Nasty Surprise

BY ED BROTAK

Pulse thunderstorms produce dangerous wind shear conditions.

The July 2, 1994, crash of USAir Flight 1016, a McDonnell Douglas DC-9-31 at the airport at Charlotte, North Carolina, U.S., is well documented.[1] The U.S. National Transportation Safety Board found that mistakes by the flight crew and by air traffic controllers in the airport tower contributed to the accident that killed 37 of the 57 people in the airplane. At the heart of the problem, though, was the weather. Strong wind shear induced by a thunderstorm at the airport caused the pilots to lose control of the airplane during a go-around.

By the time of this accident, the threat of wind shear associated with thunderstorm downdrafts was well known and was being addressed by wind shear sensors and Doppler radar. However, the thunderstorm in this case represented a type of storm that still presents great risks to

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aviation — a "pulse storm" that can develop quickly, without warning. It may appear benign, but suddenly can produce the type of extreme weather conditions more commonly associated with classic severe storms.

So, how is a pulse storm different? First, there are three types of thunderstorms: single-cell, multi-cell and supercell. "Cell" in this case refers to the central updraft of the storm.

Supercells are the monster thunderstorms most common in the Great Plains of the United States in the late spring. These storms always produce some type of severe weather — that is, large hail or strong straight-line winds — and are the major tornado-makers. They have a single, tilted, very powerful updraft that rotates and can last for hours.

Multi-cell storms are the most common thunderstorms. They have multiple updrafts in various stages of development. They can occur singly or with other storms in various formations such as squall lines. Although they can produce severe weather, that is much less likely than with supercells.

Single-cell storms have one vertical updraft that tends to dissipate fairly quickly. They rarely produce severe weather. These types of storms are common to the U.S. and in parts of Australia, South America, Asia and central Europe, any place with warm, moist air. Pulse storms are a subset of this category.

As the name suggests, the storm develops and then dissipates, sort of a "pulse" of energy. Although some references classify all single-cell storms as pulse storms, the U.S. National Weather Service (NWS) defines the pulse storm as the rare single-cell storm that produces severe weather. Although pulse storms seldom produce tornadoes, they can generate large hail and, most commonly, strong winds.

One of the reasons pulse storms are difficult to anticipate is that they develop in what appears to be a benign environment, not one that seemingly could support a severe storm. There are basically two situations in which thunderstorms develop — what meteorologists call "free" or "forced" convection.

Free convection produces the classic air mass thunderstorm that develops solely due to heating by solar radiation. Air mass thunderstorms are most numerous during and just after the warmest part of the day. In terms of the synoptic weather situation, nothing much is going on. These storms develop usually on the west side of a high pressure area away from any fronts or low pressure areas; the upper-level jet stream is not involved. They are most common in the summer.

Forced convection is synoptically forced; in other words, there are additional sources of lifting other than just local diurnal heating. Fronts, low pressure areas and the jet stream can be involved. They can develop at any time of the day and are most common in the spring. These storms have a much higher probability of becoming severe.

Pulse storms develop under "unforced" conditions. They are the rare severe storms unrelated to significant weather features.

Looking at the vertical structure of the atmosphere, the environment again belies the actual threat. In most severe storm situations, there are notable winds at least in the lower part of the atmosphere. Often, the winds veer with height. There is some pre-existing wind shear in the atmosphere. For pilots, it is this wind shear aloft which can be brought down and concentrated in a thunderstorm downdraft and produce wind problems near the ground. This is not the case with pulse storms. There are no significant winds aloft. The winds are generated within the storm itself. This poses a major problem in forecasting them.

Another problem with pulse storms is that they can develop very rapidly and produce severe weather not long after inception. The life cycle of a pulse storm was first depicted in 1949 as a result of the Thunderstorm Project, a research effort conducted by the U.S. Weather Bureau, as it was then called. In fact, this model of storm development is often referred to as the Byers/Braham Model, in honor of the two lead meteorologists of the project.

