Research and Development Directorate
National Air Traffic Services

CS Report 9539

Review of the Departure Noise Limits at Heathrow, Gatwick and Stansted Airports

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J B Ollerhead

Prepared on behalf of the Department of Transport
by the Civil Aviation Authority London

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RDD File Reference
8CS/115/7

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SUMMARY

This report describes the technical studies undertaken in support of the review of departure noise limits at the London airports performed by the Department of Transport's Aircraft Noise Monitoring Advisory Committee (ANMAC). Following an analysis of a large sample of noise and radar measurements obtained from the Noise and Track-keeping Monitoring System, a modelling exercise was carried out to evaluate the effects of changes to the number and disposition of noise monitors, as well as the noise limits, on the overall performance of the system for noise infringement monitoring. On the basis of the results, ANMAC recommended increasing both the efficiency and the stringency of the present system, by extending the monitor arrays and lowering the current limits.

Prepared on behalf of the Department of Transport
Civil Aviation Authority, London, December 1995

ISBN 0 86039 653 3

EXECUTIVE SUMMARY

OBJECTIVES

1 The current departure noise limits at Heathrow, Gatwick and Stansted Airports have been in place for many years and, in 1993, the Minister for Aviation thought it was timely for reductions in the limits to be considered. He therefore asked the Aircraft Noise Monitoring Advisory Committee (ANMAC) to review the limits and to recommend what, if any, changes should be made to the monitoring provisions at the three London airports. The overall study into monitoring practices was split into three phases: the aim of the first phase reported here was to review the present departure noise limits, and to consider the effects of lower limits and different monitor placements. Later phases of the study will cover the possibility of (i) aircraft type specific differential departure noise limits and (ii) approach noise monitoring.

2 ANMAC commissioned DORA1[1] to undertake a data collection exercise to acquire representative operational data, and a modelling exercise to enable the effects of different limits and better positioning of monitors to be quantified.

BACKGROUND

3 The present limits, which date back to the original Heathrow noise monitoring system installed in 1958, are expressed in PNdB (the unit considered then to best represent human judgement of the noisiness of aircraft noise events). The limits were set at 110 PNdB daytime (0700 - 2300 local), and 102 PNdB night-time, at any monitor, which related to the maximum noise levels which it was considered those living in the major built-up areas closest to the airport should be expected to tolerate. The highest noise levels at that time were produced by non-noise certificated jet aircraft, ie pre-Chapter 2.

4 In 1992/3 the present Noise and Track-Keeping monitoring system was installed. Noise data is obtained from a total of twelve fixed monitors spread between the three airports (in addition up to 24 mobile monitors are available for special studies). This is combined in the system with weather data, radar data, aircraft type and other flight details. Event noise levels are measured in L_{Amax}, so dBA equivalents of the original PNdB limits are specified. These are 97 and 89 dBA respectively.

5 Several limitations of the present system are apparent, principally inconsistencies between the monitor arrays for the various runways and airports - in terms of the distances of monitors from start-of-roll, distances to the side of

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Note: An earlier version of this Executive Summary was annexed to the DoT Consultation Paper "Review of Noise Limits for Departing Aircraft at Heathrow, Gatwick and Stansted Airports" (October 1995).

[1] See the Glossary for definitions of terms and abbreviations.

tracks, monitor elevations and monitor spacing - and it was clear to ANMAC that major improvements could be made.

6 Since the present noise limits were set, non-noise certificated jets have been phased out and the proportion of Chapter 2 aircraft has steadily decreased. This continuing trend towards quieter aircraft types has caused a significant fall in infringement rates since the late 1970s.

NOISE MONITORING CRITERIA AND CONSTRAINTS

7 It was agreed that the main objectives of the departure noise limits are to detect and penalise excessively noisy movements, to discourage operations by the noisiest aircraft types, and to encourage the use of quieter types.

8 The difficulty of setting limits by defining subjective 'effects' thresholds at specific points by reference to precise and relevant criteria (eg speech interference or sleep disturbance) was noted; rather, it was decided that noise limits should have a sound empirical base resting on measured data which defines what is operationally achievable. The night-time limit should be suitably lower than the daytime one, although in principle it should also be compatible with the Night Restrictions Scheme which reflects the findings of successive sleep disturbance studies. ANMAC concluded that noise limits should be defined in terms of L_{Amax}.

9 It was agreed that the aim should be to have noise limits that are uniform between the three airports and between departure routes: a constant overall limit (the ‘Base Limit’) should apply at a fixed track distance of 6.5 km from start-of-roll (the ‘Reference Distance’). This is the distance of the flyover noise measurement point for certification - there are few built-up areas closer in than this at the three airports. A basic requirement is that noise levels diminish along the track after an aircraft passes a monitor.

10 Adjustments are required to the limits applying at individual monitors (ie ‘Infringement Levels’) to allow for variations in the monitor positions relative to the flight paths (track distance and monitor elevation). ANMAC also considered methods of allowing for the lateral displacement of tracks relative to each monitor, but concluded there were no practical means of doing this. It was therefore concluded that increasing the number and better positioning of monitors should be investigated, although obstacles to the ideal positioning of noise monitors were recognised (these include the multiplicity of routes, especially at Heathrow, the lack of suitable monitor sites due to the local terrain, and the costs of providing, installing and servicing additional fixed monitors, especially those proposed for remote locations).

11 For differential monitoring, consideration will have to be given to some form of classification of aircraft by type. Appropriate classification was also a necessary part of Phase 1 of the review, where one important criterion for the

classes chosen was that they indicate how the phase-out of Chapter 2 aircraft might bear upon subsequent revisions to the limits. The implications of particular noise limits for each aircraft type could be assessed by reference to statistical distributions of normalised ‘Reference Levels’. ANMAC decided that the measured data should be analysed by the following groups, based on similarities of noise characteristics:-

A	Concorde
B	All Boeing 747s
B2	Chapter 2 Boeing 747 (sub-group of B)
B3	Chapter 3 Boeing 747 (sub-group of B)
C	Heavy Chapter 2[2]
D	Heavy Chapter 3
E	Light Chapter 2
F	Light Chapter 3[2]
G	Propeller-powered
H	Executive jets

12 It was agreed that the analysis of monitoring options should focus primarily on the most critical aircraft type for noise infringements, which is the Chapter 2 Boeing 747. Chapter 3 B747s, with a similar slow climb performance, are expected to be the noisiest aircraft operating in significant numbers after the Chapter 2 phase-out is completed.

MEASUREMENTS

13 The measurement exercise was designed to collect data for flights which passed overhead (or very near) noise monitors, to eliminate the need for any lateral positional adjustments to be applied. The intention was that after applying suitable adjustments for monitor elevation and track distance, Reference Levels from different monitors could be pooled subject to satisfactory statistical test results. All the sites used were as close as practical to the Reference Distance; information from seven of the fixed monitors was augmented by data from seven mobile monitors, so that departures from each end of each relevant runway at all three airports were covered.

14 Measurements were made at the three airports during April and May 1994. Data was acquired 24 hours a day and a total of 81,913 noise measurements were obtained (of these, approximately 3% were rejected due to unacceptable weather conditions). The radar data was analysed to calculate the distance between the monitor and each flight track at its closest point of approach. For flights close to overhead, this formed the basis for the adjustment applied to the measured noise level to give the ‘Reference Level’ at the Reference Distance, and results were obtained for 21,989 flights, split between airports, monitors and aircraft type groups.

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[2] With some minor qualifications - see Notes 2 and 3 to Table 1 of main text.

15 Detailed checks showed that for the most important aircraft types, noise level differences between the airports and between day and night were not statistically significant. Pooled distributions of Reference Level and the equivalent (‘best-fit’) Normal curves were analysed for each aircraft type group and for all aircraft combined, enabling exceedance rates based on the Normal curves to be studied.

16 It was shown that, at higher noise levels, the ‘all aircraft’ distributions differ by about 6 dB between day and night. This is mainly because proportionately fewer of the noisier types operate at night.

ESTIMATION OF SYSTEM PERFORMANCE

17 An initial analysis to study monitor placement effects was undertaken on the basis that any flight which exceeded the adjusted Base Limit at some point on the ground beneath it, at or beyond the 6.5 km point, even if it passed to the side and therefore did not exceed the limit at the monitor, was an ‘offender’. It was found however that if a system were designed along these lines, then this could result in significant numbers of ‘non-offenders’ also being penalised. This was not considered appropriate. It was agreed therefore that the limits should apply only at the fixed monitors, and that the individual Infringement Levels should be adjusted for the monitor elevation and track distance (using the least negative adjustment where more than one departure route passes close to the monitor).

