

PROBLEMS PILOTS FACE INVOLVING WIND SHEAR

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Wind shear has been with us as long as there has been wind, but only recently re-discovered as a limitation to flight. Early pioneers of flight knew of some of the problems of wind shear effects upon their aircraft. In 1896, aviation pioneer Otto Lilenthal was killed in a glider probably for the same reason modern hang glider pilots are being killed, that is, lack of lateral control sufficient to handle the turbulent wind conditions close to the ground. Recognizing this problem and devising a means of lateral control was probably the Wright Brothers' most important contribution to early flight--and also the subject of a bitter patent infringement suit against Glenn Curtiss for his use of an aileron.

Early flight manuals tell about the air losing its lift, air pockets and so forth to describe wind shear phenomena, but it has generally been regarded for several decades that modern aircraft could fly through any meteorological phenomenon except possibly a tornado. Educating pilots and the aviation industry to the contrary has been our biggest problem. In Pogo terminology "we have met the enemy and he is us". Having heard about the wind shear related accidents which were caused by "pilot error", we have been ill prepared to cope with strong wind shears because we depend upon our ability and skill to manipulate aircraft and do not easily admit we could make a mistake or error which would result in a serious accident.

When I first described how an aircraft could hit short in a decreasing tailwind shear (1969), published meteorological literature at the time expressed the conclusion that the strongest probable wind shears were on the order of 10 knots per 100 feet vertical travel. Meteorologists still call this vertical wind shear which the engineer and student of fluid dynamics calls horizontal wind shear. We don't even have a common language--which brings us to the pilot's second most pressing problem--the need for a language to discuss wind shear encounters with other pilots so that the reaction of the aircraft to the wind shear encounter can be accurately described without expecting all pilots to be experts in wind shear analysis. For several years I have been suggesting the use of positive and negative shear as follows:

Positive Shear: A shear which results in the aircraft having a tendency to increase airspeed and/or overfly the glidepath.

Negative Shear: A shear which results in the aircraft having a tendency to decrease airspeed and/or underfly the glidepath.

These definitions are important, I think, because reporting a decreasing tailwind shear or a tailwind to headwind shear does not accurately describe the reaction in all cases and requires interpretation. As I have consistently pointed out, a decreasing tailwind which is always a decreasing tailwind can change from a positive effect to a negative effect if the pilot corrects for the rate of encounter and if the rate of encounter subsequently decreases, (See Figure 1). In this case if "wind shear" is simply reported, a following pilot could interpret

the positive effect as the only effect and be even more unaware than if he heard no report at all. A report in this case such as "a positive shear at the outer marker with a moderate negative shear at the middle marker" would accurately describe to a following pilot what to expect. This type effect usually is encountered in the situation such as that which caused the Iberia DC-10 to crash at Boston, that is, shortly after a cold front has passed the airport so that most of the approach is done with a decreasing tailwind aloft. For positive shears which occur all the way to the ground, it is important that following pilots are aware of the type effect they are expected to deal with. Otherwise they are likely to add far too much speed to complete a successful landing.