A pulse storm has three life stages (Figure 1, p. 14). The developing stage features a vertical updraft and a developing cumulus cloud, with no precipitation or wind at the surface. Precipitation-size water droplets develop, but they initially are held high in the cloud by the force of the updraft. Eventually, the weight of the precipitation becomes too much to suspend and it begins to fall. Some air is dragged along, producing a downdraft. Since the precipitation and sinking air are falling straight back through the updraft, the updraft begins to weaken. This is the mature stage of the storm, when there is both an updraft and a downdraft. The precipitation and the downdraft reach the surface. This is when strong winds can occur near the ground. The final, dissipating stage occurs when the updraft has been eliminated. A dissipating cloud with weakly sinking air is all that is left, with only light rain possible at the surface. From start to end, the complete process can take as little as 30 minutes.

Eventually, the weight of the precipitation becomes too much to suspend and it begins to fall.

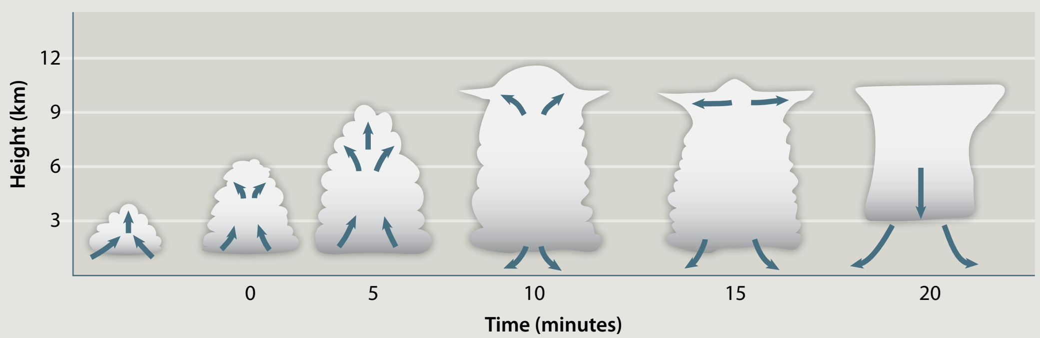
As is typical with pulse storms and other severe-weather-making thunderstorms, the highest probability of severe weather (strong winds) does not occur at the time of maximum intensity (maximum updraft strength), but somewhat afterwards. You need significant descending motions in the storm to transport the energy down toward the surface.

The difference between a pulse storm and a non-severe single-cell thunderstorm has to do initially with the strengths of the updraft and the downdraft. Pulse storms develop in a more unstable environment and have stronger updrafts. These stronger updrafts are capable of holding precipitation aloft longer. On radar displays, this "core" of the storm is higher and more reflective than in non-severe storms. But once this core begins to descend, it comes down in a rush, producing abnormally strong downdrafts. These can be classified as "downbursts" or even stronger and more concentrated "microbursts," as was the case with the USAir crash.

The situation that developed on July 2, 1994, in North Carolina illustrates the problems that are presented by a pulse storm. On the morning weather map, nothing significant was going on. The nearest front was hundreds of miles away in the Ohio Valley. The weak jet stream was well to the north. Just a warm, moist air mass was in place over the Southeast. Morning soundings showed an unstable environment but with only weak winds aloft. Nothing indicated the possibility of severe weather. It seemed like a typical summer day.

In the afternoon, showers and thunderstorms began to develop because of daytime heating. The NWS WSR-88D weather radar at Columbia, South Carolina, 77 nm (143 km) to the south of the crash scene, had a clear view of the Charlotte Douglas International Airport. At 1823 local time the radar showed a weak but growing cell near the airport. The storm's estimated top was 20,000 to 25,000 ft. By 1829, it showed as a strong low-level echo, a VIP Level 3.[2] The mid-level reflectivity was even stronger, indicating a probable thunderstorm at VIP Level 5. The top was estimated at 25,000 to 30,000 ft. By 1835, 12 minutes after first detection, the cell had maxed out — top near 30,000 ft, VIP Level 5. Indications were that the storm would shortly enter the dissipating stage, the stage when downdrafts are most likely with this type of cell.

Life Cycle of a Pulse Storm



Source: Burgess, D.W. and L.R. Lemon, 1990, "Severe Thunderstorm Detection by Radar," *Radar in Meteorology* (D. Atlas, ed.), American Meteorological Society, 619–647.

