WIND SHEAR:
THE MYSTERY OF THE VANISHING AIRSPEED

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■■ On June 24, 1975, an Eastern Airlines Boeing 727 crashed on short final approach to New York's JFK International Airport. More than 100 passengers perished, making this one of the worst air disasters in U.S. history.

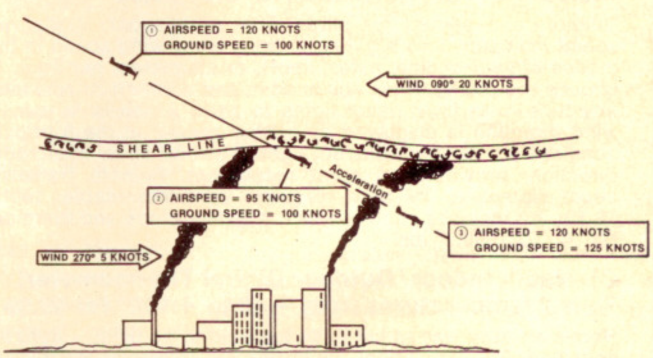
Based on the initially available facts, it appears that wind shear was an influential factor in the accident, if not the primary cause.

Because of this accident's spectacular nature, considerable attention is suddenly being focused on wind shear. It is almost shameful that a disaster of this magnitude was required to attract industry-wide attention to a phenomenon with which pilots have always had to cope.

Air carrier aircraft, of course, are not the exclusive victims of this invisible hazard. General aviation aircraft also fall prey to this misunderstood, underestimated menace. Hundreds, if not thousands, of accidents presumably caused by pilot error were direct or indirect results of wind-shear encounters. It is imperative, therefore, that pilots become familiar with the potentially lethal effects of wind shear and the various conditions during which these effects are most likely to occur.

Simply stated, wind shear is a variation in wind velocity (speed and/or direction) that occurs over a relatively short distance. *Airspeed is affected* when an airplane is flown from one wind condition—through a wind shear—into another wind condition in less time than *ground speed* can adjust to the new environment. The consequences can range from annoying power and attitude corrections to complete loss of control.

Figure 1



Wind shear is a unique hazard not only because it is frequently undetectable, but because so many pilots are unable to acknowledge the threat. They consider it incredible that a change in wind velocity can alter airspeed; it is contrary to their earliest lessons in flight.

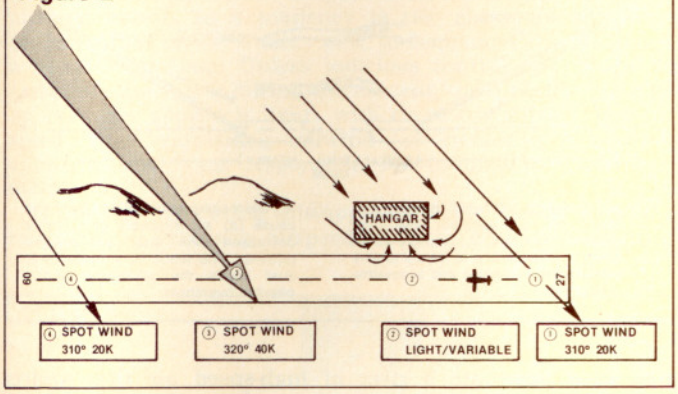
"Airspeed," they were taught, "is determined solely by variations in aircraft attitude, configuration and power setting; wind affects only track and ground speed."

Unfortunately, this simplistic axiom is but the tip of another iceberg and applies only when the wind is constant or changes gradually. Unless a pilot examines what lies beneath the surface, he is liable to fly unwittingly into the jaws of what is coming to be regarded as one of aviation's most insidious killers.

The subject is seldom taught in ground school because instructors either don't want to complicate a student pilot's comprehension of the basic airspeed/ground-speed relationship or don't fully comprehend wind-shear fundamentals.

To understand wind shear is to recognize that an airplane has inertia and as a result resists a change in ground speed. This is best stated by paraphrasing Sir Isaac Newton, the brilliant English physicist who developed the inescapable laws of motion: An aircraft in flight at a given ground speed tends to remain at the same ground speed unless acted upon by an exterior force.

