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LOW ALTITUDE WINDSHEAR

1 Introduction

1.1 This Circular has been produced to provide an understanding of the nature of windshear, and an appreciation of its dangers. Guidance on how best to avoid windshear and how an aircraft may have to be handled during a windshear encounter is also included. It should be noted that research and experiment continues to take place in relation to the phenomenon, nevertheless, windshear encounters still continue to be cited as a primary or contributory cause of accidents and incidents. Although aircraft flying in United Kingdom airspace can experience windshear events, the severity of such encounters and the intensity of the probable causative events are often much less than that experienced elsewhere in the world. Windshear has been the direct cause of accidents; it is not a phenomenon to be treated lightly. Pilots and operators are therefore urged to understand the phenomenon and if planning to fly to destinations or areas where severe weather, turbulence or windshear is known or likely to occur, to obtain appropriate briefings, training and instruction. This circular is written for guidance only, all suggestions regarding flying techniques and similar procedures in this document do not supersede appropriate operations or flight manual instructions.

2 Definitions

2.1 In discussing windshear, it is not easy to find a definition that will satisfy both meteorologist and pilot. **As a consequence, it is possible to find circumstances where an alert has been issued concerning windshear, but where the meteorological understanding of the event differs from that expected by the flight crew.** Thus it is important if operating to areas where windshear can be a regular phenomenon that flight crews fully understand that which is being forecast. At its simplest, windshear can be described as a change in wind direction and/or speed including both downdraughts and updraughts.

2.2 The definitions of windshear used in this circular are:

(a) Windshear:

Variations in the wind vector along the flight path of an aircraft with a pattern, intensity and duration that will displace an aircraft **abruptly** from its intended flight path such that **substantial control input and action is required** to correct it.

(b) Low altitude windshear:

Windshear along the final approach path or along the runway and along the take-off and initial climb-out flight paths.

2.3 Additional qualifying conditions/descriptions related to windshear:

(a) Vertical windshear:

The change of horizontal wind vector with height, as might be determined by two or more anemometers at different heights on a mast.

(b) Horizontal windshear:

The change of the horizontal wind vector with horizontal distance, as might be determined by two or more anemometers mounted at the same height along a runway.

(c) Updraught or downdraught shear:

The changes in the vertical component of wind vector with horizontal distance.

2.4 If the basic windshear definition in paragraph 2.2 (a) is set aside, it can be seen that the additional definitions and qualifying statements allow for changes in wind vector which could include the relatively minor or benign. Notwithstanding these possible (academic) variations in description, this circular is concerned with the basic definition, in particular, the emphasis on **abrupt** displacement of an aircraft from the desired flight path, at low altitude, together with the necessity for **substantial control action** to counteract it. Windshear is therefore highly dynamic which can be extremely uncomfortable and frightening; to think of windshear as an aggravated form of wind gradient is unwise. Windshear can strike suddenly and with devastating effect beyond the recovery powers of both experienced pilots flying the most modern and powerful aircraft. **Thus the first and most vital defence is avoidance; this should be taken to be the recurrent theme of the rest of this circular**.

3 Meteorological Background

3.1 Among the most potent examples of windshear are those associated with thunderstorms, however, windshear can also be experienced in association with other meteorological features such as the passage of a front, a marked temperature inversion, a low level jet (wind maximum) or a turbulent boundary layer. Topography or buildings can create substantial local windshear effects that can be considerably more than might be expected from the average strength of a prevailing wind.

