. Safety is probably not an issue as long as the current separation standards are maintained. The FAA would save resources on the wake vortex program as well as on a number of other capacity-related programs. This was the course selected by the FAA in 1982.

However, the outlook is grim concerning the capabilities of the high-traffic-density airports to meet forecasted demand and to respond effectively to costly delays. The growth of aviation at the busy airports would need to be curtailed by restrictions on the number of operations. Construction of additional runways and airports would become the primary means to foster the expansion of aviation. Alternatives also include abandoning the "first-come, first-served" philosophy and the segregation of aircraft both spatially (dedicated runways for specific aircraft categories and diversion of some traffic to less congested airports) and temporally (mandatory scheduling to avoid peaks in demand). Safety might become an issue in VFR as the air traffic control system contends with the increasing mix of commuter-sized aircraft with the Heavy and heavier Large aircraft.

8.2 RESURRECT VAS

Another option would be to resurrect the effort on the VAS. The VAS previously was unacceptable primarily due to procedural problems. The exercise was worthwhile as vortex behavior knowledge was significantly expanded and the requirements for effective solutions to the wake vortex problem are becoming clear. Thus, a program option would be to resurrect VAS first by elucidating the requirements for acceptable vortex solutions and then by planning the research needed to translate these requirements into effective solutions.

The requirements can be divided into three types — basic, procedural, and systems. The basic requirements are those which affect any concept to mitigate the problem of wake vortices. Examples of such basic requirements are the use of the concept in VMC and IMC, the impact on the ATC system (mandatory go-arounds, precision approaches, effect of controller blunders, etc.), and the minimum separation standards. Procedural requirements are those imposed when translating the results of extensive data collection efforts into revised ATC procedures. Primary examples are the possible reclassification of aircraft based on vortex behavior and the use of parallel or intersecting or staggered runways. How much of a specific type of data are required, in what form they should be presented, and what other rules or procedures that bear upon the procedure under review must also be examined. System requirements are those which pertain to the design of any ground-based or airborne (including alleviation) system. Examples of system requirements are the coverage or region monitored, criteria for certification, interfaces with other ATC equipment, etc. As indicated by the experience with VAS, it is imperative to formulate the requirements with the appropriate agency and user organizations before pursuing any specific development effort.

It has been suggested by some members of the aviation community that a VAS based on a pure crosswind criterion would be more acceptable than the proposed wind algorithm. It was felt that pilots and controllers could more easily relate to something with which they are more familiar, since most of the previous literature (AIM, controller's handbook, etc.) discuss the possibility of a vortex hazard in terms of the magnitude of the crosswind. This conversion is trivial to implement technically as it would require only a relatively minor modification to the system software with no hardware changes. But, first, there would be a measurable drop in the effectiveness of the VAS using a crosswind criterion since more area would be taken from the green region where reduced separations are allowed. Second, there is the undesirable implication that crosswind runways would be preferred to runways with headwinds since the crosswind runway would offer reduced interarrival separations.

Although 3-nautical-mile separations are claimed to be safe using the VAS, in reality initially the separations would be closer to 3, 3.5, 4.5, and 5.5 nautical miles rather than 3, 4, 5, and 6 nautical miles, respectively. This is attributed to no longer needing the 0.5-nautical-mile buffer used by air traffic control to maintain the separation standards at runway threshold (Section 7.2). Perhaps VAS would be more palatable if it were introduced as a system affecting only the separation of Large and Small aircraft following Heavy aircraft (VAS-reduced minimum separation of four nautical miles for these aircraft pairs). Once operational experience is gained using this approach, a reduction to a three-nautical-mile minimum standard could be pursued. Such a course of action was suggested by ALPA representatives.

8.3 ENHANCED VAS

The ATC system is capable of accommodating three-nautical-mile spacings for controlling arrival aircraft during IMC. Because of possible hazardous vortex encounters, the separation standards are increased for certain leader/follower aircraft pairs. This increase in separation is highly conservative since the actual wake vortex hazard is significant for only a small fraction of the time. Under most conditions the vortices will have dissipated or drifted out of the approach flight path before the arrival of a following aircraft at a three-nautical-mile spacing.

A system developed to reduce the impact of the very conservative separation standards is the VAS. The VAS identifies wind conditions when wake vortices were never observed to linger in the path of a following aircraft at a three-nautical-mile separation for over 70,000 landings. The VAS is also very conservative in that the detection threshold for the sensor used to collect the data (GWVSS) is considerably below the vortex hazard threshold. The VAS does not exhibit high effectiveness (i.e., the fraction of the time that three-nautical-mile separations may be employed is smaller than necessary; Ref. 106) since wind measurements alone do not accurately predict all the times when vortices are not a problem. The VAS would allow 3-nautical-mile spacings on the order of 20 percent of the time, while there is no vortex problem 99 percent of the time behind a B-747 at a three-nautical-mile separation. This is because the VAS uses a wind criterion only, and an extremely conservative one at that, while vortex behavior is dependent on a number of additional parameters.

The low effectiveness of the VAS contrasts markedly with the successful use of VMC to deal with the wake-vortex problem. Since the use of VAS solely in IFR conditions has introduced problems, it appears that part of the cost of introducing the VAS to decrease IFR delays is the loss of VFR capacity obtained by operating below the IFR and vortex separation standards. The culprit in this scenario is the poor effectiveness of the VAS. The VAS effectiveness could be significantly improved by (1) using a more realistic hazard threshold, (2) finding additional predictors of vortex behavior (such as atmospheric stability and/or turbulence criteria) to supplement simple wind measurements, and (3) including vortex sensors for real-time updates of vortex behavior. These three improvements might be taken singly or in combination to substantially increase the VAS effectiveness. If such an improved VAS could justify the reduced separations in VMC, it could be capable of increasing overall capacity at the major hub airports.

The risks entailed with this option are twofold: First, some of the present procedural problems with the acceptance of the VAS will need to be addressed, such as the double missed approach. Second, research is required to identify the specific enhancements; the limited effort to date indicates that it is probable that enhancements can be made, but the ultimate effectiveness of the system is unknown. The tasks will involve collecting and analyzing data on the correlation of atmospheric stability and turbulence with vortex behavior, and a detailed study of all long-lived vortices. Once a technique or techniques are identified, further data collection may be required to satisfy the user community.

8.4 GROUND-BASED SYSTEMS

The hierarchy of systems (VAS, enhanced VAS, vortex tracking, Wake Vortex Warning System) offers flexibility in implementation and development as each more complex system builds on the use of the less complex system(s). Based on current needs and near term projections, about 20 to 30 airports in the US could benefit with a VAS and about 6 of these airports could employ the benefits of a full Wake Vortex Warning System. The capacity/delay-savings involved are extensive. Expected delay savings for 1985 to 1995 at the top 20 airports, using FAA-projected demands, are $1.25 billion (1976 dollars) for a 40-percent effectiveness VAS versus today's standards, and an additional $4 billion for a 60-percent effectiveness VAS operating with a 2.5-nautical-mile standard (Ref. 107).

For systems more advanced than the VAS, a vortex tracking/measuring system is required. Developments with the GWVSS hold considerable promise for such a system in the middle marker to runway threshold region. If vortex coverage is required when aircraft are at higher altitudes (to the outer marker, say), then much work remains to test and develop such a sensor system (e.g., various forms of lidar or radar). At the present time, it appears that the terminal-area standards beyond the outer marker will need to be reduced to achieve less than three-nautical-mile separations at the runway threshold. The need, however, for a complex sensor system has not been firmly established, nor have the operational requirements and limitations been identified. The next logical step would be to formulate these requirements, determine whether sensors can be incorporated into an advanced vortex avoidance system, develop such sensors, and determine how such a vortex avoidance system would operate in the air traffic control system.

Combining the VAS with a real-time vortex tracking system would meet some of the objections raised by the aviation community concerning use of the VAS alone. Such a system with real-time tracking of vortices would increase the effectiveness of the VAS and be used both in IFR and VFR. Sufficient data exist to determine the viability of this concept, the technical risk being the ability to develop the sensor and the attendant data processing algorithms for real-time application. If the real-time vortex tracking system can be coupled with the results of VAS enhancement, the effectiveness should be better than 90 percent in both IFR and VFR.

8.5 AIRBORNE SENSOR SYSTEMS

The feasibility of using an airborne sensor for detecting vortices needs to be investigated, with emphasis in two major areas. First, a review of some of the more recent advancements in sensing techniques should be conducted; there have been many developments in the infrared, visible, and microwave regions, as well as accelerometers and gyroscopes, which could be applied to sensor development. Second, a set of operational requirements needs to be defined which should allow the determination if a useful sensor can be developed, while at the same time providing a reliable detection of a possible vortex hazard. The variability and unpredictability of aircraft flight paths make the precise definition of sensor requirements somewhat difficult. However, in order to be useful in a vortex avoidance system concept, there are a number of definitive sensor requirements that must be met.

The major risk of the system is that the sensor and how it would be used are both unknowns. If this option has merit, a detailed requirements study should be undertaken. Based on the requirements, system concepts can be defined and evaluated, and a demonstration sensor system designed, built, and tested. Part of the evaluation phase should include the feasibility of the system as perceived by the aviation community in light of the probability and range of detection and the false-alarm rate. However, as noted in Section 6.3.2, both a ground-based and an airborne sensor approach can be followed as an airborne sensor by itself is not a solution. A VAS, enhanced VAS, or Vortex Warning System will still be required on the ground so that reduced separations can be forecast and the air traffic controllers can appropriately sequence and position aircraft at the reduced separations.

8.6 ALLEVIATION

The primary goal of the alleviation program is to find a configuration that produces satisfactory alleviation with acceptable costs. The tests to date indicate that static configurations are not likely to be successful; dynamic configurations are more likely to yield satisfactory results. An immediate task is to understand fully past results and suggest new configurations that can be achieved with an acceptable ride, performance (fuel economy, landing speed, etc.), and stress on the generating aircraft. An important support task for the alleviation program is a determination of what constitutes "satisfactory" alleviation. How weak must a vortex be to be considered benign?

The implementation of an alleviation system will require several efforts and should be pursued as a joint NASA/FAA endeavor. First, the criteria for acceptance must be established. Second, the system must be certified as effective and airworthy. The following aircraft must be assured that the alleviation system is operating. Third, the costs associated with the system must be defined. Fourth, an implementation plan must be devised. The incentives for an individual airline to install alleviation are difficult to envision since the benefits apparently accrue to the following rather than the generating aircraft.

8.7 PROCEDURES

One area that has received little attention as a means for increasing/improving the flow of traffic from the standpoint of wake vortices has been the possible use of revised procedures. Much has been learned about vortex behavior, but little of this tremendous increase in knowledge has been applied to establishing new or revised rules for expediting traffic. In the operation of parallel and intersecting runways there are cases (such as offset parallels, etc.) where logical application of basic knowledge of vortex behavior should improve overall efficiency. Simple wind criteria and/or segregation of aircraft could be used to expedite traffic flow. Intersecting runway operations especially may require case-by-case examination to achieve optimal procedures.

8.7.1 Reclassification

The current classification of aircraft into Small, Large, and Heavy is based on the maximum certificated gross takeoff weight, with boundary limits of 12,500 lb and 300,000 lb (not actual weight), respectively, between classes. The same classes are used to describe both generator and follower aircraft, although the important parameters may be different in the two situations. The most notable feature of the current classes is the extreme range of aircraft size in the Large class. The separation standards are designed to be conservative in that the separation must be safe for all generator-follower pairs under the worst of conditions. The separation standard is therefore nominally set by the two following limiting cases:

(1) The strongest generator and the most susceptible follower in the respective classes, the former at maximum weight, the latter nearly empty; and

(2) The meteorological conditions leading to the longest vortex persistence.

The most obvious and perhaps easiest improvement in the current classification might be obtained by splitting the Large class into two; in the United Kingdom, the present scheme of four classes is similar to the result of such a change.

The goal of reclassification is to optimize the aircraft classes and separation standards for maximum airport capacity subject to the constraints of safety, efficiency, and acceptable complexity. The basic variables of reclassification are the number of size classes and the dividing lines between the classes. Other factors such as wingspan and engine placement may be combined with weight to derive an optimum size parameter. Incorporating the best understanding of wake vortex decay and an improved hazard model into the wake vortex classes and separation standards may produce a significant improvement in airport capacity over the present standards.

