WEATHER TO FLY

BY DAN GUDGEL

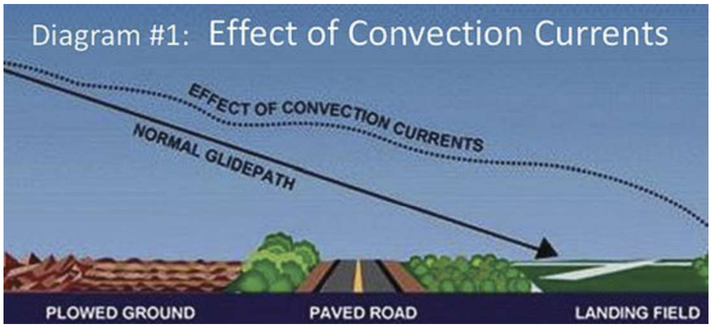
"Turbulence"

While an understanding of weather is not only of interest to aviators, it is a subject area that must be understood to remain safe while flying, and especially so for the soaring community since vertical atmospheric motion provides the lift mechanism for soaring flight. Weather-related accidents plague aviation, past and present, so weather topics reviewed by the Federal Aviation Administration's (FAA) current "Got Weather" campaign [Reference Website: <www.faa.gov/about/initiatives/got_weather >] are being presented as thought-provoking discussions under the auspices of my "Weather To Fly" column. These FAA program discussions on meteorological subjects should not be considered comprehensive due to the space limitations within the column. Rather, I am presenting some aspects of the monthly subject for the reader's contemplation and subsequent research to enhance one's aeronautical knowledge.

This month I would like to broach the subject of "Turbulence." Courtesy of the *Glossary of Meteorology*, turbulence is defined as "a state of fluid flow in which the instantaneous velocities exhibit irregular and apparently random fluctuations so that in practice only statistical properties can be recognized and subjected to analysis." To paraphrase in airman lay terms; wind gusts, shears, and atmospheric eddies typically micro-scale in size constitute or develop turbulent air flow. An acceleration force is experienced by an aircraft transiting one air current to another (experiencing changes in air flow direction and/or speed). This zone of change leads to bumps or jolts on an aircraft and crew. In severe enough form, rapid encounters in wind velocity (speed and direction changes in either vertical or horizontal directions) result in accelerations and forces that can threaten the structural integrity of one's aircraft.

Where can turbulence occur in our soaring? The FAA's *Advisory Circular (AC) 00-6A, Aviation Weather* devotes a chapter addressing atmospheric processes that can develop turbulent flow. Within that chapter on turbulence, the AC discusses turbulence in general, convective turbulence, thunderstorms, mechanical turbulence, wind shear, clear air turbulence, and wake turbulence. Do we understand and/or have we recently reviewed conditions that potentially generate turbulence? With the exception of high-altitude clear air turbulence, any or all the aforementioned types of turbulence generators are commonplace in our soaring flight realm.

