Outmaneuvered AIRFLOW

BY WAYNE ROSENKRANS

U.S. wake vortex science safely updates approach and departure concepts essential to NextGen capacity gains.

Today's portable sensors and data-analysis techniques enable scientists worldwide to visualize dimensions, measure velocities and track positions of wake vortices generated by specific variants of large commercial jets. That's a far cry from igniting elevated smoke pots for low-level overflights in the early 1970s, says Steven Lang, director of the U.S. Center for Air Traffic Systems and Operations at the John A. Volpe National Transportation Systems Center.

"Wake turbulence is an inevitable consequence of flight — aircraft lift generation," Lang said during a Web briefing for news media in November 2012. "Wake turbulence separations in a sense reduce capacity at airports because you have to add spacing behind the larger aircraft for safety mitigation."

The evolving precision partly explains how several redesigns of air traffic procedures have been accomplished recently, he said, summarizing a paper published in October.[1] In the United States, Volpe and the Federal Aviation Administration (FAA), often in partnership with European counterparts, have used field research to build safety cases verifying that risks in proposed changes to air traffic control (ATC) procedures are acceptable.

Essentially, the National Airspace System has begun to see the results of a decision in 2001 that set near-term, mid-term and long-term goals "to focus on operationally feasible solutions rather than just looking at wake science as a solution," Lang said. Flexibility was added, too, to explore solutions to practical problems other than encounters with heavy-jet wake vortices (see "Airbus Measures Relative Wake Vortex Characteristics," p. 14). Lang also credited clear-cut, stakeholder advisory processes launched then under the FAA's safety management system.

In the past 30 years, various sensors and techniques incrementally improved study of wake generation, transport and decay. The most radical change came from pulsed lidar, which Lang described as "a radar-laser type of device that actually measures the vortex as it's generated from the aircraft [and] shed from the aircraft. …

The entire safety region that we have to be concerned with is now measurable by pulsed lidar."

Cooperation among global networks of scientists also has accelerated the development of practical solutions for wake vortex mitigation. Another factor has been bringing together pilots, airline safety specialists, air traffic controllers, the science community and regulators. "Before that, it was purely a science effort," he recalled. "The scientists decided what they wanted to study, what they wanted to research and there was little involvement from the people that actually had to fly or operate the system."

The ATC innovations discussed fall into two types: closely spaced parallel runway operations and single-runway in-trail wake separation operations. The FAA defines closely spaced parallel runways as runways that have less than 2,500 ft (762 m) between their centerlines.

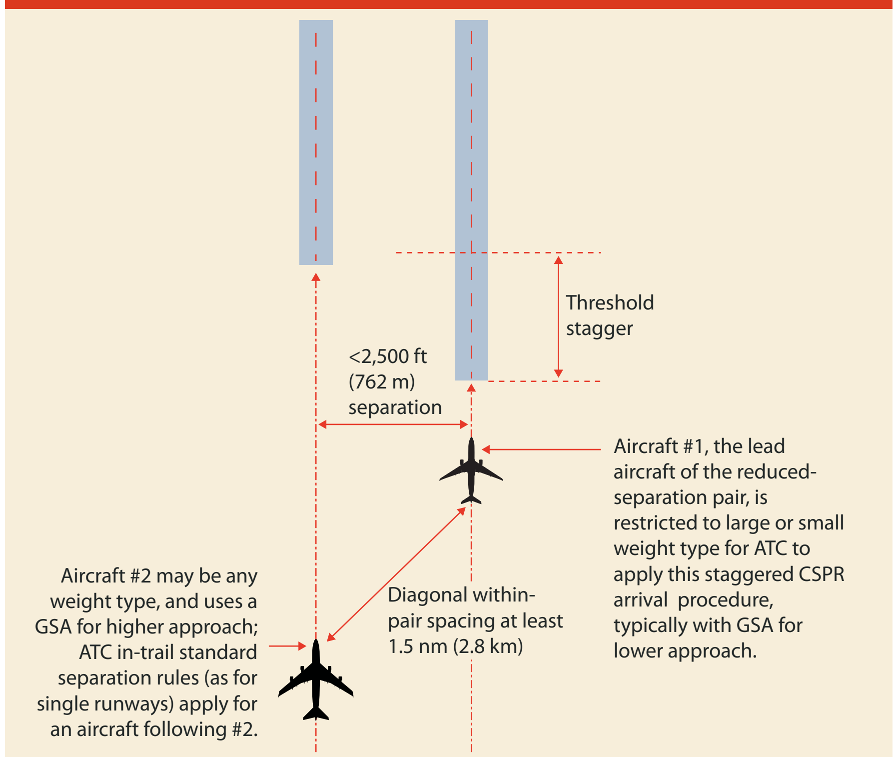
In planning the Next Generation Air Transportation System (NextGen), increased system capacity will come partly from satellite-based communication, navigation and surveillance advances that enable aircraft to be operated with *minimum* spacing needed for safety. But Lang said, "All those things are wonderful, but the last piece … is the *maximum* spacing needed, which is wake turbulence separation. … It's good that you did all of that navigation improvement and surveillance improvement and everything else that goes along with that, but if you don't solve the wake problem, you can't put aircraft closer together. … So it's very important that wake turbulence gets solved in time for NextGen. … Unless wake turbulence is addressed, you're stuck with what you have. … Many concepts would not realize their full potential."

