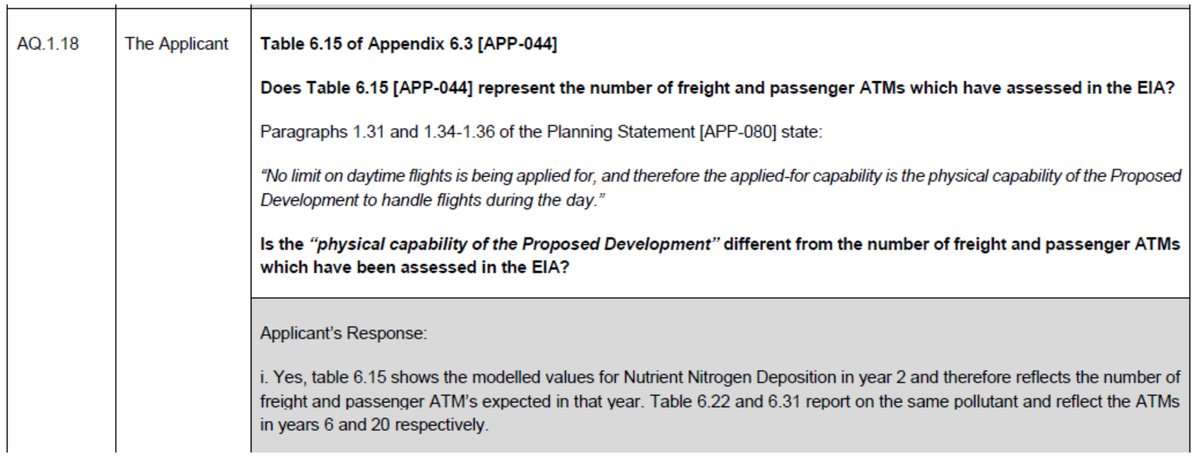
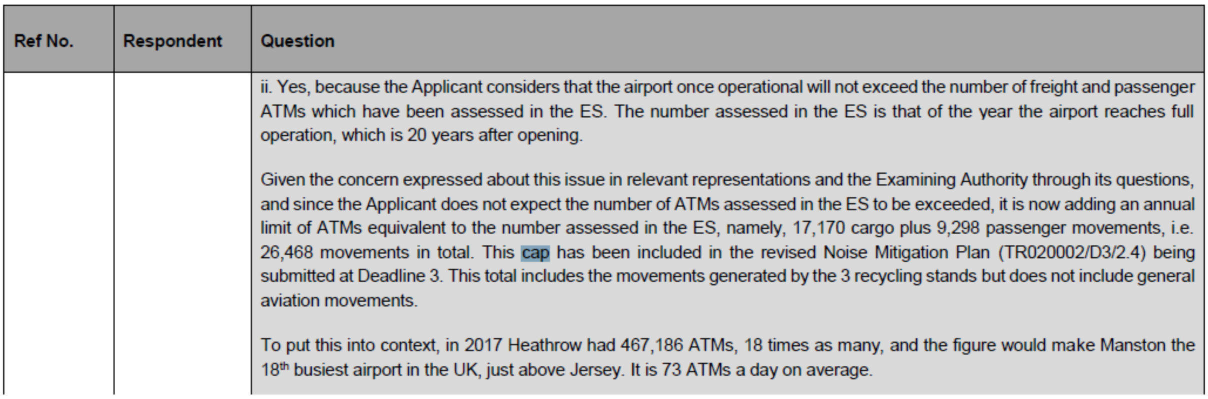
Public Safety Zones

In my submission to PINS 1 I included a section on Public Safety Zones (PSZ) in section 3 and I quote *“Our submission notwithstanding that 10000 ATM’s are unachievable RSP should have considered whether Manston Airport needs a PSZ because they state that the potential number of ATM’s is 83220 and they also state they will not cap the number of flights. The logic says that both 83220 and PSZ’s are potentially capable they should be considered together (worst case scenario)”*[1]

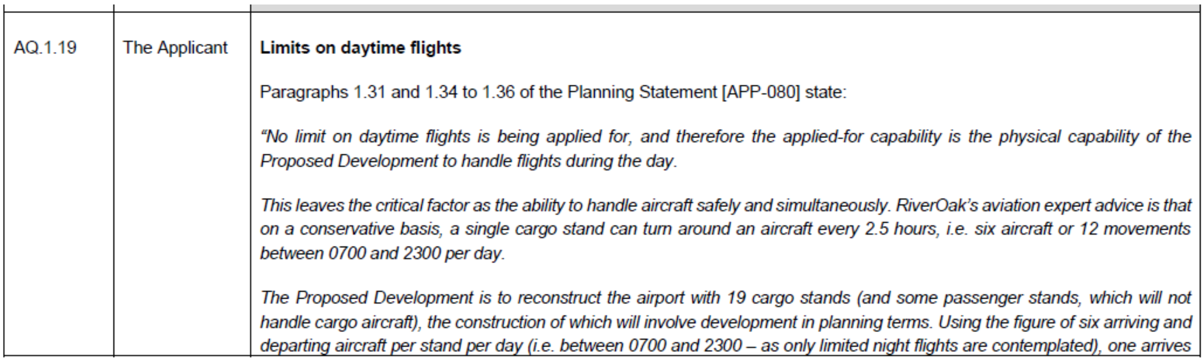
However since the submission RSP have responded to a number of questions from the ExA and the answer to questions AQ1.18 and AQ 1.19 are relevant to the point of PSZ’s and their “worst case scenario”.



AQ.1.18	The Applicant	**Table 6.15 of Appendix 6.3 [APP-044]** **Does Table 6.15 [APP-044] represent the number of freight and passenger ATMs which have assessed in the EIA?** Paragraphs 1.31 and 1.34-1.36 of the Planning Statement [APP-080] state: *“No limit on daytime flights is being applied for, and therefore the applied-for capability is the physical capability of the Proposed Development to handle flights during the day.”* **Is the *“physical capability of the Proposed Development”* different from the number of freight and passenger ATMs which have been assessed in the EIA?**
		Applicant’s Response: i. Yes, table 6.15 shows the modelled values for Nutrient Nitrogen Deposition in year 2 and therefore reflects the number of freight and passenger ATM’s expected in that year. Table 6.22 and 6.31 report on the same pollutant and reflect the ATMs in years 6 and 20 respectively.

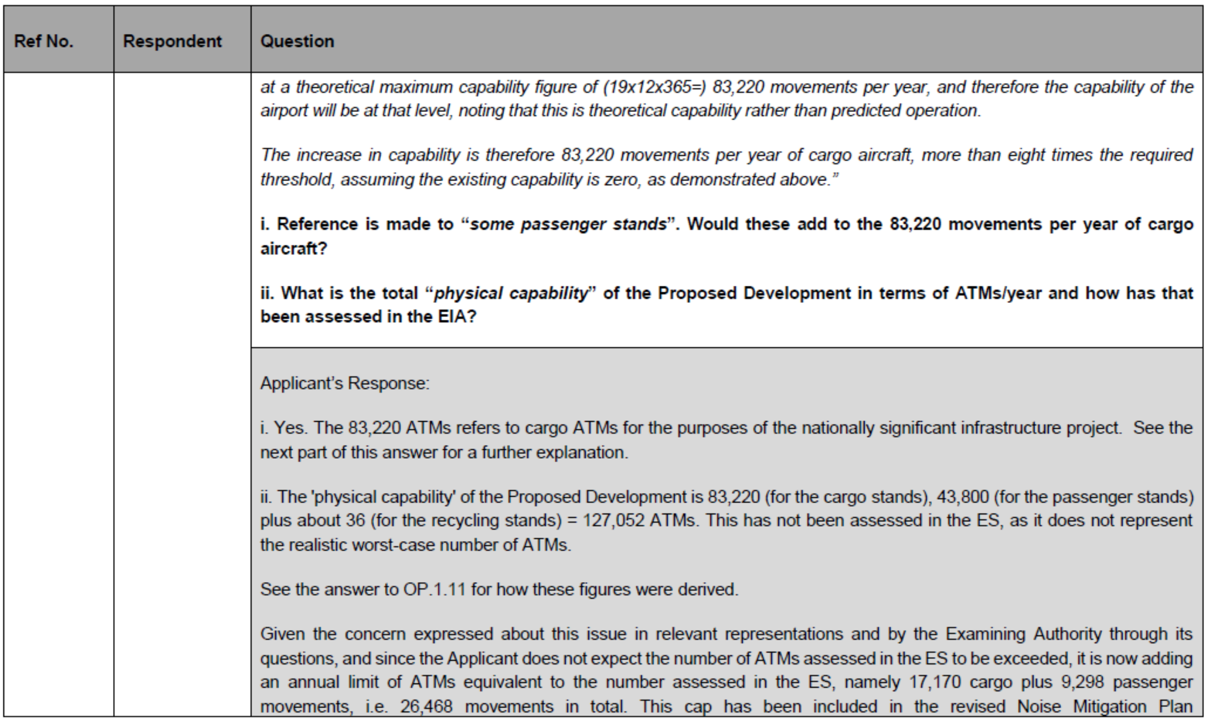


Ref No.	Respondent	Question
		ii. Yes, because the Applicant considers that the airport once operational will not exceed the number of freight and passenger ATMs which have been assessed in the ES. The number assessed in the ES is that of the year the airport reaches full operation, which is 20 years after opening. Given the concern expressed about this issue in relevant representations and the Examining Authority through its questions, and since the Applicant does not expect the number of ATMs assessed in the ES to be exceeded, it is now adding an annual limit of ATMs equivalent to the number assessed in the ES, namely, 17,170 cargo plus 9,298 passenger movements, i.e. 26,468 movements in total. This cap has been included in the revised Noise Mitigation Plan (TR020002/D3/2.4) being submitted at Deadline 3. This total includes the movements generated by the 3 recycling stands but does not include general aviation movements. To put this into context, in 2017 Heathrow had 467,186 ATMs, 18 times as many, and the figure would make Manston the 18th busiest airport in the UK, just above Jersey. It is 73 ATMs a day on average.



AQ.1.19	The Applicant	**Limits on daytime flights** Paragraphs 1.31 and 1.34 to 1.36 of the Planning Statement [APP-080] state: *“No limit on daytime flights is being applied for, and therefore the applied-for capability is the physical capability of the Proposed Development to handle flights during the day.* *This leaves the critical factor as the ability to handle aircraft safely and simultaneously. RiverOak’s aviation expert advice is that on a conservative basis, a single cargo stand can turn around an aircraft every 2.5 hours, i.e. six aircraft or 12 movements between 0700 and 2300 per day.* *The Proposed Development is to reconstruct the airport with 19 cargo stands (and some passenger stands, which will not handle cargo aircraft), the construction of which will involve development in planning terms. Using the figure of six arriving and departing aircraft per stand per day (i.e. between 0700 and 2300 – as only limited night flights are contemplated), one arrives*

Public Safety Zones



Ref No.	Respondent	Question
		at a theoretical maximum capability figure of (19x12x365=) 83,220 movements per year, and therefore the capability of the airport will be at that level, noting that this is theoretical capability rather than predicted operation. *The increase in capability is therefore 83,220 movements per year of cargo aircraft, more than eight times the required threshold, assuming the existing capability is zero, as demonstrated above."* **i. Reference is made to "*some passenger stands*". Would these add to the 83,220 movements per year of cargo aircraft?** **ii. What is the total "*physical capability*" of the Proposed Development in terms of ATMs/year and how has that been assessed in the EIA?**
		Applicant's Response: i. Yes. The 83,220 ATMs refers to cargo ATMs for the purposes of the nationally significant infrastructure project. See the next part of this answer for a further explanation. ii. The 'physical capability' of the Proposed Development is 83,220 (for the cargo stands), 43,800 (for the passenger stands) plus about 36 (for the recycling stands) = 127,052 ATMs. This has not been assessed in the ES, as it does not represent the realistic worst-case number of ATMs. See the answer to OP.1.11 for how these figures were derived. Given the concern expressed about this issue in relevant representations and by the Examining Authority through its questions, and since the Applicant does not expect the number of ATMs assessed in the ES to be exceeded, it is now adding an annual limit of ATMs equivalent to the number assessed in the ES, namely 17,170 cargo plus 9,298 passenger movements, i.e. 26,468 movements in total. This cap has been included in the revised Noise Mitigation Plan

In particular the answer to the number of flights is being capped at an annual 26,468 (as opposed to the potential capacity of 83220 which was an exercise in foot in mouth publicity). This however doesn't change the dynamic of PSZs which are an absolute requirement for any airport which proposes more than 1500 Air traffic movements (ATMs) per month or 18000 annually.

"*Given the concern expressed about this issue in relevant representations and the Examining Authority through its questions, and since the Applicant does not expect the number of ATMs assessed in the ES to be exceeded, it is now adding an annual limit of ATMs equivalent to the number assessed in the ES, namely, 17,170 cargo plus 9,298 passenger movements, i.e. 26,468 movements in total. This cap has been included in the revised Noise Mitigation Plan (TR020002/D3/2.4) being submitted at Deadline 3. This total includes the movements generated by the 3 recycling stands but does not include general aviation movements."*

There are several issues here however it doesn't invalidate the original statement from my original submission as both are above the 18000 annual ATMs.

Firstly I make the point that at no time have RSP/ROIC ever consulted with the population most affected about either 83220 or 26,468 ATMs, neither have they ever made this a "worst case scenario.

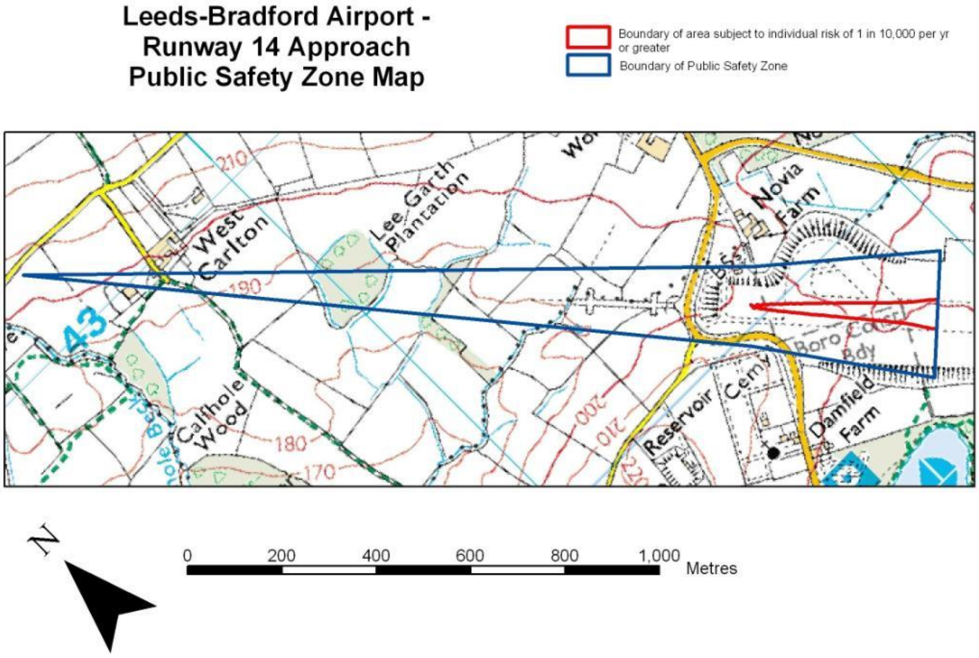
"It is not the role of the ExA to consider RSP's consultation process. NNF understands that. However, the proposal now before the ExA is not the proposal that RSP consulted on (we deal with this in our submission NNF01 Section B). In addition, RSP's habit of systematic misinformation during all of its consultations casts doubt on the extent to which the developer is fit and proper to own and operate an infrastructure project of national significance. In our view, this is an issue that should be considered by the ExA."[2]

Secondly the point that more than 18,000 ATMs is now the cap on flights should mean a PSZ at both ends of the runway should be a major part of the Environmental Impact Assessment (EIA), and should therefore be part of any compensation offered to those residents impacted within the PSZ.

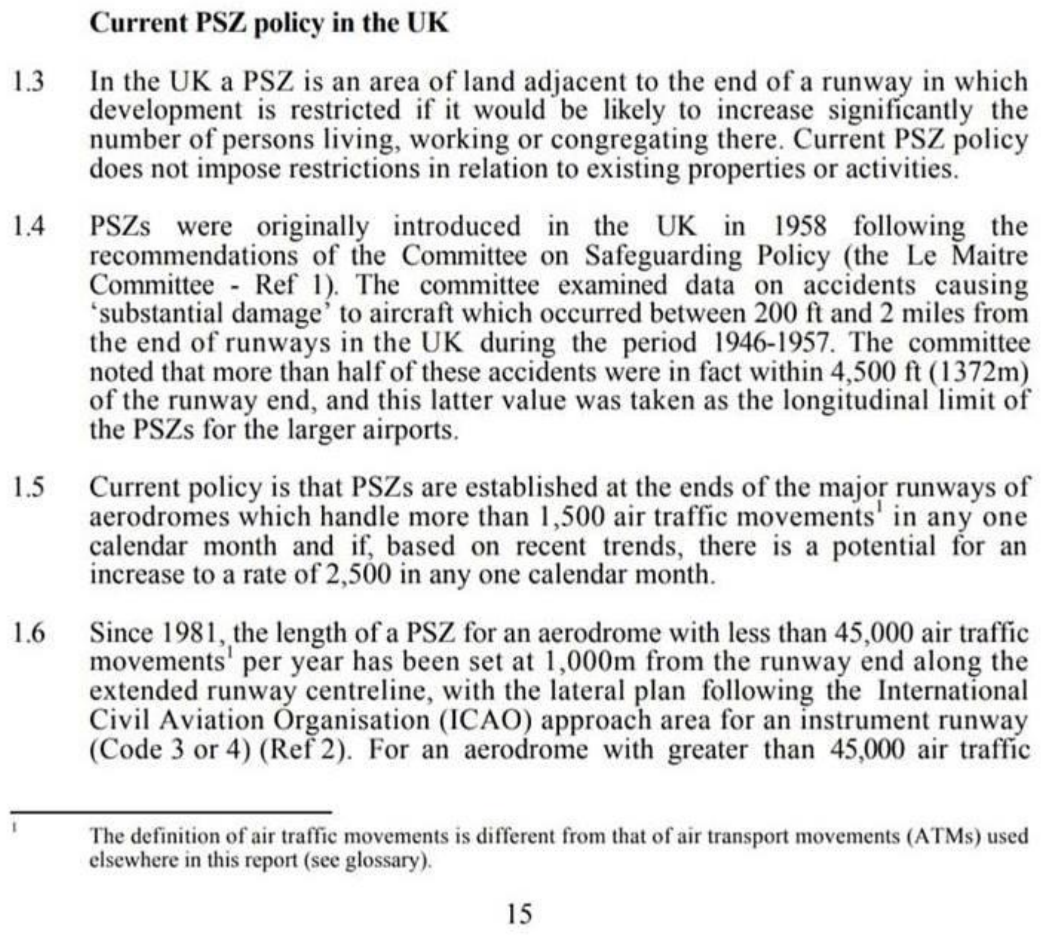
Public Safety Zones

Measure distance
Click on the map to add to your path
Total distance: 4.99 km (3.10 mi)

As one end (to the West) extends over relatively open countryside I have limited the area of PSZ to the East where most residents live. I have also modelled the area of Manston Green (785 houses given Planning Permission but yet to be built) onto the PSZ. The blue triangle indicates the 1:100000 risk contour and the red the 1:10000. This is modelled on the Bradford / Leeds airport but is similar to many regional airports.



Public Safety Zones



Current PSZ policy in the UK

1.3 In the UK a PSZ is an area of land adjacent to the end of a runway in which development is restricted if it would be likely to increase significantly the number of persons living, working or congregating there. Current PSZ policy does not impose restrictions in relation to existing properties or activities.

1.4 PSZs were originally introduced in the UK in 1958 following the recommendations of the Committee on Safeguarding Policy (the Le Maitre Committee - Ref 1). The committee examined data on accidents causing 'substantial damage' to aircraft which occurred between 200 ft and 2 miles from the end of runways in the UK during the period 1946-1957. The committee noted that more than half of these accidents were in fact within 4,500 ft (1372m) of the runway end, and this latter value was taken as the longitudinal limit of the PSZs for the larger airports.

1.5 Current policy is that PSZs are established at the ends of the major runways of aerodromes which handle more than 1,500 air traffic movements[1] in any one calendar month and if, based on recent trends, there is a potential for an increase to a rate of 2,500 in any one calendar month.

1.6 Since 1981, the length of a PSZ for an aerodrome with less than 45,000 air traffic movements[1] per year has been set at 1,000m from the runway end along the extended runway centreline, with the lateral plan following the International Civil Aviation Organisation (ICAO) approach area for an instrument runway (Code 3 or 4) (Ref 2). For an aerodrome with greater than 45,000 air traffic

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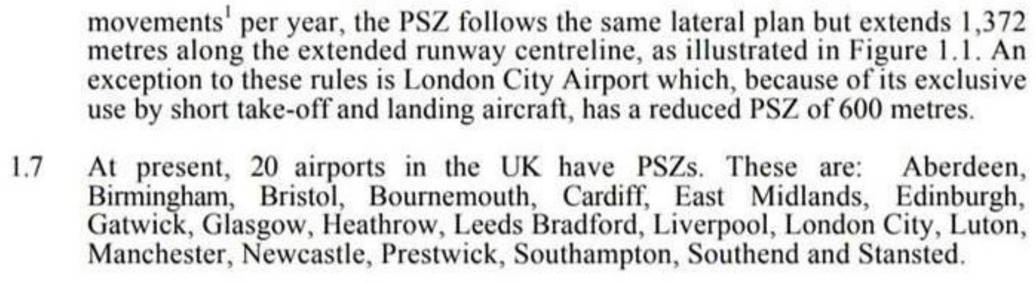
[1] The definition of air traffic movements is different from that of air transport movements (ATMs) used elsewhere in this report (see glossary).



movements[1] per year, the PSZ follows the same lateral plan but extends 1,372 metres along the extended runway centreline, as illustrated in Figure 1.1. An exception to these rules is London City Airport which, because of its exclusive use by short take-off and landing aircraft, has a reduced PSZ of 600 metres.

1.7 At present, 20 airports in the UK have PSZs. These are: Aberdeen, Birmingham, Bristol, Bournemouth, Cardiff, East Midlands, Edinburgh, Gatwick, Glasgow, Heathrow, Leeds Bradford, Liverpool, London City, Luton, Manchester, Newcastle, Prestwick, Southampton, Southend and Stansted.

[3] THIRD PARTY RISK NEAR AIRPORTS AND PUBLIC SAFETY ZONE POLICY

Conclusion

It is apparent that there is a reason that RSP/ROIC have consistently refused to discuss PSZs in their consultations and in their DCO submission and that is the possibility that compensation payments would create a cash flow problem as Manston Green (Southern) falls under the 1:10000 contour where under normal circumstances no building would be allowed. Even inside the 1:100000 restrictive planning legislation would make compensation much more likely and therefore less affordable to RSP/ROIC. [4]

Public Safety Zones

1. https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/TR020002/TR020002-002993-Barry%20James%20-%20Written%20Representation.pdf
2. NNF12 (available on PINS as a zip file)
3. Appendix 1 (THIRD PARTY RISK NEAR AIRPORTS AND PUBLIC SAFETY ZONE POLICY)
4. Appendix 4 (Control of planning within a PSZ)

R&D Report 9636

THIRD PARTY RISK NEAR AIRPORTS AND PUBLIC SAFETY ZONE POLICY

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P B Foot
S M Mason
I G Parker
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Research and Development Directorate
National Air Traffic Services Limited

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8CS/091/03/10

R&D REPORT 9636

THIRD PARTY RISK NEAR AIRPORTS AND PUBLIC SAFETY ZONE POLICY

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SUMMARY

Using the most appropriate models available, individual risk contours are produced for five example UK airports. Constrained cost benefit analysis using the calculated risk levels is used to identify possible changes to Public Safety Zones policy. It is concluded that there is no case for removing existing development outside the 10^{-4} contour, but that new development should be restricted as far out as the 10^{-5} contour. Four options for defining the areas in which development restrictions should apply are proposed.

This study was carried out under contract to the Department of Transport. Views expressed in this report are those of the authors. They do not represent NATS or DoT policy.

National Air Traffic Services Limited, London, June 1997

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EXECUTIVE SUMMARY

1 This report describes a study undertaken for the Department of Transport (DoT) in support of their review of airport Public Safety Zone (PSZ) policy. The study has been undertaken in two parts. In the first part (chapters 2 to 8), a risk modelling approach for use in developing PSZ policy is identified, and applied to five example airports with 1994 traffic. In the second part of the study (chapters 9 to 12), proposals for setting tolerability limits for airport third party risk are developed and possible options for a future PSZ policy are suggested.

2 Different measures for calculating third party risk around airports (such as crash risk, individual risk, and societal risk) were examined, and it was concluded that individual risk was the most appropriate for PSZ policy development. This conclusion was based on the requirements of both risk modelling and risk tolerability criteria.

3 The calculation of individual risk for different locations around an airport allows a risk contour map to be built up. The contours join points which are subject to the same individual risk. The regions most at risk from crashes can then be readily identified. This is of particular use for determining the most appropriate areas for PSZs.

4 The calculation of individual risk contours requires three basic quantities:

(i) the annual probability of a crash occurring near a given airport
(**crash frequency**);

(ii) the distribution of such crashes with respect to location
(**crash location model**); and

(iii) the size of the crash area and the proportion of people likely to be killed within this area
(**crash consequence model**).

5 Crash frequencies for airports are calculated by multiplying crash rates (crashes per movement) by annual movements for each aircraft type or group of types operating at the airport. The only practical method to calculate crash rates is to use historical information on crashes and movements.

6 Following a review of available data sources, the database of aircraft accidents maintained by Airclaims Ltd was identified as the most appropriate and easily accessible source for information on crashes involving western airliner jets and turboprops. Movement data were obtained from historical timetable information held in the Official Airline Guide (OAG) database. These data were used to calculate specific crash rates for western airliner jets and turboprops for airports in first world countries. Crash rates for other types of aircraft (e.g. executive jets and piston-engine aircraft) were estimated

separately. These were combined with traffic data to produce crash frequencies for each of the five example airports.

7 The review of available crash location models identified a model recently developed by the National Air Traffic Services Ltd. (NATS) as the most appropriate for the analysis of airport traffic above 4 tonnes in weight. The NATS location model consists of mathematical probability distributions which are based on the positions of 354 past accidents. Light aircraft were treated separately using an older location model specific to light aircraft.

8 The consequence models reviewed varied widely in their predictions of crash consequences - areas affected by crashes and the proportion of people killed in these areas. However those consequence models which were based on historical accident data (empirical models) were generally in closer agreement with each other than with other models. An empirical consequence model developed by NATS was used for the analysis, but an alternative model produced by the Dutch National Aerospace Laboratory (NLR) was also used to test the sensitivity of the calculations to these parameters.

9 An important conclusion from the reviews of location and consequence models was that, in general, empirical models (based on actual crash data) are likely to be more appropriate than deterministic models (which are based on assumptions about crash scenarios). Although some empirical models are likely to be more reliable than others, overall they tend to be broadly compatible with each other. For example, the predictions of consequence areas obtained using different empirical consequence models were generally within a factor of two of each other. Similarly the empirical location models all predict risk contours off the runway ends which are wide near the runway ends, becoming much narrower with increasing distance from the runway to eventually form a point (i.e. roughly triangular in shape).

10 This broad compatibility between different empirical models (although there are differences in important details) indicates that, despite all the inherent statistical and modelling uncertainties, the overall modelling approach adopted in this study is robust enough to form the basis of new PSZ policies. These new policies will have a much sounder foundation than those in current use which date back nearly forty years.

11 Individual risk contours were calculated for all five of the example airports and are presented in Figures 7.1 to 7.5. It was found that the area subjected to a specific level of risk in the vicinity of an airport was principally determined by the number of movements at the airport. It should be noted however, that the models used also predict an increase in risk with increasing size of aircraft (if all other factors remain the same). This may be an important consideration at large airports which are currently operating at or close to capacity in terms of movements. Future development at such airports may involve an increase in the average size of aircraft without an offsetting decrease in crash rates.

12 Individual risk calculations are subject to a considerable degree of inherent uncertainty, mainly because of the limitations in the amount and quality of data available. The assumptions made in the modelling can also influence the results. A number of sensitivity analyses were undertaken to give some indication of the possible variability in the calculations.

13 The second part of the report considers methods for setting tolerability criteria for airport third party risk. It is concluded that constrained cost benefit analysis (CBA) would be the most appropriate method for determining PSZ policy. Constrained CBA requires two key parameters: the upper limit to the tolerable individual risk, and the value for statistical life. Risks assessed to lie above the upper tolerable risk level are required to be reduced below that level irrespective of the costs involved. Further risk reduction would, however, only be appropriate if the benefits of doing so exceeded the costs. It should be noted that NATS has not endorsed this methodology for decision-making in air traffic system investments or for regulatory purposes. However, the DoT has used a similar approach for a number of years in road safety investments and both surface rail and London Underground have also recently adopted standard valuations of statistical life.

14 For the upper tolerable risk level for members of the public, the only widely used value is a risk of death of 10^{-4} per year. This is recommended by the Health and Safety Executive (HSE) for use in other safety critical industries. For the value of statistical life a range of different values are currently in use. For instance for road transport purposes a value of £0.8 million in 1995 prices (or £0.7 million in 1993 prices) is used, but higher values are used in other industries. Rather than adopting values for the two parameters uncritically, a specific investigation into attitudes to third party risk near airports was undertaken as part of this study.

15 The survey work took the form of a series of focus group meetings in which people living near to airports were asked a series of questions about their attitudes to risk. This work concluded that the current HSE value of 10^{-4} for the upper tolerable risk limit would be appropriate for PSZ policy and that the value of statistical life should be about the same as that used for road transport safety assessments.

16 The application of constrained cost benefit analysis to the five sample airports resulted in the following conclusions for PSZ policy:

i) There is a strong case in principle for PSZ policy to require the removal of existing housing and of other development occupied by third parties for a high proportion of the day, from within the 10^{-4} individual risk contour. It is estimated that a small number of properties are within the 10^{-4} contour at Heathrow, but at most airports there is unlikely to be any existing development within this contour.

ii) There is no case for removing existing housing outside the 10^{-4} individual risk contour.

ii) There is a case for inhibiting new housing development as far as the 10^{-5} individual risk contour.

iv) There is a case for permitting extensions to existing houses within the 10^{-5} individual risk contour.

v) There is no case for removing non-housing existing development outside the 10^{-4} individual risk contour.

vi) There is a case for inhibiting most new non-housing development, including transport terminals, as far as the 10^{-5} individual risk contour, but not beyond.

vii) An exception to (vi) is that there is a case for allowing new development with a low density of human occupation, averaged over the day, within the 10^{-5} and up to the 10^{-4} individual risk contour.

viii) There is no case for diverting existing transport links near airports, and probably also no case for diverting proposed links, though the latter should be considered on their individual merits. Low cost measures to prevent vehicles routinely coming to a stand within the 10^{-5} contour might be worthwhile, if not already adopted.

17 In addition to the development restrictions within the 10^{-5} individual risk contour indicated above, it might also be sensible to restrict development for new, sensitive or high density land uses, such as schools, hospitals, or places of assembly, somewhat beyond the 10^{-5} contour. Such restrictions should be considered on a case by case basis.

18 Four possible options for setting the areas for PSZs corresponding to the zones which experience individual risk of 10^{-5} or greater are proposed:

i) base the area directly on the zone within the modelled 10^{-5} contour;

ii) use triangles at the ends of the runways with dimensions based on a simple expression incorporating crash rates, crash areas and movements;

iii) use triangles at the ends of the runways with dimensions based on a simple expression incorporating movements only; and

iv) divide airports requiring development restrictions into two classes based on their movements and use triangles with fixed dimensions of 0.35

kilometres width and 3.5 kilometres long for the busier airports and two thirds of these values for the less busy airports.

19 It should be noted that, whatever process is adopted, the affected areas for an individual airport should take account of forecast traffic growth to an appropriate planning horizon.

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CONTENTS **Page No**

APPENDICES

Note: Tables and Figures are numbered according to the chapter from which they are first referred, i.e. 3.1 etc.

GLOSSARY OF TERMS

Air traffic movement	Take-offs or landings by all commercial and military aircraft (other than light training aircraft). Excludes local pleasure, private, aero club and official flights.
Air transport movement	Take-off or landing of aircraft engaged in the transport of passengers, cargo or mail on commercial terms. All scheduled movements, including those operated empty, loaded charter and air taxi movements are included.
Aircraft movement	An aircraft take-off or landing at an airport. For airport traffic purposes one arrival and one departure are counted as two movements.
Airliner	Any aircraft type which was designed and built specifically for airline use or which has entered service with airlines in significant numbers. General aviation types such as the Beechcraft King Air which may be in limited airline use, but which were not originally designed for that purpose are not considered airliner aircraft.
Consequence area	General term for area on the ground affected by accident consequences.
Constrained cost benefit analysis	Risk appraisal principle under which individual risk is required to be reduced to a tolerable level irrespective of cost, and then further reduced if and only if the benefits of doing so exceed the costs.
Cost benefit analysis	Quantification of the costs and benefits of a proposed policy or project to whomsoever they accrue, and the valuation of those in monetary terms.
Crash consequence models	Mathematical expressions or computer programs used to estimate the consequences of accidents (often relating them to aircraft weight or type of terrain).
Crash frequency	The expected number of crashes in a year.
Crash location models	Mathematical expressions or computer programs which determine the statistical distributions of crash locations in the vicinity of an airport.
Crash rate	The expected number of crashes per movement for a particular aircraft type or set of aircraft types.
Crash risk	The expected annual number of crashes per unit area at a given

	location.
Debris area	Area on the ground over which pieces of the aircraft wreckage are dispersed as a result of an aircraft accident.
Destroyed area	Area on the ground which was effectively destroyed as a result of an aircraft accident (including post-accident fires).
Development value	Difference between the value of land with permission for a specified type of development and its value without that permission.
Discounting	Attribution of lower values in real terms to costs and benefits accruing in the future than the values that would be attributed to them if they were to accrue immediately.
Executive jet	Non-airliner jets.
First world countries	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Hong Kong, Iceland, Ireland, Italy, Japan, Luxembourg, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, The Netherlands, UK, USA.
FN curve	Graph plotting the frequency, F, of accidents in which there are N or more fatalities against N (usually plotted with logarithmic scales).
Hectare	Metric unit for area corresponding to 10,000 m^2 (which is approximately equal to 2.470 acres or 0.0039 square miles).
Human capital	Method for valuing reduction in the risk of an accidental fatality under which the value of statistical life is taken to be the value of the average output lost as a result of one accidental death among the people at risk.
Individual risk	The risk of death per year to a representative or specified individual as a result of the realisation of specific hazards.
Intolerable risk	Individual risk which exceeds a specified limit, and which cannot be justified save in extraordinary circumstances.
Lethality	The proportion of people present in an area affected by a crash killed as a direct result of the crash.
Major partial loss	Aircraft accident in which the cost of repairs is equal to or exceeds US1$ million or 10% of the aircraft's value, which ever is the

	lower.
Movements	The sum of take-offs and landings.
Non-scheduled or charter services	Includes all air transport movements other than scheduled services.
Occupier’s surplus	Difference between the market price of a property and that at which the current occupier would be a willing seller.
Opportunity cost	The value of what must be forgone when a specified decision or action is taken.
Overrun	An accident during a landing or an aborted take-off, when the pilot is unable to prevent the aircraft from leaving the paved surface of the runway, either from its ends or from its sides.
Present value	Value of a stream of future costs and benefits discounted to the present, or another specified, date.
Public Safety Zones (PSZs)	Areas adjacent to the end of a runway in which development of the land is restricted for the safety of people on the ground.
Risk contours	Lines of equal risk displayed on a map.
Scheduled services	Flights performed according to a published timetable, including those supplementary thereto, available for use by members of the public. Includes freight services.
Societal risk	Either: (i) the relationship between the frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specific hazards; or (ii) the risk of a widespread or large scale detriment from the realisation of a defined hazard, the implication being that the consequence would be on such a scale as to provoke a socio-political response.
Third party	People in the vicinity of an airport whose presence is not associated with the activities of the airport (i.e. excluding passengers and workers at the airport).
Tolerable risk	Individual risk which is tolerated by society, provided that it is reduced as low as reasonably practicable.
Total Loss	Type of aircraft accident defined as a total loss in the aircraft insurance contract (or those accidents which would have been

	considered total losses had the aircraft been insured). In general, aircraft involved in total loss accidents are irreparable, but in some cases the aircraft is reparable but deemed beyond economic repair.
Value of statistical life	Financial value put on the loss created by the death of a statistical individual for the purpose of conducting cost/benefit analysis.
Veer-offs	Overruns in which the aircraft leaves the side (as opposed to the end) of the runway.
Willingness-to-pay	Method for valuing the reduction in the risk of an accidental fatality under which the value of a statistical life is derived from the amount that individuals would be willing to pay for a small reduction in risk that when aggregated represents the average value for saving one fatality.
x co-ordinate	The x co-ordinate represents a distance perpendicular from the extended runway centreline.
y co-ordinate	The y co-ordinate represents a distance along the extended runway centreline.

GLOSSARY OF ABBREVIATIONS

ACARRE	Australian Centre of Advanced Risk and Reliability Engineering Ltd
ACI	Airports Council International
ADREP	Accident Data Report
ALARP	As Low As Reasonably Practicable
ATM	Air Transport Movement
BR	British Railways
CAA	Civil Aviation Authority (UK)
CBA	Cost Benefit Analysis
DoE	Department of the Environment (UK)
DoT	Department of Transport (UK)
ERG	Economic Regulation Group (of the CAA)
FAA	Federal Aviation Administration (USA)
GDP	Gross Domestic Product
HSC	Health and Safety Commission (UK)
HSE	Health and Safety Executive (UK)
ICAO	International Civil Aviation Organisation
MLR	Major Loss Record
MORS	Mandatory Occurrence Reporting Scheme
MTWA	Maximum Total Weight Authorised
NATS	National Air Traffic Services Ltd. (UK)
NLR	Nationaal Lucht-en Ruimtevaartlaboratorium (National Aerospace Laboratory) (The Netherlands)
NTSB	National Transportation Safety Board (USA)
OAG	Official Airline Guide
PSZ	Public Safety Zone
SP	Scheduled Passenger
USNRC	US Nuclear Regulatory Commission

Note on Statistics

All numbers have been rounded to the final digit shown. Some averages and sums of percentages will therefore show rounding errors.

1 INTRODUCTION

1.1 This report describes the results of a study undertaken for the Department of Transport (DoT) in support of their review of policy on airport Public Safety Zones (PSZs). The objectives of the study are to:

(i) provide an authoritative view of the scope for detailed modelling of the size and shape of risk contours around airports and produce appropriate contours for a number of airports; and

(ii) suggest tolerability criteria for third party risk which could be used to determine the size, shape and development conditions for PSZs.

1.2 The requirement for a policy on land use in the vicinity of airports is based on the fact that, historically, the majority of aircraft crashes have occurred in these areas. This means that some areas close to busy airports are subject to above average risks of damage due to aircraft crashes. The numbers of people and structures on the ground subject to this higher risk from crashes can be controlled by applying planning restrictions to the affected areas. At present, in the UK, the areas affected by these sorts of restrictions are termed PSZs, and they are designated by the DoT. PSZ policy is not concerned directly with aircraft safety but is designed only to control third party risks (i.e. the risk to people and property in the vicinity of an airport). There are also separate regulations concerning the heights and locations of structures in the vicinity of airports which are designed to reduce the risk of aircraft colliding with ground structures. These have not been considered here.

Current PSZ policy in the UK

1.3 In the UK a PSZ is an area of land adjacent to the end of a runway in which development is restricted if it would be likely to increase significantly the number of persons living, working or congregating there. Current PSZ policy does not impose restrictions in relation to existing properties or activities.

1.4 PSZs were originally introduced in the UK in 1958 following the recommendations of the Committee on Safeguarding Policy (the Le Maitre Committee - Ref 1). The committee examined data on accidents causing ‘substantial damage’ to aircraft which occurred between 200 ft and 2 miles from the end of runways in the UK during the period 1946-1957. The committee noted that more than half of these accidents were in fact within 4,500 ft (1372m) of the runway end, and this latter value was taken as the longitudinal limit of the PSZs for the larger airports.

1.5 Current policy is that PSZs are established at the ends of the major runways of aerodromes which handle more than 1,500 air traffic movements[1] in any one

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[1] The definition of air traffic movements is different from that of air transport movements (ATMs) used elsewhere in this report (see glossary).

calendar month and if, based on recent trends, there is a potential for an increase to a rate of 2,500 in any one calendar month.

1.6 Since 1981, the length of a PSZ for an aerodrome with less than 45,000 air traffic movements[1] per year has been set at 1,000m from the runway end along the extended runway centreline, with the lateral plan following the International Civil Aviation Organisation (ICAO) approach area for an instrument runway (Code 3 or 4) (Ref 2). For an aerodrome with greater than 45,000 air traffic movements[1] per year, the PSZ follows the same lateral plan but extends 1,372 metres along the extended runway centreline, as illustrated in Figure 1.1. An exception to these rules is London City Airport which, because of its exclusive use by short take-off and landing aircraft, has a reduced PSZ of 600 metres.

1.7 At present, 20 airports in the UK have PSZs. These are: Aberdeen, Birmingham, Bristol, Bournemouth, Cardiff, East Midlands, Edinburgh, Gatwick, Glasgow, Heathrow, Leeds Bradford, Liverpool, London City, Luton, Manchester, Newcastle, Prestwick, Southampton, Southend and Stansted.

Land use restrictions in other countries

1.8 Other countries also restrict the use of land close to airports, in particular the USA and the Netherlands.

1.9 In the USA, Runway Protection Zones (RPZs) are established at the ends of runways (Ref 3). Their function is ‘to enhance the protection of people and property on the ground’. This is achieved through airport owner control over RPZs, including clearing RPZ areas of incompatible objects and activities. While it is considered desirable to clear all objects from the RPZ, some uses are permitted provided they do not attract wildlife and do not interfere with navigational aids. Thus golf courses - but not club houses - and agricultural operations are permitted in RPZs, and car parks may also be permitted.

1.10 Land uses prohibited in the RPZs are residences and places of public assembly, e.g. churches, schools, hospitals, offices, and shopping centres. It should be noted that the areas of RPZs are considerably smaller than the current UK PSZs, e.g. the largest RPZ is 750m long, compared with 1372m for a UK PSZ.

1.11 In the Netherlands, an extensive review of safeguarding policy in the vicinity of airports, focused specifically on Schiphol, has recently been completed. The review included work on the development of methodologies for calculating third party risk. The results of the study were used to derive a general policy for land use in the vicinity of airports based on the levels of third party risk calculated for the surrounding area. The land use restrictions range from removal of existing housing to restrictions on new housing and offices (Ref 4).

Overview of the present study

1.12 After the recent work undertaken by the Netherlands authorities and also the strong interest shown in the subject of third party risk at the public inquiry into the proposed second runway at Manchester airport, the UK DoT decided to carry out a review of its policy on PSZs. In particular, the review would consider whether any changes were required to the size and shape of PSZs, and whether simple rules relating to traffic levels and types of traffic could be drawn up for the setting of PSZ policy at airports. The current study has been undertaken in support of this policy review.

1.13 The initial objective of the work undertaken for the DoT was to investigate the feasibility of using mathematical models to calculate the geographical distribution around airports of the third party risks associated with aircraft crashes. Existing methodologies and data for modelling third party risk were reviewed to determine if an acceptable level of accuracy could be achieved, and the best existing models for this purpose were identified. These models were then used to calculate the levels of third party risk around five example airports in the UK: Heathrow, Gatwick, Manchester, Birmingham and Leeds Bradford.

1.14 In order to develop a land use policy from risk calculations it is necessary to determine the levels of risk which should require a specific land use restriction. This requires the development of suitable risk tolerability criteria. Existing approaches to risk appraisal were reviewed, and it was concluded that the most appropriate of these for PSZs was constrained cost benefit analysis (described in Chapter 9). Its application requires two key parameters: the upper limit to the tolerable risk for third parties, and the value for statistical life. Possible values for these parameters were explored in focused fieldwork to elucidate the attitudes and valuations of risk by people living near to airports.

1.15 The following four chapters of this report are concerned with the calculations and models used to quantify risk in the vicinity of airports. Chapter 2 gives an overview of different technical approaches to third party risk estimation, while Chapter 3 describes the estimation of crash rates and crash frequencies. Crash location, and crash consequence models are covered in Chapters 4 and 5 respectively. Chapter 6 describes the calculation of the input parameters required for the individual risk calculations. Chapters 7 and 8 deal with the results of these calculations and their sensitivity and uncertainty. The subsequent chapters of this report cover risk tolerability criteria: Chapters 9, 10, and 11 deal with the general principles for risk appraisal, the results of the risk tolerability fieldwork, and the application of these principles to PSZ policy respectively. Chapter 12 discusses the implications of applying different zoning and land usage restrictions.

2 OVERVIEW OF APPROACHES TO THIRD PARTY RISK ESTIMATION

2.1 This chapter gives an overview of approaches for quantifying third party risk in the vicinity of airports and considers which approach might be most appropriate for developing a future PSZ policy. The three principal risk metrics which could be used to measure third party risk around airports are:

- *Crash risk:* defined as the expected annual number of crashes per unit area at a given location.

- *Individual risk:* defined generally as the risk of death per year to a representative or specified individual as the result of the realisation of specific hazards. For airport third party risk modelling purposes, the individual concerned is assumed to reside at a particular location for 24 hours a day, every day of the year. The risk relates to death as a direct result of an aircraft crash.

- *Societal risk:* has been defined as ‘the relationship between frequency and number of people suffering a specified level of harm in a given population from the realisation of specific hazards’ (Ref 5). A broader definition is the risk of widespread or large scale detriment from the realisation of a defined hazard, the implication being that the consequence would be on such a scale as to provoke a socio-political response (Ref 6).

Crash risk

2.2 In order to calculate the crash risk for a particular location at an airport, two probabilities are needed:

(i) the annual probability that a crash occurs in the vicinity of the airport (crash frequency); and

(ii) the probability, given a crash has occurred in the vicinity of the airport, that the crash affects a particular location.

2.3 Crash frequencies are derived by combining data on the amount and type of traffic at the airport with corresponding crash rates (crash probabilities per movement). Although in principle crash rates could be derived from theoretical models, in practice they are usually derived from historical data on numbers of crashes and movements.

2.4 Different crash rates can be calculated for different categories of aircraft (i.e. jets, turboprops, piston-engine aircraft, etc.) and for application to specific types of operations (i.e. operations from first world airports, scheduled passenger flights etc.). When using historical data to estimate a crash rate it is important that the data on both crashes and movements are complete. Any missing data will lead to inaccuracies in the crash rate estimates - missing crashes result in an underestimate of the crash rate whilst missing movements result in an overestimate. In general, complete data on accidents are more readily available than complete data on movements. Therefore, the extent to which appropriate crash rates for third party risk calculations at UK airports can be calculated is determined largely by the availability of movement data. Crash rate estimation is discussed more fully in Chapter 3.

2.5 Having derived a crash frequency for the vicinity of an airport the next step is to determine the statistical distribution of crashes, in respect of location. To achieve this some form of crash location modelling is needed (crash location models are discussed in Chapter 4). Crash location models may be based on an analysis of the historical positions of crashes around airports, on theoretical models of the behaviour of crashing aircraft or on a combination of the two. Combining crash frequencies with a crash location model allows the annual probability that a crash will occur in a given location in the vicinity of an airport to be estimated. This type of information is commonly presented in the form of a crash risk contour map in which the contours join areas which are subject to the same crash probability. In this way the areas most at risk from crashes can readily be identified.

Individual risk

2.6 Crash risk estimates allow the risk of a crash occurring within a particular area to be assessed. However, if a large aircraft crashes, it might well affect not only the area at its immediate point of impact, but also adjacent areas through the effects of fire or debris. Individual risk estimates for an airport provide a means of assessing the overall risk to a person at a particular location from any crashes in their vicinity, not just those that occur precisely at their location. Individual risk estimates normally only consider the most serious potential consequence of a crash, that is the risk of death, and do not take account of the risk of suffering injuries. In principle, it would be possible to include injuries but this has not been done in this analysis.

2.7 In order to calculate individual risk around an airport a means of estimating the potential effects of an accident is also required. Models to perform this calculation are termed crash consequence models. Crash consequence models usually determine both the area likely to be affected by a crash and the proportion of people present in this area who would be killed as a result of the crash (termed the ‘lethality’). As with crash location models, consequence models may be based on an analysis of historical incidents or on the theoretical behaviour of aircraft in crashes or on a combination of the two. Consequence modelling is covered in Chapter 5.

2.8 Combining a crash consequence model with the results of crash risk calculations gives an estimate of the individual risk at any point in the vicinity of an airport in terms of the probability of death per year due to aircraft crashes. It is important to note that, for third party risk calculations around airports, the individual risk at a location is normally assessed for a 'nominal' person who remains permanently (i.e. 24 hours per day) there - this will be an overestimate of the risk to people who are only present for part of the time. No account is taken here of possible variations in the number of people at the location at different times of day. This means that the assessed individual risk for a location is not affected by whether or not anyone actually lives there. As with crash risk the results of individual risk calculations are commonly represented as contours on a map. Individual risk has been used by the HSE to derive safety criteria for other major industries such as nuclear power generation (Ref 7).

Populations affected

2.9 To determine the number of people affected by different levels of risk it is necessary to combine the geographical distribution of crash risk or individual risk with data on the geographical distribution of the population in the relevant areas. The availability of data on population distributions largely determines the degree of precision possible in these types of calculation.

2.10 The most commonly available information on population distributions in the UK is based on population census data. Census data can be used to determine the geographical distribution of the residential population in an area but it provides no information on non-residential populations (i.e. office workers, students at schools and colleges, cinema goers, etc.) or on diurnal variations in the residential population. This limits estimates of the numbers of people exposed to the calculated risk levels to those actually living in the affected area. However, the residential population does represent a group of people likely to spend the highest proportion of their time in the affected areas and so such calculations can be useful.

Societal risk

2.11 Societal risk is concerned with the accident repercussions that are wider than their effects on individual risk. One common form of expression of the societal risk of an activity is the activity's 'FN curve'. FN curves show the expected frequency (F) of accidents resulting in N or more fatalities plotted against N (see Chapter 9 for examples of FN curves). Societal risk criteria then place upper limits on the frequencies F that are regarded as tolerable for various values of N, as discussed in Chapter 9. FN calculations combine the output of the models used for estimating individual risk with detailed data on the locations of the people at risk (including non-residential populations and any diurnal patterns).

2.12 No criteria based on FN curves have been proposed for use in this study for the following reasons. First, the criteria used in this study include cost-benefit analysis (CBA) as well as individual risk criteria, and it is arguable that FN criteria are unnecessary when CBA is used, because CBA is itself a 'social' criterion. Second, there are serious problems in deriving suitable tolerability criteria for FN curves. This is not to deny that certain sorts of accidents may have wider repercussions than are accounted for by individual risk criteria or CBA, but it is suggested in Chapter 9 that such possibilities are better taken into account informally than by quantified criteria.

