VAISALA / APPLICATION NOTE

Wind shear - an invisible threat to flight safety

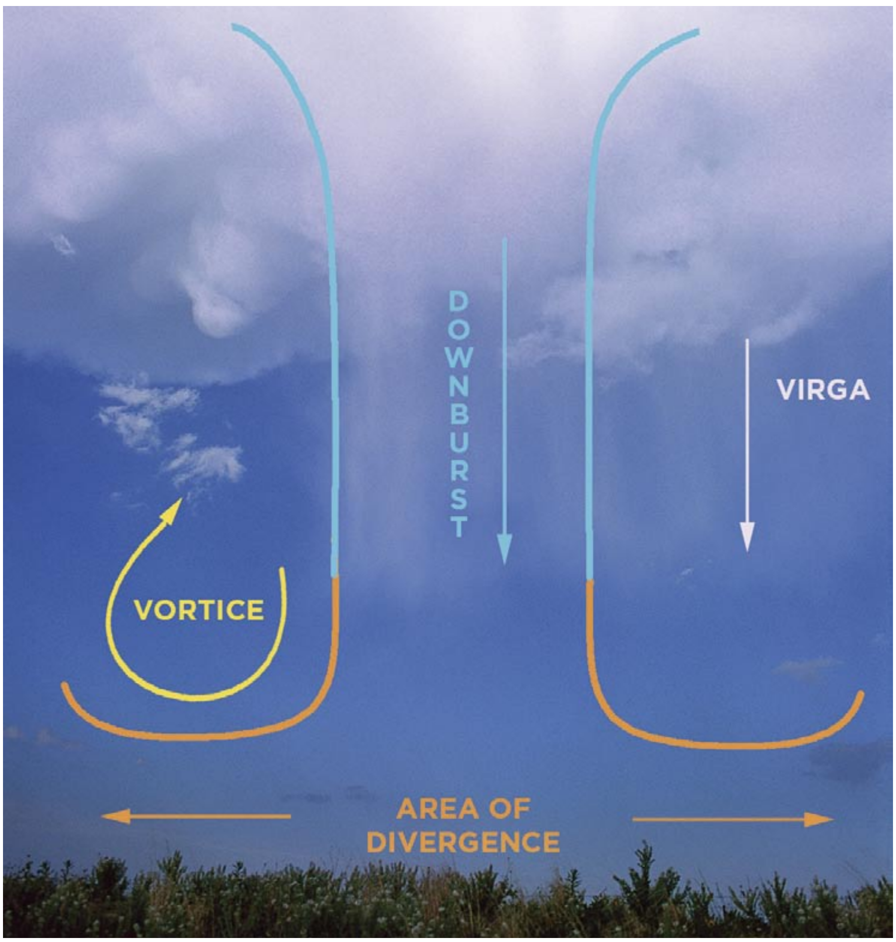


Fig. 1 Elements of a microburst, showing downburst, area of divergence and horizontal outflow of wind, an example of vortices, and virga. (Picture: Sari Jay)

Summary

Wind shear is a sudden change in wind speed and/or direction. Wind shear is usually caused by microburst-generated downdrafts hitting the ground and rapidly spreading in all directions. Unpredictable changes in wind speed and direction make it difficult to control the aircraft, with headwinds, tailwinds and up and down drafts all in quick succession. At worst, it can cause a sudden and dramatic loss in altitude resulting in a serious accident. Air traffic controllers have no means to directly detect a low-level wind shear hazard and are not capable of warning pilots during take-off and landing.

Methods to detect wind shear:

- The Low-level wind shear alert system (LLWAS) is specifically designed to determine wind shear of 15–30 knots and microbursts of over 30 knots up to 1,000 feet above ground level.
- Doppler weather radar rapidly scans boundary-level winds within the area of coverage at an airport can provide graphical and numerical data on wind shear events.
- A wind profiler provides vertical profiles of horizontal wind speed and direction, and vertical wind velocity up to an altitude of 3 km above ground level.

Introduction

Over 40 years ago, in the 1960s, low level wind shear was just being identified as the cause of serious and fatal accidents. At the time very little was known about clear air turbulence or its causes. Serious research was only started, in 1976, after a Boeing 727 crashed on landing at JFK Airport, USA. Theodore Fujita[1)] attributed low level wind shear, on the final approach to the runway, to be the cause of the crash. This accident instigated a systematic study, by the NTSB in the USA, of clear air turbulence and low level wind shear.