For example, one of the long-term ATC standards within NextGen will be dynamic pairwise separation. "That's where the aircraft weight configuration, the weather condition … the time of arrival, the route of flight are all taken into account and then [ATC will] develop the separation standard for that specific scenario," he said. "So one day, you might be 4 nm [7.4 km] behind an aircraft; the next day you might be 3 nm [5.6 km] behind the aircraft because of the configuration, the weight and the [meteorological] conditions. … So it's a system that … delivers a spacing, a yea-or-nay spacing, to the controller that [says] 'Yes, you can do it,' or 'No, you cannot do it.'"

With that still on the far horizon, FAA and Volpe also revisited procedures that had been based on now-outdated wake vortex measurements. One effort proved with safety-case data that positioning a smaller aircraft at least 1.5 nm (2.8 km) from any larger aircraft during their arrivals to closely spaced parallel runways could be done safely (Figure 1). Safety cases now are being prepared to add two more airports to the eight for which such runway pairings were authorized as of October 2012.

"By using the parallel runways, you actually reduce the risk of a wake encounter for the parallel-runway

Staggered ILS Approaches to Closely Spaced Parallel Runways



ATC = air traffic control
CSPR = closely spaced parallel runways
GSA = glide slope angle
ILS = instrument landing system
IMC = instrument meteorological conditions

Note: This ATC procedure during IMC has been implemented at eight major U.S. airports, enabling controllers to safely apply this minimum 1.5-nm within-pair spacing regardless of wake vortices or wind conditions. GSAs vary from 2.75 to 3.1 degrees.

Source: Steven R. Lang and U.S. Federal Aviation Administration Air Traffic Organization, "1.5-Nautical Mile Dependent Approaches to Parallel Runways Spaced Less Than 2,500 Feet Apart," Policy JO 7110.308 CHG 3, effective Oct. 30, 2012.

Figure 1

Airbus Measures Relative Wake Vortex Characteristics

Wake vortex encounters severe enough to threaten an upset of one large commercial jet flying behind another have been rare for simple reasons, suggest recent presentations of data from experiments by Airbus. Benign encounters are very common, however, says Claude Lelaie, senior vice president and product safety officer, Airbus, and a former Airbus test pilot and airline captain.

"The probability to have a severe encounter is in fact very low," Lelaie said. "Why? Because you have to enter the vortex, a very small tube … about 6 m [20 ft] diameter. You have to enter exactly in the center, and you have to enter with the proper [10-degree] angle. … If you have turbulence and so on, everything disappears. … Even when trying to have a strong encounter every time, we did not manage to have a strong encounter every time."

Nevertheless, the Airbus analysis also has concluded that "there is a possibility to have a severe encounter in flight where there is a type of generating aircraft at a distance [more than] the standard minimum 5 nm [9 km] separation and with 1,000 ft vertical separation," he said.