Third Party Risk Estimates and the Development of PSZ Policy

2.13 In previous studies of the consequences of aircraft accidents, the crash risk approach has mainly been used to determine the risk of an aircraft crashing on particularly important sites, such as nuclear installations (see for example Refs. 8, 9, 10, 11, 12, 13).

2.14 Crash risk contours would be very relevant to PSZ policy if the present 'philosophy' of PSZs were to be retained (i.e. an area containing a major proportion of airport-related crashes - see Chapter 1). Methods for estimating crash risk contours could be used to define a better shape for the PSZs than at present, as the PSZ could then be the area inside a particular crash risk contour representing the desired proportion of crashes. This would enable the PSZ area to be defined more 'efficiently' than at present, as it would then correspond to the minimum area needed to contain the required proportion of crashes.

2.15 As stated earlier, tolerability criteria for other safety critical industries in the UK, such as the nuclear power industry (Ref 7), have been based on individual risk (see Chapter 9 for a discussion of tolerability criteria). In the development of PSZ policy, individual risk is a superior measure to crash risk because it also takes into account crash consequences, as well as simply crash location. The use of individual risk with appropriate tolerability criteria, would also bring PSZ policy closer into line with these other industries. The analysis presented in this report has therefore concentrated on developing a methodology for deriving individual risk contours in the vicinity of airports and exploring options for setting tolerability criteria for individual risk.

Summary

2.16 In summary, individual risk contours for crashes in the vicinity of airports are likely to provide the most useful input to the review of PSZ policy. Methods for estimating individual risk require three basic quantities:

(i) the annual probability that a crash occurs near a given airport
(**crash frequency**);

(ii) the distribution of these crashes with respect to location
(**crash location model**); and

(iii) the size of the crash area and the lethality within this area (**crash consequence model**).

2.17 The details of the methods adopted for each of these three stages, together with the rationale behind the choice of method, are presented in Chapters 3, 4, and 5. The calculation of the input parameters for the individual risk modelling is described in Chapter 6 and the results of the individual risk assessments for each of the five example airports are described in Chapter 7.

3. CRASH RATE AND FREQUENCY ESTIMATION

3.1 In order to estimate annual crash frequencies (the expected number of crashes per year) for an airport it is necessary to multiply airport related crash rates (expected number of crashes per movement) by the annual number of movements at the airport. This chapter describes the calculation of crash rates and annual crash frequencies.

Overview of crash rate estimates

3.2 In principle, crash rates could be derived using theoretical models which would use the measured probabilities of all the possible causal factors to predict the probability of a crash. However, such a theoretical approach is very problematic since accidents are usually the result of a combination of many separate causal factors with unknown probabilities and complex interrelationships. An alternative method, which was the approach adopted in this study, is to use historical data on accidents and on aircraft movements to calculate crash rates. This second method does of course assume that the historical rate of accidents will continue into the future, which, if there are future safety improvements, may lead to an overestimate for crash rate in future years.

3.3 In order to estimate crash rates from historical data it is necessary to have complete data on airport related crashes and the corresponding numbers of movements. The completeness of the data is important when calculating crash rates. If any relevant crashes are omitted the crash rate will be underestimated, while if any relevant movements are omitted the crash rate will be overestimated.

3.4 In some previous studies, separate crash rates for take-offs and landings (Refs. 14, 15, 16) have been produced, while for others a common crash rate for both was used (Refs. 8, 17, 18). Some studies derive separate crash rates for different groups of aircraft (e.g. fixed wing/rotorcraft, civil/military, aircraft of different weights) (Refs. 8, 9, 13, 16, 17, 19, 20). In studies which have focused on particular airports, the crash estimates have often been 'tailored' to reflect certain features (e.g. type of traffic, operational or topographical aspects) of the airport in question. Even in studies which are not specific to a particular airport, criteria are usually set for selecting those accidents deemed relevant, i.e. crashes near airports.

3.5 One of the most important selection criteria is based on the geographical location of the airport. Some studies consider crashes from only one country or a group of countries (e.g. Refs. 8, 21), because accident statistics from different parts of the world indicate that some regions of the world have better safety records than others (Ref 22).

3.6 If crash rates are to be used in the estimation of individual risk, specific requirements on accident selection are needed. The crash set selection criteria should, as far as practicable, match those used in the crash location model. For instance, some models exclude accidents which occur on the runway so the crash set for such models should also exclude these. Crash location models are reviewed in Chapter 4.

3.7 Because of the variety of selection criteria used, great care should be taken when comparing crash rates from different studies. For example, the exclusion of crashes on the runway (as mentioned above) would give a lower estimate of the crash rate than would be the case if they were included. Similarly the ratio of take-off to landing crash rates may vary between different studies because of the different selection criteria used.

3.8 Although crashes are in general caused by a large variety of different events, different types of aircraft will have different crash rates because of variations in their design (for instance, single engine aircraft might be expected to suffer more accidents due to engine failure than multiple engine aircraft). Ideally, historical accident data could be used to calculate separate crash rates for each type of aircraft using UK airports. However, this approach is not sensible because aircraft type specific crash rates of necessity would be based on very small numbers of crashes and this would lead to estimates with very low precision. An alternative approach is to group aircraft types together into larger generic groups, which are likely to have similar accident characteristics, and then to derive crash rates for these groups.

3.9 Clearly, it is important that the data on movements for the airports considered can also be split into the same groups so that crash frequencies can be calculated by multiplying the movements for each group by the appropriate crash rate. The extent to which aircraft types can be broken down into groups for the derivation of crash rates is therefore also dependent on the availability and detail of the data on movements at the airport set. The following sections of this chapter explain the groups selected for the PSZ analysis.

Derivation of generic aircraft groups for crash rates

3.10 As mentioned above, in this report historical data is used to estimate crash rates as this leads to more reliable estimates than the use of theoretical models. Appendix A presents a review of available sources of data on crashes and movements together with the results of completeness tests on the selected data sources. Based on this review, the chosen sources of data for this analysis were the Airclaims CASE database (Ref 23) for crashes and the Official Airline Guide (OAG) (Ref 24) database for scheduled passenger movements. The Airclaims database contains world-wide accident data by aircraft type for jet airliner total and major partial losses, turboprop total losses, and executive jet total losses. The OAG database has historical airline scheduled passenger flights by aircraft type and by country.

3.11 Figure 3.1 shows how the world-wide crash and movement data were subdivided to form the generic aircraft groups used in the calculation of crash rates in this study. Since both the Airclaims crash data and the OAG movement data can be disaggregated by country, their use allows the derivation of ‘first world’ crash rates (i.e. based on accidents and movements in first world countries, as defined in the glossary). Crash rates corresponding to first world countries are more likely to be representative of UK crash rates than those based on world-wide data, and so the initial breakdown was into first world crashes and movements.

3.12 The next major step involved subdividing the aircraft into generic aircraft type groups. First, the aircraft were classed according to their type of engine as follows:

- Jets
- Turboprops
- Piston-engine

3.13 The above initial grouping was based on the assumption that different engine types would be associated with different levels of reliability (e.g. piston engines would probably have higher failure rates than jet engines). Within the limitations of the available data, further breakdowns were undertaken for these engine type groups, and are described in the following sections.

Jets

3.14 Figure 3.1 shows that the jet data was next divided into three groups; western airliner jets, executive jets and eastern jets. The OAG movement data shows that the western airliner jets (such as the B737, the DC10 and the A310) constitute the great majority of the first world’s scheduled passenger movements, and are therefore particularly important for UK airports. In contrast, the eastern jets (such as Ilyushins or Tupolevs) and the executive jets (such as the Learjets, Gulfstreams and Falcons) make far fewer first world scheduled passenger movements.

3.15 Previous studies have shown that earlier types of jets generally have higher crash rates than later ones (Ref 25). The western airliner jets were therefore further subdivided by age based on the classes used by Boeing (Ref 25). The Boeing Classes are based on when the aircraft was first developed and entered service and are as follows:

- Class I: First Generation Jets, e.g. Comet, Boeing 707
- Class II: Second Generation Jets, e.g. B727, VC-10
- Class III: Early Wide Bodied Jets, e.g. B747, Tristar

- Class IV: Subsequent Types, e.g. Airbus 310, B757

3.16 Table 3.1 shows a list of the aircraft types contained in the different classes. Because of the limitations of the data on scheduled movements contained in the OAG database, it is not possible to distinguish reliably between different variations of some jet aircraft in Classes II-IV. (For example, spot checks showed that the OAG database does not reliably distinguish between movements for the B737-100 and the B737-400 - see Appendix A.) Therefore just two classes were used for western airliner jets: Class I and Class II-IV. This is not a major limitation because Reference 25 indicates that the greatest variation in crash rates is between Class I and the other groups, whereas the Class II, III and IV crash rates are similar.

Turboprops

3.17 Airclaims (Ref 23) records total losses for western-built turboprops designed and built for airline use. In this study the turboprop class is divided into western airliner turboprops and ‘unclassified’ turboprops. The unclassified turboprop class includes eastern turboprops, and smaller western-built turboprops not originally designed for airline use (e.g. Beechcraft King Air). Without the appropriate crash data for this second group, an assumption had to be made regarding the crash rate for this class - see Chapter 6.

3.18 Airclaims defines groups for the western airliner turboprops based on MTWA (Ref 26). However, initial crash rate analyses performed in the current study using these groups did not produce conclusive results, although there was some evidence that aircraft in the heaviest group had higher crash rates than the other groups. An analysis was performed in order to investigate whether it was appropriate to put airliner turboprops in groupings similar to the western airliner jets, using the dates when the different types entered service. The analysis found that turboprop types which were first delivered in the 1950s and 1960s had similar crash rates, but these were significantly higher than for those types first delivered in the 1970s and 1980s.

3.19 On the basis of this analysis it was decided to divide the turboprops into the following two groups based on date of first delivery for the type:

(i) aircraft with first delivery in and after 1970 (group T1); and

(ii) aircraft delivered earlier (group T2).

Table 3.2 shows a list of the aircraft types contained in the two western airliner turboprop classes used for the calculation of crash rates. Note that turboprop aircraft types which are not used (or very rarely used) for scheduled passenger movements in the UK have been excluded.

Piston-engine aircraft

3.20 The Airclaims database does not contain data on crashes for piston-engine aircraft and hence it was not possible to further subdivide this category. Chapter 6 describes how a crash rate for piston-engine aircraft was obtained.

Summary

3.21 The full breakdown of aircraft by type for the calculation of crash rates is therefore (see Figure 3.1):

- Class I western airliner jets
- Class II-IV western airliner jets
- Eastern jets
- Executive jets
- Western airliner turboprops delivered in and after 1970 (T1)
- Western airliner turboprops delivered before 1970 (T2)
- Unclassified turboprops
- Piston-engine aircraft

3.22 With the exception of the executive jets, unclassified turboprops and piston-engine aircraft, first world scheduled passenger crash rates can be estimated for the above groups using Airclaims crash data and OAG movement data. The details of these calculations and the estimates made for the other aircraft crash rates are described in Chapter 6.

3.23 The predicted crash frequency (expected number of crashes per year) at any given airport for a particular group of aircraft is the product of the crash rate (crashes per movement) appropriate to that category of aircraft and the annual number of movements of such aircraft at the airport in question. The overall crash frequency is the sum of the crash frequencies for the different categories of aircraft.

3.24 The movements at the sample airports examined here must therefore be split into the same groups of aircraft types listed above which were used in the derivation of crash rates. Appendix B gives a breakdown of the movements into the aircraft groups at each of the five UK airports studied in this report. Appendix B shows that a complete classification of the airport movements using these categories was not possible. A final category for ‘other non-commercial’ flights (e.g. test and training, military, official) was therefore also included to cover those movements at the sample airports not included in the other categories. Chapter 6 gives the results of the crash frequency calculations at the five airports.

4 CRASH LOCATION MODELS

Introduction

4.1 This chapter reviews methods for determining the statistical distribution of crash locations in the vicinity of an airport (crash location models) and describes the method adopted for the analysis of the five example airports. Crash location models can be used together with crash frequency estimates (see Chapter 3) to estimate the annual probability that a crash will occur at a particular location in the vicinity of an airport. This is the second stage in the process of calculating individual risk distributions around an airport.

4.2 Crash sites are not uniformly distributed in the vicinity of airports. Because the aircraft involved in airport related crashes are all flying to or from a runway, the likelihood of a crash occurring at a particular location is closely correlated with the position of the location relative to the runway. The distance from the runway threshold along the extended runway centreline and the perpendicular distance from the extended runway centreline are both key factors in regard to an accident occurring at a particular location.

4.3 Figures 4.1 and 4.2 illustrate how crashes are distributed as a function of their distance from the runway ends and perpendicularly from the extended runway centreline respectively. These distributions are based on data from crashes which occurred between 1970 and 1995.

4.4 From Figure 4.1 it can be seen that crashes are much more likely to occur close to the runway ends than at large distances from them. The distribution of accidents with respect to the runway threshold is termed the longitudinal crash distribution.

4.5 Similarly Figure 4.2 illustrates that crashes also tend to occur much more frequently close to the extended runway centreline than further out. The distribution of crashes with respect to the extended runway centreline is called the lateral crash distribution.

4.6 A number of different crash location models have been developed which represent the distribution of accidents around an airport. The majority of these models have been produced by fitting mathematical probability distributions to the historical geographical pattern of accidents (empirical models). A notable exception to this is the crash location model developed by DNV Technica (Refs. 15, 21, 27, 28) which uses a series of postulations about the behaviour of crashing aircraft to estimate the distribution of crashes (and is thus a ‘deterministic’ model).

4.7 The distinction between empirical and deterministic models is not always complete - empirical models may contain a few assumptions, while deterministic models may have a few parameters based on data. The models reviewed here have been classified according to whether their main features are determined by empirical data or by modelling assumptions. If the literature provides a mathematical expression for the model this is identified.

Deterministic Models

Technica location model

4.8 DNV Technica used their crash location model to perform risk calculations for Schiphol Airport in Amsterdam (Ref 15, 27, 28). The model was subsequently developed and used in an analysis for the public inquiry into a second runway for Manchester Airport in the UK (Ref 21).

4.9 For the Schiphol study the longitudinal distributions in the model were based on data from a relatively small set of accidents (eight take-offs and eight landings). For the Manchester analysis the longitudinal distributions were based on information from the World Airline Accident Summary (Ref 29) on the total distances of crashes from the runway for 119 landings and 51 departures.

4.10 For the lateral crash distributions, Technica divided crashes into two types: those with steep dive angles and those with shallow dive angles. For each type a Gaussian statistical distribution of divergence about the average dive angle was assumed. Steep angle crashes were assumed to arise from major losses of control and their divergence was assumed to be larger (between 20 and 40 degrees standard deviation) than for shallow crashes (2 degrees standard deviation).

4.11 For the Schiphol study (Ref 15) 91% of crashes on approach were taken to be shallow, while for the Manchester analysis (Ref 21) the corresponding proportion was 60%. The proportions of shallow and steep dives on take-off were deemed to depend on the distance from the runway. For the Schiphol calculations all take-off crashes less than 1 km from the runway were initially assumed to be shallow (this was later revised in Reference 15 to 50% of crashes within 1 km) and all of those crashing after this distance were assumed to be steep. For the Manchester calculations the corresponding dividing distance was 0.5 km (Ref 21).

4.12 The Technica crash location model tries to takes account of the possibility that a pilot might retain partial control of a crashing aircraft and attempt to direct the aircraft to a lesser populated area. In the Schiphol calculations, approximately 90% of shallow-angled crashes of jets on approach were taken to be partially controlled in this sense, while for Manchester, the corresponding proportion was taken to be 50%.

4.13 The Technica model has the advantages from an explanatory viewpoint that it can take account of the intended routes of aircraft, treats take-off crashes and landing crashes separately and takes some account of the possibility that pilots will retain some control of crashing aircraft and avoid populated areas. However the model does depend on several major assumptions about the behaviour of aircraft in crashes, most of which are based on an analysis of a limited amount of historical data. This will lead to a high level of uncertainty in the results.

Empirical Models

4.14 In virtually all the empirical models reviewed, difficulties were encountered in obtaining a sufficiently large and representative set of crash location data points with which to fit a probability distribution function. Some studies use separate distributions for take-off and landing accidents (Refs. 14, 21, 30), while others derive separate distributions for different type/weight groups of aircraft (Refs. 13, 17). However, subdividing the modelling in this way would only produce better results in terms of predictive accuracy if each group is in some sense homogeneous (in terms of their crash locations) and if each contains a sufficiently large amount of statistical data.

4.15 Many of the crash distributions represent the crash location with respect to the runway threshold and the extended runway centreline (Refs. 13, 17, 30, 31). However, as many airports have curved departure routes (curved approaches are much rarer), some models (Refs. 14, 16) attempt to relate the crash location to the intended route. The main problem with this approach is that information about the intended route of an aircraft is very often not recorded in published accident reports. The ability to relate crash location probabilities to the intended route of the aircraft is only a significant advantage if detailed modelling of actual routeings at a particular airport is to be performed.

4.16 The most recently published empirical models are summarised below.

AEA location models

4.17 AEA Technology initially derived crash distributions for commercial/military aircraft and for light aircraft (with MTWA less than 2.3 tonnes) based on USA and Canadian accidents (Ref 17). Common distributions were used for take-offs and landings. The equations for airport-related crash distributions (in crashes per km^2) are given on page 13 in Reference 17, and the corresponding contours are given in Figures 2 and 3 of Reference 8.

4.18 A later study focused particularly on accidents occurring within 5 miles of an airport, involving aircraft with MTWA greater than 2.3 tonnes (Ref 31). Three sources of data were used in this study: 54 accidents from an earlier study by the USA Nuclear Regulatory Commission (USNRC) covering accidents up to 1977, 36 accidents from US National Transportation Safety Board (NTSB) reports for 1977 to 1990, and 31 reports on crashes to RAF aircraft from 1977 to 1989. The AEA model is therefore based on a total of 121 accidents. Separate distributions were produced for take-off and landing accidents.

4.19 The statistical distributions fitted to the data used Cartesian (x,y) co-ordinates with the y axis representing the distance along the extended centreline from the threshold and the x axis the distance from the centre-line[2]. Initially, consideration was given to the use of a function of the form F(x,y)=f(y)g(x,y). This would have allowed the 'width' of the distribution to change as the distance from the threshold increased (to allow for the fact that crash locations become more 'spread out' further from the runway). Although Reference 31 states that there was some evidence in the data that the width of the g(x,y) distribution increased with y, they found that 'the limited number of accidents in the database meant that large statistical fluctuations arose from the partitioning of the data'. Because of this problem it was decided to use simple distribution functions of the form F(x,y)=f(y)g(x). These expressions are given on page 13 in Reference 31.

RAND location model

4.20 The RAND crash location model (Refs. 16, 32) was developed and used for Schiphol. The crash data was based on that produced by Boeing on hull loss accidents world-wide between 1982 and 1992. Of the 114 hull loss accidents in Boeing's database for this time period, there were 53 crashes (41 landings and 12 take-offs) with recorded crash positions more than 500 metres from the runway. Reference 16 does not make it clear why RAND considered only crashes more than 500 metres from the runway; it is surmised that this criterion was used to exclude crashes inside the airport boundary.

4.21 A single distribution was fitted to the data for both the landing and take-off accidents. The fitted function related crash location to the distance from the runway threshold and distance from the extended runway centreline. However, in order to take some account of curved departure routes, the distribution was 'bent' around the intended routes (i.e. they used the (x,y) distribution which corresponded to distances from the runway threshold and the centreline as if it corresponded to distances from the intended route).

NLR Location model

4.22 NLR developed a statistical model which was also for use at Schiphol. The model described in Reference 14 was based on historical data on 181 commercial aircraft accident locations, based on a co-ordinate system representing locations with respect to the nominal route of the aircraft. Where the nominal route of the aircraft was available in the accident reports NLR used this information. However in many cases it was not available, and in these cases NLR assumed that, unless the accident report stated otherwise:

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[2] The x and y co-ordinate convention used here and throughout this report differs from that used by AEA in Reference 31.

(i) landing aircraft which crashed within a distance of 12 km from the runway end along the extended runway centreline and 6 km left or right of the extended centreline were on an intended route along the centreline; and

(ii) departing aircraft which crashed within a distance of 6 km along the extended centreline were on an intended route along the extended centreline.

4.23 The NLR model consists of three accident location distributions, one for each of the following types of accidents:

- take-off accidents (overruns and non-overruns)
- landing accidents (non-overruns)
- landing overruns

The derivation of the NLR model is described in Reference 14. However, the equations and data on which they are based are not publicly available as they are commercial products. Crashes on or adjacent to the runway are excluded from the published NLR model (Ref 14), although NLR also have an additional unpublished model for adjacent crashes (based on 124 crashes). All of these distributions are based on accidents which involved aircraft of 5.7 tonnes (MTWA) or above. NLR have also recently developed a separate model for light aircraft (defined as being for aircraft with MTWA less than 5.7 tonnes - Ref 33) but the details of this model have not yet been published.

NATS location model

4.24 The NATS location model (Ref 34) has only recently been completed. It is based on position information from 354 crashes involving aircraft in airport-related phases of flight and with MTWAs of 4.0 tonnes or above. Four tonnes was chosen as the cut off, as this includes the vast majority of aircraft used for commercial operations. Below this value most types are predominantly used for non-commercial operations which might be expected to have a different crash location distribution because of the different types of flying activities in which they are used. The model consists of four separate distributions (given in Ref 34) for different types of crash as follows:

- landing overruns (including veer-offs)
- landing crashes from flight
- take-off overruns (including veer-offs)
- take-off crashes from flight

4.25 No attempt to ‘bend’ the distributions around the arrival and departure routes was made for this model and all crash locations were measured relative to the runway ends and the extended runway centreline. The reason for this decision was that only a small proportion of crash reports record in detail the intended route of the aircraft prior to an accident. Even when this is recorded it is not always clear how to relate the intended route of the aircraft to the eventual accident location. For example, on departure a serious problem (which ultimately causes a crash) may arise before the intended route deviates from a straight path. In this case, the pilot would not attempt to follow the intended curved route, and therefore the actual crash location would be the same irrespective of whether the intended route was curved or straight.

4.26 The fact that aircraft do not always follow straight routes will to some extent be implicit in the NATS model, as some of the historical crashes would have occurred while aircraft were on curved routes. Thus the ‘average’ effect of aircraft routeing on crash location is taken into account in the NATS model. The effects of curved routes are likely to be small, where the risk is greatest, close to the runway ends.

Method Adopted for the PSZ Assessment

4.27 Table 4.1 summarises the important features of the five recently developed crash location models which are described in the preceding paragraphs. Because of the problems involved in verifying the assumptions required for a deterministic model it was decided that an empirical model would be used for the PSZ work.

4.28 Of the four recent empirical models the NATS model is the most recently completed and is based on the largest data set. The NATS model also has the advantage that all the accidents on which the distributions are based and the mathematical functions for the distributions are publicly available and are therefore open to scrutiny. After consultation with the DoT, it was therefore decided to use the NATS model for the main part of the crash location calculations. Appendix C describes the NATS model in more detail.

4.29 All of the empirical models reviewed were based on data for relatively large aircraft (predominantly those used for commercial operations). The NATS model considered aircraft with MTWA of 4.0 tonnes and above. Many UK airports have significant proportions of flights by light aircraft. It could be assumed that the distribution of crashes involving light aircraft would be the same as for larger aircraft, but this could result in inaccuracies, as the activities of light aircraft differ significantly from those of commercial aircraft and their crash distributions would also be expected to be different. It was therefore decided to model light aircraft crashes with a separate distribution specifically developed for small aircraft.

4.30 There are very few published models specifically on light aircraft crash distributions. NLR are known to have developed a location model for aircraft with MTWA less than 5.7 tonnes (Ref 33) but details on this have yet to be published. The earlier published models for light aircraft crash locations seem fairly crude, but the best of these simple models appears to be that developed by

AEA Technology based on USA and Canadian light aircraft data (Ref 17). Therefore this was used for light aircraft in the calculations. Appendix C also describes the detail of the AEA light aircraft crash location model.

5 CRASH CONSEQUENCE MODELS

5.1 The third (and final) stage in assessing individual risk in the vicinity of airports is to combine the crash risk distributions with crash consequences. Methods for providing estimates of the consequences of accidents are called consequence models. This chapter reviews the available crash consequence models and describes the method adopted for this study.

5.2 The consequences of an aircraft accident depend upon a large number of factors including size of aircraft, impact velocity, impact angle, whether or not the aircraft breaks up on impact, the amount of fuel on board, whether a fire occurs (and the extent of the fire), the terrain at the crash site etc. Consequence models need either explicitly or implicitly to produce two estimates: consequence area (the region on the ground affected by an accident - different models have different definitions) and lethality (the proportion of the people in the consequence area at the time of the crash who would be expected to be killed).

5.3 As with crash location models there are two basic approaches to developing crash consequence models: a deterministic approach and an empirical approach. Deterministic models of the consequences of a crash can be developed based on theories and assumptions about the effects of the various factors which might affect consequences. Empirical models are based on analysis of what actually happened in past accidents. The consequence models reviewed here have been divided into these two broad groups.

5.4 The main problem with deterministic models is that they are based on a number of modelling assumptions, which, although apparently reasonable, are difficult to validate in a quantitative sense. Alternative assumptions could be made which would generally lead to very different results. Therefore with little evidence to support particular assumptions and parameters, the choice of assumptions may be hard to justify.

5.5 The main problem with empirical models is finding sufficient data on which to base them. The detail with which data on consequences of accidents is recorded is very variable. Also, the consequences of historical accidents show large variation. This results in high levels of uncertainty in the results from empirical models, but it is difficult to see by what means this uncertainty could be reduced.

Deterministic Models

5.6 In order to model accurately the accident consequences using a deterministic approach, a detailed understanding of the influence of all the major factors which could affect the consequences of a crash and knowledge of the probabilities of different outcomes occurring is required. Because of the large number of factors and outcomes potentially involved and the difficulty of validating the model components, the development of a detailed deterministic model is very complex.

5.7 However, some simplified deterministic models have been developed which consider just a small number of different outcomes and make modelling assumptions about the probabilities of the relevant variables. Three such consequence models which have been applied in recent years to the modelling of third party risk around airports are those used by RAND (Refs. 16, 32) for Schiphol, DNV Technica (Refs. 15, 21, 27, 28) for Schiphol and Manchester, and by ACARRE for Sydney (Kingsford Smith) Airport (Ref 35). These will be referred to here as the RAND, Technica and ACARRE consequence models respectively. These models are summarised and compared below.

RAND consequence model

5.8 The first component of the RAND model is the mortality rate, M, which is the proportion of people killed in a given structure within the area affected by the crash. RAND produced a matrix of values of M for different aircraft sizes (Small, Medium, and Large) and for two groups of structures (small and large). The values in the matrix were based 'on prior studies, limited data on prior accidents, and a heuristic parameter approach'. It was suggested that the 'no building' case would result in a similar mortality to that for small buildings.

5.9 The second component of the RAND consequence model is the crash area. A matrix of crash areas for large, medium and small aircraft types, for steep and shallow crash angles, in 'open field' conditions was produced. This was again said by RAND to be based on prior studies. In their study of risk in the vicinity of Schiphol, RAND used the mortality corresponding to small buildings and steep impact angles. Tables 5.1 and 5.2 summarise these parameters.

ACARRE consequence model

5.10 The ACARRE model considered the damage resulting from the impact of the aircraft and wreckage, and any subsequent fire. For fire damage two scenarios were considered: a pool fire or a fireball. It was assumed that fireballs would occur in 5% of accidents and pool fires in the remaining 95%.

5.11 For scheduled aircraft crashes the size of the zone of 'high risk of fatality' was taken as the greater of the impact area and the fire affected areas. It was assumed that anyone in the impact area would be killed and that 30% of the people in the fire affected areas outside the impact area would be killed. The number of people killed on the ground was estimated from the average population density in the affected area.

5.12 ACARRE derived numbers of fatalities for 'Other' aircraft from a review of historical crashes of non-airline aircraft. Crashes involving these aircraft were found to result in much smaller numbers of fatalities than those derived for scheduled aircraft. The parameters of the ACARRE model are summarised in Table 5.3 for Scheduled aircraft (represented by a Boeing 767-200) and Other aircraft (e.g. general aviation aircraft represented by a BAe Jetstream 31)

Technica consequence model

5.13 The Technica model used in calculations for Manchester (Ref 21) appears to be the same as that used in their work for Schiphol (Ref 15, 27, 28). Technica assumed that the speed at which all the crashes took place was about 50% of take-off or landing speed (different crash velocities were not considered), and that fuel ignition always occurred.

5.14 The Technica crash location model (see Chapter 4) divided crashes into steep and shallow angle impacts. For the consequence calculations it was assumed that steep-angle crashes could be approximately modelled as areas of concentrated impact and fire damage surrounded by areas of scattered impact damage. For shallow-angle impacts it was assumed that both wings would be damaged as the aircraft slid along the ground giving rise to pool fires; the area of damage would be determined by the size of the pool fires and the skid length and width of the remaining aircraft structure. The size of the crash area is thus dependent on the size of the impacting aircraft, the impact angle, and the fuel load available for ignition. The Technica model assumes that all individuals within the area impacted by a crashing aircraft would be killed. Table 5.4 summarises the parameters of the Technica model.

Empirical models

5.15 The alternative to the use of deterministic models is to derive consequence areas and mortality factors from historical crash data. Three recently produced consequence models, the NLR model (Ref 14), the Eddowes model (Ref 36) and the NATS model (Ref 34) are empirically based.

NLR consequence model

5.16 NLR analysed historical accident data to relate the consequence area to the MTWA of the crashing aircraft. They assumed that the relationship between MTWA and the consequence area was linear and produced three different relationships relating to three different types of terrain: Built-up, Open, and Wooded and Water. As the consequences were not well correlated with MTWA, NLR did not perform a statistical analysis to fit the data. Instead the average of the ratios between consequence areas and MTWA for the accidents in their dataset was used.

5.17 The model (described in Ref 14) used a constant lethality (see glossary) of 0.3, which was assumed to be the same over the whole of the consequence area. This value was the average lethality of the accidents involving third party casualties that NLR analysed. NLR assumed the consequence area to be ‘nondirectional' and therefore represented it as a circle with its centre at the aircraft wreckage location. NLR later produced a refined model which predicts smaller consequence areas than their published model (see Ref 33). However, the details of the refined model have not yet been published. Table 5.5 summarises the parameters for the published NLR model.

5.18 The NLR model was based on an analysis of a relatively small number of crashes whose consequences are known in detail. This resulted in a substantial degree of statistical uncertainty. Diagrams of the data used in the NLR analysis in Reference 14 also indicate that the correlation between MTWA and consequence area is not very strong. NLR consider their model to be cautious (i.e. tending to overestimate the consequences).

Eddowes consequence model

5.19 Eddowes developed a consequence model which was presented at the public inquiry into the proposed second runway at Manchester airport (Ref 36). Eddowes' consequence model was based on an analysis of historical accident data which provided estimates of three quantities: the number of ground casualties, houses destroyed, and residential area affected, all per unit weight of aircraft.

5.20 Eddowes analysed data on more than 30 accidents involving ground casualties and found that ground casualties and aircraft MTWA were linearly correlated (22 casualties per 100 tonnes MTWA). An analysis of a smaller set of accidents (eight) showed that the extent of property damage also increased with the weight of the aircraft (6.3 houses destroyed per 100 tonnes MTWA). The relationship between aircraft weight and numbers of houses affected together with an estimate for the average number of houses per hectare was used to derive the average area affected by a crash as a function of aircraft weight (0.25 hectares per 100 tonnes MTWA).

5.21 It was noted that the speed of aircraft is generally higher for modern aircraft than for many of the older aircraft. The casualty rate, therefore, could be expected to be higher for modern, faster aircraft than that which would be predicted on the basis of data from historical accidents covering a wider range of accident types. As a consequence Eddowes considered that the model would tend to underestimate the number of casualties for a given weight of aircraft.

NATS consequence model

5.22 Data on the consequences of aircraft accidents had been extracted concurrently with the extraction of data on crash positions for the NATS crash location model (described in Chapter 4 and in more detail in Reference 34). It was decided to use this available data to develop a set of simple empirical expressions for consequence areas.

5.23 NATS obtained information on the areas on the ground effectively destroyed as a result of the accident (including post-accident fires) and also the areas over which pieces of the aircraft wreckage were dispersed (debris area). Analyses of the dependence on MTWA were performed for both the debris area (based on 126 crashes) and the destroyed area (based on 56 crashes) which found that there was a low correlation between MTWA and these areas. Both linear relationships between areas and MTWA, and relationships between the logarithms of both these values were examined. The data are shown in Figures 5.1 and 5.2. The effects of terrain (i.e. built up, open, wooded etc.) were also investigated but were found to have no significant correlation with destroyed or debris areas.

5.24 Both linear and log-log relationships could be obtained between debris area and MTWA. However it proved impossible to obtain a meaningful linear relationship for the destroyed area as no significant dependence on MTWA could be found with a linear fit. It was also noted that log-log relationships have an important advantage over linear ones when fitting data with a high degree of ‘scatter’; in the former case, individual points with extreme values do not have as great an influence on the fitted relationship. Therefore log-log relationships were chosen in preference to linear ones for both debris and destroyed areas.

5.25 The log-log relationships obtained from the regression analysis are shown in Table 5.6. As can be seen from the R^2 values (which measure the extent to which the MTWA can explain the variation in the areas), only about a quarter of the statistical variation in debris areas could be attributed to MTWA, and the fit was substantially worse for the destroyed areas. It appears than the area affected by a crash is dependent upon a number of other factors (specific to individual crashes) that could not be taken into account in the analysis.

5.26 No attempt was made to extract data on the lethality in the accidents analysed for the NATS model. The reason for this was that, although the number of people on the ground killed in an accident is usually recorded, the number of people present at the time of the accident is very rarely directly available.

5.27 An assumption can be made that everyone would be killed within the destroyed area, but to extend this assumption to the debris areas would probably substantially overestimate the risk. The NATS database includes 32 accidents in which people on the ground were killed or injured and there was no evidence that any of these casualties occurred in areas which were not destroyed. Although the data in the NATS database is only a subset of all accidents which have resulted in ground fatalities, and clearly casualties could occur within the debris area, the use of destroyed area combined with an assumption of 100% lethality would still probably be slightly cautious. One reason for this is that, in some accident reports, the destroyed areas correspond to regions in which post crash fires spread through trees and crops; escape from such fires would probably have been possible in some cases. For this reason the log-log relationship between MTWA and destroyed areas and a 100% lethality was adopted as the NATS consequence model despite the degree of uncertainty in this relationship. This model has been used in the calculations presented later in this report.

5.28 It should be noted that the NATS model predicts a lower dependence on MTWA than the linear dependence used in the Eddowes and NLR models. The high degree of scatter in the data (shown in Figure 5.2) makes it difficult to have a high degree of confidence in the form of the weight dependence obtained in the analysis. Nevertheless, a relatively weak weight dependence (compared with linear models) may not be unreasonable given that many factors influence values for areas on the ground destroyed. In some accidents aircraft dimensions (particularly its wingspan) appeared to influence the area destroyed (wingspan has a less than linear dependence on MTWA).

5.29 Other details relating to the nature of the accident itself and the ground features in its vicinity may also be a strong influence on the accident consequences. This is indicated by the fact that, as mentioned above, the accident data on destroyed areas used in the NATS model includes destruction to forested areas and fields of crops by post-crash fires as well as by direct impact. Areas of property destruction (where property includes items ranging from buildings, cars, fences to power lines and airport lights) were included in the destroyed areas. These different types of destroyed areas may well account for some of the high degree of variability in the data, and the difficulty in finding a clear trend in relation to aircraft weight.

5.30 The NATS consequence model has been used in the calculations presented later in this report. As mentioned above, the fact that the NATS model has a weaker MTWA dependence than the linear relationship in the published NLR model will lead to lower estimates of the consequences for accidents involving aircraft with MTWA of 80 tonnes or more. It was therefore decided to examine the effects of using the NLR model in the calculations for Heathrow as part of the sensitivity analysis described in Chapter 8.

Comparison of the Models

5.31 Six recent consequence models have been described in this chapter: three deterministic models and three independent empirical models. These models were based on different assumptions and data analyses. In order to compare how different these models are in terms of their influence on the result of individual risk calculation, ‘effective consequence areas’ were calculated for each of the models for a Boeing 767 aircraft, chosen only because this was the ‘typical’ scheduled aircraft used by ACARRE.

5.32 The ‘effective consequence areas’ are consequence area sizes which are adjusted to take account of the different lethality values assumed in the models, so as to make each of them equivalent to a 100% lethality area. For example, as the lethality assumed in the original NLR model is 30% over the area of a crash, the effective consequence area for the NLR model would be 0.3 times NLR’s total estimated consequence area. In other words, the effective consequence areas calculated are directly proportional to the number of people expected to be killed in the event of an ‘average’ Boeing 767 crash.

5.33 Table 5.7 shows the results of the comparison. The comparison highlights the considerable differences in the results obtained with these consequence models. It can be seen that the deterministic models tend to have similar effective consequence areas - the ACARRE, Technica, and RAND models are all within a factor of two of each other.

5.34 Table 5.7 also shows that the predicted areas from the empirical models are markedly smaller than those of the deterministic models (although these also are within a factor of two of each other). This apparently substantial difference between the results of using empirical versus deterministic approaches indicates that some of the assumptions used in the deterministic models - e.g. in modelling of the post-crash fires - are somewhat pessimistic in the light of empirical data. However, although empirical models might be expected to be more reliable on average than deterministic approaches, because they are derived from measured data, all the empirical models reviewed appear to be based on relatively small numbers of crashes which may not be representative of the circumstances of a particular crash at any given airport.

Summary

5.35 It is clear from the review of crash consequence models presented above, that this part of the process in calculating individual risk has a high level of uncertainty. The deterministic models appear to predict markedly larger consequence areas than those actually observed, while the empirical models are (necessarily) based on limited data and are therefore subject to considerable uncertainty. Because of the difficulty in validating the deterministic model assumptions, it was decided to use an empirical model for the PSZ analysis.

5.36 Of the three empirical models reviewed here, neither the NLR nor the NATS model are well correlated with the variable used as a predictor (MTWA). This implies a low degree of confidence about the form that any MTWA dependence should take (e.g. logarithmic, linear, polynomial etc.), as well as a substantial degree of uncertainty in the fitted parameters. A reasonably good correlation was obtained in the Eddowes model between number of houses destroyed and MTWA, but as this is based only on eight datapoints this may have been simply fortuitous. If MTWA alone is not a good predictor of consequence area for an individual crash, this implies that consequence area is determined by additional factors. Without far more accident consequence data it is not be possible to incorporate these different factors into these models.

5.37 This does not necessarily imply that these empirical models contain too much uncertainty for them to be useful for determining average values of individual risk at any given location. If the datasets upon which these models were based are broadly representative of the airports for which these calculations are being performed, then the other factors influencing consequence areas may be expected, to some extent, to 'average out'.

5.38 Despite the level of uncertainty inherent in individual empirical models, it also appears that they can produce consequence areas which are broadly compatible with each other. For example, the predictions of consequence areas obtained using different empirical consequence models shown in Table 5.7 were generally within a factor of two of each other. This indicates that empirical consequence modelling may actually be more robust than is initially indicated by the high degree of 'scatter' in the data, although it is still possible that this apparent compatibility may simply be fortuitous.

Method adopted for the analysis

5.39 The NATS model was selected for the baseline calculations (see Chapter 7). The choice of the NATS model over the NLR consequence model was largely based on the inherent advantages of using an 'in-house' model, namely a detailed knowledge of the data, method of analysis, and limitations of the model. The fact that the NATS model has a weaker MTWA dependence than the linear relationship assumed in the published NLR model will lead to lower estimates of the consequences for accidents involving heavier aircraft. The effects of using the NLR model in the calculations for Heathrow were examined as part of the sensitivity analysis described in Chapter 8.

6 CALCULATION OF INPUT PARAMETERS

6.1 As noted in Chapter 2, the calculation of individual risk in the vicinity of airports requires three main quantities: crash frequency (crashes per year), a method for determining the distribution of crashes with respect to location (crash location model), and a method for determining the consequence areas resulting from a crash (crash consequence model). This section describes the estimation of the various parameters which are required for individual risk calculations for each of the five sample airports.

Calculation of crash rates

6.2 Chapter 3 gave an overview of the process for the calculation of crash rates and crash frequencies. Crash rates for an aircraft type group are derived by dividing the total number of crashes involving aircraft in the group by the total number of movements (take-offs and landings) made by the aircraft types in the group. As described in Chapter 3 crash rates for the following aircraft groups have been calculated: Class I jets, Class II-IV jets, eastern jets, executive jets, T1 turboprops, T2 turboprops, unclassified turboprops, piston-engine aircraft, and other non-commercial flights. The estimation of these crash rates is described below.

Crash rates for western airliner jets

6.3 For western airliner jets crash rates were calculated for scheduled passenger (SP) flights only. The reason for this was that complete movement data broken down by airport and aircraft type was only available for SP flights (see Appendix A). Therefore crash rates specific to first world airports such as those in the UK could only be calculated for SP flights. A comparison of the world-wide SP crash rate for Class II-IV jets with the world-wide crash rate for all Class II-IV flights (including charter, cargo etc.) indicated that the SP crash rates are representative of the overall crash rates for these types of aircraft (see Appendix A). Therefore the SP crash rates were used for all western airliner jet movements at the sample airports. The use of alternative assumptions about the crash rates for non-SP jets were investigated in the sensitivity analysis presented in Chapter 8.

6.4 The extract from Airclaims database (see Appendix A), for the period 1979 to 1995 inclusive, of total losses to aircraft in airport-related phases of flight was used as the source of accident data for the western airliner jet crash rates. The reason for this choice was that it provides a reliable and complete set of relevant accidents; it is also in PC readable format. All the accidents which involved SP western airliner jets were then extracted from the Airclaims dataset to form the initial crash set. A small percentage (less than 8%) of these accidents were found not to be flight-related, e.g. fire occurring after a successful landing, and these were removed from the crash set.

6.5 The aircraft in the initial crash set were categorised as Class I or Class II-IV (see Table 3.1), and also according to whether the accident occurred at a first world airport. Movements made by aircraft in each of the classes for the period 1979 to 1995 at first world airports and world-wide, were obtained from the OAG database (Ref 24).

6.6 Crash rates for each category, both world-wide and for first world airports only, were then calculated. The results of these calculations are shown in Table 6.1; the crash rates are lower for first world countries than world-wide. The first world crash rates were used in the baseline calculations (Chapter 7): these are 1.114 and 0.148 (per million movements) for Class I and Class II-IV jets respectively. A sensitivity analysis (described in Chapter 8) was performed using the world-wide crash rates.

Crash rates for western airliner turboprops

6.7 The crash rates for western airliner turboprops were also based on SP movements and crashes to obtain first world crash rates. As discussed in Chapter 3, for the purposes of crash rate estimation, turboprops were divided into 2 groups:

- Aircraft with first delivery in or after 1970 (denoted as group T1)
- Aircraft delivered earlier (denoted as group T2)

Table 3.2 lists the aircraft types in each of these groups.

6.8 As for western airliner jets, the Airclaims database extract for total losses to aircraft in airport-related phases of flight for the period 1979 to 1995 inclusive was used as the source for crash data. Scheduled passenger accidents involving turboprop aircraft in each of the groups were used for the initial crash dataset. The accidents in this initial crash dataset were categorised into each of the two groups (T1 and T2), and those which occurred at first world airports were identified. Again, a small percentage of these accidents were found not to be flight-related, and these were removed from the crash set.

6.9 Corresponding movements made by aircraft in each of the classes for the period 1979 to 1995 at first world airports and world-wide, were obtained from the OAG database (Ref 24).

6.10 Crash rates for each category, both world-wide and for first world airports only, were then calculated. The results of these calculations are shown in Table 6.2; the crash rates are lower for first world countries than world-wide. The first world crash rates for the period 1979-1995 are 0.270 and 0.733 (per million movements) for T1 and T2 turboprops respectively.

Unclassified turboprops

6.11 There was insufficient data on crashes and movements to allow a specific crash rate to be calculated for those turboprop aircraft which could not be classified in the two groups for western airliner turboprops (i.e. eastern-built turboprops and some smaller western turboprops). These represent a small proportion of turboprops at the airports studied. The larger of the two turboprop crash rates, that is that used for the T2 group (pre 1970 turboprops), was assigned to this group.

Eastern jets

6.12 The Airclaims database records accidents which involved eastern jets, but the OAG database does not have complete records for movements made by eastern jets world-wide (although movements by eastern-built jets at first world airports are complete). For this reason it was not possible to calculate a world-wide crash rate for eastern jets.

6.13 Only one total loss accident involving an eastern jet making a scheduled passenger operation was recorded at a first world airport for the period 1979-1995. The corresponding first world crash rate calculated using the first world SP movements (from OAG) for the period 1979-1995 is 0.9 per million movements (about a factor of five greater than the corresponding crash rate for Class II-IV jets). However, this crash rate was based on a single total loss, so the statistical validity of this estimate is necessarily very poor.

6.14 As Tables B2 to B6 (Appendix B) show, movements by eastern-built jets at the five example UK airports did not comprise more that 0.5% of the total movements at any of them in 1994. The high degree of uncertainty in eastern-built jet crash rate estimates should not therefore have a large influence on the overall crash frequency.

Executive jets

6.15 It is not possible to estimate a SP crash rate for executive jets from OAG sources. This is because OAG records only 50,000 SP movements world-wide between 1979 and 1995, and no SP crashes are recorded in the Airclaims database (most executive jet movements are charter or private flights). As the vast majority of executive jets are produced by western aircraft manufacturers to similar standards to those applied to commercial passenger jets, it could be assumed that the crash rates for these types would be the same as those for western airliner jets. However, the sort of operations for which these types of aircraft are used are very different from those of western airliner jets. Therefore for the analysis it is assumed that executive jets have the same crash rate as that calculated for the post 1970 turboprops (approximately twice the rate for Class II-IV jets). This may be a conservative assumption, but since the proportion of executive jet movements in 1994 was less than 3% for the airports studied (see Tables B2-B6), the results should not be particularly sensitive to this assumption.

Piston-engine aircraft

6.16 Crashes for piston-engine aircraft are not recorded by Airclaims, therefore it is not possible to estimate these crash rates in a similar manner to those for airliner jets and turboprops. The traffic analysis for the five airports showed that the vast majority of piston-engine aircraft movements are by aircraft with MTWAs less than 4.0 tonnes (and generally less than 2.3 tonnes), and these movements are typically for aero club or private flights. There are a small percentage of piston-engine aircraft with MTWA above 4.0 tonnes such as DC3s. Reference 8 provides a crash rate of 3.00 crashes per million movements for aircraft with MTWA less than 5.7 tonnes. This was applied to all the traffic below 4.0 tonnes and, in the absence of any other data, this same rate was also used for the small percentage of piston-engine aircraft above this weight.

Other non-commercial flights

6.17 This category of flights only appear in the traffic samples for Birmingham and Leeds Bradford and represent only a small percentage of the total movements at these airports. The risk calculations will therefore be relatively insensitive to the crash rates used for these traffic groups. In the absence of any detailed information on these non-commercial flights the same crash rate as that used for piston-engine aircraft was used, i.e. 3.00 crashes per million movements. This should be a conservative assumption as this is the highest of the estimated crash rates used in this analysis.

Miscellaneous

6.18 Some movements at Heathrow, Gatwick and Manchester were made by aircraft types which did not fall into any of the above categories (for instance military jets). As for the above category (other non-commercial flights) these only comprised a very small proportion of the total movements and they were again assigned the same crash rate as for piston-engine aircraft.

Summary

6.19 Table 6.3 shows a summary of the crash rates for the aircraft groups used in this analysis. These crash rates were used to calculate average crash rates for each of the sample airports for use in the crash location models as described in the following paragraphs. Note that the SP crash rates for western airliner jets and turboprops in Table 6.3 were used for both SP and non-SP aircraft. The effect of making an alternative assumption about non-SP aircraft is examined in Chapter 8.

Calculation of crash rates for use in the crash location models

6.20 Two crash location models were used in the analysis, the NATS model and the AEA model (see Chapter 4 and Appendix C). The NATS crash location model was used for all aircraft in each of the groups except for the piston-engine group. For the 1994 traffic samples used, this includes all of the traffic at Heathrow and Gatwick, a high proportion of the traffic at Birmingham and Manchester, and over half the traffic at Leeds Bradford (an analysis of the traffic at each of the airports is presented in Appendix B).

6.21 The piston-engine group was divided into two according to the type of operation for which they were being used at each airport. Unless there was evidence that they were being used for commercial operations, the piston-engine aircraft were associated with the AEA light aircraft model. Otherwise, they were associated with the NATS model. Some piston-engine aircraft with MTWA less than 4.0 tonnes were therefore associated with the NATS model. This decision was based on the assumption that commercially operated piston-engine aircraft would more nearly resemble other commercial operations than those of other small aircraft. The extent to which this division was possible depended upon the data available on movements at each individual airport and is described in Appendix B. The crash rate for piston-engine aircraft (3 crashes per million movements) was used for both groups of movements.

6.22 To calculate crash rates for use with the NATS model, the first stage involved estimating an average crash rate for each of the airports for the groups of aircraft not covered by the AEA model. For each group at each airport, the annual number of movements was multiplied by the appropriate crash rate to calculate an annual crash frequency for the group. The crash frequencies for each group were then added together to obtain a total annual crash frequency for the aircraft covered by the NATS model. This total annual crash frequency was then converted to an average crash rate by dividing by the total movements made by the appropriate aircraft. The results of these calculations for each of the airports are presented in Tables 6.4 to 6.8[3].

6.23 As mentioned in Chapter 4, the NATS model consists of four separate distributions for the following types of crashes:

- Take-off crashes from flight
- Take-off overruns (including veer-offs and aborted take-offs)

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[3] It should be noted that the differences between the crash rate and frequency estimates for the airports only reflect differences in the amount and mix of traffic. No attempt was made to quantify any effects of differences in local operating conditions, airport facilities or local terrain.

- Landing crashes from flight
- Landing overruns (including veer-offs)

6.24 The proportions of each of the four types of crash was estimated from the airport-related total losses (582 accidents world-wide) recorded in the Airclaims database (Ref 23) for the period 1979-1995 for jets and turboprops. From this data the proportions were: 20% take-off crashes from flight, 8% take-off overruns, 52% landing crashes from flight and 20% landing overruns. The average crash rate calculated for each airport was divided up between each of the model components in these proportions and these component crash rates were used as inputs to the NATS crash location model.

6.25 It is also necessary to divide the movements at each airport into take-off and landings on each of the available runways. This information was supplied by NATS Statistics and Forecasting section for the airports where ATC services are supplied by NATS, i.e. Heathrow, Gatwick, Birmingham and Manchester. A six year average was taken over the period 1990 to 1995. For Leeds Bradford, no published runway data was available and the proportions of traffic on the different runways was based on an estimate provided by the airfield services manager. The movements on each runway and the crash rates used for each of the model components for each airport are summarised in Tables 6.9 to 6.14.

Crash consequence modelling

6.26 As described in Chapter 5, the NATS consequence model for destroyed area was used in this analysis. This relates the expected area destroyed by a crashing aircraft to its MTWA, and it is assumed that all people within the destroyed area at the time of the crash would be killed. The average destroyed area for each of the airports is the final input required for the analysis.

