

Gravity

Nearly impossible to predict and difficult to detect, this weather phenomenon presents a hidden risk, especially close to the ground.

Gregory Bean, an experienced pilot and flight instructor, says he wasn't expecting any problems while preparing for his flight from Burlington, Vermont, to Plattsburgh, New York, U.S. His Piper Seneca checked out fine. The weather that April evening seemed benign. While waiting for clearance, he was taken aback by a report of winds gusting to 35 kt from 140 degrees. The air traffic controller commented on rapid changes in pressure he was observing. He said the

National Weather Service observer referred to this as a "gravity wave." Neither the controller nor Bean knew what the weather observer was talking about.

Deciding he could deal with the wind, Bean was cleared for takeoff. The takeoff and initial climb were normal but he soon encountered turbulence "as rough as I have ever encountered." He wanted to climb to 2,600 ft. With the vertical speed indicator (VSI) "pegged," he shot up to 3,600 ft. Finally controlling the airplane, Bean opted to turn

around and land back at Burlington. The wind had now swung around to 270 degrees at 25 kt. At this point, he recalled, his rate of descent became "alarming." The VSI now pegged at the bottom of the scale. Despite the control difficulty, he landed the aircraft without further incident. Bean may not have known what a gravity wave was, but he now knew what it could do to an airplane.¹

Gravity waves are just waves as most people normally think of them.

Waves

BY ED BROTAK

Mountain waves can produce lenticular clouds.

Waves in the ocean are technically gravity waves, for example. The “gravity” part of the term probably confuses the meaning outside the field of meteorology. Gravity is only one of the forces that affect waves. Getting a little into the science here, gravity waves are *physically* induced waves, as opposed to *thermally* induced waves. Thermally induced waves are the result of temperature and density contrasts. Most standard weather systems both at the surface and aloft are thermally induced

waves. Some oceanic circulations would also fall into this category.

A gravity wave is the result of a physical disturbance in an otherwise flat fluid flow. You can see waves in water because the water itself is visible. You can’t directly see waves in air because air is invisible. A simple way of visualizing gravity waves, however, is to think of what happens when you throw a rock in a pond. Waves move out in all directions from the disturbance. The same thing happens in the atmosphere.

Various disturbances produce gravity waves in the atmosphere.

How do gravity waves form? To start, air must be physically forced up, forming the crest of a wave. If the environment is stable, this displaced air will tend to come back down to its starting or equilibrium point. A stable atmosphere is usually one in which a cooler layer of air sits under a warmer layer. The displaced air will start to sink and gain downward momentum. Due to the momentum, the air will sink below its

starting elevation. This forms the trough of the wave. But thermodynamic forces — or buoyancy — will make the air rise again toward its original level. If it overshoots again, this time on the upside, another wave crest is formed. Usually numerous waves in a set, an undulating “wave train,” will be formed.

For pilots, the best-known atmospheric gravity waves are the mountain and lee waves formed when winds blow across mountainous terrain. The horizontal vortex, or rotor, which can form immediately on the lee side is associated with extreme turbulence. These rotors are a threat to even large aircraft, and numerous accidents have been associated with them. Often these waves are indicated by specific cloud formations such as lenticular or rotor clouds. If the air is drier, the danger zone may not be clearly visible. However, these waves tend to be stationary or propagate downstream with the wind. Thus, they normally can be avoided.

What is usually referred to in meteorology as a “gravity wave” is a mobile wave in the atmosphere, which presents more of a threat. Gravity waves have a multitude of causes: wind shear

associated with the jet stream, the formation of a front or low, thunderstorms and hurricanes. All of these events can produce gravity waves. These waves often are damped out in the atmosphere and pose no problem. Other times they can propagate for hundreds of miles. Stable parts of the atmosphere are best for propagating waves.

Gravity waves are relatively small-scale features, with wavelengths varying from roughly 5 to nearly 300 nm (approximately nine to 555 km). The period or time between waves in a set can vary from minutes to hours. They can at times move very quickly, up to about 80 mph (130 kph). The pressure amplitude — pressure change you would see on a barograph trace — can vary between a few tenths of a millibar to more than 10 millibars (0.3 in Hg) for the strongest waves.