18 It was agreed that monitor arrays for each runway should be designed to optimise their effectiveness in detecting offenders; this ‘monitoring efficiency’ was assessed in conjunction with the effects of increased system stringency (ie lowering the Base Limit). The analysis was based on the performance of the most critical aircraft type for infringement monitoring, the Chapter 2 Boeing 747. Daytime monitoring efficiencies under the present regime range between 4% and 20% for the various runways’ monitor arrays. Efficiency could be improved by lowering Infringement Levels, and/or adding more (laterally displaced) monitors.

19 In general, it is not possible to set up ideal ‘fences’ of monitors because of the lack of accessible secure sites or interference from other noise sources, eg roads and railways. The performance of the system also has to be balanced against the cost. Practical monitor arrays will necessarily have a limited number of monitors, unevenly spaced and at different track distances and elevations.

20 Analysis showed that the performance of the present arrays in terms of efficiency could be more than doubled by adjusting the individual Infringement Levels to allow for the monitor displacements from the Reference Distance and runway elevation.

IMPROVED MONITORING OPTIONS

21 Further improvements in performance could be obtained by relocating all monitors to the Reference Distance, and optimising the lateral positions with respect to the traffic on different departure routes.

22 If the total numbers of monitors were to be doubled, to reduce the likelihood of aircraft tracks avoiding monitors, theoretical efficiencies in excess of 50% could be obtained.

23 Initial assessments of such ‘optimum’ arrays indicated that lowering the Base Limit by 5 dB from the equivalent present daytime limit would increase the proportion of Chapter 2 Boeing 747 departures registered as infringements from about 6% to approximately 50% under current operating procedures.

24 In addition to a full study of theoretical monitor arrays of varying complexity, it was important that practical options were assessed. Provisional sites as close as possible to the desired theoretical monitor locations were sought at each airport, and the analysis was repeated for these ‘practical’ arrays. For each runway at each airport, the most cost-effective practical monitor array was determined which would give a monitoring efficiency close to 50%. It was shown that this would require a total of about 23 fixed monitors, 11 more than at present[3]. It should be noted that the locations suggested for proposed new noise monitors are only theoretical; BAA are investigating necessary permissions and connection of services, but the actual availability of specific sites is not yet known.

FACTORS AFFECTING CHOICE OF LIMITS

25 ANMAC decided that the new limits should have a sound empirical base of measured data, which defines what is operationally achievable at the present time. This implies that the number of operational infringements should be a realistic but not excessive proportion of the total number of departures. In addition to a consideration of infringement rates, a number of other factors were taken into account, including the phase-out of Chapter 2 aircraft and particularly the impact of the noisiest common aircraft type, the Boeing 747, and the relationship between the night limit and the Night Restrictions Scheme.

26 For each of the practical arrays considered, the effect was calculated of lowering the present limits on: (i) the percentage of offenders, (ii) the percentage of infringements and (iii) the monitoring efficiency. About 5% of all Chapter 2 Boeing 747 departures would be identified as offenders with a Base Limit equal to the current daytime limit; if the limit were reduced by say 3

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[3] Although there are a total of 12 fixed monitors at present, monitor number 1 at Cranford has been excluded from consideration in Heathrow assessments for this study because of its specialised role in relation to Runway 09L departures.

dB to 94 dBA, the proportion would rise to about 20%. For night-time, if the Base Limit were reduced by 2 dBA from 89 to 87 dBA, the infringement rate of these aircraft would increase from around 65% to 85%.

27 As an illustration of the possible future situation when all Chapter 2 aircraft are phased out, about 5% of Chapter 3 B747s would record infringements with a 94 dBA daytime limit, and 55% - 60% of such aircraft would register night-time infringements if the night limit were reduced to 87 dBA.

CONCLUSIONS

28 The needs were clearly identified for both an increase in stringency and improvements to the monitoring efficiency of the present Noise and Track-Keeping monitoring systems at Heathrow, Gatwick and Stansted airports. The concept of a uniform 'Base Limit', with positional adjustments applied for each individual monitor, would achieve the objective of applying consistent and fair limits for all runways at all airports.

29 An increase in stringency could be achieved by reducing the Base Limit below the present daytime and night-time limits. ANMAC's wishes were that the limits should be expressed in L_{Amax}, should continue to be enforced only at the fixed monitor positions, and should be consistent with daytime and night-time Base Limits (at 6.5 kin from start-of-roll) of 94 dBA and 87 dBA respectively, based largely on the analysis of the measured data acquired during this study, and therefore reflecting what is operationally practicable. The suggested night-time limit is broadly compatible with the aims of the current Night Restrictions Scheme. These proposed 'transitional' reductions of 3 dBA in the daytime limit and of 2 dBA in the night-time limit were accompanied by the recommendation that a further review of the limits be conducted before the phase-out of Chapter 2 aircraft is completed in 2002.

30 Some improvement in efficiency would be achieved by implementing just the above proposals, but much greater gains could be realised by repositioning some monitors and increasing the total number of monitors. Analysis of a wide range of monitoring options was undertaken in an attempt to optimise the monitor arrays for each runway. Subject to permission from landowners, planning permission, and provision of services, practical arrays appear to be possible at each airport which, for every runway, would ensure that between 40% - 50% of Chapter 2 Boeing 747 departures exceeding a Base Limit of 97 dBA would be detected (at present the daytime monitoring efficiency varies widely between airports, ranging between 4% and 20%). With a Base Limit at 89 dBA the corresponding detection rate at night would be 70% - 85% (compared with 15% - 50% at present). With lower limits, the efficiency would be even higher.

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GLOSSARY OF TERMS

Frequently used terms and symbols are defined below: others which are only used locally in the text are defined where they first occur.

ANCON-1	The CAA Aircraft Noise Contour Model used for calculating contours of noise exposure around airports (Ref 4).
ANMAC	Aircraft Noise Monitoring Advisory Committee.
Base Limit	Chosen overall limit on L_{Amax} to apply to departing aircraft at the Reference Distance and runway elevation.
Chapter 2, 3	(Abbreviated to Ch 2 and Ch 3.) ICAO standards governing the noise certification of aircraft (Ref 2). Chapter 2 applies to jet aircraft certificated before October 1977. Subsequently new aircraft types were covered by the more stringent standards of Chapter 3.
dB	Decibel units describing sound level ‘L’ or changes of sound level.
dBA	Decibel units of sound level measured on the A-weighted scale, ‘LA’.
DORA	Department of Operational Research and Analysis; CAA/NATS department responsible for aircraft noise studies.
DoT	Department of Transport (UK).
Efficiency	See Monitoring Efficiency.
Emission level	An expression used to describe the amount of sound emitted by an aircraft in decibel terms.
EPNdB	Decibel units of sound level measured on the EPNL scale.
EPNL	Effective Perceived Noise Level (measured in EPNdB). Aircraft noise event level scale used internationally for the noise certification of aircraft. Its measurement involves analyses of the frequency spectra of noise events (it is calculated from the time history of PNL with extra weightings for pure tones). Like SEL it also accounts for event duration.

Event level	The noise level of an aircraft noise event; experienced when a single aircraft passes by.
Event threshold	The sound level at which a noise monitor is triggered; set to 65 dBA for all monitors used to collect data in this study (except Gatwick Russ Hill which is set at 70 dBA).
Exceedance rate	The number of offenders expressed as a fraction of the total number of departures of a specified group of aircraft.
Flight Information System, FIS	BAA computer system at each airport which stores details of each arrival/departure (eg aircraft type, registration, time).
Ground track	The vertical projection of an aircraft flight path onto level ground.
ICAO	International Civil Aviation Organisation.
Infringement	Any departure that exceeds the Infringement Level at any fixed monitor.
Infringement Level	The infringement threshold level set at an individual monitor. This might differ from the Base Limit to allow for positional displacements of the monitor relative to the Reference Distance and runway elevation. Under the present monitoring regime, the Infringement Levels at all fixed monitors (except Russ Hill at Gatwick, where a 2 dB adjustment applies because of the ground elevation) are the same and equal to the prescribed daytime and night-time limits.
Infringement Rate	The fraction of the total number of departures of a specified group of aircraft that are registered as Infringements.
L	Sound level in decibels, dB. The magnitude of sound expressed on conventional logarithmic scales of sound energy. All levels are expressible as 10 times the log (to the base 10) of an acoustic energy ratio.
LA	A-weighted sound level, a decibel scale of noise measured using a frequency dependent weighting which approximates the characteristics of human hearing. Measurements are referred to as A-weighted sound levels, in dBA; they are very widely used for noise assessment purposes.
L_{Amax}	The highest instantaneous sound level recorded during a noise event, in dBA (measured using a standard ‘slow’ meter setting).