6.27 For Heathrow, Gatwick and Manchester, where detailed traffic breakdowns by aircraft type were available (see Appendix B), the average destroyed areas were calculated as follows. A destroyed area was calculated using the NATS consequence model for each of the different aircraft types using the airport. These were then combined with movement data to calculate a mean destroyed area for each of the aircraft groups at the airport (e.g. Class II-IV jets, T1 turboprops etc.). Finally the average destroyed areas were weighted by the crash frequencies for each group to obtain an average destroyed area for each airport.

6.28 For Birmingham and Leeds Bradford, mean destroyed areas were calculated for the commercial movements in the same way as for Heathrow, Gatwick and Manchester. However, for non-commercial movements, where detailed data on aircraft types was not available in an easily accessible form, it was necessary to estimate an average MTWA for the group using the available data. The average MTWA was then used with the NATS consequence model to calculate the mean destroyed area for the group. The mean destroyed areas for each of the groups at the airport were then combined with crash frequencies to calculate the average destroyed area for the airport.

6.29 Tables 6.4 to 6.8 show the mean destroyed areas for each traffic group in the five airports together with the overall average destroyed area for that airport's traffic which was used in the individual risk calculations. The results of the individual risk calculations are described in the following chapter.

Summary

6.30 The estimation of the main input parameters for the individual risk calculations for each of the five UK airports have been described, and the parameters themselves are shown in Tables 6.4 to 6.8.

7 INDIVIDUAL RISK CALCULATIONS

7.1 The individual risk calculations were performed using a computer program (which is described in Appendix D) for the actual modelling calculations with the input data described in Chapter 6. The results are plotted in the form of contours showing lines of equal risk in Figures 7.1 to 7.5. The contours shown correspond to third party individual risk values of one in 10,000 (10^{-4}), one in 100,000 (10^{-5}), and one in 1,000,000 (10^{-6}). The regions in between contours correspond to risks intermediate between the contour values. The size of the areas, and numbers of people and residences affected in these risk bands, are given in Table 7.1.

7.2 The numbers of people and residences affected were estimated using the population database[4] produced by CACI (Ref 37). This population database was produced from the amalgamation of data from three sources:

- population data derived from the results of the 1991 census of population,
- a record of addresses (delivery points) in each postcode, and
- an Ordinance Survey grid reference for each postcode with a resolution of 100 metres.

7.3 As a postcode is a set of delivery points (defined by the Post Office) as opposed to a set of households (defined by the Office of Population Censuses and Surveys (OPCS)), an apportionment method was used by CACI to link the Post Office and OPCS data with respect to any mismatch of definitions. For example, a mismatch could occur with houses converted into flats with a single letterbox; this is a single delivery point for postal purposes, but multiple households for census purposes.

7.4 Table 7.1 and Figures 7.1 to 7.5 show that, as expected, the larger airports tend to give rise to higher levels of third party risk and consequently have larger areas affected by the risk bands.

7.5 The level of risk at any given point near an airport varies in an approximately proportional fashion to the number of movements, the average crash rate, and the average destroyed area (resulting from a crash), for that airport. These parameters were given in Tables 6.4 to 6.8, which show that, in general, when comparing airports of different sizes, smaller airports tend to be associated with higher crash rates but smaller destroyed areas. This is because traffic at smaller

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[4] Due to the location resolution of the population database, and the fact that it is based on a combination of data from different sources, only approximate values for the people and residences in different risk bands can be obtained. For the lower risk bands where there are greater numbers of people and houses affected, these values are likely to be good approximations; however for the higher risk bands where there are fewer (if any) people, the percentage uncertainty in the estimates of people and residences affected will be greater.

airports has a higher proportion of lighter aircraft, such as turboprops and piston-engine aircraft, which tend to be at a higher risk of crashing than large jets; however, when lighter aircraft crashes occur, they cause much less damage. Thus, when comparing the risks associated with different size airports, the effects of crash rates and area destroyed can ‘cancel out’ to some extent, so that movement numbers are the most important factor in determining the differences in risk levels.

7.6 Table 7.1 also shows that only at Heathrow does anyone reside in the areas where the calculated risk is greater than 10^{-4}. For the case of risk levels between 10^{-5} and 10^{-4}, Heathrow records a significant number of residents (2222); at Gatwick, Manchester, Birmingham and Leeds Bradford there are 2, 367, 102 and 81 residents recorded respectively. The reason that Gatwick has so few residences in this risk band, despite being the second largest airport analysed here, is merely a consequence of fewer people living close to this airport than is the case for the smaller airports.

Summary

7.7 The results of the calculations (the ‘baseline’ cases) which correspond to a ‘best estimate’ of individual risk near these airports are summarised in Table 7.1. It will be clear from the preceding chapters that these results depend critically on the assumptions made in the calculations of the crash rates, the choice of models, etc. The effects on the results of using some alternative models and assumptions are investigated in the following chapter.

8 EFFECTS ON RESULTS OF ALTERNATIVE MODELLING ASSUMPTIONS

8.1 This chapter describes a number of additional calculations which were performed to investigate the effects of using different modelling assumptions in the calculations. Although there is uncertainty in all three components of the risk modelling (crash rates, crash location and consequence modelling), these alternative calculations focused on crash rates and consequence models. Alternative location models were not considered here as the only other location model based on a substantial amount of data is the NLR model for which the equations are not publicly available as they are commercial products.

8.2 The details of the input data for these calculations are given in Appendix E, and the cases themselves and the individual risk results are described below.

Alternative input assumptions

Crash rates

8.3 One of the key inputs to the individual risk calculations was the average crash rate for the traffic at the airports. As airliner jets and turboprops tend to be the most numerous groups at the larger airports, the crash rates for these aircraft has a significant influence on the individual risk results. As discussed in Chapter 6, crash rates for airliner jets and turboprops were calculated using first world SP aircraft crashes and movements, with the definition of crash corresponding to an accident involving a total loss (as defined in Ref 26).

8.4 Three additional individual risk calculations were performed using different approaches to the estimation of crash rates:

- use of world-wide crash rates
- inclusion of ‘major partial losses’ (as defined in Ref 26) for overruns
- assuming the crash rate for non-SP jets is twice that of SP jets (rather than equal)

8.5 The calculation using world-wide crash rates (instead of those restricted to the lower, first world statistics) was performed to illustrate the importance of using data from appropriate geographical regions. This is a very pessimistic example, as there is no reason to assume that air transport in the UK is any less safe than in other first world countries, but it does illustrate the effect of much higher crash rates.

8.6 Issues involving assumptions about non-SP jet crash rates and whether there is a need to include less serious accidents in the overrun crash rates are less clear cut. Although, given UK safety regulations, it would seem unlikely that an aircraft of a given type involved in non-SP activities would be significantly more likely to be involved in an accident in the UK than one operating a SP service, it is useful to determine how sensitive the individual risk results are to the crash rates used for non-SP jets.

8.7 The case involving the inclusion of additional accidents in the overrun crash rate was performed in order to investigate the results of adopting less stringent criteria for accident selection. The exclusion of major partial losses could result in an underestimate of the overrun crash rates. The baseline case used overrun crash rates based on total loss accidents because about 80% of the accidents on which the crash location model was based were total loss accidents (Ref 34). A calculation of the individual risk results based on the inclusion of major partial loss accidents in the overrun crash rates allows the use of more cautious assumptions to be investigated.

8.8 The calculation using world-wide crash rates was performed for Heathrow (the largest airport studied), the calculation with the higher value for the non-SP crash rates was based on Manchester (which has a relatively high proportion of movements by these aircraft), and calculations using overrun crash rates with major partial loss accidents included were performed for both Heathrow and Manchester.

8.9 The results of the individual risk calculations using these variant crash rates in terms of the areas, numbers of people and households in the different risk bands are compared with the baseline calculations in Tables 8.1 and 8.2.

Consequence models

8.10 The aspect of the calculations which is likely to be subject to the largest amount of uncertainty concerns the modelling of accident consequences. In addition to the consequence model produced by NATS, a number of other empirical consequence models have been derived by other organisations (see Chapter 5 for the review of consequence models).

8.11 In order to investigate the effects of using an alternative consequence model with a stronger dependence on aircraft weight than the NATS model, a calculation was performed for Heathrow (which has the highest proportion of heavier aircraft of the airports studied) using the published NLR consequence model (Ref 14) which assumes a linear dependence on MTWA. The results are given in Table 8.1.

8.12 The NATS consequence model was derived using data predominantly from crashes involving heavier aircraft. To investigate the sensitivity of the results for Leeds Bradford (which has the highest proportion of light aircraft), a calculation was performed to investigate the effect of using a smaller consequence area for these aircraft, arbitrarily set at 0.01 hectares (as opposed to the 0.06 hectares used in the baseline case). The results are compared with those of the baseline case in Table 8.2.

Discussion

8.13 The results of Tables 8.1 and 8.2 show that, as expected, the areas affected by different levels of individual risk are quite sensitive to changes to some of the input parameters. The largest change resulted from using world-wide instead of first world crash rates; this is not surprising given the average crash rate for Heathrow calculated using world-wide crash rates for the airliner jets and turboprops is around a factor of 2.5 times greater than the first world value used in the baseline calculations.

8.14 For both the 10^{-5}-10^{-4} and 10^{-6}-10^{-5} risk bands, neither the inclusion of major partial accidents in the overrun crash rates, nor the assumption of a higher crash rate for non-SP jets (assumed to be a factor of two greater than SP jets) has a strong influence on the areas affected by different levels of risk. The changes to numbers of people and residences affected tend to be more pronounced than the changes to areas. This is because, as the risk contours 'move out' into the more populated areas, the percentage increase in people affected can be greater than that for the areas.

8.15 For risk greater than 10^{-4}, the percentage differences in area affected between the baseline case, and those cases involving higher crash rates are very much greater than for the lower risk bands. This may be an 'artefact' of the resolution of the area calculation. In the calculation of areas affected, each hectare 'cell' is assigned to a risk band on the basis of the value of the risk averaged over it. Therefore there may be many cells near the contour lines where the risks are 'borderline' between different risk bands. When the calculated risks are increased (e.g. by using higher crash rates in the calculation), a relatively large number of borderline cells may change to a higher risk band. This effect would be most pronounced in the case of risks greater than 10^{-4}. Since the area in the baseline case is small (54 hectares for Heathrow and 14 hectares for Manchester), the boundary cells represent a much large proportion of its area than is the case for the lower risk bands (which have much larger baseline areas).

8.16 The comparison of the results of using the NLR consequence model showed that, as expected, the use of a model predicting greater consequences increases the areas affected by risk. The NLR model may produce cautious (i.e. pessimistic) estimates as NLR have later produced a refined version of the model (mentioned in Ref 33) which predicts lower consequences than their published model. However, given that the NATS model is less strongly dependent on aircraft weight than the other empirical models, it is important to investigate the effects of using a stronger mass dependence on an airport such as Heathrow which has a relatively high proportion of heavier aircraft.

8.17 The reduction in the destroyed area for light aircraft in the Leeds Bradford calculations from the 0.06 hectares obtained using the NATS model, to a probably more realistic (but arbitrary) value of 0.01 hectares does not have as large an effect as some of the other changes discussed in this chapter. This shows that although Leeds Bradford has a significant proportion of light aircraft (around 45%), these aircraft have a much smaller influence on the areas affected by higher risks near the airport than might initially be expected.

8.18 This is probably because flight paths of light aircraft are often much less concentrated along the extended runway centre-line than those of larger aircraft, a substantial proportion of which make Instrument Landing System (ILS) approaches. This will result in a ‘spreading out’ of the crash distribution. The AEA light aircraft crash location model reflects the different behaviour of these aircraft by ‘spreading out’ the risk around the airport compared with location models based predominantly on heavier aircraft.

8.19 The fact that the overall results for Leeds Bradford do not appear very sensitive to assumptions about light aircraft indicates that their greater uncertainty (in relation to crash rates, destroyed area and the use of a less detailed crash location model for these aircraft) is not a serious cause for concern.

8.20 The results above illustrate the effects on individual risk levels near airports (and on the areas exposed to different risk levels) of changes to some of the modelling assumptions and data used in the calculations. Although, as expected, the risk results are sensitive to changes to the inputs to the calculations, the baseline cases ‘best estimates’ are used in the assessment of the tolerability of risks near airports, the subject of chapters 9-11.

Summary of the modelling of individual risk near airports

8.21 This completes the description of the part of the study that deals with the risk modelling calculations. In summary, the different components to the modelling of risk near airports have been reviewed. The effects of making alternative assumptions regarding choice of accident dataset (inclusion of major partial accidents) and also the relationship between SP and non-SP crash rates have been explored and found not to have an overly strong influence on the results. A greater change resulted from replacing first world crash rates with world-wide crash rates, but this is probably a pessimistic calculation.

8.22 An important conclusion from the reviews of location and consequence models was that, although some models were considered more reliable than others, the empirical models tended to be broadly compatible with each other. For example, the predictions of consequence areas obtained using different empirical consequence models were generally within a factor of two of each other (although given the high degree of variability in the empirical consequence data, it is still possible that this ‘agreement’ was merely fortuitous).

8.23 Similarly the empirical location models would all predict risk contours off the runway ends which are wide near the runway ends, becoming much narrower with increasing distance from the runway to eventually form a point (i.e. roughly triangular in shape). This can been seen by comparing the shapes of the individual risk contours shown in Figures 7.1 to 7.5 with those shown in Reference 8 for the AEA model, and in Reference 38 for the NLR model.

8.24 The broad compatibility between different empirical models (although there are important differences in detail) and the fact that overall the results are not strongly influenced by realistic alternative crash rates indicate that the risk estimates are likely to be sufficiently robust for use in PSZ policy. The appraisal of these risks is dealt with in the following chapters.

9 GENERAL CRITERIA FOR RISK APPRAISAL

Introduction

9.1 Chapters 9 to 12 review general criteria for risk tolerability, and apply them to PSZs. This chapter reviews general criteria in use for the appraisal of risk. Chapter 10 summarises the results of fieldwork aimed at estimating the values of important parameters necessary for the appraisal of PSZs. Chapter 11 applies the general criteria to PSZs, using the risk estimates from the Chapter 7, the appraisal parameters from Chapter 10 and data on property values. Chapter 12 appraises different possible land use policies in PSZs, using the results of Chapter 11.

9.2 There are three types of quantitative criteria in general practical use for risk appraisal. These are the following:

(i) cost-benefit analysis (CBA);

(ii) criteria concerned with individual risk; and

(iii) criteria concerned with societal risk, or in other words criteria concerned with the frequency of accidents.

9.3 This list excludes criteria based on aircraft crash risk, mentioned in Chapter 2, because this metric is specific to the aviation industry. Hitherto, PSZs have been determined so that they cover the locations of a specified proportion of crashes near airports. It would clearly be possible to continue to determine PSZs in that way, but that approach is not considered further here, because it does not address the two criteria that are now generally regarded as most important in risk appraisal: the level of individual risk, and the costs and benefits of safety measures.

9.4 Quantified risk appraisal is generally used to make informed decisions concerning safety regulation and the adoption of safety measures, but not to determine what those decisions should be. Responsibility and accountability for the decisions lies with the relevant body, such as the managers or directors of the system concerned, or safety regulators. This implies that the decision making body must form its own view about the judgements that underlie the quantified criteria, and also about any wider issues that may not be incorporated in the criteria. The importance of the quantified criteria compared with other considerations is a matter of debate, both in general and in the context of any particular decision.

9.5 The use of CBA in the appraisal of safety measures originated in road transport. The use of individual and societal risk criteria originated in the appraisal of risks associated with hazardous industry. Although they have different origins, CBA and individual risk criteria can be sensibly combined into a joint appraisal framework, which is now widely accepted (Ref 39). However, societal risk does not easily fit into the framework, and is a more contentious concept.

Cost-benefit analysis

9.6 CBA is well established in the appraisal of road safety measures. Its use in road safety is supported by the DoT, which publishes and annually updates ‘standard’ road casualty valuations. Reference 40 provided a literature review for the DoT, which formed the basis for the DoT's current valuation of statistical life in road accidents. Reference 41 provides a comprehensive account of the DoT's methods. The use of CBA in road safety is widely accepted internationally, though there are wide variations in the valuation of statistical fatalities: Reference 42 presents results of a 14-country European co-operative research project, and Reference 43 provides international comparisons for 20 countries. Reference 44 gives a good general review of the use of CBA in transport safety.

9.7 CBA is less well established elsewhere in safety, though its use is increasing. The only transport modes in the UK besides road which have so far adopted explicit ‘standard’ valuations of statistical life are surface rail (Ref 45), and London Underground (Ref 46). Hazardous industries often make use of CBA internally for the appraisal of safety measures, but usually do not publish their analyses. The HSE routinely produces CBAs in support of new proposals for legislation, although the Health and Safety Commission has not formally endorsed any specific statistical valuation of human life. The CAA uses CBA techniques in support of project appraisals but has not endorsed the use of a statistical human life valuation for decision-making in air traffic system investments, or for regulatory purposes.

9.8 CBA starts with proposed safety measures, and compares their benefits and costs in monetary terms. The decision criterion in CBA is that a safety measure should be adopted if and only if the benefits exceed the costs. The benefits of safety measures include reductions in:

(i) the numbers of fatalities and injuries;

(ii) physical damage; and

(iii) disruption and loss of business.

9.9 For a CBA, in principle all these must be valued, though in practice there are always some costs and benefits that cannot usefully be expressed in monetary terms, and which are included as part of the wider considerations. In the analysis of safety measures, the most important benefit is often (though not always) a reduction in the risks of death and injury, and this benefit is valued.

Valuation of statistical life

9.10 In the past a number of different methods have been used for valuing reductions in risk, but there is an increasing support for the so-called willingness-to-pay argument (Ref 40), at least among those who accept the principle of valuing reductions in the risk of death and injury at all. However, other methods are still in use.

9.11 Under the willingness-to-pay argument, the value of a statistical life is derived from the amounts that individuals would be willing to pay for a small reduction in risk which when aggregated represents the average value for saving one fatality. The main reason for the acceptance of this argument is that willingness-to-pay for goods and services by those who would benefit from them is the general valuation principle used in prescriptive economics. The DoT adopted the willingness-to-pay argument for valuing fatalities in road accidents in 1988, and for valuing injuries in 1993.

9.12 In principle, two main types of empirical data can be used for estimating the value of statistical life. These are:

(i) observations of the trade-offs made by people in the market place between risk and money, principally either in the labour market, where people may be willing to accept higher wages in return for somewhat riskier occupations, or else in markets where they may spend money to purchase safety devices which lower their risk; and

(ii) the results of questionnaires in which people are asked more or less directly how much they would be willing to pay to reduce their risk in specified contexts.

References 40 and 44 review these methods and the results of a number of studies.

9.13 Before the DoT adopted the willingness-to-pay method for valuing statistical life in road safety in 1988, the DoT used the so-called human capital method. In the human capital method, the loss attributed to a fatality is taken to be the discounted present value of the future output lost by a person's premature death, averaged over all those who are at risk. An arbitrary allowance for ‘pain, grief and suffering’ is then sometimes added. The objection to the human capital approach, and the reason why the DoT altered its valuation method, is that people’s lives are not principally valued for their contribution to output, but for what might be termed their ‘intrinsic worth’ to themselves and their families.

9.14 The individual valuations of statistical life emerging from willingness-to-pay studies have a very wide range, and even the average or median valuations show a variation of about a factor of 3 from one study to another (from about £500,000 to £1,500,000 at 1987 prices). However, the willingness-to-pay method generally gives much higher average valuations than the human capital method. When the DoT changed its valuation method in 1988, it adopted a willingness-to-pay value of statistical life at the low end of the range from empirical studies; even then the new value - £500,000 at 1987 prices - was about twice the previous value. The

DoT adopted a value at the low end of the empirical range because in the presence of uncertainty, it wished to take a cautious line in valuing the benefits from reductions in road accidents.

9.15 The 1987 value of £500,000 has since been uprated using the index of GDP per head, because the DoT has assumed that individuals' willingness-to-pay for risk reduction approximately rises in line with income. The latest published value is £812,000 at 1995 prices (Ref 47), though in this study the 1993 valuation of £744,000 is used, because the latest available housing land price data are for 1993, and in Chapter 11 the value of risk reduction is compared with property values. The conclusions of this study are not sensitive to the precise year of valuation.

9.16 The UK is now one of seven developed countries to have adopted the willingness-to-pay approach to valuing life, along with Denmark, Finland, New Zealand, Sweden, Switzerland, and the USA. The values for the countries using this approach are generally higher than those of the countries that do not. Because the DoT's value of statistical life was chosen at the low end of the range, it is sometimes argued that it should be replaced with a value nearer the average from empirical studies (Ref 48). This would imply approximately doubling the present value, to about £1.5 million at 1993 prices.

9.17 Recently, the DoT concluded a research programme aimed at providing corresponding willingness-to-pay based valuations of non-fatal injuries in road accidents (Ref 41). The most recent valuation of a serious road injury is 11 per cent of that of a fatality, and that of a slight injury is 0.88 per cent of a fatality. The relative valuations of injuries in non-road accidents may be different from those in road accidents, because the range of injuries may be different.

9.18 The current UK road valuation of statistical life appears to be low in comparison with values used or discussed in other safety contexts. For example, Reference 49 indicates that BP International uses values in the range US$1 million to US$10 million - about £0.7 million to £7 million; values within that range are chosen with reference to other considerations. The HSE have in the past suggested that a value of at least £2 million would be appropriate where risks with the possibility of wide repercussions are involved, as for example in Reference 50. This does not appear to be based on specific research; rather it would seem to have been a reflection of the view that the current DoT value appears low, given the amount that organisations themselves are willing to spend to avoid a statistical fatality, the implicit cost of some of the HSE's own requirements in certain industries, and public aversion to certain kinds of risk.

9.19 The Railway Group Safety Plan 1995/96 (Ref 45) states that the normal valuation for railway fatalities should be the same as that used by the DoT for roads (that is £744,000 at 1993 prices), but that higher values of up to £2 million should be considered where the individuals concerned are recognised as being at high individual risk, or for passengers in train accidents (though not other accidents), or for other circumstances where risk may be perceived to be particularly important.

9.20 The only recent British empirical work on willingness-to-pay for public transport safety is that of Jones-Lee and Loomes (Ref 48) in respect of London Underground: they sought to estimate the value of an Underground fatality relative to that of a road fatality. They presumed that there might be two sorts of reason why the Underground value might be higher than the road value, which they labelled scale effect and context effects. The scale effect stems from the fact that the proportion of multiple-fatality accidents is greater on rail than road, and there is a widely-held view (for example Refs. 7, 51) that people are more averse to death in large accidents than in small ones, and therefore might be willing to pay more to reduce the risks of these.

9.21 The context effects stem from findings of work on risk perception (Ref 52, Chapter 5) that people are more averse to risks when they are not under their own control, not voluntarily assumed, not their own responsibility, and perhaps in a hostile environment, such as in the air, in a tunnel or at sea. Road risks generally have, or are perceived to have, the opposite of these features, so again people might be willing to pay more to reduce Underground or rail risks than road risks. It may be noted that the risks to third parties from aircraft are probably more like rail risks than road risks in these respects.

9.22 Jones-Lee and Loomes surveyed a sample of 225 participants, and found that people appeared to be willing to pay 50% more on average to reduce the risk of an Underground fatality than they would to reduce the equivalent road risk; this premium was entirely due to context effects, and not at all to the scale effect. This implies that, if the official 1993 road value is taken as the starting point, the value of statistical life on the Underground would be £1.1 million. The London Underground Ltd Board has now approved the use of a value of statistical life of £1.1 million. However, higher values, up to a maximum of £3.3 million, are also considered in specified circumstances (Ref 46).

9.23 As part of the fieldwork for the present study, Jones-Lee and Loomes (Ref 53) carried out a survey aimed at estimating people's valuations of the risk of death due to crashing aircraft near airports relative to the valuation of the risk of death in road accidents. They employed similar methods to those used in the London Underground study, though with a smaller sample. The results are reported in Chapter 10.

Individual risk criteria

9.24 The leading contributions to the development of criteria for individual risk and societal risk have come under the auspices of the HSE and the Royal Society. The first major quantified work was the study by HSE in 1978 of the Canvey Island industrial complex (Ref 54), which has been very influential in determining practical safety standards. The most important current document is 'The

Tolerability of Risk from Nuclear Power Stations' (Ref 7), which covers the risks of major hazards generally (despite its narrower-seeming title). This presents HSE's so-called tolerability of risk framework, which adopts many of the ideas developed in a Royal Society Study Group report on risk assessment (Ref 51). The Royal Society (Ref 52) later published a second report on risk, with much more on risk perception and risk management than the first, but with little new conceptually on the basic ideas of tolerability or on the economics of safety. The HSE (Ref 39) have recently published a review of the methods for risk assessment used by themselves and other government departments. The HSE (Ref 55) have also described their approach to risk appraisal for land-use planning in the vicinity of major industrial hazards, which has obvious relevance to PSZs, whether or not the same criteria are used.

9.25 In contrast to CBA, which is concerned with the changes in risk brought about by specified safety measures, individual risk criteria are concerned with absolute levels of risk. Individual risk is usually defined as the probability of death per year to a representative individual or member of a group, as a result of some activity, though it may also be defined more generally. The concept has a long history in industrial and occupational risk: it was used in the Canvey Island study mentioned above, and is now the key variable in the HSE's tolerability of risk framework (Ref 7).

9.26 Figure 9.1 presents HSE's much-used diagram of the tolerability of risk framework, taken from (Ref 7). There is actually only one axis in the diagram, which runs vertically, and represents individual risk, with low values at the bottom, and higher values at the top. The narrowing triangle is intended to do no more than illustrate diminishing individual risk.

9.27 The range of individual risk is divided into three regions by two boundary points, called the intolerable risk threshold and the acceptable risk, the former being greater than the latter. Individual risks greater than the intolerable risk level are declared intolerable; they must be reduced below that threshold without regard to cost, or the activity must cease. Individual risks lower than the acceptable risk level are so low that they merge into the background risks of life, and they require no action. Individual risks between these levels must be made "as low as reasonably practicable" (ALARP), and this region is therefore often called the ALARP Region.

9.28 "Reasonably practicable" is a difficult phrase: both its words require judgements to be made. The informal day-to-day interpretation of what is reasonably practicable is the adoption of good practice in health and safety for the activity concerned. When a more formal analysis is required, cost benefit analysis is increasingly being used: risk reduction is defined to be practicable if and only if it is possible to find cost-beneficial risk reduction measures.

9.29 The general justification for having an upper limit to the tolerable individual risk is to ensure equity in the distribution of risk, that is to ensure that no individual or small group carries a disproportionate share of risk. There is less justification for the lower limit, because if cost-beneficial safety measures could be found to reduce low risks even lower, there is no obvious reason not to adopt them, except in so far as this could divert resources or attention away from higher risks. However, the risk appraisal process itself involves costs, and the lower limit does have the practical importance that, if the individual risk from an activity can be shown to be below the lower limit, there is no requirement to seek measures to reduce risk further.

9.30 The widely-accepted upper limit to the tolerable risk for employees is a risk of death of 1 in 1,000, or 10^{-3}, per year. This limit was suggested in the Royal Society Study Group report (Ref 51), and also adopted by the HSE. The justification for this risk is that it is broadly the highest risk,

> "that is ordinarily accepted by substantial groups of workers in any industry in the UK, with that level only being exceeded by fishermen and relatively small sub-groups such as helicopter pilots, divers, and demolition workers" (Ref 7, paragraph 169).

9.31 It is estimated that a lifetime exposure to such a risk would shorten the expectation of life by about 3 years. This is calculated by superimposing a continuous additional risk of death of 10^{-3} per year on the pre-existing age-specific mortality rates. Such a risk might be just tolerable if voluntarily assumed in return for some benefit, and perhaps if it were not sustained for a large fraction of a lifetime. However, the HSE adopts a lower value for the upper limit to the tolerable risk to third parties from hazardous industry of 1 in 10,000, or 10^{-4}, per year. The HSE says:

> "If the maximum tolerable risk for any worker is set at around 1 in 1,000 per annum, it seems clear that the maximum level that we should be prepared to tolerate for any individual member of the public from any single large scale hazardous plant...could not be less than ten times lower, i.e. 1 in 10,000. Such a level would as it happens equate to the average annual risk of dying in a traffic accident..." (Ref 7, paragraph 172).

9.32 A lifetime exposure to this risk would shorten the expectation of life by about 3 months. Of these two upper limits recommended by the HSE, it is only the third party one that is relevant to PSZs. Note that even if some of the people affected by a PSZ worked at the airport in question, the PSZ risk could not reasonably be regarded as part of their occupational risk.

9.33 The HSE's recommended upper limits to the tolerable risks for employees and third parties have been used in industry for about a decade, and have not been seriously challenged. However, the sort of arguments quoted above are the only justification for the adopted limits.

9.34 The third party limit is of particular relevance to public safety zones, and was cited - without detailed analysis or criticism - by both defenders and opponents of the proposed second runway at the Manchester airport public inquiry (Refs. 21, 36).

9.35 The lower boundary of the ALARP-region, or acceptable level of risk in Figure 9.1, is usually taken to be a risk of death of 1 in 1,000,000, or 10^{-6}, per year, as suggested by both the Royal Society (Ref 51) and by HSE (Ref 7). That figure is consistent with 'background risks', but the precise figure is largely arbitrary. As indicated above, it is less important than the upper boundaries, because fewer safety-critical decisions depend on it.

9.36 When individual risk is in the ALARP-region, as it usually is in most practical applications, risks must be reduced "as low as reasonably practicable". The wording in the tolerability of risk framework (Figure 9.1) indicates that the interpretation of what is reasonably practicable must take account of the level of risk. The precise wording is that risks at the upper end of the ALARP-region can be deemed tolerable only if the cost of reducing them is "grossly disproportionate" to the improvement gained; whereas, at the lower end of the scale, risks are tolerable if the cost of reducing them would merely exceed the value of the improvement.

9.37 The inference is that costly safety measures might be regarded as reasonably practicable if the individual risk were at the upper end of the ALARP-range, but not if the risk were at the lower end. This implies that the value of statistical life to be used in the tolerability of risk framework is not constant: it is implicitly higher at the upper end of the ALARP-range of risk than at the lower end.

9.38 Higher values of statistical life at the upper end of the ALARP range are consistent with a theoretical argument that willingness-to-pay to reduce risk should be an increasing function of the level of risk (Ref 56). However, the literature contains no practical estimate of what the function might be, therefore there is no way of using such a function in practice, except by taking higher values of statistical life at higher risks in an arbitrary fashion. The most common manner in which this is done, for example by the surface railways (Ref 45), is to take the road valuation as the base value for low risks, and then make arbitrary additions to this when the individual risk approaches the tolerability limit.

9.39 A logical objection to this procedure is that road risks are high, not low, on the ALARP-region scale, which runs from 10^{-6} to 10^{-4} for third parties using the limits above, and 10^{-6} to 10^{-3} for employees. (The annual risk of death on the road averaged over the whole population has been about 10^{-4} over the last decade, though it has been falling, and reached about 0.6×10^{-4} in 1994.) Therefore the road value of statistical life corresponds not to a low point on the ALARP-scale, but to a high point; it would then follow that most adjustments to the valuation of life to take account of the absolute level of risk would actually take the form of subtractions from the road value, not additions to it.

9.40 In addition to tolerability limits, many organisations also set themselves target levels of individual risk that are lower (i.e. better) than the intolerable level. For example, the Railway Group aims to ensure that "working on Railtrack controlled infrastructure does not pose a risk of fatality greater than 1 in 10,000 per annum" (Ref 45), which is a factor of 10 better than the intolerable level for employees.

9.41 Such targets can be interpreted as the organisation's view of what potentially can be achieved by reasonably practicable safety measures for that activity. If in practice it did not prove reasonably practicable, or if it proved practicable to achieve an even lower level of risk, then the target for that activity could be adjusted by the organisation. By contrast, a tolerable level of risk must be achieved whether it is reasonably practicable or not. The same distinction between targets and tolerable risks also applies to societal risk criteria, discussed below.

Combining cost-benefit and individual risk criteria: constrained CBA

9.42 Cost-benefit analysis and individual risk criteria can be sensibly combined (Refs. 39, 51, 57), giving what is sometimes called constrained CBA. In constrained CBA, safety measures are adopted if either:

(a) their benefits exceed their costs, calculated using appropriate valuations of statistical life; or

(b) without them, certain individuals would be at intolerable risk, in which case the safety measures must be implemented without regard to cost.

It may be noted that constrained CBA makes use of both of the key parameters discussed above, namely:

(i) the value of statistical life, for the purpose of calculating which safety measures meet criterion (a); and

(ii) the intolerable level of individual risk.

9.43 It follows that values of these two parameters are required for any application of constrained CBA. As discussed above, `standard' values exist for both, but there may be good reasons for seeking different figures to meet the needs of particular applications. Both have been covered in the fieldwork for the present study, discussed in Chapter 10.

9.44 It may also be noted that in any particular application of constrained CBA, in principle only one of the two criteria above will be active or binding, and the other will be redundant. If risks are low, or if safety measures are relatively inexpensive, the tolerability limit will not bind, and the implemented safety measures and resulting level of risk will be determined by CBA alone. On the other hand, if risks are high, and if safety measures are relatively expensive, the tolerability limit may bind.

9.45 In the latter case, safety measures to achieve the tolerable limit have to be implemented without regard to cost, so that CBA is irrelevant. In practice, in most applications the first situation applies: the tolerable limit does not bind, and safety measures are determined by CBA. However, in some circumstances the tolerability limit does bind.

9.46 The reason why it is desirable to combine CBA with individual risk criteria is that each contributes a different and important consideration to the appraisal of risk. CBA is concerned with the efficient use of resources in risk reduction; individual risk criteria are concerned with equity in the distribution of risk.

Societal risk

9.47 Suppose now that constrained CBA has been adopted, and that safety measures have been implemented accordingly. That is, risk tolerability criteria have been met for all individuals, and all cost beneficial safety measures have been implemented. Therefore, by assumption, any further measures are not cost-beneficial. The question then is: are there any circumstances in which such further safety measures ought to be adopted? That leads into the question of societal risk.

9.48 Societal risk is a much less well defined concept than individual risk. The most precise and much-quoted definition of societal risk is that given by the Institution of Chemical Engineers (Ref 5, p6):

> “the relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specific hazards”.

9.49 This definition was also used by the HSE for some years, for example in their land-use planning paper (Ref 55), but recently they have adopted much broader definitions, such as that proposed in their recent discussion document on risk terms (Ref 58, p25-6):

> “Societal risk...is the risk of widespread or large scale detriment from the realisation of a defined hazard, the implication being that the consequence would be on such a scale as to provoke a socio/political response...”

9.50 The second definition is so broad that it is difficult to see how general quantitative tolerability criteria could be established for it. However, the first definition, which defines societal risk in terms of the number of people affected by an accident, is associated with a standard form of quantified tolerability appraisal, which is now discussed. Again, both the defenders and opponents of the second runway proposal at Manchester (Refs. 21, 36) put forward this form of appraisal, but without methodological criticism of the approach.

9.51 As with individual risk, it is usual to use fatalities as the indicator of the severity of accidents (although a more complete analysis would also include injuries). It is common to present descriptive information on the distribution of numbers of fatalities in accidents in the form of so-called FN curves, which plot the frequency, F, of accidents in which there are N or more fatalities against N, usually on double-logarithmic scales. Such graphs can be used equally well to present empirical information on the numbers of fatalities in past accidents, or on the distribution of fatalities in accidents as estimated in a risk model. Descriptive FN curves present the same information as histograms, but in a different way. As illustrations, Figure 9.2 shows empirical FN curves for British road and civil aviation (including general aviation) accidents in 1963-1992 (Ref 59) and the solid line in Figure 9.3 shows the modelled frequency of accidents of different sizes in the Channel Tunnel (Ref 60).

9.52 If societal risk is defined according to the first definition above, the FN curve for an activity may be regarded as a representation of its societal risk. For the purpose of judging the tolerability of societal risk, it is then natural to draw on the graph a pair of criterion lines, labelled the intolerable line and the negligible line, as illustrated by the dotted lines in Figure 9.3. (In that example, the criterion lines are determined by the Channel Tunnel Safety Authority’s requirement that the Tunnel be at least as safe per passenger-kilometre as the existing British or French railways, and therefore they are derived by scaling, smoothing and extending BR’s existing empirical FN curve.) The reason why it appears natural to draw such criterion lines is that they seem to be the two-dimensional analogues of the tolerability boundaries for individual risk discussed previously.

9.53 The region above the upper line is then the intolerable region; that between the lines is the ALARP region; and that below the lower line is the negligible region. The decision rules are that if the FN curve crosses the upper criterion line into the intolerable region, then risks must be reduced without regard to cost; if the FN curve is in the ALARP region, the risks must be made as low as reasonably practicable; if the FN curve is below the lower line, no particular action is required. This procedure was introduced by the HSE for the first time in the study of the transport of dangerous substances (Ref 50), and has since been used in several other studies; as mentioned above, it was used in the evidence presented at the Manchester Airport inquiry.

9.54 The procedure does, however, raise a series of questions:

(1) Are societal risk criteria, that is criteria based on the frequency of accidents, necessary and desirable as complements to constrained CBA?

(2) If so, should the tolerability criteria be based, as in the case of the above procedure, on accident size?

(3) If so, is the above procedure using FN-criterion lines a sensible method by which to apply such criteria?

(4) Should people killed in large accidents be given more 'weight' than those in smaller accidents?

9.55 The first question may be rephrased as at the beginning of this section: if all cost-beneficial safety measures have already been implemented, and if individual risk criteria are already met, are there any grounds for doing more and going further? The Royal Society's (Ref 51) and the HSE's answers are that there may be. The justification for this view is that some types of major accident may have effects that go beyond the immediate casualties and damage, and provoke socio-political responses.

9.56 If these responses carry high costs, such as subsequent requirements for unwarranted and cost-ineffective regulation or safety measures, or the over-estimation of risk by customers, those costs can be reasonably attributed to the accident. Therefore their avoidance is part of the benefit of reducing the risk of such accidents in the first place, but this benefit is not taken into account in the constrained CBA discussed previously.

9.57 The most convincing examples of this are accidents which provoke the over-estimation of risk by customers, who may respond by ceasing to use a service that they would otherwise wish to use. This happened on the London Underground after the 1987 Kings Cross fire (Ref 61), and is a constant concern of airlines, whose safety reputations are commercially important. Such considerations may justify safety measures well beyond those that would be justified on the arguments of the previous section.

9.58 The argument that major accidents provoke requirements for unwarranted safety measures is less convincing, because it is possible to refrain from imposing such requirements, but there is no doubt that such requirements have been imposed in the past. Again, the Kings Cross fire provides examples such as some of the underground station alterations required under the Fire Precautions (sub-surface Railway Stations) Regulations 1989 (see Ref 62 for a discussion). The conclusion is that there may be a case for criteria concerning the frequency of major accidents, but the nature of the argument should be made clear in each application.

9.59 If the argument for criteria concerning the frequency of accidents is accepted, should the criteria be related to the number of fatalities in accidents, as in the standard FN-graph? It is reasonable to accept that the number of fatalities is an important determinant of whether an accident provokes a wide response, but it is obviously not the only factor. For example, there have been accidents with no deaths which nevertheless provoked a wide response, such as the 'Three Mile Island' or the 'Exxon Valdez' incidents. However, the number of fatalities is probably the best general numerical proxy for the importance of an accident, and therefore, if criteria concerning the frequency of accidents are to be used at all, it seems reasonable to base them on numbers of fatalities.

9.60 Such criteria raise a difficult question in the case of third party accidents near airports, namely: should the number of fatalities (or injuries) to people in the aircraft be added to those to people on the ground, or not? Not to add them would seem to offend common sense, since it is the total number of fatalities that is the most important aspect of an accident, not its distribution between categories of people. On the other hand, if the categories are combined, then third party fatalities would have little weight compared with those to people on board aircraft, because the latter generally account for the large majority of aviation fatalities.

9.61 If it is accepted that tolerability criteria based on the frequencies of accidents with different numbers of fatalities are desirable, then are FN-criterion lines, such as those illustrated in Figure 9.3, the correct way to implement such criteria? The authors' response is No. The point is that such lines may lead to judgements that are both inconsistent and unreasonable (Ref 63).

9.62 The problem stems from the fact that an FN curve is equivalent to a probability distribution, that of the number of fatalities in an accident. If judgements about probability distributions are to be consistent, they must obey certain rules for decision-making under uncertainty. Judgements about FN curves should obey the same rules, but the FN-criterion line procedure violates these rules.

9.63 However, the situation can easily be retrieved by replacing the FN-procedure with one correctly grounded in decision theory. This is the following: (a) decide on the relative weighting to be given to fatalities in accidents of different sizes; (b) calculate the mean weighted number of fatalities per year, using the accident size distribution implicit in the FN curve; (c) compare the result with some criterion value, and declare the system tolerable or intolerable according to the results of this comparison. This does what the proponents of the FN-criterion appear to believe that they are doing anyway; however, it cannot easily be shown in a graph.

9.64 Should fatalities in large accidents be given more weight than those in smaller ones? There is no consensus on this question, though the Royal Society and HSE both advocate that criteria should include a 'scale effect'. In particular, the HSE (Ref 55) adopt more stringent criteria in their advice on the granting of planning permission for large groups of houses near hazardous industrial sites than they do for smaller groups, even though the individual risk for any particular occupant is obviously the same. The only piece of relevant quantified empirical evidence is the finding in (Ref 48) that there is no 'scale effect' in what people are willing to pay to reduce risk on the Underground: that is, people are not willing to pay more to reduce the risk of a fatality in a large accident than in a small one.

9.65 However, even if that finding were generally true, it would not necessarily rule out giving more weight to fatalities in large accidents, because Jones-Lee and

Loomes were concerned with the direct effects of accidents, and not with the wider social, economic and political responses that large accidents may provoke. Therefore the question of whether more weight should be given to fatalities in large accidents is still open.

Uncertainty in risk estimates

9.66 Estimates of the frequency and consequences of rare accidents can often be made only with considerable uncertainty. Aircraft crashes world-wide are more frequent than the realisation of many major industrial hazards, and therefore the risk estimates are likely to be relatively good compared with those of major industrial hazards, but there is still considerable uncertainty about third party risks near airports.

9.67 There has been little formal analysis of the effects of uncertainty on risk appraisal. One obvious and important qualitative effect is that uncertainty renders it impossible to guarantee that a system meets its tolerability limits, because, however low the risk may seem to be, there is always a possibility that the true risk is higher, and indeed so high that it breaches the tolerability limit. For this reason, the HSE has argued that a conservative policy should be adopted when risks are uncertain. That is, the effective upper limit to tolerable risk should be reduced in the presence of uncertainty, to reduce the probability that the real limit is inadvertently breached. This view is supported by a small study by Evans and Verlander (Ref 64).

Summary

9.68 Constrained cost benefit analysis takes into account both efficiency of use of resources for safety measures, and the distribution of risk between individuals. This is the HSE's tolerability of risk framework, in which 'as low as reasonably practicable' is interpreted as meaning that safety measures within the ALARP region should be implemented if and only if their benefits exceed their costs.

9.69 The application of the framework requires two key parameters: the upper limit to the tolerable individual risk, and the value of statistical life. There are values for both of these which are widely used, even though they are not very well based. However, because these parameters are so important, they have both been the subject of empirical work in this study, which is summarised in Chapter 10.

9.70 If safety policy is implemented in accordance with 'constrained CBA' the case for further measures under the heading of 'societal risk' is doubtful, notwithstanding the fact that analyses using FN curves are commonplace. The best argument for further measures is that some types of accident may have effects which go beyond the immediate casualties and damage in the accident; the benefits of avoiding such accidents would therefore be greater than the immediate analysis would suggest. However, such considerations can be converted into policy only on a judgmental basis at present.

10 FIELDWORK ON ATTITUDES TO THIRD PARTY RISK NEAR AIRPORTS

10.1 The conclusion of Chapter 9 is that ‘constrained CBA’ provides a suitable general framework for appraising third party risk near airports. The application of this framework requires numerical values for two key parameters. These are:

(i) the upper limit to tolerable individual risk; and

(ii) the value of statistical life in the context of third party risk near airports.

10.2 As discussed in Chapter 9, ‘standard’ values exist for both these parameters, but they are not well based. The DoT decided at the outset not to adopt these values uncritically for the purpose of this review, but to commission a specific investigation of attitudes to third party risk near airports, in order to help decide whether to adopt or modify the standard values of the parameters.

10.3 The investigation into attitudes to third party risk near airports was carried out by Jones-Lee and Loomes, using methods similar to those which they used in their work on risk valuation for London Underground (Ref 48). This Chapter provides a summary of the methods, main results and conclusions. Jones-Lee and Loomes (Ref 53) have produced a separate report on their investigation, which provides full details.

Objectives of the fieldwork

10.4 The main objectives of the fieldwork were the following:

(i) to investigate whether there is an absolute upper limit to the risk from aircraft accidents near airports that people would tolerate as third parties, and, if so, to estimate what that limit is; and

(ii) to investigate how people’s valuation of statistical life in third party aviation accidents compares with that in road accidents.

10.5 So far as is known, no previous research has attempted to investigate attitudes of the public to risk tolerability limits in any context, so objective (i) breaks new ground. As discussed in Chapter 9, HSE does have a standard value of the upper limit to the tolerable risk of death to third parties, but that is not directly based on research into attitudes of the public. The HSE’s tolerability of risk framework was subject to extensive scrutiny at the Hinkley Point public inquiry (Ref 65).

10.6 Objective (ii) is similar to a corresponding objective in Jones-Lee and Loomes’ work for London Underground. Note that no attempt was made either in that research or in the present fieldwork to place an absolute valuation on the risk of death; instead, what is estimated is the premium or discount that people would place on the value of statistical life in the specified non-road context relative to that in a road accident. This premium or discount can then be applied to the standard road valuation to obtain absolute valuations in the non-road contexts.

10.7 As in the London Underground work, two possible reasons for differences in valuations were investigated, labelled the ‘context effect’ and the ‘scale effect’. The former is the possibility that people place different valuations on fatalities in similar-sized accidents because of their different circumstances; the latter is the possibility that people place different valuations on fatalities in similar types of accidents but with different numbers of fatalities.

Focus groups

10.8 The information about attitudes to risk was elicited in a series of sixteen focus group meetings, all moderated by Loomes. Six meetings were held in the neighbourhoods of each of Gatwick and Leeds Bradford, and four near Luton Airport in evenings in May 1996. Each group was planned to have six participants, though ‘no-shows’ sometimes reduced the numbers, and in the event there were ten groups with six participants, five with five, and one with four, making 89 participants in all, of which 45 were male and 44 were female. Participants were recruited by a market research firm, using quota guidelines intended to produce groups consisting of three males and three females, and representative of the local socio-economic spectrum.

10.9 Each meeting lasted about 70 minutes and followed the same format. After a general introduction, Loomes gave each participant a questionnaire, and the rest of the meeting was devoted to going carefully through the seven questions on it, question by question. Participants were asked to write their answers on their questionnaire and encouraged to discuss their answers. It was made clear at the outset that, if participants wished to modify their answers in the light of points raised in discussion, they should feel free to do so.

10.10 Of the seven questions, three were designed directly to fulfil the objectives of the fieldwork. One concerned the tolerability of risk; one concerned the ‘context effect’ in the valuation of statistical life; and one concerned the ‘scale effect’ in the valuation of statistical life. All these questions were complex, so the other four questions were designed as ‘lead-ins’ to the three main questions, and were intended to help participants understand what they were being asked. In this report, only the results of the three main questions are summarised; details of all questions, and of the individual answers, are given in Reference 53.

Risk tolerability

10.11 In the main question on risk tolerability, participants were asked to imagine that the pattern of use of the nearby airport was altered is such a way as to place their house in a zone with a specified level of risk, which was first taken to be equal to that from accidental electrocution; this level of risk was also described numerically as a chance of an aircraft crashing into their house of 1 in 1,000,000 per year.

10.12 Participants were asked to suppose that there would be full compensation for any loss of property value if and when someone sold their property and left the higher-risk zone. They were also asked to suppose that so long as a household remained in the zone, it would receive an annual payment as compensation for bearing the increased risk. If any household considered that the amount offered was not sufficient to compensate its members for bearing the risk, they could exercise the option of being relocated, free of charge, to an equivalent property outside the higher-risk zone, with a lump-sum payment to cover all inconvenience and removal expenses. Exercising this option effectively meant that, after the relocation, household members would be in the same position - in terms of quality of life and level of risk - as they were before the risk was increased.

10.13 Participants were provided with a list of possible levels of compensation, ranging in increasing steps from zero, which was described as the risk being "too small to worry about", through £50 per year, £100 per year, £250 per year, etc., up to £5,000 per year and finally "more than £5,000 per year". For each level of compensation, participants were then asked to write down whether they would find it acceptable, whether they were uncertain, or whether they would find it unacceptable and require relocation. After answering the question for the initial level of risk, participants were then asked to repeat the question with increased hypothetical levels of risk, which were again presented in both comparative and numerical ways. The levels of risk considered were equivalent to that of death in a domestic fire (1 in 100,000 per year); death in a road accident (6 in 100,000 per year); and injury in a road accident (60 in 100,000 per year).

10.14 Strictly speaking, an individual's tolerability limit should be defined as the level of risk for which no finite sum would be acceptable as compensation. But for practical purposes in the context of PSZs, the limit was taken as being the point at which nothing less than a fully-compensated relocation to a safer area would be acceptable. Moreover, given that the cost to the authorities of effecting a fully compensated relocation would generally not exceed the amount that would generate a (net of tax) annuity of £5,000 per year, the rejection of that level of compensation can be regarded as a good operational basis for determining tolerability limits with respect to third party risks of death near airports.

10.15 Although the tolerability question was the most complex of those asked, 81 out of the 89 participants provided useable responses. The results are summarised in Table 10.1. The table shows that 47 out of 81 participants (about 60%) stated that a risk of 10^{-6} per year of an aircraft crashing into their house was too small to worry about. At the other end of the scale, 36 out of 81 (about 45%) of participants stated that they would reject compensation of £5,000 per year at a risk of 6×10^{-5} per year, implying that they would regard this risk as effectively intolerable, and 60 out of 81 (about 75%) did so at a risk of 6×10^{-4} per year.

10.16 It would be surprising if data generated by a sample of ordinary people gave precise and consistent boundaries between tolerable and intolerable risk, or - at the other end of the scale - between tolerable and negligible risk. However, given that a single upper tolerability limit is being sought, the conventional level of 10^{-4} per year is in reasonable agreement with the data. Admittedly, about 25% of participants stated that they would still accept compensation for risks as high as 6×10^{-4} per year, but against that it might be argued that, if the risks were real rather than hypothetical, one might expect rather greater aversion. At the other end of the scale, where about 40% of participants stated that they would require compensation or relocation at a risk of 10^{-6} per year, the same argument might suggest that the boundary point below which risk are too small to worry about is closer to 5×10^{-7} than the conventional value of 10^{-6}.

10.17 Regulatory bodies such as the HSE make judgements for public inquiry purposes about the maximum levels of risk that are to be considered tolerable for third parties in specified contexts, and these may not necessarily match individuals' judgements. Nevertheless individuals' judgements are an important input to regulatory judgements, and the finding that these are broadly in line with the conventional value adopted by the HSE does provide support for this value. In the light of this finding, the conventional upper tolerable limit of a risk of death of 10^{-4} per year is adopted for the purpose of this study.

