CIVIL AVIATION AUTHORITY

CAA PAPER 97003

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A survey and recommendations to reduce operating risks to aircraft

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## A survey and recommendations to reduce operating risks to aircraft

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# Executive Summary


Disturbances resulting from winds flowing over and around local topographical and man-made features on and in the vicinity of airports can cause difficulties to aircraft in flight during take-off and landing, and when moving on the ground. Such wind disturbances (wind shear) sometimes limit operations at particular airports. Following an incident at Sumburgh in 1991 the Air Accidents Investigation Branch asked the CAA to review wind hazards at UK airports.

This study has included analysis of incident and accident data between 1985 and 1994 recorded on the CAA database, review of existing warnings in the UK Air Information Publication and in the Aerad and Jeppeson airport plates, a survey of 65 UK airports by questionnaire whose movements are reported annually by the CAA, visits to 11 airports and some contributions by pilots.

The incident data was reviewed to eliminate records that were not wind related and a total of 150 accidents were identified at the 65 airports during the 10 year period. Closer analysis identified incident rates of about 2·1 per million movements for Air Transport operations and about 6·7 per million for other types of operations such as training, testing and private flying. Wind shear was a contributory factor in 40% of the incidents, and crosswinds in about 29%. A relative incident rate for each airport compared with the average has been calculated from data on movements for different types of operations at particular airports and the average incident rates. The largest relative incident rate is at Bembridge, Isle of Wight which has a rate that is 6·5 times the UK average. Sumburgh has a relative rate of 3·4, which would be higher if it were not for the insistence on briefings on local conditions and specific training flights by airlines using the airport.

There was an excellent response to the questionnaire with only 9 airports not replying out of 64 (a questionnaire was not sent to RAF Manston – Kent International airport). Of the 55 replies some 60% had local wind shear problems and in a total of 47% (26 airports) these problems could cause a hazard. The most hazardous conditions were caused by 'Nearby hills and valleys' which affected 14 airports. The other most common cause of potentially hazardous conditions was 'Buildings, including railway embankments' which were a significant problem at 13 airports.

From the data it has been possible to suggest guidelines for topographical feature characteristics that would be expected to cause wind shear problems at an airport. The preliminary guidelines on building size and location are particularly useful when considering proposals for new buildings on or near airports.

Wind measurements at and near airports are an important parameter for informing pilots of local wind conditions and there is discussion of general issues as well as local situations at some airports.

It is concluded that wider use of warnings in the UK AIP and other publications would help reduce incident rates, and recommendations are presented for 14 airports where specific actions would be expected to reduce incident rates.

# Contents

# 1 INTRODUCTION

In an accident report[1] following an incident where a British Aerospace ATP aircraft suffered damage in strong winds the Air Accidents Investigation Branch included the following items relating to winds in their recommendations:

'4 Safety Recommendations

The following Safety Recommendations were made during the course of the investigation:

4.6 The CAA should instruct all UK operators to include in their Operations Manuals upper wind limits for operating a revenue service (Recommendation 92-105).

4.7 Sumburgh airport should be equipped with additional windsocks located close to the threshold of each runway (Recommendation 92-106).

4.8 The CAA should, with the assistance of the Meteorological Office:

(a) Sponsor practical trials to assess the combinations of strong wind, topography and convective instability which may combine to create a significant windshear hazard.

(b) Increase the number of airfields provided with a windshear alerting service to encompass those airfields most at risk to windshear.

(c) Review the list of airfields at Appendix B of CAP 573 with a view to including UK airports which support domestic scheduled air services and which are prone to hazardous wind conditions.

(Recommendation 92-107).'

In addition the Safety Regulation Group of the CAA are aware that wind related incidents continue to occur at many United Kingdom airfields from their Incident Reports database. This present study was commissioned to investigate the extent of wind and wind shear related incidents and accidents at UK airfields, consider any special problems related to local terrain or building features at individual airports, to recommend any changes in wind alerting systems, procedures and training that could reduce the risk of wind related incidents or accidents, and to recommend studies or research that could result in further significant reductions in these risks.

The study has concentrated on UK airfields, and those in the Channel Islands and the Isle of Man, with significant commercial movements as listed in 'UK Airports. Annual statements of Movements, Passengers and Cargo 1993'[2]. A total of 65 airfields, (Annex A), have been included in the study and range from all 38 International Commercial Air Transport airfields, such as Heathrow, through 27 of the major Licensed General Aviation airfields and a small selection of the many Licensed Light Aviation Airfields in the UK. The main Channel Island and Isle of Man airports are also included.

Information for the study has been obtained by the following means:

(a) serious incidents and accidents between 1985 and 1994 were extracted from the Incident database at the CAA;

(b) all the 64 civil airfields listed in Annex A were sent a questionnaire and 55 responded (one other airfield on the list – Kent International – is operated by the Ministry of Defence (RAF) and did not receive a questionnaire);

(c) visits were made to 11 airfields representative of a cross-section of types of operations and local terrain;

(d) existing information in the UK Air Information Publication (AIP) and the Aerad and Jeppeson airfield plates was reviewed; and

(e) a selection of opinion was obtained from a few pilots with current experience of operating in the UK.

In assessing the significance of risks of incidents due to wind or wind shear it is important to include the effects of operational pressures from the frequency of movements and types of aircraft, and also recognise differences between pilots with a lot of local experience and inexperienced or visiting pilots. These effects have been included among many factors considered in this report.

This report is presented in the following sections:

1 Introduction

2 A brief review of wind disturbances, their causes and effects on different classes of aircraft

3 Summary and analysis of wind related incidents and accidents reported to the CAA between 1985 and 1994

4 Analysis of the survey of UK airports

5 Suggestions for guidelines to identify airports with significant wind related problems

6 Suggestions for improvements in sensing and providing appropriate information to pilots

7 Conclusions and general recommendations.

## 2 WIND EFFECTS ON AIRCRAFT OPERATIONS

Aircraft operating on, approaching or taking-off from airports are affected by the overall strength and relative direction of the wind and by short term changes in the horizontal and vertical wind. The overall strength and direction of the wind is particularly important when it approaches or exceeds the crosswind limits for an aircraft, when it becomes strong enough to blow aircraft off course or turn them over when taxying, and ultimately when it becomes strong enough to move parked aircraft. It is interesting to note that even parked B747 aircraft have been moved and damaged by strong winds at UK airports.

Short term changes are often referred to as gusts, turbulence, up or down draughts, or wind shear. If the changes are of very short duration they will be felt in the aircraft as a brief change in acceleration (usually vertical, lateral or rotational acceleration). Brief changes in acceleration have some affect on controllability and in very extreme conditions can cause structural damage, but they are too short in duration to directly affect the flight path of an aircraft. Longer duration disturbances can be more hazardous because they do affect the flight path or ground track.

The effects of both mean winds and wind changes are included in this report. Short duration changes (wind shears) are less predictable and can depend on particular features of local topography near a particular airport. Characteristics of different types of wind shear are described in the following section.

## 2.1 Wind shear

The full definition of 'wind shear' is any change of wind speed or direction with time or distance that requires a significant control input from a pilot to minimise changes to the flight path of an aircraft. Both horizontal and vertical wind fluctuations are included in this definition, which includes all wind fluctuations that affect an aircraft for longer than about 2 seconds and up to about 40–60 seconds. A wind disturbance lasting for a longer period becomes almost steady conditions. Wind disturbances of less than 2 seconds are turbulent disturbances that do not usually change a flight path, but are experienced as accelerations.

In meteorological discussions wind shear is often restricted to the gradient of horizontal wind with altitude, which is a very limited example of wind shear.

In wider aviation discussions wind shear is sometimes restricted to unexpected wind changes (mainly horizontal) caused by weather events such as thunderstorms. Any up or down draughts are often not included as wind shear but as separate wind effects. Again this is a restricted view of wind shear.

To avoid confusion in this report the generic term 'wind disturbance' will be used to describe all wind changes that can affect an aircraft flight path, and includes up and down draughts. A convenient summary of the characteristics of wind disturbances (wind shear) with examples and a description of effects on aircraft is presented in Ref. [3], which also includes 22 useful references for further study.

Ref. 3 describes how all wind disturbances are generated by two basic causes, which are

(a) Wind flowing past large natural or man made objects; and

(b) Wind changes generated by thermal gradients and discontinuities in the atmosphere.

Local topography, such as hills and mountains; large volumes of water, such as lakes or seas; and the level of solar radiation, which is related to latitude, will all contribute to both causes. Thus specific airports can be prone to particular types of wind disturbances. This report is concerned with wind disturbances that are specific to individual airports. Wind disturbances generated in the vicinity of thunderstorms are some of the most severe that can be encountered by an aircraft and wind shear alerting systems should address these disturbances as well as those specific to an individual airport, but this important more general issue is not within the scope of this report.

Among eight types of wind disturbances described in Ref. 3 the following three are particularly dependent on local topography.

### 2.1.1 *Large scale gusts*

As wind strength increases there is a corresponding increase in the probability of encountering random turbulent gusts with a duration greater than 2 seconds. This probability is increased by the presence of distant groups of large buildings or rugged terrain, both of which increase the general level of turbulence at a particular wind speed. Variation of air temperature and winds with height will also affect turbulence levels.

Pilots partially compensate for the possibility of encountering such wind disturbances through the usual practice of increasing approach speed by a proportion of the headwind. However, it can still be hazardous to encounter a large disturbance, particularly close to the ground.

### 2.1.2 *On-shore wind*

Airports close to large water areas will experience on-shore winds during the day if the land becomes significantly warmer than the water (or the reverse effect in temperatures around freezing where water may be warmer than the land). Such on-shore winds occur in a shallow layer close to the ground that typically extends up to heights around 300–600ft. Wind in this layer will be measured on the ground at the airfield. The effect will be an increasing headwind during an approach as an aircraft descends into the on-shore wind layer, because aircraft operate into any significant surface wind.

This type of wind disturbance is generally benign because it is easily predictable, wind disturbances occur at a reasonable height, and, for the more critical approach conditions, the disturbance will tend to cause a height increase.

### 2.1.3 *Topographical and building disturbances*

In moderate and strong winds the airflow around large hills, mountains, cliffs or down large valleys can be very different from the mean wind and change dramatically with small changes in position relative to the objects. There can also be large localised eddies. Even large man-made objects close to runways, such as hangars and multi-storey car parks, or nearby wooded areas can produce significant local disturbances.

In general the size of any disturbance will relate to the size of the object that is its cause, and effects will decay with distance because of mixing induced by turbulence that is always present and related to wind strength.

Two particularly significant types of topographical disturbances are large changes in wind speed and direction as an aircraft leaves or enters a shielded region of relatively light wind; and vortices, sometimes referred to as rotors, that are shed from sharp edges such as cliffs, or generated in the lee of steep hills.

Airports that suffer from these effects are well known to pilots. Some prime examples are Hong Kong (Kai Tak), Gibraltar, Nice, Anchorage and Sumburgh.

These effects can be severe and can limit operations from airports when winds exceed certain speeds from particular directions. In general the most severe effects are from vortices (rotors), particularly because these energetic wind shears dissipate relatively slowly and can be carried by the wind into the approach and take-off flight paths of aircraft.

Such topographical wind shears contributed to an incident involving a BAe ATP twin turbo-prop aircraft that struck and damaged a wing tip during take-off from Sumburgh Airport in the Shetland Islands in a mean wind of 56 kt [1].

## 2.2 Effects of wind on aircraft

Wind shear is a transient event. It has a duration of typically between 2 and 40 seconds which is long in relation to the dynamic responses of pilots. Thus pilot control actions are always going to play an important part in any response of an aircraft to wind shear. In flight these control inputs will be of two basic types:

(a) stabilising inputs to damp dynamic oscillations;

(b) inputs to achieve the necessary flight path or optimum performance.

Stabilising inputs in the longitudinal plane to control pitch attitude and speed will continue to be primarily the pitch control inputs that stabilise the lightly damped controls-fixed phugoid mode[4] of the aircraft. The phugoid mode has a long period of many seconds and is easily controlled by small pitch control inputs to maintain constant pitch attitude. This is the normal way of flying aircraft.

Some early studies of the effects of wind shear looked at the response of an aircraft with controls fixed[5]. However, without controlling pitch attitude, the response is dominated by large oscillations of the lightly damped phugoid mode, where speed and height are exchanged at almost constant energy. This oscillation will not be present in practice because it is easily suppressed by a pilot or autopilot. Thus it is impossible to obtain a meaningful measure of the response of an aircraft to wind shear without including pitch stabilising control inputs[6]. The simplest case is to consider an aircraft with perfect pitch attitude stabilisation, i.e. pitch attitude remains constant. The two references (Refs. 5 & 6) show the phugoid response to wind shear and then the response of a piloted simulation to the same wind shear. In the simulation the height excursions of the aircraft were dramatically less because phugoid motion was suppressed by the pilot in the normal way.

When an aircraft is stabilised in pitch, then the characteristic dynamic modes in the longitudinal plane become:

(a) a strongly convergent exponential angle of attack mode with a time constant in approach and take-off conditions of around 0·5 – 1 sec.

(b) an exponential speed (or flight path) mode that is usually close to neutral stability during approach and take-off.

Aircraft response to wind shear is studied in some detail in Ref.3 and it is shown that both a loss of headwind and a downdraught will result in a loss of height. This can be countered by increasing thrust and increasing pitch attitude to increase the angle of attack. The potential height loss from a headwind shear is shown[3] to be proportional to aircraft wing loading and inversely proportional to the amount of excess thrust available. The potential height loss from a downdraught is inversely proportional to airspeed.

When an aircraft is in contact with the ground during the landing and take-off run or taxying, there are forces and moments due to the combination of wind and aircraft ground speed. Above certain wind strengths and directions a particular aircraft can become uncontrollable and it may leave the runway or taxyway. It may also collide with other aircraft or obstacles, it can get into a 'ground loop', or it may even be blown over.

## 3 MAJOR INCIDENTS/ACCIDENTS BETWEEN 1985 AND 1994 WHERE WIND WAS A FACTOR

Data has been extracted from the CAA Incident and Accident Database for all major incidents and accidents at UK, Channel Islands, and Isle of Man airports between 1985 and 1994 inclusive. The data has been carefully edited to eliminate irrelevant incidents such as those due primarily to an aircraft system failure, incidents to balloons, etc. A total of 374 events remained after editing and 170 of these events occurred at the 65 airports in this study. In 20 events the aircraft was parked without engines running and Air Traffic Services could not have had any direct influence, although some incidents may have been alleviated if arrangements could have been made for parking aircraft into wind when strong winds are forecast. The remaining 150 events occurred in various flight and ground phases as summarised in Table 1. The terms used for Flight Phases and Wind incident types are defined in Annexes B & C respectively. In particular it should be noted that 'Final approach' includes flare and touchdown, i.e. all the essentially airborne elements before the 'Landing run' where the weight is mainly on the wheels, and 'Pilot error' is used for events where the wind was a major factor but it was likely that the incident could have been much less severe if good airmanship had been used by the pilot.

**Table 1: Wind incidents/accidents 1985 – 1994**

| *Flight Phase* | *Crosswind* | *Moderate wind (15-30kt)* | *Strong wind (>30kt)* | *Pilot error* | *Wind shear – Bdg* | *Wind shear – Topog* | *Wind shear – Wx* |
|---|---|---|---|---|---|---|---|
| Final approach | 8 | 1 | | 9 | 1 | 4 | 35 |
| Helicopter landing | | | | | 1 | | 3 |
| Helicopter take-off | | | | | | | 1 |
| Initial climb | | | | | | 2 | 2 |
| ***Total (Airborne)*** | 8 | 1 | | 9 | 2 | 6 | 41 |
| Landing run | 31 | 1 | | 6 | 1 | | 10 |
| Take-off run | 4 | 1 | | 3 | | 1 | 4 |
| Taxy | | 6 | 7 | 3 | | | 5 |
| ***Total (Ground)*** | 35 | 8 | 7 | 12 | 1 | 1 | 19 |
| **Totals:** | 43 | 9 | 7 | 21 | 3 | 7 | 60 |

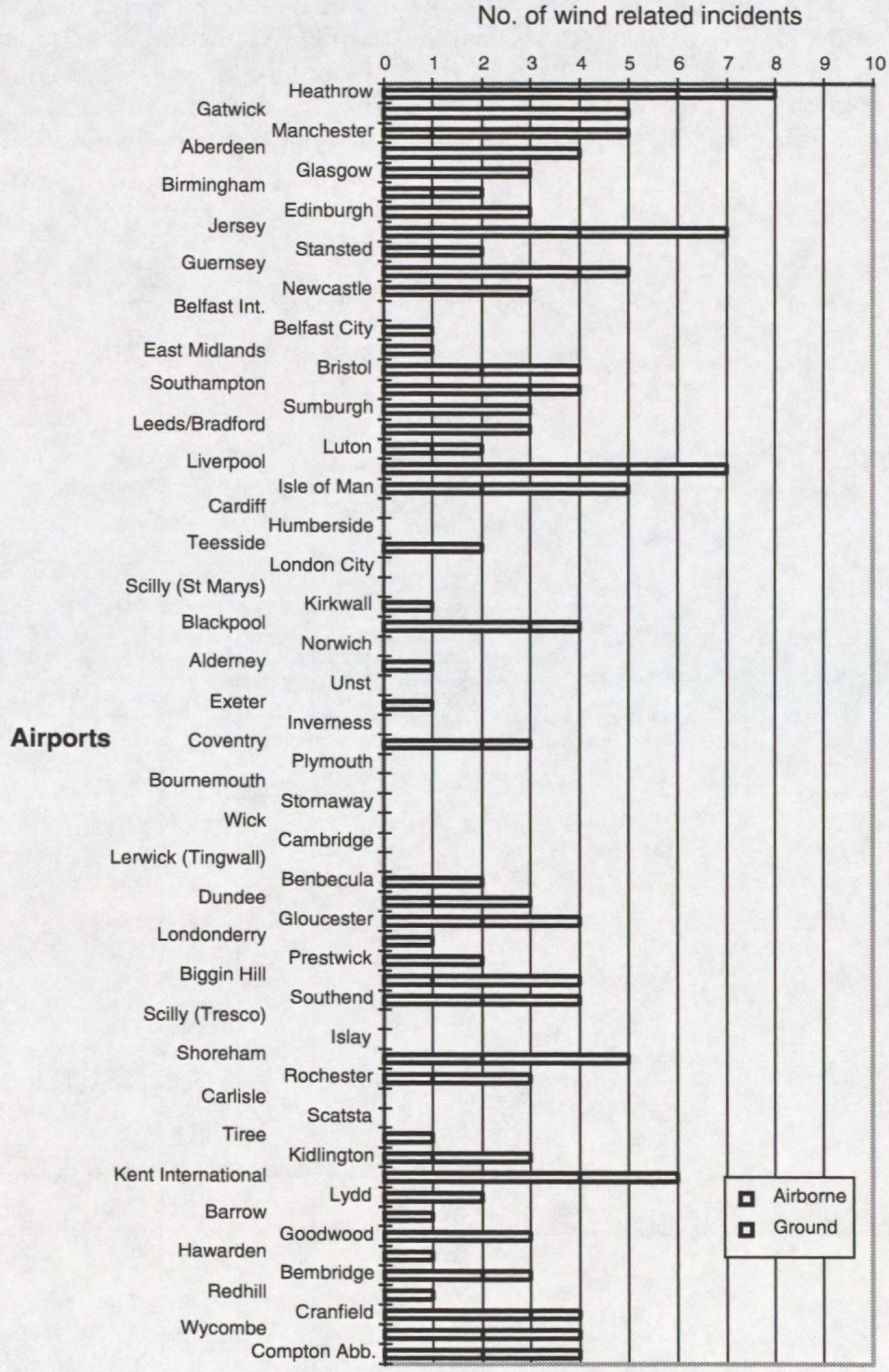



**Fig. 1 Major wind related incidents at UK Airports between 1985 and 1994**

It is to be expected that most of the events in 'Moderate wind' and in 'Strong winds' would occur during taxying as it is then that an aircraft is likely to have to turn and receive the full force of the wind sideways or from behind. Strong winds from these directions can cause an aircraft to roll over, to be blown off course, or to pitch onto its nose.

'Crosswinds' are mainly a problem during 'Landing runs', and less frequently during flare and touchdown ('Final approach') or 'Take-off runs'. Whereas 70% of 'Wind shear' events occur during airborne phases.

The largest group of events – 40% of the total – have 'Wind shear' as a major contributory factor, and 'Crosswind' is the next largest at 29%. It has not been feasible to relate crosswind events to the effects of entering or leaving the lee of airport buildings or local wooded areas. It is known that this can be a problem at some airports and such events should be more properly classified as 'Wind shear – Bdg.'.