8.7.2 Parallel/Intersecting Runways

Many airports were developed with the most often used runways constructed in parallel pairs to maximize traffic flow in peak demand periods. Since, in general, these plans were generated before the advent of the Heavy jets, the lateral separation was dependent mostly on available land and the requirements for radar coverage and ILS navigation procedures. However, the possibility of a vortex from an aircraft operation on one runway transporting across to interfere with an operation on a parallel runway led to the establishment of restrictive procedures when the runways are used for simultaneous operations. When these procedures were developed, very little detailed information on vortex behavior was available and the resultant procedures now seem to be excessively conservative. The various aircraft wake-vortex sensing systems have produced an initial data base on long transport vortex behavior which can be used to develop an initial set of more efficient procedures, but more data (measurements) are required to finalize a standard. Operational procedures for the use of intersecting runways and intersection departures have similar conservative restrictions. Although these situations must be treated as individual cases, similar data analyses may be used to increase the efficiency of these operations.

9. RECOMMENDED WAKE VORTEX PROGRAM

Many options or strategies were suggested in the previous Section. They range from terminating any further work to the development of a full wake vortex avoidance system. A recommended wake vortex program is sketched below which is a combination of the various options/strategies; the intent is to lay out a complete and logically consistent program building on the extensive efforts of the 1970's by the FAA Technical Center, NASA, and VNTSC. Ten components are identified, many of which are dependent on or derive from other activities. These recommendations are those of the author.

9.1 REVIEW PAST ACTIVITIES

Because of the hiatus in the wake vortex research and development, the past activities must be reviewed and in some cases documented. Reports such as this one are needed to place future data collection activities into proper perspective by concentrating on improved and more complete meteorological information.

9.2 CAPTURE VAS REQUIREMENTS

The exercise of attempting to implement an operational VAS at Chicago O'Hare brought to light many hitherto unexpressed requirements. These requirements should be reviewed, analyzed, and documented as a means for obtaining the aviation community's early approval of the concept of a ground-based system for decreasing interarrival separations of aircraft.

9.3 DEVELOP VORTEX SENSORS

Many sensors have been employed to record vortex motion and decay. An active ground-based vortex sensor will be required in any eventual operational vortex system deployed at an airport. Efforts are needed to develop such a sensor system that can operate unattended, around the clock, and in all weather conditions. The feasibility of an airborne vortex sensor should also be pursued.

9.4 ADDITIONAL DATA COLLECTION

Additional data collection activities are required. Six areas need to be addressed in the data collection:

(1) New aircraft types,
(2) Developing and verifying an enhanced VAS,

(3) Developing and verifying atmospheric (as applied to vortex behavior) forecasting models,
(4) Developing and verifying hazard model(s),
(5) Additional data for reclassification, and
(6) Parallel/intersecting runway standards.

Many new aircraft types are now in use which were not around during the previous data collection programs (B-747-400, A-310, A-320, B-757, B-767, MD-11). Data must be collected on these aircraft for vortex behavior modeling. An enhanced VAS will incorporate new meteorological parameters; data must be collected to develop and verify the algorithms which translate the measurements into vortex separation standards. For any vortex system to be accepted into the airport environment, vortex behavior must be forecasted so that air traffic control can schedule reduced separations well before the aircraft land, as well as deal with impending changes when the system indicates that reduced spacings may not be appropriate at some forecasted time in the future. The hazard model employed directly affects the design of any system as well as any reclassification scheme; data is needed to further refine and verify any proposed new hazard models. Reclassification may in itself lead to gains in capacity, but additional data, particularly on the new aircraft types, must be collected before developing a new matrix for wake-generating and following aircraft separation standards. Finally, data is required to examine the parallel and intersecting runway standards to determine how best to use these runways from a vortex point of view. Initial emphasis should be on landing aircraft, but takeoffs will need to be examined for the same six ares.

In the longer term, more complicated separation schemes involving individual aircraft type, actual weight, configuration, and the like will become feasible, including separation standards specified in fractions of a nautical mile.

9.5 VORTEX MODELING

Models (i.e., computer algorithms) are needed to predict vortex behavior under various meteorological conditions. The efforts begun by Greene (Ref. 109) and others need to be expanded to describe vortex behavior (motion and decay) more completely. In addition, a forecasting model needs to be developed; such a model would incorporate both vortex behavior measurements and meteorological measurements to estimate if and when vortex separations may need to be changed.

9.6 HAZARD DEFINITION

The definition of a vortex hazard is only crudely known. More effort is required as a hazard model is included in vortex systems (albeit a simple one) and is of paramount importance in reclassification efforts. The better one can describe the hazard, the more efficient the vortex system or classification of aircraft.

9.7 RECLASSIFICATION

The methodology for setting vortex separations needs to be documented for review. The current standards are based on three weight classes. Incorporation of more complete vortex behavior and hazard criteria into the definition of aircraft classes should lead to more efficient groupings of aircraft for vortex separation purposes.

9.8 AIRPORT TEST SITE

An airport test site needs to be established for the long-term data collection activities discussed above. In addition, the test site would become the demonstration airport for an enhanced VAS, real-time vortex tracking system, and/or the Wake Vortex Warning System.

9.9 ALLEVIATION

NASA should be encouraged to continue its efforts in seeking an aerodynamic solution to the wake vortex problem. Such a solution could conceivably be effective for all phases of flight and would be effective at all airports (not just those with a vortex system installed).

9.10 AIRBORNE VORTEX SENSORS

NASA should be encouraged to continue its efforts in finding an airborne vortex-sensing system. Such a system permits the pilot to "see and avoid" wake vortices. Such sensors will increase safety, but, as noted in Section 6.3.2, a ground-based system will still be required to forecast and set up reduced separations in the terminal environment.

9.11 FINAL NOTE

A wake vortex program has been re-established. Capacity problems at the major airports demand that vortex-imposed restrictions be reduced when possible and without compromising safety.

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APPENDIX

4-C

Wake Turbulence Training Aid Guidelines and Issues

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Summary of Wake Turbulence Training Aid Guidelines

Administrative:

1. The Wake Turbulence Training Aid will be a consensus of the Industry Team and receive FAA endorsement.

2. It was agreed to track issues that lack agreement or remain unresolved by the Industry Team.

3. The FAA will develop distribution lists and be responsible for distributing the training aid.

Training Aid:

1. The name of the training aid will be Wake Turbulence. This is a broader term than wake vortex and deals with the effect of the vortex.

2. The Wake Turbulence Training Aid should be generally similar to the Windshear and Take-off Training aids. The FAA will develop a computer base instruction program. Simulator training is impracticable for inclusion into the training aid. FAA/ATC will determine if simulator training is applicable for the academy tower operator training.

3. The Wake Turbulence Training Aid should be targeted equally toward air traffic controllers, FAR Part 91, 121 and 135 operators. Emphasis should be placed on controller and pilot situational awareness.

4. The Wake Turbulence Training Aid should be primarily developed around existing data and capability. It is recognized that there are still unanswered questions concerning wake turbulence and that research of the phenomenon is continuing. It was felt that pilots and air traffic controllers should have some awareness of this, therefore the training aid should also include information on what is still unknown or what is being developed if it is necessary to satisfy an objective. Examples are aircraft flightpaths and control, and wake-turbulence detection and avoidance systems.

5. It was acknowledged that the target audience would be larger than that of previous aids and that the aid should be developed taking this increased distribution into consideration. The Aid should also be structured to be easily reproducible in anticipation of "secondary" distribution by those on the initial distribution of the aid.

6. The wake-turbulence video should be a stand-alone module and show dynamics that can not be easily described or portrayed in the document. Key inputs will be identified during the training aid development for inclusion into the video. The video should use a variety of aircraft types and scenarios and cover aircraft arrival and departure phases of flight. It should be approximately 20 minutes in duration and equally target both air traffic controllers and pilots. It is acknowledged that there are synergistic benefits of having only one video, but during development a determination will be made on whether there are overriding reasons for two separate videos.

7. It is desirable that the structure of the training aid easily accommodate updates, changes and the inclusion of new materials.

8. The goals of the aid should align with the FAA Integrated Wake Vortex Program Plan.

9. The NTSB will author section two, "A review of typical accidents and incidents."

10. FAA/ATC will be responsible for authoring section two, "Air traffic control responsibilities for maintaining airplane separation" and "Air traffic control considerations associated with applying separation criteria."

Wake Turbulence Training Aid Issues

1. Determine if a single training aid can accommodate Parts 91, 121, 135 pilots as well as air traffic controllers.

   Conclusion: A single training aid can accommodate all pilots and air traffic controllers.

   Closed 6/21/94.

2. Determine if the Wake Turbulence Training Aid should be mandatory or optional for air traffic controllers.

   Conclusion: This is the responsibility of the FAA/ATC.

   Closed 6/21/94

3. Determine if air traffic controllers should have wake-turbulence avoidance responsibility expanded beyond current requirements.

   Conclusion: This is the responsibility of the FAA/ATC and outside the scope of the training aid working group.

   Closed 6/21/94.

4. Should the scope of the training aid be expanded to include CAA/other separation criteria?

   Conclusion: The training aid will be written and formatted for international use with consideration for mitigating updates and changes.

   Closed 6/21/94.

5. What recommendation should the training aid include for wake-turbulence separation in VMC for both controlled and visual operations?

   Conclusion: No recommendation should be made.

   Closed 6/21/94.

6. Determine how to best portray information in the video so as to mirror air traffic controllers' mental process for controlling traffic.

   Conclusion: The video scenario includes wake-turbulence situations that air traffic controllers confront on a routine basis. It also includes an air traffic controller who discusses wake-turbulence considerations for controllers. The wake-turbulence industry and government working group is satisfied that this issue is accommodated.

   Closed 11/10/94.

7. To what extent should procedures be developed and included in the training aid for pilots to use if wake turbulence is encountered?

   Conclusion: The training aid emphasizes wake-turbulence avoidance. Procedures for encounters should not be included.

   Closed 11/10/94.

8. Can the training aid state that flightpath control is the solution for wake-turbulence avoidance while acknowledging the difficulty in determining the flightpath location or should it recommend glideslope control or both?

   Conclusion: Both.

   Closed 6/21/94.

9. Should surface winds of 12 knots or greater be the point where wake-turbulence avoidance separation criteria do not have to be applied?

   Conclusion: The resolution of this is the responsibility of the FAA and the Integrated Wake Vortex Program Plan.

   Closed 11/10/94.

10. Should pilots be required to notify air traffic control when a higher than normal flightpath approach is being flown?

    Conclusion: Pilots should not be required to notify air traffic control when a higher than normal flightpath approach is being flown. The training aid includes the potential wake turbulence hazards associated with flying steep descents and warns pilots and air traffic controllers of the ramifications. It also encourages coordination and a disciplined flow of information between pilots and air traffic.

    Closed 11/10/94.

11. Should IFR controlled minimum separation distances be included in the training aid? If they are included, how and where should they be incorporated? Refer to number 4.

    Conclusion: Wake turbulence take-off weight categories and IFR separation distances for the FAA, United Kingdom and ICAO are provided in Appendix 4-F.

    Closed 11/10/94.

12. Information on the use of Traffic Alert and Collision Avoidance System (TCAS) as a visual technique for wake-turbulence avoidance was initially included in the training aid. A consensus could not be attained within the working group for including it. A decision was made to withdraw the information and retain this issue in an open status.

    Status: Open.

APPENDIX

4-D

FAA Integrated Wake Vortex Program Plan

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DOT/FAA/RD-94-16
DOT-VNTSC-FA427-94-2

Research and Development
Service
Washington, D.C. 20591

FAA Integrated Wake-Vortex Program Plan in Support of the DOT/FAA/NASA Memorandum of Agreement Concerning Wake-Vortex Systems Research

Program Plan
August 1994

U.S. Department of Transportation
Federal Aviation Administration

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FAA INTEGRATED WAKE-VORTEX PROGRAM PLAN
IN SUPPORT OF THE DOT/FAA/NASA
MEMORANDUM OF AGREEMENT CONCERNING
WAKE-VORTEX SYSTEMS RESEARCH

This is not an acquisition program. However, the plan contains all steps necessary for such a program should it proceed. These steps are carried out per Circular A-109 and per FAA Order 1810.1F. This program also includes coordination with the NASA Program and other NASA activities.

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1. INTRODUCTION

This program plan is a "living-working" document that will be updated as events require. The Federal Aviation Administration (FAA) provides guidelines, advisories, and regulations that assure the safe and efficient conduct of civil aviation activity. Much of this is done by applying the results of scientific inquiry to the solution of aviation problems. One such area of inquiry is the wake-vortex phenomenon. Frequently asked questions regarding wake vortices are: (1) Are aircraft classification standards, as they exist today, adequate to achieve the desired level of safety? and (2) Why are greater wake-vortex spacings required under Instrument Flight Rules (IFR) than are used routinely by pilots operating under Visual Flight Rules (VFR)? These are reasonable questions, since during VFR operations there have been no documented instances of an accident or an injury occurring when the recommended practices of Section 3, Chapter 7 of the Airman's Information Manual (AIM) (reference 1) have been followed.