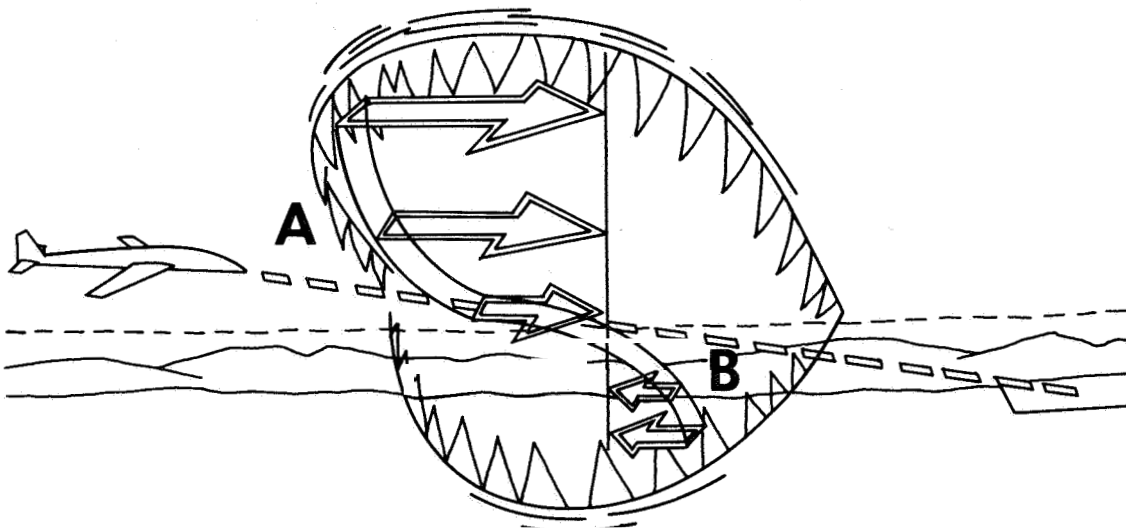


Figure 1

CAUTION! Shears associated with thunderstorm downdrafts are likely to cause pilots to report strong positive shears which will become strong negative shears as a thunderstorm downdraft moves from the far end to the approach end of the runway. Initial encounters will be only with the front side of the downdraft base area since the aircraft will be on the ground before passing through the base area (See Figure 2). All wind shears which are associated with thunderstorms should be considered as having the potential for severe negative reaction regardless of how they are reported.

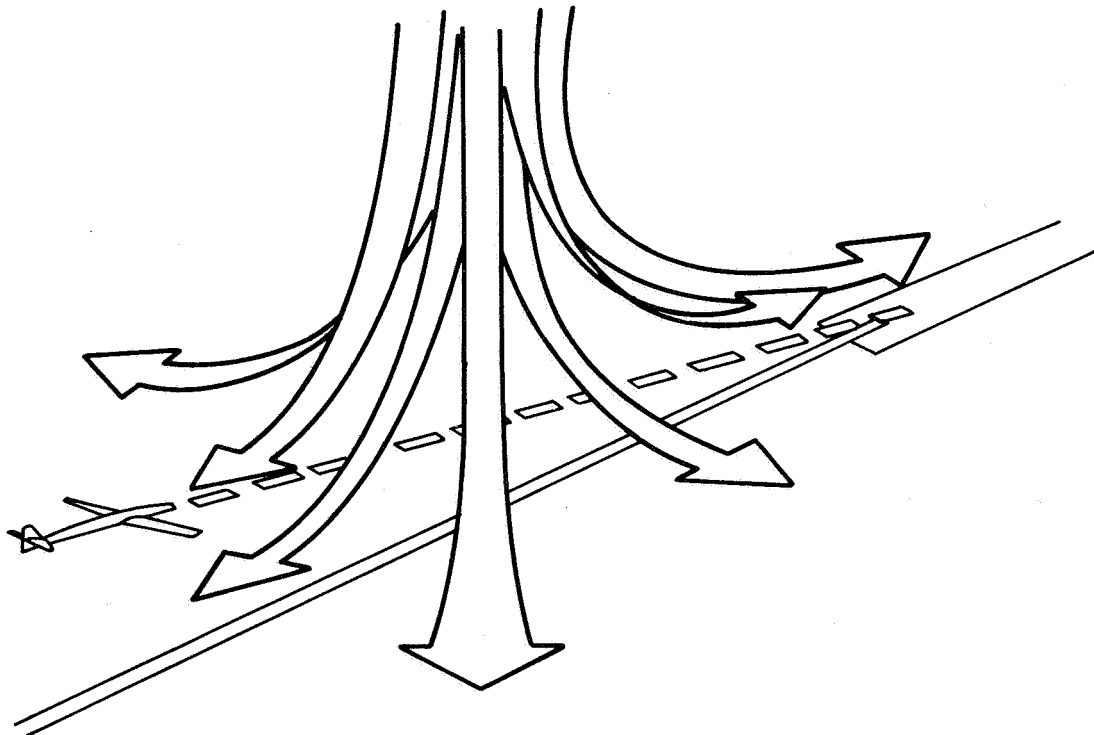


Figure 2

It appears at present that the severe downdraft or downburst, as named by Dr. Fujita, is very rare. They apparently can come from small thunderstorms as well as large ones, but in both cases the cells must have rapid development. This presents a real problem to pilots. We have all flown beneath thunderstorms with very little adverse effect. In fact, this was recommended when I went through flight training. Downbursts are rare and unpredictable, and pilots want to complete their mission. Adequate training and communication between pilots could help avoid some downburst accidents since there has usually been some evidence to preceding pilots before the accident or incident. Although a warning of severe wind shear can reduce a pilot's recognition and reaction time, only a refusal to fly though the area will guarantee safety since no commercial aircraft, in the takeoff or landing configuration can adequately cope with an encounter of the base area of a downburst with outflowing winds on the order of 60 knots or more. Our best bet now, that is immediately attainable, is a network of anemometers along the arrival and departure routes to an airport with an automatic monitor to signal any gross deviation of wind condition to tower controllers so they can take appropriate action.

Dr. Fernando Caraceno, atmospheric physicist at NOAA, also suggests measuring pressure and temperature to determine these areas of significant deviation.

