

Wake Turbulence: Understand and Avoid the Danger

"I felt as though we had hit a twenty-foot thick concrete wall"

-A corporate pilot after hitting the wake from a heavy aircraft in a slow descent across his flight path.

The crash of American Airlines flight 587 has brought Wake turbulence into limelight. Both pilots and air traffic controllers should remember that wake turbulence is still out there and hence all possible efforts should be made to avoid wake encounters. "The best defense against wake turbulence is to know and avoid areas where it occurs."

By Capt. N.P. Puri & FLT. LT. Flt Lt Ramiah Saravanan

What is Wake Turbulence?

This is one topic which can be easily learned and understood but can be quickly forgotten as well. All aircraft in flight generate wake turbulence. The interesting fact is that, the heavier the aircraft the more severe the turbulence. Defined by ICAO (Doc 9426) the term wake turbulence is used to describe the "effect of two rotating air masses generated behind the wing tips of large jet aircraft". The terms 'wake vortex' and 'wake vortices' are other terms of 'wake turbulence', which describes the nature of the air masses. Such wake vortices are two counter-rotating cylindrical air masses trailing from the aircraft (see fig 1), which are generated the moment the aircraft lifts from the ground and ends when it touches down. A vortex circulation is outward, upward and around the wing tips when viewed from either ahead of or behind the aircraft.



Figure 1 The Rolling up Process

Source: FAA Advisory Circular AC NO: 90-23. Oct 1991.



Figure 2

Source: FAA Advisory Circular AC NO: 90-23. Oct 1991.

Generation and Movement of Vortex

Wake Vortex is a by product of lift and is present behind every aircraft in flight. Lift is generated by the creation of a pressure differential over the aircraft wing surfaces.

The pressure differential over the wing (where low pressure occurs) and under the wing (where high pressure occurs) triggers the rollup of the airflow aft of the wing, resulting in rotating air masses trailing down stream of the wing tips. Once the aircraft is airborne, two counter rotating cylindrical vortices like those shown in figure 1 are created, which are hazardous to the following aircraft, especially during take off, initial climb, final approach and landing.

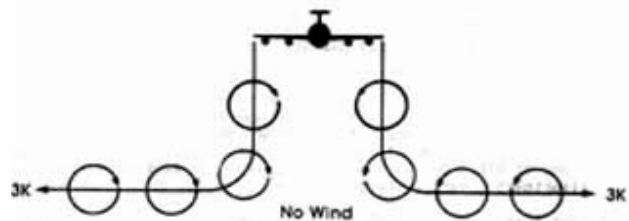


Figure 3 Vortex movement near ground – no wind

Source: FAA Advisory Circular AC NO: 90-23. Oct 1991.

Close to ground, the wake vortices tend to drift down and move sideways from the track of the generating aircraft but may rebound upwards as well. (see figure 2 above).

Even though research conducted by FAA (Federal Aviation Administration) showed most of the energy is with in a few feet of the centre of each vortex, "pilots are advised to avoid a region within about 100 feet of the vortex core". (Advisory Circular, AC NO:90-23 E, FAA. 01 Oct 1991)

CRASH OF AMERICAN AIRLINES FLIGHT 587

November 12, 2001, at approximately 9:17 a.m., American Airlines flight 587, an Airbus A-300-600, N14053, crashed into a neighbourhood in Belle Harbor, New York, several minutes after taking off from Kennedy International Airport, killing 265 persons. In 1994, the same aircraft had experienced a turbulence incident. But after inspection, the American Airlines maintenance personnel declared 'no damage' to the tail structure. (NTSB Advisory dated 20 Nov 2001)

Accident Sequence

As per NTSB, the Flight Data Recorder (FDR) and the Cockpit Voice Recorder (CVR) [a combination of these two make a Black Box] of flight 587 has revealed that the flight encountered **two wake vortices generated by JAL flight 47, a Boeing 747**. Both the wake encounters averaged about 0.1 G side to side movement. More over, during the last 8 seconds of FDR data, the plane experienced three **strong lateral movements**, two to the right and the third to the left. These lateral forces corresponded in time with rudder (this part is at the tail fin of an aircraft and is used for left/right turn of a plane in flight) movements. The rudder and tail fin were found first in the wreckage path, followed by the engines and then by the main wreckage impact point.