The current wake separation standards were established during the 1970s. At that time there were logical break points in aircraft size by which to categorize aircraft. 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, and there were very few smaller "commuter size" aircraft. Today there is almost a continuum of aircraft size as the "aircraft family" concept has been widely adopted and there are many new transport aircraft. This continuum of aircraft in terms of initial wake-vortex strength is illustrated in Figure 1. The theoretical predictions for maximum landing weight and empty operating weight are discussed in reference 2. In this figure the calculated vortex strengths have been normalized to a value of 1 for a mid-weight B-737. The data points superimposed on this figure were obtained during field measurements made by the Volpe Center at O'Hare during 1976/1977 and at Idaho Falls Airport (IDF) in 1990, and tower measurements made at IDF by National Oceanic Atmospheric Administration (NOAA) in 1990. The measured data and theoretical calculations show excellent agreements, including the data point for the stripped down B-767. The important point of Figure 1 is that there is no natural break point in wake-vortex strength for the continuum of aircraft. In addition, there has been evolutionary growth of existing aircraft models such as the DC-9 and the B-737 and there are new, much larger aircraft on the drawing boards. Also, new operational procedures have been adopted that relate to noise abatement approaches and fuel conservation approaches.

In view of the need to increase system capacity and of the change in the fleet size and mix, it is appropriate to review the aircraft classifications and vortex separation standards. We have learned that, in addition to the dependence of wake vortices on wing span, weight, and span ratio, there is a strong dependence on the characteristics of the atmosphere. Different spacings have evolved for IFR and VFR operations. The greater spacings used under IFR were developed for a variety of reasons, and are usually not needed solely to satisfy wake-vortex constraints.

By developing proper training and system technology, separation standards for IFR operations may be reduced, with increased spacing used only when necessitated by weather or particular aircraft pairings. This will result in increased capacity under IFR when it is needed most; meanwhile special advisories can be developed to improve safety under VFR operations. To accomplish the goals of this program, a joint effort by the FAA and the National Aeronautics and Space Administration (NASA) has been initiated through a Memorandum of Agreement (MOA) (reference 3).

Both FAA and the NASA will ensure the participation of industry and the international community throughout this program. The NASA wake-vortex effort is an element of a larger NASA Terminal Area Productivity (TAP) Program effort and is a significant undertaking with an overall goal of ameliorating wake-vortex constraints on system capacity. The FAA portion of the program will address training; capacity improvement, e.g., through runway spacing; validation of proposed wake-vortex solutions leading to potential validation/reduction of separation standards; and air traffic system integration. The NASA portion of the program is structured to meet the needs of the FAA by focusing on development of sensor technology, wake-vortex prediction techniques, automated approach spacing concepts, human factors considerations, system integration techniques, and hazard modeling technology. Figure 2 illustrates the rationale underlying the Wake-Vortex Program, and depicts the "why, who, what, how, and when" elements of the program. It is noted that the program will culminate in a technology validation and demonstration of a system concept that includes dynamic, adaptive separation criteria.

The Wake-Vortex Program includes a review and recommendation for changes in aircraft classification and separation standards with the aim of maintaining the current high level of safety. A primary objective of the program is to mitigate the influence of wake vortices on separation. This in turn may lead to increased airport capacity and system capacity through implementation of several vortex capacity improvement concepts: more efficient wake-vortex separation standards; a system designed to increase capacity for close-spaced parallel, converging, and single-runway configurations; and an automated real-time separation system. Figure 2 illustrates all of the program elements needed to develop and implement wake-vortex capacity improvements. For all candidate capacity improvement concepts, the effectiveness of the algorithms and recommended procedures will be determined by means of validated vortex decay and vortex encounter hazard models which are based on vortex data, and encounter simulations. The utility of an improvement concept will be determined through capacity studies and simulation. A tactical safety vortex sensor will be used to assure system safety during system demonstration and may become a permanent part of the system where needed. The recommended operational concept may require interfacing with airport weather systems such as the Integrated Terminal Weather System (ITWS), and will provide outputs to air traffic controllers (ATC), and automated separation systems such as Center TRACON Automated System (CTAS) and Converging Runway Display Aid (CRDA).

All of the elements of Figure 2 now exist in some form for some of the intended capacity improvement options. The program tasks are designed to upgrade and validate all system components to the level where safety and utility can be assured.

The Wake-Vortex Program will be carried out jointly by the FAA, NASA, and industry in a manner that utilizes the unique strength of each agency and organization. NASA's wake-vortex efforts are part of the NASA Program to increase IFR airport capacity to the level achieved in VFR. The FAA and NASA will work together on many of the development activities shown in Figure2. Initial steps have been taken to develop cooperation with France, Germany, The Netherlands, Canada, and the United Kingdom to ensure that the program will use to best advantage the contributions of all participants.

The FAA, as the regulatory agency, will have primary responsibility for developing system requirements and coordinating efforts with other program offices, such as Terminal Air Traffic Control Automation (TATCA), ITWS, etc., as required to accomplish program goals. NASA responsibilities include the meeting of program requirements, vortex-encounter modeling, vortex-hazard definition, sensor technology development, and system concept work described in Figure3. As a part of NASA's TAP Program the NASA effort will be aimed at the development and demonstration of a specific concept designated as Aircraft Vortex Spacing System (AVOSS). The role of industry will emphasize training and, through government partnership, aid in system design and implementation.

2. BACKGROUND

2.1 BASIC PROBLEM

Wake vortices are generated as a consequence of lift generated by the wings (or rotor) of an aircraft or helicopter. The vortices from one aircraft may pose a hazard to following aircraft. In the U.S., aircraft are currently classified in three classes: Heavy, Large, and Small, which have specified minimum separation standards for following aircraft. These standards have been established on the basis of runway occupancy time, with the intention of preventing hazardous encounters. The program participants have agreed that according to all known records no wake-vortex-related accidents have occurred when air traffic standards and procedures (reference4) and the recommended practices of the AIM were followed. The fundamental aims of this plan are to reduce, if possible, these separation standards and to develop procedures and/or systems to further increase capacity.

2.2 PRIOR FAA PROGRAM ACTIVITIES

Early FAA wake-vortex activities are documented in several publications. A brief history of the results may be found in references 5, 6, 7, 8, and 9. A synopsis of past work is described in this section.

1. The early years (1969-1976) of the FAA Wake-Vortex Program were devoted to the initial exploration of the vortex phenomenon and to defining the current separation standards. An extensive data collection effort showed that the original 1969 separation standards were indeed safe for commercial aircraft, but that an additional mile of separation was needed for Small following Heavy and Large aircraft (these standards changed in 1976).

2. The FAA Wake-Vortex Program completed a decade of major data collection efforts in 1980. These efforts were designed with the expectation that a better understanding of wake-vortex behavior would help in recovering some of the capacity lost as a result of the imposition of increased separation standards. The program was terminated in 1981 after the data had been reduced, but before all of it had been analyzed. During this period the first vortex-encounter hazard and vortex-decay models were developed and used to study alternative separation standards.

3. In the late 1970s, the first wake-vortex system, the Vortex Advisory System (VAS) was developed. This system was tested but did not become operational.

4. In 1984, the program was reactivated to investigate helicopter wake-vortex issues and to complete the analysis of the earlier data. Several reports were written during this period but were never published because the program was terminated in 1987. **These reports are under evaluation at this time and analysis will determine their suitability for publication.** During this period an aircraft classification model that considered both landing and take-off was developed.

5. The FAA Wake-Vortex Program was again reactivated in 1989 and terminated at the end of 1991. During this period, vortex data were collected during tower fly-by operations leased B-727, B-757, and B-767 aircraft at Idaho Falls, ID. Data was also collected on aircraft landing at Dallas-Fort Worth (DFW) airport. As in 1981, the data from these tests have been reduced, but very little analysis has been carried out. It should be noted that the Idaho Falls tests were conducted using single-tower fly-by procedures that produce useful measurements, such as velocity, but do not produce information related to decay of wake-vortex strength. **However, a reevaluation of the Idaho Falls Test Procedures and Analysis has been under way since September 1993, and will be part of the current program. Any useful data will be reduced and compiled in a comprehensive database that will include all work completed to date. This database will be prepared and made available to interested members of the scientific and international community, and aviation policy makers.**

FAA-sponsored wake-vortex work has produced a better understanding of vortex behavior and created several databases containing aircraft-specific vortex characteristics. In addition to the 1976 change in the Small aircraft separation standards, this information has been used to support Localizer (Type) Directional Aid (LDA) (reference 1) approaches, with the reduction in IFR landing separations to 2.5 miles for selected Large and Small aircraft. The sensing systems, analysis methodologies, and the system requirements developed during the past two decades provide the foundation for the current plan.

2.3 ON-GOING ACTIVITIES

1. NASA is addressing the problem of defining and validating an accurate vortex-encounter hazard model. The basic parameters of the simple static model previously used to assess the wake-vortex hazard were uncertain by as much as a factor of two. The new NASA model will take into account the dynamics of the encounter, including both pilot and aircraft response times, and will be validated through flight tests.

2. German investigators are studying operations using closely spaced parallel runways (500 meters – 1,700 feet) at Frankfurt. They measured the transport of wake vortices between the runways using a lidar and anemometers and are developing a system concept (based on the measured crosswind) which is not yet completed. They attempted to determine the effects of turbulence on vortex lifetime, but have not obtained definitive results.

3. In the United Kingdom a vortex incident reporting system has been in operation for more than twenty years. Most of the data is specific to Heathrow Airport. The incident statistics have been used to justify a number of changes in longitudinal separation standards. In connection with this effort some modeling work is also being performed in India.

4. The French involvement is in the area of modeling. A recent international meeting examined this work and other efforts which has been undertaken with varying resources. Most areas of interest were site specific and did not encompass the wide range of meteorological and site variations that exist in the United States (U.S.) today. The conclusion was that these other efforts should continue with coordination and data exchange to the maximum extent possible.

A major result of the program will be a scientific understanding of wake vortices. The science and technology gained from the successful windshear program and the wake-vortex program should lead to technology and guidelines for avoidance of aeronautical hazards, both en route and in the terminal area. NASA's TAP Program addresses this goal for the terminal area, and the study of the wake-vortex phenomena, which is being performed in cooperation with the FAA, is an important element of this program. The TAP Program has been coordinated with the FAA and was presented to the FAA Research and Development Committee on August 24, 1993. The results from this area of study are expected to lead to an increase in airport capacity for operations under IFR by mitigating the effect of wake vortices on aircraft without compromising safety.

3. APPROACH

The approach adopted for the current Wake-Vortex Program is to define a multi-year program comprising a number of initiatives which will result in operationally implementable products. An important point about the program is that no wake-vortex-avoidance system will make use of techniques for "encountering and flying through vortices." It is the intention of the program to ensure the understanding of how the wake vortex is integrated into the environment and how it responds to the variables within that environment. Any recommended practices that result from the program will be aimed at wake-vortex avoidance.

3.1 FAA ACTIVITIES

Six specific areas of activity have been identified. In all areas, the goal is to minimize the limitations caused by the wake-vortex on separation standards.

1. ***Training.*** Initial steps have been taken to develop a training program aimed at ensuring avoidance of hazardous encounters with wake vortices made by other aircraft. The training program development will follow the same procedures as were used in the development of the training for avoidance of encounters of microburst wind shears during the course of the successful joint FAA/NASA Wind Shear Program. Training will be developed to support the implementation of each phase of the Wake-Vortex Program as necessary.

2. ***Capacity Analysis.*** A comprehensive review and validation of airport capacity studies and assessment of the fundamental algorithms applied to assure that the capacity improvements of proposed wake-vortex solutions can be realistically achieved. Incorporated into this analysis will be the results of a review of current aircraft classification and separation standards. This review will determine the rationale for following aircraft spacings, and will demonstrate the relationship of wake-vortices to these spacings.

3. ***Parallel-Runway System.*** Development of a system for improving capacity at airports with closely spaced (<2500 feet) parallel runways.

4. ***Intersecting-Runway System.*** Development of an intersecting-runway system and modification of existing separation standards to increase capacity.

5. ***Single-Runway Separation Standards.*** Modification of existing separation standards to increase capacity.

6. ***Aircraft Vortex Spacing System (AVOSS).*** Comprehensive airport system for providing adaptive separation requirements to automated air traffic control.

