Into Harm's Way

NASA Langley tackles wind shear, a deadly threat to air travel
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A team of NASA scientists tackles a deadly threat to air travel by facing it head on.

by Carl A. Posey

To anyone viewing it from the rain-soaked salad of tracts and farmlands around Orlando, Florida, the airplane must seem to be in trouble. Instead of following the austere paths of most low-flying Boeing 737s—aircraft usually seen at this speed and altitude only when landing or leaving—this one weaves ominously around the countryside below the tops of a trio of strobing 1,600-foot television towers. Now and then it drops to within 800 feet of the ground to charge shafts of rain beneath budding thunderstorms like a tricolor bee attacking lavender flowers. Despite its altitude and erratic behavior, however, NASA 515, its pilots—three of them in all—and its flight deck—both of them—are calm. Indeed, the men and women aboard are looking for trouble, provided it can be found in a tolerable form.

The trouble for which they forage on this August afternoon in 1992 is a sometimes-fatal weather condition known as wind shear. Wind shear is a term that refers to any abrupt change in wind speed and direction. In its deadliest form, the microburst, relatively small downdrafts of cold air—less than 2.5 miles in diameter—explode toward the ground from the rising cloud towers. Like inverted mushroom clouds, these invisible cataracts break against the ground and spray out horizontally, producing winds that flow away in all directions (see “The Might of the Microburst,” August/September 1986).

Microbursts and their shearing winds can be a rough surprise for pilots, especially during takeoff and landing, when the airplane is flying low and slow. The problem is not really the amount of wind, although downdrafts often have muscle. The danger lies in the element of surprise, the sudden swipe by something you can’t see.

An airplane flying into one side of a microburst’s descending current first encounters a strong wind blowing toward it—a headwind—which causes a sudden increase in airspeed, the speed of air moving past the airplane. Unaware of the danger ahead, a pilot might respond by reducing power. By then, however, the craft will have crossed to the far side of the downdraft, where the wind blows from behind it—a tailwind—causing a sudden drop in airspeed. An attempt by the pilot to add power may come too late to push the airplane out of harm’s way.

As H.G. Wells pointed out more than a century ago, however, being invisible is not the same as being undetectable. Dogs could smell Wells’ invisible man, his moist breath visibly condensed in cold air, he became a ghostly envelope of droplets in the rain, and his invisible feet left footprints in snow. Likewise, microbursts, in the view of the scientists flying aboard NASA 515, can be seen indirectly through different windows in the electromagnetic spectrum.

They are proving it in this second and final summer of stalking the invisible man of the atmosphere, and learning how to spoil his ability to surprise.

Dick Yenni, a fit, compact man in his 50s, is pilot in command: copilot Michael Phillips sits to his right. The pair flies a strenuous several hours almost every day, but the most taxing part may be the intervals when they are merely lookouts and the airplane is controlled from its second cockpit. There, Lee Person, a former Marine fighter jock who has spent much of his career gleefully flying blind for NASA, sits in the left seat of a molded fiberglass 737 nose and windscreen that, like a ship in a bottle, has been created inside the fuselage of NASA 515.

Airborne, the research cockpit is eerily out of touch with the real world. Its only visual clue to external reality is a small color monitor fed by a video camera in the nose. On Person’s right sits Michael Lewis, the 30-year-old engineer and deputy project manager who links the airplane to the science. Behind him sits Roland Bowles, the soft-spoken Virginian leading the project. They and seven dozen colleagues are in Orlando under the auspices of the Federal Aviation Administration and NASA’s Langley Research Center in Hampton, Virginia, where they are based.