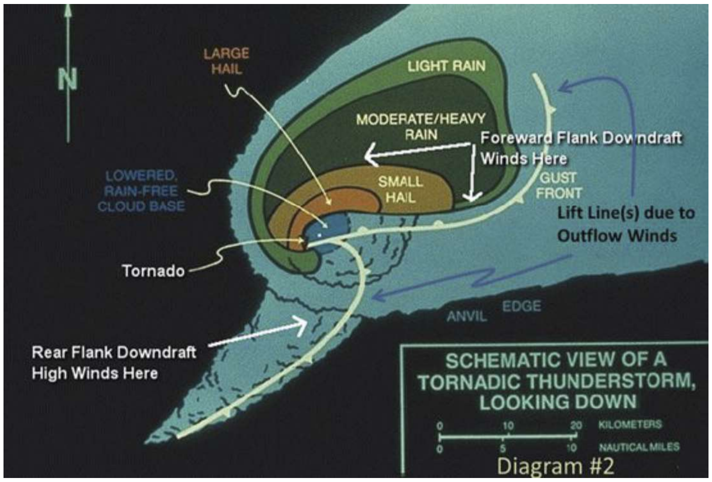
Diagram #1



Stress on an aircraft airframe from atmospheric turbulence or pilot control input requires airspeed considerations. Flight in turbulent conditions mandates reducing the aircraft airspeed. On airspeed indicators, the *Yellow Arc* denotes the "*Caution Range*" whereby flight should only be conducted if there is no rough air. Some rough air can be accommodated with flight speeds within the *Green Arc* as the "*Normal Operating Range*" with the top of this arc considered the "*Maximum Structural Cruising Speed*." However, substantially rough air and/or subsequent control inputs that may require full or large control deflections mandates flight at airspeeds at or below "*Maneuvering Speed*" of the aircraft, and may not be marked on airspeed indicators.

Convective turbulence is that associated with the varying degrees and changes in direction of vertical air motion within the atmosphere. Obviously, soaring flight utilizes the rising columns or bubbles of warmed air that we know as "thermals" for lift purposes. But in flying cross-country in powered aircraft (airplanes, helicopters, motor-gliders, etc.) or gliders, turbulence will be encountered as thermal up-drafts, and then adjacent down-drafts are transited. Air velocity (speed and direction) changes experienced in short periods of time and space result in turbulence. Convective turbulence doesn't exclusively occur at the point of air moving between up- and downdrafts. It results also from simple differential heating across adjacent dissimilar ground textures and properties [See **Diagram #1**: *Effect of Convection Currents*]. This dissimilar surface heating and resulting subtleties in vertical air motion is one of the contributing factors that makes every glider landing pattern unique, rather than an automatic routine of fixed control inputs. Once out of the atmospheric boundary or surface-based mixed air layer caused by surface heating and its resulting turbulence, flight becomes typically smooth. In reference materials, the example shown for this condition depicts that of cross-country flight above cumu-

Diagram #2

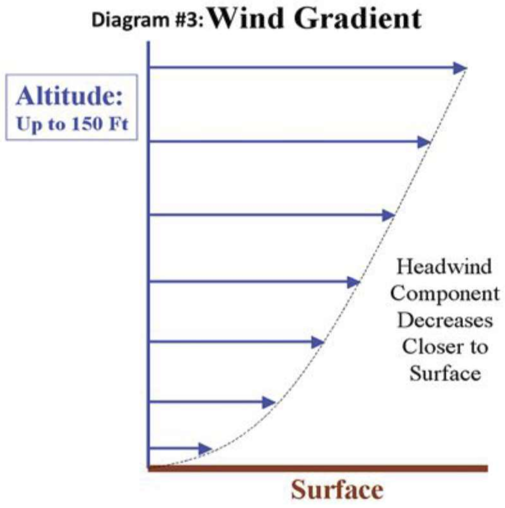


lus clouds or flight above the maximum altitude of thermals as being smooth.

Thunderstorms are essentially "Mother Nature's Severe Weather Generator" toward aviation operations. A couple of aspects of thunderstorms are responsible for generating turbulence; the scale and intensity of the aforementioned convective up- and down-drafts within or outside a thunderstorm cell is much larger; inflow – and the much larger outflow winds from thunderstorms – cause turbulence due to large changes in wind speed and direction over short distances around any thunderstorm cell [See **Diagram #2**: *Schematic View of a Tornadic Thunderstorm*].

A downdraft from the thunderstorm cell at the onset of precipitation in a mature thunderstorm can be relatively benign, with downward vertical motion of only a few hundred feet per minute. However – and in the extreme with micro- or downburst conditions – a thunderstorm downdraft can reach *6000 feet per minute*! With a tremendous strong vertical downdraft, and subsequent transition to a horizontal component of air motion at contact with the ground, wind velocity differences result in severe to extreme turbulence. For the Glider Category, the leading edge of the thunderstorm outflow wind boundary provides uplift that can generate cloudiness due to that lifting action. A sailplane utilizing such lifting may not be able to maintain visual flight along the gust front line unless the pilot elects to change course out of the strongest portion of the lift line.

