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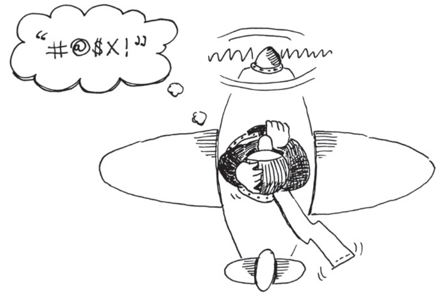

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WHAT MAKES THE BUMPS

You don't mind a few bumps along the road, but when you start smacking the headliner it's time to fly a smarter path.

by Scott C. Dennstaedt

When a pilot is injured in an aircraft in flight, turbulence is usually to blame. Unlike icing, which is generally limited to FL300 and below, turbulence can bite you at any altitude and at any time of the year. Even though turbulence causes the most anxiety with passengers, it is rarely the cause of a fatal accident. What is the definition of turbulence? Turbulence is random spin in the atmosphere. The key word is random. Random means it's difficult to forecast.

Outside of convective activity, turbulence can be the hardest adverse weather element to visualize on the weather map. Since turbulence is a mesoscale feature, it's not directly identifiable on a typical synoptic weather map. Can you plot a route and altitude for smoothest ride? Pilot reports, AIRMET Tango, SIGMETs or the SIGWX progs help but so does understanding the various kinds of turbulence and the meteorological reasons behind them.

Thermal Turbulence

Thermal or convective turbulence not occurring in frontal zones is perhaps the turbulence we most frequently encounter at lower altitudes. The primary cause of these bumps is alternating currents of warm air rising and cooler air descending within relatively strong winds aloft.

Three ingredients must be present before thermal turbulence becomes a problem. First, the area must have moderate or strong winds aloft. Second, low-level heating (insolation) must develop and maintain convective thermals. Third, instability near the surface must enhance the buoyancy of the rising air. If any one of these three elements is missing, the likelihood of thermal turbulence diminishes.

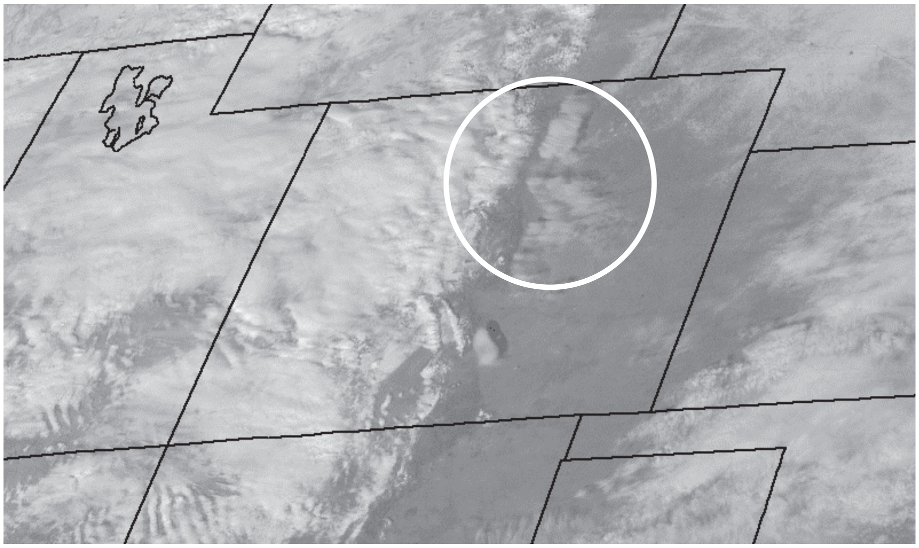
On cloud-free days the sun warms the ground easily. As the ground is heated, this heat is transferred to the air just above the surface. I'll call this an *air parcel*. If the temperature difference between the parcel of air and the temperature of the air around it is large enough, this parcel of air becomes more buoyant (less dense) than the surrounding ambient air and rises. Large lapse rate (rapid cooling with altitude) means the air parcel has positive buoyancy and will continue to rise.

If the clouds have really hard edges, turbulence in those clouds is likely light.

