Clearing the Air About Turbulence

A fearful flier's foray

By RON COWEN

It's an embarrassing confession: I'm a space science reporter, but I'm afraid to fly.

It's not the takeoffs. It's not the landings. It's that eternity in between, when the jumbo jet is cruising 30,000 feet above solid ground. Each time the seat belt sign comes on, my heart starts racing and my stomach begins doing flips.

I dread even the hint of turbulence.

Despite my fears, I have to admit I've been lucky—at least until April 16, when I boarded United Airlines Flight 925 from London to Washington, D.C. As usual, I asked to meet the pilots. While we shook hands, the captain, a man named Dan, assured me there would be only "a bit of weather" as we neared the U.S. coast—and even that promised to be minor.

The first part of the trip was indeed smooth. When the sign telling passengers to fasten their seat belts came on 6 hours into the flight, there was nary a cloud in the sky, and I had no more than my usual anxiety. Then the plane began shaking violently. Pilot Dan ordered the flight attendants to their seats.

Up and down, up and down. A few moments of calm and then trapped once more in a plummeting elevator. A rattled stewardess yelled a warning to watch out for objects flying through the air. I gripped my wife's fingers tightly in one hand and my sister-in-law's hand across the aisle in the other. My eyes were shut, waiting for the roller coaster ride to end. Or for the plane to crash.

Then, after a few last tremors, the turbulence was over. A food cart had tumbled on its side, and the dinner—not that anyone was hungry—was in ruins. In a shaky voice, the stewardess announced that the last few minutes had been the worst turbulence she had experienced in 20 years of flying.

Strapped tightly in my seat, I prayed we would land without another encounter.

Aviation experts define turbulence as random, unpredictable motion that occurs at the boundary between layers of air moving at different speeds. Just as the smooth flow of an ocean wave breaks up into a maelstrom of swirls and eddies when it crashes on the shore, uniformly moving layers of the atmosphere that brush against each other fragment into vortices, and other small-scale disturbances.

NASA

Flying over mountain ridges in Colorado, researchers are testing an experimental laser system designed to detect turbulence in clear air and provide advance warning.

Turbulence is often triggered when energy released by the sun-warmed ground or by a group of forming clouds heats a parcel of air at low altitude. The heated parcel rises, distorting the wind-flow pattern at higher altitudes and generating chaotic motion.

Although rarely powerful enough to toss a 747 around, turbulence is essentially "a natural state of the atmosphere," says Larry Cornman of the National Center for Atmospheric Research (NCAR) in Boulder, Colo. In a thick fluid like molasses, friction between molecules smoothes out differences in motion and allows only broad, sluggish movements. In contrast, air molecules have very little friction between them. Thus, when parcels of air at different speeds encounter each other, they're more likely to break up into turbulent, unpredictable patterns, he notes.

According to the Federal Aviation Administration (FAA), turbulence is the leading cause of nonfatal accidents to airline passengers and flight attendants, costing commercial airlines in the United States an estimated $100 million a year. From 1981 to 1996, the major air carriers reported 252 incidents of turbulence, resulting in 2 deaths, 63 serious injuries, and 863 minor injuries. Seat belts help avoid accidents: Both fatalities and 61 of the 63 passengers who were seriously injured were not wearing them. Last December, turbulence caused a Boeing 747 en route from Japan to Hawaii to plummet 100 feet. An unbelted passenger died after her head hit the ceiling. More than 100 others were injured.

Pilots and meteorologists don't always know when turbulence will strike, so buckling up only when the seat belt sign comes on isn't a reliable way to avoid injury. Storm clouds and heavy rain are good indicators that turbulence lies ahead, but about half of all passenger aircraft encounters with choppy air occur in cloudless skies, says Cornman. "There may not be a cloud around for 500 miles, yet a plane gets bounced around," says Kenneth Leonard of the FAA in Washington, D.C.

This kind of clear air turbulence is common above mountains. When an air mass slams into a mountain, it's forced upward. This parcel of air, denser than the surrounding air at that altitude, subsequently sinks back down to below its original height. The oscillations generated as the parcel continues to rise and fall create what's known as mountain-induced, or terrain-induced, turbulence.

"It takes a while for such a disturbance to settle out, and the [air] could be fairly turbulent downstream of the mountain," says Rodney Bogue of NASA's Dryden Flight Research Center in Edwards, Calif. The effects of mountain-induced turbulence may be felt more than 20,000 feet above a 12,000-foot range, he adds.

