Study of the extent of exposure to low flying military aircraft noise in the United Kingdom

FINAL REPORT

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Study objectives

It has been suggested that noise caused by low flying military aircraft might contribute to adverse non-auditory health effects in exposed populations. The scientific evidence in support of a direct linkage between this type of noise exposure and adverse health outcomes over the long term is very weak, but it has not so far been possible to provide a completely convincing demonstration that there is no such linkage. The primary objective for this study was to investigate the feasibility of carrying out a large scale prospective epidemiological comparison of exposed and non-exposed populations in the UK to provide definitive data on this issue. An essential first step was to estimate the extent of exposure to low flying miltary aircraft noise over the population as a whole to determine the availability of suitable exposed and non-exposed populations for study. A secondary objective was to carry out calculations of the statistical power of alternative study designs using the observed exposure distributions.

Research tool development

The UK low flying system encourages the widest possible distribution of flight tracks over all those areas of the country which are not specifically designated as avoidance areas. In addition, there are no centrally kept records of actual flight tracks to the level of precision which would be required to determine actual noise exposure on the ground. This means that it was necessary to develop an innovative set of research tools to integrate flight routing statistics, noise calculation algorithms and small area population statistics using a Geographic Information System (GIS) and other software systems to achieve the study objectives. These research tools were tested in an initial trial of a 50 km by 50 km preliminary study area, and reasonable assumptions were then made to allow for extrapolation to the rest of the UK.

Conclusions

The main conclusions drawn from the work to date can be summarised as follows;

- The available input data and the research tools which have been developed during the study are capable of providing robust estimates of the extent of exposure to low flying military aircraft noise in the United Kingdom.

- There are approximately 390,000 residents in the overflyable parts of the Vale of Evesham initial study area. This figure probably represents between 1/10 and 1/20 of the total overflyable population of the UK. Of these 390,000, many thousands are potentially exposed (when at home) to significant overflight noise levels several times per day. This degree of noise exposure is sufficient to justify the future work programme proposals set out below:

- Initial estimates of the sample size required to carry out a definitive study are of the order of 20,000 to 24,000 persons interviewed at the outset, to leave of the order of 12,000 to 13,000 persons remaining in the study at the end of the five year study period.

Future work

A large number of assumptions were made in arriving at the initial estimates of the extent of exposure in the Vale of Evesham study area, in extrapolating these results to the rest of the UK and in estimating the required sample size to be able to carry out a definitive epidemiologic study. These assumptions should be tested under a future work programme before proceeding with the pilot studies for the full scale epidemiologic study. A detailed work programme is outlined in the body of the report, but the main features are as follows;

- Extend the GIS model to the entire UK.
- Extend the available low flying information to the entire UK.
- Conduct field monitoring exercises to validate the low flying route assumptions.
- Further develop the Monte Carlo flight track modelling technique.
- Further develop the population surface model for rural areas.
- Carry out further statistical power calculations with the refined data.
- Consider the detailed design and protocols for a pilot epidemiologic study.

Introduction

Military low flying

Current United Kingdom, United States, and Canadian military tactics include flying at high speeds at very low altitudes over enemy territory to increase the element of surprise and thus enhance survivability. Low flying aircraft cannot be detected by air defence units on the ground until they are very close. The maintenance of low flying skills requires an extensive low flying training programme. Unfortunately, low flying high speed military aircraft can generate high maximum noise levels (L_{Amax}) over short durations at points on the ground within a few hundred metres on either side of the flight track. In addition, the noise level time history often exhibits a rapid onset, such that there is little warning of a low flying high speed approach. Short duration high noise levels often lead to a startle response, particularly where the noise event is unexpected. The effect is normally increased by a rapid stimulus onset time. Startle is associated with immediate cardiovascular, hormonal, and other autonomic responses and can lead to increased annoyance. Startle can also lead to direct physical consequences on rare occasions such as, for example, falling off a ladder after being startled.

Possible hearing damage risk

It is well known that prolonged exposure to continuous high level noise can lead to noise induced hearing loss, but the risk of hearing damage caused by occasional overflights by military aircraft is very small. The UK Ministry of Defence have imposed restrictions on the heights and speeds at which military aircraft are permitted to fly to ensure that noise levels on the ground do not exceed 125 dBA. The risk of instantaneous or traumatic hearing damage at this noise level is so low as to be considered either non-existent or at least so rare that it has not featured in the medical literature. The risk of noise induced hearing loss after an extended period of exposure to several events of this magnitude per day is also very low, as the cumulative noise dose is still quite small in comparison to the type of cumulative noise dose caused by continuous noise which is associated with noise induced hearing loss in industrial situations. The 125 dBA maximum noise limit is not exceeded under normal circumstances and most overflights in practice give lower maximum noise levels. The highest maximum noise levels are only reached where the noisiest types of aircraft fly directly overhead at the lowest permitted altitudes and at the highest permitted speeds. In addition, people on the ground underneath flight tracks are often indoors, or otherwise protected, leading to lower maximum noise levels at the ear on most occasions.

Taken together, these points indicate that the risk of hearing damage caused by occasional exposure to high speed low flying military aircraft noise in the general case must therefore be considered negligible. Hearing damage risk is not further considered in this report, although the measurement of the extent of exposure over the population as a whole is pertinent to the assessment of risk.

Non-auditory health effects

It has been suggested that low flying military aircraft noise might contribute to the aetiology of long term non-auditory health problems on the basis of some kind of direct linkage between possible short term effects on the autonomic system and long term damage. The amount of acoustical energy which is directly transmitted to the body by even a high noise level low flying military aircraft is only a fraction of a watt for an equivalent duration of one second or less and there is no possibility that such a small amount of physical energy could directly lead to structural change in the tissues through some mechanism of physical disruption. This means, that to be plausible, the hypothetical mechanism for long term adverse health effects must be associated with the biological response to the sound stimulus. In theory, it is possible that transient effects on blood pressure or other autonomic system variables might lead to permanent change if repeated often enough. However, the most plausible mechanism for long term health effects would appear to be the possibility of chronic psychological stress associated with the annoyance caused by unwanted events leading to long term health problems in certain individuals.

Individual differences

Large differences in individual susceptibility to possible long term health effects can be expected, particularly in terms of the psychological stress hypothesis. This is because psychological stress depends on personality, attitudes, and annoyance, and there is a wide range of annoyance response to the same noise stimulus. In addition, there are many other individual and environmental factors which might contribute to the aetiology of any long term health effects which might otherwise have been associated with low flying military aircraft noise. This means that any future investigation addressed to the possible link between low flying military aircraft noise and long term health effects must be very carefully designed to take individual differences and confounding variables into account. There is a general consensus that a large scale prospective epidemiologic study carried out by comparing the development of a small number of key health variables over time in exposed and non-exposed populations is the method of choice. Large sample populations are necessary to obtain statistically significant results, particularly in this type of study where there are large individual differences in the different health variables in the normal population; where there are a large number of potential confounding variables; and where the expected relative risk ratio (a measure of the ratio of the increased risk of adverse health effects in an exposed population as compared to the risk of adverse health effects in a non-exposed population) is quite small.

The prospective epidemiologic study

In view of this uncertainty, the UK Ministry of Defence, the United States Air Force, and the Canadian Department of National Defense have been taking steps towards carrying out a prospective epidemiological study in the UK to investigate the matter properly. The UK was selected as the study area because the population density in overflown areas is much greater than in the USA or Canada. After lengthy discussions concerning the best way to progress towards an eventual epidemiological study, the Institute of Sound and Vibration Research and the Department of Social Statistics at the University of Southampton were commissioned to carry out a study to determine the size of the exposed population in the UK; to identify potential study sites for a proposed long term prospective epidemiological study; and to carry out preliminary calculations of the statistical power of alternative study designs using the observed exposure distributions.

Pre-requisites for an epidemiologic study

Advice from the Medical Research Council Environmental Epidemiology Unit at Southampton confirmed that some knowledge of the extent of exposure across the population as a whole and the distribution of exposed populations on the ground was an essential pre-requisite to being able to determine the feasibility of designing any such long term epidemiological study. The expected low relative risk ratio means that large population samples would be required to give statistically meaningful results. The geographical distribution of the sample population has a significant effect on the resources required to carry out the study. The low population densities in overflyable areas increases the costs and difficulty of access to individual residents, and significantly restricts the proportion of study sites where calculated estimates of the physical noise exposure can be validated against field measurements. Finally, it is important to be able to identify control areas which include populations with otherwise similar characteristics to the noise exposed populations except that they are only rarely or never overflown. This requires a detailed understanding of the long term pattern of low flying in each study area, the effects of this pattern in terms of noise exposure on the ground, and the interaction of this pattern with the geographical distribution of the population on the ground.

Detailed population statistics are necessary to allow for the proper selection and control matching of individual participants in the study.

Geographic Information System approach

There has been no requirement in the past in the UK to maintain a comprehensive database of flight tracks as flown to the level of accuracy that would be required to allow for an accurate retrospective determination of noise exposure on the ground. Similarly, there has been no requirement in the past for a comprehensive field study of noise exposure on the ground which would allow for extrapolation to the rest of the country. This meant that the first step was to consult as widely as possible within the UK MoD to determine the quality and amount of available information and records which could be used towards the overall assessment. The nature of this information then determined the approach to the rest of the study. It was soon realised that there was no possiblity of being able to determine the extent of exposure on a precise, flight by flight, basis. The study team therefore turned to the use of a PC based Geographic Information System to allow the available and somewhat coarse flight routing statistics to be integrated with the geographically referenced avoidance area information which is now published as digitised aeronautical charts. The selection of the most appropriate Geographic Information System and the resulting data collection took up a considerable proportion of the available resources, which meant that the eventual scope of the study was limited to firm estimates of the extent of exposure in an initial study area only, with extrapolation to the remainder of the UK.

The study team

The University of Southampton was selected for this study because the Institute of Sound and Vibration Research and the Department of Social Statistics have the necessary research skills for working on this type of problem and have considerable experience of working together on similar multi-disciplinary projects. In addition, the range of related facilities at or around the University of Southampton constitutes a unique combination of expertise in related issues. For example, the Medical Research Council Environmental Epidemiology Unit is based at Southampton. The staff of this unit were consulted on a number of occasions when planning the study, to ensure that the results would be of maximum utility for epidemiologic assessment. The Department of Geography at Southampton have developed the population surface model used in the statistical analysis. The main offices of the Ordnance Survey (the official UK mapping organisation) are also based at Southampton. The staff at the Institute of Sound and Vibration Research have developed a close working relationship with the National Physical Laboratory at Teddington over many years. The National Physical Laboratory have developed the standard UK low flying military aircraft noise calculation model, as used in this study. The staff at the Department of Social Statistics have worked closely with the Office of Population Censuses and Surveys over many years, and have taken an active part in the validation of the 1991 UK Census data.

The UK low flying system

Height limits

The general definition of low flying includes all flying below 2000 feet, but most low flying training takes place at much lower altitudes above the ground. The UK low flying system is a system of rules and procedures which have been evolved over the years to mitigate the aggregate adverse effects of low flying military aircraft noise as far as is reasonably practicable, while still allowing flexibility for realistic training. Aircraft are generally limited to a minimum height above the ground of 250 feet except in specially designated tactical training areas where the population density is very low. Minimum heights above the ground of 100 feet are sometimes permitted in tactical training areas.

Protected locations and avoidance areas

Low flying is not permitted over towns and built-up areas. In addition, there are a large number of protected locations across the country where low flying is not permitted for environmental, radio, safety, and air traffic control reasons. This leaves approximately half of the UK available for low flying. The actual proportion of the UK land area which is regularly used for low flying training is less than this, because the geographical disposition of airbases, training areas and avoidance areas makes low flying in certain overflyable areas much more common than in others. Aircrew are encouraged to disperse their routes as widely as possible over the permitted low flying areas so as to minimise the aggregate noise load on any one receiver point. Nevertheless, there are a number of areas of concentration where all aircraft following a particular general route are constrained to fly between relatively narrowly spaced protected locations. The population density in these areas of concentration is generally quite low.

Low flying records

Records of planned flights are kept for up to 6 months, but are not in a form which allows precise ground track information to be extracted. In addition, all flights are booked into a log maintained by the Tactical Booking Cell at West Drayton so that aircrew can be warned of other aircraft operating in the same area and to co-ordinate any last minute warnings and restrictions. The Tactical Booking Cell can provide statistics of the numbers and types of aircraft booked to operate in each low flying area, of which there are 19 in the United Kingdom. There are no central records kept of actual flights into each low flying area, but it is understood that the majority (i.e. of the order of 95%) of booked flights actually take place. There is no indication that the differences between the numbers of booked and actual flights are significant in terms of aggregate noise exposure.

Not all low flying generates high maximum noise levels on the ground. Low level high speed flight by fast jets is the most significant from the noise point of view, but there are also many flights at lower speeds and higher altitudes, and slower transport aircraft also use the low flying system. The Tactical Booking Cell statistics, together with advice from the MOD staff based on practical experience, allow for reasonable estimates to be made of the proportion of booked flights which generate significant maximum noise levels on the ground.

The Tactical Booking Cell statistics do not provide any information as to the actual flight tracks flown within the separate low flying areas. Current policy ensures that only a small proportion of flights booked into a particular area will go near any particular point on the ground within that area. This means that estimates of the noise exposure at specifically identified points on the ground require additional information as to the most likely general routes (i.e. north or south) through particular low flying areas, and the distribution of flight tracks across any general route. These general routes vary depending on the aircraft mission and on the destination. A considerable amount of this type of information has been obtained by interviewing RAF and MOD staffs, and then incorporated into the current assessment. However, such information is largely based on personal interpretation and common sense. There must therefore be a strong case for one or more field investigations of the validity of this general route information by means of a limited sample of extended field measurement exercises at some point in the future.

AWACS data

AWACS aircraft have a limited technical capability to record flight track distributions on the ground against height information transmitted back to the AWACS aircraft by the target aircraft. This can provide a further check on the flight track distribution assumptions. The main difficulties with this approach are that the number of AWACS flights over the various potential study sites in the UK is very limited, and that the process of extracting data in a suitable form from the AWACS computers is very expensive. This means that AWACS data could provide a useful supplement to data available from other sources, but could not be relied upon as the main source of flight track distribution data.

Operational procedures
The main emphasis in low flying training is flexibility. This means that there are few specific training routes, and pilots are free to adapt their route within the low flying system to best achieve their particular objectives on the day. With respect to low level fast jet flying, most of the low flying work will be done in formations of between two and four aircraft. The leader of a formation has to plan a route around and between protected and avoidance areas to allow for the following aircraft in the formation, who will normally be behind the leader and off to one side or the other. There are specific procedures for turns of particular angles to allow the formation to be maintained after the turn, and this often involves the following aircraft swopping over to the other side. A typical flight track for a formation could be up to 2 km or more wide, with the outside aircraft flying right up to the edges of protected areas on occasions. Various drawing aids are available to assist aircrew when planning routes in detail on the map to show typical turn radii at different speeds and bank angles, and these provide further assistance in maintaining correct formations through a turn by standardising on the bank angle. A sample of one of these drawing aids has recently been provided to the study team by the MOD staffs.

In general terms between 70 and 80% of low level fast jets will transit through low flying areas at around 420 knots at a height above ground of between 300 and 600 feet. Tactical work for specific training objectives normally involves an increase in speed to 450 or 480 knots and the height above ground will come down to between 250 and 300 feet. The lower altitudes significantly increase pilot workload when travelling at very high speeds, and are not therefore used unless specifically required for the mission. The amount of time spent at the higher speeds would typically be less than 10 minutes or so out of a 90 minute flight. Routes would normally be chosen to fly around protected areas rather than over them, because flying up above the 2000 feet low flying ceiling might encounter clouds and could require entry into controlled airspace, where operational flexibility could be restricted.

Technical approach

Areas of high concentration

Two alternative technical approaches were considered by the research team at the beginning of the project. The first approach considered was to study the known areas of high concentration, as relatively high numbers of overflights could be guaranteed. Unfortunately, these areas are relatively small in size and sparsely populated, leading to small total population samples. Large exposed populations are required for epidemiological studies where the relative risk factor is estimated to be quite low, and where there are many potential confounding factors, as in this case. The total population available for study in these areas was deemed to be too small to justify concentrating on this approach at the beginning of the project.

Figures 1 to 4 show the 1991 population totals in four areas which are representative of the twenty or so known areas of high overflight concentration. The figures show the 1991 census enumeration district (ED) boundaries in relation to the nearby centres of population. There is a large arrow superimposed on each map to indicate the main low flying route through each area in general terms. Figure 1 shows the Wash/Fenland gap between Spalding and the Wash training area. It can be seen that the total population exposed in this area is one or two thousand at the most. In general, the census enumeration district boundaries and population totals shown at these figures are likely to overestimate the true exposed population as the greater part of the population in enumeration districts bordering onto towns is located within, or adjacent to, the built up area of the town, and would not therefore be overflown. Figure 2 shows the Humberside/Scunthorpe gap near to the River Humber. Figure 3 shows the area to the west of Sheffield and Chesterfield with a constrained route for flying south to avoid the Liverpool/Manchester conurbation. Figure 4 shows the area south of Peterborough, where westerly flights are constrained between the Peterborough conurbation and the controlled airspace around Alconbury and Wyton airfields. The overall population counts in these areas can be seen to be quite small, particularly when proper account is taken of the previous comment with respect to the tendency for the greater part of the population in enumeration districts bordering onto towns to be located within, or adjacent to, the built up area of the town.

It is possible to make a very approximate estimate of the total overflown population available under the known areas of overflight concentration on the basis that the actual overflown population in any one area is unlikely to exceed one thousand, and will normally be less. Assuming that there are as many as twenty or so of this type of area gives a maximum estimate in the region of twenty thousand, and a minimum estimate of a considerably smaller number. It is not possible to be more precise without carrying out a complete analysis using the GIS and census data modelling tools which have been developed as part of the study, but which were not available at the time that the decision to move on to the second technical approach (outlined below) was made.

A study of the whole UK

The second technical approach considered was to study the whole of the UK in the first instance to determine initially the distribution of the total numbers of the population exposed to different numbers of significant overflights per day, per month, or per year, etc. This approach was adopted because it would provide a much better overview of the scale of the problem, and would also answer a number of questions raised at the beginning of the study by the Medical Research Council (MRC) Environmental Epidemiology Unit. The MRC unit was concerned that it was not possible at that time to define the extent of the problem in terms of the numbers of people exposed on a national basis and the extent of their exposure. This information is required to be able to rank the relative importance of the possible health effects of low flying military aircraft noise against other environmental stressors that might have greater assumed relative risk ratios of adverse health effects.

One of the main objectives of the overall approach is therefore to produce a distribution curve of population totals exposed at different numbers of overflights per month. On the reasonable assumption that flight tracks would tend to fan out when approaching or leaving points of concentration, it was considered likely that there would be much greater population totals in overflyable areas near to points of concentration than the population totals actually underneath the points of concentration. It was expected that the greater numbers exposed at lower numbers of overflights might provide sufficient numbers in terms of the eventual study design, whereas it was considered unlikely that the population totals actually underneath the points of concentration would be sufficient.

The overall approach has the additional advantage that suitable control areas would more easily be identified with otherwise similar characteristics to the noise exposed study sites except for a lack of, or a much reduced number of, overflights.

Geographic Information System

The only realistic method for dealing with the large amount of information available from the different MOD and RAF sources was to develop a computer database model of the low flying system as part of a Geographic Information System (GIS). Using a GIS gives the considerable technical advantage that all subsequent calculations of the numbers exposed, etc. can be carried out automatically, and that once set up, it is a relatively simple matter to interrogate the database with new questions that arise during the course of the research. The GIS model (when completed) also allows the low flying route information to be overlaid on geo-referenced population maps as derived from the 1991 UK Census. The SPANS GIS system was selected at a technical planning and progress meeting held in January 1993, and appropriate steps were then taken to set up a digital map database incorporating all the required geographical and aeronautical information, such as could be made available from a number of different sources. The population data was obtained separately by using the population surface census data redistribution model as developed by the Geography Department at the University of Southampton.

Digitised aeronautical charts

Geographic Information Systems are based around digital maps, where geographic data is stored in a computer readable database. Digital maps are normally derived from existing printed map information by direct scanning, but direct scanned data usually requires a considerable amount of manual checking and even interpolation to come up with a fully satisfactory digital version. Individual data points can be entered or checked either against numeric co-ordinates, or by hand digitising from a printed map. A complete set of digitised aeronautical charts was required for this project, to include all UK operational airbases and training areas, all designated protected and avoidance areas, all urban boundaries which are defined as avoidance areas by definition, and all potentially overflown areas where residential occupation is impractical because of landscape features such as rivers, dense forests, or even industrial complexes. Ground contours are also required where these define valleys which might be preferentially used by formation commanders when planning flights, together with landmarks such as church steeples, railway lines, and bridges, which might tend to be used as route markers or waypoints.

Up to date large scale digital maps are expensive because of the manpower resources which are required to ensure that they are cartographically accurate and because of the copyright implications of being able to print off unlimited paper copies. The UK

MOD are beginning to change over to digitised aeronautical charts for the UK. The new digital versions will considerably simplify the task of supplying updated charts which properly reflect changing circumstances and will also be useful for various computerised displays. A preliminary version of one of these charts was made available for use in this study and then converted from a mainframe computer data tape format to PC readable format at Southampton University. The aeronautical data provided with the digital chart was supplemented by hand digitising from printed maps to provide complete coverage of the Vale of Evesham initial study area which is described below. It is anticipated that complete and fully verified digital versions of the UK aeronautical charts will be readily available by the time that any further work on this project is commissioned.

In principle, there is no difficulty in simply scanning from a printed map to produce a digitised version. The resulting raster scanned map is useful for archival storage and simplifies the display and printing processes. The main problem with a raster representation is that the individual features on the map are not identified except in terms of their cartographic representation. Software exists to convert raster scanned images to the desired vector format data, where each feature on the map is described by name and by appropriate co-ordinates, but this cannot yet match the ability of the human operator to classify and interpret the data. Vector format data is required for this project. The changeover to digital mapping techniques is proceeding rapidly in many survey organisations, but it is not yet complete, chiefly because of the manpower resources required to produce accurate vector data.