A gravity wave’s effect on sensible weather makes it important to meteorologists and aviators. The undulating waves and their interaction with the prevailing wind field instigate vertical motions in the atmosphere. Lifting motions are maximized just ahead of the wave crest (Figure 1). Sinking motions

are strongest just ahead of the trough. What does this mean in terms of flying conditions? Obviously, the updrafts and downdrafts would directly affect the vertical motion of an aircraft. This is even more of a concern if convection is also initiated, which would exacerbate the lifting and sinking motions of the air.

Moderate to extreme turbulence could be expected. In addition, horizontal air motions would increase, leading to strong and quickly shifting winds. The maximized lift area often could be associated with heavier precipitation rates and subsequent decreases in visibility. And, with gravity waves commonly occurring at low levels, these effects would be maximized close to the surface, such as during takeoffs and landings, with the greatest potential for the waves to affect aircraft flight path.

Forecasting gravity waves is extremely difficult. Computer models handle large-scale features very well but have trouble with factors as small as gravity waves. The grids used by the models usually are too big to identify gravity waves. Another problem is that false indications of gravity waves can be generated by the models themselves. Very often, mathematical filters are used to eliminate gravity wave indications so the models can run efficiently.

Meteorologists usually can determine situations where gravity waves are likely. Even then, it is impossible to know if the waves will produce significant weather. On the other hand, once a wave or set of waves gets started, meteorologists can track them and determine speed and direction of movement. This information then can be used to make short-term forecasts to warn those downstream of the coming weather.

What gravity wave situations should pilots look for? The classic winter situation involves gravity waves occurring

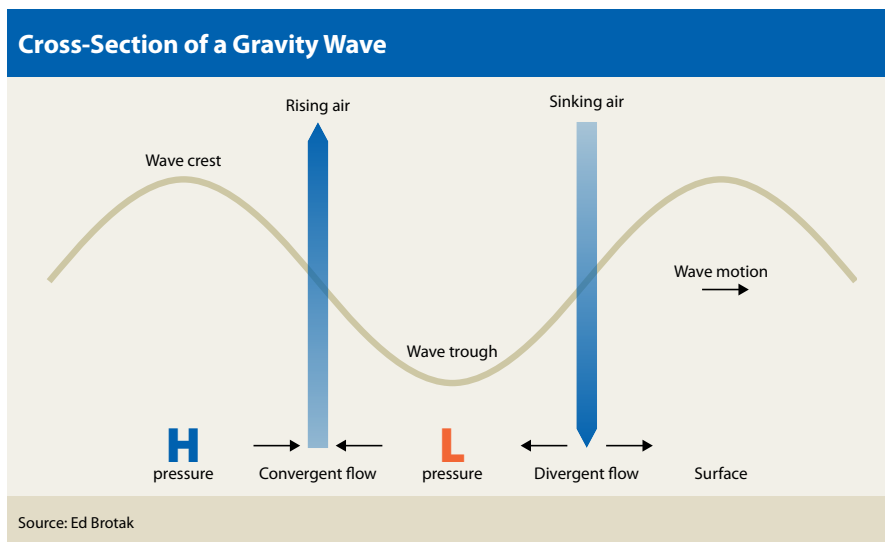


Figure 1

north of a warm front and northeast of the surface low (Figure 2). Strong jet stream winds well aloft are to the southwest. The gravity waves propagate northward within the sloping frontal layer above the ground. In these situations, the effects on sensible weather are often profound.

For example, a major winter storm was affecting northern Illinois and Chicago O'Hare International Airport. Light to moderate snow was falling with visibility reduced to ½ mi (0.8 km). Winds were blowing steadily from the northeast at 20 kt (37 kph). Then a gravity wave began to affect the region. Within minutes, the visibility dropped to 1/16 mi (0.1 km) in heavy snow. Thunder was heard. Winds gusted to 56 kt (104 kph).

Gravity waves generated by thunderstorms or thunderstorm complexes develop in a similar manner. In these cases, cooler air from the thunderstorm downdrafts hits the ground and spreads out, the leading edge of this outflow forming the familiar gust front. Behind this feature, a sloping frontal surface separates cooler air near the ground from warmer air above. Gravity waves can develop and propagate within the cooler, stable air.