L_{eq}	Equivalent Sound Level in dBA (often called equivalent continuous sound level). The sound level averaged over a specific period of time, eg 16 hours, 24 hours etc. It is sound *energy* that is averaged, not the decibel level - whence the expression 'energy-averaging'.
LT	Local time, i.e. British Summer Time (BST) in summer, Universal Time Co-ordinated (UTC) (= Greenwich Mean Time) in winter.
Monitor array	An arrangement of several noise monitors designed to provide adequate coverage of a swathe of dispersed aircraft flight paths.
Monitoring	The percentage of offenders that are recorded as Infringements Efficiency at one or more of the monitors in an array.
NATS	National Air Traffic Services (UK).
Noise monitor (or Monitor)	Fixed or mobile noise monitor linked to the NTK system.
Noise monitoring	A set of microphones arranged around an airport, connected via a data transmission system to a data processing unit, designed to monitor the noise levels generated locally by aircraft using the airport.
Normal distribution	A mathematical relationship used in statistical theory to represent distributions of random variables. Also known as the Gaussian Distribution.
NTK	The Noise and Track-Keeping monitoring system covering the three London airports. A noise monitoring system expanded to relate noise levels to aircraft flight paths shown by secondary surveillance radar.
Offender	A departing aircraft that does or would generate a noise level in excess of the Base Limit at or beyond the Reference Distance at runway elevation.
PNL, PNdB	Perceived Noise Level (measured in PNdB): PNL was devised for measuring the annoyance-evoking potential of aircraft noise. 'Perceived noisiness' is defined as a measure of how "unwanted, objectionable, disturbing or unpleasant" (rather than how "loud") the sound is. The noisiness of a sound is obtained via spectrum analysis (octave or 1/3-octave). Each band level in the spectrum is converted to a noisiness value and these are summed in a special way to obtain the total noisiness of the sound. As

	originally used, a single value of PNL was recorded for the flyover - corresponding as nearly as possible to the maximum value, PNL_{max}. There is no simple relationship between LA and PNL, but in practice it is found that there is a fairly high correlation between the two measures; the approximation commonly used is $PNL \approx L_{Amax} + 13$.
Reference Arc	The approximate locus of Reference Distances of aircraft departing a particular runway covering one or more departure routes.
Reference Distance	A Track Distance of 6.5 km measured from start-of-roll; equivalent to the distance of the ICAO Annex 16 flyover noise certification point.
Reference Level:	The noise level L_{Amax} generated by an aircraft at the Reference Distance and runway elevation.
Reference Mean Level, RML	Arithmetic mean of the Reference Levels of an aircraft type or group (equal to the 50th percentile for Normal distributions).
Reference Point	Point at Reference Distance on ground track at runway elevation; hypothetical in the case where the local ground elevation is higher than runway elevation.
Runway elevation	The ground elevation at a particular point on the airport as published in the UK Air Pilot; used as the datum level for noise monitoring purposes.
SEL	The sound exposure level generated by a single aircraft at the measurement point, in dBA. This accounts for the duration of the sound as well as its intensity; it is equal to the sound level of that 1-second burst of steady sound which would contain the same (A-weighted) acoustic energy as the aircraft sound.
Start-of-roll	Average position on a runway where aircraft commence their take-off runs.
Stringency	The effect of the choice of Base Limit upon the Exceedance Rate and ultimately upon the Infringement Rate.
Track Distance	Distance measured along the ground track from start-of-roll (ie not simply a straight line distance).

1 INTRODUCTION

1.1 The current departure noise limits at Heathrow, Gatwick and Stansted Airports have been in place for many years, and in 1993 the Minister for Aviation thought it was timely for reductions in the limits to be considered. He therefore asked the Aircraft Noise Monitoring Advisory Committee (ANMAC) to review the limits and to recommend what, if any, changes should be made to the monitoring provisions at the three London airports. The overall study into monitoring practices was split into three phases: the aim of the first phase reported here was to review the present departure noise limits, and to consider the effects of lower limits and different monitor placements. Later phases of the study will cover the possibility of (i) differential departure noise limits for each aircraft type, and (ii) approach noise monitoring.

1.2 ANMAC commissioned DORA to undertake a data collection exercise to acquire representative operational data, and a modelling exercise to enable the effects of different limits and better positioning of monitors to be quantified. This report describes the technical studies undertaken by DORA. Entirely of an analytical nature, they were carried out to provide information to aid ANMAC's recommendations for improvements to noise monitoring practices.

1.3 During the study, a great deal of detailed analysis was undertaken, much of it of an exploratory nature. This report describes its essential parts and results - those which had a direct bearing on the outcome. Section 2 outlines the background to the study, the history of noise monitoring at the London airports and the need for the review. Section 3 sets out ANMAC's objectives, the criteria governing the performance of a system for monitoring compliance with aircraft noise limits, the constraints that affect practical installations, and the method used for assessment of the likely performance of a noise monitor array, which is the basic building block of a monitoring system. Section 4 summarises the data collection and analysis work. Section 5 gives an illustration of the evaluation of the performance of different monitor arrays. In Section 6, the model is applied to a variety of hypothetical and practical monitoring options to illustrate the kind of improvements that could theoretically be achieved at each airport. Section 7 assesses the effects of lower noise limits, and the study conclusions and ANMAC's recommendations are summarised in Section 8.

1.4 A variety of technical terms are used in the report and most are defined in the Glossary. Those which have been specially coined, or have particular meanings for this study, are printed in italics where they are introduced.

2 BACKGROUND

Previous Noise Monitoring at Heathrow and Gatwick

2.1 Noise monitoring systems were first installed at Heathrow and Gatwick in 1958 and 1974 respectively. The monitors were sited to 'protect' certain built-up areas around each airport; in most cases at the first populated areas under each departure route (see Appendix A). It was a requirement that each aircraft should be flown in such a way that after it has passed the monitor the noise level beneath it should continue to diminish.

2.2 At Heathrow this resulted in thirteen monitors being placed at distances between about 5 and 8 km from start-of-roll, giving reasonable coverage of all departure routes. The closest was at Cranford to monitor the occasional departures from Runway 09L and to 'protect' that community.

2.3 The limits set when the Heathrow system was installed were expressed in units *of Perceived Noise Level,* considered in the 1960s to best represent human judgement *of* the noisiness *of* aircraft noise events: 110 PNdB by day (0700 - 2300 *LT)* and 102 PNdB by night (2300-0700 LT) - at any monitor[1]. The highest noise levels at that time were produced by first generation subsonic jet aircraft. (Concorde was subsequently exempted from the requirement to meet these limits.)

2.4 The same limits were subsequently applied at Gatwick, although the relative monitor positions at Gatwick were very different from those at Heathrow; each *of* the four monitors was located at greater distances from start-of-roll and well to the side of the mean departure tracks.

Present NTK System and Limits

2.5 In 1992/3, BAA installed a new system which monitors the noise and the flight paths of all aircraft using Heathrow, Gatwick and Stansted airports. This is known as '*NTK'*, the Noise and Track-Keeping monitoring system. Noise data is obtained from a total of twelve fixed monitors and up to 24 mobile monitors. The system merges the noise data with weather data monitored at either end of each airport, radar data providing aircraft *ground tracks* and heights, and aircraft type and other flight details. Of the twelve fixed monitors, there are seven at Heathrow, two at Gatwick and three at Stansted.

2.6 The present NTK system retains the same day/night monitoring periods, and the same numerical noise limits. The limits, specified in the UK Aeronautical Information Publication (Ref 1) and applying at each *of* the fixed monitoring locations, are given as "110 PNdB (97 dBA)" by day (0700-23 00) and "102

[1] The levels were not actually measured in PNdB but in D-weighted decibels, with an empirical correction applied.

PNdB (89 dBA)" at night. However, as the present system actually measures event noise levels in L_{Amax} values, it should be recognised that the PNL values are approximate equivalents (assuming PNL ~ L_{Amax} + 13).

2.7 Appendix A describes some effects of the changes from the old to the present monitoring systems. Particularly important is that the present system at Gatwick brought the effectiveness of monitoring there more into line with that at Heathrow.