3.2 FAA CAPACITY IMPROVEMENT PRODUCTS

The program is designed to provide one capacity improvement product in each program time frame (near term, mid-term and long term). Section 7 details the program products and milestones needed to achieve the capacity improvement products.

Near Term (1994-1996): Parallel-Runway System

A parallel-runway system can be implemented in the near term for three reasons:

1. Studies in this area are under way in Germany at this time with projected completion/implementation dates of 1995-1996. The program has initiated coordination with Germany in this area.

2. Vortex sensor development is under way at NASA and expected results from this work should allow for recommendations within 18 months.

3. The training program will be scheduled to follow the developments necessary for operations with the parallel-runway system.

Mid-Term (1997-1998): Single-Runway Separation Standards

The demonstration of improved single-runway separation standards will be coordinated with the development of sensors capable of detecting and measuring stalled vortices on runways. The evaluation of multiple sensor technologies will begin in mid-1994; preliminary reports will be available by early 1995. New separation standards, including vortex sensors for single-runway operations, will be validated at a demonstration airport during this time period.

Long Term (1998+): AVOSS

The AVOSS concept will perform the function of providing adaptive vortex-based separation criteria to the ATC system. The AVOSS concept will integrate knowledge of the state of the weather, sensor data, wake-vortex behavior, generating aircraft high-level characteristics, hazard definition, and FAA requirements and regulatory constraints. The AVOSS output to ATC will consist of separation constraints (at to-be-determined resolution and frequency), and time-critical information to indicate when previously predicted separation becomes inadequate (hazard warning). The FAA will participate in operational evaluation and readiness assessment of the AVOSS concept. The FAA will be responsible for the development of a prototype AVOSS for operational deployment.

3.3 AVOSS PERFORMANCE LEVELS

The FAA and NASA have agreed that a properly configured AVOSS structure will be capable of various levels of system performance. This capability will permit AVOSS to be implemented early and to take on additional capability as weather data become available, wake-vortex sensor performance is improved, and wake-vortex knowledge improves. Examples of levels of capability include:

1. Today's "AVOSS," consisting of current and historical separation rules. Update rate to ATC is now on the order of a change every 5 to 10 years.

2. AVOSS consisting of revised rules as historical rules are subjected to examination and contemporary wake-vortex studies produce results leading to recommended changes in separation rules. Update rate to ATC can be on the order of once per year.

3. AVOSS consisting of sensors for use in determining the length of time that wake vortices remain on approach or departure paths. Update rates to ATC may be achievable once per hour.

4. AVOSS integrating knowledge of the state of the weather, rules based on validated models of wake-vortex transport characteristics, and error limits on these predictions. This version would not include wake-vortex sensors, wake-vortex hazard definition, or wake-vortex location reporting capability. An update rate of once an hour to ATC may be achievable.

5. AVOSS in this version being the same as 4 above, with the improved performance of wake-vortex sensor verification of wake-vortex transport.

6. AVOSS in this version being the same as 5 above, with the added capability of integrating knowledge of wake-vortex decay and hazard definition.

7. This version of AVOSS being the same as 6 above, with the added capability of incorporating ITWS products for use in predicting separation criteria in 20-minute frames. The update rate to ATC is to be determined.

3.4 NASA WAKE VORTEX ACTIVITIES

While the NASA wake-vortex effort is a long-term program that will result in tools for an automation system to be deployed about the year 1998, the FAA and NASA have agreed that shorter term gains in levels of safety and capacity can be achieved as certain technological milestones (e.g., training and education, accurate 3D models, sensor development) are reached. The framework of the current program evolved during the development of the successful joint FAA/NASA Wind Shear Research Program. The basic structure of this interagency and industry cooperative research has remained intact throughout budget fluctuations in both agencies.

The NASA activity requires close cooperation with the FAA in providing support for:

1. Determining requirements and priorities
2. Sharing data in order to optimize results
3. Working with both the domestic and international communities to assure that knowledge and technology are widely distributed

3.4.1 NEAR TERM

For the near term (one to three years), NASA's program will focus on developing and validating basic vortex and hazard modeling technology. As the technology is developed, it will be applied to evaluate relative safety and potential capacity improvements. These improvements might result from changes in current procedures and separations. These changes will, in turn, require an evaluation of the number of classes and weight-class boundaries for determining separations necessary for minimizing wake-vortex hazards. In addition, the following three types of validation experiments will be conducted:

1. Wind-tunnel measurements will be taken using B-747 and DC-10 model aircraft as both leading and following aircraft in order to evaluate the wake characteristics of this aircraft pair. Results of these tests will be available in mid-1994.
2. Tunnel tests with powered flying models will be used to examine wake encounters behind a fixed wing in a NASA-LaRC wind tunnel. Preliminary results of these tests will be available by late 1994.
3. A heavily instrumented OV-10 aircraft (for which the roll inertia can be varied to simulate a wide range of commuter aircraft) will be used to evaluate large and commuter aircraft wake encounters and potential changes in weight class boundaries or number of aircraft classes in 1995.

3.4.2 MID-TERM

For the medium term (five years or less), the NASA program has four elements:

1. The development of a wake-vortex-encounter hazard algorithm and a simulation methodology for establishing a safe separation distance for any given pair of aircraft. The schedule for the completion of this effort is late 1995.
2. The development of a validated weather-related wake-vortex transport and decay model for use in determining when wake-vortex-imposed separations are not required. Validation of this effort is scheduled for late 1995.

3. The development of ground-based and/or airborne vortex detection technology to serve as a tactical safety net if needed for use with vortex forecasting. This work is scheduled for completion in 1996.

4. The design, fabrication, deployment, and performance evaluation of the AVOSS concept. This work is scheduled for completion by 1998-1999.

3.4.3 LONG TERM

Upon completion of operational evaluation and demonstration of the AVOSS concept, NASA, in cooperation with the FAA, will assess operational readiness, and provide design criteria and guidelines for FAA development of a prototype AVOSS.

In addition, NASA's Advanced Subsonic Technology Program includes a goal of developing wake prediction and high-lift flap system design methods which can be introduced into aircraft for maximum performance, low noise, and minimum wake hazard. The time frame for implementation of this technology is greater than 10 years. This is the only program goal of NASA which does not totally parallel the FAA goals for this program. This is reasonable, as the FAA, as well as the aviation community, has looked to NASA for development of alleviation techniques.

3.5 INDUSTRY WAKE-VORTEX PROGRAM ACTIVITIES

The major role of industry will be in the areas of training, data base analysis, design, and implementation. In the near term, emphasis will be in the areas of education and training, instrumentation, field testing, and database development. Longer term participation, through government partnership, will include prototype development for both semi-automatic and automatic systems, installation, and independent verification and validation procedures.

4. PROGRAM IMPLEMENTATION

4.1 REQUIREMENTS

The basic requirements and planning assumptions common to any wake-vortex system or changes to operational procedures are as follows:

1. ***User Involvement.*** The success of prior programs, such as the successful Wind Shear Program, was based on participation of the whole aviation community and a process of information exchange within the industry. This process will continue. Offices of Air Traffic and Flight Standards, and the Office of System Capacity have been participants in the formulation of this plan. Participation will be expanded to include other members of the aviation community.

2. ***Effectiveness.*** The product must provide a meaningful measurable improvement in airport and system capacity.

3. ***Performance.*** The current IFR level of integrity and safety must be maintained and is a part of the program goal. Vortex sensors will verify system performance in all demonstration activities and may become an integral part of some systems.

4. ***Workload.*** This program will consider controller and flight crew workloads with the intent of precluding any impact on these workloads. It is expected that results of this program will complement FAA automation programs and therefore support increased productivity.

5. ***International.*** U.S. citizens do not fly solely on U.S. airlines or aircraft, or solely in U.S. airspace. However, they are the most traveled passengers in the world. They fly on many different types of airplanes from, and in, many different countries. Therefore international acceptance of program results is necessary. Thus, this program will proceed in the same manner, internationally, as was done during the recently completed successful Wind Shear Program.

6. ***Operations and Maintenance.*** This program will develop such requirements as may be needed for operations and maintenance of any system, interfaces, or equipment developed in the course of the program. The program will also develop a recommended maintenance concept if required.

4.2 ACTIVITIES

4.2.1 Training and Education

One of the first tasks to be undertaken in the current program will be a review, analysis, and assessment of the various existing capacity studies and simulations to assess their validity for deriving realistic potential benefits of the program. If the existing capacity methodologies prove to be inadequate for predicting the effects of wake-vortex separation changes, they will be expanded to meet these requirements. In concert with these efforts, comprehensive education and training techniques will be developed to assure that current standards, procedures, and recommended practices are fully understood. This is an important aspect of the program. As changes are recommended, the training and education program will be modified to reflect these changes.

4.2.2 Capacity Analysis

In order to determine the potential benefit of any vortex capacity improvement concept, the expected capacity change must be quantified. A number of airport capacity studies have been conducted over the years. In addition, a number of simulations have been designed and implemented in order to determine the sensitivity of runway and airport capacity to a number of variables, such as longitudinal spacing between aircraft.

One of the capacity issues to be studied is the difference in capacity during IFR and VFR operations. Standards established for IFR will be reviewed from both safety and capacity standpoints. The difference in capacity under VFR and IFR is the driving force behind the overall program, where the goal is to achieve VRT capacity levels under IFR operations.

The airport capacity model selected will be validated by comparing its predictions with airport operations data. The Air Route Traffic System (ARTS) surveillance data tapes for selected airports will be analyzed to provide validated capacity data and to determine the differences in airport operations under IFR and VFR.

4.2.3 Parallel-Runway/Intersecting-Runway System

A Parallel-Runway System aimed at the reduction of longitudinal approach separations by means of parallel runways separated by less than 2500 feet is under evaluation in Frankfurt, Germany. The mode of operations will depend upon the magnitude and direction of crosswinds. This work will be assessed for contributions to this program.

This system may be adapted to increase capacity at airports with intersecting runways, such as La Guardia and St. Louis where the capacity of the landing runway is adversely affected by departing aircraft. The Converging Runway Display Aid (CRDA) is being operationally evaluated at St. Louis.

4.2.3.1 Parallel-Runway System Definition

Under current IFR procedures, parallel runways separated by less than 2500 feet must be treated as a single runway for wake-vortex longitudinal separation purposes. This is due to the possibility that the vortex from one runway might be transported to the other runway. Thus, a Large aircraft landing behind a Heavy aircraft must ordinarily maintain a five-mile separation, no matter on which runway the two aircraft land.

Germany is developing a Parallel-Runway System for application at Frankfurt Airport where the runways are separated by 1700 feet. The system will use measurements and predictions of the crosswind to reduce longitudinal separation. Studies indicate that a minimum time of 20 minutes is required for the prediction of crosswinds. The following three conditions apply:

1. ***Crosswind speeds so low that vortices will not travel from one runway to the other.*** Aircraft simply alternate runways.

2. ***Crosswind speeds so high that the vortices will leave the region of one runway before the next airplane arrives at 3-mile separation.*** Aircraft simply land in sequence on one runway.

3. ***Intermediate crosswind speed values.*** The Heavy aircraft land on the downwind runway and Large aircraft land on the upwind runway.

Where two modes of operation are possible, the system will be designed to provide preferred options to the controllers for selection of the mode that is most likely to persist. This will require consideration of both current and forecast meteorological conditions.

4.2.3.2 Intersecting-Runway System Definition

The cross-vortex encounter experienced for perpendicular runways is quite different from the axial-vortex encounter of concern for single and parallel runways. Calculations indicate that large vertical accelerations may be experienced. Since vortex transport will control the location of such vortex encounters, the parallel-runway system may be useful for preventing cross-vortex encounters in intersecting runway operations. Algorithms for predicting potential encounters will depend upon the detailed runway geometry. Validated transport and decay models (in and out of ground effect) will be critical for gains in this area. Full understanding of these transport and decay characteristics of vortices may be useful in the development of modified procedures to assure that the crossing aircraft is at least at or above the level of the vortex generating aircraft. This is an area where sensors may be useful.

4.2.3.3 Review of Existing Data

Available vortex lateral transport data will be reviewed and compared to assess whether the data and the algorithm(s) are consistent. The dependence of the algorithm on runway spacing will be determined and a tentative system algorithm will be defined. Work is already under way to consolidate and publish previously unpublished data. Previous work included a vortex encounter model for parallel runways that may be used as part of the safety analysis for the Parallel-Runway System.

4.2.3.4 System Implementation

The system concept will be validated for both safety and improved capacity by demonstration at an appropriate airport. The selected airport(s) should have parallel runways spaced at less than 2500 feet, be limited in capacity, and have enough terrain to locate vortex sensors in the approach region both between and outside the runway centerlines. The goal is to select an airport that is scheduled for CTAS installation.