Figures 5 to 7 show the features included at the first set of incomplete aeronautical charts which were made available in digital format. Figure 5 shows the main avoidance areas around the London, Liverpool and Manchester, and Scottish conurbations. There are a number of other avoidance areas such as Birmingham and the East Midlands which are not shown. Figure 6 shows controlled airspace around civilian airports and military airbases. Figure 7 shows a large number of additional avoidance zones and protected areas around the UK. The UK Low Flying Handbook gives a considerable amount of additional data which will be included in future versions of the digital charts. It was necessary to add this data manually to the digital map database for the Vale of Evesham initial study area described below. This type of manual data entry is not cost effective for national coverage in the context of this study, but future versions of the digitised aeronautical charts will effectively eliminate the need for manual data entry.

Software tools

A number of public domain and proprietary software tools were assembled and developed to produce the required information. The basic aeronautical information on airbases, training areas, and protected and avoidance areas was included in a map database set up under SPANS using the preliminary versions of the MOD digitised aeronautical charts, together with hand digitising from printed maps. A number of special programmes were written to support the transfer of data from the MOD supplied format to PC readable format. This information was overlaid on digitised main road, geographic feature, and settlement boundary information obtained from a number of sources which are licensed for use in University research. The public domain data tends to be less accurate than proprietary data as the supplier would not normally devote significant resources to verification, but the general level of accuracy is acceptable for overall calculations of the type carried out for this report.

A simple GIS analysis can calculate the proportion of the total land area which is overflyable in each designated Low Flying Area, but it does not by itself count up the overflyable population or calculate the extent to which flights are concentrated in certain areas and are less common in other overflyable areas. In this report, overflyable areas refers to all areas which are theoretically open to low flying, even if there are local circumstances which might make actual overflights rare. The overflyable population can be counted within the GIS by overlaying the calculated overflyable areas on a geo-referenced set of population counts, which in this case were derived by applying the population surface model (described below) to 1991 Census data. The population surface model was applied to redistribute the population from the wide spaced census enumeration district counts supplied as the basic form of census data across a much more narrowly spaced grid which takes non-populated grid points into account. Further software tools were developed and integrated to model flight track distributions within overflyable areas (see Technical Appendix 1) and to calculate the statistical power of different sampling strategies for the proposed epidemiologic study (see Technical Appendix 2).

Aircraft noise calculations

The UK National Physical Laboratory (NPL) was commissioned as part of this study to provide advice as regards actual noise levels on the ground resulting from overflights by different aircraft types under different operating conditions. NPL supplied appropriate output as produced by the FLYBY military aircraft noise calculation programme (see Technical Appendix 3) to show the rate of fall-off of maximum noise level on the ground with distance off to either side for a range of different aircraft types and operating conditions. NPL shouldered the responsibility of ensuring that the output from the FLYBY programme was fully consistent with the output of the various USAF military aircraft noise calculation programmes which have been produced over the past few years, as part of their ongoing collaboration with the USAF. The maximum noise level on the ground can be calculated by the FLYBY programme to within an acceptable degree of accuracy from the flight track, aircraft type and operating conditions. This means that actual noise level calculations at this stage become superfluous, as the flight track distribution on the ground provides an acceptable estimate of the extent of exposure when used for overall assessment purposes. The output of the FLYBY programme was used to provide estimates of the significantly affected ground track width underneath each flight, in terms of the sideline distance which includes maximum noise levels which exceed 95 dBA.

The Vale of Evesham initial study area

Description of the initial study area

An initial study area in the Vale of Evesham was selected to develop and prove that the various software tools which had been obtained from a number of sources could be made to work together successfully, with the intention that the analysis would then be extended to the rest of the country merely by extending the database incorporated in the GIS. This extension to the rest of the UK will now take place during the next phase of the project to take full advantage of the later versions of the digitised aeronautical charts which are becoming available. The UK wide estimates provided in this report have been made on the basis of assumptions regarding the representativeness of the Vale of Evesham study area which require verification by this further work.

The initial study area is a 50 km by 50 km square which covers the towns and cities of Worcester, Stratford upon Avon, Redditch, Evesham, the southern part of the Birmingham conurbation and many smaller towns and villages. The initial study area is shown superimposed on a map of the low flying areas at Figure 8. It can be seen that the study area covers only a small part of low flying area 4 and just extends into low flying area 8. The overlap of the study area into low flying area 8 is of no importance because this area is within the Birmingham avoidance area, and would therefore only be overflown in controlled airspace at heights above 2000 feet. Noise levels on the ground for flying at 2000 feet and above are insignificant for the purposes of this study.

This particular study area was selected because it was considered likely to contain a representative mix of the geographical characteristics contained in other overflyable areas. The area is fringed by a number of towns and large villages which would not normally be overflown, but there are also large areas of reasonably well populated countryside which are overflyable. There are a number of valleys and ridges which could be exploited for tactical flying, but which might be ignored for transit flying. A general outline of the area is given at Figure 9.

National Grid references

The national grid references for the area are as follows;

NW corner	381448	281900
NE corner	432205	281642
SW corner	381710	231676
SE corner	432205	232205

Typical flight routes

The area is generally overflown by aircraft transiting between airbases on the east coast and training areas in the west. Such aircraft must find an efficient route through the various protected and avoidance areas in the Midlands general area. A number of additional 'rules' have been imposed in this area. These include the 'West Midlands Weather Corridor' which channels the majority of west to east transit flights to the north of Redditch and Stratford upon Avon. Most west to east flights enter the area either north or south of Kidderminster, with a small proportion entering south of Worcester. Most flights in the West Midlands Weather Corridor are at a height of between 1000 and 2000 feet as aircraft would normally be returning to base on the east coast after having largely completed their training mission. Noise levels on the ground from flights at this height are far less significant than at 250 feet, and the onset times are much greater leading to a much reduced startle effect.

Most flights from east to west traverse the southern part of the study area. This area is generally representative of many UK low flying areas with a typical mixture of rural and urban districts and low flying route possibilities. Transit flights en route to the western training areas would typically enter the square just below the West Midlands Weather Corridor and travel in a fairly straight line to exit the area near to the SW corner. There are few opportunities for entry to and exit from the area along the north boundary. Entry from the south is rare, although the MOD staff have estimated that somewhere between 20% and 25% of east to west flights leave the area along the south boundary to pass south of Cheltenham.

The aggregate west to east traffic through this area is less than the east to west traffic as many pilots might choose to transit controlled airspace above 2000 feet when simply returning to base on the east coast after completing a training mission. The west to east weather corridor is quite restricted in available route possibilities and the training value of a low level transit is therefore limited.

Overflyable population estimates - preliminary analysis

The total land area of the United Kingdom (Great Britain and Northern Ireland) is approximately 244,046 km^2. The initial study area has a land area of 2500 km^2. This means that it represents approximately 1% of the total UK land area. Spatial analysis using the GIS shows that the defined protected and avoidance areas enclose approximately 15% of the total land area of the initial study area, leaving approximately 2100 km^2 of overflyable land area. Much of this overflyable area would not in fact be overflown frequently, and could therefore provide control areas for any future epidemiologic study.

The next step is to estimate the total population resident in the overflyable areas within the initial study area. This requires an estimate of the geographical distribution of the population to be overlaid on the overflyable area map. The population surface model as developed by the Geography Department at the University of Southampton was used to provide estimates of the total population as distributed over a 200 m grid. The population surface model works by taking the 1991 census data for each census enumeration district, and redistributing it on the basis of the distance of each grid point from the enumeration district centroid points. The final calculation is then adjusted to give the same overall total population. This calculation was repeated for a range of different population age and sex categories for the more detailed analysis discussed below.

The total population in the initial study area of 2,500 km^2 was estimated to be around 990,000 persons. Of these, approximately 600,000 persons are resident in protected and avoidance areas, leaving approximately 390,000 persons resident in the 2,100 km^2 of overflyable areas. This is not unexpected, as one of the main objectives of the low flying restrictions is to prevent low flying over densely populated areas. The mean population density is then approximately 180 to 190 persons per km^2 in the overflyable areas. This figure is approximately 1/3rd of the average UK population density and indicates that overflyable areas generally have a much lower population density than the UK average which includes a considerable number of built-up areas.

It is likely that a large proportion of overflyable areas are not often overflown. Many overflyable areas are in cul-de-sacs in that they are well away from the more obvious routes for transiting aircraft. Even assuming that the greater part of the overflyable areas are not often overflown means that there are still many tens of thousands of residents in the Vale of Evesham study area who are regularly overflown and could therefore be included as participants in any future epidemiologic study.

Extrapolation to the rest of the UK

The initial study area represents approximately 1% of the total UK land area. However, any crude extrapolation based on this figure alone would be innaccurate for a number of reasons. Large parts of the total UK land area are only very rarely overflown by high speed jet aircraft, even though low flying would be permitted if requested. In addition, a significant proportion of the total population are resident in large conurbations which are not overflyable and therefore not overflown. This means that the overflyable population resident in the initial study area represents a much greater proportion of the total overflyable population over the UK as a whole than the simple land area proportion suggests. Further work is required to be able to make an accurate extrapolation of the Vale of Evesham figures to the rest of the UK, but crude estimates have been made on the following basis.

Populations resident in major conurbations

According to the 1991 census data, approximately 16,500,000 persons were resident in the eight metropolitan counties in England in 1991 (and therefore not overflyable) as follows;

Inner London	2,210,292
Outer London	3,942,616
Greater Manchester	2,399,087
Merseyside	1,345,838
South Yorkshire	1,221,745
Tyne and Wear	1,058,114
West Midlands	2,452,560
West Yorkshire	1,938,146

There are further large conurbations in the UK which are not defined as metropolitan counties, but which nevertheless represent large densely populated areas and are therefore not overflown. Taken in aggregate, these conurbations account for a much greater proportion of the total population (up to about half) than of the total land area (10% or less, depending on the urban boundary definition adopted).

In addition, many of the rural areas in the Vale of Evesham initial study area have a higher population density than in other overflyable areas in other parts of the UK. For example, many parts of Wales, Scotland, and the border districts are overflyable, but the population density is much lower. Taken together, the above information indicates that the total overflyable population in the UK might be somewhere between 10 and 20 times the total overflyable population in the initial study area, rather than the 100 times factor which would be implied by the land area proportion. Assuming an extrapolation factor of between 10 and 20 indicates a total overflyable population resident in the UK between 3,900,000 to 7,800,000. This indicates that the overflyable and thus potentially exposed population is therefore more than sufficient to support a large scale epidemiologic study. Even large errors in the above assumptions would still leave a substantial number of potentially overflown residents, which would still be likely to be more than sufficient to support any future large scale epidemiologic study.

Aggregate noise exposure in the initial study area

As described above, the NPL FLYBY military aircraft noise calculation programme was used to show the rate of fall-off of maximum noise level on the ground with distance off to either side for a range of different aircraft types and operating conditions. This data was then used to estimate the likely aggregate noise exposure of overflown residents in the initial study area in terms of the numbers of high speed low level overflights by the noisier types aircraft passing either directly overhead or within 250 m to either side. The numbers of significant overflights (i.e the noisier types of aircraft flying at high speed and low level with a flight track within 250 m or some other defined distance off to either side) was then used as a proxy variable to give an indication of the degree of noise exposure. It is a simple matter to calculate the actual degree of noise exposure in terms of any conventional noise metric from the significant overflight statistics at some appropriate stage, but this was not actually necessary for this study. The number of significant overflights was calculated on two levels, first to provide initial estimates on the basis of the aggregate number of overflights and the width of the significantly affected area on the ground underneath and to each side of the flight track, and secondly on the basis of a more complex statistical model of the individual flight track distributions which is described later in this report.

The Tactical Booking Cell low flying statistics for Low Flying Area 4 have been tabled on a month by month basis for 1989, 1990, 1991, and 1992 at Figures 10, 11, and 12. These give the overall numbers of flights and the numbers of fast jet flights in Low Flying Area 4 as follows;

	overall	fast jet
1989	18,952	14,099
1990	20,281	15,420
1991	13,817	10,153
1992	17,531	13,429

The statistics are not strictly comparable from one year to the next as the data for September 1989, and November and December 1991 and 1992 are missing. The definition 'fast jet' includes the Bucaneer, F4, F111, Harrier, Hawk, Jaguar, Tornado in both variants and F15. Other aircraft types are included in the overall figure. The tables indicate that the average number of fast jet flights booked into Low Flying Area 4 is of the order of 10,000 to 15,000 per year. A reasonable assumption for the average number of fast jet flights booked into Low Flying Area 4 would therefore be 12,000 per year.

The NPL data from the FLYBY military aircraft noise calculation model indicates that maximum noise levels on the ground are likely to exceed approximately 95 dBA (95 L_{Amax}) within approximately 250 m off to each side of the flight track for most low level operations by aircraft types included within the definition of fast jet in the previous paragraph. The 95 L_{Amax} noise level is the lower limit for a noise significant overflight considered here. Most high speed low level overflights within 250 m of any measurement point would exceed 95 L_{Amax} and could range up to the MOD limit of 125 L_{Amax}, depending on the distance of the aircraft flight track from the measurement point, the type of aircraft, the altitude and speed, and the operating conditions.

We assume in the first instance that the threshold maximum noise level for a noise significant overflight is 95 L_{Amax}. This assumes that all lower maximum noise levels caused by aircraft passing by at more than 250 m separation distance, or at lower speeds or greater altitudes, are not significant from the potential adverse health effects point of view, although such overflights might well be clearly visible and audible to persons on the ground down to much lower maximum noise levels. Each low flying fast jet then sweeps a 500 m wide ground track, within which the noise event is assumed to be potentially significant for the purposes of this study. This means that each low level high speed flight through the Vale of Evesham study area from east to west exposes all persons on the ground within an area of approximately 25 km^2 to a a maximum noise level in excess of 95 L_{Amax} but below 125 L_{Amax}. Advice from MOD staff indicates that transit flights through the West Midlands Weather Corridor from west to east will not be as significant in noise terms as they would normally use heights of between 1000 feet and 2000 feet and have therefore been ignored for the purposes of this preliminary assessment. Assuming that half of the assumed 12,000 fast jet flights booked into Low Flying Area 4 fly across the lower half of the Vale of Evesham study area to produce significantly exposed ground tracks of 500 m wide, then this aggregates to a total significantly overflown area of 150,000 km^2, to be accomodated within the 1050 km^2 overflyable land area within the southern half of the study area.

Random flight track allocation

Assuming a completely random allocation of flight tracks from east to west across the southern half of the study area then indicates that each point on the ground is overflown by approximately 143 fast jet flights per year to produce a maximum noise level in the range between 95 L_{Amax} and 125 L_{Amax}. This is of the order of one significant overflight every two days when averaged over the 365 days in a year. Spatial analysis using the GIS shows that there are about 200,000 people resident in overflyable areas in the southern part of the study area who might be exposed on average to this level of overflight activity (typically 143 significant overflights per year).

In practice, significant overflights would be likely to be bunched together with longer gaps of weeks or more between bunches as a result of formation flying and special training exercises. The MOD staff advise that there are typically 200 flying days per year, with the majority of overflights in the study area tending to peak at around 1100 hrs and again at around 1400 hrs.

The above analysis disregards the west to east route in the northern half of the initial study area on the basis of MOD staff advice that the majority of flights in the northern part of the study area pass through at between 1000 feet and 2000 feet. In addition, a proportion of west to east flights do not use the low flying system at all, indicating that the east to west flights form more than half of the booked totals. On the other hand, the MOD staff advise that probably 75% of aircraft booked into low flying area 4 actually pass through the initial study area, as it is possible for a proportion of aircraft to enter and leave Low Flying Area 4 without crossing the initial study area. Taken together, this supports the assumption made above that approximately half of the booked fast jet flights in Low Flying Area 4 pass through the southern part of the initial study area from east to west.

Flight track concentration

Of course, the flight track distribution on the ground is not random, as it is constrained by the need to plan routes to avoid protected areas and to accommodate formation flying and specific training objectives. The simplest way of modelling the effects of flight track concentration is to make an assumption as to the extent to which most flights are concentrated within a reduced area. Assuming a very high degree of concentration onto specific training routes would imply a small number of points on the ground exposed to very high numbers of significant overflights. Assuming a limited spread of flight tracks reduces the number of significant overflights for each point on the ground but increases the numbers of points on the ground which are exposed to the lower numbers of significant overflights. Assuming a random allocation of flight tracks gives the largest number of points on the ground exposed to the lowest number of significant overflights.

A reasonable assumption might be that most flights are concentrated into 1/10 of the available overflyable area. This is not unreasonable when the geography of the study area and the geographical distribution of the various protected and avoidance areas are taken into account. This would then indicate that approximately 20,000 residents within the southern half of the study area would be exposed on average to approximately 1,430 significant overflights (i.e. overflights that generate maximum noise levels exceeding 95 L_{Amax} outdoors on the ground) per year. This figure equates to about 4 significant overflights per day when averaged over 365 days per year, or about 7 significant overflights per day when averaged over the average numbe of about 200 flying days per year. In practice, the frequency of significant overflights per day would be much greater on some days than others, with periods of a few days or even weeks when the overflight frequency would be very much lower.

Assuming that the overflyable population within the study area is representative of between 1/10 and 1/20 of the total UK overflyable population (as discussed above) would then imply that the total UK population exposed to a yearly average of 4 or more significant overflights per day would be in the range between 200,000 and 400,000. This calculation does not take into account that a large proportion of persons resident in any particular area spend considerable periods of time away from their place of residence where they would not be exposed to low flying military aircraft noise, or they might spend considerable periods of time indoors where the maximum noise levels would be lower than outdoors. In addition, there is a further population who are not resident in significantly overflown areas but who are nevertheless exposed to low flying military aircraft noise because they move into significantly overflown areas during the day. Further work is required to properly estimate the magnitude of these two effects.

Flight track distribution modelling

This section of the report briefy describes the material which is covered in more depth in Technical Appendix 1. The basic problem is that it is necessary to have some record of either actual flight tracks or estimated flight tracks to be able to calculate aggregate noise exposure at different points on the ground. Continuous acoustic monitoring at large numbers of rural sites would be able to record actual noise exposure at any desired site on the ground but it is impractical in the context of this project for two main reasons. First, extensive coverage would be extremely expensive as long term noise monitoring equipment is quite expensive and a very large number of instruments would be required to be able to provide large scale coverage over long periods of time. Second, there is a problem of source identification. A trained observer can easily identify the different types of military aircraft by sight, and may be able to estimate height and track to within an acceptable degree of accuracy for the purposes of a project of this type. It is very difficult to achieve accurate source identification automatically, and it is likely that considerable manpower resources would be required in order to resolve ambiguous data as recorded by unattended noise monitoring equipment. Various pattern recognition techniques, such as by using neural network based systems, have been developed which can achieve accurate source identification under a limited range of circumstances, but these systems have not yet been developed to the level of functionality that would be required for a project of this type.

The alternative technique is to estimate actual noise exposure on the ground from flight track records. The main problem here is that there is no method available of precisely recording actual flight tracks over large areas of the countryside on a routine basis. The technology exists to record ground tracks using AWACS aircraft or sophisticated flight data recorder systems, but again, this type of technology is impractical for general use on a large scale in the context of this type of project.

The only remaining alternative is to estimate the flight track distribution by modelling the various 'rules' which govern the ways in which different aircraft are actually flown, and then to validate the various flight track distribution rules which have been developed by selective field observation at key sites. The Monte Carlo simulation technique is a well known method of taking random variability into account by following the stated rules through on a large number of repeated trials with different random inputs in a computer model and then taking a statistical count of the different routes that emerge from this process. In this case the main rules were that aircraft were constrained to fly within legitimate overflyable areas and the likelihood of turning either left or right (or continuing straight ahead) was defined in advance.

The resulting flight track distributions were then effectively overlaid on various population surface grid maps to derive the estimates given at the enclosed tables. The modelled flight track distribution is shown at Figure 13.

Power calculations

The statistical power of any epidemiologic study is very important as there is no point to carrying out a study which has too small a sample size in relation to individual variability to have a high probability of generating definitive results. Technical Appendix 2 describes a series of statistical calculations which were carried out under a wide range of different assumptions to be able to estimate the overall sample sizes required to have a high probability of producing definitive results at the end of the study.

The preliminary conclusions from this part of the work were that an interview sample size of the order of 20,000 to 24,000 people would be required at the start of the project, to achieve 16,000 active participants in the long term study. A small but steady drop out rate must be expected during the study, to leave of the order of 12,000 to 13,0000 participants remaining at the end of a 5 year study. A final sample size of this magnitude is required in order to be able to carry out definitive statistical analyses of the main experimental effects, in the light of the various known confounding factors such as age and sex, and in the light of known levels of individual variability in blood pressure as determined from other large scale surveys. Any hypothesised linkage between exposure to occasional high noise level low flying military aircraft overflights and adverse non-auditory health outcomes over the long term is likely to have a low relative risk ratio in terms of comparing noise exposed experimental groups and non-noise exposed control groups. This means that the sample size must be quite large to be reasonably certain of not missing a real but small effect, particularly when it is recognised that the most plausible linkage mechanism between noise exposure and possible adverse health outcomes in the long term is the stress hypothesis. Individuals appear to vary a great deal in terms of their response to stress across different potential stressors, and this might further serve to conceal any real but small effects unless the study is very carefully designed.

Future programme of research

A future programme of research is recommended as follows;

- The GIS model of the low flying system should be extended to the entire UK using the definitive digitised aeronautical charts as they become available.
- The detailed low flying information as supplied by MOD staff in respect of typical operations in the Vale of Evesham initial study area should be extended to cover the entire UK, and incorporated into the GIS system.
- This information is largely based on practical experience tempered with common sense and should therefore be validated against actual field experience by deploying field monitoring equipment for extended periods at a representative sample of potential study sites.
- The flight track simulation model using Monte Carlo techniques should be further developed to take typical turn radii and formation flying into account. This approach appears to show considerable promise.
- The population surface model requires further development to improve the level of accuracy when applied to rural areas with physically large census enumeration districts, by taking other sources of data such as postcode data and possible field observational data into account.
- Appropriate steps should be taken to consider the detailed design of a prospective epidemiologic study in terms of the requirements for access to exposed and control populations, to determine the resource implications of accepting widely distributed study locations.

The above work items would take up to a year to complete, depending on the scale of resources allocated to this project. The next stage of the work would then be a pilot phase for the full epidemiologic study, to allow the field research protocols and techniques to be perfected. The full epidemiologic study would normally be expected to last for five years before useful results would become available, to allow for the expected latency period in the development of stress related health effects. Taken together, this implies a total study period of around seven years before useful results become available.

Conclusions

The main conclusions drawn from the work to date can be summarised as follows;

- The available input data and the research tools which have been developed during the study are capable of providing robust estimates of the extent of exposure to low flying military aircraft noise in the United Kingdom.