The Need for a Review of Noise Limits

2.8 In terms of their noise and performance characteristics, the aircraft fleets currently using the London airports are very different from those for which the noise limits were set more than 25 years ago. Then, the noisiest aircraft were 'non-certificated', i.e. they did not meet the noise standards that were subsequently adopted internationally. The first standards were defined in Chapter 2 of the ICAO rules (Ref 2); aircraft which met them became known as '*Chapter* 2'aircraft and these were rather quieter than many of their non-certificated predecessors. From 1977 onwards, new aircraft designs have been required to meet significantly more stringent standards defined in Chapter 3 of the rules. Non-certificated aircraft were prohibited after the mid-1980s. Now, Chapter 2 aircraft are being phased out under Government regulations based on an EC Directive. Already the majority of aircraft now using the London airports are '*Chapter* 3' types; by 2002 the commercial subsonic jet fleet will be 100% Chapter 3.

2.9 One effect of this progress is that, despite increased traffic, overall noise exposures have diminished. This is reflected in the continuing shrinkage of the noise contours, the lines of constant Leq shown on maps published annually by the DoT. Another is a significant fall in the rates of *infringement* of the noise limits, implying a lessening in the effectiveness of noise monitoring as a noise mitigation measure for the current traffic mix. It was for this reason that the Minister for Aviation asked ANMAC to recommend what changes, if any, should be made to the monitoring provisions at the three London airports.

3 NOISE MONITORING CRITERIA AND CONSTRAINTS

Objectives of Departure Noise Monitoring

3.1 After considerable debate, ANMAC agreed that the principal objectives of departure noise limits, and the procedures for monitoring adherence, are the following:-

(a) deterring excessively noisy movements by detecting and penalising them;
(b) encouraging the use of quieter aircraft and best noise abatement operating practice; and

(c) measuring the effectiveness of noise abatement measures by analysing infringement rates.

3.2 Overall limits are only likely to influence operations of the noisiest aircraft types. More general achievement of objective (b) would require some form of ‘differential limits’, i.e. limits set individually for those types or categories of aircraft that are unlikely to be penalised by the overall ‘blanket’ limit. Differential monitoring is not considered further here; it will be the subject of further study to be described in a later report.

System Performance Criteria

3.3 In deciding how and where to monitor the noise of departing aircraft, it is necessary to consider the patterns of noise exposure below and around their flight paths and the way in which these are affected by the performance characteristics of the aircraft. Figure 1 depicts an aircraft noise ‘footprint’ and the three standard points used for measuring ‘certificated noise levels’ (Ref 2). These measurements of ‘approach’, ‘lateral’ (or ‘sideline’), and ‘flyover’ noise level, made under very strictly controlled test conditions, reflect the noise generated by aircraft during three critical flight phases: arrival, take-off, and reduced-power climb. ‘Take-off’ covers acceleration along the runway and an initial maximum-power climb, usually to a height of more than 1000 feet above *runway elevation.* Beyond that point, after ‘cutback’, the climb continues at reduced power settings. The lateral measurement point captures the maximum noise condition - which actually affects a relatively small fraction of the total noise footprint. The flyover point, 6.5 km from start-of-roll, was chosen to determine the noise of continuing climb that often tends to dominate the departure footprint (although this is not evident in the stylised diagram in Figure 1).

3.4 The noise certification process is aimed at ‘worst case’ maximum weight aircraft noise emissions. The operating procedures and conditions met in normal service are less critical but follow the same general pattern, i.e. a high power climb followed by a power cutback. The high power condition is determined by safety requirements; the pilot has little opportunity to reduce noise during take-off and initial climb. The power cutback reduces engine noise; the noise exposure on the ground depends upon that reduction but also upon the ensuing rate of climb - the degree of cutback in a ‘noise abatement operating procedure’ involves a balance between these two factors. As it is really only during this phase of the departure that noise lies within the control of the operator, it is normal airport practice to monitor noise beyond the cutback point.

3.5 Although, in theory, noise could be measured at various points within and around the footprints (mobile monitors could be placed at different places at different times), it is usual practice to set airport noise limits at specific positions where adherence can be continuously monitored. ANMAC considered this to be a continuing requirement here; any proposals for change should be based on a reasonable number of fixed monitors.

3.6 Appendix A shows that the present fixed noise monitoring coverage varies somewhat between the airports. This is due to differences between the *monitor* array geometries for the various runways and routes - in terms of the distances of monitors from start-of-roll, distances to the side of tracks, monitor elevations and monitor spacing. Although it was clear to ANMAC that improved monitor placements were desirable, the requirements were by no means obvious. Fixed monitors could be placed, for example:-

- in specific noise sensitive areas,
- on or either side of particular departure routes, or
- at different points along each route.

To meet the specified objectives it was concluded that, as far as possible, monitors should be placed (a) to verify low-noise aircraft operating practice, (b) to register meaningful *event levels* for the greatest possible number of aircraft movements, and (c) to ensure that all excessively noisy operations have an equal chance of being detected (at all three airports on all routes). The review showed that these aims could best be met by locating monitors at constant distances from start-of-roll; this was considered to be more important than placing monitors in particular noise-sensitive locations such as areas of housing.

3.7 The two key criteria governing the performance and operation of a monitoring system are its *efficiency* and *stringency*. In this context, ‘efficiency’ relates to the fraction of departing aircraft that the system will detect; i.e. the numbers of aircraft that come within adequate range, which in turn depends primarily upon the numbers and positions of monitors. ‘Stringency’ dictates the accompanying rate of infringement; this depends principally upon the specified noise limits.

Base Limits

3.8 It was recognised that practical limits involve a compromise between the desirable and the possible and, in contrast to average noise exposure - for which L_{eq} provides guidance on likely average annoyance - there is, as yet, no generally-accepted body of relevant noise effects research to define what constitutes acceptable event levels. In any case, practical limits cannot be applied uniformly to all populated areas; they have to be set at points close to the flight paths on the assumption that noise levels will be lower at more distant locations.

3.9 Notwithstanding the above, it was agreed that the night-time limit should remain lower than the daytime one. Furthermore, the night limit should in principle be compatible with the aims of the night restrictions regime (Ref 3) which reflect the findings of several studies of noise induced sleep disturbance.

3.10 In order to ensure uniformity of departure noise limitation between the airports, and between different aircraft routes, it was agreed that fixed *Base Limits* would be defined (one for day - 0700 to 2300 LT - and another for night - 2300 to 0700 LT) in relation to a fixed *Reference Point - at* runway elevation and at a *track distance* of 6.5 km from start-of-roll (the *Reference Distance).* This is equivalent to the certification 'flyover' point and there are few residential areas closer than this to the three airports. In normal practice, noise levels at greater track distances will be lower; this is a requirement specified by instructions given in the UK Aeronautical Information Publication (Ref 1).

Noise Units

3.11 ANMAC considered the merits of the various scales and units that are used to measure aircraft noise. Although they appreciated that EPNL - which is used for aircraft noise certification - and SEL - which is an 'ingredient' of L_{eq} (the noise exposure scale used to define airport noise contours) both take account of the duration of noise events, members concluded that L_{Amax} was preferable because it was more readily comprehensible and it maintained continuity with the current regime. The data for the study was collected and analysed on the premise that the limits would be stated in terms of L_{Amax}.

Infringement Levels

3.12 Obstacles to the ideal positioning of noise monitors include the multiplicity of routes (especially at Heathrow), features of the local terrain and built environment, problems of land ownership and accessibility, and the costs of providing, installing and servicing the monitors, especially in more remote locations. Thus it will not usually be possible to locate monitors precisely at 6.5 km, from start-of-roll and, in any event, aircraft are not able to follow precisely defined ground tracks; departures on a particular route are dispersed in a 'swathe'. It was therefore necessary to consider how the monitoring procedures would account for: (a) the longitudinal displacement of the monitor from the Reference Distance, (b) the lateral displacements of the aircraft from the monitor, and (c) the height of the monitor relative to the runway elevation (this is particularly important in the case of the Russ Hill monitor at Gatwick which is 185 ft (56 m) above runway elevation). It was concluded that, to avoid the inconsistencies that result from the different track distances and elevations of the present monitors, individual *Infringement Levels* should be set at each monitor by applying suitable adjustments to the Base Limit.