The jet stream, a broad ribbon of high-speed air moving from west to east at altitudes of 30,000 to 45,000 feet, also drives clear air turbulence. A craft entirely immersed in the jet stream moves at a steady, uniform rate. Indeed, eastbound planes often fly in the jet stream to take advantage of the wind pushing them along. At the boundaries of the stream, however, where it moves over slower air, wind shear can generate severe turbulence. In winter, when the stream lies at


B. Martner

Produced by the strong winds circulating around Alaska's Mt. McKinley, this cloud creates atmospheric disturbances that may generate severe turbulence.

lower altitudes and latitudes, such turbulence is more common, Cornman notes.

Complicating matters, the distinction between clear air turbulence and convective turbulence, in which storm clouds play a major role, is not always clear-cut, notes Cornman. Unsettled weather can create convective turbulence 20 miles away, in regions where clouds may be few and far between.

Convective turbulence is more prevalent during spring and summer, when storms over North America are more frequent, he adds. Radar systems, which bounce radio waves off raindrops, ice, and snow as many as 60 miles ahead of a craft, can warn pilots of suspicious weather patterns 10 minutes in advance.

Researchers are investigating whether radar could detect convective turbulence more directly by tracking the motion of rain or ice particles entrained in a turbulent region. "This would be a new use for [on-board] radar," says Leonard.

First, notes meteorologist David Pace of General Sciences Corp. in Laurel, Md., "we have to determine exactly what the signature of different types of turbulence looks like." He notes, for example, that if ice or rain particles are moving at wildly different speeds and directions—an indicator of turbulence—the frequency of the reflected radio wave will shift to higher or lower values, resulting in a wider spread in the frequencies of the reflected spectra.

"If we can develop an algorithm that will help us determine where turbulence is or where it might develop, based on something reflecting off the radar beam, that would improve both detection and forecast of turbulence," says Leonard.

Detecting clear air turbulence poses a greater challenge, notes Cornman. Radio waves can only sense relatively large particles, such as rain or frozen water. In clear air, where no such particles exist, radar cannot detect turbulence.

To help accomplish that feat, researchers have developed a laser system that shoots a beam of infrared light into the craft's flight path. Tiny dust particles, volcanic ash, and other natural aerosols, many less than a micrometer in diameter, reflect the laser light back to its source. If these particles happen to be entrained by turbulence, their swirling motion changes the frequency of the reflected light.

Scientists tested a laser device in the mountain ridges of Colorado in late March and early April. During 15 hours of flying, light and moderate turbulence were detected 3 to 4 miles ahead of a research aircraft. "The system measured the turbulence, and then we felt the buffeting motion as we flew into it," says Bogue.

He adds that tests of the system on commercial aircraft may begin within 3 years. Developed by Coherent Technologies of Lafayette, Colo., in conjunction with NASA, the laser system may provide adequate warnings on passenger craft in 5 to 7 years.

Another detection strategy relies on the premise—as yet unproved—that turbulence produces traveling sound waves that can be detected by a craft miles away from the choppy air. This early warning system employs low-powered laser light that travels just a short distance, over a set path, before being reflected back to its source. The speed of the laser light, and hence its travel time, may vary with changes in atmospheric pressure induced by the sound waves.

"Sound waves generated by turbulence propagate through the atmosphere and have unique characteristics that we can detect, classify, localize, and track," asserts Sam Kovat, chief executive officer of Flight Safety Technologies, a New London, Conn., company that designed the experimental laser system.

At Kennedy International Airport last month, scientists tested a two-laser, ground-based version of the system known as Socrates. It will take 3 to 5 years to perfect a ground system capable of detecting turbulence 100 miles away, says Kovat, and several more years before a system can be tested in the cockpit. Cornman cautions that if turbulence does generate sound waves, a supposition that is by no means certain, the waves may be too weak to be detected 100 miles from where they were created.

Mountains loom above Alaska's Juneau airport, severely limiting departure routes and creating complex wind patterns. To take off safely, pilots typically have to execute a hairpin turn as the craft gains altitude. "It's one of the few airports where the pilots have to brief the passengers that they're going to be making a sharp 30° bank to the left and a sharp 30° bank to the right and then turn around," says Leonard.

Depending on the direction and speed of the prevailing winds, some turbulence is almost inevitable, he adds. Even veteran flier Cornman got sick to his stomach when his research craft flew in and out of the choppy air above Juneau for 2 hours.

To reduce the risk of accidents at the airport, the FAA and NCAR are attempting to develop a detection and early warning system. To measure wind speed more accurately, Cornman and Robert Barron of NCAR have set up a trio of ground-based devices known as Doppler wind profilers. These instruments gauge wind speed and turbulence, in 180-foot increments, from the ground to altitudes as high as 1.5 miles.

Scientists at Juneau are also examining a set of radar devices, normally used to detect turbulence at low altitudes in the presence of rain or snow, to test whether these instruments can also detect turbulence at higher altitudes. In addition, the team is testing a laser system to search for turbulence in clear air.