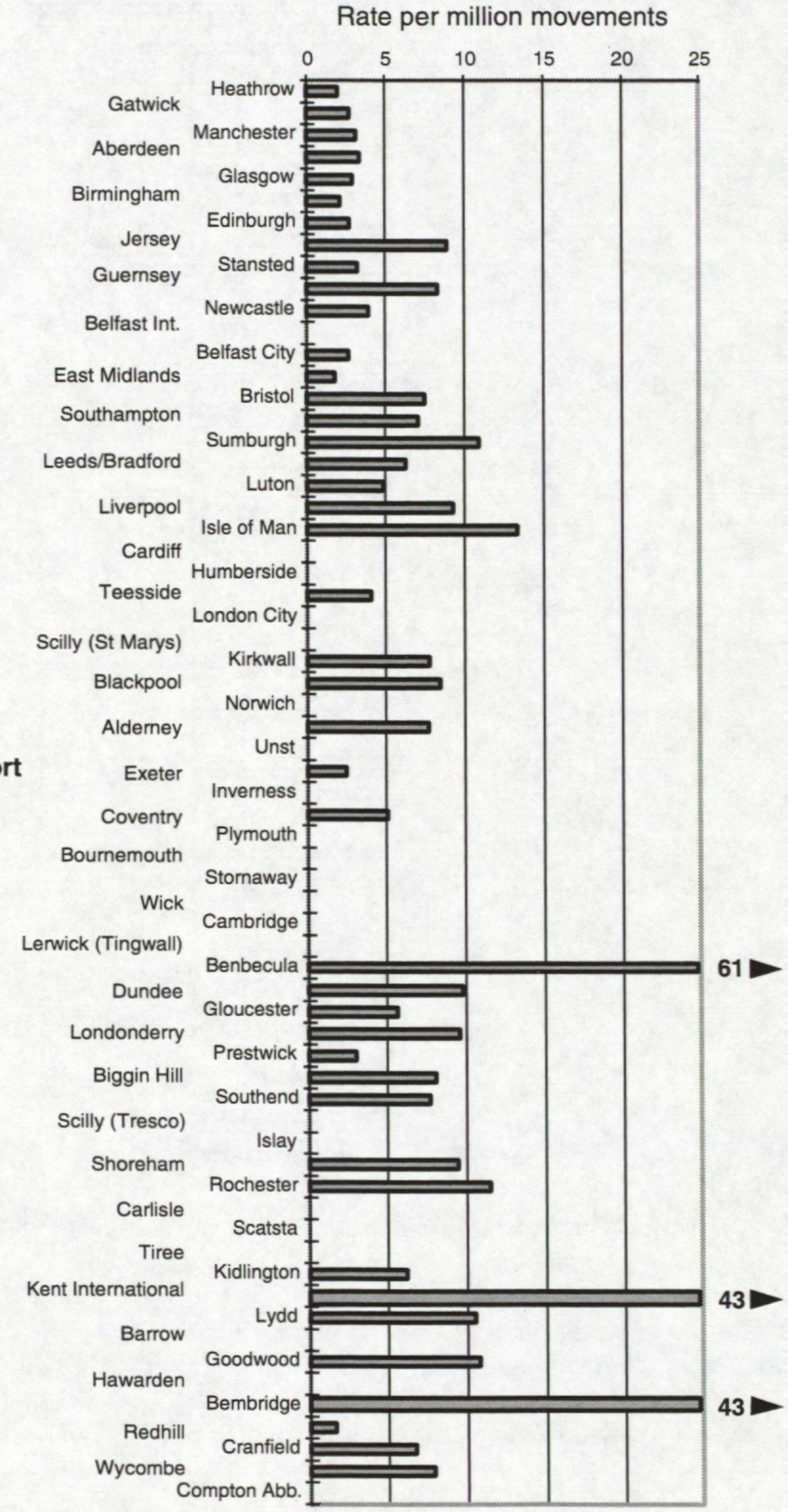



**Fig. 2 Wind related major incident rate per million movements at UK Airports**

Numbers of incidents in airborne and ground phases of operations at individual airports, excluding events when an aircraft was parked without engines running, are presented in Fig. 1, and listed in Annex D together with aircraft movement details and diversions during 1993. Incident rates per million movements have been estimated assuming that movements per year were constant over the 10 year period, Fig. 2, and the average for the airports in the study is 4·5 per million. Incident rates give a reliable measure of the magnitude of wind related operating difficulties at different airports when there have been several incidents during the period, and when the level of movements is high. However it is not a reliable measure when only one or zero incidents have occurred during the period and movements are low (say, less than 10,000 a year). For example, there is no evidence to support the implications that could be drawn from the enormously high incident rate of 110 per million movements at Tiree, where there was one incident during the ten years and only 906 movements in 1993, compared with a rate of 11 per million at Sumburgh, where there were 3 incidents and 27,533 movements in 1993. Tiree is reputed to be significantly less prone to wind problems than Sumburgh. Thus incident rates have not been calculated where there were only one or zero incidents *and* there were fewer than 10,000 movements in 1993.

It is anticipated that incident rates should be significantly lower for Air Transport movements* than for Training, Test and Private movements. By studying the incident rates at those airports where movements are more than 90% Air Transport, and those airports where movements are more than 90% Training, Test and Private movements, it is possible to quantify incident rates for each type of operation. It is found that the average Air Transport Incident rate is 2·1 per million and the average for Training, Test and Private movements is 6·7 per million movements. A Relative Incident Rate is calculated for each airport in Annex D based on these averages to account for widely differing mixes of operations.

It is interesting to note that there appears to be no correlation between wind incidents and diversions. This is probably because the main causes of diversions are low cloudbase and poor visibility, which are not directly related to winds or wind shear. Also winds are more reliably forecast than visibility and pilots can decide to delay departures rather than risk diversion.

## 4 SURVEY OF UK AIRPORTS

A survey of the perception of wind related operating problems at 64 of the 65 airports in the study – Kent International is operated by the Ministry of Defence (RAF) and was not included in this survey – was conducted by means of a Questionnaire, by visits to 11 airports, and by a review of information in Air Pilot (UK Air Information Publication (AIP)) and in the Aerad and Jeppeson Airport Plates for the UK. Information for all these sources comes primarily from Airport Operations based on information from Air Traffic and liaison with Aircraft operators at a particular airport.

### 4.1 Questionnaire data and information from visits to airports

A questionnaire (Annex E) was designed to obtain detailed information about the types of operation, any wind or storm problems that are particular to individual airports, and details of their wind measuring systems. A total of 55 airports returned completed questionnaires, and one of the airports visited was Aberdeen, which was

* In this context Air Transport movements are any scheduled or charter flights.

the only airport with more than 7,000 air transport movements per annum, i.e. Airports Nos. 1 – 32, that did not reply. The airports that were visited and those that returned completed Questionnaires are identified with a Y (= Yes) in Annex D.

Of the airports that replied, 33 (60% of replies) said they had some degree of wind related operating problems, and 26 (47% of replies) said that their problems might become hazardous (Severity Scale of 2 or more, Annex E, p 68). The total number of entries for various causes of wind shear and different levels of severity are summarised in Table 2. Many airports had several different problems and thus there are more entries than the number of airports that reported problems. A separate entry was made for each type of wind shear problem, for either or both of the landing or take-off flight phases and for each runway direction.

Eight airports identified a source of problems that they did not think was among the 6 causes identified in the Questionnaire. Five of these 'Other' causes related to Severity Scale Level 2 and 3 to Level 1. All the Level 1 cases and 3 of the Level 2 cases could be placed with the existing types of causes. Three related to the effects of nearby railway embankments, which are a similar man-made obstacle to buildings; two related to nearby hills and one to proximity to the sea. The two remaining 'Other' causes were from the Isle of Man and Stornoway and have been summarised under 'Island effects'.

**Table 2: Wind shear causes and severity (Initial Questionnaire replies)**

| *Wind shear problem* | *Total entries (Severity > 1)* | *Predictable, non-hazardous difficulties (Severity 1)* | *Problems could become hazardous (Severity 2)* | *Radio warnings issued (Severity 3)* | *Diversions, or operations temporarily suspended (Severity 4)* |
|---|---|---|---|---|---|
| Sea or large lake causing on-shore winds | 11 | 18 | 8 | 2 | 1 |
| Nearby hills | 27 | 15 | 16 | 9 | 2 |
| Nearby cliff(s) | 11 | 4 | 6 | 5 | |
| Buildings, inc. railway embankments | 18 | 13 | 13 | 5 | |
| Trees or woods | 7 | 1 | 6 | 1 | |
| Distant hills or mountains | 19 | 6 | 17 | 2 | |
| Island effects | 14 | 6 | 14 | | |

The 'Island effects' problem was not anticipated. It does not appear in the usual descriptions of wind problems, but it was identified by two airports located near the sea shore on islands with hills or mountains above about 200m high. The effect, described as 'super backing' at the Isle of Man airport, is seen as a very large change in surface wind direction over a period of only a few minutes, and as a dramatic change in wind strength and direction with height.

Nearby hills, which include the combined effects of hills and valleys near the airport, produce the greatest number of entries at 27 (25%). Man made obstacles, such as buildings on the airport or railway embankments close to runways, at 18 entries, and distant hills or mountains at 19 entries (17%) are next in frequency.

## 4.2 Review of wind related problems at particular airports

The character of each of the wind related problems is described in the following sections including data from replies to the Questionnaire, data from incident reports, and information from a study of local topographical features. Tables of the number of conditions affecting take-off or landing on individual runways at airports are produced based initially on Questionnaire replies and adjusted to reflect additional information from wind incidents and topographical study. At the end of the section is a revised table of wind shear causes and Severity taking account of all the available information in addition to that provided by airports in the Questionnaires.

### 4.2.1 *Sea or large lake causing on-shore winds*

The general characteristics expected during on-shore winds are described in Section 2.1.2 above as predictable and usually not a significant problem. However, there were 11 entries in the Questionnaires at Level 2 or above including 2 entries at Level 3 and one at Level 4. Guernsey reported a Level 4 Severity associated with strong winds and a valley ½ mile from the threshold of Runway 27, which would be more appropriate under 'Nearby Hills' (see the next Section).

Entries at Level 3 were reported by Isles of Scilly (St. Mary's) and refer to the effects of local terrain on strong winds from the sea, rather than direct effects from on-shore winds and should be included with 'Nearby Hills' (see the next Section).

Level 2 entries were from Alderney (1), Isle of Man (1), Newcastle (1), Shoreham (4) and Stornoway (1). The entry from Alderney is for a valley effect, which should be included with 'Nearby hills'. The entry by the Isle of Man is for a combination of strong crosswinds and poor visibility, often in rain, which can be combined in island situations. It is an effect that relates to the presence of the sea, although it is different from on-shore winds. The Newcastle entry refers directly to on-shore winds and mentions shear of up to 30kt. The Shoreham entries are all for gale force winds, which are not specifically due to the sea or any other local feature. The Stornoway entry is specifically for on-shore breezes combined with the effects of the beach and sand dunes. Thus one entry should be transferred to 'Nearby hills', 4 entries are not specific to the airport, and 3 entries remain relevant.

**Table 3: Number of conditions by Airports for Sea or large lake causing on-shore winds**

| *Airport* | *Severity Level 2* | *Severity Level 3* | *Severity Level 4* |
|---|---|---|---|
| Isle of Man | 1 | | |
| Newcastle | 1 | | |
| Stornoway | 1 | | |

After redistributing entries, Table 3, the total number above Level 1 is 3 at Level 2, and there are no entries at Levels 3 or 4. The 2 entries at Level 2 which relate to sea breezes suggest that effects can sometimes be significant, particularly for light aircraft and when combined with flow over dunes and thermal up/down draughts.

### 4.2.2 *Nearby Hills and Valleys*

This category was intended to deal with local undulating terrain, as compared with local steep escarpments such as cliffs. However it is clear from replies that some airports have problems associated with nearby valleys and were uncertain as to which type of cause was appropriate. This category of 'Nearby Hills' should have been defined as 'Nearby Hills and Valleys'. Thus some entries that should be classified as 'Nearby hills' appeared in 'Other' and some entries in 'Sea ....'.

This category was mentioned more frequently than any other with 31 (30%) of the entries at Level 2 or above. It also has all of the most severe entries (Level 4), which were reported by Guernsey and Bembridge.

All 14 airports with conditions at Level 2 or above are listed in Table 4. Effects are described in detail for airports where the Severity Level is 3 or greater, for Aberdeen where no Questionnaire was completed, and for Teesside which implied a Severity Level 3 entry that has been reduced to Level 1.

**Table 4: Number of conditions by Airport for Nearby Hills and Valleys**

| *Airport* | *Severity Level 2* | *Severity Level 3* | *Severity Level 4* |
|---|---|---|---|
| Aberdeen | 2 | | |
| Alderney | 1 | | |
| Bembridge | | 2 | 2 |
| Dundee | | 2 | |
| Glasgow | | 1 | |
| Guernsey | | | 1 |
| Jersey | 1 | | |
| Kirkwall | | 1 | |
| Leeds/Bradford | | 1 | |
| Plymouth | 5 | 1 | |
| Rochester | 1 | | |
| Scatsta | 4 | | |
| Shoreham | 2 | | |
| Stornoway | 2 | | |

#### 4.2.2.1 Bembridge, Isle of Wight

Bembridge provides a good illustration of some of the problems experienced if an airport is close to a large hill. There is a ridge about 1½km long at a height of 300ft above the runway and parallel to the runway about 1km SSW of the airport (Fig.3). This ridge (Bembridge and Culver Downs) falls away steeply at either end and becomes part of Culver Cliffs on the south side at the east end. Wind over and around this hill produces severe turbulence in winds above 25kt blowing from between 090° and 230°. Winds between about 180° and 200° produce a tailwind on both ends of the runway below about 300ft caused by the airflow diverting round the hill as indicated in Fig.3. The runway is on the small estuary plain and only 55ft above mean sea level.

Bembridge has a very high incident rate (Fig.2) of 43 per million movements and a high relative incident rate of 6·5 times the average. This supports the Severity rating of Level 4 (Diversions occurring or operations temporarily suspended because of wind hazards) given by the Airport. Three incidents were recorded in the CAA Incident Database between 1985 and 1994; two involved wind shear and one was mainly a crosswind.

Bembridge has one anemometer and one wind sleeve, which are both located abreast of the mid point of the 837m long runway and about 400m to the NNE.


**Fig. 3 Terrain effects at Bembridge Airport, Isle of Wight (Ordnance Survey)**

4.2.2.2 Guernsey, Channel Islands

Guernsey has a problem on approach to Runway 27 with a significant valley at about ½ nm before the threshold. This causes severe turbulence in winds above 30kt from between 180° and 240°. However 4 out of the 5 recorded incidents involve difficulties during the landing run in crosswinds, and only one involves wind shear near touchdown. Guernsey also has problems from the wake of buildings S to SW of the threshold of Runway 27, and these will be discussed in Section 4.2.4. The relative incident rate at Guernsey is 2·3 times the UK average, and it is significant that the incidents are largely of one type.

4.2.2.3 Aberdeen

At Aberdeen there is a less severe and more complex version of the flow around hills that is seen at Bembridge. There are two significant hills rising to about 600ft above the airport with Tyrebagger Hill at 3·5km to the W and Brimmond Hill at 4km to the SW of the airport. (Fig.4). These are part of a N-S ridge with a 300ft deep valley between them. To the south of Brimmond Hill the land is also about 300ft below the hilltop. In


**Fig. 4 Area around Aberdeen Airport (Ordnance Survey)**

the north the land is about 500ft below the top of Tyrebagger Hill. These hills have significant effects on surface winds at the airport when the 1000ft wind is between about 200° and 320°, and surface winds can differ by up to 100° in direction from the 1000ft wind. The surface wind can also change dramatically in strength and direction with only small changes in the 1000ft wind, and wind strength and direction can vary significantly between the ends of the same runway, and this has been observed from the behaviour of the wind sleeves at either end of the runway. This means that surface wind is unpredictable when the forecast winds are from SW to NW.

These effects should be noticeable in moderate and strong winds, and wind shear reports are quite frequent at Aberdeen in winds above about 10kt. The biggest shears tending to occur between about 200ft and 500ft height on the approaches in strong winds.

There is also reported to be a significant disturbance at about 500ft height above the airport in SW winds which is believed to come from Dyce Quarries, which are NW of the airport and about 1km to the west of the approach path.

There are four incident reports for Aberdeen between 1985 and 1994 and these are all 'ground' incidents. The relative incident rate of 1·1 times the UK average suggests that there may be no major problems. Two of the incidents involved crosswind problems for light aircraft, which may be related to the effects of the hills producing crosswinds that vary along the runway and differ from the anemometer indication.

In the absence of a completed Questionnaire, the information received in discussions during a visit to the airport, the local topography, a Meteorological Office summary for the airport, pilot inputs and the incident reports, all indicate that Aberdeen should be included among airports with Severity Level 2 conditions relating to 'Nearby Hills' for landings on Runways 16 and 34 in surface winds from about 200° to about 320° at a strength above about 15kt.

4.2.2.4 Dundee

The airport at Dundee is on the north bank of the Firth of Tay with a runway 10/28 and the ground rises rapidly to the N and NE to hills of 480ft height at a distance of about 1·4km from the runway centreline. The city of Dundee is built around these hills with the Dundee Law Memorial atop the tallest hill. This combination of hills and an urban area would be expected to produce variability and uncertainty in wind direction, and increased turbulence.

Dundee has a relative wind incident rate of 1·5 times the UK average. Only one of the three incidents between 1985 and 1994 was due to severe turbulence from flow around these hills in a surface wind of 10-15kt. This is probably because moderate or strong northerly winds are not as frequent as wind from other directions.

4.2.2.5 Glasgow

There are steep escarpments rising to around 1000ft about 6-10km to the N and NE of the airfield. The Questionnaire reply suggests that these in part cause some severe turbulence and wind shear problems. The incident rate at Glasgow is just below the UK average. All the three incidents between 1985 and 1994 were caused by wind shear and turbulence whilst airborne. In two cases, where wind is reported, the wind was strong and westerly.

When approaching in strong westerly winds there would be a moderate updraught and turbulence caused by the escarpment and conurbation at Bearsden at around 5-6km, i.e. about 800-1000ft above the airport, and then the updraught would decrease as the approach continued.

4.2.2.6 Kirkwall

The airport is about 40ft above mean sea level and is bounded by Inganess Bay to the N and NE. In all other directions there are hills at around 1·5km distance and varying in height from 100ft to 200ft above the airport. These hills cause turbulence below about 400ft on the approach to Runway 27 and can result in occasionally severe wind shear in winds over 20kt from SW to NW.

The only incident reported between 1985 and 1994 was an aircraft landing short in conditions with a headwind of 25kt gusting to 40kt.

4.2.2.7 Leeds/Bradford

The Questionnaire reply identifies some difficulties with wind shear when landing on Runway 34 with winds above 35kt from 240° to 280°. In these conditions the wind is passing over the valley of the River Aire, which is about 300ft below the airport, then rising over the hill SE of the conurbation of Yeadon which is about 100ft above the airport at a distance of 1·5km. This would be expected to cause wind shear in strong winds.

The relative incident rate at Leeds/Bradford is about 1·3 times the UK average, and all the incidents are 'ground' situations. Two of the three recorded incidents involved crosswinds from the SSW, and the small hill between the airport and Rawdon may have increased the variability of the wind along Runway 14 in these conditions.

4.2.2.8 Teesside

In the Questionnaire reply from Teesside there is mention of turbulence when inbound for Runway 23 in NW winds. Details of Severity Level and wind strength are not given, although another entry implies a Severity level of 3. The average level of incident reports combined with the relatively flat terrain indicate that the effect is probably nearer to Level 1 and the entry has been deleted from Table 4.

**Table 5 Number of conditions by Airport for Nearby Cliffs**

| *Airport* | *Severity Level 2* | *Severity Level 3* | *Severity Level 4* |
|---|---|---|---|
| Bembridge | | 2 | |
| Isles of Scilly (St. Mary's) | 4 | | |
| Jersey | | 1 | |
| Kirkwall | 2 | | |

4.2.3 *Nearby Cliff(s)*

Cliffs can be expected to produce large updraughts and curl over the top when they are into wind and a strong downwind rotor when they are out of wind, Fig.5. In general, aircraft will be taking off over them when they are into wind and any updraught will be beneficial during normal take-offs. There can be a significant wind reduction under the curl-over and this could cause difficulties to any aircraft taking off that is lower than a height of about 80ft over the end of the runway. This can occur if an aircraft is near the maximum weight for safe take-off or if a power loss is experienced during take-off.

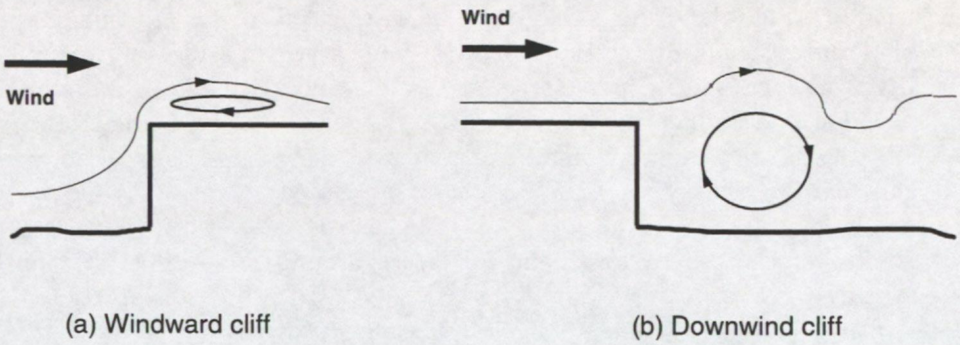



**Fig. 5 Airflow over cliffs**

When an aircraft is approaching to land with a cliff at the downwind end of a runway then the rotor will result in a loss of headwind and a downdraught followed by an increase in headwind and an updraught. These effects will be stronger if an aircraft is below the normal glidepath. Thus an aircraft that is low may sink even lower initially before being lifted back up. In general the updraught and increase in headwind will tend to be strongest and aircraft will tend to land long. Exceptionally, a strong decrease in wind may occur as part of the natural gustiness in strong winds and, if this coincides with the region where a headwind increase would normally occur and the aircraft is low on the glidepath, then the aircraft may be in a hazardous situation. It is inadvisable to get low on a glidepath with a strong wind over a nearby downwind cliff.

