Low Level Wind Shear: Using Smoke Plumes for Guidance

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Low Level Wind Shear

Wind shear is defined as any rapid change in wind direction or velocity. Often, there is little or no turbulence associated with wind shear. Wind shear has long been recognised as one of the major aviation hazards in the airport environment. Severe wind shear is defined as a rapid change in wind direction or velocity causing airspeed changes greater than 15 knots or vertical speed changes greater than 500 feet per minute (Lankford, 2001). The operational requirement for information on wind shear in the lowest 600 metres (2,000 feet) of the atmosphere in the vicinity of aerodrome has been the subject of increasing interest because of their effects on aircraft - particularly during approach to land and take-off phases.

The degree of wind shear effect depends on a number of factors; with the most significant being aircraft momentum (which changes directly with aircraft mass and speed). Wind shear effects become noticeable when the wind changes faster than the rate at which the aircraft can be accelerated or decelerated. Thus a light training aircraft and a heavy transport aircraft, in the same flight conditions, may experience quite different degrees of wind shear effects. Clearly no prediction can be made of degree of shear effect. However, many weather services issue advisories, based on meteorological criterion that indicates the possibility of a wind shear encounter. These allow the pilot the opportunity to take appropriate action to minimise any effect.

Low level wind shear advices are generally based on recognition of fairly clearly defined meteorological phenomena (or synoptic situations), or measure vertical wind shears over layers of 1,000 or 500 feet. The criterion for forecasting low level wind shear is, in general, drawn from many American and overseas studies.

Several types of weather phenomena are conducive for the development of LLWS, namely: thunderstorms; fast moving fronts; low-level jets; temperature inversions; and strong surface winds.

Effect of Wind Shear

Although wind shear can occur at any altitude, it is particularly hazardous when it happens over a short period of time and within 2,000 feet of the ground, during takeoff or landing. During this phase of flight, the aircraft operates only slightly above stall speed, and a major change in wind velocity can lead to a loss of lift. If the loss is great enough that power response is inadequate, it results in a steep descent. The altitude at which the encounter occurs, pilot reaction time, and airplane response capability determine if the descent can be altered in time to prevent an accident.

Normally we think of changes in wind speed or direction as having an effect only on an aircraft's ground speed (GS) and track. However, when there is a very rapid shift in wind speed or direction there is a noticeable change in the aircraft's indicated airspeed (IAS) as well.

In a situation where there is a sudden increase in headwind (or decrease in tailwind) the aircraft's momentum keeps it moving through space at the same ground speed as before. This means that the aircraft will be moving through the air faster than before and there will be an increase in its indicated airspeed. The aircraft will react to this increase by pitching up and by tending to climb (or descend more slowly). When there is a sudden increase in a tailwind (or decrease in the headwind), just the opposite occurs. There will be a loss of indicated airspeed accompanied by a tendency to pitch down and descend.

Wind Shear in METARs

In some countries (e.g., Canada, United States) LLWS is presented in METARs. This group is used when LLWS within 1,600ft AGL is reported along takeoff or approach paths. The runway designator, (i.e., L, C, or R) may also be included. If there is wind shear on all runways, the term "WS ALL RWY" is used.

Montreal, Quebec:

METAR CYUL 112000Z 28010KT 15SM BKN036 BKN220 21/12 A3025 **WS RWY 06R** RMK SC6CI1 VIRGA S TCU EMBDD SLP262

Meaning: Wind shear reported off runway 06 Right. It can be seen that Virga to the south of the airport with embedded towering cumulus clouds is also observed.

In addition to the wind shear group in the METAR, valuable information can appear in the RMK section. This data can be cross referenced with the wind section of the METAR to indicate LLWS. The following two examples illustrate the value of "reading between the lines" to locate possible LLWS hazards.

Greenwood, Nova Scotia:

CYZX 261500Z **06007KT** 4SM -SHRA BR OVC040 03/01 A2968 RMK SC8 **WNDY HILL 11018G24KT** SLP050

Meaning: Wind observed at the Greenwood airport is from 060°T at 7 knots, however wind observed on top of Windy Hill (AUTO station located just north of CYZX – which is in a valley) is from 110°T at 18 knots, gusting 24 knots.

Wind Shear in TAFs

Wind shear can also appear in TAFs in some countries. For example, Canada and the United States have adopted this format of forecasting low-level **non-convective wind shear**. LLWS forecasts are included whenever strong wind shear that could adversely affect aircraft operations within 1,500ft AGL, can adequately be predicated.