- There are approximately 390,000 residents in the overflyable parts of the Vale of Evesham initial study area. This figure probably represents between 1/10 and 1/20 of the total overflyable population of the UK. Of these 390,000, many thousands are potentially exposed (when at home) to significant overflight noise levels several times per day. This degree of noise exposure is sufficient to justify the future work programme proposals set out below.

- Initial estimates of the sample size required to carry out a definitive study are of the order of 20,000 to 24,000 persons interviewed at the outset, to leave of the order of 12,000 to 13,000 persons remaining in the study at the end of the five year study period.

Future work

A large number of assumptions were made in arriving at the initial estimates of the extent of exposure in the Vale of Evesham study area, in extrapolating these results to the rest of the UK and in estimating the required sample size to be able to carry out a definitive epidemiologic study. These assumptions should be tested under a future work programme before proceeding with the pilot studies for the full scale epidemiologic study. A detailed work programme is outlined in the body of the report, but the main features are as follows;

- Extend the GIS model to the entire UK.
- Extend the available low flying information to the entire UK.
- Conduct field monitoring exercises to validate the low flying route assumptions.
- Further develop the Monte Carlo flight track modelling technique.
- Further develop the population surface model for rural areas.
- Carry out further statistical power calculations with the refined data.
- Consider the detailed design and protocols for a pilot epidemiologic study.