Why do we feel the bumps? Similar to mountainous terrain these thermals act as obstructions to the winds aloft. The wind must deviate around the rising thermals, resulting in the random spin or turbulent eddies we feel as bumps. These eddies get carried downstream and may eventually dissipate. How bumpy it gets depends on the intensity of the thermals and the velocity of the wind. Weak winds of 15 knots or less will generally result in little or no convective turbulence.

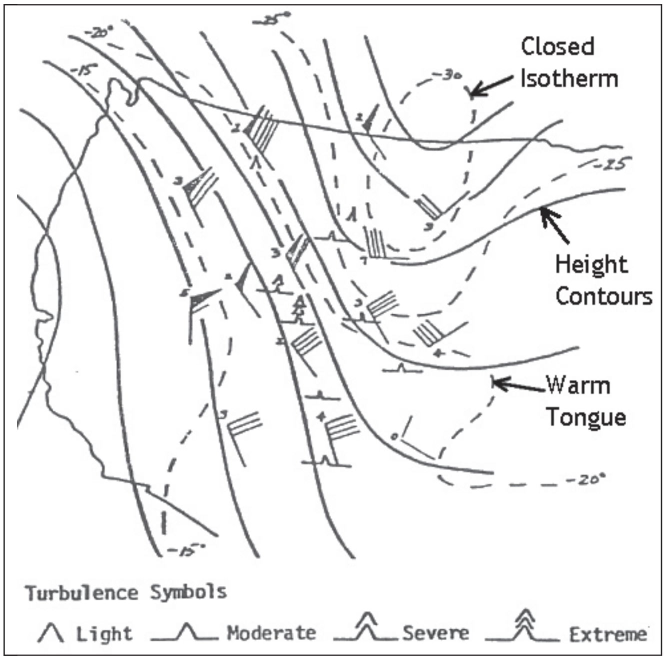
When the heating at the surface is reduced by an overcast sky or by nightfall, the production of thermals ceases. This is true even if a large atmospheric lapse rate exists near the surface. Finally, a temperature inversion or stable atmosphere is normally responsible for capping the turbulent layer and will inhibit the development of thermals.

In some cases, rising thermals expand, cool, and reach saturation producing cumulus clouds. The billowing white puffy cumulus clouds you see are saturated rising air parcels. If these clouds have really hard edges, the winds aloft are likely minimal and the turbulence in these clouds is likely light. Torn or tattered edges to these clouds typically mean moderate or greater turbulence in



Right: *The gap between the ridgeline and the clouds (Foehn gap) indicates turbulent lee waves. Non-turbulent lee waves often have no visible gap.*

and around the clouds. Climbing to an altitude above this cumulus field normally means a smooth ride.



Above: *Clear air turbulence was found in every case of a moving, closed, cold-air isotherm (dashed lines) at 500 mb (18,000 feet) when the height contours (solid lines) of the trough were not closed. A warm tongue ahead of the trough was also noted in these events.*

Mountain Wave

One of the easiest forms of turbulence to forecast and visualize is turbulence generated by mountain waves. Some mountain waves can be turbulent (called breaking waves) and they also can be non-turbulent. The waves are also called *lee waves* as they form downwind from the top of the ridges.

There are three basic ingredients for the typical genesis of mountain waves. First, there must be cold air flowing nearly perpendicular to a mountain range or mountain ridge. A wind of at least 20 knots or greater at the top of the ridge must be present. The likelihood of mountain waves decreases with winds lighter than 20 knots at the ridgeline.

Very little change of wind direction with height is also a requirement. It is not unusual for the wind to gradually increase well into the troposphere with little or no shift in the wind direction with altitude.

Finally, there needs to be a stable layer just above the mountain top level and an unstable layer below. As the unstable air flows up and over the mountain ridge, it expands and cools as it meets this stable layer aloft. The air becomes negatively buoyant and descends back down into the unstable layer, compresses and heats up. Once again in unstable air, it rises. This process repeats for hundreds of miles downwind.

Standing lenticular clouds (altocumulus lenticularis) may appear on a satellite image. Distinct ripples in the clouds parallel to the ridges will also form on the lee side of the mountains. In the turbulent wave scenario, rotor clouds may form on or under the caps of these waves, assuming, enough moisture is present. The absence of rotor clouds does not imply the absence of turbulence, however.