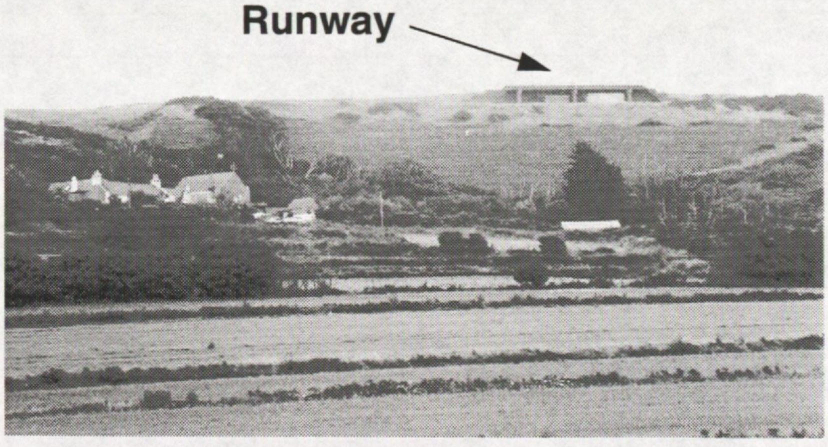



**Fig. 6 Cliff near the threshold of Runway 09 at Jersey.
View looking E.**

Five airports report wind problems with nearby cliffs. One of these was Dundee, which was uncertain whether the steep hill to the north of the airport was a 'Nearby Hill' or a 'Nearby Cliff' and reported the same effects under both headings. In this case it should be regarded as a 'Nearby Hill' and it is already included in the previous Section. The other 4 airports are all island airports with nearby cliffs varying between 50 and 350ft in height. The cliff closest to a runway threshold among these airports is at Jersey where there is a cliff about 170ft high and only 160m from the displaced threshold of Runway 09, Fig.6. Wind shear incidents occur at Jersey that may be associated with rotor flow at the cliff, but none prevented a successful landing.

Airports and the number of entries at Severity Level 2 and above are listed in Table 5. At Bembridge the cliffs are to one side of the approach and contribute to high levels of turbulence and probably produce a stable rotor in winds between about 170° and 220° or shed intermittent large pieces of rotor, which would be seen as severe turbulence, in winds between about 220° and 270°. Any stable rotor is likely to be close to the airport and would be expected to cause large changes in crosswinds along and near the runway.

At St Mary's and Kirkwall the cliffs are around 50 – 100ft and further from the runways.

4.2.4 *Buildings, including railway embankments*

Typically runways will be several hundred metres from buildings. At these distances buildings generate a disturbed wake where wind strength is significantly reduced, and some particular combinations of building shapes, sizes and wind directions can produce intermittent pieces of rotating flow that are carried downstream by the wind. Disturbance will occur from approximately 1½ times the building height downwards and cause difficulties in the final stages of landing or in directional control during landing. The wake from buildings can also affect anemometers and windsocks.

**Table 6 Number of conditions by Airports for Building Wakes**

| *Airport* | *Severity Level 2* | *Severity Level 3* | *Severity Level 4* |
|---|---|---|---|
| Bournemouth | | 1 | |
| Guernsey | | 1 | |
| Isle of Man | 1 | 1 | |
| London Gatwick | 1 | | |
| London Heathrow | 1 | | |
| Manchester | 1 | | |
| Newcastle | 2 | | |
| Plymouth | 1 | 2 | |
| Rochester | 1 | | |
| Southampton | 2 | | |
| Southend | 1 | | |
| Stornoway | 2 | | |
| Wick | 1 | | |

There is continuing commercial pressure to erect new buildings on or near airports and a need to develop criteria to prevent the construction of buildings that will affect the safety or operational capacity of an airport. To assist in developing criteria the situation has been examined in this section for all airports reporting problems at Severity Level 2 and above.

Railway embankments have relatively steep sides and generate significant upflow on the upwind side followed by downflow and a small rotor on the downwind side. They will only produce significant effects when aircraft are below a height of about 3 – 4 times the height of the embankment. The effects will be greater on aircraft that are below the standard approach path; and in correcting for any sink on the downwind side of the embankment they may subsequently rise more than expected as they encounter the updraught. This can lead to landing long or hard. Several airports are close to railway lines and at Birmingham, Edinburgh and Southend there is an embankment near the threshold of an active runway. Southend reported a problem at Level 2, the other two airports reported a Level 1 problem (Predictable and not likely to be hazardous).

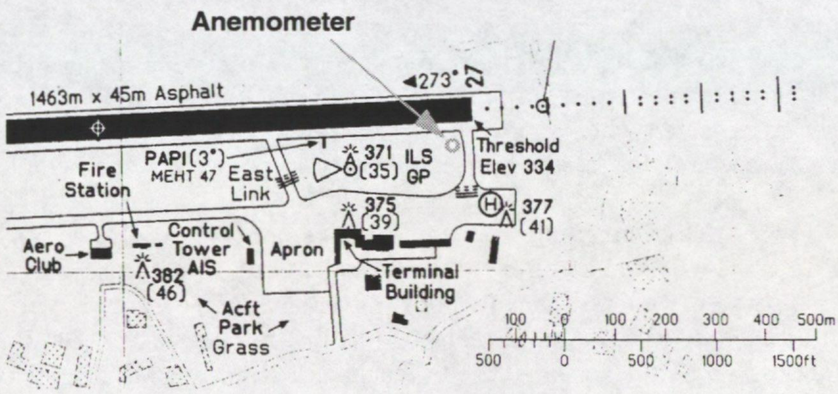



**Fig. 7 Buildings at Guernsey Airport (from UK AIP)**

4.2.4.1 Guernsey, Channel Islands

If an airport has wind problems caused by 'Nearby Hills and Valleys' or by 'Buildings' then there may be uncertainty about whether a particular problem is caused by buildings or terrain. In many cases the height at which problems occur is a measure of whether the problem is due to buildings, which will always be below about 150ft, or terrain, which will extend above 150ft, although some effects may also be present below 150ft. Guernsey is an airport that has reported both problems and the location of the airport terminal buildings, and a hangar and Cargo sheds to the east of the terminal buildings is shown in Fig.7. These buildings are about 250m from the runway and SW of the threshold of Runway 27. The sole anemometer is also close to the same threshold.

All 5 of the incidents at Guernsey recorded in the CAA Database between 1985 and 1994 included crosswinds and 4 occurred during the landing run. This suggests that the buildings may be a significant factor either directly or through some shielding of the anemometer leading to indication of crosswinds lower than will be experienced further along the runway.


**Fig. 8 Panoramic view to the SW of the Maintenance area at the east of London Heathrow Airport**

4.2.4.2 London Heathrow and Gatwick

There are warnings about wind shear or turbulence in strong S/SW winds due to buildings in UK AIP, Aerad and Jeppeson for London Heathrow and London Gatwick. No warnings are published for any of the other airports in Table 6. The warning at Heathrow relates to the large group of buildings around 100ft high and about 500m south of the extended centreline of Runway 27R in the British Airways Maintenance Area at the east of the airport, see the panorama photo montage in Fig.8 and the plan in Fig.9, which can cause problems when approaching Runway 27R. Similar problems might be expected when approaching Runway 27L in strong N/NW winds because the maintenance area is situated between the two runways, but such winds are quite rare.

At Gatwick there is a similarly located Maintenance Area (No.1) SW of the threshold of Runway 26L. Although the buildings are slightly lower in height at around 80ft and the hangars are generally smaller in dimensions. Details are shown in the panoramic photo montage, Fig.10, and the plan, Fig.11. The complex of Terminal buildings and Offices at the South Terminal are taller than the buildings in Maintenance Area 1, and

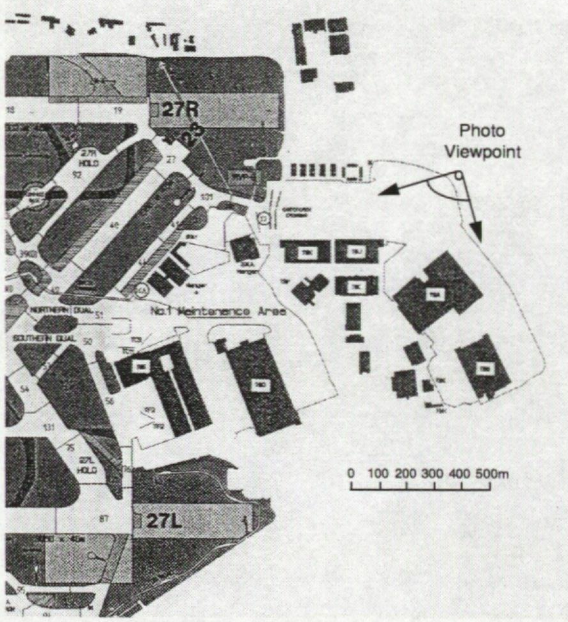



**Fig. 9 Plan of the east end of Heathrow showing the Maintenance area (Courtesy of BAA)**

would be potentially more likely to cause a wind shear problem, but they are further east of the threshold and strong N to NW winds are rarer. Aircraft on the normal approach path will usually be above the wake from the South Terminal. However there could be problems for an aircraft below the normal approach path, particularly in a strong Northerly wind. In general building induced wind shear problems would be expected to be less severe at Gatwick than at Heathrow in a given wind strength.

Incidents due to building induced wind shear are avoided at Heathrow by changing the landing runway when pilots start to report significant, but non-hazardous problems. This is typically at wind strengths greater than about 15kt.

There is less scope for avoiding building induced wind shear effects at Gatwick, although using Runway 26R would alleviate the problem, but it is normally only available when 26L is out of use and it cannot be used at the same time as 26L because of the small lateral separation between them. Also there are no instrument landing aids on 26R and it is significantly shorter than 26L.

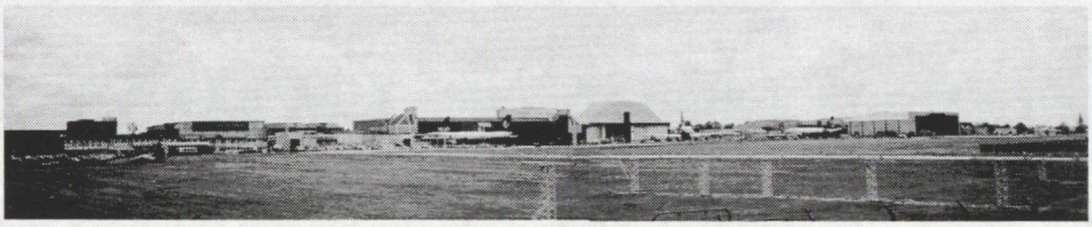


**Fig. 10 Panoramic view of the No.1 Maintenance area at Gatwick looking SW from near 'A Hold N'**

Thus perhaps it is not surprising that Gatwick has a greater proportion of incidents in airborne flight phases than Heathrow (100% airborne incidents at Gatwick compared with 25% at Heathrow) and that the overall incident rate is slightly higher at Gatwick

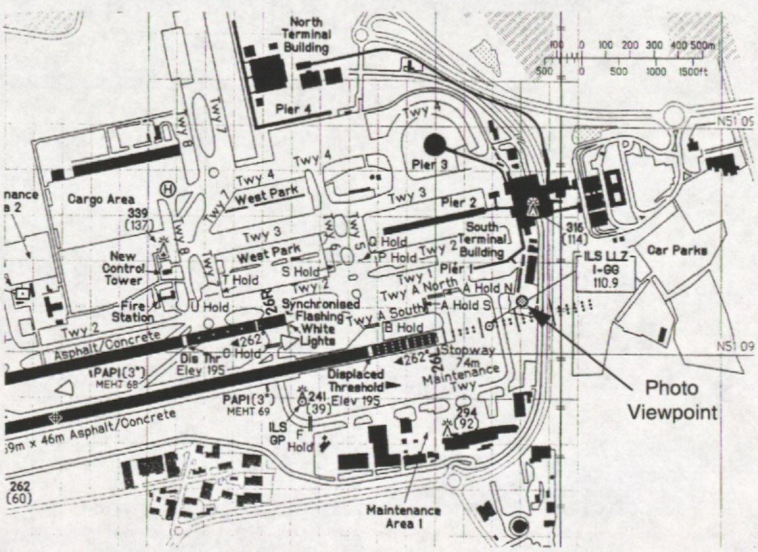



**Fig. 11 Plan of the east end of Gatwick showing the Maintenance area (from UK AIP)**

(2·7 per million movements) compared with Heathrow (1·9 per million movements). Both airports are around the UK average in this study with relative incident rates of 0·9 for Heathrow and 1·2 for Gatwick.

Another factor contributing to more ground movement phase incidents at Heathrow could be partial shielding from crosswinds caused by the large 'central island' buildings. However, relative to their height, these buildings are much further away from the runways than large buildings at some other airports and it could need very strong crosswinds of perhaps more than 30kt before any problem might appear. There were two incidents between 1985 and 1994 involving aircraft taking off in strong crosswinds.

4.2.4.3 Isle of Man (Ronaldsway)

There is a warning in the UK AIP and the Aerad and Jeppeson airfield plates for the Isle of Man of wind shear on short finals to Runway 08 in SE winds. In discussions with staff at the airport there was disagreement on whether the cause was turbulence from Langness or from King William's College. The relative location of these features is shown in Fig.12. In the questionnaire this wind shear is attributed to Langness, which is a low peninsula about 2km SE. It is about 80ft high and has low cliffs of about 50ft on the east side. King William's College, Fig.13, is a large building about 60ft high with a tower up to 110ft. It is about 300m south of the threshold of Runway 08 and is about 100m long. Its long axis is in the direction of 115/295°. There is also a small knoll on the sea shore south of the college called Hango Hill with a small ruin on the top.

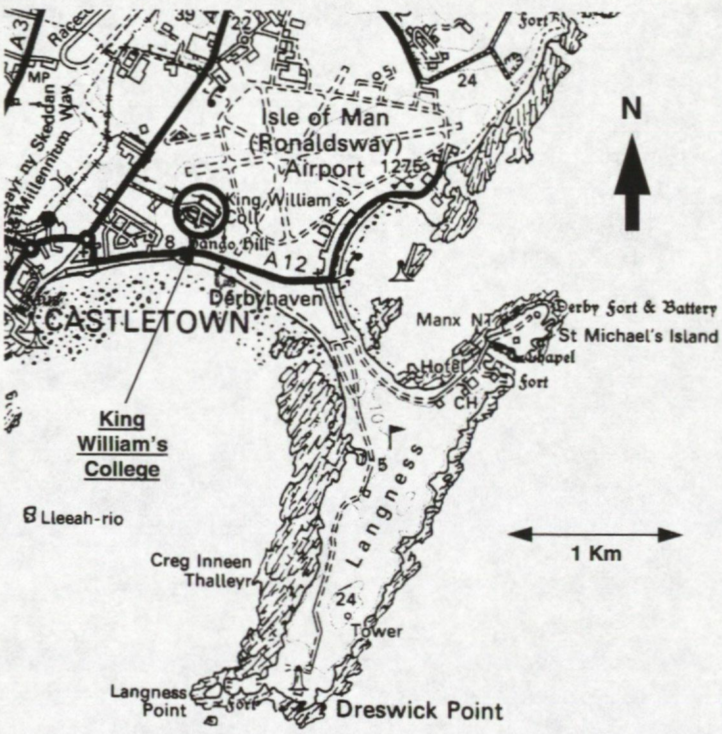



**Fig. 12 Location of features SE of the Isle of Man airport**

It seems most likely that the wind shear on short finals is mainly due to the College and perhaps the knoll. Langness is not large enough or close enough to generate discrete wind shear although it would be expected to add to a general increase in turbulence be-low about 150ft. Disturbances from the College would be expected to be noticeable in winds between about 090° and 160°. Thus it seems appropriate to move the entry from 'Nearby Hills' to 'Buildings', and it is rated at Severity Level 2/Occasional 3, which should be listed as Level 3.

**Fig. 13 King William's College from the south (Hango Hill)**
(Picture taken in poor light)

There are also some problems at Severity Level 2 at the Isle of Man for light aircraft taking off on Runway 03 in northerly winds because of the wake from hangars.

There were no major incidents at the Isle of Man on the CAA Database between 1985 and 1994 where building wakes could be a significant factor.

4.2.4.4 Manchester

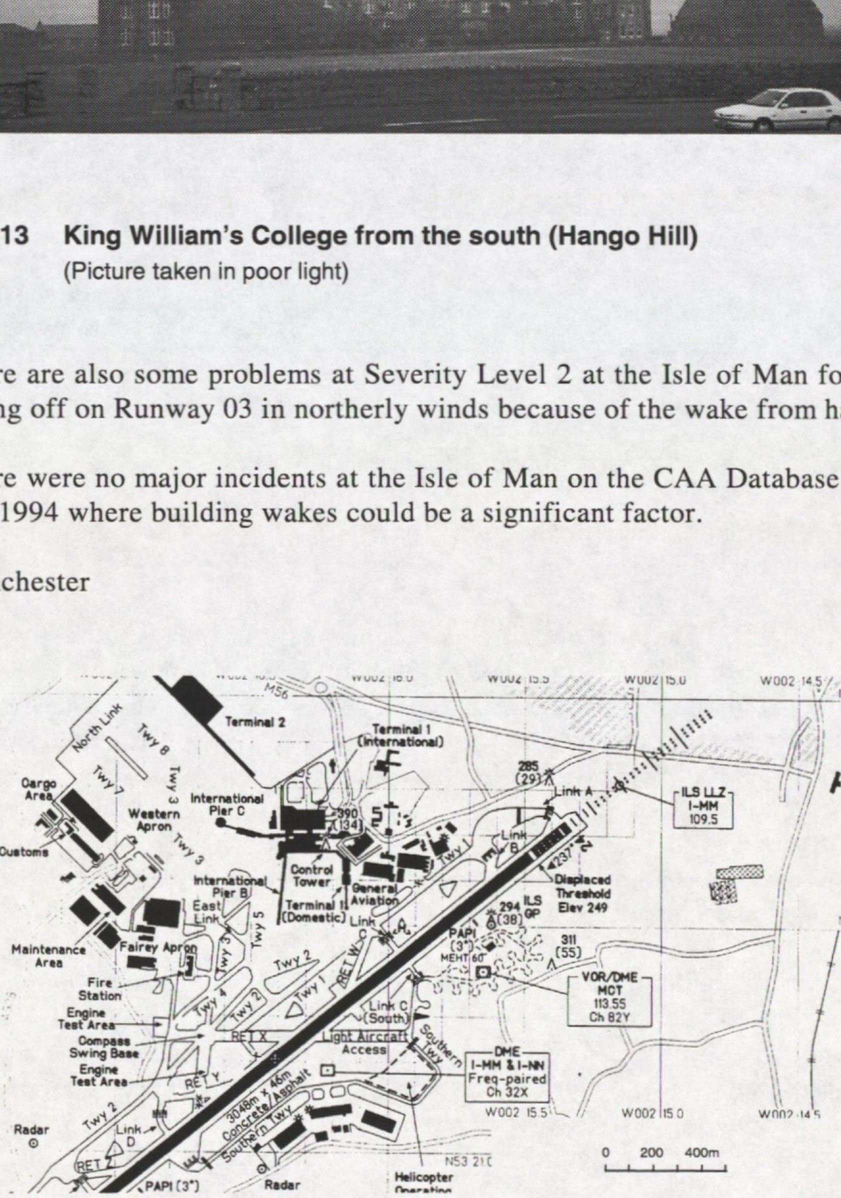
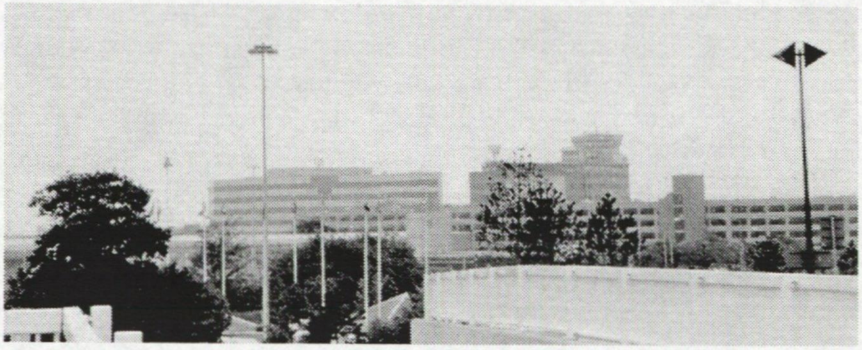
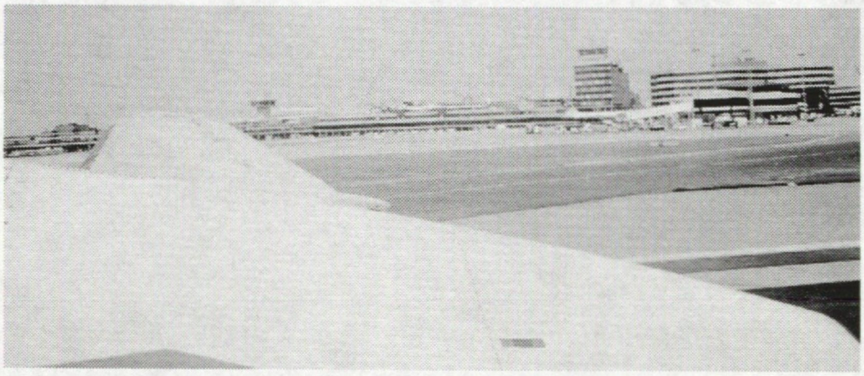



**Fig. 14 Plan of the NE end of Manchester Airport (from UK AIP)**



(a) Olympic House and Control tower from the NW (from Terminal 2)



(b) Olympic House and Control Tower from the S (from runway 24)

**Fig. 15 Buildings at Manchester Airport**

In 1990 a B737 pilot reported a large updraught at about 100ft on the approach to Runway 24 in a light wind (310°/05kt) and suggested that it may be due to a new building (Olympic House) near the Control Tower. The Questionnaire answer acknowledges this incident and gives a Severity Level 3 for building wakes on the approach to Runway 24. The light wind at the time of the incident, it's direction, study of the plan of the airport, Fig.14, and the picture of the relevant buildings, Fig.15, suggest that it was very unlikely to be an affect from the buildings and more likely to have been a thermal updraught. There are no other recorded incidents where building wakes may be implicated.