Figures

Figure 1 Wash/Fenland gap

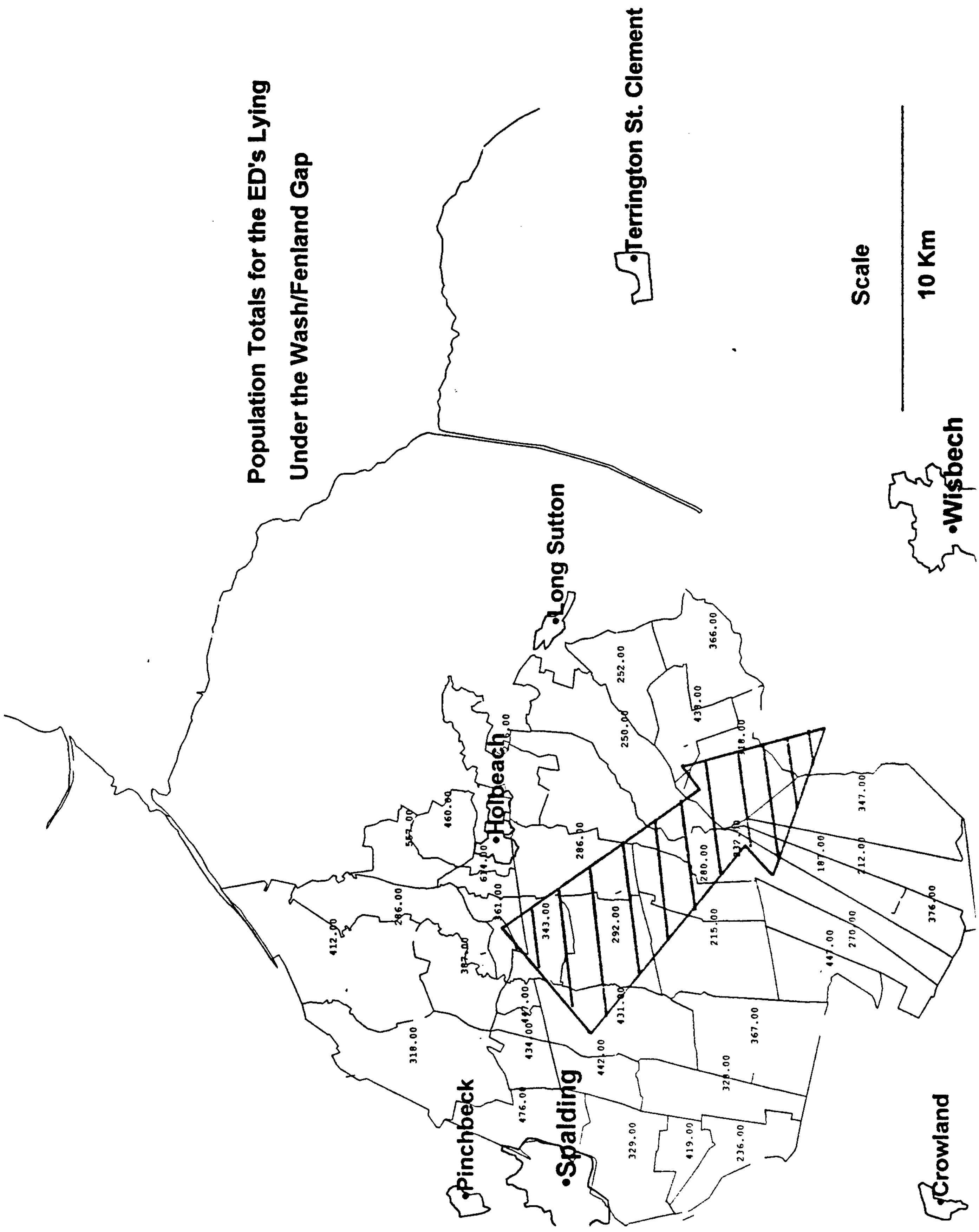


Figure 2 Humberside/Scunthorpe gap

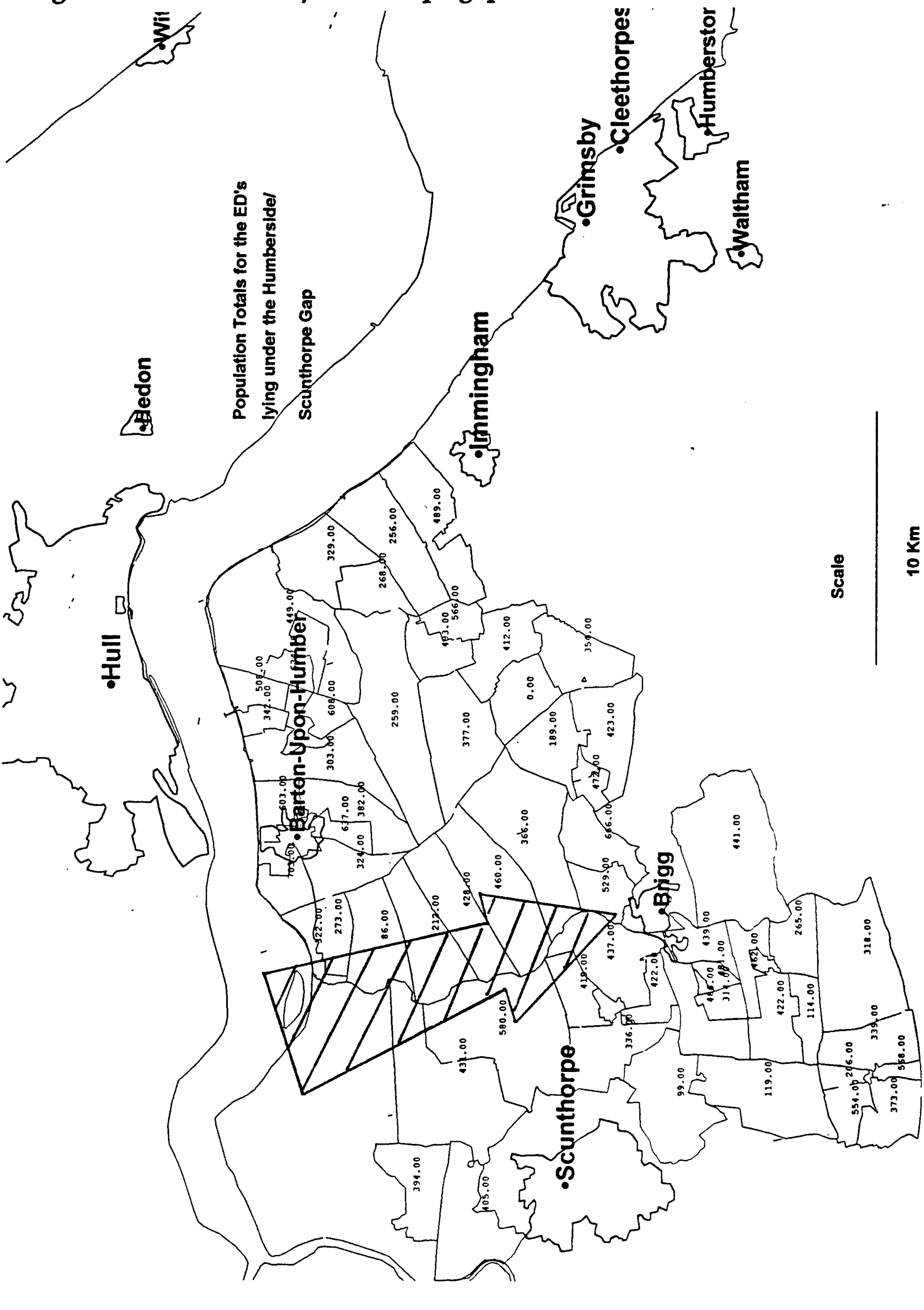


Figure 3 Liverpool/Manchester and Sheffield

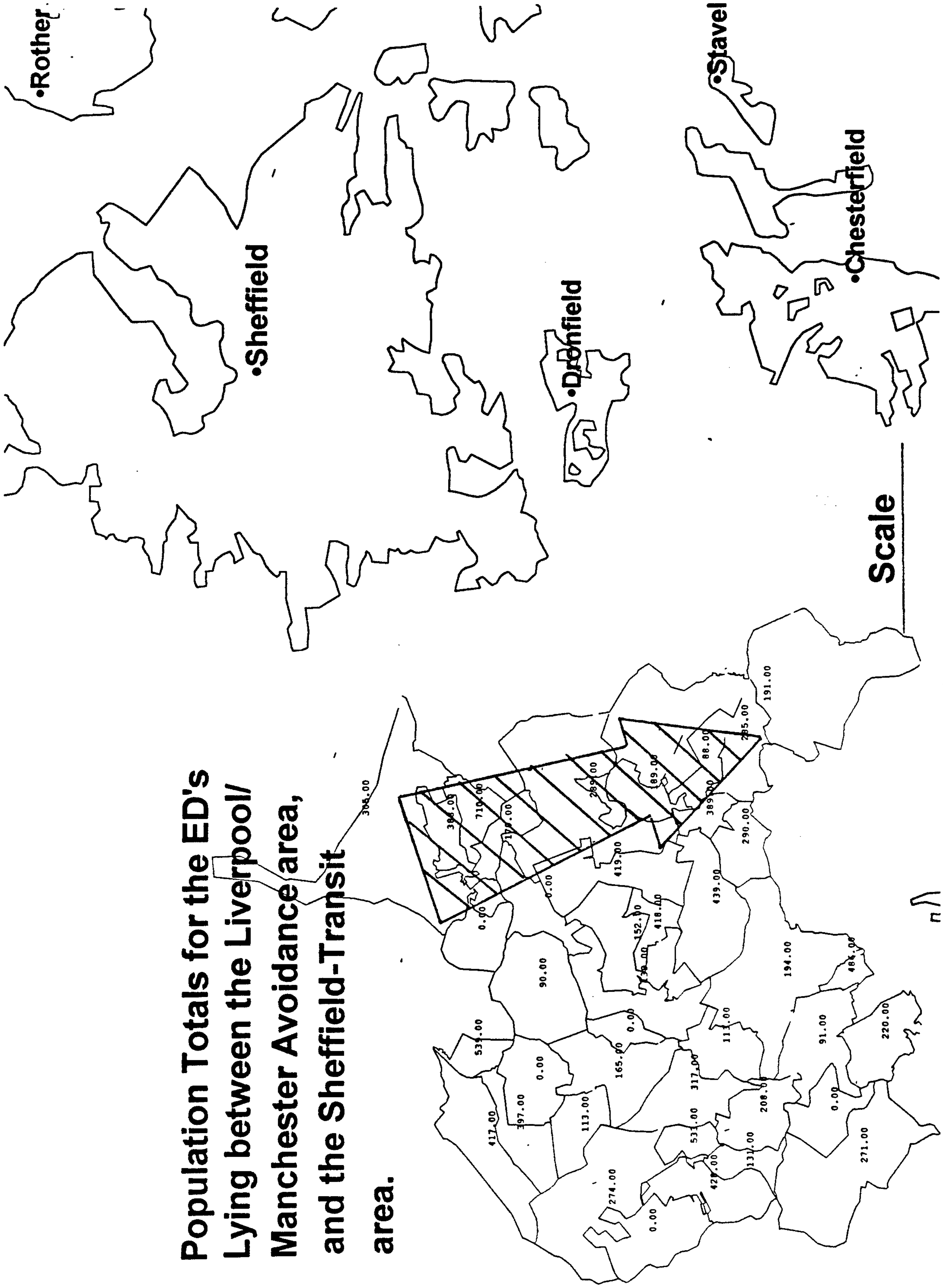


Figure 4 Peterborough

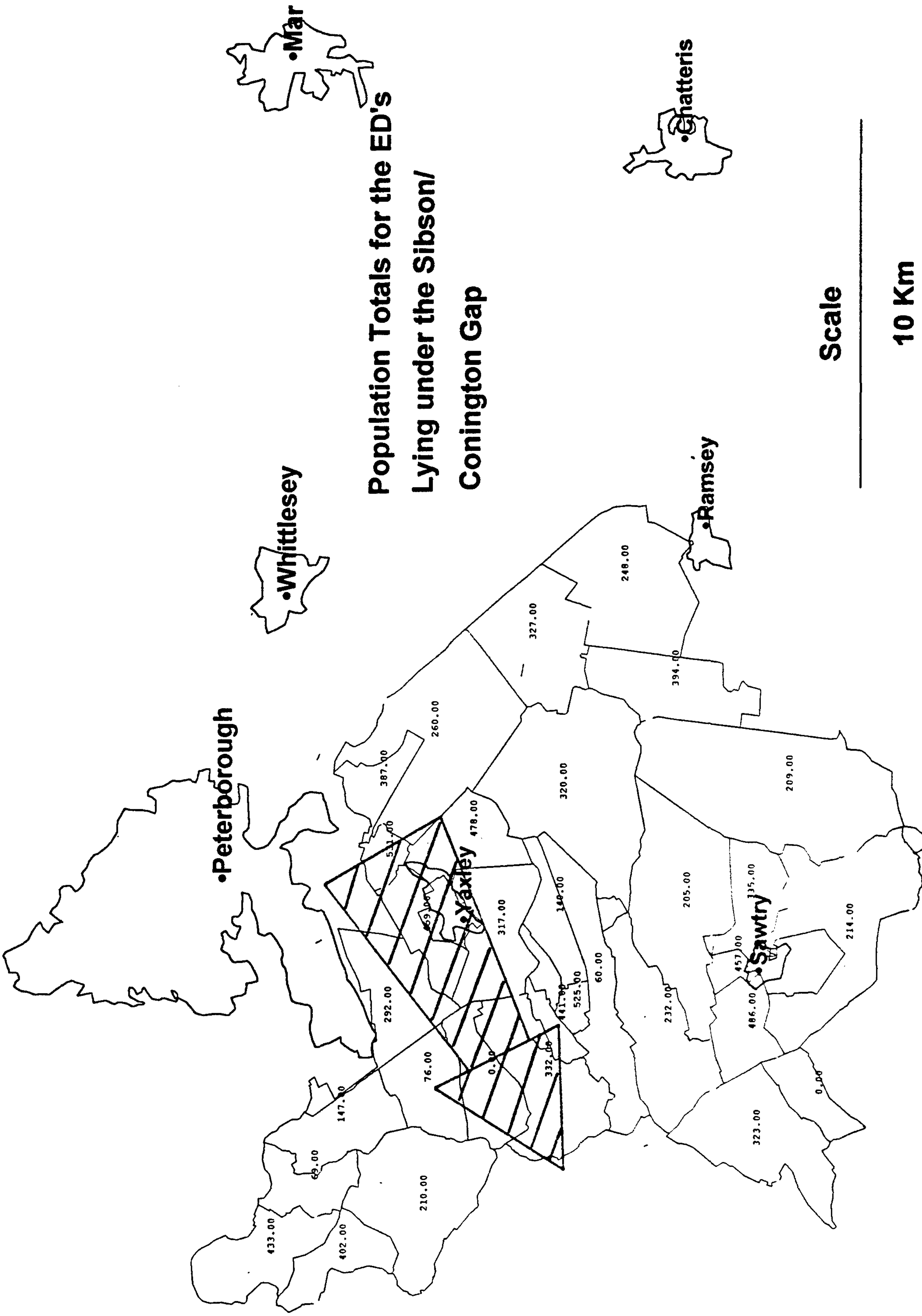


Figure 5 Major conurbations

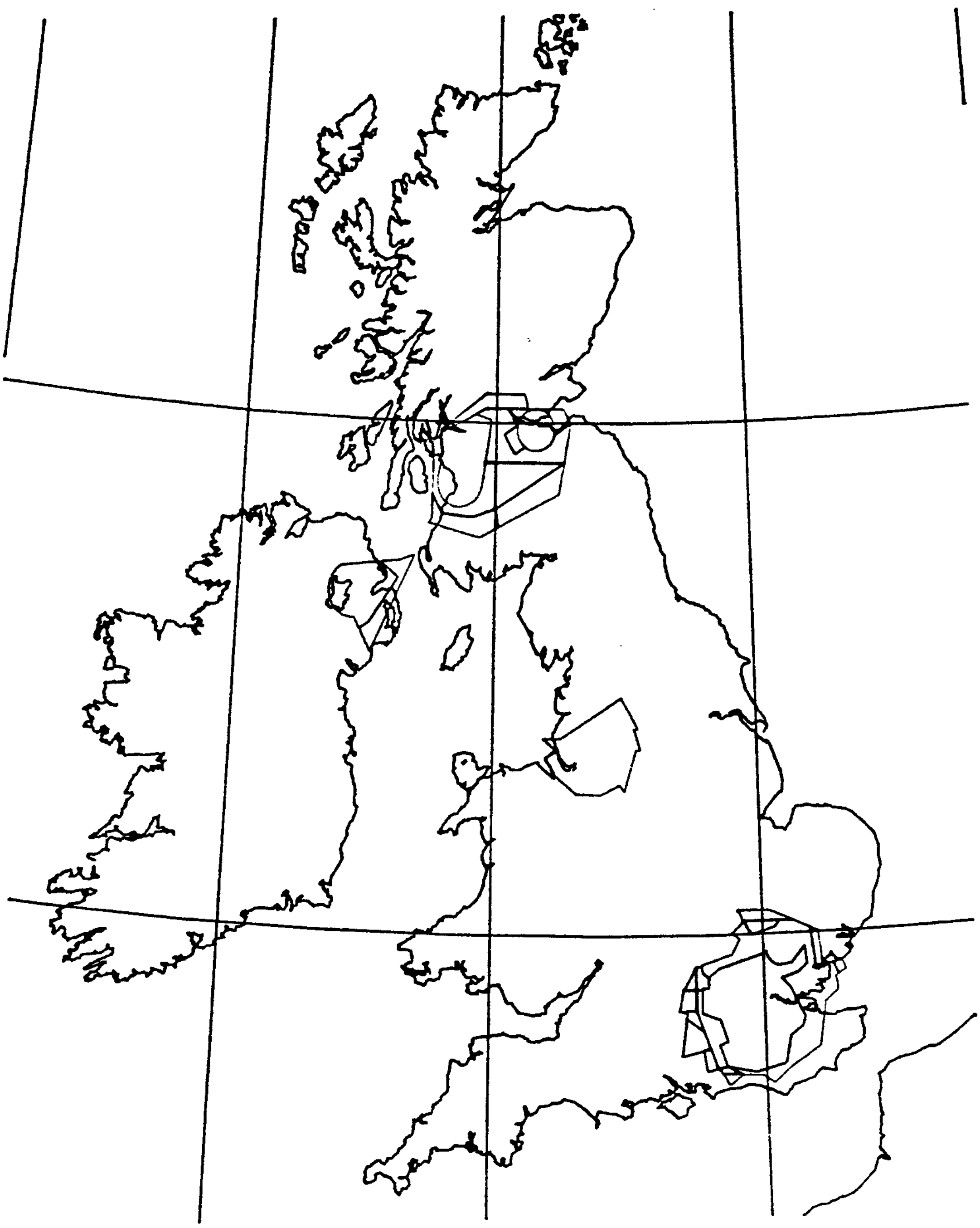


Figure 6 Controlled airspace

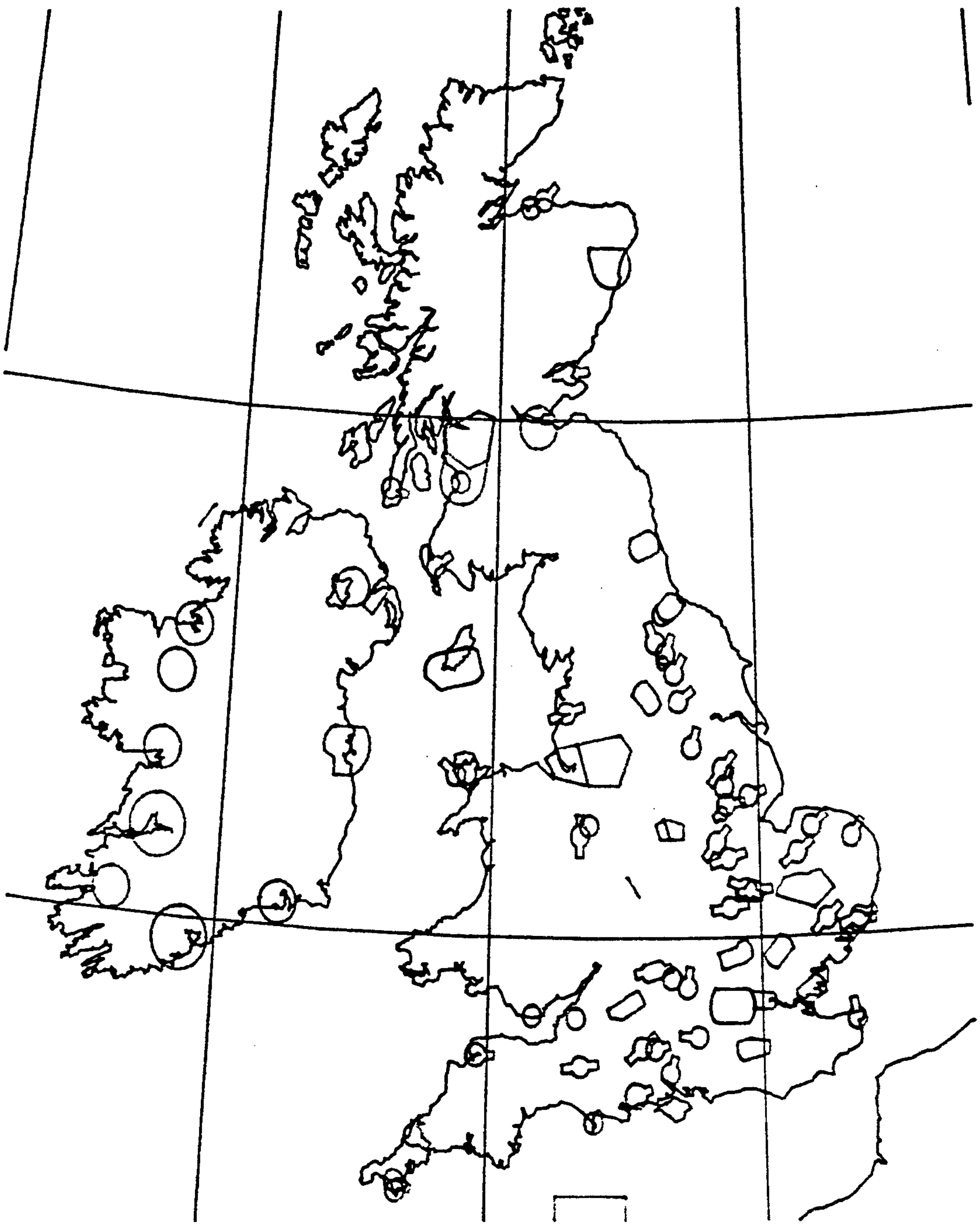


Figure 7 Avoidance zones and protected areas

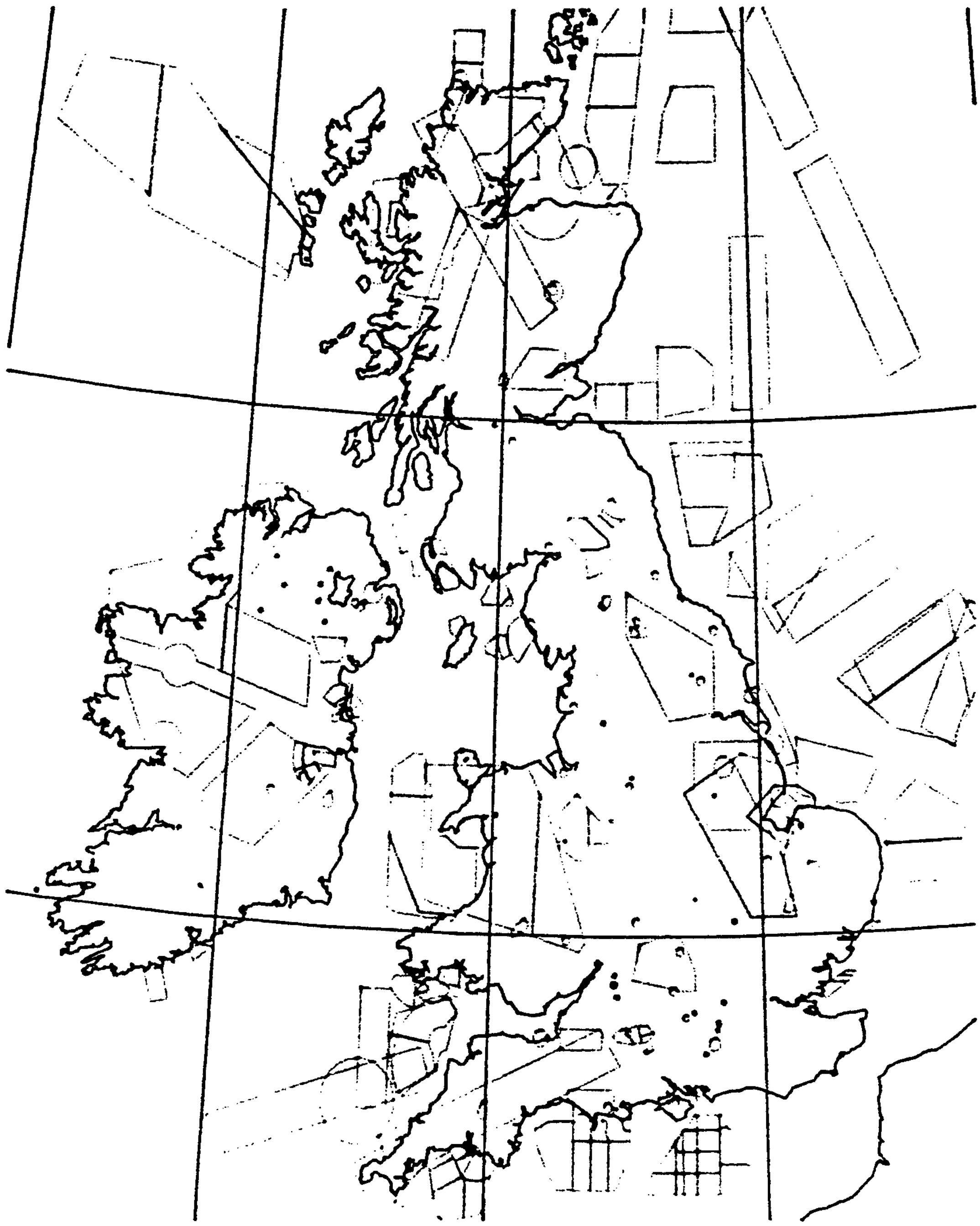
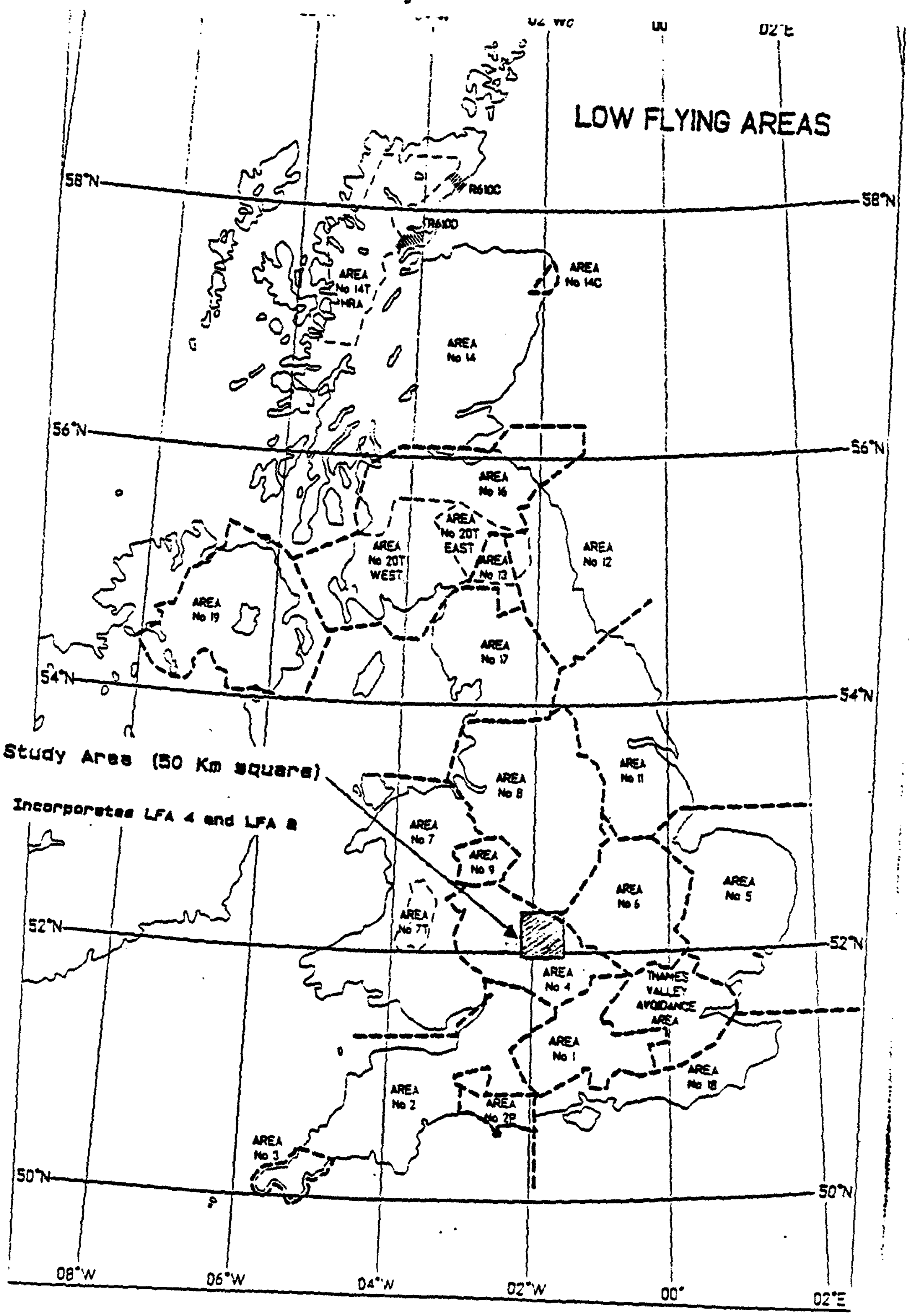
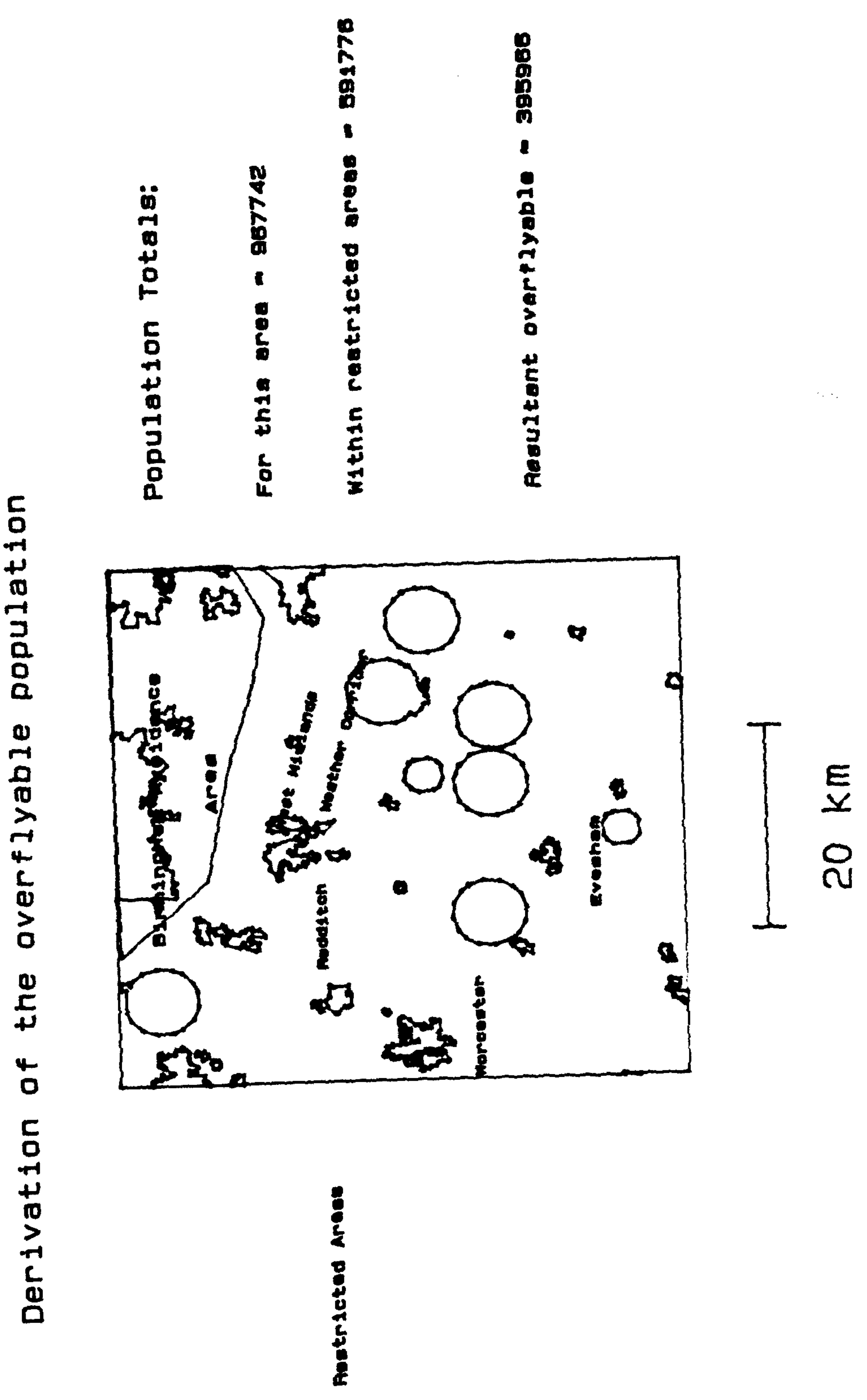


Figure 8 Vale of Evesham study area



Taken from Low Flying Handbook.

Figure 9   Vale of Evesham study area



LFAN90														All aircraft	Fast jets
Booked movements in Low Flying Area 4													1990 total	20281	15420
1990 statistics													1989 total	18952	14099
Aircraft		January	Februar	March	April	May	June	July	August	Septem	October	Novemb	Decemb	Annual	Aircraft
A10	TY	116	76	134	78	149	130	231	114	70	163	60	103	1424	A10
	LY	108	72	150	120	122	178	293	114		140	77	96	1470	
Buccaneer	TY	4	5	5	8	2	10	3	7	44	9	4	3	104	Buccaneer
	LY	8	25	10	3	5	10	3	11		2	8	1	86	
Hercules	TY	60	50	97	98	114	82	117	22	7	9	45	6	707	Hercules
	LY	113	107	104	87	88	90	128	64		66	54	55	956	
Chinook	TY	5	6	15	7	11	15	42	7	7	2	5	2	124	Chinook
	LY	8	10	14	12	49	16	4	2		12	10	5	142	
F4	TY	19	13	22	20	28	2	30	19	30	19	22	19	243	F4
	LY	22	17	26	25	10	8	29	11		7	23	16	194	
F111	TY	32	16	94	60	131	95	95	91	53	34	46	19	766	F111
	LY	30	30	39	15	52	56	78	78		50	24	44	496	
Harrier	TY	154	164	252	83	157	158	300	285	188	256	205	174	2376	Harrier
	LY	307	196	168	304	225	459	154	137		207	148	15	2320	
Hawk	TY	312	376	699	404	535	468	590	466	482	375	356	191	5254	Hawk
	LY	431	284	309	420	343	521	373	524		386	369	65	4025	
Helicopter	TY	38	77	111	50	87	91	86	64	69	56	82	19	830	Helicopter
	LY	57	75	47	122	80	96	82	74		38	95	24	790	
Jaguar	TY	108	24	219	104	142	94	346	75	54	84	44	21	1315	Jaguar
	LY	346	208	78	182	266	167	329	236		159	71	27	2069	
Jet Provost	TY	31	90	195	64	170	99	110	159	75	84	86	16	1179	Jet Provost
	LY	82	124	35	132	106	144	118	146		174	84	7	1152	
Tornado GA	TY	342	368	639	415	647	329	500	520	432	453	318	272	5235	Tornado GA
	LY	536	561	267	527	469	490	644	555		436	307	96	4888	
Tornado F3	TY							37	14	15	32	2	27	127	Tornado F3
	LY	2	1	4		9	5							21	
Light aircraft	TY	1		9	11	2	1	10	1	1		4	1	41	Light aircraft
	LY	48	40	16	30	67	44	6	2		3			256	
Other	TY	8	10	54	18	46	17	59	33	32	65	34	10	386	Other
	LY							17	27		23	15	5	87	
Tucano	TY					7		49	21	38	7	25	23	170	Tucano
	LY														

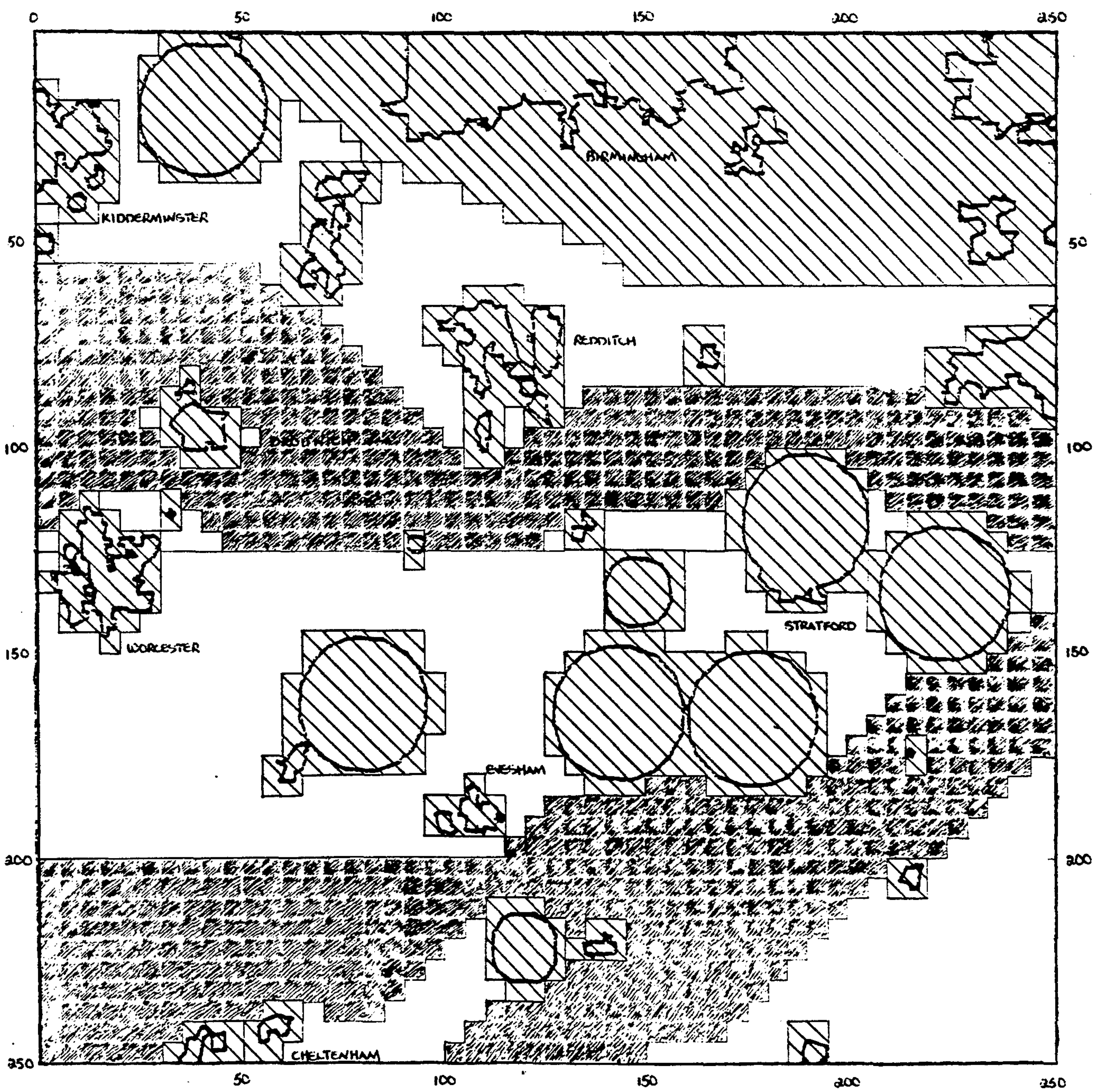
Figure 11 1991 statistics

LFAN90														All aircraft	Fast jets
Booked movements in Low Flying Area 4													1991 total	13817	10153
1991 statistics													1990 total	20281	15420
Aircraft		January	Februar	March	April	May	June	July	August	Septem	October	Novemb	Decemb	Annual	Aircraft
A10	TY	98	30	166	108	58	170	105	55	74	64			928	A10
	LY	116	76	134	78	149	130	231	114	70	163	60	103	1424	
Buccaneer	TY	5	1	3	6	6	3	8	3	9	3			47	Buccaneer
	LY	4	5	5	8	2	10	3	7	44	9	4	3	104	
Hercules	TY	15	21	4	39	13	53	58	101	108	55			467	Hercules
	LY	60	50	97	98	114	82	117	22	7	9	45	6	707	
Chinook	TY	1		8	1	3	7	6	7	8	4			45	Chinook
	LY	5	6	15	7	11	15	42	7	7	2	5	2	124	
F4	TY	12		11	16	55	37	2	12	25	56			226	F4
	LY	19	13	22	20	28	2	30	19	30	19	22	19	243	
F111	TY	18	23	41	137	112	83	66	72	30	9			591	F111
	LY	32	16	94	60	131	95	95	91	53	34	46	19	766	
Harrier	TY	113	96	142	132	177	174	134	94	139	184			1385	Harrier
	LY	154	164	252	83	157	158	300	285	188	256	205	174	2376	
Hawk	TY	153	177	276	282	387	320	445	348	454	256			3098	Hawk
	LY	312	376	699	404	535	468	590	466	482	375	356	191	5254	
Helicopter	TY	40	46	55	59	69	53	45	37	69	46			519	Helicopter
	LY	38	77	111	50	87	91	86	64	69	56	82	19	830	
Jaguar	TY	89	59	27	87	166	127	128	62	64	130			939	Jaguar
	LY	108	24	219	104	142	94	346	75	54	84	44	21	1315	
Jet Provost	TY	62	53	117	75	58	194	105	63	37	48			812	Jet Provost
	LY	31	90	195	64	170	99	110	159	75	84	86	16	1179	
Tornado GA	TY	216	131	208	505	430	335	529	337	409	442			3542	Tornado GA
	LY	342	368	639	415	647	329	500	520	432	453	318	272	5235	
Tornado F3	TY	6	8	8	33	39	45	102	33	31	20			325	Tornado F3
	LY							37	14	15	32	2	27	127	
Light aircraft	TY	1		1	2	2	1	3	1	2				13	Light aircraft
	LY	1		9	11	2	1	10	1	1		4	1	41	
Other	TY	12	12	22	90	62	140	95	43	83	79			638	Other
	LY	8	10	54	18	46	17	59	33	32	65	34	10	386	
Tucano	TY	27	5	2	10	27	44	19	30	51	27			242	Tucano
	LY					7		49	21	38	7	25	23	170	