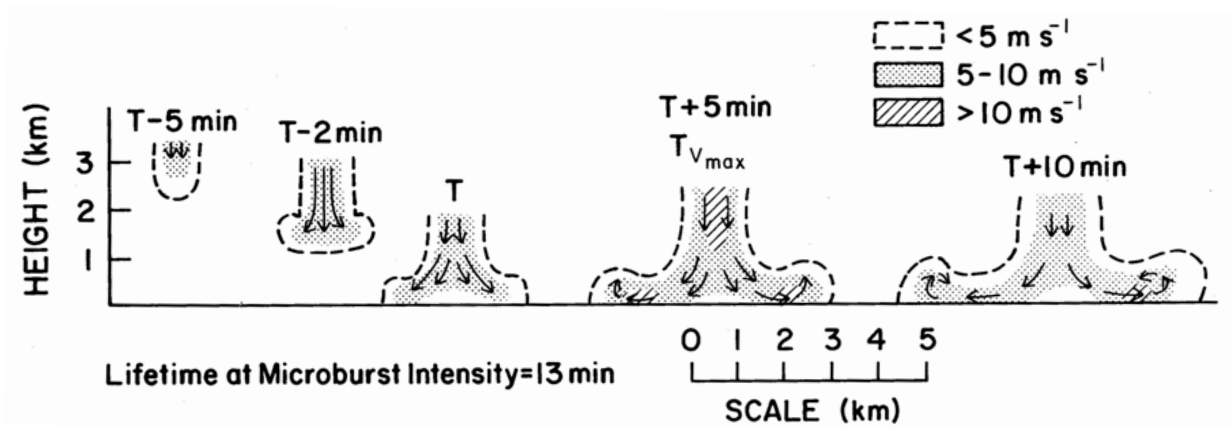


Fig. 2 Characteristics of a microburst (Source: NCAR)

In 1982, Theodore Fujita[2] participated in the Joint Airport Weather Studies (JAWS) project [3], which analysed more than 70 microbursts, and his paper, 'The Downburst', explains in great detail, the phenomena of microbursts. The definition of the microburst had a significant impact on the education of pilots. The Wind-shear Training Aid, 1987, [4] issued by the Federal Aviation Administration (FAA) of the USA, states: "avoidance is the best defence against the hazards of wind shear. A severe wind shear condition is beyond the handling ability of commercial aircraft and even highly skilful pilots." Better information on wind shear would help the pilot to deal with the effects. In addition, a wind shear alerting system would help ATC to maintain a traffic flow, despite the disruption caused by the phenomena.

What is wind shear?

Wind shear is a sudden change in wind speed and/or direction that results from a variety of meteorological conditions. These include temperature inversions, land and sea breezes, frontal systems, strong surface winds and, significantly, thunderstorms. Severe wind shear is defined as a rapid change in wind causing aircraft airspeed changes of greater than 15 knots, or vertical speed changes of greater than 500 feet per minute.

The wind shear associated with thunderstorms is referred to as a microburst (the vertical element is also known as a downburst). A microburst is an intense, localized downdraft of air that spreads radially on the ground. A microburst comprises of vertical, horizontal components and vortices. The vertical component is a powerful downdraft. The horizontal component is the divergent surface wind. The third element are the vortices around the downburst area. (See fig. 1) Microbursts are associated with convective weather, cumulus congestus and cumulonimbus clouds, and grow in strength as storm clouds mature. The downbursts can normally be expected below thunderstorm clouds, but the downburst may be at an angle which adds to the unpredictability of the downburst location.

When the downburst hits the earth's surface it radiates, and the strength of the horizontal winds may also be asymmetrical. There could be a greater flow in one direction and a lesser flow in the other direction. Around divergent area, vortices form that can have an upper limit of nearly 2000 feet above ground level, and they feed air back into the cloud. The horizontal outflow area is usually between 1 and 2 nautical miles (NM), about 2 to 3.6 km. The thunderstorm related downburst is usually a few hundred feet to a few thousand feet in diameter, about 100 m to 1000 m. (See Fig. 2)

The strength of the downburst is increased by precipitation. Regardless of whether the precipitation is rain, hail or virga, during their descent some moisture evaporates absorbing energy from the surrounding air. This causes the air to cool, to become denser, and thus the heavier air falls faster. The additional weight of large hail stones also contributes to the acceleration of the downburst. The life span of a microburst is associated with that of the mature stage of the thunderstorm, and is usually about 15 to 20 minutes, rarely longer than 30 minutes. They are known to generate winds of greater than 145 knots, 75 m/s or 270 km/h.

