HAZARDOUS WEATHER PHENOMENA

Wind Shear

Wind shear is a common phenomenon within the atmosphere, occurring at any level where adjacent layers or columns of air have different velocities. It can produce sudden changes in aircraft altitude and speed.

Introduction

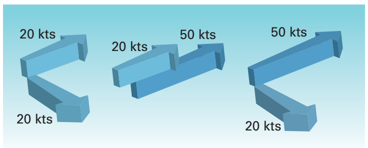
Wind shear is defined as a wind direction and/or speed change over a vertical or horizontal distance.

It is significant when it causes changes to an aircraft's headwind or tailwind such that the aircraft is abruptly displaced from its intended flight path and substantial control action is required to correct it.

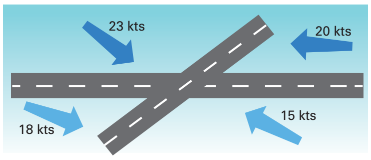
Although wind shear may be present at all levels of the atmosphere, its occurrence in the lower levels is of particular importance to aircraft taking-off and landing. During the climb-out and approach phases of flight, aircraft airspeed and height are near critical values, rendering the aircraft especially susceptible to the adverse effects of wind shear. The response of aircraft to wind shear is extremely complex and depends on many factors including the type of aircraft, the phase of flight, the scale on which the wind shear operates relative to the size of the aircraft, and the intensity and duration of the wind shear encountered.

It should be noted that wind shear is always present in turbulent air, but windshear can occur without turbulence being present.

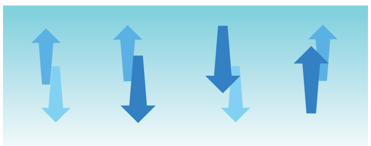
Types of wind shear



Vertical wind shear.



Horizontal wind shear.



Updraft and downdraft wind shear.

Vertical wind shear is defined as change of horizontal wind direction and/or speed with height.

Horizontal wind shear is the change in wind speed and/or direction at the same level.

Updraft and downdraft wind shear is the change in vertical wind velocity across adjacent columns of air. This type of shear is often encountered with convective activity.

Aircraft taking-off may be significantly affected by changes in headwind and tailwind components which create changes in the amount of lift experienced. A decrease in the vertical headwind component, or an increase in the tailwind component, will result in a reduction in airspeed, and in extreme cases the resulting loss of lift may be enough to cause the aircraft to stall or fly into the ground.

For aircraft landing, a decrease in the headwind component (undershoot shear) may cause it to drop below the target descent path and to land short of the runway threshold. An increase in the headwind component (overshoot shear) may cause it to fly above the target descent path leading to a late touchdown and possible overrun.

The crosswind component of shear does not impact flight to the same extent as headwind/tailwind or vertical shear. In general it does not affect the airspeed and angle of attack and hence does not alter the equilibrium of forces on the aircraft in the vertical plane. It does, however, affect the drift and side-slip angles, which can cause added complications for the pilot if flying conditions are otherwise difficult.

Australian Government
Bureau of Meteorology

Causes of Wind Shear

Significant wind shear is often encountered with and in the vicinity of:

- Thunderstorms
- Frontal systems
- Sea breezes
- Frictional shearing
- Temperature inversions
- Obstacles
- Rotors
- Wake vortices

A wet microburst spreading outward from the main rain shaft with associated reverse flow evidenced by the rolling cloud/ dust (image © Jimmy Deguara, sourced from Manual of Aviation Meteorology 1st ed. 2003).

Wind Shear Associated with Thunderstorms

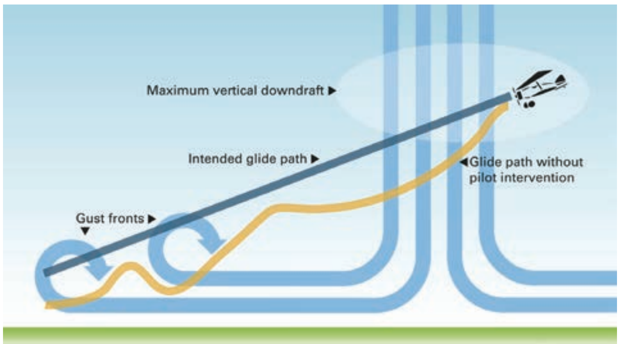
When thunderstorms (cumulonimbus clouds - CB) are forecast, pilots should be aware of the potential for significant wind shear. Towering cumulus clouds (TCU) may also create similar wind shear effects.

Wind shear between adjacent **updrafts** and **downdrafts** within such clouds can generate extreme turbulence. The danger is two-fold:

(a) Severe loadings may be imposed on the aircraft structure; and

(b) Violent changes in aircraft attitude may induce stall or other conditions in which an attempted recovery may exceed the design limitations of the aircraft.