Figure 12 1992 statistics

LFAN90														All aircraft	Fast jets
Booked movements in Low Flying Area 4													1992 total	17531	13429
1992 statistics													1991 total	13817	10153
Aircraft		January	Februar	March	April	May	June	July	August	Septem	October	Novemb	Decemb	Annual	Aircraft
A10	TY	46	59	68	54	62	36	25	26	26	26			428	A10
	LY	98	30	166	108	58	170	105	55	74	64			928	
Buccaneer	TY	7	12	2		4	4	4	16	16	16			81	Buccaneer
	LY	5	1	3	6	6	3	8	3	9	3			47	
Hercules	TY	57	86	115	98	104	92	112	109	109	109			991	Hercules
	LY	15	21	4	39	13	53	58	101	108	55			467	
Chinook	TY	7	8	7	28	6	7	12	3	3	3			84	Chinook
	LY	1		8	1	3	7	6	7	8	4			45	
F4	TY	3	27	9	5	28	3	20	17	17	17			146	F4
	LY	12		11	16	55	37	2	12	25	56			226	
F111	TY	9	5	21	70	50	40	46	39	39	39			358	F111
	LY	18	23	41	137	112	83	66	72	30	9			591	
Harrier	TY	199	189	183	257	608	157	151	308	308	308			2668	Harrier
	LY	113	96	142	132	177	174	134	94	139	184			1385	
Hawk	TY	202	441	465	425	573	380	570	401	401	401			4259	Hawk
	LY	153	177	276	282	387	320	445	348	454	256			3098	
Helicopter	TY	24	110	80	72	83	107	86	78	78	78			796	Helicopter
	LY	40	46	55	59	69	53	45	37	69	46			519	
Jaguar	TY	22	76	90	77	62	108	134	123	123	123			938	Jaguar
	LY	89	59	27	87	166	127	128	62	64	130			939	
Jet Provost	TY	9	34	69	63	51	22	69	42	42	42			443	Jet Provost
	LY	62	53	117	75	58	194	105	63	37	48			812	
Tornado GA	TY	194	444	441	490	550	458	390	553	553	553			4626	Tornado GA
	LY	216	131	208	505	430	335	529	337	409	442			3542	
Tornado F3	TY	6	20	24	16	53	36	12	62	62	62			353	Tornado F3
	LY	6	8	8	33	39	45	102	33	31	20			325	
Light aircraft	TY			3	6	3	8	0	4	4	4			32	Light aircraft
	LY	1		1	2	2	1	3	1	2				13	
Other	TY	8	32	36	26	59	50	73	48	48	48			428	Other
	LY	12	12	22	90	62	140	95	43	83	79			638	
Tucano	TY	39	49	45	77	52	67	64	126	126	126			771	Tucano
	LY	27	5	2	10	27	44	19	30	51	27			242	
F15	TY			2	2			8	39	39	39			129	F15
	LY														

Figure 13 Modelled flight track distribution



Technical Appendix 1

Flight track distribution modelling

This section of the report describes the methodology for estimating the number of people exposed to low flying military aircraft in the initial study area on the basis of a probabilistic model of the flight track distribution. The method is based on estimating the proportion of the total number of flights through the initial study area which overflies each 200 m grid square within the overflyable area. The analysis is carried out to a spatial resolution of 200 m as defined by the 200 m grid spacing, which is of the same order of magnitude as the 500 m wide significantly exposed ground track assumption made in the previous section of the report. The overall estimated exposure figures consist of total numbers exposed in each category of overflights (0, 1-7, 8-14, 15-49, 50-99 and 100+) and the breakdown of these figures by age and sex (both total numbers and proportions).

Software tools

The estimation of the numbers exposed to low flying military aircraft is a complicated task. It involves the use of census data, a model of where the people live, a simulation model and a tabulation of those exposed by age, sex and number of overflights per unit time. This requires the use of four different computer packages, these being:

- **SASPAC91** (Small Area Statistics Package),
- the **POPULATION SURFACE** model,
- **FORTRAN**, and
- **SPSS** (Statistical Package for the Social Sciences).

1991 Census data

The small area statistics package SASPAC91 was specifically designed for interrogating the 1991 UK census database. The Vale of Evesham initial study area incorporates parts of four different counties. The four counties are Gloucestershire, Hereford and Worcestershire, Warwickshire and the West Midlands, and a separate SASPAC91 program was written and then submitted to obtain data for each county. The resulting four separate data files were then merged into one file to represent the requested population statistics for the initial study area.

The data requested for each county included:

- an Ordnance Survey grid reference for each Enumeration District centroid,
- a count of the population in age groups (0-4, 5-9, 10-14, 15, 16-17, 18-19, 20-24, 25-29, ..., 90+) for both male and female residents in each Enumeration District.

The population surface model

The population surface model redistributes the population counts into individual cells on a 200 m grid spacing using the distance decay algorithm (population density decreases with distance from the Enumeration District centroid). Thus each of the 62,500 cells in the 50 km square study area will contain a count of the population, for each of the eleven selected population categories (the population surface model was run eleven times). These categories are:

- total population,
- males 15-24, 25-34, 35-44, 45-54, 55-64 (five categories),
- females 15-24, 25-34, 35-44, 45-54, 55-64 (five categories).

The 62,500 cells of the 50 km square initial study area consist of a 250 by 250 square grid of cells, with 250 rows and 250 columns. The output after running the population surface model is of the following form:

- a row identifier (1-250), which replaces the Ordnance Survey 'Northing' a column identifier (1-250), which replaces the Ordnance Survey 'Easting', and
- a count of the exposed population in the relevant cell and for the relevant category (if not equal to zero).

The (row, column) identification scheme simply makes the next stage of computer programming easier. The (1,1) cell represents the top left corner of the study area and the (250,250) cell represents the bottom right corner.

Flight track distribution model

The first trial calculations were carried out by assuming that the entire initial study area is available for low flying. Once the basic method had been proven, the next step was to take the protected and avoidance areas into account by blocking out the relevant 200 m grid points to a spatial resolution of 1 km. These areas are shown by diagonal cross hatching on Figure 13. The next calculation step assumes a uniform distribution of flight tracks from east to west or from west to east. Each aircraft is assumed to either fly straight ahead or to turn to either the left or right with a defined probability. A probability vector was set up for each of the remaining cells (which had not been blocked out due to lying within a protected or avoidance area). The first assumption for this probability vector was a relative probability of 0.8 to fly straight ahead and much lower probabilities for turning either to the left (0.1) or to the right (0.1). This would give a minimum turn radius of effectively 200 m, which the most recent information supplied by the MOD staff indicates is rather tight. However, any errors in the assumed minimum turn radius are not significant in terms of the global analysis carried out using this model.

To ensure aircraft fly around restricted areas (rather than up and over them for example), and to take into account cells where the available directional choices are limited due to proximity of protected or avoidance areas off to one sidea, the probability vector was manually adjusted for the relevant cells (200 m grid points) on the following basis:

- (0.5,0.5,0.0) for straight ahead and right only,
- (0.5,0.0,0.5) for straight ahead and left only,
- (0.0,1.0,0.0) for right only,
- (0.0,0.0,1.0) for left only,

and so on for any other combinations.

The probability vectors at each cell were adjusted to constrain the available flight tracks to the areas indicated by the full shading at Figure 13. In general terms, these assumed flight track areas are loosely based on the available information, such as is set out in the Low Flying Handbook. Other assumptions about the flight tracks have also been made. These include:

- Entries to the initial study area from the eastern side occur just below the West Midlands Weather Corridor,
- Exits on the western side will occur in the lowest ten kilometres of the square, with twenty per cent exiting south of Cheltenham,
- Entries from the western side occur between Kidderminster and Worcester, and never fly in the lower half of the square,
- East to west flights account for seventy-five per cent of all flights, with west to east flights accounting for the remainder.

- Transit flights will take a direct route wherever possible and will therefore avoid detours into and out of effective cul-de-sacs created by the relative proximity of protected and avoidance areas on two or three sides of an otherwise overflyable area.

Notice that there are some areas of concentration arising from the assumed layout of overflyable areas. In the upper half of the square there is an area of concentration in the area just south of Droitwich and to the north-east of Worcester. In the lower half of the square there is an area of concentration to the south of Evesham. The number of overflights in these areas will be much higher than the rest of the square.

Simulation programme

A special simulation program was written in FORTRAN to simulate flight paths across the initial study area, both East to West (in the lower half of the grid) and West to East (in the upper half of the grid). The end product was a count of the total population overflown on the basis of the number of times that each cell was overflown in 900 overflights east to west and 300 overflights west to east (thus all figures are based on 1,200 overflights per month, which is based on an assumption of around 15,000 fast jet overflights per year in low flying area 4). The program executes the following tasks:

- reads all the data necessary to initiate a run, the size of the square (number of cells in each row/column, here this is 250), the number of cells with a population count, and the number of simulation runs required (900 or 300 here),
- initialises the probability vector to (0.8,0.1,0.1) for each cell and then reads the file which alters this vector according to the position of the aircraft in the grid,
- reads the population counts for each 200 m grid cell, excluding major conurbations and the protected and avoidance areas (these have been set to zero),
- calculates a random entry point for the overflight.

For a west to east flight the entry point lies between rows 56 and 120 inclusive (65 possibilities) and for an east to west flight the entry point lies between rows 141 and 175 inclusive (35 possibilities), (row and column numbers are indicated on Figure 13). Each entry point has an equal probability of being chosen (1/65 and 1/35).

The program then simulates a particular flight path by taking the direction indicated by a random number (between 0.0 and 1.0 inclusive)

- For the following probability vector: (0.8,0.1,0.1), if the random number was 0.0 to 0.8 the aircraft would go straight ahead, 0.8 to 0.9 the aircraft would go right, 0.9 to 1.0 the aircraft would go left.

- If the vector was: (0.5,0.0,0.5), if the random number was 0.0 to 0.5 the aircraft would go straight ahead, 0.5 to 1.0 the aircraft would go left (the aircraft cannot go to the right in this case).

The same general rule applies throughout.

The population exposed is noted (if there is any) and the variable for the number of overflights is incremented by one for that cell. The process continues until the aircraft exits the square.

After the required number of simulations the output is written to a file. The general method of using repeated simulation runs using a random number generator to produce small differences on a probabalistic basis between each run, and then calculating the mean result on a statistical basis is known as a Monte Carlo method because of the obvious similarity to gambling.

The program output takes the following form:
row, column, population exposed (if not zero), number of overflights (per 900 or 300)

An example of a small portion of the program output for females aged 55-64, west to east (300 overflights) is given below:

row	column	population	flights
95	165	5.26	0
95	166	5.26	0
95	204	4.00	89
95	205	4.00	82

The simulation was repeated for each of the eleven files, in each direction (22 simulations). The output file was read by SPSS to produce the exposure tabulations.

Overflight distribution

The number of overflights in each cell per 1200 overflights in total were grouped into different exposure categories as follows:

0, 1-7, 8-14, 15-49, 50-99, and 100+

These categories represent the number of significant overflights per month (in this case on the assumption of an effective 200 m wide ground track enclosing the significantly affected area on the ground) based on 1200 booked flights into low flying area 4 per month, or 15,000 booked flights per year. The zero category is maintained in a group by itself as these are the people who are potentially overflyable but not actually overflown, and could therefore be used as controls in any future study. The remainder of the distribution has a long tail, with the number of overflights extending to two or three hundred (effectively per month) in some cells. The categories are therefore chosen to represent a fairly even spread of the population over the whole range of exposure, that is, a similar proportion of the population in each category. A total count of the population exposed in each category was then produced, along with the proportion of the population in each category, as shown at Tables 1 to 6.

Summary

Table 1 gives a total potentially overflyable population in the shaded areas indicated at Figure 13 of approximately 140,000. This is less than the crude estimate of 390,000 overflyable residents outlined in the previous section because the overflyable area is now further delimited by the likely route possibilities in addition to the protected and avoidance areas. Of these 140,000 residents, the flight track simulation model indicates that the majority are not exposed at all, and that most of the flights are concentrated over a minority of the overflyable residents. The flight track simulation model indicates that approximately 6000 residents are exposed to more than 100 significant overflights per month. This result is generally consistent (i.e. of the same order of magnitude) with the earlier crude estimate of approximately 20,000 residents exposed to more than 120 significant overflights per month because the assumed width of the significantly affected ground track has been significantly reduced by the way in which significant overflights are counted in the flight track simulation model, by counting only those grid cells which are directly underneath the simulated flight tracks (to a spatial resolution defined by a 200 m grid). This could account for a difference between the respective estimates by the ratio of 200 to 500. In addition, the population density in the assumed overflyable areas indicated at Figure 13 is likely to be lower than the population density in the non-protected and non-avoidance areas because of the 1 km guard banding adopted around towns and other protected areas for the flight track simulation model.

The population statistics given at Tables 1 to 6 also indicate the different numbers of residents in different age and sex categories for each monthly exposure category. There is an emphasis on the 15-64 age range because, while this age range only includes approximately 70% of the total population, it is generally considered to be more appropriate for the design of a long term study.

Table 1

Breakdown of the Population by Age and Sex.

West to East - All Population.

O/F	Exposed (All)	Exposed (15-64)	(15-64)/All
0	52,976.79	36,378.53	0.69
1-7	7,227.60	5,251.66	0.73
8-14	2,644.70	1,638.58	0.62
15-49	2,697.92	1,725.56	0.64
50-99	840.35	569.46	0.68
100+	0.00	0.00	----
Total	66,387.36	45,563.79	0.69

East to West - All Population.

O/F	Exposed (All)	Exposed (15-64)	(15-64)/All
0	58,578.42	42,405.00	0.72
1-7	1,719.01	1,058.06	0.62
8-14	402.68	239.72	0.60
15-49	2,808.46	1,762.41	0.63
50-99	2,316.34	1,406.36	0.61
100+	5,999.83	3,844.70	0.64
Total	71,824.74	50,716.26	0.71

Both Directions - All Population.

O/F	Exposed (All)	Exposed (15-64)	(15-64)/All
0	111,555.21	78,783.53	0.71
1-7	8,946.61	6,309.72	0.71
8-14	3,047.38	1,878.30	0.62
15-49	5,506.38	3,487.97	0.63
50-99	3,156.69	1,975.82	0.63
100+	5,999.83	3,844.70	0.64
Total	138,212.10	96,280.05	0.70

Table 2

Breakdown of the Population by Age and Sex.

West to East - Male Population.

O/F	15-24	25-34	35-44	45-54	55-64
0	3,470.81	3,359.81	4,342.48	3,972.86	3,135.50
1-7	510.59	540.72	593.55	537.12	469.31
8-14	147.00	174.85	222.45	177.29	119.08
15-49	157.37	181.04	216.06	193.16	129.67
50-99	70.15	30.75	71.34	77.30	43.54
100+	0.00	0.00	0.00	0.00	0.00
Total	4,355.93	4,287.16	5,445.90	4,957.74	3,897.10

East to West - Male Population.

O/F	15-24	25-34	35-44	45-54	55-64
0	4,173.53	3,783.56	4,860.73	4,570.97	3,740.43
1-7	102.83	87.43	128.35	110.43	100.73
8-14	21.69	23.40	23.62	27.43	25.30
15-49	164.29	153.40	196.07	179.77	174.59
50-99	143.37	114.74	155.15	157.26	123.86
100+	369.31	374.00	457.98	383.60	318.53
Total	4,975.03	4,536.54	5,821.90	5,429.45	4,483.44

Both Directions - Male Population.

O/F	15-24	25-34	35-44	45-54	55-64
0	7,644.34	7,143.37	9,203.21	8,543.83	6,875.93
1-7	613.42	628.15	721.90	647.55	570.04
8-14	168.69	198.25	246.07	204.72	144.38
15-49	321.66	334.44	412.13	372.93	304.26
50-99	213.52	145.49	226.49	234.56	167.40
100+	369.31	374.00	457.98	383.60	318.53
Total	9,330.96	8,823.70	11,267.80	10,387.19	8,380.54

Table 3

Breakdown of the Population by Age and Sex.

West to East - Female Population.

O/F	15-24	25-34	35-44	45-54	55-64
0	3,301.57	3,465.92	4,353.89	3,893.85	3,081.84
1-7	506.01	571.77	586.91	519.47	416.21
8-14	116.30	208.72	217.96	134.28	120.65
15-49	145.92	208.45	195.56	178.46	119.87
50-99	51.65	32.90	75.89	73.34	42.60
100+	0.00	0.00	0.00	0.00	0.00
Total	4,121.44	4,487.75	5,430.20	4,799.41	3,781.16

East to West - Female Population.

O/F	15-24	25-34	35-44	45-54	55-64
0	4,026.04	3,949.39	4,841.80	4,532.29	3,926.26
1-7	100.99	85.59	132.51	104.40	104.80
8-14	18.49	26.92	27.34	21.34	24.19
15-49	152.95	152.97	218.36	178.95	191.06
50-99	134.12	115.72	159.26	159.40	143.48
100+	350.13	415.20	439.07	377.83	359.05
Total	4,782.72	4,745.79	5,818.34	5,374.22	4,748.83

Both Directions - Female Population.

O/F	15-24	25-34	35-44	45-54	55-64
0	7,327.61	7,415.31	9,195.69	8,426.14	7,008.10
1-7	607.00	657.36	719.42	623.87	521.01
8-14	134.79	235.64	245.30	155.62	144.84
15-49	298.87	361.42	413.92	357.41	310.93
50-99	185.77	148.62	235.15	232.74	186.08
100+	350.13	415.20	439.07	377.83	359.05
Total	8,904.16	9,233.54	11,248.54	10,173.63	8,529.99

Table 4

Breakdown of the Population by Age and Sex (Proportions).

West to East - All Population.

O/F	Exposed (All)	Exposed (15-64)
0	0.7980	0.7984
1-7	0.1089	0.1153
8-14	0.0398	0.0360
15-49	0.0406	0.0379
50-99	0.0127	0.0125
100+	0.0000	0.0000

East to West - All Population.

O/F	Exposed (All)	Exposed (15-64)
0	0.8156	0.8361
1-7	0.0239	0.0209
8-14	0.0056	0.0047
15-49	0.0391	0.0348
50-99	0.0322	0.0277
100+	0.0835	0.0758

Both Directions - All Population.

O/F	Exposed (All)	Exposed (15-64)
0	0.8071	0.8183
1-7	0.0647	0.0655
8-14	0.0220	0.0195
15-49	0.0398	0.0362
50-99	0.0228	0.0205
100+	0.0434	0.0399

Table 5

Breakdown of the Population by Age and Sex (Proportions).

West to East - Male Population.

O/F		Age	
0	0.7968	15-24	0.1899
1-7	0.1156	25-34	0.1869
8-14	0.0366	35-44	0.2374
15-49	0.0382	45-54	0.2161
50-99	0.0128	55-64	0.1699
100+	0.0000		

East to West - Male Population.

O/F		Age	
0	0.8369	15-24	0.1971
1-7	0.0210	25-34	0.1797
8-14	0.0048	35-44	0.2306
15-49	0.0344	45-54	0.2151
50-99	0.0275	55-64	0.1776
100+	0.0754		

Both Directions - Male Population.

O/F		Age	
0	0.8178	15-24	0.1936
1-7	0.0660	25-34	0.1831
8-14	0.0200	35-44	0.2338
15-49	0.0362	45-54	0.2155
50-99	0.0205	55-64	0.1739
100+	0.0395		

Table 6

Breakdown of the Population by Age and Sex (Proportions).

West to East - Female Population.

O/F		Age	
0	0.8000	15-24	0.1822
1-7	0.1150	25-34	0.1984
8-14	0.0353	35-44	0.2401
15-49	0.0375	45-54	0.2122
50-99	0.0122	55-64	0.1672
100+	0.0000		

East to West - Female Population.

O/F		Age	
0	0.8353	15-24	0.1878
1-7	0.0207	25-34	0.1863
8-14	0.0046	35-44	0.2284
15-49	0.0351	45-54	0.2110
50-99	0.0280	55-64	0.1864
100+	0.0762		

Both Directions - Female Population.

O/F		Age	
0	0.8187	15-24	0.1852
1-7	0.0651	25-34	0.1920
8-14	0.0191	35-44	0.2339
15-49	0.0362	45-54	0.2116
50-99	0.0206	55-64	0.1774
100+	0.0404		

TECHNICAL APPENDIX TWO

POWER CALCULATIONS

TABLE OF CONTENTS

SUMMARY

The required sample size for the proposed prospective study is strongly influenced by the choice of outcome variable (either 5mm/Hg change in blood pressure or clinical hypertension), desired power for detecting effects, the relative risk of disease, the relative frequency of exposed and nonexposed persons as well as other factors such as expected dropout rates. The recommended sample size is based on two study requirements. First, the study is powerful enough in terms of sample size to be highly likely to detect a consequential health effect if one exists and to have a very low probability of producing spurious findings. Second, the study must provide sufficient information on the qualitative relationship between amount of noise exposure (dose) and degree of specific health consequences (effect). We assume four levels of exposure: (1) no exposure: none, (2) low exposure: 1-7 overflights per month, (3) medium exposure: 8-49 overflights per month and (4) high exposure: 50+ overflights per month (high exposure). We estimate the distribution of exposure as 80.7% with none, 6.5% with low, 6.2% with medium and 6.6% with high exposure.

The recommended sample size is on the order of 20,000 to 24,000 persons interviewed, to achieve 16,000 willing to participate (assuming 20% to 33% unwilling to be interviewed and permit blood pressure measurements) and 12,800 to remain in the study for 5 years (assuming 20% drop-out over 5 years).

INTRODUCTION AND ASSUMPTIONS

This appendix describes the sample size and power calculations. It first reviews the statistical concepts associated with sample size calculation. Sample size estimates are provided for both continuous and discrete outcomes. Namely, for a 5mm/Hg change in systolic blood pressure (continuous outcome) and for clinical hypertension (discrete outcome).

The sample size estimates for a 5mm/hg change in blood pressure are based on the following assumptions

- alpha level of 5%
- power of 95%
- comparisons between four equal-sized exposure groups (none, low, medium and high) are desired
- estimates are desired for 8 age-sex subgroups of the population since the hypothesised causal effects may vary by age and sex.
- standard deviation of systolic blood pressure for a given age-sex group based on the Health and Lifestyle survey
- 20% drop out rates over 5 years.