Aircraft aerodynamics and wind shear

The wings of an aircraft are designed to be at the optimum angle of attack for straight and level flight. When the speed of the air over the wing changes or if the angle of attack changes the ratio of lift changes. When an aircraft suddenly passes through a downburst, the angle of attack of the wing to the airflow becomes negative, a pocket of low pressure forms below the wing, and the wing falls to fill it. The aircraft now only has forward speed, but is losing very rapidly in height. Should tail wind and downdraft occur close to the ground during landing, there is practically no time to recover before hitting the ground.

During take-off, the aircraft is usually fully laden, and then a good headwind is favorable for take-off. If a microburst is over the centre or the end of the runway, then the outflow will be seen as a good headwind. The aircraft takes off with the wings in an angle for optimum climb. Climb is effective as long as the headwind holds steady. If the aircraft should pass through the downburst at this critical phase, the lift is lost. Next, the aircraft is hit by an equally strong tailwind. (See Fig. 3)

Identifying the incidence of wind shear

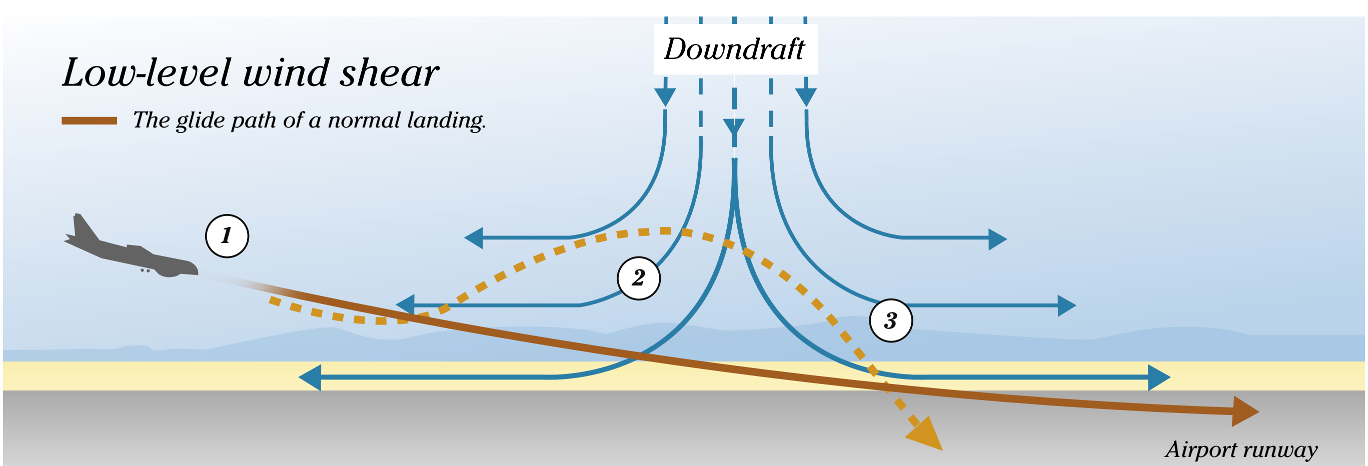
A thunderstorm in the vicinity of an airport is a visible clue of the possibility of wind shear, but not all convective storms spell wind shear. Normally anvil-head storm clouds are clear indicators of wind shear, but pin-pointing the downburst area is not that simple. It is easy to assume that closer to the ground, the horizontal flow of wind is away from the cloud, but it is difficult to assess the wind speed.

At airports, a network of wind sensors helps to see anomalies in wind speed and direction. If the data from these sensors are shown on separate displays, it requires that the air traffic controller (ATC) checks all of them to assess the possibility of wind shear. Normally, the ATC gives wind shear readings to the pilot in conjunction with the clearance to land. Pilots need to be vigilant, and to take note of wind readings given to aircraft landing and taking-off ahead of them, in order to prepare themselves for the variable wind conditions.

In cases of severe wind shear, the wind shear information can be transmitted by the airport's Automatic Terminal Information Service, (ATIS). In any case, as wind shear cannot be predicted, the start of the event, when the down draft hits the ground and outflow begins, it surprises everyone, ATC and pilots alike. If, for example, the aircraft's tailwind tolerance is 10 knots, a typical microburst wind shear of even 40 knots, would be devastating as a downdraft or a tailwind.