As a part of the international coordination for the program, the forecast algorithm under development at Frankfurt, Germany will be used as a starting point. Using the Frankfurt algorithm as a basis, a 20-minute wind forecast algorithm will be developed by the program team for evaluation at the demonstration airport. The Low-Level Windshear Alert System (LLWAS) could be one source of data for this study.

Once the airport evaluation process is completed, and if the capacity analysis shows system feasibility, system installation will be initiated. When installation is completed, system test, evaluation, and demonstration will be conducted.

4.2.4 Single-Runway Separation Standards

Methods for improving single-runway capacity will be examined. Current separation standards consist of two parts: aircraft classifications (Heavy, Large, Small) and the separations required between classes for various operations; and the good practices recommended in the AIM. As the program progresses, different opportunities for changes will be examined. One example of such an opportunity would be a change in the number of weight classes, which may provide the opportunity for reduced separations between specific aircraft pairs.

In the long term, automated traffic control systems, for example, the Center TRACON Automated System (CTAS), will be able to define the arrival times of aircraft at the runway threshold to within a few seconds. In this environment, runway capacity can be increased by refining the wake-vortex separation requirements to specify required time separations (to the second) for each pair of aircraft types. Since current aircraft classes include a wide variety of aircraft sizes, the required separations must be conservative enough to apply to the largest leading aircraft of a class and the smallest following aircraft of a class. Runway time is therefore wasted for other members of the leading and following classes. Note that the separation times that will be used for CTAS are more in harmony with the nature of wake-vortex decay than the distance separations used for manual air traffic control (ATC). In this effort, the goal is to achieve VFR capacity under IFR operations.

4.2.5 Separation Consideration

4.2.5.1 Manual Air Traffic Control Separations

Various schemes such as development of alternative weight classifications that may be required for Heavy aircraft and new large aircraft now on the drawing board are under evaluation. Reducing separations for lighter-weight categories would allow some capacity gains. Improved models and quantification of the wake-vortex hazard should provide the means for determining new separation standards to achieve these gains while maintaining the current high levels of safety. Emphasis must be placed on the recommended flying practices of the AIM and on the support of flight crews in meeting wake-vortex procedures.

4.2.5.2 Automated Air Traffic Control Time Separations

Automated ATC systems (e.g., CTAS) will permit aircraft time separations to be individually tailored for each aircraft pair. As the automated systems are ready for implementation, fully developed and validated transport and decay models will permit sophisticated separation matrices to be introduced. This should result in increased capacity under IFR operations and increased safety under VFR operations.

4.2.5.3 Takeoff Separations

Previous studies have emphasized landing operations. Takeoff separation standards that may be required will also be evaluated. The newly developed models will be used to evaluate separations of departing pairs. For example, the U.K. is currently permitting departures of a B-747 following a B-747 to be one minute apart. Takeoff operations may permit the use of pair separations defined to the second without ATC automation. This may be accomplished by allowing flight crews to time their departures according to the preceding aircraft type.

4.2.5.4 Safety Analysis

The safety analysis, Section 5.2, used to analyze separation standards is strongly dependent upon the validity of the vortex hazard and decay models that are used. A number of improvements have been made in the models; some of these will require additional vortex decay data. The safety analyses will be repeated whenever the models are updated. The following work can be carried out without additional vortex data:

1. The NASA effort on vortex hazard will lead to more realistic vortex-hazard models and play a more integral part in achieving a wake-vortex prediction capability.

2. The existing databases of landing and takeoff vortices (measured with an acoustic sensor and laser doppler velocimeters) will be further processed to improve existing vortex decay models.

3. Recently collected data and new data on aircraft types will be analyzed and compared with earlier data and theoretical predictions to validate the prediction model. This validated model will be used to assess the classification of existing and new aircraft types.

4.2.6 Wake Vortex/Meteorological Sensors

4.2.6.1 Vortex Sensors

The requirement for sensors and their development, where necessary, is carefully planned in the wake-vortex portion of the NASA TAP Program. The selection of required sensors is scheduled to be complete in 1996. The emphasis of the TAP Program is on continued development of the sensors that were developed during the windshear program (lidar and doppler radar). In addition, sensors suitable for detection of wake vortices during the final mile of approach will be evaluated. Lidar studies have already determined the ability of lidar to detect vortices. Certain program goals and requirements, such as the detecting, locating, tracking, and quantifying of wake vortices, require a degree of maturity not yet demonstrated by existing sensors.

4.2.6.2 Meteorological Sensors

The transport and decay of wake vortices are believed to be primarily functions of wind, vertical wind shear, turbulence, and stratification of the atmosphere along and under the path of the generating aircraft. The requirements for and development of meteorological sensors to adequately measure these meteorological phenomena are currently under way with a schedule consistent with vortex sensor development and vortex transport and decay modelling efforts.

4.2.7 Aircraft Vortex Spacing System (AVOSS)

The AVOSS concept will provide adaptive separation requirements in the automated ATC environment of CTAS. AVOSS will be designed as a total airport system including single-, parallel-, and intersecting-runway operations. Deployment of candidate technology resulting from this program will be based on criteria developed from a cost-benefit analysis.

The AVOSS concept will use real-time meteorological data from meteorological sensors and the Integrated Terminal Weather System (ITWS) and real-time vortex measurements to reduce the required time separations, when permitted by meteorological conditions, for both parallel-runway and single-runway operations. In the AVOSS time frame, variable separations can be provided to the automated control systems (e.g., CTAS). The AVOSS concept is thus a more general version of the Parallel-Runway System that will be designed to operate in an automated ATC environment. A version of the AVOSS concept for manual ATC or current weather systems will be defined in the event that CTAS or ITWS is not available when AVOSS is ready for demonstration.

4.2.7.1 System Definition

4.2.7.1.1 Parallel Runway/Intersecting Runway

The parallel-runway application of the AVOSS concept will interface with CTAS and use real-time vortex measurements and/or predictive models along with meteorological measurements as required to improve vortex behavior predictions. More sophisticated separation algorithms will go beyond the simple effects of the ambient wind on vortex transport effects, and will include the effects of other weather parameters on vortex-decay. Refined algorithms for dealing with specific aircraft pairs will also be developed.

4.2.7.1.2 Single Runway

The single-runway separation algorithm will adjust separations according to both weather data obtained from meteorological sensors and the ITWS and vortex sensor measurements. The data required to develop and justify adaptive separation algorithms will be collected at the single-runway demonstration airport.

4.2.7.2 Meteorological Effects and Parameter Forecast

An analysis of the existing U.S. databases on vortex decay to assess meteorological effects is currently under way. This analysis includes the data and results of a previous analysis of O'Hare landing data which showed little change in vortex lifetime during normal working hours (0800-1600 hours). In contrast, longer lifetimes were noted early in the morning and at night in the Idaho Falls and DFW data collected in 1990 and 1991. One of the results of this analysis is the justification of additional data collection to improve our understanding of the variations in wake-vortex lifetime at specific high-density traffic airports under a variety of meteorological conditions.

Data will be collected from the selected parallel-runway and single-runway test airports to improve our understanding of how meteorological parameters affect wake vortices. The primary improvements of this effort will be in obtaining this data around the clock and the collection of data from new aircraft types for which there is no data.

Use of meteorological parameters for predicting separation requirements is an area that will be addressed. Certain site-specific data may be required and any special instrumentation needed for this data would become a part of the AVOSS.

4.2.7.3 Implementation

The AVOSS concept is part of the automation package to be used in an adaptive separation system and as such will be implemented towards the end of this joint program. The potential requirements for interfacing with other programs such as ITWS and CTAS need to be ascertained as early as possible in order that tasks can be assigned/modified.

5. PROGRAM SPECIAL CONSIDERATIONS

5.1 AUTOMATIC DATA COLLECTION AND ANALYSIS

All past wake-vortex studies have been labor intensive in both the data collection and the data reduction phases. This limitation has resulted in the following problems:

1. Data were collected only at certain times of the day or for limited periods of time. Existing databases therefore do not contain data acquired under rare conditions (e.g., fog) or at inconvenient times (e.g., night). Data on rare aircraft types are also limited.
2. Statistically significant results of data reduction have not been available until long after the data collection had been completed.
3. Some data reduction procedures were so arduous that the measurements were simply never processed.

Efforts will be made to develop both automated data collection and a near real-time data reduction and analysis capability. Therefore, statistics of the data collection will be available in near real-time and proper decisions can be made about the data collection process. Moreover, this automation is required for an operational system. This will prepare the way for the automatic data processing required for the final vortex system. The only possible loss associated with real-time processing is that improved processing algorithms may be developed by a later date. To avoid this problem, selected raw data will be saved for subsequent off-line processing. The automated data collection will be augmented through use of information gained from questionnaires and data sheets for users (i.e., flight crews and controllers).

5.2 SAFETY ANALYSIS

Changes in vortex procedures must be justified by a safety analysis that is convincing to the public as well as the users of the system. Increases in separations have been relatively easily justified on the basis of perceived increased safety. Decreases in separations are more difficult to justify since they may be perceived to result in reduced levels of safety. Four rather different approaches have been proposed for evaluation of reduced IFR separations. The first two apply only to weather-dependent separation standards and allow no vortex encounters, while the second two can be applied to either fixed or weather-dependent separation standards and maintain the existing level of vortex encounters:

1. Perhaps the most convincing is the demonstration and calculation that the ambient wind will consistently remove wake vortices from the path of the following aircraft (single runway), or will not cause vortices to drift into the path of the following aircraft (parallel runways). While it is well known and understood that vortices can be transported by winds, little is known of the impact of this knowledge when applied to an operational system.
2. Vortex decay is less well understood than vortex transport due to winds. Therefore, if a vortex is not removed from the path of the following aircraft by winds, only decay can eliminate the vortex. This safety analysis method identifies the weather conditions which result in the absence of hazardous vortices remaining at the time of arrival of the next aircraft.
3. The probability of wake vortices remaining hazardous at the time of arrival of the following aircraft under the existing separation standards is quantifiable once a hazard criterion is developed. Since no accidents have occurred when existing standards and recommended practices were followed, the level of "hazard probability" must have been operationally safe. This safe level can then be used as a first estimate to assess the vortex safety of other separation standards. The method to be used is based on vortex decay models derived from vortex measurements and on current vortex hazard models. Improvements and validation for these models will increase user confidence in the results of the safety analysis.

4. A method used by air traffic for justifying a reduction in IFR separations is a comparison with the actual aircraft separations used by pilots under Visual Flight Rules (VFR) operations. Air Traffic developed a formal demonstration method for validating the safety of such reduced separations and used it to justify the adoption of 2.5-mile separations on the final approach within 10 miles of the airport for certain aircraft types at airports where the runway occupancy time is 50 seconds or less (reference 10). Heavy aircraft and the Boeing B-757 are permitted to participate only as the trailing aircraft. The wake-vortex safety of such operations was originally demonstrated at several airports by conducting 500 landings at 2.5-mile separations by volunteer pilots. The test was to be stopped in the event of any reported wake-vortex encounters. Wake-vortex sensors and video monitoring will be used in future demonstration programs involving reduced separations to provide objective information relating to any reported encounter.

The combination of more than one safety approach is worthwhile. For example, the separation model of item 3 was used to evaluate the 2.5-mile separations that were primarily justified by demonstration (item4). The program tests and demonstrations at test airports will include wake-vortex sensors. Such sensors, however, may or may not become part of the final system.

A demonstrated wake-vortex detection and avoidance system must maintain existing safety levels that have been achieved under IFR, approach the goal of capacity levels of VFR under IFR, and produce fewer wake-vortex incidents under VFR than currently experienced by flight crews. This result will be independent of planned MLS curved approaches and/or precision Global Positioning System (GPS) approaches which will require separate evaluation for wake vortex considerations.

5.3 WORKLOAD ANALYSIS (HUMAN FACTORS)

Two basic approaches are available for developing the procedures associated with a new system and determining their workload impact:

1. If recommended changes are perceived as incremental to existing operations, then the procedures and impacts can be assessed through evaluation by the operational personnel involved. The system can then be installed and operated off-line to train the operational personnel in the use of the system and later operated on-line as a demonstration of system performance. This approach is advantageous since the time and cost is much less than that of the second approach, which follows.

2. The most complete method of assessing the impact of a new system requires that training personnel evaluate it in a complete ATC simulation where both controllers and pilots use the new system. This approach will be necessary if the proposed changes are not perceived as incremental.