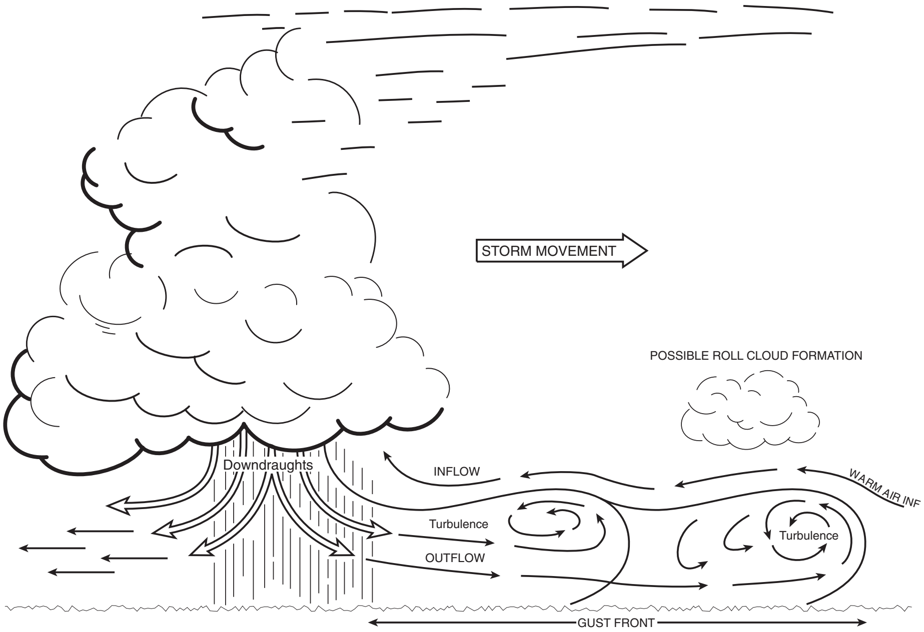

Figure 1 : Wind flows in the vicinity of thunderstorms

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3.2 Thunderstorms

3.2.1 The principles of thunderstorm formation are already covered in AIC 81/2004 (Pink 66). For the purposes of this Circular it is sufficient to remark that thunderstorms are violent events, unpredictable, and associated with turbulence, windshear, lightning and precipitation as separate or joint hazards. Shears will occur, and draughts can strike from all angles. The assessment of the aircraft's actual angle of attack in relation to some of the wind flows will be difficult to judge and in consequence the closeness of the aircraft to the stall will be harder to gauge. In relation to low altitude windshear there are features of thunderstorms which merit further description:

(a) **Gust Front:** Some thunderstorms may have a well-defined area of cold air flowing out from a downdraught, but tending to lead the storm along its line of movement. This is labelled a "gust front" (see Figure 1) and may extend some distance (up to 30 km) from the storm centre and affect the area from the surface up to 6000 ft. If the storm is part of an organised line of storms, the gust front may extend an even greater distance from the centre line of the storms. ‘Gust fronts’ manifest themselves as regions of great turbulence with a potential for vertical shears between out-flowing cold air as it undercuts warmer air. The leading edge of the ‘gust front’ could be encountered without warning, although roll cloud effects can be associated with it.

(b) **Microburst:** A microburst is a highly concentrated and powerful downdraught of air, typically less that 5 km across, which lasts for about 1 to 5 minutes. (It should be noted that the word ‘microburst’ is also associated with a phenomenon called ‘gap flow microburst’, associated with topographical effects and strong winds and is a very strong horizontal shear effect with the energy loss effect on the aircraft as shown in Figure 2). Microbursts associated with thunderstorms have proved to be a most lethal form of windshear giving downdraught speeds of 60 kt or more. As this vertical shaft of air approaches the ground it will ‘splay out’ and lose its vertical speed component, nevertheless, vertical (downward) components have been recorded as low as 300 ft with surface wind differences of as much as 90 kt. Although these figures are extreme examples they do illustrate that a microburst should not be treated lightly. Microbursts have been well documented in the United States but could easily be found elsewhere in association with thunderstorm activity. Microbursts can be ‘wet’ or ‘dry’, ie associated with or without precipitation. The ‘dry’ microbursts will therefore be difficult to detect on weather radar, but are often associated with high-based cumulus, alto-cumulus or the cirrus cloud overhang from a cumulonimbus cloud. In each case when precipitation falls from the clouds (indicated by ‘virga’) it evaporates in the dry air beneath the cloud. This evaporation process requires energy, which further cools the falling air thus enhancing the speed of the downdraught. A ‘wet’ microburst is associated with intense precipitation that falls in shafts below a cumulonimbus cloud.

3.3 **Frontal Passage**

3.3.1 Fronts vary in strength and normally only well-developed active fronts, with narrow surface frontal zones and with marked temperature differences between the two air masses are likely to carry a windshear risk. Weather charts showing sharp changes in wind direction across the front, temperature differences of 5°C or more, or a speed of frontal advance in the region of 30 kt or more may indicate a potential windshear hazard. Frontal windshear is also a hazard as the following incident illustrates. A twin-jet aircraft was about to land in the UK and was caught by the passage of a cold front. In 10 seconds, the wind changed such that a 10 kt crosswind from the left (with a slight tail wind) changed to an 8 kt crosswind from the right coupled with a 14 kt head wind. A missed approach, from very low level was carried out as directional control became difficult. The actual numerical values of wind speed change in this actual incident may appear less than dramatic to some readers, however, the control difficulties experienced during this incident were considerable. Similar wind **velocity** changes, with an aircraft at critical phases of flight will always be hazardous.