Shearwater, Nova Scotia:

TAF CYAW 181935Z 182008 16008KT **WS012/27045** P6SM SCT015 BKN250 FM2300Z 18003KT P6SM SCT005 OVC200 TEMPO 0003 2SM BR BKN005 FM0300Z 12005KT 3SM BR FEW001 OVC005 TEMPO 0307 1/4SM FG VV001 FM0700Z 12008KT 3SM -SHRA BR SCT003 OVC009 TEMPO 0708 1/2SM -SHRA FG VV003 RMK NXT FCST BY 02Z=

Meaning: Wind shear expected to exist from the surface to 1,200ft AGL. The wind at 1,200ft AGL is expected to be 270°T at 45 KT.

Through arguably, in the interest of flight safety, expected wind shear conditions should always be plainly shown in forecasts; it is current practice for pilot to have to infer wind shear conditions when convective activity is expected. For example:

Peterborough, Ontario:

TAF AMD CYPQ 210004Z 2100/2102 **VRB30G45KT 1SM +TSRA** BR BKN007 OVC020CB TEMPO 2100/2101 15010KT P6SM -SHRA BKN040 PROB40 2100/2101 VRB35G50KT 1/2SM +FC +TSGRRA BKN030CB FM210100 20010KT P6SM BKN030 TEMPO 2101/2102 5SM -SHRA BR BKN020 PROB40 2101/2102 VRB20G35KT 1SM +TSGRRA BR BKN007 OVC020CB RMK FCST BASED ON AUTO OBS. NXT FCST WILL BE ISSUED AT 210945Z=

Meaning: Between 0000Z and 0200Z, wind will be variable at 30 knots, gusting 45 knots in thunderstorms with heavy rain. Pilots should expect downbursts (i.e., mircro/macroburst activity).

Low Level Wind Shear Classification

LLWS is very difficult to predict, especially with limited data. However, with the classification and knowledge of conditions conductive to LLWS, it is possible to forecast LLWS. Despite forecasting with this knowledge, LLWS conditions may or may not appear. Further, the actual vs. forecasted intensity may differ significantly. Table 1 provides a summary of conditions that are associated with LLWS.

Table 1: Low Level Wind Shear Classification

Transient	Non-transient
Convective • Cold Air Outflow • Gust Front Nose • Downburst • Microburst	Frontal Boundaries • Warm Front • Cold Front
Gravity Waves	Land Breeze /Sea Breeze
	Troughs
	Inversions
	Low Level Jet streams
	Downslope Winds (Katabatic)
	Lee Winds
	Mountain Waves (Rotor Clouds)
	Obstacles to prevailing wind flow (i.e., due to terrain)

It should be noted that **transient** refers to the fact the phenomena are usually short lived. Whereas, **non-transient** refers to the fact that the phenomena are either regular local occurrences and/or their effects are usually “felt” longer in comparison to transient.

LLWS and Temperature Inversions

When the lapse rate temperature increases with altitude, there is a temperature inversion. Even though this produces a stable atmosphere, inversions can cause turbulence at the boundary between the inversion layer and the surrounding atmosphere. The resulting turbulence can often cause a loss of lift and airspeed near the ground, such as when a headwind becomes a tailwind, creating a decreasing-performance wind shear. Hence, it is important to know how to recognise and anticipate an inversion in flight so you can prepare and take precautions to minimise the effects. If you are caught unaware, the loss of lift can be catastrophic because of your proximity to the ground. Inversions often develop near the ground on clear, cool nights when the winds are light and the air is stable (i.e., under High Pressure areas). If the winds just above the inversion grow relatively strong, wind shear turbulence can result.

Figure 1 shows a wind shear zone and the turbulence that developed between the calm air and stronger winds above the inversion. When taking off or landing in near-calm surface winds under clear skies within a few hours of sunrise, watch for a temperature inversion near the surface. If the wind at 2000 to 4000 feet AGL is 25 knots or more, expect a shear zone at the inversion. Pilots should prepare themselves, allow a margin of airspeed above normal climb or approach speed if turbulence or a sudden change in wind speed occurs in order to counteract the effects of a diminished headwind or increased tailwind at and below the inversion.