6. SYSTEM INTERFACES

6.1 WEATHER SYSTEMS

In the near term, vortex systems must interface with individual existing weather systems (e.g., LLWAS) using additional meteorological sensors to augment the required meteorological data. In the long term, integrated airport weather data will likely be required (e.g., ITWS).

6.2 AIR TRAFFIC CONTROL SYSTEMS (E.G., CTAS, ETMS, AERA)

Conservative adjustments in separation standards expected as intermediate products of this joint effort will be recommended as procedural changes with the express intent of maintaining controller workload at current levels. The end goal of this activity is the inclusion of these products in the final results of the TAP program and an automation system maximizing operating efficiencies.

6.3 COCKPIT TECHNOLOGY

Provisions will be provided for crew training, airborne sensors (if required), data link interfaces, FMS interfaces, operations procedure development, and human factors considerations in the same manner as was done for the Wind Shear Program.

7. PROGRAM PRODUCTS

The following sections list the program products according to the time frame. Capacity improvements are presented in boldface.

7.1 NEAR TERM (1994-1996)

1. A training program that will be developed in 1994, based upon the present air traffic procedures and upon the recommended practices of the Airman's Information Manual. The training program will be coordinated with users, industry, flight crews, and the appropriate flight standards and air traffic control offices of the FAA. Training will be modified as required by developments of the program.

2. Validated methodology for:
   a. Quantification of the difference between VFR and IFR capacity
   b. Quantification of the capacity gains from wake-vortex solutions

3. Exploration of interim enhancements for the air traffic control system. These include identification of wind levels suitable for reduced separations consistent with wake vortex considerations for both single- and parallel-runway operations. In addition, reduction in separation standards as a result of modified classification of aircraft will be assessed. Suitable wind levels for single- and parallel-runway operations and modified aircraft classifications along with modified separation standards will be recommended by mid-1994.

4. Development of a relational data base of all applicable wake-vortex data already gathered for use by the program team members and the scientific community.

5. Selection of parallel-runway, converging-runway, and single-runway demonstration airport with baseline definitions of VFR and IFR capacity for each and predictions of the performance of baseline wake-vortex solutions.

6. **Implementation of parallel-runway system at demonstration airport.**

7. Report on separation standards methodology.

8. Establishment of new single-runway separation standards.
   a. Manual air traffic control
   b. Automated air traffic control

9. Report on how meteorological conditions affect duration of vortex hazard.
   a. O'Hare data
   b. Idaho Falls, DFW data
   c. NASA-MIT/LL tests performed in 1994

10. AVOSS System Requirements.

11. Vortex sensing technology assessment
    a. Status of current sensors
    b. Recommendations for parallel-runway and single-runway vortex sensors
    c. Recommendations for development leading to AVOSS vortex sensors

12. Meteorological sensing technology assessment
    a. Status of current sensors
    b. Recommendations for support of parallel-runway and single-runway operational system concepts
    c. Recommendations for support of AVOSS

7.2 MID-TERM (1997-1998)

1. Evaluation of capacity gains relative to predictions for a parallel-runway system and new single-runway separation standards. Assessment of capacity gains at all other airports where these methods may be deployed.

2. **Demonstration of new separation standards at the single-runway demonstration airport, including single-runway vortex sensor for validation.**

3. Predicted capacity gains of AVOSS at parallel-runway and single-runway demonstration airports.

4. System specification for parallel-runway system (if decision to deploy).

5. AVOSS baseline system definition.
    a. Separation algorithm
    b. Vortex sensor requirements
    c. Meteorological data requirements/forecast algorithm

6. Development of AVOSS vortex sensors.

7. Development of AVOSS meteorological sensors

7.3 LONG TERM (1998 +)

1. **AVOSS implementation at parallel-runway and/or single-runway demonstration airports.**

2. AVOSS demonstration.

3. Evaluation of capacity gain relative to predictions for complete AVOSS demonstration systems.

4. Assessment of capacity gains at all other airports where complete/partial AVOSS systems may be deployed.

8. MILESTONES TO ACHIEVE PRODUCTS

1994

- Benefit analysis (parallel/converging-runway reduced separation distances), early 1994
- Training Program initiation, early 1994
- Interim recommendations for revised aircraft classification and separation standards, mid-1994
- Recommendation of interim wind level/reduced aircraft separations for single- and closely spaced parallel-runway operations, mid-1994
- Assessment of current separation/classification criteria (U.S., U.K., Germany, ICAO), mid-1994
- Rationale for current separation standards (VFR & IFR), mid-1994
- Initiation of development of wake-vortex database, mid-1994
- Measurement of wakes during final mile of approach, mid-1994
- Application of anemometry to collect wind data during final mile of approach, mid-1994
- Evaluation of ARTS data, mid-1994
- Re-assessment of NOAA Idaho Falls data, mid-1994
- Validation of airport selection criteria and confirmation of airport selection, mid-1994
- Operational readiness of field facility for measurements of effects of meteorological conditions on wake-vortices, late 1994
- Scattering mechanisms for microwave and laser illumination of wakes, late 1994
- Updated empirical wake-vortex decay model, late 1994
- Initial AVOSS functional requirements, late 1994
- Close-spaced parallel runway safety analysis, late 1994
- Workshop to exchange information, mid-1994
- *Wake-Vortex Program review, late 1994*

1995

- Wake Vortex Sensor requirements, early 1995
- Meteorological sensor requirements, early 1995
- Determination of current controller/pilot workload criteria, early 1995
- Report documenting measurements describing meteorological effects on wake vortices, mid-1995
- Revised aircraft spacing/classification recommendations, mid-1995
- AVOSS functional requirements defined, mid-1995
- Wake-vortex hazard criteria based on sensor measurables, mid-1995
- Wake-vortex transport and decay model in ground effects (3D), mid-1995
- Initial revised approach procedures consistent with AVOSS requirements, late 1995
- Candidate wake-vortex prediction algorithm defined, late 1995
- Initial adaptive separation criteria, late 1995
- Sensor technology selection, late 1995
- Meteorological sensor technology selection, late 1995
- Determination of feasibility of modifying existing separation standard for single-runway configuration, late 1995
- Development of demonstration plan for single- and parallel-runway concepts, late 1995
- Simulation of independent parallel-runway concept, e.g., using St. Louis airport data, late 1995
- International user conference to exchange information, mid-1995
- Wake-Vortex Program review, late 1995
- Continuation of field measurements program, throughout 1995

1996
- Adaptive separation algorithm defined, early 1996
- Wake-vortex detection hardware/software final design and initiation of sensor build, mid-1996
- Adaptive separation criteria for CTAS automation, mid-1996
- Implementation of parallel runway system at demonstration airport, mid-1996
- Demonstration of modified separation standards for single-runway operations, mid-1996
- System concept simulation to evaluate adaptive separation procedures and quantify capacity impact, late 1996
- User conference, late 1996
- Wake-Vortex Program review, late 1996
- *Continuation of field measurements program, throughout 1996*

1997
- Completion of take-off separation standards criteria, mid-1997
- Wake Vortex transport, decay, and hazard prediction subsystem validation, mid-1997
- Wake-vortex detection system operational, late 1997
- Initial wake-vortex detection system field experiments, late 1997
- User conference, late 1997
- Wake-Vortex Program review, late 1997
- *Continuation of field measurements program, throughout 1997*

1998
- Validation of wake-vortex integrated detection and prediction system, late 1998
- User conferences, late 1998
- *Wake-Vortex Program review, late 1998*

1999
- Demonstration of operational feasibility of AVOSS concept (linked to A-109), mid-1999
- Release of AVOSS system design guidelines for operational implementation, late 1999
- *User conference, late 1999*
- Wake-Vortex Program review, late 1999

9. SCHEDULE

The schedule of activities is shown in Figure 4. The primary key decision point is shown to occur in 1994. The milestone schedule by financial year (FY) is shown in Figure 5.

10. WAKE-VORTEX PROGRAM MATRIX TEAM

The Wake Vortex Program will proceed in the same manner as that of the completed windshear program. The organization will be that of a matrix team. The members of this team are FAA, NASA, John A.Volpe National Transportation Systems Center, MIT Lincoln Laboratory, and industry. This matrix team is illustrated in Figure 6.

11. MILESTONE INTERRELATIONSHIPS

The interrelationships of the Wake-Vortex Program Plan milestones are illustrated in Figure 7. In addition to the interrelationships, this figure illustrates the relationship of the FAA Wake-Vortex Program Steering Committee to the technical elements of the program. Note that the Memphis (MEM) field measurements are indicated both by a solid block and a dotted block. This indicates that the MEM (or other airport) field measurements will continue throughout the development phases of the program.

APPENDIX A

SUMMARY OF PROGRAM GOAL AND OBJECTIVES

GOAL:

- To support increased system capacity

OVERALL OBJECTIVE:

- To remove wake vortices from the separation "equation"

SPECIFIC OBJECTIVES:

- To identify and validate aircraft classification requirements
- To reduce separation standards
  - Single-runway operations
  - Parallel-runway operations
  - Converging-runway operations

APPENDIX B

REFERENCES

1. Airman's Information Manual.

2. "NASA Wake-Vortex Research," AIAA Paper 93-4004, by H. Paul Stough, III, et al., presented at the AIAA Aircraft Design, Systems, and Operations Meeting, August 11-13, 1993, Monterey, California.

3. Memorandum of Agreement between DOT/FAA and NASA Concerning Wake-Vortex Systems Research.

4. 7110.65H Air Traffic Control

5. Hallock, J. N. *Aircraft Wake Vortices: An Assessment of the Current Situation.* Report No. DOT-FAA-RD-90-29, January 1991.

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7. Wood, William D., ed. *FAA/NASA Proceedings Workshop on Wake Vortex Alleviation and Avoidance.* Report No. FAA-RD-79-105, U.S. Dept. of Transportation, November 28-29, 1978.

8. Garodz, L. J. *Federal Aviation Administration Full-Scale Aircraft Vortex Wake Turbulence Flight Test Investigations: Past, Present, Future.* AIAA 71-97, 1971.

9. Hallock, J. N. *Aircraft Wake Vortices: An Annotated Bibliography (1923-1990).* Report No. DOT-FAA-RD-90-30 or DOT-VNTSC-FAA-90-7, U. S. Dept. of Transportation, January 1991.

10. 7110.65H Air Traffic Control (CHG 1), paragraph 5.72f., page 5-5-2. Also see 7210.3K, Facility Operation and Administration (CHG-1), Paragraph 12-46, pages 12-4-3 and 12-4-4.

APPENDIX C

ILLUSTRATIONS

1. Calculated Inital Vortex Strength
2. Wake-Vortex Program Planning Methodology
3. Aircraft Vortex Spacing System (AVOSS) Concept
4. Program Schedule
5. Program Milestones
6. Wake-Vortex Program Matrix Organization
7. Wake-Vortex Program Plan Milestone Interrelationships

