London City Airport

Wake Turbulence Study

Final Report

December 2010

Halcrow Group Limited

Halcrow Group Limited
Elms House 43 Brook Green London W6 7EF
Tel +44 (0)20 3479 8000 Fax +44 (0)20 3479 8001
www.halcrow.com

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Executive Summary

1. The purpose of this study is to satisfy obligations in the Section 106 Agreement (S106) which accompanies the planning permission (07/01510/VAR) granted by the London Borough of Newham (LBN) on 9 July 2009 for an increase in permitted annual aircraft movements to 120,000. The S106 planning agreement requires London City Airport (LCY) to submit a Wake Turbulence Study to LBN by 8 January 2011 for approval. The purpose of the study is to investigate any damage arising to buildings around the Airport as a result of wake turbulence, together with recommendations (to the extent necessary) to address such damage or the risk of such damage and procedures that should be adopted in order to handle any claims for compensation arising from such damage.

2. Because damage has only been reported at one location near LCY the assessment of risk must be based on a combination of empirical research and experience from airports with a record of turbulence damage. The sensitivity of the issue makes access to data on vortex damage incidence at other airports difficult. Studies have therefore had to rely on sources in the public domain, including industry and academic research, public inquiry evidence, and airport publications such as consultative committee minutes.

3. A review of research into wake vortex generation and behaviour indicated the impracticality of quantifying vortex damage risk by empirical methods. To cause damage at ground level the initial energy of an aircraft vortex must be preserved as it descends, so that air speeds within it are sufficient to generate air pressures that can lift roof tiles. The process of vortex decay and dispersal of that energy is sensitive to a number of factors, particularly weather conditions. While research has made vortex generation and initial physical characteristics reasonably predictable, their behaviour between aircraft and ground remains uncertain. It is not, therefore, feasible to quantify empirically how many vortices will reach ground level with potentially damaging energy or how many of those will cause actual damage.

4. The assessment of vortex damage risk around LCY has therefore been based on statistics of damage from there and other airports and comparison, between those airports and LCY, of the factors that affect damage incidence. Data has been gathered from seven UK airports where vortex damage is known to have occurred,

including Heathrow, which has by far the highest incidence, but also airports with traffic and other characteristics closer to those of LCY.

5. The study examined the causes of aircraft wake vortices and their effects, in terms of property damage and wind speeds and noise perceived by people on the ground. All aircraft in flight generate vortices all the time. The strength of the vortices is proportional to aircraft weight and inversely proportional to wingspan and airspeed. The highest energy and most persistent vortices are generated by large aircraft flying slowly, which is typical of aircraft on approach to landing.

6. Vortices decay as they descend to ground, so the lower the aircraft the shorter the descent time and the greater the chance of a vortex reaching the ground with enough energy to cause damage. The very great majority of damage incidents are therefore experienced beneath the approaches to a runway, with the frequency and concentration of strikes generally increasing closer to the threshold. Damage is almost entirely confined to traditionally-built roofs, and consists of the displacement of slates or tiles. It can be avoided by the application of additional nailing or special clips to tiles, to better resist lifting forces.

7. Research at Heathrow has shown a strong correlation between damage incidence and two factors; weather conditions and aircraft size. Damaging strikes occur most frequently when conditions are calm, because there is then less natural air turbulence to encourage dispersal of vortex energy. Larger, heavier aircraft generate the highest vortex air speeds and suction forces, making the preservation of damaging energy levels more likely. However, while Heathrow's record certainly indicates the majority of damaging strikes are caused by large, wide-bodied aircraft, evidence from other airports shows that smaller aircraft can and do cause vortex damage.

8. Available records from six airports were analysed to derive a rate of damaging strikes per 1,000 aircraft arrivals. These ranged from 2.30 strikes/1,000 arrivals at Heathrow to 0.04 at Belfast City. Because property damage can only occur if the vortex falls in a developed area, these strike rates were then adjusted to take account of the differing degrees of residential development beneath the approaches to the runways concerned and the amount of developed land around LCY. This gave a potential annual number of damaging strikes for the LCY situation (at 120,000 annual ATMs) ranging from 78/year based on the Heathrow rate to 2/year using the Belfast City rate and 5/year based on the strikes to date at LCY itself.

9. Clearly, there are major traffic, operational and physical differences between Heathrow and LCY which will affect the likely strike rate; particularly maximum aircraft size and glide slope angle. Heathrow has a very high proportion of large aircraft, whereas the A318 (one fifth the weight of a B747) is the largest seen at LCY and the majority are smaller types. Other airports with significant strike rates, such as Birmingham and Manchester, also serve wide-bodied aircraft. The glide slope at LCY is 5.5^0, while the standard elsewhere is 3^0, putting LCY aircraft about 80% higher at any point on final approach and correspondingly increasing vortex decay time. The only damage location at LCY is very close to the runway threshold. Taking these factors into account, it is considered that the potential strike rate at LCY will be at the low end of the range of rates seen elsewhere. Comparison with the rate from Southampton, with further adjustment for site-specific factors, indicates a worst case potential damage rate at LCY of 2 or 3 strikes/year. If all available land beneath the approaches was to be developed with traditionally-built houses, this rate would be expected to increase. In practice, it is unlikely that all land in these areas can or will be developed or that such development would be of a type susceptible to roof damage.

10. Consideration of the air speeds likely to be generated by vortices at ground level, against established criteria for public safety, indicated that physical disturbance of people in the open by vortices is very unlikely. It is likely, however, that people in areas near the runway will perceive vortices, particularly in calm weather, by brief increases in air movement and their characteristic noise.

11. The study clarifies that liability for damage or injury caused by the operation of an aircraft lies with the aircraft owner. Because it is usually difficult or impossible for a property owner to identify the aircraft which generated a damaging vortex, and so claim under property insurance, most airports where incidents are common have voluntarily established schemes to repair damage at no cost to the owner. In most cases this includes reinforcement of the roof to resist further strikes. All these schemes are limited to private residential property.

12. The study concludes with proposals for implementation of a vortex damage repair scheme at LCY, and provides details of schemes in place at other airports. It is proposed that claimants for roof damage are offered repair and strengthening of the roof against future strikes. Pre-emptive or blanket roof replacement is not considered appropriate at the anticipated low rate of incidence.

13. The need for publicity about the scheme is emphasised, both to facilitate access for claimants and to explain the causes and nature of vortices to reassure the general public. The need for independence in assessing claims is also noted. Because structural damage, although relatively minor in most cases, has some potential to lead to injury, LCY may wish to consider the inclusion of personal injury and third party cover in any scheme.

14. Any risk of damage will be reduced if the number of susceptible roofs in the area is minimised. The London Boroughs of Newham and Greenwich might consider conditioning future development consents in a defined area, or issuing advisories, drawing attention to the potential for damage and the advantages of using vortex-resistant roof coverings.

1 Introduction

1.1 Scope

1.1.1 This report details work commissioned by London City Airport (LCY), the scope of which was set out in an invitation to Halcrow Group Ltd issued on 02.11.09. The purpose of this study is to satisfy obligations in the Section 106 Agreement (S106) which accompanies the planning permission (07/01510/VAR) granted by the London Borough of Newham (LBN) on 9 July 2009 for an increase in permitted annual aircraft movements to 120,000. The S106 requires London City Airport (LCY) to submit a Wake Turbulence Study to LBN by 8 January 2011 for approval. The Study is defined in the S106 as:

> **"an investigation into any damage arising to buildings surrounding the Airport as a result of Wake Turbulence, together with recommendations (to the extent necessary) to address such damage or the risk of such damage and procedures that should be adopted in order to handle any claims for compensation arising from such damage" (Definitions, p.18)**

LBN's requirements were discussed further in a subsequent telephone conversation between Halcrow and LBN's representative (see Appendix A). This confirmed that, at that time, there was no record of wake vortex damage at LCY and that only one expression of concern about this issue had been received. LBN's expectations of this study were discussed and confirmed as centring on assessment of the extent of any vortex problem and the measures should be put in place to deal with any future complaints or damage.

1.2 Experience

The Halcrow Group has provided consultancy services relating to wake vortex risk on a number of projects for BAA. These include; Third Party Risk inputs to the EIA for the proposed second runway at Stansted; Third Party Risk scoping studies for the Gatwick North Terminal Expansion; and, currently, Third Party Risk planning and EIA inputs to BAA's proposals for a third runway at Heathrow.

1.3 Approach

1.2.1 Experience indicates that the extent to which wake vortex damage is likely to be seen around an airport is highly site-specific. In broad terms, vortex damage incidence is related to the number of aircraft movements, aircraft types operating, topography, building types and weather. With so many variables involved, the situation is obviously complex and there is no established theoretical or practical methodology for predicting damage incidence at any given airport.

1.2.2 There exists a substantial amount of research information – mainly into vortex generation but also some into damage effects – and experience of damage and remediation from such sites as Heathrow. Our approach has therefore been based on assembling relevant and usable research and incidence data, and using our expertise and experience to synthesise from it a robust assessment of likely damage incidence. Based on the level of risk, we have considered which of the available approaches to mitigation and claim management would be most appropriate to this case.