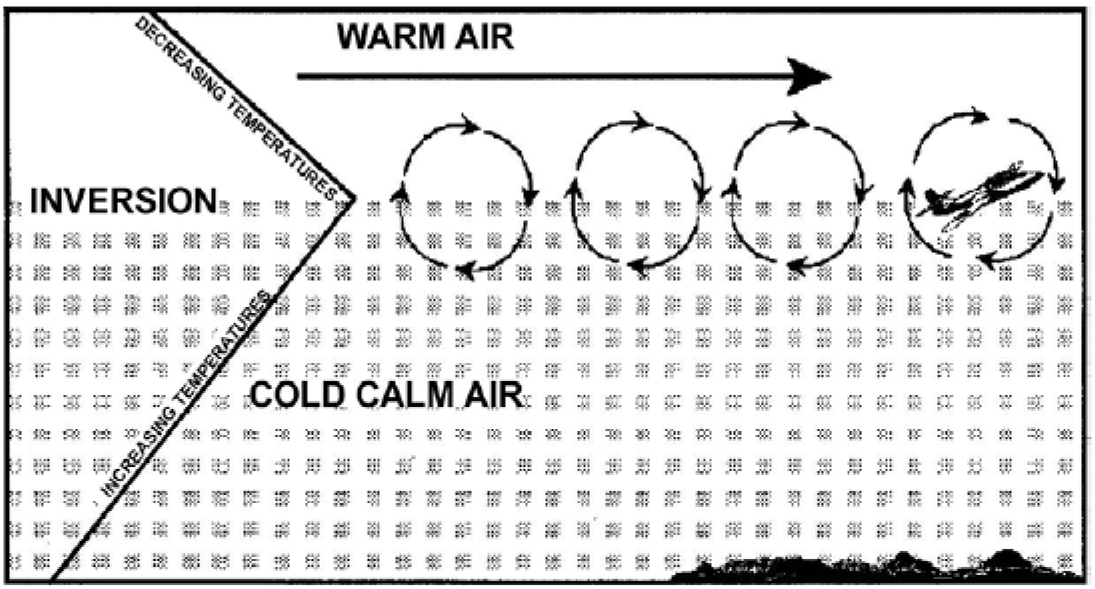


Figure 1. Wind Shear Associated With a Temperature Inversion[1]

Visual Indications of Stability

Stability in the boundary layer can vary greatly diurnally. Knowledge of the boundary layer is useful for several reasons. If a low-level inversion is present, generally any wind at the surface will be light and not representative of the synoptic flow pattern. Here are some generalities you can use to determine stability from the surface:

- Unstable conditions commonly occur during the day, and more stable conditions during the night.
- Convective type clouds, gusty surface winds, and dust devils are all indicative of unstable conditions.
- Flattening of convective clouds, stratus clouds, and definite tops of haze layers are indicative of stable conditions.

[1] (Naval Air Training Command, 2003, p.5-11)

- Strong winds generally cause sufficient mechanical mixing to produce a lapse rate near adiabatic, even at night.

You can use visible indicators such as smoke or steam plumes to determine boundary layer stability by observing the behaviour fires, smokestacks or steam vents. Figures 2 through 6 show the lapse rates and how smoke or steam diffusion patterns appear.

Low-Level Lapse Rates and Vertical Diffusion

Notes:

Environmental Lapse Rate (ELR): This is the rate in degrees Celsius per thousand feet at which the temperature of the actual air falls.

Dry Adiabatic Lapse Rate (DALR): 3.0°C/1000ft.

Saturated Adiabatic Lapse Rate (SALR): 1.5°C/1000ft

Stable Conditions **(See Figure 2)**

ELR < DALR = Stable Environment.
Causes "Fanning" of the Smoke Plume.