However the buildings are substantial with a spread of about 300m wide by 80ft high perpendicular to winds from W through NW, and they are about 700m west of the threshold of Runway 24. This group of buildings is smaller than those at London-Heathrow and about twice the distance from the place where aircraft will be at a height of about 100ft. This arrangement would be expected to produce a noticeable reduction in wind strength below about 100ft in the final stages of an approach to Runway 24 in winds between W and NW, but the effects would probably not be sufficient to cause major problems.

Thus there does not appear to be sufficient evidence to justify an entry at Severity level 3 and it has been reduced to Level 2. Unpublished data from a report by a University also agrees that the building wake should not cause problems. The relative incident rate at Manchester of 1·1 times the UK average also suggests that there is no significant problem.

4.2.4.5 Newcastle

In the reply to the Questionnaire, Newcastle reports disturbances due to a 'large building close and to the S of the runway'. This is either Woolsington Hall, which is about 500m from the runway, or one of the buildings in the Maintenance Area, which is about 200m from the runway (Fig.16). The distance from the runway and size of Woolsington Hall suggests that it is not likely to be the cause of any problems. Woolsington Hall is smaller and nearly twice the distance from the runway when compared with King William's College in the Isle of Man.

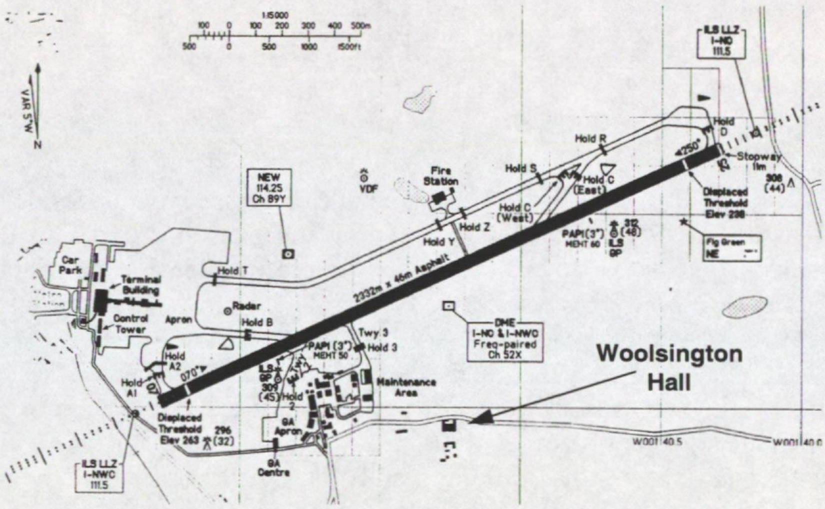



Fig. 16 Newcastle Airport (from UK AIP)

Two of the three wind incidents reported between 1985 and 1994 at Newcastle were in crosswind conditions and building wakes (or the wake from a wood) could be implicated.

4.2.4.6 Plymouth

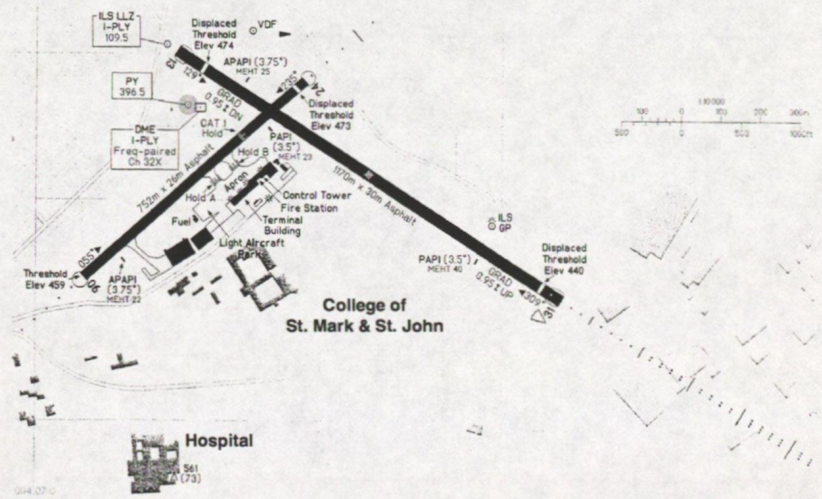



Fig. 17 Plymouth Airport (from UK AIP)

Plymouth Airport is on top of a hill and tightly surrounded by built-up areas, Fig.17. The Airport buildings are not particularly high (approx. 60ft) but are only about 100m from Runway 06/24. The college and hospital buildings are tall but do not intrude into airspace because they are down hill from the airport. However wind flows more or less parallel to the ground and can produce disturbances over the airport and it's approaches. The buildings around the approach to Runway 31 are a group of Light Industry with warehouse buildings.

There were no major incidents at Plymouth on the CAA Database between 1985 and 1994, but pilots find quite strong turbulence in winds over about 18kt from between 070° and 180° when landing on Runways 06 and 13, and between 270° and 360° when taking off on Runway 31. This indicates that the airport buildings and the College are likely to be the main sources of disturbances.

4.2.4.7 Bournemouth

The Questionnaire reply from Bournemouth reports Severity Level 3 problems with Wind shear and Moderate or Severe Turbulence on approaches to Runway 26 with winds over 25kt between 210° and 240°. These problems are attributed to buildings SW of the threshold of Runway 26, Fig.18. There are local procedures in Air traffic Services in these wind conditions.

From the AIP it appears that none of the buildings are tall enough to warrant a height warning and the plan sizes of the various buildings are not particularly large. The scattered positions of the buildings and their distance from the approach path to Runway 26 of around 800-1200m would tend to generate increased turbulence and some loss of wind strength below about 150ft in strong winds.

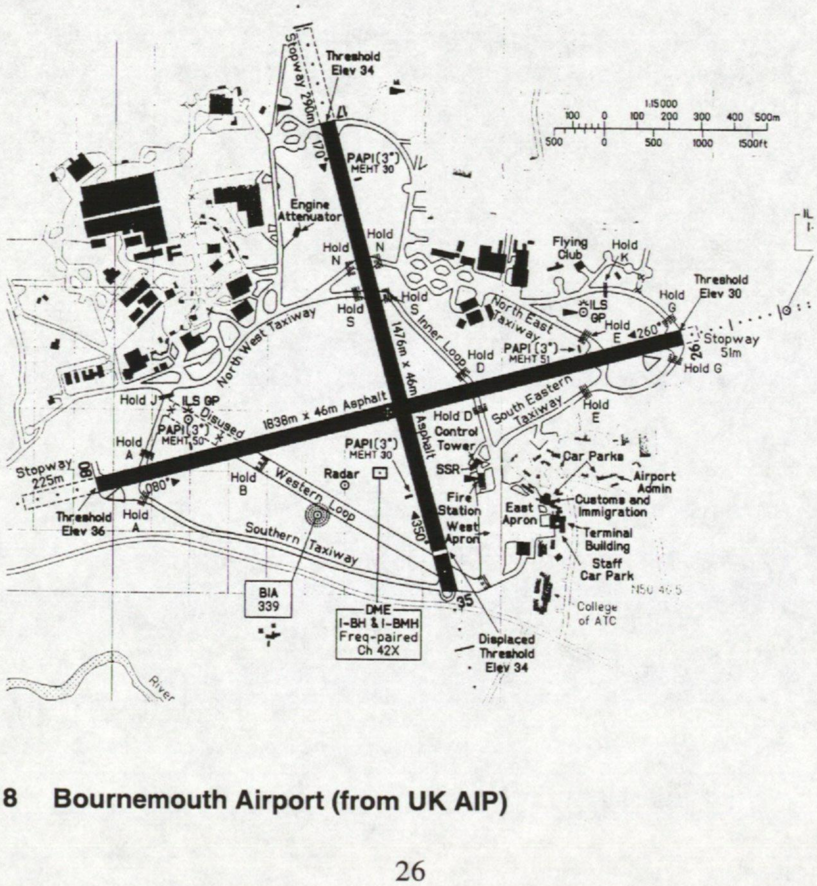



**Fig. 18 Bournemouth Airport (from UK AIP)**

No wind related incidents of any type have been reported between 1985 and 1994. However, Air Traffic Services issue warnings in appropriate wind conditions and Severity Level 3 is appropriate.

4.2.4.8 Southampton

There is particular reference to turbulence from the Railway Sheds on short finals to Runway 20 in the reply to the Questionnaire from Southampton, and also a general problem at Severity Level 2 for winds above 20kt from all directions. Air Traffic Services issue warnings when the wind is above 20kt and the runway is 20. The layout of the airport is shown in Fig.19 and some of the Railway sheds are shown in the top right hand corner of the Figure. It would be expected that these buildings could cause significant turbulence in the final 100-150ft descent to touchdown in SE winds. The other feature of note in Fig.19 is the closeness (250-300m) to the runway of the airport buildings, the factory to the SW of the airport, and housing west of the threshold of Runway 20.

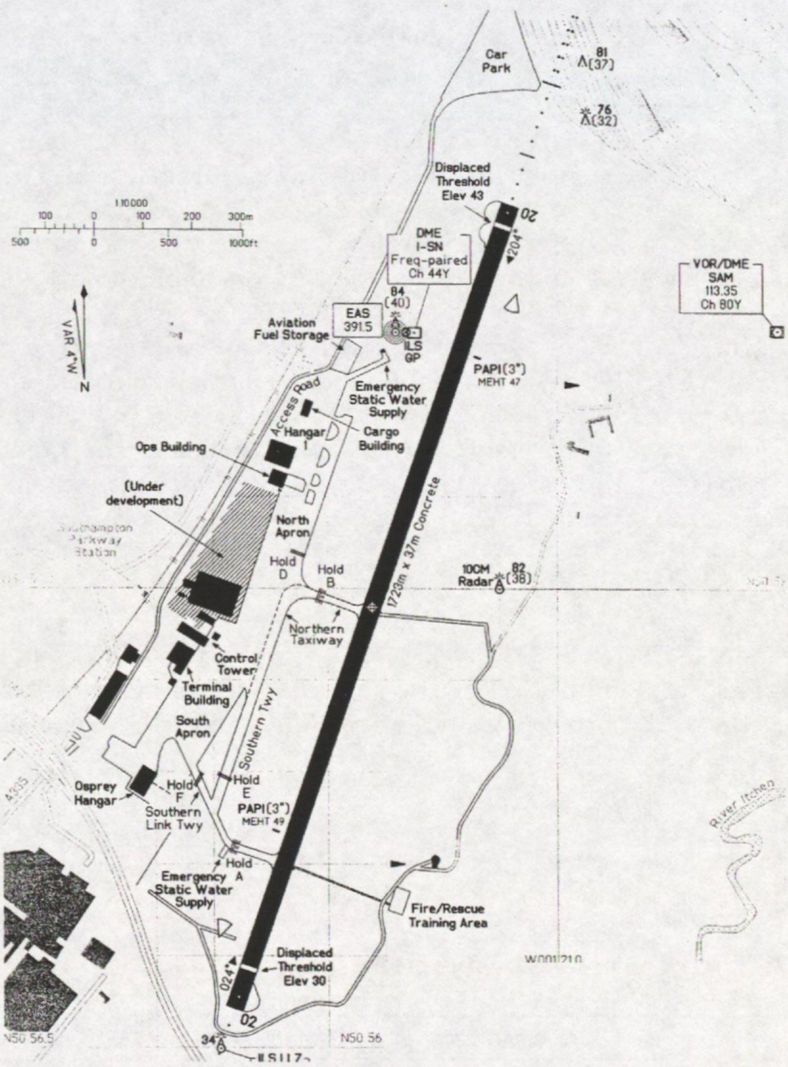



**Fig. 19 Southampton Airport (from UK AIP)**

It is noticeable that 3 of the 5 incidents reported from Southampton involve leaving the runway in crosswinds, and the other two incidents were not related to the particular layout or location of the airport (i.e. one of these incidents involved pilot error in landing with excessive tailwind, and the other was a structural problem following damage when parked in gale force winds).

The airport buildings, in particular, would be expected to provide intermittent shielding from SW to W winds during touchdown, landing run and take-off from Runway 20. The same should apply to operations on Runway 02 in winds from NW to N, but it is relatively rare to have winds in this quarter. Such intermittent shielding will make control in strong crosswinds significantly more difficult than in a steady crosswind. Also with some shapes of building combined with particular wind directions there may be local patches of swirling winds.

Two of the three crosswind incidents were during landings on Runway 20 in winds of around 270° at about 15kt. (The wind is not identified in the summary of the third crosswind incident.)

It is relevant that problems with building wakes in 20-30kt winds are also identified at Stornoway and Wick where significant buildings are also only about 250m from a runway.

4.2.4.9 Southend

Southend report some problems at Severity Level 2 from a small railway embankment about 150m from the displaced threshold and above the threshold height of Runway 24. Edinburgh also report a Severity Level 1 problem with a larger railway embankment about 500m from the displaced threshold of Runway 25.

No incidents at either airport can be attributed to the presence of the embankment. However some small downdraught followed by a more significant updraught would be expected as an aircraft crosses above an embankment at low altitude; and the effect would be expected to be more pronounced at Southend than Edinburgh despite the lower embankment, because aircraft will only be around 15-25ft above the embankment and often in the early stages of the landing flare.

4.2.4.10 Rochester

At Rochester there are buildings all around the airport including factory buildings to the W of short finals to Runway 20. It is also situated on top of a large hill. It is not surprising that problems are encountered, particularly in winds over 15-20kt from SW to W.

4.2.5 *Trees or Woods*

Four airports have reported problems with Trees or Woods close to the airport causing wind disturbances.

**Table 7: Number of entries by Airport for Trees or Woods**

| *Airport* | *Severity Level 2* | *Severity Level 3* | *Severity Level 4* |
|---|---|---|---|
| Bournemouth | | 1 | |
| Compton Abbas | 2 | | |
| Newcastle | 2 | | |
| Plymouth | 2 | | |

4.2.5.1 Bournemouth

The Questionnaire reply from Bournemouth gives the same wind and runway combinations for Building wakes and Trees & Woods. During late finals on the approach to Runway 26 the approach path passes over and between the extensive wooded areas of Hurn Forest and Sopley Common. However the wind direction of 210° to 240° appears to be more directly related to building effects rather than the woods (Fig.18, p26). Turbulence may be expected from the woods with winds between the greater range of 170° and 350°. It may be that buildings and woods combine to generate the turbulence problem between 210° and 240°, whereas each on their own would not cause a problem, and this may explain why relatively small buildings that are a long way from the approach path appear to cause significant problems.

4.2.5.2 Compton Abbas

At Compton Abbas there is a large wood along most of the S side of the runway at a distance of about 100-150m, Fig.20. The wood is about 70ft high and the anemometer for the airfield is above the Clubhouse at a height just below the top of the wood and about 30m from the edge of the wood. The Airfield Operator believes that the anemometer location is acceptable because it is representative of conditions on the runway even when partly shielded by the trees from winds between about 080° and 270°. This may be a reasonable assumption for winds between 090° and 240° when the runway will be in the lee of the woods. Between 080° and 090°, and between 240° and 270° the anemometer would be expected to indicate a lower wind than that experienced on the runway, but, as these directions are almost aligned with the runway, there will not be any safety issues arising.

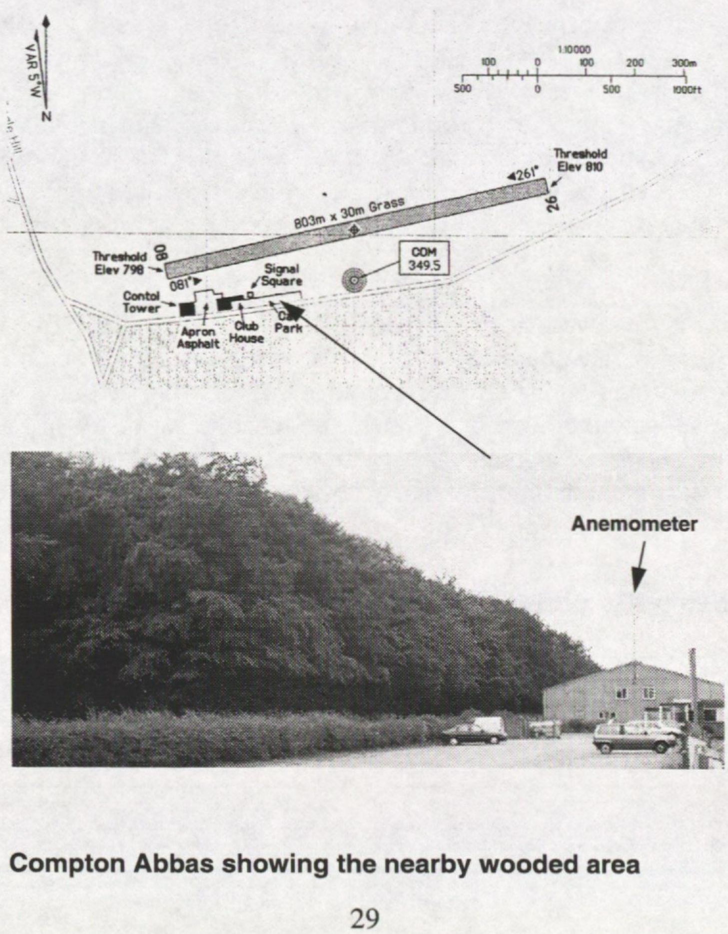



**Fig. 20 Compton Abbas showing the nearby wooded area**

The four reported wind incidents between 1985 and 1994 are all associated with turbulence and wind shear in winds from over the woods as might be expected. Rapid changes in wind as aircraft descend below about 120ft and an increase in turbulence make landings in crosswinds difficult when wind strength is above about 10-15kt. However, the effects are consistent and predictable.

4.2.5.3 Newcastle

Newcastle, as did Bournemouth, report the same problem for Buildings and for Woods in the Questionnaire reply. Study of the plan in the UK AIP (Fig.16, p 24) and the Ordnance Survey 1:50,000 map show a small wood about 150m wide and about 500m SSE from the threshold of Runway 25. There are also buildings in a Maintenance Area about 200m from the runway near the W end and a larger building, Woolsington Hall at 500m from the runway. The location of the woods and buildings are well separated at Newcastle and thus they would not be expected to combine in their effects as they seem to do at Bournemouth. Both the wood and the maintenance area are close to the runway at Newcastle and either, or both, could contribute to the crosswind incidents.

The relative incident rate is 0·9 times the UK average at Newcastle.

4.2.5.4 Plymouth

Plymouth Airport has a narrow strip of trees that are close to the thresholds of Runways 06 and 24. Beyond the trees is a built-up area and it seems likely that the turbulence experienced when landing on either runway will be a combination of effects from the built-up area and the strip of trees.

4.2.6 *Distant Hills or Mountains*

Wind over large distant hills or mountains, and related valleys, can generate wave and rotor motions in the air that can affect aircraft some miles away from the mountains. Generally wave motions will result in wind shear above about 500ft and not present a major problem. However, rotor motions are almost horizontal vortices that can be strong and may become detached from the hill, cliff, or promontory that generated it and travel downstream with the wind whilst slowly decaying in strength. Some combinations of temperature inversions and wind gradients with height can generate breaking waves with rotor flow.

In the context of wave motion 'distant' could mean 10 or 20 miles for a major range of mountains and be encountered at heights near the mountain tops. For the rolling terrain more typically found in the UK the term 'distant' can mean within a mile of the terrain and an altitude above the ground of less than the local height of the hill above the valley. For rotor motion the term 'distant' may mean 1 to 3 miles. Of the airports in the survey only Sumburgh has a significant problem with rotor flow. Gibraltar is perhaps the most well known example of this type of flow in the vicinity of an airport outside the UK.