Note that sample sizes estimates are provided for ten age-sex groups rather than eight. In order to minimise dropouts due to migration and mortality we recommend either the youngest or oldest age groups not be enrolled in any study. We have included estimates for these groups for completeness. Note that while we recommend that equal numbers of participants come from the four exposure groups we also present sample size calculations based on ratios of exposed to non-exposed varying from 1:1 to 1:4 in case increased numbers of controls (no exposure) are desired.

The sample size estimates for clinical hypertension (yes/no) are based on the following assumptions

- logistic regression model
- estimate of rate of hypertension in the target population of 9.98% based on Health and Lifestyle survey data
- alpha level of 5%
- range of power levels, i.e., 80%, 85%, 90%, 95%, 99%
- range of relative risks, i.e., 1.1, 1.2, 1.3, 1.4, 1.5
- four category distribution of exposure

Overflights per month	%
0	80.7
1-7	6.5
8-49	6.2
50+	6.6

- or six category distribution of exposure

Overflights per month	%
0	80.7
1-7	6.5
8-14	2.2
15-49	4.0
50-99	2.3
100+	4.3

- 20% dropout rate over 5 years.

Sample size estimates for discrete outcomes are produced using EGRET SIZE (Statistics and Epidemiology Research Corp., 1992). The estimates are based on a logistic regression model for cohort data, which is explained in full in the section entitled "SAMPLE SIZE ESTIMATION FOR HYPERTENSION". Sample size estimates for continuous outcomes are produced using PC-SIZE (Dallal, 1990). However, the estimates are not based on an ordinary linear regression model (which would be analogous to the logistic regression model used for a discrete outcome) because none of the dozen or so packages at our disposal provided estimates based on an ordinary linear regression model. PC-SIZE calculates the sample size when using independent samples to compare two population means.

A section on The Health and Lifestyle Survey is also included, as estimates of variability in systolic blood pressure for various age-sex groups as well as estimates of the rate of hypertension in the population are needed for the power and sample size calculations and these are obtained from this study.

STATISTICAL CONCEPTS

If the proposed prospective study is carried out, tests will be performed to see whether the exposure variable, the number of overflights experienced per month, has any effect on varied outcome variables, for example, hypertension (yes or no) or a 5mm change in blood pressure level. In any study one would formulate two arguments, or hypotheses:

- H_0, the null hypothesis, that the exposure variable has no effect on the outcome, e.g., that being overflown by military aircraft does not cause clinical hypertension,

- H_A, the alternative hypothesis, that the exposure variable does have an effect on the outcome, e.g., that military overflights do cause clinical hypertension.

A hypothesis is always carried out at some *level* or *size*, usually called the *alpha-level* (most often 5%). The *alpha-level* is defined as:

alpha-level = probability of rejecting H_0 when H_0 is actually true, (often called the level of significance).

The *power* is the counterpart of the *level* of a test. The *power* is defined as:

power = probability of rejecting H_0 when a specific alternative hypothesis is true.

The power can also be seen as the probability of detecting a significant difference between the risk in the exposed group and the risk amongst the non-exposed. The relative risk is defined as:

$$\text{Relative Risk} = \frac{\text{Probability(hypertensive given exposed)}}{\text{Probability(hypertensive given non-exposed)}} .$$

SAMPLE SIZE ESTIMATION FOR A 5 MM/HG CHANGE IN BLOOD PRESSURE

The data on which the continuous outcome sample size calculations are based is given in Table 10, in the section titled "The Health and Lifestyle Survey".

PC-SIZE (Dallal, 1990) calculates the required sample size when using independent samples to compare to two population means. It is based on the formula

$$N=\frac{(r+1)^2(z_{\alpha/2}+z_\beta)^2\sigma^2}{r\theta^2}$$

where:

r represents the ratio of the size of the exposure group to the non-exposed,

$z_{\alpha/2}$ represents the size of the test (the alpha level), here assumed 0.05,

z_{β} represents the power, here assumed 95 per cent,

σ^2 represents the variance, the square of the standard deviation,

θ represents the difference in means which one wishes to detect, here assumed to be a 5 mm/Hg difference.

As $z_{\alpha/2}$, z_{β} and θ are fixed, the sample sizes will depend on r and σ^2 only.

All continuous outcome calculations are based on the assumption that one is trying to detect a 5 mm/Hg difference between the systolic blood pressure levels of two groups, which we will generically refer to as "exposed" and "non-exposed". We assume that all two group comparisons between the four equal-sized exposure groups are desired, i.e. none vs low, none vs medium, none vs high, low vs medium, low vs high and medium vs high. However, while our final recommendations are based on an assumed 1:1 ratio of the sizes of the two groups, for completeness we also present calculations based on ratios from 1:1, 1:3 and 1:4 as well. On the basis of this assumption the resulting sample sizes are shown in Tables 1 to 4.

The final row in each table represents the population between ages 18 and 69, which treats both sexes between these ages as a homogeneous population. Here the sample size required is a similar size to the sample size required for a specific age-group for a given sex. The TOTAL value is simply the sum of the required sample sizes for all ten subgroups.

Comment: If one refers to Table 10, it can be seen that the resulting sample sizes are related to the standard deviation of systolic blood pressure. The reason for this is that when r is fixed, the only quantity that varies in the sample size formula is σ^2, the square of the standard deviation. Thus when σ^2 increases the result is a larger sample size. This is clear to see when looking at Tables 10 and 1 to 4 in conjunction.

Recommendation: The recommended sample size is 12,800 participants. This is based on the assumption of a continuous outcome and that mean difference comparisons are desired between four equal-sized exposure groups (no exposure, low exposure, medium exposure and high exposure). The worst case scenario involves 400 participants in each group compared (for females 60-69) which yields 1600 participants (4 exposure groups of 400 each) for each age-sex group. Eight age-sex groups yields 1600 x 8 = 12,800 participants. The use of the worst case scenario involves some conservatism in that the range of required sample sizes in each group varies from 124 (best case) to 400 (worse case). These values depend on the estimated standard deviation of the systolic blood pressure which is imprecise, so that some conservatism is justified.

TABLE 1 : SAMPLE SIZES FOR A 1:1 RATIO OF EXPOSED TO NON-EXPOSED

SEX	AGE	EXPOSED	NON-EXPOSED
M	18-29	155	155
M	30-39	153	153
M	40-49	193	193
M	50-59	287	287
M	60-69	396	396
F	18-29	124	124
F	30-39	153	153
F	40-49	207	207
F	50-59	356	356
F	60-69	400	400*
TOTAL		2424	2424
BOTH	18-69	297	297

* worst case scenario

TABLE 2 : SAMPLE SIZES FOR A 1:2 RATIO OF EXPOSED TO NON-EXPOSED

SEX	AGE	EXPOSED	NON-EXPOSED
M	18-29	116	232
M	30-39	114	228
M	40-49	145	290
M	50-59	215	430
M	60-69	297	594
F	18-29	93	186
F	30-39	114	228
F	40-49	155	310
F	50-59	267	534
F	60-69	300	600*
TOTAL		1816	3632
BOTH	18-69	223	446

* worst case scenario

TABLE 3 : SAMPLE SIZES FOR A 1:3 RATIO OF EXPOSED TO NON-EXPOSED

SEX	AGE	EXPOSED	NON-EXPOSED
M	18-29	103	309
M	30-39	102	306
M	40-49	128	384
M	50-59	191	573
M	60-69	264	792
F	18-29	82	246
F	30-39	102	306
F	40-49	138	414
F	50-59	238	714
F	60-69	267	801*
TOTAL		1615	4845
BOTH	18-69	198	594

* worst case scenario

TABLE 4 : SAMPLE SIZES FOR A 1:4 RATIO OF EXPOSED TO NON-EXPOSED

SEX	AGE	EXPOSED	NON-EXPOSED
M	18-29	97	388
M	30-39	95	380
M	40-49	120	480
M	50-59	180	720
M	60-69	248	992
F	18-29	77	308
F	30-39	95	380
F	40-49	130	520
F	50-59	223	892
F	60-69	250	1000*
TOTAL		1515	6060
BOTH	18-69	186	744

* worst case scenario

SAMPLE SIZE ESTIMATION FOR CLINICAL HYPERTENSION

The standard model used for analysing discrete outcome cohort data such as clinical hypertension (yes or no) is a logistic regression model. A cohort study is a prospective study of a group of individuals about which exposure information is collected, in this study exposure to low flying military aircraft.

When performing power calculations for a logistic regression model one must take into account the distribution of the exposure variable and any confounding variables. A confounding variable is one which is directly related to the outcome. For example, ones risk of becoming hypertensive may increase as one gets older. In this study there are three variables to be considered, of which two are confounding variables, namely:

FLIGHTS: Exposure variable: 6 levels: 0, 1-7, 8-14, 15-49, 50-99 and 100+ overflights per month.

AGE: Confounding variable: 5 levels: 15-24, 25-34, 35-44, 45-54 and 55-64.

SEX: Confounding variable: 2 levels: male and female.

The distributional information for each variable must also be taken into account for the sample size calculations. This information can be calculated from the distribution of overflight exposure. For the exposure variable only the sampling fraction for each level of exposure is required, i.e., the percentage in each category of the variable FLIGHTS. The distribution is shown in Table 5.

TABLE 5 : DISTRIBUTION OF THE NUMBER OF OVERFLIGHTS PER MONTH

LEVEL OF EXPOSURE	SAMPLING FRACTION
0	80.71%
1-7	6.47
8-14	2.20
15-49	3.99
50-99	2.29
100+	4.34
	100.00%

TABLE 6 : AGE DISTRIBUTION BY LEVEL OF EXPOSURE

AGE	SAMPLING FRACTION FOR EXPOSURE LEVEL					
	0	1-7	8-14	15-49	50-99	100+
15-24	19.01%	19.34%	16.16%	17.79%	20.21%	18.71%
25-34	18.48	20.38	23.10	19.95	14.89	20.53
35-44	23.35	22.84	26.16	23.68	23.36	23.33
45-54	21.54	20.15	19.18	20.94	23.65	19.81
55-64	17.62	17.29	15.40	17.64	17.89	17.62
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

TABLE 7 : SEX DISTRIBUTION BY LEVEL OF EXPOSURE

SEX	SAMPLING FRACTION FOR EXPOSURE LEVEL					
	0	1-7	8-14	15-49	50-99	100+
M	50.02%	50.42%	51.22%	50.04%	49.98%	49.51%
F	49.98	49.58	48.78	49.96	50.02	50.49
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

For each category of the variable FLIGHTS, a breakdown by AGE and SEX is required. The distributions of AGE and SEX for given levels of exposure are shown in Tables 6 and 7.

The only additional information required to calculate the sample size is an estimate of the rate of hypertension in the target population. The Health and Lifestyle Survey, described later, estimates, that 9.98 per cent of the sample aged 25-34 are hypertensive in 1991/92. There is no figure for the age-group 15-24 because all individuals sampled in the original 1984/85 survey were over 18. However, the figure for the 18-24 age-group in 1984/85 showed that less than one per cent were hypertensive. Using the figure 9.98 per cent in EGRET SIZE yields the sample sizes estimates of Tables 8 and 9. Estimates presented are based on six and four exposure categories because the estimated number of overflights per month is very variable (see Table 5). While our final recommended sample sizes are based on an continuous outcome for our equal-sized exposure groups, the figures in Table 9 provide a useful comparison based on a discrete outcome.

TABLE 8 : SAMPLE SIZES FOR SIX EXPOSURE CATEGORIES* TO AIRCRAFT OVERFLIGHT, ALPHA = 0.05

RELATIVE RISK	POWER 80%	85%	90%	95%	99%
1.1	224,728	252,114	288,536	346,540	468,245
1.2	58,380	65,494	74,956	90,024	121,640
1.3	27,777	31,162	35,664	42,833	57,876
1.4	16,200	18,174	20,421	24,981	33,754
1.5	10,769	12,081	13,826	16,605	22,437

* CATEGORIES: 0, 1-7, 8-14, 15-49, 50-99, 100+ overflights per month

TABLE 9 : SAMPLE SIZES FOR FOUR EXPOSURE CATEGORIES* TO AIRCRAFT OVERFLIGHT, ALPHA = 0.05

RELATIVE RISK	POWER 80%	85%	90%	95%	99%
1.1	165,210	186,404	214,746	260,182	356,444
1.2	43,032	48,552	55,934	67,769	92,842
1.3	20,523	23,156	26,676	32,321	44,278
1.4	11,997	13,536	15,594	18,894	25,884
1.5	7,992	9,017	10,388	12,586	17,242

* CATEGORIES: 0, 1-7, 8-49 and 50+ overflights per month

In Tables 8 and 9, as expected a very large sample size is needed for a very small relative risk of 1.1, and the required sample size decreases as the relative risk increases. It is also noticeable that the sample size increases as the power increases. This is because a greater degree of precision requires a higher number of subjects to obtain this precision. Note that the sample sizes in Table 9 with four exposure categories are much less than the sample sizes in Table 8 with six exposure categories.

Figures 1 to 10 graph power versus sample size for relative risks ranging from 1.5 to 1.1. In Figures 1 to 5 the distribution of monthly overflights has been categorized into six categories and in Figures 6 to 10 the distribution of monthly overflights has been categorized into four categories. Note once again the required sample sizes are much lower for four categories of overflights.

THE HEALTH AND LIFESTYLE SURVEY

The Health and Lifestyle Survey (HALS) is a nationwide survey, conducted in 1984/85 and then again in 1991/92, of the physical and mental health, attitudes and lifestyles of a random sample of 9,003 British adults over the age of eighteen (Cox, 1987), Its principal objective is to examine the relationship of lifestyles, behaviours and circumstances to the physical and mental health of these individuals. The Survey focuses in detail on four major areas - diet, physical exercise, cigarette smoking and alcohol consumption. Data on a number of physiological measures such as systolic arterial pressure (SAP) and diastolic blood pressure (DAP) was also collected by a nurse after the initial interview. Their definition of hypertension is SAP≥160mm/Hg and DAP≥ 95mm/Hg.

Table 10 presents data on systolic blood pressure from the Health and Lifestyle Survey. Note that the mean systolic blood pressure increases with age, in both male and female subjects, and is higher for males than for the corresponding category of females. The standard deviation of the mean also increases with age, and is slightly higher for females than for the corresponding category of males.

TABLE 10 : MEAN AND STANDARD DEVIATION OF SYSTOLIC BLOOD PRESSURE FOR MALES AND FEMALES AGED 18-69

SEX	AGE	SYSTOLIC MEAN	S.D.	N
M	18-29	121.7 mm/Hg	12.2	732
M	30-39	124.0	12.1	691
M	40-49	127.1	13.6	564
M	50-59	133.4	16.6	503
M	60-69	137.1	19.5	453
F	18-29	111.6 mm/Hg	10.9	877
F	30-39	114.3	12.1	929
F	40-49	119.5	14.1	707
F	50-59	128.5	18.5	601
F	60-69	135.7	19.6	557
BOTH	18-69	123.5	16.9	6605

Note that in the first Health and Lifestyle Survey 12,254 valid addresses were visited by interviewers and yielded 9003 successful interviews, 2341 refusals, 646 failure to contact any occupant and 264 other non-responses. Therefore, 73.5% of valid addresses yielded a successful interview. Of the 9003 successful interviews, only 82.4% agreed to the future visit by a trained nurse who collected the physiological measurements including blood pressure. Seven years later the second Health and Lifestyle Survey was able to interview 65.31% of those alive with 8.97% of the HALS 1985 respondents having died before 1991/92.

RECOMMENDATIONS

The recommended sample size is 12,800 participants. This is based on the assumption of a continuous outcome and-that mean difference comparisons are desired between four equal-sized exposure groups (no exposure, low exposure, medium exposure and high exposure). The worst case scenario involves 400 participants in each group compared (for females 60-69) which yields 1600 participants (4 exposure groups of 400 each) for each age-sex group. Eight age-sex groups yields 1600 x 8 = 12,800 participants. The use of the worst case scenario involves some conservatism in that the range of required sample sizes in each group varies from 124 (best case) to 400 (worse case). These values depend on the estimated standard deviation of the systolic blood pressure which is imprecise, so that some conservatism is justified.

Note that sample sizes estimates are provided for ten age-sex groups rather than eight. In order to minimise drop outs we recommend either the youngest or oldest age groups not be enrolled in any study. We have included estimates for these groups for completeness.

Note that a sample size of 12,800 yields for a alpha level of 5% and relative risk of 1.5, 95% power of detecting increased hypertension based on a logistic model (see Table 9). However, if the relative risk was 1.3 then a sample size of 20,523 would be needed for 80% power.

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1. DALLAL G E (1990) "PC-SIZE : Consultant - A Program for Sample Size Determinations", The American Statistician, 44, 243.

2. Statistics and Epidemiology Research Corporation (1992) EGRET SIZE - Sample Size and Power for Nonlinear Regression Models, Manual Revision 20, Seattle, Washington.

3. COX B D et al (1987), The Health and Lifestyle Survey, Health Promotion Research Trust.

Figure 1 : Power versus sample size based on a relative risk of 1.5, an alpha level of 0.05 and an assumed distribution of overflights per month : 0 overflights (80.71%), 1-7 (6.47%), 8-14 (2.20%), 15-49 (3.98%), 50-99 (2.28%), 100+ (4.34%).

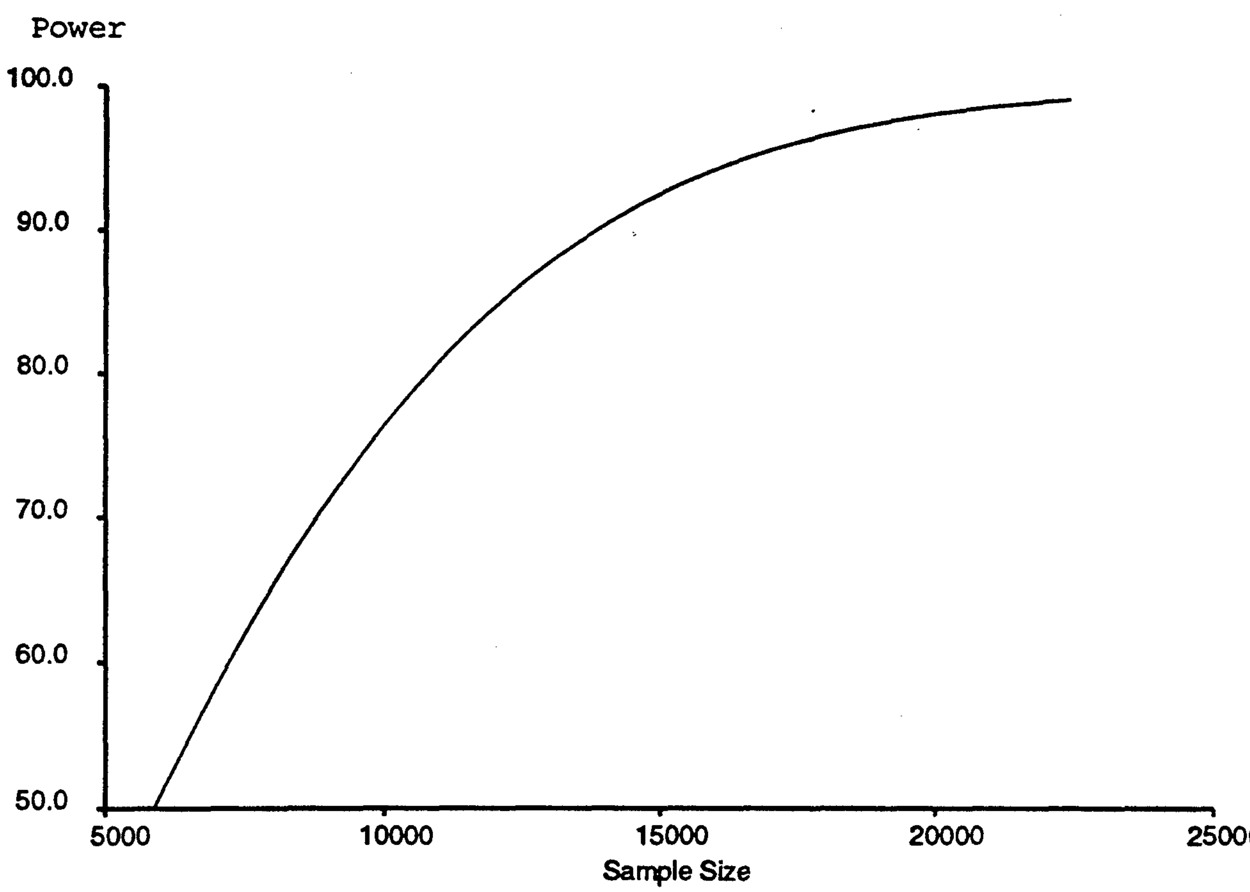


Figure 2 : Power versus sample size based on a relative risk of 1.4, an alpha level of 0.05 and an assumed distribution of overflights per month : 0 overflights (80.71%), 1-7 (6.47%), 8-14 (2.20%), 15-49 (3.98%), 50-99 (2.28%), 100+ (4.34%).

