FLIGHT SAFETY FOUNDATION

MARCH–APRIL 2002

FLIGHT SAFETY DIGEST

SPECIAL DOUBLE ISSUE

Data Show That U.S. Wake-turbulence Accidents Are Most Frequent at Low Altitude and During Approach and Landing

FLIGHT SAFETY FOUNDATION
SINCE 1947

Flight Safety Digest

Vol. 21 No. 3–4 **March–April 2002**

In This Issue

Cover photo: Dryden Flight Research Center, B-727 Vortex Study, U.S. National Aeronautics and Space Administration (NASA)

Flight Safety Foundation is an international membership organization dedicated to the continuous improvement of aviation safety. Nonprofit and independent, the Foundation was launched officially in 1947 in response to the aviation industry's need for a neutral clearinghouse to disseminate objective safety information, and for a credible and knowledgeable body that would identify threats to safety, analyze the problems and recommend practical solutions to them. Since its beginning, the Foundation has acted in the public interest to produce positive influence on aviation safety. Today, the Foundation provides leadership to more than 880 member organizations in more than 145 countries.

Data Show That U.S. Wake-turbulence Accidents Are Most Frequent at Low Altitude and During Approach and Landing

In wake-turbulence accidents and incidents from 1983 through 2000, about 10 percent of the aircraft weighed more than 30,000 pounds/13,600 kilograms, and two-thirds of the pilots held commercial pilot certificates or airline transport pilot certificates.

—

Patrick R. Veillette, Ph.D.

From January 1983 through December 2000, there were 130 aircraft accidents and 60 aircraft incidents in the United States involving wake turbulence (Figure 1; Figure 2, page 2).[1] Among these, there were 14 fatal accidents (11 percent of the total) and 20 serious-injury accidents (15 percent of the total). Thirty-five people were killed, 25 people were injured seriously, and 57 people received minor injuries; 36 of the accident aircraft were destroyed, and 76 accident aircraft received substantial damage.[2]

To identify trends involved in the accidents, the author conducted a study that included analysis of U.S. National Transportation Safety Board (NTSB) reports on the 130 accidents and U.S. Federal Aviation Administration (FAA) reports on the 60 incidents from 1983 through 2000. The study also included analysis of U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS)[3] reports involving 165 aircraft that were flown into wake turbulence between January 1988 and December 1999 (see Appendix, page 33).

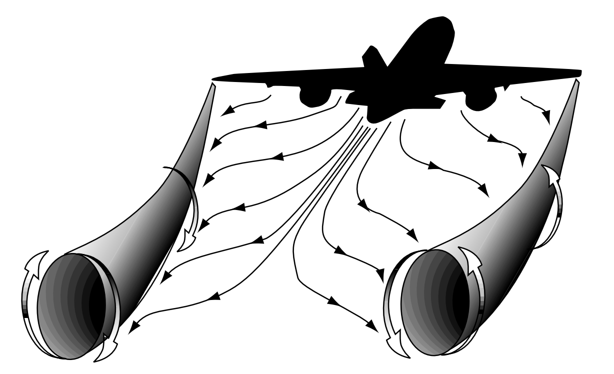
The study found that, of the 130 accidents in the NTSB database, the 60 incidents in the FAA database and the 165 events in the ASRS database:

- Seventy-four accidents (57 percent), 41 incidents (68 percent) and 106 events (64 percent) occurred during the approach-and-landing phase of flight (Table 1, page 2; Table 2, page 3; Table 3, page 3).[4] Twenty-four accidents (18 percent), 13 incidents (22 percent) and 37 events (22 percent) occurred during the takeoff phase of flight;

- Eighty-seven accidents (67 percent), 47 incidents (78 percent) and 78 events (47 percent) occurred as a result of wake turbulence at and below 200 feet above ground level (AGL [Figure 3, page 4; Figure 4, page 5, Figure 5, page 5]);

- Wake-turbulence accidents and wake-turbulence incidents most frequently involved small aircraft that were flown

Wake Vortex Formation



Source: U.S. Federal Aviation Administration

Figure 1

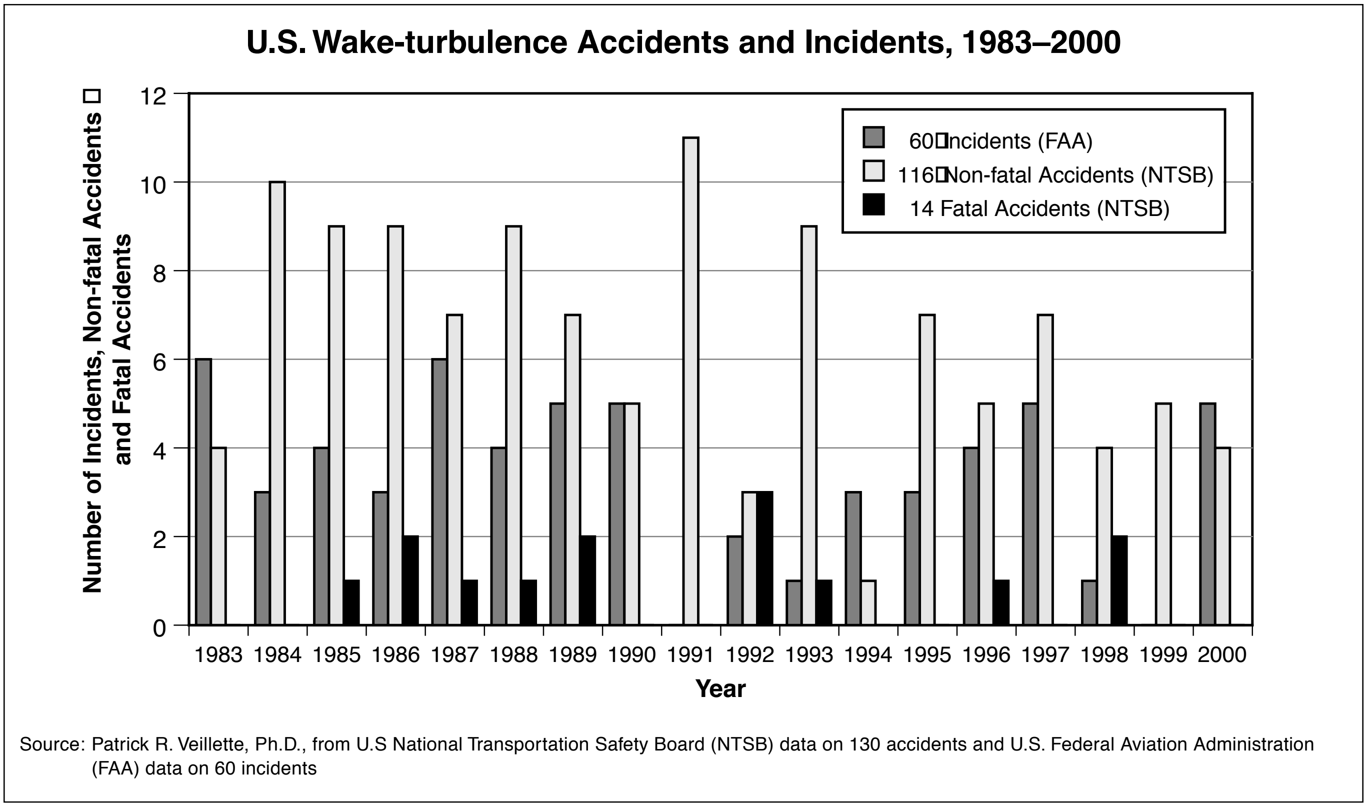


Figure 2

into the wake turbulence of other small aircraft — in 92 accidents (71 percent) and 37 incidents (62 percent). *In this study, except where noted otherwise, aircraft weight categories are those defined by ASRS. (ASRS weights in kilograms are rounded.)* Small aircraft are defined using ASRS criteria as weighing 5,000 pounds/2,300 kilograms or less (Table 4, page 6). Nevertheless, 13 accidents (10 percent) and nine incidents (15 percent) involved aircraft weighing more than 30,000 pounds/13,600 kilograms (Table 5, page 7; Table 6, page 8; see "Civil Aviation Authorities Use Different Weight Categories, Separation Requirements," page 9); and,

- Eighty-six accidents (66 percent), 27 incidents (45 percent) and 110 events (67 percent) occurred during wind conditions of 10 knots or less (Figure 6, page 12; Figure 7, page 12; Figure 8, page 13).

Various Forms of Wake Turbulence Create Problems

Wake turbulence is defined by FAA as "phenomena resulting from the passage of an aircraft through the atmosphere."[5] The term refers to several forms of wake turbulence, including wake vortices, which are defined by FAA as "circular patterns of air

Table 1
Phase of Flight of U.S. Wake-turbulence Accidents, 1983–2000

Trailing Aircraft / Phase of Flight	Leading Aircraft: Takeoff	Cruise	Approach and Landing	Maneuvering	Unspecified	Row Total
Takeoff	19	–	2	2	1	24
Cruise	–	3	6	–	–	9
Approach and Landing	7	–	64	2	1	74
Maneuvering	–	–	–	23	_	23
Column Total	26	3	72	27	2	130

Source: Patrick R. Veillette, Ph.D., from U.S. National Transportation Safety Board data on 130 accidents

Table 2
Phase of Flight of U.S. Wake-turbulence Incidents, 1983–2000

Trailing Aircraft	Leading Aircraft					
Phase of Flight	**Takeoff**	**Cruise**	**Approach and Landing**	**Maneuvering**	**Unspecified**	**Row Total**
Takeoff	5	–	–	–	8	**13**
Cruise	–	4	–	–	1	**5**
Approach and Landing	6	–	16	–	19	**41**
Maneuvering	–	–	–	1	_	**1**
Column Total	**11**	**4**	**16**	**1**	**28**	**60**

Source: Patrick R. Veillette, Ph.D., from U.S. Federal Aviation Administration data on 60 incidents

Table 3
Phase of Flight of U.S. Wake-turbulence Events, 1988–1999

Trailing Aircraft	Leading Aircraft				
Phase of Flight	**Takeoff**	**Cruise**	**Approach and Landing**	**Maneuvering**	**Row Total**
Takeoff	30	0	7	0	**37**
Cruise	0	14	8	0	**22**
Approach and Landing	13	1	92	0	**106**
Maneuvering	0	0	0	0	**0**
Column Total	**43**	**15**	**107**	**0**	**165**

Source: Patrick R. Veillette, Ph.D., from U.S. National Aeronautics and Space Administration Aviation Safety Reporting System data on 165 events

created by the movement of an airfoil through the air when generating lift."[6] Other forms of wake turbulence include thrust-stream turbulence (jet blast), propeller wash and rotor wash (see "Data Show That 13 U.S. Accidents From 1983–2000 Involved Helicopter Wake Turbulence," page 15).

All aircraft generate wake vortices, but the intensity of the wake vortices generated by a specific aircraft is determined by many factors, including the aircraft's weight, speed, wingspan (or rotor-blade design), and the atmospheric conditions in which the aircraft is being flown (see "Atmospheric Conditions, Aircraft Characteristics Determine Intensity of Wake Vortices," page 19). Wake vortices are generated in part by the same forces that provide lift to the airplane. High-pressure air from the lower surface of the wing flows around the wing tip into low-pressure air above the wing. The result is a pair of wake vortices that rotate from the wings in opposite directions — as viewed from behind the airplane, the right-wing vortex rotates counterclockwise, and the left-wing vortex rotates clockwise — creating an area of turbulence behind the airplane. (Some airplanes, especially those with multiple flaps and cutouts [gaps] between the flaps, initially produce multiple vortices, which quickly combine into one vortex for each wing.)

Typically, a vortex develops a circular motion around a core region. The core varies in size from several inches in diameter to several feet in diameter. The speed of the air movement within the core can be more than 300 feet (92 meters) per second. The core is surrounded by an outer region of the vortex, as large as 100 feet (31 meters) in diameter, with air moving at speeds that decrease as the distance from the core increases.[7] The wake vortices can extend as far as 10 nautical miles (19 kilometers) behind a large aircraft, typically descending for about 30 seconds at a rate of about 300 feet per minute to 500 feet per minute. The descent rate typically slows to near zero between 500 feet and 900 feet below the aircraft's flight path. Wake vortices can persist as long as three minutes, depending on various factors, including wind conditions.[8]

The typical risk to an aircraft flown into wake turbulence is an induced roll, in which the intensity of the vortices forces the aircraft to roll. In some occurrences, an induced roll can exceed

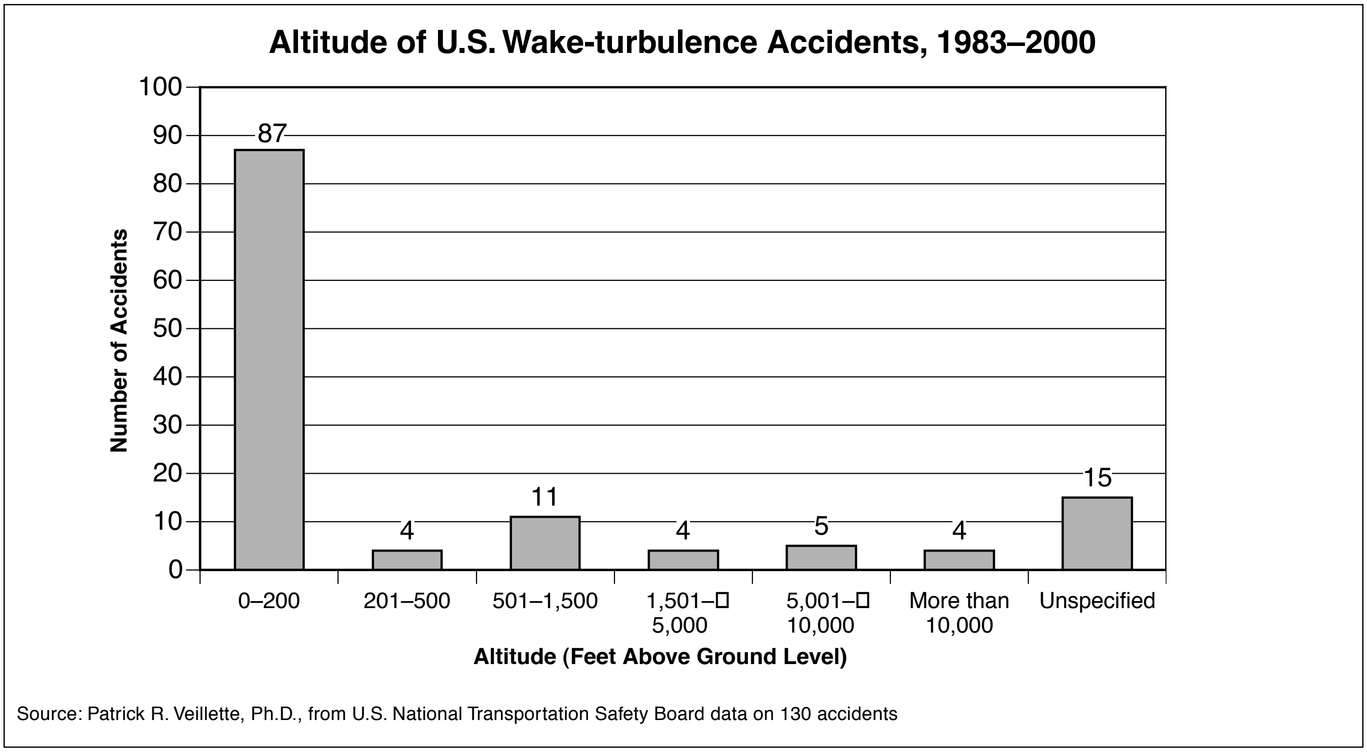


Figure 3

the roll-control authority of the aircraft. Flight into wake turbulence sometimes causes in-flight structural damage to aircraft and fatal injuries to occupants.

More Than Half of Wake-turbulence Accidents Occur During Approach and Landing

Data show that wake-turbulence accidents, incidents and events were more frequent during approach and landing than during any other phase of flight. Of the 130 wake-turbulence accidents in the NTSB database, 74 accidents (57 percent) occurred during approach and landing; in 64 of those accidents (86 percent), the leading aircraft (the aircraft that generated the wake turbulence) also was in the approach-and-landing phase.

In 16 of the 41 approach-and-landing incidents (39 percent) in the FAA database and 92 of the 106 approach-and-landing events (87 percent) in the ASRS database, the leading aircraft also was in the approach-and-landing phase.

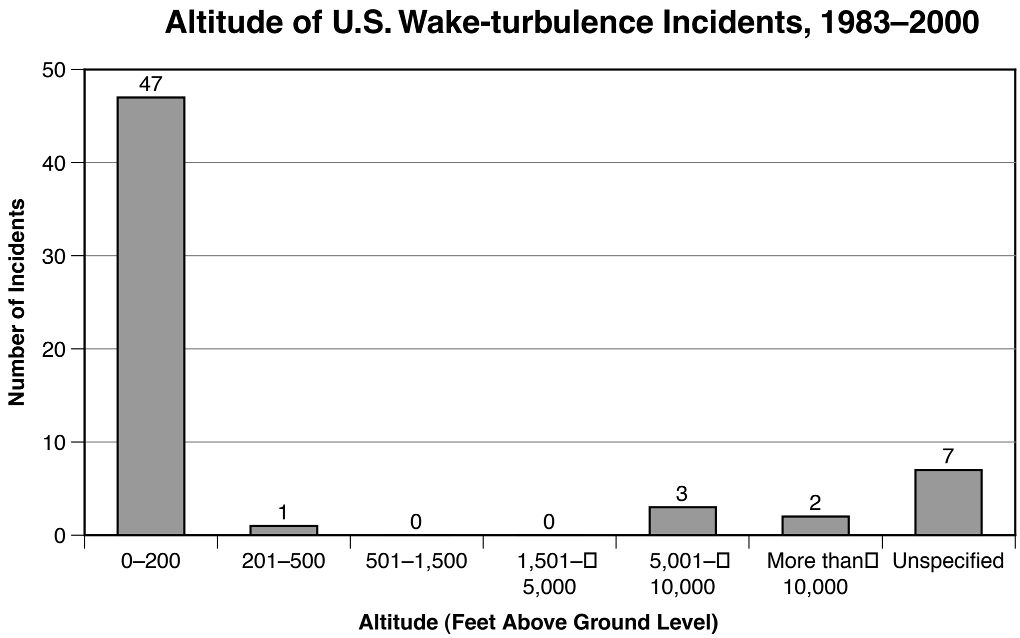
Of the 130 wake-turbulence accidents, 24 accidents (18 percent) occurred during takeoff; the leading aircraft also was in the takeoff phase of flight in 19 of the 24 accidents (79 percent). Of the 60 incidents, 13 incidents (22 percent) occurred during takeoff; the leading aircraft also was in the takeoff phase of flight in five of the 13 incidents (38 percent.) Thirty-seven (22 percent) of the 165 events occurred during takeoff; of the 37 events, 30 events (81 percent) involved leading aircraft that were in the takeoff phase or were in the initial-climb phase of flight.

Because wake vortices move with the wind, and aircraft typically take off or land into the wind, wake vortices often drift toward other aircraft at the departure end of the runway or on final approach. Studies by the U.S. Air Force and NASA have found that a trailing aircraft can avoid wake turbulence by lifting off 3,000 feet before the rotation point of the leading aircraft.[9] The studies said that lighter aircraft should remain upwind of larger aircraft and above their flight paths — a recommendation similar to that contained in the FAA *Aeronautical Information Manual* (*AIM*).[10]

Although the recommendation to fly an aircraft above the leading aircraft's flight path to avoid wake turbulence may have been effective in the past, because of the increased climb performance of the current generation of transport aircraft, many trailing aircraft do not have sufficient performance to fly above the flight path of a high thrust-to-weight-ratio transport airplane.[11]

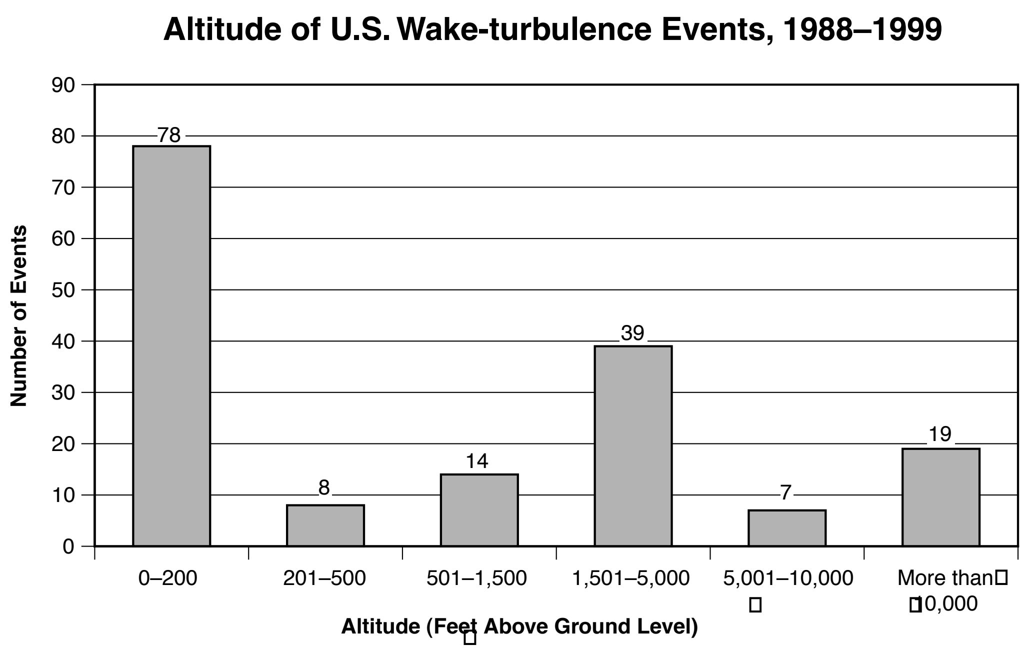
Of the 130 accidents in the NTSB database, 23 accidents (18 percent) occurred during maneuvering — a category that includes such diverse activities as conducting stall-recovery procedures in a practice area, conducting 360-degree turns for spacing and conducting agricultural-application flights. In each accident, the leading aircraft also was maneuvering. Most of these accidents involved aircraft conducting agricultural operations, and some involved aircraft that were flown into their own wake turbulence.

Of the 130 accidents, nine accidents (7 percent) occurred during the cruise phase of flight. Of the 60 incidents, five



Source: Patrick R. Veillette, Ph.D., from U.S. Federal Aviation Administration data on 60 incidents

Figure 4



Source: Patrick R. Veillette, Ph.D., from U.S. National Aeronautics and Space Administration Aviation Safety Reporting System data on 165 events

Figure 5

incidents (8 percent) occurred during cruise. Of the 165 events, 22 of them (13 percent) occurred during cruise.

Because their duties require movement in the cabin, flight attendants are particularly vulnerable to the effects of unexpected flight into wake turbulence. Each of the accidents and incidents that occurred during cruise flight resulted in injuries to flight attendants; some occurrences also resulted in injuries to passengers. Four accidents resulted in serious injuries to a total of four flight attendants; five

Table 4
Aircraft Categories Used by NASA ASRS

Aircraft Category	Weight in Pounds	Weight in Kilograms
Small	5,000 or less	2,300 or less
Small Transport	5,001 to 14,500	2,300 to 6,600
Light Transport	14,501 to 30,000	6,600 to 13,600
Medium Transport	30,001 to 60,000	13,600 to 27,200
Medium-large Transport	60,001 to 150,000	27,200 to 68,000
Large Transport	150,001 to 300,000	68,000 to 136,000
Heavy Transport	more than 300,000	more than 136,000

Note: Figures in kilograms have been rounded.

Source: U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS)

accidents and five incidents caused minor injuries to 10 flight attendants, and three accidents caused minor injuries to 14 passengers. The accident/incident reports did not say how the passengers were injured or whether they were wearing seat belts.

Wake vortices sometimes persist longer at high altitudes than at lower altitudes. This can be attributed to two factors:

- Because aircraft are in the clean configuration (with landing gear and flaps retracted) during cruise flight, they generally generate more coherent but weaker wake vortices during cruise than during other phases of flight. (Coherent vortices are generated by smooth wing surfaces, uninterrupted by the presence of multiple flaps and cutouts between sections of flaps. These smooth surfaces generate one large vortex, instead of the multiple vortices that initially are generated by wing surfaces with multiple flaps and that quickly combine into one larger vortex from each wing.); and,

- Atmospheric turbulence, which helps dissipate wake vortices, typically is not as prevalent at higher cruise altitudes. Therefore, the absence of atmospheric turbulence also results in an environment that enables wake vortices to remain coherent and to persist for longer periods of time.[12,13]

Winds, Atmospheric Turbulence Influence Wake-vortex Development

Wake-turbulence accidents, incidents and ASRS events occurred in varying wind conditions, but data showed that most occurred when winds were between three knots and 10 knots. (Data on wind conditions were not available in all reports.)

Of the 130 accidents in the NTSB database, 79 accidents (61 percent) occurred when winds were between three knots and 10 knots (Figure 6). Of the 60 incidents in the FAA database, 26 incidents (43 percent) occurred in winds between three knots and 10 knots (Figure 7). Of the 165 events in the ASRS database, 99 events (60 percent) occurred in winds between three knots and 10 knots (Figure 8).

The speed and direction of the wind determine the horizontal motion of the wake vortices. When wake vortices are formed near the ground or descend toward the ground, wind speed and wind direction influence the effects of vortices on landing aircraft and departing aircraft. If the wind is calm or is moving along the runway heading, a pair of vortices moves apart and away from the flight path of a landing aircraft or departing aircraft. With a crosswind of one knot to five knots, the lateral movement of the upwind vortex slows and the lateral movement of the downwind vortex increases; as a result, the upwind vortex can remain near the flight path, and the downwind vortex can move more quickly toward another runway. With a crosswind of more than five knots, the vortices move quickly across the flight path.[14]

A tail wind can move the vortices of a leading aircraft forward into the touchdown zone. The *AIM* says that a light quartering tail wind requires "maximum caution" and that pilots must be aware of large aircraft upwind from their approach flight paths and takeoff flight paths and take appropriate action to avoid wake turbulence.[15]

Of the 130 accidents in the NTSB database, 16 accidents (12 percent) occurred on or near closely spaced parallel runways when winds were less than eight knots, as did four (7 percent) of the 60 incidents in the FAA database and 28 (17 percent) of the 165 events in the ASRS database.

A study of the cross-runway movement of wake vortices at Frankfurt (Germany) Airport, where parallel runways are used frequently, found that under stable atmospheric conditions, wake vortices could persist up to 3.5 minutes and could travel about 1,641 feet (500 meters) perpendicular to the runway when influenced by crosswinds of six knots to eight knots, measured about 33 feet AGL.[16]

Other research found that:

- In crosswinds of 15 knots or more, a vortex may exhibit significant rotational speed even after moving 2,500 feet (763 meters);[17,18]

- A downwind vortex from a Boeing 757 has sufficient force after 87 seconds to upset a McDonnell Douglas DC-9 on a closely spaced parallel runway;[19] and,

- Downwind vortices typically ascend while moving downwind, which places the vortices at higher altitudes than most pilots expect.[20]

Table 5
Weight Categories of Trailing Aircraft and Leading (Wake-generating) Aircraft in U.S. Wake-turbulence Accidents, 1983–2000

Trailing Aircraft: Categories	Leading Aircraft: Small[1]	Small Transport[2]	Light Transport[3]	Medium Transport[4]	Medium-large Transport[5]	Large Transport[6]	Heavy Transport[7]	Unspecified	Row Total
Small[1]	29	14(1F)	6	6(1F)	15(4F)	12(4F)	4	6	**92**
Small Transport[2]	–	4	1	2(1F)	4(1F)	1	7(1F)	2	**21**
Light Transport[3]	–	–	–	–	1	2(2F)	1	–	**4**
Medium Transport[4]	–	–	–	1	2	–	3	–	**6**
Medium-large Transport[5]	–	–	–	–	1	2	3	–	**6**
Large Transport[6]	–	–	–	–	–	–	–	–	**0**
Heavy Transport[7]	–	–	–	–	–	–	1	–	**1**
Column Total	**29**	**18**	**7**	**9**	**23**	**17**	**19**	**8**	**130**

Notes: The number of fatal accidents (F) is shown in parentheses. Numbers in kilograms have been rounded.

[1] U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) defines small aircraft as weighing 5,000 pounds/2,300 kilograms or less.

[2] NASA ASRS defines small transport aircraft as weighing 5,001 pounds/2,300 kilograms to 14,500 pounds/6,600 kilograms.

[3] NASA ASRS defines light transport aircraft as weighing 14,501 pounds/6,600 kilograms to 30,000 pounds/13,600 kilograms.

[4] NASA ASRS defines medium transport aircraft as weighing 30,001 pounds/13,600 kilograms to 60,000 pounds/27,200 kilograms.

[5] NASA ASRS defines medium-large transport aircraft as weighing 60,001 pounds/27,200 kilograms to 150,000 pounds/68,000 kilograms.

[6] NASA ASRS defines large transport aircraft as weighing 150,001 pounds/68,000 kilograms to 300,000 pounds/136,000 kilograms.

[7] NASA ASRS defines heavy transport aircraft as weighing more than 300,000 pounds/136,000 kilograms.

Source: Patrick R. Veillette, Ph.D., from U.S. National Transportation Safety Board data on 130 accidents

Most Wake-turbulence Accidents Occur Near Runway Threshold

Of the 130 accidents in the NTSB database, 87 accidents (67 percent) occurred at or below 200 feet AGL (Figure 3). Of the 60 incidents in the FAA database, 47 incidents (78 percent) occurred at and below 200 feet AGL (Figure 4). Of the 165 events in the ASRS database, 78 events (47 percent) occurred at and below 200 feet AGL (Figure 5).

Similar findings resulted from an earlier study of data gathered by the U.K. Civil Aviation Authority (CAA) Wake Vortex Reporting Program (WVRP), involving 515 wake-turbulence occurrences in the United Kingdom from 1982 through 1990. The study found that most wake-turbulence occurrences were 100 feet to 200 feet above the runway threshold; the next-most-frequent altitude for wake-turbulence occurrences was between 2,000 feet AGL and 4,000 feet AGL (where aircraft typically level off during instrument landing system [ILS] approaches).[21]

A simulator-based study of nine Learjet pilots was conducted in 1977 to determine their criteria for assessing the risks of a wake-vortex occurrence and aircraft response. The pilots said that the maximum acceptable vortex-induced bank angle depended on the altitude of the occurrence and whether the flight was in visual meteorological conditions (VMC) or instrument meteorological conditions (IMC).[22]

The Learjet pilots' primary criteria for rating an occurrence as hazardous were altitude at the time of the occurrence and the amount of altitude lost as a result of the occurrence. The pilots' ratings of risk became more consistent as altitude decreased. The study participants based their judgments on the lack of time and/or altitude to safely recover the aircraft from the vortex-induced motion.

The pilots said that in VMC at 100 feet AGL, the maximum acceptable induced bank angle was six degrees to eight degrees. The pilots said that in VMC at 500 feet AGL, the maximum acceptable induced bank angle was 20 degrees to 25 degrees. Responses varied among the study's participants because of their experience in different aircraft types.

The pilots said that in IMC, seven degrees was the maximum induced bank angle considered acceptable at a breakout altitude (altitude of transition from instrument references to

Table 6
Weight Categories of Trailing Aircraft and Leading (Wake-generating) Aircraft in U.S. Wake-turbulence Incidents, 1983–2000

Trailing Aircraft: Categories	Leading Aircraft: Small[1]	Small Transport[2]	Light Transport[3]	Medium Transport[4]	Medium-large Transport[5]	Large Transport[6]	Heavy Transport[7]	Unspecified	Row Total
Small[1]	4	3	2	3	2	1	1	21	**37**
Small Transport[2]	–	–	–	–	4	1	–	4	**9**
Light Transport[3]	–	–	–	–	1	–	1	3	**5**
Medium Transport[4]	–	–	–	–	–	2	1	1	**4**
Medium-large Transport[5]	–	–	–	–	–	–	2	2	**4**
Large Transport[6]	–	–	–	–	–	–	1	–	**1**
Heavy Transport[7]	–	–	–	–	–	–	–	–	**0**
Column Total	**4**	**3**	**2**	**3**	**7**	**4**	**6**	**31**	**60**

Note: Numbers in kilograms have been rounded.