**Table 8: Number of conditions by Airport for Distant Hills or Mountains**

| Airport | Severity Level 2 | Severity Level 3 | Severity Level 4 |
|---|---|---|---|
| Glasgow | 2 | | |
| Isle of Man | 12 | | |
| Plymouth | 2 | | |
| Sumburgh | 3 | | |

Airports with problems relating to 'Distant Hills or Mountains' are shown in Table 8. Glasgow refer to mountain waves and have not specified a Severity Level, which would be expected to be Level 1 or 2 and 2 has been used in this report. The nearest mountains or high hills are around 20km from the airport and these are not very rugged. The other three airports in the list have some problems associated with winds following contours of the local terrain such as the edge of Dartmoor and the valley of the River Plym at Plymouth.

On the Isle of Man the airport is in a rolling landscape but only about 8km from the lee of the rugged west coast where mountains rise sharply from the sea to around 1500ft and then drop quite steeply to the rolling countryside around the airport. In winds above about 20kt, and particularly if a temperature inversion and the vertical wind flow generate breaking waves, there would tend to be large rotors in the lee of the mountains that could affect the flow in the region of the airport. Such affects are noted in the Questionnaire answers for winds between WNW and NNE. Rotor flow can cause as much as a 180° change in wind direction between the surface and, say, 2000ft.

4.2.6.1 Sumburgh, Shetland Islands

Sumburgh is the air transport airport in the UK with the greatest problems from wind shear and turbulence. It is the only airport in the UK where airlines require air transport pilots to become qualified in operating at that airport because of the local weather problems. It is also the airport where the incident took place that led to this study. There are many problems in coping with the extremes of weather that can occur at this island north of Scotland. It has frequent very strong winds, cloud and fog. Sometimes these can even come together to give fog with a 50kt wind.

The most severe wind problems arise from rotors shed either by Fitful Head, which has steep cliffs rising to about 1000ft and is 4·5km to the WNW of the airport, or by Sumburgh Head, which has steep cliffs rising to about 350ft and is 2·5km to the SSE of the airport. (Fig.21). Sumburgh Head also deflects the wind so that a SW wind at the centre of the airport would be a tailwind rather than a crosswind at the threshold of Runway 33. Fitful Head looks almost innocuous in the photograph inset in Fig.21, which was taken from a distance of 4·5km in typical misty Shetland weather with cloud over the top part of the Head. It can be seen in all its sheer grandeur when approaching Sumburgh for a landing on Runway 09, or perhaps from the oil tanker that ran onto the rocks at the foot of the Head.

The most severe wind problems affect take-off and are avoided by using curved flight paths to avoid the location of the rotors, which are well known to pilots who have used the airport for many years. This procedure is more difficult for pilots with less experience of the locality and in low visibility. Landings are not permitted on Runway 15/33 at night (except in an emergency) because of rising terrain at both ends of the runway (the approach to Runway 15 is 4° rather than the more usual 3° to provide adequate clearance over the village of Toab), and only specially certificated operators approved by the CAA can use the runway for night take-offs. There are general wind shear and turbulence warnings in the UK AIP and on the Aerad and Jeppeson Airfield Plates.

The specific wind directions that cause rotors for the different runways are

Runway 15 Winds between 060° and 170°
Runway 27 Winds between 280° and 340°
Runway 33 Winds between 240° and 340°


**Fig. 21 The area around Sumburgh Airport (Ordnance Survey) and (Inset) Fitful head from Scat Ness**

Rotor problems are particularly significant in winds above 30kt. There is also moderate to severe turbulence when landing on Runway 27 in all winds above 30kt. There is a predictable 'jolt' at about 500ft height when approaching Runway 27 in SW winds that is probably the rotor shed by Sumburgh Head.

Safe operation at Sumburgh in strong winds is only possible because pilots receive specific briefings on local conditions. It is because of this that the levels of severity reported in the Questionnaire are not as high as they could become if the airport were regularly visited by pilots without local knowledge.

There were 3 wind related incidents reported from Sumburgh between 1985 and 1994, which is in an incident rate of 10·9 per million movements, and all were in airborne phases of flight. One was the incident described in Ref.1. The relative incident rate is 3·4 times the UK average.

The relative incident rate is high, but so are those at Jersey (2·4), Guernsey (2·3) and the Isle of Man (2·9). The relative similarity in rates would be remarkable given the much more severe local terrain and weather at Sumburgh were it not for the influence of the 'local knowledge' factor. Incidents are often less frequent in places where danger is expected and users are trained to handle the situation, than they are when an unusual situation arises in places that are expected to be safe. People are more likely to trip over a cable on the floor of an office than one on the floor of an aircraft maintenance hangar.

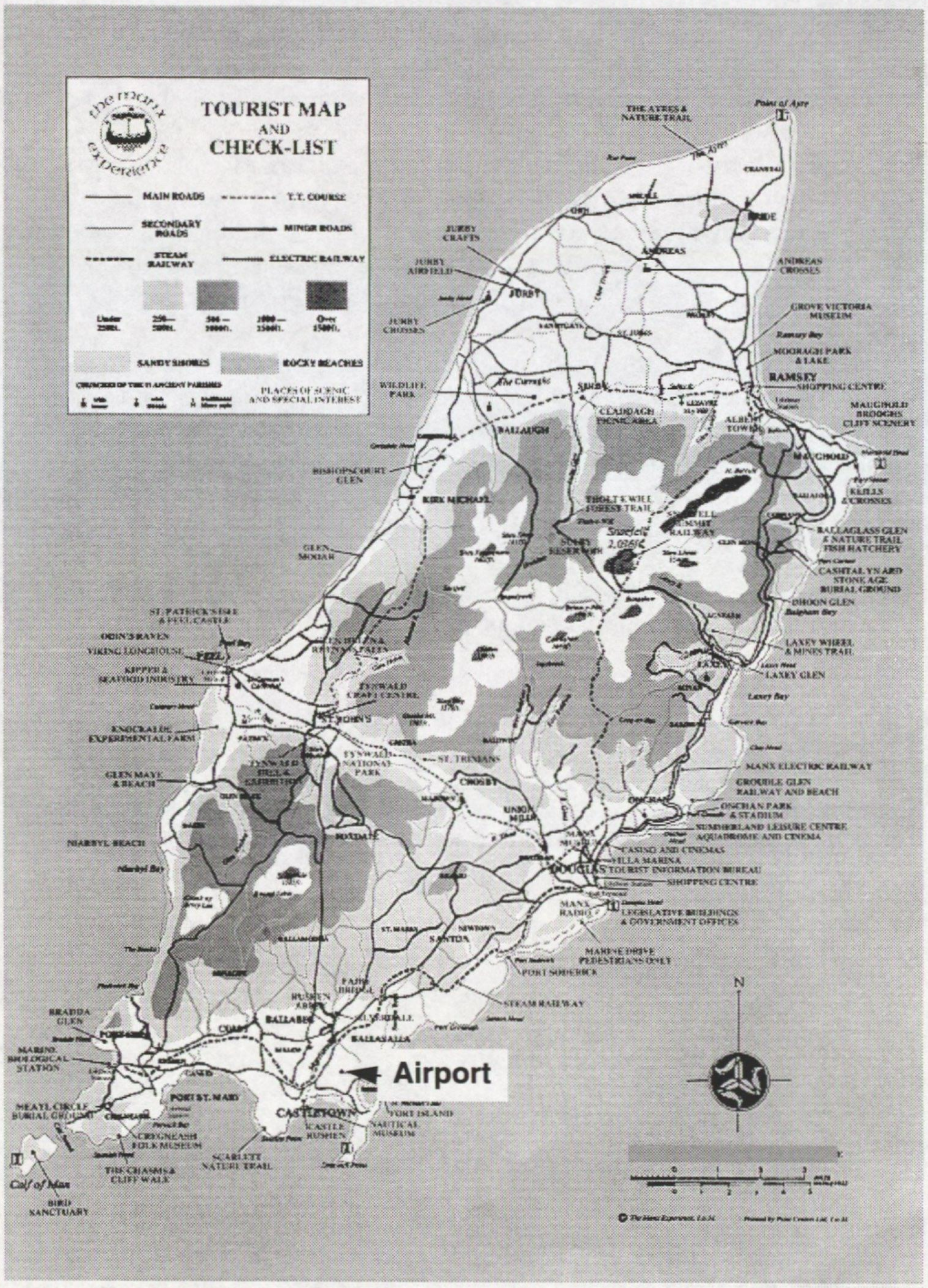



**Fig. 22 Topographical plan of the Isle of Man (The Manx Experience, IoM)**

4.2.7 *Island effects*

**Table 9: Number of conditions by Airport for Island Effects**

| *Airport* | *Severity Level 2* | *Severity Level 3* | *Severity Level 4* |
|---|---|---|---|
| Isle of Man | 6 | | |
| Stornoway | 8 | | |

Island effects are the effects that the main mountainous land mass of an island can have on flow at lower heights in the vicinity of an airport. The effects are similar to those described for the hills near Bembridge and Aberdeen Airports in Section 4.2.2 but on a much larger scale. The same effects could occur inland if an airport were near an isolated mountain or ridge but this type of topography is more commonly found on islands. Flow is diverted by the mountains and can also form large rotors in their lee. This means that flow directions and strength near the surface can be markedly different from the winds near the tops of the mountains, and the surface wind can change dramatically when the direction of the upper wind changes by a relatively small amount. This is particularly true if the mountain has a roughly elliptical rather than circular planform. The greater the ratio of major to minor axes then the more extreme the shifts in surface wind at an airport can be as a small change in the direction of the upper wind can change the surface flow from the influence of flow deflection to the influence of a rotor. There will also be less dramatic shifts in surface wind as the stagnation point of the upper winds shifts rapidly around the 'sharp' end of the ellipse with a small change in upper wind direction. Two islands reported this type of wind behaviour as shown in Table 9.

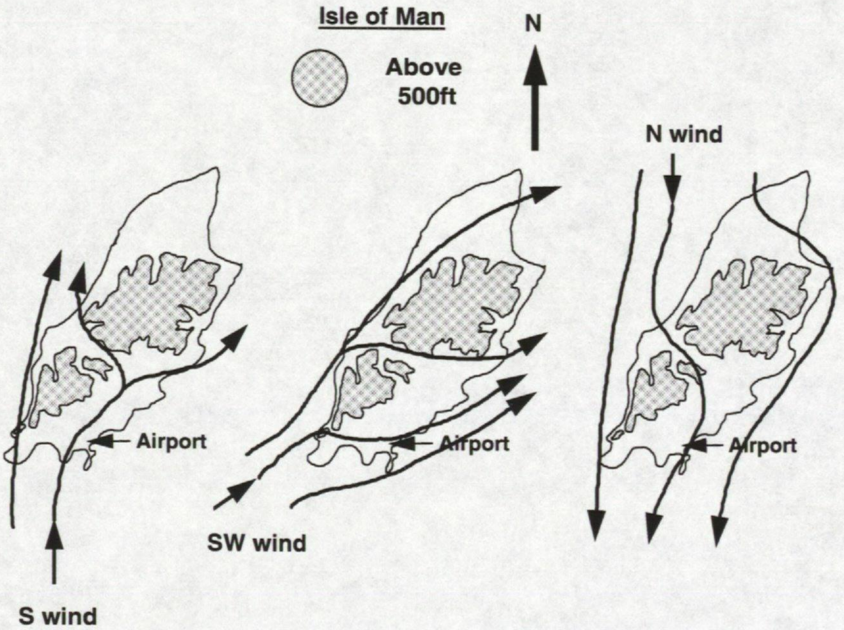



**Fig. 23 Diagrammatic sketches of surface airflow on the Isle of Man in different upper wind directions**

The same effect of airflow deviation around the hills/mountains also produces dramatic changes in wind direction with height. One documented case at the Isle of Man airport had a wind at 1000ft of 220°/54kt with a surface wind of 080°/12kt. On another occasion at the same airport the surface wind changed suddenly from a steady 310°/10kt to 200°/13kt.

In practice there will be irregular hill shapes, valleys and steep escarpments (these can create rotors) and the relationship between airflow at the surface and at, say 1000ft (300m) will be complex. It is possible that the large differences in the documented examples at the Isle of Man were due to excessive backing caused by flow around the hills during the passage of a warm front, or due to a horizontal rotor in the lee of the steep escarpments around Port Erin and The Stacks about 10km east of the airport (Fig.22).

As an example, consider the Isle of Man, Fig.22, where there is a mountainous ridge running from SW to NE for about 30km with a gap after about 12km. The mountain tops are around 1500ft in the southern portion which has the greatest influence on winds at the airport, and up to around 2000ft (Snaefell is 2036ft) in the northern portion. There is a substantial area above 500ft. Diagrammatic sketches of the form of airflow deviation that would be expected at the surface in winds approaching the island from S, SW and N are shown in Fig.23. Differences of up to about 45° can be expected between the local surface wind and the direction of the wind approaching the island. If the direction of the wind approaching the island changes significantly, as it will during the passage of a front, then, if the wind direction changes from one side of the major axis (SW or NE) to the other, the surface wind will change direction by rather more than the frontal direction change.

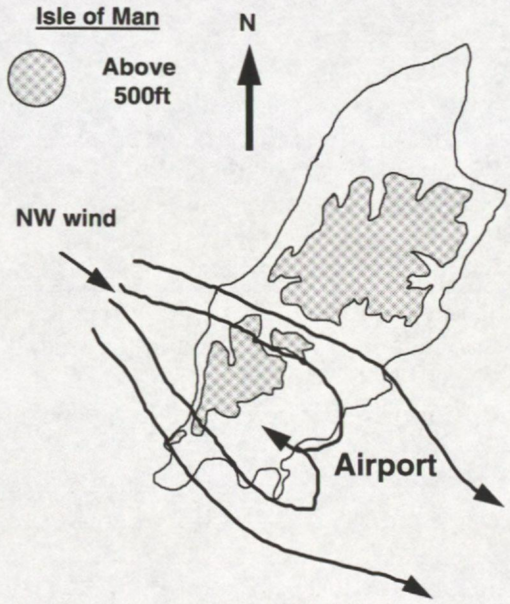



**Fig. 24 Diagrammatic rotor airflow over the Isle of Man Airport in a NW wind**

However, the most dramatic changes occur when the direction of the wind approaching the island is around NW, and particularly when low altitude temperature inversions are present, when the airport is affected by rotor flow in moderate to strong undisturbed winds. This is shown diagrammatically in Fig.24. The airport will be affected by rotor flow for a relatively small range of 'undisturbed wind' directions between about 310° to 330° and any shift in the direction of the 'undisturbed wind' that goes into or out of this narrow band will produce an almost 180° shift in the direction of the surface wind.

Thus in the presence of an isolated mountainous ridge there can be very large changes of surface wind direction in a short period of time, which can typically be 2 minutes or less, i.e. less than the time taken for a typical approach to land.

The topography near Stornoway on the Isle of Lewis also has high ground to the W and NW from the airport with mountains up to around 900ft at distances of about 12-15km. The topography is not as clearly defined as on the Isle of Man, but reports in the Questionnaire response of winds changing by nearly 180° in 2 minutes or less during the passage of fronts are most probably due to the airport being affected by a lee rotor before or after the front moves through the area. Synoptic fronts do not usually change wind direction by more than about 90° in a few minutes. Storm fronts in the vicinity of thunderstorms can cause larger and more sudden changes of direction, and usually winds will change from light and variable to a stronger wind behind the storm gust front.

4.2.8 *Summary of Wind shear causes and severity*

Following the detailed study of Questionnaire replies, incident reports and local topography the table of Wind shear causes and Severity, Table 2, has been adjusted for Severity Levels 2 or greater and is presented in Table 10. An 'entry' is any combination of a runway direction and either take-off or landing.

The more detailed review has not changed the balance with 'Nearby hills or valleys' still the largest group with 29 entries (30%), and followed by 'Buildings, inc. railway embankments' and 'Distant hills or mountains' both with 19 entries (20%). In terms of numbers of airports affected, then 'Nearby Hills or valleys' and 'Buildings.....' are almost equal with 14 and 13 airports (50%) respectively out of a total of 26 airports that have wind shear problems at Severity level 2 or greater. This is the number of airports with a clear indication of wind shear problems out of the total of 56 who responded to the Questionnaire or were visited in the study.

A summary of all UK airports that satisfy at least one of the following criteria is given in Annex F:

1 Wind shear Severity confirmed as Level 2 or greater

2 Warnings are published in at least one of the UK AIP, or the Aerad or Jeppeson Airfield Plates

3 The relative incident rate based on the actual mix of Air Transport and 'Other' movements is more than 1·5 times the UK average

**Table 10: Wind shear causes and Severity (after review).**
**(Numbers of airports in each category are shown in brackets)**

| *Wind shear problem* | *Total entries* *(Severity > 1)* | *Problems could become hazardous* *(Severity 2)* | *Radio warnings issued* *(Severity 3)* | *Diversions, or operations temporarily suspended* *(Severity 4)* |
|---|---|---|---|---|
| Sea or large lake causing on-shore winds | 3(3) | 3(3) | | |
| Nearby hills or Valleys | 29(14) | 18(8) | 8(6) | 3(2) |
| Nearby cliff(s) | 9(4) | 6(2) | 3(2) | |
| Buildings, inc. railway embankments | 19(13) | 14(11) | 5(4) | |
| Trees or woods | 7(4) | 6(3) | 1(1) | |
| Distant hills or mountains | 19(4) | 19(4) | | |
| Island effects | 14(2) | 14(2) | | |

Of the 9 airports in the original study list that did not reply to the questionnaire (or, in the case of Kent International, did not receive one):

> 4 airports (Barrow-in-Furness, Carlisle, Redhill and Inverness) have no significant wind incidents recorded between 1985 and 1994 and thus do not merit further study. ( An incident at Barrow was in a strong wind greater than 30kt.)
>
> 3 airports (Biggin Hill, Cranfield and Wycombe Air Park) do have significant incidents but the relative incident rates of 1·2, 1·0 and 1·2 respectively are close to average for airports like these that are used almost entirely for Club and light aircraft flying, and thus no further study is recommended.
>
> 1 airport (Coventry) has no special features and has a relative incident rate of 0·8 times the UK average and thus no further study is recommended.
>
> 1 airport (Kent International at RAF Manston) is mainly used for Club and light aircraft flying with occasional Air transport and military activity, but it has an incident rate of 43·9 per million movements and a relative rate of 6·6 times the UK average. Thus it merits further consideration.

RAF Manston is located on a small plateau about 170ft above sea level with the Minster Marshes (the remains of a narrow sea channel that separated the Isle of Thanet from the rest of Kent a long time ago) about 2km to the south. The sea is about 2km to the SE and 5km to the E and N, and Chislet Marshes, which connect to Minster Marshes, are 5km to the W. The conurbations of Ramsgate, Broadstairs and Margate are on the coast to the E and N. The nearest built-up area is the small village of Manston about 1km NNE from the threshold of Runway 28, and the RAF Quarters about 1km N of the middle of the runway. There are no large buildings near the runway. The majority of the incidents, i.e. 5 out of 6, were problems in crosswinds from varying directions in winds of around 10-20kt. There is no indication of any consistent pattern.

Comments received from RAF, Manston, who operate the airfield, suggest that the movement statistics considerably understate the actual movement level. Movement records at the airport for 1993 were 56,505 compared with the level of 13,668 reported in CAP 630. This would reduce the incident rate to about 1·5 times the UK average, which would still be high enough to warrant study, but is much more compatible with levels that might be expected in relation to local conditions than the apparent relative rate of 6.6.

During the last year the single anemometer has been relocated to a position near the middle of the runway to give more reliable wind measurements, and also the managers of the civil unit (Kent International Airport) have agreed to publish a warning in the UK AIP about slight turbulence on short final to Runway 28 in NW winds, which is probably caused by the Kent International Airport buildings. Both these actions should reduce wind related incident rates. Thus Kent International Airport (RAF, Manston) should not require further study.

## 5 SUGGESTIONS FOR GUIDELINES TO IDENTIFY WIND SHEAR PROBLEMS AT AIRPORTS

Having reviewed wind shear problems at 65 airports it is possible to make a start towards developing guidelines that should indicate whether the location of the airport, local topography or the location and size of nearby buildings might be expected to cause significant wind shear problems. These guidelines cannot be hard criteria because of the wide mix of different aircraft that may use a particular airport, and because of different levels of piloting experience and capability. However guidelines could be very useful when deciding whether a deeper investigation or study is needed for a particular new airport site or when considering proposals for new buildings on or near existing airports.

In practice there will also be a wide range of other meteorological, environmental and economic factors that will have to be considered, but it is important to include wind shear factors as these can limit operations.

Suggestions for guidelines are developed for each of the 7 types of wind shear problem.

### 5.1 Airport very close to the sea or to a large lake

There will usually be an on-shore breeze associated with such a location, but this is predictable and does not usually cause problems. High dunes and thermals over sandy areas can cause up and down draughts that could be a problem to light aircraft particularly if they get below the normal glidepath.

No specific guidelines recommended.