3.13 Adjustments for monitor height and longitudinal displacement of the monitor, i.e. along the flight path, may readily be related to the minimum acceptable aircraft climb gradient (see paragraph 5.10). However, adjusting for lateral displacements is more complicated, because there is no lateral equivalent of minimum climb rate. Variations of measured noise level attributable to lateral dispersion of the ground tracks are substantial, even within a relatively narrow ‘swathe width’. If Infringement Level adjustments were to take account of lateral displacements relative to the monitor, they would have to be calculated individually for each aircraft flight path.

3.14 Several possible ways of dealing with the problems of lateral track dispersion were investigated. One involved lowering the Infringement Level to compensate for the effects of lateral displacement; another was based on an analysis of radar flight path data. ANMAC rejected the first because it could falsely identify some compliant aircraft as infringements. On the second, it concluded that techniques involving analysis of track data were not practicable for setting noise limits, at least in the short term. It was also noted that under present powers there is no scope for penalising the operator of any aircraft identified as having flown a ‘deviant’ track. The preferred solution was for sufficient monitors to be deployed to ensure that virtually all aircraft tracks are within a reasonable distance of at least one monitor.

Assessment of Monitor Arrays

3.15 In order to evaluate possible improvements to the present noise monitoring regime, a means was required of relating its efficiency and stringency to the positions and Infringement Levels of its monitor arrays. For this purpose, a relatively simple mathematical model was used to estimate the fraction of offenders that would be identified as infringements.

3.16 For any particular flight, the flyover noise event level recorded at a particular monitor depends upon-

(a) the aircraft type
(b) its position relative to the microphone
(c) its noise emission at the time (power settings)
(d) the weather conditions

3.17 Thus the event levels in any sample of measurements from a particular monitor vary considerably. The effects of factors (a), (b) and (c) can be represented in a statistical way. However, the effects of (d) are complex and, within the scope of this study, it was not practicable to quantify them directly. Rather it was considered reasonable to assume that the contribution of weather effects to the variance of event levels was, on average, fairly uniform over time and would be reflected in the data collected for this study.

3.18 In practice, the analysis was confined to a single aircraft type or category. Figure 2 depicts a cross-section through a hypothetical swathe of flight paths passing a noise monitor at a particular track distance. In the analysis the following assumptions were made, largely on the basis of previously acquired data used in the preparation of airport noise contours:-

(1) At any track distance, the aircraft heights follow a Normal (or Gaussian) distribution[2].

(2) At the Reference Distance, the mean height and variance are the same on all routes.

(3) The aircraft noise *emission levels* follow a Normal distribution with constant means and variances.

(4) At any track distance, the lateral positions of the aircraft on a particular route (the ground tracks) follow a Normal distribution.

(5) Over the relatively short distances between the Reference Point and the monitor, the swathe dimensions, i.e. height mean and variance and track variance, increase linearly in proportion to the distance of the aircraft from a nominal lift-off point.

(6) The relative noise level generated at the monitor by an aircraft depends on its noise emission level, slant range and angle of elevation (angle of the joining line to the horizontal). The levels are calculated using the *ANCON-1* sound propagation algorithm (Ref 4), assuming the monitor lies in the plane of the swathe cross-section. The mean flight path (the mid-point of the two-dimensional distribution) is assumed to be vertically above the nearest point to the monitor on the mean track.

(7) Any particular aircraft maintains the same relative position in the swathe cross-section (i.e. there are no crossovers between flight paths in the region between the Reference Arc and the monitor plane).

3.19 Simplifying assumptions of this kind were necessary to keep the computer analyses within manageable proportions. Based on examinations of NTK data, they were judged to be reasonable for the purposes of ANMAC's task; differences between the model and real operations would have relatively minor effects upon the conclusions of the study. The method was a general one which could be applied to any airport, runway, route combination, monitor combination and aircraft type group.

3.20 The necessary inputs to the model were derived from an extensive analysis of a large quantity of NTK data that was specially processed for the purposes of this study. This is described in Section 4.

Grouping by Aircraft Type

3.21 A single overall (day or night) noise limit does not, of course, affect all aircraft types equally. Larger, slower climbing aircraft are more likely to exceed the

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[2] See Appendix B for explanation of 'Normal distribution' and other statistical terminology.

limit than smaller, faster climbing aircraft. A practical single limit must be set at a level which penalises a reasonable proportion of the noisiest aircraft types; because some of the small faster climbing aircraft are so much quieter than the large slower climbing aircraft, their noise levels would never reach such a limit. It was nevertheless important to distinguish between different types, first to establish what the implications of particular limits would be for different aircraft types and, second, to derive results that could be adequately characterised by conventional statistics. For example, it would be unlikely that the noise levels generated by a wide mixture of aircraft types would follow, even approximately, a Normal distribution - the basis of most statistical data analysis. Although such Normality is not essential, it would help to generalise the conclusions from the study, and it would be more likely to be appropriate to sub-sets of data grouped by aircraft type; this question is discussed in Appendix B.

3.22 Additional reasons for grouping aircraft data in this way were the needs for:-

(a) an indication of how the phase-out of Chapter 2 aircraft is likely to bear upon subsequent reviews of the limits; and

(b) guidance on the question of the day-night differential, given that the current night restrictions were designed to control both the total noise exposure and single event levels - by the restrictions on the use of the noisiest types of aircraft at night, and the fact that the restrictions are not uniform throughout the period 2300 - 0700 when the night noise limits apply[3].

3.23 Various grouping options were considered, but it was not until some detailed analysis of the results had been completed that the groupings could be finalised. They are summarised below:-

A	Concorde:	Non-certificated supersonic aircraft; operates in small numbers but much noisier than any current subsonic type; not covered by noise limits.
B2	Boeing 747, Chapter 2:	Earlier versions of what is currently the largest, noisiest 4-jet subsonic aircraft operating in significant numbers at the London airports.
B3	Boeing 747, Chapter 3:	Later versions; incorporate advanced noise treatments; still noisy because of size but somewhat less so than Group B2.
C	Heavy Chapter 2:	Other long-range 4-jets of early design; noisy because of low bypass engines.

3 Under the present night restrictions regime aircraft classified as QC/8 may not take off between 2300 and 0600, those classified as QC/16 may not take off between 2300 and 0700. Delayed departures by QC/8 and QC/16 aircraft may be permitted between 2300 and 2330.

D	Heavy Chapter 3:	Later medium/long range 2, 3 and 4 jets, quieter, high bypass engines.
E	Light Chapter 2:	Early short range, noisy low bypass twinjets.
F	Light Chapter 3:	Modem short range twinjets, high bypass, significantly less noisy.
G	Propeller:	All non-jets, mainly 2-engine regional/commuter aircraft.
H	Executive jets:	Small, private/corporate jets of all types (Chapter 2s are rather noisier than Chapter 3s).

The allocation of specific aircraft types to each group is shown in Table 1. It was agreed that the study of monitoring options should focus primarily on the most critical aircraft type for noise infringements, which currently is the Chapter 2 Boeing 747 (Group B2). Movements of other ‘noisier’ types, taking the three airports as a whole, are comparatively infrequent. After the Chapter 2 phaseout is completed, the Chapter 3 Boeing 747s (Group B3) will be the most critical aircraft type.

4 MEASUREMENTS

Data Requirements

4.1 The basic aim of the measurement programme was a simple one: to determine the distributions of Reference Level for each of the aircraft type groups, where, for each departure, the *Reference Level* is the event level L_{Amax} at the standard Reference Point. These distributions would then (a) indicate what *infringement rates* would result from any choice of Base Limit, and (b) provide the statistical inputs required for the system design analysis. This approach also allowed data from different monitors and different airports to be merged.

4.2 As it was not practically possible to measure noise at the Reference Point for each and every flight, it was necessary to apply appropriate adjustments to the measurements that could be made, choosing measurement locations where the adjustments would be as small as practicable. The adjustment process itself was based on three assumptions: (1) that noise radiated from the aircraft is axially symmetric (i.e. that it is the same along propagation paths to the left and right of, as well as along, the vertical), (2) that L_{Amax} falls 8 dB with each doubling of distance from the aircraft (the assumption that underpins the CAA aircraft noise model ANCON-1 (Ref 4)), and (3) that the distance between monitor and Reference Point is sufficiently small that changes to engine power settings can be disregarded. To apply this adjustment, it was necessary to determine, from the radar data, the minimum slant distance between the aircraft and the monitor and the height of the aircraft above the Reference Point. As the 8 dB distance adjustment mentioned in (2) above is only applicable for propagation paths within 30° from the vertical above the monitor (where so-called 'lateral attenuation' is negligible), measurements that fell outside this range were rejected.