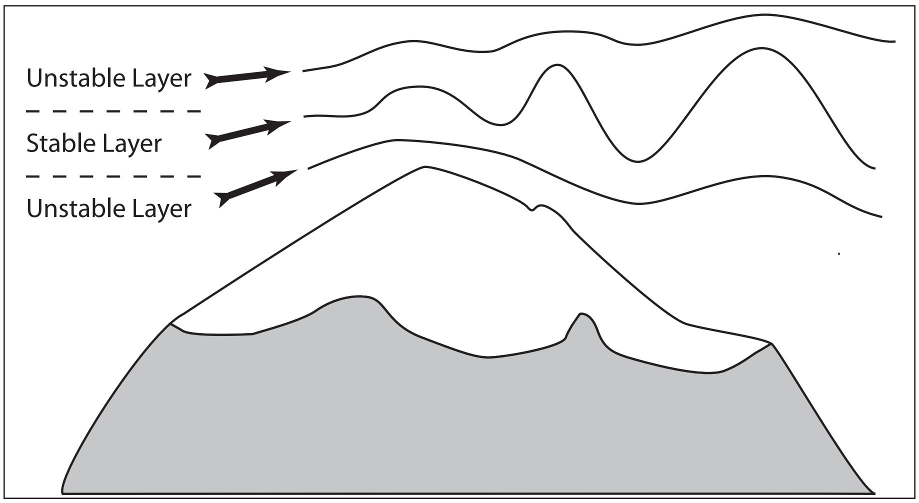
It doesn't take huge mountains like the Rockies or Cascades to generate mountain waves. The Appalachian Mountains can create serious mountain waves that can be felt nearly 300 miles downwind. Frequently in the eastern U.S. these waves are non-turbulent.

Downwash is the issue in these non-turbulent waves. You may find yourself with full power at Vy and still descending. Tell ATC you are caught in a wave and cannot maintain altitude. Ask for a block altitude and a turn perpendicular to the ridge to exit the wave as soon as possible.

Mechanical Turbulence

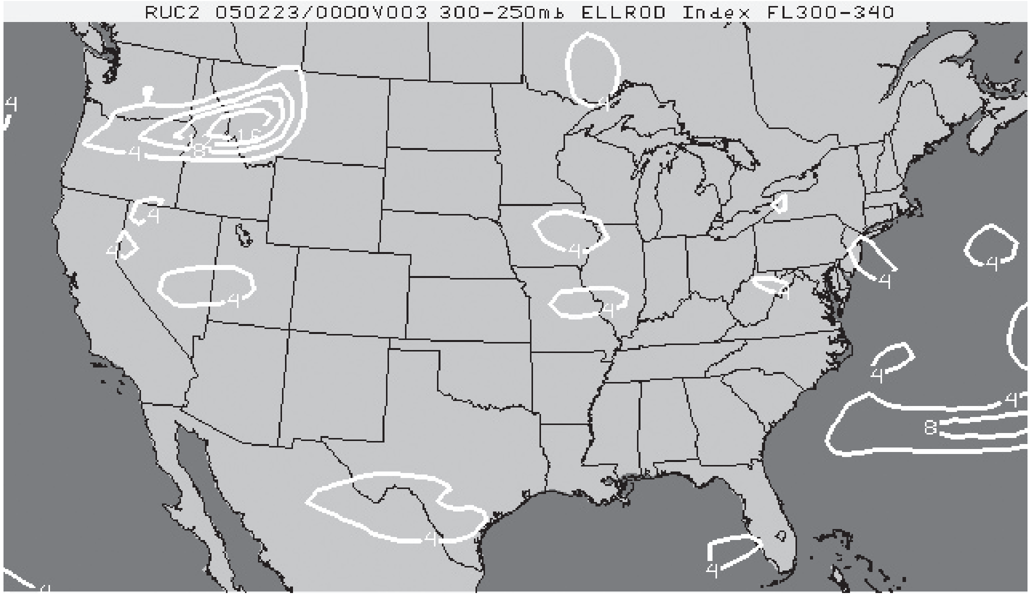
Mechanical turbulence or shear turbulence is caused by a fast wind flowing over rough terrain or by a rapid change in wind speed or direction over a short distance. The air that is caught in this shear zone tends to rotate or spin, producing the turbulence we feel.

