Secret Whirlwinds

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Swirling eddies of air[1] near the ground, often invisible, pose potential danger to all aircraft and even to ground-based support equipment. These microscale atmospheric eddies, often called whirlwinds, develop when the lower atmosphere is unstable, causing strong thermals that glider pilots seek.

Besides whirlwinds from atmospheric instability, structures or natural obstructions on the ground also cause near-surface atmospheric eddies that threaten aircraft controllability when encountered at the critical landing phase of flight. After all, contact with firm ground needs to be in a controlled manner, as the aircraft we fly are essentially fragile starched fabric. As we fly through the air, it behooves us pilots to be aware that invisible eddies are present, often strong, and have planned options should we encounter them in the process of landing or during ground handling.

I present a number of encounters with whirlwinds as a means to enlighten and provoke thought in regard to these eddies in the fluid we know as the atmosphere.

As a reference, Bob Thompson wrote a long, well-researched essay on rogue turbulence of all types in Soaring magazine (October, 2014, pp 20-29) that merits a careful read and also can be found at https://tinyurl.com/rogue-air.

A Crop Duster's Encounter

A couple of decades ago, a young crop duster pilot consulted me (at his wife's insistence) about multiple bruises. As his aviation medical examiner and personal physician, I inquired how these bruises had come about. In response, he simply handed me an envelope full of snapshots. The snapshots at first glance showed what appeared to be a rolled-up ball of steel tubing resting in a bean field. "What's that?" I asked. "It's my helicopter," he said, and further explained, "I was spraying the field and flew into a dust devil."

Incipient Spin on Low Final

The local soaring pilot returned early from a cross-country flight in June 2020, even though the atmospheric instability was still supporting the development of strong thermals. His approach speed was the usual 51 kt; he was perfectly set up for landing on the paved runway, when suddenly the nose lifted, the airspeed increased to a bit more than 60 kt, and his landing aim point shifted to the far end of the runway. He applied a little bit of backstick pressure to decrease airspeed and applied a small amount of additional spoiler to resume descent – but suddenly the glider *dropped!*

The pilot put the stick forward to regain some airspeed and control authority, and was able to level out at the last second just above the runway. During descent, the glider had yawed to the right and the right wingtip touched the runway first. Application of left rudder and left aileron realigned the glider straight down the runway after touchdown, and full spoilers prevented another gust from lifting it off. The right wingtip wheel, attached securely for a decade with double-stick tape, had been knocked off and was located back at the touchdown point, and paint on the wingtip extension trailing edge had been lightly scratched. A local mechanic happened to observe the glider landing. He said, "You were about 50 ft above ground level (AGL) and you just dropped like a rock and turned. I thought we'd be picking up pieces. You were lucky." Yes.

Obviously, transparent, swirling air had caused a low altitude stall and even an incipient spin from which the pilot was fortunate to have recovered adequately. With this encounter, the pilot changed his landing procedure so that he flies faster to the touchdown and plans to make higher energy wheel landings rather than full stall landings when low level atmospheric mixing is still quite active.

Soaring pilots from the West react to this story by some variant of, "Stall landings are crazy."

Air "Pocket" at Flare

The local soaring pilot on a windy, sunny autumn day half a decade ago made a soaring flight of a couple of hours duration. Upon returning to the airfield, the observed wind direction was a left-quartering headwind with wind gusts estimated at 20 kt. The pilot opted to land on the adjacent, parallel grass runway. As he began to transition, approximately 8 ft AGL, to flare, he observed his airspeed drop in one second from an indicated 50 kt quickly down to only 30 kt. The glider abruptly dropped hard onto the sod. The gear retracted, the gear doors knifed into the sod and ripped off, the wet compass mounted on the instrument panel glare shield punched through the canopy. Other than a bruised ego, the pilot was unharmed.

Crash on Final 1

The late, experienced cross-country and competition pilot, Bill Gawthrop, relayed the story of his 2014 crash

[1] "Eddy" is the formal meteorologist's term of art for small-scale swirlings of the wind. This implies to DrDan the gentle swirlings of water in a stream rather than powerful glider-scale eddies that may drop us into the ground or wreck us on the ground. "Whirlwind" was of yore sometimes used in meteorological literature, and has a suitably violent implication. We leave the nuance to your imagination.

that occurred short of the runway at Truckee (*Soaring* magazine; March, 2015, pp 12-17). Because dry air eddies are often invisible, Bill could not possibly have seen the air motion that he encountered. His description of the event suggests that a whirlwind may have caused a sudden unexpected loss of airspeed thus leading to a stall/spin on final approach. "My initial feeling was that at almost a 2:1 glide ratio I was going to be too high for the 60:1 glide ratio of my JS-1 Sailplane so I started to pull extra spoilers. Unexpectedly sudden, I was dropping like a stone and being pushed into a left turn by the wind."