The $20 million-plus FAA/NASA Airborne Windshear Sensor Program started in 1986 following a series of dramatic and deadly accidents for which wind shear was to blame. On June 24,

The storm looming before NASA’s research 737 looks ominous, but the biggest danger the aircraft routinely faced was an invisible one: wind shear.
1975, an Eastern Airlines 727 crashed at Kennedy airport in New York, killing 113 of 124 aboard. Another 727, Pan Am's flight 759, crashed at New Orleans on July 9, 1982, killing all 145 passengers and eight people on the ground. And on August 2, 1985, Delta flight 191, a Lockheed L-1011, landed short at Dallas-Fort Worth, killing 134 of the 163 people aboard, along with the occupant of a vehicle on the ground.

In response to these accidents, the FAA launched a multi-pronged attack on wind shear, including the development of a pilot training program and a ground-based system, Terminal Doppler Weather Radar, capable of detecting the phenomenon.

The TDWR produces a very complex, very smart display, but it also has a down side. The radar can look at only one place at a time, and, because it scans a wide area, its wind shear measurements are updated only once a minute. Sometimes the delay between displays exceeds the time for the quick, lethal growth of a microburst over the field; sometimes the radar's vantage point is not the best for any of the runways. Even if the TDWR could see everything all the time and its readout was piped directly into the cockpits, it would still not be enough: of the 800 or so airports in the continental United States handling commercial traffic, only 47 are slated to receive a TDWR.

Accordingly, the agency moved to improve the instrumentation on the flight deck as well as on the ground, directing that commercial aircraft carry one of two types of wind shear detection devices: either, by the end of 1993, a "reactive" device that detects wind shear once an airplane has entered it or, by the end of 1995, a device that provides 20 to 40 seconds' advance warning of wind shear. The FAA turned to Langley for the development and testing of these "forward looking" sensors.

As it happened, Langley had just the cockpit for such a project. Years earlier NASA had acquired the prototype of the Boeing 737, which first flew on April 9, 1967. Rescued from the scrap heap by Boeing and NASA, it was rebuilt into a flying laboratory, complete with double cockpits, to test instrumentation then being developed for the supersonic transport. The refurbished 737 moved to Langley in 1974 and, like all government machinery, was given a numbing acronym: TSRV, for Transport Systems Research Vehicle.

What the wind shear team installed in the 737's aft cockpit is on Mike Lewis' side of the instrument panel. A single compact computer display shows a col-

**Seeing the Winds**

The research aircraft's Doppler radar and lidar (for "light detection and ranging") sensors for detecting wind shear operate similarly. Each transmits pulses of energy at a single frequency: radio waves with radar, light waves with lidar. When the pulses are reflected off raindrops or aerosols, respectively, in winds ahead of the aircraft, their frequencies change, revealing the wind's movement.

-transmitted pulses

higher frequency indicates headwinds

lower frequency indicates tailwinds
Following wind shear alerts, the airplane flew directly into the danger zones. Most of the flying was done blind from a research cockpit in the 737's first class section (left). For wind shear penetrations, control returned to the true cockpit (right).

A marvelous boon to pilots about to fly into invisible trouble. A third instrument—a passive infrared sensor—peers through a third window. The sensor can be used to infer from thermal data the presence of a downdraft—cold air falls—and at some threshold of threat set off a cockpit warning light. Viewed by this trio of sensors, the invisible man of the atmosphere becomes a naked little guy 20 to 40 seconds ahead of the airplane—at least that is the hope of NASA's wind shear team.

The onboard system takes the display one step further: combining such factors as performance, airspeed, attitude, and altitude with the measured wind shear conditions, the computer comes up with what Langley people call the F-factor, an index of the degree of hazard ahead. In fact, the F-factor indicates what the wind shear will do to the airplane's rate of climb—that is, its ability to climb out of trouble. The threshold of hazard, an F of 0.105, represents a situation in which a pilot can expect to have 1,500 feet per minute sliced off his airplane's rate of climb for about 15 seconds. At that F-factor, the computer display flashes a bold "ALERT." The higher the F-factor, the greater the hazard. "If you give crews the right information," says Roland Bowles, who developed the algorithm for the hazard index, "they do the right thing with it." For NASA 515, the right thing is to fly into the indicated shear zone so that other sensors can probe what the radar, lidar, and infrared indicate they see.