3.4 **Inversions**

3.4.1 A change in wind strength is nearly always present in the boundary layer, ie close to the ground. This is frequently described as 'windshear' but as this normally involves a gradual change in strength with which pilots will be most familiar, it does not fit the definition already given in this circular. A proper windshear hazard can exist, however, when an unexpectedly strong vertical change develops. This is often associated with the following situations:

(a) A low level jet (more accurately referred to as a low level wind maximum) can form just below the top of, or sometimes within, a strong radiation inversion which may develop at night under clear skies. Other low level jets may develop in association with a surface front, particularly ahead of cold fronts.

(b) On occasions, low-level inversions may develop and decouple a relatively strong upper flow from layers of stagnant or slow moving air near the surface. Shear effects may be pronounced across the interface.

4 The Effects of Windshear on an Aircraft in Flight

4.1 Windshear will affect aircraft in many different ways and during an encounter the situation will be constantly changing, especially during the more dynamic encounters. Conventional thought, in the past, has suggested that such encounters are associated only with thunderstorms; however, there is evidence to show that equally dynamic encounters can be expected with other windshear causes. Particular types of aircraft will vary in their reaction to a given shear; a light high wing piston-engined aircraft may react in a totally different way to a heavy four-engined swept wing jet aircraft. The notes and diagrams that follow describe stylised windshears and the progressive effects that can occur. Windshear can be encountered at any height and the effects will be similar. If the windshear event is at low-level it can be a great hazard and it is this that must be borne in mind in relation to the described effects.

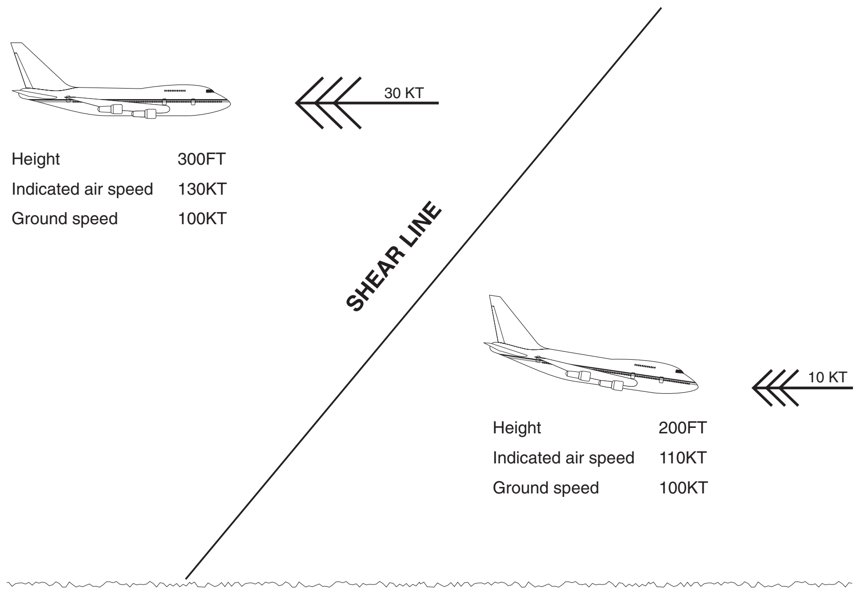

Figure 2 : Effect of loss of headwind - Energy Loss

4.2 To understand the effects of windshear it is important to note the relationship of an aircraft to two reference points. One reference point is the ground below the aircraft and the other is the airmass in which the aircraft is moving. In a windshear encounter it is not only the magnitude of the change of the wind vector, but the rate at which it occurs. For example, an aeroplane at 1000 ft above ground level (agl) may have a head wind component of some 30 kt, but the aerodrome surface report shows this as a 10 kt component close to the runway. That 20 kt difference in wind strength may taper off evenly from 1000 ft to touchdown with no changes in direction; thus its effect and relationship to the aircraft will be that of a reasonable wind gradient with height with which all pilots will be familiar. On the other hand, if the 20 kt difference still exists at 300 ft, it will be obvious that the change, when it occurs, is going to be far more sudden and its effect more marked. Windshear, from the definition, implies a narrow borderline, and the 20 kt of wind strength may be lost over a short vertical distance. If this strength is lost over 100 ft the effect will be as shown in the diagram, with the concomitant loss of aircraft energy.