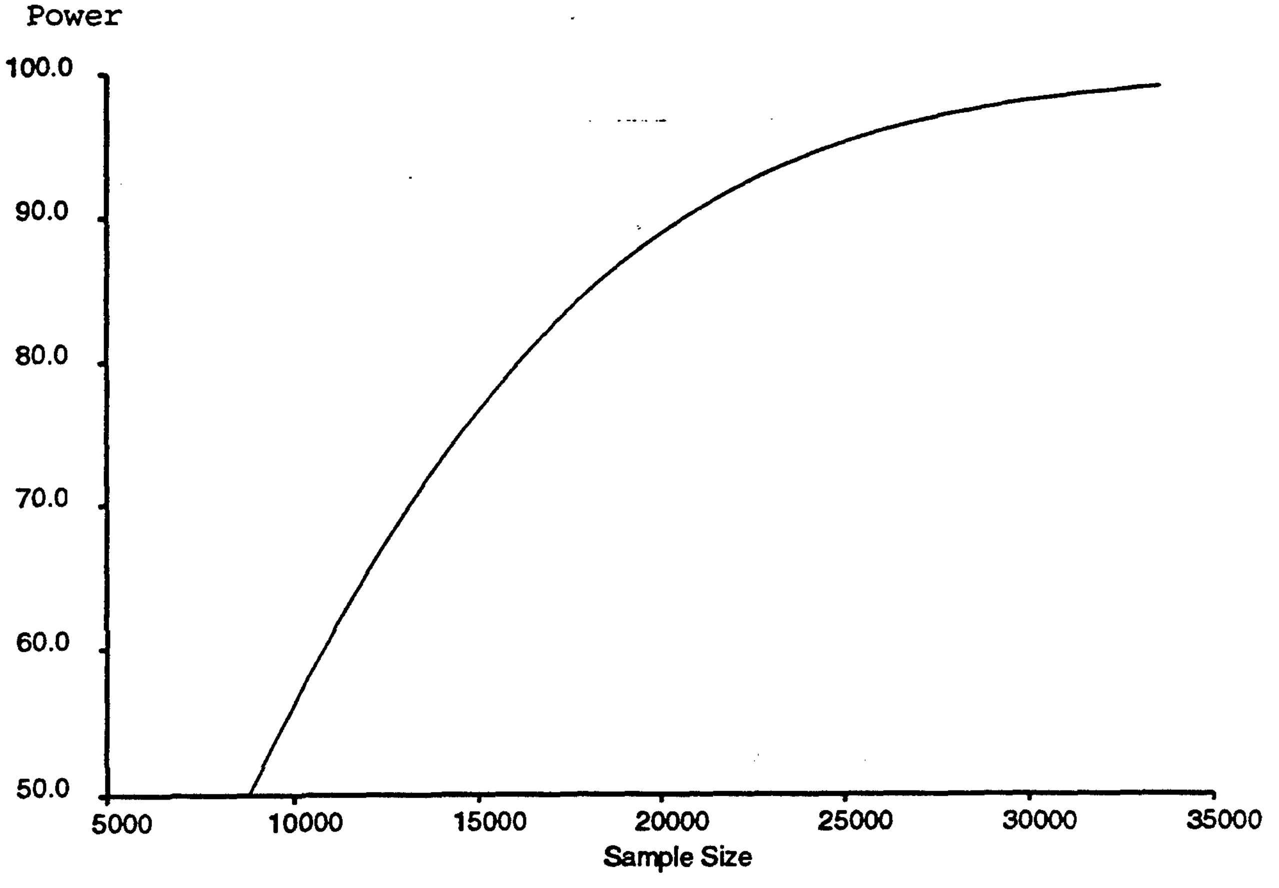


Figure 3 : Power versus sample size based on a relative risk of 1.3, an alpha level of 0.05 and an assumed distribution of overflights per month : 0 overflights (80.71%), 1-7 (6.47%), 8-14 (2.20%), 15-49 (3.98%), 50-99 (2.28%), 100+ (4.34%).

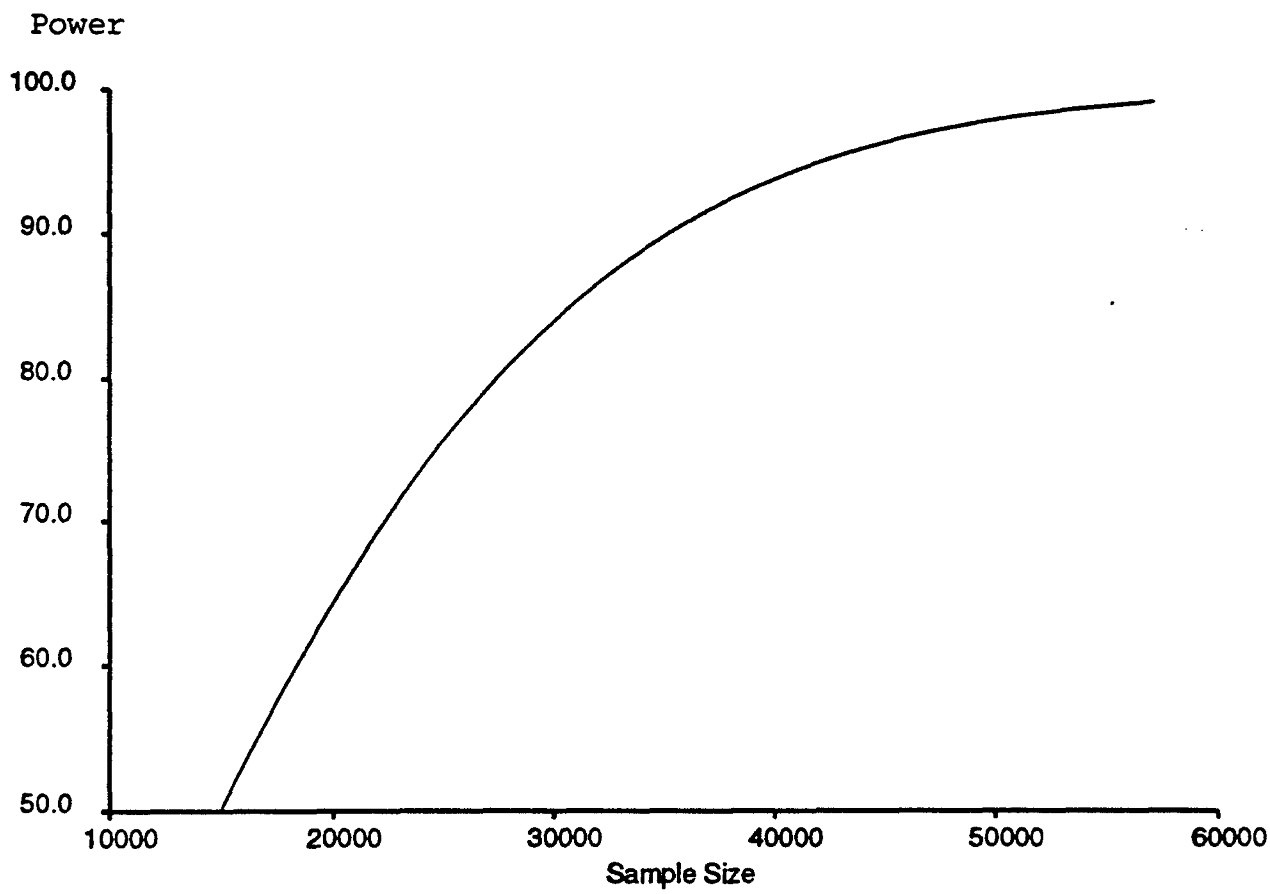


Figure 4 : Power versus sample size based on a relative risk of 1.2, an alpha level of 0.05 and an assumed distribution of overflights per month : 0 overflights (80.71%), 1-7 (6.47%), 8-14 (2.20%), 15-49 (3.98%), 50-99 (2.28%), 100+ (4.34%).

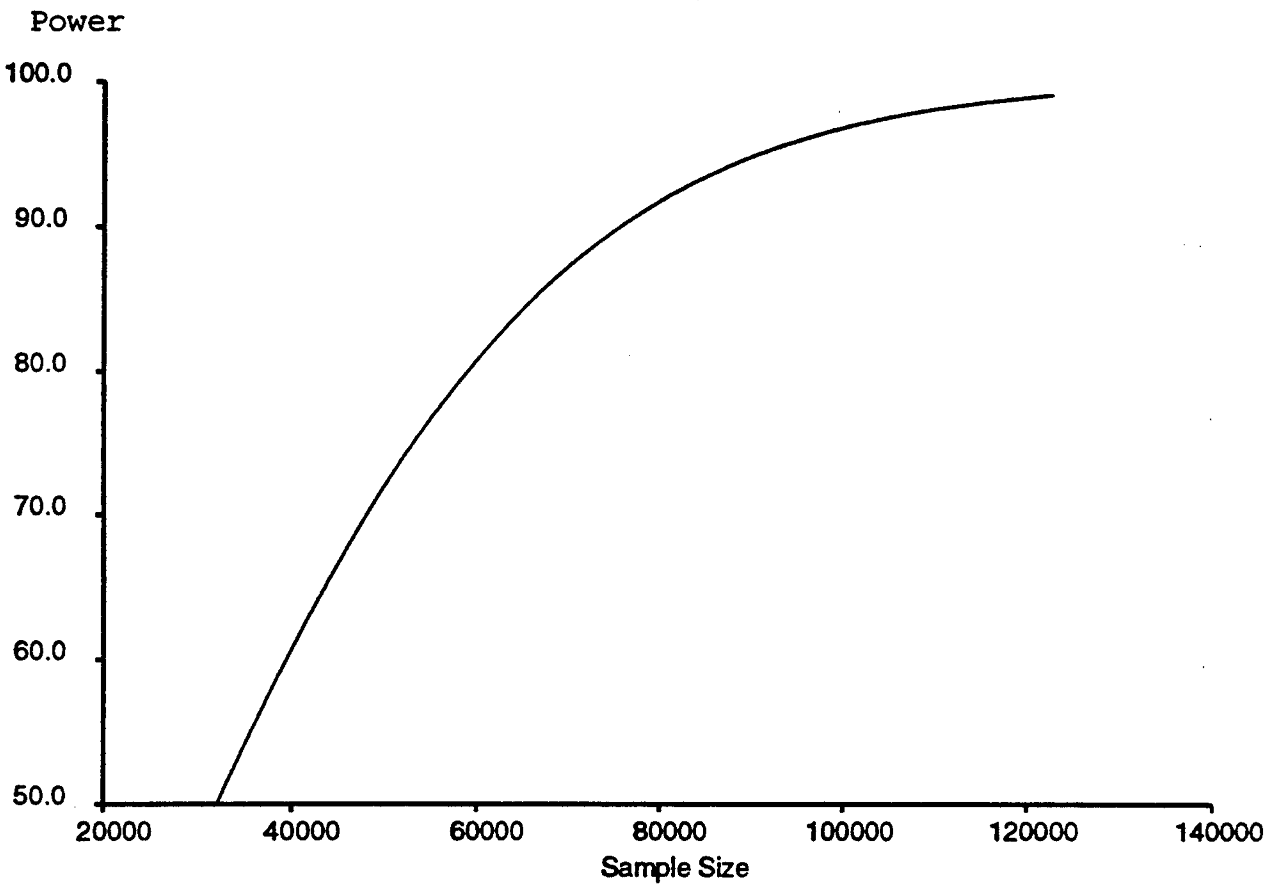


Figure 5 : Power versus sample size based on a relative risk of 1.1, an alpha level of 0.05 and an assumed distribution of overflights per month : 0 overflights (80.71%), 1-7 (6.47%), 8-14 (2.20%), 15-49 (3.98%), 50-99 (2.28%), 100+ (4.34%).

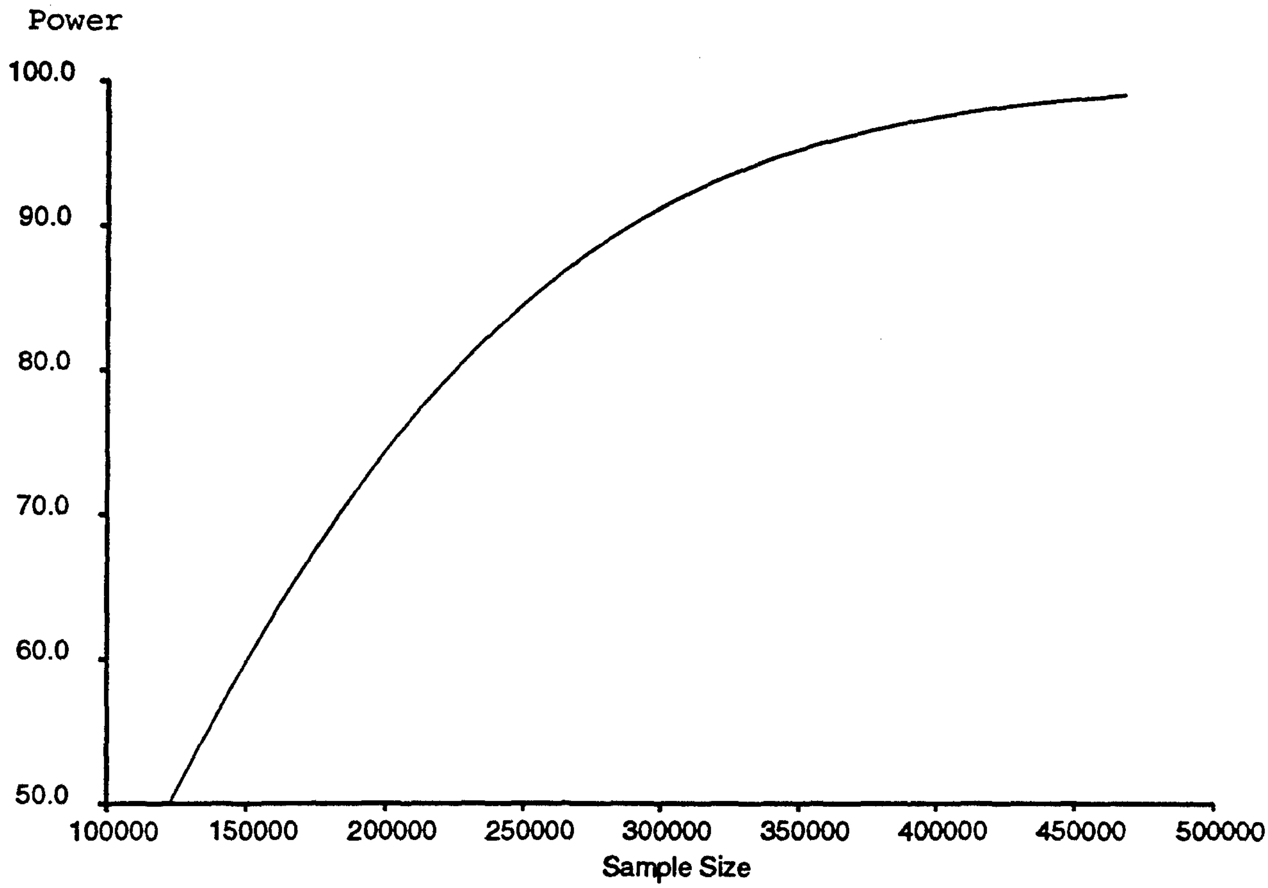


Figure 6 : Power versus sample size based on a relative risk of 1.5, an alpha level of 0.05 and an assumed distribution of overflights per month : 0 overflights (80.71%), 1-7 (6.47%), 8-49 (6.19%), 50+ (6.63%).

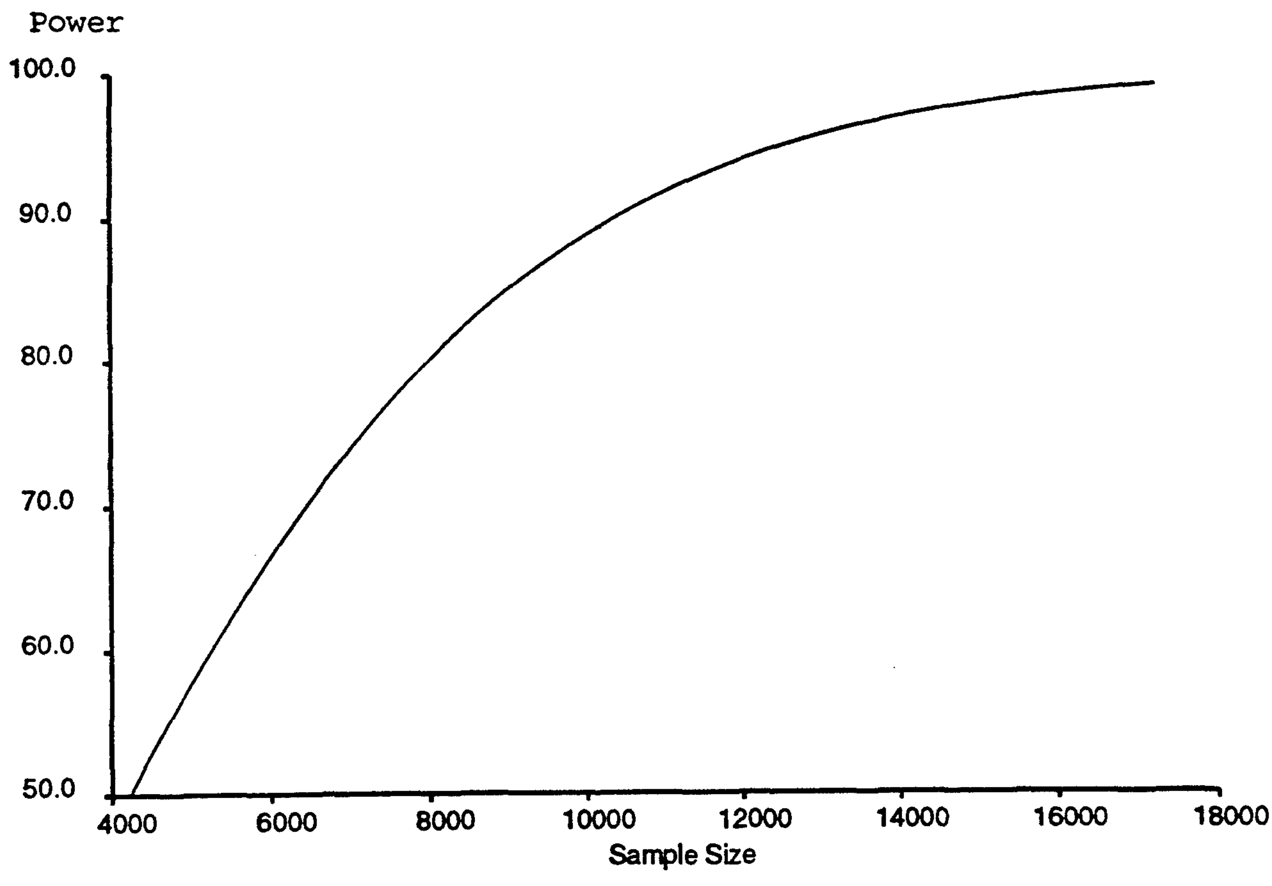


Figure 7 : Power versus sample size based on a relative risk of 1.4, an alpha level of 0.05 and an assumed distribution of overflights per month : 0 overflights (80.71%), 1-7 (6.47%), 8-49 (6.19%), 50+ (6.63%).

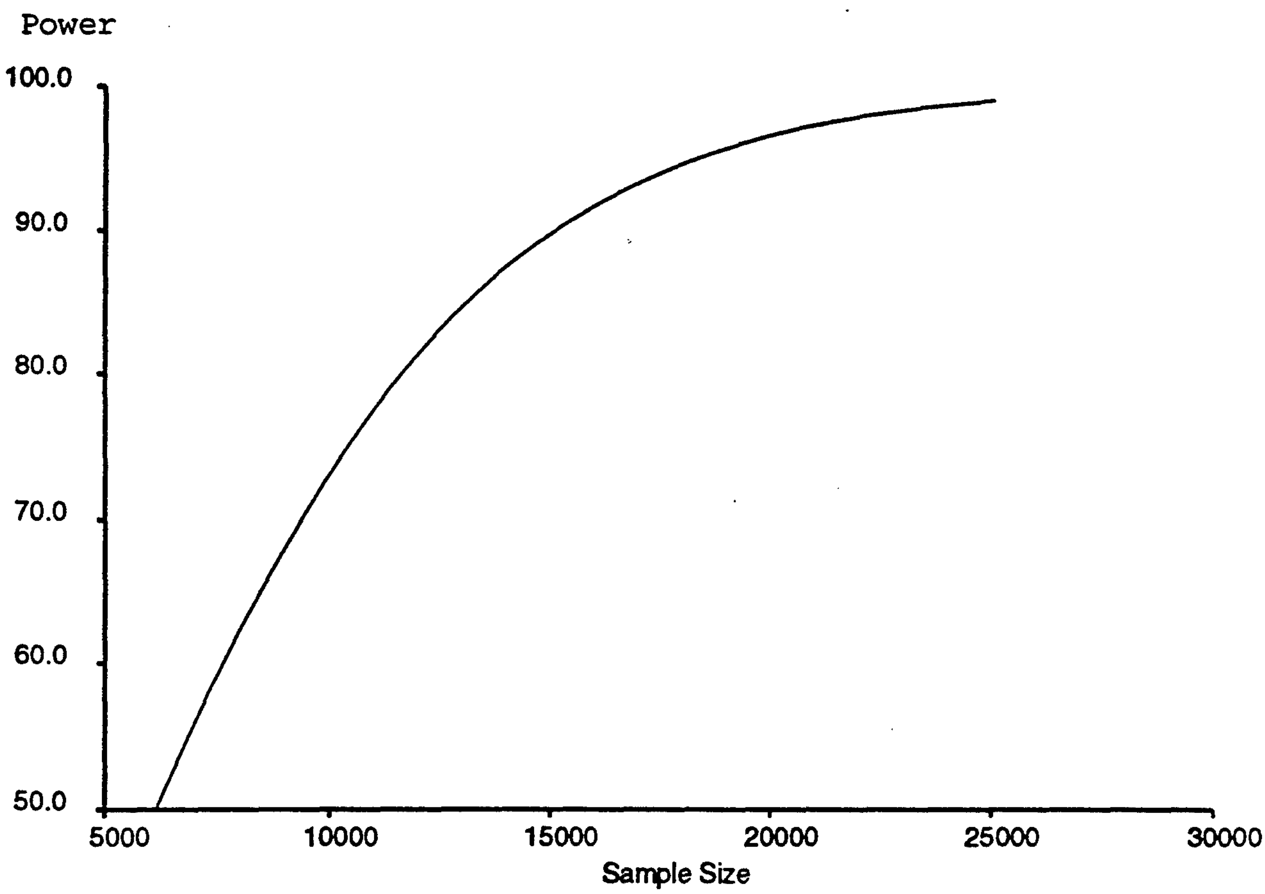


Figure 8 : Power versus sample size based on a relative risk of 1.3, an alpha level of 0.05 and an assumed distribution of overflights per month : 0 overflights (80.71%), 1-7 (6.47%), 8-49 (6.19%), 50+ (6.63%).