[1] U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) defines small aircraft as weighing 5,000 pounds/2,300 kilograms or less.

[2] NASA ASRS defines small transport aircraft as weighing 5,001 pounds/2,300 kilograms to 14,500 pounds/6,600 kilograms.

[3] NASA ASRS defines light transport aircraft as weighing 14,501 pounds/6,600 kilograms to 30,000 pounds/13,600 kilograms.

[4] NASA ASRS defines medium transport aircraft as weighing 30,001 pounds/13,600 kilograms to 60,000 pounds/27,200 kilograms.

[5] NASA ASRS defines medium-large transport aircraft as weighing 60,001 pounds/27,200 kilograms to 150,000 pounds/68,000 kilograms.

[6] NASA ASRS defines large transport aircraft as weighing 150,001 pounds/68,000 kilograms to 300,000 pounds/136,000 kilograms.

[7] NASA ASRS defines heavy transport aircraft as weighing more than 300,000 pounds/136,000 kilograms.

Source: Patrick R. Veillette, Ph.D., from U.S. Federal Aviation Administration data on 60 incidents

visual references) of 200 feet AGL. For altitudes above 350 feet AGL in IMC, the pilots said that a 10-degree bank angle induced by a wake vortex was the maximum bank angle for acceptable risk.[23]

In the following ASRS report, the first officer of a Boeing 737-300 described his airplane's flight into wake turbulence — and the resulting vortex-induced roll of 15 degrees — just after takeoff in VMC behind an Airbus A320:

> [The airplane] encountered severe wake turbulence at 200 feet AGL on takeoff behind an Airbus. … There was normal takeoff spacing behind this non-heavy aircraft. At 200 feet, we encountered wake [turbulence] that required full right aileron to counter. Even though total roll … was only approximately 15 degrees to the left, the acceleration we felt was very pronounced. Without immediate aileron input, the roll to the left would have been much more severe. … The experience made me a firm believer that it doesn't take a "heavy" to cause severe wake turbulence if you hit it just right.[24]

Some aircraft can tolerate a smaller bank angle at touchdown than others. For example, a Boeing 727 can tolerate only a 12-degree bank angle when touching down in a normal flare. Any bank angle greater than 12 degrees causes the outboard sections of the flaps (which, because of the aircraft's design, are close to the ground during takeoff and landing) to strike the ground. If the aircraft is descending at a slightly faster sink rate upon touchdown, a 7.5-degree bank angle can result in the outboard sections of flaps striking the ground. This is primarily a result of the higher nose-up pitch attitude associated with a faster sink rate.[25]

More Than 25 Percent of Wake-turbulence Events Occur at Major Metropolitan Airports

Data from the 165 events in the ASRS database showed that flight into wake turbulence occurred at various types of airports.

Of the 165 events, 26 events (16 percent) occurred at airports used primarily as major hubs for air carrier traffic; light

Continued on page 11

Civil Aviation Authorities Use Different Weight Categories, Separation Requirements

The International Civil Aviation Organization (ICAO) has developed standards for aircraft wake-turbulence separation minimums based on a system that groups aircraft into three categories according to weight (Table 1).

Table 1
International Civil Aviation Organization (ICAO) Recommended Minimum Wake-turbulence Separation Distances[1]

Leading Aircraft	Trailing Aircraft	Minimum Separation Distance
Heavy[2]	Heavy	7.4 kilometers (4.0 nautical miles)
Heavy	Medium[3]	9.3 kilometers (5.0 nautical miles)
Heavy	Light[4]	11.1 kilometers (6.0 nautical miles)
Medium	Light	9.3 kilometers

Note: Numbers in pounds have been rounded.

[1] These wake-turbulence radar separation minimums apply to aircraft during the approach phase and the departure phase when the aircraft is operating behind another aircraft at the same altitude or less than 1,000 feet below that aircraft, when both aircraft are using the same runway or parallel runways separated by less than 760 meters (2,494 feet) or when an aircraft is crossing behind another aircraft at the same altitude or less than 1,000 feet below that aircraft. Non-radar separation minimums include the following: for timed approaches, a two-minute separation for a medium aircraft behind a heavy aircraft, and a three-minute separation for a light aircraft behind a heavy aircraft or a medium aircraft; for departing aircraft in most situations, a minimum separation of two minutes between a light aircraft or a medium aircraft taking off behind a heavy aircraft and between a light aircraft taking off behind a medium aircraft.

[2] ICAO defines a heavy aircraft as weighing 136,000 kilograms/ 300,000 pounds or more.

[3] ICAO defines a medium aircraft as weighing less than 136,000 kilograms and more than 7,000 kilograms/15,000 pounds.

[4] ICAO defines a light aircraft as weighing 7,000 kilograms or less.

Source: International Civil Aviation Organization

The U.K. Civil Aviation Authority (CAA; Table 2) and the U.S. Federal Aviation Administration (FAA; Table 3, page 10) are among the authorities that have modified their definitions of aircraft weight categories and their separation minimums in the past 20 years following separate analyses of wake-turbulence occurrence data.

(The three sets of definitions differ from those used for data-gathering and analysis purposes by the U.S. National Aeronautics and Space Administration Aviation Safety Reporting System[1] [Table 4, page 6].)

CAA established the Wake Vortex Reporting Program (WVRP), a voluntary reporting system, in 1972 to gather data on wake-turbulence occurrences.[2] In 1982, citing WVRP data, CAA changed its aircraft-weight categories from three categories to four categories to require greater separation distances for some types of aircraft that data showed may be more vulnerable to upset by wake turbulence when following heavy aircraft.[3]

Table 2
U.K. Civil Aviation Authority (CAA) Minimum Wake-turbulence Separation Distances[1]

Leading Aircraft	Trailing Aircraft	Minimum Separation Distance
Heavy[2]	Heavy	4.0 nautical miles (7.4 kilometers)
Heavy	Medium[3]	5.0 nautical miles (9.3 kilometers)
Heavy	Small[4]	6.0 nautical miles (11.1 kilometers)
Heavy	Light[5]	8.0 nautical miles (14.8 kilometers)
Medium[6]	Medium	3.0 nautical miles (5.6 kilometers)
Medium	Small	4.0 nautical miles
Medium	Light	6.0 nautical miles
Small	Medium or Small	3.0 nautical miles
Small	Light	4.0 nautical miles

Note: Numbers in pounds have been rounded.

[1] These minimum separation distances apply to aircraft on final approach. For aircraft departing from the same takeoff position on the same runway or departing from parallel runways less than 760 meters (2,494 feet) apart, a minimum separation of two minutes is required for medium aircraft, small aircraft or light aircraft following heavy aircraft and for light aircraft following medium aircraft or small aircraft.

[2] U.K. CAA defines a heavy aircraft as weighing 136,000 kilograms/300,000 pounds or more.

[3] U.K. CAA defines a medium aircraft as weighing more than 40,000 kilograms/90,000 pounds and less than136,000 kilograms.

[4] U.K. CAA defines a small aircraft as weighing more than 17,000 kilograms/37,500 pounds and less than 40,000 kilograms.

[5] U.K. CAA defines a light aircraft as weighing 17,000 kilograms or less.

[6] When the leading medium aircraft is a Boeing 757, McDonnell Douglas DC-8, Boeing 707, Ilyushin Il-62 or BAE Systems VC10, the minimum separation distance is four nautical miles.

Source: U.K. Civil Aviation Authority

An analysis of wake-turbulence incidents reported to CAA between 1972 and 1990 found that "[Boeing] 747 and [Boeing] 757 airplanes appear to produce significantly higher incident rates than the other airplanes considered, indicating … that they produce stronger and more persistent vortices than the other aircraft in their respective weight categories. … The cause of the higher B-757 incident rates is uncertain," said CAA. (The B-757 is the largest airplane in its CAA category — medium.) The analysis showed that the trailing aircraft most often affected by wake turbulence from the B-747 and B-757 were the McDonnell Douglas DC-9, the British Aircraft Corp. BAC 1-11 and the B-737.[4]

In the United States, FAA imposed no wake-turbulence aircraft-separation standards before the early 1970s. Instead, air traffic control (ATC) radar operating limits and, to a lesser extent, runway-occupancy restrictions dictated separation standards. In 1972, however, after an accident involving a Delta Air Lines DC-9-14 at Fort Worth, Texas, U.S., the U.S. National Transportation Safety Board said that FAA should

Continued on page 10

Table 3
U.S. Federal Aviation Administration (FAA) Minimum Wake-turbulence Separation Distances

Leading Aircraft	Trailing Aircraft	Minimum Separation Distance (before 1994)	Minimum Separation Distance (1994 and later)[1]
Heavy[2]	Heavy	4.0 nautical miles (7.4 kilometers)	4.0 nautical miles[3]
Heavy	Large[4]	5.0 nautical miles (9.3 kilometers)	5.0 nautical miles[3]
Heavy	Small[5]	6.0 nautical miles (11.1 kilometers)	5.0 nautical miles[3] 6.0 nautical miles[6]
Large	Large	3.0 nautical miles (5.6 kilometers)	NA
Large	Small	4.0 nautical miles	4.0 nautical miles[6]
B-757[7]	Heavy	NA	4.0 nautical miles[3]
B-757[7]	Large	NA	4.0 nautical miles[3]
B-757[7]	Small	NA	5.0 nautical miles[3] 5.0 nautical miles[6]

Note: Numbers in kilograms have been rounded.

[1] Time or distance intervals are provided for aircraft departing behind a heavy aircraft or a B-757: either two minutes or the appropriate minimum separation distance of four nautical miles or five nautical miles.

[2] Before 1994, FAA defined a heavy aircraft as weighing more than 300,000 pounds/136,000 kilograms. The definition was changed in 1994 to include aircraft weighing more than 255,000 pounds/115,600 kilograms.

[3] Applies when the trailing aircraft is at the same altitude or less than 1,000 feet below the leading aircraft.

[4] Before 1994, FAA defined a large aircraft as weighing 12,500 pounds/5,670 kilograms to 300,000 pounds. The definition was changed in 1994 to include aircraft weighing more than 41,000 pounds/18,600 kilograms to 255,000 pounds.

[5] Before 1994, FAA defined a small aircraft as weighing less than 12,500 pounds. The definition was changed in 1994 to include aircraft weighing 41,000 pounds or less.

[6] Distance from the landing threshold after landing by the specified type of larger aircraft.

[7] FAA established a separate category for Boeing 757 aircraft in 1994, after a series of accidents and incidents involving aircraft that were flown behind B-757s during visual approaches to landing.

Source: U.S. Federal Aviation Administration

"re-evaluate wake-turbulence separation criteria for aircraft operating behind heavy jet aircraft" and should develop new ATC separation standards that considered the effects of wake turbulence on trailing aircraft.

(In that accident on May 30, 1972, the DC-9 was flown into the wake turbulence of a McDonnell Douglas DC-10 that had been 2.25 nautical miles (4.17 kilometers) ahead on the approach. The DC-9 struck the ground and was destroyed; the airplane's four occupants were killed.)[5]

After conducting flight tests in the early 1970s to determine wake-turbulence characteristics of jet aircraft, FAA established wake-turbulence aircraft separation criteria by categorizing aircraft, based upon their maximum takeoff weight, as heavy (more than 300,000 pounds/136,000 kilograms), large (more than 12,500 pounds/5,670 kilograms to 300,000 pounds) and small (12,500 pounds or less).

Those criteria were used until the early 1990s, when a series of accidents and incidents occurred involving aircraft that were being flown behind B-757s during visual approaches to landing. In December 1993, FAA issued a notice requiring specific wake-turbulence advisories to be issued by ATC to the crews of aircraft being flown behind heavy jets or B-757s.[6] FAA also issued a bulletin cautioning pilots about the possibility of wake turbulence, especially when following a heavy jet or a B-757.[7]

In 1994, FAA modified the weight categories for purposes of wake-turbulence separation and established separate wake-turbulence separation criteria for aircraft following B-757s. The weight categories, still in effect, are for heavy aircraft (capable of takeoff weights of more than 255,000 pounds/115,600 kilograms), large aircraft (with maximum certificated takeoff weights of more than 41,000 pounds/18,600 kilograms to 255,000 pounds) and small aircraft (with maximum certificated takeoff weights of 41,000 pounds or less).[8]

Current procedures in Order 7110.65N, *Air Traffic Control,* require controllers to take various actions to help pilots avoid wake turbulence, including the following:

- To "issue wake turbulence cautionary advisories and the position, altitude if known, and direction of flight of the heavy jet or B-757" to pilots of visual flight rules (VFR) aircraft and pilots of instrument flight rules (IFR) aircraft who have accepted a visual approach or visual separation. Similar cautionary advisories are to be issued to the pilots of small aircraft following large aircraft;
- To issue similar advisories to pilots of aircraft being landed on the same runway or a parallel runway less than 2,500 feet (763 meters) away behind a heavy jet or a B-757 or to pilots of small aircraft being landed behind large aircraft;
- To separate aircraft on departure behind a heavy jet or B-757 by two minutes (i.e., a takeoff clearance should be issued two minutes after the beginning of a takeoff roll by a heavy jet or B-757); and,
- To issue cautionary information to pilots of "any aircraft if, in your opinion, wake turbulence may have an adverse effect on it. When traffic is known to be a heavy aircraft, include the word 'heavy' in the description."[9]

In the *Procedures for Air Navigation Services — Rules of the Air and Air Traffic Services,* ICAO provides procedures for wake-turbulence avoidance, including the following:

- Pilots should use the word "heavy" after the aircraft call sign in their first radio communication with ATC;
- Wake-turbulence radar separation minimums should apply when an aircraft is operating behind another aircraft at the same altitude or less than 1,000 feet below

the other aircraft, when both aircraft are using the same runway or parallel runways separated by less than 2,494 feet (760 meters) or when an aircraft is crossing behind another aircraft at the same altitude or less than 1,000 feet below the aircraft; and,

- Non-radar wake-turbulence separation minimums should provide for medium aircraft to follow heavy aircraft by two minutes in timed approaches and for light aircraft to follow heavy aircraft and medium aircraft by three minutes. During takeoffs from the same runway, from parallel runways separated by less than 2,494 feet or from other parallel runways or crossing runways if the trailing aircraft will cross the projected flight path of the leading aircraft at the same altitude or less than 1,000 feet below, a two-minute separation should be imposed (in most situations) for light aircraft and medium aircraft behind heavy aircraft and for light aircraft behind medium aircraft.[10]♦

— Patrick R. Veillette, Ph.D.

Notes

1. The U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) is a confidential incident-reporting system. The ASRS Program Overview said, "Pilots, air traffic controllers, flight attendants, mechanics, ground personnel and others involved in aviation operations submit reports to the ASRS when they are involved in, or observe, an incident or situation in which aviation safety was compromised. … ASRS de-identifies reports before entering them into the incident database. All personal and organizational names are removed. Dates, times and related information, which could be used to infer an identity, are either generalized or eliminated."

   ASRS acknowledges that its data have certain limitations. ASRS *Directline* (December 1998) said, "Reporters to ASRS may introduce biases that result from a greater tendency to report serious events than minor ones; from organizational and geographic influences; and from many other factors. All of these potential influences reduce the confidence that can be attached to statistical findings based on ASRS data. However, the proportions of consistently reported incidents to ASRS, such as altitude deviations, have been remarkably stable over many years. Therefore, users of ASRS may presume that incident reports drawn from a time interval of several or more years will reflect patterns that are broadly representative of the total universe of aviation-safety incidents of that type."

2. The U.K. Civil Aviation Authority Wake Vortex Reporting Program (WVRP) was established to receive and review data on wake-turbulence occurrences. A report of a wake-turbulence occurrence typically is submitted by the crew of the aircraft involved or by air traffic control (ATC), although formal procedures for reporting wake-turbulence occurrences by ATC exist only at London City Airport and Heathrow Airport. Additional data are collected from pilots of the aircraft that generated wake turbulence; the Meteorological Office; London Air Traffic Control Center, which provides recorded radar data; and airlines, which provide flight data recorder data. The data are analyzed to determine if the cause of each reported occurrence was, in fact, wake turbulence. WVRP was transferred in 1989 to the Air Traffic Control Evaluation Unit.

3. Critchley, J.B.; Foot, P.B. "U.K. CAA Wake Vortex Database: Analysis of Incidents Reported Between 1972–1990." In *Proceedings of the Aircraft Wake Vortices Conference,* Washington, D.C., U.S. Oct. 29–31, 1991.

4. Ibid.

5. U.S. National Transportation Safety Board. *Aircraft Accident Report: Delta Air Lines, Inc. McDonnell Douglas DC-9-14, N3305L, Greater Southwest International Airport, Fort Worth Texas, May 30, 1972.* NTSB-AAR-73-3.

6. U.S. Federal Aviation Administration (FAA). *FAA General Notice Issued on December 22, 1993.* (Cited and reprinted in NTSB. *Special Investigation Report: Safety Issues Related to Wake Vortex Encounters During Visual Approach to Landing.* NTSB/SIR-94-01. Washington, D.C., U.S. 1994.)

7. FAA. *Wake Turbulence Accident Prevention Program* FSAT 93-38 and FSGA 93-15. Dec. 29, 1993.

8. FAA. Order 7110.65N, *Air Traffic Control.* Feb. 21, 2002.

9. Ibid.

10. International Civil Aviation Organization (ICAO). *Procedures for Air Navigation Services — Rules of the Air and Air Traffic Services.* 13th Edition, 1996. Amendment 3.

transport aircraft (defined by ASRS as those weighing 14,501 pounds/6,600 kilograms to 30,000 pounds) were the trailing aircraft in 21 of these events. Twenty-one events (13 percent) occurred in airspace surrounding major hub airports; light transport aircraft were involved in seven of these events, and general aviation aircraft (small aircraft) were involved in 14 events.

Analysis of events also showed that:

- Seventy events (42 percent) occurred at airports that serve both air carrier aircraft and general aviation aircraft;

- Military aircraft generated wake turbulence in 10 events (6 percent), nine of which occurred at airports that served both military aircraft and civil aircraft; and,

- Thirty-four events (21 percent) occurred at airports that serve primarily general aviation aircraft.

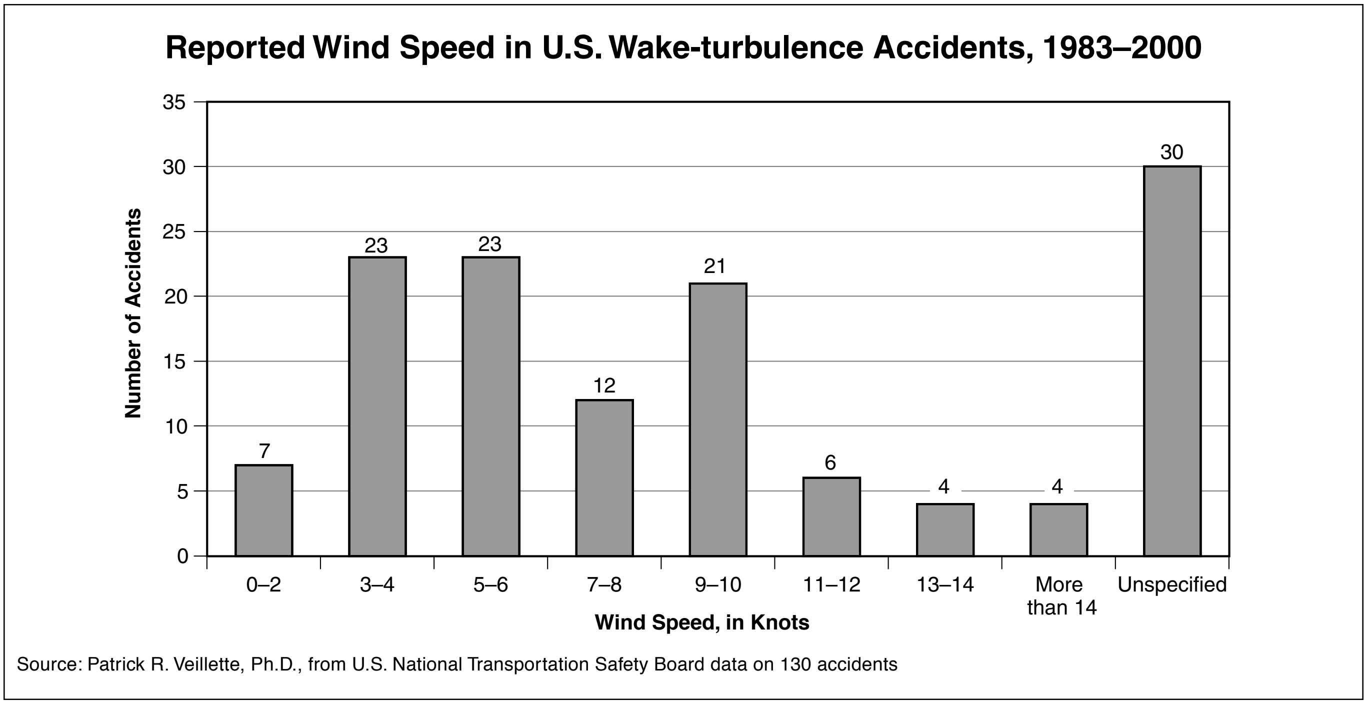


Figure 6

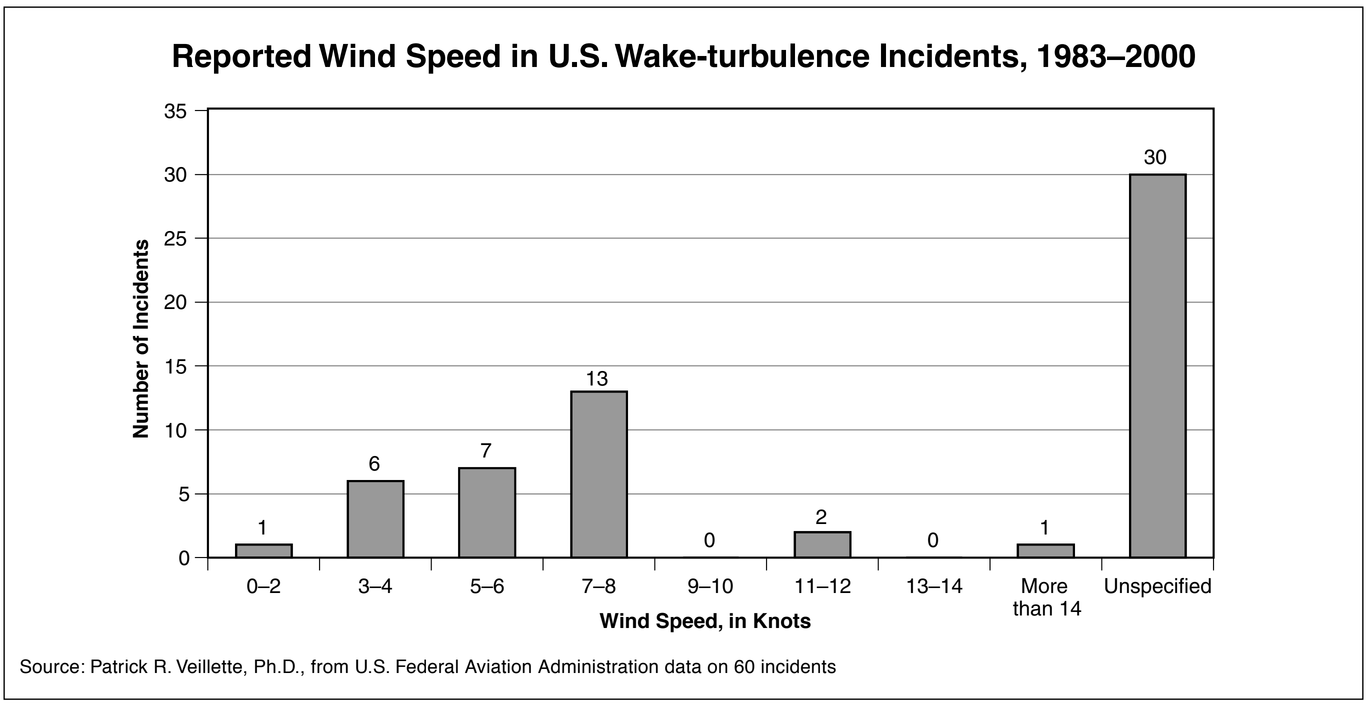
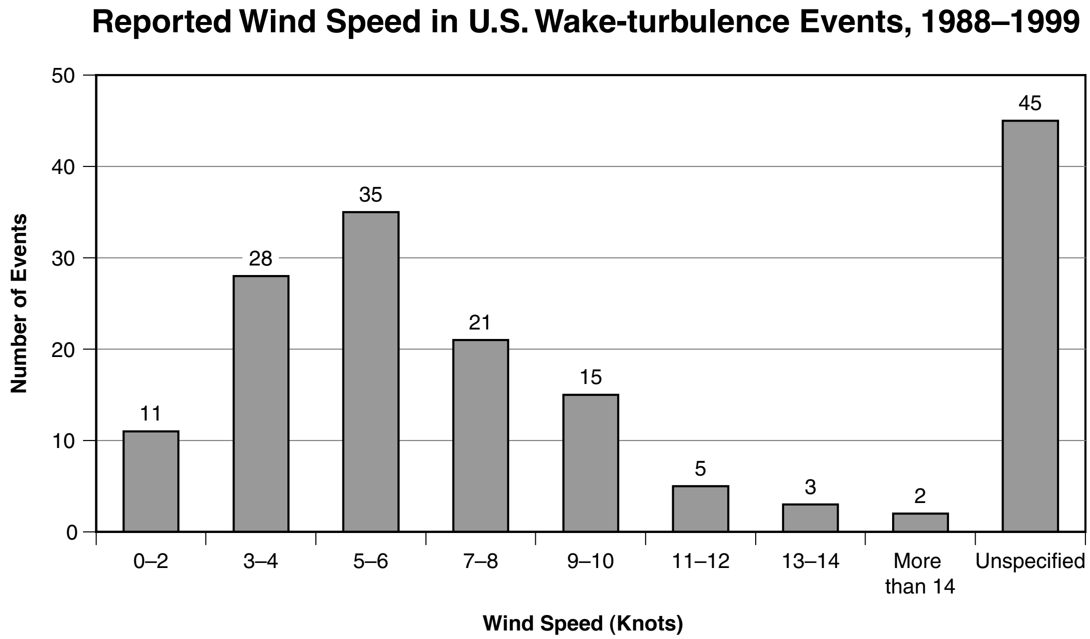


Figure 7

Accidents, Incidents Most Often Involved Small Aircraft

Small aircraft were involved more often than aircraft of other weight categories as trailing aircraft in accidents caused by wake turbulence. Of the 130 accidents in the NTSB database, small aircraft were the trailing aircraft in 92 accidents (71 percent); in those accidents, the wake turbulence most frequently (in 29 accidents, or 32 percent) was generated by other small aircraft (Table 5).

Of the 60 incidents in the FAA database, small aircraft were the trailing aircraft in 37 incidents (62 percent; Table 6); of the 37 incidents, 21 incident reports (57 percent) did not specify the type of aircraft that generated the wake turbulence. The reports that included that information said that the wake



Source: Patrick R. Veillette, Ph.D., from U.S. National Aeronautics and Space Administration Aviation Safety Reporting System data on 165 events

Figure 8

turbulence most frequently (in four incidents, or 11 percent) was generated by other small aircraft.

Of the 165 events in the ASRS database, 42 events (25 percent) involved small aircraft as the trailing aircraft (Table 7, page 25). In the 42 events, the wake turbulence most frequently was generated by medium transport aircraft (in 10 events, or 24 percent). (ASRS defines medium transport aircraft as those weighing 30,001 pounds/13,600 kilograms to 60,000 pounds/27,200 kilograms.) Four events (10 percent) involved small aircraft that were flown into wake turbulence generated by other small aircraft.

Small Transport Aircraft Involved in Wake-turbulence Accidents

Of the 130 accidents in the NTSB database, 21 accidents (16 percent) involved small transport aircraft (5,001 pounds/2,300 kilograms to 14,500 pounds/6,600 kilograms) as the trailing aircraft (Table 5). Of these, seven accidents (33 percent), including one fatal accident, involved wake turbulence generated by heavy transport aircraft (more than 300,000 pounds/136,000 kilograms).

Of the 60 incidents in the FAA database, nine incidents (15 percent) involved small transport aircraft as the trailing aircraft (Table 6). Of these, four incidents (44 percent) involved aircraft being flown behind medium-large transport aircraft (60,001 pounds/27,200 kilograms to 150,000 pounds/68,000 kilograms). The same number of incidents involved wake turbulence generated by aircraft of unspecified size.

Of 165 events in the ASRS database, 15 events (9 percent) involved small transport aircraft as the trailing aircraft (Table 7). Of these, six events involved wake turbulence generated by large transport aircraft (150,001 pounds/68,000 kilograms to 300,000 pounds).

Light transport aircraft were the trailing aircraft in four accidents (3 percent) of the 130 accidents (Table 5). Of the four accidents, two accidents, both fatal, occurred while the aircraft were being flown behind large transport aircraft. Light transport aircraft were the trailing aircraft in five incidents (8 percent) of the 60 incidents (Table 6). Of the five incidents, three incidents involved wake turbulence generated by unspecified aircraft. The other incidents involved wake turbulence generated by one medium-large transport aircraft and one heavy transport aircraft. Light transport aircraft were the trailing aircraft in 17 ASRS events (10 percent; Table 7). Of the 17 events, eight events (47 percent) involved wake turbulence generated by large transport aircraft.

Pilots of Larger Aircraft Describe Effects of Wake Turbulence During Approach

Of the 130 accidents, medium transport aircraft were the trailing aircraft in six accidents (5 percent; Table 5); of the six accidents, three accidents occurred while the aircraft were being flown behind heavy transport aircraft. Of the 60 incidents, medium transport aircraft were the trailing aircraft in four incidents (7 percent; Table 6); of the four incidents, two incidents occurred while the aircraft were being flown behind large transport aircraft. Of the 165 events, medium transport aircraft were the trailing aircraft in 28 events (17 percent; Table 7); of the 28 events, 14 events (50 percent) involved wake turbulence generated by heavy transport aircraft.

Medium-large transport aircraft were the trailing aircraft in six of the 130 accidents (5 percent; Table 5). Of these, three accidents involved wake turbulence generated by heavy transport aircraft. Medium-large transport aircraft were the trailing aircraft in four incidents of the 60 incidents (Table 6). Of these, two incidents occurred while the aircraft were being flown behind heavy transport aircraft, and two incidents occurred while trailing aircraft of unspecified weight categories. Medium-large transport aircraft were the trailing aircraft in 27 events (16 percent; Table 7) of 165 events. Of these, 13 events (48 percent) involved wake turbulence generated by heavy transport aircraft.