Airbus presented these data and conclusions to the Wake Vortex Study Group of the International Civil Aviation Organization (ICAO), which has been updating recommendations for flight crews and air traffic controllers. Lelaie also briefed Flight Safety Foundation's International Air Safety Seminar in October 2012 in Santiago, Chile.

The 200 encounters Airbus studied were carefully orchestrated missions — at a cruise altitude of about 35,000 ft — to insert a follower aircraft into the center of the strongest/worst wake vortices/contrails to induce effects associated with in-flight upset, Lelaie said. The missions involved precisely positioning the generator-follower pairs in ideal, repeatable calm-weather conditions. An Airbus A380 with an adjacent A340-600 or a Boeing 747-400 on a parallel flight path were used as the wake vortex–generators. The A340-600 and an Airbus A318 took turns as follower aircraft. He described one test protocol.

"Two aircraft were flying side by side [into the wind], the A380 and the reference aircraft, which was either a 340-600 or the 747," Lelaie said. "An A318 was flying behind and below at a distance between 5 and 15 nm, and we had above a Falcon 20 from the DLR [German Aerospace Center] with an onboard lidar."[1] A 10-degree entry angle was considered the most critical case. "If you are almost parallel, you will be ejected from the vortex," he said. "If you cross perpendicularly, [the encounter] will be very short and almost nothing will happen."

Some findings ran counter to conventional assumptions about wake vortex effects on the existing design of reduced vertical separation minimums operations, notably what he termed an incorrect assumption that wake vortices from a 747 do not descend more than 800 or 900 ft.

Airline pilot knowledge and training to correct an unexpected roll remain sufficient mitigations for wake vortex encounters involving one large commercial jet behind another, he noted. "In the vortex … you can get strong vertical acceleration, positive or negative," Lelaie said. "For the vortex encounter, what we clearly recommend [to Airbus flight crews] is please do nothing. Release controls and do nothing, and once you have passed the vortex, nothing will happen. … The roll [response] is just normal roll control." International guidance on airplane upset prevention and recovery has been published by government and industry.[2]

One part of the Airbus study focused on measuring the rate of descent of wake vortices from each generator aircraft. Another focused on effects on the follower aircraft. The most important effect was roll acceleration, the direct indicator of vortex strength (Table 1, p. 16). Less interesting to researchers in practical terms were altitude loss, bank angle, vertical acceleration and roll rate, he said. Scientific instruments and video cameras also documented the bank, buffeting and the pilot's correction of uncommanded bank.

Regarding the rates of descent of vortices while flying at Mach 0.85, there was no difference between the A380 and 747-400, Lelaie said. He noted, "There was a slight difference with the A340-600 flying at Mach 0.82, but at the end of the day, all vortices [had descended] 1,000 feet at around 12, 14, 15 nm [22, 26, 28 km]. … This showed clearly that … at 15 nm behind any of these aircraft, you can find a vortex. … The [strength/roll rate acceleration] decrease with the distance is rather slow. At 5 nm, you have a good encounter; at 15 [nm] you have decreased [strength of] maybe 30 to 40 percent, it's not a lot."

As expected, lateral-acceleration maximum load factor and minimum load factor were significantly different in the forces recorded at the back of the follower-aircraft fuselage versus those felt by occupants because the airplane's turning point actually is in front of the aircraft. "These load factors are not what the passenger or what the pilot can feel," he said. "[They're] much higher." Nevertheless, occupants may feel strong lateral acceleration on the order of 2.5 g, 2.5 times normal gravitational acceleration. "Even at 18 nm [33 km], we have with all aircraft 2 g, again at the back," he added, and data in some cases showed small negative-g values.

"One which is interesting is this one, 747 and A318," he said. "Look at that: –0.7 [g]," he said. "In the middle of the fuselage it would have been –0.4 or –0.3 [g] but the [unrestrained person] in that seat will bump on the ceiling." Cases of the A380 followed by the A318 and the A380 followed by the

Continued on p. 16

aircraft versus going in-trail," Lang said, explaining that "by placing an aircraft in a staggered position, it has less risk of a wake encounter than if you put it single file to the same runway."