Relative valuation of statistical life

10.18 In the main question on the 'context effect' in the valuation of statistical life, participants were asked to imagine that an aviation safety project had been proposed which could be expected to save the lives of 25-30 people on the ground in a number of light aircraft accidents over a period of about 25 years, each killing 1, 2 or 3 people on the ground. An alternative way of spending the public money would be on a road safety project.

10.19 Participants were first asked to suppose that the road safety project could be expected to save the same number of lives as the aviation project. They were then asked to state whether they would prefer to see the aviation project chosen, would not mind which project was chosen, or would prefer to see the road project chosen. Those who preferred the road project were then asked to suppose that the road project would actually save fewer lives than the aviation project, and were asked to write down the (lower) fatality band at which they would switch to preferring the aviation project. Those who initially preferred the aviation project were then asked to suppose that the road project would actually save more lives than the aviation project, and were asked to write down the (higher) fatality band at which they would switch to preferring the road project. The combination of the answers to these questions gives the distribution of the numbers of lives saved in the road project that are judged to be 'equally as good as' 25-30 lives on the ground saved in small-scale aviation accidents.

10.20 Table 10.2 presents the results. All 89 participants provided useable answers. When both projects would save the same number of lives, about 30% of participants did not mind which was chosen. Of the rest, those favouring the road project outnumbered those favouring the aviation project by 2 to 1, although almost half of these said that they would switch to the aviation project if the road project would save only 20-24 lives. Thus, while there is evidence that preventing deaths on the road has an edge over preventing deaths among people on the ground from light aircraft crashes, it is only a slight edge, and is probably insufficient, given the spread of responses, to justify using a lower value of statistical life for light aircraft crash victims on the ground than for road accident victims.

10.21 The main question on the 'scale effect' was structured in a similar way to that on the 'context effect'. Participants were asked to imagine that an aviation safety project had been proposed which could be expected to save one large aircraft accident during the next 25 years, which in turn would be expected, on average, to prevent 25-30 people on the ground being killed. An alternative way of spending the public money would be on a different aviation project aimed at preventing small aircraft accidents.

10.22 As before, participants were first asked to suppose that the small-accident project could be expected to save the same number of lives as the large-accident one. They were then asked to state whether they would prefer to see the small-accident project chosen, would not mind which project was chosen, or would prefer to see the large-accident project chosen. Those who preferred the small-accident project were then asked to suppose that it would actually save fewer lives than the large-accident project, and were asked to write down the (lower) fatality band at which they would switch to preferring the large-accident project. Those who initially preferred the large-accident project were then asked to suppose that the small-accident project would actually save more lives than the large-accident one, and were asked to write down the (higher) fatality band at which they would switch to preferring the small-accident project. The combination of the answers to these questions gives the distribution of the numbers of lives saved in the small accidents that are judged to be 'equally as good as' 25-30 lives on the ground saved in one large accident.

10.23 Table 10.3 presents the results. Again all 89 participants provided useable answers. Eight participants favoured the large-accident project so strongly that they would require the small-accident one to save more than 60 lives before they would switch to it. Apart from these, 36 of the remaining 81 participants would not mind which project was chosen, and the distribution of the other responses is broadly symmetrical. Therefore, although the strength of preference among the group of 8 indicates some overall tendency towards a higher value of statistical life for large-scale relative to small-scale accidents, the effect is not substantial.

10.24 When the answers to the question on the 'scale effect' are combined with those to the question on the 'context effect', a reasonable point estimate of the ratio of the valuation of statistical life for third parties on the ground in aviation accidents to that in road accidents is about 1.15. However, this estimate is not statistically different from 1; that is, given the spread of individual responses, the estimate is consistent with the hypothesis that the two valuations of statistical life are equal. Therefore, for the base calculations in the application of constrained CBA to PSZs, the hypothesis of equal valuations will be accepted. It should be noted that, even if the ratio of 1.15 had turned out to be statistically significantly different from 1, a difference of about 15% is small in comparison both with the uncertainty in the road valuation itself and with the uncertainty in the other quantities in the constrained CBA calculations, which are discussed in Chapter 11.

10.25 It should also be noted that surveys aimed at estimating preference-based values of safety are complex and difficult, and that, as mentioned in Chapter 9, different surveys in the past have obtained widely varying results. This is a field in which definitive findings are not to be expected. Therefore, the results of the fieldwork presented in this chapter should be regarded as useful indicators of the key parameters to be used in appraising PSZs, but they should not be regarded as at all precise.

10.26 It is interesting that the results of the present fieldwork are somewhat different from those of Jones-Lee and Loomes' work (Ref 48) for London Underground. In the Underground case there was a premium on the valuation of statistical life relative to the road value of about 50%, due entirely to the 'context effect'. In this case there is no statistically significant premium, but, if anything, it is the 'scale effect' rather than the 'context effect' that is influential.

Summary

10.27 In the light of the findings from the fieldwork, the base values adopted for the key parameters necessary to apply 'constrained CBA' to PSZs are the following:

(i) the value of the upper limit to tolerable individual risk of death is taken to be the conventional value of 10^{-4} per year; and

(ii) the value of statistical life for third party deaths in aviation accidents is taken to be the same as that in road accidents. (The DoT's value at 1993 prices was £744,000).

10.28 An obvious sensitivity test is to explore the effect of a higher value of statistical life. This is mainly because, as discussed in Chapter 9, the official valuation of statistical life in road accidents is towards the low end of the range found in empirical studies. It is also useful to explore what would be the effect on PSZs if a higher value of statistical life were to be adopted for third party aviation fatalities than for road fatalities.

11 APPLICATION OF THE GENERAL CRITERIA TO PUBLIC SAFETY ZONES

Introduction

11.1 The application of 'constrained CBA' to the determination of PSZs in principle requires the following steps:

(i) identify the risk contour corresponding to the individual tolerability limit of a risk of death of 10^{-4} per year;

(ii) at each point outside the 10^{-4} contour, compare the benefits from reducing risk, using the appropriate valuation of statistical life, with the costs of removing or prohibiting activities at that point; and

(iii) designate the PSZ as the area within the contour in (i) together with the area in which the benefit in (ii) exceeds the cost.

11.2 There are clearly many practical issues to be considered in establishing a workable PSZ policy, but these would be the principles on which it would be based.

11.3 As indicated in Chapter 9, if PSZ policy were established in accordance with these principles, the case for further restrictions on development under the heading of 'societal risk' does not appear to be compelling. The case for further restrictions would rest on an argument that certain types of accident have ramifications beyond those of 'ordinary' accidents.

11.4 The types of development to which such considerations might particularly be applicable are places where people assemble in large numbers. It would therefore seem sensible to give these special consideration, much as the HSE (Ref 55) already does for such developments in the vicinity of hazardous industrial sites. However, there are no obvious general principles for determining precisely what, if any, additional restrictions should apply in these cases.

Value of land and development

11.5 If the use of a piece of land is forgone for safety reasons, other than for agriculture, what is the value of what is lost? This is the so-called 'opportunity cost' of the decision to forgo the use of the land. Table 11.1 shows the components of the opportunity cost. The table indicates that the value depends crucially on what buildings are already on the land, and, if there are no buildings already on the land, on what buildings would otherwise be permitted.

11.6 The category of land for which it is most difficult to value the opportunity cost of inhibiting development is land on which development would be permitted if it were not for the PSZ, that is category (c) in Table 11.1. Development land typically has a value that is very much greater than agricultural land; the difference between the value of land with permission for a specified type of development and its value without that permission is labelled its ‘development value’. Therefore inhibiting development on a piece of land greatly reduces its value. However, it does not follow that the social cost of inhibiting development on a specified piece of land is the full development value of the land; that depends on what substitute pieces of land are available, or can be made available.

11.7 At one extreme, there may be no substitutes at all for the restricted land. In that case, the opportunity cost of inhibiting development would indeed be the development value of the land. This is because the development value is presumed to reflect the social benefit of the development, and this is lost entirely if the development cannot take place at all. At the other extreme, alternative sites for the development may be made available that are as good as the first site. In that case, the social opportunity cost of inhibiting the development in the PSZ would be zero, though there would still be a redistribution of value between the sites.

11.8 It is clear that the social opportunity cost of inhibiting development in any particular case would lie between these extremes. However, there appears to be no research on just where within that wide range typical values might lie. One reason for this may be that there is no general answer: the consequences of any particular planning decision may depend too much both on the specific circumstances and on other decisions.

11.9 For the purpose of this review, it has been assumed that the opportunity cost of inhibiting development is a small fraction of the land’s development value: 10% has been taken as a representative value. The rationale for taking a relatively small value is the following. The existence of development value is primarily a consequence of the British land-use planning system, which generally imposes tight constraints on development, while permitting it in specified places. The economic consequences of the land use planning system are a matter of debate (see, for example, Ref 66), but the system itself is widely regarded as beneficial, which implies that any extra costs that the system imposes on development are regarded as outweighed by the benefits of a controlled and orderly development process. Even if that might be questioned, this review is not an appropriate place to do so. In the context of the land use planning system as it is, any constraint on development imposed for PSZ reasons is a relatively small addition to the many other constraints on development imposed by the planning system. Therefore it is reasonable to presume that PSZ constraints could be absorbed at little net social cost, especially if PSZs are taken into account at the stage when development plans are prepared, when alternative land can be made available relatively easily.

11.10 It is useful also to note that adopting a relatively low opportunity cost for development land has the effect of making it cost-beneficial to extend PSZs further than otherwise, and thus ‘erring on the side of safety’. This is sensible because development, once built, cannot easily be moved.

11.11 The only other item in Table 11.1 needing discussion is 'occupiers' surplus'. This recognises that the value of a building to its occupiers may be greater than its market value. Occupiers' surplus is the difference between the price at which the occupier would be a willing seller and the market price of a building. The expression is a generalisation (to a wider class of building) of the term "householders' surplus", which was coined by the Commission on the Third London Airport (Ref 67, Appendix 23), to describe the occupiers' surplus for dwellings. The Commission estimated householders' surplus as 52% of the market value of dwellings for the purpose of their cost benefit analysis. They also added 16% for removal expenses, so that the opportunity cost of a compulsorily purchased dwelling was assumed to be 168% of the market price.

House and land price data

11.12 Table 11.2 presents official statistics on average house prices, housing land prices, and agricultural land prices by region in England and Wales for 1993, which is the most recent year for which reasonably complete data on housing land prices are available. There are no official statistics of development land prices for other purposes, but housing land prices provide a useful indication of the value of development land for the purpose of this review.

11.13 Table 11.2 shows that, as indicated above, there is enormous variation between the values of the various categories of land in Table 11.1. The average price of agricultural land in England and Wales in 1993 was £0.0035 million per hectare, and that of housing development land was £0.331 million. If it is assumed that existing houses in England and Wales have the same density as housing land sold in 1989-1993, 23.4 houses per hectare, and that their average price is £63,000, then the average value of a hectare of land with existing houses was £1.47 million. If these were all occupied, and the householders' surplus is as estimated by the Commission on the Third London Airport, then the opportunity cost of ceasing to use the houses would be 68% more than the value of the houses, or £2.48 million.

11.14 In terms of house plots or houses, the average value of a piece of agricultural land of the same size as the average house plot was £3,480 divided by the average housing density of 23.4 houses per hectare, or £150. The average value of a house plot was £14,200. The average development value of a house plot was the difference between these figures, or about £14,000. If, as discussed above, it is assumed that the social opportunity cost of inhibiting housing for PSZ reasons is 10% of the development value, then this opportunity cost would be £1,400 at 1993 prices. The average value of an unoccupied house was £63,000. The average opportunity cost of ceasing to use an occupied house, including the householders' surplus, would be 68% more than this, or £106,000.

11.15 An important conclusion from the price data is that because the opportunity cost of forgoing the use of developed land is very different from that of undeveloped land, it is reasonable to expect that on cost benefit grounds a consistent PSZ policy would impose different restrictions on different land categories.

Value of safety

11.16 The average number of people per household in the neighbourhood of the five airports discussed in Chapter 7 was 2.65 at the time of the 1991 census. This is slightly higher than the national average, presumably because airports are located in the outer areas of cities, where dwellings are on average slightly larger than in inner areas. If it is assumed that each dwelling contains one household, and that the value of statistical life is £744,000, as discussed in Chapter 10, the value of the statistical lives of the people living in the average dwelling in the neighbourhood of airports was £2.0 million at 1993 prices. This is much larger than the average value of the dwelling itself, which was £63,000.

11.17 It may therefore be deduced that the principal benefit from the reduction of third party risks near airports takes the form of reductions in casualties rather than reductions in property damage. Correspondingly, the principal losses, or disbenefits, if risks were increased, would be increases in the number of casualties. Therefore, the value of avoidance of property damage can be regarded as negligible.

11.18 If the value of statistical life does not vary with the absolute risk, the value of the risk at any location is proportional to the absolute individual risk level, say *r*. Let the average number of occupants per dwelling be *n* (taken as 2.65 above), and let the value of statistical life be *v* (taken as £744,000 above). Then the value of the statistical lives of the occupants of the average house is *nv*, and if the house is located on risk contour *r*, the annual value of the risk is *nvr*. If this risk is maintained for *m* years, and the discount rate for future costs and benefits is *d*, the present value of the disbenefit from the risk is:

$$nvr \left| 1 + \frac{1}{(1+d)} + \ldots + \frac{1}{(1+d)^{m-1}} \right| = nvr \left(\frac{1 - \frac{1}{(1+d)^m}}{1 - \frac{1}{1+d}} \right) \qquad (11.1)$$

11.19 The DoT have advised that for the purpose of this review, the discount rate, *d*, for the base case should be taken as 3.5 per cent per year, and the time horizon, *m*, should be taken as 30 years. The justification for the 3.5% is that the standard public sector discount rate is 6% per year, but this is reduced in respect of safety, because the value of safety can be expected to rise in real terms in the long term with growth in real income per head, as indeed does the DoT value of statistical life in road accidents. It is assumed that the growth in real income per head will be 2.5% per year, giving a net discount rate for safety benefits of about 3.5% per year. The time horizon of 30 years is arbitrary, but some limit is desirable, because it is possible that technology will change so that PSZs will not produce benefits in perpetuity.

11.20 With d = 3.5% and m = 30, the term in large brackets on the right-hand side of equation (11.1) is 19.04. Therefore, with the values of n and v used above, the value of the stream of risks to the occupants of the average house on contour r is £37.5r million. Therefore, for example, the present value of the risk per house located on the 10^{-4} contour is about £3,750.

Applying constrained CBA to PSZs

11.21 Figure 11.1 illustrates the shape of the risks resulting from the application of constrained CBA to PSZs. The vertical axis in Figure 11.1 is individual risk, as in HSE's tolerability of risk diagram (Figure 9.1); the horizontal axis is the value per house or per house plot that would be forgone if the house or plot were given up. Note that both scales are logarithmic; this is purely to permit the wide range of risks and values to be shown on a single graph.

11.22 The diagonal line is where the value of the plot or house is equal to the present value of the risk, given above as £37.5r million; because the value of the risk is directly proportional to r, the line has a slope of +1 on these double-logarithmic scales. Above the diagonal line, the present value of the risk is greater than the value of the property; below the line, the value of the property is greater than the present value of the risk. The horizontal line represents the upper limit to tolerable individual risk of death, which is taken to be 10^{-4} per year, as discussed in Chapter 10; risks above the line are intolerable, and risks below the line must be reduced if the benefits of doing so exceed the costs.

11.23 Figure 11.1 shows that if the opportunity cost of property is low, at the left-hand end of the horizontal scale, then the risk level should be determined by the cost-benefit line. It is worthwhile reducing the risk below the tolerable limit because the opportunity cost of doing so is relatively low. In the context of PSZs, this might apply to undeveloped land, where substitutes are available.

11.24 However, at the other end of the horizontal scale in Figure 11.1, where the opportunity cost of property is high, it would not be cost-beneficial to give up property to avoid the risk, but it would be necessary to do so if otherwise the tolerability limit is breached. In the context of PSZs, high opportunity costs would typically apply to existing houses.

11.25 Therefore, the level of third party risk resulting from the application of constrained CBA would theoretically follow the solid kinked line in Figure 11.1. For low property values, the risks are given by the diagonal segment, determined by CBA. For high property values, the risks are given by the horizontal segment, determined by the tolerable risk limit. The location of the kink between the segments is the present value of the risk per house or plot at the tolerable limit of 10^{-4}, which was calculated above as £3,750. In the paragraphs which follow, the application of this framework to existing housing and to housing development land is discussed, using the risk and property values previously presented.

Existing housing

11.26 Table 11.2 shows that the market value of the average house was £63,000 at 1993 prices. It was calculated above that if the 'householders surplus' and removal expenses are added at the same rate as that assumed by the Commission on the Third London Airport, the opportunity cost of giving up the use of an average occupied house would be £106,000. This value is shown in Figure 11.1, and is much greater than the 'kink value' of £3,750. Therefore on the 'constrained CBA' principle, the risk for existing houses would be determined by the tolerable limit. There would be no case on cost benefit grounds for abandoning average-price houses with lower risks than 10^{-4} per year. Therefore there would be no case for PSZ policy to require the removal of such existing housing outside the 10^{-4} contour.

11.27 If an existing house were unoccupied, the average opportunity cost of its removal would be £63,000, which is also well above the 'kink value' in Figure 11.1. Therefore, PSZ policy for unoccupied houses should be the same as for occupied ones.

11.28 In practice, it is not average prices that would determine the cost-benefit balance for existing houses near any particular airport, but the local prices of houses within the potential PSZ, which might be different. However, the gap between the 'kink value' and the typical value of houses anywhere is so large that even the lowest valued houses would still have a value above the kink, so that the same PSZ policy should be applied everywhere.

11.29 A more difficult question of principle for PSZ policy with regard to existing housing concerns the extent to which the 10^{-4} tolerability limit is to be regarded as absolute. That is to say what the policy should specify for houses inside the 10^{-4} contour. As shown in Figure 11.1, for most of these the cost benefit balance would favour retention; for those only just inside the 10^{-4} contour, the net loss from their removal would be large. However, in HSE's words (Figure 9.1), because they breach the tolerability limit, the "risk cannot be justified save in extraordinary circumstances". The conclusions from the fieldwork discussed in Chapter 10 support this. This suggests that PSZ policy should require the removal of houses within the 10^{-4} contour. However, in practice the HSE does not require the removal of such houses near hazards for which they are the regulator.

11.30 It appears that from the risk estimates in Chapter 7 that the 10^{-4} contours are so close to the airport runways at most airports that there are no houses within them. However there appears to be a small number of houses just within this contour at Heathrow. Therefore, although the question of whether existing houses within the 10^{-4} contour should be removed will not generally arise, it may do so in a few specific instances.

11.31 It is interesting to note that the Netherlands government has followed similar reasoning in the case of Schiphol, but with a more stringent individual risk tolerability limit of 5×10^{-5}. In that case, the policy does require taking about 40 existing houses out of residential use. This is planned to take place gradually over the period up to 2015. The lower tolerability limit is in line with generally more stringent risk limits in the Netherlands, but no surveys have been carried out of the kind discussed in Chapter 10.

Housing development land

11.32 The main difficulty in applying constrained CBA to PSZ policy for housing development land is the problem, discussed above, of valuing the opportunity cost of forgoing development. This is a problem that arises in any attempt to apply CBA to land use planning decisions. For reasons given above, in this review the base value of the opportunity cost of inhibiting development is taken to be 10% of the development value of housing land. The average value of this quantity for England and Wales was previously calculated to be £1,400 per plot at 1993 prices; corresponding regional figures range from £720 in Wales to £2,260 in the south-east outside London.

11.33 All these figures are less than the ‘kink value’ of £3,750 per plot in Figure 11.1, and therefore under the constrained CBA principle the extent to which the development of housing land is inhibited for safety reasons is determined not by the tolerability limit but by CBA. In other words, the area in which the development of land is restricted for safety reasons should be wider than the 10^{-4} contour. If the opportunity cost of forgoing a housing plot is £1,400, the risk at which the costs and benefits of inhibiting development are in balance is 3.7×10^{-5}, as shown in Figure 11.1; if the opportunity cost is £720, the balancing risk is 1.9×10^{-5}; if the opportunity cost is £2,260, the balancing risk is 6.0×10^{-5}.

11.34 It follows that in principle the extent of PSZ restrictions on the development of land should depend on local land values. However, given the substantial uncertainty in opportunity cost of forgoing the use of development land anywhere, it seems desirable that practical PSZ policies should not be over-sensitive to land values, and therefore it is doubtful whether local variations in PSZ policies are justified. Local variations might be justified if land values varied by as much as an order of magnitude, but the evidence is that they do not. A possible exception is London, but high land values in London are to a substantial extent counterbalanced by high densities.

Sensitivity of results to values of parameters

11.35 The value of the risk to the occupants of a house located on risk contour r depends on the number of occupants, n; the value of statistical life, v; the discount rate, d; and the time horizon, m. The effect of changing the value of any of these parameters is to shift the diagonal line in Figure 11.1 horizontally: if the value of the risk is increased, the diagonal line shifts to the right; if the value of the risk is reduced, the diagonal line shifts to the left.

11.36 Figure 11.2 shows the diagram in which the value of statistical life has been doubled, from £744,000 to £1,488,000; the previous location of the diagonal line is indicated by the dashes. The effect of increasing the value of statistical life is to reduce the balancing level of risk for land plots with any specified opportunity cost. For example, in the case of land plots with opportunity cost of £1,400, doubling the value of statistical life reduces the level of risk at which the opportunity cost is equal to the value of risk from 3.7×10^{-5} to 1.9×10^{-5}. In other words, the area in which development is restricted for safety reasons is extended.

11.37 However, most plausible combinations of parameter values and regional land values give 'balancing risks' in the range 10^{-4} to 10^{-5}. Therefore, there is little or no reason to restrict housing development outside the 10^{-5} contour. Given the uncertainties in the parameter values, the opportunity costs, and also the risk estimates, a robust general policy for housing would be to prevent development out as far as the 10^{-5} contour, but allow it beyond that contour. On balance, such a policy probably errs on the side of caution, in that it might be over-restrictive near the 10^{-5} boundary, but, as noted above, because development is difficult to reverse, it is appropriate to be cautious.

Extensions to existing houses

11.38 The risk reduction benefits from inhibiting extensions to existing houses are similar to those for new houses, assuming that the density of occupation is similar. However, the opportunity cost of inhibiting such extensions would be higher, at least for extensions that are intended for use by the existing occupier, for example to provide space for a growing household, because the alternative might be that the household would have to move, with consequent loss of 'occupiers' surplus'. This suggests that in general the cost benefit balance would favour extensions to existing houses between the 10^{-4} and 10^{-5} contours, and that therefore PSZ policy should permit these.

Other types of development

11.39 As mentioned above, the only official statistics for property prices identified, are those of the type in Table 11.2. Therefore for other development it is not possible to perform the same calculations as those above. However, it is possible to use the same reasoning in a less formal manner, and to compare other types of development with housing.

11.40 It should be noted first that the risk contours in Figures 7.1 to 7.5 are calculated on the assumption that a person is present at a specified location for 24 hours per day. No one can be present for more than 24 hours per day, and therefore the risk contours provide an upper limit to the individual risk at any location. Therefore, whatever the activity may be, no one outside the 10^{-4} risk contour can be at a risk level that breaches the upper tolerability limit. It was shown in Chapter 7 that the 10^{-4} contours are close to the runways at most airports, so that there is likely to be little third-party activity within them. However, in so far as there is activity within these contours, there is a case in principle for removing it if individuals are present for a substantial proportion of the day. For all development and activities outside the 10^{-4} contour, PSZ policy should be based on the relevant cost-benefit balance.

11.41 The benefits from inhibiting an activity at a specified location take the form of reduced risk. Following the same reasoning as for housing, the value of risk reduction for a single person present for 24 hours per day on risk contour r is given by equation (11.1) with n set to 1. If this is evaluated with the parameters v, d, and m set to their base values (£744,000, 3.5% per year, and 30 years respectively), the value of risk reduction for a single person is found to be £14.16r million. If the density of persons present at that location, averaged over the 24-hour day, is p persons per hectare, the value of risk reduction per hectare is £14.16pr million. Therefore, the benefit of inhibiting activity is proportional to p and r.

11.42 In the case of housing, the average value of p near airports is the product of the number of persons per house and the number of houses per hectare, which was assumed above to be 2.65×23.4, or 62.0 persons per hectare. Therefore the average benefit of inhibiting or removing housing is £878r million per hectare. On the 10^{-4} risk contour, this is £87,800 per hectare; on the 10^{-5} risk contour, it is £8,780 per hectare. The same benefits per hectare would apply to any other land use or activity that had the same average density of persons present as housing, 62.0 per hectare; lower benefits would apply to lower densities, and higher benefits to higher densities.

11.43 The cost of inhibiting or removing activities is the opportunity cost of forgoing the use of the land, the components of which are shown in Table 11.1. As with housing, this opportunity cost depends crucially on what buildings are already on the land. For any existing activity with a density of occupation of the same order of magnitude as that of housing, such as employment, the value of the buildings and any 'occupiers' surplus' would almost certainly exceed £87,800 per hectare, and therefore the opportunity cost of their removal would exceed the benefits, even if they were located on a risk contour as high as 10^{-4}. For activities with lower densities of occupation the value of the buildings might be reduced somewhat, but then the benefits of their removal would also be lower, so the cost-benefit ratio might be rather similar; the same argument would also apply in reverse to activities with higher densities. The conclusion is that there would be no case in general for PSZ policy to require the removal of existing buildings near airports, except in circumstances where they are within the 10^{-4} contour.

11.44 The appraisal of development land for non-housing purposes raises the same problems as that for housing land, namely that of estimating the opportunity cost of forgoing the use of development land. For land uses with average densities of occupation of land of the same order of magnitude as that of housing, it would seem sensible to adopt the same PSZ policy as for housing land, that is to prevent all new development out to the 10^{-5} contour. Again, this might err on the side of caution.

11.45 It may be considered reasonable to make an exception in favour of new development within the 10^{-5} contour for activities with average densities of human occupation that are much lower than the 62.0 persons per hectare assumed for housing. This is because the benefits of inhibiting development were shown above to be proportional to the average density of occupation, p, and therefore inhibiting low density activities would have low safety benefits. Long-stay car parking or warehousing are examples of development that might be justified. Moreover, because such development could be airport-related, it might also have a relatively high economic value.

Transport links

11.46 Transport links commonly pass close to airports: for example, Figure 7.1 shows that major roads pass through the 10^{-4} contour at Heathrow, and the M25 passes through the 10^{-5} contour; Figure 7.2 shows that the London-Brighton railway passes through the 10^{-5} contour at Gatwick.

11.47 For a 40-metre wide, six lane motorway operating near capacity with 2,000 vehicles per lane per hour, each carrying an average of 1.5 persons and moving at 80 kilometres per hour, the average density of human occupation is 56 persons per hectare. By chance, this is close to the 62.0 calculated above for housing. The person-flow on such a motorway is 18,000 persons per hour in both directions combined, which is of the same order of magnitude as that of a high-density passenger railway. A railway is narrower than a motorway, so its average density of human occupation could be somewhat higher, but not of a different order, though for the railway the distribution of occupation in time is different, with some periods of zero occupation, and other periods of high-density occupation. It follows that the safety benefits of removing either motorways or railways would be of the same order as those of removing housing, that is about £9,000 per hectare on the 10^{-5} contour, and £90,000 per hectare on the 10^{-4} contour. These figures are much lower than the costs of diverting a motorway or railway, so that there would be no case for diversion of existing links. Similar arguments would also apply to lesser roads, because although the costs of their diversion would be lower, so also would the benefits.

11.48 There would also probably be no case for diverting proposed links, since the costs of even minor route changes might exceed the benefits. However, proposed transport links are usually subjected to cost-benefit analyses in their own right, in which case the safety benefits of avoiding the relatively high-risk locations near airports could be directly taken into account at the time that the transport links were planned.

11.49 Even though it may not be cost-beneficial to divert transport links from relatively high-risk locations near airports, low-cost risk-reduction measures on transport links might well be worthwhile. The obvious measures would be devices to prevent trains and road vehicles from routinely coming to a halt in PSZs (because that increases the average density of human occupation), for example, by the careful siting of rail and road traffic signals.

11.50 Transport terminals have higher densities of human occupation than transport links, and therefore the benefits per hectare of reducing risk are higher. However, the benefits of removing existing terminals would be much less than the costs. On the other hand, it might well be cost-beneficial to avoid placing new transport terminals within the 10^{-5} risk contour.

Conclusions

11.51 The conclusions from the application of constrained CBA to PSZ policy are the following:

(i) there is a strong case in principle for PSZ policy to require the removal of existing housing, and of other development occupied by third parties for a high proportion of the day, from within the 10^{-4} individual risk contours. It is estimated that a small number of properties are within this contour at Heathrow, but at most airports the 10^{-4} contours are so close to the runways that there is no development within them.

(ii) there is no case for removing existing housing outside the 10^{-4} individual risk contour;

(iii) there is a case for inhibiting new housing development as far as the 10^{-5} individual risk contour, but not beyond;

(iv) there is a case for permitting extensions to existing houses within the 10^{-5} individual risk contour;

(v) there is no case for removing non-housing existing development outside the 10^{-4} individual risk contour;

(vi) there is a case for inhibiting most new non-housing development, including transport terminals, as far as the 10^{-5} individual risk contour, but not beyond;

(vii) an exception to (vi) is that there is a case for allowing new development with a low density of human occupation, averaged over the day, within the 10^{-5} and up to the 10^{-4} individual risk contour. This might include long-stay car parking and warehousing; and

(viii) there is no case for diverting existing transport links near airports, and probably also no case for diverting proposed links, though the latter should be considered on their individual merits. Low cost measures to prevent vehicles from routinely coming to a stand within the 10^{-5} contour might well be worthwhile, if not already adopted.

Summary

11.52 A brief and simple summary of these conclusions is that the boundary of the PSZs for each airport should follow approximately the 10^{-5} individual risk contour. New development within the PSZs should be inhibited, with the exceptions of extensions to existing houses, development for activities with low average densities of human occupation, such as long-stay car parking and warehouses, and surface transport links. However, all existing development within PSZs should be permitted to remain, within the exception of that within the 10^{-4} contour.

11.53 A conclusion of Chapter 9 was that some types of accident could have repercussions that go beyond their direct effects, and therefore the benefits of avoiding such accidents would be greater than the immediate analysis indicates. In the context of PSZs, such accidents might involve sensitive or high-density land-uses, such as schools, hospitals or places of assembly. Given the findings of this chapter that the values of existing buildings located between 10^{-4} and 10^{-5} contours are generally much greater than the benefits of their removal, it seems unlikely that there would be a general case for the removal of existing buildings of the type mentioned above. However, there might well be a case for extending restrictions on sensitive new development somewhat beyond the 10^{-5} contour. As suggested in Chapter 9, such decisions are probably best made on a case by case basis.

12 PROPOSALS FOR PUBLIC SAFETY ZONES

12.1 This chapter assumes from the conclusions of Chapter 11 that PSZ boundaries will be based on the 10^{-5} individual risk contours, and considers their possible shapes and sizes using the risk contours for the five airports - Heathrow, Gatwick, Manchester, Birmingham and Leeds Bradford - analysed in Chapter 7.

12.2 A glance at Figures 7.1 to 7.5 shows that areas within the 10^{-5} contours at all the airports comprise narrow strips alongside the runways, together with shapes stretching along the extended main runway centrelines that approximate to thin isosceles triangles based on the ends of the runways. Figure 12.1 shows the shape of a typical such triangle. Some airports (Heathrow, Birmingham and Leeds Bradford) have cross-runways in addition to the main runways, but none of these are used to the extent that they materially affect the 10^{-5} risk contours. The cross-runways are therefore disregarded for PSZ purposes.

12.3 The widths of the strips alongside the runways average at most about 150 metres on each side of the centreline, including the runway itself, even at the busiest airports. From Figures 7.1 to 7.5 it appears these are within the airport boundaries, and therefore they have been neglected for PSZ purposes. Therefore the PSZs should be based on what might be labelled the ‘end-of-runway triangles’.

12.4 Table 12.1 shows the areas within that region of the 10^{-5} contour which is off the runway ends for each of the five airports, along with data on 1994 movements (excluding light aircraft traffic which have a more ‘spread-out’ crash distribution). When these two quantities are plotted against each other in Figure 12.2, the areas within the 10^{-5} contours off the runway ends are found to be approximately proportional to the number of movements.

12.5 The close correlation between the 10^{-5} areas off the runway ends and the traffic at the airports indicates that the movements can be used as a predictor of these areas, thereby avoiding the need to calculate risk contours for every airport. The linear fit obtained by linear regression was very good ($R^2 = 99.3\%$):

$$A = 523M + 16.19 \tag{12.1}$$

where A is the total area in hectares inside the 10^{-5} contour off the runway ends and M is the number of annual aircraft movements in millions (excluding light aircraft). A constant term was allowed in order to obtain the best fit to the data for the airports studied, although this means that equation (12.1) will probably not be appropriate for airports with very small numbers of movements.

12.6 The number of separate 10^{-5} regions off the ends of runways at an airport is, of course, equal to the number of main runway ends, E. If these regions are to be approximated by triangles at each of the main runway ends with total area inside all triangles at each airport given by equation (12.1), each triangle must have area equal to A/E.

12.7 The ratio of base width (w) to length (l) for these equivalent area triangles can be determined by approximating each of the individual 10^{-5} areas off runway ends by a triangle and then taking the ratio of length to width. These ratios are given in Table 12.2. The average of these ratios ($\rho = 9.0$) can be taken as the ratio used to determine the length and width of the equivalent triangles defined below.

12.8 The expression for the area of a triangle in hectares in terms of its linear dimensions l and w in kilometres is ½100lw. Therefore:

$$\frac{1}{2}100lw = \frac{A}{E} \tag{12.2}$$

The relationship between w and l is:

$$l = \rho w \tag{12.3}$$

Substituting for A from equation (12.1) and w from equation (12.3) in equation (12.2) gives:

$$l = \sqrt{\frac{\rho(10.46M + 0.324)}{E}} \tag{12.4}$$

Substituting for l in equation (12.3) then gives:

$$w = \sqrt{\frac{(10.46M + 0.324)}{\rho E}} \tag{12.5}$$

12.9 Table 12.3 compares each of the 10^{-5} areas off main runway ends with those for the average airport triangle obtained using the expressions above. The length and width of the triangles used to approximate each individual 10^{-5} contour are compared with those of the average airport triangles given by equations (12.4) and (12.5) respectively. It will be seen that a good fit was obtained across the whole spectrum of airport sizes.

12.10 It is somewhat surprising that the expressions for the areas of the end-of-runway triangles based only on movements fit so well across the spectrum of airports, as the mix of aircraft types used is very different at the different airports: at Heathrow a high proportion of the movements are by large airliner jets; at Leeds Bradford, a high proportion are of small turboprop and piston-engine aircraft. One reason is that the risks imposed by the different aircraft types are not as variable as might be expected: small aircraft have smaller crash areas than large ones, but this is to some extent offset by the fact that they have higher crash rates.

12.11 However, a disadvantage of an expression based only on aircraft movements is that at large busy airports (such as Heathrow) the future number of movements and the crash rates may not change much, but the average size of aircraft may increase markedly. For example, runway capacity or other constraints may limit movement numbers, and the proportion of traffic by airliner jets (which have low crash rates) may be nearly 100% and therefore cannot increase further. If there was an increase in the proportion of larger jets at such airports, the actual individual risk would increase because average consequence areas would increase, but that would not be reflected in a PSZ expression based only on movements. Therefore, it is useful to consider a expression incorporating crash rates and consequence areas as well as movements.

12.12 As the individual risk at any point would be expected to be approximately proportional to the product of the crash rate, movement numbers, and consequence area appropriate to the airport in question, the usefulness of using the product of these variables as a predictor of the area of individual risk within the 10^{-5} contour off the runway ends was investigated. The product of these variables was plotted against the risk areas in Figure 12.3, and the values plotted are shown in Table 12.4. A linear relationship is again observed and the linear regression fit of the product of these variables against 10^{-5} area is also very good (R^2=99.97%). This fit produced the following relationship:

$$A = 6470MCD + 19.09 \tag{12.6}$$

where, as above, A is the total area in the 10^{-5} regions off runway ends in hectares, and M is the number of annual aircraft movements in millions, and C and D are average crash rates and destroyed areas (in hectares) for traffic (other than light aircraft which have more ‘spread out’ crash distributions, and sometimes use different runways to heavier traffic).

12.13 If these regions are to be approximated by triangles at each of the main runway ends with total area inside all triangles at each airport given by equation (12.6), each triangle must have area equal to A/E, where A is given by equation (12.6) and E is the number of runway ends.

12.14 Using the relationship between the average triangle width (w) and length (l), results in the following expressions for l and w:

$$l = \sqrt{\frac{\rho(129.4MCD + 0.382)}{E}} \tag{12.7}$$

$$w = \sqrt{\frac{129.4MCD + 0.382}{\rho E}} \tag{12.8}$$

12.15 Table 12.5 compares each of the 10^{-5} areas off main runway ends with those for the average airport triangles obtained using the expressions above. The length and width of the triangles used to approximate each individual 10^{-5} risk contour are compared with those of the average airport triangles given by equations (12.7) and (12.8) respectively. It can be seen that this fit is also good across the whole spectrum of airport sizes.

Possible options for PSZs

12.16 Although the previous discussion and results have been based on 1994 traffic, it would be more appropriate to base PSZ policy on forecast traffic rather than current, as the application of planning restrictions now would achieve benefits in future, when the movements and therefore the individual risks were greater. The choice of assumptions upon which these forecasts should be based, and which future period they should cover is beyond the scope of this study.

12.17 In the light of the preceding discussion, a number of options can be proposed for defining simple PSZs. The development restrictions would be the same in any of them, and would be those outlined at the conclusion of Chapter 11. Four options could be considered:

(a) Define the boundary of the PSZs to be that given by the forecast 10^{-5} contour. **Advantages**: clear rationale; fits contours exactly (by construction) and therefore corresponds to best estimate for risk; reflects traffic volume and mix, including any asymmetric use of runways. **Disadvantages**: the details of the calculation may not be transparent to the general public; requires the risk model to be run for every airport; and therefore would require forecasts of all inputs to the model.

(b) Specify the PSZs at each airport to be end-of-runway triangles with dimensions based on the expression incorporating crash rates, crash areas and movements at the airport, that is, given by equations (12.7) and (12.8) above. **Advantages**: simple to apply if input variables are known; reflects important features of air activity; responsive to changes to traffic mix. **Disadvantages**: the fits to the contours are not as close as with option (a) (see Table 12.3); requires forecasts of all three input parameters.

(c) Specify the PSZs at each airport to be the end-of-runway triangles with dimensions based on the number of movements at the airport, that is, given by equations (12.4) and (12.5) above. **Advantages**: simple to apply if input variables are known; does not require detailed forecasts of traffic mix; reflects aircraft movements. **Disadvantages**: the fits to the contours are not as close as with option (a) (see Table 12.5); does not take explicit account of the characteristics of the airport traffic; requires forecasts of movements.

(d) Divide airports requiring development restrictions into those that are busiest, and those that are less busy, as is done currently for PSZs. For the busy airports, specify the PSZs to be end-of-runway triangles with fixed dimensions (say) 3.5 kilometres long and 0.35 kilometres wide at the base (based on the dimensions of the 10^{-5} regions at Heathrow to the nearest half kilometre and 50 metres respectively). For the less busy airports, specify the linear dimensions to be (say) two thirds of those of above, that is 2.3 kilometres long and 0.23 kilometres wide. Based on current traffic levels, the latter group would include airports such as Birmingham and Leeds Bradford in which the 10^{-5} contour around these airports is contained within this reduced area. **Advantages**: simple, easy to apply, similar to the present PSZs in application (though the sizes and shapes are different). **Disadvantages**: fits the 10^{-5} individual risk contours least well of the options (though it is still not bad); does not take explicit account of the characteristics of the airport traffic.

12.18 Table 12.6 compares the total areas covered by PSZs under each of these options for the five airports, assuming 1994 conditions, and also compares the areas for the options with the areas of the present PSZs shown in Figure 1.1. The area of a single existing standard PSZ is 43.3 hectares, and that of an extended PSZ is 67 hectares. For option (d), Table 12.6 assumes that Heathrow, Gatwick and Manchester would have ‘large’ PSZs, and that Birmingham and Leeds Bradford would have ‘standard’ ones. Figure 12.4 shows a comparison of the old and new (option (d)) PSZs for large airports.

12.19 Table 12.6 shows that the area covered by the new PSZs under any of the options would not be dissimilar to that covered by the existing PSZs, although the shape would be quite different. However it should be remembered that the areas for Table 12.6 are based on 1994 traffic, and as mentioned above in paragraph 12.16, it would be more appropriate to base PSZ areas on forecasts of future traffic; these areas are likely to be larger than those shown in Table 12.6.

12.20 Whichever of the above options is adopted, as with current PSZ policy, a decision would have to be made on the minimum airport size for the establishment of PSZs. At present, this corresponds to airports with greater than 1,500 air traffic movements in any calendar month. Converting this movement threshold to an annual value and applying it to equation (12.4) results in end of runway triangles of length 1.5 km, which is 50% larger than the length of the current PSZs for airports with less than 45,000 movements per year.

Other issues to be considered

12.21 The dimensions and areas of the PSZ options discussed above were calculated from the baseline cases. The need for considering future traffic in the setting of PSZs has already been highlighted in this chapter. Other factors to be taken into account are that certain assumptions had to be made in the input calculations for baseline cases and that there are also inherent sources of uncertainty in the actual models and data used.

12.22 Chapter 8 looked at the results of a number of calculations in which other assumptions were made. These calculations considered different assumptions in the calculation of crash rates, and consequence models; alternative location models were not considered as the only other model based on a relatively large dataset was that produced by NLR which was not publicly accessible.

12.23 The results of these other calculations are given in Tables 8.1 and 8.2. In the region most relevant to PSZ policy, the area between the 10^{-4} and 10^{-5} contours, the change in area from the baseline case arising from these calculations (other than the world-wide crash rate case which is unrealistic for UK airports) was 20% or less.

12.24 However, given that there is a significant amount of uncertainty in the baseline calculations (particularly in relation to the modelling of accident consequences), the question of whether it may be appropriate to base PSZ policy on more conservative calculations as opposed to 'best estimates' should be considered. An alternative approach for taking the uncertainty in the baseline calculations into account would be to base PSZ policy on a lower individual risk contour; on the other hand, it should also be born in mind that the initial choice of 10^{-5} (see Chapter 11) was based already on fairly cautious assumptions to take account of uncertainties in the cost-benefit analysis. All these factors may be relevant to the setting of a new PSZ policy.

Summary

12.25 Four options for new PSZs have been proposed and their advantages and disadvantages outlined. The new proposals involve PSZs which would have broadly similar areas than the existing PSZs, although they are quite different in shape.

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TABLE 3.1

Western Airliner Jets Grouped using the Boeing Classes

CLASS	AIRCRAFT TYPE
I	AEROSPATIALE CARAVELLE BAe COMET BOEING 707/720 GENERAL DYNAMICS CV880 GENERAL DYNAMICS CV990 McDONNELL DOUGLAS DC-8
II	BAe (BAC) ONE-ELEVEN BAe (HS) TRIDENT BAe (VICKERS) VC-10 BOEING 727 BOEING 737 100/200 DASSAULT MERCURE FOKKER F28 McDONNELL DOUGLAS DC-9 VFW 614
III	AIRBUS INDUSTRIE A300 BAe/AEROSPATIALE CONCORDE BOEING 747 LOCKHEED TRISTAR McDONNELL DOUGLAS DC-10
IV	AIRBUS INDUSTRIE A310 AIRBUS INDUSTRIE A320/321 AIRBUS INDUSTRIE A330 AIRBUS INDUSTRIE A340 BAe 146 BOEING 737 300/400/500 BOEING 757 BOEING 767 BOEING 777 CANADAIR REGIONAL JET FOKKER 70 FOKKER 100 McDONNELL DOUGLAS MD11 McDONNELL DOUGLAS MD80

TABLE 3.2

Western Airliner Turboprops Grouped According to Date of First Delivery

(i) T1: turboprop aircraft designed and first delivered after 1970.

Aircraft types in group T1
AEROSPATIALE ATR 42
AEROSPATIALE ATR 72
BAe ATP
BAe JETSTREAM 31
BAe JETSTREAM 41
De HAVILLAND DASH 7
De HAVILLAND DASH 8
DORNIER 228
DORNIER 328
EMBRAER BRASILIA - EMB110
EMBRAER BANDEIRANTE - EMB120
FOKKER 50
SAAB 340
SAAB 2000
SHORTS 330
SHORTS 360

(ii) T2: turboprop aircraft designed and first delivered prior to 1970.

Aircraft types in group T2
BAe (HS) 748
BAe (VICKERS) VANGUARD
BAe (VICKERS) VISCOUNT
CONVAIR 540/580/600/640
HANDLEY PAGE DART HERALD
De HAVILLAND TWIN OTTER
FAIRCHILD F27
FAIRCHILD FH227
FAIRCHILD METRO
FOKKER F27
GULFSTREAM 1
LOCKHEED HERCULES
LOCKHEED ELECTRA
SHORTS SKYVAN

TABLE 4.1

Summary of Five Recent Crash Location Models

Model	Data Set	Components	Route Variation
Technica 1990 & 1994	N/A (see Chapter 4)	Take-offs Landings	Yes
AEA 1991	121 crashes	Take-offs Landings	No
RAND 1993	53 crashes	Single distribution	Yes
NLR 1993	181 crashes	Take-off crashes and overruns Landing overruns Landings	Yes
NATS 1996	354 crashes	Take-off overruns and veer-offs Take-offs Landing overruns and veer-offs Landings	No

TABLE 5.1

RAND Mortality Rate Given a Crash

Structure	Aircraft size	Flight Phase	Mortality (M)
Small	Large	Take-off Landing	0.90 0.75
	Medium	Take-off Landing	0.40 0.30
	Small	Take-off Landing	0.20 0.15
Large	Large	Take-off Landing	0.50 0.40
	Medium	Take-off Landing	0.30 0.20
	Small	Take-off Landing	0.10 0.10

TABLE 5.2

RAND Consequence Areas Following a Crash

Impact Angle	Aircraft size	Flight Phase	Area (hectares)
Steep	Large	Take-off Landing	5.18 3.89
	Medium	Take-off Landing	3.89 2.59
	Small	Take-off Landing	1.30 1.30
Shallow	Large	Take-off Landing	6.48 5.18
	Medium	Take-off Landing	5.18 3.89
	Small	Take-off Landing	3.89 2.59

TABLE 5.3

ACARRE Consequence Areas Following a Crash

Aircraft Type	Impact Area (hectares)	Fireball Effect Area (hectares)	Pool Fire Effect Area (hectares)
Scheduled Aircraft	0.95	15.0	4.0
Other Aircraft	0.12	0.5	0.3

TABLE 5.4

Technica Consequence Areas Following a Crash

Aircraft size	Landing accident area (hectares)		Take-off accident area (hectares)	
	Steep	Shallow	Steep	Shallow
Small	0.20	0.26	0.21	0.37
Medium	0.59	0.69	0.66	0.78
Large	1.65	2.58	1.67	2.81
Intercontinental	1.65	2.58	2.10	4.84

TABLE 5.5

NLR Crash Consequence Areas Following a Crash

Lethality	Terrain	Consequence Area (m^2) per Tonne (MTWA)
0.30	Built-up Areas	200
0.30	Open Terrain	250
0.30	Wooded and Water	150

TABLE 5.6

NATS Consequence Areas Following a Crash

Consequence parameter	Fitted relationship	R^2
Debris Area	$\text{Log}_e(\text{area}^{(1)}) = -8.53 + 0.80\text{Log}_e(\text{MTWA}^{(2)})$	29%
Destroy Area	$\text{Log}_e(\text{area}^{(1)}) = -6.36 + 0.49\text{Log}_e(\text{MTWA}^{(2)})$	8%

(1) Area in hectares
(2) Weight in kilograms

TABLE 5.7

Comparison of the Effective Consequence Areas* Predicted by Different Consequence Models for a Boeing 767 Crashing in a Built up Area

Model	**Effective consequence areas (hectares)**
RAND	3.8
ACARRE	2.0
Technica (1)	2.2
NLR (2)	0.9
Eddowes	0.4
NATS	0.6

* Effective consequence areas are area values, adjusted to take account of the different lethality values used by different models to make them equivalent to an 100% lethality area. In other words, the effective consequence areas calculated are directly proportional to the number of people expected to be killed by a B767 crash.

(1) Assumes that 50% of crashes were ‘steep’.
(2) The refined NLR models predicts areas about half this size (Ref 33).

TABLE 6.1

Scheduled Passenger Crash Rates for Western Airliner Jets - First World and World-wide(OAG data)

	First world			World-wide		
Class	Movements(1)	Crashes(2)	Crash rate (per million movements)	Movements(1)	Crashes(2)	Crash rate (per million movements)
I	4,488,656	5	1.114	7,670,788	20	2.607
II-IV	283,378,066	42	0.148	355,975,396	147	0.413

(1) Scheduled passenger movements, 1979-1995, from OAG data.
(2) Total losses, 1979-1995, from Airclaims database.

TABLE 6.2

Scheduled passenger crash rates for Western Airliner Turboprops - First World and World-wide (OAG Data)

	First world			World-wide		
Group	Movements(1)	Crashes(2)	Crash rate (per million movements)	Movements(1)	Crashes(2)	Crash rate (per million movements)
T1	77,777,804	21	0.270	88,758,754	43	0.484
T2	51,814,954	38	0.733	73,546,590	116	1.577

(1) Scheduled passenger movements, 1979-1995, from OAG data.
(2) Total losses, 1979-1995, from Airclaims database.

TABLE 6.3

Summary of First World Crash Rates for Aircraft Type Classes used in the Base Case Calculations

Aircraft class	**Crash Rate(1) (Crashes per million movements)**
Class I jets	**1.114**
Class II-IV jets	**0.148**
Eastern jets	**0.930**
Executive jets	**0.270**
Turboprops T1	**0.270**
Turboprops T2	**0.733**
Turboprops (unclassified)	**0.733**
Piston-engine	**3.000**
Other non-commercial	**3.000**
Miscellaneous	**3.000**

(1) The crash rates are quoted here to three decimal places. These values are used in the calculations but the accuracy is spurious.

TABLE 6.4

Aircraft Movements, Crash Rates, Crash Frequencies, Average MTWA and Average Destroy Area at Heathrow Airport in 1994 Subdivided by Aircraft Class.