The following ASRS report was filed by the captain of a McDonnell Douglas MD-82:

> Glideslope was out of service. [On final approach] … at eight [nautical] miles [15 kilometers], I visually acquired my interval aircraft, which was three [nautical miles; 5.6 kilometers] to four [nautical] miles [7.4 kilometers] ahead … in a steep, descending, left-hand turn to final, 500 [feet] to 1,000 feet above my altitude. … When it stabilized on final approach course, lacking glideslope guidance, I observed it — another [McDonnell Douglas] DC-9-82 type, [which appeared] to be flying a significantly steeper approach than I was. Weather was clear — visibility 10 nautical miles in haze, calm winds at all altitudes below 10,000 feet. Aircraft ahead stabilized 2.5 [nautical miles; 4.6 kilometers] to three nautical miles ahead of my aircraft, [0.5 degree] to one degree above my approach course.
>
> At outer-marker crossing, we switched to … tower [frequency]. Almost immediately, the aircraft — which had been stable and trimmed up at 170 knots, flaps 15 degrees, gear up — rolled approximately 30 degrees to the right, then "snapped" to the left. I applied progressively larger right aileron [input] and right rudder input; however, these seemed to have no effect upon the aircraft's roll rate. The aircraft stopped its roll approximately 70 [degrees] to 80 degrees left wing down, then gradually righted itself, becoming again responsive to the flight controls. The nose lost perhaps five [degrees] to 10 degrees of pitch, but we lost little additional altitude.
>
> I simultaneously added power to correct for the descent and [to] fly a high approach path, completed the "dirty up" [extension of the landing gear and flaps in preparation for landing] on schedule, and made a brief … announcement to the 80 passengers about the cause of the roll and [telling them] to not be concerned excessively.
>
> Contributing factors: calm winds, lack of glideslope information, previous aircraft's steep approach, close separation typical of [the airport's] arrival complex, lack of my crew's appreciation for the amount of wake vortex a similar DC-9 aircraft can produce and its effect on other turbojet aircraft.[26]

An ASRS follow-up interview with the pilot who filed the report revealed the following:

> An encounter could have been anticipated, as there were calm winds; no knowledge of the glide [path flown by] the preceding aircraft; [the] preceding aircraft['s] steep approach meant [that the reporting pilot's airplane] would go through the wake somewhere; [the] 2.5-[nautical]-mile separation; and [the] realization that any jet can cause severe turbulence. His ideas for what to do next time are: Fly above [the] other aircraft's glide path, carry an extra 10 knots of speed, be ready for a go-around at any sign of wake turbulence. This [pilot] had no roll control as the encounter progressed. He applied 45 degrees of aileron and heavy rudder, but response to control inputs was slow to take effect. He was positive the bank angle reached at least 70 degrees, if not more, and the event lasted at least six seconds.[27]

There were no accidents among the 130 accidents in the NTSB database in which large transport aircraft were affected by wake turbulence (Table 5). One of the 60 incidents in the FAA database involved a large transport aircraft being flown behind a heavy transport aircraft (Table 6). Pilots of large transport aircraft filed reports on 25 events (15 percent; Table 7) of the 165 events in the ASRS database. Sixteen of those events (64 percent) occurred while the aircraft were being flown behind heavy transport aircraft.

Educational material typically cautions pilots to avoid wake turbulence generated by heavier aircraft but seldom discusses the possibility of upsets from the wake turbulence of smaller aircraft. Nevertheless, of the 165 events in the ASRS database, nine events (5 percent) involved large transport aircraft following other large transport aircraft, and six of the nine events involved leading aircraft that were smaller than the trailing aircraft.

Pilots of heavy transport aircraft have reported upsets caused by the wake turbulence of lighter aircraft. The 165 events in the ASRS database include four events (2 percent) in which crews of heavy transport aircraft described wake-turbulence upsets — two events involving a medium-large transport aircraft as the leading aircraft and two events involving a large transport aircraft as the leading aircraft (Table 7).

Continued on page 17

Data Show That 13 U.S. Accidents From 1983–2000 Involved Helicopter Wake Turbulence

Of 130 wake-turbulence accidents in the U.S. National Transportation Safety Board database from 1983 through 2000, 13 accidents (10 percent) occurred when an airplane was flown through wake turbulence generated by a leading helicopter. Four (31 percent) of the 13 accidents occurred when small general aviation aircraft were landing or taking off while helicopters were being hovered near the runway. All 13 accidents occurred within the immediate vicinity of an airport, either on a runway or in a traffic pattern.

Three (5 percent) of 60 wake-turbulence incidents in the U.S. Federal Aviation Administration (FAA) database from 1983 through 2000 involved wake turbulence generated by helicopters.

Of 165 wake-turbulence events reported from 1988 through 1999 to the U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS),[1] 11 events (7 percent) involved airplanes that were flown into wake turbulence generated by military helicopters during night training operations. In six events, the helicopters were being operated with their navigation lights off while the crews used night-vision goggles. In five events, the helicopter crews were communicating on different radio frequencies and were not providing position reports on the common traffic advisory frequency. The airplane pilots were unaware that unlighted helicopters were being flown in the area.

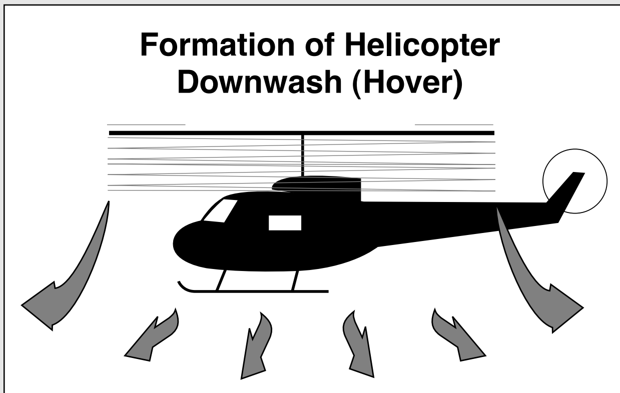
Helicopter wake turbulence results when high-pressure air below the surface of the rotor blades flows around the rotor-blade tips into the low-pressure air above the rotor blades.

The wake turbulence takes different forms, depending on how a helicopter is being flown:

- During stationary hovering or a slow hover taxi, a helicopter generates downwash — high-velocity outwash vortices that extend to a distance about three times the diameter of the rotor (Figure 1). The outwash vortices resemble airplane vortices, although the helicopter outwash vortices circulate outward, upward, around and away from the main rotor (or main rotors) in all directions.[2] FAA says that pilots should not operate small aircraft within three rotor diameters of a helicopter in a stationary hover or a slow-hover taxi;[3] and,

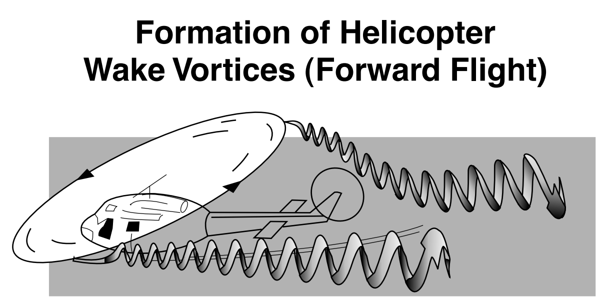
- During forward flight, a helicopter generates a pair of spiraling wake vortices from the rotor blades (Figure 2). Wake turbulence also occurs in the rotating air beneath the helicopter.[4,5] The FAA *Aeronautical Information Manual (AIM)* says that the wake vortices are similar to those of larger fixed-wing aircraft. FAA says that pilots of small aircraft should use caution when trailing helicopters in forward flight.[6]

A 1962 report on flight tests by the NASA Langley Research Center to examine the in-flight characteristics of helicopter wake turbulence said that roll rates of more than 36 degrees per second resulted when a two-place, tricycle-gear military training airplane was flown into the wake turbulence of a three-blade, single-rotor helicopter 100 feet below and 200 feet below the helicopter's flight path. The airplane's induced bank angles were 40 degrees. Flight into wake turbulence during a descent resulted in moderate rolling and a doubled descent rate. The test helicopter weighed 6,900 pounds (3,130 kilograms) and had a rotor diameter of 53 feet (16 meters); the test airplane weighed 7,400 pounds (3,357 kilograms) and had a wingspan of 41 feet (13 meters).[7]



Source: U.S. Federal Aviation Administration

Figure 1



Source: U.S. Federal Aviation Administration

Figure 2

Another flight-test program was conducted in 1991 by FAA. Helicopters of various sizes were used: a Bell UH-1H, a Sikorsky S-76A, a Sikorsky UH-60 Black Hawk, a Sikorsky CH-53E Super Stallion and a Boeing Vertol CH-47D Chinook. Each helicopter was outfitted with a smoke-generating device to mark the helicopter's wake turbulence.[8]

The test airplanes were a Beechcraft T-34C — a 4,300-pound (1,950-kilogram), 715-horsepower (533-kilowatt [kW]),

Continued on page 16

low-wing turboprop monoplane with a 33-foot (10-meter) wingspan — and a Bellanca 8KCAB Super Decathlon — an 1,800-pound (816-kilogram), 180-horsepower (134-kW) high-wing reciprocating-engine airplane.

FAA found similarities in the wake turbulence of airplanes and helicopters. In both categories of aircraft, wake vortices generated at low airspeeds initially were more intense than those generated at higher airspeeds, heavier aircraft generated more intense wake vortices than lighter aircraft, and larger aircraft generated larger wake vortices than smaller aircraft.

The wake vortices generated by a helicopter's advancing blade and by its retreating blade are different. Because the retreating blade operates at a lower relative airspeed, it must have a higher angle-of-attack to produce as much lift as the advancing blade. As a result, the wake vortices behind the advancing rotor blade are consistently smaller and more coherent, especially as the helicopter's forward speed increases above 80 knots. The wake vortices behind the advancing rotor blade result in more abrupt roll excursions and yaw excursions in the trailing aircraft than the retreating-blade vortices. In the flight tests, the vortices behind the retreating blade were characterized by a larger diameter, less-dense smoke marking and a greater cross-sectional area.

The wake vortices were was generated differently, depending on whether the helicopter was ascending or descending. The vortex cores were observed moving farther apart during descents and closer together during ascents.

The helicopter wake vortices did not sink in a predictable manner, perhaps because a large amount of power was required to generate lift and, as a result, hot exhaust was trapped in the wake vortices. The hot exhaust contributed to the buoyancy of the wake vortices.

The area affected by the wake turbulence of a helicopter is larger than the area affected by the wake turbulence of an airplane of comparable size and weight, especially at speeds below 70 knots to 80 knots. The number of rotor blades appears to affect the size of a helicopter's wake vortex. For example, the UH-1H — with two blades — generated smaller wake vortices than the S-76A — with four blades — even though both helicopters are about the same weight. (The UH-1H has a maximum certificated takeoff weight [MCTOW] of 9,500 pounds [4,309 kilograms], and the S-76A has a MCTOW of 10,000 pounds [4,536 kilograms]. Both have main rotors with 44-foot [13-meter] diameters.)

In the 1991 FAA flight tests, the airplane pilots conducted "parallel" entries and "cross-track" entries into the helicopter's wake turbulence. A parallel entry occurs when a trailing aircraft is flown behind and below the leading aircraft (the aircraft generating wake turbulence) in about the same direction. This can cause an intense rolling reaction when an aircraft is flown into the wake turbulence. A cross-track entry involves an aircraft flown through wake turbulence at a large angle. Cross-track entries usually result in short, sharp vertical jolts with little roll or yaw; in these occurrences, the primary risk is to the structural integrity of the aircraft.[9]

FAA test pilots flew the airplanes into the helicopters' wake turbulence in parallel entries by flying above, below, left and right of the vortices. At small separation distances, the airplanes typically experienced more severe upsets (in the form of roll, pitch and/or yaw excursions) when the helicopters were flown at slower speeds. Smaller separation distances resulted in loss of control; at larger separation distances, upsets typically were more severe.

In the flight tests, the airplanes had the following reactions:

- The T-34C recorded induced bank angles of 45 degrees when being flown about one nautical mile (1.9 kilometers) behind the Black Hawk, which has a maximum takeoff weight of 20,250 pounds (9,185 kilograms) and four rotor blades with a rotor diameter of about 53 feet (16 meters). The Black Hawk was being flown at 70 knots to 80 knots. When the separation distance was reduced to 0.5 nautical mile (0.9 kilometer), induced bank angles increased to 75 degrees to 90 degrees. When the helicopter was flown at a slower speed (thus generating more intense vortices), the T-34C was rolled beyond 90 degrees when it was flown one nautical mile behind the Black Hawk and rolled beyond 180 degrees when flown 0.5 nautical mile behind the Black Hawk;

- The T-34C was rolled between 30 degrees and 75 degrees while flying between three nautical miles (5.6 kilometers) and five nautical miles (9.3 kilometers) behind the UH-1H; several of the test points caused much more pronounced roll excursions and led to loss of control and spins;

- The Chinook, a heavy-lift helicopter with a tandem-rotor configuration, an MCTOW of 50,000 pounds (22,680 kilograms) and a 60-foot (18-meter) rotor diameter, generated wake turbulence strong enough while being flown at 120 knots to roll the test airplanes 90 degrees. At distances less than 0.8 nautical mile (1.5 kilometers), the roll excursions varied from 90 degrees to 210 degrees, and many roll excursions resulted in loss of control and spins;

- The Super Stallion, with an MCTOW of 69,750 pounds (31,639 kilograms) and a seven-blade rotor system with a 79-foot (24-meter) diameter, generated wake vortices that rolled the trailing aircraft more than 90 degrees with a separation distance of one nautical mile. At 0.5 mile, the trailing aircraft rolled nearly 180 degrees and entered a spin; and,

- Several flight tests with the Super Decathlon behind the CH-53E were halted when the Decathlon unexpectedly shuddered, which the test pilot characterized as a "flapping of the wings." The tests were stopped because of the risk of catastrophic wing flutter. The engineers said that the vortices of the individual rotor blades were present in the overall wake-turbulence pattern downstream from the helicopter and that the individual vortices probably created the rhythmic pattern.♦

— Patrick R. Veillette, Ph.D.

Notes

1. The U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) is a confidential incident-reporting system. The ASRS Program Overview said, "Pilots, air traffic controllers, flight attendants, mechanics, ground personnel and others involved in aviation operations submit reports to the ASRS when they are involved in, or observe, an incident or situation in which aviation safety was compromised. … ASRS de-identifies reports before entering them into the incident database. All personal and organizational names are removed. Dates, times, and related information, which could be used to infer an identity, are either generalized or eliminated."

   ASRS acknowledges that its data have certain limitations. ASRS *Directline* (December 1998) said, "Reporters to ASRS may introduce biases that result from a greater tendency to report serious events than minor ones; from organizational and geographic influences; and from many other factors. All of these potential influences reduce the confidence that can be attached to statistical findings based on ASRS data. However, the proportions of consistently reported incidents to ASRS, such as altitude deviations, have been remarkably stable over many years. Therefore, users of ASRS may presume that incident reports drawn from a time interval of several or more years will reflect patterns that are broadly representative of the total universe of aviation-safety incidents of that type."

2. U.S. Department of Transportation (DOT); U.S. Federal Aviation Administration (FAA). *Wake Turbulence Training Aid,* DOT/FAA/RD-95/6. April 1995.

3. FAA. *Aeronautical Information Manual (AIM).* Chapter 7, Section 3: Wake Turbulence.

4. Belotserkovski, Sergei M. "Computerized Study of Vortex Aerodynamics of Aircraft and Helicopters." In *Proceedings of the Aircraft Wake Vortices Conference*, Washington, D.C., U.S. Oct. 29–31, 1991.

5. DOT, FAA.

6. FAA.

7. Connor, A.B.; O'Bryan, Thomas. "A Brief Evaluation of Helicopter Wake as a Potential Operational Hazard to Aircraft." NASA TN D-1227, NASA Langley Research Center, Hampton, Virginia, U.S. March 1962.

7. Tymczyszyn, Joseph J.; Biehl, Keith J.; Teager, Stephen A. "Flight Test Investigation of the Wake Vortices Generated by Rotorcraft." In *Proceedings of the Aircraft Wake Vortices Conference*, Washington, D.C., U.S. Oct. 29–31, 1991.

9. Tymczyszyn et al.

The following ASRS report was filed by the pilot of a B-757 (categorized by ASRS as a large transport aircraft):

> I was flying a B-757 on an approach to Runway 22L. The wind at the time was reported [from 190 degrees at 10 knots]. We had been following a B-727 by only approximately 2.5 [nautical] miles. ... This did not seem to be a problem, as we did not feel any unusual turbulence during the approach. The B-727 landed and turned off the runway.
>
> At approximately 50 feet AGL (on speed and glideslope), the aircraft suddenly began a hard, rapid roll to the left. I tried to counteract with right-aileron input, but it took almost full right aileron to stop the roll. … After a slight hesitation, the aircraft began to respond and roll back toward the right. I started to release the right-aileron input. ... However, as soon as the right-aileron pressure was eased, another rapid left roll began. I … reached full right-aileron input just prior to left wheels ground contact. As the left wheels hit the ground, a rapid roll to the right began, and the left wing attempted to lift from the ground. I pushed the nose forward in an attempt to get, and keep, both wheel trucks on the ground. This action worked and the nosewheel was lowered normally.
>
> Rollout was uneventful. I can think of no phenomena that could have caused this event except possibly the vortices from the B-727 that landed just ahead of us.[28]

An ASRS follow-up interview with the pilot who filed the report revealed the following:

> The first officer said that the weather conditions were good, occasional light turbulence with the winds [from] 180 degrees at eight knots. He [said that he] was flying the B-757-200 at "bug [landing reference

speed] plus five knots, and everything was perfect until the roll started." The B-727 ahead of [his] aircraft did not report any disturbances. At about 50 feet, the initial roll began. Then, just prior to touchdown, the second roll started. … [He said that] the first roll took "all of the aileron authority I had, and when the second one began, I decided that I had better put the aircraft on the runway." The touchdown was firm. The first officer, who had been a highly experienced captain at another air carrier, stated that he had not experienced such persistent roll in a wake before this.[29]

Wake Turbulence Cited in One Heavy Transport Aircraft Accident

The NTSB database includes one accident in which a heavy transport aircraft was affected by wake turbulence (Table 5). The leading aircraft also was a heavy transport aircraft. There were no incidents in which heavy transport aircraft were the trailing aircraft. The ASRS database includes 11 events (7 percent) in which heavy transport aircraft were flown into wake turbulence (Table 7). In seven of those events (64 percent), the wake turbulence was generated by another heavy transport aircraft.

The following ASRS report was filed by the captain of a McDonnell Douglas DC-10:

> We intercepted final about five [nautical] miles [9.3 kilometers] outside the final approach fix and proceeded to fly a normal approach using the FMS/ILS [flight management system/instrument landing system] and standard air carrier procedures. An approach check was re-accomplished to identify the Runway 36R localizer and confirm the new minimums for that approach. The first officer flew the FCP [flight control panel] until we broke out of the weather after crossing the final approach fix. We checked in with [the] tower and were cleared to land on Runway 36R. At about 500 feet AGL, the copilot disconnected the autopilot and began to hand-fly the aircraft, with the autothrottles still connected. Since the aircraft had been fully configured for landing earlier, the autopilot had it trimmed up, and I did not detect major trim changes … by the copilot, nor did the "stabilizer motion" alert sound after the autopilot was disconnected. The approach was flown on course and glide path. Later analysis of the flight data recorder did not show any discernible difference between the autopilot and the copilot flying. A well-stabilized, power-on approach was flown down to about 100 feet AGL.
>
> As the runway threshold lights were passing under the nose, the aircraft entered into a series of abrupt and violent roll excursions, which I estimate to be in the range of 15 [degrees] to 20 degrees of bank. There were three or four of these roll reversals, which ended as abruptly as they began. At this point, I would estimate the aircraft altitude at about 15 feet, with the nose slightly higher than the normal flare attitude. The aircraft seemed to hang there for a second, and then the nose came down, and we touched down very hard in what felt like a flat, three-point touchdown. The nose rose up in the air and then settled back to the runway. I took control of the aircraft immediately after touchdown because I anticipated blown tires or steering problems, but there were none. I slowed the aircraft and taxied to the ramp.
>
> The entire episode — violent rolls, ending of the roll motions prior to landing and then the hard landing — lasted about three [seconds] to four seconds. It seemed to me that all this started at about the point where a flare would be initiated. Given the short, abrupt and violent nature of these gyrations, I didn't have a chance to call for a go-around, much less assume control and accomplish [a go-around]. Later analysis of the flight data recorder confirms my recollection of this incident. The data trace shows abrupt and rapid roll excursions, which end as suddenly as they begin, followed by a second or so of level flight and then a g-load spike [sudden increase in gravity-loading], which occurs on the hard touchdown. Given the stabilized approach flown by the first officer, I would discount the probability of pilot-induced oscillations, at least with the beginning of the roll excursions. Furthermore, the sudden onset and termination of the roll motions tell me that the roll inputs of the first officer were in reaction to external forces and [the first officer] succeeded in damping them out prior to touchdown.
>
> The tower winds at the time were northwesterly at seven knots, less than reported on ATIS [automatic terminal information service]. We landed one minute behind a large transport, and our landing gross weight was 429,000 pounds [194,595 kilograms], well below the maximum of 471,000 [pounds (213,646 kilograms)] for the wide-body. I would speculate that the upwind … vortex from the large transport would drift over the runway threshold in that amount of time, which would cause at least the initial roll motion at precisely the time when our aircraft was most vulnerable.[30]

A follow-up interview by ASRS with the pilot who filed the report revealed the following:

> The closest preceding aircraft was a large transport [that had] landed three minutes 50 seconds earlier. No known

Continued on page 24

Atmospheric Conditions, Aircraft Characteristics Determine Intensity of Wake Vortices

The initial intensity of wake vortices is determined primarily by the weight, speed, configuration, wingspan and angle-of-attack of the leading aircraft (the aircraft generating the wake vortices). The most important variables in determining the intensity of a vortex beyond a distance of 10 wingspans to 15 wingspans from the leading aircraft are atmospheric stability, wind, ground effect and turbulence.[1]

Development of a wake vortex occurs in several stages.[2,3]

The first stage is formation of the vortex. Current aerodynamic theory models the airflow over the wing as a series of wake vortices. A dominant pair of vortices absorbs the weaker vortices, rolling into a "trailing edge vortex sheet," which then rolls into a more coherent, or more unified, vortex. This roll-up occurs within two wingspans to four wingspans behind the aircraft.[4]

Space Administration (NASA), vortices created by a heavy transport aircraft (maximum gross weight of 300,000 pounds/ 136,000 kilograms, wingspan of 140 feet [43 meters] and approach speed of 150 knots) sank at 350 feet per minute (fpm). Vortices generated by an aircraft with a maximum gross weight of 35,000 pounds (15,876 kilograms), wingspan of 95 feet (29 meters) and approach speed of 100 knots settled at 150 fpm.[6]

Research on Boeing 727, 757 and 767 airplanes found that the rate at which wake vortices sink depends on aircraft configuration, atmospheric conditions and aircraft/vortex proximity to the ground. Table 1 shows the sinking rates of vortices and the approximate altitudes where ground effect becomes a factor. In general, vortices that form from wings with extended flaps sink more rapidly than vortices that form from wings with retracted flaps.[7]

Table 1
Characteristics of Vortex Motion by Aircraft Type and Configuration

Airplane Model	Wingspan	Separation of Vortex Pair (aircraft gear and flaps retracted)	Separation of Vortex Pair (aircraft in landing configuration)	Height of Ground Effect (aircraft gear and flaps retracted)	Height of Ground Effect (aircraft in landing configuration)	Vortex Sink Velocity (aircraft gear and flaps retracted)	Vortex Sink Velocity (aircraft in landing configuration)
Boeing 727-100/ -222	108.0 feet 32.9 meters	85.0 feet 26.0 meters	65.0 feet 20.0 meters	42 feet AGL	33 feet AGL	8.2 fps 2.5 mps	10.7 fps 3.3 mps
Boeing 757-200	124.8 feet 38.1 meters	98.0 feet 30.0 meters	74.0 feet 23.0 meters	49 feet AGL	37 feet AGL	7.4 fps 2.3 mps	9.9 fps 3.0 mps
Boeing 767-200	156.0 feet 47.6 meters	123.0 feet 38.0 meters	82.0 feet 25.0 meters	61 feet AGL	41 feet AGL	6.2 fps 1.9 mps	9.3 fps 2.8 mps

AGL = Above ground level fps = Feet per second mps = Meters per second

Source: Patrick R. Veillette, Ph.D., from data in "Vortex Characteristics of B-757-200 and 767-200 Aircraft Using the Tower Fly-by Technique," by Leo J. Garodz and Kirk L. Clawson. U.S. National Oceanic and Atmospheric Administration Technical Memorandum ERL ARL-199. Air Resources Laboratory, Silver Spring, Maryland, U.S. January 1993.

The second phase of wake-vortex development involves the effects of the vortices on each other. Each vortex induces an airflow pattern (called a velocity field) that causes the other vortex to sink. Additionally, because of the generation of lift on the wing, there is an equal and opposite reaction on the airflow, which induces a downward motion.

If no other factors influenced vortex motion, the two vortices would sink in this stable manner, remaining a constant distance from each other, until they are 100 feet to 200 feet above ground level (AGL). Then they would slow and move outward, away from each other, at a speed of two knots to three knots.[5]

The actual sinking velocities of the wake vortices may vary. In flight tests by the U.S. Air Force, the U.S. Federal Aviation Administration (FAA) and the U.S. National Aeronautics and

(Although all airplanes generate wake vortices, most of the studies cited in this report examined the wake-vortex-generating characteristics of Boeing airplanes — which comprised the largest percentage of the U.S. fleet during the 1970s, 1980s and 1990s, when the studies were conducted.)

Peak velocities within the vortex core (tangential velocities) can attain high values. For example, a peak velocity of 326 feet (99 meters) per second was recorded during research involving a B-757 in the landing configuration being flown on a three-degree glideslope.[8]

The third phase of wake-vortex development is distinguished by the growth of the vortex axis and possible wavelength disturbances (in which the vortex develops waves). Several

Continued on page 20

critical parameters, such as atmospheric turbulence, can increase wavelength disturbances that eventually result in dissipation of the vortex.[9] Because the vortex remains highly coherent during this phase, the hazard to aircraft persists.

During the fourth phase, wavelength disturbances can increase. Often, the two vortices link together at points of minimum separation (the locations where waves in the two vortices are close together), and the linkages lead to a series of vortex rings (in which the airflow no longer rotates around a horizontal axis but moves instead around a circle) and a further decrease in vortex intensity.[10] Linking is the primary means by which vortices lose intensity in air that is free of atmospheric turbulence.[11,12,13] In atmospheric turbulence, wake vortices lose intensity through vortex "bursting" — a condition in which the structure of a vortex changes abruptly. Bursting is the most common form of vortex dissipation in turbulent atmospheric conditions.[14]

The fourth phase also involves the sudden increase in the size of the core of the vortex, followed by a decrease in tangential velocity. Often during this phase, the vortices change orientation and become distorted, resulting in turbulent airflow.[15]

Sometimes, wake vortices can be heard. Researchers who have been beneath the final-approach paths of landing jet aircraft — especially B-757-200 and B-767-200 aircraft — have heard a whistling sound that they have attributed to the shearing action between the tightly rolled vortices and the surrounding air mass. Researchers have described the sound as similar to that generated by an artillery shell passing overhead. Whistling sounds also have been heard from B-727-100 aircraft.[16,17]

In flight tests, the intensity of the vortex whistling sound varied, depending on flap configuration. The B-767-200 whistling sound became louder as flaps were retracted and became a "roar" when the flaps were fully retracted for two holding-configuration tests. The most repeatable whistling sound occurred when the B-767 was in takeoff configuration with the flaps set at one degree (in that configuration, leading-edge devices on the B-767 also are deployed).[18]

Temperature Gradient Remains Primary Predictor of Wake-vortex Intensity

The most reliable predictor for wake-vortex intensity and persistence is the atmospheric temperature gradient.[19] As vortices sink, they are affected by viscous forces (in which the viscosity of the atmosphere extracts energy from the vortices and reduces their strength) and buoyancy forces (in which vortices move upward because they are less dense than the surrounding atmosphere).

As a wake vortex sinks, it is compressed by increasing atmospheric pressure, and the temperature within the wake vortex increases. The warming of a wake vortex adds to its buoyancy, which in some temperature conditions can cause the wake vortex to maintain a constant height, rather than to continue sinking; sinking would be more characteristic behavior.[20]

Testing at the Idaho (U.S.) Nuclear Engineering Laboratory (INEL) found that the most persistent wake vortices and the most intense wake vortices were generated in a "neutrally stable" atmosphere.[21] A neutrally stable atmosphere is a condition in which the atmospheric temperature changes at a rate equivalent to the rate of temperature change within the wake vortex. The resulting neutral buoyancy causes the vortices to remain at a relatively constant altitude. In other tests of wake vortex activity in a neutrally stable atmosphere, wake vortices persisted longer than 3.5 minutes and were moved more than 1,640.5 feet (500 meters) downwind by winds of about six knots to 10 knots.[22]

The phenomenon of the neutrally stable atmosphere helps to explain why some trailing aircraft are flown into wake vortices long after the leading aircraft has passed. Atmospheric conditions that are less stable than the neutrally stable atmosphere result in faster dissipation of wake vortices.

The general relationship between atmospheric turbulence and vortex intensity was discovered during flight tests at INEL that showed that nearly all vortices with tangential velocities of more than 142 knots (or 240 feet [73 meters] per second) developed in conditions of a near neutrally stable atmosphere. The recorded data showed that many of the vortices persisted at fairly high tangential velocities for more than 60 seconds, even with relatively unstable conditions in the atmosphere.

The effects of turbulence on vortex persistence have been the subject of several studies.[23,24,25,26] Nevertheless, many details of the relationship between turbulence and vortex persistence are not well understood,[27] and direct measurement of atmospheric turbulence is difficult.

Near the Ground, Vortices Decelerate and Separate

The behavior of wake vortices at very low altitudes differs from wake-vortex behavior at higher altitudes and has been the subject of many scientific studies.

Research conducted during the 1990s found that vortices generated when the aircraft is being flown in ground effect typically do not sink — and that suggests that pilots of trailing aircraft may not have sufficient time or sufficient altitude to recover their aircraft from the influence of the vortex-induced motion.[28] A 1982 report by the U.S. Department of Transportation had said that wake vortices separate and rebound (move higher into the air) after reaching the ground.[29]

The ground modifies the trajectory of a wake vortex generated during takeoff and landing by acting as a reflection plane so that the vortex — after striking the ground — rebounds.[30] In a 1991 study, vortices generated near the ground by a B-767 were observed to move above the point where they were generated.[31] Researchers also have said that wake vortices can "bounce" from the ground to heights equal to twice the wingspan of the vortex-generating aircraft.[32,33] The FAA *Aeronautical Information Manual* (*AIM*), however, says that "no one can say what conditions cause vortex bouncing, how high they bounce, at what angle they bounce, or how many times a vortex may bounce."[34]

As a vortex sinks close to the ground, it creates a secondary vortex rotating in a direction opposite that of the primary vortex. One of the effects of the secondary vortex is to induce upward movement of the primary vortex.[35] Studies show that such an upward movement is more pronounced when the surrounding air is smooth than when the surrounding air is turbulent.[36] Thus, some vortices may be present in locations where pilots may not anticipate them. For example, pilots who fly their aircraft on a higher glide path as a preventive measure inadvertently may position their aircraft near wake vortices.

Winds, Atmospheric Turbulence Influence Wake-vortex Development

Research has shown a correlation between wind, the movement of the vortex and the persistence of the vortex. The most persistent vortices during crosswind conditions are upwind vortices, which linger at the approach end of the active runway and typically gain intensity because of the influence of the crosswind.[37] Because the ambient wind speed (the wind speed in the air surrounding a vortex) is greater at the top of the vortex than at the bottom, the crosswind increases the upwind vortex rotation.[38] In contrast, the crosswind diminishes the intensity of the downwind vortex.

Ambient wind speed also is associated with vortex persistence. In flight tests involving military transport aircraft (Lockheed C-130E, Lockheed C-141B and Lockheed C-5A/B), wake vortices were persistent when winds were from three knots to 10 knots.[39] Vortices that persisted longer than 60 seconds generally were generated during winds of three knots to 10 knots; stronger winds dissipated vortices more quickly.

During tests involving B-727, B-757 and B-767 aircraft, all vortices that persisted longer than 85 seconds were generated when the wind speed was less than five knots. Vortices that persisted longer than 35 seconds were generated when the wind speed was 10 knots or less. All vortices with tangential velocities of more than 200 feet per second were generated when ambient wind speeds were from five knots to 10 knots. Higher ambient wind speeds and stronger wind shear typically led to dissipation of vortices. Nevertheless, low wind speeds indicated less atmospheric turbulence and were associated with more persistent vortices. The most persistent vortices were generated during ambient wind speeds from three knots to five knots.[40]

Slower Aircraft, Smaller Wingspans Generate More Intense Vortices

Aircraft speed and size also influence wake-vortex generation and dissipation, and the severity of a wake-turbulence occurrence. For example, more intense vortices are generated as an aircraft slows because there is greater circulation of air around the wing. (The lift of a wing is proportional to the circulation of air around it. Greater circulation of air creates greater lift. At a constant angle-of-attack, higher airspeed creates greater lift. As an aircraft slows, less air moves over the wing, and to create the same amount of lift, the aircraft must be flown at a higher angle-of-attack. As the angle-of-attack is increased, the circulation increases.) Aircraft with smaller wingspans generate more intense wake vortices than aircraft with equivalent weights and longer wingspans; this is because the vortex is generated within a smaller distance. Heavier aircraft generate more intense vortices because of their greater lift requirements.