4.3 The reverse effect will occur when an aeroplane is taking off through such a shear line. In this case however, the gain in energy would be beneficial with aircraft gaining some additional 20 kt of airspeed in a short distance. However, this could potentially produce some handling difficulties, particularly if the aircraft was approaching a flap limiting speed (for example) as the shear line was crossed.

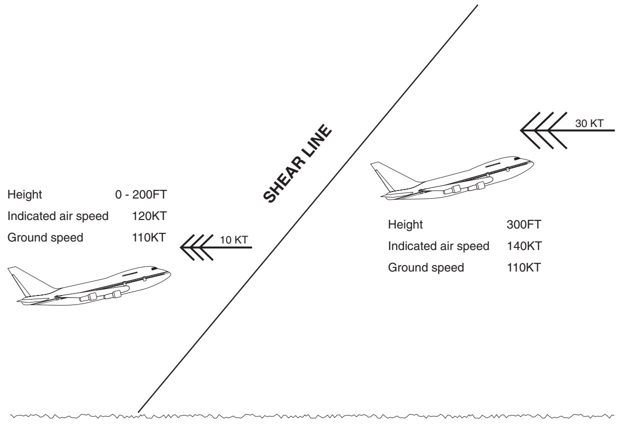

Figure 3 : Effect of Increased headwind - Energy Gain

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4.4 In an encounter with a downdraught, the relative airflow across the aircraft's wing will change direction. Normally, an aircraft could be expected to be flying into a head wind and as the downdraught is encountered, this head wind will reduce markedly, thus reducing the energy of the aircraft. In the downdraught itself, the relative airflow across the wing will change as shown in the diagram below. Its effect will be to effectively decrease the angle of attack of the wing, which will be counteracted by the pilot manoeuvring the aircraft in response to the downburst effect, ie increasing the angle of attack. This might be beneficial in terms of increased lift. However, if the wing is already at steep attack angle (eg during an approach), any subsequent changes in airflow may result in the aircraft being very close to the stall.

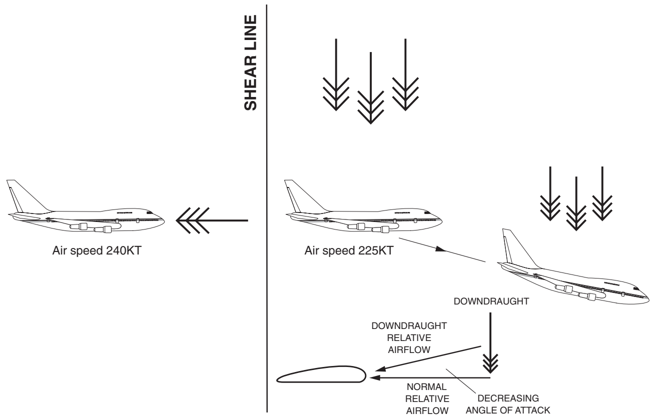

Figure 4 : Effect of downdraught - Energy Loss

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4.5 Another version of a windshear event is that occasioned by an encounter with a microburst. Classically, a microburst, as illustrated below, is associated with thunderstorm or similar convective activity associated with areas of heavy rain. However, the term ‘microburst’ is also associated, in some locations, with very severe windshear warnings, possibly without associated convective activity. (See paragraph 3.6 (c)). **Therefore, if ‘microburst’ warnings are given, flight crew should be fully aware of which phenomenon they are being warned about and take appropriate action.**