Diagram #3



As a fluid, moving air interacts with the ground and obstructions to the air flow, thereby producing friction and creating eddies that result in varying degrees of *mechanical turbulence*. Right at the ground the wind speed is zero, but with elevation wind speed increases subsequently, resulting in a wind gradient in the lowest layer of air next to the surface [See **Diagram #3**: *Wind Gradient*]. With higher wind, this surface wind gradient becomes larger – along with wind gusts caused by friction or obstruction eddies – necessitating higher approach speeds for adequate aircraft control through the landing flare.

The most insidious of turbulence generators, because there might not be any visible clues to its existence, *clear air turbulence,* is quite dangerous, and can be generated in several ways. ☛

A relatively quick change in wind vectors across time and/or space results in a wind shear and subsequent turbulence. The aforementioned *surface wind gradient* is a form of wind shear. Nocturnal (night-time), *surface-based temperature inversions*, with typically calm wind in the air layer below the inversion in clear conditions, combined with gradient wind above, creates a wind shear at the upper boundary of that inversion. The top of the inversion may only be a few hundred feet above the ground. This situation occurs frequently in the winter months in mountain valleys or basins.

Cold air drainage from adjacent higher terrain, combined with additional surface radiational cooling on the basin floor through the long night, results in very cold air next to the ground, creating a strong temperature inversion [See **Diagram #4**: *Wind Shear at a Temperature Inversion Top*]. Wind shear is often amplified across such an inversion, as a scalar wind speed differential of 30 knots or greater can exist in a narrow layer of air. This situation occurs frequently in intermountain areas, ahead of oncoming frontal systems with increasing pre-frontal gradient winds aloft, in combination with residual cold air (and calm wind) established beneath clear night-time skies.

Cloud-shrouded much of the time due to air mass lifting, wind shear also is present *across frontal boundaries*. However, drier air-mass types may not produce much cloudiness at the frontal uplift boundary. The frontal boundary is an area of wind shear due to the differing wind vectors between the conflicting air-masses, and subsequently leads to turbulence in the vicinity of the frontal temperature inversion.

The classic phenomenon known for generating clear air turbulence is the *jet stream*. Typically located at high altitudes (25,000 to 35,000 feet) and well within Class A Airspace, very high wind speeds of 150 knots or more may occur within the jet stream core. This results in a strong wind shear all around the lateral perimeter of the jet core, thereby producing severe to extreme turbulence.

Another phenomenon well noted by the soaring community in generating clear air turbulence is the *mountain (lee) wave* [See **Diagram #5**: *The Mountain Wave*]. Wind shear and turbulent flow within a mountain wave's rotor zone resident below the wave crests can reach the severe to extreme turbulence levels. Additionally, mechanical turbulence near terrain is also generated due to the high wind speeds associated with the mountain wave.

Within the "Special Emphasis Area" of the FAA's *Practical Test Standards*, knowledge of *wake turbulence* is required. While most glider club and fixed base operations will not typically have glider operations affected by wake turbulence, motorgliders and their increased cross-country flight capabilities, along with the occasional glider recovery operation at airports handling larger aircraft, can expose aircraft and pilots to wake turbulence. Produced by larger aircraft with high wing loading while at high angles-of-attack, this aircraft-generated turbulence poses a loss-of-control threat to all following aircraft, including gliders. Intense wing-tip vortices develop when larger aircraft are flaring for landing or rotating for take-off. These vortices come off the wing-tips of the aircraft and settle downward around 500 feet per minute and, if encountering the ground, then drift to either side of the aircraft's flight path approximately 5 miles per hour (in calm wind). Gliders or tow planes approaching to land behind landing larger aircraft need to land beyond the touchdown point of that larger aircraft; and plan take-offs such that your rotation point is beyond where the larger aircraft touched down. If the larger aircraft is taking off, then the tow plane/glider should rotate, break ground, and climb out off to the side of the runway (the upwind side if there is a crosswind component) well before the larger aircraft's rotation point. Landing behind a larger aircraft's take-off necessitates landing before the rotation point of that departing aircraft. The FAA has updated their AC in regard to wake turbulence, and reading the new AC provides an excellent review of the subject [See **References**: *Advisory Circular 90-23G, Aircraft Wake Turbulence*].