Wind shear alerting is necessary

The unpredictability of wind shear complicates the ATC's role while



1. *A headwind slows and lifts the aircraft above its normal flight path.* ***2.*** *While the pilot compensates for the headwind by dipping the nose, the aircraft enters a downdraft.* ***3.*** *A tailwind dangerously reduces the aircraft's speed.*

Fig 3 Wind shear's effect on flying.

controlling air traffic. The rapid changes in wind, as the microburst sweeps across or past the airport, may lead to quick runway changes, which interferes with traffic patterns and Air Traffic Management (ATM) processes. The danger of a sudden, dramatic loss in height during landing and take-off could cause a serious accident, so it is important to avoid situations that threaten the safety of aircraft.

Efficient handling of air traffic in and out of an airport, with tools that improve airport safety installed, increases traffic figures and profitability. Having wind shear data conveniently at hand, eases the ATC's burden, and increases the pilot's confidence in flying at that airport.

How could ATC be alerted of wind shear the instant it begins? One solution would be a system that gathers wind data from a network of wind sensor sets, analyses the data, and alerts ATC when significant variability in wind speed and direction is detected.

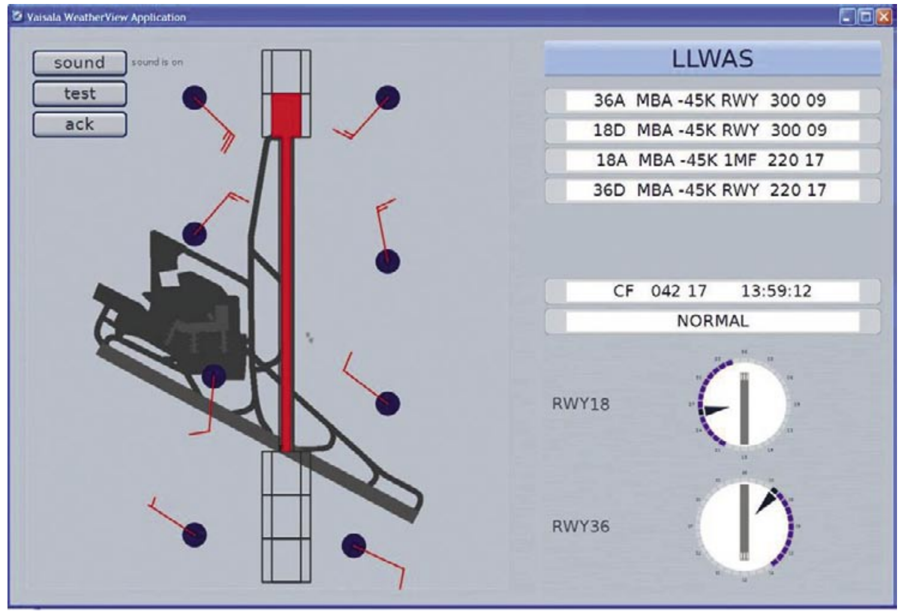


Fig. 5 An LLWAS display showing the sensors and wind shear information.

Methods for countering wind shear

Low-level wind shear alert system

In 1985, the FAA funded a second initiative, the Classify, Locate, and Avoid Wind Shear (CLAWS) project [5], which developed an algorithm for a Low-Level Wind Shear Alert System (LLWAS). The LLWAS was specifically designed to determine wind shear of 15–30 knots and microbursts of over 30 knots up to 1000 feet above ground level.

The system comprises wind speed and direction sensors sited around the runway area, connected to a data collection unit, on site. The data collection unit powers the