Figure 2



An application of this is illustrated in Figure 1. A temperature inversion overlies a coastal city from the ground to 2,000 feet. Within the inversion, the wind is westerly at 5 knots. Immediately above, the wind is easterly at 20 knots (not an unusual situation). The narrow band separating the two "air masses" is called a "shear line."

An aircraft descending toward the shear has an airspeed of 120 knots; its ground speed is obviously 100 knots. This ground speed represents aircraft momentum with respect to the earth and, according to Newton's First Law of Physics, is the quantity that resists change.

As the aircraft penetrates the shear line and enters the inversion, ground speed will increase, but not instantly. Because of aircraft inertia, ground speed after crossing the narrow shear line is very nearly what it was earlier, 100 knots.

But since the aircraft is now under the influence of a 5-knot tailwind, something has to give. That something, unfortunately, is airspeed, which reduces from 120 knots (above the shear line) to 95 knots (below the shear line), a net and rapid airspeed loss of 25 knots. Notice that the theoretical airspeed loss (25 knots) is equal to the difference between the headwind and tailwind components above and below the shear line.

The reduced airspeed, of course, results in reduced drag. Assuming that neither attitude nor power is changed, the aircraft accelerates to its original trimmed airspeed (120 knots), at which thrust and drag are again in balance. But because of inertia, this acceleration takes time; lost airspeed cannot be recaptured instantly.

Just how long it takes to recover lost airspeed was dramatized in a USAF report by Major C. L. Hazeltine. He demonstrated that if a given aircraft, maintaining a constant altitude and power setting, encounters an abrupt 20-knot loss (due to wind shear), recovery of only 10 knots would require 78 seconds; recovery of 16 knots would require 176 seconds. Adding power and/or sacrificing altitude reduces recovery time significantly and points out the alarming need for pilots to be particularly alert for a low-level wind shear when on final approach or when climbing out at marginal airspeeds. The problem of airspeed recovery is critical if the airspeed loss results in the drag rise associated with flight behind the power curve, when required power and altitude may not be available.

(In reality, the airspeed loss is not quite as large as shown in Figure 1 because some acceleration occurs while the aircraft crosses the shear line, depending on the line's width.)

Would the pilot in Figure 1 have any warning about the impending airspeed loss? In this case, yes. When two opposing air currents rub shoulders, there is bound to be some frictional turbulence. The degree of turbulence increases in proportion to the change in wind velocity and decreases in proportion to the width of the shear line. For similar reasons, the air surrounding a jet stream is often turbulent, even though a smooth ride can be had within the core.

The aircraft in Figure 1 encountered a rapidly decreasing headwind, which has the same effect as an increasing tailwind: an airspeed loss. If the direction of the aircraft is reversed, so that it flies into an increasing headwind (or decreasing tailwind), airspeed will *increase* when the shear line is crossed. The theoretical gain is 25 knots.

The effect of wind shear is similar to what happens to a hobo who jumps from a bridge to the top of an express train passing below. As the man leaves the bridge, his ground speed (forward motion) is nil. The train, however, is clipping along at 60 mph. When the hitchhiker first touches down, it should be obvious that he cannot remain on the roof at the point of initial contact. His inertia prevents him from being accelerated so rapidly, from 0 mph to 60 mph. Instead, the hapless hobo will fall and roll backwards with respect to the train. Eventually, the friction of the train acting on his body will accelerate him to 60 mph. Whether he survives to realize this is questionable.

If the unfortunate chap were to misjudge and jump immediately in front of the train, the locomotive would force his body to adapt quite rapidly to the speed of the train. But the acceleration would exert such overwhelming and crushing G-loads that the hobo would instantly regret not having purchased a ticket and boarded the train under more comfortable circumstances.

For those who cannot correlate the hobo and the train with an aircraft in flight, consider this extreme, but illustrative, example. A Cessna 150 is cruising at an airspeed of 100 knots, directly into the teeth of a 100-knot headwind. The 150's ground speed is obviously nil. Assume also that the headwind disappears, suddenly and without warning.