1.4 Sources

1.3.1 The information used in this study has been gathered from sources in the public domain. Vortex damage is a sensitive issue and, while most or all airport operators where the problem exists have accepted the responsibility for compensation, they are generally unwilling to publish detailed information on incidence or location. Nor is there any statutory requirement for them to do so.

1.3.2 The material used is taken, therefore, from published research work, planning inquiry records, and various internet sources. References are given throughout.

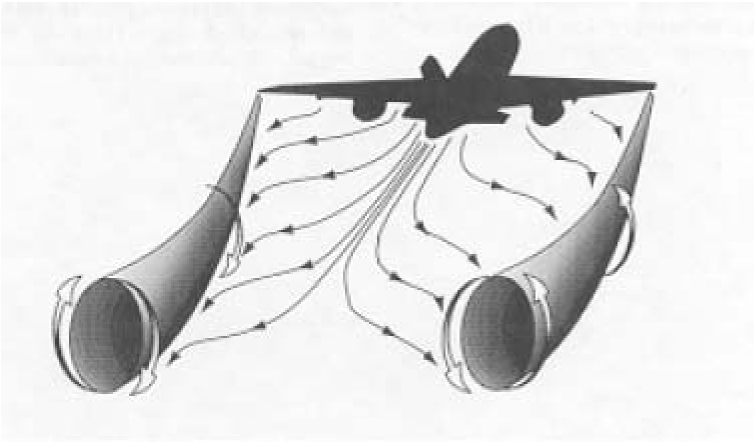
2 Causes of Wake Vortex

2.1 Vortex Generation

2.1.1 In generating the lift forces necessary to allow an aircraft to fly, its wings generate movements in the volume of air through which the aircraft passes. The most significant of these are spiralling movements of air flowing from each wingtip. These pairs of wake vortices trail behind the aircraft and tend to descend as they rotate, eventually dissipating into the general air turbulence. The picture below shows a wingtip vortex (in this case from a light aircraft during vortex research) visualised by injecting coloured smoke, and the sense of rotation of a pair of vortices is indicated in the diagram that follows it.

Figure 2-1: Wake Vortices Visualised for Research Purposes

Figure 2-2: Rotation of Wake Vortices



Source: Ref 1

2.1.2 The tangential speed of the air circulating in the vortex can be very high relative to the surrounding air and air pressure within the vortex is reduced below atmospheric. Vortex diameter is relatively small at the point of generation and increases over time.

2.1.3 Vortices are an unavoidable consequence of aerodynamic lift and are generated by all aircraft in all phases of flight. Their existence has been recognised since the earliest days of flight but became a safety issue with the introduction of large, wide-bodied aircraft. If a following aircraft flies into a vortex generated by a large aircraft, aerodynamic forces can upset its stability. If the following aircraft is a small one, the consequences of an upset can be serious. A great deal of research effort has subsequently gone in to describing the generation, movement and decay of wake vortices. Aircraft manufacturers have sought ways to reduce vortex generation through wing design, but most research has been into operational measures to reduce the likelihood of aircraft flying into vortices.

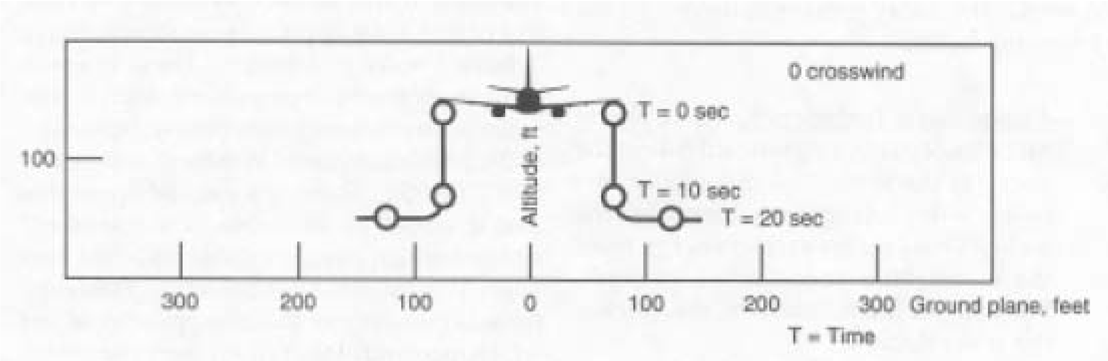
2.1.4 It is believed the issue of damage to buildings first arose at Heathrow as larger aircraft came into service there. Research into this aspect of aircraft vortices has focused on Heathrow, as the UK airport with by far the highest incidence of property damage due to vortex strikes.

2.1.5 Property damage occurs when a vortex generated by an aircraft at low altitude survives long enough to reach the ground, and with sufficient remaining air velocity to generate damaging suction forces. While all aircraft generate vortices, only a very small proportion reach ground level with enough energy left to cause damage.

2.2 *Vortex Behaviour*

2.2.1 Vortices are generated at the aircraft wingtips as they move through the air and, as the aircraft moves on, the vortex pair is left behind and immediately begins to descend at several hundred feet per minute. If generated at altitude, the vortices from a large aircraft will stop descending after falling about 500 to 900feet. If the aircraft was at relatively low altitude, the vortices will fall to about 100 to 200 feet above the ground, where they will stop descending and begin to separate laterally. The following diagram illustrates this low-altitude behaviour and shows the approximate timings of vortex movement.

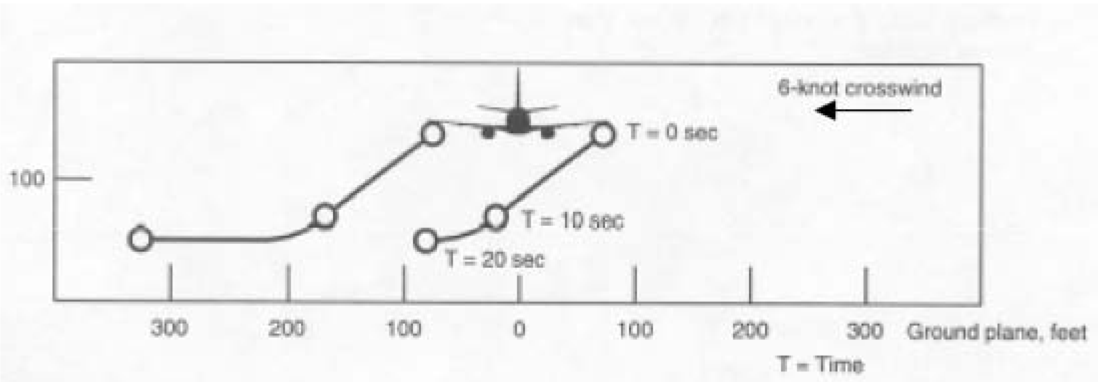
Figure 2-3: Movement of Vortices from a Low-flying Large Aircraft



Source: Ref 1

If there is a crosswind component, the vortices will drift laterally, as illustrated below for a 6kt wind.

Figure 2-4: Lateral Drift of Vortices in a Crosswind



2.2.2 Throughout its descent and drift the energy of the vortex will gradually increase in diameter and its air velocities will reduce, and it will dissipate, through friction and interaction with the background turbulence of the air. Strong winds and turbulence caused by the wind blowing over ground features tend to accelerate vortex decay.

2.2.3 Whether a vortex persists for sufficient time and with sufficient energy to cause damage at or near ground level depends on its energy at generation, the height at which it originated and weather conditions. A ground level vortex strike is more likely to occur and be damaging when conditions are still and the aircraft low. The initial strength of the vortex is proportional to the aircraft's weight but reduces with aircraft speed and wingspan. The strongest vortices are therefore generated by heavy aircraft flying at low speed, as during approach and take-off.

2.2.4 The use of lift-enhancing wing devices such as flaps and slats can affect vortex generation. Extended flaps generate their own vortices, which interact with those from the wingtips, which tends to increase turbulence and encourage dissipation of the vortices.

2.2.5 Increasing numbers of aircraft types today are fitted with winglets, including many operating at LCY, such as the A318, Embraer 170 and 190. The primary function of these wingtip devices is to improve fuel economy by reducing the drag induced at the wingtip. For this reason they are designed to have their optimum effect at cruise speeds. Winglets have the secondary effect of reducing the intensity of wingtip vortices, but the magnitude of this effect at landing speeds is difficult to quantify. It is reasonable to assume, however, that the vortices generated by winglet-equipped aircraft will be of lesser intensity, and therefore less likely to cause damage at ground level, than those from equivalent aircraft not so equipped.

3 Effects of Wake Vortex

3.1 Incidence

3.1.1 To consider the potential effects of wake vortex it is necessary to look at airports where vortex damage is a known problem and which therefore provide a body of data. In making any comparisons with other airports it should be kept in mind that LCY has many features that differentiate it from them. First, there has been only one confirmed case of vortex damage at LCY. Second, the mix of aircraft types in use at LCY is narrow and in the lower range of public transport aircraft size; the largest being the A318. Third, aircraft approaching LCY do so on a much steeper glide slope than is used at any other UK airport, which means the vortices they generate have more time to decay before reaching the ground.