Till 1996, NTSB has documented 51 instances of wake turbulence which resulted in 27 fatalities and 40 destroyed aircraft. (Ben Rich, 1996)

Effects on Aircraft

The effects (ICAO DOC 9426) of wake turbulence on an aircraft can be of following three types:

1. Induced roll:
2. Loss of height:
3. Structural Stress:

Out of these three, induced roll is considered to have most dangerous effect on aircraft and will be discussed here. The following figure shows a typical induced roll.

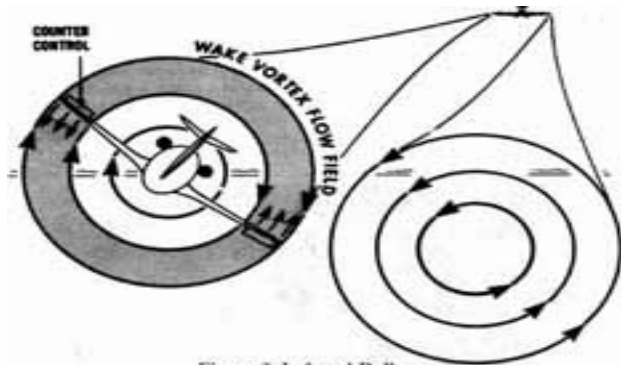


Figure 4 Induced Roll

Source: FAA Advisory Circular AC NO: 90-23. Oct 1991.

Induced roll is especially dangerous during take-off and landing when there is little altitude or speed for recovery. The tests conducted by NASA (Flight Safety Australia, Nov 2000) have shown that the capability of an aircraft to counteract induced roll primarily depends on wingspan and counteract responsiveness. Even high performance aircraft, if they have a short wing span, may feel greatest induced roll effect and it is more difficult for such aircraft to counter the imposed roll induced by the vortex.

According to the reported roll angle, wake turbulence may be classified into following three categories:

- *Severe:* Reported roll angle in excess of 30 degrees.
- *Moderate:* Reported roll angle of 10 to 30 degrees.
- *Slight:* Reported roll angle of less than 10 degrees.

At times a pilot may not even know that he is encountering a wake because a wake encounter is not necessarily hazardous. It may be one or more jolts with varying severity depending on the factors like direction of encounter, point of encounter, and distance from the generating aircraft.

Strength and Behaviour of Vortex

The strength of the vortex is directly proportional to the wingspan, weight and speed of the aircraft. However, the weight of the aircraft is the basic factor, that is to say, the heavier the aircraft, the stronger the wake vortex. In other words, the “strongest vortices are produced by heavy aircraft flying slowly with flaps extended”. Moreover, the strength of the vortex diminishes with time and distance behind the generating aircraft. So how do we categorize an aircraft as heavy? ICAO DOC 4444 wake turbulence categorization of aircraft are as follows:

S.No	Category	Maximum Certified Take off Mass
1	HEAVY (H)	All aircraft types of 136,000 kg or more
2	MEDIUM (M)	Aircraft types less than 136,000 kg but more than 7000 kg.
3	LIGHT (L)	Aircraft types of 7000 kg or less

A peak vortex tangential speeds up to almost 92 meters per second (300 feet per second) have been recorded (FAA).

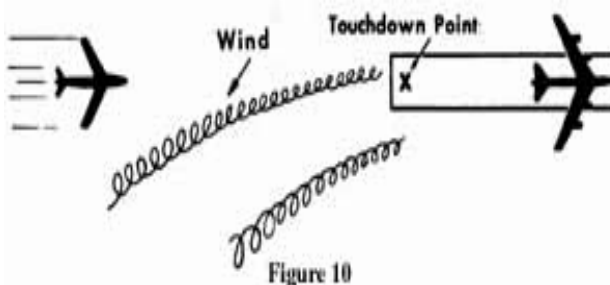


Figure 5

Source: FAA Advisory Circular AC NO: 90-23. Oct 1991.

Flight tests (ICAO DOC 9426) have shown that vortices sink at a rate of about 2 to 2.5 meters per second (400 to 500 feet per minute) and tend to level off at about 275 m (900 feet) below the flight path of the generating aircraft. The direction of the wind plays an important role in the presence and disappearance of wake vortices. A wake may take more time to diminish during a nil or light wind conditions where as a strong cross wing may swiftly drift the wake vortices.

Break up of vortices

Vortices break up in one of the following three ways (ICAO DOC 9426)

1. *Turbulent Diffusion:*
This occurs over a long period of time when each vortex gets enlarges, merges and then dissipates.
2. *Sinuuous Oscillations:*
Due to disturbances along the length of the vortex, become unstable and the vortices touch and link together.
3. *Vortex Break-down:*
The vortices burst suddenly and the vortex core is widened.

