Exhaustive, first-of-a-kind wake-turbulence testing program sets stage for major reevaluation of wingtip-vortex hazards. Widely accepted thoughts about phenomenon's behavior are proven in error

Vortex Danger Underestimated

by LEW TOWNSEND / AOPA 376636

Wake turbulence, one of the most unwelcome hazards for pilots, to say nothing of their passengers, has been vastly underrated in the past, according to details recently released on a Federal test program involving the B-747 and other "heavy generators." The detailed findings require an updated list of pilot recommendations for dealing with the phenomenon.

Emphasizing the importance are new assessments by FAA, based on the test program, that general aviation aircraft can encounter up to a 75° forced roll rate when penetrating, within three miles or less, the wingtip vortices created by the B-747 and other aircraft grossing over 500,000 pounds.

"This fact is very important to the lighter aircraft, from an engineering view," said FAA's William M. Flener, director, Air Traffic Service. It is important, he said, "because, with the structural capability of the aircraft to stand that type of aileron or roll rate, some aircraft just cannot stand up structurally.

"In other words, what we're saying is, under certain circumstances, a light aircraft would break up structurally."

The wingtip vortices, or wake turbulence, of the B-747s and other large jets are capable of throwing out of control practically all general aviation aircraft, and the bulk of aircraft in the current airline fleet, it was related. Concern over airline aircraft extends up to and includes at least the 90-passenger DC-9 jetliner.

Flener, along with James F. Rudolph, FAA director, Flight Standards Service, provided the FAA's new assessment of wake-turbulence dangers. They revealed that the testing program uncovered some major erroneous beliefs about wake-turbulence characteristics.

One of three major findings was that the wind velocities within the wingtip vortices created by the B-747 and certain other large jets are far greater than FAA officials had anticipated they would be, or had even given credence to that they could be.

They also surfaced the fact that, contrary to long-held beliefs, the wingtip vortices of the big jets *do not dissipate* when they are formed in the higher altitudes around 30,000 feet, where most airliners normally cruise during their en route stages between large airport terminals. The wingtip vortices in the higher altitudes remain intact, complete with their compact balls of high-velocity winds churning in circular fashion.

If they could be seen, which they cannot, unless the jets are giving off an inordinate amount of engine smoke or are kicking up dust near the ground, the wingtip vortices might be likened to huge replicas of ancient reading scrolls. The rolled up portions at either end of the scrolls are the two wingtip vortices.

The third major finding, and also completely opposite from what FAA engineers earlier believed, was that the wingtip vortices do not descend downward ad infinitum. After they take shape aft of the tail, they descend in their scroll-like formation at a rate of about 450–500 f.p.m., as previously thought, *but they then level off somewhere between 700 and 900 feet below the flightpath of the generating aircraft.*

Stating that the vortices are 50 to 65 feet in diameter, Rudolph reported, "It does start breaking up in *certain* atmospheric conditions . . . but, in essence, this vortex does not continue to descend on down ad infinitum as the earlier [research] papers indicated.

"And, in the lower altitudes, in the lower atmosphere below 5,000 feet a.g.l., it does in fact start to break up. The environmental conditions working on it break it up. In the higher altitudes, however, this breaking up does not necessarily take place. But in the higher altitudes where it does not break up at all, we're talking about 30,000 feet."

Though stating wingtip vortices do begin dissipating below 5,000 feet a.g.l., there was no specific information on how long it takes for the "breaking up" process at these altitudes, nor how complete the dissipation is. There also was no specific word on the breaking-up charactistics of wingtip vortices generated by the big jets between 5,000 and 30,000 feet. The testing program was in two parts, with the first phase completed in February [April PILOT, page 34]. It was indicated the missing information would be sought in the final phase of the testing program, with results made public possibly in August.

Results of the first-phase testing, according to FAA, confirmed that wingtip vortices begin taking shape off the wingtips. As the wings plow through the air, wakes of disrupted air spill off the wingtips and create progressively growing wakes, much like the wakes created by the bow of a boat in motion.