3.1.2 The largest single concentration of vortex damage incidence, far in excess of the numbers seen at any other site, is at the UK's busiest airport; Heathrow. A scheme to repair and replace roofs in residential areas off the runway ends has been operated by BAA at Heathrow since 1993. Numbers affected are not available but one source (Ref 2; 5.1) states a figure in 1998, after five years of the Heathrow scheme, of 1,741 properties re-roofed. Current literature relating to the Heathrow repair scheme claims an incidence of less than 0.01% of aircraft movements, while Birmingham puts incidence at 0.005%.

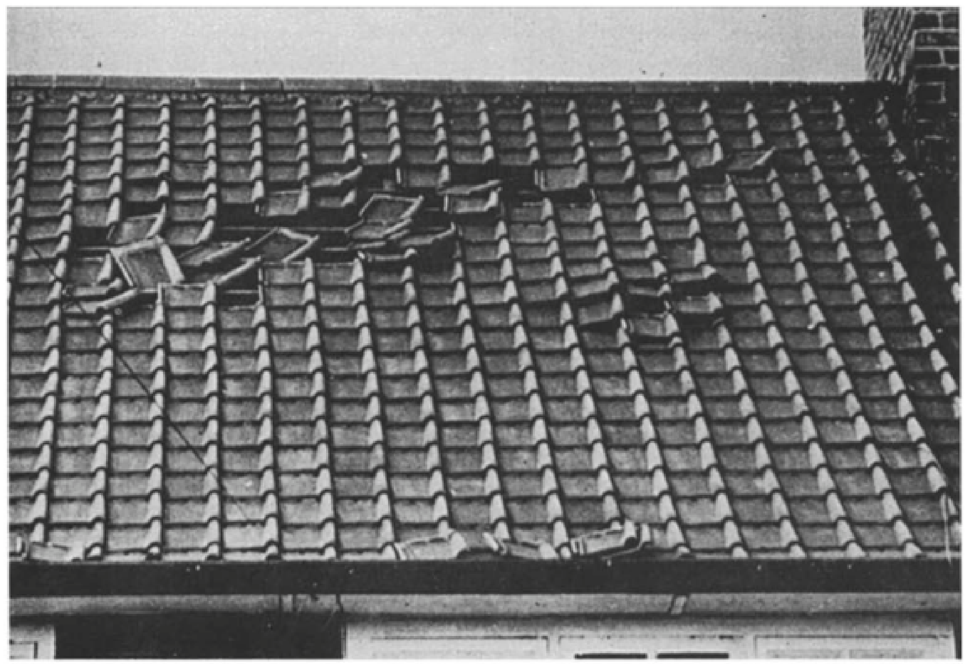
3.1.3 Heathrow is not the only airport to experience building damage due to vortex strike. Property repair schemes have been set up at Birmingham and Manchester Airports, where about 250 and 500 properties respectively have been re-roofed. A small number of cases have been dealt with at Stansted. A small number of cases have been reported at Southampton Airport (14 cases up to 2008), and a single case of damage occurred at Belfast City Airport in 2009. The one confirmed case of damage due to vortex strike at London City Airport was reported in May 2010.

3.1.4 Because all aircraft generate vortices an increase in the number of aircraft movements overflying an area will tend, all other factors being equal, to increase the likelihood of vortex strike over a given period.

3.2 Damage Characteristics

3.2.1 The great majority of vortex damage incidents involve the disturbance or complete displacement of tiles or slates on the roofs of traditionally-constructed houses. As distinct from 'normal' damage due to high winds, vortex damage is characterised by its pattern and location on a roof. The image below shows a typical case.

Figure 3-3: Typical Roof Vortex Damage



Source: Ref 3

3.2.2 The disturbance of tiles is confined to the central area of the roof, as opposed to the edge or ridge damage usually seen after high winds. Tiles are lifted and rotated, with some completely displaced. In some cases tiles will slide down the roof, as here, and may fall off completely, causing damage to other parts of the building, such as conservatories or garages. Some incidents have resulted in consequential damage to cars and other property by falling debris.

3.2.3 A tile or slate roof can be made proof against vortex damage by fastening the individual elements down to the roof framework by means of purpose-designed clips or nailing systems. This prevents the initial lifting of the tiles by vortex suction and preserves the interlock between elements.

3.2.4 As far as can be ascertained from publicly available information (which evidently is limited by commercial confidentiality and the sensitivity of the issue) there have been no cases of personal injury due directly to vortex strike or to falling debris caused by a strike.

3.3 Wind Speed and Other Effects

3.3.1 The speed of air movement in a vortex descending to ground level could cause discomfort to or physical disturbance of people out of doors, for example walking or cycling. If the vortex component adds to a significant natural wind speed its disturbing effect could be amplified. We have found no evidence, at LCY or elsewhere, of such effects causing sufficient disturbance to give rise to complaint to an airport operator. We have found no evidence, at LCY or elsewhere, of vortices leading to personal harm, by either immediate cause or any long-term effect.

3.3.2 If the relative high rotational speed and coherence of vortices are preserved long enough to reach ground level, a characteristic noise may be perceived. This may be described as a whine or whistle accompanying the increased air movement, which lasts up to a few seconds. There is no evidence of research into whether such noise causes annoyance to people.

4 Risk

4.1 Current Situation

4.1.1 There has been one case of damage to a building near LCY as a result of aircraft wake vortex. One expression of concern about possible damage, disturbance and noise due to vortices has been received by LCY [redacted], 02.07.08 relating to West Thamesmead Riverside).

4.1.2 The one case reported at LCY, in May 2010, was of damage to the roof of an office and shower block in the marina at Gallions Point, immediately east of the threshold of Runway 27. The location is illustrated in Figure 4.1 and is approximately 750m from the threshold and about 20m right of centreline.

Figure 4.1: Damaged Building in Marina

4.1.3 The roof of this single-storey building is of traditional tiled construction and, as shown in Figure 4.2, the damage appears to be typical of that caused by a wake vortex strike. The disturbance of tiles appears to be confined to the aspect of the roof closest and parallel to the extended runway centreline. This roof has in fact suffered more than one strike. As shown in Figure 4.3, there are two distinct areas of damage. There is evidence (from another, copyright source) that the damage area at the east end of the roof, on the right in Figure 4.3, pre-dates the damage reported in May 2010. Although the building is in almost daily use, the disturbance to the roof tiles is slight and therefore had not been noticed until the detailed examination in May 2010.

Figure 4.2: Main Area of Damage to Roof of Marina Building

Figure 4.3: Areas of Damage

4.1.4 Given the length of time that LCY has been operating and this evidence of only one or two strikes, the current level of risk of vortex damage must be considered low. As the following sections show, however, a historical absence or very low incidence of damage does not guarantee future freedom from such incidents. There is currently little development close to LCY of the type of property susceptible to vortex damage. It is possible that potentially damaging vortex strikes do occur here but have no discerned effect because much of the area is river, docks or undeveloped land.

4.1.5 We attempt below to assess the likely future level of vortex strikes around LCY and their potential to cause property damage. Potential effects on people are also considered.

4.2 Components of Risk

4.2.1 The risk of damage being caused by aircraft wake vortex is made up of two elements;

- the probability of a vortex arriving at or near ground level with adequate energy to cause damage, and
- the presence of buildings susceptible to damage by the vortex.

4.2.2 These two elements are, obviously, connected, in that the energy needed to cause damage will depend on the strength or integrity of the structure concerned. Virtually all cases of damage recorded, at Heathrow and elsewhere, relate to the displacement of roof tiles or slates. Disturbance of tiles and slates requires relatively low forces because each component of the roof structure is relatively light and not strongly fixed to the underlying structure. Typically, slates or tiles are nailed at one or two points and resistance to natural wind forces relies substantially on the interlock between individual tiles. Research has shown (Ref 3; 7) that, because strong vortex forces act only over a very small area, roofing elements larger than about $1m^2$ or sheet-type roof systems will not be affected.

4.2.3 If land beneath runway approaches is undeveloped, or if development is of a non-susceptible nature, damage by vortex is highly unlikely. Non-susceptible development includes residential development that does not have traditional tiled or slate roofing, and industrial or commercial buildings roofed with large-component or sheet roof systems. Such roof systems are made of heavy individual components or light metal or composite sheeting, which are strongly attached to the roof framework.

4.2.4 Whether development is present or not, there remains the possibility of disturbance of people by increased air speed or noise.

4.2.5 Our assessment of risk therefore focuses on the likelihood at LCY of vortices reaching the ground with sufficient remaining energy to present a risk of damage or disturbance. This considers the following factors:

- Vortex generation and strength
- Vortex decay
- Weather
- Location.

4.3 Vortex Generation and Strength

4.3.1 All aircraft in flight generate vortices. The strength or intensity of the vortex is in simple terms proportional to the weight of the aircraft and inversely proportional to its wingspan and its airspeed. In broad terms, the heavier and slower the aircraft, the stronger the vortex. Aircraft are moving at their slowest on approach to landing, so the strongest vortices are likely to be seen when aircraft are descending close to the ground.

4.3.2 Evidence indicates that the very great majority of damaging strikes occur on approach to landing. There is some evidence that go-arounds can lead to strikes, as aircraft are likely to be at low altitude and in a 'clean' wing configuration after aborting a landing, but the number of such incidents is likely to be very small compared to landing cases.