Aircraft class	Movements(1)	Crash rate(2)	Crash frequency(3)	Average MTWA (tonne) (4)	Average destroyed area (hectare) (5)
NATS model					
Class I jets	1069	1.11	1.2×10^{-3}	149.3	0.60
Class II-IV jets	401511	0.15	59.5×10^{-3}	123.4	0.51
Eastern jets	2045	0.93	1.9×10^{-3}	127.1	0.55
Executive jets	8956	0.27	2.4×10^{-3}	15.8	0.19
Turboprops T1	5821	0.27	1.6×10^{-3}	17.2	0.20
Turboprops T2	3218	0.73	2.4×10^{-3}	26.7	0.25
Turboprops(6)	164	0.73	0.1×10^{-3}	10.8	0.14
Piston-engine	271	3.00	0.8×10^{-3}	3.7	0.09
Miscellaneous(7)	330	3.00	1.0×10^{-3}	-	-
Totals	423385		70.9×10^{-3}		
Averages		0.168(8)		113.0(9)	0.48(10)

Notes:

(1) Movements from Table B2 (movements = total of landings + take-offs).
(2) Crashes per million movements from Table 6.3.
(3) Crash frequency (per year) = annual movements multiplied by crash rate.
(4) Mean MTWA for aircraft class.
(5) Mean destroyed area for aircraft class from NATS consequence model.
(6) Not classified as western airliner turboprops.
(7) Unusual aircraft types which could not be readily classified.
(8) Average crash rate (movement weighted).
(9) Average MTWA (crash frequency weighted).
(10) Average destroyed area (crash frequency weighted).

TABLE 6.5

Aircraft Movements, Crash Rates and Crash Frequencies, Average MTWA and Average Destroy Area at Gatwick Airport in 1994 Subdivided by Aircraft Class.

Aircraft class	Movements(1)	Crash rate(2)	Crash frequency(3)	Average MTWA (tonne) (4)	Average destroyed area (hectare) (5)
NATS model					
Class I jets	1904	1.11	2.1×10^{-3}	150.1	0.60
Class II-IV jets	153026	0.15	22.7×10^{-3}	104.2	0.47
Eastern jets	814	0.93	0.8×10^{-3}	73.9	0.42
Executive jets	2403	0.27	0.6×10^{-3}	12.9	0.17
Turboprops T1	26741	0.27	7.2×10^{-3}	14.1	0.19
Turboprops T2	5237	0.73	3.8×10^{-3}	21.0	0.23
Turboprops (6)	308	0.73	0.2×10^{-3}	6.0	0.12
Piston-engine	811	3.00	2.4×10^{-3}	3.3	0.09
Miscellaneous(7)	16	3.00	0.0×10^{-3}	-	-
Total	191260		40.0×10^{-3}		
Averages		0.209(8)		73.6(9)	0.37(10)

Notes:

(1) Movements from Table B2 (movements = total of landings + take-offs).
(2) Crashes per million movements from Table 6.3.
(3) Crash frequency (per year) = annual movements multiplied by crash rate.
(4) Mean MTWA for aircraft class.
(5) Mean destroyed area for aircraft class from NATS consequence model.
(6) Not classified as western airliner turboprops.
(7) Unusual aircraft types which could not be readily classified.
(8) Average crash rate (movement weighted).
(9) Average MTWA (crash frequency weighted).
(10) Average destroyed area (crash frequency weighted).

TABLE 6.6

Aircraft Movements, Crash Rates and Crash Frequencies, Average MTWA and Average Destroy Area at Manchester Airport in 1994 subdivided by aircraft class

Aircraft class	Movements(1)	Crash rate(2)	Crash frequency(3)	Average MTWA (tonne) (4)	Average destroyed area (hectare) (5)
NATS model					
Class I jets	48	1.11	0.1×10^{-3}	147.3	0.59
Class II-IV jets	102639	0.15	15.2×10^{-3}	95.8	0.46
Eastern jets	810	0.93	0.8×10^{-3}	94.1	0.47
Executive jets	1617	0.27	0.4×10^{-3}	9.2	0.15
Turboprops T1	44248	0.27	11.9×10^{-3}	16.4	0.20
Turboprops T2	1369	0.73	1.0×10^{-3}	43.1	0.31
Turboprops(6)	1835	0.73	1.3×10^{-3}	42.9	0.26
Piston-engine(7)	2250	3.00	6.8×10^{-3}	5.5	0.10
Miscellaneous(8)	231	3.00	0.7×10^{-3}	-	-
Total	155047		38.2×10^{-3}		
Averages		0.247(9)		50.0(10)	0.30(11)
AEA light aircraft model					
Piston-engine(12)	11157	3.00	33.5×10^{-3}	0.9	0.05
Grand Total	166204		71.7×10^{-3}		

Notes:

(1) Movements from Table B2 (movements = total of landings + take-offs).
(2) Crashes per million movements from Table 6.3.
(3) Crash frequency (per year) = annual movements multiplied by crash rate.
(4) Mean MTWA for aircraft class.
(5) Mean destroyed area for aircraft class from NATS consequence model.
(6) Not classified as western airliner turboprops.
(7) MTWA's greater than 4.0 tonnes or aircraft making commercial flights.
(8) Unusual aircraft types which could not be readily classified.
(9) Average crash rate (movement weighted).
(10) Average MTWA (crash frequency weighted).
(11) Average destroyed area (crash frequency weighted).
(12) Other piston-engine aircraft with MTWA's less than 4.0 tonnes.

TABLE 6.7

Aircraft Movements, Crash Rates and Crash Frequencies, Average MTWA and Average Destroy Area at Birmingham Airport in 1994 Subdivided by Aircraft Class

Aircraft class	Movements(1)	Crash rate(2)	Crash frequency(3)	Average MTWA (tonne) (4)	Average destroyed area (hectare) (5)
NATS model					
Class I jets	9	1.11	0.0×10^{-3}	88.3	0.45
Class II-IV jets	52282	0.15	7.7×10^{-3}	59.1	0.37
Eastern jets	139	0.93	0.1×10^{-3}	98.2	0.49
Executive jets	537	0.27	0.1×10^{-3}	19.3	0.22
Turboprops T1	16626	0.27	4.5×10^{-3}	17.2	0.20
Turboprops T2	1008	0.73	0.7×10^{-3}	23.1	0.23
Turboprops(6)	337	0.73	0.2×10^{-3}	4.6	0.11
Piston-engine	123	3.00	0.4×10^{-3}	3.0	0.09
Positioning/local(7)	1865	0.19	0.4×10^{-3}	-	-
Private(8)	1175	0.27	0.3×10^{-3}	10.0	0.16
Other(9)	611	3.00	1.8×10^{-3}	-	-
Total (NATS model)	74712		16.4×10^{-3}		
Averages		0.219(11)		40.4(12)	0.29(13)
AEA light aircraft model					
Aero club	11132	3.00	33.4×10^{-3}	0.9	0.05
Private(10)	5352	3.00	16.1×10^{-3}	2.3	0.08
Total (AEA model)	16484		49.5×10^{-3}		
Averages				1.4(12)	0.06(13)
Grand Total	91196		65.9×10^{-3}		

Notes:

(1)-(6) See notes on Table 6.4.

(7) Commercial movements not classified as ATMs (crash rate = weighted average of other commercial movements).

(8) Executive jets and turboprops taken as 18% of private flights.

(9) Non-commercial flights including Test and Training, Official and Military.

(10) Piston-engine aircraft taken as 82% of private flights.

(11) Average crash rate (movement weighted).

(12) Average MTWA (crash frequency weighted).

(13) Average destroyed area (crash frequency weighted).

TABLE 6.8

Aircraft movements, crash rates, crash frequencies, average MTWA and average destroy area at Leeds Bradford airport in 1994 subdivided by aircraft class.

Aircraft class	Movements(1)	Crash rate(2)	Crash frequency(3)	Average MTWA (tonne) (4)	Average destroyed area (hectare) (5)
NATS model					
Class I jets	0				
Class II-IV jets	4914	0.15	0.7×10^{-3}	57.6	0.37
Executive jets	143	0.27	0.0×10^{-3}	7.7	0.14
Eastern jets	86	0.93	0.1×10^{-3}	96.0	0.48
Turboprops T1	14444	0.27	3.9×10^{-3}	13.3	0.17
Turboprops T2	3174	0.73	2.3×10^{-3}	20.2	0.23
Turboprops (6)	60	0.73	0.0×10^{-3}	5.4	0.11
Piston-engine	154	3.00	0.5×10^{-3}	3.0	0.09
Positioning/local(7)	1530	0.33	0.5×10^{-3}	-	-
Private(8)	1129	0.27	0.3×10^{-3}	10.0	0.16
Other (9)	2309	3.00	6.9×10^{-3}	-	-
Total (NATS model)	27943		15.2×10^{-3}		
Averages		0.546(11)		19.5(12)	0.20(13)
AEA light aircraft model					
Aero club	16621	3.00	49.9×10^{-3}	0.9	0.05
Private(10)	5146	3.00	15.4×10^{-3}	2.3	0.08
Total (AEA model)	21767		65.3×10^{-3}		
Averages				1.2(12)	0.06(13)
Grand Total	49710		80.5×10^{-3}		

Notes:

(1)-(6) See notes on Table 6.4.

(7) Commercial movements not classified as ATMs (crash rate = weighted average of other commercial movements).

(8) Executive jets and turboprops taken as 18% of private flights.

(9) Non-commercial flights including Test and Training, Official and Military.

(10) Piston-engine aircraft taken as 82% of private flights.

(11) Average crash rate (movement weighted).

(12) Average MTWA (crash frequency weighted).

(13) Average destroyed area (crash frequency weighted).

TABLE 6.9

Heathrow Airport - Input Parameters for Baseline Individual Risk Calculations

Movements on runways(1)

	09L	27R	09R	27L
Landings	57529	70461	5696	78007
Take-offs	0	76542	63225	71925
Grand total	423385(2)			

Crash rates (3)

	Crashes	Overruns	Total
Landings	0.087	0.034	0.121
Take-offs	0.033	0.014	0.047
Totals	0.120	0.048	0.168(4)

Notes:

(1) Proportions on runways based on six year average from 1990 to 1995; westerly:easterly ratio of movements = 70:30.
(2) Total 1994 movements from Table 6.4.
(3) Per million movements (movements = total of landings + take-offs).
(4) Average crash rate (associated with NATS crash location model) from Table 6.4.

TABLE 6.10

Gatwick Airport - Input Parameters for Baseline Individual Risk Calculations

Movements on runways(1)

	08R	26L	08L	26R
Landings	31205	63911	142	371
Take-offs	31288	64011	60	272
Grand total	191260(2)			

Crash rates (3)

	Crashes	Overruns	Total
Landings	0.108	0.042	0.150
Take-offs	0.041	0.018	0.059
Totals	0.149	0.060	0.209(4)

Notes:

(1) Proportions on runways based on six year average from 1990 to 1995; westerly:easterly ratio of movements = 67:33.

(2) Total 1994 movements from Table 6.5.

(3) Per million movements (movements = total of landings + take-offs).

(4) Average crash rate (associated with NATS crash location model) from Table 6.5.

TABLE 6.11

Manchester Airport - Input Parameters for Baseline Individual Risk Calculations

Movements on runways(1)

	Runway	
	06	24
NATS model		
Landings	14111	63412
Take-offs	14111	63412
AEA light aircraft model		
Landings + take-offs	5579	5579
Grand total	166204(2)	

Crash rates (3)

NATS model	**Crashes**	**Overruns**	**Total**
Landings	0.128	0.050	0.178
Take-offs	0.048	0.021	0.069
Total	0.176	0.071	0.247(4)
AEA light aircraft model			
Total	3.000(5)		

Notes:

(1) Proportions on runways based on six year average from 1990 to 1995; westerly:easterly ratio of movements = 82:18.
(2) Total 1994 movements from Table 6.6.
(3) Per million movements (movements = total of landings + take-offs).
(4) Average crash rate, associated with NATS model, from Table 6.6.
(5) Crash rate, associated with AEA light aircraft model, from Table 6.6.

TABLE 6.12

Birmingham Airport - Input Parameters for Baseline Individual Risk Calculations

Movements on runways(1)

	Runway			
	33	15	06	24
NATS model				
Landings	19705	13856	1113	2682
Take-offs	20543	13124	1053	2636
AEA light aircraft model				
Landings + take-offs	7410	7410	832	832
Grand total	91196(2)			

Crash rates (3)

NATS model	**Crashes**	**Overruns**	**Total**
Landings	0.114	0.044	0.158
Take-offs	0.043	0.018	0.061
Total	0.157	0.062	0.219(4)
AEA light aircraft model			
Total	3.000(5)		

Notes:

(1) Proportions on runways based on six year average from 1990 to 1995; westerly:easterly ratio of movements = 61:39.
(2) Total 1994 movements from Table 6.7.
(3) Per million movements (movements = total of landings + take-offs).
(4) Average crash rate, associated with NATS model, from Table 6.7.
(5) Crash rate, associated with AEA light aircraft model, from Table 6.7.

TABLE 6.13

Leeds Bradford Airport - Input Parameters for Baseline Individual Risk Calculations

Movements on runways(1)

	Runway			
	32	14	28	10
NATS model				
Landings	9780	4193		
Take-offs	9780	4193		
AEA light aircraft model				
Landings + take-offs	5041	5041	5841	5841
Grand total	49710(2)			

Crash rates (3)

NATS model	**Crashes**	**Overruns**	**Total**
Landings	0.283	0.110	0.393
Take-offs	0.107	0.046	0.153
Total	0.390	0.156	0.546(4)
AEA light aircraft model			
Total	3.000(5)		

Notes:

(1) Proportions on runways based on estimates supplied by Leeds Bradford airport.
(2) Total 1994 movements from Table 6.8.
(3) Per million movements (movements = total of landings + take-offs).
(4) Average crash rate, associated with NATS model, from Table 6.8.
(5) Crash rate, associated with AEA light aircraft model, from Table 6.8.

TABLE 7.1

Population, Number of Households and Area in Risk Bands

	Exposed population	No of households	Area (hectare)
Risk Band >10^{-4}			
Heathrow	4	2	54
Gatwick	0	0	25
Manchester	0	0	14
Birmingham	0	0	0
Leeds Bradford	0	0	0
Risk Band 10^{-5} - 10^{-4}			
Heathrow	2222	748	406
Gatwick	2	1	168
Manchester	367	155	144
Birmingham	102	40	86
Leeds Bradford	81	28	62
Risk Band 10^{-6} - 10^{-5}			
Heathrow	45022	16534	2652
Gatwick	572	210	965
Manchester	10845	4319	901
Birmingham	5917	2520	590
Leeds Bradford	3136	1294	401

TABLE 8.1

Population, Number of Households and Area in Risk Bands: Various Sensitivity Calculations for Heathrow

Airport	Crash rates	Consequence model	Exposed population	No of households	Area (hectare)
		Risk Band >10^{-4}			
Heathrow	*First world*(1)	*NATS*(1)	*4*	*2*	*54*
Heathrow	World-wide for jet and turboprop	NATS	91	38	181
Heathrow	First world including major partials	NATS	11	4	128
Heathrow	First world	NLR published model(2)	11	4	100
		Risk Band 10^{-5} - 10^{-4}			
Heathrow	*First world*(1)	*NATS*(1)	*2222*	*748*	*406*
Heathrow	World-wide for jet and turboprop	NATS	8848	3103	761
Heathrow	First world including major partials	NATS	2182	732	391
Heathrow	First world	NLR published model(2)	4440	1542	488
		Risk Band 10^{-6} - 10^{-5}			
Heathrow	*First world crashes*(1)	*NATS*(1)	*45022*	*16534*	*2652*
Heathrow	World-wide jet and turboprop	NATS	119094	46408	4979
Heathrow	First world including major partials	NATS	45933	16875	2622
Heathrow	First world crashes	NLR published model(2)	63182	23831	3288

Notes:

(1) Baseline cases.

(2) Debris area = 200 m^2/tonne; lethality = 0.30.

TABLE 8.2

Population, Number of Households and Area in Risk Bands: Sensitivity Calculations for Manchester and Leeds Bradford Airports

Airport	Crash rates	Consequence model	Exposed population	No of households	Area (hectare)
Risk Band $>10^{-4}$					
Manchester	*First world*(1)	*NATS*(1)	*0*	*0*	*14*
Manchester	First world including major partial losses	NATS	0	0	40
Manchester	Higher values(2) assumed for non-SP jets and turboprops	NATS	0	0	23
Leeds Bradford	*First world*(1)	*Light aircraft destroy area:0.06*	*0*	*0*	*0*
Leeds Bradford	First world	0.01	0	0	0
Risk Band 10^{-5} - 10^{-4}					
Manchester	*First world*(1)	*NATS*(1)	*367*	*155*	*144*
Manchester	First world including major partial losses	NATS	444	184	158
Manchester	Higher values(2) assumed for non-SP jets and turboprops	NATS	495	205	163
Leeds Bradford	*First world*(1)	*Light aircraft destroy area:0.06*	*81*	*28*	*62*
Leeds Bradford	First world	0.01	79	27	61
Risk Band 10^{-6} - 10^{-5}					
Manchester	*First world*(1)	*NATS*(1)	*10845*	*4319*	*901*
Manchester	First world including major partial losses	NATS	11055	4399	914
Manchester	Higher values(2) assumed for non-SP jets and turboprops	NATS	13511	5391	1081
Leeds Bradford	*First world* (1)	*Light aircraft destroy area:0.06*	*3136*	*1294*	*401*
Leeds Bradford	First world	0.01	2113	877	268

Notes:

(1) Baseline cases.

(2) Non-SP jets and turboprops assumed to have crash rates a factor of two higher than jets.

TABLE 10.1

Attitudes to tolerability of risk near airports

Average level of risk of death per year	Distribution of responses from 81 survey respondents		
	Too small to worry about	Would require compensation	Effectively intolerable
1 in 1,000,000	47	29	5
1 in 100,000	13	52	16
6 in 100,000	6	39	36
60 in 100,000	1	20	60

TABLE 10.2

Attitudes to third party aviation fatalities in small accidents relative to road fatalities

Distribution of number of road fatalities considered equivalent to 25-30 third party fatalities in small-scale aviation accidents								
Road fatalities	**<5**	**5-14**	**15-24**	**25-30**	**31-40**	**41-50**	**51-60**	**>60**
Number of responses	8	6	28	26	5	7	5	4

TABLE 10.3

Attitudes to third party aviation fatalities in small accidents relative to those in large ones

Distribution of number of third party fatalities in small aviation accidents considered equivalent to 25-30 third party fatalities in one large accident								
Fatalities in small accs	**<5**	**5-14**	**15-24**	**25-30**	**31-40**	**41-50**	**51-60**	**>60**
Number of responses	1	7	16	36	16	1	4	8

TABLE 11.1

Components of value of forgoing use of land

Development present or permitted	**Value of what would be foregone if use of land ceased, except for agriculture**
(a) Occupied buildings	(1) Value of land and buildings (2) Any “occupiers' surplus”
(b) Unoccupied buildings	Value of land and buildings
(c) No buildings, but development permitted	Opportunity cost of not using land for its permitted purpose
(d) No buildings, and development not permitted	Nothing

TABLE 11.2

Average house prices and land prices: England and Wales: 1993

Region	Average house price £	Average housing land price			Average Agricultural land price £ per hectare
		£ per hectare	Plots per hectare	£ per plot	
North	49,300	244,000	23	10,700	3,850
Yorks. & Humberside	54,300	239,000	23	10,200	3,260
East Midlands	53,400	314,000	25	12,600	3,320
East Anglia	58,000	302,000	22	13,500	3,070
Greater London	78,400	1,330,000	65	20,400	-
Rest of South East	74,600	478,000	21	22,800	3,830
South West	60,800	267,000	23	11,600	3,640
West Midlands	58,300	434,000	25	17,500	4,320
North West	54,900	270,000	23	11,900	4,220
Wales	52,000	170,000	23	7,300	2,380
England and Wales	63,000	331,000	23.4	14,200	3,480

Sources:

House prices: *Housing and Construction Statistics 1984-1994*, Table 10.9, DoE; Housing land prices per hectare: *Housing and Construction Statistics 1984-1994*, Table 10.1; plots per hectare are the average for 1989-1993 from *Housing and Construction Statistics 1984-94*, Table 10.1; prices per plot calculated by authors using these densities.

Agricultural land prices: *Inland Revenue Statistics 1994*, Table 17.3. Data are for the year ending 30 September 1993. No distinction is made in these data between Greater London and the Rest of the South East; it is assumed that all agricultural land sales were in the Rest of the South East.

TABLE 12.1

Movements and 10^{-5} risk areas off runways

Airport	Movements for traffic (excluding light aircraft)(1)	Total areas within 10^{-5} off runway ends
Heathrow	423385	240.40
Gatwick	191260	113.73
Manchester	155047	93.66
Birmingham	74712	48.14
Leeds Bradford	27943	40.86

(1) Movements from Tables 6.4 - 6.8.

TABLE 12.2

Ratios of width (w) to length (l) for triangles approximating 10^{-5} areas off the landing ends of each runway

Airport	Runway	$l^{(1)}$*(km)*	$w^{(1)}$*(km)*	*l/w*
Heathrow	27L	3.72	0.36	10.3
	27R	3.51	0.30	11.7
	09L	3.41	0.38	9.0
	09R	2.42	0.36	6.7
Gatwick	08R	2.94	0.33	8.9
	26L	3.18	0.31	10.3
Manchester	06	2.77	0.33	8.4
	24	2.94	0.30	9.8
Birmingham	33	1.83	0.21	8.7
	15	1.79	0.22	8.4
Leeds Bradford	14	1.90	0.22	8.6
	32	1.58	0.22	7.2
Average of above				9.0

(1) Measured from triangles drawn to approximate 10^{-5} contours.

TABLE 12.3

Comparison of dimensions of individual triangles (with areas predicted using movements) with 10^{-5} areas off the landing ends of runways

Airport	Runway	Length (km)		Width (km)		Area	
		10^{-5} Contour⁽¹⁾	triangle	10^{-5} Contour⁽²⁾	triangle	10^{-5} Contour⁽³⁾	triangle
Heathrow	27L	3.72	3.27	0.36	0.36	67.2	59.4
	27R	3.51	3.27	0.30	0.36	59.1	59.4
	09L	3.41	3.27	0.38	0.36	68.9	59.4
	09R	2.42	3.27	0.36	0.36	45.2	59.4
Gatwick	08R	2.94	3.23	0.33	0.36	56.6	58.1
	26L	3.18	3.23	0.31	0.36	57.2	58.1
Manchester	06	2.77	2.96	0.33	0.33	46.5	48.6
	24	2.94	2.96	0.30	0.33	47.1	48.6
Birmingham	33	1.83	2.23	0.21	0.25	23.6	27.6
	15	1.79	2.23	0.22	0.25	24.6	27.6
Leeds Bradford	14	1.90	1.67	0.22	0.19	22.1	15.4
	32	1.58	1.67	0.22	0.19	18.7	15.4

Notes:

(1) Length of triangle which closest approximates in shape the individual 10^{-5} contour off the runway ends (from Table 12.2).

(2) Width of triangle which closest approximates in shape the individual 10^{-5} contour off the runway ends (from Table 12.2).

(3) Actual area of 10^{-5} contour off runway ends.

TABLE 12.4

Product of Movements, Crash Rates and Destroyed Areas and 10^{-5} off Runways

Airport	Product of movements, average crash rate and destroyed area(1)	Total areas within 10^{-5} off runway ends
Heathrow	34141.8	240.40
Gatwick	14790.1	113.73
Manchester	11489.0	93.66
Birmingham	4745.0	48.14
Leeds Bradford	3051.4	40.86

(1) Traffic associated with NATS crash location model; data from Tables 6.4 - 6.8.

TABLE 12.5

Comparison of dimensions of individual triangles (with areas predicted using product of movements, crash rates and destroyed areas) with 10^{-5} areas off the landing ends of runways

Airport	Runway	Length (km)		Width (km)		Area (hectare)	
		10^{-5} Contour(1)	triangle	10^{-5} Contour(2)	triangle	10^{-5} Contour(3)	triangle
Heathrow	27L	3.72	3.29	0.36	0.37	67.2	60.0
	27R	3.51	3.29	0.30	0.37	59.1	60.0
	09L	3.41	3.29	0.38	0.37	68.9	60.0
	09R	2.42	3.29	0.36	0.37	45.2	60.0
Gatwick	08R	2.94	3.21	0.33	0.36	56.6	57.4
	26L	3.18	3.21	0.31	0.36	57.2	57.4
Manchester	06	2.77	2.90	0.33	0.32	46.5	46.7
	24	2.94	2.90	0.30	0.32	47.1	46.7
Birmingham	33	1.83	2.12	0.21	0.24	23.6	24.9
	15	1.79	2.12	0.22	0.24	24.6	24.9
Leeds Bradford	14	1.90	1.87	0.22	0.21	22.1	19.4
	32	1.58	1.87	0.22	0.21	18.7	19.4

Notes:

(1) Length of triangle which closest approximates in shape the individual 10^{-5} contour off the runway ends (from Table 12.2).

(2) Width of triangle which closest approximates in shape the individual 10^{-5} contour off the runway ends (from Table 12.2).

(3) Actual area of 10^{-5} contour off runway ends.

TABLE 12.6

Comparison of areas of PSZs under different options: 1994

Airport	**Total Area within PSZs (hectares)**				
	Option (a)	Option (b)	Option (c)	Option (d)	Existing PSZs
Heathrow	240.4	240.0	237.6	245.0	268
Gatwick	113.7	114.8	116.2	122.5	134
Manchester	93.7	93.4	97.3	122.5	134
Birmingham	48.1	49.8	55.3	52.9	87
Leeds Bradford	40.9	38.8	30.8	52.9	87

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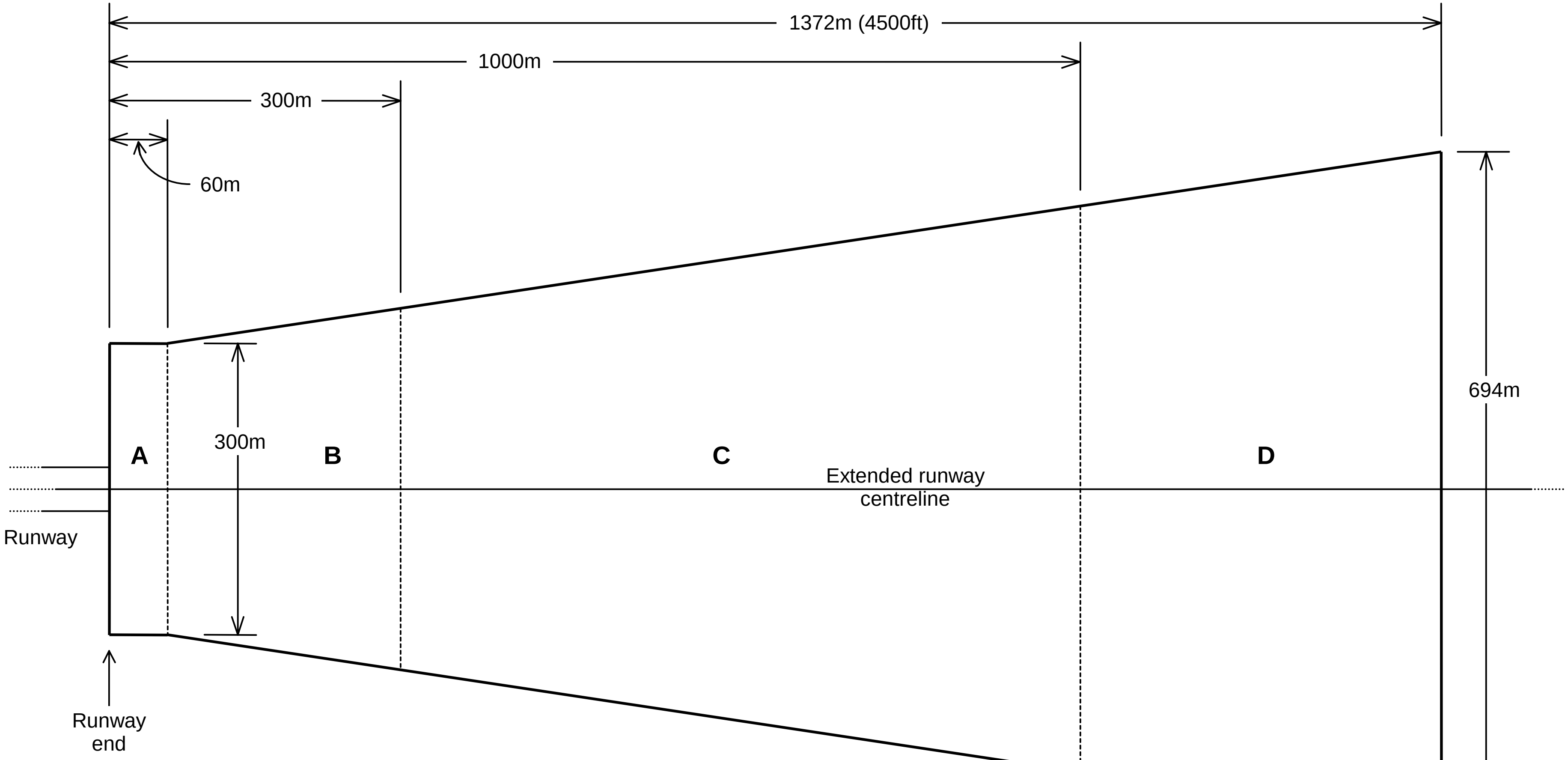
FIGURE 1.1

Plan and Dimensions of Public Safety Zone



A - Area additionally safegaurded by ICAO regulations

B - Inner band of PSZ with strict safeguarding

C - Outer band of standard PSZ

D - Additional area of extended PSZ

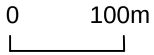


FIGURE 3.1

Sub-division of World-wide Crash and Scheduled Passenger Movement Data into Generic Groups

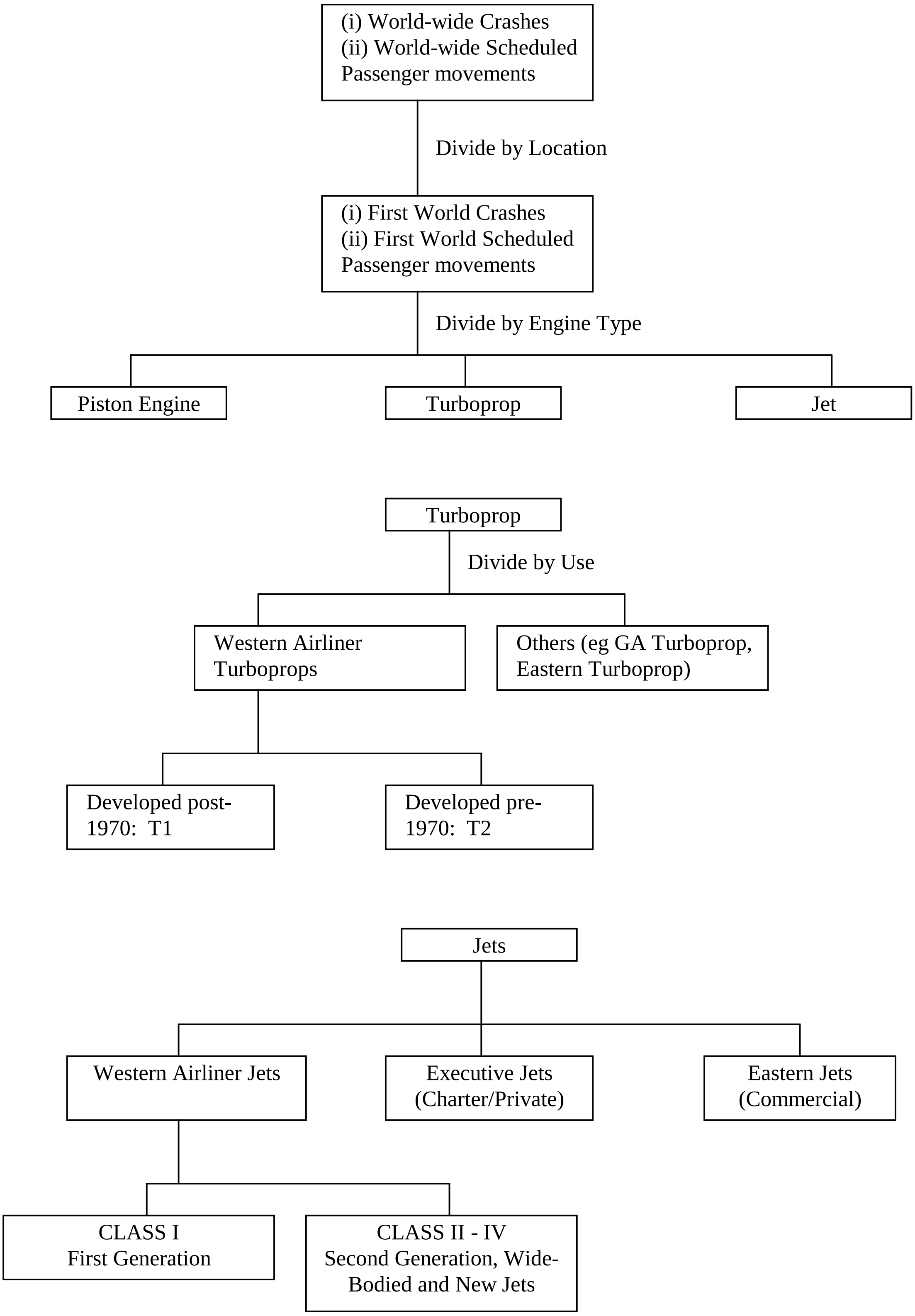


FIGURE 4.1

Number of landing impacts as a Function of Distance Along the Centreline from the Runway

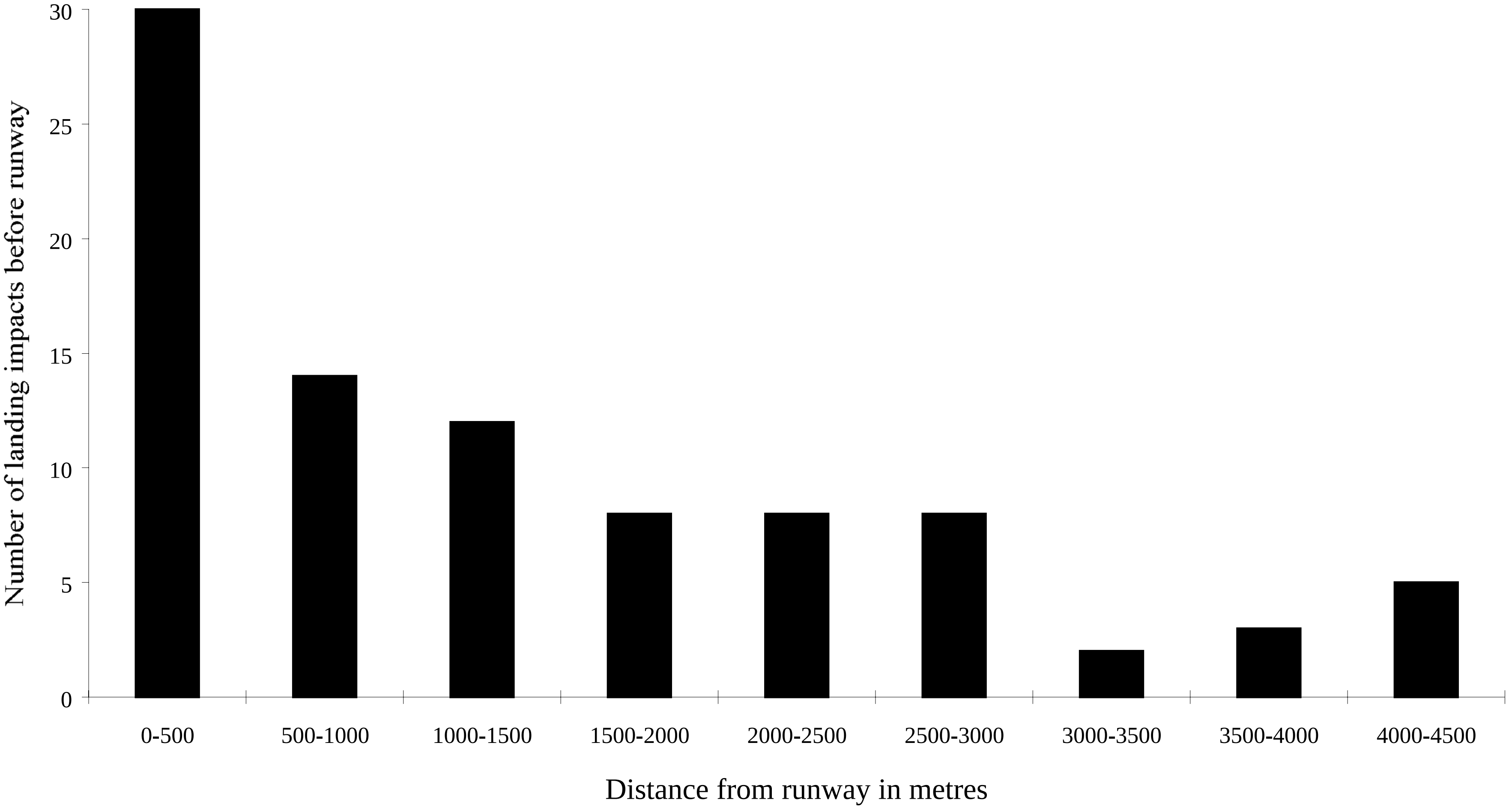


FIGURE 4.2

Number of Landing Impacts as a Function of Perpendicular Distance from Centreline

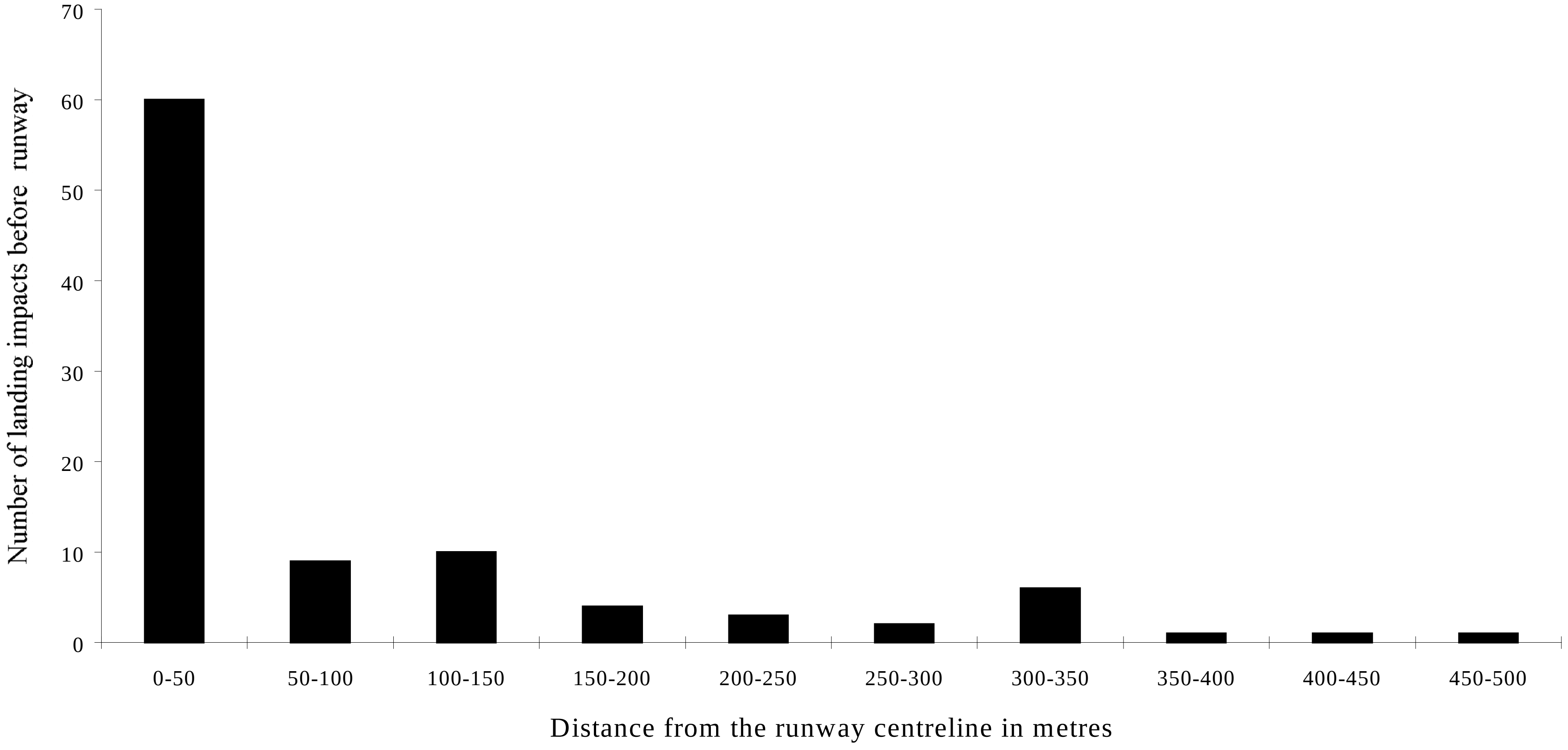
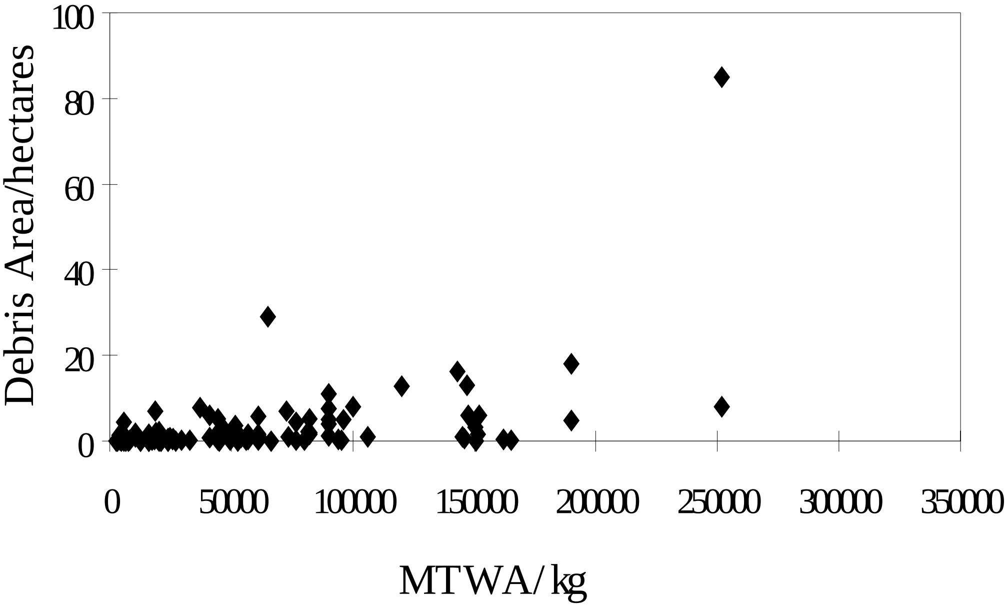


FIGURE 5.1

Scatterplot: Debris Area vs MTWA



Scatterplot: Destroy Area vs MTWA

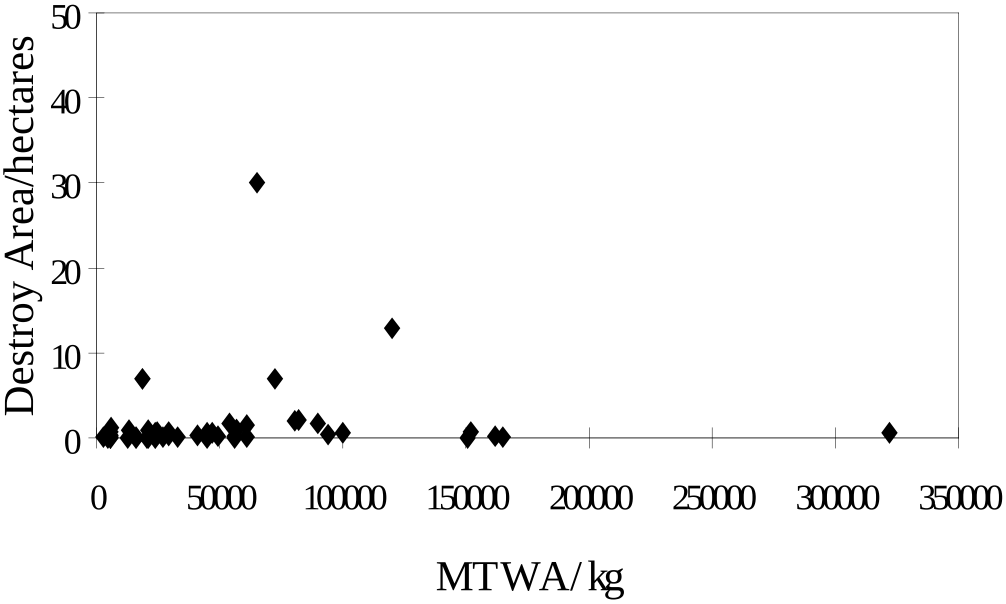
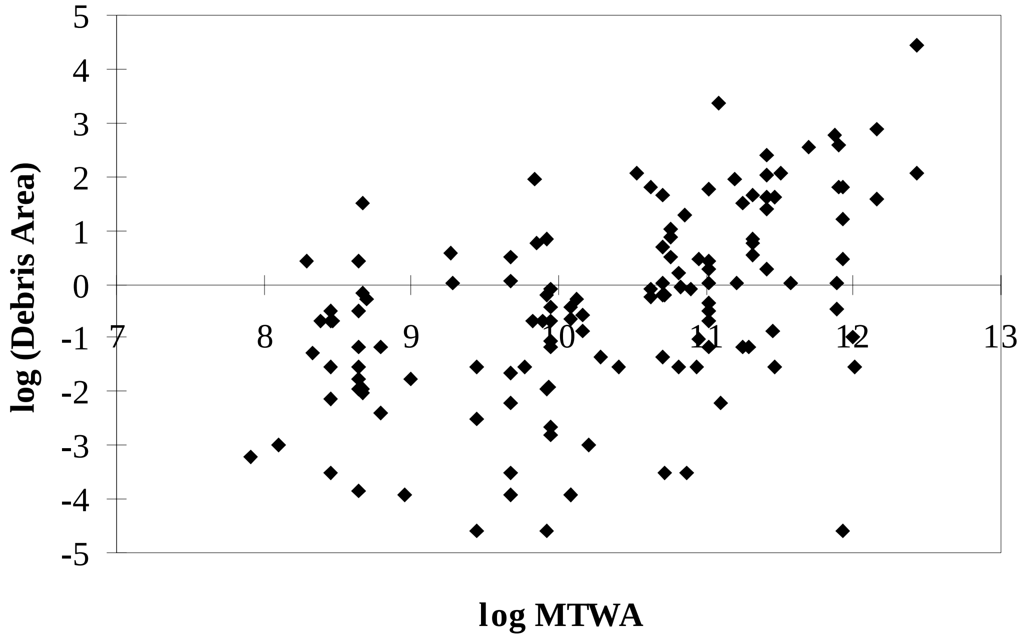


FIGURE 5.2

Scatterplot: $\log_e$ (Debris Area) vs $\log_e$ MTWA



Scatterplot: $\log_e$ (Destroy Area) vs $\log_e$ MTWA

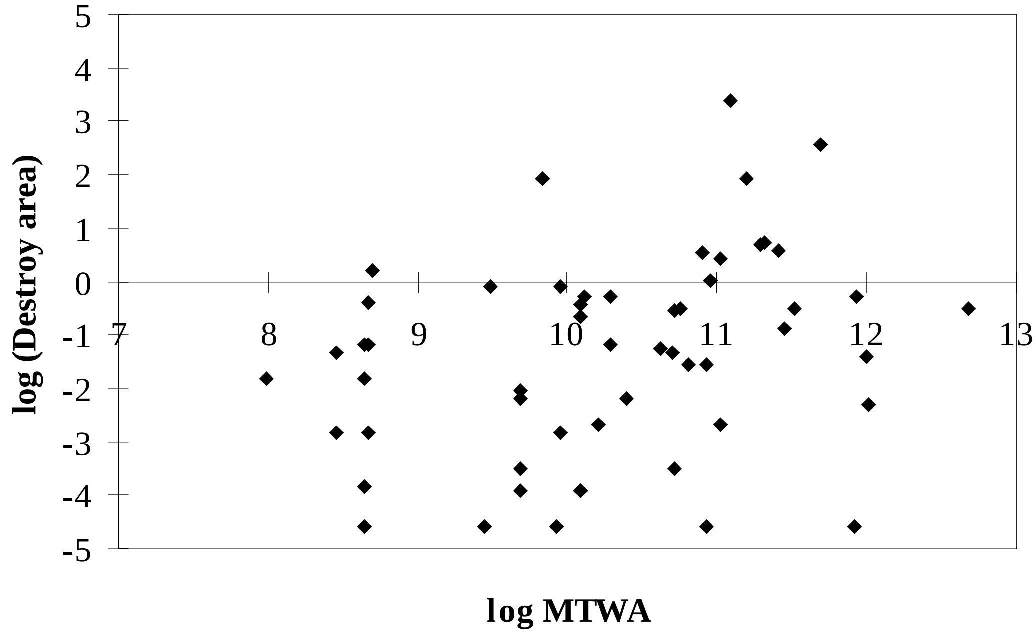
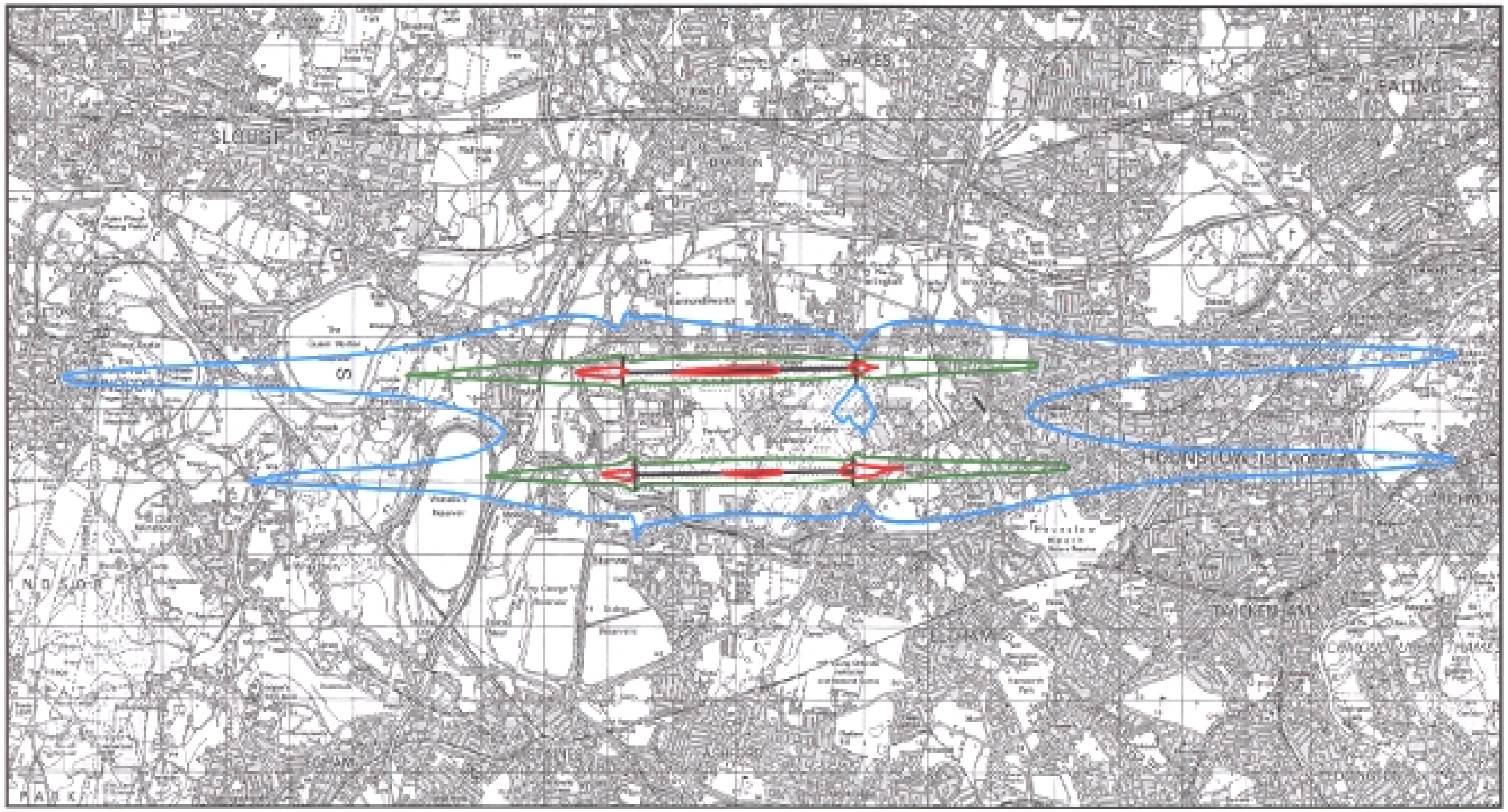