Air wakes, however, drift back and toward the aft of the tail, fall in-trail behind the generating aircraft, and join together to produce two large and separate air masses of high-velocity winds, the wingtip vortices. Completely the reverse of what was earlier believed, FAA said the two vortices remain linked together by air currents and do not spread farther and farther apart behind the generating aircraft, as do the wakes behind a boat. The distance between the two swirling air masses of the B-747 is about 200 feet, FAA said.

Though failing to provide any estimates of the wind velocities within the vortices at the higher altitudes, FAA did give estimates of those created by various types of large aircraft when they are flying as slow as 150 knots at sea level in a maximum takeoff configuration. It earlier had been determined that the intensity—wind velocities—of the big jets' wingtip vortices is greatest when the aircraft are flying comparatively slow and during the landing and takeoff phases.

The calculated "vortex strength" of various airline aircraft ranged from 2,355 feet per second, for the 98,000-pound British Aircraft Corporation 111 (BAC-111), to 7,700 feet per second for the 710,000-pound Boeing 747. A chart accompanies this article, listing the calculated vortex strengths for all major types of airline aircraft. It also includes the calculated vortex strength for the still-to-fly Boeing SST, a supersonic aircraft that has been under fire in Congress over FAA's role and that of the Government in financing its development and manufacture.

According to FAA, the Boeing SST will create wingtip vortices having wind velocities on the order of 11,200 feet per second, about 1½ times that of the B-747, and nearly three times that of the 302,000-pound Boeing 707-300, an aircraft now in wide use.

The potentially increased dangers to other aircraft operations from the SST wake turbulence can readily be seen by the fact that the B-707-300 itself, as well as some other existing aircraft, already unleashes vortices capable of literally knocking a large number of today's smaller aircraft right out of the skies.

The B-747 and the coming SST, however, are only two of an especially troublesome trio of Boeing aircraft, where wake turbulence is concerned, it was learned. The third aircraft drawing FAA's attention is the B-727. Like the B-707-300, the B-727 currently is used extensively by a host of airlines. The B-727 is unique in that it sports tail-mounted engines, as opposed to the more conventional wing-mounted engines.

FAA officials said the wake-turbulence tests showed that the B-727's wingtip vortices are disproportionately greater in intensity than those spawned by comparably sized large jets. "For some unknown reason," said FAA, "that airplane develops a very high vortex. And we guess it's the tail-mounted engines, but we don't know why."

Flener reported the FAA was not considering the establishment of special restrictions on those aircraft creating the largest safety hazards to other aircraft operations. Rather than confine and limit such aircraft operations, the FAA indicated that if the big jets' wake turbulence caused problems, the agency would restrict and/or eliminate operations of those aircraft the big jets endanger.

Such an approach was viewed as deviating from past governmental practices in almost all fields of endeavor, where curbs and restraints are placed on known dangerous persons and activities to guard the general public from unnecessary harm.

Flener strongly indicated that at some point in the future the FAA would attempt to publicly embark on a program of "splitting out" and prohibiting certain aircraft from using airports and airspace now used or planned for use by the big jets. The "splitting out" process probably would be based on a still undefined program of "aircraft compatibility," it was said.

In connection with such a program, and likely the yardstick for bringing about such a radical change within the air transportation system, is a new formula FAA said it developed from the tests for determining capability of aircraft to withstand wake turbulence. Without delving too deeply into the formula, it can be said that the formula has led FAA officials to believe that the larger the wingspan of an aircraft, the greater its ability to cope with the high-velocity winds within the vortices created by the "heavy generators." Currently, heavy generators are designated as those having a gross takeoff weight of 300,000 pounds or more.

Though the final portion of the wake-turbulence tests had not been completed at the time of FAA's recent reassessment, Flener and Rudolph left little doubt that previously established five-mile separation standards between "heavy generators" and general aviation aircraft would soon be increased to at least seven miles. Changes in flight rules to accommodate the B-747 were detailed in an April PILOT article entitled "B-747 Turbulence Represents Danger."

In presenting the reassessment, Flener said, "One of the things that we feel we honestly must do, and do as thoroughly as we can, is get the word to everybody, particularly the general aviation pilot . . . The 'name of the game,' as far as the pilot is concerned, is just 'use more caution than you have used in the past,' because this bird [B-747] develops something much stronger than anything we've encountered before—this bird and some others."