Studies of the effect of wake vortices generated by aircraft with large wingspans have found that vortices can cause a reduction of lift on a trailing aircraft. This effect becomes more significant as the angle-of-attack of the leading aircraft is increased. For example, if the leading aircraft is flown at an angle-of-attack of about eight degrees, the wing of the trailing aircraft experiences a zero-lift angle-of-attack of nearly seven degrees and a 30 percent decrease in the maximum lift coefficient.[41]

Airplanes with flaps extended produce multiple vortices, which weaken somewhat as they merge. The extra drag and turbulence produced by flap extension accelerate dissipation. On most airplanes, the greater the flap extension, the weaker the tangential speed of the wake vortices.

There are exceptions, however. The B-757 wing was designed so that, when flaps are extended, lift is distributed more evenly across the entire wing, compared with other wings. When the flaps are extended, the B-757 has a continuous wing-flap trailing edge with no cutouts (gaps) between the inboard flaps and outboard flaps in the jet-exhaust area. The result is relatively even wingspan load distribution. The absence of cutouts decreases or eliminates the generation of multiple vortices when the airplane is in the landing configuration at various settings of flaps and wing-tip leading-edge devices. Multiple vortices typically interact with each other, causing a decrease in vortex tangential velocities downstream from the airplane. The geometry of the B-757 wing — with a relatively low wing sweep of 25 degrees and a relatively straight trailing edge — also may contribute to the decrease in tangential velocities.[42,43] In flight tests with the aircraft in landing configuration on a three-degree glide path, the tangential velocity of the wake vortices created by the B-757 (at 193 knots) was 50 percent higher than the tangential velocity created by other aircraft tested.[44]

Continued on page 22

A 1994 report by the U.S. National Transportation Safety Board (NTSB) said that NTSB had studied five wake-turbulence accidents and incidents from December 1992 through December 1993 in which B-757s were the leading aircraft. The report said that NTSB initially focused on why the B-757 apparently had been involved in a disproportionate number of wake-vortex occurrences and found "little technical evidence to support the notion that the wake vortex of a B-757 is significantly stronger than indicated by its weight."[45]

The report said that most researchers believe that the primary factor in determining the risk associated with wake-vortex occurrences is not the airspeed within the core of the vortex but the vortex circulation, a measure of the angular momentum of the air in the airflow field. The report said that the B-757's vortex circulation was greater than that of the B-727 and less than that of the B-767. Flight tests by the U.S. National Oceanic and Atmospheric Administration, however, produced different results. In those tests, the B-757 showed the highest average vortex circulation — 1,173 feet (358 meters) per second — during flight tests of the three aircraft. The B-757's vortex circulation was about 10 percent greater than the vortex circulation from the heavier B-767.[46]

Research using the C-130 showed little correlation between vortex speeds and flap deflection. The C-130's four turboprop engines accelerate the air behind the engine nacelles to create a localized high-velocity airflow pattern in four areas along the wing. This high-velocity flow-field creates turbulence, which has a twofold effect. First, the turbulence breaks up the coherence of the overall wake vortex and reduces its intensity. Second, turbulence accelerates the dissipation of a vortex. As the flaps are extended, additional engine thrust is required, creating additional turbulence within the developing vortex. Light transport aircraft with similar engine configurations may have similar wake-vortex generating characteristics.[47]

Flap design also affects the behavior of wake vortices. Studies of various Airbus aircraft found that the A320 and the A321 have different wake-vortex patterns, apparently because the A320 has single-slotted flaps and the A321 has double-slotted flaps.[48] (Other studies of the A321 found that vortices that formed around the flaps were more intense than vortices that formed around the wing tips. Similar studies of an A310, however, showed that flap vortices and wing tip vortices were the same intensity.)[49]

Low-slung engines, such as those on the C-141 and C-5A, diminish the interaction of wake vortices with jet engine exhaust, thus increasing vortex persistence. Engines that are low enough below the wing that no flap cutouts are needed preclude the generation of multiple-flap vortices, which typically would accelerate vortex dissipation during takeoff or landing.[50]

The engine exhaust plume may affect vortex motion in another way. The extent to which exhaust gas is trapped in the air in sinking vortices depends on the location of the engines and the location of the wake-vortex cores. Studies of the trapped portions of exhaust plumes have found that these portions of exhaust plumes are cooled in a different way than the portions of exhaust plumes that are not trapped within the vortex. Because of the intense confining effect of the vortex core, the temperature of the vortex core affects vortex motion.[51] Engine exhaust is warm, and on some aircraft in certain configurations, the warm exhaust is trapped in the wake vortices. The warm air resists the settling motion of the vortices and acts as a buoyancy force that keeps the vortices aloft.[52]

The position of the landing gear also affects wake-vortex generation. An extended landing gear produces an airflow disturbance that helps to dissipate wake vortices.

Other variations in wake-vortex behavior are associated with wing configurations (high-wing or low-wing) and the type of aircraft tail (T-tails or conventional tails). All the military transport aircraft tested (C-5A, C-141B and C-130) have high wings and high aspect ratios. Researchers have said that, because of the induced-drag characteristics and interference-drag characteristics of these aircraft, the undisturbed flow of air over the top of the wing provides more lift than mid-wing designs or low-wing designs.[53]

The T-tail surface is a lifting surface, although the lift is produced in the downward direction. The high T-tails on the B-727, C-5A and C-141 may contribute to the persistence of vortices. The T-tail produces its own pair of vortices, above and separate from the wing. These T-tail vortices typically are not integrated into the wing vortices or the downwash field. High T-tail designs result in little interaction or no interaction between the wing vortices and the T-tail vortices — a condition that increases the persistence of the wake vortices. Embedded vortices are more likely to be generated by aircraft with conventional tails, such as the B-737 and B-747.[54]

Other factors that determine the severity of a wake-turbulence occurrence include the trailing aircraft's design characteristics. A lighter aircraft, for example, is more likely to be upset by wake turbulence than a heavier aircraft. The distribution of weight within the trailing aircraft also is a factor because aircraft with weight concentrated in the wings have more resistance to induced rolling forces.

The wingspan of the trailing aircraft affects the pilot's control of the aircraft's reaction to wake turbulence. If the wingspan of the trailing aircraft is greater than the diameter of the wake vortex from the leading aircraft, ailerons may help counteract the roll. If the wingspan of the trailing aircraft is smaller than the vortex diameter, however, the ailerons will be within the vortex and, therefore, less able to counteract the roll.

In NASA flight tests in 1971, a Lockheed C-5A at 12,000 feet was trailed in different flights by a McDonnell Douglas DC-9, a Cessna 210 and a Gates Learjet. Flight into the C-5A's wake vortices resulted in bank angles of more than 30 degrees for the trailing aircraft at separation distances of about eight nautical miles (15 kilometers) and a time lapse of 2.7 minutes. The wake vortices sank nearly 1,300 feet below the C-5A's altitude about three minutes after aircraft passage, and the vortices remained intact for more than 10 nautical miles (19 kilometers) behind the aircraft — about three minutes after the aircraft's passage. The tangential velocity was measured at about 3,600 feet (1,098 meters) per minute as far as 1.5 nautical miles (2.8 kilometers) behind the C-5A, or for 30 seconds after the aircraft's passage.[55]♦

— Patrick R. Veillette, Ph.D.

Notes

1. Greene, George. "An Approximate Model of Wake Vortex Decay." *Journal of Aircraft* Volume 23 (July 1986): 566–573.

2. Delisi, Donald P.; Robins, Robert E.; Altman, Donald B. "Laboratory and Numerical Studies of Vortex Evolution in Ideal and Realistic Environments." In *Proceedings of the Aircraft Wake Vortices Conference*, Washington, D.C., U.S. Oct. 29–31, 1991.

3. Zamyatin, A.N. "Real Research of Different Class Airplane Vortex Wakes." In *Proceedings of the Aircraft Wake Vortices Conference*, Washington, D.C., U.S. Oct. 29–31, 1991.

4. Chow, Jim; Zilliac, Greg; Bradshaw, Peter. "Initial Rollup of Wingtip Vortex." In *Proceedings of the Aircraft Wake Vortices Conference*, Washington, D.C., U.S. Oct. 29–31, 1991.

5. U.S. Federal Aviation Administration (FAA). *Aeronautical Information Manual (AIM).* Chapter 7, Section 3: Wake Turbulence.

6. Wetmore, Joseph W. "Aircraft Trailing Vortices — A Hazard to Operations." *Astronautics and Aeronautics* (December 1964): 44–50.

7. Garodz, Leo J.; Clawson, Kirk L. "Vortex Characteristics of B-757-200 and 767-200 Aircraft Using the Tower Fly-by Technique." U.S. National Oceanic and Atmospheric Administration (NOAA) Technical Memorandum ERL ARL-199. Air Resources Laboratory, Silver Spring, Maryland, U.S. January 1993.

8. Garodz, Leo J.; Clawson, Kirk L. "Vortex Characteristics of C5A/B, C141B, and C130E Aircraft Applicable to ATC Terminal Flight Operations Tower Fly-by Data." NOAA Technical Memorandum ERL ARL-190. Air Resources Laboratory, Silver Spring, Maryland, U.S. August, 1991.

9. Delisi et al.

10. Liu, H.T.; Hwang, P.A.; Srnksy, R.A. "Physical Modeling of Ground Effect on Vortex Wakes." *AIAA Journal of Aircraft* Volume 29 (November–December 1992): 1027–1034.

11. Crow, S.C. "Stability Theory for a Pair of Trailing Vortices." *AIAA Paper* 70–53, January 1970.

12. Hall, M.G. "Vortex Breakdown." *Annual Review of Fluid Mechanics* Volume 4 (1972): 195–218.

13. Bilanin, A.J.; Widnall, S.E. "Aircraft Wake Dissipation by Sinusoidal Instability and Vortex Breakdown." *AIAA Paper* 73–107, January 1973.

14. Liu et al. 1992.

15. Delisi et al.

16. Garodz, L.J. "Federal Aviation Administration Full-scale Aircraft Vortex Wake Turbulence Flight Test Investigations: Past, Present Future." In *Proceedings of the Ninth Aerospace Sciences Meeting*, New York, New York, U.S. Jan. 25–27, 1971.

17. Garodz, L.J.; Lawrence, D.M.; Miller, N.J. "The Measurement of the Boeing 727 Trailing Vortex System Using the Tower Fly-by Method." FAA-RD-74-90. U.S. Department of Transportation, Washington, D.C., U.S. 1974.

18. Garodz, Clawson. 1993.

19. Garodz, Clawson. 1991.

20. Greene.

21. Page, Richard D.; Clawson, Kirk L.; Garodz, Leo J.; Rudis, Robert P. "Panel Discussion on Tower Fly-by Testing, 1990 Fall Series." In *Proceedings of the Aircraft Wake Vortices Conference*, Washington, D.C., U.S. Oct. 29–31, 1991.

22. Delisi et al.

23. Tombach, I. "Observations of Atmospheric Effects of Vortex Wake Behavior." *Journal of Aircraft* Volume 10 (1973): 641–647.

24. Tombach, I.H.; Lissaman, P.B.S.; Mullen, J.B. "Aircraft Vortex Wake Behavior and Decay Near the Ground." In *Proceedings of the Aircraft Vortex Wake Conference,* Cambridge, Massachusetts, U.S. March 15–17, 1977.

25. Crow, S.C.; Bate, E.R. "Lifespan of Trailing Vortices in a Turbulent Atmosphere." *Journal of Aircraft* Volume 13 (1976): 476–482.

26. Crow. 1970.

27. Garodz, Clawson. 1993.

28. Liu et al. 1992.

Continued on page 24

29. Burnham, D.C. "B-747 Vortex Alleviation Flight Tests: Ground-Based Sensor Measurements." U.S. Department of Transportation Report no. DOT-TSC-FAA-81-19. Washington, D.C., U.S. 1982.

30. Liu et al. 1992

31. Delisi et al. 1991.

32. Liu, H.T. "Effects of Ambient Turbulence on the Decay of a Trailing Vortex Wake." QUEST TP 268. Quest Integrated, Kent, Washington, U.S. 1991.

33. Tetzlaff, G.; Franke, J. "Wake Vortex Propagation in the Atmospheric Boundary Layer." In *Proceedings of the Aircraft Wake Vortices Conference*, Washington, D.C., U.S. Oct. 29–31, 1991.

34. FAA. *AIM.* 7-3-3.

35. Harvey, J.K.; Perry, F.J. "Flowfield Produced by Trailing Vortices in the Vicinity of the Ground." *AIAA Journal* Volume 9 (1971): 1659–1669.

36. Bilanin, A.J.; Teske, M.E.; Hirsh, J.E. "Neutral Atmospheric Effects on the Dissipation of Aircraft Vortex Wakes." *AIAA Journal* Volume 16 (1978): 956–961.

37. Bedard, A.J. "Use of Remote Sensors and Lab Scale Models in Wake Vortex Advisory Systems." In *Proceedings of the Aircraft Wake Vortices Conference*, Washington, D.C., U.S. Oct. 29–31, 1991.

38. Garodz, Clawson. 1993

39. Garodz, Clawson. 1991.

40. Garodz, Clawson. 1993.

41. Olwi, I.; Ghazi, M. "Effect of Wing Tip Vortices on a Trailing Aircraft." *AIAA Journal* Volume 30 (September 1992): 2186–2187.

42. Garodz, Clawson. 1991.

43. Garodz, Clawson. 1993.

44. Garodz, Leo J. et al. "Panel Discussion on Tower Fly-by Testing, 1990 Fall Series." In *Proceedings of the Aircraft Vortex Wake Conference,* Cambridge, Massachusetts, U.S. March 15–17, 1991.

45. U.S. National Transportation Safety Board (NTSB). *Special Investigation Report: Safety Issues Related to Wake Vortex Encounters During Visual Approach to Landing.* NTSB/SIR-94-01. Washington, D.C., U.S. 1994.

46. Garodz, Clawson. 1993.

47. Garodz, Clawson. 1991.

48. Dornheim, Michael A. "A380 Fights Weight Growth With New Technologies." *Aviation Week & Space Technology* Volume 155 (June 18, 2001): 118–126.

49. Nordwall, Bruce D. "DERA Presses To Correlate Wake Vortex Research." *Aviation Week & Space Technology* Volume 152 (May 15, 2000): 53–54.

50. Garodz, Clawson. 1991.

51. Miake-Lye, R.C.; Martinez-Sanchez, M.; Brown, R.C.; Kolb, C.E. "Plume and Wake Dynamics, Mixing and Chemistry Behind a High Speed Civil Transport Aircraft." *Journal of Aircraft* Volume 30 (July–August 1993): 467–478.

52. Greene.

53. Garodz, Clawson. 1991.

54. Ibid.

55. McGowan, William A. "Aircraft Wake Turbulence Avoidance." *AAIA Journal of Aircraft* Volume 9 (March 1972): 197–198.

high-power run-ups [were being conducted] in [the] area. [The captain] said the roll did not feel like wake turbulence — its onset was sudden, without the slight ripple that is felt momentarily before [many] wake-turbulence encounters. The aircraft was loaded at the maximum forward center-of-gravity limit. The yaw damper had been worked on in Anchorage [Alaska, U.S.], and the flight data recorder showed some sort of upper rudder input at about the time of the incident. Flight data recorder readout showed the maximum bank was about 7.5 degrees, and the touchdown was at 700 [feet per minute] and 2.8 g [2.8 times standard gravitational acceleration]. A bulkhead in the nosewheel area was buckled but not so seriously that its replacement could not wait until the next [maintenance] C check. The aircraft landed on the left-main gear first, bounced and then landed flat on all three gear simultaneously."[31]

A 1991 report on 140 wake-turbulence events reported to ASRS from 1983 through 1990 said that more than half of all reported wake-turbulence occurrences in the United States occurred between transport aircraft. The report said that in 40 percent of the events, the leading aircraft was a heavy aircraft (defined by FAA at the time as weighing more than 300,000 pounds), and in 53 percent of the events, the leading aircraft was a large aircraft (then defined by FAA as weighing more than 12,500 pounds/ 5,670 kilograms to 300,000 pounds). The trailing aircraft was a large aircraft in 52 percent of the events, and a small aircraft (then defined by FAA as weighing 12,500 pounds or less) in 36 percent of the events. Twenty-five percent of the events involved a large aircraft trailed by another large aircraft, 22 percent

Table 7
Weight Categories of Trailing Aircraft and Leading (Wake-generating) Aircraft in U.S. Wake-turbulence Events, 1988–1999

		Leading Aircraft							
	Categories	Small[1]	Small Transport[2]	Light Transport[3]	Medium Transport[4]	Medium-large Transport[5]	Large Transport[6]	Heavy Transport[7]	Row Total
Trailing Aircraft	Small[1]	4	3	7	10	7	5	6	42
	Small Transport[2]	–	–	–	2	2	6	5	15
	Light Transport[3]	–	–	–	2	1	8	6	17
	Medium Transport[4]	–	–	–	2	2	10	14	28
	Medium-large Transport[5]	–	–	–	2	3	9	13	27
	Large Transport[6]	–	–	–	–	–	9	16	25
	Heavy Transport[7]	–	–	–	–	2	2	7	11
	Column Total	4	3	7	18	17	49	67	165

Note: Numbers in kilograms have been rounded.

[1] U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) defines small aircraft as weighing 5,000 pounds/2,300 kilograms or less.

[2] NASA ASRS defines small transport aircraft as weighing 5,001 pounds/2,300 kilograms to 14,500 pounds/6,600 kilograms.

[3] NASA ASRS defines light transport aircraft as weighing 14,501 pounds/6,600 kilograms to 30,000 pounds/13,600 kilograms.

[4] NASA ASRS defines medium transport aircraft as weighing 30,001 pounds/13,600 kilograms to 60,000 pounds/27,200 kilograms.

[5] NASA ASRS defines medium-large transport aircraft as weighing 60,001 pounds/27,200 kilograms to 150,000 pounds/68,000 kilograms.

[6] NASA ASRS defines large transport aircraft as weighing 150,001 pounds/68,000 kilograms to 300,000 pounds/136,000 kilograms.

[7] NASA ASRS defines heavy transport aircraft as weighing more than 300,000 pounds/136,000 kilograms.

Source: Patrick R. Veillette, Ph.D., from U.S. National Aeronautics and Space Administration Aviation Safety Reporting System data on 165 events

involved a large aircraft trailed by a heavy aircraft, and 21 percent involved a large aircraft trailed by a small aircraft.[32]

Most Wake-turbulence Accidents Occur In Visual Meteorological Conditions

Most wake-turbulence accidents, incidents and events in the author's study occurred in VMC. Of the 130 accidents in the NTSB database, 127 accidents (98 percent) occurred in VMC. Of the 60 incidents in the FAA database, 59 incidents (98 percent) occurred in VMC. Of the 165 events reported to the ASRS database, 143 events (87 percent) occurred in VMC. Day lighting conditions prevailed during 124 accidents (95 percent), all 60 incidents and 124 events (75 percent). Night lighting conditions prevailed during four accidents (3 percent) and 41 events (25 percent). Lighting conditions were not specified in two accident reports.

Air traffic controllers are required to provide lateral separation guidance and vertical separation guidance between aircraft that are operated under instrument flight rules and that are receiving air traffic control (ATC) services. The separation criteria are intended to minimize the risk of midair collisions and wake-vortex occurrences. Controllers may issue a clearance for a visual approach when an aircraft is the first one in an approach sequence, when an aircraft crew is told to follow a leading aircraft and the crew says that the leading aircraft is in sight, or when a crew says that the airport or the landing runway is in sight but the leading aircraft is not in sight. (In that situation, radar separation must be maintained by ATC until the leading aircraft is in sight and visual separation can be maintained.)

During peak traffic periods, controllers use visual approaches to increase traffic capacity and to reduce delays. Pilots may accept visual-approach clearances, yet be unable to maintain adequate separation from the leading aircraft without additional maneuvering, reconfiguration of the aircraft or reductions of airspeed. Thus, a "compression effect" can be created in which the risk of a wake-turbulence occurrence increases for each successive arriving aircraft.

Thirty-seven of the 165 reports in the ASRS database (22 percent) involved events that required extensive maneuvering to maintain safe separation. Fifteen reports (9 percent) referred to events in which ATC had requested "tight patterns" or had used similar phrases. ATC instructions were cited in 24 reports (15 percent) as contributing factors to wake-vortex occurrences.

The following ASRS report was filed by the captain of a Dassault Falcon 10C:

> TRACON [terminal radar approach control] cleared my aircraft for a visual approach to Runway 35R to follow a B-757 turning right base to final — also on a visual approach. Our separation from the B-757 was six [nautical] miles [11 kilometers], as reported by the approach controller. I briefed my copilot regarding my intentions to avoid the vortices of the B-757: We would maintain a glide path at least one dot above the glideslope and fly an airspeed of V_{REF} [landing reference speed] plus 15 knots.
>
> After the briefing, approach control issued instructions for me to maintain an airspeed of 180 knots to the outer marker. I complied with the instructions and observed the B-757 fly what appeared to be a visual approach that was on the glideslope. [The B-757's] touchdown point on the runway was between the 1,000-foot [marker] and 1,500-foot marker [305-meter marker and 458-meter marker]. I continued my approach and maintained a flight path one [dot] to two dots above the glideslope. At approximately 350 feet AGL, my aircraft encountered the wake vortices of the B-757. Three rapid full-aileron deflections were made (right-left-right) to regain control of my aircraft. This action [was] followed by an immediate missed approach with an uneventful landing made on Runway 26. … Tower reported wind was [from] 170 [degrees] at five knots when we reported in on the visual approach to Runway 35R.[33]

An ASRS follow-up interview with the captain revealed the following:

> [The captain] says the most significant cause of the wake-turbulence encounter was the ATC instruction to maintain 180 knots to the marker. Initially, the separation from the B-757 was six [nautical] miles, but when [the B-757] slowed at the marker and [the captain's airplane] was [being flown at] 180 knots, the separation rapidly decreased to within [an] estimated three [nautical] miles when the encounter occurred. [The captain] also thinks the tail wind causes an aberration in the dissipation of vortices and that the tail wind may tend to keep the vortices at altitude longer, rather than dissipate downward.[34]

Pilots of Most Accident Aircraft Held Advanced Flight Certificates

Data show that 50 (38 percent) of the 130 pilots-in-command (PICs) of the accident aircraft held commercial pilot certificates, and 30 PICs (23 percent) held airline transport pilot (ATP) certificates (Table 8). Of the 50 PICs with commercial pilot certificates, 20 PICs had been cautioned about wake turbulence by ATC. Of the 30 PICs with ATP certificates, six PICs had been cautioned about wake turbulence by ATC. Pilots with private pilot certificates flew the trailing aircraft in 36 (28 percent) of the 130 accidents; 12 pilots had been cautioned about wake turbulence. Of 14 student pilots (11 percent) who flew the trailing aircraft in wake-turbulence accidents, seven pilots had been cautioned about wake turbulence.

Table 8
Pilot Certificate Held by Pilots-in-command of Aircraft in U.S. Wake-turbulence Accidents, 1983–2000

Type of Certificate	Number of Pilots	Number of Pilots Who Had Been Cautioned by ATC About Wake Turbulence
Student	14	7
Private	36	12
Commercial	50	20
Airline transport pilot	30	6
Total	**130**	**45**

ATC = Air traffic control

Source: Patrick R. Veillette, Ph.D., from U.S. National Transportation Safety Board data on 130 accidents

Table 9 shows the distribution of certificates held by pilots involved in incidents in the FAA database and in events in the ASRS database. In the 60 incidents, ATPs flew 24 (40 percent) of the trailing aircraft, commercial pilots flew nine (15 percent) of the trailing aircraft, private pilots flew 20 (33 percent) of the trailing aircraft, and student pilots flew seven (12 percent) of the trailing aircraft. In the 165 events, 127 ATPs (77 percent), 26 commercial pilots (16 percent) and 12 private pilots (7 percent) flew the trailing aircraft.

Table 9
Type of Pilot Certificate Held by Pilots-in-command of Aircraft in U.S. Wake-turbulence Incidents, 1983–2000, and Events, 1988–1999

Type of Certificate	Number of Pilots in Incidents	Number of Pilots in Events
Student	7	0
Private	20	12
Commercial	9	26
Airline transport pilot	24	127
Total	**60**	**165**

Source: Patrick R. Veillette, Ph.D., from U.S. Federal Aviation Administration data on 60 incidents and U.S. National Aeronautics and Space Administration Aviation Safety Reporting System data on 165 events

Figure 9 shows that, of the 130 pilots of trailing aircraft involved in accidents, 37 pilots (28 percent) had more than 5,000 flight hours. Of the 60 pilots of trailing aircraft involved in incidents, 15 pilots (25 percent) had more than 5,000 flight hours, and of the 165 pilots of trailing aircraft involved in events, 107 pilots (65 percent) had more than 5,000 flight hours.

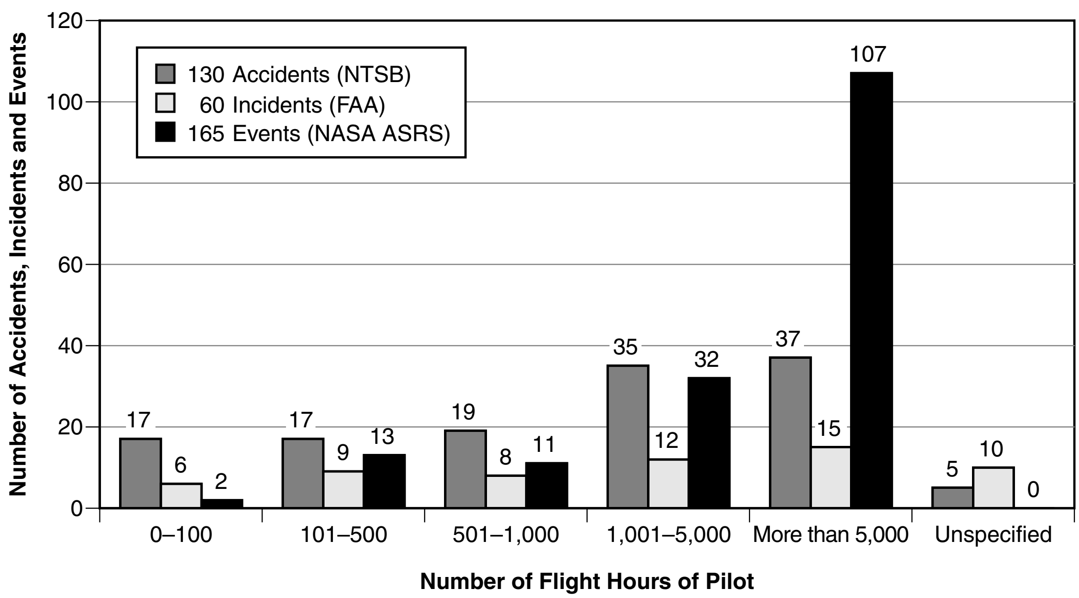
Many Pilots Described Wake-turbulence Events as 'Violent' or 'Severe'

Many of the 165 wake-turbulence events reported to the ASRS database had severe effects on the trailing aircraft. In 49 reports (30 percent), the event was described as "violent" or "severe" (Figure 10, page 28). Forty-two reports (25 percent) said that the event involved a "moderate" upset. Reports on 70 events (42 percent) said that there was a temporary loss of control; reports on 16 events (10 percent) said that pilots had refused to accept a takeoff clearance because of wake turbulence, and reports on nine events (5 percent) said that pilots rejected a takeoff because of the risk of a wake-turbulence occurrence.

The following ASRS report was filed by the pilot of an airplane identified only as a light transport aircraft:

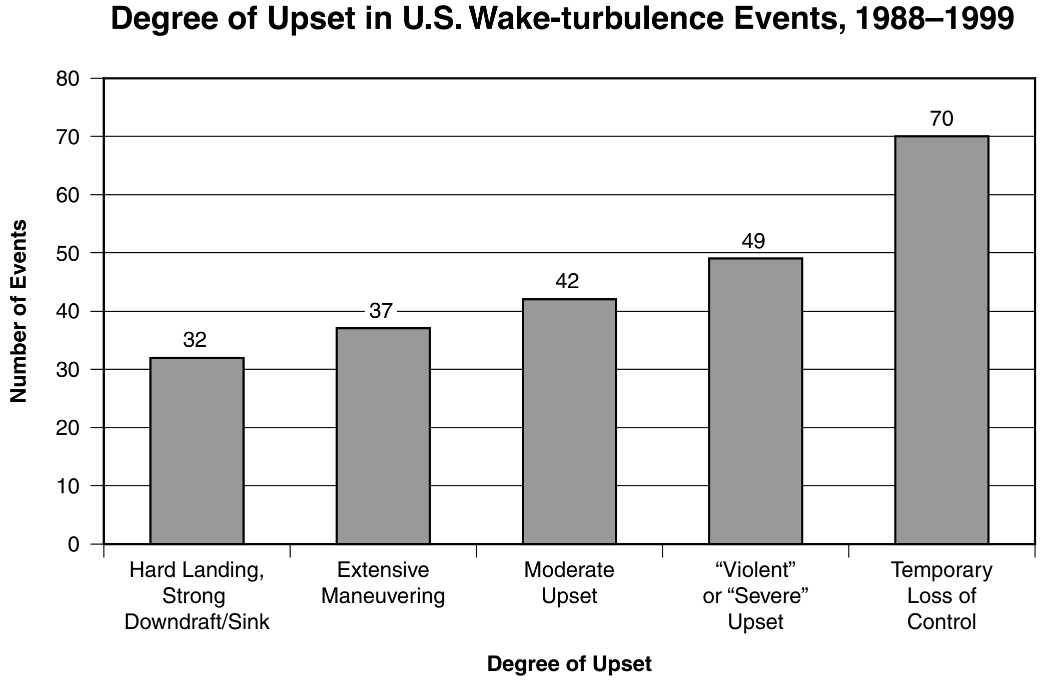
> [We were] approaching [the] airport from the northwest, following medium-large transport traffic, when the controller saw an opportunity to allow us to land on Runway 35R. We were 3,000 feet MSL [above mean sea level] at 210 knots indicated airspeed (the assigned airspeed) when told to follow the [medium-]large transport over the locator outer marker for Runway 35R. [Our airplane] crossed behind the medium-large transport on final for Runway 36L. [Our airplane was] still at 3,000 feet and intercepted the localizer for Runway 35R. [We] switched to tower frequency and were told we had a 70-knot overtake on the large transport and began slowing.
>
> [We] began descent from 3,000 feet, noting [that] we were full deflection above glideslope. I judged this to be perfectly acceptable, knowing the nasty reputation the [medium-]large transport has for generating wake turbulence, and, in fact, [I] fully intended to remain high on final. Tower advised "cleared to land following traffic 2.5 [nautical] miles ahead, caution wake turbulence." I thought we would be safely above his wake.
>
> Shortly thereafter, my aircraft … rolled to the right to an angle of approximately 100 degrees (more than 90 degrees). Full opposite control input did not have any effect in stopping this roll. Indicated airspeed began dropping, and throttles were then firewalled. As we rolled right, we had also turned slightly in that direction, and I assume we flew out of that vortex and were able to right the aircraft. Then we hit what

Flight Hours of Pilots Involved in U.S. Wake-turbulence Accidents and Incidents, 1983–2000, and in Wake-turbulence Events, 1988-1999



Source: Patrick R. Veillette, Ph.D., from U.S National Transportation Safety Board (NTSB) data on 130 accidents, U.S. Federal Aviation Administration (FAA) data on 60 incidents and U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) data on 165 events

Figure 9



Note: Some of the 165 events were recorded in more than one category.