Data collection and building of safety cases for arrivals positioned FAA/Volpe to pursue similar concepts to make simultaneous departures of disparate-size aircraft on closely spaced parallel runways feasible mainly by taking into account the effect of a favorable wind direction and velocity through a new *wake turbulence mitigation for departure* (WTMD) system.

To mitigate the risk of a wake encounter, "physics tells you that if [one aircraft] is a heavy jet, you would have to stop this [other, lighter] aircraft from departing for three minutes in this geometry (Figure 2) or two minutes if this [runway end is staggered by] less than 500 ft [152 m]," he said. "If the wind is blowing this direction, this wake for the most part cannot transport against the wind and get over to that [parallel] runway. … The controllers have a system in the control tower at … three airports — going live in January at Houston and then in San Francisco and Memphis." The system advises the controller with a red light/green light display when the required conditions exist.

When fully available in Houston, "we envision [WTMD] will increase their capacity significantly [by] three, maybe four departures an hour," Lang added.

The third focus of practical solutions derived from advanced measurement has been single-runway solutions. Essentially, this program recategorizes aircraft from their legacy ATC-spacing categories, based on wide ranges of maximum takeoff weights and wingspans, to a new set of six categories based on different parameters. Under the legacy system, both a Boeing 747 that weighs about 900,000 lb (408,233 kg) and a 767 that weighs about 320,000 lb (147,417 kg) were in the *heavy* category B.

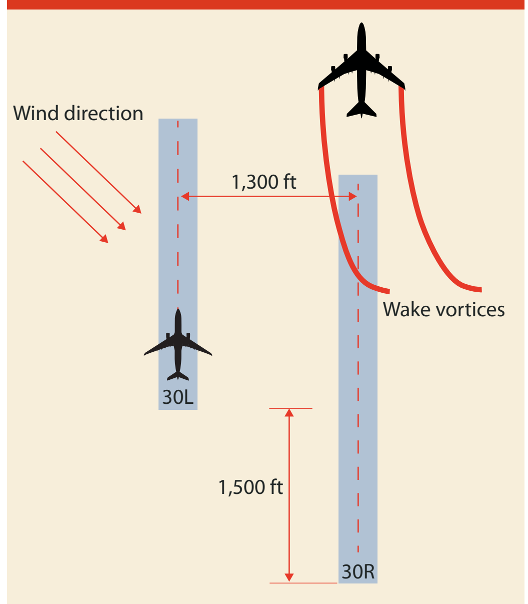
"These two aircraft have to be 4 nm apart because they are in that same category, regardless of [which] is in front, [and that] doesn't make a lot of sense," he said. "The [767] behind [the 747] probably needed 4 nm but the 747 following [the 767] did not need 4 nm." The resulting program, implemented in Memphis in November, is called Wake RECAT phase 1 and includes additional safety buffers for the lightest aircraft types.[3] Preliminary reports estimate at least a 10-percent capacity boost, and possibly 20 percent.

"In Memphis, the one observation that FedEx has made is they used to have backups at the runway both for arrivals and departures, and now they find themselves 'drying up,' as they call it," he said. "Recategorization has now made it [so] that there is no queue, and now they're having to rethink how they get the aircraft out of the ramp areas, out to the runway to be able to take advantage of the empty runway." This system operates independently of meteorological conditions.

The main reason that other airports cannot implement Wake RECAT phase 1 in the same time frame has involved local variations in ATC automation systems, he said. Wake RECAT phase 2, also under way, supports ATC static pairwise separation — that is, separation based on airport-specific categories of aircraft. As noted, the long-term move to ATC dynamic pairwise separation will be supported in weather-based phase 3. Lang said that such changes typically take time to generate predictable and measurable capacity benefits while the local ATC personnel become accustomed to new procedures.

Related applications of wake vortex data have enabled the FAA to divide three variants of the 757 within U.S. ATC separation and in separation standards of the International Civil Aviation Organization. Another example he cited was Volpe's wake data collection for Boeing during testing of the 747-800 for standards development.