Rudolph, who described most of the details of the testing program, as well as provided new tips for pilots, said, "The en route is not the problem. The problem is in the final approach and in the whole traffic area." He, like Flener, contended that though the vortices are now known to remain completely intact and in scroll-like formation at high altitudes, the odds were minimal that another aircraft would hit them in the en route stages.

Regarding the airport terminal area, and specifically the final approach, Rudolph reported, "The vortex does descend from the airplane [and contact the ground] and it does roll out. In a no-wind condition, the vortex from the right wingtip rolls outward to the right, and the left vortex rolls outward to the left. It rolls out at about five knots.

"Now, what happens when you put a crosswind on it? Well, they [earlier researchers] predicted for us what would happen. And it happens just that way, so we still have problems with parallel runways that are close together, such as those at Los Angeles and San Francisco [LAX and SFO]. With a slight crosswind, this vortex will actually move right out and across the parallel runway where another aircraft may be landing

VORTEX STRENGTHS*

(150 knots IAS at sea level)

Aircraft	Gross Takeoff Weight	Wingspan	Vortex Strength (in feet per second)
BAC 111	98,000	88′	2,355
B-737	107,000	93′	2,433
DC-9-30	108,000	93′3″	2,500
Trident	143,000	98′	3,086
CV-880	184,000	120′	3,243
B-727	169,000	108′	3,309**
B-720	213,000	130′10″	3,439
B-720B	230,000	130′10″	3,705
B-707-100	247,000	130′10″	3,988
B-707-100B	258,000	130′10″	4,165
C141	316,000	159′	4,203
CV-990	246,000	120′	4,335
B-707-300	302,000	145′9″	4,375
DC-8-61	325,000	148′5″	4,644
DC-8-30	314,000	142′5″	4,677
B-707-300 B/C	323,500	145′9″	4,759
DC-8-62	335,000	148′5″	4,771
VC 10	335,000	146′	4,853
DC-8-63	355,000	148′5″	5,056
B-52	488,000	185′	5,580
L-1011	409,000	155′	5,581
DC-10	410,000	155′	5,595
C5A	764,000	222′	7,260
B-747	710,000	195′	7,700
Concorde	385,000	84′	9,650
B-2707 (SST)	750,000	141′10″	11,200
B-70	530,000	105′	10,675

* Source: FAA

** Despite calculated figure for B-727, FAA officials said "for some unknown reason" this aircraft develops wingtip vortices having higher wind velocities than comparably sized jetliners. No estimates other than that shown here were provided.

or taking off adjacent to and close to the heavy generating aircraft [on the main runway]. There is a point where this crosswind will get above 15 knots —and I wish we knew exactly what this is, but we have not been able to find out yet—where above 15 knots, and in that area, the vortex is destroyed and no longer becomes a concern to us.

"Visualize vortices 50 to 65 feet in diameter, very tight vortices that have velocities in them of 140 feet per second —*tangential* velocities, that is—and put a small airplane in it. If he gets into it, he'll get thrown out of it. And he won't stay in it at three miles. If he gets into it, he'll get thrown out the way he drifted into it."

Continuing, Rudolph related, "The final approach to the airport is a point of concern to us . . . If you were to fly in a no-wind condition, or if you were to fly with a slight headwind condition and you stayed right on this airplane's [big jet's] flightpath, or right on the glideslope if you're shooting the glide-slope, you would in fact encounter no vortex.

"If you had a slight tailwind, or quartering tailwind, the vortex could be blown above the airplane's flightpath," he noted, then, emphasizing his first three words carefully, added, "Boeing tells us, from their limited testing program, that someplace around 70 feet [when jet is 70 feet a.g.l. on approach or takeoff], we need not concern ourselves with it because the vortex is no longer wrapped up tight—it is very loose.

"We do not necessarily disagree or agree with them," Rudolph said of Boeing's evaluations. "The vortices do settle behind the airplane [unless blown above the flightpath by tailwind or quartering tailwind—Ed.], they do draw together to about a quarter to a half a span [wingspan], and they do sit there on the ground. And, in a still-wind condition, they have been measured to sit in there for 160 seconds."