Source: Patrick R. Veillette, Ph.D., from U.S. National Aeronautics and Space Administration Aviation Safety Reporting System data on 165 events

Figure 10

> I assume was [the other aircraft's] right-wing vortex, and the aircraft (mine) began to roll left. We flew through this vortex fairly quickly, probably due to our new (uncommanded) heading, and our bank did not exceed 60 degrees. We recovered from this roll on a heading of about 80 degrees and declared a missed approach. Tower asked if we could enter a base for Runway 31R and land. We did, and landed without further incident.
>
> The large transport had obviously been very high on his approach for some reason. … Our attention had been focused on the medium transport we were originally following; thus, I was unaware of the large transport's glide path. I feel someone (controllers) should have noticed this and realized a wake encounter was inevitable.[35]

Figure 11 (page 29) shows the types of motion induced by flights into wake turbulence by the aircraft involved in the NTSB accidents, the FAA incidents and the ASRS events. The most common type of motion induced among the 130 accident aircraft was a rolling motion in one direction, experienced by 46 aircraft (35 percent). Veering/yawing motions were most prevalent among the 60 incident aircraft; in 17 incidents (28 percent), the aircraft experienced veering/yawing. A rolling motion in one direction was most prevalent among the 165 events; in 37 events (22 percent), the aircraft experienced primarily a rolling motion in one direction.

Compressor stalls or similar engine anomalies occurred in 12 events (7 percent) described in ASRS reports. The pilots said that the engines had ingested part of the leading aircraft's wake, resulting in a severe disturbance of inlet airflow and subsequent compressor stalls. The following ASRS report was filed by the pilot of a DC-10:

> The wind was calm when we landed immediately after a heavy [Lockheed] L-1011 took off. We experienced an air burble in the flare from the jet blast. We also experienced light buffeting during rollout. Normal reverse was established … and held until 80 knots. At 70 knots, all three engine-reverse levers were in the stowed position. At about 50 knots, two loud bangs were heard. [The] no. 1 [engine] and no. 3 engine had compressor stalls. They were shut down. [The] no. 2 engine was normal, and we taxied to the gate on one engine. Reverse and landing procedures were normal. The heavy aircraft had lifted off right about where the engines stalled. Calm winds, heavy aircraft with strong wing vortices and engines with a history of stall problems … combined to create a problem on what should have been a normal landing.[36]

Severity of Wake Turbulence Determined by Many Factors

The severity of a wake-turbulence occurrence depends on many factors, including the weight and wingspan of the trailing

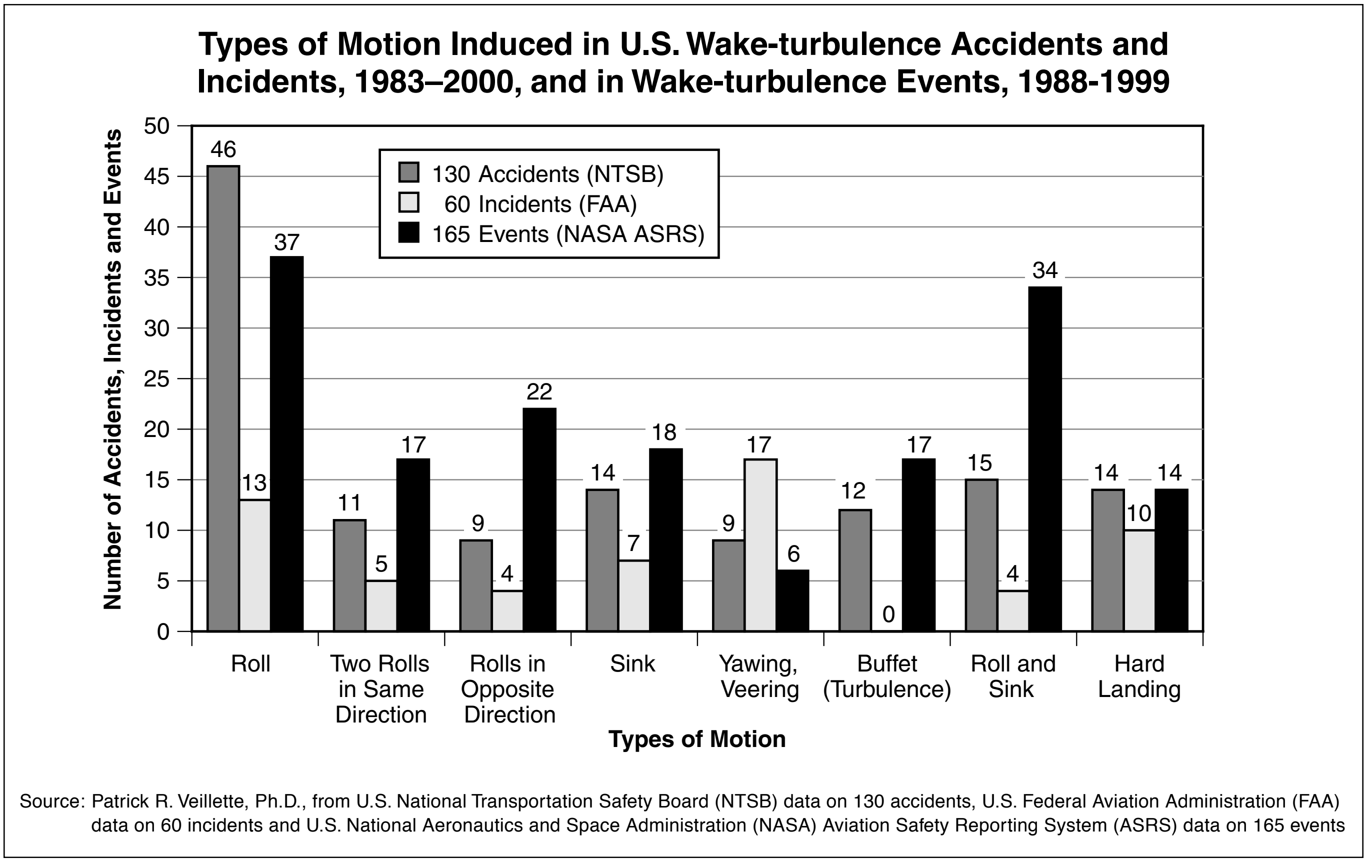


Figure 11

aircraft and the relative positions of the trailing aircraft and the wake vortices. In most of the 130 accidents, 60 incidents and 165 events, the maximum bank angle induced by wake turbulence was 30 degrees or less.

Of the 113 accidents, 46 incidents and 57 events involving small aircraft and small transport aircraft as the trailing aircraft, 81 accidents (72 percent), 25 incidents (54 percent) and 27 events (47 percent) resulted in a maximum bank angle of 30 degrees or less (Table 10, page 30).

Of the four accidents, five incidents and 17 events involving light transport aircraft as the trailing aircraft, three accidents (75 percent), four incidents (80 percent) and nine events (53 percent) resulted in a maximum bank angle of 30 degrees or less (Table 11, page 30).

Of the six accidents, four incidents and 28 events in which medium transport aircraft were the trailing aircraft, five accidents (83 percent), three incidents (75 percent) and 17 events (61 percent) resulted in a maximum bank angle of 30 degrees or less (Table 12, page 30).

Of the 25 events in which large transport aircraft were the trailing aircraft, 21 events (84 percent) resulted in a maximum bank angle of 30 degrees or less, and four events (16 percent) resulted in a maximum bank angle from 31 degrees through 60 degrees. In the one accident and 11 events in which heavy transport aircraft were the trailing aircraft, the maximum bank angle was 30 degrees or less.

Of the 130 accidents, 60 incidents and 165 events, 14 accidents (11 percent), 10 incidents (17 percent) and nine events (5 percent) involved hard landings, which sometimes result from the sinking that accompanies an "along-track penetration between vortices" (flight between a pair of vortices) — one of three categories of wake-turbulence occurrences, according to the direction of the aircraft's entry into the vortices. (The other two categories are "along-track penetration of the vortex center" [or flight into a vortex] and "cross-track penetration" [or flight perpendicular to a pair of vortices].) In an along-track penetration between vortices, the wake vortices produce a predominant downwash (downward flow of air) and the trailing aircraft reacts as though it were entering sinking air — either with a decrease in the rate of climb, a high sink rate or a hard landing.

The downwash produced by the wake vortices of a B-727 was measured by NASA — two minutes after the airplane passed by — at 1,400 fpm, which is greater than the climb performance of some light transport aircraft. The studies calculated that after three minutes, the sink rate induced by B-727 downwash would be 1,200 fpm. The sink rate would be most severe if the trailing aircraft were at the same altitude

Table 10
Maximum Roll Angles Induced in Small Aircraft and Small Transport Aircraft in U.S. Wake-turbulence Accidents and Incidents, 1983–2000, and in Events, 1988–1999

Roll (Bank) Angle	Accidents	Incidents	Events
(Unspecified)	11	4	16
0–30 degrees	81	25	27
31–60 degrees	1	9	11
61–90 degrees	9	6	2
More than 90 degrees	11	2	1
Total	**113**	**46**	**57**

The U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) defines a small aircraft as weighing less than 5,000 pounds/2,300 kilograms and a small transport aircraft as weighing 5,001 pounds/2,300 kilograms to 14,500 pounds/6,600 kilograms. Numbers in kilograms have been rounded.

Source: Patrick R. Veillette, Ph.D., from U.S. National Transportation Safety Board data on 130 accidents, U.S. Federal Aviation Administration data on 60 incidents and U.S. National Aeronautics and Space Administration Aviation Safety Reporting System data on 165 events

Table 11
Maximum Roll Angles Induced in Light Transport Aircraft in U.S. Wake-turbulence Accidents and Incidents, 1983–2000, and in Events, 1988–1999

Roll (Bank) Angle	Accidents	Incidents	Events
(Unspecified)	0	0	2
0–30 degrees	3	4	9
31–60 degrees	0	0	4
61–90 degrees	0	1	2
More than 90 degrees	1	0	0
Total	**4**	**5**	**17**

The U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) defines a light transport aircraft as weighing 14,501 pounds/6,600 kilograms to 30,000 pounds/13,600 kilograms. Numbers in kilograms have been rounded.

Source: Patrick R. Veillette, Ph.D., from U.S. National Transportation Safety Board data on 130 accidents, U.S. Federal Aviation Administration data on 60 incidents and U.S. National Aeronautics and Space Administration Aviation Safety Reporting System data on 165 events

as the vortices. As the aircraft was forced beneath the vortices, the sink effect would be reduced. Near the ground, however, the result could be loss of control, and if a pilot were to attempt to correct the sink rate by applying back elevator, the aircraft could stall.[37]

Of the three categories of direction of entry into vortices, an along-track penetration of the vortex center is considered the most dangerous because the trailing aircraft penetrates the vortex core and experiences a strong rolling motion.

Table 12
Maximum Roll Angles Induced in Medium Transport Aircraft in U.S. Wake-turbulence Accidents and Incidents, 1983–2000, and in Events, 1988–1999

Roll (Bank) Angle	Accidents	Incidents	Events
(Unspecified)	0	0	2
0–30 degrees	5	3	17
31–60 degrees	1	1	8
61–90 degrees	0	0	1
More than 90 degrees	0	0	0
Total	**6**	**4**	**28**

The U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) defines a medium transport aircraft as weighing 30,001 pounds/13,600 kilograms to 60,000 pounds/27,200 kilograms. Numbers in kilograms have been rounded.

Source: Patrick R. Veillette, Ph.D., from U.S. National Transportation Safety Board data on 130 accidents, U.S. Federal Aviation Administration data on 60 incidents and U.S. National Aeronautics and Space Administration Aviation Safety Reporting System data on 165 events

In flight tests in which pilots attempted to fly their aircraft into the center of a wake vortex, the aircraft often were deflected or "thrown out" of the vortex, sometimes before entering the core. The deflection occurred with a rapid onset of the rolling motion, and the pilots temporarily lost control of the aircraft. In some situations, the aircraft were deflected from the wake vortex or rolled into the other wake vortex and then rolled again in the opposite direction. These reactions were common when the test aircraft was directly behind the leading aircraft and flying directly into the vortex. Test flights in which pilots attempted to fly into the vortex at a slightly skewed angle resulted in a combination of pitching and rolling, which typically deflected the aircraft away from the wake.[38,39]

Cross-track penetrations are most frequent in the terminal area when two aircraft are in different phases of flight. The trailing aircraft crosses the wake vortices at a right angle, resulting in pitching motions and vertical loads similar to those that occur when the aircraft is flown into a wind gust. Cross-track penetration typically is short-lived and without loss of aircraft control. Nevertheless, structural failures can occur and temporary loss of control near the ground may preclude recovery of the aircraft. Of the 130 accidents in the NTSB database, the 60 incidents in the FAA database and the 165 events in the ASRS database, six accidents (5 percent) involved structural damage, and the reports describing 11 events (7 percent) said that cross-track penetrations had resulted in substantial turbulence and had increased load factors on the aircraft.

Data show that small aircraft most frequently are involved as the trailing aircraft and that wake-turbulence occurrences involving small aircraft are most likely to result in bank angles of more than 30 degrees. Nevertheless, wake turbulence affects aircraft of all sizes. Researchers have recommended that the best method for pilots to avoid the risks of wake turbulence is to be aware of how wake turbulence forms.♦

Notes

1. The U.S. National Transportation Safety Board (NTSB) defines an accident as "an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage." NTSB defines an incident as "an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations."

2. NTSB defines substantial damage as "damage or failure which adversely affects the structural strength, performance, or flight characteristics of the aircraft and which would normally require major repair or replacement of the affected component. Engine failure or damage limited to an engine if only one engine fails or is damaged, bent fairings or cowling, dented skin, small punctured holes in the skin or fabric, ground damage to rotor or propeller blades, and damage to landing gear, wheels, tires, flaps, engine accessories, brakes, or wing tips are not considered 'substantial damage.'"

3. The U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) is a confidential incident-reporting system. The ASRS Program Overview said, "Pilots, air traffic controllers, flight attendants, mechanics, ground personnel and others involved in aviation operations submit reports to the ASRS when they are involved in, or observe, an incident or situation in which aviation safety was compromised. … ASRS de-identifies reports before entering them into the incident database. All personal and organizational names are removed. Dates, times, and related information, which could be used to infer an identity, are either generalized or eliminated."

   ASRS acknowledges that its data have certain limitations. ASRS *Directline* (December 1998) said, "Reporters to ASRS may introduce biases that result from a greater tendency to report serious events than minor ones; from organizational and geographic influences; and from many other factors. All of these potential influences reduce the confidence that can be attached to statistical findings based on ASRS data. However, the proportions of consistently reported incidents to ASRS, such as altitude deviations, have been remarkably stable over many years. Therefore, users of ASRS may presume that incident reports drawn from a time interval of several or more years will reflect patterns that are broadly representative of the total universe of aviation-safety incidents of that type."

4. The approach-and-landing phase of flight begins when an airworthy aircraft under the control of the flight crew descends below 5,000 feet above ground level (AGL) with the intention to conduct an approach and ends when the landing is complete or the flight crew flies the aircraft above 5,000 feet AGL en route to another airport.

5. U.S. Federal Aviation Administration (FAA). *Aeronautical Information Manual (AIM)*. Pilot/Controller Glossary.

6. Ibid.

7. U.S. Department of Transportation (DOT); FAA. *Wake Turbulence Training Aid,* DOT/FAA/RD-95/6. April 1995.

8. FAA.

9. McGowan, William A. "Aircraft Wake Turbulence Avoidance." *AIAA Journal of Aircraft*, Volume 9 (March 1972): 197–198.

10. FAA.

11. Veillette, Patrick. "Wake Vortex: the Horizontal Tornado." *Aviation Safety*, July 1993.

12. Veillette, Patrick. "Beware of the Horizontal Tornado, Part II." *Air Line Pilot* Volume 63 (February 1994).

13. McGowan.

14. FAA.

15. Ibid.

16. Pengel, K.; Tetzlaff, G. "Report of Wake Vortex Measurements with a Ground Wing Vortex Sensing System Using U-V-W Anemometer." Presentation at FAA and U.S. National Oceanic and Atmospheric Administration (NOAA), 1984. Institute of Meteorology and Climatology, University of Hannover, Hannover, Germany.

17. Koepp, Friedrich. "Experimental Investigation of Wake Vortex Structure." In *Proceedings of the Aircraft Wake Vortices Conference*, Washington, D.C., U.S. Oct. 29–31, 1991.

18. Delisi, Donald P.; Robins, Robert E.; Altman, Donald B. "Laboratory and Numerical Studies of Vortex Evolution in Ideal and Realistic Environments." In *Proceedings of the Aircraft Wake Vortices Conference*, Washington, D.C., U.S. Oct. 29–31, 1991.

19. Garodz, Leo J.; Clawson, Kirk L. "Vortex Characteristics of B-757-200 and 767-200 Aircraft Using the Tower Fly-by Technique." NOAA Technical Memorandum ERL ARL-199, Air Resources Laboratory, Silver Spring, Maryland, U.S. January 1993.

20. Koepp.

21. Critchley, J.B.; Foot, P.B. "U.K. CAA Wake Vortex Database: Analysis of Incidents Reported Between 1972–1990." In *Proceedings of the Aircraft Wake Vortices Conference,* Washington, D.C., U.S. Oct. 29–31, 1991. The U.K. Civil Aviation Authority Wake Vortex Reporting Program (WVRP) was established to receive and review data on wake-turbulence occurrences. A report of a wake-turbulence occurrence typically is submitted by the crew of the aircraft involved or by air traffic control (ATC), although formal procedures for reporting wake-turbulence incidents by ATC exist only at London City Airport and Heathrow Airport. Additional data are collected from pilots of aircraft that generate wake turbulence; the Meteorological Office; London Air Traffic Control Center, which provides recorded radar data; and airlines, which provide flight data recorder data. The data are analyzed to determine if the cause of each reported incident was, in fact, wake turbulence. WVRP was transferred in 1989 to the Air Traffic Control Evaluation Unit.

22. Sammonds, R.I.; Stinnett, G.W.; Larson, W.E. "Criteria Relating Wake Vortex Encounter Hazard to Aircraft Response." *AIAA Journal of Aircraft* Volume 14 (October 1977): 981–987.

23. Ibid.

24. NASA ASRS. Report no. 366882. April 1996.

25. Kitty Hawk Air Cargo. *B-727 Aircraft Operations Manual,* Section 4-1:44–45.

26. NASA ASRS. Report no. 314684. August 1995.

27. Ibid.

28. NASA *Callback*, No. 194, July 1995

29. NASA ASRS. Report no. 301722. April 1995.

30. NASA ASRS. Report no. 260432.

31. Ibid.

32. Johnson, Amanda. "Trends in Wake Vortex Incidents." In *Proceedings of the Aircraft Wake Vortices Conference*, Washington, D.C., U.S. Oct. 29–31, 1991.

33. NASA ASRS. Report no. 319820. October 1995.

34. Ibid.

35. NASA ASRS. Report no. 238067. April 1993.

36. NASA ASRS. Report no. 279362. August 1994.

37. Wetmore, Joseph W.; Reeder, John P. "Aircraft Vortex Wakes in Relation to Terminal Operations." NASA TN D-1577, Washington, D.C., U.S. April 1963.

38. "FAA Vortex Concern Mounting." *Aviation Week & Space Technology.* May 25, 1970.

39. "Wake Vortex Sensing Efforts Advance." *Aviation Week & Space Technology*. Aug. 25, 1977.

About the Author

Patrick R. Veillette, Ph.D., a professional pilot with more than 13,000 flight hours, is a Raytheon Hawker 800XP first officer for a major U.S. corporation. He formerly was a Boeing 727 first officer for a U.S. Federal Aviation Regulations Part 121 air carrier, and also has flown fixed-wing emergency medical services operations, aerial fire fighting operations and charter-aircraft flight operations. He formerly investigated failure modes, weaknesses and performance capabilities of aircraft involved in accidents and was an accident investigator for the U.S. Department of Agriculture. Veillette received a bachelor's degree in aeronautical engineering from the U.S. Air Force Academy and a doctorate in civil engineering from the University of Utah. He has conducted numerous research projects on flight deck automation and human error in high-risk environments. Veillette has an airline transport pilot certificate and is a former U.S. Federal Aviation Administration designated pilot examiner.

Further Reading From FSF Publications

FSF Editorial Staff. "Strategies Target Turbulence-related Injuries to Flight Attendants and Passengers." *Cabin Crew Safety* Volume 36 (January–February 2001).

FSF Editorial Staff. "Rudder Malfunction Causes Loss of Control of Boeing 737." *Accident Prevention* Volume 56 (September 1999).

Fewing, Rodney. "Ultra-high Capacity Aircraft Will Intensify Airport Safety Issues." *Airport Operations* Volume 21 (January–February 1995).

Coleman, Patricia J. "Turbulence-related Injuries Pose Continued Risk to Passengers and Cabin Crew." *Cabin Crew Safety* Volume 29 (May–June 1994).

Editorial Staff Report. "U.S. Report: No Conclusive Evidence Found to Explain Boeing 737 Crash." *Accident Prevention* Volume 50 (May 1993).

Bablitz, Matthew J. "Just a Slip of Caution." *Accident Prevention* Volume 46 (May 1989).

Crockett, Doug. "How to Deal With Induced Turbulence." *Helicopter Safety* Volume 14 (September–October 1988).

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Oct. 26, 2000	Falmouth, Kentucky	Canadair CL-600	none	50 uninjured

An in-flight upset occurred while the aircraft was being flown over the Falmouth very-high-frequency omnidirectional radio at 11,000 feet. Visual meteorological conditions (VMC) prevailed. The airplane, which was in level flight with the autopilot engaged, rolled left. The captain disconnected the autopilot and manually returned the airplane to level flight. Preliminary data from the airplane's digital flight data recorder (DFDR) showed that the airplane rolled 10 degrees left in 1/2 second and about 22 degrees left in another 1/2 second before reaching a maximum bank of 24 degrees. During the roll, the left aileron reached a maximum downward deflection of six degrees, and the right aileron reached a maximum upward deflection of six degrees. Pitch attitude had been about two degrees nose up when the airplane entered the roll, then increased to five degrees nose up during the roll. Preliminary radar data showed that the flight was at 10,850 feet. Eighty-four seconds earlier, a Boeing 767-300 had flown through the same area at 11,000 feet.

Oct. 19, 2000	Camp Springs, Maryland	Cessna 172	substantial	1 uninjured

The Cessna 172 was substantially damaged when it was flown into wake turbulence from a Boeing 727-200 about four miles south of Andrews Air Force Base. The pilot was in contact with Andrews Approach Control. The B-727 was on final approach for Runway 1L, on a northerly heading. The pilots of each airplane were advised of the location of the other airplane, and the pilot of the Cessna was given a wake-turbulence advisory. As the Cessna neared the Boeing, the Cessna pilot began a climb from 1,300 feet to 1,600 feet. As the airplane neared 1,600 feet, it was flown into turbulence and rolled left. The pilot was thrown about the cockpit, and when the turbulence ended, the airplane was descending in a nose-low attitude. After landing, the pilot noticed wrinkles and deformed skin on the top surface of the right wing and on the left aileron.

Sept. 11, 2000	Anchorage, Alaska	Piper PA-31-350	substantial	1 uninjured

As the pilot flew the airplane toward a visual flight rules (VFR) reporting point, he was in contact with air traffic control (ATC) and was given air traffic advisories for airplanes departing the Lake Hood Seaplane Base. He was not given an advisory about a McDonnell Douglas MD-11 that was on final approach to land on Runway 14 at Anchorage International Airport. His airplane's flight path was behind and below the MD-11. The pilot said that after the MD-11 passed his position, his airplane entered wake turbulence that produced violent vertical wind shear. The right winglet and right landing-light assembly separated from the airplane. A post-flight inspection of the airplane revealed upward bending and wrinkling of the upper wing surfaces.

Aug. 20, 2000	Tooele, Utah	Piper PA-28-181	minor	1 uninjured

The airplane was on final approach to Runway 34. Near the approach end of the runway, a sudden nose-up pitch occurred, followed by repeated oscillations until the airplane struck the runway, then skidded off the runway to the right. The nosewheel collapsed. Just before the landing, a turbine-powered fire tanker heavily loaded with fire retardant departed from the runway, generating wake turbulence.

Aug. 11, 2000	Cleveland, Ohio	ATR 42-320	none	none*

The airplane was upset by Boeing 757 wake turbulence at 7,000 feet and approximately five nautical miles (9.3 kilometers) behind the B-757.

June 22, 2000	Colorado Springs, Colorado	Cessna T-41	none	1 uninjured

A U.S. Air Force Academy T-41, flown by a student pilot, entered wake turbulence from a Grumman OV-10 experimental exhibition aircraft whose pilot was conducting a go-around above the T-41.

May 20, 2000	Cedar Rapids, Iowa	Piper PA-28-140	minor	1 uninjured

During landing on a cross-country solo flight, the student pilot lost directional control of the airplane. The student pilot was not familiar with landing on a wide runway, and there was a quartering tailwind. A jet aircraft previously had departed downfield, and the wake vortices had drifted across the runway.

April 11, 2000	Seattle, Washington	Cessna 172	substantial	1 uninjured

The pilot of the accident aircraft was cleared for a touch-and-go landing on Runway 31R. The pilot was cautioned about possible wake turbulence from a B-767 landing on a parallel runway. The winds were from 310 degrees at nine knots. The Runway 31R threshold was 4,800 feet (1,464 meters) beyond the Runway 31L threshold, and the runway centerlines were about 360 feet (110 meters) apart. The accident aircraft landed hard, and the landing gear collapsed when the aircraft stopped in the displaced threshold short of the runway.

March 30, 2000	Santa Ana, California	Gulfstream AA-5	minor	2 uninjured

The pilot lost control of the airplane at low speed during landing. The airplane landed on Runway 19L, entered wake turbulence from an airliner, bounced several times and ran off the left side of the runway, striking a runway marker light.

Oct. 7, 1999	Bay City, Texas	Air Tractor AT-502-B	substantial	1 minor

The pilot was conducting an agricultural-operations flight and had completed his eighth pass over the field at about 300 feet above ground level (AGL) in a 60-degree bank when he flew through the wake turbulence from his previous pass. The airplane stalled, rolled sharply right, then left, and then struck the ground.

Sept. 15, 1999	Denver, Colorado	Boeing 737-500	none	94 uninjured

The crew of the Boeing 737-500 flew the airplane into wake turbulence from another B-737 during a visual approach to Runway 35L. At 1,500 feet AGL, the airplane rolled right, prompting the first officer (the pilot flying) to conduct a missed approach. After recovery from the first roll, the airplane again rolled right about 30 degrees, followed by another recovery.

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Aug. 3, 1999	Kenai, Alaska	Cessna 152	substantial	1 uninjured

The solo student pilot was departing on Runway 19R. Before being cleared for takeoff, a de Havilland DHC-8 departed in the opposite direction on the same runway. According to ATC tapes, the student pilot began her takeoff 109 seconds later. The aircraft veered left off the runway into a ditch. U.S. Federal Aviation Administration (FAA) Order 7110.65, *Air Traffic Control,* said that there should be a three-minute interval between departures of large aircraft and small aircraft and that a wake-turbulence cautionary advisory should be issued before the pilot of a small airplane receives a takeoff clearance. (FAA defines large aircraft as weighing more than 41,000 pounds/18,600 kilograms to 255,000 pounds/115,600 kilograms and small aircraft as weighing 41,000 pounds or less.)

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 6, 1999	Peachtree City, Georgia	Air Shark II	destroyed	1 serious

The airplane was departing on Runway 13. After takeoff, the airplane rolled left. Attempts to correct the roll were unsuccessful, the roll increased to 90 degrees of bank, and the left wing struck the ground. The airplane cartwheeled and stopped between the runway and taxiway.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Jan. 15, 1999	Plainfield, Pennsylvania	MD DC-9	none	1 serious, 59 uninjured

The flight crew was cleared for descent from Flight Level (FL) 290 (29,000 feet) to 17,000 feet. The captain briefed the first officer on the approach and said that he would keep the airplane above a preceding Boeing 747's flight path. The B-747 was 12 nautical miles (22 kilometers) ahead and also was descending to 17,000 feet. The DC-9 captain began a 3,500-feet-per-minute descent and slowed the airplane to 280 knots. While descending through 23,500 feet, there was a moderate jolt. The captain pitched the airplane's nose up to fly out of the turbulence and asked ATC for additional separation between the two airplanes. During the wake-turbulence occurrence, a flight attendant in the galley slipped and injured her right ankle. Radar data showed that the airplane was about two minutes behind and 1,000 feet below the B-747. Winds at 23,000 feet were from 195 degrees at 90 knots.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Oct. 3, 1998	Middlebury, Connecticut	Super Cat	destroyed	1 fatal

The pilot of the open-cockpit airplane conducted a takeoff minutes after a Hawker 1000 business jet. The pilot's body was found about one nautical mile (1.9 kilometers) north of the airport; the wreckage of the airplane was found in a wooded area 845 feet (258 meters) north of the body. The pilot's shoulder harness, seat belts and buckles were found intact and unfastened.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Sept. 17, 1998	Chicago, Illinois	ATR 42	none	1 serious, 15 uninjured

The Avions de Transport Regional ATR 42 was at 4,900 feet and 18 nautical miles (33 kilometers) from the airport on the instrument landing system (ILS) approach to Runway 9 when it was flown into wake turbulence from a B-737-300, which was vectored onto the approach from the north in front of the ATR 42. Radar data showed that the B-737-300 intercepted the localizer 17.5 nautical miles (32 kilometers) from the airport, while descending from 5,200 feet to 4,800 feet. Separation of the two airplanes was about 4.8 nautical miles (8.9 kilometers). Vertical acceleration of the flight varied from 2.36 g (2.36 times standard gravitational acceleration) to 0.55 g during the encounter.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Sept. 15, 1998	Salt Lake City, Utah	Boeing 737	none	3 minor injuries*

The airplane was being vectored to final at 8,000 feet when it was flown into wake turbulence from a B-767 that was three minutes 45 seconds ahead. Three flight attendants were treated for minor injuries.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Aug. 7, 1998	McConnellsburg, Pennsylvania	Boeing 737	minor	10 minor, 122 uninjured

The B-737 began an uncommanded roll during climb, just before passing through 29,700 feet. The captain said that the airplane was flown into light chop, which quickly intensified. The airplane yawed slowly, then suddenly rolled right, then left. DFDR data showed that the aircraft rolled right a maximum of 37 degrees, and then within two seconds, reached the maximum left roll of 27 degrees. Vertical acceleration reached a low of minus 0.6 g. The captain recovered the aircraft and diverted to a nearby airport. The weather was clear and the air was smooth before and after the event. Radar analysis revealed that a McDonnell Douglas DC-10, about 10 nautical miles (18.5 kilometers) ahead, had climbed through the area about 600 feet higher, 71 seconds earlier.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Aug. 4, 1998	Saint Joseph, Missouri	Cessna 140	destroyed	2 fatal

The pilot of the accident airplane was advised that wake turbulence would be present during the approach to Runway 35. U.S. Air Force Lockheed C-130s were being landed on Runway 31. Witnesses observed the accident airplane as it was flown toward Runway 35 at a low altitude, banked left about 35 degrees and then rapidly banked right more than 90 degrees. The airplane's right wingtip was about 20 feet above the ground when the nose dropped and the airplane struck the ground. A C-130 had been landed on Runway 31 about 10 seconds before the accident airplane reached the threshold of Runway 35.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
July 17, 1998	Olathe, Colorado	Bell 47G-3B1	substantial	1 uninjured

The pilot was conducting an agricultural-operations flight and had made three passes over the same path. He said that the wind increased as he turned the helicopter for a fourth pass, and the helicopter was flown into its own wake turbulence. The helicopter had insufficient power to overcome the ensuing descent and settled onto the ground in a nose-low attitude, causing the main-rotor blades to strike the tail boom and sever it from the aircraft.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
April 9, 1998	Seattle, Washington	Cessna 150	minor	1 minor

While the pilot attempted to land long behind a departing Beech D-18, the Cessna was flown into wake turbulence that caused a sudden roll to the left. The pilot rejected the landing and added full power while attempting to maintain aircraft control. By the time the pilot returned the airplane to wings-level flight, the airplane had veered left and was turned almost 90 degrees from the runway. The pilot climbed the airplane straight ahead, and the airplane became entangled in electrical transmission lines. An investigation determined that the pilot had not repositioned the flaps to 20 degrees as recommended in the pilot's operating handbook.