FIGURE 7.1

Individual Risk Contours at Heathrow Airport

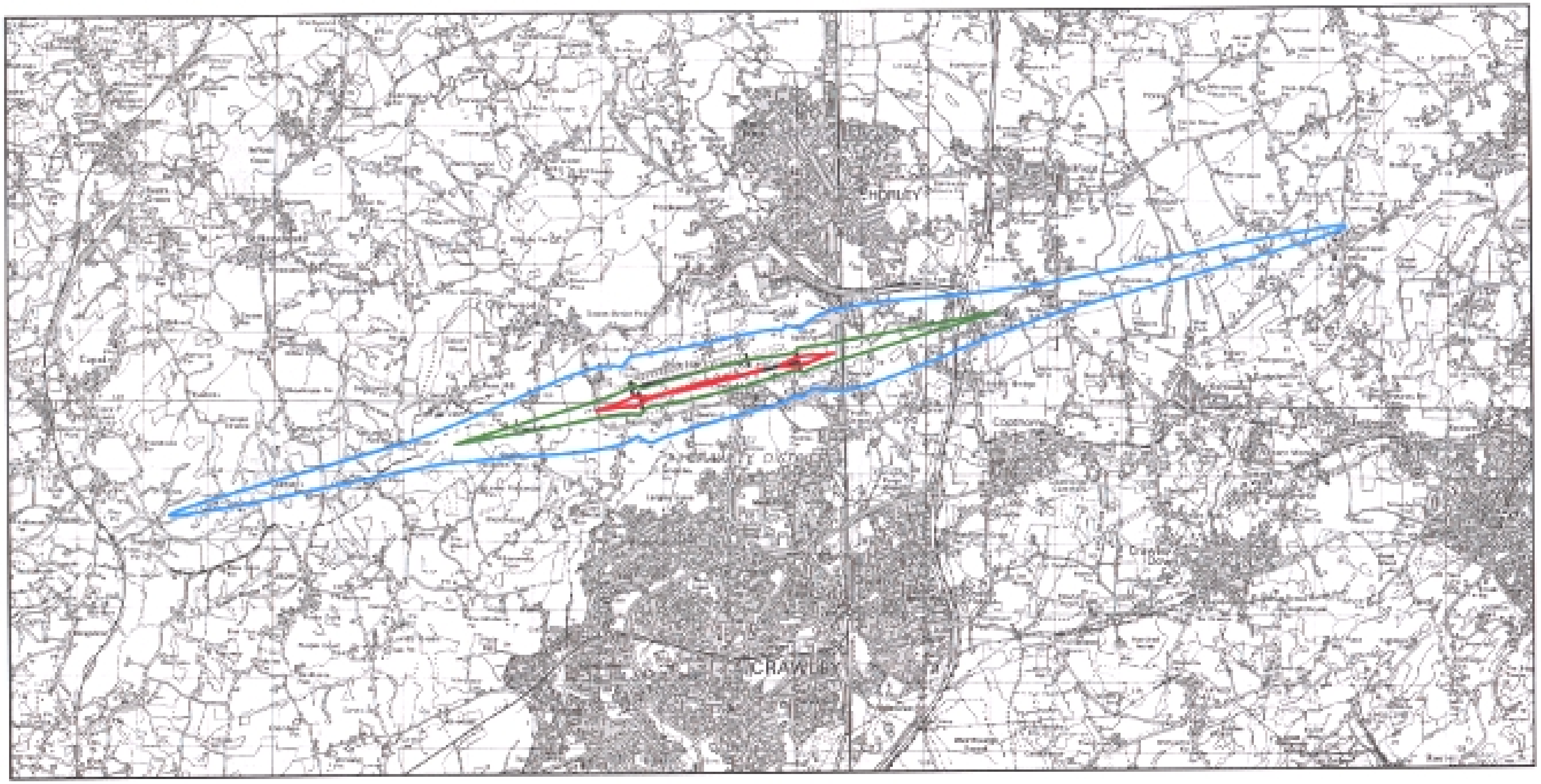


Scale 1 : 100,000

10^{-6} Blue 10^{-5} Green 10^{-4} Red

FIGURE 7.2

Individual Risk Contours at Gatwick Airport

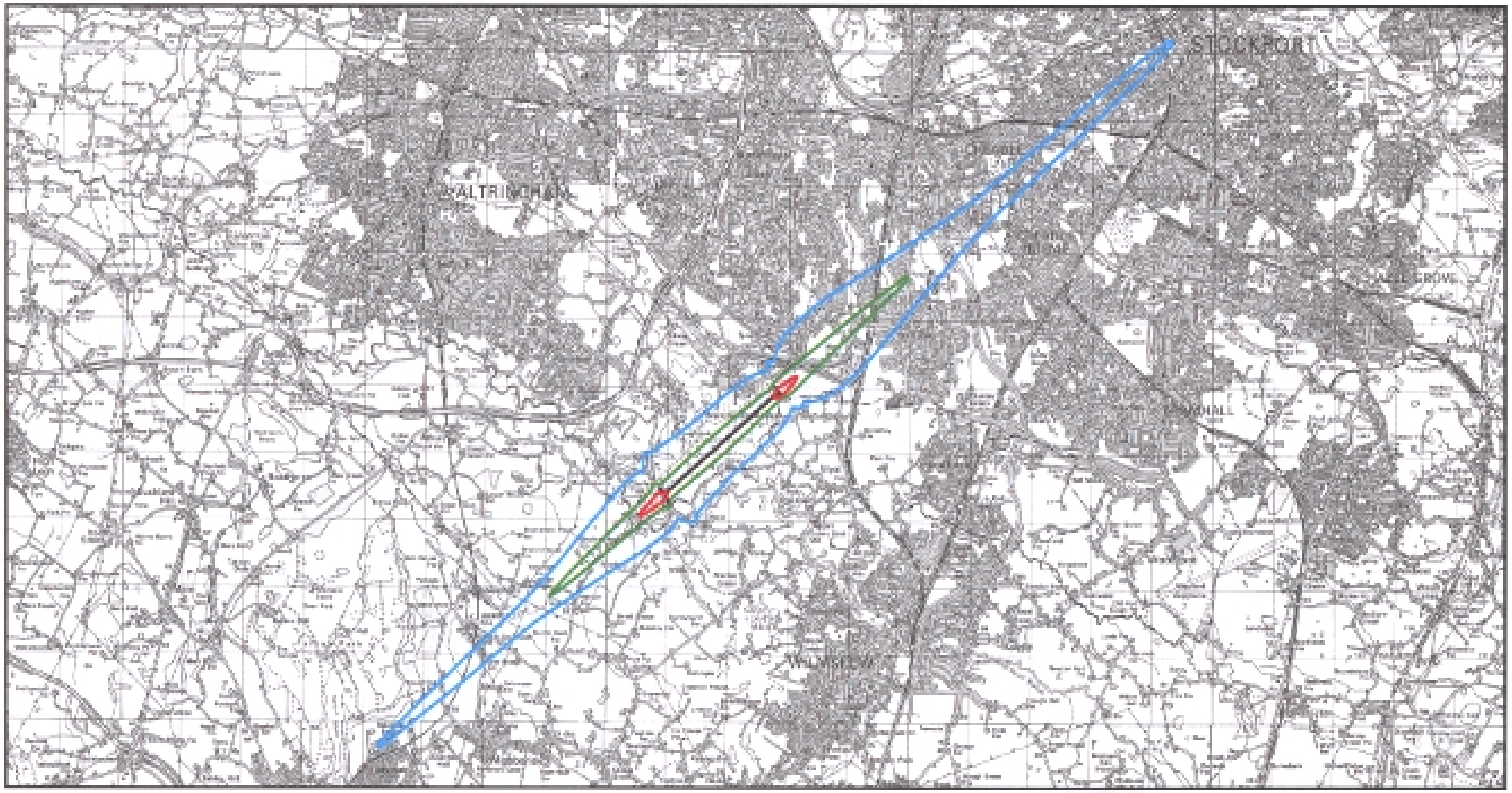


Scale 1 : 100,000

10^{-6} Blue 10^{-5} Green 10^{-4} Red

FIGURE 7.3

Individual Risk Contours at Manchester Airport



Scale 1 : 100,000

10^{-6} Blue 10^{-5} Green 10^{-4} Red

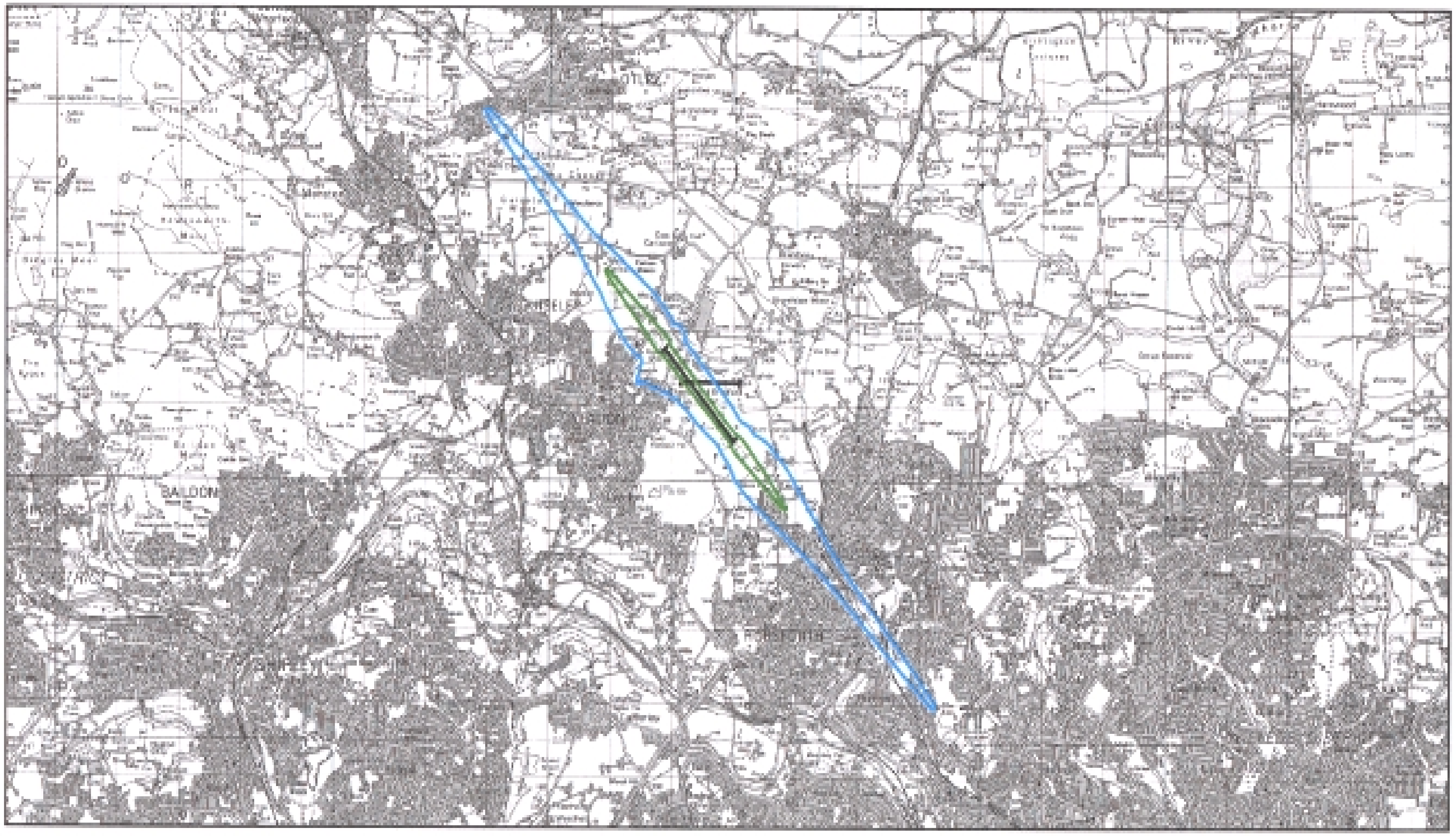
FIGURE 7.4

Individual Risk Contours at Birmingham Airport

Scale 1 : 100,000

10^{6} Blue 10^{5} Green

Individual Risk Contours at Leeds Bradford Airport

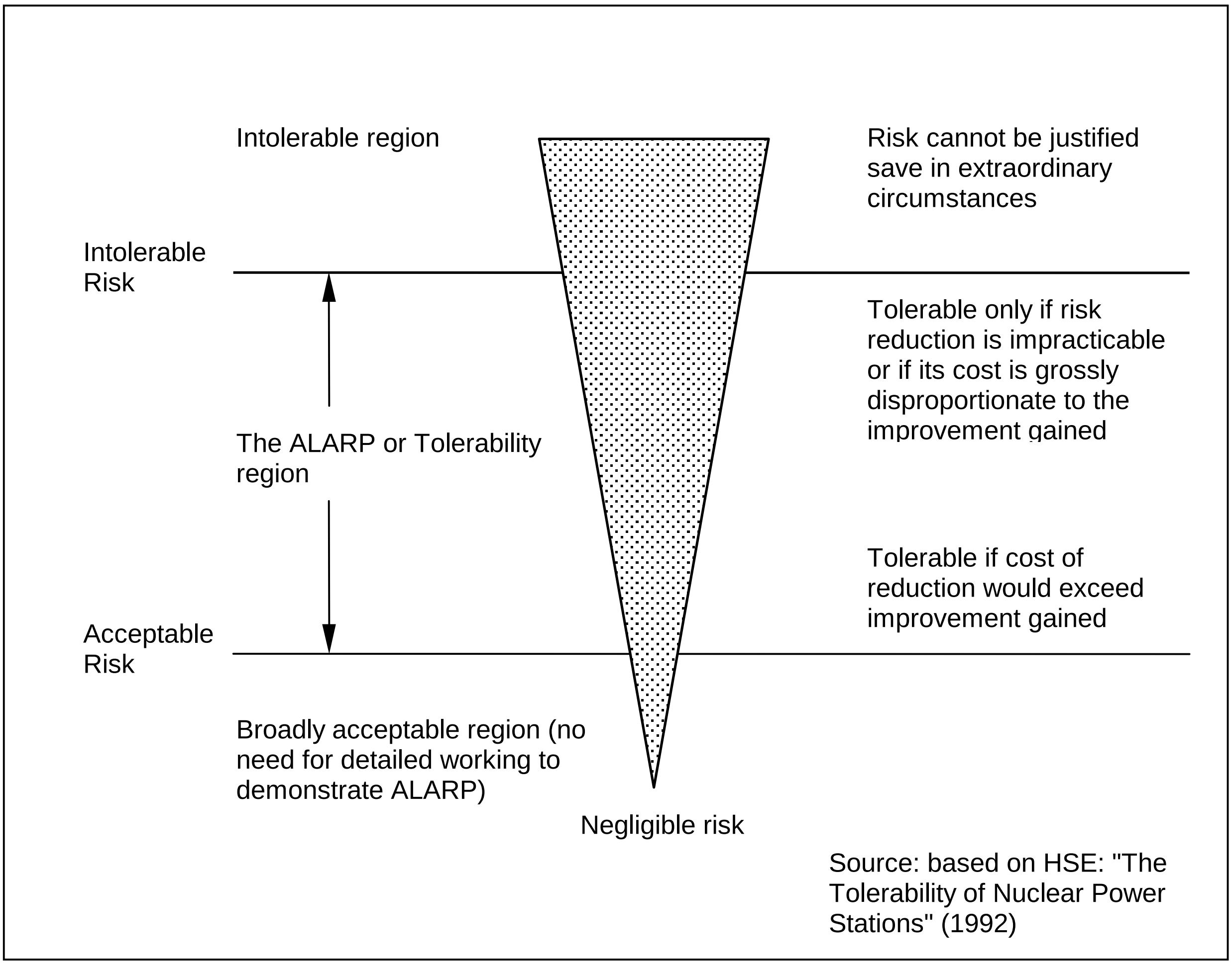


Scale 1 : 100,000

10^{-6} Blue 10^{-5} Green

FIGURE 9.1

HSE Tolerability of Risk Framework



Source: based on HSE: "The Tolerability of Nuclear Power Stations" (1992)

FIGURE 9.2

FN Curves for British Road and Civil Aviation Accidents

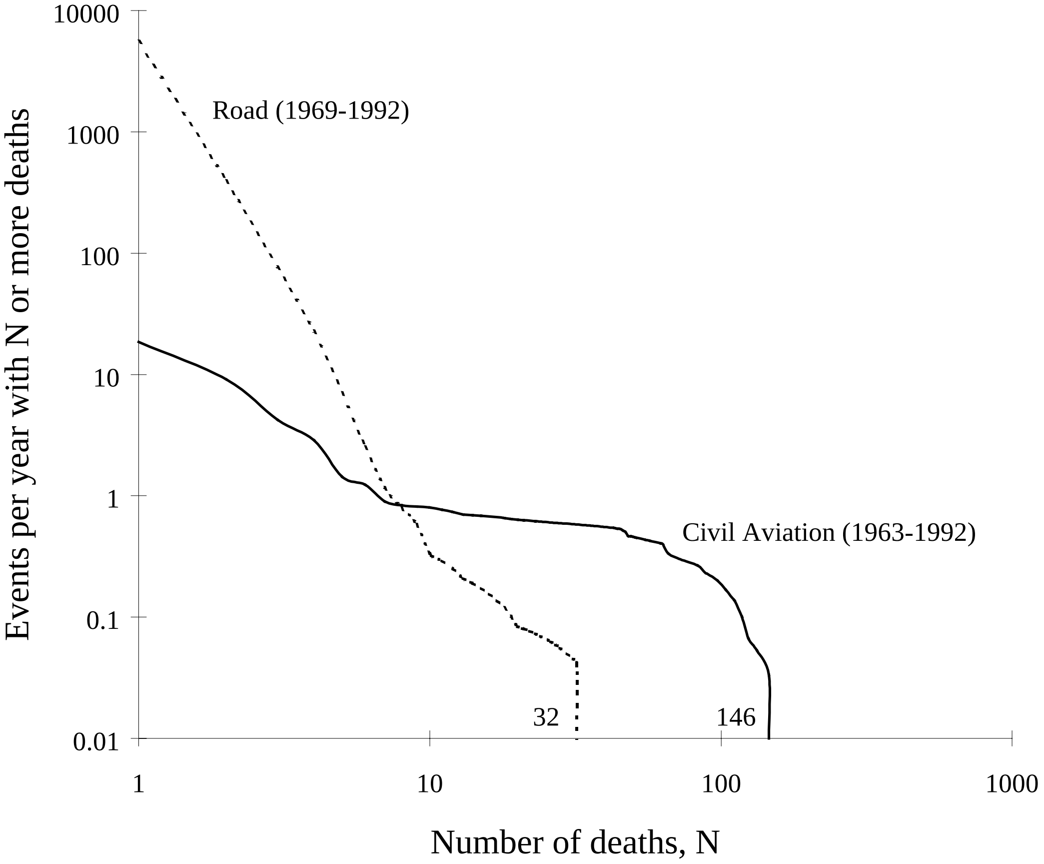
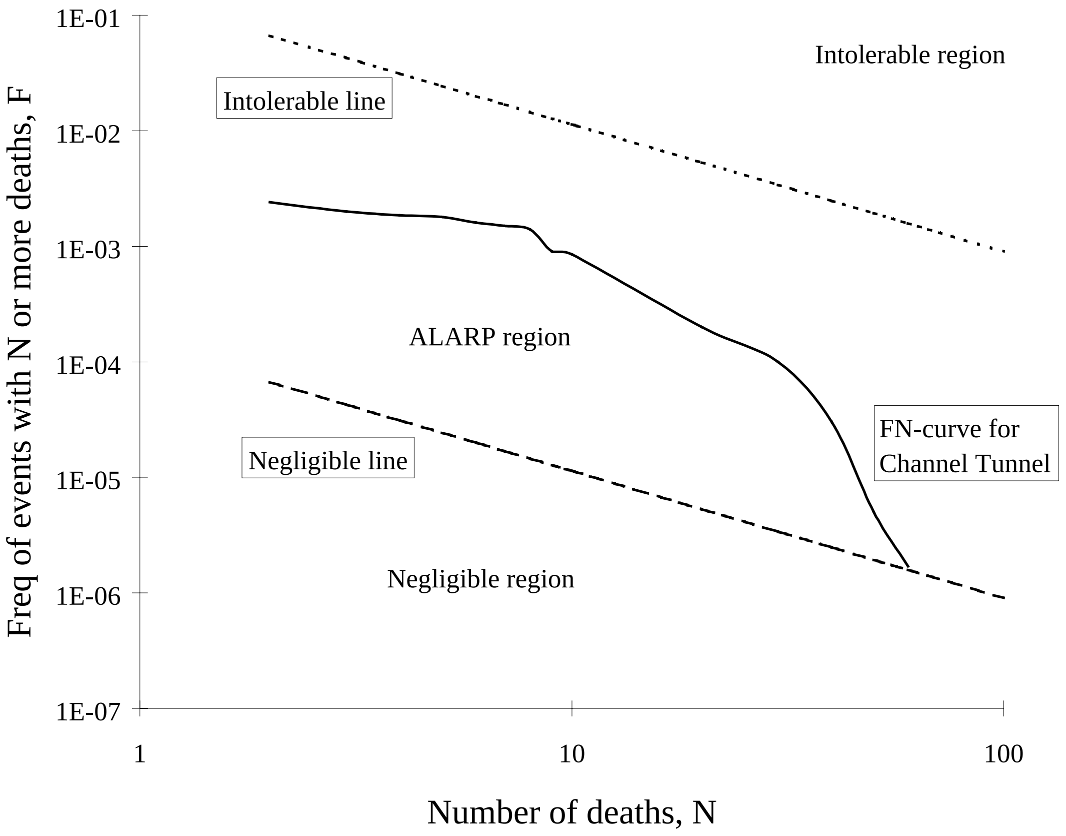


FIGURE 9.3

FN Curve and Criterion Lines: Channel Tunnel



Notes:

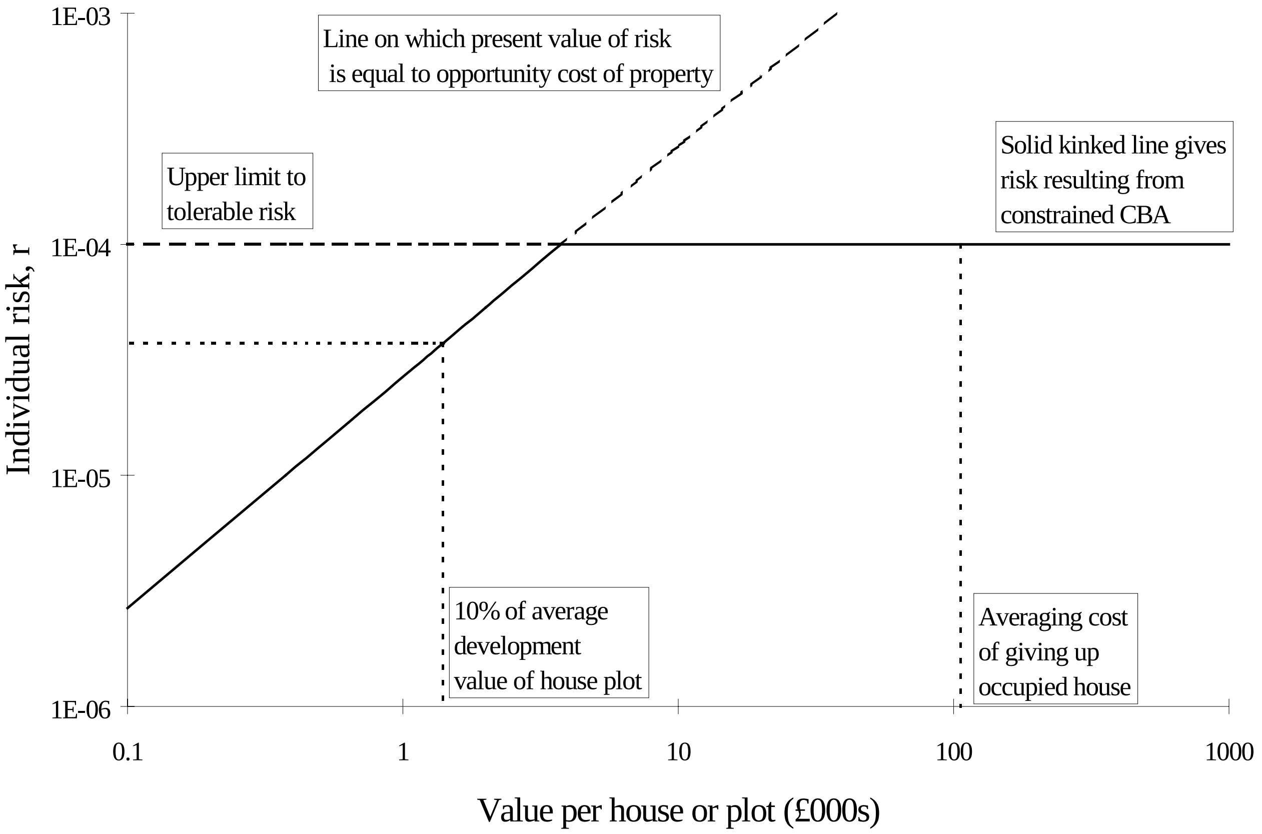
(1) The notation for the frequency of events per year is:

1E-02 which means: 1×10^{-2}

1E-03 which means: 1×10^{-3}

FIGURE 11.1

Constrained Cost Benefit Analysis: Risk and House or Plot Values



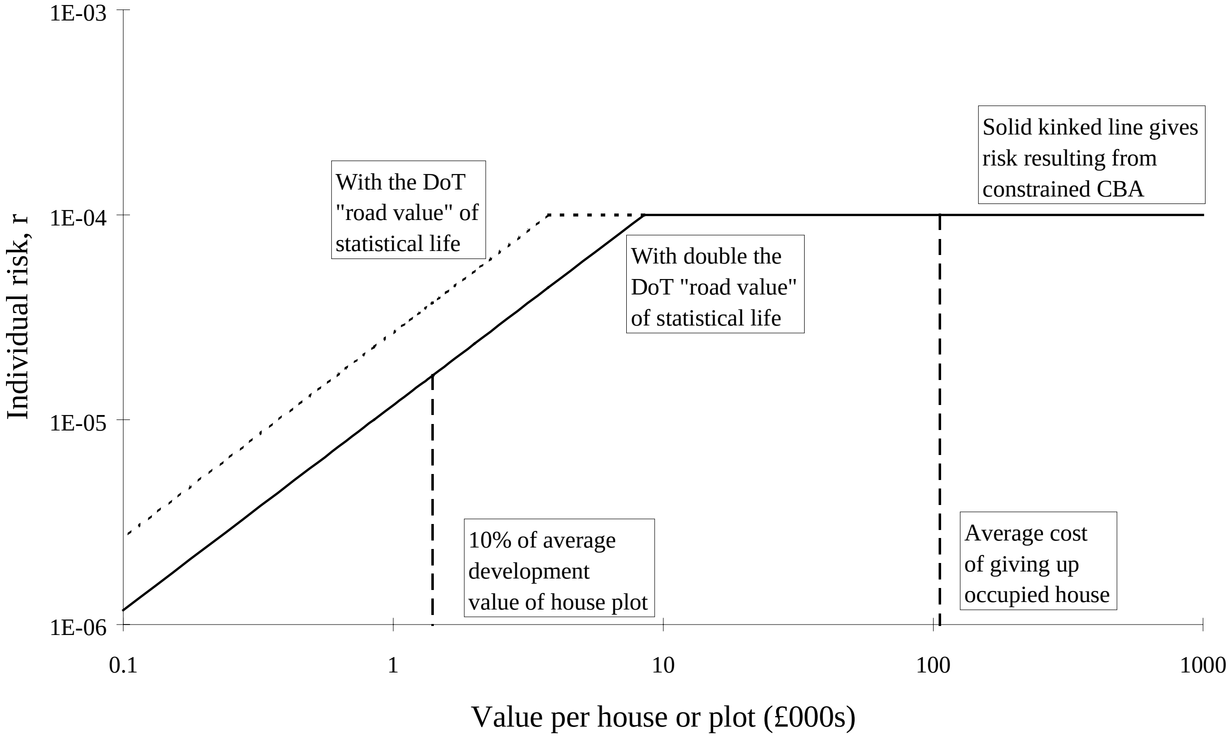
<u>Notes:</u>

(1) The notation for individual risk, r, is:

1E-03 which means: 1×10^{-3}
1E-04 which means: 1×10^{-4}

FIGURE 11.2

Constrained Cost Benefit Analysis: Effects of Using Twice the Value of Statistical Life



Notes:

(1) The notation for individual risk, r, is:

1E-03 which means: 1×10^{-3}

1E-04 which means: 1×10^{-4}

FIGURE 12.1

End of Runway Contour Corresponding Approximately to the 10^{-5} Risk Contour

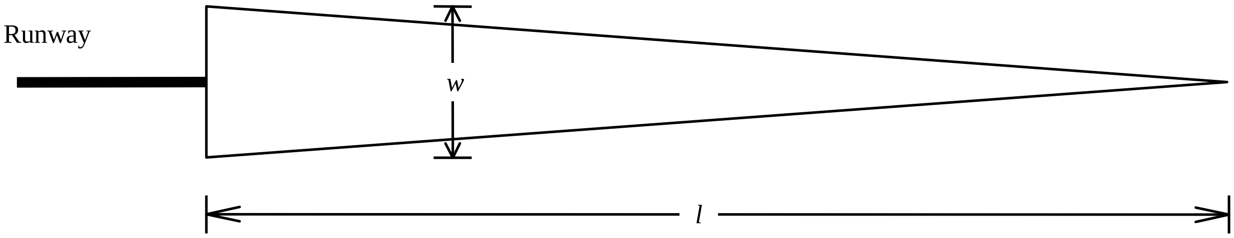


FIGURE 12.2

Movements and 10^{-5} Risk Data for Five Airports 1994

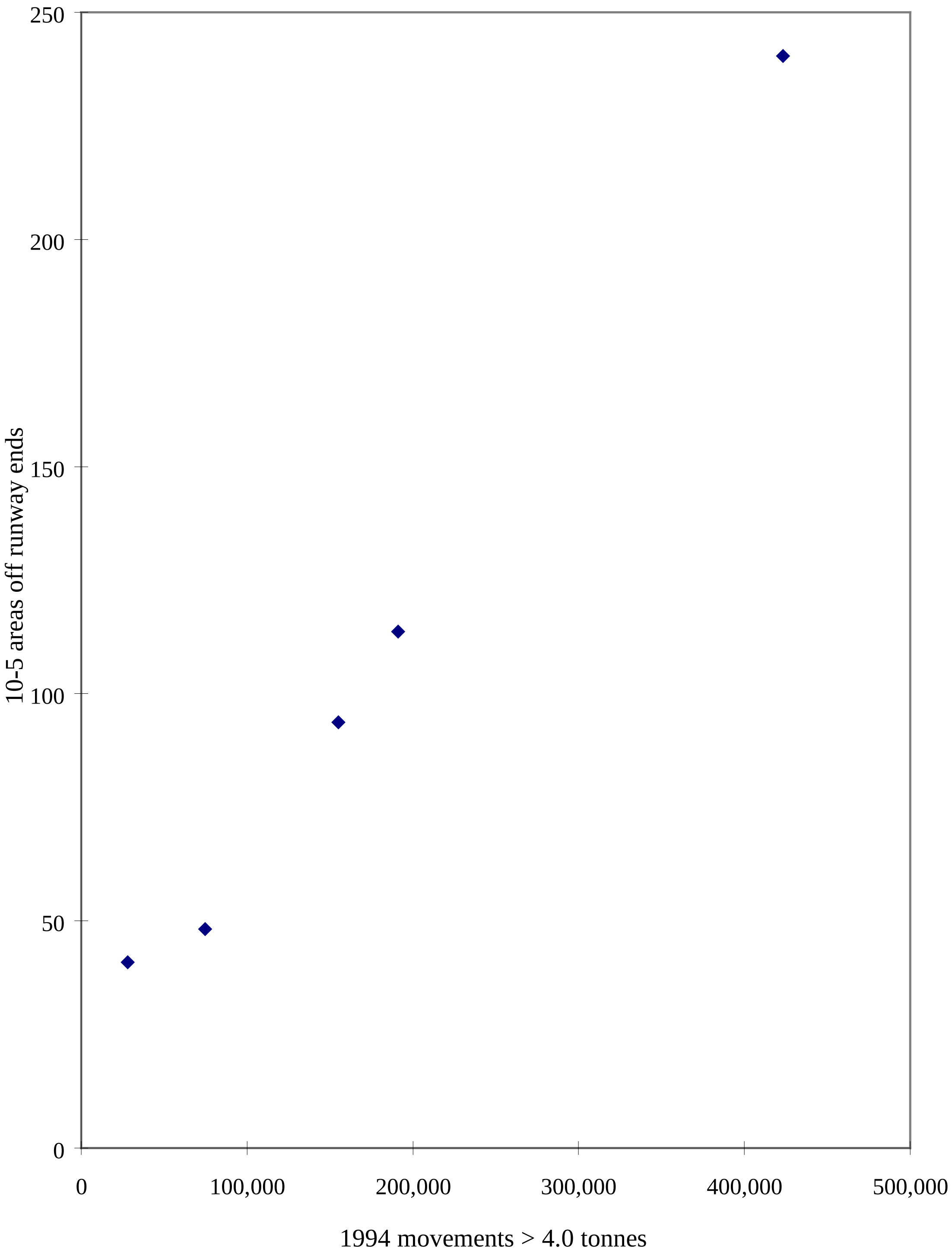


FIGURE 12.3

Risk in 10^{-5} Areas and Product of Movements, Crash Rates and Destroyed Areas

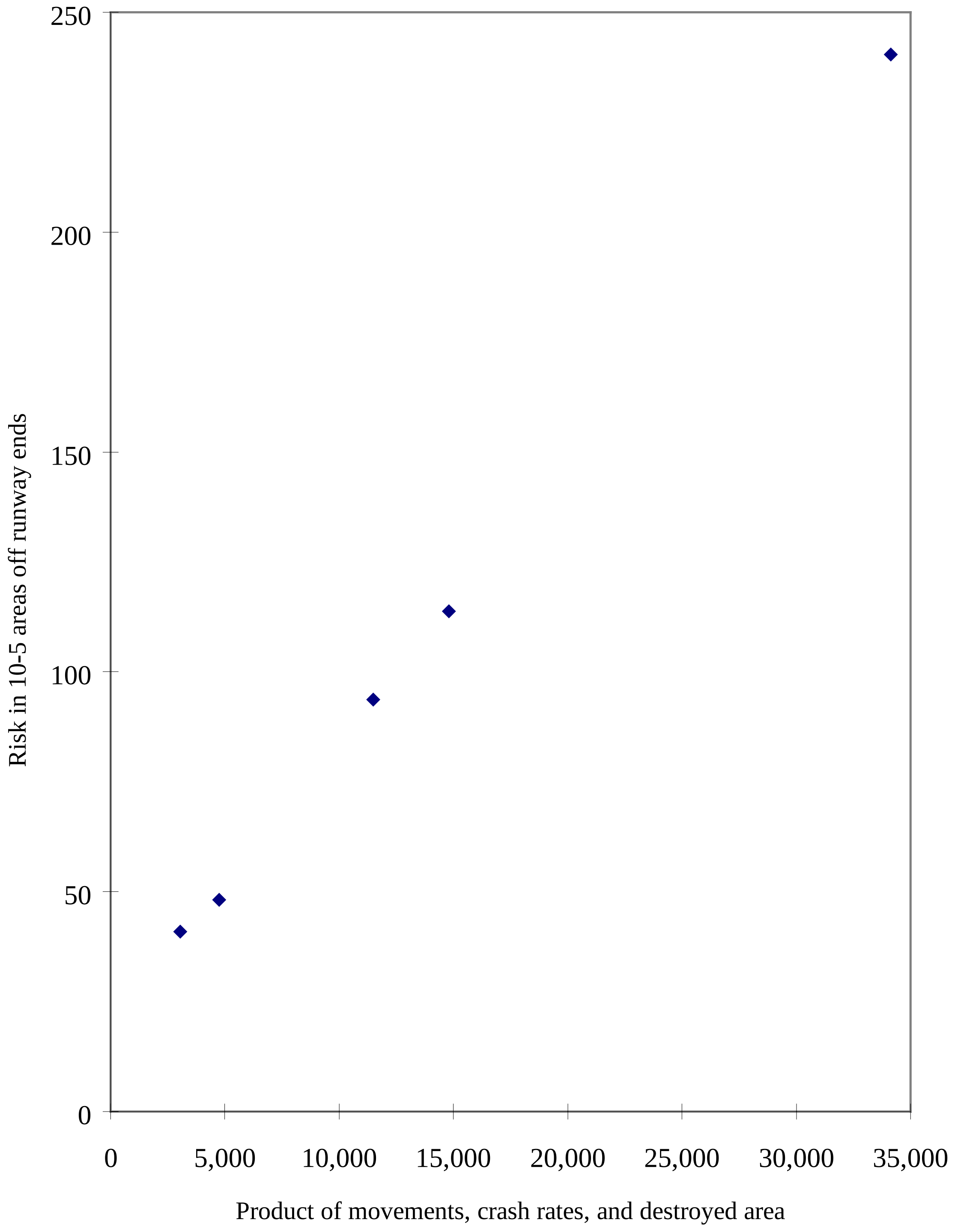
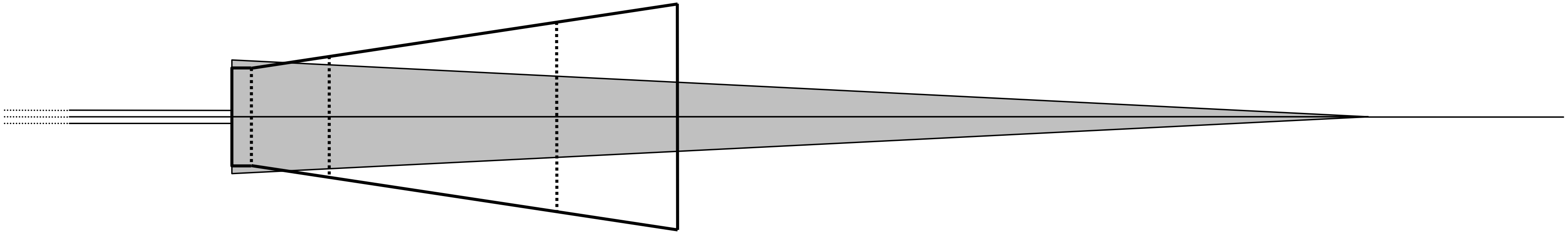


FIGURE 12.4

Comparison of existing PSZ with Option (d) large PSZ



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APPENDIX A

REVIEW OF WORLD-WIDE ACCIDENT AND MOVEMENT DATA

A1 This appendix presents a review of available sources of data on crashes and movements together with the results of completeness tests on the selected data.

Accident Data

A2 Useful sources of accident data include:

- World airline accident summary (WAAS) (Ref A1). This reference contains data collected world-wide on accidents involving civil aircraft over 5.7 tonnes MTWA.

- ADREP database (Ref A2). This is maintained by ICAO and data from it are available to ICAO members on request. However, it tends not to be completely up-to-date for the most recent few years.

- Airclaims Limited, a commercial organisation, maintains a detailed database of world-wide accidents called the CASE database, and produces a number of publications such as the Major Loss Record (MLR) (Ref A3) which contains accident data on jet airliner total and major partial losses, turboprop total losses, and executive jet total losses. Extracts in spreadsheet format can be produced from the CASE database of world-wide major accidents to different types of aircraft which can then be classified according to phase of flight (e.g. total losses suffered by jet and turboprop airliners/commuters during take-off and landing phases of flight).

- Mandatory Occurrence Reporting Scheme (MORS) database (Ref A4) maintained by Safety Regulation Group, CAA. As well as UK reportable occurrences (incidents), this database also contains data on world-wide accidents to aircraft over 5.7 tonnes MTWA which resulted in substantial (or worse) accidents. This information was obtained from sources such as ADREP and Airclaims. However, since the middle of 1993, records of foreign accidents are no longer routinely included in the MORS database.

Movement data

A3 Finding sources of data with details of historical movements by aircraft type and by geographical location is a more difficult task. There are two primary sources of movement data: that recorded by airports and that recorded by airlines. Data collected from airports will usually be available by geographical location, but not often by aircraft type, while data obtained from airlines tend to give aircraft details, but not geographical information. The main sources of airport and airline based movement data are reviewed below.

Airport data

A3 Sources of airport movement data include both national organisations (e.g. CAA, FAA, National Transportation Safety Board (NTSB), and international organisations (e.g. Eurocontrol, ICAO, Airport Council International (ACI)).

A4 National organisations: This information varies considerably in content and level of detail. Organisations may subdivide published movements into commercial/non-commercial, scheduled/charter, or national/international movements. However, movement data by aircraft type are not commonly included.

A5 International organisations: Eurocontrol can provide European movements by airport and aircraft category, but only as far back as 1988, and extraction of the data is time-consuming. The ACI publishes movement data for 188 European airports but its published data are only available for recent years and do not include movements by aircraft type. ICAO publishes world airport movement data annually (Ref A5), but this does not include movements by aircraft type. The data do not cover all airports and can be incomplete even for those airports which are included. Reference A6 concluded that overall some 50% of the total world-wide movements are missing from the ICAO airport data. Missing data results from the fact that the information is supplied by countries/airports on a voluntary basis and ICAO does not always receive the necessary information each year.

Airline data

A6 ICAO produces an annual publication, Traffic by Flight Stage (Ref A7). This contains data on the international movements by scheduled airlines between pairs of cities categorised by aircraft type. However, the data only cover revenue traffic and are not complete for similar reasons to those noted in the paragraph above. ICAO also publish ‘Traffic Commercial Air Carriers’ (Ref A8) which contains movements by airlines. This does not subdivide movements into aircraft types, nor is it complete.

A7 Movement data are published by Airclaims (Ref A9) for western airliner jets by aircraft type, but not by country or airport. The data are based on returns made by the airlines to manufacturers (although it does contain a proportion of estimates for the most recent year and also for the oldest jets).

A8 In order to check the completeness of the Airclaims information, a comparison was made with world-wide movement data produced independently by Boeing for western-built jets (Ref A10) which showed a high degree of consistency between the two sources (within 3%). The Airclaims movement data are therefore considered to have a high degree of completeness.

A9 An alternative to using actual historical movement data would be to use historical airline ‘timetabled’ movements. These are available for scheduled passenger flights by aircraft type and by country from the Official Airline Guide (OAG) (Ref A11) from 1979 to 1995. The data are in a computerised form and are therefore readily analysed. However, as these are timetabled movements as opposed to actual movements, there is the possibility of them being either incomplete or in some cases ‘overcomplete’, (i.e. some flights which took place may not be included, while others may be included which, though on the timetable, did not take place).

Completeness of data sources

A10 The OAG database was the preferred source for movement data because the information on aircraft type and airport allows crash rates for first world airports to be calculated (these are more appropriate for use at UK airports than world-wide crash rates). The preferred source of data on crashes was the Airclaims database because the data could be obtained in an easily used PC readable format. In order to be confident in the crash rates calculated from these sources of data, completeness tests were carried out and these are described below.

OAG scheduled passenger movement data

A11 The completeness of the OAG movement data world-wide could not be checked by direct comparison with another (complete) source such as Airclaims jet movements because OAG data represent scheduled passenger (SP) flights only, whereas the Airclaims movements include charter and freight. However it is possible to make ‘spot checks’ by comparing the OAG timetable movements for aircraft of different types at particular airports during particular time-periods, with actual airport statistics for those airports.

A12 Actual aircraft movements at Heathrow and Manchester were provided by the CAA’s Economic Regulation Group (ERG). The data consists of a complete breakdown by aircraft type, and by type of operation (Scheduled Passenger, Scheduled Cargo, Charter Passenger or Charter Cargo) for commercial ATMs at the two airports. The total scheduled passenger movements for each aircraft type over the period 1992 to 1994 inclusive were compared with the OAG timetabled movements. (The time period 1992 to 1994 was chosen to exclude the Gulf War and any disruption this may have cause to air traffic, although the overall conclusions for the period 1990 to 1994 were very similar.)

A13 The OAG and ERG movements for each aircraft type[4] are presented in Tables A1 and A2 for Heathrow and Manchester respectively. The ratio OAG/ERG is

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[5] Both the OAG and ERG data are even more detailed than presented in Tables A1 and A2. For example Boeing 737s are divided into -100, -200,-300, -400, and -500 series aircraft in both sets of data.

also given (as a percentage). This is a measure of the difference between the expected timetabled movements and the actual movements. Tables A3 shows a summary of the movement data for the generic groups of aircraft used in the calculation of scheduled passenger crash rates (Class I jets, Class II-IV jets, T1 and T2 turboprops and eastern jets).

A14 The data shows that OAG data may be used with confidence for many classes of aircraft. There may be wide discrepancies between ERG and OAG data for individual aircraft types (see Tables A1 and A2), but for classes of aircraft with large numbers of movements, the OAG/ERG ratio is often close to 100% (see Table A3). It would appear from this analysis that the overall number of flights follows the OAG schedules closely but that airlines often change the timetabled aircraft for one of a similar type (usually in the same class).

A15 Class II-IV jets, turboprops types T1 and T2 and eastern jets at Heathrow and Manchester have OAG/ERG ratios between 90.2% and 108.2%. This indicates that the OAG data were reasonably accurate estimates for the actual movements of these aircraft. The accuracy of the OAG data for predicting Class I jets is unclear because there are very few movements at either airport. As the proportions of these aircraft at UK airports are small (and decreasing with time), this will not be a significant source of uncertainty for this study.

A16 It is also possible to compare world-wide scheduled passenger crash rates for Class I to IV airliner jets calculated using OAG movements with the world-wide ‘all’ (scheduled, non-scheduled, passenger, cargo etc.) crash rates for these aircraft calculated using Airclaims movements. The results of this comparison (see Table A4) show that for Class II-IV jets the crash rates calculated using both methods are similar. This indicates that scheduled passenger crash rates are representative of the overall crash rates for these types of aircraft. The agreement is not good for Class I jets, but as noted above this should not present a problem for UK airports.

Airclaims accident data

A17 Reference A12 contains data on world commercial aircraft accidents for jets and turboprops from 1946 to 1993. The accidents included in the data were those that resulted in the loss of the airframe or caused one or more fatalities, or both. The data was compiled from a large number of references, but the Airclaims database is not included in this list. Reference A12 and Airclaims are therefore reasonably independent sources of accident data.

A18 To check the completeness of the Airclaims accident data, the airport-related accidents world-wide from both sets of data were checked against each other for

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However, the match between the movements at this level of detail is very poor. Therefore the movements for each variant of a particular aircraft type have been summed and these are the values presented in Tables A1 and A2.

Class II-IV jets from 1979 to 1993. The two main results from this comparison were as follows:

(i) all 164 total losses in Airclaims list of airport-related accidents for this period were contained in Reference A12. A further 9 accidents were identified in Reference A12 which were not in Airclaims list. 5 of these accidents were found to be en-route according to Airclaims accident précis, occurring long distances from the origin/destination airport. 1 accident was specified as a major partial loss by Airclaims with no details for the remaining 3 accidents. However, none of these 3 accidents were first world scheduled passenger flights which were used in the crash rates in this report; and

(ii) only 9 out of 184 accidents classified as major partial losses by Airclaims were contained in Reference A12. However, all of these accidents were described as major, rather than accidents where the aircraft was destroyed (although the aircraft was written-off in four of the nine cases). This further comparison shows that there are very few accidents which are perhaps more appropriately designated as total losses as opposed to major partial losses.

A19 The conclusion from this is that Airclaims list of Total Losses is essentially complete although some accidents are borderline cases. This is not unexpected as total losses (especially for scheduled passenger flights) are unlikely to go unreported. It is, however, more difficult to comment on the completeness of Airclaims data on major partial loss accidents. Airclaims defines major partial losses as those accidents where the repair estimate is believed to have been 10% or more of the insurance value but did not become a total loss. MORS and the WAAS define substantial accidents as accidents that require an aircraft to be taken out of service for repair. Both MORS and WAAS therefore include substantial accidents that are not contained in Airclaims major partial loss data. An examination of Airclaims accident data showed that virtually all the major partial loss accidents relevant to third party risk were overruns. It was therefore decided to use Airclaims data for Total Losses for the baseline crash rates (see Chapter 3 and Chapter 6) and investigate the effect of including major partial loss accidents as part of the sensitivity studies (see Chapter 8).

Data adopted.

A20 Based on the above analysis, the Airclaims crash data and the OAG movement data were selected for the calculation of crash rates for western airliner jets and turboprops.

References

A1 World Airline Accident Summary: Civil Aviation Authority: CAP 479: 1995.

A2 Accident Data Reports (ADREP database): ICAO: Montreal.

A3 Major loss record: Aviation Information Services Limited: Airclaims: Heathrow Airport: May 1994.

A4 Mandatory Occurrence Reporting Scheme (MORS database): Safety Data and Analysis Unit: CAA: Gatwick.

A5 ICAO Digest of Statistics: Series AT (Airport traffic).

A6 Piers M A, Loog M P et al: The Development of a Method for the Analysis of Societal and Individual Risk Due to Aircraft Accidents in the Vicinity of Airports: National Aerospace Laboratory: Netherlands: NLR CR 93372 L: November 1993.

A7 ICAO Digest of Statistics: Series TF (Traffic by flight stage): Published annually.

A8 ICAO Digest of Statistics: Series T (Traffic commercial air carriers): Published annually.

A9 Airliner Loss Rates: Airclaims: Heathrow Airport: 1996.

A10 Statistical Summary of Commercial Jet Aircraft Accidents: World-wide Operations 1959-1993: Boeing Commercial Airplane Group: March 1994.

A11 Official Airline Guide (OAG): Back Information Services: USA, 1995.

A12 Kimura, C Y: World Commercial Aircraft Accidents: 3rd Edition: 1946-1993: Vol 1 Jet and turboprop accidents: Lawrence Livermore National Laboratory: June 1994.