Concept of Wake Turbulence Mitigation for Departures



STL = Lambert–St. Louis International Airport
IAH = Houston Intercontinental Airport
MEM = Memphis International Airport
SFO = San Francisco International Airport

Note: An operational demonstration at three U.S. airports with closely spaced parallel runways (IAH, MEM and SFO; not including STL used here for illustration) permits upwind-runway departures to occur simultaneously with downwind-runway departures that meet specified real-time wind criteria with conditions of approximately 3 mi (5 km) visibility and a minimum 1,000 ft ceiling.

Source: Steven R. Lang, John A. Volpe National Transportation Systems Center, U.S. Department of Transportation

Figure 2

Airbus Measures Relative Wake Vortex Characteristics (continued)

A340-600 also showed that "you can have something quite strong in terms of g," he said.

Lelaie also pointed to ongoing work by a Eurocontrol–Delft University of Technology study, looking at the correlation between actual wake vortex encounters and mapped hot spots, areas where encounters were predicted based on European air traffic data, as a promising path to further risk reduction.

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Notes

1. *Lidar* means light detection and ranging, and pulsed lidar combines laser and radar sensor technology to visualize and measure wake vortex characteristics.

2. One such resource that discusses wake turbulence is the *Airplane Upset Recovery Training Aid, Revision 2* (November 2008) available at <flightsafety.org/archives-and-resources/airplane-upset-recovery-training-aid>.

Wake Vortex-Induced Main Upsets for Selected Cases in Encounters Tested by Airbus

	Vertical Separation <1,000 ft					Vertical Separation >1,000 ft		
Generator airplane	A380	A340-600	B747-400	B747-400	A380	A380	B747-400	A380
Follower airplane	A318	A318	A318	A318	A340-600	A318	A318	A340-600
Horizontal separation (nm)	12.2	12.3	5.32	14.9	13.5	18.1	15.8	19.3
Vertical separation (ft)	838	608	432	832	851	1,015	1,038	1,168
Roll acceleration (deg/s^2)	49	75	69	146	24	68	109	12
Roll rate (deg/s)	24	35	18	36	5	20	31	7
Bank (degrees)	46	38	35	31	10	29	34	10

deg/sec^2 = degrees per second per second
deg/sec = degrees per second

Note:
The A318, A340-600 and A380 are Airbus aircraft types; the 747-400 is a Boeing aircraft type. Airbus also reported the lateral and vertical accelerations of the follower aircraft; these are not shown.

Source: Claude Lelaie

Table 1

Rethinking wake turbulence risk has involved more than the research capability. For example, meteorological and short-term wind nowcasting have improved significantly. "One thing FAA is has been pursuing, and we have been supporting, is getting wind [data] off the aircraft [in real time]," Lang said. "Currently, that's probably the best sensor in existence [but so far] the system does not receive wind off of the aircraft."

Volpe also has been working with FAA's Aviation Safety Information Analysis and Sharing program and the FAA-industry Commercial Aviation Safety Team in seeking to eventually acquire aggregated, de-identified data that might better link the scientists to airline experiences with wake encounters.

Notes

1. Tittsworth, Jeffrey A.; Lang, Steven R.; Johnson, Edward J.; Barnes, Stephen. "Federal Aviation Administration Wake Turbulence Program — Recent Highlights." Paper presented to Air Traffic Control Association Annual Conference and Exhibition, Oct. 1–3, 2012. <ntl.bts.gov/lib/45000/45900/45912/Lang__Wake_Turbulence_Program.pdf>

2. FAA. "1.5-Nautical Mile Dependent Approaches to Parallel Runways Spaced Less Than 2,500 Feet Apart." Air Traffic Organization Policy JO 7110.308 CHG 3, effective Oct. 30, 2012.

3. FAA. "Guidance for the Implementation of Wake Turbulence Recategorization Separation Standards at Memphis International Airport." Air Traffic Organization Policy N JO 7110.608, effective Nov. 1, 2012.