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

<table>
<tr><th>Date</th><th>Location</th><th>Aircraft Type</th><th>Aircraft Damage</th><th>Injuries</th></tr>
<tr><td>Nov. 19, 1997</td><td>Beaumont, Texas</td><td>Cessna 310</td><td>destroyed</td><td>1 serious</td></tr>
<tr><td colspan="5">As the pilot positioned the airplane on the runway, an Embraer EMB-145 made a low pass to the right of the runway at about 100 feet AGL. The pilot said that he had the jet in sight. After the jet passed, the tower cleared the pilot of the Cessna for takeoff, and the pilot immediately began the takeoff roll. No cautions for wake turbulence were issued by tower personnel, and the pilot did not request a delay. After the airplane achieved a positive rate of climb, the pilot retracted the landing gear, and the airplane rolled right. The right wing struck the ground and the airplane cartwheeled, then stopped inverted. The position of the aircraft during takeoff/initial climb was in the area of the EMB-145's wake turbulence.</td></tr>
<tr><td>Nov. 4, 1997</td><td>Cleveland, Ohio</td><td>Embraer EMB-120</td><td>none</td><td>2 uninjured</td></tr>
<tr><td colspan="5">Approach control did not tell the crew to switch to the tower radio frequency. The Embraer EMB-120 was following a Lockheed L-1011 on final and was flown into wake turbulence.</td></tr>
<tr><td>Oct. 21, 1997</td><td>West Palm Beach, Florida</td><td>DA 20-A1</td><td>substantial</td><td>2 serious</td></tr>
<tr><td colspan="5">The pilot said that, as he flew the airplane over the airport, he was cleared to land on Runway 27R. While on final approach at 200 feet, a McDonnell Douglas MD-80 passed near the accident airplane on the right. The controller warned the pilot of possible wake turbulence. The airplane then rolled upside down and struck the ground. ATC audio tapes showed that the pilot was cleared to land on Runway 27L. After the pilot received the clearance, the airplane was observed deviating toward Runway 27R. Controllers observed the nose of the airplane rise before the airplane rolled left, striking the ground left-wing low and partially inverted.</td></tr>
<tr><td>Oct. 2, 1997</td><td>Lake Elmo, Minnesota</td><td>Beech 18-E18S</td><td>substantial</td><td>2 uninjured</td></tr>
<tr><td colspan="5">The pilot said that the airplane lifted off at 70 knots and, after accelerating in ground effect, became unstable in the roll axis. The pilot added power. The left wingtip struck the ground about three-quarters of the way down the runway. The pilot added more power, and the left wing struck the grass near the left side of the departure end of the runway. The pilot then reduced power to idle and landed the airplane in the grass, where the landing gear collapsed. Investigation revealed that another Beech 18 had taken off from the same runway in the opposite direction less than one minute before the accident.</td></tr>
<tr><td>Aug. 15, 1997</td><td>Newark, New Jersey</td><td>ATR 42-320</td><td>none</td><td>39 uninjured</td></tr>
<tr><td colspan="5">The airplane was flown through wake turbulence. The pitch mode of the autopilot disconnected, and the flight crew hand-flew the airplane to the airport.</td></tr>
<tr><td>Aug. 2, 1997</td><td>Oshkosh, Wisconsin</td><td>Cessna 182-P</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">While the Cessna was on final approach, another high-wing airplane was flown over the Cessna's flight path in preparation for landing on the same runway. The pilot of the other airplane conducted a go-around. The pilot of the accident airplane lost control because of wake turbulence, and the airplane landed hard.</td></tr>
<tr><td>Aug. 2, 1997</td><td>Norfolk, Nebraska</td><td>Cessna 188</td><td>substantial</td><td>1 uninjured</td></tr>
<tr><td colspan="5">The pilot was unfamiliar with the area, so he flew his airplane behind another Cessna 188 to the field for agricultural operations. The pilot said that after arriving over the field, the pilot of the lead aircraft descended to about 20 feet AGL and flew the airplane across the field from south to north. The pilot of the accident airplane circled to line up the airplane for a spray pattern along the eastern edge of the field. He positioned the airplane for the second pass and leveled the airplane four feet above the crop. The pilot said that the airplane almost immediately was flown into "bad air" and struck the ground. The lead airplane had been flown perpendicular to his path about one minute earlier.</td></tr>
<tr><td>July 22, 1997</td><td>Burlington, Vermont</td><td>Piper PA-28-180</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The airplane was being landed behind a C-130 whose crew was conducting touch-and-go landings on Runway 33. The winds were from 320 degrees at nine knots. The airplane bounced twice during landing before the nose landing gear struck the ground and collapsed.</td></tr>
<tr><td>June 19, 1997</td><td>Richmond, Virginia</td><td>Cessna 172</td><td>minor</td><td>1 uninjured</td></tr>
<tr><td colspan="5">On approach, ATC advised caution for wake turbulence. The pilot conducted a normal approach, and just before touchdown, he felt a buffet, then a more violent force to the left. The pilot added power to bring the airplane back to the centerline, but the propeller struck a runway-edge light, damaging the tips of the propeller.</td></tr>
<tr><td>May 29, 1997</td><td>Orlando, Florida</td><td>Embraer EMB-120</td><td>none</td><td>1 minor, 29 uninjured</td></tr>
<tr><td colspan="5">The aircraft was being flown on approach when ATC told the crew of an L-1011 to descend through the EMB-120's altitude to conduct its approach. The L-1011 was turned onto the same heading as the EMB-120, placing the EMB-120 directly behind the L-1011. The flight attendant was injured as the EMB-120 rolled sharply. The pilots regained control.</td></tr>
<tr><td>May 18, 1997</td><td>Galion, Ohio</td><td>Cessna 172</td><td>substantial</td><td>2 uninjured</td></tr>
<tr><td colspan="5">The pilot was conducting a takeoff from Runway 23 while a helicopter was approaching the south side of the runway from the east. During the initial climb, about 50 feet AGL, the airplane was flown into the helicopter's wake turbulence. The airplane descended and struck the ground.</td></tr>
<tr><td>March 25, 1997</td><td>Chicago, Illinois</td><td>ATR 42-300</td><td>none</td><td>1 minor, 2 uninjured</td></tr>
<tr><td colspan="5">About 15 nautical miles (28 kilometers) from the runway on approach to Runway 27L, the airplane was flown through wake turbulence generated by a DC-10 five nautical miles ahead. A flight attendant was thrown against a bulkhead and received minor injuries.</td></tr>
<tr><td>Dec. 25, 1996</td><td>West Palm Beach, Florida</td><td>Cessna 172P</td><td>minor</td><td>1 uninjured</td></tr>
<tr><td colspan="5">The airplane entered wake turbulence and veered off the runway, striking a runway light and damaging the propeller.</td></tr>
</table>

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Nov. 30, 1996	Santa Ana, California	MS 760 II	destroyed	3 fatal

After takeoff, the pilot of the Morane-Saulnier MS 760 II declared an emergency and told ATC he wanted to return to the airport for landing because an external boarding ladder was still attached to the airplane. The controller cleared the pilot to land on the departure runway. As the pilot flew the airplane toward the airport, a B-757 was landed on the same runway. Then, as the accident airplane was flown to intercept the final-approach course about one nautical mile from the runway threshold, the accident airplane suddenly rolled right until it was inverted. The airplane entered a spiral and struck a building.

Nov. 20, 1996	Salt Lake City, Utah	Cessna 152	substantial	1 uninjured

The student pilot was cautioned about wake turbulence when he received ATC clearance to land on Runway 32. Radar data showed that a Learjet had landed on Runway 35 about 74 seconds before the accident aircraft. (Runway 32 and Runway 35 intersect at the approach ends.) The airplane ballooned slightly, and as the pilot applied back pressure on the control yoke to prepare for touchdown, the airplane suddenly was blown sideways. The winds were from 360 degrees at 10 knots before the landing clearance. The airplane bounced about 10 feet to 15 feet, landed hard and rolled forward before nosing over.

Sept. 4, 1996	Morristown, New Jersey	Cessna 182	minor	1 uninjured

While practicing touch-and-go landings, the pilot attempted a takeoff behind a departing Dassault Falcon 20. The Cessna was flown into wake turbulence at about 50 feet. The airplane settled onto the runway, then ran off the runway and struck runway lights.

July 27, 1996	Portland, Oregon	Cessna 182	substantial	2 minor

ATC told the pilot to expedite his approach and follow an MD-80 on a straight-in final. The Cessna pilot told ATC that he had the MD-80 in sight and complied with ATC instructions. The Cessna was flown into the MD-80's wake turbulence about 200 feet AGL on final. The pilot lost control of the airplane, which struck the ground. At their closest, the Cessna was 0.9 nautical mile (1.7 kilometers) behind the MD-80 and 200 feet below the MD-80's glide path.

July 27, 1996	Liberal, Kansas	Air Tractor AT-301	destroyed	1 serious

While completing the pass on an agricultural-operations flight, the pilot turned right 270 degrees. The pilot said that he flew the airplane through its wake turbulence. He lost control of the airplane, which struck the ground.

June 5, 1996	Eugene, Oregon	Cessna 402	none	1 uninjured

The airplane was flown into wake turbulence from a landing jet, the airplane rolled, and the pilot recovered the airplane at 500 feet AGL. The airplane was landed normally.

May 16, 1996	Anchorage, Alaska	MD-11	substantial	1 minor, 1 uninjured

The MD-11 was cleared for a visual approach to Runway 24R, three nautical miles (11 kilometers), about one minute, behind a B-747 landing on Runway 24L. The two runways are 500 feet (153 meters) apart, and the threshold of Runway 24L is 4,300 feet (1,312 meters) beyond the threshold of Runway 24R. On final approach, the 21-knot left crosswind diminished to about five knots. At 100 feet AGL, the MD-11 rolled left, then right, yawed slightly and entered a high sink rate. The captain began a go-around and raised the nose of the airplane. The lower-aft fuselage struck the runway, and the MD-11 bounced. The captain discontinued the go-around, and the MD-11 bounced two more times.

April 10, 1996	Lakeland, Florida	Cessna 152	minor	1 uninjured

The airplane was landed on Runway 9, then ran off the left side of the runway, striking a wingtip and damaging the propeller.

March 30, 1996	Fullerton, California	Cessna 172	substantial	1 uninjured

The student pilot said that he was practicing full-stop landings on Runway 24. The student pilot attempted a go-around and added full power. The left wingtip struck the ground, and the airplane struck the median between the runway and the taxiway. Investigators said that the probable cause of the accident was the student pilot's inadequate compensation for the wake turbulence of a preceding small aircraft.

Sept. 30, 1995	Avondale, Arizona	Grumman G-164B	substantial	1 uninjured

The pilot was conducting an agricultural-operations flight. He typically sprayed a field while flying the airplane in a wide circling pattern, but this time, he sprayed half of the field and flew the airplane in more steeply banked turns. During one turn, the airplane entered wake turbulence from a previous pass. The pilot pushed the control yoke forward to recover from the wake turbulence, but the airplane's altitude was insufficient for normal recovery and the airplane struck the ground.

Sept. 23, 1995	Kona, Hawaii	Cessna 150	substantial	1 minor

On her second unsupervised solo flight, the student pilot planned to remain in the airport traffic pattern to practice soft-field takeoffs and landings. The pilot said that on her eighth landing, she received ATC clearance for a stop-and-go landing behind a military C-130 transport airplane and was told to extend the downwind leg to follow that airplane. She was aware of the wake-turbulence risks and planned to fly an approach above the glide path of the C-130. About 10 feet above the runway, the airplane suddenly veered right and struck the runway.

Aug. 18, 1995	Long Beach, California	Cessna 152	minor	1 uninjured

In the landing flare, the airplane was blown to the left and struck a visual approach slope indicator (VASI) light. The airplane had been flown through the wake turbulence of a departing jet.

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
July 25, 1995	Elyria, Ohio	Tri-Q200	destroyed	1 minor

The airplanes departed as a flight of two in a staggered takeoff. As the airplane ahead and to the left began to lift off, the pilot of the accident airplane began a takeoff roll on the right side of the runway with a left crosswind. When the airplane reached 80 miles (129 kilometers) per hour, the pilot rotated the airplane for takeoff. When the airplane was 20 feet AGL to 30 feet AGL, the left wing dipped. The airplane sank to the runway and struck the ground on the left side of the runway. The winds were from the southwest at 12 knots.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
July 25, 1995	New York, New York	Avro RJ70	none	24 uninjured

The Avro RJ70 was being flown on approach about 1,500 feet AGL, with the autopilot engaged, when it was flown into wake turbulence from a preceding Airbus A340 and rolled left. The pilot flying, who occupied the right seat, reached for the yoke to disconnect the autopilot and to apply corrective aileron input. He applied large and/or abrupt movement of the ailerons before achieving an autopilot disconnect. The pilot continued the approach and conducted a normal landing.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 1, 1995	College Station, Texas	Cessna 120	substantial	1 uninjured

Witnesses said that the pilot was conducting a touch-and-go landing on Runway 10 following a Saab 340. The wind was from 200 degrees at four knots. The pilot said that he had believed that his airplane was two nautical miles (3.2 kilometers) behind the Saab. The pilot of the accident airplane conducted a wheel landing, and the airplane was rolling on the main-landing-gear tires when the airplane entered wake turbulence from the preceding airplane and departed the runway to the left. The main-landing-gear tires stuck in the soft mud at the edge of the runway, and the airplane nosed over to an inverted position.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
May 22, 1995	Honolulu, Hawaii	Beech B18	minor	1 uninjured

The airplane rolled sharply after liftoff and scraped a wingtip on the runway. The pilot rejected the takeoff. A B-737 had departed before the incident aircraft's takeoff.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
May 3, 1995	Redding, California	Piper PA-34-200T	minor	2 uninjured

The airplane was landed behind a B-737 and entered wake turbulence. The nose landing gear struck the runway and collapsed.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Feb. 23, 1995	Elmira, California	Cessna A188	substantial	1 uninjured

The pilot of the agricultural-operations flight completed his second run with the airplane on a heading of 225 degrees. He rolled the airplane into a turn at 100 feet AGL. The pilot said that after rolling the airplane out of a left turn and into a right turn, he felt the airplane enter wake turbulence generated by another aircraft that had just departed the area where he was working. The wake turbulence caused his airplane to descend abruptly. The right wing struck the ground, and the airplane rolled onto its right side.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Jan. 1, 1995	Houston, Texas	Boeing 737	none	66 uninjured

During descent for the landing approach, the flight crew experienced uncommanded rolls while the airplane was being flown at 240 knots, in clean condition and with the power reduced. The airplane was behind an MD-80. The initial divergence was a 20-degree right roll. As the right roll was developing, the pilot applied a left correction and the airplane rolled 30 degrees left. The pilot then applied right rudder, and the wings returned to level attitude.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 29, 1994	Newark, New Jersey	ATR 42-320	none	1 minor, 11 uninjured

Eight miles behind an Airbus A300 in smooth air, the ATR 42 made an abrupt 30-degree roll. A flight attendant suffered a head injury.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 17, 1994	Chicago, Illinois	MD DC-9	none	1 minor*

A flight attendant was injured when the airplane was flown into wake turbulence from an MD-11 during cruise flight.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
May 12, 1994	Hickory, North Carolina	type unspecified	minor	none*

The pilot landed the aircraft while another aircraft was departing in the opposite direction. The landing gear collapsed.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
April 23, 1994	Santa Monica, California	Fairchild SA-227	minor	1 minor, 19 uninjured

The airplane was at 7,100 feet approaching Los Angeles (California) International Airport when it was flown into wake turbulence from a B-747-400 five nautical miles ahead. The airplane rolled left. The first officer applied full right aileron, but the airplane continued to roll until it was inverted. During recovery from the inverted attitude, the airplane's nose pitched down, and the airplane rolled right before returning to level flight.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Dec. 15, 1993	Santa Ana, California	IAI 1124A	destroyed	5 fatal

The crew of an Israel Aircraft Industries 1124A Westwind was vectored for a visual approach to land on Runway 19R following a B-757. Before receiving ATC clearance for the visual approach, the Westwind was 3.5 nautical miles (6.5 kilometers) from the B-757 on a converging course. Crews of the B-757 and the Westwind were told to slow to 150 knots. The B-757 was slowed to less than 150 knots and was high on final approach and descending on a 5.6-degree glide path. The Westwind converged to 2.1 nautical miles (3.9 kilometers) behind the B-757 on a three-degree approach. ATC did not tell (and at the time was not required to tell), the Westwind crew that they were behind a B-757. The Westwind captain discussed possible wake turbulence, flew the airplane one dot high on the glideslope and was aware of the location of the B-757. While descending through 1,100 feet, the Westwind entered wake turbulence from the B-757, rolled into a steep descent and struck the ground. The crew had not received training to recover from a wake-turbulence upset.

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Nov. 9, 1993	Salt Lake City, Utah	Cessna 182R	destroyed	1 minor, 2 uninjured

The pilot received ATC clearance into the traffic pattern and subsequent clearances to fly the airplane behind a B-727 on final approach for Runway 35 and to land the airplane on Runway 32. ATC requested that the pilot make a left 360-degree turn. After the turn was completed, the crew of a B-757 was cleared to land on Runway 35 and was advised of the Cessna traffic. ATC told the Cessna pilot that there was additional Boeing traffic on a one-nautical-mile final and that he should fly the airplane to the numbers on Runway 32. The pilot flew the airplane on the extended centerline for Runway 32 over the threshold of Runway 35 and prepared for a landing with full flaps. The airplane flew into slight wake turbulence, and the pilot added power because he expected more wake turbulence. As the power was added, the airplane pitched up, rolled right and struck the ground.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Oct. 15, 1993	Colorado Springs, Colorado	Cessna 172	substantial	1 uninjured

The student pilot was on his first solo flight and was following a C-130. The winds were calm, and the student pilot was cleared for a touch-and-go on Runway 17R. As the student pilot began the flare, the airplane pitched up, rolled right, struck a taxiway sign and nosed over.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Sept. 22, 1993	Surprise, Arizona	Rockwell S2-600	substantial	1 minor

Two airplanes were being flown on agricultural-operations flights in the same field. The accident airplane was flown into the other airplane's wake turbulence during a turn-around maneuver at 65 feet AGL and struck the ground.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Sept. 14, 1993	Reno, Nevada	R&K Special 01	destroyed	1 serious

The pilot was flying his homebuilt experimental biplane in a timing run around a small racecourse at the Reno National Air Races. Witnesses said that, after several laps at a higher altitude, the pilot flew the airplane to the same lower altitude that previous pilots had used to qualify — about 50 feet. He flew the airplane around pylons and was flying down the east straightaway when witnesses observed a slight roll, a roll correction and an immediate pitch down. The airplane struck the ground.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
July 31, 1993	Anchorage, Alaska	Piper PA-18	substantial	1 minor

Just before touchdown, the floatplane's wings rocked several times, then the left wing struck the water. The pilot and a witness said that the airplane was flown into the wake turbulence from a de Havilland DHC-2 Beaver that had been landed seconds earlier. The pilot said that she landed a normal distance behind the Beaver, but a witness on the shore said that the approach and landing were too fast and too close behind the Beaver.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
July 30, 1993	Verdi, Nevada	Robinson R22	substantial	2 uninjured

The helicopter was one of four helicopters being flown in a mountain-flying course that included pinnacle landings and takeoffs. The flight instructor allowed the student pilot to follow another helicopter on departure from the pinnacle. The helicopter was flown into the preceding helicopter's wake turbulence and immediately turned right. The student pilot applied left-pedal corrective action, but the main-rotor revolutions per minute began to decrease. The flight instructor took the controls, lowered the collective and applied full throttle, but the rear skids struck the ground. The flight instructor returned the helicopter to a level attitude, but the helicopter then struck rocks.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
July 24, 1993	Vacaville, California	Cessna 172	substantial	4 uninjured

The pilot received ATC clearance to conduct a straight-in approach to Runway 20 following a large helicopter. ATC cautioned the pilot of possible wake turbulence. While nearing the runway threshold, the airplane was flown into wake turbulence and the pilot initiated a go-around. During the go-around, the airplane was flown into more severe wake turbulence, and the pilot could not control the airplane. The airplane struck the runway and skidded to a stop.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 2, 1993	Walnut Ridge, Arkansas	Grumman G-164B	minor	1 uninjured

The agricultural-operations airplane was flown through its own wake turbulence, and both main landing gear struck a levee. The airplane then was landed safely.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
April 23, 1993	Denver, Colorado	Boeing 737-522	none	133 uninjured

On a visual approach to Runway 26L, the flight crew of the B-737 experienced an uncommanded roll of about 23 degrees at 882 feet AGL. The crew corrected the roll and conducted a go-around and a normal landing. The B-737 was behind a B-757, which was on a visual approach to Runway 26R. The two runways were 600 feet (183 meters) apart, and the threshold for Runway 26L was about 1,300 feet (397 meters) east of Runway 26R. The wind at the onset of the incident was from the northwest at five knots to 10 knots. The two aircraft were 1.3 nautical miles (2.5 kilometers), or 32 seconds, apart. The B-757 wake vortices had settled about 100 feet and moved laterally toward the glide path of Runway 26L. Weather data showed evidence of possible interaction between the wake turbulence from the B-757 and an outflow boundary (a boundary between two small air masses) that was moving through the area.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
March 1, 1993	Orlando, Florida	MD-88	no damage	none*

The crew of the McDonnell Douglas MD-88 was conducting a visual approach to Runway 18R while following a B-757 to the airport. The crew of the MD-88 said that the airplane 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 DFDR indicate that at about 110 feet AGL, the roll angle reached 13 degrees right-wing down. The crew regained control and conducted a normal landing. Recorded radar data show that at the point of upset, the MD-88 was about 2.5 nautical miles (4.6 kilometers), or 65 seconds, behind the B-757. The flight-path angle of both airplanes was 3.0 degrees.

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Dec. 18, 1992	Billings, Montana	Cessna 550	destroyed	8 fatal

During descent, the airplane was sequenced behind a B-757, and the crews of both airplanes received ATC clearance for visual approaches. About 1.5 nautical miles (2.8 kilometers) from the runway, the accident airplane was observed to roll rapidly to the inverted position and to descend almost vertically into the ground. ATC transcripts and the airplane's cockpit voice recorder revealed that the crew had maintained visual awareness of the position of the B-757 throughout the approach. At the time of the upset, vertical separation between the airplanes was 600 feet to 1,000 feet, and horizontal separation was decreasing below 2.6 nautical miles (4.8 kilometers). One of the Cessna captain's last comments was "almost ran over a 757."

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Nov. 11, 1992	Los Angeles, California	Boeing 737-322	none	none*

The airplane was on approach when it rolled right because of wake turbulence. The airplane was landed safely.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Oct. 27, 1992	Saipan, Northern Mariana Islands	Cessna 310	destroyed	3 fatal

Witnesses said that the accident airplane began its takeoff from an intersection about 2,700 feet (824 meters) from the departure end of the runway about the same time a DC-10 was lifting off the ground. They said that the accident airplane was flown to about 200 feet to 250 feet AGL and banked about 45 degrees right, then about 30 degrees right and then — suddenly — 120 degrees right. Witnesses said that the airplane began an uncontrolled descent and struck the runway inverted.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Oct. 24, 1992	Apopka, Florida	Velocity	substantial	1 fatal

The experimental airplane and a B-727 were being flown in controlled airspace in VMC, and pilots of both airplanes were in contact with ATC. The pilots were advised of each other's position and heading. Both airplanes were on a southeasterly heading, with the B-727 overtaking the experimental airplane but being flown higher and to the left. The pilots of the B-727 were told to maintain visual separation and were cleared to descend. The B-727 passed over the experimental airplane at 10,000 feet, as the experimental airplane's pilot began a descent from 9,500 feet. About 3 1/2 minutes later, the pilot of the experimental airplane told ATC that he had lost control of the airplane, which was upside down. His last transmission was, "I hit the prop wash — the vortex."

Date	Location	Aircraft Type	Aircraft Damage	Injuries
July 7, 1992	Okeechobee, Florida	Maule MX-7-180	substantial	1 minor

The pilot filed a VFR flight plan but did not obtain notices to airmen about his route of flight. En route, he told U.S. Air Force Avon Park operations that he planned to fly his airplane south of the restricted area at Avon Park. While in cruise flight at 1,400 feet over Instrument Route 34, the Maule was flown near a flight of four F-16 aircraft at 1,500 feet. The F-16s were being flown at 500 knots in wide formation. The lead aircraft performed a six-g pull-up to avoid a collision with the Maule, which was flown into wake turbulence.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 2, 1992	Delaware, Ohio	Beech B35	substantial	1 minor

The airplane was following a U.S. Army AH-1S helicopter on approach to landing. The helicopter crossed the runway threshold at 200 feet AGL, and the airplane pilot planned a touchdown 1,500 feet (458 meters) from the approach end. Before the helicopter, which weighed 8,400 pounds (3,810 kilograms), touched down, the airplane crossed the threshold and rolled left. The left wing struck the ground. The airplane continued across a taxiway and stopped in an aircraft parking area. The airplane pilot said that he thought there was adequate separation between his airplane and the helicopter.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
April 22, 1992	Austin, Texas	Cessna 310P	substantial	2 uninjured

A military transport helicopter was flown on an approach to Runway 13R ahead of the accident airplane. The helicopter pilot terminated the approach and hovered the helicopter at 300 feet over the runway. The pilot of the accident airplane requested vectors for separation; ATC said, "Separation should be just fine." Soon afterward, as the airplane was over the threshold of Runway 13R, the pilot requested confirmation that her airplane was supposed to be behind the helicopter. ATC said, "You were cleared to land on the left runway." The pilot responded, "Okay, understand we were one-three right." As the airplane was being flared, it encountered wake turbulence from the helicopter, and the pilot lost control.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Feb. 28, 1992	Anaheim, California	Beech 90	none	1 minor, 3 uninjured

The airplane was flown into wake turbulence when a B-737 crossed its path. A passenger whose seat belt was not fastened was hurt.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Nov. 20, 1991	Chicago, Illinois	ATR 42	none	1 minor, 21 uninjured

The airplane was flown into wake turbulence while the flight crew was complying with radar vectors for landing. A flight attendant sustained minor injuries. Radar data show that a similar category airplane was four nautical miles (7.4 kilometers) in front of the incident airplane when the first airplane was descended to the same altitude as the incident airplane and remained at that altitude. The two airplanes were separated by 4.6 nautical miles (8.5 kilometers), when the ATR 42 was flown into the wake turbulence.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Sept. 13, 1991	Prescott, Arizona	Cessna 172N	substantial	1 uninjured

The recently certificated private pilot, with 81.9 hours total time and 3.7 hours as pilot-in-command at night, attempted a dark-night takeoff on a 7,616-foot by 150-foot (2,323-meter by 46-meter) runway. About 30 seconds earlier, a Beech 1900 had been flown from the same runway. The private pilot said that the airplane shook during the takeoff roll and that he applied brakes and rudder but could not maintain directional control. The airplane veered off the runway and collided with a dirt bank.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Sept. 7, 1991	Marion, Ohio	S-7 Courier	substantial	1 serious, 1 minor

The pilot of an experimental airplane conducted a takeoff from Runway 22, immediately behind a larger aircraft. The accident airplane rolled inverted and struck the runway in a steep nose-down attitude. Witnesses said that they saw the airplane's wings rock before the accident.

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Aug. 17, 1991	Seagraves, Texas	Piper PA-25-150	destroyed	1 minor

The pilot was conducting a formation agricultural-operations flight and lost control of the airplane when it was flown into wake turbulence from the lead aircraft. The altitude was insufficient for recovery.

June 28, 1991	Clinton, Minnesota	Piper PA-25-235	destroyed	1 uninjured

The pilot was conducting a tandem agricultural-operations flight with another pilot. As his airplane approached the field, he was unable to see the marker flag in time to make a proper pass. He conducted a go-around and re-entered a left pattern for the field. The pilot said that his airplane was in straight-and-level flight when he flew into wake turbulence that rolled the airplane into a steep right bank. The airplane struck the ground.

June 20, 1991	Salt Lake City, Utah	Cessna 210	substantial	2 uninjured

The airplane was being flared to land when it passed through wake turbulence generated by a helicopter that was taking off near the runway. The airplane landed hard.

March 16, 1991	Pullman, Washington	Cessna 140	substantial	1 uninjured

The pilot of the Cessna 140 said that his airplane was flown into wake turbulence on short final approach, a few minutes after a Swearingen Metroliner commuter aircraft was landed. The accident airplane rolled right and landed hard, collapsing the right-main landing gear.

March 11, 1991	Santa Ana, California	Cessna 152	destroyed	1 uninjured

The pilot was conducting a fourth touch-and-go landing on Runway 19L. ATC cautioned the pilot about possible wake turbulence from a B-757 that was being landed just ahead of the accident airplane on Runway 19R. The airplane was being flared when it suddenly rolled right and struck the runway. A post-accident fire destroyed the airplane. The winds were from 240 degrees at 12 knots.

Feb. 4, 1991	Greensboro, North Carolina	Piper PA-28-180	substantial	1 minor

The student pilot, who was disoriented and off course, observed the Piedmont Triad International Airport and attempted to land the airplane on Runway 23 about 100 feet (31 meters) behind a McDonnell Douglas DC-9 that was being landed on the same runway. The Piper was flown into wake turbulence and struck the runway.

Jan. 21, 1991	Sacramento, California	Cessna 172	destroyed	1 serious

Approach control radar tracked the accident airplane as it entered controlled airspace at 1,300 feet on a northwesterly heading. The aircraft turned west, descended to 800 feet and crossed the extended centerline of Runway 34L behind an arriving MD-80. The airplane crossed the flight path of the MD-80 one nautical mile behind the transport airplane and 100 feet below, then abruptly disappeared from radar. Tower controllers observed the lights of the Cessna pass behind and just below the MD-80, then descend toward the ground.

Jan. 12, 1991	Camarillo, California	Quickie	substantial	1 uninjured

The pilot was flying the experimental aircraft on final approach behind a landing North American T-6. When the experimental aircraft was about 15 feet to 20 feet above the ground, the aircraft encountered wake turbulence from the T-6. The aircraft rolled right and descended to the ground.

Sept. 16, 1990	Poteet, Texas	Cessna 188	minor	1 uninjured

The agricultural-operations airplane took off with a full load in high temperatures and was flown into wake turbulence during the takeoff. The pilot conducted an emergency landing.

July 14, 1990	Seattle, Washington	North American P-51	substantial	1 uninjured

The airplane entered wake turbulence while being flown on final approach for a formation landing behind a Hawker Sea Fury. The airplane rolled 70 degrees to 75 degrees left. The pilot had insufficient control authority to recover. The airplane struck the runway with the left wing low at about 45 degrees of bank, damaging the left wing and partially collapsing the left-main landing gear.

June 28, 1990	Ojai, California	Bellanca 17-30A	none	1 minor

The pilot of a U.S. Navy Grumman F-14 had received clearance to descend from 9,000 feet to 5,000 feet on a southeasterly course. The westbound Bellanca was in level flight at 8,500 feet. The F-14 pilot observed the Bellanca when the aircraft were within 100 feet (31 meters) to 300 feet (91 meters) of each other and abruptly climbed the airplane. The Bellanca's right-wing main wooden spar was broken when the airplane was flown into the F-14's wake turbulence.

June 28, 1990	New York, New York	Beech 1900	none	13 uninjured

The airplane entered wake turbulence on landing and was moved sideways. Two of the airplane's tires failed.

June 2, 1990	Rialto, California	Cessna 152	substantial	2 minor

The pilot was conducting the initial climb after takeoff when he saw a Bell 412 helicopter hovering near a taxiway. The airplane then was flown into the helicopter's wake turbulence, and the pilot lost control of the airplane.

May 31, 1990	Anchorage, Alaska	Cessna 195	substantial	3 uninjured

The pilot landed the airplane close behind a departing B-757 and subsequently lost directional control. He had been cautioned by the tower about the potential for wake turbulence.