4.3 The study was carried out using the NTK system and additional DORA data analysis facilities. Figures 3, 4 and 5 for Heathrow, Gatwick and Stansted respectively show 6.5 km *Reference Arcs* - approximate loci of Reference Distances for each runway. The fixed monitors that were close enough to both the relevant Reference Arcs and appropriate departure routes to provide useful data were:-

Heathrow:	Monitor 6 (Wraysbury Reservoir) Monitor 2 (Hounslow West)
Gatwick:	Monitor 1 (Russ Hill) Monitor 2 (Redeham Hall)
Stansted:	Monitor 1 (Broxted) Monitor 2 (Latchmore Bank) Monitor 3 (Howe Green)

However, these fixed monitors alone did not provide adequate coverage and it was therefore necessary to augment them with seven mobile units[4]. BAA established acceptable sites using mobile monitors close to the Reference Arcs: four at Heathrow, one at Gatwick and two at Stansted. The positions of all the fixed monitors and the mobile monitors used in the study are shown in Figures 3, 4 and 5 relative to the routes.

4.4 For each aircraft movement, the following data were recorded:-

- Aircraft type and variant (including engines)
- Runway
- Departure route and destination
- Flight path (i.e. position v time)
- Weather: temperature, pressure, relative humidity, wind speed/direction;

and for each noise event monitored:-

- Time
- Noise level L_{Amax}
- Shortest distance between aircraft and microphone (calculated from flight path data).

4.5 After rejecting unreliable data, the results were analysed to determine for each aircraft movement:-

4 The fixed and mobile monitors have their microphones at different heights above the ground: 6m and 3m respectively. In preliminary investigations, the effects of this height difference on the measured event levels were found to be not statistically significant. Data from the fixed and mobile monitors were therefore merged without adjustment.

- Aircraft type group
- Estimated Reference Level;

and, for each route/monitor/group combination:-

- Distributions of Reference Levels (including, for example, means and levels exceeded by 1%, 5%, 10%, and 50% of flights).

4.6 To meet the requirements of statistical accuracy discussed in Appendix B, the expected variations of noise level indicated that, ideally, at least 30 - 40 measurements would be required for aircraft in each group, at each airport and in each time period (day and night). As data would be collected more or less continuously for a set period of time, actual sample sizes would of course be dictated by the traffic patterns at the three airports. Differences in traffic mix between the airports are illustrated in Table 2, which gives the numbers of departures during the 1994 average 24-hour summer day (mid-June to mid-September) broken down by day and night and by aircraft group. Also, the fact that the aircraft groupings could not be finalised until after the data had been collected caused a further degree of uncertainty concerning the required sample sizes for each group.

Data Analysis

4.7 Measurements were made at the three airports during April and May 1994. Table 3 summarises the data acquired. Except when various monitors were occasionally unserviceable, data was acquired 24 hours a day. A total of 81,913 identified noise measurements were obtained.

4.8 The analysis required to determine Reference Levels from the measured noise event levels is illustrated schematically in Figure 6. Each aircraft flight path was defined by radar data extracted from NTK. From this, the height of the aircraft at the Reference Distance, and the shortest distance between the aircraft and the monitor, were estimated-using procedures to minimise errors attributable to the limited resolution of radar measurement (see below).

4.9 These procedures were as follows:-

1) Discard unreliable noise data, e.g. for flights with more than one noise event. (This occurs if the ‘instantaneous’ noise level drops below the 65 dBA event threshold and then subsequently goes above it again.)

2) Eliminate data obtained under extreme meteorological conditions. The limits were maximum relative humidity 95%, and maximum wind speed 15 kt. (Approximately 3% of the identified noise measurements were rejected for this reason.)

For each remaining flight, extract aircraft details and departure routeing from the *Flight Information System* (FIS)[5]; then:-

3) Assign to an aircraft type group[6].
4) Using radar data from NTK calculate the aircraft slant distance at its 'closest point of approach' to the monitor. This process includes the need to 'smooth' the radar data so as to minimise the effects of random radar errors[7].
5) Discard cases in which it would normally be assumed that lateral attenuation may have affected the measured noise level (i.e. aircraft more than 30° from the vertical above the monitor - see Ref 4).
6) Determine the Reference Point for each flight, and calculate the aircraft height at this position[8].
7) Estimate the noise level at the Reference Point from the noise level measured at the monitor, by applying a slant distance adjustment using the '8 dB per doubling of distance' rule - taking proper account of any difference in ground height between the monitor and the runway.

Finally, combine the data from all monitors and produce a single set of Reference Level statistics for each airport for each aircraft type group.

Results

4.10 A large proportion of the 81,913 noise measurements did not meet the lateral position and weather criteria referred to above, and were thus excluded from the analysis. Table 3 shows how the remaining 21,989 cases were split between airports, monitors and aircraft type groups.

4.11 It is evident that, for the reasons noted, the sample sizes vary widely between airports, aircraft groups and monitors. For groups E and F (light Chapter 2 and Chapter 3 twins respectively) very large samples were obtained at all three airports. However, for less common aircraft, notably Group C (heavy Chapter 2 types), samples were very small. Due to the much lower traffic levels, most

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5 At the time of the study the NTK system was unable to identify aircraft automatically; in advance of the installation of this facility, an alternative method was developed involving off-line amalgamation of NTK events with aircraft movement data from the airports' FIS.

6 84 (out of 1336) B747s for which the noise certification standard could not be readily determined were excluded at this stage.

7 Radar provides aircraft position coordinates at intervals of approximately four seconds. Because of the limitations on the resolution of radar data, horizontal positions are subject to an accuracy of approximately ±120 m. Height data is rounded to the nearest ±50 ft (15 m). To minimise the effects of these errors on the slant distance estimates, the radar-measured flight paths were 'smoothed' by calculating values of slant range against time from the radar coordinates in the vicinity of the 'closest point of approach' (CPA), and then fitting a quadratic curve using the method of least squares. The minimum distance from this curve provided a good estimate of slant range at the CPA. The height and angle of elevation at CPA were then estimated also.

8 The height of the aircraft as it passed over the Reference Point was calculated in a similar way to (4), by determining the CPA to the Reference Point.

Stansted samples were small, particularly in the large aircraft categories. Also, although not shown by Table 3, night-time samples at all three airports were inevitably small.

4.12 Statistical tests discussed in Appendix B were used to compare data from individual aircraft types, by airport and, for each airport, by day and night. These showed that, in many cases, noise level differences were not statistically significant, i.e. no greater than would be expected as a chance result. In others, although statistically significant, they were small in absolute terms and attributable to differences in the aircraft type mixes within the groups[9]. In a few cases, the data samples were too small to draw conclusions.

4.13 Thus, although over a period of time any particular limit would be exceeded by approximately the same percentage of flights of aircraft from a particular group, regardless of the airport or time of day, some small differences would be likely, as may be seen from the detailed results given in Appendix C.

4.14 Despite these differences, all data were pooled by aircraft group because of the need to treat all airports consistently, to reduce the complexity of the analysis, and to compensate for the lack of data in some cases. Generalised relationships could then be used to indicate how infringement rates are likely to vary with changes in the noise limits.

4.15 These generalised trend lines are 'equivalent Normal distribution curves'[10] which are explained in Appendices B and C. These help to clarify, in a consistent way, trends at the upper ends of the Reference Level distributions where limits are likely to be set. Figure 7 shows these curves for each aircraft group overlaid upon the pooled data. Nominal *exceedance rates* based on these Normal curves are given in Table 4. These are used extensively in the remainder of this report to assess both the performance of the monitor systems and the effects of changing the noise limits.

4.16 Deviations from the equivalent Normal distributions in the individual airport samples may be seen in Figures C1 to C8 of Appendix C. These are attributed to different mixes of types within groups, as well as to 'sampling fluctuations' (see Appendix B). However, for the aircraft groups that are most affected by overall noise limits, i.e. groups B2, B3, C and E, the between-airport differences are small.

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9 In one case, that of the Boeing 747-400s at Heathrow, there was an exceptionally large mean difference between day and night levels, 7.6 dBA. This was because all the night-time measurements were of a particular flight at low take-off weight on a short onward leg.

10 Normal distributions with the same mean values and the same standard deviations as the measured samples; these are estimates of the distributions of the 'populations' of <u>all</u> similar events. Figure 7 and Table 4 give 'cumulative' distributions, the percentage of events which exceed different levels.