4.3.3 Although aircraft tend to be at their heaviest on take-off, because of high fuel loads, speeds are also higher, reducing vortex strength. Vortex strength is also affected by the use of lift-enhancing wing devices such as flaps and slats. These are almost invariably used on landing and they produce their own vortices, which can interact with those from the wingtips to introduce turbulence and reduce the coherence of the resulting vortices. This effect tends to reduce vortex strength and accelerate decay. Deployment of the landing gear will also increase the turbulence of the air behind the aircraft, further contributing to vortex decay (Ref 4; p11). Early research into vortex generation using actual flight tests (e.g. Ref 5; p46) showed that aircraft in a 'clean' configuration, without flaps and with landing gear stowed, generate the most coherent and long-lasting vortices.

4.3.4 An indicator of the energy contained in a vortex is the quantity referred to as 'circulation' (Γ). Also, the tangential velocity of the air circulating in the vortex is an indicator of its potential damaging power. At the point of generation the circulation of vortices from aircraft of different sizes can be compared, at typical approach speeds (see Appendix B for details). Tangential air velocity at a given diameter can similarly be compared.

Table 4.1: Vortex Circulation and Velocities

Aircraft	**Max landing weight Kg**	**Vortex circulation m^2/s**	**Tangential air velocity at 5m dia. Knots**
B747-400	285,764	637	78
Avro-RJ85	38,556	267	33

4.3.5 It is generally believed that damaging strikes are caused only by large, wide-bodied aircraft. A correlation between vortex strikes and wide-body numbers has been demonstrated in the past at Heathrow (Ref 6). However, evidence of strikes at airports where such aircraft do not operate, such as Southampton, Belfast City, and recently at LCY, indicates that smaller aircraft can cause damaging strikes in certain conditions. The figures shown above support an assumption that smaller aircraft produce vortices with substantially lower energies and air velocities, which are less likely to persist long enough to reach the ground. It is therefore reasonable to suggest that the smaller the aircraft operating at an airport, the lower the probability of damaging vortex strikes.

4.3.6 In this context, a connection might be imputed between the introduction to LCY of the current largest aircraft type, the A318, in September 2009 and the first report of vortex damage in early 2010. It should be stressed that there is no evidence of this or any other specific aircraft type being the source of the damaging vortex in that case. As the following sections indicate, there are many variables at play in the generation and characteristics of vortices and in whether they cause damage at any given location. The available data does not support any deterministic relationship between damage incidence and any one aircraft type, at LCY or any other airport.

4.4 Vortex Decay

4.4.1 As soon as they are generated at the aircraft wingtip, vortices begin to decay. That is, their energy begins to dissipate, their diameter to increase and their internal air velocities to reduce. This decay has two primary causes; friction or shear forces between the moving air in the vortex and the surrounding air, and disruption by the natural turbulence of the atmosphere.

4.4.2 In broad terms, atmospheric turbulence is caused by the wind blowing over the natural roughness of the ground, i.e. terrain, trees, buildings etc. It is present at almost any wind speed and acts in all directions; with the wind, at right angles to it and vertically.

4.4.3 Much research effort has gone into the investigation of vortex decay and movement, because of its importance in the avoidance of aircraft upset. Research sources appear to differ considerably in their conclusions on the 'life' of vortices, i.e. the time between their generation and their disappearance into the general background turbulence. Their rate of descent to ground level is also the subject of differing views. The research at Heathrow, where a house roof was instrumented to record vortex strikes (Ref 3), indicated that vortices were arriving at the test site about 8-12 seconds after generation. Given the location of the house some 1,400m from the threshold of Runway 27R, this indicates average vortex descent speeds of 1,500 to 2,300 ft/min. This is considerably faster than the speeds indicated in Reference 1 (see Figure 2.3). Other sources (e.g. Ref 4) indicate vortex lives measured in minutes and relatively slow descent rates. This work also notes that any degree of atmospheric turbulence will promote vortex decay and reduce the rate of descent, and that vertical temperature gradients in the air may significantly prolong vortex life.

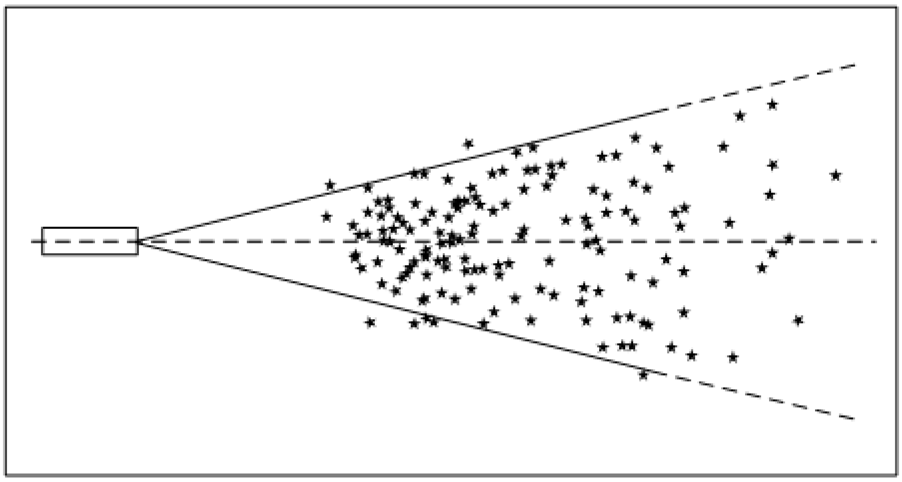
4.5 Weather

4.5.1 There is evidence (Ref 3; 2.1) that ambient air temperature, atmospheric pressure and humidity have little or no direct effect on vortex strength or life. This and other research establishes, however, a correlation between ambient wind speed and the incidence of ground level vortex strikes and damage. In the Heathrow study, over 70% of damaging strikes in a 2-year period were found to have occurred in wind speeds below 10kt (5m/s). During the 12-month instrumented roof experiment only one vortex strike occurred at the site in an ambient wind speed above 19.5kt (10m/s). It is clear that low wind speeds and particularly still conditions tend to prolong vortex life and allow time for more vortices with higher energies to reach ground level.

4.6 Location

4.6.1 The closer a property lies to a runway the less time is required for a vortex from an arriving or departing aircraft to descend to ground level and the greater its retained energy. In general terms, therefore, the more likely the property is to sustain damage. However, records show that damaging vortex strikes can cover a wide range of distance from the runway threshold and lateral distance from the extended centreline. It appears, as a result, that there is a 'funnelling' effect on damaging strike distribution; a high proportion of incidents occur in a relatively narrow area close to the runway, with fewer incidents spread over an area widening with distance from the runway, as illustrated in Figure 4.4. At Heathrow, 80% of damage cases recorded between 1988 and 1991 occurred within 2.1km of the runway end (Ref 2; 2.2). Other evidence (Ref 6; 3) indicates the very great majority of all Heathrow strikes up to 1990 falling within 4km.

Figure 4.4: Illustrative Typical Distribution of Damaging Strikes

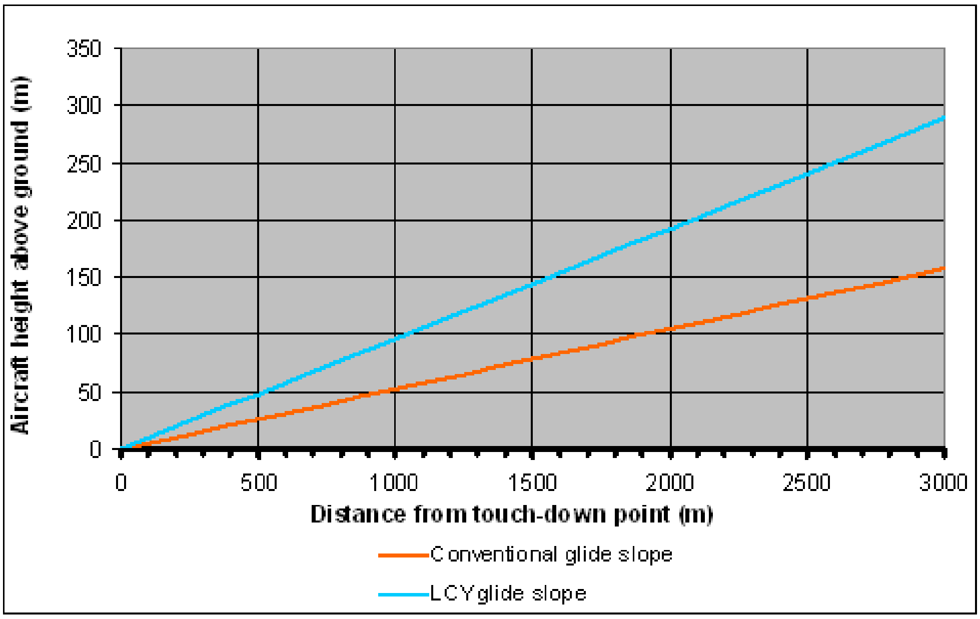


4.6.2 The standard glide path for landing aircraft is set at 30, descending to the touch-down point (not the threshold). At Heathrow, for example, this puts arriving aircraft about 70m above the houses closest to Runway 27L, and about 250m above the centre of Hounslow. The density of residential development close to Heathrow's Runway 27R is illustrated in Figure 4.5.