### 5.2 Nearby hills or valleys

These are a major cause of wind shear, particularly where there is a single hill or short ridge close to the airport. Such a hill can introduce large wind variations along a runway together with severe turbulence in moderate to strong winds. The hills at Bembridge and Dundee, which cause major problems in winds over about 20kt, have a ratio of height to distance from the runway of about 0·1. At Aberdeen and Glasgow the effects are not so severe and the ratio of height to distance is about 0·05. These hills can produce local wind directions and strengths that are not necessarily the same as indicated by airfield anemometers; they can increase turbulence and also produce crosswinds that vary significantly along the runway and can cause directional control problems on the ground.

It is suggested that a hill or ridge with a ratio of height to distance from the runway of around 0·05 or greater will cause wind shear problems and these will be severe if the ratio is around 0·1 or greater.

### 5.3 Nearby cliffs

This refers to cliffs below the airport. Cliffs rising above the airport are considered under 'Nearby hills.....' or 'Distant hills......'. Cliffs close to an airport produce both horizontal wind shear and up/downdraughts and the effects are more severe if an aircraft is below the normal glidepath. However the overall sequence of shears tend to cancel each other and are not usually dangerous unless an aircraft is already slow and descending, or unless an inexperienced pilot overreacts to the situation.

Experience at Jersey with a 170ft cliff only 160m from the end of the runway suggests that wind shear is not uncommon but successful landings were made following reported incidents. Thus cliffs below the airfield can cause problems but are unlikely to be a significant wind shear hazard.

### 5.4 Buildings, including Railway embankments

Establishing guidelines for acceptable building sizes and locations on or near airports is complicated by the type of wakes shed by different shapes of buildings. All buildings have a region with reduced winds in their lee, but some buildings can also shed pieces of rotors with winds in certain directions. These pieces of rotating flow are energetic and decay relatively slowly while they are advected downwind, and they cannot be predicted solely by considerations of building size and distance from the runway or flight path. These pieces of rotating flow are a significant component of the building wake from the Engineering Base at Heathrow that can cause problems during the final 150ft descent to Runway 27R.

However, another set of problems from building wakes arise from local shielding of a runway resulting in directional control difficulties during landing and take-off. This shielding is more directly related to building size and distance from the runway and it is possible to suggest guidelines for this problem based on this study. In general it will be necessary to confirm any possible problems identified by these guidelines using Boundary Layer Wind tunnel tests on an appropriate model, particularly if there is a possibility of problems from rotational flow.

During all approaches to Runway 27R at Heathrow in SW winds above about 15kt there is a noticeable reduction in crosswind and headwind as an aircraft descends below about 120ft (the buildings at the Engineering Base are about 100ft high). During around 1 in 4 approaches in these conditions there is also a marked roll disturbance at around 140ft height which is caused by encountering a piece of rotating flow. It is the combination of the roll disturbance and the effects of the changes in wind strength that determines the severity of the problem.

The Civil Aviation Authority have commissioned a study to try and produce guidelines about likely building wake problems on and in the vicinity of airports. The results from this present report will provide data for the building wake study and examples where present building wakes affect operations. Study of airports where there are problems caused by building wakes provides a basis for some initial guidelines that can be used until the more complete study is completed.

Loss of wind velocity in the lee of a wide building depends primarily on the height of the building and the distance to the leeward. Details of the building shape can also affect this wind velocity. Groups of buildings that are separated by less than about the building height act much as a single building. Details of building heights are not readily available, but using estimates based on typical aircraft tail heights (B747-400 fin height above the ground is about 20m) relative to airport buildings suggests that buildings, or groups that act as a single building, that are more than 50-100m wide will cause problems in winds around 15-20kt if they are closer than 20 building heights in the wind direction from a runway. This is an initial step at forming a guideline and will need to be refined in the light of better data on building profiles. The building width guideline assumes that a wake duration of about 2 sec. is needed to have a significant affect on an aircraft. Typical groundspeeds of around 100kt (50m/s) for transport aircraft and 50kt (25m/s) for light aircraft give the corresponding building width of at least 50-100m.

This guideline would predict possible problems in winds above 15-20kt at Guernsey, London-Heathrow (Engineering Base but not the Central Island), Isle of Man (King William's College), Newcastle (Maintenance Area, but not Woolsington Hall), Southampton (Airport buildings) and Plymouth (Airport buildings). All these were identified as problems for these airports in Section 4.2.4. Airports with possible building wake problems discussed in Section 4.2.4 that are not predicted by this guideline are

London-Gatwick: Buildings are about 25×'Building height' from the runway, but as the problems are mainly in the airborne flight phases it is likely that there are pieces of rotational flow adding to the problem.

Manchester: Buildings are about 24×'Building height' from the runway and there is no evidence of a problem.

Bournemouth: Buildings are about 60×'Building height' from the runway and it seems likely that any problems may be mainly due to trees. The buildings may add slightly to the tree problems.

The above cases are all outside the suggested guideline and confirm that it is appropriate as an indicator of possible problems on the runway, but other factors may need to be considered in assessing affects during the final 150ft of descent to landing.

The guideline can be used for greater wind strengths and increases approximately with wind strength. Thus it would be expected that the Central Island at London-Heathrow could cause some directional control problems in winds above about 25kt direct crosswind, or more typically above about 35kt winds from the SW. Incidents with aircraft running off the edge of a runway have occured at Heathrow during take-off in strong winds. This supports the choice of guideline values.

There is too little data to develop more than an informed opinion for a guideline relating to railway embankments. In general there are unlikely to be new rail developments close to runway thresholds at existing airports, and it would be preferable to keep any embankment further than 60×'Embankment height' from the runway threshold under any approach path. The normal building guideline can be used for embankments parallel to a runway.

5.5 **Trees or Woods**

There is limited data from which to develop guidelines, but the effects of woods are similar to buildings and in the absence of more definitive data it is recommended that the same guidelines should be used. The ragged edges of woods will prevent the formation of pieces of rotational flow.

5.6 **Distant Hills or Mountains**

Wave effects can cause difficulties but are usually experienced above about 500ft. The most significant problems relate to rotor flow formed in the lee of rugged high ground such as the 350ft high Sumburgh Head near Sumburgh Airport and the even more rugged 1000ft high Fitful Head near the same airport. Formation of rotor flow depends on the strength of the wind, its direction relative to the crest of a ridge, and the gradients both sides of the ridge. The strength, size and position of a rotor depends on wind strength and direction, the height of the ridge above local terrain and the gradients on both sides of the ridge. In specific situations, e.g. Sumburgh and Gibraltar airports, the location and strength of these rotors is very consistent and procedures can be developed to avoid them and operate safely. This is how safe operations are conducted at these airports.

There are two types of rotor to consider:

Lee rotor, which is formed directly in the lee of a ridge with an approximately horizontal core aligned parallel to the ridge.

Shed rotor, which can form when the wind is at a glancing angle to the ridge line and has an approximately horizontal core and advects with the wind from the downwind end of the ridge. This may appear as pieces of rotational flow in turbulent wind conditions.

The precise form and strength of these rotors depend on detailed geometry of a particular ridge, and specific model and flight tests will be needed to evaluate the problem. However it is possible to give rough guidelines that will indicate whether rotors may be a problem in a particular location, i.e. they are likely to impinge on either the approach or take-off paths of an aircraft.

It is suggested as a rough guide that there may be problems with rotors in winds above about 20kt

if a ridge has a leeward gradient of more than 15% and the change between the leeward and windward gradients is greater than 30%

and if the ridge is nearer than 20×'Ridge height above local terrain' laterally from the extended centre line of a runway or nearer than 40×'Ridge height above local terrain' along the extended centre line from a runway.

These numbers are based on approximate lee rotor locations at 10×'Ridge height above local terrain' and significant effects extending to a height of about $^4/_3$ × 'Ridge height above local terrain'.

At Sumburgh (Fig.21, p32), Fitful Head is 10×'Ridge height' laterally from Runway 15 centre line and about the same distance along the extended centre line. It is also about 5×'Ridge height' laterally from Runway 27 centre line and about 12×'Ridge height' along Runway 27 extended centre line. Sumburgh Head is about 12×'Ridge height' laterally from Runway 09 centre line and 6×'Ridge height' along Runway 09 extended centre line.

The ridge at Bembridge and Culver Downs near Bembridge Airport (Fig.3, p13) would be expected to produce rotor flow. The lee rotor should be located just S of the airport with significant effects up to about 300ft above ground. A shed rotor would be expected to add to the turbulence on final approach to Runway 30 in winds from around 220° where a normal glidepath will pass above the shed rotor.

### 5.7 Island effects

For most situations the deflection effects will need to be assessed based on details of the local topography. However if there is a well defined ridge it is possible to use the guidelines for lee rotor flow to give an indication as to whether an airport may suffer reverse flow from a lee rotor. This may be a possibility if an airport is within about 6 to 14×'Ridge height above local terrain' downwind of a ridge. If a ridge is short, or non-existent, then reverse flow can still exist but distances from the ridge or hill are more difficult to predict. On the Isle of Man the airport is about 12×'Ridge height above local terrain' from the ridge to the NW and reverse flow does occur.

## 6 SUGGESTIONS FOR IMPROVEMENTS IN SENSING AND PROVIDING APPROPRIATE INFORMATION TO PILOTS

There are four types of information that can assist all pilots operating at airports where the locality, topography and buildings cause wind shear problems in particular weather conditions. These are

1 Warnings in the UK AIP, Aerad or Jeppeson Plates, or in local instructions

2 Meteorological forecasts

3 Current wind information from Air Traffic Services (ATS) and wind sleeves on the airport

4 Wind shear warnings from ATS following reports from other aircraft.

In addition some pilots can develop local knowledge if they operate frequently from a particular airport.

Another important factor is general pilot training in forecasting, identifying and responding to different forms of wind shear.

In this section each of the types of information are reviewed and suggestions made that may result in general improvements. A final part of the section recommends specific improvements that should improve the safety and effectiveness of operations at specific airports. It is not possible to assess the impact of clearer guidance about local wind shear problems and current wind conditions on incident rates, but it can only be beneficial. Only study of incidents over a period of about 10 years can show how beneficial any changes have been for a busy airport.

Some wind shear or severe turbulence conditions can occur at any airport and pilots should already be well aware of dangers in the vicinity of energetic thunderstorms, and in very strong winds. These aspects are not considered in this study but many of the suggested improvements should be beneficial in relation to these more general wind shears.

## 6.1 Documented warnings

Details of airports that have documented warnings in the UK AIP, Aerad or Jeppeson Plates are shown in the list in Annex F. A total of 9 of the airports in the study have entries in both the UK AIP and the Jeppeson Plates. The same 9 airports and 3 others have warnings in the Aerad Plates and details of the Aerad warnings are given in Annex G.

Of airports with published warnings there are two (Cambridge and East Midlands) that did not identify any wind shear problems in their Questionnaire replies and which have much lower than average incident rates. A third airport (Cardiff) identified a Severity Level 1 problem (Predictable but unlikely to be hazardous) and has had no incidents. Lower than average incident rates may well be due to the influence of the warnings in the presence of a Severity Level 1 problem rather than the absence of a problem.

Where warnings are published they are generally specific and helpful, but not all airports with significant problems have taken advantage of the opportunity to publish warnings. It would be helpful if the warning for Guernsey in the Aerad Plates were available in the UK AIP and Jeppeson Plates.

In view of the high relative incident rates at Bembridge and Benbecula it would be highly desirable for these airports to publish appropriate warnings. Other airports without warnings and with relative incident rates above 1·5, which are Bristol, Liverpool, Londonderry, Rochester, Lydd and Goodwood, may wish to consider publishing warnings. The high incident rate at Kent International airport (RAF Manston) appears to be a consequence of anomalies in reporting movement rates, and the actual relative rate should be 1·5. RAF Manston in co-operation with Kent International Airport management have changed the anemometer location and are providing a warning about turbulence on late finals for the UK AIP.

## 6.2 Meteorological forecasts

Meteorological forecasts are particularly important for alerting Air Traffic Services and pilots about wind conditions that could cause problems at particular airports. They are even more helpful if there are appropriate published warnings for an airport. In some circumstances the ATS staff at an airport need to be aware of local topographical influences on the surface wind, and, although ATS staff with plenty of local experience can anticipate some local effects, the possible legal consequences of modifying a Meteorological Office forecast and the withdrawal of local Meteorological Office Forecasters from most airports has reduced the quality of local forecasts for pilots.

It would help to improve the situation if Meteorological Office forecasts for airports with topographically induced wind shear problems could give specific guidance to those airports in relation to the forecast for the appropriate area. Perhaps the Meteorological Office could develop some surface wind pattern information in consultation with local ATS staff. This would be particularly helpful for the Isle of Man, Aberdeen and Stornoway.

At airports affected by flow around and across large hills it may well be helpful to consider placing a remote weather station on the brow of the hill in a position where it is able to get a good measurement of wind direction. It will be affected by the presence of the hill but it should be possible to calibrate the local errors and make a short term forecast of the surface wind at the airport. A rugged anemometer will be needed to survive in the strong winds and other weather, but such remote weather stations already exist.

### 6.3 Current wind information

#### 6.3.1 *Anemometry*

ATS provide current wind information to pilots from measurements by an anemometer situated in an appropriate location. Both the location and any processing of the signals are relevant to the quality of this information. Wind at any location is affected by natural turbulence, local topography and buildings and the operation of aircraft in the vicinity. The first priority in locating an anemometer is to try and avoid it being shielded from the wind, and then to locate it as close as possible to the thresholds of operational runways. Sometimes it is necessary to have more than one anemometer so that only one is shielded in any wind direction, and at the same time the opportunity is taken to locate the extra anemometers near another runway threshold. The move towards using more anemometers and locating them near runway thresholds is generally to be encouraged. That is unless such a location results in shielding in winds that would normally be chosen for making the runway active, e.g. the area near the threshold of Runway 27 at Guernsey is in the wake of the airport buildings in SW winds. Although it may be argued that the anemometer is still giving the appropriate information for the touchdown, it is likely to be under-reading the crosswind that pilots will experience during much of the landing and take-off runs, which could lead to directional control problems.

There is a requirement to install modern averaging anemometer systems at all airports with Air transport operations to meet the latest ICAO standards. These recent standards require the information provided to ATS to be the running 2min. average of wind speeds and maximum speed fluctuations lasting for more than 3sec. This new standard will improve the consistency of wind reports by ATS but will produce significantly different values from those interpreted by ATS from a few seconds observation of instantaneous wind values on a meter. In particular the level of fluctuations in a given level of turbulence will be significantly lower in the new system because many gusts last less than 3sec.

The standard has been introduced after much discussion, but this author believes that fluctuations lasting as little as 1½ – 2 seconds are significant to many aircraft, and the averaging period of 2 minutes can attenuate significant mean wind changes. The duration of the high speed portion of a landing or take-off run is typically around 30 seconds and it is suggested that a rolling average of around 30 seconds would be more appropriate for wind displays. Particularly since even a rolling average gives a value for the past averaging period and is unable to respond rapidly to sudden changes. It seems likely that the currently required form of averaging will reduce the ability of ATS to give timely advice to pilots when winds are changing rapidly, as can occur with topographically induced wind shear and with storm fronts.

6.3.2 *Wind sleeves*

Wind sleeves are cheaper and easier to locate at various points around an airport and are particularly valuable indicators of local wind direction. Again they are particularly useful if pilots have been warned about possible wind shear problems.

Lighting wind sleeves to make them visible at night is a good idea in principle, and they are being introduced at many airports. It is noticeable that airports such as Sumburgh with major wind problems tend to have more wind sleeves, even if as at Sumburgh they wear out in a few months, or sometimes days, and frequently have to be replaced.

### 6.4 Wind shear warnings from other aircraft

The most reliable indication of the presence of a wind shear problem is a report of a significant wind shear from an aircraft (or preferably from 2 aircraft). ATS always respond to such information by setting a Wind shear alert which remains in place until pilot reports of encounters have ceased for a significant period. ATS inform all pilots of the possibility of encountering Wind shear while the alert is in operation.

Time is often not available to give pilots any details other than the fact that there is a wind shear alert and the approximate location were an encounter might be expected. It would be helpful if pilots were informed that the alert was from a reported wind shear (or a forecast wind shear at other times). Although all wind shear alerts should be taken seriously, there is no doubt that an alert following a reported encounter is a much more certain indicator of the presence of wind shear. Many of the fatal accidents in wind shear in the USA could have been avoided if the pilot had known and taken note of the experience of preceding aircraft.

### 6.5 Pilot training

The very severe wind shear associated with downbursts in the vicinity of energetic thunderstorms and the several fatal accidents from this type of wind shear in the USA has tended to push the dangers and significance of other types of wind shear into the background. However, even in the USA about 50% of wind shear accidents are due to shears other than downbursts, and it would be expected that in the UK less than 5% of wind shear incidents would be due to downbursts. It is thus important that pilots should be trained to expect the wide variety of wind shear that can be encountered. Down burst training is always relevant in terms of pilot response in wind shear, but they should be able to predict many of the topographical and building wake disturbances they will find at airports and anticipate some of the problems they will experience.

Some UK Airlines, particularly those with international routes, include wind shear training on their flight simulators, but such training is not mandatory in the UK. Providing pilot training to respond appropriately in wind shear will reduce excursions from the desired flight path when a significant wind shear is encountered. This training can be achieved through technical advice and in flight simulators. The Wind Shear Training Aid package and simulator requirements in the USA are a good example of such a training package.

It would be helpful if training simulators could have some wind shear patterns available that are appropriate to particular airports, as well as the usual visual scene, lighting and navigation aids. However, it is important not to use a single 'canned' example as this may cause pilots to lose some of their flexibility to respond to the many varieties found in the real world.

### 6.6 Suggestions for improving information at specific airports

The following suggestions are made in the expectation that they will provide better or new information to pilots that will help to reduce further the small number of wind related incidents at UK airports. In some cases there is not sufficient information from this present study to make constructive recommendations without further investigation of the local situation. In these cases further investigation is suggested.

Account has been taken of the existing level of flight movements and the relative incident rate in selecting airports where further action may be beneficial. Airports are selected from Annex F and listed in decreasing order of Air transport movements.

6.6.1 *London – Heathrow*

1 There is an indication from a small number of incidents that the wake from the central island may cause directional control difficulties in mean crosswinds that are over 25kt and near the operational crosswind limits for an aircraft. The airport should consider publishing a warning in the UK AIP and similar documents.

2 From the relative location of buildings and the runway a building wake problem during approaches to Runway 27L might be anticipated in NW winds that is only slightly less severe than that on Runway 27R in SW winds. The airport should approach resident airlines and Air Traffic Services to see if any problems have been noticed and, if appropriate, consider publishing a warning in the UK AIP and similar documents.

6.6.2 *Aberdeen*

1 The present single anemometer is located on the east side and about a third of the way along from the threshold of Runway 16. It is not always a good measure of conditions near the threshold of Runway 34, particularly in winds from W to NW. It is recommended that a second anemometer should be installed in a suitable location near the threshold of Runway 34.

2 There are indications that the hills to the West can cause significant changes in wind strength and direction during an approach in upper winds between about SW and NW. The airport should consider publishing a warning in the UK AIP and similar documents.

3 The airport should consider together with the Meteorological Office whether a remote weather station situated on the hills to the west would provide a worthwhile improvement in surface wind forecasting at the airport.

6.6.3 *Jersey*

Incidents indicate some directional control difficulties can be experienced in strong crosswinds from between SE and SW from the effects of the wake from the airport buildings. The airport should consider publishing a warning in the UK AIP and similar documents.

6.6.4 *Guernsey*

1 The airport should investigate to see if there is any significant shielding of the present anemometer by the airport buildings in particular wind directions. If there is shielding then the possibility of resiting the anemometer, or adding a second anemometer, should be urgently considered.

2 Incidents indicate some directional control difficulties can be experienced in strong crosswinds from between SE and SW from the effects of the wake from the airport buildings. The airport should consider publishing a warning in the UK AIP and similar documents.

6.6.5 *Bristol*

The relative incident rate due to wind, which takes account of the local mix of operations, is about 1·7 times the UK average. There is no pattern in the type of incidents, except perhaps the turbulence associated with strong winds. The airport should consult the main operators to see if there are any consistent wind related problems where publishing a warning in the UK AIP and similar documents would make pilots better prepared to deal with any difficulties.

6.6.6 *Southampton*

Incidents indicate some directional control difficulties can be experienced in strong crosswinds from between SW and NW from the effects of the wake from the airport buildings. The airport should consider publishing a warning in the UK AIP and similar documents.

6.6.7 *Sumburgh*

There is some concern that more pilots are visiting Sumburgh less frequently and local knowledge may be being diluted. It is strongly recommended that the accumulated knowledge of local pilots should be collected together into a briefing note with ATS having control of the distribution. This note should be made available to all pilots currently using Sumburgh and all pilots starting to familiarise themselves with the airport for the first time.

6.6.8 *Liverpool*

The relative incident rate due to wind, which takes account of the local mix of operations, is about 1·7 times the UK average. There is no pattern in the type of incidents, except perhaps the turbulence associated with strong winds. The airport should consult the main operators to see if there are any consistent wind related problems where publishing a warning in the UK AIP and similar documents would make pilots better prepared to deal with any difficulties.

6.6.9 *Isle of Man*

The Airports Division of the Isle of Man Department of Transport, including the Airport management and Meteorological Officer, should consider whether a remote weather station situated on the hills to the west would provide a worthwhile improvement in surface wind forecasting at the airport.