TABLE A1

Differences Between Actual Scheduled Movements and OAG Timetabled Movements at Heathrow Airport 1992-1994

		Movements		OAG/ERG
Aircraft Type	**Class (1)**	ERG	OAG	(%)
Boeing 707	J I	305	196	64.3
McDonnell-Douglas DC8	J I	17	0	0.0
BAe(BAC)1-11	J II	535	730	136.4
Boeing 727	J II	11542	9434	81.7
Fokker F28	J II	13243	14260	107.7
McDonnell-Douglas DC9	J II	71764	68484	95.4
Airbus A300	J III	26757	28314	105.8
BAC/Aerospatiale Concorde	J III	4908	4904	99.9
Boeing 747	J III	128375	127306	99.2
Lockheed L-1011 Tristar	J III	3237	3040	93.9
McDonnell-Douglas DC10	J III	5020	4822	96.1
Airbus 340 series	J IV	1582	1468	92.8
Airbus A310	J IV	53631	52686	98.2
Airbus A320	J IV	99538	103634	104.1
BAe 146	J IV	9162	7506	81.9
Boeing 737	J IV	358606	366872	102.3
Boeing 757	J IV	166704	167648	100.6
Boeing 767	J IV	101843	99924	98.1
Canadair Regional jet	J IV	6	0	0.0
Fokker 100	J IV	6195	3600	58.1
McDonnell-Douglas MD-11	J IV	6610	6524	98.7
McDonnell-Douglas MD-80	J IV	64152	63820	99.5
Airbus A321	J IV	0	214	-
Avro International Avroliner	J IV	0	1704	-

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TABLE A1 (continued)

Aircraft Type	**Class** (1)	**Movements** ERG	 OAG	OAG/ERG (%)
ATR 42-300	T 1	21	0	0.0
BAe Jetstream 41	T 1	62	64	103.2
British Aerospace ATP	T 1	5465	6512	119.2
De Havilland DHC-7 Dash-7	T 1	10018	10494	104.8
De Havilland DHC-8 Dash-8	T 1	1011	956	94.6
Dornier 228-100/200	T 1	2	0	0.0
Embraer EMB-120 Brasilia	T 1	51	0	0.0
Fokker 50	T 1	3159	3464	109.7
Saab 2000	T 1	18	0	0.0
Saab Fairchild 340	T 1	34	0	0.0
Shorts 360	T 1	19	0	0.0
BAe (HS) 748	T 2	1	0	0.0
Fokker F27 100-400/600	T 2	8127	8370	103.0
Lockheed L-100 Hercules	T 2	2	0	0.0
Ilyushin 96	EJ	2	0	0.0
Ilyushin IL-62	EJ	957	706	73.8
Ilyushin IL-76	EJ	2	0	0.0
Ilyushin IL-86	EJ	1508	1532	101.6
Tupolev TU-134	EJ	533	136	25.5
Tupolev TU-154A/B	EJ	2716	4610	169.7
Tupolev TU-154M	EJ	1958	0	0.0
Yakovlev YAK-42	EJ	223	142	63.7
Canadair CL-600/601 Challenger	Exec. Jet	1	0	0.0
Dassault Breguet Falcon 50	Exec. Jet	1	0	0.0
Gulf American Gulfstream II	Exec. Jet	2	0	0.0
Gulf American Gulfstream III	Exec. Jet	1	0	0.0
Gulf American Gulfstream IV	Exec. Jet	9	0	0.0

Class (1)	
J I, II, III, IV	Jet aircraft classified according to Boeing Classes (see Table 3.1)
T1, T2	Turboprop aircraft classes as described in Chapter 3 (see Table 3.2)
EJ	Eastern jets.
Exec. Jet	Executive Jets.

TABLE A2

Differences Between Actual Scheduled Movements and OAG Timetabled Movements at Manchester Airport 1992-1994

Aircraft Type	Class (1)	Movements ERG	Movements OAG	OAG/ERG (%)
Boeing 707	J I	2	0	0.0
BAe(BAC)1-11	J II	11839	11934	100.8
Boeing 727	J II	284	420	147.9
Fokker F28	J II	121	1056	872.7
McDonnell-Douglas DC9	J II	3106	2916	93.9
Airbus A300	J III	727	640	88.0
BAC/Aerospatiale Concorde	J III	11	0	0.0
Boeing 747	J III	6763	3592	53.1
Lockheed L-1011 Tristar	J III	1962	1944	99.1
McDonnell-Douglas DC10	J III	49	0	0.0
Airbus 330	J IV	40	0	0.0
Airbus A310	J IV	4090	2808	68.7
Airbus A320	J IV	1351	2358	174.5
BAe 146	J IV	735	548	74.6
Boeing 737	J IV	93890	93982	100.1
Boeing 757	J IV	17668	17608	99.7
Boeing 767	J IV	10480	8982	85.7
Canadair regional jet	J IV	1249	2398	192.0
Fokker 100	J IV	1726	806	46.7
McDonnell-Douglas MD-11	J IV	549	576	104.9
McDonnell-Douglas MD-80	J IV	7461	7832	105.0

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TABLE A2 (continued)

Aircraft Type	**Class** [(1)]	**Movements** ERG	 OAG	OAG/ERG (%)
ATR 42-300	T 1	7	0	0.0
BAe Jetstream 41	T 1	2689	7228	268.8
BAe (H.P.) Jetstream 31/32	T 1	13576	9938	73.2
Beechcraft 200 Superking Air	T 1	14	0	0.0
British Aerospace ATP	T 1	54126	56130	103.7
De Havilland DHC-8 Dash-8	T 1	825	822	99.6
Dornier 228-100/200	T 1	4695	4904	104.5
Embraer EMB-120 Brasilia	T 1	2796	2786	99.6
Embraer EMB-110 Bandeirante	T 1	473	1124	237.6
Fokker 50	T 1	7217	7604	105.4
Saab 2000	T 1	1	0	0.0
Saab Fairchild 340	T 1	6378	6180	96.9
Shorts 330	T 1	4825	5668	117.5
Shorts 360	T 1	4491	3300	73.5
Fairchild SA-227 Metro III	T 2	2	0	0.0
Fokker F27 100-400/600	T 2	2183	2246	102.9
Gulf American Gulfstream I	T 2	2	0	0.0
Swearingen Metro II	T 2	60	0	0.0
Vickers Viscount 800	T 2	9	0	0.0
Beech Kingair 90	T Un	6	0	0.0
Cessna 441 Conquest II	T Un	2	0	0.0
Mitsubishi MU2	T Un	6	0	0.0
Piper PA-31T Cheyenne I/II	T Un	153	0	0.0
Piper PA-42 Cheyenne III/IV	T Un	1230	0	0.0
Reims-Cessna F406/Caravan II	T Un	403	0	0.0

Continued on next page.

TABLE A2 (continued)

Aircraft Type	**Class** [(1)]	**Movements** ERG	OAG	OAG/ERG (%)
Ilyushin IL-62	EJ	62	42	67.7
Tupolev TU-134	EJ	333	148	44.4
Tupolev TU-154A/B	EJ	339	540	159.3
Gates Learjet 35A/36A	Exec. Jet	2	0	0.0
Cessna (All series)	P	0	488	-
Cessna 401/402/411/421	P	6	0	0.0
Cessna 404 Titan	P	4	0	0.0
Pilatus BN-2A Islander	P	106	516	486.8
Pilatus BN-2A Trislander MK3	P	0	160	-
Piper PA23 Aztec/Apache	P	18	0	0.0
Piper PA31/31P Navajo/Chieftain	P	164	0	0.0
Piper (all series)	P	0	2328	-

Class [(1)]	
J I, II, III, IV	Jet aircraft classified according to Boeing Classes (see Table 3.1)
T1, T2	Turboprop aircraft classes as described in Chapter 3 (see Table 3.2)
T Un	Turboprops not classified as western airliner turboprops.
EJ	Eastern jets
Exec. Jet	Executive Jets
P	Piston-engine aircraft

TABLE A3

Comparison of major aircraft classes between Actual Scheduled Movements and OAG Timetabled Movements 1992-1994

(i) Heathrow Airport

Aircraft Class	**Movements** ERG	OAG	OAG/ERG (%)
Class I jets	322	196	60.9
Class II-IV jets	1133410	1136894	100.3
Turboprops T1	19860	21490	108.2
Turboprops T2	8130	8370	103.0
Eastern Jets	7899	7126	90.2

(ii) Manchester Airport

Aircraft Class	**Movements** ERG	OAG	OAG/ERG (%)
Class I jets	2	0	0.0
Class II-IV jets	164101	160400	97.7
Turboprops T1	102113	105684	103.5
Turboprops T2	2313	2246	97.1
Eastern Jets	734	730	99.5

TABLE A4

World-wide Crash Rates Calculated for OAG movements Compared with Airclaims Movements

Western Airliner Jet Class	OAG data(1)			Airclaims data(2)		
	Movements	Crashes	Crash rate (per million movements)	Movements	Crashes	Crash rate (per million movements)
I	7670788	20	2.607	16583800	82	4.945
II/III/IV	355975396	147	0.413	395740400	182	0.460
Total	363646184	167	0.459	412324200	264	0.640

(1) Data for scheduled passenger flights only

(2) Data for all flights (scheduled, non-scheduled, passenger, cargo, etc.)

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TRAFFIC ANALYSIS FOR THE FIVE SAMPLE UK AIRPORTS

B1 This appendix gives an overview of the analysis of the traffic in 1994 at the five UK airports for which individual risk calculations are performed in this study.

B2 The CAA's ERG publish details of the movements at UK airports (Ref B1). Table B1 shows the movements at the five study airports broken down by type of operation for 1994. ERG also supplied a detailed breakdown by aircraft type for the commercial ATMs for each airport. However, only the total movements were available for the other commercial and non-commercial categories shown in Table B1.

B3 In addition to ERG's data, a complete breakdown of all the traffic by aircraft type was available from the airports in computer-readable form for Heathrow, Gatwick, and Manchester, but only in 'paper' form for Birmingham. For Leeds Bradford, the only set of traffic data available was the breakdown supplied by ERG.

B4 As explained in Chapter 3, crash rates have been developed by collecting aircraft types into generic groups. The groups chosen are to a large extent dependent on the availability of the appropriate first world scheduled passenger movements; some groups however depend on the detail of the movements at the individual airports. In either case, the movements at the five sample airports have to be split into the same groups for which crash rates have been derived so that crash frequencies can be calculated by multiplying the movements for each group by the appropriate crash rate. The tables presented in this appendix therefore split the airport traffic data into the same groups as listed in Table 6.3.

B5 As explained in Chapter 4, two crash location models are used in this report, the NATS model (for aircraft with MTWA greater than 4.0 tonnes), and the AEA light aircraft model (for aircraft with MTWA less than 2.3 tonnes). The movements have therefore been further subdivided according to which crash location model they are associated with in the individual risk calculations. To avoid making this additional subdivision too complex, two simplifications were made:

(i) the analysis of the MTWAs for the aircraft at the five airports showed that, with the exception of piston-engine aircraft, the vast majority of the other aircraft types have MTWA greater than 4.0 tonnes. In practice very few turboprops and jets have MTWA less than 4.0 tonnes. It was decided therefore to associate all the turboprop and jet movements with the NATS model; and

(ii) the majority of the piston-engine aircraft (using the five airports) have MTWAs less than 2.3 tonnes, and virtually all have MTWAs less than

4.0 tonnes. Most of these movements were therefore associated with the AEA model; the remaining movements, which were considered to be either commercial or had MTWAs greater than 4.0 tonnes, were associated with the NATS model.

B6 Helicopter movements have not been included in any of the movement breakdowns since both the NATS and the AEA crash location models apply only to fixed-wing aircraft. Analysis of the available data showed that in 1994 the percentage of helicopter movements at Heathrow, Gatwick, Manchester and Birmingham were 0.3, 0.2, 1.1 and 4.3 percent respectively. The exact number of helicopter movements at Leeds Bradford is not available.

Analysis of traffic data for Heathrow, Gatwick, and Manchester

B7 Tables B2 and B3 show the 1994 movements for Heathrow and Gatwick, subdivided into the appropriate groups. No movements are appropriate to the light aircraft AEA model. The data supplied by BAA show that about 97 and 95% of the movements at Heathrow and Gatwick respectively are commercial ATMs. The remaining movements (described as ‘others’ or ‘general aviation’) are mainly turboprops or executive jets. The miscellaneous class include aircraft such as military jets which are not readily classified in the other groups.

B8 Table B4 shows the breakdown of the 1994 movements for Manchester. The data supplied by Manchester does not distinguish between types of operation (e.g. ATM or non-commercial) but the ERG data (Ref B1) shows that about 86% of the movements are ATMs, and a further 4% are commercial movements (positioning or local flights). The Manchester data shows that the airport, unlike Heathrow and Gatwick, has a significant proportion of piston-engine flights (about 8%); comparison with ERG data (Ref B1) suggests that these are generally Aero Club or private flights. All movements of aircraft with MTWA less than 2.3 tonnes were appropriate to the light aircraft AEA model. The remaining piston aircraft movements were considered to be mainly commercial operations (although the data does not make this completely clear) and were associated with the NATS model.

Analysis of traffic data for Birmingham

B9 As the full breakdown of traffic by aircraft type from Birmingham was not available in computer readable form, the traffic analysis was based largely on the data supplied by ERG (in computer-readable form) supplemented by information from the ‘paper’ traffic details provided by the airport.

B10 The ERG data divides the traffic into commercial and non-commercial movements. As detailed breakdowns by aircraft type were available on the commercial ATMs, these movements were analysed in a similar manner to that described above for Heathrow, Gatwick and Manchester.

B11 The ERG non-commercial movements were supplied in the following groups: Aero Club, Private, Military, Official, Test and Training, and Other Flights by Air Transport Operators. The paper traffic breakdown showed that all of the Aero Club movements were made by piston-engine aircraft with MTWA less than 2.3 tonnes. 82% of Private movements were made by piston-engine aircraft with MTWA less than 4.0 tonnes, with the other 18% of Private movements being made by executive jets or turboprops. All the piston-engine movements were associated with the AEA model. The movements described in the ERG data as being by Military, Official, Test and Training and Other were not analysed further using the paper traffic details as these comprise much smaller percentages of the total non-commercial movements. The traffic analysis for Birmingham is shown in Table B5.

Analysis of Traffic data for Leeds Bradford

B12 The only information available to the study for Leeds Bradford was the traffic data supplied by ERG. As detailed breakdowns by aircraft type were available for the commercial ATMs, these movements were analysed in a similar manner to the other airports described above.

B13 In the absence of any further information, the non-commercial movements were assumed to be subdivided in the same manner as for Birmingham, namely all of the Aero Club and 82% of Private movements were taken to be by piston-engine aircraft with MTWA less than 4.0 tonnes and were associated with the AEA light aircraft model. The other 18% of Private movements were assumed to be by executive jets or turboprops. The Leeds Bradford traffic analysis is shown in Table B6.

Reference

B1 Civil Aviation Authority: CAP 604 UK Airports Annual Statement of Movements, Passengers and Cargo: April 1995.

TABLE B1

Breakdown of movements at the five sample UK airports in 1994 supplied by CAA's ERG

		Commercial Movements			Non-Commercial Movements					
Airport	Total	Air Transport	Positioning Flights	Local Mvts	Test and Training	Other Flights by Air Transport Operators	Aero Club	Private	Official	Military
Heathrow	424557	411608	4680	78	688	13		6248	853	389
Gatwick	191646	181879	7540	4	47	68		2002	3	103
Manchester	169908	145549	7279	219	180	682	7191	8429	5	374
Birmingham	95278	71068	1865	2590	485	26	11132	8012	8	92
Leeds Bradford	49737	23002	1269	262	2016	99	16620	6275	29	165

Source: CAA ERG

TABLE B2

Numbers and percentages of movements by aircraft type at Heathrow in 1994.

Aircraft class	Movements	Percentage
Class I jets	1069	0.3
Class II-IV jets	401511	94.8
Executive jets	8956	2.1
Eastern jets	2045	0.5
Turboprops T1	5821	1.4
Turboprops T2	3218	0.8
Turboprops (unclassified(1))	164	0.0
Piston-engine	271	0.1
Miscellaneous(2)	330	0.1
Total	423,385	

(1) Not classified as western airliner turboprops.
(2) Unusual aircraft types which could not be readily classified.

TABLE B3

Numbers and percentages of movements by aircraft type at Gatwick in 1994.

Aircraft class	Movements	Percentage
Class I jets	1904	1.0
Class II-IV jets	153026	80.0
Executive jets	2403	1.3
Eastern jets	814	0.4
Turboprops T1	26741	14.0
Turboprops T2	5237	2.7
Turboprops (unclassified(1))	308	0.2
Piston-engine	811	0.4
Miscellaneous(2)	16	0.0
Total	191260	

(1) Not classified as western airliner turboprops.
(2) Unusual aircraft types which could not be readily classified.

TABLE B4

Numbers and percentages of movements by aircraft type at Manchester in 1994.

Aircraft class	Movements	Percentage
Class I jets	48	0.0
Class II-IV jets	102639	61.8
Executive jets	1617	1.0
Eastern jets	810	0.5
Turboprops T1	44248	26.6
Turboprops T2	1369	0.8
Turboprops (unclassified(1))	1835	1.1
Piston-engine (NATS)(2)	2250	1.4
Piston-engine (AEA)(3)	11157	6.7
Miscellaneous(4)	231	0.1
Total	166204	

(1) Not classified as western airliner turboprops.

(2) Piston-engine aircraft with MTWAs greater than 4.0 tonnes, or making commercial flights: movements are associated with NATS crash location model.

(3) Other piston-engine aircraft with MTWAs less than 4.0 tonnes: movements are associated with AEA light aircraft crash location model.

(4) Unusual aircraft types which could not be readily classified.

TABLE B5

Numbers and percentages of movements by aircraft type at Birmingham in 1994.

Aircraft class	Movements	Percentage
Class I jets	9	0.0
Class II-IV jets	52282	57.3
Executive jets	537	0.6
Eastern jets	139	0.2
Turboprops T1	16626	18.2
Turboprops T2	1008	1.1
Turboprops (unclassified(1))	337	0.4
Piston-engine (NATS)(2)	123	0.1
Piston-engine - Aero club(3)	11132	12.2
Piston-engine - private (AEA)(4)	5352	5.9
Positioning/ local - commercial	1865	2.0
Private(5)	1175	1.3
Others(6)	611	0.7
Total	91196	

(1) Not classified in as western airliner turboprops.

(2) Piston-engine aircraft with MTWAs greater than 4.0 tonnes, or making commercial flights: movements are associated with NATS crash location model.

(3) Piston-engine aircraft with MTWAs less than 4.0 tonnes: movements are associated with AEA light aircraft crash location model.

(4) 82% of private flights classified as piston-engine aircraft with MTWAs less than 4.0 tonnes: movements are associated with AEA light aircraft crash location model

(5) 18% of private flights classified as executive jets and T1 turboprops.

(6) Includes Test and Training, Official and Military flights.

TABLE B6

Numbers and percentages of movements by aircraft type at Leeds Bradford in 1994.

Aircraft class	Movements	Percentage
Class I jets	0	0.0
Class II-IV jets	4914	9.9
Executive jets	143	0.3
Eastern jets	86	0.2
Turboprops T1	14444	29.1
Turboprops T2	3174	6.4
Turboprops (unclassified(1))	60	0.1
Piston-engine (NATS)(2)	154	0.3
Piston-engine - Aero club(3)	16621	33.4
Piston-engine - private (AEA)(4)	5146	10.4
Positioning/ local - commercial	1530	3.1
Private(5)	1129	2.3
Others(6)	2309	4.6
Total	49710	

(1) Not classified as western airliner turboprops.

(2) Piston-engine aircraft with MTWAs greater than 4.0 tonnes, or making commercial flights: movements are associated with NATS crash location model.

(3) Piston-engine aircraft with MTWAs less than 4.0 tonnes: movements are associated with AEA light aircraft crash location model.

(4) 82% of private flights classified as piston-engine aircraft with MTWAs less than 4.0 tonnes: movements are associated with AEA light aircraft crash location model

(5) 18% of private flights classified as executive jets and T1 turboprops.

(6) Includes Test and Training, Official and Military flights.

CRASH LOCATION MODELS USED

C1 This appendix describes the crash location models utilised in the calculation of the individual risk contours.

C2 The fundamental purpose of crash location models is to predict, in the event of an airport-related crash, the probability that the aircraft will crash at any particular location relative to an airport. Since the model is built up from a set of two-dimensional probability density functions, the crash probability is given in terms of probability per unit area.

The NATS model

C3 The NATS model (Ref C1) is defined relative to a single runway, i.e. a runway on which movements occur in one direction only and for which the centre-line and end points are defined. The model produces crash probability densities relative to that runway.

C4 The model consists of a set of four probability density functions (pdfs), each one representing the crash distribution associated with a particular type of crash. Airport related crashes, i.e. those that occur while an aircraft is in an airport related phase of flight or on a take-off or landing run, are divided into four types of crashes for the purpose of the model: landing overruns; landing non-overruns (i.e. crashes from flight); take-off overruns and take-off non-overruns.

C5 Positions are specified relative to the runway in terms of distances along the centreline (the y direction, with positive y being the direction of operations on the runway) and at right angles to the centreline (the x direction).

C6 The origin of the co-ordinate system depends on the type of crash being considered. For landing crashes (both impacts from flight during landing and overruns occurring after landing) the origin of the co-ordinate system is taken as the intersection of the threshold nearer the landing end of the runway and the centreline. For take-off accidents, the origin is the intersection of the threshold nearer the take-off end of the runway and the centreline (see Figure C1 (a) and (b)). The reason for adopting the landing crash origin is that the threshold in use is a reference point common to all landing manoeuvres and so the model should be applicable to landing movements on any landing runway. For take-off crashes the choice of a suitable origin was less obvious but it was found that the ‘take-off threshold’ origin would result in a model which would be the most generally applicable.

C7 For the non-overrun crashes, the pdfs represent the distribution of the point of impact, i.e. the point at which the aircraft impacts the ground from flight. For the overrun crashes, the pdfs represent the wreckage location distributions, i.e.

the position of the main piece of wreckage after a crash. The reasons for adopting this convention are:

(i) for non-overrun crashes more data is available for impact locations than for wreckage locations and the data is more precise, since wreckage can be spread over large areas (impact and wreckage locations are often similar in any case). It was assumed that the larger amount of more precise data would result in a more reliable location model; and

(ii) for overrun accidents, an ‘impact point’ could be defined as the point at which an aircraft leaves the runway. However, this would be of limited utility since the distribution, by definition, would be confined to the runway edge. The wreckage distribution on the other hand is more meaningful since it represents the final locations of aircraft after overrunning.

Note that the above discussion only refers to locations and not the area damaged or destroyed in an accident.

C8 Each pdf is composed of two basic components: a longitudinal crash distribution and a lateral crash distribution. The longitudinal crash distribution gives the distribution of crashes along the extended centreline and is represented by $f_y(y)$. The lateral distribution gives the distribution of crashes with respect to perpendicular distance from the centreline. Since the shape of the lateral distribution in most cases depends on the position along the centreline, it is represented by $f_{x|y}(x,y)$, i.e. the distribution with respect to x *given* the y position. The overall two-dimensional crash pdf is then given in each case by:

$$f(x,y) = f_y(y) f_{x|y}(x,y) \tag{1}$$

C9 The four crash location pdfs are now described separately. In each equation, x and y are in metres, and the probability density is therefore in probability per square metre.

Landing non-overrun crashes

C10 This pdf represents the impact location probability (relative to the threshold at the landing end of the runway) for an accident from a landing phase of flight, given that such an accident has occurred.

$$f_{LI}(x,y) = p f_y(y) f_{x|y}(x,y) \qquad (y>0) \tag{2}$$

$$f_{LI}(x,y) = (1-p) f_y(y) f_{x|y}(x,y) \qquad (y<0) \tag{3}$$

where

$$f_y(y) = ab|y|^{a-1} \exp(-b|y|^a) \qquad \text{for all } y \neq 0 \tag{4}$$

and

$$f_{x|y}(x,y) = gh|x|^{g-1}|y|^{gc}\exp(-h|x|^{g}|y|^{gc})\big/2 \qquad \text{for all } y\neq 0,\ x\neq 0 \tag{5}$$

and the parameter values are:

a = 0.636
b = 0.00620
c = -1.006
g = 0.482
h = 3.156
p = 0.306

Take-off non-overrun crashes

C11 This pdf represents the impact location probability (relative to the take-off end of the runway) for an accident after take-off, given that such an accident has occurred.

For $y > 0$

$$f_{TI}(x,y) = pf_{y}(y)\,f_{x|y}(x,y) \tag{6}$$

where

$$f_{y}(y) = r\exp(-r|y|) \tag{7}$$

and

$$f_{x|y}(x,y) = mn|y|^{mc}\,|x|^{m-1}\exp(-n|y|^{mc}\,|x|^{m})\big/2 \qquad x\neq 0 \tag{8}$$

while for $y \leq 0$

$$f_{TI}(x,y) = (1-p)\,f_{y}(y)\,f_{x|y}(x) \tag{9}$$

where

$$f_{y}(y) = b\exp(-b|y|) \tag{10}$$

and

$$f_{x|y}(x) = gh|x|^{g-1}\exp(-h|x|^{g})\big/2 \qquad x\neq 0 \tag{11}$$

where in each case the parameters are:

b = 0.000769
c = -0.534
g = 0.628
h = 0.0367
m = 0.434
n = 0.615
p = 0.597

r = 0.000769

Landing overrun crashes

C12 This pdf represents the wreckage location probability (relative to the landing end of the runway) for an overrun after landing, given that such an accident has occurred. Note that in this case, y is always greater than zero, since landing overruns, by definition, do not occur before the runway.

$$f_{LO}(x,y) = f_y(y) f_{x|y}(x,y) \qquad (y>0) \qquad (12)$$

where

$$f_y(y) = \frac{y^{a-1} b^a \exp(-by)}{\Gamma(a)} \qquad (13)$$

and

$$f_{x|y}(x,y) = ghy^{gc} |x|^{g-1} \exp(-h|x|^g y^{gc}) / 2 \qquad (14)$$

where the parameters are:

a = 4.306
b = 0.00229
c = 0.558
g = 0.846
h = 0.00145

Take-off overrun crashes

C13 This pdf represents the wreckage location probability (relative to the take-off end of the runway) for an overrun during take-off, given that such an accident has occurred.

$$f_{TO}(x,y) = pf_y(y) f_{x|y}(x,y) \qquad (y>0) \qquad (15)$$

$$f_{TI}(x,y) = (1-p) f_y(y) f_{x|y}(x,y) \qquad (y<0) \qquad (16)$$

where, in both cases

$$f_y(y) = b \exp(-b|y|) \qquad (17)$$

and

$$f_{x|y}(x,y) = k|y|^c \exp(-k|x||y|^c) / 2 \qquad (18)$$

The parameters are, for $y > 0$:

b = 0.00303
c = 0.664
k = 0.000919

p = 0.813

while for $y < 0$ the parameters are

b = 0.000727
c = -0.312
k = 0.123
p = 0.813

AEA Crash Location Model

C14 A model produced by AEA (Ref C2) for the distribution of airport-related crashes for aircraft less than 2.3 tonnes in MTWA was used to model the effect of light aircraft activity on the individual risk. The model was adopted for aircraft with MTWA less than 4.0 tonnes because it was assumed that the traffic patterns for such aircraft would in general be similar to those of aircraft with MTWA less than 2.3 tonnes.

C15 The model used was a pdf which represented the probability of an airport related crash in relation to a given end of a runway. However, the model did not distinguish between take-off and landing crashes, i.e. the pdf modelled the combined effect of take-off and landing crashes.

C16 The co-ordinate system used for this model is a runway based polar system with co-ordinates represented by (r,θ), where r is the distance in kilometres (km) from the end of the runway (i.e. the intersection of the centreline and the threshold nearest the end of the runway in question) and θ is the angle in radians from the extended centreline, zero radians being along the centreline pointing away from the runway (See Figure C1(c)). ($\theta = 0$ corresponds to the positive y direction in the co-ordinate system used for take-off crashes in the NATS model.) In the AEA model the units of probability density are probability per square km.

C17 The crash distribution model adopted for aircraft less than 4.0 tonnes MTWA is:

$$f_{<4.0}(r,\theta) = 0.08\exp(-r/2.5)\exp(-3\theta/\pi) \qquad (18)$$

C18 For multi-runway airports, the models must be applied to each runway in turn before the total probability of a crash at a particular location can be calculated. The final probability values calculated must also take into account the relative occurrence rates for each type of accident and the relative numbers of movements on each runway. Normally the risk at the point is calculated directly using the appropriate crash rates and movement numbers, as explained in Appendix D.

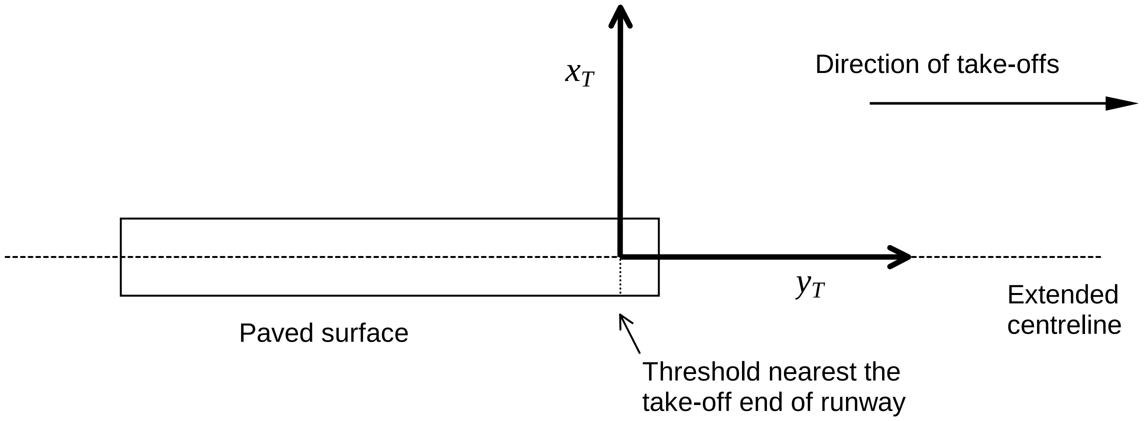
References

C1 Cowell P G et al: A Crash Location Model for Use in the Vicinity of Airports: NATS R&D Report 9705: 1997.

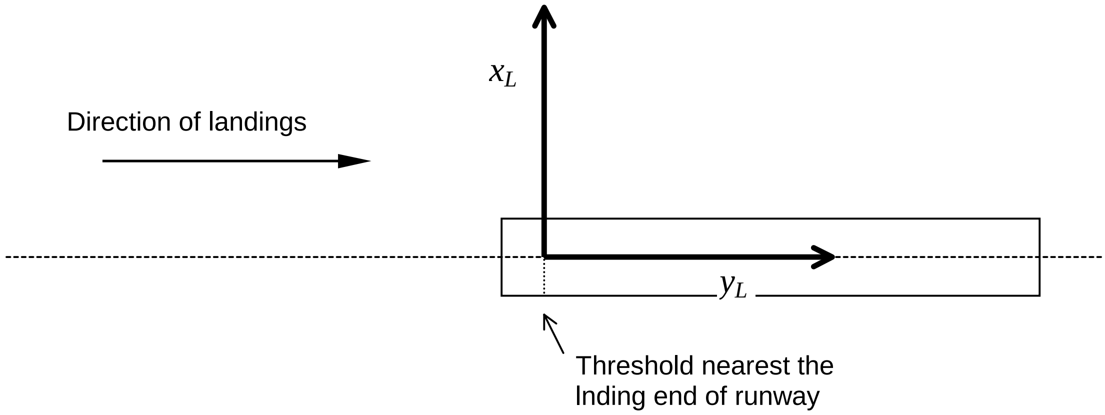
C2 Phillips D W: Criteria for the Rapid Assessment of the Aircraft Crash Rate onto Major Hazards Installations According to Location: SRD/HSE/R435. July 1987.

FIGURE C1

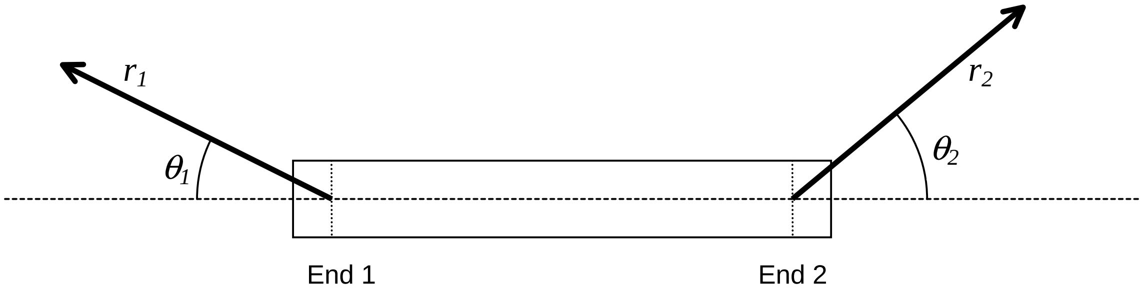
Co-ordinate Systems used for the Crash Location Distributions



(a) Co-ordinate system used for take-off accidents



(b) Co-ordinate system used for landing accidents



(c) Co-ordinate system used for light aircraft accidents

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CONTOUR CALCULATIONS

D1 This Appendix describes the basic method for calculating the individual risk levels and the risk contours due to airport related accidents using the crash distribution model probability density functions.

Crash risk

D2 Since each pdf uses one of two runway based co-ordinate systems, each point on the ground must initially be uniquely referenced with respect to some fixed co-ordinate system. The most useful such system is the Ordnance Survey (OS) grid system, in which each point is referenced by its distance measured in metres east and north from the OS grid origin. The position co-ordinates of a point on the ground in this system are represented here as (E, N). For the purpose of the calculations, the intersections of the runway centrelines and runway thresholds are also specified in the this co-ordinate system; e.g. for Manchester the intersection of the centreline with the threshold nearest the landing end on runway 06 has (E, N) = (380938, 383440).

D3 Before using the crash pdfs, the (E, N) co-ordinates are converted to the appropriate runway co-ordinates, utilising an algorithm which uses the OS co-ordinates of the runway ‘endpoints’ to define the new axes.

D4 Each pdf is specified in relation to a runway based co-ordinate system, as described in Appendix C. If all four crash types are considered for each runway, then two separate co-ordinate systems will be used for that runway, with their origins at the take-off end and landing ends respectively. The co-ordinate system based at the landing end of the runway is used for the NATS landing impact and landing overrun distributions while the other co-ordinate system is used for the NATS take-off crash distributions. These co-ordinates are represented as (x_L, y_L) and (x_T, y_T) for landings and take-offs respectively.

D5 For crashes to aircraft less than 4.0 tonnes MTWA, modelled using the AEA distribution, landings and take-offs are not distinguished. Instead, the total number of movements at each end of the runway are used in calculations. The runway based co-ordinates for such crashes are also obtained from the OS co-ordinates by an appropriate algorithm. In this case the runway ends are numbered 1 and 2, to distinguish the co-ordinates based at each end. That is, the co-ordinates are represented by (r_1,θ_1) and (r_2 θ_2).

D6 The method of calculating the risk at a given location is based on the following equation:

crash risk per unit area per year =
(expected number of crashes at the airport per year)
× (probability of impact per unit area given that a crash has occurred) (1)

The expected number of crashes of a given type is the product of the relevant crash rate and the number of take-offs or landings per year, while the probability of impact is given by the appropriate pdf (a factor of 2 is included since crash rates are defined with respect to the *total* number of movements, ie the *sum* of take-offs and landings). Hence, the risk can be expressed as:

$$\text{Risk}(x, y) = 2.R.M.f(x, y) \tag{2}$$

where

R = crash rate for the crash type (take-off or landing) under consideration
M = number of take-offs or landings per year
$f(x, y)$ = the pdf for the crash type under consideration.

D7 Hence, to calculate the risk at a point (E, N) due to movements on a single runway on which all types of crash can occur, the following sum is performed:

$$\begin{aligned}\text{Risk(E, N)} = {} & 2R_{LI}M_L f_{LI}(x_L, y_L) + 2R_{LO}M_L f_{LO}(x_L, y_L) \\ & + 2R_{TI}M_T f_{TI}(x_T, y_T) + 2R_{TO}M_T f_{TO}(x_T, y_T) \\ & + R_{<4.0}M_{<4.0_1} f_{<4.0}(r_1, \theta_1) + R_{<4.0}M_{<4.0_2} f_{<4.0}(r_2, \theta_2)\end{aligned} \tag{3}$$

where the functions are defined in Appendix C. Crash rates are given by R and movements by M, while for the subscripts, L refers to Landing, T refers to Take-off, I to Impact and O to Overrun. For the less than 4.0 tonne MTWA distribution, 1 and 2 refer to the opposite ends of the runway.

D8 If, during a year, operations can occur in both directions on a runway, then for each point the above calculation is repeated for each direction (the co-ordinate system as well as the movements being different for each direction). More generally, if an airport has m runways, the risk at each point (E, N) is found from:

$$\text{Risk(E, N)} = \text{Risk}_{>4.0}\text{(E, N)} + \text{Risk}_{<4.0}\text{(E, N)} \tag{4}$$

where

$$\text{Risk}_{>4.0}\text{(E, N)} = \sum_{i=1}^{m} \left\{\begin{aligned} & 2R_{LI}M_L^i f_{LI}(x_L^i, y_L^i) + 2R_{LO}M_L^i f_{LO}(x_L^i, y_L^i) \\ & + 2R_{TI}M_T^i f_{TI}(x_T^i, y_T^i) + 2R_{TO}M_T^i f_{TO}(x_T^i, y_T^i)\end{aligned}\right\} \tag{5}$$

and

$$\text{Risk}_{<4.0}\text{(E, N)} = \sum_{i=1}^{m} \left\{R_{<4.0}M_{<4.0_1}^i f_{<4.0}(r_1^i, \theta_1^i) + R_{<4.0}M_{<4.0_2}^i f_{<4.0}(r_2^i, \theta_2^i)\right\} \tag{6}$$

where the superscript *i* refers to runway *i*. For example, (x^i_L, y^i_L) refer to the co-ordinates (E,N) in the co-ordinate system for landings on the *i*th runway, R_{LI} is the landing impact rate, and M^i_L is the number of landings per year on the *i*th runway.

D9 For each of the pdfs the units of risk are, if necessary, converted to numbers of crashes per year per square metre.

Individual risk

D10 The result of the above calculation gives the risk per square metre of a crash at a given location. Clearly, the risk of a third party, at a given location, being struck by aircraft debris is higher than this, since aircraft are generally tens of metres across and the area on the ground destroyed is in general even larger.

D11 To calculate the individual risk, the risk given by equation (4) must be summed over the region in which a crash would result in a fatality at the given point, known also as the lethality area. This area is assumed in this study to be equivalent to the area destroyed by a crash. The lethality area is a parameter statistically derived from the consequence data. Note that in this study the value of this parameter was assumed (after consideration of the statistical analysis) not to depend on the nature of the terrain. The lethality area does depend, however, on the weight of the aircraft involved in the crash.

D12 To calculate the third party risk at a point the sum is evaluated as an integral over the lethality area A. An average lethality area $A_{>4.0}$ was found for the commercial traffic (i.e. > 4.0 tonnes MTWA) using an airport, and a separate lethality area $A_{<4.0}$ was found for light aircraft. The individual risk is represented as:

$$\mathrm{IR}(\mathrm{E},\mathrm{N}) = \int_{A_{>4.0}} \mathrm{Risk}_{>4.0}(\mathrm{E},\mathrm{N})\,dA_{>4.0} + \int_{A_{<4.0}} \mathrm{Risk}_{<4.0}(\mathrm{E},\mathrm{N})\,dA_{<4.0} \qquad (7)$$

where IR(E,N) is the individual risk at the point (E,N).

D13 All of the computations for this study have been carried out on a square grid with the grid points 100m apart, based on the Ordnance Survey grid.

D14 Since all of the calculations are on a square lattice, the lethality region is also modelled as a square, aligned with the grid and equal in area to the lethality area.

D15 The value calculated for each grid point is the individual risk averaged over a 100m square centred on the grid point. The average individual risk for such a grid point is given by:

$$\overline{\mathrm{IR}}_{\mathrm{cell}}(\mathrm{E},\mathrm{N}) = \frac{1}{100^2}\int_{\mathrm{N}-50}^{\mathrm{N}+50}\int_{\mathrm{E}-50}^{\mathrm{E}+50} \mathrm{IR}(\mathrm{E},\mathrm{N})\,d\mathrm{E}\,d\mathrm{N} \qquad (8)$$

where the subscript ‘cell’ refers to the 100m square cell or grid square.

D16 The numerical method employed to evaluate the above integrals was an extension of Gaussian quadrature to two dimensions. For the majority of integrations, where the underlying pdfs were smoothly varying, the integration procedure is very accurate. However, to ensure reliable results in locations near to extended runway centrelines and thresholds, where the pdfs can vary rapidly, the accuracy of the integration procedure was locally enhanced.

D17 The density values given by some of the pdfs at the origin or on the extended centreline were undefined or infinite. Probability density functions may exhibit this property so long as they are correctly normalised (i.e. the integral of the pdf over its range is unity). To avoid computational problems at these locations, the pdfs very close to the these locations were replaced by simple functions, correctly normalised and giving non-zero values.

D18 The end product of the above numerical procedure is a set of OS co-ordinates with an average individual risk associated with each co-ordinate. Contours of equal individual risk are produced by interpolation between the risk values at the grid locations.

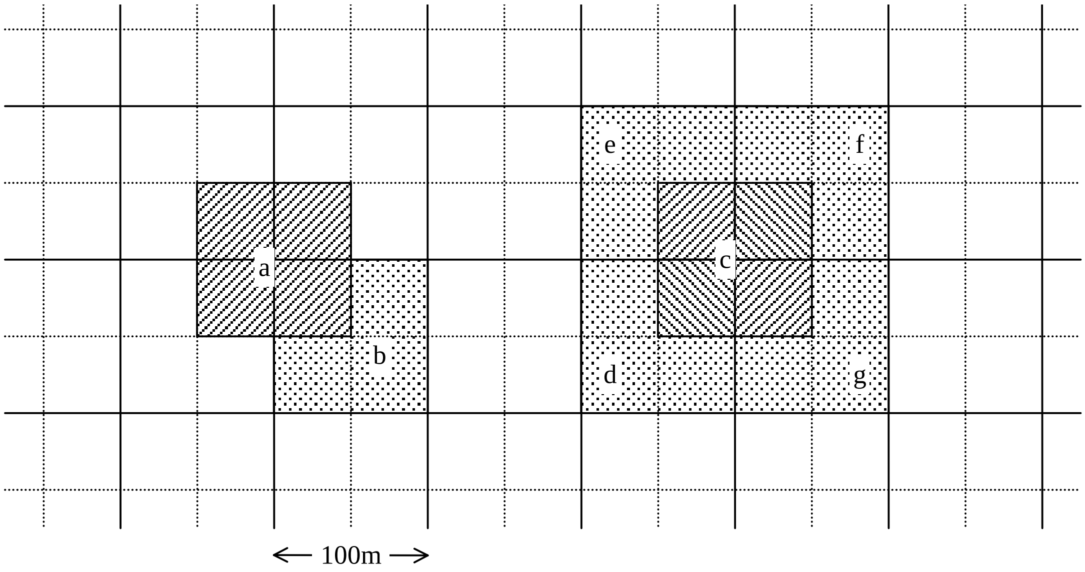
Population and houses exposed to given levels of risk

D19 The population and number of houses located in regions of a given individual risk range was estimated by summing the respective numbers within each 100m square cell centred on OS grid points within the specified risk range.

D20 The number of people and houses at given locations was approximated from files generated from postcode data and population census data. The files available for this study contained data referring to locations spaced 100m apart on the OS grid. It was assumed that the number of people and houses associated with each grid point represented the number within a 100m square centred on the postcode grid point. However, the grid points supplied with the postcode data were offset from the grid points used for the individual risk calculations by 50m (e.g. (E,N) = (876250, 466750)) (See Figure D1).

D21 The numbers of people and houses were actually estimated by assuming that 1/4 of the people and 1/4 of the houses in each of the four 100m postcode squares that touch an individual risk point, were contained in the 100m square over which the individual risk was averaged.

Co-ordinate Systems used for the Crash Location Distributions



Notes:

The solid lines represent the Ordnance Survey grid at 100m risk evaluation intervals. The average individual risk is evaluated at the intersections of the solid lines (point a) and is averaged over a 100m × 100m (1 hectare) square, as shown by the hatched area at a.

Postcode data (number of people and houses in a 1 hectare square) are reported at the intersections of the dashed lines (which are midway between the OS grid lines). An example is square b, the centre co-ordinates of which are at the South East corner of square a.

To estimate the number of people and houses covered by the average individual risk in square c, for example, it is assumed that ¼ of the people and houses in each of the overlapping postcode data squares (d, e, f and g) lie inside square c.

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APPENDIX E

INDIVIDUAL RISK CALCULATIONS USING DIFFERENT CRASH RATES AND CONSEQUENCE MODELS

E1 Chapter 8 described calculations performed to investigate the effects of using alternative crash rates and consequence models. The input data for the calculations are summarised in Tables E1 to E6.

E2 Tables E1 and E2 respectively show the input parameters for the Heathrow calculations using crash rates derived from world-wide (as compared with first world used in the baseline cases) jet and turboprop crashes, and those including major partial accidents in the overrun crash rates.

E3 Table E3 shows the input data for the Heathrow calculations using the published NLR consequence model (Ref E1).

E4 Tables E4 and E5 show the input data for the Manchester calculations involving higher values for non-SP crash rates and the inclusion of major partial loss accidents in the overrun crash rates respectively.

E5 Table E6 describes the input for the calculation which investigates the effect of reducing the consequence area for light aircraft (from 0.06 hectares to 0.01 hectares). The calculation is for Leeds Bradford which has the highest proportion of light aircraft of the five airports studied.

Reference

E1 Piers M A, Loog M P et al: The Development of a Method for the Analysis of Societal and Individual Risk due to Aircraft Accidents in the Vicinity of Airports: National Aerospace Laboratory: Netherlands: NLR CR 93372 L: November 1993.

TABLE E1

Heathrow Airport - Input Parameters for Individual Risk Calculations Using World-wide SP Jet and Turboprop Crash Rates

Movements on runways(1)

	09L	27R	09R	27L
Landings	57529	70461	5696	78007
Take-offs	0	76542	63225	71925
Grand total	423385(2)			

Crash rates (3)

	Crashes	Overruns	Total
Landings	0.226	0.088	0.314
Take-offs	0.086	0.037	0.123
Totals	0.312	0.125	0.437

Average area destroyed (per aircraft impact) = 0.49 hectares

(1) Proportions on runways based on six year average from 1990 to 1995; westerly:easterly ratio of movements = 70:30.
(2) Total 1994 movements from Table 6.4.
(3) Per million movements (movements = total of landings + take-offs).

TABLE E2

Heathrow Airport - Input Parameters for Individual Risk Calculations Using Overrun Crash Rates which Include Major Partial Accidents

Movements on runways(1)

	09L	27R	09R	27L
Landings	57529	70461	5696	78007
Take-offs	0	76542	63225	71925
Grand total	423385(2)			

Crash rates (3)

	Crashes	Overruns	Total
Landings	0.087	0.092	0.179
Take-offs	0.033	0.037	0.070
Totals	0.120	0.129	0.249

Average area destroyed (per aircraft impact) = 0.48 hectares

(1) Proportions on runways based on six year average from 1990 to 1995; westerly:easterly ratio of movements = 70:30.
(2) Total 1994 movements from Table 6.4.
(3) Per million movements (movements = total of landings + take-offs).

TABLE E3

Heathrow Airport - Input Parameters for Individual Risk Calculations Using NLR Model for Destroyed Area(1)

Movements on runways(2)

	09L	27R	09R	27L
Landings	57529	70461	5696	78007
Take-offs	0	76542	63225	71925
Grand total	423385(3)			

Crash rates (4)

	Crashes	Overruns	Total
Landings	0.087	0.034	0.121
Take-offs	0.033	0.014	0.047
Totals	0.120	0.048	0.168(5)

Average area destroyed (per aircraft impact) = 0.68 hectares

(1) Destroy area = 200 m^2/tonne; lethality = 0.30

(2) Proportions on runways based on six year average from 1990 to 1995; westerly:easterly ratio of movements = 70:30.

(3) Total 1994 movements from Table 6.4.

(4) Per million movements (movements = total of landings + take-offs).

(5) Average crash rate (associated with NATS crash location model) from Table 6.4.

TABLE E4

Manchester Airport - Input Parameters for Individual Risk Calculations Using Overrun Crash Rates which Include Major Partial Accidents

Movements on runways(1)

	Runway	
	06	24
NATS model		
Landings	14111	63412
Take-offs	14111	63412
AEA light aircraft model		
Landings + take-offs	5579	5579
Grand total	166204(2)	

Crash rates (3)

NATS model	**Crashes**	**Overruns**	**Total**
Landings	0.128	0.121	0.249
Take-offs	0.048	0.048	0.096
Total	0.176	0.169	0.345
AEA light aircraft model			
Total	3.000(4)		

Average area destroyed (per aircraft impact):

(i) associated with NATS crash model	= 0.31 hectares
(ii) associated with AEA light aircraft model	= 0.05 hectares

(1) Proportions on runways based on six year average from 1990 to 1995; westerly:easterly ratio of movements = 82:18.
(2) Total 1994 movements from Table 6.6.
(3) Per million movements (movements = total of landings + take-offs).
(4) Crash rate, associated with AEA light aircraft model, from Table 6.6.

TABLE E5

Manchester Airport - Input Parameters for Individual Risk calculations using crash rates which assume non-scheduled passenger jet operations involve higher crash rates than scheduled passenger jet operations (by a factor of two)

Movements on runways(1)

	Runway	
	06	24
NATS model		
Landings	14111	63412
Take-offs	14111	63412
AEA light aircraft model		
Landings + take-offs	5579	5579
Grand total	166204(2)	

Crash rates (3)

NATS model	**Crashes**	**Overruns**	**Total**
Landings	0.150	0.058	0.208
Take-offs	0.057	0.024	0.081
Total	0.207	0.082	0.289
AEA light aircraft model			
Total	3.000(4)		

Average area destroyed (per aircraft impact):

(i) associated with NATS crash model = 0.32 hectares
(ii) associated with AEA light aircraft model = 0.05 hectares

(1) Proportions on runways based on six year average from 1990 to 1995; westerly:easterly ratio of movements = 82:18.
(2) Total 1994 movements from Table 6.6.
(3) Per million movements (movements = total of landings + take-offs).
(4) Crash rate, associated with AEA light aircraft model, from Table 6.6.

TABLE E6

Leeds Bradford Airport - Input Parameters for Individual Risk Calculations Using Reduced light aircraft Destroy Area(1)

Movements on runways(2)

	Runway			
	32	14	28	10
NATS model				
Landings	9780	4193		
Take-offs	9780	4193		
AEA light aircraft model				
Landings + take-offs	5041	5041	5841	5841
Grand total	49710(3)			

Crash rates (4)

NATS model	**Crashes**	**Overruns**	**Total**
Landings	0.283	0.110	0.393
Take-offs	0.107	0.046	0.153
Total	0.390	0.156	0.546(5)
AEA light aircraft model			
Total	3.000(6)		

Average area destroyed (per aircraft impact):

(i) associated with NATS crash model = 0.20 hectares
(ii) associated with AEA light aircraft model = 0.01 hectares

(1) 0.01 hectares as opposed to 0.06 hectares in baseline calculations.
(2) Proportions on runways based on estimates supplied by Leeds Bradford airport.
(3) Total 1994 movements from Table 6.8.
(4) Per million movements (movements = total of landings + take-offs).
(5) Average crash rate, associated with NATS model, from Table 6.8.
(6) Crash rate, associated with AEA light aircraft model, from Table 6.8.