Flener said that VFR pilots are on their own in assuring avoidance of the invisible wingtip vortices, and that FAA's air traffic controllers would play only a minimal role in aiding pilots in the terminal area. "In many of our big airports today," he said, "the tower is way to hell and gone at the far end. We have to place the dependence upon the pilot, particularly the general aviation pilot, to be aware and understand what this [wake turbulence] is. The controller is not in a position to make a determination, hour after hour, aircraft after aircraft, as to what he [the pilot] should or should not do."

Controllers have been instructed to provide position reports on the "heavy generators" to VFR pilots in radio contact, Flener stated. Limited frequencies and controller personnel, of course, preclude the possibility that every aircraft can be in radio contact with controllers at all times and thereby be constantly advised as to the location of the big jets and their dangerous wake turbulence.

Asked whether controller assistance was worded in FAA instructions as they "shall" provide position reports on the big jets, or whether they "can" provide it on a workload-permitting basis, Flener said, "They *shall.*"

"Remember," he added, "we're talking VFR. When we're talking instrument conditions and radar separation, the responsibility is the controller's. But, you see, under VFR the pilot is on his own as far as his separation. He makes his own determination as to how far back he should be. We're still placing the responsibility on the pilot, as far as that VFR pilot is concerned. We can't do anything else. There are too many of them, and there's such a volume of traffic at some of these locations. We spoonfeed a great deal of the system as it is today, and we're trying to place the responsibility where it belongs."

In the way of a quickie recommendation on wake turbulence, Flener offered, "Land high and long. Take off quick and climb high." The main thing for VFR pilots to learn, it was pointed out, is that they now should maintain a greater distance between themselves and the "heavy generators" than they have in the past.

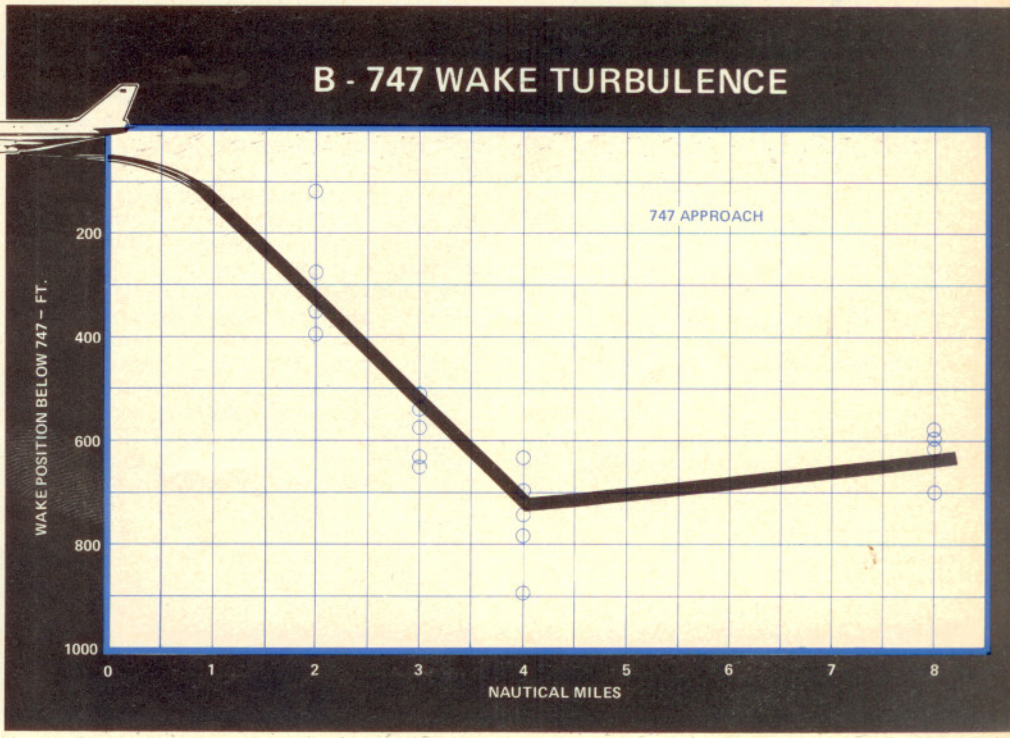
Following are comments offered by Rudolph that were interpreted as updated recommendations for pilots, general aviation pilots in particular, for coping with airborne wake turbulence:

Flight at "lower altitudes"—"As far as the general aviation man is concerned, if he's in the lower altitudes and he encounters one of these heavy generators, I would not want him to fly underneath it at a couple of hundred feet, or even two, three, four, or five hundred feet. I want him to evade it. I don't want him to be flying under the flightpath of the big generator."