In training pilots we must make them aware of the fact that there must be inertial acceleration of the aircraft to correct **for** a negative shear, and that this acceleration which they feel can cause them to under react to the shear. In all cases when they detect a strong negative shear condition close to the ground they should advance full thrust and prepare for a go around if necessary.

Incidentally several instrument systems and autopilot/ autothrottle systems use longitudinal accelerometers to modulate the response rate, which means that for normal conditions when the aircraft has longitudinal acceleration, the response rate is retarded. In a strong negative shear condition through where longitudinal acceleration is required and the response rate needs to be increased, it will instead be decreased for these systems. This is one reason why a well trained pilot can beat the automatic system. Also, it is the reason why a potential flight path instrument or display will not work in a wind shear.

Another problem is the flight director which gives a centered pitch command for a given angular displacement from the glide slope. What may be sufficient for normal conditions may be inadequate for strong wind shear conditions. I have objected to the use of this as pitch command since I first saw one. They should instead be called flight path command and should not center unless the aircraft is actually correcting to the flight path.

This opens the whole arena of aircraft instrumentation. Basic to our present problem is that our primary instrument, the attitude indicator, does not tell us where we are going relative to the horizon. The pilot must integrate into his thinking the descent rate and glide path position to determine where he is going. However, under good visual conditions he has instant recognition of where he is going because he sees the aircraft's trajectory, terminating at that point on the runway that doesn't move. Limitations to a pilot's recognition of a hazardous situation which are inherent to his instrument system and operational procedures may be the determining factor in many accidents. One recent aid has been the Ground

Proximity Warning System (GPWS). Even though pilots are generally annoyed at the false warnings, this warning of glide path departure may be the pilot's first clue to a deteriorating situation. The GPWS is a band aid approach though. With better instrument systems we would be aware of a deteriorating situation before the GPWS told us about it.

A special problem in pilot recognition time occurs when the auto-pilot increases the aircraft's pitch close to the ground. While the pitch is increasing, the pilot's normal visual cue that the aircraft is going to hit short is obscured because he does not observe the runway rise in his field of view. If he is not aware of the condition and especially if he has just transitioned from a heads down instrument approach to a heads up visual landing, he will be several seconds late in recognizing his predicament. Even though in some wind shear accidents it can be proved theoretically that the aircraft could have made a successful landing or go around, we must consider the entire system which includes the pilot. His recognition and reaction times are often the crucial element. By training we can reduce the recognition time somewhat, but with better instrumentation displays we could cut the recognition time to a minimum.

Related to the instrument system is the method of flight control. Approach couplers utilize a method of flight control whereby pitch changes are used to correct for errors in flight path position and resultant changes in air-speed are expected to be corrected for with thrust. Flight directors command this type response. Aside from the fact that magnitudes of pitch correction which are suitable for stable wind conditions are not suitable for wind shear conditions, there is a serious conflict with aerodynamic theory--partly recognized in some late model systems which have coordinated inputs to pitch and thrust. To change the

direction of an aircraft's inertial vector requires centripetal force supplied at a change in lift. An increase in lift is accompanied by an increase in induced drag which if not immediately offset by thrust means a decrease in airspeed will result. In addition, to fly a less negative flight path angle requires a definite amount of thrust increase. Thus for a known thrust deficient condition where the aircraft is going below the glide slope, thrust must be added along with a change in pitch. However, except for the brief application of centripetal force requiring a momentary increase in angle of attack, the net result of the pitch change is to maintain a constant angle of attack, while the change in thrust is the major contributor to a new flight path. The old rule "Attitude plus power equals performance" is as correct today as when I went through navy flight training.

Those who explain to themselves and others the effects of wind shear based on an assumption of instantaneous change in airspeed. Their view imposes an assumption that a change in airspeed is the first observable effect of a shear, and of course they argue for a thrust correction to rectify the situation. I certainly agree that whatever causes the pilot to first observe a thrust deficient condition should cause immediate corrective action. However, in a negative shear condition of a reasonably finite rate, an aircraft with positive longitudinal stability will of its own accord pitch over to maintain its trimmed airspeed. Only after the aircraft departs from the glide slope will the autopilot (or pilot) exert an elevator input which will cause an airspeed decrease. The deficient thrust condition should be recognized before the airspeed decrease, but again if the airspeed decrease

is the pilot's first observation of the condition, he should certainly respond.