Figure 4.5: Development on Approach to Heathrow 27R

4.6.3 The glide path at LCY is set at 5.5⁰. At the same distance from touch-down, therefore, aircraft landing there will be significantly higher above properties, as shown in Figure 4.6.

Figure 4.6: Comparison of Aircraft Heights on Approach



4.6.4 At both Heathrow and LCY surrounding land is at approximately the same level as the runways. If there is high ground beneath an approach track, any property there is more likely to receive vortex strikes, as the time for a vortex to descend from the flight path to the ground is reduced. This is the case on the approach to Runway

02 at Southampton, where a number of damaging strikes have occurred in an area some 40m above runway level, or about 50m below the glide slope.

4.6.5 Vortices drift laterally in a crosswind, so strikes may occur some distance to either side of the extended centreline of the runway. Vortices moving laterally at low level will tend to decay rapidly in the more disturbed air close to the ground. This disturbed air close to ground features may also account for some buildings being struck relatively frequently while others nearby are not struck at all. Local features such as higher buildings, trees etc. may effectively shield some areas by causing rapid vortex decay (Ref 7; 1.3)

4.7 Strike Incidence

4.7.1 The available vortex research provides a basis for qualitative assessment of the likelihood of damaging vortices occurring at a given location, it does not support quantitative calculation of risk. While vortex characteristics at the point of generation may be calculated with some reliability, descent speeds, decay times and residual energy are subject to too many variables to allow prediction of when and where damaging vortices will come to ground.

4.7.2 Any estimate of future strike risk must rely on past experience at airports with a record of vortex damage, although the research may be useful in assessing the effect of site-specific factors such as terrain. As there have been only two strikes at LCY, we have to rely on available data from airports with a record of damage. As already noted, the data available - particularly recent data - is limited due to commercial confidentiality, but Table 4.2 summarises what can be found.

Table 4.2: Historical Vortex Incidence

Airport	Vortex repair scheme	Incidence of damage	Aircraft traffic volume, annual movements approx.	Sources of data
Heathrow	Established 1974. All verified cases repaired and roof strengthened. All roofs replaced in streets where > 65% houses struck.	Current level unknown. Up to 1998, 1,741 properties re-roofed. 714 in 27 months to March 1991 = av. 317/yr.	470,000	Ref 3; 2.1
Stansted	Ad hoc scheme. All verified cases are repaired.	8 damage strikes between August 03 and August 07	170,000	Ref 8
Birmingham	Properties are only re-roofed if damaged.	250 properties re-roofed as at 200, 117 at Sept 2006. So 133 in 2 yrs 2007, 2008. Kitts Green and Tile Cross areas?	102,000	Press Ref 9, 10
Manchester	Scheme areas are defined under approaches to 05L, 05R and 23R. All verified cases are repaired, but re-roofing only in defined scheme areas.	ACC Report 2007 quotes 500 roofs replaced. Only 23R is significantly built-up.	191,000	Ref 11
Edinburgh	All verified cases are repaired.	No data available.	113,000	ACC Ref 12
Southampton	Ad hoc scheme. All verified cases are repaired.	14 events between 1998-2008, 3 in 2008. Bitterne Park area identified.	44,000	ACC Ref 13, 14, 15
Belfast City	No scheme	1 incident reported; Parkgate Crescent, August 2009	40,000	Ref 16
LCY	No scheme	2 incidents (only one reported) Gallions Point Marina, May 2010	70,000	LCY

4.7.3 As can be seen, little of this data is entirely up to date and substantial approximations have been necessary. No data on numbers of incidents can be found for Edinburgh so no estimate of incidence per arrival is possible there.

4.7.4 Using the data in the table, broad estimates can be made, for each airport, of the rate of damaging strikes expressed per arrival Aircraft Movement (Table 4.3). In most of these the estimate is based on the number of strikes in a known period. For Belfast City and LCY, with only one or two incidents, the rate is assessed on the basis of 10 years' traffic, using two strikes for LCY. Estimates are based on the number of landings (see 4.3.5) using the approach beneath which all or the majority of strikes occurred.

Table 4.3: Estimated Damaging Strikes per Arrival

Airport	Damaging strikes per 1000 Arrival ATMs
Heathrow	2.30
Stansted	0.02
Birmingham	2.38
Manchester	0.89
Edinburgh	No data
Southampton	0.19
Belfast City	0.04
LCY	0.01

4.7.5 As can be seen, the range of strike rates is extremely wide. Heathrow traffic contains a very high proportion of large, wide-bodied aircraft (approximately 34% in 2006). The Stansted rate is very low, but residential development beneath the approaches there is extremely sparse.

4.7.6 Birmingham and Manchester traffic will include a much lower proportion of wide-bodied aircraft but actual numbers are not known. The Birmingham rate appears inordinately high, and we believe the source of the numbers and periods used in the estimate is unreliable. The airport claims that 0.005% of flights (or 0.1 strikes per 1000 arrivals) cause vortex damage. The Birmingham rate has therefore been discounted.

4.7.7 Neither Southampton nor Belfast City handle large aircraft, as their runways are too short, with take-off runs of 1,650m and 1,767m respectively. Traffic at both is confined to a maximum aircraft size of B737 and equivalents, and includes a high proportion of turboprops. As such, these two airports are probably the nearest equivalents to LCY, which has a take-off run of 1,199m and where the largest aircraft is the A318. The Belfast rate is based on a single reported case of damage in a period of scheduled operations there of over 20 years.

4.7.8 The 14 Southampton cases are believed all to have occurred in an area of high ground beneath the south approach. Property in this area is up to 40m above runway level, which will tend to substantially reduce vortex descent and decay times.

4.7.9 Records indicate that vortex damage is a significant and ongoing issue at Heathrow, Stansted, Birmingham and Manchester, almost certainly attributable to both traffic growth and changes in aircraft fleets. Incidence at Southampton continued over a period of some years but has not persisted; it may have been due to operations of a particular aircraft type but no evidence is available to determine this. With only one or two incidents recorded it is not possible in the Belfast City or LCY cases to establish any airport-specific relationship between damage incidence and changes in traffic or other conditions. We have therefore projected the strike rates for all these airports onto the future situation at LCY, and applied knowledge of the similarities and differences between these airport operations to arrive at a likely future rate of incidence there.

4.7.10 The strike rate estimates need to be adjusted to take account of the degree of residential development of the land under the approach. Only traditional housing is significantly susceptible to damage. Potentially damaging strikes may occur but not be recorded because they fall on open land or areas of development that are not susceptible to damage, such as industrial or commercial zones. Rates have been adjusted in this way for the current land use situation around LCY, much of which consists of docks and the River Thames, and for a future worst case which assumes all currently undeveloped land beneath the approaches (excluding that within the PSZs) is used for traditional-style housing development. Details of the analyses are given in Appendix C.

4.7.11 The numbers of damaging strikes that might be expected in a year if these adjusted strike rates occurred at LCY are shown in Table 4.4. These figures assume a future LCY traffic volume of 120,000 Aircraft Movements/year.

Table 4.4: Theoretical Annual Damaging Strikes Around LCY for Range of Estimated Strike Rates

Strike rate based on...	**Theoretical annual damaging strikes based on..**	
	current level of development around LCY	potential max. residential development around LCY
Heathrow	78	139
Manchester	54	96
Stansted	20	35
Southampton	7	13
Belfast City	1.5	2.6
LCY	0.5	0.9

4.7.12 Application of the Heathrow strike rates to LCY would be unrealistic. While the available data does not support a definitive conclusion, vortex research and evidence from Heathrow (Ref 6; 7) clearly indicate that a very high proportion of damaging strikes are attributable to large, wide-bodied aircraft, which will not operate at LCY. Empirical analysis of vortex generation and strength supports this view. This will also be a factor in the Manchester rates, the data for which is, in any case, of uncertain accuracy. Stansted Airport has relatively few wide-body aircraft operating, but the low number of damage cases there and the sparseness of housing make extrapolation of Stansted rates to LCY unreliable.

4.7.13 The number of strikes at Southampton, Belfast City and LCY - albeit low at 17 in total - shows that smaller aircraft can and do cause vortex damage. The incidence at Southampton is almost certainly increased by the high terrain beneath the approach, but we believe this range of rates provides the only reasonable basis for assessing <u>potential</u> vortex damage incidence at LCY.

4.7.14 The terrain on both approaches to LCY is flat and aircraft approach on a glide slope of 5.5^0. The descent-to-ground time at any point of a vortex generated by an aircraft approaching LCY would be almost twice that seen at the other airports, allowing a corresponding dissipation of vortex energy. The one damage location at LCY is very close to the runway and there have been no reports of damage in developed areas further out. For these reasons, we believe the strike rates should be factored downwards to be applicable to LCY. We think it reasonable to assume a worst case, potential damage rate, with the current level of surrounding development at LCY, of 2 or 3 strikes at 120,000 aircraft movements per year.

4.7.15 If all the currently undeveloped land along the approaches was to be developed with housing, this rate could be expected to increase. Currently, only about 15% of residential development under the LCY approaches is single-family houses with traditional roofing (see Figure 4.4). The majority of this is in the Thamesmead area, over 2Km from the runway. Residential development would not be permitted in the PSZs. Furthermore, given the type of development recently seen in this area, it appears unlikely that future development would be single-family homes with traditional tiled or slated roofing. Significant growth in damage incidence due to development therefore appears unlikely.