The outflow from the cloud's downdraft can produce damaging winds on and near the ground. The term **microburst** is used to describe a downburst which causes damage over an area with horizontal dimensions of less than four kilometres. The microburst is the most violent form of wind shear produced by CBs. If it occurs over an airport, aircraft landing or taking-off may encounter strong headwinds, then



Microburst effects on an aircraft glide path while landing. The microburst spreads out rapidly once it contacts the surface. The horizontal outflow is a region of strong vertical and horizontal wind shear, which reaches its maximum in the first vortex.

strong downdrafts followed by strong tailwinds. As microbursts can be symmetric or asymmetric, pilots should not expect to always experience the standard sequence of microburst encounter. Microbursts can be wet (i.e. occurring with precipitation) or dry.

A **gust front** is the leading edge of the cold air outflow from a CB after a downdraft reaches the ground and spreads out in all directions, undercutting the surrounding warmer air. In this respect it resembles a shallow cold front except that the associated wind shear is generally far higher in the gust front. The gust front initially travels along the ground equally in all directions. However if the CB itself is moving, as is generally the case, the gust front advances furthest and fastest ahead of the CB in the direction of the cloud's movement. There is marked horizontal wind shear at ground level following the passage of the leading edge of the front, and because the front may be tens of kilometres ahead of the parent storm cell, such a sudden change in the surface wind may take pilots completely by surprise. The change in the surface wind direction is often as much as 180 degrees and the speed of the gusting winds following passage of the front can exceed 50 knots. The gust front ahead of squall line thunderstorms (a multicell thunderstorm where cells are arranged in a long line) can be tens of kilometres wide, i.e. spanning the length of the multicell storm.

Wind Shear Associated with Frontal Systems

Frontal systems consist of air masses of different temperature separated by a narrow zone called the frontal zone, the region where wind shear significant to aviation is most likely to occur. Vertical wind shear occurs at and behind the cold front, and since the frontal zone usually slopes back with height, the height above a specific location at which maximum vertical wind shear occurs will increase with time following the passage of the cold front at that location. At ground level there is also horizontal wind shear across the front although, given the usual speed of movement of fronts across an aerodrome, this may be short-lived.

Wind Shear Associated with Sea Breezes

A sea breeze is essentially a shallow cold front because cooler air is replacing warmer air. Wind shear occurs predominantly at the surface along the leading edge as the front

Wind shear is caused by a change in wind speed and/or direction resulting in a change in headwind or tailwind that can displace an aircraft abruptly from its intended flight path, requiring substantial control action to be taken.

This compares with turbulence which may disturb the aircraft's attitude about its major axis, and cause rapid bumps or jolts to be experienced, but in most cases it does not significantly alter the aircraft's flight path.

penetrates inland, although wind shear of lower magnitude exists at higher levels. The extent of a sea breeze at any particular location is influenced considerably by the surrounding topography and therefore may be of a localised nature. If the prevailing wind is offshore, the sea breeze front may be marked by a line of convergence and vigorous convection that in favourable circumstances gives rise to lines of showers or even thunderstorms.

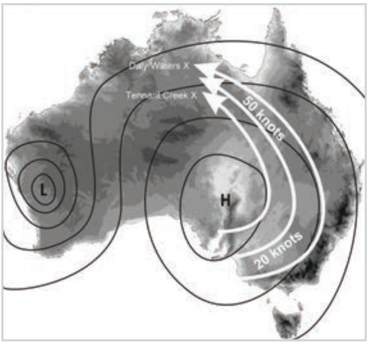
Wind Shear Associated with Frictional Shearing of Surface Winds

The lower atmosphere is sheared by frictional forces dragging airflow towards zero at the surface. This can result in significant differences between the surface wind speed and that at higher levels. The resultant shear intensity can be greater over flat and open land than over rougher terrain because the rougher elements generate turbulence to a greater depth, having the effect of mixing out layered velocity fluctuations.

Wind Shear Associated with Strong Temperature Inversions

Frictional shearing is enhanced when low-level winds are decoupled from upper level winds due to overnight radiation inversions. Such inversions can almost completely cut off the downward transfer of the horizontal wind momentum to the boundary layer, resulting in large differences between surface flow (which may be light or even calm due to frictional effects) and the flow above the inversion. An aircraft descending through an inversion would pass through a zone of turbulence before experiencing a dramatic loss or gain of lift and airspeed. Temperature inversions are more pronounced in clear skies and wind shear is strongest around the inversion height.

When the inversions are very strong, **low-level jets** may form overnight, possibly just a few hundred feet above a calm surface wind. The jet speed can be enhanced ahead of an approaching cold front, and also windward of barriers such as hills and escarpments. The inversion is effective in shielding the flow above from surface frictional effects, allowing the wind speed to increase in a narrow band near the top of the inversion, with surface winds being very light or calm. A broad scale low-level nocturnal jet can extend over southern Queensland and the Northern Territory during the cooler months. The core of this jet is often located between Daly Waters and Tennant Creek, with a maximum speed of about 50 knots occurring around 3000 feet. It is usually strongest around dawn and dissipates by late morning. Funnelling of the wind through valleys and ravines may produce similar effects on a local scale.