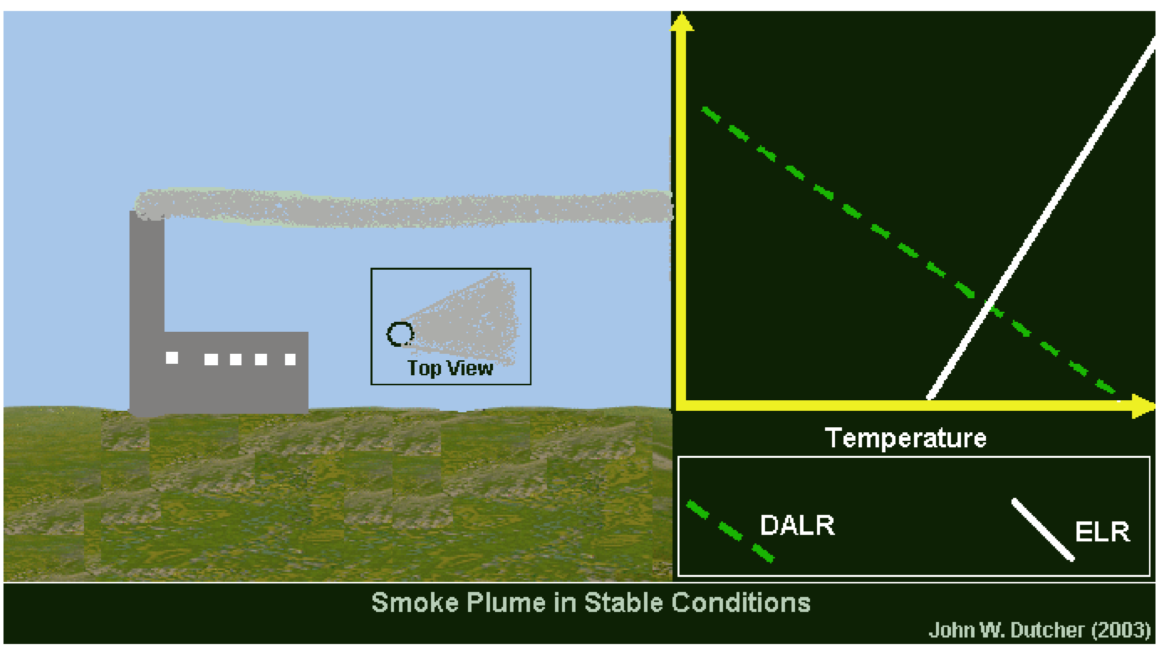


Figure 2. Stable Conditions

***Above Inversion Layer* (See Figure 3)**

Below the emissions stack, the ELR < DALR, thus a Stable Environment. As a result of the Inversion Layer the smoke plume cannot descend; thus it is trapped above the Inversion Layer.

Above the emissions stack (where the smoke plume 'sits,' the ELR = DALR, thus Neutral Stability). This results in the smoke plume not being able to raise.

This set of temperature profiles causes "Lofting" of the smoke plume.

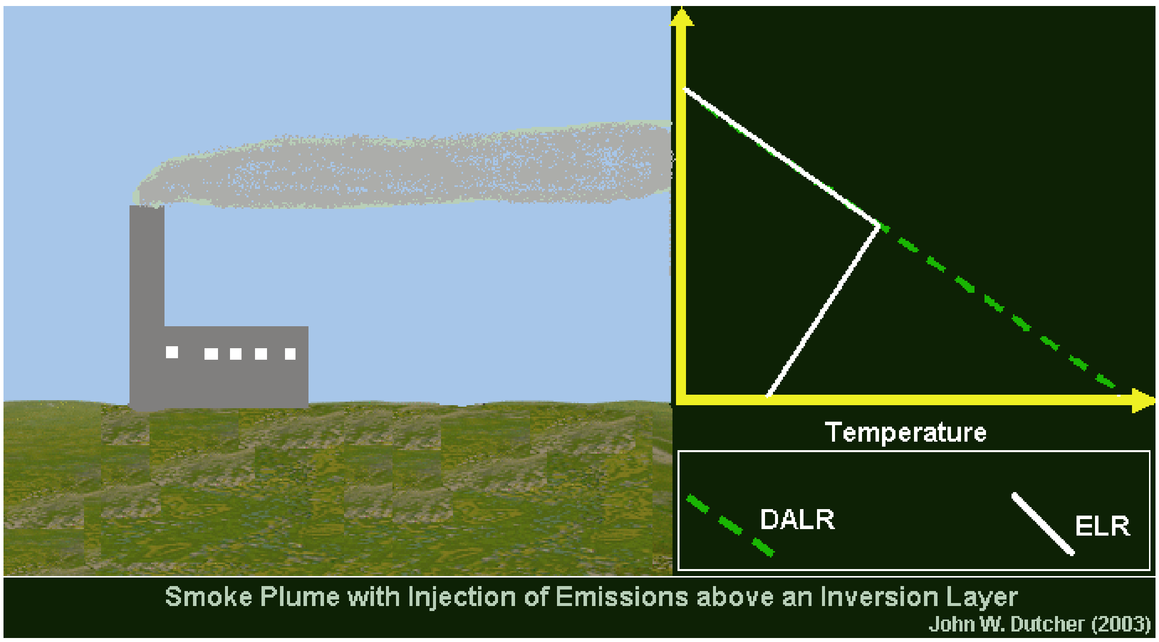
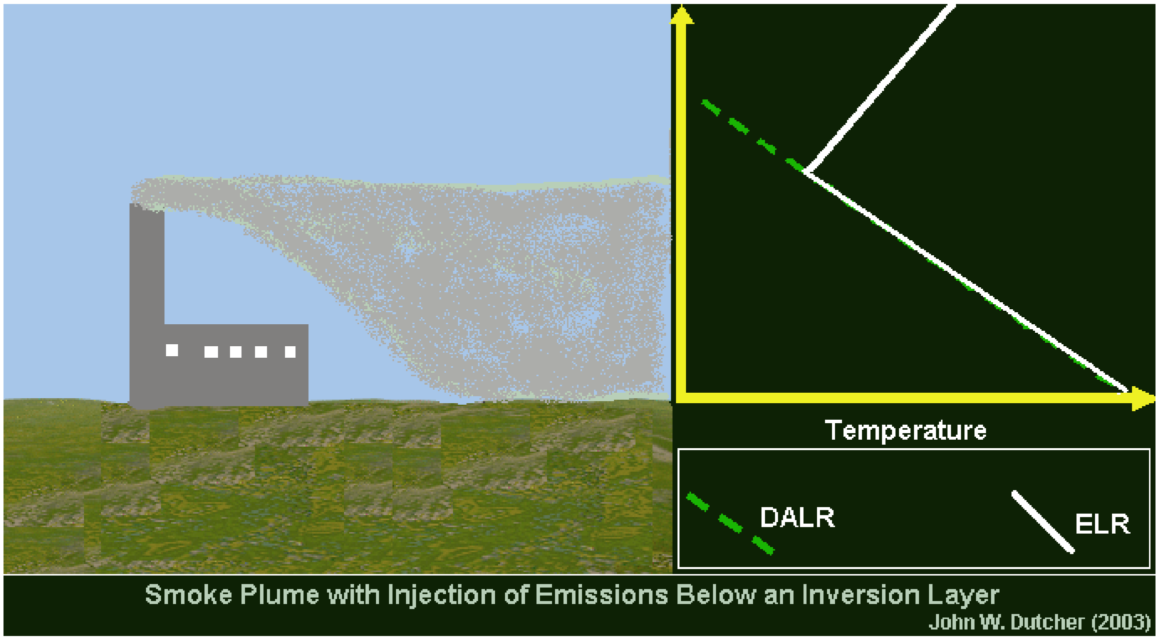