6.6.10 *Plymouth*

There were no wind related incidents at Plymouth between 1985 and 1994, but it is clear that there are some local wind disturbances. The airport should discuss these with operators and consider publishing warnings in the UK AIP and similar documents.

6.6.11 *Stornoway*

The airport should consider publishing a warning in the Jeppeson Plates and in the UK AIP in addition to the existing warning in the Aerad Plates.

6.6.12 *Benbecula*

The rate of reported incidents at this airport is very high, but, because of the low level of movements, this is not conclusive evidence of local wind problems. The airport should ask operators if there are any significant local problems and, if there are, it should consider publishing a warning in the UK AIP and similar documents.

6.6.13 *Rochester*

The relative incident rate due to wind, which takes account of the local mix of operations, is about 1·8 times the UK average. It appears that this may be due to the close proximity of buildings to the airfield. The airport should consider publishing a warning in the UK AIP and similar documents, which would make pilots better prepared to deal with any difficulties.

6.6.14 *Kent International*

The relative incident rate due to wind, which takes account of the local mix of operations, appears to be about 6·6 times the UK average. However, movement rates reported by the airport are much higher than those reported in CAA CAP630 and the relative incident rate should be only 1·5 times the UK average. RAF Manston and the civil unit have moved the anemometer nearer to the middle of the runway and are preparing an entry on turbulence for the UK AIP. No further actions are recommended.

6.6.15 *Bembridge*

The relative incident rate due to wind, which takes account of the local mix of operations, is about 6·5 times the UK average. This rate is very high but can be explained by the problems caused by Culver Down. There would seem to be a need for appropriate warnings in the UK AIP and similar documents, and it is strongly recommended that a briefing note for pilots about wind problems at the airport should be produced by local operators, held by the local ATS and distributed to pilots.

## 7 CONCLUSIONS

The study objective was to review evidence of wind disturbances (wind shear) at UK airports, identify features that are particular to individual airports and recommend ways of reducing the risk of incidents at those airports. This task was achieved by the following series of related activities:

1 Analysis of wind related incidents and accidents at UK airports recorded by the CAA between 1985 and 1994

2 Review of existing warnings published in the UK Air Information Publication (AIP) and in the Aerad and Jeppeson Airfield Plates, together with a limited selection of piloting experiences

3 Evaluate responses from up to 64 individual airports to a formal Questionnaire on this subject, and visits to 11 airports to gain supplementary information

4 From the results of these analyses and reviews, suggest guidelines to help identify when wind shear may cause problems in a particular local situation.

5 From the results of these analyses and reviews, suggest general and specific improvements in the gathering and dissemination of information to pilots that should increase awareness of possible problems and their ability to respond effectively to wind disturbances.

Wind shear is a collective term for all wind disturbances that are likely to produce a significant change in aircraft trajectory in the air or on the ground, and which require positive pilot control actions to minimise these changes. They are usually disturbances that affect an aircraft for between about 2sec. up to about 40sec. Disturbances shorter than about 2sec. or longer than about 40sec. usually do not significantly affect the trajectory. A brief description of the characteristics of various types of wind shear and the affects of wind shear on an aircraft are summarised in Section 2.

Airports selected for study (Annex A) were all those with some Air Transport movements listed in the 'UK Airports. Annual statements of Movements, Passengers and Cargo 1993, CAA CAP 630' plus Cranfield and Wycombe Air Park, which also appear in CAP 630, and Compton Abbas as an example of a Licensed Private Airport that has had several incidents. This gave a total of 65 airports to include in the study.

Analysis of wind related incidents and accidents at UK, Channel Island and Isle of Man airports, including the Channel Islands, for the 10 year period from 1985 to 1994 yielded a total of 374 events where wind was a major contributory factor. This produced 170 events at the 65 airports in this study. Twenty events while an aircraft was parked have been removed before analysing the data. Wind shear of various types was a clear contributory factor in 40% of these events and 'Crosswinds' in 29%. Significant errors of judgement by pilots in windy conditions contributed to about 14% of these incidents. The remaining 17% were due to the strength of the wind.

It would be expected that incident rates per million movements would be lower in the highly trained and regulated Air Transport category. Analysis of the data indicates that the average rate of incidents in Air Transport movements in the UK is about 2·1 per million, whereas the corresponding rate for all other movements, i.e. training, testing and private flying, is about 6·7 per million. These averages together with data on Air Transport and total movements at airports has been used to calculate the ratio of actual incidents to the UK average taking into account the actual mix of movement types for 54 airports where significant data exists. The data is listed in Annex D.

Questionnaires were sent to 64 airports and replies have been received from 55. This is an extremely high response rate and demonstrates the commitment of airport operators to safety issues. Some 60% of the replies declared that they had some wind related operating problems, and 47% of the total, i.e. 26 airports, believed that the problem could become hazardous. Inevitably there was some uncertainty as to which particular category to use for a particular problem and, after studying local incidents, topography and buildings, it has been possible to combine these with the replies to the Questionnaire and generate (Table 10, p37) a summary of wind shear problems and the number of conditions (and airports) where these may be present at different severity levels. The most common and severe type of wind shear problem arises from 'Nearby Hills or Valleys' which affects 50% of the airports with problems. Building wakes also affect 50% of these airports and each of the other problems affect about 10-15%. One of the airports that did not reply to the Questionnaire was visited. None of the other 8 airports that did not reply has any unusual incidents and they are all around or below the UK average for their mix of movement types. One airport operated by the RAF, which was not sent a Questionnaire, appears to have an unusually high incident rate relative to the UK average, but investigation has shown that this is due to under-reporting the number of movements at this airport. The true relative incident rate is only slightly above average for the UK.

It has proved possible to suggest guidelines for the size and location of some features that would be expected to cause wind shear problems at an airport as a result of the data analyses. These guidelines provide a preliminary indication that there may be problems and more detailed study would be needed to confirm the magnitude of any problems. Areas where some guidelines are given in Section 5 are 'Nearby Hills and Valleys', 'Buildings, including Railway embankments', Trees or Woods', 'Distant hills or Mountains' and 'Island Effects'. The guidance on 'Buildings' could be particularly useful as there is continuing pressure to build on or near airports. This guidance deals with building wake effects on directional control on the ground which could have contributed to many crosswind incidents, but it does not address possible problems from pieces of rotational flow that may be shed from the tops of buildings in some wind conditions and cause difficulties in the final stages of an approach to landing.

In considering the provision of information to pilots it is emphasised that published warnings are particularly useful in raising pilots awareness of potential problems. Eighteen of the 26 airports reporting significant problems do not have any warnings published, although some airports report that action is being taken to improve this situation. Some concern is expressed at the weakening of local content in Meteorological Forecasts for airports with the disappearance of local forecasters. It is suggested that it may be possible to develop agreed guidelines to help forecasters generate suitable local forecasts for airports, such as the Isle of Man and Aberdeen, where local topography has significant effects on the surface winds. It is also suggested that it may be helpful to provide data at the airport from a Remote weather station on the top of the main part of the local hills that distort the direction of the surface winds at the airport.

The location of anemometers is considered and the move to install anemometers near each threshold of operational runways is encouraged. Some concern is expressed that the latest ICAO standards for averaging wind data may attenuate the effects of sudden wind changes that are important to pilots. The use of wind sleeves is encouraged but it may need to be combined with published warnings to encourage pilots to make more use of the information they can provide.

The importance of information on wind shear from preceding aircraft cannot be over emphasised and it is suggested that pilots should be informed when a wind shear alert has originated from a pilot or a forecast.

In pilot training it is stressed that pilots need to be aware that types of wind shear other than downbursts in the vicinity of energetic thunderstorms can also be a serious threat. It is recommended that a Wind Shear Training Aid package similar to that used in the USA should be used by UK operators and pilots. Also, it is suggested that variable wind shear relating to local topography and buildings could be incorporated in the representation of specific airports on training simulators.

Finally, suggestions are made for improving information available to pilots at specific airports.

## 8 REFERENCES

1 Report on the accident to British Aerospace ATP, G-BTPE at Sumburgh Airport, Shetland Isles, on 23 December 1991, Aircraft Accident Report 6/92, Air Accidents Investigation Branch, The Department of Transport, 1993

2 UK Airports. Annual statements of Movements, Passengers and Cargo 1993, CAP 630, Civil Aviation Authority, 1994

3 A A Woodfield 'Wind shear and its effects on aircraft', Paper 5, AGARD Lecture Series 197 'Flight in an Adverse Environment', Nov, 1994

4 B Etkin 'Dynamics of Flight', Chap. 6, John Wiley & Sons, New York, 1959

5 B S Turkel & W Frost, Pilot-Aircraft System Response to Wind Shear', NASA Contractor Report 3342, 1980

6 W Frost, B S Turkel & J McCarthy, Simulation of Phugoid Excitation due to Hazardous Wind Shear', AIAA 20th Aerospace Sciences Meeting, AIAA-82-0215, January 1982

## Annex A: UK Airports included in the study.

(NB Airport number in decreasing order of Air Transport movements.)

| Airport | |
|---|---|
| *No.* | *Name* |
| 4 | Aberdeen |
| 30 | Alderney |
| 61 | Barrow |
| 13 | Belfast City |
| 12 | Belfast International |
| 64 | Bembridge |
| 42 | Benbecula |
| 47 | Biggin Hill |
| 6 | Birmingham |
| 28 | Blackpool |
| 37 | Bournemouth |
| 15 | Bristol |
| 40 | Cambridge |
| 22 | Cardiff |
| 54 | Carlisle |
| 70 | Compton Abbas |
| 34 | Coventry |
| 66 | Cranfield |
| 43 | Dundee |
| 14 | East Midlands |
| 7 | Edinburgh |
| 32 | Exeter |

| Airport | |
|---|---|
| *No.* | *Name* |
| 5 | Glasgow |
| 44 | Gloucester |
| 62 | Goodwood |
| 10 | Guernsey |
| 63 | Hawarden |
| 23 | Humberside |
| 33 | Inverness |
| 50 | Islay |
| 21 | Isle of Man |
| 26 | Isles of Scilly (St Marys) |
| 49 | Isles of Scilly (Tresco) |
| 8 | Jersey |
| 59 | Kent International |
| 58 | Kidlington |
| 27 | Kirkwall |
| 18 | Leeds/Bradford |
| 41 | Lerwick (Tingwall) |
| 20 | Liverpool |
| 25 | London City |
| 2 | London Gatwick |
| 1 | London Heathrow |
| 19 | London Luton |

| Airport | |
|---|---|
| *No.* | *Name* |
| 9 | London Stansted |
| 45 | Londonderry |
| 60 | Lydd |
| 3 | Manchester |
| 11 | Newcastle |
| 29 | Norwich |
| 35 | Plymouth |
| 46 | Prestwick |
| 65 | Redhill |
| 53 | Rochester |
| 55 | Scatsta |
| 51 | Shoreham |
| 16 | Southampton |
| 48 | Southend |
| 38 | Stornoway |
| 17 | Sumburgh |
| 24 | Teesside |
| 56 | Tiree |
| 31 | Unst |
| 39 | Wick |
| 67 | Wycombe Air Park |

The following airports listed in 'UK Airports. Annual statements of movements, passengers and cargo 1993. CAP630' are not included in the study:

| | | | |
|---|---|---|---|
| | Penzance Heliport | Airport No. | 36 |
| | Battersea Heliport | Airport No. | 52 |
| | Hatfield (Airport closed 1994) | Airport No. | 57 |

# Annex B: Definitions of 'Flight Phases' used in wind incident analyses

These phases have been selected for this present study of wind shear problems at airports and only relate to operations near and on the ground at airports. They have been chosen to relate closely to the aircraft condition, e.g. aerodynamic lift level, power setting, control mode, etc, and are not necessarily the same definitions as those used when data was entered in the CAA Database.

| *Name* | *Definition* |
|---|---|
| Final approach | All flight modes up to touchdown where an aircraft is dependent on aerodynamic lift from wing or rotor. This includes the landing flare and the instant of touchdown. |
| Helicopter landing | All flight modes in the vicinity of the ground up to the moment of touchdown, including hovering, hover taxying, and descent to touchdown. |
| Landing run | All the run from touchdown until the aircraft is down to normal taxying speeds. In this phase the aircraft still partially responds to aerodynamic controls. |
| Taxy | Low speed transit on the ground at low power settings. The aircraft would not normally respond to aerodynamic controls. |
| Take-off run | High power acceleration to lift-off airspeed. This phase ends once the aircraft is airborne. |
| Helicopter take-off | The process of applying collective and lifting clear of the ground. |
| Initial climb | The first few hundred feet of climb after take-off, which is still at high power and when configuration changes are taking place, e.g. undercarriage retraction, flap and slat changes, etc. |

## Annex C: Definitions of 'Wind incident types' used in the analyses

These 'Wind incident types' have been selected for this study to relate to the different types of wind hazard used in the Questionnaire. The type of effect that probably contributed most to a particular incident is used as the sole descriptor. Other wind effects may be present but only the primary effect is considered in the analyses.

| *Name* | *Definition* |
|---|---|
| Crosswind | Directional control problems were experienced and/or a sidegust lifted a wing |
| Moderate wind (15-30kt) | The incident was caused by the strength of the wind |
| Strong wind (>30kt) | The incident was caused by the strength of the wind |
| Wind shear - Bdg | The incident was caused by the disturbed wake from a man made object such as a building or a railway embankment |
| Wind shear - Topog | The incident was caused by the disturbed wake around local natural topographical features such as hills, valleys or cliffs |
| Wind shear - Wx | The incident was caused by meteorological disturbances that are not related to the topography or buildings of a specific airport |
| Pilot error | The incident was caused by the inability of the pilot to control the aircraft in wind conditions that would not usually cause any problems to an experienced pilot |

# Annex D: Movements, Diversions and Wind related incidents

| Airport | | Questionnaire | | 1993 Movements and Diversions (CAP630) | | | | | | | | CAA Incident Database | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Movements | | | | | | Diversions | | Wind Incidents 1985 - 94 | | | |
| No. | Name | Replied | Visited | Total | Air transport | Test & trg | Air transport, Test and Trg., % | Military | Military, % | No. | per 1000 | Airborne No. | Ground No. | Total per million | Relative incident rate |
| 1 | London Heathrow | Y | Y | 411173 | 396087 | 575 | 96% | 481 | 0% | 233 | 0.6 | 2 | 6 | 1.9 | 0.9 |
| 2 | London Gatwick | Y | Y | 184714 | 175313 | 45 | 95% | 58 | 0% | 202 | 1.1 | 5 | 0 | 2.7 | 1.2 |
| 3 | Manchester | Y | Y | 160202 | 135504 | 264 | 85% | 392 | 0% | 108 | 0.7 | 4 | 1 | 3.1 | 1.1 |
| 4 | Aberdeen | | Y | 119585 | 93227 | 9911 | 86% | 196 | 0% | 80 | 0.7 | 0 | 4 | 3.3 | 1.1 |
| 5 | Glasgow | Y | | 103511 | 77360 | 1112 | 76% | 1350 | 1% | 135 | 1.3 | 3 | 0 | 2.9 | 0.9 |
| 6 | Birmingham | Y | | 95168 | 68754 | 751 | 73% | 144 | 0% | 65 | 0.7 | 1 | 1 | 2.1 | 0.6 |
| 7 | Edinburgh | Y | | 110997 | 58724 | 1059 | 54% | 20588 | 19% | 40 | 0.4 | 0 | 3 | 2.7 | 0.6 |
| 8 | Jersey | Y | Y | 78505 | 50117 | 752 | 65% | 908 | 1% | | 0.0 | 3 | 4 | 8.9 | 2.4 |
| 9 | London Stansted | Y | | 62664 | 47542 | 2715 | 80% | 100 | 0% | 146 | 2.3 | 1 | 1 | 3.2 | 1.0 |
| 10 | Guernsey | Y | | 60263 | 39814 | 585 | 67% | 396 | 1% | | 0.0 | 1 | 4 | 8.3 | 2.3 |
| 11 | Newcastle | Y | | 76706 | 36358 | 1833 | 50% | 1241 | 2% | 68 | 0.9 | 0 | 3 | 3.9 | 0.9 |
| 12 | Belfast International | Y | | 92118 | 34592 | 1299 | 39% | 38951 | 42% | 15 | 0.2 | 0 | 0 | 0.0 | 0.0 |
| 13 | Belfast City | Y | | 37952 | 30512 | 408 | 81% | 4804 | 13% | 25 | 0.7 | 1 | 0 | 2.6 | 0.9 |
| 14 | East Midlands | Y | | 55959 | 27123 | 1341 | 51% | 480 | 1% | 56 | 1.0 | 1 | 0 | 1.8 | 0.4 |
| 15 | Bristol | Y | Y | 53224 | 25859 | 1355 | 51% | 602 | 1% | 143 | 2.7 | 2 | 2 | 7.5 | 1.7 |
| 16 | Southampton | Y | | 56434 | 21375 | 642 | 39% | 344 | 1% | 36 | 0.6 | 1 | 3 | 7.1 | 1.4 |
| 17 | Sumburgh | Y | Y | 27533 | 21193 | 1882 | 84% | 56 | 0% | 47 | 1.7 | 3 | 0 | 10.9 | 3.4 |
| 18 | Leeds/Bradford | Y | | 47660 | 20677 | 2093 | 48% | 197 | 0% | 181 | 3.8 | 0 | 3 | 6.3 | 1.3 |
| 19 | London Luton | Y | | 41122 | 19598 | 2528 | 54% | 59 | 0% | 58 | 1.4 | 1 | 1 | 4.9 | 1.1 |
| 20 | Liverpool | Y | | 75265 | 18785 | 1504 | 27% | 577 | 1% | 33 | 0.4 | 2 | 5 | 9.3 | 1.7 |
| 21 | Isle of Man | Y | Y | 37553 | 16938 | 1680 | 50% | 449 | 1% | 21 | 0.6 | 3 | 2 | 13.3 | 2.9 |
| 22 | Cardiff | Y | | 55030 | 13730 | 3161 | 31% | 409 | 1% | 42 | 0.8 | 0 | 0 | 0.0 | 0.0 |
| 23 | Humberside | Y | | 32882 | 11898 | 2738 | 45% | 92 | 0% | 20 | 0.6 | 0 | 0 | 0.0 | 0.0 |
| 24 | Teesside | Y | | 48998 | 11412 | 1070 | 25% | 358 | 1% | 12 | 0.2 | 0 | 2 | 4.1 | 0.7 |

| Airport | | Questionnaire | | 1993 Movements and Diversions (CAP630) | | | | | | | | CAA Incident Database | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Movements | | | | | | Diversions | | Wind Incidents 1985 - 94 | | | |
| No. | Name | Replied | Visited | Total | Air transport | Test & trg | Air transport, Test and Trg., % | Military | Military, % | No. | per 1000 | Airborne No. | Ground No. | Total per million | Relative incident rate |
| 25 | London City | Y | Y | 11663 | 11354 | 63 | 98% | 0 | 0% | 27 | 2.3 | 0 | 0 | 0.0 | 0.0 |
| 26 | Isles of Scilly (St Marys) | Y | | 11306 | 10207 | 0 | 90% | 60 | 1% | | 0.0 | 0 | 0 | 0.0 | 0.0 |
| 27 | Kirkwall | Y | | 12828 | 9746 | 241 | 78% | 56 | 0% | 10 | 0.8 | 1 | 0 | 7.8 | 2.4 |
| 28 | Blackpool | Y | | 47277 | 8969 | 786 | 21% | 619 | 1% | | 0.0 | 1 | 3 | 8.5 | 1.4 |
| 29 | Norwich | Y | | 31103 | 8190 | 14929 | 74% | 129 | 0% | 23 | 0.7 | 0 | 0 | 0.0 | 0.0 |
| 30 | Alderney | Y | | 13002 | 8013 | 38 | 62% | 47 | 0% | | 0.0 | 1 | 0 | 7.7 | 2.0 |
| 31 | Unst | Y | | 9727 | 7446 | 919 | 86% | 2 | 0% | 22 | 2.3 | 0 | 0 | | |
| 32 | Exeter | Y | | 40662 | 7203 | 16726 | 59% | 5403 | 13% | 10 | 0.2 | 0 | 1 | 2.5 | 0.4 |
| 33 | Inverness | | | 27196 | 6381 | 1948 | 31% | 697 | 3% | 6 | 0.2 | 0 | 0 | 0.0 | 0.0 |
| 34 | Coventry | | | 58902 | 6233 | 35379 | 71% | 0 | 0% | 44 | 0.7 | 1 | 2 | 5.1 | 0.8 |
| 35 | Plymouth | Y | Y | 30733 | 5241 | 293 | 18% | 12277 | 40% | 24 | 0.8 | 0 | 0 | 0.0 | 0.0 |
| 37 | Bournemouth | Y | | 77571 | 3906 | 307 | 5% | 11778 | 15% | | 0.0 | 0 | 0 | 0.0 | 0.0 |
| 38 | Stornoway | Y | | 6854 | 3824 | 791 | 67% | 596 | 9% | 1 | 0.1 | 0 | 0 | | |
| 39 | Wick | Y | | 6529 | 3274 | 275 | 54% | 55 | 1% | 5 | 0.8 | 0 | 0 | | |
| 40 | Cambridge | Y | | 44633 | 3171 | 522 | 8% | 22039 | 49% | 6 | 0.1 | 0 | 0 | 0.0 | 0.0 |
| 41 | Lerwick (Tingwall) | Y | | 2420 | 2336 | 20 | 97% | 2 | 0% | 1 | 0.4 | 0 | 0 | | |
| 42 | Benbecula | Y | | 3276 | 2264 | 26 | 70% | 286 | 9% | | 0.0 | 0 | 2 | 61.1 | 17.3 |
| 43 | Dundee | Y | | 30625 | 2122 | 2348 | 15% | 188 | 1% | | 0.0 | 2 | 1 | 9.8 | 1.5 |
| 44 | Gloucester | Y | | 70557 | 1797 | 3489 | 7% | 358 | 1% | 2 | 0.0 | 2 | 2 | 5.7 | 0.9 |
| 45 | Londonderry | Y | | 10430 | 1757 | 596 | 23% | 28 | 0% | 1 | 0.1 | 0 | 1 | 9.6 | 1.6 |
| 46 | Prestwick | Y | | 66784 | 1609 | 6443 | 12% | 2907 | 4% | 4 | 0.1 | 0 | 2 | 3.0 | 0.5 |
| 47 | Biggin Hill | | | 49525 | 1439 | 630 | 4% | 340 | 1% | 3 | 0.1 | 3 | 1 | 8.1 | 1.2 |
| 48 | Southend | Y | | 51875 | 1170 | 2910 | 8% | 497 | 1% | 11 | 0.2 | 2 | 2 | 7.7 | 1.2 |
| 49 | Isles of Scilly (Tresco) | Y | | 1167 | 1150 | 0 | 99% | 0 | 0% | | 0.0 | 0 | 0 | | |
| 50 | Islay | Y | | 2076 | 1123 | 265 | 67% | 19 | 1% | 1 | 0.5 | 0 | 0 | | |
| 51 | Shoreham | Y | | 52879 | 1112 | 1058 | 4% | 68 | 0% | | 0.0 | 3 | 2 | 9.5 | 1.4 |