191THE TOLERABILITY OF THIRD PARTY RISK AND THE VALUE OF RISK REDUCTION NEAR AIRPORTS

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APPENDICES

1. INTRODUCTION

1.1 This survey, which was part of a larger study of Public Safety Zones (PSZs) around airports commissioned by the Department of Transport (Evans *et al.* 1997), was intended:

a) to explore attitudes to risk tolerability limits on the part of people living near airports;

b) to examine the relativity between the preference-based value of preventing a third party fatality in a "small-scale" (light aircraft) accident on the one hand, and the corresponding value for preventing a road fatality on the other;

c) to examine the relativity between the preference-based values of preventing third party fatalities in large and small-scale aircraft accidents.

1.2 The exploration of people's attitudes to tolerability limits is an area where there is a paucity of empirical work. However, the illustrative example of the application of constrained cost-benefit analysis to PSZs given in Evans *et al.* (1997) indicates the potential importance of the role played by tolerability limits, and it is therefore necessary to examine these attitudes. This was done by presenting each participant in a number of focus groups with a short series of questions involving different magnitudes of increased third-party risk, and eliciting for each in turn some indication of the amount of money the participant would regard as adequate compensation for bearing that extra risk, with a view to identifying the point at which nothing less than a fully-compensated relocation to a safer area would be acceptable. Although this point should normally be reached at something less than the tolerability limit strictly defined (i.e. defined as the level of risk for which no finite sum of money would be adequate compensation), in the context of the present study, the point at which nothing less than relocation would be acceptable would appear to be a good operational basis for determining tolerability limits with respect to third-party aviation risks.

1.3 In the case of relativities between preference-based values of safety in different contexts, there is rather more existing empirical work to draw upon. In particular, the "small-scale third party vs roads" and the "large-scale vs small-scale" relativities were investigated using variants of the so-called "matching" questions employed by the authors in a study of the valuation of Underground safety relative to road safety. Essentially, matching questions seek to establish the number of fatalities that respondents would require one particular safety programme to prevent in order for that programme to be judged "equally as good as" an alternative programme (of the same cost and duration) that would be expected to prevent some given number of fatalities in a different setting.

1.4 One such question addressed the issue of context by comparing a progamme aimed at preventing a number of third-party fatalities resulting from separate small-scale aircraft incidents with an alternative programme intended to prevent a number of road traffic fatalities. Responses to this latter question were intended to establish the basic relativity between the value of preventing third-party aviation fatalities and the DoT's value for the prevention of a road fatality. A second question controlled for context and focused on the issue of scale by comparing a programme aimed at preventing a number of third-party fatalities resulting from separate small-scale aircraft incidents with an alternative programme intended to prevent a single large-scale incident involving multiple fatalities. The purpose of this question was to establish the existence/absence of a premium related to scale *per se*.

1.5 Our reason for focusing on relative values - rather than attempting to determine willingness to pay/accept for third-party risk directly - is that previous experience with direct contingent valuation (CV) questions has suggested that when the risk magnitudes are very small, the implied value of statistical life can appear implausibly large, with estimates liable to vary unduly, depending on the particular size of risk change presented to respondents (see Ives *et al.* 1995, page 153). In addition, in the case of third-party aviation risks, the authors were not optimistic that it would be easy to devise CV questions that would isolate preferences for safety from considerations of noise and nuisance.

1.6 To some extent, these difficulties might also have been a factor in our attempts to probe the tolerability issue, but in this context they were arguably less pernicious, since we were here trying to distinguish between different orders of magnitude as the location of a threshold, rather than trying to provide a particular estimate of the value of statistical life.

1.7 Moreover, our experience suggested that these difficulties would not beset the matching questions to anything like the same extent. In work for London Underground and MAFF, where the baseline risks were very small, matching questions seemed able to deliver reliable and robust estimates of relativities, in the sense that both pilot and main studies produced very similar results. Of course, reliability is not the same thing as "truth", but in this field there is no external objective "gold standard" against which these estimates can be judged.

1.8 Our decision to organise the fieldwork via focus groups of 5-6 participants reflected two main considerations. First, the focus group format encourages discussion of key issues and gives respondents the opportunity to explore the kinds of factors that might influence their concerns about various risks: for example, considerations of voluntariness, control, responsibility, the scale of incidents, and so on. Second, even if we had wished to collect all the data via (say) one-to-one interviews (which we did not), the timescale and budget for the survey would not have permitted this.

2. FIELDWORK

2.1 Following a pilot study at Newcastle airport, the main study fieldwork was conducted at three sites: Gatwick (7th, 8th and 9th May); Leeds-Bradford (14th, 15th and 16th May); and Luton (21st and 22nd May). On each evening, two focus groups were convened. The 7.00 p.m. groups consisted of respondents aged between 18 and 40, while the 8.30 p.m. groups consisted of respondents over the age of 40. Six people were recruited for each group by Wilson Research Consultancy, using quota guidelines intended to produce groups each consisting of three males and three females representative of the local socioeconomic spectrum. As requested by the Steering Group, respondents were recruited from a good spread of areas in the vicinity of each airport, with no more than two members of any group being employed at the airport.

2.2 Out of the total of 96 people recruited, there were 7 “no-shows”, so that the actual sample size was 89: 45 males and 44 females in ten groups of 6, five groups of 5 and one group of 4.

2.3 All focus groups followed essentially the same format. After a general introduction, the moderator (GL) took each group through the questionnaire, one question at a time: that is, he read through the question with them, took any points of clarification, asked them to write their answer(s) in their questionnaire, and then encouraged them to discuss the answers given to that question. It was made clear at the outset that if, in the light of points raised during the discussion, any respondent wished to modify any of their answers, they should feel free to do so.

3. RESULTS

3.1 This section reviews the responses to each question in the order in which it appears in the questionnaire, a copy of which is appended to this report. Also appended to the report are a set of Tables showing all responses to each question.

3.2 Questions 1 and 2 were essentially “warm-up” questions, intended to encourage respondents to give thought to different levels of risk which would be utilised in Question 3, which was the question about tolerability.

3.3 **Question 1** asked respondents to consider four potential causes of premature death - accidental electrocution, road accidents, domestic fires, and an aircraft crashing into where they live or work - and to rank them according to their perceptions of which hazards were more or less likely to threaten their lives during the next 10 years.

3.4 The great majority of respondents (82 out of 87, two missing responses) identified road accidents as presenting the highest probability of premature death, while almost as many (75 out of 87) identified an aircraft crashing into their home or place of work as the least probable of the four potential causes of death. There was less agreement about the relative risks presented by accidental electrocution and domestic fires: 22 thought that they were more at risk from accidental electrocution, 47 considered that domestic fire represented the greater risk to them, and 18 felt about equally at risk from both hazards.

3.5 **Question 2** then asked respondents to consider each hazard in turn, and to express a view about how their personal risk of death from that cause stood *relative to the average for the population of Britain as a whole*. In order to arrive at a judgement, it was suggested that for the hazard under consideration they might think about which types of people are most at risk, which types are least at risk, and whereabouts they stand on the spectrum between these two extremes.

3.6 They were invited to answer in whatever form they felt most comfortable with - i.e. either verbally or numerically. Most used some form of words - “slightly above average”, “a lot below average”, etc.; but a proportion attempted to quantify their judgement.

3.7 Generally, the reasons advanced for their judgements in the ensuing discussion seemed appropriate, and exhibited a reasonable grasp of relevant risk factors. However, given that all respondents were drawn from the vicinity of fairly (and in the case of Gatwick, very) busy airports, it might be thought surprising that fewer than half - 42 out of 88, with 1 missing response - regarded themselves as being above average in terms of the risk of an aircraft crashing into where they live or work, compared with the average for the British population as a whole. Of the rest, 27 felt that their risk was about average, while 19 judged themselves to be at less than the average risk.

3.8 From what was said, two explanations could be put forward to account for these latter, apparently implausible, judgements. First, a number of respondents may not have been envisaging the population as a whole, but may have been focusing on a more local reference population. Second, many perceived the risk to be a very small one indeed, and it could well be harder to conceive of one’s risk as being appreciably higher than average when it is actually felt to be almost imperceptible.

3.9 However, the discussion associated with this element of Question 2 often led quite nicely into Question 3, which was the principal objective of the first part of the questionnaire.

3.10 **Question 3** involved a more lengthy explanation than any other question, and was undoubtedly fairly challenging, so GL spent some time fleshing out the scenario.

Respondents were introduced to the general notion of mapping out zones around an airport where the probabilities of crashes could be expected to be higher than for other areas. Then, having been reassured that there were no plans for major changes at their airport in the near future, respondents were asked to imagine a situation where certain changes in the volume of traffic and the landing and take-off arrangements might cause the zones to be redrawn in such a way that their homes now fell inside one of the higher risk zones.

3.11 Both forms of compensation were explained, but respondents were asked to focus on compensation in the form of an annual payment to households who remained in a zone rather than opting to be relocated. They were then asked to consider four zones - E, F, G and H - where the risk of an aircraft crashing into their home became progressively higher. An overhead transparency was displayed reproducing the Question 3 grid and table of values, and above each column E to H the appropriate average risk was added: 1 in 1,000,000 for zone E (corresponding to the approximate average annual risk of death from accidental electrocution); 1 in 100,000 for zone F (the approximate average annual risk for death in a fire); 6 in 100,000 for zone G (average annual risk of road fatality); and 60 in 100,000 - also written as 6 in 10,000 - for zone H (average annual risk of death or serious injury on the roads).

3.12 By combining historical frequency data with respondents’ own perceptions about their relative exposure to various “everyday” hazards - a variant of what is sometimes known as the “risk ladder” method - we sought to give respondents some reasonable feel for the broad order of magnitude of risks in the various zones.

3.13 GL then demonstrated on the overhead transparency various ways in which people with differing attitudes might express these attitudes in the columns of the grid. To be specific, columns F - H were covered, in order to focus initially on zone E where the risk was 1 in 1,000,000. GL explained that someone who considered a risk of 1 in 1,000,000 to be “too small to worry about”, and who would therefore accept whatever annual compensation payment was offered, should simply put a tick in the first row - and such a tick was added in green pen to the transparency. By contrast, someone who would reject lower amounts of compensation - and opt for relocation instead - should put crosses against the amounts that would not be acceptable; but, working down the column, should put a tick against the minimum amount that *would* be adequate to compensate for the risk. This type of response was demonstrated in blue on the overhead. Finally, someone who would not accept any amount up to and including £5,000 per year should indicate this by putting crosses from top to bottom (or a cross at the top and at the bottom, connected by a line through the column); and this way of responding was illustrated in red on the transparency.

3.14 Respondents were then asked to enter their responses for zone E, and then work progressively through zones F to H. When all had finished, there was a discussion about the various ways in which different people had responded. This helped some people to clarify any misunderstanding, and prompted several to modify their responses, or make it clearer on the page what they intended to convey.

3.15 There is no doubt that this *was* a demanding exercise, and although most people coped well, some did not: apart from one respondent who understood the question but objected to the notion of money payments to individuals to compensate for imposed risks of death, there were 7 others altogether whose responses could not be interpreted unambiguously, and who therefore were entered as “missing values” for this question. Thus overall there were 81 useable sets of responses to this question.

3.16 Before discussing the pattern of responses in more detail, it may be worth reviewing the rationale behind this question. Bearing in mind what was said in Chapter 7 of the Stage 1 Report about “constrained cost-benefit analysis”, the objective was to see whether some "tolerability limit" could be established which would indeed constrain the analysis in the manner discussed in the Stage 1 Report.

3.17 Strictly speaking, an individual's tolerability limit should be defined as the level of risk for which *no finite sum* would be acceptable as compensation. But for practical purposes, in the context of PSZs, this limit may be regarded as being the point at which nothing less than a fully-compensated relocation to a safer area would be acceptable. Moreover, given that the average house price in England and Wales is currently about £64,000, and given the current level of interest rates, a fully compensated relocation would, on average, not be expected to exceed an amount that would generate a (net of tax) annuity of roughly £5000. Hence rejection of that level of annual compensation can be regarded as a good operational basis for determining tolerability limits with respect to third-party aviation risks of death. The supposition in the Stage 1 Report was that the tolerability limit would be in the region of 10^{-4}.

3.18 At the other end of the spectrum, standard economic theory would suggest that, all other things being equal, even very small marginal increases in the risk of death would diminish individuals' wellbeing to *some* degree, so that some non-zero amount of compensation would be required to offset this reduction in wellbeing. However, for practical purposes it is often supposed that there is some level below which this reduction in wellbeing can be regarded as too small to merit action, and in the Stage 1 Report it was conjectured that this level might be about 10^{-6}. Question 3 was designed to examine this conjecture too.

3.19 In the Table below, the 81 useable responses for each zone are divided into three categories: Too Small To Worry About; Requiring Compensation (£50 - £5,000 inclusive); Requiring Relocation (effectively intolerable).

Zone + Average Risk	Too Small To Worry About	Requiring Compensation	Requiring Relocation
Zone **E**: 1 in 1,000,000	47	29	5
Zone **F**: 1 in 100,000	13	52	16
Zone **G**: 6 in 100,000	6	39	36
Zone **H**: 60 in 100,000	1	20	60

3.20 It would be surprising if data generated by a random sample of people conformed precisely with two dividing lines at 10^{-4} and at 10^{-6}; but if one wanted a simple approximation, those upper and lower cut-off points organise the data fairly well. Of course, one should not ignore the fact that at risk levels closer to 10^{-3} a quarter of the sample were still willing to accept compensation. But against that, one might argue that if the risks were real rather than hypothetical, rather greater aversion might be expected. However, if that argument is applied at the other end of the spectrum, where more than 40% either require compensation or relocation when the hypothetical risk is 10^{-6}, it could point to something closer to half that risk - i.e. 5×10^{-7} - as being the level of real third-party risk where the loss of wellbeing would be regarded as negligible by the great majority of members of the public.

3.21 In summary, the data from Question 3 suggest that a risk of 10^{-5} (Zone F) lies squarely in the compensatable region, with approximately two-thirds of the sample deeming some compensation necessary, and the remaining one-third split more or less equally between those who said that the risk was too small to worry about, and those who said that they would require relocation. And while there are no very sharp upper and lower cut-off levels, allowing for some "hypothetical bias" might well point to 10^{-4} as a reasonable upper bound on tolerability. By the same token, it might be unwise to assume that anything less than 10^{-6} would be too small to worry about: in the context of third-party risks of the kind being considered here, a figure closer to 5×10^{-7} might be more appropriate.

3.22 **<u>Question 4</u>** was primarily intended to prepare the way for the "matching" exercise in Question 5 involving road safety and safety of people on the ground from light aircraft crashes. Question 4 therefore presented respondents with four propositions - which, it was explained, were typical of diverse *opinions* expressed by members of the public in earlier discussions - and invited them to indicate their agreement or disagreement. Those propositions, together with the total numbers responding in each of the five possible ways, are reproduced below.

I. Being killed in a road accident is a worse way to die than being killed on the ground by a crashing aircraft.

J. People have some control over their own safety on the roads, but they have no control over the risk of being killed on the ground by a crashing aircraft.

K. The authorities must bear most of the responsibility for protecting members of the public from aircraft accidents, but they have less responsibility for road safety.

L. Road accidents are much more often due to human error than aircraft accidents. It is more important to try to protect people from being the victims of other people's errors than to try to protect them from "natural" mechanical failures.

Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I	9	32	31	14	3
J	1	9	3	58	18
K	14	31	7	30	7
L	7	18	14	41	5

(4 missing values for Question L)

3.23 In response to Question I, a number of people who circled "Neutral" said that this indicated that they felt both ways of dying were equally bad; but some others who felt this way circled "Disagree", since they were disagreeing with the proposition that a road accident death was actually worse. We cannot tell from this question alone what proportion of people felt that being killed by a crashing aircraft was strictly worse, but it is clear that only a minority (about 20%) felt that death by road accident was intrinsically a worse prospect.

3.24 As might be expected, the great majority (85%) thought that people had more control over their own safety on the roads. But note that this does not translate directly into a view that the authorities have less responsibility for road safety than for protecting members of the public from aircraft accidents: indeed, although about 40% agreed with the proposition in Question K, 50% disagreed with it. Part of the reason may be suggested by the responses to Question L: although individuals may have more control over their own safety on the roads, they may also be more vulnerable to human error (often referred to in discussion in terms of other people's errors - the "lunatics out there"), and feel that the authorities have a role to play protecting them from this. It is worth noting, however, that there was at least some verbally expressed doubt or dissent from the notion that aircraft accidents - especially those involving light aircraft - were predominantly due to "natural" mechanical failure: pilot error in particular was thought to be a factor in a number of cases.

3.25 Had time allowed, it would have been interesting to have explored these and other "roads vs aviation" issues more fully. However, under the constraints of this study, Question 4 was really only intended to raise some of the possible reasons why road safety and the safety of people on the ground *might* be treated differently, prior to answering the relevant "matching" question which followed.

3.26 As explained above, matching questions ideally aim to establish the number of fatalities respondents would require one particular safety programme to prevent in order for that programme to be judged "equally as good as" an alternative programme (of the same cost and duration) that would be expected to prevent some given number of fatalities in a different context.

3.27 **Question 5** sought to achieve this objective in the following way. Respondents were asked to consider a Project M which would, over a period of 25 years, be expected to prevent 25-30 deaths of people on the ground as a result of light aircraft accidents, and to compare it with a Project N which would use the same amount of money to target road accident fatalities. The light aircraft scenario was chosen in order to control for the scale of the incident, i.e. to make the number of fatalities in any one fatal accident roughly similar - typically, 1, 2 or 3 - in both contexts. Respondents were asked to suppose that there was not enough money to undertake both projects simultaneously, so that one would have to be given precedence over the other.

3.28 To begin with, they were asked to consider the case where both projects were expected to prevent the same number (25-30) of fatalities, and to indicate, by ticking one of the three boxes on the left-hand side of the page, whether under these circumstances they would (i) not mind which project was chosen, or (ii) prefer the aviation project to be given precedence, or (iii) favour the road project.

3.29 The responses of those who ticked (i) are recorded in the Table appended to this Report as 27.5, this being the mid-point in the 25-30 range. Those who ticked (ii) were asked to consider how they would feel if the road project were expected to prevent *more* than 25-30 deaths; and in particular, to indicate at which point they would switch their preference to Project N. These responses are also recorded in the Table as the middle values in the ranges circled as being the point at which the switch would occur (with the "more than 60" response being recorded as 65.5). Analogously, those who ticked (iii) were asked to consider how they would react if the road project were expected to prevent *fewer* than 25-30 deaths by circling the range where they would switch their preference to Project M. Again, middle values are shown in the Table, with "fewer than 5" being denoted by 2.5. The overall pattern of responses is summarised below.

<5	**5-14**	**15-24**	**25-30**	**31-40**	**41-50**	**>50**
8	6	28	26	5	7	9

3.30 It is tempting to suppose that the appropriate way in which to interpret data of this type is to divide the individual responses by 27.5 and then regard the arithmetic mean of the resultant ratios as providing the basis for deriving an estimate of the premium (or discount) for the value of statistical life (VOSL) for light aircraft crashes relative to the VOSL for road accident victims. Unfortunately matters are not so straightforward. To see why, consider a highly simplified example involving just three respondents whose answers to question 5 are 55, 27.5 and 11 respectively. Dividing these responses by 27.5 and then taking the arithmetic mean of the resultant ratios gives 1.13, suggesting that for this sample the VOSL for light aircraft crash victims should stand at a 13% premium in relation to the corresponding VOSL for road fatalities. But now take the geometric mean of the ratios instead. This gives 0.93, implying a discount of 7% for the light aircraft VOSL relative to its roads counterpart. In turn, it is clear that the median response entails that the two VOSL's should be equal. In fact it turns out that the question of which central tendency measure to apply to data such as this is quite subtle - for a discussion of some of the key issues see the Appendix to Jones-Lee and Loomes,1995. Essentially, the question can be definitively answered for any particular data set only if one has access to more detailed information concerning the preferences of individual respondents than it was possible to establish within the timescale and budget of this study. For this reason, and in view of the difficulty of obtaining precise estimates in an area such as this, we believe that it would be inappropriate to attempt to arrive at a hard and fast quantitative premium or discount from the responses to Question 5 and that the data should instead be regarded as being indicative rather than definitive. In this spirit we would offer the following observations.

3.31 When both projects would prevent the same number of fatalities, just under 30% of respondents did not mind which one was chosen. Of the rest, those favouring the road project outnumbered those favouring the avaiation project by 2 to 1, although almost half of these said they would switch to the aviation project if the road project would only save 20-24 lives. Thus, while there is evidence that preventing deaths on the roads has an edge over preventing deaths among people on the ground from light aircraft crashes, it is only a slight edge, and is probably insufficient, given the spread of responses, to justify using a different - and lower - value of statistical life (VOSL) for light aircraft crash victims on the ground than for road accident victims.

3.32 **Question 6** attempted to prepare the ground for the Question 7 matching exercise, where this time the focus was on small vs large aircraft accidents. Once again, the four propositions are reproduced below, followed by a summary of the responses and some discussion.

P. Large aircraft accidents are probably more often due to mechanical failure, whereas smaller aircraft accidents probably have a bigger element of human error. It is more important to try to protect people on the ground from being the victims of other people's errors than to try to protect them from "natural" mechanical failures.

Q. 25-30 deaths of people on the ground as a result of a single large aircraft accident is worse than 25-30 people on the ground being killed in a number of separate smaller accidents.

R. The experts probably have a pretty good idea about the causes of smaller aircraft accidents and the number of people on the ground likely to be killed in such accidents during the next 25 years, but they have much less idea about the chances of large aircraft accidents and the number of people on the ground likely to be killed in this type of accident during the same 25-year period.

S. You can be pretty sure that if you spend more money trying to prevent smaller aircraft accidents, fewer of them will occur. But however much you spend trying to prevent large aircraft accidents, it probably won't make much difference: in some cases, they might not have happened anyway, and in other cases, some freak set of circumstances may still cause them to occur.

Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
P	5	25	19	40	0
Q	9	29	27	23	1
R	2	20	29	33	4
S	5	27	12	41	2

(1 missing value for Question R, 2 for Question S)

3.33 Generally speaking, the pattern of agreement and disagreement for these propositions tend to favour preventing fewer large accidents rather than more smaller ones, and for those tend to favour small over large, suggests that opinion was fairly evenly balanced in this respect. And this conclusion is further supported by responses to the subsequent matching task.

3.34 **Question 7** asked respondents to consider a Project X which would be expected, on average, to prevent one large aircraft accident during the next 25 years which in turn would be expected, on average, to prevent 25-30 people on the ground being killed in that accident. The alternative use for the same amount of money would be a Project Y, aimed at reducing the number of lighter aircraft accidents during the same 25-year period.

3.35 As in the earlier matching exercise, the first stage was for respondents to consider the case where both projects were expected to prevent the same number of fatalities, and to tick one of the three boxes on the left-hand side of the page, depending on whether, under these circumstances, they would (i) not mind which project was chosen, or (ii) prefer the single large accident to be prevented, or (iii) favour the prevention of a number of separate smaller accidents. As before, those ticking either (ii) or (iii) were asked to go on and identify a point where some differential in the number of lives saved would cause them to switch their preference to the other project. The overall pattern was as follows.

<5	5-14	15-24	25-30	31-40	41-50	>50
1	7	16	36	16	1	12

3.36 While precisely the same caveats apply to the interpretation of these results as were noted in the case of the responses to Question 5, we believe that the following observations are pertinent.

3.37 Apart from a group of 8 respondents who favoured Project X so strongly that they would require Project Y to prevent more than 60 deaths before they would switch to it, the rest of the distribution looks broadly symmetrical, with just over 40% of respondents ticking box (i), while 32% and 27% ticked boxes (ii) and (iii) respectively. So although the apparent strength of preference among that group of 8 would suggest, overall, a slight tendency towards a higher VOSL for large-scale relative to smaller-scale incidents, the effect is not pronounced. Thus, when this pattern of responses is combined with the pattern exhibited in Question 5, the conclusion is much the same as the one drawn from the Pilot Study, namely that preventing deaths among people on the ground as a result of aircraft crashes should not be valued markedly differently from preventing road accident deaths.

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APPENDIX 1

RESPONSES TO THE QUESTIONNAIRE

Question 1

Idno	**A**	**B**	**C**	**D**		Idno	**A**	**B**	**C**	**D**
1	1	3	2	4		**46**	2.5	1	2.5	4
2	3	1	2	4		**47**	3	1	2	4
3	3	1	2	4		**48**	3	1	2	4
4	3	1	2	4		**49**	4	1	3	2
5	2	1	3	4		**50**	3	1.5	1.5	4
6	x	x	x	x		**51**	3	1	3	3
7	x	x	x	x		**52**	2.5	1	2.5	4
8	3	1	2	4		**53**	3	1	2	4
9	3.5	1	2	3.5		**54**	3	1	2	4
10	3	1	2	4		**55**	3.5	1	3.5	2
11	2	1	3	4		**56**	2.5	1	2.5	4
12	4	1	3	2		**57**	2.5	1	2.5	4
13	2.5	1	2.5	4		**58**	2	1	3	4
14	2	1	3	4		**59**	4	1	2	3
15	2	1	3	4		**60**	2	1	3	4
16	2	1	3	4		**61**	2	1	3	4
17	2	1	3	4		**62**	3	1	2	4
18	2.5	1	2.5	4		**63**	2	1	3	4
19	2	1	3	4		**64**	3	1	2	4
20	4	1	3	2		**65**	2	1	3	4
21	3	1	2	4		**66**	3	1	2	4
22	4	1	2	3		**67**	2.5	1	2.5	4
23	4	1	2	3		**68**	3	1	2	4
24	2.5	1	2.5	4		**69**	2.5	1	2.5	4
25	3	1	2	4		**70**	3	1	2	4
26	3	1	2	4		**71**	3	1	2	4
27	2.5	1	2.5	4		**72**	3	1	2	4
28	2	1	3	4		**73**	1	2	3	4
29	3	1	2	4		**74**	3	1	2	4
30	2.5	1	2.5	4		**75**	3	1	2	4
31	3	1	2	4		**76**	2	2	2	4
32	3	1	2	4		**77**	3	1	4	2
33	2.5	1	2.5	4		**78**	2.5	1	2.5	4
34	3	1	2	4		**79**	4	1	3	2
35	3	1	2	4		**80**	3	2	1	4
36	3	1	2	4		**81**	3	1	2	4
37	3	1	2	4		**82**	2	1	3	4
38	2	1	3	4		**83**	4	1	3	2
39	2	1	3	4		**84**	2.5	1	2.5	4
40	2.5	1	2.5	4		**85**	3	1	2	4
41	2	1	3.5	3.5		**86**	3	1	2	4
42	3	1	2	4		**87**	1	2	3	4
43	3	1	2	4		**88**	3	1	2	4
44	2	1	3	4		**89**	3	1	2	4
45	3	1	2	4						

Idno = individual identifying number; x = uninterpretable answer

Question 2

Idno	**A**	**B**	**C**	**D**		Idno	**A**	**B**	**C**	**D**
1	>ave	>ave	<<ave	>>ave		**46**	<ave	>ave	<ave	>ave
2	<ave	ave	ave	<<ave		**47**	0.6	1.6	ave	ave
3	1.5	ave	ave	100.0		**48**	<ave	>ave	<ave	<ave
4	<ave	>ave	ave	>ave		**49**	>>ave	>ave	ave	>ave
5	ave	>ave	<ave	>ave		**50**	0.2	0.75	3.0	2.0
6	x	x	x	x		**51**	ave	ave	<ave	>ave
7	ave	ave	>ave	>ave		**52**	<ave	<ave	<ave	>ave
8	0.1	ave	ave	1.3		**53**	0.01	0.25	0.1	ave
9	0.5	ave	ave	1.1		**54**	ave	>ave	>ave	ave
10	<ave	>ave	<ave	>ave		**55**	<ave	>>ave	ave	<ave
11	<ave	>ave	ave	>ave		**56**	<ave	ave	<ave	>ave
12	ave	>ave	ave	>ave		**57**	ave	ave	<ave	ave
13	>ave	>ave	ave	>ave		**58**	ave	3.0	<ave	ave
14	ave	ave	<ave	>>ave		**59**	ave	ave	>ave	ave
15	>ave	ave	<ave	<ave		**60**	>ave	ave	ave	ave
16	>ave	>ave	<ave	ave		**61**	>ave	ave	<<ave	ave
17	ave	ave	<ave	>ave		**62**	<ave	ave	>ave	ave
18	ave	>ave	ave	<ave		**63**	0.4	2.5	ave	2.0
19	ave	ave	ave	>ave		**64**	ave	ave	>ave	ave
20	<ave	>ave	<ave	ave		**65**	1.4	1.6	0.6	ave
21	>ave	>>ave	<ave	>ave		**66**	<ave	<ave	<ave	<<ave
22	<ave	ave	ave	>ave		**67**	ave	1.5	ave	1.5
23	<ave	>ave	ave	>>ave		**68**	1.2	1.4	ave	0.8
24	0.2	0.5	0.6	0.7		**69**	<ave	ave	>ave	>ave
25	<ave	>ave	<<ave	>ave		**70**	<<ave	ave	<ave	<<ave
26	<ave	3.0	<ave	ave		**71**	<ave	ave	<ave	ave
27	3.0	2.0	ave	5.0		**72**	<ave	>ave	ave	<<ave
28	0.5	0.67	0.25	0.67		**73**	ave	ave	ave	>ave
29	<ave	>>ave	>ave	<ave		**74**	<ave	>ave	ave	<<ave
30	ave	>ave	ave	<ave		**75**	<ave	>ave	<ave	>ave
31	<ave	ave	ave	ave		**76**	ave	ave	ave	ave
32	<ave	>>ave	ave	<<ave		**77**	<ave	ave	<ave	<ave
33	>ave	>>ave	ave	>ave		**78**	0.9	ave	0.9	3.0
34	<ave	>>ave	ave	>ave		**79**	<ave	<ave	ave	>>ave
35	ave	ave	ave	ave		**80**	>ave	ave	ave	>ave
36	<ave	ave	<ave	ave		**81**	<ave	>ave	<ave	<ave
37	<ave	>>ave	<ave	ave		**82**	<ave	>ave	<ave	>ave
38	<ave	<ave	<<ave	ave		**83**	<ave	ave	ave	>ave
39	>ave	>ave	<ave	ave		**84**	ave	ave	<ave	<ave
40	0.33	1.5	0.2	0.01		**85**	ave	<ave	ave	ave
41	ave	4.0	0.75	2.0		**86**	<ave	ave	<ave	ave
42	0.5	3.0	ave	2.0		**87**	>ave	ave	<ave	>ave
43	<ave	<ave	<ave	ave		**88**	0.1	ave	>ave	>ave
44	2.0	3.0	0.5	ave		**89**	0.1	<ave	ave	ave
45	ave	>ave	ave	>ave						

Idno = individual identifying number; x = uninterpretable answer;
>, >> = above, very much above; <, << = below, very much below.

Question 3

Idno	**E**	**F**	**G**	**H**		Idno	**E**	**F**	**G**	**H**
1	NOA	NOA	NOA	NOA		**46**	250	500	9999	9999
2	0	500	1000	9999		**47**	500	3000	9999	9999
3	0	500	1000	9999		**48**	0	250	500	1000
4	2000	3000	9999	9999		**49**	0	0	9999	9999
5	0	2000	9999	9999		**50**	0	100	1000	2000
6	x	x	x	x		**51**	1500	1500	3000	5000
7	x	x	x	x		**52**	3000	9999	9999	9999
8	x	x	x	x		**53**	0	0	9999	9999
9	0	0	0	0		**54**	0	0	9999	9999
10	1000	2000	9999	9999		**55**	250	500	1000	2000
11	4000	9999	9999	9999		**56**	4000	9999	9999	9999
12	5000	5000	5000	5000		**57**	0	1000	5000	9999
13	0	500	1000	2000		**58**	9999	9999	9999	9999
14	0	0	0	2000		**59**	0	1500	9999	9999
15	1500	500	4000	9999		**60**	0	9999	9999	9999
16	0	2000	4000	9999		**61**	500	1000	9999	9999
17	3000	5000	5000	5000		**62**	0	0	0	9999
18	5000	5000	5000	9999		**63**	0	3000	9999	9999
19	9999	9999	9999	9999		**64**	1000	2000	9999	9999
20	x	x	x	x		**65**	1000	250	9999	9999
21	9999	9999	9999	9999		**66**	100	100	2000	9999
22	0	1000	5000	9999		**67**	0	500	2000	9999
23	0	1000	1500	9999		**68**	0	500	2000	9999
24	2000	9999	9999	9999		**69**	0	0	0	9999
25	0	9999	9999	9999		**70**	0	0	100	500
26	0	100	2000	9999		**71**	0	9999	9999	9999
27	250	500	2000	9999		**72**	0	250	9999	9999
28	250	3000	5000	9999		**73**	0	250	500	1500
29	500	2000	1000	1500		**74**	0	100	250	1500
30	x	x	x	x		**75**	500	9999	9999	9999
31	500	1000	5000	9999		**76**	0	0	9999	9999
32	0	1000	3000	5000		**77**	9999	9999	9999	9999
33	0	500	4000	9999		**78**	0	1500	4000	9999
34	0	2000	9999	9999		**79**	0	0	5000	9999
35	0	100	250	2000		**80**	0	250	1500	9999
36	3000	9999	9999	9999		**81**	500	2000	9999	9999
37	0	1500	9999	9999		**82**	1000	9999	9999	9999
38	0	9999	9999	9999		**83**	0	250	1000	2000
39	0	2000	9999	9999		**84**	9999	9999	9999	9999
40	0	1000	2000	9999		**85**	x	x	x	x
41	1000	1500	9999	9999		**86**	4000	4000	4000	4000
42	0	1000	2000	4000		**87**	0	0	0	9999
43	0	0	1500	9999		**88**	x	x	x	x
44	250	500	500	2000		**89**	0	0	0	1500
45	0	1000	1500	2000						

NOA = No answer; x = uninterpretable answer; 9999 = would not accept £5000.

Questions 4 and 5

Idno	**I**	**J**	**K**	**L**	**Q5**		Idno	**I**	**J**	**K**	**L**	**Q5**
1	1	4	1	1	27.5		**46**	4	5	2	1	27.5
2	3	4	4	4	27.5		**47**	3	5	1	2	33
3	3	4	2	4	27.5		**48**	2	4	2	3	7
4	3	4	4	3	2.5		**49**	2	4	2	4	2.5
5	3	4	4	4	55.5		**50**	2	4	4	2	65.5
6	3	4	3	4	22		**51**	2	4	4	3	65.5
7	3	2	4	3	22		**52**	4	4	2	4	27.5
8	3	4	3	4	48		**53**	4	4	1	4	22
9	3	4	4	4	22		**54**	3	4	1	x	27.5
10	3	5	3	5	27.5		**55**	5	5	4	4	55.5
11	4	5	4	2	48		**56**	2	4	4	4	48
12	3	4	4	4	22		**57**	3	4	2	2	55.5
13	3	4	4	4	7		**58**	2	4	2	4	12
14	3	4	2	3	22		**59**	2	4	4	4	22
15	2	5	2	4	17		**60**	2	2	2	2	27.5
16	2	5	1	3	22		**61**	3	4	2	2	12
17	3	4	3	2	43		**62**	5	4	1	4	17
18	4	5	3	4	2.5		**63**	1	2	1	3	22
19	3	5	5	1	22		**64**	3	4	2	2	27.5
20	1	3	5	4	27.5		**65**	1	2	2	2	27.5
21	2	3	4	1	27.5		**66**	1	4	2	5	17
22	3	2	4	2	17		**67**	2	4	4	x	27.5
23	2	4	3	3	22		**68**	2	4	4	4	27.5
24	3	4	1	4	22		**69**	2	4	2	4	27.5
25	2	4	2	2	22		**70**	3	3	4	4	48
26	4	5	5	4	27.5		**71**	2	5	1	1	27.5
27	2	5	5	5	2.5		**72**	4	5	4	4	2.5
28	3	4	4	4	17		**73**	3	4	2	3	27.5
29	4	4	5	3	17		**74**	3	4	1	3	2.5
30	4	4	3	4	7		**75**	3	4	2	4	33
31	2	4	2	4	2.5		**76**	4	4	5	x	27.5
32	4	2	2	4	27.5		**77**	2	4	4	4	33
33	5	2	2	4	55.5		**78**	1	5	5	2	17
34	3	4	2	2	65.5		**79**	2	4	4	4	38
35	1	4	4	2	22		**80**	4	5	2	2	65.5
36	2	4	2	3	22		**81**	3	5	4	4	33
37	4	4	2	4	22		**82**	2	2	1	4	2.5
38	3	4	2	4	27.5		**83**	3	4	4	x	22
39	2	4	4	4	55.5		**84**	2	4	4	3	27.5
40	2	4	4	5	7		**85**	2	5	2	4	43
41	2	4	1	2	17		**86**	3	2	2	4	22
42	2	5	4	2	27.5		**87**	2	4	2	3	22
43	2	4	2	2	27.5		**88**	1	4	4	5	17
44	4	4	2	4	43		**89**	2	4	1	1	27.5
45	1	1	1	1	27.5							

1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree.
In Question 5, all entries are mid-points of ranges, except 2.5 = ‘Fewer than 5’ and 65.5 = ‘More than 60’.

Questions 6 and 7

Idno	**P**	**Q**	**R**	**S**	**Q7**		Idno	**P**	**Q**	**R**	**S**	**Q7**
1	1	1	2	1	27.5		**46**	2	2	2	1	12
2	4	3	4	4	27.5		**47**	2	1	4	2	2.5
3	4	4	4	4	27.5		**48**	4	2	4	4	27.5
4	3	2	4	4	27.5		**49**	3	4	3	4	27.5
5	2	4	4	4	55.5		**50**	2	1	4	2	17
6	3	3	3	4	38		**51**	3	3	4	5	22
7	4	3	4	4	65.5		**52**	2	2	4	2	27.5
8	4	3	3	4	55.5		**53**	3	4	5	4	65.5
9	4	3	4	4	27.5		**54**	2	3	4	4	22
10	1	4	4	1	27.5		**55**	2	3	3	4	17
11	3	4	2	4	33		**56**	3	3	3	3	27.5
12	3	3	3	4	55.5		**57**	2	2	3	x	22
13	3	2	2	4	33		**58**	4	2	2	2	12
14	3	4	2	3	65.5		**59**	4	4	3	4	27.5
15	4	2	3	2	65.5		**60**	2	1	1	2	65.5
16	4	3	4	4	12		**61**	3	4	3	4	7
17	2	3	x	3	27.5		**62**	4	2	2	2	38
18	4	3	3	3	65.5		**63**	2	4	5	2	38
19	1	3	3	3	33		**64**	2	1	2	2	27.5
20	4	4	4	4	27.5		**65**	2	2	3	4	17
21	2	2	4	3	27.5		**66**	2	4	5	2	22
22	4	3	2	4	22		**67**	2	2	3	2	17
23	4	3	4	2	33		**68**	4	2	3	4	17
24	4	4	4	4	38		**69**	2	3	3	x	27.5
25	4	4	3	2	27.5		**70**	4	2	3	4	65.5
26	4	3	4	4	27.5		**71**	1	1	3	2	27.5
27	3	2	2	4	33		**72**	2	2	2	4	27.5
28	4	4	4	1	27.5		**73**	3	2	3	3	27.5
29	4	3	2	4	27.5		**74**	2	2	3	2	27.5
30	4	3	3	3	33		**75**	4	4	4	2	38
31	4	3	4	4	48		**76**	4	4	4	4	38
32	4	3	4	2	27.5		**77**	4	3	4	4	33
33	4	1	3	2	55.5		**78**	2	4	2	1	33
34	2	2	4	4	12		**79**	3	4	4	4	22
35	2	4	2	4	27.5		**80**	3	2	2	3	7
36	3	2	2	2	27.5		**81**	4	3	4	4	33
37	4	2	4	5	17		**82**	4	2	3	4	27.5
38	4	3	2	2	27.5		**83**	4	3	4	4	22
39	4	2	4	4	65.5		**84**	2	4	3	3	27.5
40	4	2	2	2	12		**85**	4	5	4	4	22
41	1	2	1	2	27.5		**86**	4	4	2	2	27.5
42	3	4	5	2	27.5		**87**	3	2	4	2	17
43	2	2	3	4	27.5		**88**	4	1	3	2	27.5
44	4	3	2	3	17		**89**	3	2	3	2	27.5
45	2	1	3	3	33							

1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree.
In Question 7, all entries are mid-points of ranges, except 2.5 = ‘Fewer than 5’ and 65.5 = ‘More than 60’.

APPENDIX 2

THE SAFETY QUESTIONNAIRE

SAFETY QUESTIONNAIRE

We have asked you here this evening as part of a research project aimed at learning more about how members of the public feel about various safety issues.

IN THE QUESTIONS THAT FOLLOW THERE ARE NO 'RIGHT' ANSWERS.

WE WOULD LIKE TO HEAR WHAT *YOU PERSONALLY* THINK AND FEEL ABOUT THE VARIOUS ISSUES WE SHALL DISCUSS.

Most people would like more safety. But most of us also want more of other things too - such as decent homes, food and clothes, rewarding jobs, quick and convenient transport, adequate health care, a good education service, and so on.

So choices have to be made. How much should be spent on safety rather than on other things? And which safety improvements should be given higher priority?

Quite a lot of public money is spent on safety, so it is important to take account of how members of the public feel about safety issues. This questionnaire aims to find out:

1. What factors **you** think should matter when deciding how public money is to be spent on safety.

2. When it comes to **your own safety**, what balances **you** would strike.

Question 1

Let us begin by considering 4 different ways in which people may be killed prematurely.

We should like you to think which of these presents the biggest risk **to you personally** during the next 10 years, which one presents the next biggest risk **to you**, and so on. That is, if you think your chances of dying during the next 10 years as a result of accidental electrocution are *higher* than your chances of dying as a result of any of the other three, indicate this by putting a **1** in the Risk Rating box next to **A**. However, if you think your chances of dying during the next 10 years as a result of accidental electrocution are *lower* than your chances of dying as a result of any of the other three, indicate this by putting a **4** in the Risk Rating box next to **A**.

If there are any two or more cases where you think your chances are about the same, give them the same Risk Rating number, and put an equals sign alongside each of those numbers.

	Risk Rating
A: Accidental electrocution.	
B: A road accident	
C: A domestic fire	
D: An aircraft crashing into where you live or work	

Question 2

Now we should like to know how you think *your* chances of dying during the next 10 years from each of those 4 types of risk *compare with the average* risk for members of the British population.

Consider each one in turn, and give each one a Relative Risk Score by writing in the right hand column.

For example, if you think your chances of dying during the next 10 years as a result of accidental electrocution are three times as high as the average in Britain, simply write **three times** in the Relative Risk Score box next to **A**. On the other hand, if you think your chances of dying during the next 10 years as a result of accidental electrocution are only a tenth of the average, put **one tenth** in the Relative Risk Score box next to **A**. If you find it difficult to put a number on it, write in words what best expresses your judgement - for example, **slightly below average**, or **quite a bit above average**.

Then move on to consider how your risk of being killed in a road accident compares with the average for the population as a whole. And so on for all four types of risk.

	Relative Risk Score
A: Accidental electrocution	
B: A road accident	
C: A domestic fire	
D: An aircraft crashing into where you live or work	

Question 3

In this question, we should like to focus on one of the types of risk you have just been considering.

Suppose that the growing volume of air traffic and changes in landing and take-off arrangements put some people on the ground at greater risk of being killed as a result of an aircraft accident. Suppose also that the authorities plan to compensate these people and their households in both of two ways:

1. There would be full compensation for any loss of property value if and when someone sells their property and leaves the higher-risk zone.

2. As long as a household remains in the zone, it would receive an annual payment as compensation for bearing the increased risk. If any household considers that the amount offered is not sufficient to compensate its members for bearing the extra risk, they can exercise the option of being relocated, free of charge, to an equivalent property outside the higher-risk zone, with a lump-sum payment to cover all inconvenience and removal expenses. Exercising this option effectively means that, after the relocation, household members would be in the same position - in terms of quality of life and level of risk - as they are now.

We should like you to focus on the second of these forms of compensation. Below, we ask you to suppose that the chance of an aircraft crashing into your house is increased by various different amounts, and in each case we should like you to tell us what annual amounts of compensation would or would not be acceptable for you and your household to remain where you are and bear the extra risk. (Remember that if the compensation offered is lower than the amount you state, the conclusion is that you would be relocated, free of charge, to an equivalent property outside the higher-risk zone.) For each case in turn, please indicate on the facing page whether or not you would find any particular amount of annual compensation acceptable.

Suppose that the changes mean that the chances of an aircraft crashing into your house become the same as:

E: Your chances of dying from accidental electrocution.

F: Your chances of dying in a domestic fire.

G: Your chances of being killed in a road accident.

H: Your chances of being killed or seriously injured in a road accident
(about ten times bigger than G).

Question 3 continued

If you definitely would **not** find a particular amount of annual compensation acceptable, please put a **cross**.

If you are **not sure** whether you would find a particular amount of annual compensation acceptable, please put a **question mark**.

If you definitely **would** find a particular amount of annual compensation acceptable, please put a **tick**.

£	**E**	**F**	**G**	**H**
Too small to worry about				
50				
100				
250				
500				
1000				
1500				
2000				
3000				
4000				
5000				
More than 5000				

Question 4

The following four statements make comparisons between the risks from aircraft crashes and the risks from road accidents. For each one in turn, please indicate how far you agree or disagree by circling one of the options.

I. Being killed in a road accident is a worse way to die than being killed on the ground by a crashing aircraft.

Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

J. People have some control over their own safety on the roads, but they have no control over the risk of being killed on the ground by a crashing aircraft.

Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

K. The authorities must bear most of the responsibility for protecting members of the public from aircraft accidents, but they have less responsibility for road safety.

Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

L. Road accidents are much more often due to human error than aircraft accidents. It is more important to try to protect people from being the victims of other people’s errors than to try to protect them from ‘natural’ mechanical failures.

Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

Question 5

Suppose that the Department of Transport has two different projects under consideration. (Each project would cost the same amount of money.)

Project M would aim to reduce the number of accidents involving smaller aircraft which can cause 1, 2 or 3 deaths among people on the ground. As a result, over the next 25 years Project M would be expected to prevent 25-30 deaths among people on the ground.

Project N would aim to reduce the number of road accidents.

However, suppose that there are not enough resources available at present to undertake both projects, so a choice has to be made. Please indicate your preference by putting a tick against one of the statements below. If you tick either **(ii)** or **(iii)**, please go on to circle the option that best expresses how you feel.

(i) If Project N was expected to prevent 25-30 deaths in road accidents during the next 25 years, **I would not mind which one of the two projects was chosen**.

(ii) If Project N was expected to prevent 25-30 deaths in road accidents during the next 25 years, **I would prefer to see Project M chosen**. However, I would switch to Project N if it was expected to prevent

31-35

36-40

41-45

46-50

50-60

More than 60 deaths

Please circle the point at which you would switch from M to N

(iii) If Project N was expected to prevent 25-30 deaths in road accidents during the next 25 years, **I would prefer to see Project N chosen**. However, I would switch to Project M if it turned out that Project N would only prevent

20-24

15-19

10-14

5-9

Fewer than 5 deaths

Please circle the point at which you would switch from N to M.

The next question asks about the two main types of aircraft accident which cause loss of life among people on the ground.

The first type is when a *large* aircraft hits a row of houses, or a building containing a number of people - a factory, office block, hotel, railway station, or suchlike. Such accidents are more rare, but when they occur, they might be expected to cause, on average, about 25-30 deaths among people on the ground. Of course, sometimes this number could be lower - maybe as low as 1 or 2 if the accident happens at a time when there are few people in the buildings. On the other hand, if the accident happens when there are more people in the buildings, the number killed might be as high as 50-60.

The second type of accident involves a *smaller* aircraft hitting a single house, or doing *some* damage to a factory, office block, hotel, or suchlike. Such accidents are rather less rare, and on average each one could cause 1, 2 or 3 deaths among people on the ground.

So the essential difference is that the less common large aircraft accident may kill quite a number of people on the ground at the same time, while the smaller aircraft accidents may kill just 1, 2 or 3 people, but they occur more frequently.

Thinking just about these two types of accident, please consider each of the four statements on the facing page and for each in turn, indicate how far you agree or disagree by circling one of the options.

Question 6

P. Large aircraft accidents are probably more often due to mechanical failure, whereas smaller aircraft accidents probably have a bigger element of human error. It is more important to try to protect people on the ground from being the victims of other people’s errors than to try to protect them from ‘natural’ mechanical failures.

Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

Q. 25-30 deaths of people on the ground as a result of a single large aircraft accident is worse than 25-30 people on the ground being killed In a number of separate smaller accidents.

Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

R. The experts probably have a pretty good idea about the causes of smaller aircraft accidents and the number of people on the ground likely to be killed in such accidents during the next 25 years, but they have much less idea about the chances of large aircraft accidents and the number of people on the ground likely to be killed in this type of accident during the same 25-year period.

Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

S. You can be pretty sure that if you spend more money trying to prevent smaller aircraft accidents, fewer of them will occur. But however much you spend trying to prevent large aircraft accidents, it probably won’t make much difference: in some cases, they might not have happened anyway, and in other cases, some freak set of circumstances may still cause them to occur.

Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

Question 7

Suppose that the authorities responsible for air safety have two different projects under consideration. (Each project would cost the same amount of money.)

Project X would be expected to prevent *one* large aircraft accident happening sometime during the next 25 years. So *on average*, Project X would be expected to prevent about 25-30 deaths among people on the ground, although the actual number might vary, depending on when the accident would have happened and how many people would have been in the buildings.

Project Y would reduce the number of accidents involving smaller aircraft. How many deaths Project Y would prevent among people on the ground would depend on how effective it was in reducing the number of these accidents.

However, suppose that there are not enough resources available at present to undertake both projects, so a choice has to be made. Please indicate your preference by putting a tick against one of the statements below. If you tick either **(ii)** or **(iii)**, please go on to circle the option that best expresses how you feel.

(i) If Project Y was expected to prevent 25-30 deaths among people on the ground during the next 25 years, **I would not mind which one of the two projects was chosen**.

(ii) If Project Y was expected to prevent 25-30 deaths among people on the ground during the next 25 years, **I would prefer to see Project X chosen**.

However, I would switch to Project Y if it was expected to prevent

31-35

36-40

41-45

46-50

50-60

More than 60 deaths

Please circle the point at which you would switch from X to Y

(iii) If Project Y was expected to prevent 25-30 deaths among people on the ground during the next 25 years, **I would prefer to see Project Y chosen**. However, I would switch to Project X if it turned out that Project Y would only prevent

20-24

15-19

10-14

5-9

Fewer than 5 deaths

Please circle the point at which you would switch from Y to X.