Crash on Final 2

NTSB Event 20130702X20438 states, "According to the pilot, he was on a one mile final approach to runway 36 at 800 feet with the glider engine stowed. He noted that the winds were changing and extended the flaps. The airspeed was between 55 and 60 knots when the airbrakes were extended to start a descent. The altitude was high and the glider began to descend at a rapid rate. The pilot closed the airbrakes to arrest the descent rate but realized he was too low and unable to land on the intended runway. The glider collided with a tree, and a post-accident examination revealed that the left wing was substantially damaged. The pilot reported no preimpact mechanical malfunctions or failures with the airplane that would have precluded normal operation.

"PROBABLE CAUSE: The pilot's improper use of wing spoilers during approach resulting in an altitude loss and collision with a tree."

I beg to differ. An experienced pilot (Jeffrey Long), in a high-performance glider, is not going to drop out of the sky into trees from 800 ft AGL simply by deploying full spoilers. Something must have happened to the invisible air that caused a severe change in the velocity of local airflow across the wings and tail – speed, angle of attack, direction – that caused a dramatic, irrecoverable descent.

This cannot be from a change in the gradient wind, which occurs over a large geographic scale, nor from entering the nocturnal inversion, which does not exist during good soaring conditions. It can only occur with a local, glider-sized *eddy* (a whirlwind), because all turbulence outside of laminar wave involves spinning air.

What Do Pilots Perceive?

It's interesting to me that Bill, Jeff, I, and others, when encountering an unexpected, invisible, and significant change of very small-scale wind velocity, feel "pushed" as if by a "giant hand." This brings out a point that I think is significant: ***We misperceive what the air is doing because we only experience its effects*** (due to the air being transparent).

If the glider ascends, we perceive an "updraft." Conversely, if the glider descends, we perceive a "downdraft." If we fly into whirling air that **increases** the air flow around wings and empennage, the glider will instantaneously ascend and we will think the cause is an "updraft." Maybe – the speed of swirling air is much greater than the speed of a thermal column. When the ascent doesn't persist and we have turned away from the invisible, assumed thermal, we attribute the deviation being "just a gust."

It's important to keep in mind that our perceptions about what has just caused a sailplane response may not be correct. Our mental picture of the structure of the air is *never* real. We need to gather more information, seldom available in the moment, to confirm or contradict our initial perception. When the sailplane's response to an atmospheric wrinkle happens close to the ground, there is no time for analysis, only for immediate reaction. Our reaction to control the sailplane in such a case is based on our perception and prior training and experience, not on the invisible, undetectable reality.

Whirling air that **decreases** local air flow around the glider results in loss of lift as well as additional downward force. The resulting sailplane descent may lead a pilot to erroneously perceive a larger scale downdraft rather than a small scale atmospheric eddy. If we fly into an eddy/whirling air that decreases the airspeed around wings and empennage to that *below stall speed*, we may assign the cause as a "downdraft" partly because the stall results in persistent descent. Noting pitch, airspeed indications, and control "feel" can correct an initial, erroneous, causal effect. If this occurs during or after the turn from base to final, we can expect ridicule and retraining.

When we are very close to the firm earth, there is no time to contemplate flight nuances and we have to respond to our perceptions. It takes discipline and training to respond by pushing the stick forward rather than perhaps an impulsive pull on the stick when close to the ground. If slow in airspeed, we must recover some energy if we are to have a hope of regaining control for a soft touchdown.