A competent pilot upon sensing a thrust deficient condition will respond with thrust and pitch, but the autopilot responds only with pitch. The pilot then must interpret the autopilot response before adding thrust. This is a serious limitation of auto coupler approaches, and flight director approaches if pitch command is used as an action uncoordinated with thrust. Fortunately most pilots coordinate the two and have learned to anticipate the approach coupler, but unfortunately some have used the uncoordinated action of the approach coupler to argue a fallacious method of flight control that can only be demonstrated by uncoordinated action. The alarming fact is that they want to force beginning instrument flight students to adopt their uncoordinated method. **An** energy trade is a more rapid response than a thrust change so they get deeper into their problem by forcing an energy trade before a thrust response. Indeed a certain amount of energy trade will occur but a pilot content with uncoordinated action will be very late in responding with thrust in a strong wind shear. An intentional energy trade should be reserved for drastic conditions which is the reason for carrying extra airspeed. Energy not traded can be used at any time, but thrust not applied is lost forever.

Since a large part of what we think we know about wind shear effects upon aircraft has come from review of past accidents and incidents, we should be careful in reviewing the data. In most cases 4 channel flight recorders were being used which means that to determine the magnitude of a shear a thrust level must be assumed. Since the Airline Pilot Association generally believes the pilots were telling the truth, we usually come up with larger shear values

than other parties who want to make assumptions of lesser thrust levels. In some cases, to come up with a modest shear or none at all, the pilots would have to have selected reverse thrust while the aircraft was several hundred feet in the air. We believe that most hard landings have been caused by wind shear and that the problem has been far greater than formerly suspected.

The most important safety hedge the pilot has had to protect himself from an adverse encounter with wind shear has been the pad of airspeed he puts on for "Mama and the Kids". I believe that many potential wind shear accidents have been avoided by pilots' good judgement in this matter. Extra airspeed is a double edged sword though--the extra energy which is so important in protecting against a strong negative shear encounter can severely limit the stopping capability with a positive shear encounter.

The effect of runway over run accidents upon approach procedures must be examined and put in their proper context. For many years the industry has not recognized a very important factor in runway over runs. In most cases the aircraft touched down long and fast, usually due to wind shear. So called safety experts have been quick to label this as pilot error. They argue that if the aircraft hadn't landed long and fast the accident wouldn't have occurred. However, in almost all cases if the stopping capability after the touchdown had been what the pilot was accustomed to having the accident also would not have occurred. The important point that has been so often overlooked is that the pilots almost invariably were aware of their long fast touchdown and believed they could stop the aircraft. Since all such previous accidents occurred from "pilot error" rather than inadequate stopping capability,

pilots have been unprepared to cope with their situation.

When a pilot gets his first case of rubber tread reversion, with water ingestion into engines causing loss of reverse thrust or a number of other factors which rapidly compound, the situation can grow into one he may be incapable of handling. The point though is that instead of recognizing the serious limitations of stopping under adverse conditions, educating the pilots and correcting the runway friction problem by grooving, the simple solution has been to insist on using low approach speeds. Now I certainly don't approve of arbitrarily adding speed increments when the need doesn't exist nor do I approve of long fast touchdowns, but I am very much against the intimidation of pilots to not use the speed required for the existing condition. I hope pilots will continue to exercise good judgement and add extra speed in turbulent conditions despite intimidation by those more interested in proving their past actions have been correct than in safe operating procedures. If so, there should continue to be cases of pilots being high and fast over the threshold. However, with proper appreciation of the stopping problem, such cases should result in go arounds instead of over runs. The rule of adding one half the steady wind plus all of the gusts is inadequate for wind conditions different than observed by the tower, but some in the industry want to rigidly limit a pilot's judgement by this rule. To do so runs the risk of causing more approach accidents short of the runway. Although the rule is generally a good one it should not be used to limit pilot judgement of the actual condition which may be totally irrelevant to the ground reported wind.

Recent emphasis has centered in downbursts related wind shear, but other types should not be disregarded. Many pilots still do not know what to expect when a front lies close to an airport, and the low level or nocturnal jet stream is practically unknown.

Joe Gera of NASA Langley, in his paper (NASA TN-D-6430, 1971) describes how a strong increasing headwind could excite the phugoid oscillation of some aircraft. It is a known fact that some jet upsets occurred while encountering strong increasing headwinds. More study needs to be devoted to this area and if a hazard exists, pilots need to be informed.

In several downdraft related wind shear accidents and incidents we have been able to produce WSR-57 radar pictures of the thunderstorm cell that caused the accident or incident, yet that vital information which was recorded at the time was unavailable to the flight crews flying beneath the cells.

If we are to have safe operations without unduly limiting them, we must better develop our information gathering and knowledge of wind shear. There is a risk of operation of anything that moves and our job is often one of risk assessment. Just as many factors come together in precise focus to cause an accident, the absence of a single one can make the difference between a fatal accident and a good story. We must not be content with single solutions as there are no panaceas. We need to unload as many chambers as quickly as possible before the hammer falls again on the proper combination.

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