Diagram #4

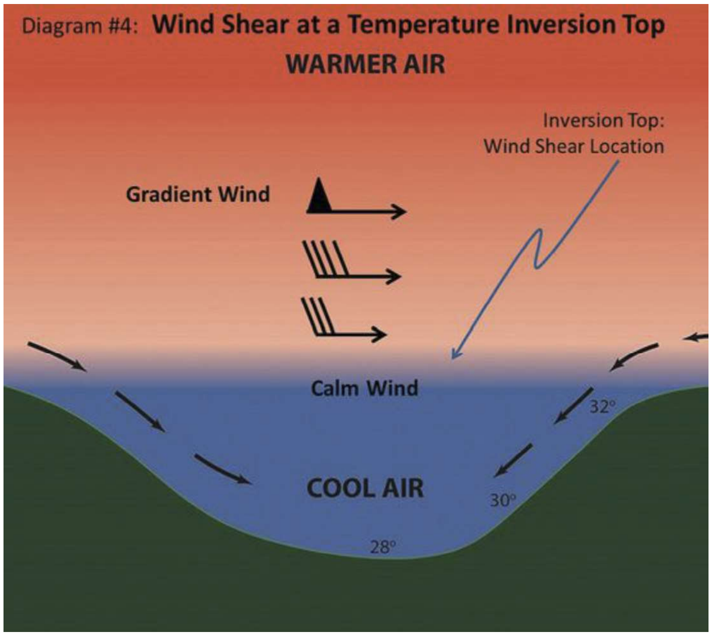


Diagram #5

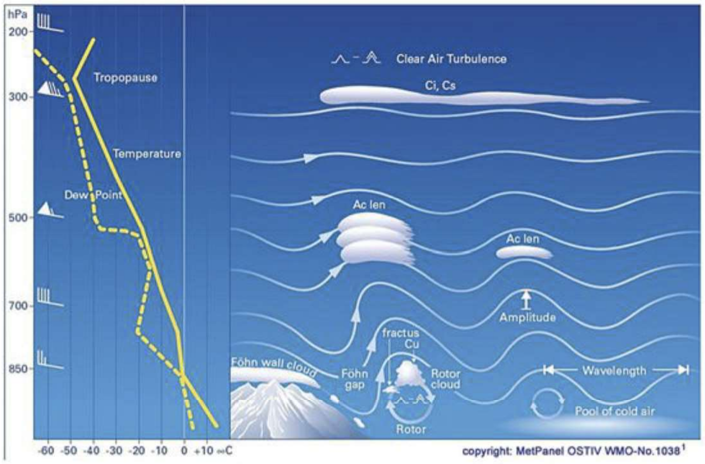


Diagram #5: **The Mountain Wave**

Being a fluid, anything that either impedes flow or provides shear is likely to generate atmospheric turbulence. It behooves the soaring pilot to understand the processes and causes that generate turbulence. The material review presented here hopefully has refreshed our knowledge in regard to turbulence generation and, to some degree, how to mitigate any adverse effects it may have for safer flying.

Reference Text Box:

"Got Weather" FAA Website: < *www.faa.gov/about/initiatives/got_weather* >

Glossary of Meteorology; Ralph E. Huschke, editor; American Meteorological Society; Boston, MA, 1959.

AC 00-06A, Aviation Weather; U.S. DOT FAA / DOC NOAA, Government Printing Office, Washington, D.C., Revised 1975.
– Wind Shear Diagram
– Convection Currents and Flight Path

Weather Forecasting for Soaring Flight; WMO-No.1038; 'The Mountain Wave'; OSTIV World Meteorological Organization, Geneva, Switzerland; 2009.

AC 90-23G, Aircraft Wake Turbulence: DOT FAA, Government Printing Office, Washington, D.C., Released Feb 10, 2014.