Catastrophe in Ground Handling

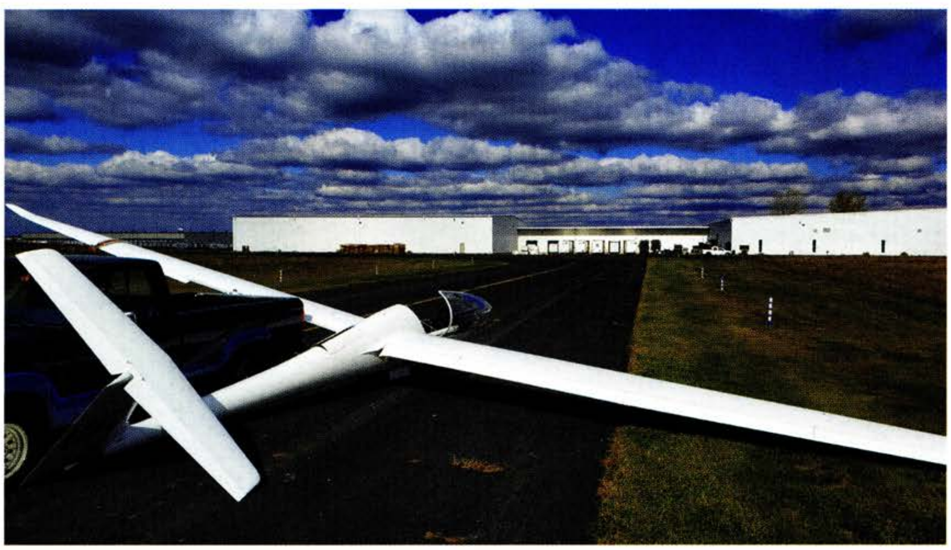
On October 18, 2020, strong, localized, excellent soaring conditions were forecast. Surface wind was to be from the northwest at 10 kt with the boundary layer winds forecast at 25 kt under clear skies. Contrary to the forecast of blue skies, there was cloud "streeting" by 10:30 am. Even with the cool air (38 °F), the Ventus sailplane was assembled quickly and by 12:30 pm it was being towed to the runway for launch. Under tow, all was quiet and uneventful along the 4,000 ft of taxiway. Because the wind speed was light, the pilot as usual towed slowly on the (crosswind) connecting taxiway while continuing to observe carefully in the mirror for any indication that the upwind wing might lift. This tow procedure allows the driver to simply stop and correct any gradual, undesired glider movement by either lowering the wing or moving the wing dolly to the now downwind wing. After about 300 ft, almost to the runway edge, the pilot-driver saw a wing rise and heard a metallic sound from behind. Braking to a stop, the glider's T-tail passed the driver-side window, the left wing crashed into the pickup's tailgate, and the glider's T-tail whacked the front fender, breaking the tail boom.

A post-event inspection revealed that the tail dolly had split at the hinge and was thrown in two pieces under the truck. The deduction was that a powerful side-wind gust had occurred. This rogue wind had weather-vaned the glider's tail past the truck and accelerated the glider until the wing crashed into the tailgate. An airplane pilot who was flying locally at the time of this event said later, "The turbulence was terrible. We got really beaten up. I'll bet the soaring would have been fantastic."

Parachute Terror

A skydiver writes, "Skydivers who have opened their canopies at around 3,000 ft AGL and are headed down to set up approaches to land at a drop zone are cautious about spotting and avoiding any dust devils since these not only can force you down into the earth as you flare (we call that *getting slammed*) but, worst of all, they can depressurize a normal canopy (especially training canopies that are lightly wing-loaded) at fifty feet above the earth. With a collapsed canopy the result is a bunch of expensive fabric in a wad over your head in this scenario generating zero lift with no possible way to get re-inflation of the primary parachute and no time to open the reserve parachute. Given the distance to fall in such an infrequent event, death is not unusual.

"Whirlwinds (marked by swirling dust or 'Dust Devils') are said to be a problem daily in the Arizona and California deserts where major parachute operations at Eloy and Perris are located; but whirlwinds do also happen here in Wisconsin at Baldwin. A whirlwind presence, unfortunately, is not always visible due to a lack of available dust. I have experienced sudden *updrafts* on final approach to land-



ing once or twice at about 600 ft AGL and they took me above the glide slope that I had established. I can only speculate what caused these updrafts. Our runway is lined on the west side by trees. On windy days, especially with wind gusts, air eddies and whirls develop due to air flow coming over the top of that 40-50-foot-tall tree line. I have seen very experienced jumpers with thousands of lifetime jumps make eye-watering, crunch landings on that kind of day. Smart people stay the hell away from Baldwin on big west-wind days. The U.S. Parachute Association Manual for Skydivers is correct in warning that turbulence extends downwind of obstructions on the ground and that the higher the wind speed the worse the turbulence."