Figure 4.4: Development on the Approaches to LCY

4.8 Disturbance Due to Wind Speeds

4.7.1 The generally accepted criteria for assessing the effect of wind speeds on people out in the open (the Lawson criteria, see Appendix D for details) indicate that conditions should be considered unsafe for the general public if a mean hourly wind speed of 15m/s (about 34mph, 29kt) is exceeded once per year. A wind speed of 15m/s corresponds to 7 on the Beaufort Scale, indicating a near gale. Weather records from LCY (Ref 17) indicate that, on the airport itself, natural wind speed is likely to exceed this value only about once per year.

4.7.2 These criteria are mainly used for assessing wind environments in areas around buildings and relate to sustained, natural wind speeds acting over a wide area. Any contribution to the wind speeds experienced locally from aircraft vortices will be very short-lived and act over a very small area. Although very high air speeds are generated in the initial vortex, they reduce rapidly as it expands and descends. When a vortex reaches the naturally turbulent zone at ground level and around buildings or other features, it rapidly loses its coherence and the air velocities within it fall rapidly to those of the surrounding air.

4.7.3 The research at Heathrow (Ref 3) showed that vortices striking roofs decayed completely within about one second or less. Air speeds within these vortices did, however, in many cases exceeded 15m/s, albeit over very short distances. A vortex is likely to require less residual energy to be perceived by a person at ground level than would be required to cause roof damage. Perceptible vortices can therefore be expected to occur much more often than damaging vortices, but the likelihood of a vortex retaining sufficient air speed for long enough to physically disturb a person appears very low.

4.7.4 People in the open are therefore likely to notice vortices but are very unlikely to be at risk from them. As with damaging vortices, the frequency and strength of perceptible vortices will be greater in areas closer to the runway and when calm weather conditions prevail.

4.9 Noise

4.8.1 No evidence was found that would allow vortex air speeds to be related to noise generation. It is known that aircraft vortices can produce a perceptible and characteristic noise but, as far as can be ascertained, there are no established criteria for relating such noise to disturbance or nuisance.

4.8.2 It is likely that noise will be a component of the perception of those vortices that do reach ground level in areas where people are out in the open, but any effect of such perception must remain highly subjective.

4.10 Risk Summary

4.9.1 The very low incidence of vortex damage to date around LCY is a good indicator of likely future incidence. The building damaged is very close to the runway threshold and almost directly beneath the approach centreline. It appears to be one of only two buildings of traditional roof construction within a kilometre of either runway end. A significant propensity for strong vortices to reach ground level over a wide area would be expected to have manifested itself in at least a few incidents in the existing areas of traditional housing further out along the extended centreline. However, those areas are relatively remote from the runway; future development of this sort closer to the runway ends might increase incidence.

4.9.2 Studies lead us to the view that LCY's characteristics - aircraft mix, glide-slope angle, surrounding land use and type of development - are likely to keep any future incidence of vortex damage to a low level.

4.9.3 It is likely that people in the open below the approaches will perceive vortices through air movement and sound, particularly if they are in areas close to the runway ends, and when weather conditions are calm. Such vortices are very unlikely to cause physical disturbance and any annoyance arising from their perception is a subjective matter.

5 Mitigation and Compensation

5.1 Liability

5.1.1 The responsibility for any damage or injury resulting from the operation of an aircraft rests with the aircraft owner. Section 76 of the Civil Aviation Act 1982 deals with liability of aircraft in respect of trespass, nuisance and surface damage. Section 76(2) provides that:

> "Where material loss or damage is caused to any person or property on land or water by, or by a person in, or an article, animal or person falling from an aircraft while in flight, taking off or landing, then unless the loss or damage was caused or contributed to by the negligence of the person by whom it was suffered, damages in respect of the loss or damage shall be recoverable without proof of negligence or intention or other cause of action, as if the loss or damage had been caused by the wilful act, neglect or default of the owner of the aircraft."

5.1.2 On this basis an airport operator is not liable for damage or injury resulting from a vortex strike caused by an aircraft landing or taking off. However, because of the obvious difficulty a property owner has in identifying the aircraft involved, airports where vortex damage occurs have tended to take responsibility for property repairs and roof strengthening, without accepting liability for the damage. Information published by all airports offering a repair scheme clearly makes this distinction.

5.1.3 As far as can be ascertained no airport operator in the UK has had to deal with any claim for personal injury arising from a vortex strike. The costs entailed in such a claim are, clearly, likely to be higher than those arising from property damage. As it is clear where liability rests under the Act, the airport's insurers are unlikely to be willing to cover such a claim. However, the precise time of occurrence of a personal injury incident is much more likely to be identifiable than that of property damage (which can occur when the property is unattended), making identification of the responsible aircraft a reasonable possibility. It is understood that the Heathrow vortex insurance scheme includes limited third party liability and personal injury cover (Ref 2; 3.2).

5.2 Compensation Schemes

5.2.1 Published details of vortex damage compensation schemes, where these are known to be in place, are reproduced at Appendix E. Under the Heathrow scheme (and it is believed similar arrangements apply elsewhere) reports of vortex damage are initially examined by an independent assessor to verify cause and extent. The assessor is usually a building surveyor. Repairs are then carried out by a term contractor, selected by competitive tender. At airports where damage is infrequent repair work is likely to be let on an *ad hoc* basis.

5.2.2 It is understood that all schemes apply only to residential property, not to commercial or industrial premises. In the Heathrow, Birmingham and Manchester cases, the scheme provides for the strengthening of any roofs that are repaired, to resist further strikes. The methods used to do this follow guidelines set out following research by the Building Research Establishment (Ref 18). Strengthening generally consists of installing new tiles retained by special clips and/or additional nailing.

5.2.3 The Manchester scheme includes the concept of 'protected' areas. Damaged properties within a defined area off the end of each runway are offered a vortex resistant replacement roof. Outside these areas, damaged properties are repaired to their original specification. A very similar scheme is operated at Birmingham.

5.2.4 In the Heathrow case, all verified claims result in immediate repairs followed up by roof strengthening (presumably when sufficient cases have accumulated to justify mobilisation of a contractor). Heathrow also designates 'blanket zones'; when 65% of properties on a road have suffered damage, all properties on that road become eligible for roof strengthening. It is believed that this policy has resulted in a steady reduction in the incidence of damage over some 20 years, despite growth in air traffic volume.

5.3 Financing

5.3.1 It is not known whether the damage repair schemes identified are financed from airport revenues or via some form of insurance policy. The costs of administering a scheme, which must be substantial in the Heathrow case and significant at Manchester and Birmingham, are likely treated as an operating cost. Property repair and strengthening costs could, in principle, be met through an insurance arrangement but setting premiums would require an insurer to estimate the level of risk. This would be relatively straightforward at Heathrow, given the long historical database of incidence and the mature traffic levels. At airports with a much smaller base of data, and certainly at LCY where incidence is likely to remain low, the potential liability may be too uncertain.

6 Recommendations

6.1 Repair Scheme

6.1.1 In view of the possibility of vortex damage in the surrounding area, and the provisions of the S106, LCY should establish a scheme to repair any property damaged by wake vortex from aircraft using the Airport. Local residents should be made aware of the scheme and procedures should be put in place to allow them ready access to it.

6.1.2 The S106 (at Schedule 7, Part 1, para 3) stipulates a procedure for dealing with vortex-related complaints, which may be regarded as a minimum requirement. We believe it would help to ensure an effective scheme if the actual terms and procedures could be agreed between LCY and the London Borough of Newham in light of this study.

6.1.3 The scheme should offer immediate repair and subsequent strengthening of any roof verified as being vortex damaged. As the incidence of such damage is likely to be low, we do not believe it would be necessary or cost effective to define a scheme coverage area or to replace roofs that have not been damaged.

6.1.4 LCY should consider, keeping in mind where liability for vortex damage actually lies, whether the scheme should include compensation for personal injury arising from the original incident, for occupants and/or third parties. In considering this, and in drawing up a form of agreement with property owners, LCY will wish to consult with its legal advisers and insurers.

6.1.5 The necessary components of a scheme would be:

- a published contact procedure for residents to report incidents and lodge claims
- an assessor to inspect properties and verify the cause of damage as vortex strike
- a contractor to carry out immediate making-safe and repair and subsequent roof strengthening
- if personal injury cover is to be included, an appropriate insurance policy.
- maintenance of a record of <u>all</u> claims and verified cases.

6.1.6 It is preferable that the damage assessor be an independent professional, to avoid accusation of bias in the event that a damage incident is judged not to be due to aircraft vortex.

6.1.7 The repair/strengthening contractor must carry appropriate operating insurance and provide an appropriate guarantee of materials and workmanship.

6.1.8 Record keeping should include, as far as practicable, time and date of incident, accurate location, nature and extent of damage, and repair cost. If it is possible to identify the aircraft movement causing the damage, the type of aircraft and the prevailing weather conditions should also be recorded. If possible, track and height data for the movement should be extracted from ATC recordings.

6.2 Monitoring

6.2.1 The number of complaints and claims relating to wake vortex should be periodically reviewed by LCY to ensure that any trends are identified. This should include reports or complaints about vortex wind speeds or noise, as well as damage claims.