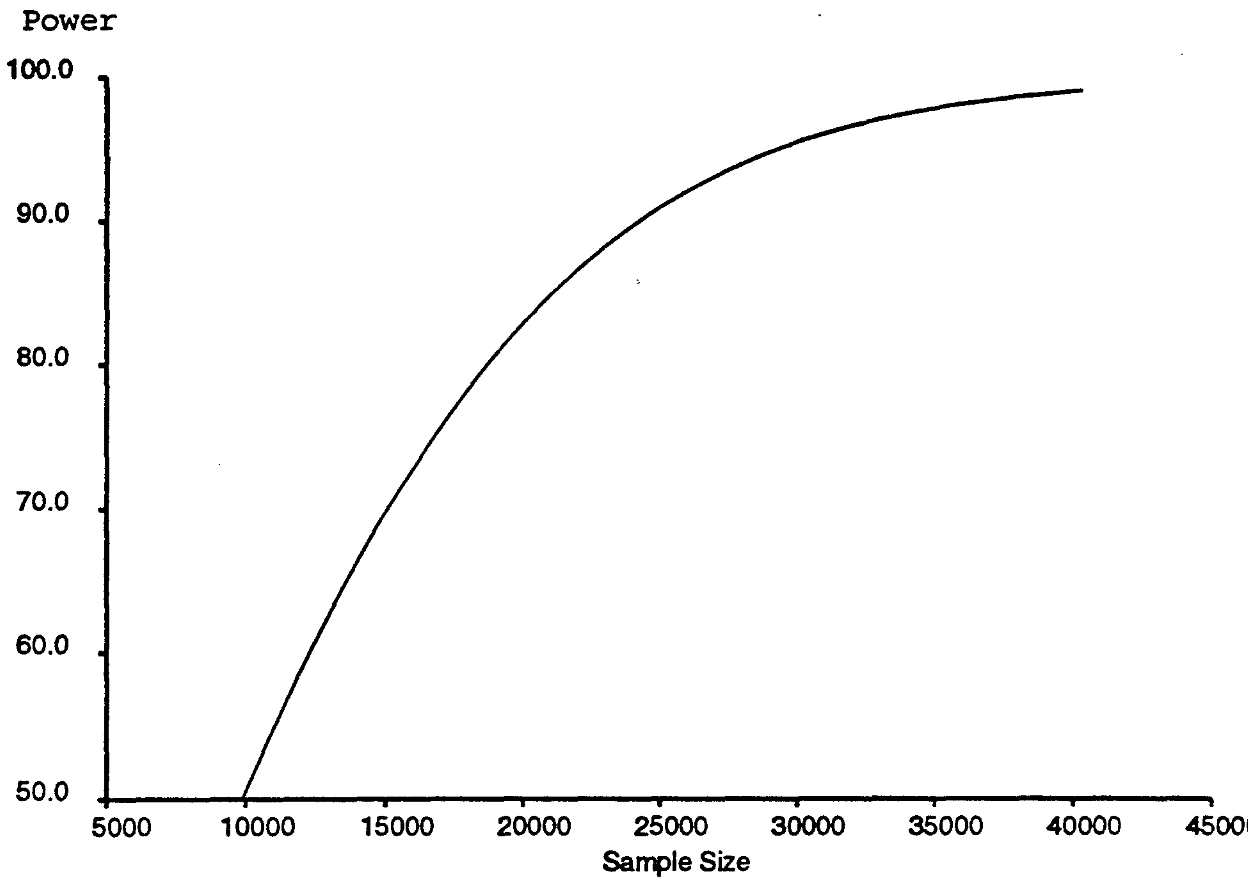


Figure 9 : Power versus sample size based on a relative risk of 1.2, an alpha level of 0.05 and an assumed distribution of overflights per month : 0 overflights (80.71%), 1-7 (6.47%), 8-49 (6.19%), 50+ (6.63%).

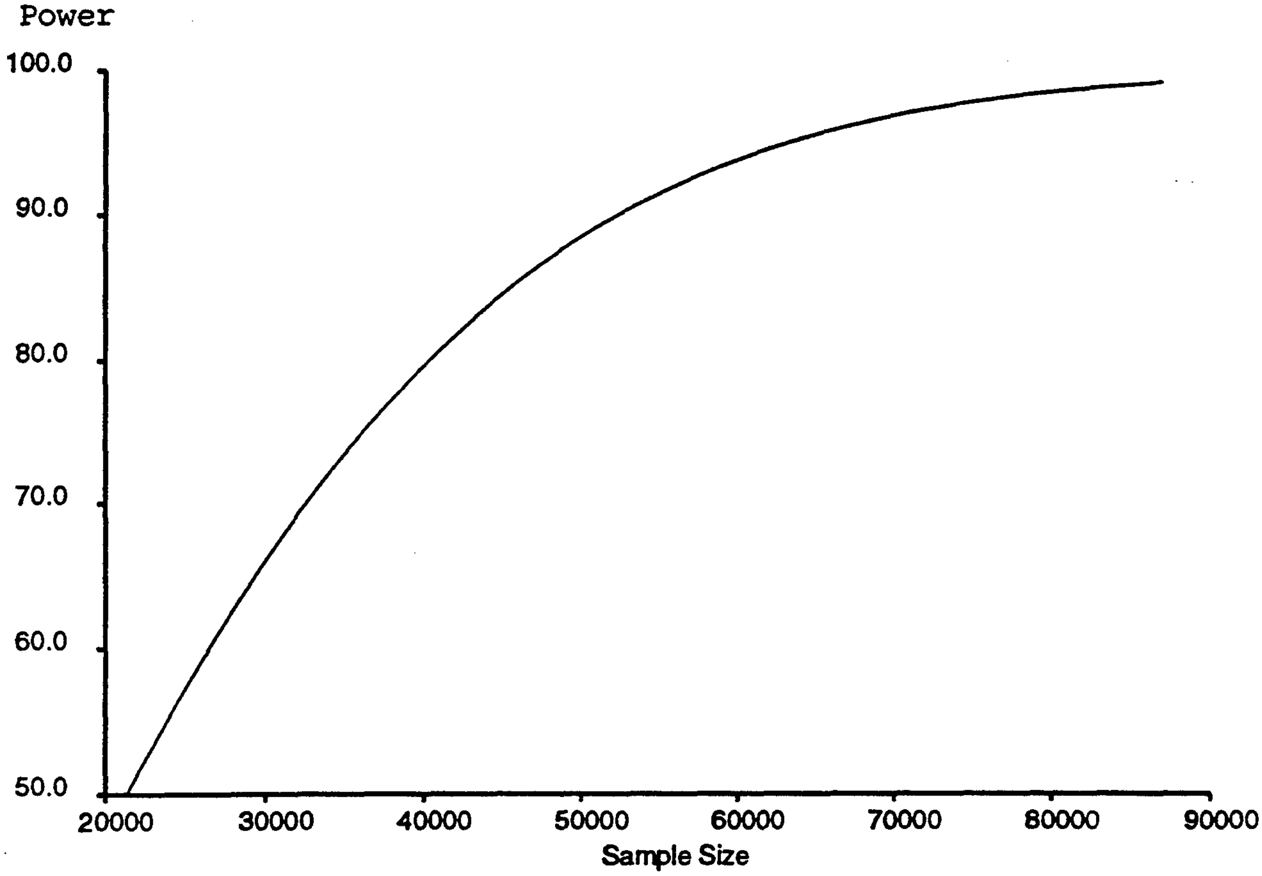
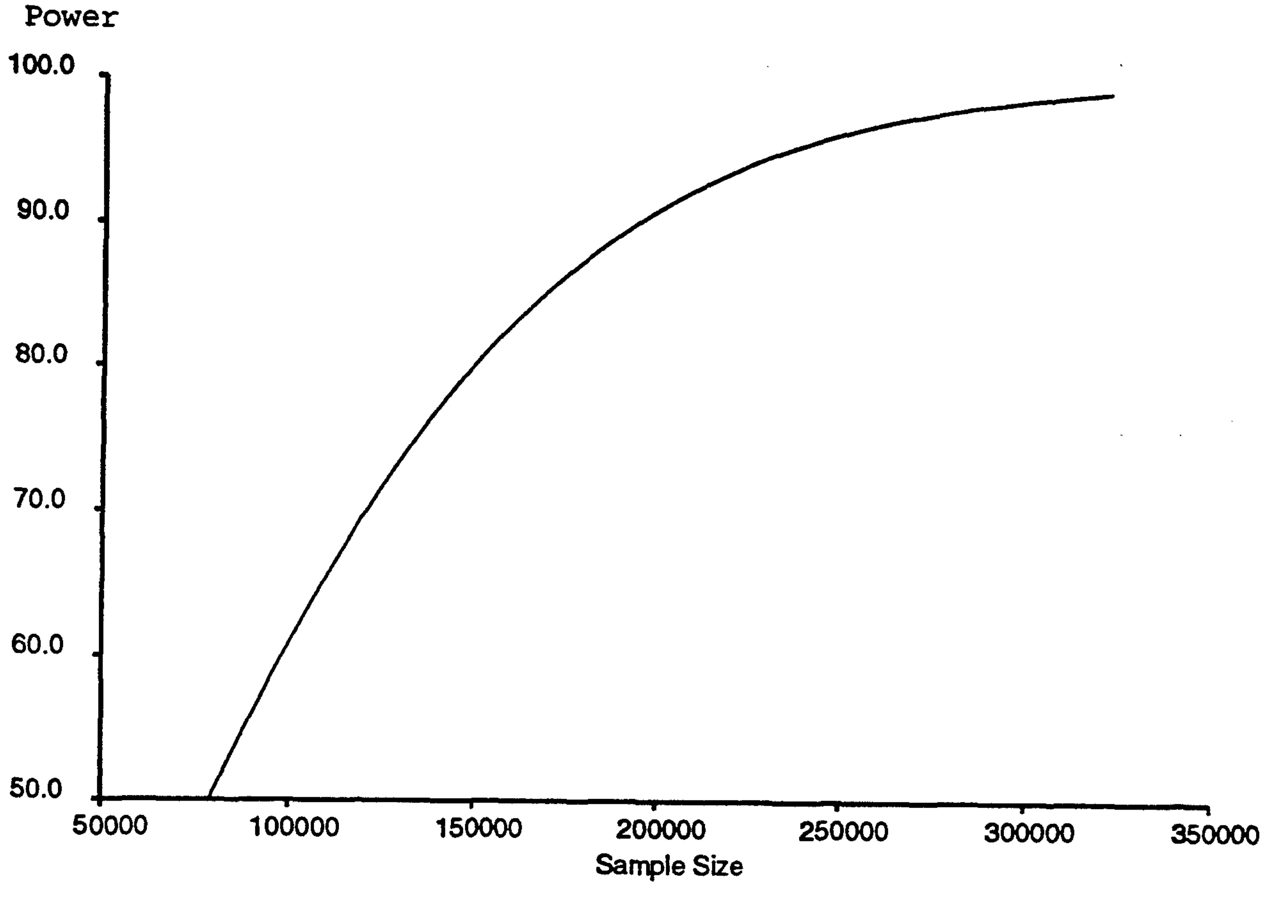


Figure 10 : Power versus sample size based on a relative risk of 1.1, an alpha level of 0.05 and an assumed distribution of overflights per month : 0 overflights (80.71%), 1-7 (6.47%), 8-49 (6.19%), 50+ (6.63%).



Technical Appendix 3

The Flyby low altitude military aircraft noise calculation model

This model was developed by the National Physical Laboratory for the UK Ministry of Defence to calculate noise levels from low flying military aircraft. The model is implemented in 'C' and can be run on a portable PC. The model is designed to calculate a time history of the A-weighted sound pressure level at a single point on the ground for a flyby of a defined aircraft type operating under defined conditions. The sound exposure level, maximum level, and rise time over the top 30 dB are calculated from the noise level time history. The calculation procedures use the noise-distance-power database of the NPL developed AIRNOISE model which is designed for calculating the overall noise for airfield operations..

The user must select an aircraft type and an appropriate source directivity correction file, the engine power setting, the aircraft height and speed, and the minimum lateral distance from the flight track to the observation point. The programme then calculates the instantaneous A-weighted sound pressure level at one tenth second intervals throughout the flyby by taking the slant distance and the angle between the line from aircraft to observation point and the flight track into account. Further details are given at the Inter-Noise 92 paper copied below.

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inter-noise 92
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A PREDICTION MODEL FOR NOISE FROM LOW-ALTITUDE MILITARY AIRCRAFT

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INTRODUCTION

For a number of years, the National Physical Laboratory, supported by the Ministry of Defence, has been developing AIRNOISE, a mathematical model for computing aircraft noise contours (1). As part of the continuous programme of development of the model we were asked to extend it to include low-altitude military operations. The objective is to predict the complete time-history of the noise of these very rapid events, thus providing information on onset rates as well as maximum levels. In order to provide high quality data with which to validate and refine the model, a special noise trial - Exercise Luce Belle - was conducted in which a number of aircraft types flew low, straight and level at various speeds and engine power settings. This paper firstly describes the noise trial and then the prediction model. The comparison of predictions with actual measurements is discussed. In particular the effects of changes in the assumptions in the model about lateral attenuation are explored.

MEASUREMENTS

The noise trial is described in detail in two NPL reports (2,3). The aircraft types used were Tornado GR1, Jaguar, Harrier GR5, Hawk T1A, F-15 and F-16. Each aircraft flew one or two sorties during which a number of conditions typical of those used in low-altitude training were replicated in a number of runs across a target area. At a primary site directly under the

flight track, four sets of microphones, some at 1.2 m high and some in the ground plane were deployed. Two similar sets were deployed at a site 1000m perpendicular to the track. All of the signals were digitally recorded using either
DAT or PCM systems. Information on the actual height, speed and ground track for each run was obtained from a combination of kine-theodilite, radar and video tracking systems. Details of the data analysis techniques and the full set of results are given in the reports. As an example, Figure 1 shows the results for the Tornado at one of the locations on the primary site. The results from the trial have been used to update the rules governing permitted heights and speeds in the UK Low Flying System (4).

THE FLYBY PREDICTION MODEL

This model is related to the AIRNOISE model for airfield operations but is separate from it. The software is designed to calculate a time-history of the A-weighted sound pressure level, at a single point on the ground, for a flyby of an aircraft operating under defined conditions. The sound exposure level, the maximum level and the rise-time over the top 30 dB are also calculated. The calculations make use of the noise-distance-power database of AIRNOISE (5). The sequence of stages of the software is as follows. The user selects an aircraft type and an appropriate source noise directivity correction file. An engine power setting is selected and the associated coefficients of the noise-distance equation are read from the aircraft data file. The user then enters the aircraft height, speed and the lateral distance from the observation point to the flight track. From this the minimum slant distance is calculated. Then at one-tenth second intervals throughout the event, the slant distance and the angle between the line from aircraft to observation point and the flight path are calculated. A level is calculated at the observation point from the noise-distance equation and the directivity correction. Corrections are then made for engine power and for lateral attenuation. From the series of levels throughout the event, the other quantities are measured. The software is written in "C" Language and runs on a portable PC.

COMPARISON OF PREDICTIONS AND MEASUREMENTS

The model was originally implemented using the SAE procedure for lateral attenuation (6). In a companion paper to this one (7), the results of the UK noise trial, together with a large quantity of data from similar noise measurements on military aircraft in the USA have been analysed and it has been shown that the SAE procedure tends to over estimate the lateral attenuation at angles of elevation between 2 and 45 degrees.
It is proposed that the correction for lateral attenuation takes the form of,

Attenuation (dB) = 20.49/Angle - 0.1818

Figure 2 shows a comparison of the measured time-history for a Tornado at a speed of 480 knots and a height of 238 feet directly overhead, with the predicted time history assuming the new proposal, labelled AL. Over the top 30 to 40 dB of the time-histories, which is the most important in terms of subjective response, there is generally good agreement between prediction and measurement. Figure 3 looks at the same event but at 100 metres to the sideline, and shows a comparison between predicted time-histories using either the SAE correction or the new proposal, and the measured event. There is a small difference between the two forms of lateral attenuation correction at the point of maximum level, but differences are most marked at times well before and after the maximum level is reached. These correspond of course to low angles of elevation. The indications are that agreement with the measured data is better when the newly proposed method is used.
Taking the results from all 18 overflights of the Tornado in Exercise Luce Belle, Figure 4 compares measured and predicted values of L_{Amax} directly beneath the flight track. Also shown are a linear regression fit to the points and the line of equality. On average the model underpredicts by about 1 dB.

CONCLUSIONS

A prediction model has been developed and implemented in "C" on a portable PC which generates time-histories of A-weighted sound pressure level for a flyby of an aircraft at a given constant speed, height and power setting. A carefully controlled noise trial has been

conducted to provide data for a range of aircraft and conditions. There is good agreement between the model predictions and measured data.

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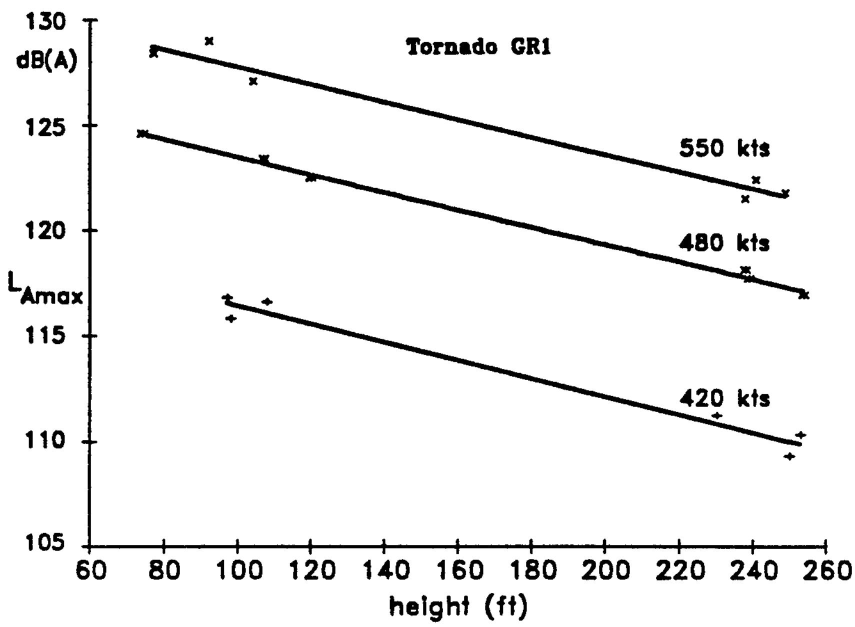

Figure 1. Maximum noise levels at primary site : Tornado

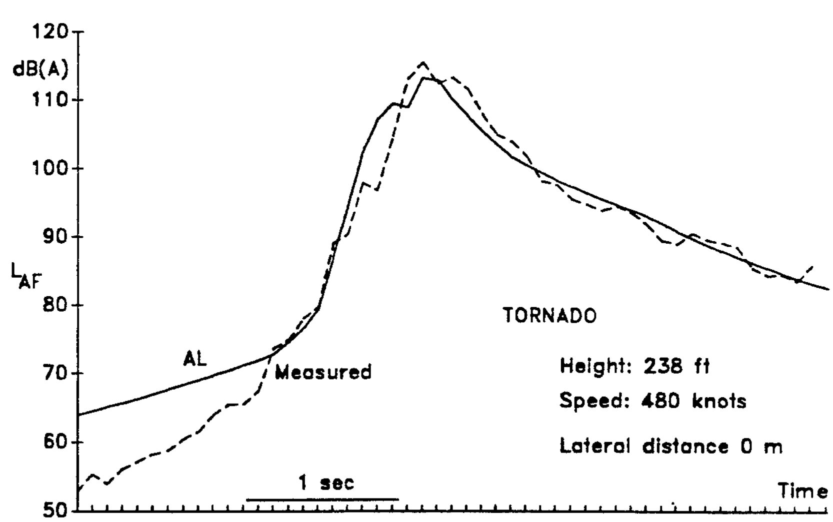

Figure 2. Comparison of measured and predicted time-histories

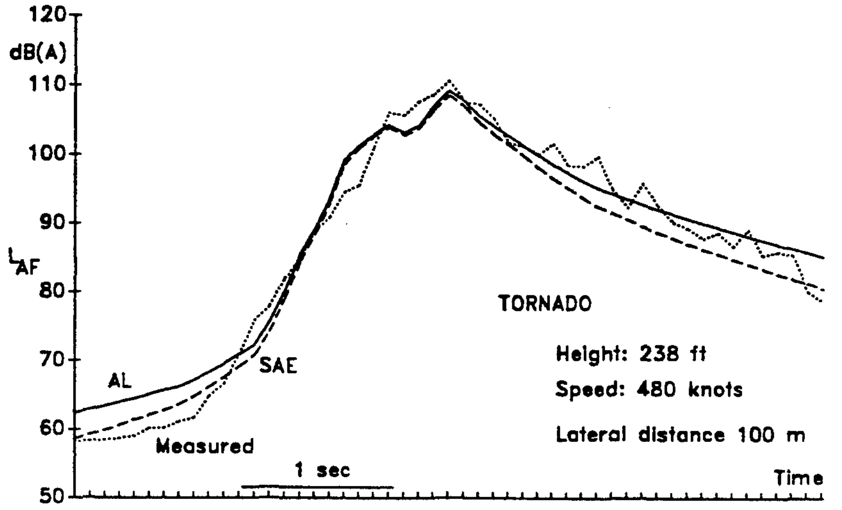

Figure 3. Comparison of measured and predicted time-histories at 100 metres to sideline.

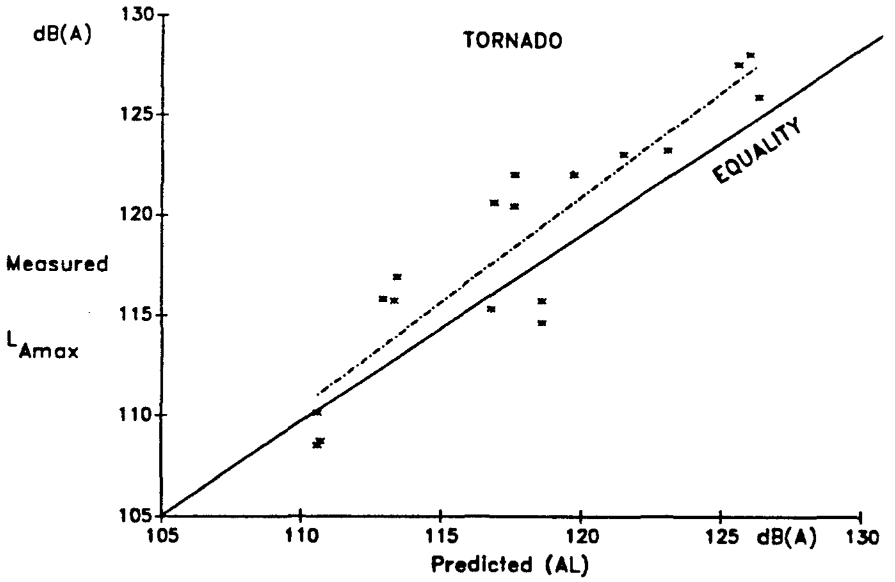

Figure 4. Measured and predicted values of L_{Amax}.