4.17 It is clear from the distributions of departure noise levels represented in Figure 7 and Tables 4 and C2 that the mean levels differ markedly between the aircraft groups, from 73.4 dBA for Group G to 92.3 dBA for Group B2. The shapes of the curves reflect the variations of noise levels; the less the variation, i.e. the smaller the corresponding standard deviation in Table C2, the steeper the curve. Most curves in Figure 7 have rather similar shapes but clear exceptions, with steep and shallow curves respectively, are groups F and C.

4.18 The noise levels of the 'light' Chapter 3 aircraft in Group F are not only relatively low - on average some 16 dB below those of the critical Group B2 - they also vary relatively little. The standard deviation is 2.7 dB. This can be explained, at least in part, by small noise differences between the specific types that make up Group F - see Table C3. In contrast, at the other extreme, Group C, with a mean level of 89.3 dBA, shows considerable variation with a standard deviation of 6 dB. This can be explained, again in part, by greater differences between individual heavy Chapter 2 types of Group C. On average, Group C aircraft are less noisy than Chapter 2 B747s (Group B2), but the noisiest among them exceed the levels of the worst 747s by up to 5dB. Thus, although they are few in number, some Group C aircraft are some of the very noisiest aircraft in terms of absolute noise level and would therefore be most likely to infringe any overall noise limits. Table 4 shows that nearly 10% of Group C aircraft are estimated to exceed a Base Limit of 97 dBA, some by more than 13 dB.

4.19 In the analysis that follows, assessments against both the daytime and the night-time limits are based on the pooled 'day + night' Reference Level data. However, although night-time data samples were generally too small for statistically reliable conclusions to be drawn, Appendix C shows that, in most aircraft groups, noise levels were generally lower at night, perhaps because of different mixes of types, take-off weights and/or operating procedures, indicating that exceedance rates might be somewhat lower than the pooled estimates.

4.20 Of course, even though, for the purposes of this analysis, individual aircraft noise level distributions are taken to be the same at all three airports, overall *infringement* rates (i.e. the percentage of all departures that would exceed a specific noise limit) would differ because of the different traffic mixes (see Table 2).

4.21 Similar considerations apply when making day-night comparisons. Figures 8a and 8b show separately for day and night the cumulative distributions of the pooled Reference Level data. (Note that Figure 8b expands the lowest 10% of the full distributions shown in Figure 8a). It may be seen that, at the higher noise levels, the differences exceed 6 dBA. This is because proportionately fewer of the noisier types operate at night.

4.22 Although the data plotted in Figures 8a and 8b is a sample of measurements, because of its large size it does provide a reasonably reliable indication of the likely long-term average differences. Table 5 compares the percentage splits by aircraft group of the 21,989 measurements with those of the 1994 average summer day (from Table 2).

5 ESTIMATION OF SYSTEM PERFORMANCE

5.1 The monitoring system criteria of particular interest are its stringency, the proportion of departures that are offenders, and its efficiency, the percentage of offenders that are detected by the system.

5.2 For present purposes, an offender is defined as any departing aircraft whose noise event level exceeds the Base Limit (at the Reference Point). Obviously, lowering the Base Limit has the direct effect of increasing the number of offenders. Whatever the number, the monitoring efficiency is the percentage of these offenders that are recorded as exceeding the set Infringement Levels at any one or more of the monitors.

5.3 In fact, as will be seen, the two factors are interrelated to the extent that, for a given noise monitor array, lowering the Base Limit in order to increase stringency also increases the monitoring efficiency. Nevertheless, in an attempt to clarify the distinction between the two criteria, efficiency and stringency are the principal considerations in Sections 6 and 7 respectively.

5.4 The theoretical efficiency of any array of monitors has been estimated using the model described in Section 3. The required statistical inputs were determined from the noise and radar data. For each runway, all routes were considered, together with a realistic distribution of the traffic between the routes. As noted in paragraph 3.23, the analysis has been confined to the critical large, slow-climbing aircraft, specifically groups B2 and B3, i.e. Boeing 747s.

5.5 The method of analysis is illustrated, for the example of departures from Heathrow Runway 09R, in Figures 9(a) to (d). The diagrams show the performance of various monitor arrays, with respect to Group B2 aircraft (Chapter 2 B747s), as functions of the selected Base Limit.

5.6 Each of the Figures 9(a) to (d) shows how the number of offenders varies with the Base Limit; the lower the limit, the greater the percentage of departing Group B2 aircraft that become offenders. The ‘total offenders’ are the same in all four diagrams; their numbers depend only upon the Base Limits and not on the practical monitor configuration. Vertical lines mark the Base Limits that are numerically equal to the current day and night limits of 97 dBA and 89 dBA. With these limits, the offenders would comprise, respectively, 8.9% and 90% of all departures.

5.7 The graphs in the four parts of Figure 9 ((a) to (d)) illustrate the performance of the different monitoring arrays by dividing the offenders into four categories. These are those which are detected by the monitors - the infringements - and those which are not – 'missed offenders'. Both the infringements and the missed offenders are split into those which exceed the Base Limit by 3dB or less, and those for which the exceedance is greater than 3dB.

5.8 Thus, for example, referring to Figure 9(a), it may be seen that if the Base Limit were set at 95 dBA, 25% of Group B2 departures would be classed as offenders. For the monitor array specific to Figure 9(a), this 25% would be divided approximately as follows:-

2% Infringements: Exceedance > 3 dB;
1 % Infringements: Exceedance <= 3 dB;
17% Missed Offenders: Exceedance <= 3 dB;
5% Missed Offenders: Exceedance > 3 dB.

5.9 Figure 9(a) illustrates the theoretical performance of the existing monitor array for Runway 09R, monitors 2, 3 and 4 (see Figure 3)[11], when, as at present, the same Infringement Level is set at each monitor. This 'base case' shows how changes to the Base Limit affect the monitoring performance. Mainly because of the displacements of the monitors from the Reference Arc, the efficiency of the current three monitor array is low - only 8% at a Base Limit of 97 dBA - so the theoretical daytime infringement rate for this group is only 0.7% (i.e. 8% of the offenders)[12]. The 7 out of 1000 Group B2 departures that are detected as offenders comprise:-

4 infringements exceeding the Base Limit by more than 3 dB;
3 infringements exceeding the Base Limit by 3 dB or less.

The 82 (89 minus 7) departures out of 1000 that are missed offenders, i.e. offenders that do not infringe at any of the monitors, comprise:-

71 exceed the Base Limit by 3 dB or less ;
11 that exceed it by more than 3 dB.

5.10 The performance of the present array could be improved just by adjusting the individual Infringement Levels to allow for the along-track and vertical displacements of the monitors from the Reference Points. Because the aircraft are continuously gaining altitude, noise levels monitored at points beyond the

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11 Monitor position number 1 at Cranford has not been included in Heathrow assessments for this study because of its specialised role in relation to Runway 09L departures. Its distance from start-of-roll is 5.1 km.

12 It should be noted that the concept of monitoring efficiency has been introduced for the purposes of this study. Under the existing monitoring regime, 'offenders' and 'infringers' are the same - departing aircraft that are observed to exceed the noise limit at any monitor. The quoted theoretical efficiency of the existing system is a purely notional one - calculated by simply setting the Base Limit numerically equal to the 97 dBA, the present daytime limit.

Reference Point tend to fall due to the greater sound propagation distances. Infringement Levels should therefore decrease accordingly. It was concluded that a fair allowance for the height effect could be based upon the lowest ‘permissible’ climb performance. Ref 1 requires aircraft to pass over the current monitors at a minimum height of 1000 ft (above ground level) and to maintain a minimum climb gradient of 4% thereafter (until at least 3000 ft altitude at Gatwick and Stansted, or 4000 ft at Heathrow). This minimum gradient has therefore been used, in conjunction with a sound attenuation rate of 8 dB per doubling of distance (Ref 4), to calculate a standardised decrease of Infringement Level with track distance from the 6.5 kin Reference Arc.

5.11 The results, in Figure 9(b), indicate that, for the Chapter 2 B747s (Group B2) and the current daytime limit, these standard adjustments would increase monitoring efficiency from 8% to 19%. However, this particular increase would be attributable mainly to an effective lowering of the limits, and thus to the creation of a greater number of offenders, rather than to an intrinsic improvement in the detection rate. Truly better performance could be obtained by relocating the three monitors to the Sites 11, 16 and 17 on the Reference Arc shown in Appendix D, Figure D1. Here the spacings between the chosen locations are not constant; they have been adjusted to provide better coverage of the three departure routes from Runway 09R. Figure 9(c) shows that the result is to improve monitoring efficiency to 46% (i.e. a further 27 out of 100 offenders would be recorded as infringements).