Devilish Turbulence

As recounted in an accident report: "At Richmond, Australia, decades ago, a Cessna 150 was taking off in almost calm conditions. The temperature was 41 °C [106 °F] and the sky was cloudless. At a height of about 100 ft it encountered a whirlwind. (The pilot believes it was in the process of forming at the time – it was not visible as he was taking off, but it later became a very large dust devil.) The pilot's first indication of the encounter was a very sudden gain of about 200 ft of height. But then the upward motion stopped so suddenly that the pilot was flung against the restraint of his seat belt and bumped his head against the cabin roof. At the same time the airspeed indicator needle shot up into the red arc! Though buffeted, the aircraft remained controllable. The pilot considered the only real danger was the effect of the gust on the aircraft's structure as the airspeed indicator showed an increase of some 60 knots." *(ASD, 1978)*

The Impossible Can Happen

An experienced pilot recalls, "With a Beech Sport at Wiley Post Airport back in 1978, I had just been cleared for takeoff on 17R one cool stable morning without other traffic, when, all but 15 seconds into my takeoff roll, the Sport suddenly rotated to the left almost 90° and lifted by about 15 feet. Thinking my private pilot career had just ended while yet performing intuitive counter actions, the Sport nearly lined back up to the desired direction and kept going higher. With very little indicated air speed I somehow successfully flew away thus setting a record for the shortest takeoff roll of any fixed wing aircraft at Wiley Post."

At this time of day, the only possible causative phenomenon would have been a rotor generated at the interface between the nocturnal inversion and the gradient wind.

Malted Milk Rotor

The local soaring pilot, when about 12 years old in a group with four other preteen boys, was taken for a highway ride in a man's Lincoln Continental convertible as an evening treat. It had been a hot day and he had bought a vanilla malt "for the road."

Moving along the highway at about 70 miles per hour and sitting in the middle of the backseat, he began to feel overfull before the malt was finished. His mind turned to physics. He reached up and felt the strong blast of the wind coming over the windshield.

He began to wonder how far behind the car the malt would hit the highway if he threw it straight up into the slipstream. Action followed thought. He threw the malt straight up and turned to see the result.

The malt went about 6 ft in the air, blew backwards over the trunk, and then, beginning to descend, it curled back toward the car. It hit him in the shirt and tumbled onto the leather seat. While humiliating, this little experience was an introduction to air movement and particularly that of small-scale air eddies.

The result of this automobile rotor was easily cleaned up with rags and warm water. If these small-scale whirlwinds or turbulent eddies occur to an unsuspecting glider pilot, the result can be shattered composite!

Turbulence Is Invisible

The biggest challenge we pilots have to safe operation is that small-scale eddies are invisible – except when dust or visible moisture helps mark its location and movement. Turbulence presence can be deduced at the interface of clear air and the visible moisture of cloud droplets or inferred from particles moving such as dust, grass, leaves, and even parachutists! Turbulence is, essentially, small or large whirlwinds. It can be oriented horizontally or vertically. Smoke, if any is permitted in your neighborhood, allows one to observe the behavior of turbulent eddies. In dry, dusty areas, whirlwinds pick up dirt and form *dust devils*. At the surface, green grass will whirl to show the presence of a whirlwind while leaves and light trash will be picked up and swirled about.

Atmospheric Research on Whirlwinds

Whirlwinds are not always visible due to a lack of available dust, trash, or loose vegetative fragments. Even in the dry California location studied by Oncley, et al, with dry clay soil that would release tiny particles, only one of the detected whirlwinds was visibly marked as a dust devil. In Oncley's research, it was stated that the surface wind must be less than 8 meters per second (m/s; equivalent to 15 kt) for dust devils to occur.

An "absolutely unstable" atmosphere is required, in which lifted air within thermals is cooling more slowly than the surrounding air and at a superadiabatic lapse rate (one that is greater than a loss of 5.4 °F per 1,000 ft gain in altitude). This temperature profile often occurs in conditions of intense surface heating and in the air layer immediately adjacent to the surface. (An additional required atmospheric parameter is the *Obukhov length* that describes the effects of buoyancy on turbulent flows must be in the range $0 < -L < \sim 20–30$ meters; but this can be comprehended only by meteorologists and I can't explain it.)