Following weather alerts from a prototype Terminal Doppler Weather Radar at Orlando International Airport, Lee Person and Mike Lewis set up the approaches to areas of suspected wind shear, usually at about 240 mph—much faster than typical approach speeds, for a margin of safety—and some 800 feet above the ground. Up front, Dick Yenni and Mike Phillips watch, sometimes nervously.

For penetrations, control goes back to Yenni in the front cockpit. "If the rain shaft doesn't look right, we won't go into it," he says. "A transparent rain shaft is fine. We don't like to go into solid walls." He grins. "We started out with such constraints that we couldn't get any data." That has changed, but Yenni's caution has not. "We've called it off twice now, to the dismay of some of the researchers. But an hour or two later we're friends again."

It would be remarkable if they were not. The platoon of pilots, scientists, technicians, and ground crew who have come to Orlando this summer following an earlier deployment in Denver share the easy camaraderie of people working hard for a worthy cause. From the day's first flight briefing, which comes at half past noon, through the status updates that often go far into the afternoon, the calm crowd lifts its collective head for announcements, then
returns to a running whist tournament, or airplane talk, or sleep. The lidar people murmur earnestly about their instrument, as do the radar team and the infrareds. One young couple shares a table with a dozen long-stemmed red roses. They were married a year ago, after meeting on the project.

Back then, the spirit in the briefing trailer mustn't have been quite so tranquil. A few weeks in Denver in 1991 netted zero alerts, and another series of flights in Orlando the same year gave them only two—a fallow, depressing deployment. This year has been many times better. They had seven alerts in Denver, and lidar revealed wind shear in clear air. The unstable skies around Orlando have been generous as well. By the time the team’s current final deployment is driven north by the approach of Hurricane Andrew on August 24, they have 13 flights, 35 penetrations of moderate to strong wind shear, and 10 alerts. “We have a mountain of data, magnificent data,” Bowles says. “We think we can put the problem behind us. Now it’s a matter of letting the marketplace take this technology and make it.”

On this August afternoon, Bowles, who says he has been with NASA “forever,” seems a happy man. Waiting for the day’s flight—one that will garner only two ambiguous alerts—he reminisces about the old days at the agency, when everything they touched seemed fresh and challenging. Solving the wind shear problem, if that is what the Langley team has done here, may be, in its economical way, like finding a way to the moon.

Even in the chancy province of the marketplace, auguries are good. Of the three sensors tested, the Doppler radar showed the most immediate promise, and three manufacturers who worked closely with the FAA and NASA throughout the project are currently in the process of applying for FAA certification for radar sensors they’ve developed. The first will probably be certified and available for commercial use by this October, the others by next winter or spring. The lidar, developed by Lockheed’s Missiles & Space Company, is still considered something of a work in progress, but the company plans to continue development with flight test help from FAA and NASA. Infrared, despite a good deal of flight experience, is not yet that far along, but it is still being pursued.

As for how these devices will alter commercial aviation, no one can say for sure. Perhaps a clue lies in an event that occurred in the first week of the Langley team’s Orlando deployment, when thunderstorms stalled commercial aviation from New York to Miami. As NASA 515 trundled out for takeoff, 17 airliners were bunched up awaiting clearance on a parallel runway. A few miles out, the sky was purple, filled with winds no one could see—well, no one but the people on NASA 515. The NASA jet was quickly cleared and took off, looking for trouble. Queried by the restless pilots queued up on the ground, to whom the winds had not yet been revealed, Dick Yenni called back to say that the way was smooth. One day soon, they will not need to ask.

Laser beams point to two of the aircraft’s wind shear sensors, the infrared and, below, the lidar. A third, the Doppler radar in the aircraft’s nose, has proven the most successful and will soon be used in commercial airliners.