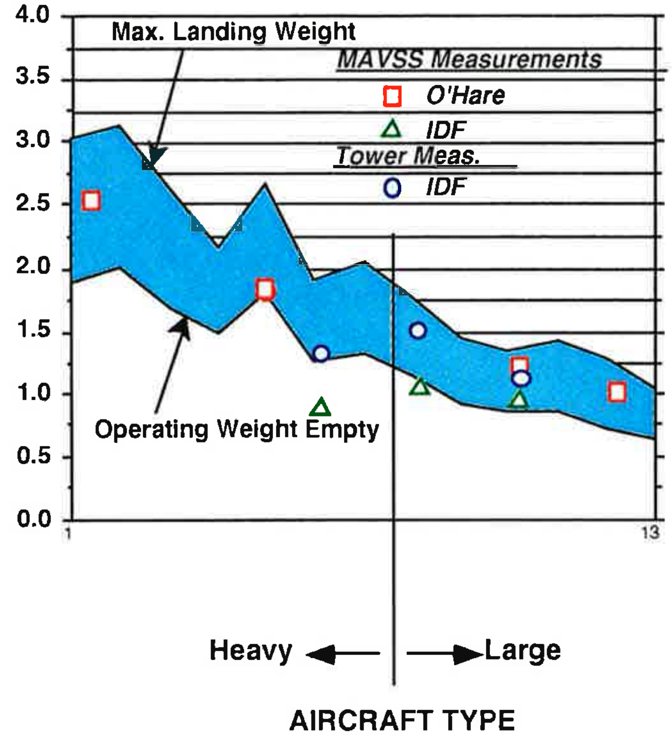

FIGURE 1. CALCULATED INITIAL VORTEX STRENGTH

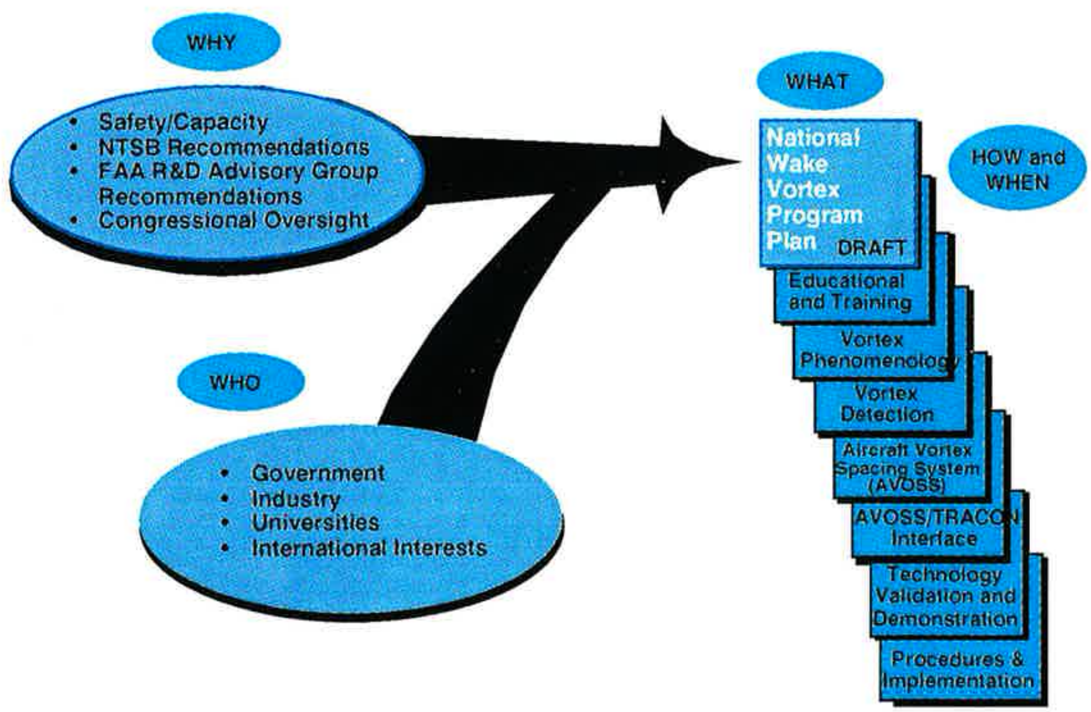

FIGURE 2. WAKE-VORTEX PROGRAM PLANNING METHODOLOGY

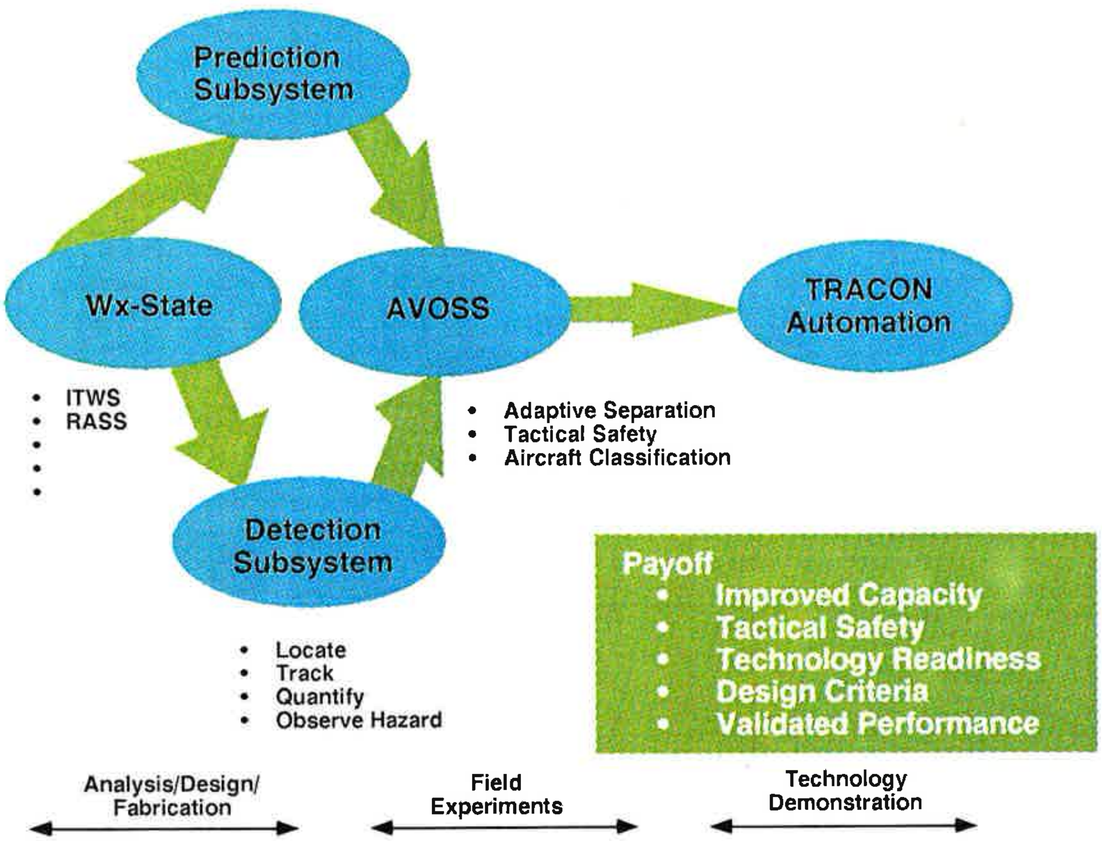

FIGURE 3. AIRCRAFT VORTEX SPACING SYSTEM (AVOSS) CONCEPT

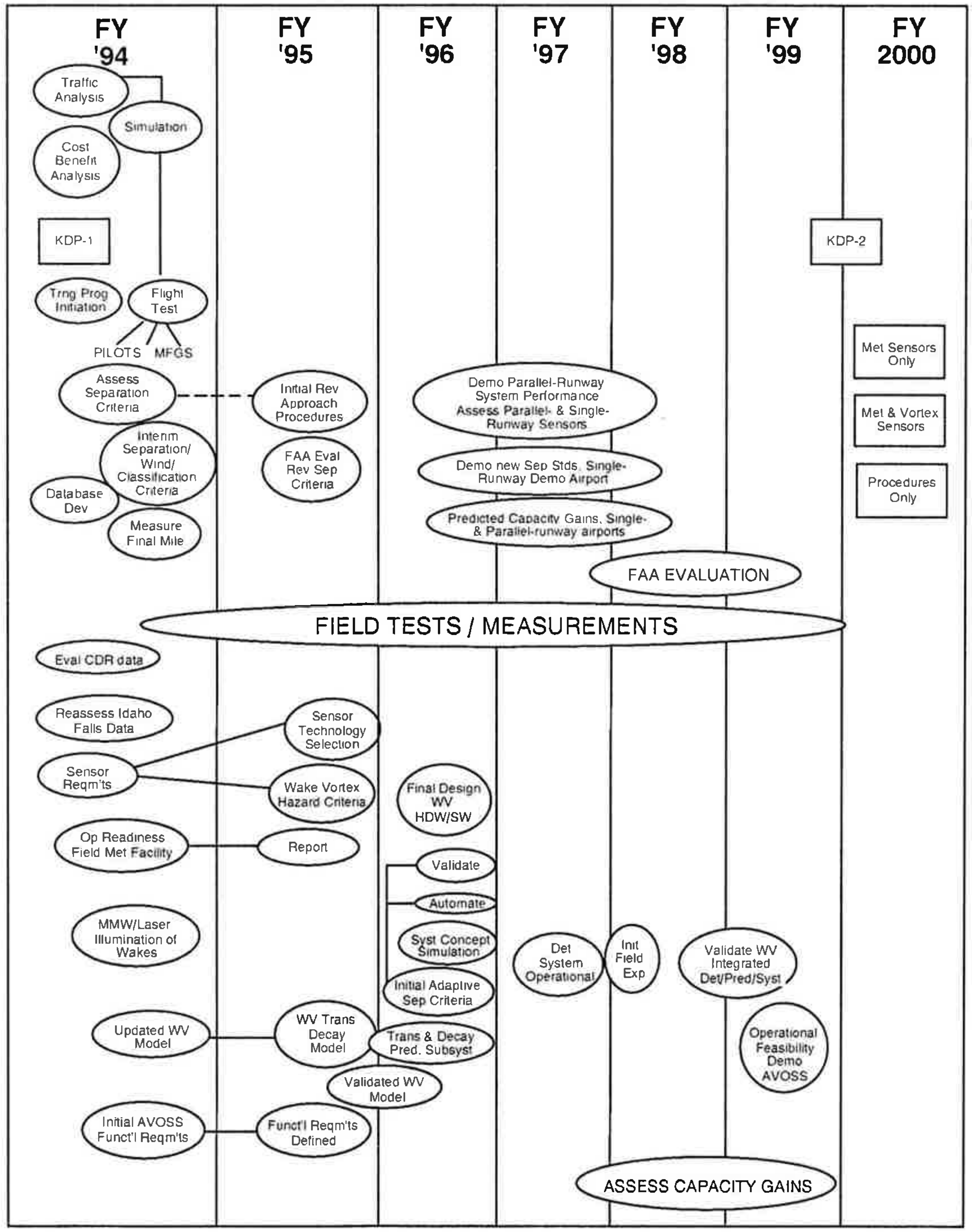

FIGURE 4. PROGRAM SCHEDULE

MILESTONES	1994	1995	1996	1997	1998	1999
Benefit Analysis	▼					
Training Program Initiation	▼					
Interim Revised Aircraft Classification/Separation	▼					
Wind Level/Reduced Separation, Single/Parallel Runway	▼					
Assess Current Separation/Classification Criteria (US, UK, ICAO, Others)	▼					
Rationale for Current Separation Standards (VFR & IFR)	▼					
Initiate Wake-Vortex Database	▼					
Wake Measurement Final Mile of Approach	▼					
Apply Anemometry Final Mile of Approach	▼					
Evaluate ARTS Data	▼					
Re-Assess NOAA Data	▼					
Demo Airport Selection	▼					
Meteorological Field Measurements Program	▼—	—	—	—▼		
Updated Empirical Wake Vortex Decay Model	▼					
Initial AVOSS Functional Requirements	▼					
Close-Spaced Parallel Runway Safety Analysis	▼					
User Conference	▼	▼	▼	▼	▼	▼
Wake Vortex Program Review	▼	▼	▼	▼	▼	▼
Wake Vortex Sensor Requirements		▼				
Meteorological Sensor Requirements		▼				
Controller/Pilot Workload Criteria		▼				
Report Meteorological Effects		▼				
Revised Aircraft Spacing/Classification Recommendation		▼				
AVOSS Functional Requirements		▼				
Wake-Vortex Hazard Criteria (Based on Sensors)		▼				
Wake-Vortex Transport/Decay Model in Ground Effect		▼				
Initial Revised Approach Procedures		▼				
Candidate Wake Vortex Predictive Algorithm		▼				
Initial Adaptive Separation Criteria		▼				
Sensor Technology Selection		▼				
Meteorological Sensor Technology Selection		▼				
Feasibility of Separation Standard, Single R/W		▼				
Develop Plan for Single- & Parallel-Runway Concepts		▼				
Simulation of Parallel R/W Concept		▼				
Adaptive Separation Algorithm			▼			
Wake-Vortex Detection Hardware/Software Design and Initiate Sensor Build			▼			
Adaptive Separation Criteria for CTAS			▼			
Parallel R/W System at Demo Airport			▼			
Demo Modified Separation Standards Single R/W			▼			
Systems Concept Simulation, Evaluate Adaptive Separation (Quantify Capacity Impact)			▼			
Complete T/O Separation Standards Criteria				▼		
Wake Vortex Transport, Decay, Hazard Prediction Validation				▼		
Wake Vortex Detection System Operational				▼		
Initial Wake Vortex Detection System Field Experiments				▼		
Validation of Wake Vortex Integrated Detection & Prediction System					▼	
Demo Operational Feasibility of AVOSS						▼
Release AVOSS System Design for Operational Implementation						▼