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
May 6, 1990	Windsor Locks, Connecticut	Cessna 172N	minor	2 uninjured
The pilot lost control of the airplane during landing. The airplane was flown into wake turbulence, veered and struck runway lights.				
April 1, 1990	Westfield, Massachusetts	Mustang 2	substantial	2 uninjured
The pilot of the experimental airplane began a takeoff roll about 20 seconds after another airplane's takeoff. As the accident airplane lifted off, it was observed to roll 90 degrees right, then 180 degrees left and then wings-level. The pilot said that he did not believe the airplane would clear the trees ahead, so he rejected the takeoff and landed the airplane. The airplane struck trees during the ground roll.				
March 9, 1990	Austin, Texas	Beech 95	minor	none*
The airplane entered wake turbulence during landing and bounced during rollout. The nosewheel and lower strut broke.				
Jan. 20, 1990	Scottsdale, Arizona	Boeing B75	none	1 uninjured
The airplane entered wake turbulence during landing and veered off the runway.				
Dec. 3, 1989	Houston, Texas	Embraer EMB-120	none	1 serious, 15 uninjured
During final approach, the airplane was flown into wake turbulence, and a flight attendant struck the ceiling.				
Oct. 5, 1989	Palm Springs, California	Piper PA-28RT-201	destroyed	4 fatal
The airplane was flown into the left traffic pattern for Runway 12. Winds were variable at six knots. A B-727 was being flown on approach to land on the same runway. ATC issued an advisory for wake turbulence. The accident airplane was abeam the approach end of the runway on a close downwind when the B-727 was landed. The pilot of the accident airplane received clearance to land. The airplane entered a steep bank and descending turn. At 100 feet AGL to 200 feet AGL, the airplane began oscillating and struck the ground.				
Oct. 1, 1989	West Palm Beach, Florida	Piper PA-38-112	minor	2 uninjured
During takeoff, the airplane was flown into wake turbulence from a departing aircraft. The pilot lost directional control, and the airplane struck runway lights.				
Sept. 26, 1989	Portland, Oregon	Piper PA-32-260	substantial	1 serious
The pilot received ATC clearance to land and was cautioned about wake turbulence from a large airplane landing ahead of the accident airplane. The pilot was told to fly the airplane in a tight pattern and follow the large airplane. On short final, the accident airplane was flown into the wake turbulence of the large airplane. The pilot was unable to maintain control, and the airplane struck terrain short of the runway.				
Sept. 14, 1989	Santa Paula, California	Cessna 152	substantial	1 uninjured
The student pilot was practicing landings in calm wind conditions. While on approach behind another airplane, he began a go-around. The airplane was flown into wake turbulence and abruptly rolled right, then collided with two other aircraft and a hangar.				
Sept. 6, 1989	Santa Ana, California	Cessna 180	substantial	1 uninjured
About one minute before the accident, the pilot was cautioned about possible wake turbulence from a B-737 departing on Runway 19L. During rollout, the left wing struck the runway, and the airplane nosed over.				
July 31, 1989	Oshkosh, Wisconsin	Cessna 210K	minor	1 uninjured
The airplane was flown into wake turbulence during landing. The right wing lowered, and the airplane turned right, departed the runway and struck a taxiway light.				
June 18, 1989	Port Huron, Michigan	Cessna 150	destroyed	1 serious
The student pilot was flying the airplane on approach to land behind a Junkers JU-52. A witness said that the accident airplane was 0.25 mile (0.46 kilometer) behind the JU-52, which touched down on the first one-third of the runway. As the Cessna was 20 feet AGL to 50 feet AGL, it banked from side to side and struck the ground.				
June 14, 1989	Columbus, Ohio	Gulfstream AA-5	destroyed	1 minor, 3 uninjured
The student and instructor were on a night instrument flight. During approach, they received clearance to land on Runway 28L behind a B-737. The airplane entered wake turbulence. The flight instructor began a go-around, but the airplane again entered wake turbulence and struck an airport ramp area. The aircraft stopped beneath the wingtip of a parked B-737 and began burning. Radar data showed that the airplane crossed the runway threshold 38 seconds after the B-737.				
May 23, 1989	Phoenix, Arizona	Piper PA-32RT-300T	substantial	1 uninjured
The airplane was being flown on a night VFR approach and landing. The pilot had been told that his airplane was following a B-737, and he could see the B-737 throughout the approach and landing. When the accident airplane was on base leg, the B-737 was turning off the runway. The pilot of the accident airplane was warned of possible wake turbulence and received clearance to land. As the airplane crossed the runway threshold, the pilot felt turbulence and increased airspeed. The airplane rolled almost 360 degrees.				
May 2, 1989	Philadelphia, Pennsylvania	Cessna T-210N	none	1 uninjured
The aircraft encountered wake turbulence during approach and landed hard. The right wingtip struck the runway.				

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
March 22, 1989	Jacksonville, Florida	Piper PA-60-600	destroyed	1 fatal

The pilot received ATC clearance for an ILS Runway 7 approach during dark-night conditions with visibility of two statute miles (3.2 kilometers) in drizzle and fog. He was told that a DC-9 was four nautical miles ahead and that he should use caution for wake turbulence. On final approach, the airplane descended below the ILS glideslope, struck trees and then struck terrain about 1.8 nautical miles (3.3 kilometers) short of the runway. A performance study by the U.S. National Transportation Safety Board showed that the airplane was two minutes 57 seconds behind the DC-9.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Feb. 3, 1989	Key West, Florida	Waco YMF	substantial	3 minor

The aircraft was being flown on a sightseeing flight over the water at about 100 feet. The pilot had observed a C-130 or similar type aircraft in the area at about 800 feet just before the accident. The pilot reversed course to the left, and while in the turn, the airplane abruptly rolled left. The airplane struck the water inverted and sank.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Jan. 19, 1989	Phoenix, Arizona	Piper PA-28-235	minor	1 uninjured

The airplane was flown into wake turbulence during landing. The right wingtip struck the runway, resulting in a fuel leak.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Dec. 31, 1988	Grand Rapids, Michigan	Cessna 152	destroyed	1 uninjured

The student pilot was attempting to land the airplane when the airplane was flown into wake turbulence from a preceding B-727. The student pilot was unable to maintain control of the airplane, which struck the runway and nosed over to an inverted position.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Nov. 19, 1988	Van Nuys, California	Piper PA-28R-201T	substantial	1 minor

The pilot lost control of the airplane while descending for landing, and the airplane struck a pole. The pilot had received clearance to land the airplane behind a Beech King Air on Runway 16R. The pilot said that at 50 feet AGL, near the threshold, the airplane entered an uncontrolled right bank and turned 90 degrees from the landing area. The airplane then struck the pole, the ground and a chain-link fence. A witness said that the accident airplane was flown a few seconds behind the landing King Air.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Nov. 15, 1988	Harkers Island, North Carolina	Cessna 152	destroyed	1 serious

The pilot was orbiting the airplane over a school of fish at 800 feet AGL when the airplane was flown into its own wake turbulence. He said that a wider orbit would have prevented him from flying the airplane back into the wake turbulence and that additional altitude would have provided more time for recovery.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Nov. 9, 1988	Gainesville, Florida	Cessna 152	substantial	2 minor

The pilot taxied the airplane to Runway 6 and was told by ATC to taxi to Runway 10 for takeoff. The pilot of a U.S. Navy Lockheed P-3 was conducting a low approach to Runway 10. The pilot of the accident airplane received a takeoff clearance and was cautioned about wake turbulence from the P-3. The pilot conducted the takeoff, and at 100 feet, the airplane abruptly rolled right, descended and struck the runway. FAA Order 7110.65, *Air Traffic Control* did not discuss takeoffs behind aircraft that were being flown in same-direction low approaches.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Nov. 1, 1988	Nashville, Tennessee	Cessna 210	destroyed	1 fatal

The pilot received vectors for a night VFR straight-in approach to Runway 02R and was told that a B-727 was to the right of his airplane, passing from right to left. He was cautioned about wake turbulence and replied, "OK, I see him." The controller told the pilot to turn inbound and to maintain visual contact with the B-727. The pilot received clearance to land on Runway 02R but was not given information about the wind, which was from 250 degrees at five knots — a direction that meant wake vortices from Runway 02L would drift toward Runway 02R. Radar data showed that the crew of the B-727 conducted a straight descent to Runway 02L and that accident airplane was about two nautical miles behind the B-727 and below its approach path. At about 1,100 feet AGL, when the accident airplane was about 200 feet below the B-727's approach path, an abrupt altitude deviation occurred. The pilot reported entering the wake-turbulence but continued inbound. The descent was stopped, but the airplane again was flown about 200 feet below the B-727's flight path. About 39 seconds after the first report of wake turbulence, radar contact was lost. The airplane struck terrain in a steep descent about one nautical mile from Runway 02L. The centerlines of the two runways are 1,650 feet (503 meters) apart; Runway 02L's threshold is 1,800 feet (549 meters) beyond the threshold of Runway 02R.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Oct. 27, 1988	El Paso, Texas	Maule M-6-235	minor	1 uninjured

The airplane was flown into wake turbulence during landing. The pilot lost control of the airplane, and a wingtip struck the runway, causing the airplane to ground-loop. The pilot had been advised about wake turbulence.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Sept. 14, 1988	Orlando, Florida	Embraer EMB-110	minor	11 uninjured

The airplane was flown into wake turbulence during landing. A loud noise was heard during recovery, and a landing-gear door and hinge were damaged.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
July 18, 1988	Cape Girardeau, Missouri	Grumman G164-A	substantial	1 uninjured

The pilot was conducting an agricultural-operations flight on a field with three radio transmission towers along one side. He said that he flew his airplane in a circle around one tower, then flew a final pass across the end of the field. At the end of the pass, the airplane was flown into its own wake turbulence. The airplane banked right and collided with two guy wires, damaging the right wingtips and propeller. The wire strike damaged the aileron system, and the pilot conducted a power-off emergency landing in a cornfield, where the airplane nosed over.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 7, 1988	Hazen, Arkansas	Grumman G164-B	substantial	1 uninjured

During an agricultural-operations flight at dawn, the airplane was flown into wake turbulence and struck a levee. The main landing gear was sheared off. The airplane nosed down, slid about 300 feet (92 meters) and nosed over.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
May 26, 1988	Yuma, Arizona	Grumman G164-B	minor	1 uninjured

During liftoff, the agricultural-operations airplane was flown into wake turbulence from a nearby helicopter. The airplane touched down hard.

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
March 19, 1988	Manter, Kansas	Cessna 188B	destroyed	1 serious

While being flown with other aircraft in an agricultural-operations flight, the airplane was flown into wake turbulence from the lead aircraft and lost altitude. The right wingtip struck terrain, and the airplane rotated in a flat attitude for about two turns. The airplane was destroyed by a post-impact fire.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Feb. 2, 1988	Saint Louis, Missouri	Beech B18	none	1 uninjured

The airplane was landed into wake turbulence behind a B-737. The pilot lost control of the airplane, which veered off the runway into mud.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Jan. 26, 1988	El Toro, California	Cessna 152	destroyed	1 uninjured

The student pilot was practicing touch-and-go landings and was cleared for an approach behind a C-130. The student pilot observed the C-130's touchdown point and planned his approach to remain above the C-130's flight path. Just before landing, at about 10 feet AGL, the airplane was flown into wake turbulence from the C-130. The airplane landed hard, and the nose landing gear collapsed. An examination of skid marks on the runway revealed that the Cessna had contacted the runway before the point that most of the C-130s had touched down.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Jan. 9, 1988	Colorado Springs, Colorado	Rotorway Executive	destroyed	1 uninjured

The pilot received ATC clearance to taxi the helicopter from a hangar on the south end of the airport to a hangar on the north end via Taxiway A, which paralleled Runway 17/35 and was 400 feet (122 meters) west. The pilot was hover-taxiing the helicopter just above the ground at three knots to five knots when the crew of a U.S. Air Force Lockheed C-141 conducted a touch-and-go landing on Runway 17. The C-141 lifted off about 500 feet to 1,000 feet (153 meters to 305 meters) ahead of the helicopter and was at 50 feet AGL to 100 feet AGL when it passed the helicopter. The helicopter entered wake turbulence from the C-141. The pilot tried to compensate for the rolling and pitching, but the helicopter touched down hard.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Dec. 9, 1987	Anchorage, Alaska	Cessna 402B	substantial	2 minor, 3 uninjured

During arrival in heavy traffic, the crew of the accident airplane conducted an approach to Runway 06R while a B-727 was being landed on Runway 06L. ATC told the crew of the accident airplane that the winds at the approach end of Runway 06R were from 340 degrees at nine knots. As the accident airplane crossed the threshold of Runway 06R at about 100 feet AGL (69 seconds after the B-727 landed), the airplane was flown into wake turbulence and rolled right more than 90 degrees. The pilot attempted to correct with aileron and power, but the airplane descended and struck the ground. ATC had not issued a wake-turbulence advisory. Calculations showed that wake vortices could have drifted from Runway 06L to Runway 06R in 28 seconds. Centerlines of the two runways were 700 feet (214 meters) apart; the threshold of Runway 06L was 4,600 feet (1,403 meters) beyond the threshold of Runway 06R.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Sept. 8, 1987	Monterey, California	Beech 95	destroyed	3 fatal

A commercial pilot was receiving multi-engine dual instruction. After takeoff, the pilot began practicing instrument approaches. After an ILS Runway 10 approach, the airplane was flown into the left traffic pattern for Runway 28, following a British Aerospace BAe 146. A witness observed the Beech in a steep nose-down descent. The configuration of the airplane indicated that the pilots may have been conducting a simulated engine-out approach when the airplane entered wake turbulence.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Sept. 8, 1987	Minot, North Dakota	Bell 47-G4A	substantial	1 uninjured

The pilot of the agricultural-operations flight conducted a takeoff from a truck with winds from the northeast at four knots to six knots. He flew an observation pass, then began a descending turn for a spraying run in the opposite direction. He was unaware of the wind shift to the northwest. The helicopter was flown into its own wake turbulence and began to settle, and the pilot increased collective to stop the descent. He attempted to release the load of chemicals, but the dump valve did not operate because of corrosion from chemicals carried on the previous flight.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Aug. 26, 1987	Devil's Lake, North Dakota	Champion 7ECA	destroyed	2 serious

The airplane was observed being flown at low altitude and circling a farm that belonged to the pilot's sister. After two passes, the airplane struck the ground in a cornfield. The pilot said that he was looking for a field in which to land and that on the second pass, the airplane was flown into wake turbulence from the previous pass. The left wing dropped and the pilot conducted stall-recovery procedures, but the airplane struck the ground.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Aug. 1, 1987	San Francisco, California	Cessna P210N	none	6 uninjured

During landing, the airplane was flown into the wake turbulence of a departing B-747. The pilot lost directional control, and the airplane departed the side of the runway.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
July 16, 1987	Boston, Massachusetts	Douglas DC-3	none	3 uninjured

The pilot momentarily lost aircraft control on final because of wake turbulence from an A300 landing on the parallel runway.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
July 14, 1987	Raleigh, North Carolina	Cessna 172M	destroyed	2 serious

The pilot received ATC vectors for landing on Runway 23R behind a B-727. ATC told the pilot that he could land his airplane on Runway 23L, but the pilot continued the approach to Runway 23R. ATC issued a landing clearance and an advisory: "caution wake turbulence." The airplane was flown into wake turbulence over the runway and was flipped inverted before striking the ground.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 28, 1987	Detroit, Michigan	Cessna 172P	minor	1 uninjured

The airplane was flown into wake turbulence on landing, causing the propeller to strike the runway.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 16, 1987	Sarasota, Florida	Cessna 172N	none	3 uninjured

The airplane struck approach lights on short final approach after being flown into wake turbulence.

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
May 31, 1987	Santa Ana, California	Gulfstream AA-5B	none	2 uninjured
The airplane was flown into wake turbulence during takeoff and settled back on the runway. The airplane then veered off the runway into dirt.				
May 22, 1987	Newport, Arkansas	Grumman G164	substantial	1 minor
The pilot was conducting an agricultural-operations flight in a rice field in formation with another airplane when his airplane experienced an in-flight upset because of wake turbulence from the other aircraft. The landing gear struck a rice levee and was sheared off. The airplane bounced from a levee and nosed over after striking the ground.				
April 22, 1987	Richmond, Virginia	Cessna 172A	minor	none*
The pilot was conducting a downwind landing when the airplane was flown into wake turbulence from an airliner. The right wingtip contacted the ground, causing minor damage.				
March 4, 1987	Miami, Florida	Piper PA-34-200	substantial	3 uninjured
The pilot was flying the airplane on final approach and received ATC clearance to land long when a B-737 was cleared for immediate takeoff. The pilot slowed the airplane for landing, and the airplane was 10 feet AGL to 20 feet AGL when it was flown into wake turbulence, rolled 60 degrees to 70 degrees right and nosed down. The pilot recovered the aircraft to a level attitude and landed on grass to the right of the runway. Radar data indicated that adequate spacing existed between the departing B-737 and the accident airplane.				
Feb. 2, 1987	Plaster City, California	Cessna 170B	substantial	2 serious
The pilot was flying the airplane about 50 feet AGL at a slow speed with 30 degrees of flaps extended to allow a passenger to photograph a motorcyclist. After completing a 360-degree turn, the airplane was flown through its wake turbulence, stalled and lost altitude. The pilot added power and retracted the flaps. The airplane struck the ground.				
Dec. 28, 1986	Chicago, Illinois	MD DC-9	minor	none*
During touchdown, the airplane was flown into wake turbulence, and a landing light was damaged.				
Dec. 19, 1986	Kansas City, Missouri	Boeing 727	minor	114 uninjured
The aircraft was flown into wake turbulence from a B-747 at FL 310 and received minor damage.				
Nov. 6, 1986	Tampa, Florida	Cessna 421C	substantial	4 uninjured
The flight crew received clearance for a visual approach behind an L-1011 and was warned of possible wake turbulence. The airplane was flown into wake turbulence at 1,600 feet AGL, and the crew lost control of the airplane, which rolled inverted. The crew performed a "split S" maneuver, regained control of the airplane at 400 feet AGL and landed the airplane. Radar data showed that the L-1011 had crossed the point of the wake-turbulence occurrence 94 seconds earlier at 2,100 feet.				
Oct. 31, 1986	Fort Pierce, Florida	Piper PA-28-181	substantial	2 uninjured
The pilot of a U.S. Coast Guard helicopter said on the Unicom frequency that he planned to land the helicopter on Runway 04, then offered to allow the airplane pilot to land the airplane first. The airplane pilot declined. The airplane pilot said later that he observed the helicopter over the runway about 0.5 nautical mile (0.9 kilometer) ahead of his airplane and that he had considered going around, but did not because the air was smooth. During the landing flare, the pilot lost control of the airplane.				
Oct. 29, 1986	England Air Force Base, Louisiana	Cessna 182	substantial	2 uninjured
The airplane was being flown on approach behind four jet fighters. The pilot said that about 200 feet past the runway threshold, at 80 miles (129 kilometers) per hour and three feet AGL, the airplane suddenly touched down on the main landing gear. It then bounced between the main landing gear and the nose landing gear about three times, damaging tips of the propeller blades and the firewall.				
Oct. 17, 1986	King Salmon, Alaska	Piper PA-18-150	substantial	1 minor, 1 uninjured
The pilot was cleared to taxi his airplane into position on the runway and to hold behind a Cherokee Six. After the Cherokee Six's departure, the pilot of the accident airplane was cleared for takeoff. Immediately after liftoff, at 10 feet AGL to 15 feet AGL, the airplane entered an uncontrollable right roll. The right wing struck the runway, and the airplane cartwheeled.				
Sept. 25, 1986	Anchorage, Alaska	Starduster SA-100	destroyed	1 serious
Shortly after departure of a B-747, the pilot of the experimental airplane was cleared for takeoff. At 200 feet, the pilot lost directional control, and the airplane struck the ground next to the runway. Before takeoff, the pilot had been issued a wake-turbulence advisory.				
Aug. 30, 1986	Rome, Georgia	Midget Mustang M-1	substantial	1 uninjured
The pilot conducted a takeoff behind a preceding aircraft, and the airplane was flown into wake turbulence. The turbulence and the left crosswind resulted in loss of control of the airplane, which struck the ground.				
June 22, 1986	Truckee, California	North American AT-6D	substantial	2 uninjured
During an air show, pilots of three North American AT-6 airplanes conducted takeoffs in what the pilot of the third airplane described as a staggered sequence. The first two airplanes gained altitude without any reported difficulty. The third airplane climbed about 25 feet and was flown into wake turbulence. The airplane violently rolled right and then left. The pilot lost control of the airplane, which struck the runway.				

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
May 17, 1986	Van Nuys, California	Socata TB-20	destroyed	1 fatal
While flying his airplane in the traffic pattern for Runway 16L, the pilot was cautioned about possible wake turbulence from a C-130 aircraft approaching Runway 16R. The pilot said that he saw the C-130, which was above his airplane and subsequently was landed. When the light aircraft was about 0.25 nautical mile north of the airport, it was flown into the C-130's wake, rolled inverted and struck terrain.				
March 31, 1986	Boise, Idaho	Cessna 210	substantial	1 uninjured
The pilot was aware of a transport aircraft being operated on a parallel runway as he attempted to land his airplane. The airplane was flown into wake turbulence, rolled and struck the ground. The pilot conducted a go-around and landed the airplane.				
March 14, 1986	Bozeman, Montana	Cessna 185	substantial	1 uninjured
After touchdown, the airplane's right wing rose, the aircraft moved left, and the left wing and horizontal stabilizer struck the ground. A B-767 had been conducting landings on the runway before the accident airplane's approach.				
Jan. 27, 1986	Reno, Nevada	Cessna 182	destroyed	1 fatal
While flying the airplane toward the airport on a VFR flight plan and in VMC, the pilot was issued three traffic advisories about a B-737 and twice confirmed that he saw the airplane. Witnesses said that the accident airplane rolled rapidly into a steep descending nose-low attitude and struck the ground while close behind the B-737.				
Jan. 15, 1986	Bermuda Dunes, California	Cessna 210E	minor	1 uninjured
Before touchdown, the airplane was flown into strong wake turbulence. The airplane rolled and struck the runway hard, damaging the propeller.				
Dec. 19, 1985	Tucson, Arizona	Cessna 150	substantial	1 serious, 1 minor
After a 45-minute wait for departure, the pilot was told by ATC to expect an additional three-minute delay because of wake turbulence from a C-130, which was approaching for a touch-and-go landing. The pilot waived the time interval for wake-turbulence separation and received takeoff clearance as the C-130 passed his airplane's position. The accident airplane climbed to between 25 feet AGL and 50 feet AGL, where it entered wake turbulence. The airplane pitched down, rolled right, descended and struck the runway, 82 seconds after receiving takeoff clearance.				
Oct. 12, 1985	Lebanon, Oregon	Cessna 172	substantial	1 uninjured
The pilot lost control of the airplane during the landing roll. The airplane veered right, struck a ditch and nosed over. A helicopter hovering left of the landing runway had generated enough wake turbulence to cause the loss of directional control.				
Sept. 25, 1985	Reno, Nevada	Piper PA-22-135	minor	1 uninjured
After being cautioned about wake turbulence, the pilot began to conduct a takeoff roll. The pilot was unable to keep the airplane's nose down and the airplane ground-looped.				
Aug. 23, 1985	Alaska (no further information)	Piper PA-18-150	none	none*
The airplane entered wake turbulence from the leading aircraft during a tandem takeoff.				
Aug. 22, 1985	Rangely, Colorado	Cessna 172RG	minor	1 uninjured
The airplane touched down short of the runway after being flown into wake turbulence from a Beech King Air.				
July 25, 1985	Bonita, Louisiana	Air Tractor AT-301	substantial	1 uninjured
The pilot was flying the second of two aircraft in a formation takeoff when his airplane was flown into severe wake turbulence from the other aircraft. The airplane touched down in a bean field and flipped over.				
July 10, 1985	Rochester, Minnesota	Cessna 152	substantial	1 uninjured
The solo student pilot was preparing to land the airplane on a 7,500-foot (2,288-meter) runway and was cautioned by ATC about wake turbulence from a departing DC-9. During the landing flare, the airplane touched down hard, swerved left, cartwheeled and nosed down.				
July 4, 1985	Dixon, Illinois	North American AT-6G	substantial	1 minor, 1 uninjured
The pilot conducted a touch-and-go landing behind another aircraft. When the airplane was four feet to five feet above the runway, it rolled right and struck the ground.				
June 13, 1985	Las Vegas, Nevada	Cessna 172	substantial	1 minor, 2 uninjured
During the landing rollout on Runway 19R, with the wind from 160 degrees at nine knots, the pilot lost directional control and the airplane veered right, then departed the runway to the left. ATC had cautioned the pilot about wake turbulence from departing heavy jet traffic. (At the time, FAA defined heavy aircraft as weighing more than 300,000 pounds/136,000 kilograms.)				
June 11, 1985	Belmar, New Jersey	Cessna 152	destroyed	1 fatal, 1 serious
During takeoff-and-landing practice for a pre-solo flight, the flight instructor saw a helicopter approach the airport and hover near the parallel taxiway near Runway 03. The airplane lifted off the runway after a touch-and-go landing, veered right and collided with the helicopter. The flight instructor said that the airplane entered the helicopter's wake turbulence.				

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000 *(continued)*

Date	Location	Aircraft Type	Aircraft Damage	Injuries
May 3, 1985	Fort Wayne, Indiana	Cessna 172P	minor	none*

The pilot lost directional control during takeoff after the airplane was flown into wake turbulence. The aircraft struck VASI lights.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
March 13, 1985	Dallas, Texas	Beech 36	none	3 uninjured

The pilot was vectored for an ILS approach to Runway 17L while a B-747 was vectored for an ILS approach to Runway 18R. ATC said that the Beech was at least three nautical miles (5.6 kilometers) behind the B-747, which was descending as it was flown toward the runway from the west. Radar data showed that ATC delayed the B-747's vector to the Runway 18R localizer and that the B-747 flew past the localizer and within 600 feet of the Runway 17L localizer. Wingtip vortices from the B-747 settled at a rate of 400 feet per minute (fpm) to 600 fpm and drifted toward the Beech's flight path.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Feb. 28, 1985	West Palm Beach, Florida	Piper PA-32	substantial	1 minor, 3 uninjured

The pilot radioed approach control to request flight-following services. The controller acknowledged the request and told the pilot to continue flying VFR. The controller asked whether the pilot would keep the airplane below 1,000 feet but did not assign an altitude. The pilot descended the airplane from 1,500 feet to 700 feet, flying south. The controller then told the pilot about heavy jet traffic at his one o'clock position 1.5 nautical miles away, heading west. About one minute later, the airplane was flown into wake turbulence. The pilot completed the flight and subsequently flew the airplane to another airport, where an inspection revealed wrinkled skin on the airplane's wings, popped rivets and firewall deformation.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Feb. 19, 1985	Holmwood, Louisiana	Boeing A75N1	substantial	1 minor

The airplane was one of two that were being repositioned. En route, the airplanes were flown into dense fog, and the pilot of the leading airplane began a 180-degree turn. The second airplane was about 100 feet behind the leading airplane at about 150 feet AGL. While turning, the airplane was flown into wake turbulence from the first airplane, entered a vertical left bank, descended and struck the ground.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Oct. 13, 1984	Miles City, Florida	Piper PA-J3-C65	destroyed	1 uninjured

The airplane became uncontrollable after takeoff when it was flown through wake turbulence generated by a departing helicopter, then struck a tree and the ground.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Oct. 4, 1984	Norfolk, Virginia	Cessna 172	substantial	1 serious

The pilot was flying an approach behind a B-727. ATC asked the pilot to fly a short approach and cautioned him about wake turbulence. On final approach at about 50 feet AGL, the airplane rolled sharply into a 90-degree bank, began to roll out of the bank, stalled and turned right about 120 degrees before striking the ground.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
Sept. 29, 1984	Houston, Texas	De Havilland DHC-6-300	minor	none*

Wake turbulence from a B-727 landing on a parallel runway caused the de Havilland to veer off the side of the runway. The crew was not warned by ATC about wake turbulence.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
July 18, 1984	Stanford, Arkansas	Grumman G164-A	substantial	1 minor

The pilot flew the agricultural-operations airplane over a set of wires, then, returning across the field, beneath the wires. The airplane was flown through its own wake turbulence and rolled. A wingtip struck the wire.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 30, 1984	Grenada, Mississippi	Cessna 172	substantial	1 minor

The pilot flew an approach to an uncontrolled airport following 0.25 nautical mile behind a Bell UH-1 helicopter. While on final approach at about 200 feet, the Cessna was flown into severe wake turbulence and rolled nearly inverted. The Cessna struck the ground about 500 feet short of the runway. The pilot said that he was not aware that helicopters produce wake turbulence.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 21, 1984	Middletown, Pennsylvania	Cessna 150M	destroyed	1 uninjured

An airplane flown by a solo student pilot was approaching the runway for landing when ATC told the pilot to go around because a Shorts 330 was on final. The pilot said that during the go-around, his airplane was flown into wake turbulence, cartwheeled and stopped with its nose buried in the ground.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
June 18, 1984	Charlotte, North Carolina	Piper PA-60-600	minor	none*

The airplane was flown into wake turbulence during takeoff, resulting in a broken right-main-landing-gear scissors.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
May 16, 1984	Clarksville, Texas	Canadair CL-600	minor	1 serious*

Cruising at FL 350, the aircraft was flown into wake turbulence from a descending B-767. The resultant upset caused an uncontrolled loss of 11,000 feet in 10 seconds to 15 seconds before the crew was able to recover. An unrestrained passenger was seriously injured.

Date	Location	Aircraft Type	Aircraft Damage	Injuries
April 14, 1984	Kent, Washington	Hughes 369	substantial	1 minor

The pilot requested clearance to fly through controlled airspace for a landing at Boeing Field. He was advised of a DC-10 being flown on departure from the Seattle-Tacoma (Washington) International Airport and was cautioned about possible wake turbulence. The DC-10 passed 600 feet above the helicopter with about 1.5 nautical miles of lateral separation. Soon afterward, the helicopter was flown into wake turbulence that caused it to exceed 90 degrees of bank and 90 degrees of nose-down attitude; the engine flamed out. The turbulence continued throughout the ensuing autorotation. The pilot tried to flare for a landing, but the main-rotor blades flexed downward and contacted the tail boom

Date	Location	Aircraft Type	Aircraft Damage	Injuries
March 19, 1984	Riverton, Wyoming	Piper PA-12	substantial	1 uninjured

The pilot observed a Convair 580 that was landed ahead of his airplane. The pilot flew his airplane on a normal glide path and planned a landing on the approach end of the runway. On short final approach at 50 feet AGL, the airplane suddenly banked more than 90 degrees left and struck the ground 150 feet (46 meters) short of the runway in a left-wing-low attitude.