Cornman and other scientists are also working to improve long- and short-range forecasting of turbulence. To that end, they plan over the next few years to install devices on several hundred passenger planes that will automatically record and relay the severity of an encounter with turbulence. Rather than rely on subjective reports from the pilot, which may not be made until many minutes after the event, researchers will have immediate, precise data. The information will also warn other pilots of turbulent conditions and be used to refine forecast models.

At the same time, NCAR scientists are developing a fuzzy logic forecast system in which selected turbulence-related parameters are fed into a computer model. Data that work best to help predict mountain-induced turbulence, for example, will be restricted to forecasting choppy air under those conditions and might be ignored in calculating storm-related disturbances. Cornman hopes to have a version of the new model in widespread use by next winter.

"It's not hard to do a better job than what's out there," he says.

Turbulence may be scary, but encounters at cruising altitudes rarely cause serious injuries. The atmosphere provides a relatively stable platform for aircraft, says Cornman. "If you're at high altitude, there's very low probability of crashing. It would take an incredible amount of force to turn [a plane] over or put it out of control. The craft may go up and down like crazy; it does feel unstable, but if you look at the average motion, it's still zero.

"There's a continuum of turbulence encounters, from little bumps to pretty good bounces to very severe motion, where people get thrown to the ceiling, but most [encounters] are moderate," assures Cornman.

At considerably lower altitudes—below 1,000 feet—the probability that turbulence would affect the plane "to the extent that you lose control is a lot greater. There's less room to recover, and you're typically going slower at a lower altitude, so there's less lift," says Cornman.

Turbulence and wind shear at the lowest altitudes—during takeoff and landing—are much more dangerous than anything you encounter at cruising height, adds Cornman.

Oh, no. Takeoffs and landings. Something new to worry about. □

Earth Science

Seabed seismic scan shows melt zone

Most of the Earth's crust forms when partially molten rock oozes from the planet's interior, emerging at mid-ocean ridges where the sea floor is spreading. This internal process has been largely hidden from the eyes of researchers. Using seismic sensors, however, scientists now have produced detailed images of magma under an ocean ridge.

Results of the Mantle Electromagnetic and Tomography Experiment, reported in the May 22 SCIENCE, offer the first evidence that molten rock, called melt, occupies a wider and deeper area under the East Pacific Ridge than some researchers had predicted.

The seismic readings, together with data from electromagnetic sensors, will help researchers develop new models of how seabed crust forms, says Donald W. Forsyth, a geologist at Brown University in Providence, R.I. He coordinated the imaging project, one of the largest marine geophysical studies.

Researchers from seven institutions deployed 51 seismic monitors on the ocean floor traversing the East Pacific Ridge about 4,000 kilometers west of South America. For six months ending in May 1996, the detectors recorded waves from a series of earthquakes around the world. The waves tended to slow down as they passed through regions of melt, which is less dense than surrounding rock. This allowed scientists to map the melt, the seismic equivalent of medicine's CAT scan.

The imaging results suggest the melt area is as much as 600 km wide, at least 170 km deep, and skewed to the west of the ridge. The finding contrasts with theories that predicted the melt was located either in a broad but shallow horizontal plane or in a thin, vertical plane falling directly beneath the ridge. Some researchers have suggested that melt might rise from deep in the earth's mantle, but the findings tend not to support that view, Forsyth says. *—J.B.*

An ever taller Everest?

A team of American climbers last month launched an effort to measure whether the world's tallest mountain is growing higher and, if so, at what rate. Wally Berg of Copper Mountain, Colo., successfully planted a Global Positioning System (GPS) receiver within about 60 feet of Everest's summit. It recorded altitude data for 5 days until another climber retrieved it. Climbers will take a second measurement from the same spot, where Berg screwed in a metal plate, in a few years.

Using GPS measurements from other locations and conventional surveying methods, researchers have estimated that Everest is rising an average of 1 to 2 inches per year, pushed up by the collision of India's continental plate with Asia's. However, erosion of the summit may ensure that record books need not be revised, says Charles Corfield of Palo Alto, Calif., science officer for the American climbing team.

The most widely accepted estimate of Everest's height, 29,028 feet, is inexact because of the limits of traditional surveying techniques. Previous GPS readings from the summit were imprecise because the rocky peak is covered by a snowcap of unknown depth that grows and shrinks over the year.

The new data recorded near the summit are the most accurate to date because Berg activated the receiver at a rocky outcrop not covered by snow. In addition, the data were cross-checked against GPS readings at nearby, lower elevations, Corfield says.

Because they can indicate the buildup of seismic stress, the readings may help researchers predict the next earthquake in the Himalayas.

The climbing team that planted the receiver is affiliated with Bradford Washburn, a noted Himalayan cartographer and founding director of the Boston Museum of Science. *—J.B.*