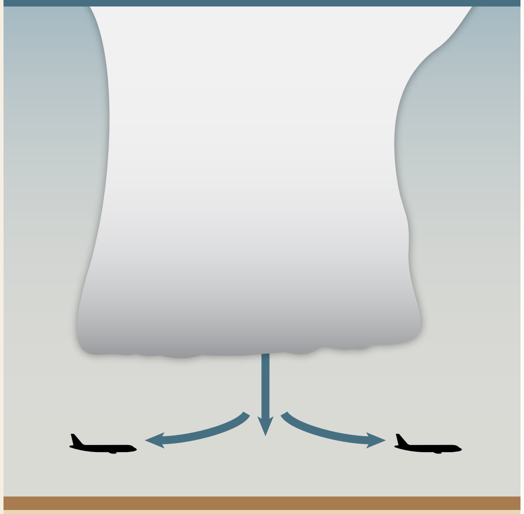
Figure 1

At 1841, two minutes before the accident, the highest radar returns were features descending through the cloud, indicating the collapse of the updraft and acceleration of the downdraft. By 1847, the cell had continued to decrease in intensity. The NWS meteorologist who testified at the public hearing saw nothing noteworthy about the storm on radar. There was nothing indicating severe weather potential. It appeared to be a typical summer thunderstorm.

The problems associated with flying through a strong thunderstorm downdraft are shown in Figure 2. As the downdraft hits the earth's surface, it spreads out in all directions. An airplane approaching this outflow first encounters strong head winds. In the case of Flight 1016, these winds were measured at 39 kt. The extra airflow over the wings increased lift and the pilots had to compensate for this. As the plane crossed through the center of the downburst, the wind quickly reversed to a tail wind. For Flight 1016, the sudden tail wind was 26 kt, giving a wind shear of more than 60 kt in a period of 15 seconds. The loss of airflow over the wing in this sort of encounter reduces lift and the plane descends unless quick adjustments are made by the pilot. Of course, wind shear near the surface most dangerously affects airplanes during takeoff or landing.

Pulse storms cannot be forecast. The best that meteorologists can do is to say whether the atmosphere is conducive to pulse storm development. When looking at current and forecast soundings, they look for signs of enhanced instability but with light winds aloft. Unstable values of the standard Lifted and Showalter Indexes[3] and high values of the more recently developed CAPE[4] would be good indicators. However, parameters that are usually helpful in forecasting severe weather, such as the SWEAT Index[5] and the helicity,[6] would be uncharacteristically small in these low-wind environments. Even in the afternoon, when it is apparent that convection will be initiated, it is difficult to pinpoint where pulse storms will develop. Minor perturbations in the environment such as weak convergence at low levels may trigger the storms. Such occurrences may be unobservable in real time and may make storm formation appear random. After the storm has developed, it is still difficult to determine its wind potential. Advanced radar analysis schemes may help with this. For the time being, early detection of the wind shear generated by pulse storms and a quick relay of this information to pilots are our best methods of preventing serious flight problems.

Thunderstorm Downdraft Affecting Flight Conditions



Source: Ed Brotak

Figure 2

Notes

1. NTSB. Accident report AAR-9503, *Flight into Terrain During Missed Approach, USAir 1016, DC-9-31, N954VJ, Charlotte/Douglas International Airport, Charlotte, North Carolina, July 2, 1994.*
2. VIP, or video integrator and processor, is a method of rating the strength of the radar return on a scale of 1–5, with 5 being the strongest return.
3. Lifted and Showalter Indexes, developed prior to computer technology, used a sounding as the basis of a quantitative thunderstorm forecast. The actual values are the differences in temperature inside a cloud and outside at 500 millibars (mb), or 18,500 ft. Negative values indicate instability and possible thunderstorms, even severe storms for values -4 and under. The difference between the two indexes is that Showalter uses 850 mb (about 5,000 ft) as the starting level; the Lifted Index can be calculated from any level, usually the layer closest to the surface.
4. CAPE, or convective available potential energy, is a measure of buoyancy that is related to the strength of the thunderstorm updraft and overall storm strength.
5. SWEAT, or severe weather threat index, is an index developed to quantify the potential for severe thunderstorms; it incorporates thermodynamics and kinematics (winds).
6. Helicity is a math term derived to represent the low-level wind shear and the tendency for a thunderstorm updraft to rotate; rotation of the updraft is key to severe weather formation.