Nocturnal low-level jet.

Wind Shear Associated With Obstacles

Strong surface winds flowing over obstacles (such as large buildings, low hills or close-planted stands of tall trees) upwind of an aerodrome can create localized areas of horizontal wind shear on a runway. In these circumstances the shear is usually accompanied by clear air turbulence (CAT). The effect that the obstacles have on the prevailing wind flow depends on a number of factors, the most important being the speed of the wind and its orientation relative to the obstacle, and the scale of the obstacle in relation to the runway dimensions.

Such wind shear, which is normally very localized, shallow and turbulent is of particular concern to light aircraft operating into smaller aerodromes but has also been known to affect larger aircraft.

Where a range of low hills lies alongside a runway, the height of the range may be insufficient to divert the airflow upstream of the range, but as a consequence of the airflow being forced upwards over the range the airflow acquires a compensating downwards vertical component downstream which, depending upon the proximity of the hills to the runway, can cause localized low-level downdrafts along the runway. Where the hills or mountains are sufficiently high to divert the low-level wind flow, the surface wind may be funnelled along the runway.

Forecasts & Warnings

Wind shear is a very difficult phenomenon to forecast and hence is only given in Wind Shear Warnings, which are issued for a limited number of aerodromes. They are issued when wind shear (that could adversely affect aircraft on the approach or take-off paths, or on the runway during the landing or takeoff phases, and during circling approach) is observed, reported or expected, between runway level and 1600 feet above that level.

Wind shear information will be included in SPECI, at airports where manual observations are provided, when reports of wind shear are received from pilots through ATC.

Lenticular cloud, image courtesy, David Miller.

Wind Shear Associated With Rotors in Lee Waves

On a larger scale, when the wind flow is forced over a mountain range a series of standing waves may be formed in the wind flow on the lee side of the mountains. The meteorological conditions most suitable for the formation of lee waves include:

- a stable layer of air sandwiched between two less stable layers, one near the ground and the other at a higher level;
- a wind in excess of 25 knots blowing within 30 degrees either side of a line perpendicular to the ridge line;
- little or no directional wind shear in the stable layer; and
- a marked mean sea level pressure differential across the mountain barrier.

If the lee waves that develop are of sufficient amplitude, a closed rotor eddy may be formed beneath a wave crest. In extreme conditions, such a rotor can penetrate to ground level and can reverse the prevailing surface wind directly below the rotor. Such stationary wave systems produce marked downdrafts close to the mountain, and also downdrafts of lesser magnitude at some considerable distance downwind from the mountain in secondary and tertiary waves.

Wind Shear Associated with Wake Vortices

Wind shear is generated behind every aircraft in flight, mainly as tip vortices forming two counter-rotating cylindrical vortex tubes trailing behind the wing tips. Such vortices are severe when generated by large, wide-bodied jet aircraft. The vortices generated by aircraft taking off can pose a significant hazard to aircraft following too closely behind. Air Traffic Control will apply appropriate separation minima to minimise the risk of wake vortex encounters.

Detection & Monitoring

Recognition of external meteorological clues to the possible presence of low-level wind shear near an airport gives the pilot an opportunity to make an early decision to avoid an encounter by going around or by delaying the approach or take-off until conditions improve. External clues that may be directly visible to the pilot include:

(a) strong, gusty surface winds, especially where the aerodrome is located near hills or where there are large buildings near the runway;
(b) virga from convective cloud, because downdrafts may still exist and reach the ground even though the precipitation itself has evaporated;
(c) a roll-cloud girding the base of a thunderstorm and advancing ahead of the storm cell, indicating the presence of a gust front;
(d) lenticular cloud (smooth lens-shaped altocumulus) indicating the presence of standing waves, usually downwind from a mountain;
(e) areas of dust raised by wind, particularly when in the form of a ring below convective clouds, indicating the presence of a downburst;
(f) wind socks indicating winds from different directions;
(g) smoke plumes, with upper and lower sections moving in different directions; and
(h) cumulonimbus clouds, which should always be assumed to have the capability of producing hazardous wind shear.

The Bureau relies on pilot reports, in the form of an AIREP, as the primary means of detecting wind shear. The AIP Book, GEN 3.6, section 11.1.1 states "A pilot in command should make a special AIREP …. as soon as practicable after encountering any …. MET condition which is likely to effect the safety .... of other aircraft."

Australian Government
Bureau of Meteorology

Airservices Australia is the official distributor of aviation forecasts, warnings and observations issued by the Bureau of Meteorology. Airservices' flight briefing services are available at www.airservicesaustralia.com. Telephone contact details for elaborative briefings are contained in Airservices' Aeronautical Information Publication Australia (AIP), which is available online through their website.

Other brochures produced by the Bureau of Meteorology's aviation weather services program can be found at www.bom.gov.au/aviation/knowledge-centre.