| Airport | | Questionnaire | | 1993 Movements and Diversions (CAP630) | | | | | | | | CAA Incident Database | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Movements | | | | | | Diversions | | Wind Incidents 1985 - 94 | | | |
| No. | Name | Replied | Visited | Total | Air transport | Test & trg | Air transport, Test and Trg., % | Military | Military, % | No. | per 1000 | Airborne No. | Ground No. | Total per million | Relative incident rate |
| 53 | Rochester | Y | | 26117 | 922 | 4 | 4% | 34 | 0% | | 0.0 | 2 | 1 | 11.5 | 1.8 |
| 54 | Carlisle | | | 27136 | 902 | 8720 | 35% | 526 | 2% | 2 | 0.1 | 0 | 0 | 0.0 | 0.0 |
| 55 | Scatsta | Y | | 870 | 756 | 86 | 97% | 4 | 0% | 2 | 2.3 | 0 | 0 | | |
| 56 | Tiree | Y | | 906 | 735 | 6 | 82% | 10 | 1% | | 0.0 | 0 | 1 | | |
| 58 | Kidlington | Y | | 48438 | 348 | 42418 | 88% | 1 | 0% | | 0.0 | 2 | 1 | 6.2 | 0.9 |
| 59 | Kent International | (Note 2) | | 13668 | 282 | 0 | 2% | (Note 2) | (Note 2) | 1 | 0.1 | 2 | 4 | 43.9 | 6.6 |
| 60 | Lydd | Y | | 19083 | 259 | 2123 | 12% | 368 | 2% | | 0.0 | 0 | 2 | 10.5 | 1.6 |
| 61 | Barrow | | | 3060 | 172 | 24 | 6% | 132 | 4% | | 0.0 | 0 | 1 | | |
| 62 | Goodwood | Y | | 27895 | 126 | 123 | 1% | 16 | 0% | 2 | 0.1 | 3 | 0 | 10.8 | 1.6 |
| 63 | Hawarden | Y | | 3991 | 46 | 868 | 23% | 44 | 1% | | 0.0 | 1 | 0 | | |
| 64 | Bembridge | Y | | 6911 | 20 | 788 | 12% | 168 | 2% | | 0.0 | 1 | 2 | 43.4 | 6.5 |
| 65 | Redhill | | | 62691 | 16 | 15318 | 24% | 40 | 0% | | 0.0 | 1 | 0 | 1.6 | 0.2 |
| 66 | Cranfield | | | 59548 | 0 | 47295 | 79% | 116 | 0% | 1 | 0.0 | 1 | 3 | 6.7 | 1.0 |
| 67 | Wycombe Air Park | | | 50792 | | | 0% | | 0% | | 0.0 | 2 | 2 | 7.9 | 1.2 |
| 70 | Compton Abbas | Y | Y | | | | | | | | | 2 | 2 | | |

NB (1) Relative incident rate based on UK averages of 2·1 incidents per million for Air transport movements and 6·7 per million for all 'Other' movements

(2) Kent International (Manston) is operated by the Ministry of Defence (RAF). Only Civil movements reported. No Questionnaire sent.

## Annex E: Questionnaire sent to UK Airports

**Woodfield Aviation Research**

## Study of Wind and Storm related Operating difficulties at UK Airports for the Civil Aviation Authority (CAA).

## Airport Questionnaire.

*The information in this questionnaire is for CAA use only.*

9 Colworth Road, Sharnbrook, Bedford MK44 1ET

Tel: 01234 781567 Fax: 01933 59199 e-mail: CompuServe 100303,3461

*Commercial - in - Confidence*

**Wind and Storm related Operating difficulties at UK Airports.**

## 1. Purpose of this Questionnaire.

The Civil Aviation Authority wish to identify airports in the UK with significant levels of Air Transport movements that have local operating difficulties due to winds, or that are particularly susceptible to frequent and severe thunderstorms. Woodfield Aviation Research has been contracted to undertake the study on behalf of the CAA, and, where flight safety could be enhanced, to recommend practical actions that could be taken to improve information given to pilots about significant local wind problems either directly through Air Traffic Control based on suitable Meteorological advice and measurements, or by other means such as Airfield Guides.

## 2. Background

Wind has been a major contributing factor in 40 accidents or major incidents per year at UK airports. About half of these accidents or incidents have occurred at airports with significant levels of Air Transport movements. Currently, Air Traffic Controllers are required to relay information from pilots who have recently experienced the effects of wind shear, and they will often use local knowledge of disturbances due to winds from particular directions to advise pilots of possible problems. However, with the exception of London Heathrow and Belfast International airports, there are no specific arrangements in the UK to ensure that pilots are warned of possible wind related problems. Accident and incident data suggest that it may be possible to improve safety significantly at some airports by providing more relevant meteorological information, and by clearer identification of potential problems in Airfield Guides.

## 3. Confidentiality

This questionnaire and information extracted from it are the property of the CAA and the Contractor (Woodfield Aviation Research) can only use the information for the purpose of this contract for the CAA. No specific information about an individual airport will be disseminated outside the CAA, or to other airports without the express permission of the manager of that airport. Woodfield Aviation Research will discuss with the relevant airport manager any recommendations they propose to make relating to specific airports before presenting recommendations to the CAA.

## 4. Replies

Thank you for taking the time to fill in this questionnaire. Please return the completed questionnaire by 31 August 1995 to

Alan A Woodfield
Woodfield Aviation Research
9 Colworth Road
Sharnbrook
Bedford MK44 1ET

Please ring 01234 781567 (or fax. 01933 59199) if you have any queries. Please return partially completed questionnaires if you do not have the information to complete answers to all the questions.

## 5. Questionnaire

### 5.1 Airport details

| No. | | |
|---|---|---|
| 1 | Airport Name: | |
| 2 | ICAO Location Indicator | |
| 3 | Airport Address: | |
| 4 | Contact Name and Position for further information: | |
| 5 | Contact Telephone No. : | |
| 6 | Contact Fax No. : | |
| 7 | Is there a resident Meteorological Officer at your airport? | Yes ☐ No ☐ |
| 8 | Please list Commercial Air Transport operators based at your airport: | |

| **No.** | | |
|---|---|---|
| 9 | Please list other Commercial Air Transport operators that regularly use your airport: | |
| 10 | Directions of Operational runways | |
| 11 | Are there any particular features of your airport that cause operational difficulties in strong winds or storms ?<br><br>*(If* 'Yes' *then please continue with the questionnaire; if* 'No' *then please date and return.)* | Yes ☐ No ☐ |

Signed: ______________________________ Date: ____________________

## 5.2 Situations causing operational difficulties

### 5.2.1 Effects in low or moderate winds

Some significant wind shears can occur when surface winds are quite moderate and there is no thunderstorm activity. These types of wind shear include strong winds (low level jets) near the top of temperature inversion layers, strong local thermal up and down draughts consistently generated between areas with contrasting surfaces, and vertical and horizontal wind changes where a local on-shore wind meets a synoptic wind from the land. The local geography of some airports can increase the chance of encountering such wind shears.

| No. | Meteorological conditions | |
|---|---|---|
| 12 | Strong temperature inversions occur regularly: | Yes ☐ No ☐ |
| 13 | Other significant wind shears occur regularly in low or moderate winds: | Yes ☐ No ☐ |
| | Brief description of cause and type of wind shear | |

### 5.2.2 Strong winds

Please identify any of the following situations that affect operations at your airport and indicate how severe the problem is by entering a number in the box for each possible cause of wind problems using the following scale of severity. Please also indicate the wind strength and range of directions that cause the problem. The intention is to identify any problems that are specific to your airport. It is not necessary to include conditions with winds greater than 50 knots, or crosswinds above 30-35 knots that would cause problems at any airport unless there are terrain features or buildings at your airport that make these effects worse.

**Table 1: Scale for Severity of operational difficulties because of wind hazards.**

| Description | Severity Scale No. |
|---|---|
| No operational problems from this cause in any wind strength or direction | 0 |
| Some predictable operating difficulties, but not likely to be hazardous | 1 |
| Operating difficulties that could become hazardous in particular wind conditions | 2 |
| Operating difficulties that require warnings to be issued by radio | 3 |
| Diversions occuring or operations temporarily suspended because of wind hazards | 4 |

| No. | Likely cause of problem | Phase of flight | Runway in use | Severity No. (Table 1) | Wind | | |
|---|---|---|---|---|---|---|---|
| | | | | | Speed above (kt) | Direction | |
| | | | | | | From | To |
| 14 | Sea or large lake near the airport | Landing | | | | | |
| | | Take off | | | | | |
| | | Brief description of feature if Severity is ≥ 2 | | | | | |

| No. | Likely cause of problem | Phase of flight | Runway in use | Severity | Wind | | |
|---|---|---|---|---|---|---|---|
| | | | | No. | Speed above | Direction | |
| | | | | (Table 1) | (kt) | From | To |
| 15 | Hills near the airport | Landing | | | | | |
| | | Take off | | | | | |
| | | Brief description of feature if Severity is ≥ 2 | | | | | |
| 16 | Cliffs near the airport | Landing | | | | | |
| | | Take off | | | | | |
| | | Brief description of feature if Severity is ≥ 2 | | | | | |
| 17 | Buildings on or near the airport | Landing | | | | | |
| | | Take off | | | | | |
| | | Brief description of feature if Severity is ≥ 2 | | | | | |
| 18 | Trees or woods on or near the airport | Landing | | | | | |
| | | Take off | | | | | |
| | | Brief description of feature if Severity is ≥ 2 | | | | | |

<table>
<tr><th rowspan="3">No.</th><th rowspan="3">Likely cause of problem</th><th rowspan="3">Phase of flight</th><th rowspan="3">Runway in use</th><th>Severity</th><th colspan="3">Wind</th></tr>
<tr><th rowspan="2">No. (Table 1)</th><th>Speed above</th><th colspan="2">Direction</th></tr>
<tr><th>(kt)</th><th>From</th><th>To</th></tr>
<tr><td rowspan="3">19</td><td rowspan="3">Distant hills, cliffs or mountains</td><td>Landing</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Take off</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Brief description of feature if Severity is ≥ 2</td><td colspan="5"></td></tr>
<tr><td rowspan="3">20</td><td rowspan="3">Other feature(s). Please describe below.</td><td>Landing</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Take off</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Brief description of feature if Severity is ≥ 2</td><td colspan="5"></td></tr>
</table>

### 5.2.3 Susceptibility to thunderstorms

Please give your opinion of the frequency and severity of thunderstorms at your airport.

| No. | | | | |
|---|---|---|---|---|
| 21 | In your opinion does your airport experience thunderstorms | Less frequently than average | Average frequency | More frequently than average |
| | (Please tick one box) | | | |
| 22 | Does your airport experience thunderstorms of severity that are | - | Average | More severe than average |
| | (Please tick one box) | - | | |
| 23 | If your thunderstorms are more frequent or more severe, please say why you think this occurs. | | | |

### 5.2.4 Accidents or major incidents in the past 10 years

Please indicate the main prevailing conditions during any wind related accidents or major incidents that you are aware happened at your airport since 1985.

| No. | Prevailing conditions | Accidents or incidents occurred, Y/N | No. of accidents or incidents |
|---|---|---|---|
| 24 | Low winds below 15 knots: | | |
| 25 | Moderate winds up to 30 knots: | | |
| 26 | Strong winds over 30 knots: | | |
| 27 | Vicinity of thunderstorms: | | |

## 5.3 Relevant operational features

Answers to the following questions will identify your current procedures and wind measurement capabilities, and you will be able to suggest improvements that you would like to see implemented.

### 5.3.1 Alerting pilots to possible wind or wind shear hazards

| No. | Procedure | Proced-ure used (Y/N) | Runway in use | Wind conditions | | |
|---|---|---|---|---|---|---|
| | | | | Speed above knots | Range of directions | |
| | | | | | From | To |
| 28 | General Meteorological Office weather alerts relayed by Air Traffic Services (ATS) | | | - | - | - |
| 29 | Meteorological advice from resident Met. Officer relayed by ATS | | | - | - | - |
| 30 | Published guidance for pilots in Airfield Guide or similar document | | | | | |
| 31 | Local ATS procedures in specific wind or thunderstorm conditions | | | | | |
| 32 | Are you aware of any other published warnings, e.g. by local operators. Please state type of publication and the organisation that is responsible | | | | | |

### 5.3.2 Wind information sources

Please identify the approximate location of anemometers and wind socks that provide wind information to Air Traffic Control or pilots. If you have more than 3 anemometers or wind socks, then please attach details of them on a separate sheet.

| No. | Measuring device | Wind sock lit (Y/N) | Nearest threshold | | |
|---|---|---|---|---|---|
| | | | Runway No. | Bearing from threshold | Distance from threshold |
| 33 | Anemometer No. 1 | - | | | |
| 34 | Anemometer No. 2 | - | | | |
| 35 | Anemometer No. 3 | - | | | |
| 36 | Wind sock No. 1 | | | | |
| 37 | Wind sock No. 2 | | | | |
| 38 | Wind sock No. 3 | | | | |

### 5.3.3 Desirable improvements in wind measurement or forecasting of disturbances

| No. | | | | |
|---|---|---|---|---|
| 39 | At your airport would you expect improvements in forecasting or measurement of wind conditions would noticeably improve (Please tick) | Safety | Movements | Both |
| | | | | |
| 40 | What changes or additions to published information, ATS procedures, or wind measurement/forecasting would you like to see at your airport ?<br><br>(Please continue on the attached sheet if you wish.) | | | |

# Annex F: UK Airports with local Wind Shear problems

| Airport | | *CAA Incident Database* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Wind Incidents 1985 - 94* | | | | *Documented Warning* | | | |
| No. | Name | *Airborne No.* | *Ground No.* | *Total per million movements* | *Relative incident rate* | *UK AIP* | *Aerad* | *Jeppeson* | *Wind Shear Severity Level* |
| 1 | London Heathrow | 2 | 6 | 1.9 | 0.9 | Y | Y | Y | 2 |
| 2 | London Gatwick | 5 | 0 | 2.7 | 1.2 | Y | Y | Y | 2 |
| 3 | Manchester | 4 | 1 | 3.1 | 1.1 | | | | 2 |
| 4 | Aberdeen | 0 | 4 | 3.3 | 1.1 | | | | 2 |
| 5 | Glasgow | 3 | 0 | 2.9 | 0.9 | | | | 3 |
| 8 | Jersey | 3 | 4 | 8.9 | 2.4 | Y | Y | Y | 3 |
| 10 | Guernsey | 1 | 4 | 8.3 | 2.3 | | Y | | 4 |
| 11 | Newcastle | 0 | 3 | 3.9 | 0.9 | | | | 2 |
| 14 | East Midlands | 1 | 0 | 1.8 | 0.4 | | Y | | |
| 15 | Bristol | 2 | 2 | 7.5 | 1.7 | | | | 1 |
| 16 | Southampton | 1 | 3 | 7.1 | 1.4 | | | | 2 |
| 17 | Sumburgh | 3 | 0 | 10.9 | 3.4 | Y | Y | Y | 2 |
| 18 | Leeds/Bradford | 0 | 3 | 6.3 | 1.3 | | | | 3 |
| 20 | Liverpool | 2 | 5 | 9.3 | 1.7 | | | | |
| 21 | Isle of Man | 3 | 2 | 13.3 | 2.9 | Y | Y | Y | 2 |
| 22 | Cardiff | 0 | 0 | 0.0 | 0.0 | Y | Y | Y | 1 |
| 26 | Isles of Scilly (St Marys) | 0 | 0 | 0.0 | 0.0 | | | | 3 |
| 27 | Kirkwall | 1 | 0 | 7.8 | 2.4 | Y | Y | Y | 3 |
| 30 | Alderney | 1 | 0 | 7.7 | 2.0 | Y | Y | Y | 2 |
| 35 | Plymouth | 0 | 0 | 0.0 | 0.0 | | | | 3 |
| 37 | Bournemouth | 0 | 0 | 0.0 | 0.0 | | | | 3 |
| 38 | Stornoway | 0 | 0 | | | | Y | | 2 |
| 39 | Wick | 0 | 0 | | | | | | 2 |
| 40 | Cambridge | 0 | 0 | 0.0 | 0.0 | Y | Y | Y | |
| 42 | Benbecula | 0 | 2 | 61.1 | 17.3 | | | | |
| 43 | Dundee | 2 | 1 | 9.8 | 1.5 | | | | 3 |
| 45 | Londonderry | 0 | 1 | 9.6 | 1.6 | | | | |
| 48 | Southend | 2 | 2 | 7.7 | 1.2 | | | | 2 |
| 51 | Shoreham | 3 | 2 | 9.5 | 1.4 | | | | 2 |
| 53 | Rochester | 2 | 1 | 11.5 | 1.8 | | | | 2 |
| 55 | Scatsta | 0 | 0 | | | | | | 2 |
| 59 | Kent International | 2 | 4 | 43.9 | 6.6 | | | | |
| 60 | Lydd | 0 | 2 | 10.5 | 1.6 | | | | |
| 62 | Goodwood | 3 | 0 | 10.8 | 1.6 | | | | |
| 64 | Bembridge | 1 | 2 | 43.4 | 6.5 | | | | 4 |
| 70 | Compton Abbas | 2 | 2 | | | | | | 2 |

NB (1) Kent International (Manston) is operated by the Ministry of Defence (RAF). Only Civil movements reported. No Questionnaire sent.

(2) Airports with Documented problems or Reporting problems at Severity Level 2 or greater in Questionnaire replies

(3) Aberdeen added following visit to the airport

(4) Airports with incident rates > 1·5 * 'UK average' (Average is 2·1 per million for Air Transport & 6·7 for Other movements)

(5) Relative incident rate based on average rates and mix of movements

## Annex G: Wind shear warning in Aerad Airport Plates

The following is a list of all the Aerad wind shear warnings for airports in the study:

| *Airport* | *Warning* |
|---|---|
| Alderney | Turbulence caused by nearby cliffs. |
| Cambridge | Turbulence and Wind shear may be experienced shortly after Take-off on Runway 18 when there is a strong NW wind. |
| Cardiff | When landing on Runway 30 in strong W to SW winds beware of the possibility of terrain induced turbulence on short finals. Possibility of turbulence created by hangar NW of Runway 21 threshold caution advised during strong NW-NE winds. |
| East Midlands | Turbulence may be expected on the approach to Runway 09 when there is a strong N or NE wind. This may be accompanied by associated down draught. |
| Guernsey | Down draught or turbulence may be experienced on approaches to either runway in strong winds from any direction due to cliffs and valleys in local terrain. |
| Isle of Man | A known Wind shear problem exists on short finals for Runway 08 when wind is from the SE and pilots should adopt appropriate operating procedures. |
| Jersey | Turbulence and variable wind condition may be experienced on final approach and landing on Runway 09 caused by nearby cliffs (100m from threshold). |
| Kirkwell | Runway 27: severe turbulence possible on short final when wind is from the SW to NW. |
| London - Gatwick | Strong S/SW winds may cause turbulence and Wind shear on approach. |
| London - Heathrow | Building induced turbulence and large Wind shear effects likely when landing on Runway 27R in strong S/SW winds. |
| Stornoway | On approach to Runway 18 turbulence can be experienced below 500ft with strong SW winds. |
| Sumburgh | Severe turbulence possible on approach to, or departure from, any runway. |