It seems from Oncley's paper that whirlwinds are initiated by marked local temperature differences in a small scale (a few meters) with a temperature difference threshold at least 4 °C (8 °F) across their test grid. This parameter requirement appeals to common sense as surface obstructions and irregularities are otherwise the only disturbance to laminar air flow, thus allowing "pockets" of dissimilar heating across the surface.

These conditions mean that whirlwinds are most common with strong surface heating, resulting in a superadiabatic lapse rate to a sufficient height that allows a heated air parcel to gain momentum as it rises due to its buoyancy.

It also seems logical that wind at the surface greater than the cited 8 m/s (15 kt) creates turbulence across surface irregularities that hinders whirlwind formation by fragmenting or shearing air parcels. The strength, size, spatial frequency, and persistence of whirlwinds must depend on the size of the superadiabatic temperature gradient, its depth, and the humidity (contributing to the air parcel energy) of the rising, heated air.

Additionally, whirlwind presence is a function of insolation (intensity of the incoming sun energy), the presence of surface irregularities or obstructions affecting the initiation, amplification, or dampening of the vortex motion, the depth of the mixing layer, and the strength of the surface wind. Oncley noted that the aforementioned atmospheric conditions prompt dust devil formation widely, including regions where there is little or no dust.

It's important for aviators of every stripe to realize that light winds and strong surface heating conditions can create severe whirling turbulence with no dust markings, even with low temperatures (in other words, temperature requirements are only a function of temperature *difference* and *not* absolute temperature). Flying aircraft in 0 °F weather across northern Wisconsin, I've run into strong thermals over forest-surrounded marshes.

Furthermore, whirlwinds should not be imagined to be a single column of rotating air. Observations show that they may be complex with multiple cores, embedded vortices, concentric rings of alternating upward and downward air movement. Whirlwinds typically are asymmetric along with having variable degrees of tilt from the vertical. They may be enhanced in convergence lines that are not necessarily linear with the size of the whirlwinds encouraged with convergence variable in size and variable wind velocities (both speed and direction).

Whirlwinds in studies have been observed to persist as long as 2 hr, although most occurrences are small and fleeting, lasting in Oncley's study about 15 seconds. Infrequently, nocturnal whirlwinds were observed with a cold updraft center not related to thermal buoyancy. Some nocturnal whirlwinds were oriented horizontally, along the axis of the wind direction, sometimes present in counterrotating pairs. These whirlwinds were small, averaging only 2.5 m in diameter and

10 m in length, and were described as two legs of a hairpin vortex.

This referenced study was limited by the size of the detection array used, necessarily reducing the detectable mean whirlwind diameter. Stronger whirlwinds are better able to scour dust from the surface, thus becoming detectable for study through Doppler radar signatures (vortices with cores as large as 120 m in diameter have been measured in this manner). *Measured* maximum wind speeds cover a wide range up to at least 9 m/s (approximately 18 kt) relative to the vortex. Occasional reports of significant damage from these phenomena suggest much greater velocities do occur.

Conclusion and Recommendations

Whirlwinds and dust devils are likely when conditions favor strong thermal lifting and a surface wind speed of less than 15 kt. Occasionally these whirlwinds are powerful enough to damage aircraft on the ground, especially by throwing or rotating them about. This is a reason for the admonitions by fixed-base operators and aircraft owners to *always* shut canopies if not within one's physical reach. During ground handling and towing aircraft on thermally active days, the crew should continually monitor for a sudden, adverse change of wind direction and speed that can occur without warning.

More important to flight safety is that most whirlwinds are invisible and the wind velocity within them may be greater than the difference between an aircraft's approach speed and its stall speed. This affects the lift on one or both wings, potentially causing loss of control resulting in a plummet to *terra too-firma*. Because of this threat, a "hot" approach speed is justified in the potential turbulence within the lowest altitudes of the final approach.

The greater heating intensity of the intermountain and desert areas of the United States produces a higher frequency of whirlwinds. This prompts higher approach speeds than many sailplane handbooks suggest. In particular, full-stall landings are hazardous on strong soaring days.

It is also plausible that encountering an invisible vortex may be an unrealized cause of some stall-spin accidents on the base-to-final approach turn. (The increased stall speed in a turn increases this risk.)

References and Acknowledgments

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