Single runway operations—"The worst condition will be with a quartering crosswind of about five knots from either side. These vortices come down and [in a no-wind condition] spread outward at about a five-knot progression. You put a five-knot wind on either of them [wingtip vortices]—it almost cancels its movement out and it will blow right up on that runway and will lie up there. It takes someplace up to 160 seconds for it to clear out."

Intersection takeoffs—"If the heavy generator is taking off and it goes through the intersection without rotation—the nosewheel is still on the ground—there is no vortex, because vortex is only generated when you put lift on the wings. If he goes through the intersection and rotates further down the runway, the only thing you have to concern yourself with is the jet blast of the engines [see chart on these pages]. If he [big jet] rotates *before* reaching that intersection, it will take at least 160 seconds to clear out of there."

Standard takeoffs and landings — "On landing, as long as the pilot stays above, or at least on, the generating aircraft's flightpath—in a no-wind condition—he can follow the same flightpath. He shouldn't land below it, because if he does, he's going to have one whale of a ride, if he doesn't have an accident. In the takeoff phase, the best procedures here have been printed in the AIM, and if these disciplines are not maintained, we're in trouble."



This FAA graph charts the descent and leveling-off process of wingtip vortices created by the B-747. As can be seen, contrary to earlier beliefs, vortices do not continue to descend downward indefinitely. They descend at a rate of about 450–500 f.p.m. for about 700 feet, then level off and remain hanging in the atmosphere to plague other aircraft. The B-747's vortices, complete with high-velocity winds, have been encountered 35 miles back of the jumbo.

The FAA officials reiterated that the big jets' heaviest wakes are generated when they are in a clean, or near-clean, configuration, such as with maximum takeoff weight, takeoff flaps, and full power. Flener stressed that the direction of the wind should now mean more to the average pilot, based on the new wake-turbulence information revealed by the recent tests.

"That wind means more to him now than it did before, because it means that vortices are moving one way or the other," Flener said, referring primarily to takeoff and landing operations. He said good takeoff procedures behind heavy wake generators include a wheels-up position prior to the point where the preceding heavy jet rotated. "Plus, if he's got a good strong wind, move over to the side of the runway that's pertinent [upwind] and take off that way. The same on landing. If he knows that he's got a crosswind and this aircraft lands ahead of him, then move over the edge of the runway in lining up. Get over to that side of the centerline where the vortices are going the other way.

Asked about the crosswind effect aloft, Rudolph replied, "The crosswind aloft moves the vortex if it's in the higher elevations where the environmental conditions—the temperatures of the ground—are not affecting it. [Earlier FAA statements indicated the "higher altitudes" referred to here are those above 5,000 feet a.g.l.—Ed.] The velocity of the wind at 30,000 feet takes the whole system and just moves it out. It literally stays in formation behind the generator until the wind floats it out of the way. And the farther it floats, the better we like it."

On possible FAA recommendations to manufacturers to beef up aircraft structures to withstand the intense winds in the vortices and the resulting excessive roll rates, Rudolph said, "Structural strength doesn't have anything to do with it, basically, because you're talking about wingspan [as being the key factor in being able to withstand the vortices]. You're going to lose control of the airplane if you get tied into one of these things real close-in," he warned general aviation pilots.

Rudolph also provided a description of what happens when two separate sets of wingtip vortices are created by jets making successive takeoffs or landings. "The two vortices don't combine to produce one vortex system of greater intensity," he said. "In fact, if one is stacked on top of the other, the more the better, because the heat and tension from the second one destroys the original one.

"They are humping this thing, remember [full throttle on takeoff], and the vortex starts descending immediately upon leaving the wings, at its rate of about 450 f.p.m. [descent rate varies slightly, based on aircraft weight], and this vortex system will never be found on the generating aircraft's flightpath. So, you can clear lightplanes one right out on top of the other, and those vortices from the heavy generators, lying on top of each other, are just fine with us. They tear each other up."