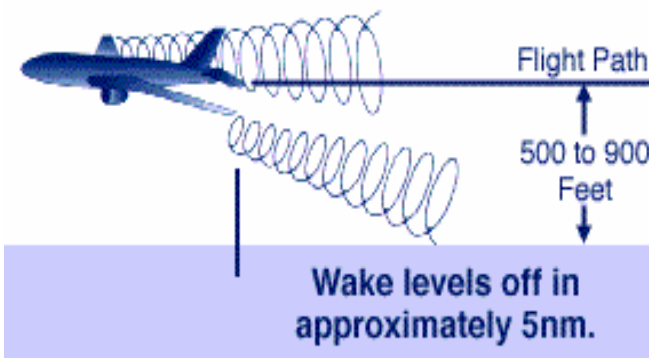


Figure 6

Source: FAA Advisory Circular AC NO: 90-23. Oct 1991.

Maneuver from Wake Turbulence

Following flight path, crossing the flight path, and flying below the flight path of a preceding heavy/medium aircraft especially during take off, climb, approach and landing phases should be avoided, unless and otherwise when ICAO wake turbulence separation minima (Radar and non radar) are applied. However, vortex sensing systems, like

Laser Doppler Velocimeter, Monostatic Acoustic Vortex Sensing System, Anemometer Windline, Socrates and Radar Acoustic Sound System facilitates better understanding of wake vortex and to modify the applicable separation standards there by increasing the airport capacity. These systems provide information on the presence and strength of the wake vortices and hence it becomes important to both pilots and air traffic controllers.

The following table shows the principle of operation and vortex measurement of vortex sensors

Conclusion

Wake Vortex is a by product of lift and is present behind every aircraft in flight. Once the aircraft is airborne, two counter rotating cylindrical are created, which are hazardous to the following aircraft, especially during take off, initial climb, final approach and landing. The strength of the vortex is directly proportional to the wingspan, weight and speed of the aircraft. However, the weight of the aircraft is the basic factor, that is to say, the *heavier the aircraft, the stronger the wake vortex*. In other words, the “strongest vortices are produced by heavy aircraft flying slowly with flaps extended”.

A wake encounter is not necessarily hazardous. It may be one or more jolts with varying severity depending on the factors like direction of encounter, point of encounter, distance from the generating aircraft and category (Heavy, Medium or Light) of the generating aircraft.

For a more elaborate version of this paper, also containing the avoidance of wake turbulence, please contact:

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SERIAL NO	TYPE OF SENSOR	PRINCIPLE OF OPERATION	MEASUREMENT OF VORTEX
1	Laser Doppler Velocimeter (LDV)	- Laser beam interaction with the wake vortex causes some of the laser light to be back scattered from the particulates trapped in the vortex. Its of two types; Continuous Wave (CW) and Pulsed System	Both CW and pulsed systems provide a measure of vortex position and strength.
2	Monostatic Acoustic Vortex Sensing System (MAVSS)	- It comprises a pair of acoustic antennas with transmitter and receiver. - Each transmitter generates an acoustic pulse, which, when interacting with a vortex back-scatters some Doppler shifted acoustic energy from the density variations in the vortex to the receiver.	Provides a measure of vortex lateral position and strength.
3	Anemometer Windline	- A linear array of fiberglass poles, each up to 30 feet high, on which are mounted propeller anemometer pairs for measuring vertical and cross wind. - As vortices descend into ground effect, the anemometers are driven with a speed and direction dictated by the portion of the wake vortex encountered.	Provides a good estimate of vortex lateral position.
4	SOCRATES	- Laser beams are used as virtual microphones for detecting, locally, acoustic signals generated by remote source such as wake turbulence.	Currently being explored by VOLPE in an extensive test program.
5	Radar Acoustic Sound System (RASS)	- An acoustic signal is generated along a path perpendicular to the approach flight path. - A radio frequency (rf) signal, generated along the same path is refracted back from the condensations and rarefaction generated by the acoustic signal. - The rf signals are also refracted when a vortex is encountered, which itself causes changes to the index of refraction of the air. - Still in the early development stage.	Provides a measure of vortex position and strength.

Source: VOLPE center. www.volpe.dot.gov 20 Nov 2001