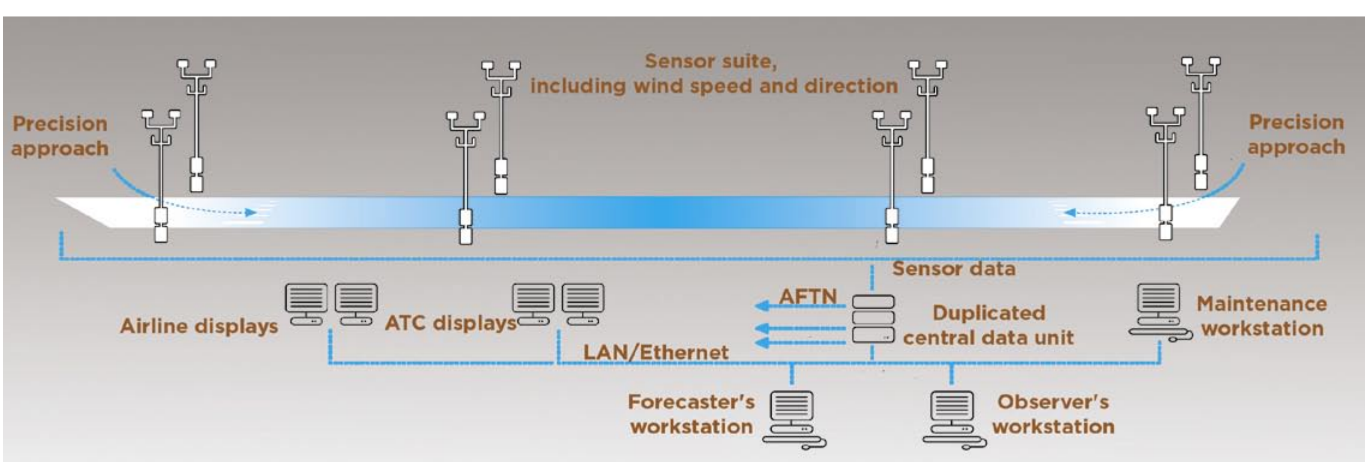


Fig. 4 A typical LLWAS consisting of field sensors, central data unit(s), communication interfaces and different workstation types.

anemometers, collects data and transmits it to the main computer. The LLWAS algorithm analyses wind differences between anemometer pairs (edges) and inside triangles using three anemometer sites. The wind data is interpreted by the LLWAS in order to identify divergence or convergence, and to estimate the effects of the wind shear on aircraft. (See Fig. 4) The sensors are placed high enough to avoid local wind interference, 15 to 30 m above the ground. The wind shear data can be displayed either as text or graphically. The alerts are presented visually and audibly. The graphical display the areas of wind shear in relation to the runway(s). (See Fig. 5)

Weather radar

The advent of the weather radar in the early 1980s introduced an alternative method of detecting weather elements which quite quickly developed to include the detection of wind and wind shear. Doppler weather radar can provide wind shear detection and reflectivity data to air traffic controllers. Doppler weather radar rapidly scans boundary-level winds within the area of coverage at an airport. This allows the radar to provide graphical and numerical data on wind shear events. The use of Doppler weather radar has played a significant part in the reduction of wind shear related accidents at airports. The wind shear alerts from Doppler weather radar may be merged with LLWAS alerts to increase probability of detection while lowering the incidence of false alarms.

Wind profiling

A third method of detecting wind shear is by wind profiling. A wind profiler is a Doppler radar which provides vertical profiles of horizontal wind speed and direction, and vertical wind velocity up to an altitude of 3 km above ground level. Wind profilers have the benefit of indicating vertical wind shear, due to the vertical profile of the wind data. Wind profilers provide wind measurements within their scope of measurement, but they do not detect or provide horizontal wind shear alerts.

A combination of systems provides a greater range of information on wind shear. The selection of one or more systems is reliant on the site and its environmental factors, also the types of wind shear that most commonly occur at the site should be considered. Obstacles at the site may be the cause of wind shear, and obstacles may also interfere with wind shear detection. Depending on the circumstances at the site and its environs, weather radar data merged with wind profiler data may provide all the data needed, while in other circumstances a combination of an LLWAS with a weather radar would be more appropriate.

The effects on airport and airline business

In the USA, between 1964 and 1985, over 25 accidents were attributed to wind shear, incurring 625 deaths and 200 injuries [6]. Following the CLAWS project, the FAA installed LLWASs at all major airports in the USA. This contributed to the safety of flight and dramatic reductions in wind shear related incidents and accidents were recorded in the following decades, in the USA. In contrast, the statistics for the rest of the world did not show reduction, even though reductions occurred in Europe and Japan, where LLWASs had been installed. One can assume that installing an LLWAS, significantly reduces the risks related to low level wind shear.

If the potential risk of suffering losses, due to accidents or delays, is reduced it can be seen as a clear benefit for airline business and airport operations.

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This application note is based on a white paper authored by Sari Jay, June 2009.

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