The pilot—just as suddenly—finds himself high and dry without any airspeed whatsoever. The beleaguered 150 pitches down rapidly and loses considerable altitude before the combined effects of diving and power can accelerate the aircraft from a standstill to an airspeed/ground speed of 100 knots in the calm air.

continued

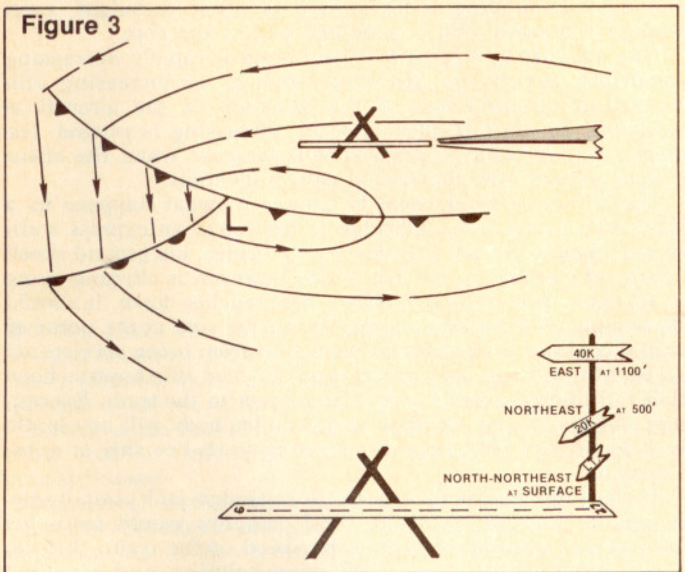
Conversely, had the 100-knot airplane been flying with a 100-knot tailwind, the ground speed would have been 200 knots. The sudden disappearance of this wind would cause an immediate pitch-up, a healthy increase in airspeed (theoretically to 200 knots), and a substantial gain in altitude.

In the foregoing examples, the pitching is a result of longitudinal stability, the designed-in characteristic of an airplane by which it automatically seeks its original trimmed airspeed.

All pilots have encountered some form of wind shear without realizing it. Perhaps, after a period of smooth flight, a pilot runs into a patch of light chop, followed by more smooth air. A comparison of ground speed/drift before and after turbulence might reveal a wind-velocity change. Airspeed fluctuations under these conditions are rarely perceptible, however. The shear line is usually wide, allowing ample time for ground speed to adjust to the new wind condition.

Whenever an approach to landing is made on a gusty day, the pilot is actually encountering numerous wind shears. Every gust of air causes extremely localized shearing. Carefully monitor the indicated airspeed during such an approach and notice how the needle shifts rapidly above and below target airspeed. Some of this erratic needle movement is caused by gusts punching the pitot tube at oblique angles, but, for the most part, actual airspeed varies every time a gust is encountered or left behind.

Figure 3



Curiously, an approach or departure in gusty air is not normally as dangerous as flying through a strong, smooth shear. This is because gusts provide a seat-of-the-pants warning of possible hazards. A pilot is more alert to needed power and attitude corrections. Also, most pilots use slightly higher approach speeds in gusty air to maintain controllability. This also provides a hedge against higher, G-load induced stall speeds and possible airspeed losses due to wind shear.

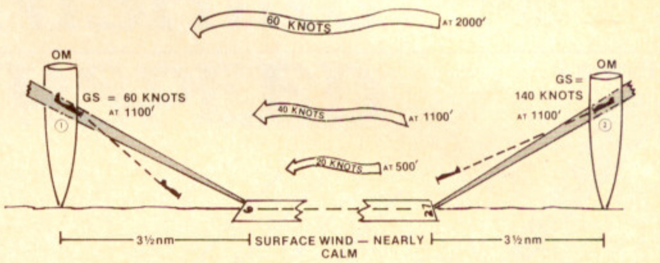
An excellent rule of thumb suggests that at least half the gust factor be added to normal approach speeds. For example, if the surface wind is reported at 22 knots, gusting to 38, the gust factor is 16 knots. At least 8 knots (half the gust factor) should be added to the normal approach speed.

This rule provides ample protection except when the turbulence is caused by nearby thunderstorms. The only protection against this type of severity is to avoid any well-developed cell by at least 10 miles, especially when taking off or landing. A healthy gust in advance of an approaching thunderstorm can quickly steal 20 to 30 knots of airspeed (or more).