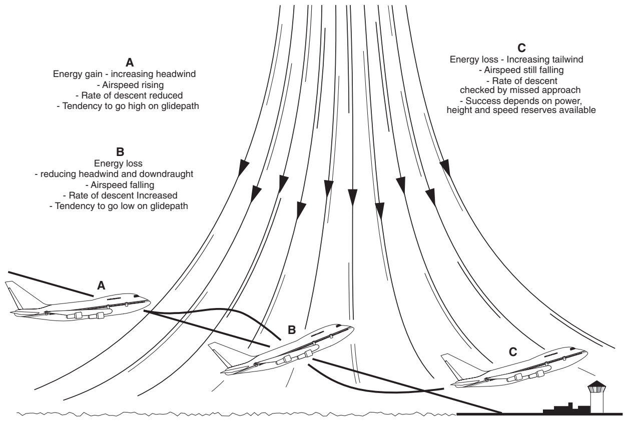

Figure 5 : Microburst effects

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4.6 The likely sequence of events during a classic (convective activity) microburst encounter is a combination of the previous events as follows. Approaching the airfield, using the aircraft weather radar, an area of strong radar returns may be observed in the vicinity of the final approach path. This may alert the pilot to the possible dangers, particularly if this is also associated with earlier meteorological forecasts. The recommended course of action would be to initiate a go-around at this early stage in the approach and hold off until the activity moved on. Some airfields may even prohibit approaches during conditions when microburst activity is anticipated. If after the initiation of the go-around, an encounter with the microburst occurred at this stage, the extra energy of the aircraft and possible increased height should ensure that no untoward events occur.

4.7 If, however, the aircraft were to continue its approach into the microburst, the sequence of probable events is as shown in the diagram. A successful go-around will depend, obviously, on the strength of the microburst, its position in relation to the approach path; the aircraft power reserves available and the rate at which they can be increased to give maximum thrust to counteract the energy loss of downdraught and increasing tail wind. The dynamic events will probably be associated with severe buffeting, heavy rain, thick cloud and probably blinding flashes of lightning, and external noise occasioned by heavy rain or hail on the aircraft skin.

4.8 A microburst encounter during take-off could be equally as hazardous notwithstanding the fact that during take-off an aircraft is already developing high thrust and is less constrained by the need to hold a precise glide path. Whilst the initial increase in head wind may improve lift and thus rate of climb, the transition to downdraught and then tail wind may totally negate this increase and the airspeed of the aircraft, possibly still close to the ground may be further reduced. A heavy aircraft, with small reserves of power may not be able to fly through the encounter successfully.

5 Techniques to Counter the Effects of Windshear

5.1 It should now be apparent that windshear can vary enormously in its impact and effect. There is as yet no international agreement on ways of grading windshears, but clearly some shears will be more severe and more dangerous than others. If the definition used by this circular is borne in mind, a windshear encounter is expected to result in **abrupt** changes to the desired flight path requiring **considerable control action** to effect recovery. Thus, if avoidance has failed, any further actions must anticipate the worst effects, bearing in mind that the shear itself will probably be invisible to the crew.

5.2 If the meteorological situation has been carefully studied in advance of flight and updated with latest reports during flight, the possibility of windshear should have already been identified. Strong winds at a destination, particularly where topography is warned as having an effect, or a forecast of thunderstorms, particularly if reinforced, near the destination, with weather radar or visible evidence should trigger a mental ‘Windshear Alert’. At this point the prudent decision would be to divert, following company procedures in the case of AOC operators.

5.3 If an approach must be attempted in such conditions, crews should consider a few basic measures to anticipate a windshear encounter. One such measure is to increase the approach speed, however, if a shear event does not materialise, the increased approach speed may then cause problems near the threshold, particularly at airfields with short runways. If an encounter with shear does occur, its overall effect will be to de-stabilise an approach, and any thrust reduction taken to counter an initial extra head wind, may have to be quickly changed to a thrust increase if the head component is removed or reversed. Actions to counter a loss of airspeed close to the ground include:

(a) Briskly increase power (to full go-around if felt necessary);

(b) Raise the nose to check descent;

(c) Co-ordinate power and pitch;

(d) Be prepared to carry out a missed approach rather than risk a landing from a de-stabilised approach.