Appendix
Wake Turbulence Accidents and Incidents in the United States, 1983–2000

Date	Location	Aircraft Type	Aircraft Damage	Injuries
March 18, 1984	Atlanta, Georgia	Cessna 172P	substantial	2 uninjured
The pilot was conducting an emergency landing because of an electrical failure. Because he was concerned about low fuel, the pilot flew the airplane relatively close behind another aircraft in the traffic pattern. The airplane was flown into wake turbulence during the landing flare. The right wing struck the ground, and the airplane slid to a stop.				
March 6, 1984	Santa Ana, California	Cessna T210 M	minor	none*
A wake-turbulence advisory was issued to the pilot during landing. The airplane was flown into wake turbulence and landed hard.				
Jan. 10, 1984	Los Angeles, California	MD DC-9	none	4 minor, 29 uninjured
The DC-9 was flown into wake turbulence from an L-1011 on approach to Runway 24L. The DC-9 was six nautical miles (11 kilometers), or 70 seconds, behind the L-1011 and 800 feet below its glide path at 6,100 feet when the incident occurred.				
Dec. 6, 1983	Barbers Point, Hawaii	Cessna 150	minor	none*
The airplane was in the landing flare when it entered wake turbulence from a departing helicopter. A wingtip struck the runway.				
Nov. 5, 1983	West Palm Beach, Florida	Mooney M20J	minor	none*
The pilot lost directional control when the airplane entered wake turbulence during the takeoff roll. The airplane veered off the runway.				
Aug. 20, 1983	Denver, Colorado	Mooney M20C	minor	1 uninjured
The aircraft was flown into wake turbulence during takeoff and settled toward the runway after the gear had been retracted. The propeller-blade tips were damaged when they contacted the ground.				
July 25, 1983	Cheyenne, Wyoming	Cessna 172RG	minor	none*
Before landing, the pilot was advised of wake turbulence caused by a jet. The pilot lost control of the airplane, which ran off the runway.				
July 18, 1983	Calipatria, California	Cessna 188	substantial	1 uninjured
The pilot conducted a precautionary landing in a cotton field during crop dusting after feeling the airplane buffet during a turn. The airplane landed hard.				
July 13, 1983	Edgar, Nebraska	Cessna 188	destroyed	1 uninjured
The pilot of the agricultural-operations airplane was completing a turn when the airplane entered wake turbulence from another aircraft spraying the same field. When the pilot attempted to climb the airplane to avoid a power line, the airplane stalled and struck terrain.				
July 1, 1983	Billings, Montana	Cessna 172R	minor	none*
The pilot was advised of wake turbulence generated by a departing Douglas B-26 fire tanker aircraft. The pilot began the takeoff and lost control of the airplane.				
June 13, 1983	Oxford, Connecticut	type not specified	minor	none*
The pilot conducted the takeoff into turbulence generated by a large U.S. Army helicopter. The pilot lost control and the airplane struck terrain.				
May 13, 1983	Boston, Massachusetts	Cessna 402	none	4 uninjured
Instrument meteorological conditions prevailed when a Cessna 402 was flown in level flight behind an A300 in descent for landing. The Cessna 402 rolled inverted. The pilot regained control and conducted a normal landing.				
Feb. 6, 1983	Tucson, Arizona	Beech 35	substantial	1 uninjured
The pilot was advised of the position of a B-727 that was being landed on Runway 29R and was cautioned about possible wake turbulence; he said that he saw the B-727 and acknowledged the wake-turbulence warning. The pilot said that while he was flying his airplane on approach, about two nautical miles from the B-727, his airplane suddenly pitched up and rolled over. He was able to continue the approach and to land the airplane safely. The Beech had crossed the path of the B-727 at approximately the same altitude about 60 seconds to 65 seconds behind the larger airplane.				

*Some reports did not include complete details about injuries.

ATR = Avions de Transport Regional

DA = Diamond Aircraft Industries

IAI = Israel Aircraft Industries

MD = McDonnell Douglas

MS = Morane-Saulnier

Source: Patrick R. Veillette, Ph.D., from reports by the U.S. National Transportation Safety Board and the U.S. Federal Aviation Administration

Data Show That U.S. Helicopter Accidents Increased in 2000 to 10-year High

The U.S. National Transportation Safety Board said that 231 accidents were recorded in 2000; the 11-year total from 1990 through 2000 was 2,211 accidents.

FSF Editorial Staff

Data from the U.S. National Transportation Safety Board (NTSB) show that 231 helicopter accidents were recorded in the United States in 2000, more than any year since 1990, when 233 accidents were recorded (Table 1, page 49).

Of the 231 accidents, 68.8 percent (159 accidents) involved general aviation helicopter operations, 10.8 percent (25 accidents) involved agricultural operations, 6.9 percent (16 accidents) involved on-demand (formerly known as air taxi)/ commercial operations, and 3.0 percent (seven accidents) involved external-load operations. In 10.4 percent (24 accidents) of the accidents, the category of the operation was unknown.

Of the 231 accident helicopters, 21.2 percent (49 helicopters) had reciprocating engines and 18.6 percent (43 helicopters) had turbine engines; in 59.3 percent (137 accidents), the engine type was unknown. (See footnote in Table 1.)

During the 11-year period, 2,211 accidents were reported. Of that number, 68.0 percent (1,503 accidents) involved general aviation operations, 11.9 percent (264 accidents) involved agricultural operations, 7.4 percent (164 accidents) involved on-demand/commercial operations, and 6.6 percent (146 accidents) involved external-load operations. In 6.1 percent (134 accidents) of the flights, the category of the operation was unknown.

Of the 2,211 accident helicopters, 47.0 percent (1,039 helicopters) had reciprocating engines and 40.6 percent (898 helicopters) had turbine engines; in 12.3 percent (272 accidents), the engine type was unknown. (See footnote in Table 1.) The data did not indicate whether the helicopters were single-engine or multi-engine helicopters.

The data show that the leading causal factor for accidents for the 11-year period was collision with trees (Table 2, page 49); 8.1 percent (180 accidents). Other causal factors included "autorotation, performed," 7.5 percent (165 accidents); "rotor, [revolutions per minute] not maintained," 6.5 percent (144 accidents); "terrain condition, none suitable," 5.7 percent (126 accidents); "clearance, not maintained," 5.3 percent (117 accidents); "aircraft control, not maintained," 5.2 percent (114 accidents); and "object, wire, transmission," 4.5 percent (100 accidents).♦

Table 1
U.S. Helicopter Accidents by Category of Operation and Engine Type,[1] 1990–2000

Year	Total Accidents	General Aviation	Air Taxi/ Commercial	External-load	Agricultural	Operation Unknown	Reciprocating	Turbine	Engine Type Unknown
1990	233	145	23	19	27	19	132	99	2
1991	198	126	20	9	32	11	122	67	9
1992	211	149	16	12	22	12	116	70	25
1993	183	119	15	17	25	7	94	76	13
1994	220	151	17	16	24	12	100	105	15
1995	164	114	10	11	24	5	84	76	4
1996	181	125	11	15	21	9	77	98	6
1997	174	124	10	15	15	10	82	80	12
1998	203	149	11	13	24	6	103	83	17
1999	213	142	15	12	25	19	80	101	32
2000[2]	231	159	16	7	25	24	49	43	137
Total[2]	**2,211**	**1,503**	**164**	**146**	**264**	**134**	**1,039**	**898**	**272**

[1]Data did not indicate whether helicopters were single-engine or multi-engine helicopters.

[2]Information was not available to categorize two helicopters according to engine type.

Source: U.S. National Transportation Safety Board

Table 2
Top 15 Causal Factors for U.S. Helicopter Accidents, 1990–2000

	Year											
Causal Factors	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Total**
Object, tree(s)	18	18	16	19	22	20	20	10	17	15	5	180
Autorotation, performed	15	17	14	11	13	12	27	17	20	12	7	165
Reason for occurrence undetermined, no modifier specified	15	17	16	17	25	7	11	18	17	13	5	161
Rotor, RPM not maintained	17	16	18	16	15	7	6	18	12	17	2	144
Terrain condition, none suitable	6	15	10	10	18	12	15	12	19	5	4	126
Clearance, not maintained	10	11	5	12	18	15	9	10	16	8	3	117
Aircraft control, not maintained	10	8	7	7	8	13	12	12	14	18	5	114
Object, wire, transmission	13	6	8	15	15	8	9	9	10	6	1	100
Autorotation, initiated	4	6	10	5	5	5	11	14	13	9	4	86
Terrain condition, water	7	11	12	8	14	10	4	6	6	5	1	84
Supervision, inadequate	4	8	9	9	7	9	11	10	6	5	1	79
Terrain condition, mountainous/hilly	3	6	10	7	14	7	9	8	7	6	1	78
Terrain condition, ground	4	9	6	2	5	4	5	5	21	11	6	78
Visual lookout, inadequate	11	8	10	11	7	4	5	4	5	3	1	69
Weather condition, tail wind	9	4	8	6	5	3	5	11	7	6	2	66

RPM = Revolutions per minute

Source: U.S. National Transportation Safety Board

Publications Received at FSF Jerry Lederer Aviation Safety Library

Report Says Coordinated Actions Will Be Required to Reduce Delays in Air Travel

A report by the U.S. General Accounting Office includes recommendations to build new airports outside metropolitan areas, increase use of underutilized airports and redistribute air traffic demand within the current system.

FSF Library Staff

Reports

National Airspace System: Long-term Capacity Planning Needed Despite Recent Reduction in Flight Delays. U.S. General Accounting Office (GAO). December 2001. GAO-02-185. 60 pp. Tables, appendixes. Available from GAO.*

The U.S. air transport system, in recent years, has not been able to accommodate efficiently all aircraft attempting to use limited airspace and busy airports. The number of airline flight delays has increased; in 2000, one flight in four was delayed.

The GAO, which conducts research for the U.S. Congress, said that solving the problem of delays requires action by several sectors of the aviation community because no single sector has the authority or the ability to solve the problem.

"The federal government, especially through the Federal Aviation Administration (FAA) and its parent agency, the Department of Transportation (DOT), plays a major role by operating the nation's air traffic control system, distributing federal funding for airports and setting operating standards for commercial aircraft and airports," the report said. "However, the nation's airports are primarily owned and operated by local units of government, so that decisions about such steps as expanding airport capacity are primarily local in nature. The nation's airlines also play a key role. Their business decisions have a strong effect on the volume and routing of flights, the type and size of aircraft used and the degree to which aircraft are upgraded to take advantage of new technology."

Each group has programs, some developed cooperatively and some independently, under way to address flight delays. Many programs, such as those to add new runways, were incorporated into FAA's Operational Evolution Plan (OEP). The OEP is a 10-year plan for increasing efficiency and capacity, managing delays, and maintaining safety. Through the OEP, FAA coordinates the implementation of new programs and changes to reduce problems involving congestion and delays. A major portion of the OEP involves the addition of runways at existing airports. The GAO said that current programs, if successful, could add substantial capacity but would not prevent delays from escalating because airports in major cities would have difficulty building additional runways and would continue to be "choke points" in the nationwide interdependent system.

The GAO said that the OEP is a positive step, but if economic conditions (which were affected by terrorist attacks in September 2001) return to or exceed pre-attack levels, the current plan will be inadequate. GAO recommendations include building new airports outside metropolitan areas, increasing use of underutilized airports near capacity-strained metropolitan airports, managing or redistributing air traffic demand within the current system and developing other modes of intercity travel.

Human Factors Design Guidelines for Multifunction Displays. Mejdal, S.; McCauley, M.E.; Beringer, D.B. U.S. Federal Aviation Administration (FAA) Office of Aerospace Medicine (OAM). DOT/FAA/AM-01/17. October 2001. 77 pp. Figures, references. Available through NTIS.**

This report was developed to provide background information and guidelines for FAA safety inspectors who approve multifunction displays (MFDs) for aircraft flight decks.

Information in the report also may be useful to those who design such displays.

The report begins with a history of flight deck displays and an explanation of terminology, including a definition of an MFD as "a display surface [that], through hardware [controlling means] or software controlling means, is capable of displaying information from multiple sources and, potentially, in several different reference frames."

MFDs are capable of layering information in integrated formats and using single display surfaces to present large amounts of information from several independent data sources. MFDs are becoming more prevalent in aviation, and there is a need for the same type of guidance for them that already exists for unifunctional displays in the form of guidelines and standards.

The report says that human factors issues arise when avionics components are designed independently, without user input. With an emphasis on human factors design, the report summarizes guidelines by type of display (air traffic, weather, navigation and others). Each section begins with background information and a general description of a type of display or automation process and includes recommended guidelines, limitations and key references from industry literature.

Books

Air Rage: Crisis in the Skies. Anonymous; Thomas, A.R. Amherst, New York, U.S.: Prometheus Books, 2001. 272 pp. Tables, appendixes.

The authors say that air rage, which they define as abnormal, aberrant and abusive behavior by some airline passengers, is the greatest threat to the safety and security of those who fly. The number of air-rage incidents is unknown because of underreporting.

To help readers understand the scope of the problem, the authors identify and discuss fundamental causes of air rage: lack of definition of air rage; a "broken" air transport system; alcohol abuse; drug transport and abuse; smoking prohibition; crowded seating conditions; confusion about carry-on baggage; deported illegal immigrants as passengers; inaccurate and inconsistent reporting of air-rage incidents; and the lack of consequences or penalties for air-rage offenders.

Air Rage: The Underestimated Safety Risk. Dahlberg, A. Aldershot, England: Ashgate Publishing, 2001. 272 pp. Figures, tables, appendixes, bibliography.

The author describes air rage as "a form of workplace violence" and says that the issue has not been acknowledged fully and has not been researched properly. She says that air rage is a system issue and that air travelers are an integral part of the aviation safety system.

One chapter discusses the concept that passengers are a part of human factors in aviation and contains models to help airline personnel focus on service and prevent conflict. The book also discusses adversarial relationships between travelers and aviation employees, with an emphasis on communication and relationships. Another chapter discusses models for airline executives to use in analyzing and developing preventive measures for passenger risk management.

Regulatory Materials

Training, Qualification and Certification of Nondestructive Inspection (NDI) Personnel. U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) 65-31. Oct. 1, 2001. 10 pp. Table. Available from GPO.***

FAA defines nondestructive testing as "inspections, tests or evaluations which may be applied to a structure or component to determine its integrity, composition, electrical or thermal properties, or dimensions without causing a change in any of these characteristics." Performance of such tests and interpretation of test results must be accomplished by trained personnel. Special skills and knowledge of appropriate technical principles and nondestructive testing methods are required.

This AC offers recommendations and criteria for experience, training, qualifying, examining and certifying of testing personnel who inspect aircraft, engines, propellers, accessories and components. This AC may be of interest to testing personnel and those who provide training and supervision of NDI personnel. The AC says that organizations should have a written program that describes guidelines used in training, qualifying and certifying personnel. Inspection personnel who qualify under this AC may be eligible for FAA certification.♦

Sources

* U.S. General Accounting Office (GAO)
P.O. Box 37050
Washington, DC 20013 U.S.
Internet: <http://www.gao.gov>

** National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161 U.S.
Internet: <http://www.ntis.org>

*** Superintendent of Documents
U.S. Government Printing Office (GPO)
Washington, DC 20402 U.S.
Internet: <http://www.access.gpo.gov>

Accident/Incident Briefs

A340 Crew Conducts Takeoff From Airport Taxiway

The incident report says that the flight crew was cleared for takeoff on Runway 32; instead, they conducted the takeoff on a taxiway nearly perpendicular to the runway.

FSF Editorial Staff

The following information provides an awareness of problems through which such occurrences may be prevented in the future. Accident/incident briefs are based on preliminary information from government agencies, aviation organizations, press information and other sources. This information may not be entirely accurate.

Air Carrier

Controllers Saw Airplane's Movement But Did Not Tell Crew to Halt Takeoff

Airbus A340-300. No damage. No injuries.

Night visual meteorological conditions prevailed for the airplane's departure from an airport in the United States for a flight to Taiwan. The flight crew taxied the airplane from the north terminal gate area to Runway 32. They taxied the airplane south on Taxiway Romeo and turned right onto Taxiway Kilo. As the crew made the turn onto Taxiway Kilo — which is nearly perpendicular to the runway — they received clearance from air traffic control (ATC) for takeoff on Runway 32.

"The airplane should have continued west on Kilo to the approach end of Runway 32," the incident report said. "Instead, the airplane accelerated west on Taxiway Kilo."

Both the local controller and a departure controller observed the takeoff roll, but neither controller made a radio call to tell the crew to discontinue the takeoff.

The distance on Taxiway Kilo from the intersection with Taxiway Romeo to the end of Taxiway Kilo is 6,800 feet (2,074 meters). Runway 32 is 11,000 feet (3,355 meters) long. After the takeoff, impressions of main-landing-gear tires were found in a snow bank at the end of Taxiway Kilo.

Landing-gear Shock-strut Door Separates From Airplane

Boeing 767-338. Minor damage. No injuries.

The airplane was being flown at an airspeed below the maximum gear-extension speed of 270 knots on approach to an airport in Australia when the flight crew extended the landing gear. They conducted a normal landing.

Maintenance personnel later told them that the right-main-landing-gear shock-strut door had separated from the airplane. An examination of the fitting attachments that remained on the door revealed fractures that were "characteristic of rapid overloading," the incident report said.

The report said that the fittings were damaged when the door separated and that they had not contributed to the initial failure.

After the incident, the manufacturer issued an engineering instruction (EI-767-032-0102 Rev 0) to "immediately inspect all B-767 [main-landing-gear] shock-strut doors and check the torque values of the door-attaching hardware." A revision

(EI-767-032-0102 Rev 1) said that the check should be conducted every three months. The report said that the manufacturer developed an engineering change to prevent the main-landing-gear shock-strut-door attach bolts from loosening.

Tail Skid Strikes Runway During Bounced Landing

Boeing 727. Minor damage. No injuries.

The airplane was being vectored for an approach to an airport in England after a flight from Turkey. Because of light turbulence and reports of wind shear, the flight crew increased their approach airspeed by 12 knots to 141 knots.

The airplane crossed the runway threshold at 50 feet and 135 knots. Then, at about 20 feet, the pilot felt the airplane sink rapidly. He raised the nose to a seven-degree or 8-degree nose-up attitude, but this had little effect on the rate of descent. The airplane touched down on the main landing gear, then bounced into the air. The pilot raised the nose further, and when the airplane touched down, the tail skid struck the runway. The impact separated the tail-skid plate from the airplane.

The pilot said that the incident was a result of wind shear, an uphill slope on the runway and his insufficient current experience in the airplane type. The report provided no further information on the runway gradient or the pilot's experience.

Air Taxi Commuter

Icing Blamed for Dual-engine Power Loss

Partenavia P.68B Victor. Substantial damage. Minor injuries.

Night instrument meteorological conditions, with rain and thunderstorms in the area, prevailed for the courier flight in New Zealand.

The pilot flew the airplane to 5,000 feet. She then checked the outside air temperature, which indicated two degrees Celsius (36 degrees Fahrenheit), and used a flashlight to illuminate the wings and engine-air intakes. There was no indication of icing. She conducted the same checks later, after the airplane entered clouds, and again observed no ice.

About 10 minutes after her second check for ice, the pilot observed that the left-engine fuel flow had decreased. An adjustment of the left-engine mixture control restored normal fuel flow, but soon afterward, the problem recurred. The pilot conducted left-engine trouble checks but did not select alternate engine-intake air because she saw no indication of icing.

The pilot told air traffic control about the unexplained power reduction, and then, as she was being given radar vectors, she said that both engines were surging. She shut down the left engine and conducted right-engine trouble checks but did not select alternate engine-intake air because there was no indication of icing. The accident report said that during the approach, the pilot "manipulated the throttle in an attempt to get some power from the engine, but it surged erratically."

The pilot conducted a landing at an en route airport. The airplane overran the runway, struck a fence, crossed a road and struck another fence.

The report said that the engine-air intakes probably became blocked by sleet, ice or hail, which caused the engine problems.

As a result of the accident, the New Zealand Transport Accident Investigation Commission (TAIC) recommended to the New Zealand director of civil aviation that the Partenavia P.68B flight manual be revised to tell pilots to open engine alternate-air doors when flying the airplane "in high humidity at any temperature." TAIC recommended to the operator that company pilots be reminded of the Partenavia's "in-flight vulnerability to engine-air-intake blockages by sleet, ice or hail … and the corrective action necessary should a blockage occur."

The recommendations were accepted.

Loss of Power on Takeoff Prompts Precautionary Landing

Cessna U206G Stationair 6. Minor damage. No injuries.

The airplane was being repositioned after a missionary flight when, at 150 feet above ground level, after takeoff from an airport in Tanzania, the pilot heard a loud popping sound from the engine bay. The pilot observed a slight decrease in power and minor engine roughness, but engine revolutions per minute were unchanged.

The pilot conducted a precautionary landing on the runway and taxied to a parking area in front of the airport fire station.

Inspection revealed that the no. 4 cylinder head had separated from the engine, causing minor damage to adjacent engine parts. The cylinder had been plated about three years earlier and had accumulated 1,015.8 operating hours before the incident. The incident report said that the cylinder baffle between the no. 2 cylinder and the no. 4 cylinder had been replaced the day before the incident; the same repair had been conducted the previous month. A laboratory was conducting metallurgical tests on the no. 4 cylinder.

Corporate Business

Fuel-flow Problem Blamed for Uncommanded Engine Shutdown

Canadair CL-600 Challenger. No damage. No injuries.

The airplane was being flown from an airport in Canada on a routine flight inspection of instrument landing system equipment when the flight crew reported an uncommanded shutdown of the right engine (General Electric CF-34-3A1). The crew declared an emergency and landed with the engine inoperative.

An inspection and ground tests of the engine revealed no engine abnormalities. Subsequent analysis of data from the flight data recorder revealed that there had been an interruption of fuel flow to the right engine. The operator was investigating to determine the cause of the fuel-flow interruption.

Airplane Strikes Ground During IFR Departure

Piper PA-32-300 Six 300. Destroyed. Four fatalities.

Instrument meteorological conditions prevailed, and an instrument flight rules flight plan had been filed for the afternoon departure from an airport in the United States.

When air traffic control (ATC) issued the takeoff clearance, the pilot was told that, after takeoff, he should turn the airplane left to a departure heading of 90 degrees. When the pilot called ATC (departure control), he said that the airplane was at 1,500 feet and climbing. ATC told the pilot to fly the airplane to 4,000 feet. Two minutes later, ATC again told the pilot to fly a heading of 90 degrees. The pilot repeated the heading assignment, but radar data show that the airplane was flown in "a wide arc to the right and back over the airport, then [in] a 360-degree turn to the right," the accident report said.

"Departure control again contacted [the pilot] to advise of the 90[-degree] heading, which the pilot acknowledged," the report said. "Departure control then advised the pilot of the apparent 360-degree turn, and the pilot acknowledged. … Departure control requested [the pilot] to say [his airplane's] present heading, and the pilot reported a heading of 240 degrees. … Departure control advised [the pilot] that the heading should be 90 degrees, and the pilot acknowledged and asked if that would be a right turn to 90 [degrees]. Departure control replied left turn to 90 [degrees]."

Radar data showed that the airplane was at 4,000 feet in a level turn that resulted in a heading of about 60 degrees. The heading then varied from 45 degrees to 74 degrees before the airplane turned right and descended.

The report said, "Departure control asked the pilot … what [he] was trying to do. The pilot reported that he was trying to get out of a spin."

One minute later, radar data showed that the airplane turned right and descended to 3,300 feet. Witnesses said that the airplane crossed a highway below clouds, apparently at a level attitude, then turned right and, in a steep, nose-low, right-wing-low attitude, the airplane struck trees.

Airplane Strikes Glacier During Approach in Instrument Conditions

Beech 300LW Super King Air. Destroyed. Two fatalities.

An instrument flight rules (IFR) flight plan had been filed for the flight from Poland to Switzerland, and visual meteorological conditions had prevailed for most of the flight.

The pilot canceled his IFR flight plan and began a visual approach to the airport, which had no instrument approach procedure. Low clouds were reported near the airport at the time of the accident, and the weather 22 nautical miles (41 kilometers) northeast of the accident site included a 2,000-foot overcast and visibility of one-half mile (0.8 kilometer) in fog. The airplane struck a glacier at 9,842 feet.

Other General Aviation

Interrupted Preflight Check Precedes Takeoff With Tow Bar on Nosewheel

Cessna 310R. Minor damage. No injuries.

A preflight check of the airplane was conducted at midday in the hangar at an airport in England. Later, the airplane was hand-towed by airport employees to the concrete apron outside the hangar. They parked the airplane and left the tow bar attached to the nosewheel.

When the pilot arrived, he began completing preflight checks but was interrupted when his cellular telephone rang. He boarded the airplane to answer his phone and was told that the flight was no longer necessary. Because he planned to start the engines to reposition the airplane in the grass parking area, he decided to fly the airplane in the traffic pattern. He started the engines and taxied to the active runway, using power for directional control, the report said.

When the airplane reached 30 miles (48 kilometers) per hour on the takeoff roll, it turned left. The pilot applied right rudder but could not stop the turn. He moved the throttle levers to idle and applied right brake. The airplane left the runway and rolled into an adjacent field, and the nose landing gear collapsed.

The accident report said that the pilot "had not completed his external check when he got into the aircraft to answer the mobile phone and had not noticed that the tow bar was still attached."

Aircraft Strikes Trees After Takeoff From Runway With Uphill Slope

Piper PA-28-151. Destroyed. No injuries.

Visual meteorological conditions prevailed for the departure from an airport in Sweden. The pilot selected 10 degrees of flaps and conducted a normal takeoff on Runway 25, which is 650 meters (2,133 feet) long with the first portion sloping uphill. Winds were from the southwest at five knots to 10 knots. The pilot said that the acceleration was sluggish and that he checked the foot brakes and the parking brake to ensure that neither was engaged.

"The airplane became airborne a few times but bounced onto the runway again prior to the final liftoff, which took place less than 50 meters [164 feet] from the runway end," the accident report said. "The stall warning was activated during a major portion of the takeoff run."

After about 100 meters (328 feet) of flight, the airplane struck a bush. Flight continued for about 200 meters (656 feet) before the airplane struck trees about three meters to four meters (10 feet to 13 feet) tall.

The report said that "for all practical purposes, the runway was too short, due to the uphill slope," and that the pilot used a "disadvantageous flap setting" and did not conduct a short-field takeoff. The report also said that correction factors for takeoffs from runways with uphill slopes were not included in the aircraft operations manual or in the Swedish Rules of Civil Aviation.

Airplane Strikes Terrain During Simulated Engine Failure

Jabiru ST3. Destroyed. Two fatalities.

Other pilots said that they heard the pilot say on the radio that he was conducting a simulated engine failure during approach to an airport in Australia before the single-engine airplane struck an embankment about 210 meters (689 feet) north of the runway on the extended centerline.

An investigation revealed that the airplane struck terrain in a nose-high, left-wing-low attitude, that the engine was producing power at the time of impact and that the airplane had no known flight control deficiencies. The accident report said that trees next to the airport caused localized turbulence, wind shear and downdrafts when the wind was from the southeast. At the time of the accident, the wind was from 150 degrees at 15 knots, with gusts to 18 knots. The report said that the airplane probably encountered turbulence and a high sink rate generated by the wind over the nearby trees.

"Given the evidence of significant power at the time of impact, it is possible that the pilot had initiated a go-around at a stage in the approach from which it was not possible to establish a positive rate of climb," the report said.

Rotorcraft

Pilot's Judgment Faulted in Autorotation Accident

Hughes 369E. Substantial damage. No injuries.

Visual meteorological conditions prevailed just before sunset in Sweden when the pilot — who had been on flight duty for 10 hours, had flown the helicopter for four hours and 20 minutes and had conducted 30 takeoffs and landings — decided to conduct a training flight that included emergency exercises.

After about 30 minutes of flight, the pilot began to conduct an autorotation and a landing. Because the helicopter's airspeed was high — about 70 knots — the pilot initiated a recovery. The accident report said that the main-rotor revolutions per minute (rpm) were low during touchdown, "and the contact with the ground proved to be hard and took place with a certain amount of forward motion. … After touchdown, the pilot noticed an object that came from behind him and passed by diagonally out to the right."

The pilot shut down the engine and observed that the tail boom had been severed by the main rotor.

The report said, "Complete autorotation maneuvers place large demands upon the pilot, and the margins for misjudgment are not large. In this case, the pilot made a miscalculation, which resulted in main-rotor rpm being too low when he initiated the final recovery prior to touchdown. … Contributory to the occurrence might have been that the pilot was somewhat tired after a long workday."

Mountain Turbulence Cited in Student Pilot's Loss of Control

Agusta-Bell 47G-2A1. Destroyed. One fatality.

Visual meteorological conditions prevailed for the student pilot's solo flight from an airport in Australia. Air traffic control radar tracked the helicopter intermittently for about 40 minutes; the helicopter was last observed on radar about seven nautical miles (13 kilometers) northeast of the accident site.

A witness observed the helicopter being flown "in a manner consistent with the pilot experiencing controllability difficulties," the accident report said. The wreckage was found on a mountain slope about one nautical mile (1.9 kilometers) off the student pilot's planned course. Notes containing preflight navigation planning calculations were found nearby, but the calculations did not take into consideration the forecast winds en route.

"Personnel at the flight-training school did not recall discussing at length the forecast weather conditions with the pilot and, in particular, they did not recall briefing the pilot about the forecast mountain waves prior to the navigation exercise," the report said.

Flight-training personnel said, however, that helicopters had been flown in the area throughout the day and that the pilots had not experienced controllability problems.

The weather forecast for the area, issued about two hours before the accident, was for isolated severe turbulence and mountain waves below 9,000 feet. Subsequent analysis of weather data indicated that at 1,500 feet — the altitude at which the pilot had planned to fly — winds were conducive to mountain waves and rotor. Photographs indicated that the helicopter probably was flown into severe turbulence from mountain waves or rotor and that the main-rotor blades may have severed the tail boom.

"This accident signature is consistent with excessive blade flapping," the report said. "The evidence indicated that a divergence of the main-rotor blade from its normal plane of rotation probably occurred as a result of severe turbulence generated by mountain wave or rotor activity, and a main-rotor blade contact with the tail boom and cockpit area ensued, resulting in a loss of control of the helicopter.

"It is also possible that the collective lever friction may have been overcome by the severe turbulence that caused the non-powered collective lever to suddenly drop. The collective lever drop would have induced a sudden nose-down attitude, and this may have caught the pilot by surprise. The pilot may have instinctively and rapidly applied aft cyclic to correct the aircraft's attitude. The rapid application of aft cyclic in this situation may have been sufficient to induce main-rotor blade contact with the tail boom."

Helicopter Strikes Highway, Motor Vehicle in Fog

Robinson R44. Destroyed. One fatality, one serious injury, one minor injury.

The helicopter was being flown to its hangar at an airport in the United States after a photographic flight. The accident report said that "visual to instrument meteorological conditions" prevailed in the area; witnesses described a dark night with fog, clouds and drizzle.

One witness said that he was driving a motor vehicle when he observed a red light about 100 feet above the highway median. He said that fog obscured his vision but that the light rose "almost straight upward another 200 feet and then began corkscrewing downward."

The helicopter struck the highway and one motor vehicle; three other motor vehicles received minor damage. The wreckage was about 200 feet southwest of power lines that cross the highway.

An investigation revealed a tear in the fiberglass portion of the front-right side of the cabin, a scratch on the right-side doors and "semicircular deformation" in the right navigation-light assembly and the tail skid. The crew of a power-line-maintenance helicopter observed a streak on the southwest side of the power lines that contained a red, white and blue material. The helicopter's color scheme was blue, with white and red designs.♦

We Encourage Reprints

Articles in this publication, in the interest of aviation safety, may be reprinted in whole or in part, but may not be offered for sale, used commercially or distributed electronically on the Internet or on any other electronic media without the express written permission of Flight Safety Foundation's director of publications. All uses must credit Flight Safety Foundation, *Flight Safety Digest*, the specific article(s) and the author(s). Please send two copies of the reprinted material to the director of publications. These reprint restrictions apply to all Flight Safety Foundation publications.

What's Your Input?

In keeping with FSF's independent and nonpartisan mission to disseminate objective safety information, Foundation publications solicit credible contributions that foster thought-provoking discussion of aviation safety issues. If you have an article proposal, a completed manuscript or a technical paper that may be appropriate for *Flight Safety Digest*, please contact the director of publications. Reasonable care will be taken in handling a manuscript, but Flight Safety Foundation assumes no responsibility for material submitted. The publications staff reserves the right to edit all published submissions. The Foundation buys all rights to manuscripts and payment is made to authors upon publication. Contact the Publications Department for more information.

Flight Safety Digest

Suggestions and opinions expressed in FSF publications belong to the author(s) and are not necessarily endorsed by Flight Safety Foundation. This information is not intended to supersede operators'/manufacturers' policies, practices or requirements, or to supersede government regulations.

Staff: Roger Rozelle, director of publications; Mark Lacagnina, senior editor; Wayne Rosenkrans, senior editor; Linda Werfelman, senior editor; Karen K. Ehrlich, web and print production coordinator; Ann L. Mullikin, production designer; Susan D. Reed, production specialist; and Patricia Setze, librarian, Jerry Lederer Aviation Safety Library

Subscriptions: One year subscription for twelve issues includes postage and handling: US$480. Include old and new addresses when requesting address change. • Attention: Ahlam Wahdan, membership services coordinator, Flight Safety Foundation, Suite 300, 601 Madison Street, Alexandria, VA 22314 U.S. • Telephone: +1 (703) 739-6700 • Fax: +1 (703) 739-6708