Pilots should also be on the alert for local obstacles, on or near the airport, that can disrupt the flow of a reportedly smooth, strong breeze. Figure 2 shows an aircraft about to touch down into a strong, quartering headwind. As the aircraft begins to flare downwind of the large hangar, the headwind component all but disappears, leaving the pilot insufficient airspeed to avoid the impending plop. Numerous hard landings (or worse) can be traced to similar circumstances.

Two small hills are situated farther down the same runway and form a venturi-like constriction. This can change normal wind flow into a river of high-speed air that squirts across the runway from between the hills. Entering such a localized condition could lead a departing pilot to believe that he has sufficient airspeed to fly. But not for long. When this "river of air" has been crossed, the resultant shear causes an airspeed loss that could be sufficient to force the aircraft back to the runway.

Figure 4



① A "decreasing headwind" gradient can cause (a) an airspeed loss, (b) increased sink rate, (c) possible pitch-down. The result is a tendency to sink beneath the glideslope and a possible undershoot.

② A "decreasing tailwind" gradient can cause (a) an airspeed gain, (b) a decreased sink rate, (c) possible pitch-up. The result is a tendency to float above the glideslope and a possible overshoot.

When the wind is strong, local velocities are easily affected by topographical features. It is not unusual for windsocks at opposite ends of a runway to point in opposite directions and indicate different wind speeds. A wind shear lies somewhere in between.

Considering the widespread use of sophisticated wind-measuring devices (anemometers), the windsock is somewhat of an anachronism. Unfortunately, however, the wind at the approach end of a runway on a windy day is frequently different from that measured from the roof of a distant, lofty control tower. A few large, brightly colored windsocks strung along the edge of a runway can be more valuable to a pilot than the wind observed by a tower operator. Windsocks allow a pilot to judge the nature and variation of the wind, something a tower report often cannot provide.

The type of wind shear that seems to catch most pilots off guard is the wind gradient, a condition where wind-velocity changes are somewhat more gradual. Although airspeed changes are not as abrupt as in the case of a narrow shear line, the final results have spectacular potential. Gradients are particularly hazardous because flight conditions can be deceivingly smooth; pilots are lulled into a sense of complacency and frequently are *unable* to determine that something is amiss until it is too late.

Figure 3 depicts a wind pattern overlying relatively flat terrain. Near the surface, the wind is light, flowing directly from high to low pressure. But as altitude is gained, the frictional effects of the ground are reduced and the influence of the earth's rotation (Coriolis force) increases. This causes wind speed to increase and wind direction to shift clockwise (in the Northern Hemisphere) so that above the ground the winds are considerably stronger than at the surface and flow approximately parallel to the isobars.

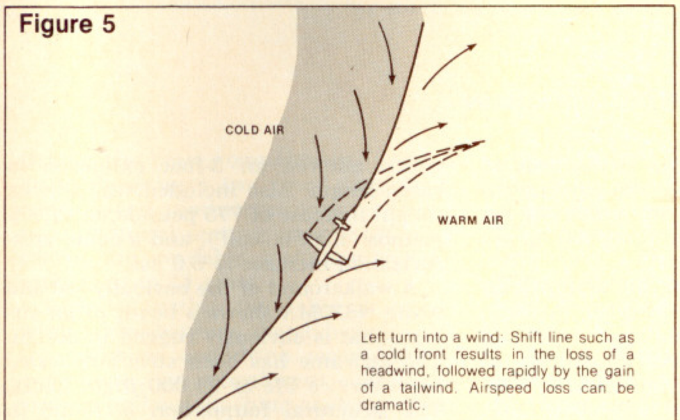
Figure 4 illustrates the problems encountered when approaching the ILS runway from either the east or the west. Assume that in each case an approach speed of 100 knots is used, and wind velocity over each outer marker (at glideslope-intercept altitude) is from the east at 40 knots.

When the aircraft is approaching from the east, ground speed over the OM is 140 knots. Over the runway threshold, where the wind is essentially calm, ground speed should be only 100 knots if the target airspeed has been maintained during the approach. During the approach, therefore, ground speed must be reduced from 140 to 100 knots, a deceleration rate of 23 knots per minute.