Flener said the FAA planned to update wake-turbulence information in the AIM to reflect the new knowledge about wingtip-vortex behavior and other details learned from the recent tests involving the B-747 and other aircraft. He helped stress the new importance that should be given this aspect of safe flight operations by announcing that FAA also planned to add specific questions relating to wake turbulence in future tests for receiving pilot certificates. □

When is a 'Boom' A 'Bang'?

■■ Youse pays your money, youse takes your cheerce! Not always.

Ever wonder about the heady and weighty problems resolved by the world's aviation technical experts when they caucus behind closed doors and harness their collective analytical powers?

Consider this:

Is a "boom" the same as a "bang"?

If not, which is best—or most soothing to the public—to describe that bungalow-shaking and window-shattering phenomenon created by aircraft crossing the sound barrier?

These questions must be answered (?). At least world aviation experts initially felt they must. And who are we to question the infinite wisdom of the experts?

The "boom" versus the "bang" controversy surfaced at a recent one-month-long meeting of aviation technical experts from around the world. They came from the world's major urban centers and the outreaches of the air transportation network.

Meeting in Montreal under the auspices of the prestigious International Civil Aviation Organization (ICAO), the experts applied their combined expertise to the "boom" versus the "bang" question. Other world-important questions reportedly also were discussed. Some were even solved.

According to minutes of the meeting, the boom-bang problem was posed first to ICAO's "Sonic Boom Panel." The panel was asked the perplexing question "whether the expression 'sonic boom' or 'sonic bang' should be used to refer to the phenomenon."

During a one-hour-plus serious discussion that followed, it was determined by the experts, according to the minutes, that there are "varied arguments based on the dictionary uses of both 'boom' and 'bang.'" It also was determined that on "*onomatopoeic* grounds," both words should be allowed.

Onomatopoeia prevailed.

Lest readers go scurrying for dictionaries, let it be known that "onomatopoeic" stems from the word "onomatopoeia," which in turns means "the naming of a thing or action by a vocal imitation of the sound associated with it (as *buzz, hiss*)."

Hence, the technical experts' quandary. Is that whatchamacallit noise from cracking the sound barrier a "boom" or a "bang"?

Following the undoubtedly well-ordered thinking processes of the world's aviation experts, nonexperts rightly might ask, "Well, what is a 'boom,' and what is a 'bang'?"

Let's answer these questions before finding out that, of all things, poets and melodious poetry apparently figured in the aviation experts' final determinations.

For aviation's purposes, the ever-helpful Webster says a "boom" is "to make a deep hollow sound." On the other hand, a "bang" is either "a resounding blow" or "a sudden loud noise."

But back to Lord Byron and his cohorts.

As stated previously, ICAO scribes duly noted that the experts, during their deliberations, considered the finding that on "onomatopoeic grounds" either word should be allowed to describe that noise. Webster helps us follow how the experts practice their expertise by informing us that the use of onomatopoeia in poetry is referred to as "onomatopoeic."

After subjecting the problem—Shall we call it a "boom" or a "bang"?—to their collective analysis, the world's aviation experts formally declared there were insufficient arguments for them to recommend "the universal adoption of either boom or bang."

It was unknown whether the avoidance of a clear-cut decision was an attempt to avoid stirring up protests from the world's poets. They might object to the aviation experts' placing restraints on possible future poems dealing with the SST, *Concorde*, and other "sonic boom-bang" creators.

Nor was it known if the nondecision approach was meant as an inducement for the poets to apply their wordsmith talents to the supersonic transport beasts.

It is known, however, that the aviation experts from around the world decided not to stand alone against any possible criticism directed at them for their wishy-washy attitude.

They shared their responsibility for failing to provide a decisive answer by adding a footnote to their formal nondecision declaration. It said, "This is in accordance with the United States' position." What's good for the United States must be good for the world—and its poets.

Rest easy, Byron. The world's most knowledgeable aviation technical experts will not take exception if your successors want to call that whatchamacallit noise a "boom" or a "bang." □