5.4 The actions required to counter the effect of a downburst or microburst on the approach or during take-off will require more stringent measures. Again, it should be emphasised that if such phenomena are either forecast or suspected, the most sensible course of action would be to delay the take-off or landing, or if airborne to divert to another airfield. In the absence of specific aircraft flight manual or operations manual guidance which must be followed, some **suggested** techniques for dealing with a microburst encounter on an approach are given below:

(a) The presence of thunderstorms should be known and obvious, so that any increase in airspeed caused by the increasing head wind should be seen as the precursor to a downburst or microburst encounter. Any hope, therefore, of a stabilised approach should be abandoned and a missed approach is the recommended action - the technique is to make this as safe as possible;

(b) The initial rise in airspeed and the rise above the approach path should be seen as a bonus and capitalised upon. Without hesitation, the power should be increased to that required for a go-around, whilst being prepared to further increase it to maximum, if necessary, and an appropriate pitch angle, consistent with a missed approach should be selected. Typically, this will be in the region of 15° and this should be held against the buffeting and turbulence that will undoubtedly occur;

(c) The initial ‘bonus’ of speed and rate of climb may now be rapidly eroded as the downdraught is encountered. Airspeed may now be lost and the aircraft may now begin to descend again despite the high power and pitch angle. It may be impossible to gauge the angle of attack, so there is a possibility that stall warnings may be triggered; in such cases the pitch angle may need to be relaxed slightly;

(d) The point at which the tail wind starts to be encountered may be the most critical. The rate of descent may lessen, but the airspeed may continue to fall and any height loss may now be close to ground obstacle clearance margins. Maximum thrust will by now have been applied and if there is now a risk of hitting the ground or an obstacle it may be necessary to raise the nose until stall warnings start to be triggered and to hold this attitude until the aircraft starts to escape from the effects.

5.5 The likely effects of windshear on take-off have already been discussed in paragraph 4.3. When there is a possibility of shear, without a clear forecast, it may be possible to use a longer runway, preferably pointing away from an area of potential threat. However, this must not be a ‘spur of the moment’ action and any such decision will need to have been pre-planned taking into account all necessary factors including runway length and obstacle clearances. The high power setting and high pitch angle after rotation may put the aircraft in a reasonable situation should an encounter now occur, however, if it has not been fully thought out there may be unexpected handling and performance difficulties. However, the aircraft will still be low, with a small safety margin. At that point, maximum power should be selected (if it is not already); noise abatement procedures should be ignored and the high pitch attitude (consistent with any stall warnings) should be maintained. Notwithstanding the above, the safest and recommended course of action would be to delay take-off until the possibility of windshear has diminished.

5.6 The vital actions for downburst/microburst encounter in both approach and take-off cases are:

(a) Early **recognition** and **committal** to the appropriate action;

(b) Follow operations manual or aircraft flight manual techniques;

(c) Use maximum power available as soon as possible;

(d) Adopt an appropriate pitch angle and try and hold it; do not ‘chase’ airspeed.

(e) Be guided by stall warnings when holding or increasing pitch, easing the back pressure as required to attain or hold a lower pitch attitude if necessary. (In many aircraft types optimum performance is very close to the point of onset of stall warning. It is important, however, not to go beyond the point of onset as it is then not possible for the pilot to know how deeply into the warning the aircraft is).

5.7 It is not possible to be prescriptive in relation to the ‘best’ technique to use as these will vary between aircraft, and may be documented in appropriate manuals, but could be expected to follow the broad guidelines above. Some of the responses required of the pilot and the attitude and trim forces to be used may sometimes appear to be counter-intuitive. Therefore, the best advice would be to use a windshear training programme, coupled with dedicated simulator exercises to practice the techniques. Any such training should **emphasise** the fact that windshears are to be avoided. The knowledge thus gained and any techniques practiced should serve to make the survival of an inadvertent encounter more possible and not encourage pilots to think that windshears can be tackled with impunity.

6 Windshear Warning and Reporting

6.1 Windshear warning is provided in the following ways:

(a) Meteorological warning;

(b) ATS warning;

(c) Pilot warnings;

(d) On board pre-encounter warnings.

6.2 Warning of windshear from meteorological sources may start at the pre-flight briefing stage and pinpoint the possibility of frontal or inversion shear. Any forecast of thunderstorm activity should alert pilots to the possibility of downdraught or microburst activity. If the planned destination is one where topographical features are known to cause shear hazards, the direction and strength of forecast winds should be noted carefully and compared with published information. In the United Kingdom, windshear warnings are provided in ATIS broadcasts at London (Heathrow) and Belfast (Aldergrove) if the following conditions exist:

(a) The mean surface wind exceeds 20 kt;

(b) The vector difference between the mean surface wind and the gradient wind at about 2000 ft exceeds 40 kt;

(c) Thunderstorms or heavy showers are within about 5 nm of the airfields.