Figure 3. Above Inversion Layer

***Below Inversion Layer* (See Figure 4)**

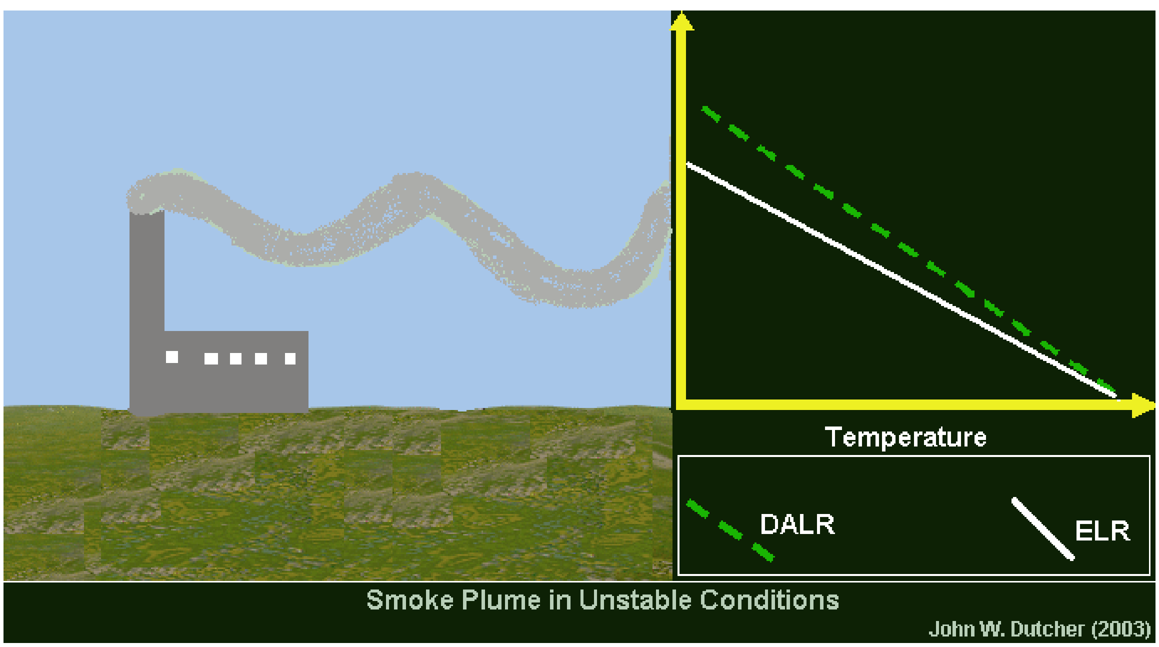
Above the emissions stack the ELR < DALR, thus a Stable environment. The Inversion layer above the emissions stack results in a "Capping Effect," effectively trapped emissions below. This is known as "Fumigation."