Often no clouds are associated with the gravity waves themselves, so they can approach unannounced to pilots. On Dec. 6, 1998, a Beech Baron crashed during approach to the airport at Norman, Oklahoma, U.S., killing the pilot. The National Transportation Safety Board concluded that severe turbulence and wind shear were the probable cause of the loss of control. Pilot weather reports from nearby aircraft were part of the support for this conclusion. The flight crew of a Boeing 737 approaching Oklahoma City's Will Rogers Field, about 30 mi from Norman, near the time of the crash reported encountering wind speed variation of 50

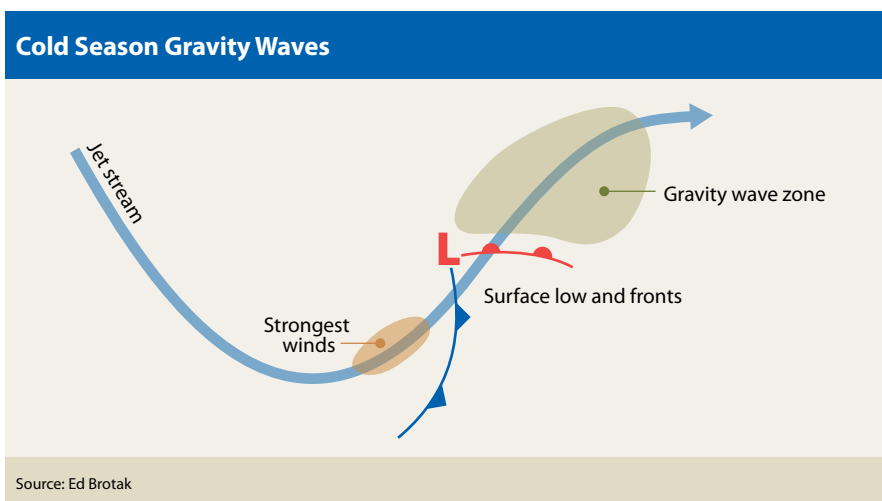


Figure 2

kt (93 kph). This variation was enough to convince the crew to conduct a missed approach. Researcher David W. Miller analyzed meteorological radar data relevant to the accident. At the time of the crash, thunderstorms were at least 10 nm (18 km) away from the crash site. Miller concluded that gravity waves generated by the storms were the likely cause of the loss of control.²

Gravity waves can interact with existing low-level boundaries and initiate new convection. Some theories even suggest that gravity waves interacting with already severe thunderstorms can help produce tornadoes. Offshore hurricanes can generate gravity waves that can move ashore and produce thunderstorms.

With such a variety of sources, gravity waves are common weather features around the world. From the cold climates to the tropics, gravity waves may be encountered. In fact, gravity waves in some form probably are omnipresent. Fortunately, most are fairly weak and don't present a threat to flight crews.

It is difficult to say how big a problem gravity waves are for the aviation industry. As noted, they can be quite difficult to detect. Thus, when incidents or accidents occur and detailed post-event

analyses are conducted, gravity waves may have not left any clue about their presence. Many such encounters go unreported in this situation. Clear air turbulence may be acknowledged but not cited as a causal factor.

Until forecasting techniques improve, the best defense that meteorologists can offer against the adverse effects of gravity waves is better detection. The first step in this is simply educating the aviation industry about the problem. The next step is for the aviation community to be alert for the situations in which gravity-wave generation is most likely. The changes in pressure and wind due to gravity waves are measurable with the meteorological instruments we now have if we know what to look for. ➔

Notes

1. Bean, Gregory. "Gravity Waves: A Pilot's Perspective." *AOPA Online: Never Again*, April 8, 2004.
2. Miller, David W. "Exploring the Possibility of a Low Altitude Gravity Wave Encounter as the Cause of a General Aviation Accident near Norman OK on Dec. 6, 1998." A presentation to the 9th Conference on Aviation, Range, and Aerospace Meteorology, September 2000, Orlando, Florida, U.S.