6.2.2 If complaints or further damage claims are seen in the future LCY may wish to commission a further review of risk levels, or other studies to identify causes and mitigation measures. The S106 (at Schedule 7, Part 1, para 4) includes a requirement to revisit the studies detailed here, in the event that a new aircraft type is brought into scheduled service at LCY.

6.3 Publicity

6.3.1 The initiation of a repair scheme should be publicised locally and contact details, claim procedure and terms should be accessible via the Airport's Consultative Committee website. Material should be included to explain to the public what aircraft vortices are, how they behave and what effects people may notice. Publicity should make clear the actual liability for damage caused by aircraft and any limits LCY places on its undertakings regarding repair, compensation or personal injury.

6.4 Future Land Development

6.4.1 The Boroughs of Newham, Greenwich and Tower Hamlets should use the development control process to minimise the risk of vortex damage. Enforcement of the Public Safety Zone policy will prevent new residential development close to the runway approaches. The Boroughs should also consider conditioning all consents for residential development within a defined area to ensure that roof structures are designed for resistance to vortex damage, or issuing advisories as to the risk of vortex damage and appropriate roof design measures. A reasonable area for such conditions or advice would be in the order of 5km from each runway end and 2km wide.

6.5 S106 Agreement

6.5.1 Execution of this study meets the first requirement of the S106 Agreement. In order to meet the remaining requirements and set up an appropriate scheme, it will be necessary for LCY and LBN to agree the detailed terms of the scheme and the legal framework for its implementation.

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13	Southampton Airport Consultative Committee, Agenda and Minutes, 12 February 2009
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Appendix A: Telecon Halcrow/LBN

Halcrow				**RECORD OF TELEPHONE CONVERSATION**	
BETWEEN:	Robin Whitehouse	**OF:**	LB Newham	**PHONE:**	02033 731845
AND:	N Kaberry	**DATE:**	23.02.10	**TIME:**	15:00
PROJECT:	LCY S106 Compliance: Wake Turbulence Study			**FILE:**	TFLLCY
SUBJECT:	LBN concerns, report content etc.				

- NK explained the purpose of the call; to confirm that Halcrow understands LBN's expectations of the Wake Turbulence Study and the subsequent report.

- RW explained that, although there was no body of complaint or major concern about wake turbulence (WT) effects, the matter had been raised in discussion of the LCY proposals, so it was necessary to consider and deal with it. He confirmed that LBN were not aware of any cases of damage as a result of WT but he understood that such remains a possibility, however remote.

- RW said that, in his view, the study was essentially about assessing the extent of the 'problem' and whether more needs to be done to deal with its possible effects.
- RW said the only complaint received was that from a [redacted], relating to a location to the east of LCY, on the far bank of the river but conveying general concerns regarding; the possibility of damage, perception of the presence of turbulence at ground level, and noise arising from WT. He said there had been no complaints from areas west of LCY or elsewhere.

- RW noted that the work was intended to provide a view of present and future risks, so needed to take account of possible future development around LCY. He said there are areas of intended development west of LCY, including Silvertown Quays, which is just south of the extended centreline. He also believes there is a consent in place for development on land to the east, in LB Greenwich.
- NK noted that development would not be permitted within the PSZs, but RW believed the proposed Silvertown Quays development may have a consent predating the PSZ, although only a very small part of the site would fall within it by 10-20m.

- RW said LBN is primarily concerned see put in place a legally-binding scheme which would avoid the need for owners of damaged property to pursue a claim for compensation through their own insurers, with all the difficulties of proving cause and responsibility that this would likely entail. It was not LBN's intention to hand residents a 'blank cheque'; given the relatively small numbers at risk – if significant risk exists – LCY's financial liability was likely to be small.

- NK explained that, at other sites such as Heathrow, damage was almost exclusively to traditional slated or tiled house roofs. Other roof types, such as felted or metal sheet coverings, are not susceptible to WT damage. Traditional roofs could easily be strengthened by increasing the fixings of each tile. RW said that development in the LCY area is usually multi-storey flats and other buildings of modern design with non-traditional roof structures.

- RW said it would be possible, in the case of future consents, for LBN to condition consent on the use of roofing systems that would be resistant to WT damage. Alternatively, an 'informative' could be included, alerting a developer to the need to take this into account in design.

- NK confirmed that a draft report was due to be submitted in about 2 weeks. This would go to LCY and RPS in the first instance.

Name of person making/taking call:	N Kaberry

Action taken/requested:

File for future reference.

Circulation

R P S	R Hesketh

Appendix B: Vortex Generation

Vortex circulation provides a measure of the energy or strength of a vortex:

Vortex circulation $$\Gamma = \frac{4.M.g}{\varrho.\pi.\,B.V} \qquad m^2/s$$

where
- M = aircraft mass, in this case MLW — kg
- g = 9.81 — m/s^2
- ϱ = density of air 1.225 — kg/m^3
- B = aircraft wingspan — m
- V = aircraft airspeed — m/s

Aircraft	B747-400	B737-300	AVRO-RJ85	ATR72-500
MLW	285,764	51,710	38,556	48,171
Span	64.4	29.0	26.3	27.0
Approach speed	140kt (71m/s)	125kt (64m/s)	110kt (56m/s)	120kt (61m/s)
Vortex circulation	637	284	267	296
Tangential air velocity at 2m dia	196kt (101m/s)	88kt (45m/s)	83kt (43m/s)	92kt (47m/s)

Sink rate (Butler, Ref 4)

$$\text{Sink rate } v = \Gamma/2.\,\pi.\,B \qquad m/s$$

Aircraft	B747-400		AVRO-RJ85	
Sink rate	1.57m/s		1.62m/s	

These values can be compared with approximate values quoted in Reference 1, of between 450ft/min (2.25m/s) and 600ft/min (3m/s).

Appendix C: Vortex Strike Rates

Existing and Projected Damaging Strike Incidences											
Airports with damage record											
Airport	**Period**	**ATMs**	**Arrivals**	**Runway**	**% Arrivals**	**Arrivals**	**Damage strikes**	**Strikes per 1000**	**% Trad housing**	**Strikes per 1000 if all housing**	**Notes**
LHR	1990	368440	184220	27R, 27L	75%	138165	317	2.29	0.66	3.49	317/yr in 1990 believed near peak strike rate
BHX	2007/08	207378	103689	15	54%	55992	133	2.38	0.43	5.59	Period may not be accurate.
											Possibly some retrospectives
MAN	2001-07	1397169	698585	23R	80%	558868	500	0.89	0.37	2.42	Period may not be accurate.
											Total may include retrospectives
STN	2003-07	905517	452759	04, 22	100%	452759	8	0.02	0.02	0.88	Development % very approximate
SOU	1999-08	360116	180058	02	40%	72023	14	0.19	0.59	0.33	Figures believed reliable.
B'fast City	10 years?	350000	175000	04	15%	26250	1	0.04	0.58	0.07	Cannot reliably establish ATMs or period.
LCY	10 yrs	700000	350000	27	66%	231350	2	0.01	0.40	0.02	Nominal 10 year period

LCY projections													
At current level of land development													
Airport	**Period**	**ATMs**	**Arrivals**	**Runway**	**% Arrivals**	**Arrivals**		**Strikes per 1000**	**% Trad housing**	**Strikes per 1000 for % housing**	**Based on rate from**	**Potential damage strikes/year**	**Total damage strikes/year**
LCY	1 year	120000	60000	9	34%	20340		3.49	0.32	1.12	LHR	22.7	
	1 year			27	66%	39660		3.49	0.40	1.40		55.4	78.1
LCY	1 year	120000	60000	9	34%	20340		5.59	0.32	1.79	BHX	36.4	
	1 year			27	66%	39660		5.59	0.40	2.24		88.7	125.0
LCY	1 year	120000	60000	9	34%	20340		2.42	0.32	0.77	MAN	15.7	
	1 year			27	66%	39660		2.42	0.40	0.97		38.4	54.1
LCY	1 year	120000	60000	9	34%	20340		0.88	0.32	0.28	STN	5.8	
	1 year			27	66%	39660		0.88	0.40	0.35		14.0	19.8
LCY	1 year	120000	60000	9	34%	20340		0.33	0.32	0.10	SOU	2.1	
	1 year			27	66%	39660		0.33	0.40	0.13		5.2	7.3
LCY	1 year	120000	60000	9	34%	20340		0.07	0.32	0.02	B'fast City	0.4	
	1 year			27	66%	39660		0.07	0.40	0.03		1.0	1.5
LCY	1 year	120000	60000	9	34%	20340		0.02	0.32	0.01	LCY	0.1	
	1 year			27	66%	39660		0.02	0.40	0.01		0.3	0.5

With potential maximum level of land development													
Airport	**Period**	**ATMs**	**Arrivals**	**Runway**	**% Arrivals**	**Arrivals**		**Strikes per 1000**	**% Trad housing**	**Strikes per 1000 for % housing**	**Based on rate from**	**Potential damage strikes/year**	**Total damage strikes/year**
LCY	1 year	120000	60000	9	34%	20340		3.49	0.48	1.66	LHR	33.8	
	1 year			27	66%	39660		3.49	0.76	2.65		105.3	139.1
LCY	1 year	120000	60000	9	34%	20340		5.59	0.48	2.66	BHX	54.1	
	1 year			27	66%	39660		5.59	0.76	4.25		168.5	222.6
LCY	1 year	120000	60000	9	34%	20340		2.42	0.48	1.15	MAN	23.4	
	1 year			27	66%	39660		2.42	0.76	1.84		72.9	96.3
LCY	1 year	120000	60000	9	34%	20340		0.88	0.48	0.42	STN	8.6	
	1 year			27	66%	39660		0.88	0.76	0.67		26.6	35.2
LCY	1 year	120000	60000	9	34%	20340		0.33	0.48	0.16	SOU	3.2	
	1 year			27	66%	39660		0.33	0.76	0.25		9.9	13.1
LCY	1 year	120000	60000	9	34%	20340		0.07	0.48	0.03	B'fast City	0.6	
	1 year			27	66%	39660		0.07	0.76	0.05		2.0	2.6
LCY	1 year	120000	60000	9	34%	20340		0.02	0.48	0.01	LCY	0.2	
	1 year			27	66%	39660		0.02	0.76	0.02		0.7	0.9

Appendix D: Lawson Criteria

Lawson Safety Criteria

The Lawson criteria and are defined in Table D.1. A comparison between the Lawson criteria and the familiar Beaufort scale is provided in Table D.2.