The warnings are broadcast as ‘Windshear Forecasts’, and if reinforced by pilot (aircraft) reports, the alert becomes ‘Windshear forecast and reported’. (See UK AIP GEN 3-5-4 for more information).

6.3 In other parts of the world, windshear warnings can be based not just on meteorological forecasts but on actual observed conditions using, for example, a series of anemometers around an airfield. With such systems, the measured differences in wind velocity between anemometers are used in conjunction with computer programmes and recorded data to produce warnings. Terminal Doppler Weather Radars (TDWR) are also used to measure wind velocities and these can also be configured to produce warnings. **However, a note of caution is necessary**. It will have been noted that no universal standard exists regarding the grading of the severity of windshear, nor is there a universal standard regarding windshear warnings. Furthermore, the term ‘microburst’ is not always used to describe the classic thunderstorm associated event. ‘Microburst’ is also used to alert crews to the possibility of a shear event from wind over 30 kt. In this context, it is not a microburst in the sense as shown in Figure 5 (and the associated text). In addition, some locations use a ‘Maximum intensity, first encounter’ rule, in warnings. This results in warnings as follows:

‘Windshear warning, 25 kt, 3 nm final’

This could be interpreted as ‘expect an encounter of 25 kt at 3 nm on final approach’. This is incorrect. The correct interpretation (as a result of maximum intensity, first encounter) is:

‘Expect encounter(s) with windshear somewhere between 3 nm and touchdown with a maximum intensity of 25 kt’

It should be noted in this context that an aircraft belonging to a UK airline experienced such events with a maximum intensity in the region of 35 (or more) kt ie an encounter with a ‘gap-flow microburst’ at an approximate height of 150 ft on an approach. From all the available evidence, it would appear that the loss of an aircraft, crew and passengers was very narrowly avoided.

6.4 Pilot reports of windshear encounters are important sources of information to warn other pilots of the danger. The UK AIP (GEN 3-5-21) contains guidance on windshear reporting, which for convenience is repeated below. In this context it should be noted that similar entries in the AIPs of other States may be slightly different and may require the use of different terminology or phraseology.

> **'Windshear Reporting Criteria**
>
> Pilots using navigation systems providing direct wind velocity readout should report the wind and altitude/height above and below the shear layer, and its location. Other pilots should report the loss or gain of airspeed and/or the presence of up or down draughts or a significant change in cross wind effect, the altitude/height and location, their phase of flight and aircraft type. Pilots not able to report windshear in these specific terms should do so in terms of its effect on the aircraft, the altitude/height and location and aircraft type, for example, 'Abrupt windshear at 500 ft QFE on finals, maximum thrust required, B747'. Pilots encountering windshear are requested to make a report even if windshear has previously been forecast or reported'.

6.5 As yet, no perfect on-board system is available for general use and trials continue in this respect. Some aircraft are fitted with predictive windshear warning system, but in most cases the pilot will not receive much advance warning of the presence of windshear. Airborne weather radar may give some clues, however, it must be remembered that most weather radars do not detect turbulence; they only detect precipitation. Warning that an aircraft is about to experience windshear may therefore come from a variety of sources, and in this context it is probably important to ensure that the more sophisticated modern aircraft are configured for a possible encounter in such a way that give the most warning and assistance to the pilot. Guidance for the best configuration to use will come from the manufacturer and it is this that should be used. For less well-appointed aircraft, early clues may come from the airspeed and vertical speed indicators; flight directors may be misleading when a windshear recovery is flown; again manufacturers' guidance should be sought. Finally, although visual clues may have assisted in the early prediction of a windshear event, they will not necessarily be available during an event and its recovery. Similarly, physiological sensations should also be ignored and flight conducted purely by reference to appropriate instruments.

7 Conclusions

7.1 Most pilots will experience changes in wind speed of some form or other; hopefully few will experience windshear as defined in this circular when considerable control inputs will be required to overcome the abrupt changes that the shear encounter has caused. There are no sure and absolute ways of determining the severity of an encounter; therefore the best advice must be to avoid them. If an encounter does occur the generic advice in this circular together with further training and knowledge should help to alleviate the effects.

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 (see paragraph 6.4) **and** using the Mandatory Occurrence Reporting Scheme, to the Civil Aviation Authority.

This Circular is issued for information, guidance and necessary action.

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