Mechanical turbulence is typically the cause of AIRMET Tango. "OCNL MOD TURB BLW 100 DUE TO INCR NW FLOW ACRS RUFF TRN" is common in the winter as strong cold fronts usher in very cold and dry air with high surface winds behind the front. On a surface prognostic chart, tightly packed isobars equate to strong surface winds and a much greater risk of mechanical



Left: *Mountain waves need a stable layer just above the ridgeline with an unstable layer below. A small or negative lapse rate (temperature inversion) is indicative of a stable layer.*

turbulence. Winds flowing over buildings, trees, hills and other large structures also create some interesting control challenges on final approach due to mechanical turbulence.



__Above:__ The Ellrod index helps flight-level drivers visualize potential moderate or severe turbulence. Any value over 16 is worthy of your attention.

Clear Air Turbulence

Clear air turbulence (CAT) is characterized by a rough, washboard-like bumpiness buffeting the aircraft in a cloudless sky. Seventy-five percent of CAT encounters are in clear air, but it can occur in cirrus clouds and haze layers without visual warnings.

CAT is caused by relatively strong vertical or horizontal shear in wind speed or wind direction. Clear air turbulence differs from convective turbulence since it is more "rhythmic" in nature and not as random. CAT is normally found above 15,000 feet outside of cumuliform clouds. Most severe cases of CAT are associated with the jet stream. Consequently, CAT is more common in the winter months.

Turbulence Forecasts

Timing is perhaps the most difficult element in forecasting turbulence. Pilot reports of turbulence have a very short shelf life. There is no one magic chart or parameter that will alert you to the onset of turbulence. The atmosphere is much too dynamic with changes at all layers of the atmosphere that can lead to the development of turbulence.

What can you do to "see and avoid" moderate to severe turbulence? Pilots can get a pretty good idea where the significant turbulence may be hiding by using a model-based product called the Ellrod Index or using the AWC's Graphical Turbulence Guidance (GTG).

The Ellrod Index forecasts CAT using numerical weather prediction models. Any Ellrod index number that is between four and eight means the potential for light to moderate turbulence. An index between 8 and 12 is a prediction for moderate turbulence. A forecast between 12 and 16 indicates a likelihood of moderate to severe CAT. Finally, any index over 16 is an area you should try to avoid. It's only calculated for altitudes that are at and above FL180 and for four to six thousand foot altitude slices. For example, one number may cover the altitudes between FL300 and FL340. The AWC tool is also restricted to the flight levels, but the same page gives you quick access to AIRMETs and PIREPSs nationwide.

Many SIGMETs for turbulence are a result of pilot-reported events. Reports of severe turbulence confirm to forecasters that an area is worthy of a SIGMET. You might think this is a little backwards. Keep in mind that the area of concern will likely already be under the protection of AIRMET Tango.

Pilot Reports

It's critical for pilots to report turbulence. As I stated in "Got PIREP" (October 2004 *IFR*), SIGMETs live and die by PIREPs. A report of negative turbulence is just as important as a report of moderate or severe turbulence. Ensure your report gets to the AWC and the remainder of us inquiring pilots by filing it directly with Flight Service or Flight Watch on 122.0 MHz. ATC might not forward it.

Reports of CAT are highly subjective. The degree of turbulence is pilot perception, which depends upon the weight, speed, and aerodynamics of the aircraft. AWC staff note that pilots of 757s and 767s normally report a half-notch higher turbulence than other commercial aircraft. So, if most commercial airliners are reporting moderate turbulence, a 767 pilot will report moderate to severe turbulence. Apparently these jets are more sensitive to the bumps.

Turbulence and You

How should you properly report turbulence? Imagine holding a full cup of coffee while George does the flying. In light turbulence, the coffee may slosh around a bit, but won't spill. In moderate turbulence, the coffee will slosh around and spill out frequently. In severe turbulence, the coffee will go all over you. In extreme turbulence, you've got more to worry about than spilled coffee.

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