FIGURE 5. PROGRAM MILESTONES

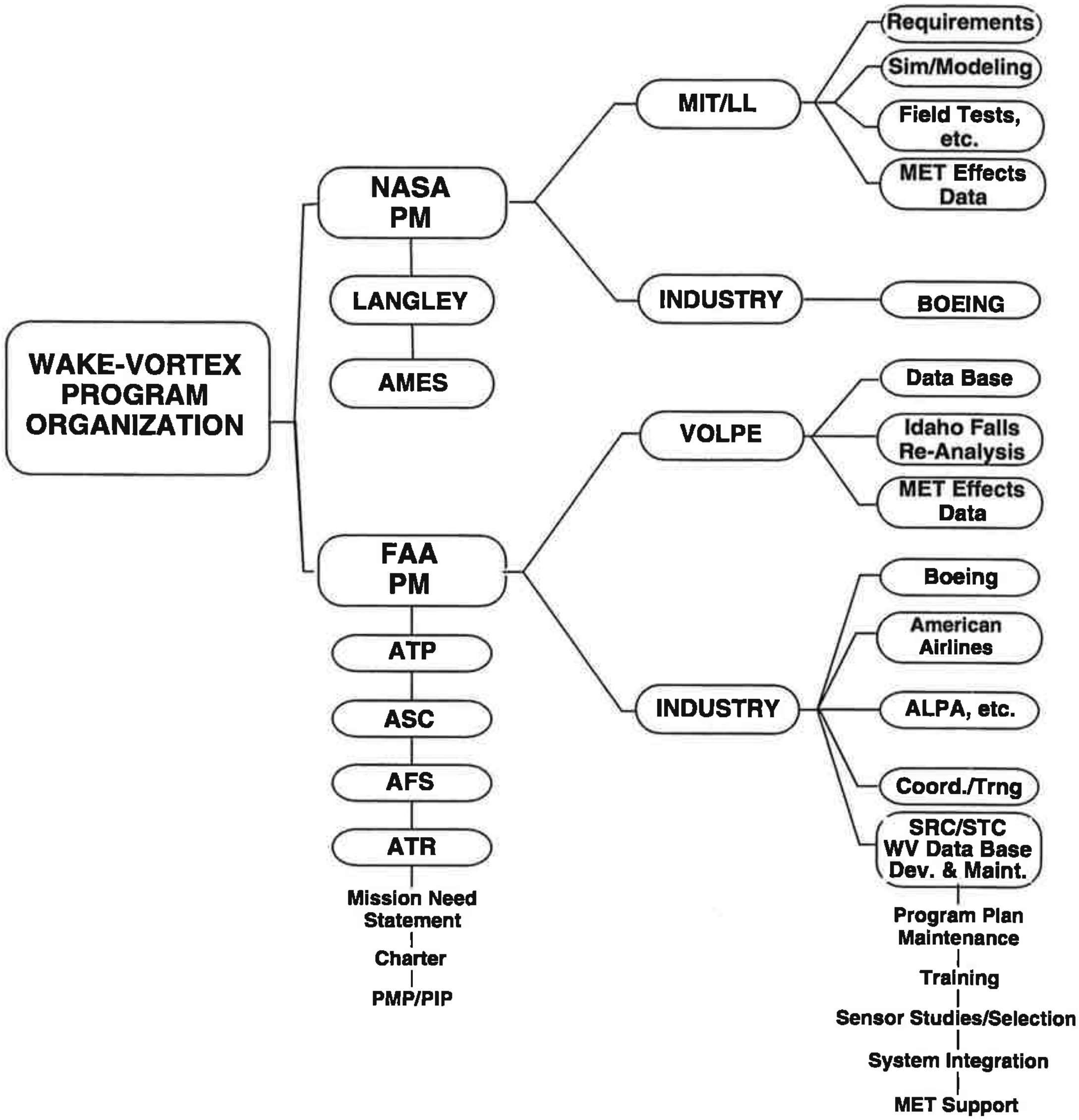

FIGURE 6. WAKE-VORTEX PROGRAM MATRIX ORGANIZATION

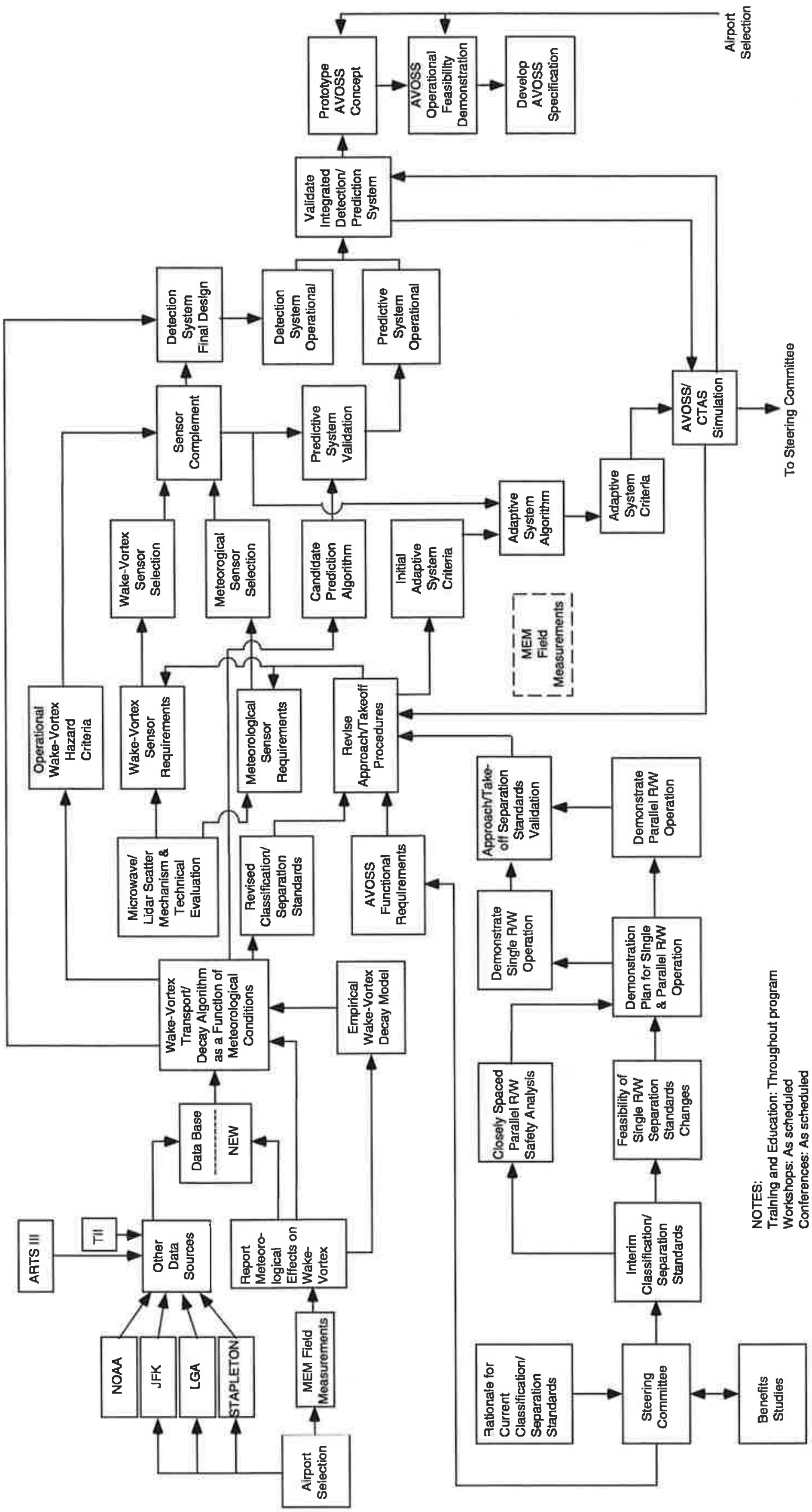

FIGURE 7. WAKE-VORTEX PROGRAM PLAN MILESTONE INTERRELATIONSHIPS

APPENDIX D

GLOSSARY OF ACRONYMS AND ABBREVIATIONS

AERA	-	Automated En Route Air Traffic Control
AFS	-	Flight Standards Service
AIM	-	Airmen's Information Manual
ALPA	-	Airline Pilots Association
App	-	Approach
ARTS	-	Air Route Traffic System
ASC	-	Office of System Capacity and Requirements
ASTA	-	Airport Surface Traffic Automation
ATC	-	Air Traffic Control
ATP	-	Air Traffic Rules and Procedures Service
ATR	-	Air Traffic Plans and Requirements Service
AVOSS	-	Aircraft Vortex Spacing System
CDR	-	Computer Data Recording
CRDA	-	Converging Runway Display Aid
CTAS	-	Center TRACON Automated System
CY	-	Calendar Year
Det	-	Detection
Dev	-	Development
DFW	-	Dallas-Fort Worth Airport
ETMS	-	Enhanced Traffic Management System
Eval	-	Evaluate
Exp	-	Experiment
FAA	-	Federal Aviation Administration
FMS	-	Flight Management System
FY	-	Fiscal Year
GPS	-	Global Positioning System
HDW	-	Hardware
ICAO	-	International Civil Aviation Organization
IDF	-	Idaho Falls Airport
IFR	-	Instrument Flight Rules
Init	-	Initial
ITWS	-	Integrated Terminal Weather System
KDP	-	Key Decision Point
LaRC	-	Langley Research Center
LDA	-	Localizer Directional Aid
LIDAR	-	Light Detection and Ranging
LLWAS	-	Low-Level Windshear Alert System
MAVSS	-	Monostatic Acoustic Vortex Sensing System
Met	-	Meteorological

MFGS	-	Manufacturers
MGT	-	Management
MIT/LL	-	Massachusetts Institute of Technology, Lincoln Laboratory
MLS	-	Microwave Landing System
MMW	-	Millimeter Wave
MOA	-	Memorandum of Agreement
NASA HQ	-	NASA Headquarters
NASA	-	National Aeronautics and Space Administration
NOAA	-	National Oceanic Atmospheric Administration
NTSB	-	National Transportation Safety Board
OMB	-	Office of Management and Budget
Op	-	Operational
PIP	-	Program Implementation Plan
PM	-	Program Manager
PMP	-	Program Master Plan
Pred	-	Prediction
Procs	-	Procedures
Prog	-	Program
RASS	-	Radar Acoustic Sounding System
Reqmts	-	Requirements
Rev	-	Revised
ROT	-	Runway Occupancy Time
SEP	-	Separation
SIM	-	Simulation
SRC	-	Systems Resources Corporation
STC	-	Science and Technology Corporation
Stds	-	Standards
SW	-	Software
Syst	-	System
TAP	-	Terminal Area Productivity
TATCA	-	Terminal ATC Automation
TR	-	Technical Representative
TRACON	-	Terminal Radar Approach Control
Trans	-	Transport
Trng	-	Training
UK	-	United Kingdom
US	-	United States
VAS	-	Vortex Advisory System
VFR	-	Visual Flight Rules
WV	-	Wake Vortex
Wx	-	Weather

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APPENDIX

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John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

This document is a comprehensive source for information on the subject of wake turbulence. The document is 386 pages in length and consists of abstracts of publications on this subject. The material is arranged alphabetically by author(s) and then by month and year of publication. Experimental and theoretical articles are included and consider the formation, structure, motion, and decay of vortices and their effect on penetrating aircraft.

Users of the Wake Turbulence Training Aid who desire additional and more extensive wake-turbulence information are encouraged to use this bibliographical source document. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161, Accession No.: ADA233161, Cost Code: PGA17 ($44.50). It is also available in microfiche for $17.50.

APPENDIX

Wake Turbulence Take-off Weight Categories and IFR Separation Distances

4-F

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Wake Turbulence Take-off Weight Categories and IFR Separation Distances (Tables 4-F.1, -2)

Category	FAA	United Kingdom	ICAO
Heavy	>300,000	>300,000	>300,000
Large	<300,000 >12,500	n/a	n/a
Medium	n/a	<300,000 >88,200	<300,000 >15,500
Small	<12,500	<88,200 >37,500	n/a
Light	n/a	<37,500	<15,500

Table 4-F-1
Wake turbulence maximum gross weight categories (pounds)

> = Greater than
< = Less than

Gross Weight Categories		Minimum Separation Distance (Nautical Miles)		
Leading Aircraft	Following Aircraft	FAA	United Kingdom	ICAO
Heavy	Heavy	4	4	4
Heavy	Large	5	n/a	n/a
Heavy	Medium	n/a	5	5
Heavy	Small	6	6	n/a
Heavy	Light	n/a	8	6
Large	Large	3*	n/a	n/a
Large	Small	4	n/a	n/a
Medium	Medium	n/a	3	3
Medium	Small	n/a	4	n/a
Medium	Light	n/a	6	5
Small	Light	n/a	4	n/a

Table 4-F-2
Wake turbulence instrument flight rules arrival separation distances

* As an interim measure, the FAA implemented procedures effective July 1, 1994, to require 4 nautical miles separation for small, large and heavy category aircraft following a B-757.

n/a Not applicable. Separation not based on wake turbulence.

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