But if the pilot is unaware of the strong tailwind over the OM, he won't anticipate the need to decelerate. This is the crux of the problem. When a tailwind decreases faster than ground speed is reduced, airspeed is forced to rise. The excess airspeed results in a tendency to rise above the glideslope (either visual or electronic) and, to compound the confusion, a possible pitch-up. Unless judicious control and power adjustments are made during the descent, the aircraft will wind up over the approach lights with excessive altitude and airspeed. The diminishing tailwind (or increasing headwind) approach has been responsible for innumerable overshoot incidents.

If the pilot executing this approach doesn't know why he is experiencing excessive airspeed and why he keeps "floating" above the glideslope, there is yet another clue (in this case) to warn him of the presence of a wind shear. As the descent continues, the counterclockwise shifting of the wind necessitates a constantly changing crab angle if the aircraft is to remain on the localizer.

Figure 5



Left turn into a wind: Shift line such as a cold front results in the loss of a headwind, followed rapidly by the gain of a tailwind. Airspeed loss can be dramatic.

This example utilizes a wind gradient of 40 knots per 1,100 feet, or 3.6 knots per 100 feet. During wind-shear studies in Florida and Texas, this has been found to be an *average* gradient. Low-level wind shears ten times this magnitude (35 knots per 100 feet) have been observed. A gradient of 10–15 knots per 100 feet is not considered unusual.

When the pilot in Figure 4 is approaching the runway from the west, conditions are reversed. Ground speed during the approach must be increased from 60 to 100 knots. If this is not done, airspeed will decay in proportion to the headwind loss that occurs during the descent.

To avoid sinking below the glideslope, losing critical airspeed, and encountering a possible pitch-down, considerable and seemingly excessive power must be applied during the descent. This poses another threat, since less reserve power is available for a pullup and missed approach. Such a loss of headwind requires considerable pilot attention and action to avoid the potential undershoot. During such conditions, aircraft have developed high sink rates and contacted the approach lights with all engines developing full power. Similarly, aircraft *departing* into an area of either an increasing tailwind or a decreasing headwind have settled into the ground, also with engines developing full power.

When a pilot finds himself nearing the ground while having difficulty maintaining a safe airspeed/sink-rate combination, he must execute a missed approach and either try again, wait for the wind shear to subside, or divert to another airport.

Anyone who is under the mistaken notion that wind gradients cannot affect him in this manner should be interested in what happened at JFK one day in April 1971. Aircraft approaching the airport encountered a decrease in tailwind of 20 knots per 1,000 feet, and during a two-hour period nine professional pilots executed missed approaches (some diverted to other airports) even though the surface wind was light and the ceiling was 700 feet with adequate visibility below.

The effect of penetrating a squall line, front, or sharp pressure trough (Figure 5) during a left turn deserves particular emphasis. This is uniquely dangerous because an aircraft could simultaneously encounter a rapid airspeed loss because of an increasing tailwind component, a sudden increase in bank angle caused by the side component of the tailwind acting on wing dihedral, a severe downdraft localized at the leading edge of the shear, and turbulence of moderate or greater intensity. Several fatal approach and departure accidents have been traced to these causes.

When you turn away from a squall line (or any severe weather condition), do so with a right turn, not a left one (in the Northern Hemisphere).

With respect to fronts, low-level wind shear can be expected during frontal penetration when the system has a speed of 30 knots (or more) or when the temperature difference across the front is 10°F (or more).

Presently, the pilot's only weapons against wind shear are caution, conservatism, wit, and attention to the elements. But the future may offer some help of a more scientific nature.

NASA and other agencies are working on methods of measuring low-level wind shear. Someday, laser and/or acoustic/Doppler devices may be installed adjacent to some runways and will accurately measure the actual wind profile throughout the approach and climbout corridors. But since wind shear is extremely dynamic and localized, such systems would be required for all runways, something not economically feasible.

Another weakness of a ground-based system is that the necessary data regarding the changing characteristics of a given wind-shear condition cannot be passed on quickly enough to the pilot, who most urgently needs the information. The Air Line Pilots Assn. (ALPA) is pressing for the development of on-board wind-shear sensors, to which pilots could refer during an approach or a departure.

In the meantime—and probably in the future—the general aviation pilot is left to his own devices. He must learn to recognize the existence of wind shear, understand how it can affect his very survival, and, above all, obey one of aviation's most golden rules: "Maintain thy airspeed lest the earth shall arise and smite thee—mightily." ☐