<u>Figure 4.</u> Below Inversion Layer

Unstable Conditions **(See Figure 5)**

ELR > DALR = Unstable Environment.
Causes "Looping" of Smoke Plume.



<u>Figure 5.</u> Unstable Conditions

Neutral Stability **(See Figure 6)**

ELR = DALR = Neutral Stability.
Causes "Coning" of the Smoke Plume.

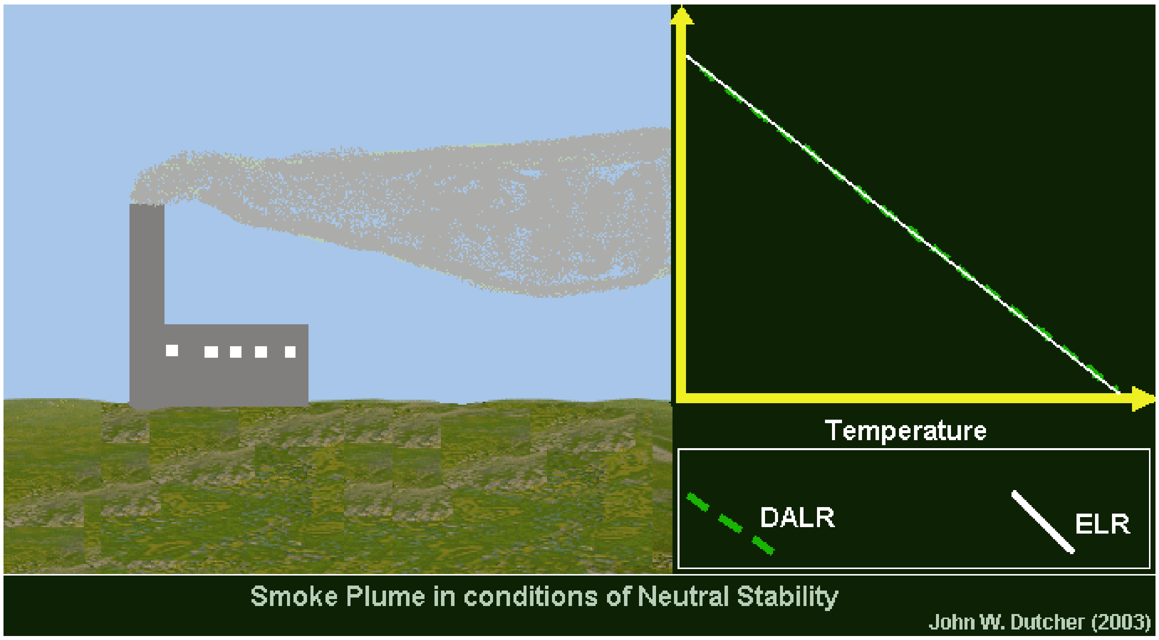


Figure 6. Neutral Stability

LLWS Recognition, Avoidance, and Recovery

The following guidance is presented in the United Kingdom's CAA AIC 19/2002 on LLWS recognition, avoidance, and recovery:

• **Recognise –** that windshear is a hazard

AND

• **Recognise** – the signs that may indicate its presence

• **Avoid –** windshear by delay or diversion

• **Prepare –** for an inadvertent encounter by a 'speed margin' if 'energy loss' is expected.

• **Recover –** know the techniques recommended for your aircraft and use them without hesitation if windshear is encountered.

• **Report –** immediately to ATC controlling the airfield at which the incident occurred.

References

Civil Aviation Authority, United Kingdom. (2002). *Low altitude windshear*. (AIC 19/2002 - Pink 28). Hounslow, UK: Author.

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Naval Air Training Command. (2003). *Aviation weather – Study guide: Preflight.* NAS Corpus Christi, USA: United States Navy. [CNATRA P-303 (Rev 03-03)].