The Lawson safety criteria are based on the once a year exceedence of an extreme threshold wind speed. A wind speed greater than 15m/s but less than 20m/s occurring once a year is classified as unsuitable for general public which includes the elderly, cyclists and children. Able-bodied users are those determined to experience distress when the wind speed exceeds 20m/s once per year.

Such safety criteria indicate the potential for danger during normal pedestrian activity, for example, a pedestrian crossing on a busy road, where the consequences of being blown over would be very serious. Other examples include access ways to hospitals and schools where the local pedestrian population is unlikely to cope safely with extreme winds. Referring again to the Beaufort scale, S2 would be classified as gale force, S1 as strong gale to storm force.

Table D.1: Safety Ratings – Assessment Criteria

Comfort Ratings	Threshold mean-hourly windspeed exceeded <5% of the time
C1+ Uncomfortable for all uses	n/a
C1 Fast or business walking	10m/s
C2 Strolling or window shopping	8m/s
C3 Short periods standing or sitting	6m/s
C4 Long periods of standing or sitting	4m/s
Safety Ratings	**Mean-hourly windspeed exceeded once per annum**
S1 Unsuitable for Able-Bodied	20m/s
S2 Unsuitable for General Public	15m/s

Table D.2 - Beaufort Scale

Beaufort Number	Description	Mean hourly windspeed (m/s)	Effect
0	Calm	0 - 0.25	
1	Light air	0.25 - 1.55	No noticeable wind
2	Light breeze	1.55 - 3.35	Wind felt on face
3	Gentle breeze	3.35 - 5.45	Hair disturbed, clothing flaps, newspaper difficult to read
4	Moderate breeze	5.45 - 7.95	Raises dust and loose paper. hair disarranged
5	Fresh breeze	7.95 - 10.75	Force of wind felt on body, danger of stumbling
6	Strong breeze	10.75 - 13.85	Umbrellas used with difficulty, hair blown straight difficult to walk steadily, wind noise unpleasant
7	Near gale	13.85 - 17.15	Inconvenience felt when walking
8	Gale	17.15 - 20.75	Impedes progress, difficulty balancing in gusts
9	Strong gale	20.75 - 24.45	People blown over

Appendix E: Vortex Protection Schemes

Heathrow

What is a vortex?

A vortex is a circulating current of air generated by aircraft. It can sometimes strike and damage the roofs of houses under the flightpath.

The scheme

BAA Heathrow runs a Vortex Protection Scheme to protect homes around the Airport. Although legal liability for vortex damage rests with the airlines, BAA Heathrow is voluntarily funding this £15 million scheme as part of its commitment to the local community.

Am I eligible?

Every house, school, church or hospital affected by a Heathrow vortex strike is eligible for vortex protection. This includes homes situated above commercial properties. The only criteria is that the damage must be verified by a BAA Heathrow-appointed vortex assessor.

As this kind of roof damage is very specific, the assessor can quickly identify whether it has been caused by an aircraft vortex.

Blanket zones

To protect homes in high risk areas, we offer blanket protection to roads which reach a 65% strike rate, now or in the future. This means that once 65% of homes in a street have received a vortex strike, the whole street is included in the scheme, including those homes which have not been affected. If you live in a road which is classified as a blanket zone, you will be contacted directly by us.

What happens next?

BAA Heathrow operates a 24-hour vortex telephone service for residents.

If you suspect you have received a vortex strike, you should report it to us immediately by calling **020 8745 7930** or **07860 323816** outside office hours. Our appointed vortex assessor will then inspect the damage. **Please do not attempt to undertake repairs prior to an inspection, as homes are only eligible if the damage has been officially verified.** If a vortex strike has occurred, free remedial repairs will be arranged immediately.

Once your roof has been repaired, your property will be added to the scheme for permanent vortex protection. This will involve strengthening the roof by fixing down new tiles with special metal clips. Clipped tiles can withstand more than the maximum force of a vortex strike and have proven to be the most effective way of protecting homes from vortex damage. The work is completed by a contractor appointed by BAA Heathrow and is free and will start as soon as possible although waiting times may vary.

The facts

- Less than 0.01 % of flights cause vortex damage
- The majority of strikes are concentrated in small areas near the ends of the runways
- Roofs in the Heathrow area are typically constructed with loose-laid tiles which makes them prone to vortex damage
- Only properties with pitched roofs are affected
- No vortex damage has been recorded at homes which have been protected under this scheme

Birmingham

Vortex Protection

Birmingham International Airport runs a Vortex Protection Scheme to protect homes around the Airport from vortex damage. Vortices are circulating currents of air created by the passage of aircraft through the sky. All aircraft shed vortices, but in most cases they are broken up before they reach the ground. However, in certain weather conditions, the vortices can reach ground level.

During the latter stages of landing, it is possible for aircraft vortices to make contact with roofs of properties close to the Airport. They can, occasionally cause the movement and slippage of roof tiles. This is known as vortex damage.

Birmingham International Airport introduced a Vortex Protection Scheme in 2003, with 250 properties already benefited with a replacement vortex proof roof. All reported vortex strikes are investigated by the Airport Company. If the damage is confirmed to be vortex related, immediate repairs will be made to the roof. The property will then be added to the schedule of properties to be re-roofed.

More details regarding the Vortex Protection Scheme can be found on the Vortex Protection Scheme leaflet.

If you would like to report a suspected vortex strike, please complete the Vortex Complaint form and a member of the Environment Team will contact you, to arrange an appointment to inspect the damage. Alternatively, contact the Environment Officer, Louise Kelly on 0121 767 7419 or the Environment Helpline on 0121 767 7433

If you discover roof damage outside of office hours please contact our Operations Duty Manager on 0121 767 7139.

Manchesterhttp://www.birminghamairport.co.uk/showpage.aspx?id=147 - #

Vortex Repair Scheme

Repairing Roof Damage

What is vortex damage?
Vortices are circulating currents of air caused by moving aircraft. Whilst most vortices are broken up by the natural flow of air before they reach the ground, sometimes they can reach roof level, causing movement or slippage to tiles. A trained assessor can identify whether or not particular roof damage resulted from an aircraft vortex.

Which areas are affected by vortex damage?
A boundary has been identified within which vortex damage is most likely to occur. Further details can be obtained by contacting our Community Relations team on 08000 967 967.

Who is legally liable if damage occurs?
Manchester Airport is not liable for vortex damage. Liability lies with the operator of the aircraft concerned - this is governed by Section 76 (2) of the 1982 Civil Aviation Act. In recognition of the fact that aircraft identification is not always possible, Manchester Airport has introduced a vortex repair scheme as part of our commitment to the local community.

What should you do if you suspect vortex damage?
Contact our Community Relations team on 08000 967 967. Please provide the following information:

- The exact time of damage, if known
- The extent and nature of the damage
- If you are the property owner, your name, address and telephone number
- If you are not the property owner, the name, address and telephone number of the owner
- Details of the aircraft concerned. If you were not able to make such identification, please supply details of why you think vortex damage was responsible for the incident

We will then appoint a specialist contractor to inspect and report on your roof. They will usually visit within 24 hours. If you have a valid claim, immediate arrangements will be made for repairs to your roof. If your property falls within the protected area, you may also be eligible for a new roof covering at a later date, using tile pinning and clipping that will make your roof resistant to future vortex strikes.

If the damage occurs at night please call careline on 090 10 10 1000 or at the weekend call the main airport switchboard on 08712 710 711. When connected ask to speak to the Airfield Duty Manager about the Vortex Repair Scheme. The Duty Manager will contact our assessor for you.

What happens if you live outside the protected area, but you suspect vortex damage?
Our appointed agent will assess any damage. Should damage be confirmed, we will undertake repairs, however this will not make your property eligible for re-roofing.

For more information, please contact see the Mitigation Schemes Brochure or contact:

Manchester Airport Community Relations
Tel: 08000 967 967 (voicemail is available outside normal working hours)