5.12 The final diagram for Heathrow 09R, Figure 9(d), corresponds to a ‘fence’ of seven monitors spaced at approximately 500 m intervals along the Reference Arc (Sites 10, 12, 13, 15, 18, 21, 22 shown on Figure D1). This idealised array would miss very few offenders that exceeded the limit by more than 3 dB. In this case the daytime efficiency is approximately 73% (i.e. another 27 out of 100 offenders would be recorded as infringements).

5.13 It should be noted that although more offenders can be detected by adding to and widening the monitor fence, the effectiveness of the outer monitors may be low because flights over them are relatively infrequent. In this regard, a more effective use of the NTK system in the longer term might be to identify the offending outliers from their radar tracks: for example, for aircraft “avoiding” the monitor fence by more than, say, 350 m (allowing 100 m for radar error) the Infringement Level could be lowered by 3 dB. To enable this to be done, though, additional software would have to be developed for the NTK system.

6 IMPROVED MONITORING OPTIONS

Theoretical Improvements

6.1 Alternative monitor arrays for each of the runways at the three airports have been analysed to assess what improvements might be achieved by expanding the coverage. As for Heathrow Runway 09R, the present and 'ideal' monitoring options include:-

Option	*Monitor array and limits*
(i)	the present monitor layout with the present 'unadjusted'[13] day and night Infringement Levels (i.e. no change);
(ii)	the present monitor layout with Infringement Levels adjusted (as described in paragraph 5. 10) to allow for monitor track distance and elevation, consistent with a Base Limit numerically equal to the present daytime or night-time limit (for those monitors with track distances less than 6.5 km, a gradient of 8% was adopted as a reasonable basis of adjustment inside the Reference Arc);
(iii)	an 'optimised' reference layout using the present number of monitors, but spaced along the Reference Arc (with adjusted Infringement Levels as (ii) above);
(iv)	extended 'reference' monitor layouts using increasing numbers of monitors; and also
(v)	for the extended array with the largest number of monitors considered, a number of cases with lower Base Limits (decreasing in 1 dB steps to 5 dB below the current limits).

(Subsequent paragraphs refer to these option numbers.)

6.2 The main findings for Chapter 2 B747 daytime (0700-2300) departures are summarised below; detailed results are listed in Table 6 for daytime and Table 7 for night-time (2300-0700)[14]. These tables identify the specific monitors included in each array and also the nominal costs of installation. (These are BAA's preliminary estimates of representative costs of supplying further sets of equipment, creating and gaining access to new sites, decommissioning old sites and upgrading associated computer facilities. Accurate costs can not, of course, be estimated until specific sites have been identified and agreed between the parties involved.)

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[13] The 'present unadjusted' case for Gatwick Runway 26L (Russ Hill monitor) incorporates the 2 dB adjustment which is presently subtracted from all monitored noise levels, to allow for the unusually high monitor elevation of 185 ft (56 m) above the runway.

[14] In Table 7, values have not been calculated for cases where the proportion of offenders would be 96% or more.

6.3 The hypothetical monitor positions in the arrays analysed are shown in Appendix D. In general, the tabulated 'reference' layouts consist of monitors positioned along the Reference Arc, with spacings that depend to some extent on the relative traffic on each route. For Heathrow Runway 27L, however, the Reference Arc crosses the Wraysbury Reservoir, and the analysis in this case had to be based on more practicable sites along a line following the edge of the reservoir (see Figure D2).

Retaining Present Numbers of Monitors

6.4 It is clear that appropriate adjustment of the Infringement Levels (Option ii) or, more effectively still, optimum positioning of the existing monitors (Option iii), could lead to significantly greater detection of offenders[15] - without lowering the Base Limits - as summarised below for daytime Chapter 2 B747 departures[16]:-

Options (i), (ii), (iii) DAYTIME MONITORING EFFICIENCY (%)

Airport, Runway	No. of monitors	-------- Present positions ----- Present limits *Option (i)*	Adjusted limits *Option (ii)*	Optimised positions* *Option (iii)*
Heathrow 09R	3	8.0	19	46
Heathrow 27L/R	3	11	21	36
Gatwick 08R	1	20	26	31
Gatwick 26	1	16	19	29
Stansted 05	1	4.2	7.5	17
Stansted 23	2	5.0	16	29

* on the Reference Arc except for Heathrow Site 6 (Runways 27L/R).

Tables 6 and 7 show that similar performance improvements would be realised for Chapter 3 B747s and by both day and night.

Increasing the Numbers of Monitors

6.5 Further improvements in efficiency could be obtained by spacing an increased number of monitors along the Reference Arcs, as tabulated below (Option iv). This would lead to substantial increases in the rates of infringement, even without any change to the Base Limit.

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[15] Again, for the purposes of this study, 'offenders' are defined, for comparative purposes, in consistent terms, i.e. as aircraft that exceed the Base Limit at the Reference Point.

[16] In this and subsequent tables, all values of Monitoring Efficiency, Exceedance Rates and Infringement Rates are given to an accuracy of two significant figures wherever possible.

Option (iv) DAYTIME MONITORING EFFICIENCY (%): CH 2 B747S

No. of monitors→	1	2	3	4	5	6	7	8
Heathrow 09R	-	-	46	55	67	69	73	-
Heathrow 27L/R	-	-	36	44	48	50	-	55
Gatwick 08R	31	51	65	73	-	-	-	-
Gatwick 26L	29	50	65	72	-	-	-	-
Stansted 05	17	31	46	-	-	72	-	-
Stansted 23	-	29	45	52	62	67	71	-

Arrays which have not been analysed are indicted by '-'.

Effect of Increasing Stringency

6.6 Lowering the Base Limit (Option v) increases the fraction of departures classified as offenders, and therefore the corresponding rates of infringement. The following table shows the effects of lowering the Base Limit in 1 dB steps on the theoretical infringement rates, for an extended array for each runway:

Option (v) DAYTIME INFRINGEMENT RATE (% OF CH 2 B747 DEPARTURES)

Case	No. of monitors	Base Limit reduction (dB) → 0	1	2	3	4	5	Present array Unadj'd
Heathrow 09R	7	6.6	12	20	30	43	55	0.7
Heathrow 27L/R	8	5.0	9.4	16	25	37	49	1.0
Gatwick 08R	4	6.6	12	19	29	41	54	1.8
Gatwick 26L	4	6.4	11	18	28	39	50	1.4
Stansted 05	6	6.5	12	20	30	43	56	0.4
Stansted 23	4	4.7	8.9	15	24	34	46	0.5

It may be seen in Tables 6 and 7 and Figure 9(d) that lowering the Base Limit has the secondary effect of further increasing the monitoring efficiency. This is because, as the limit is reduced, there are more noise events exceeding the limit within the lateral range of the monitors, hence a lower percentage of offenders will be missed.

6.7 The performances of monitor arrays with the same number of monitors differ between airports and runways because of the varying alignments with respect to the spread of departure tracks.

Cost Effectiveness and Limitations on Efficiency Gains

6.8 The performance of the system has to be balanced against the cost. Figure 10 illustrates the gains in monitoring efficiency[17] that could be expected for each of the extended monitor configurations analysed, plotted against the nominal costs. The numbers marked against each point represent the number of monitors considered.

6.9 Use of more extensive monitor arrays (Option iv) to achieve efficiencies greater than 50% would require expenditures between £50,000 and £100,000 per runway direction. The most difficult case is that of Heathrow 27L/R, where positions on the southern portion of the Reference Arc are unavailable because of the presence of the reservoir. It may be seen that, for the Heathrow cases in particular, efficiency gains from larger investments are subject to the law of diminishing returns (although in terms of total numbers of offenders detected, returns would be lowest at Stansted).

Practical Monitoring Improvements

6.10 The above analyses have shown what system performance improvements might be achieved by optimal positioning of the noise monitors. However, in general, it will not be possible to set up such ideal arrays of monitors due to lack of accessible secure sites or interference from other noise sources, e.g. roads and railways. Practical monitor arrays will necessarily have to have a limited number of monitors, unevenly spaced and at different track distances and elevations.

6.11 Following an assessment of the analysis described above, ANMAC recommended that the target at each airport should be a monitoring efficiency of 50% (relative to the present daytime limit) for the aircraft types most likely to be affected. It was also decided to recommend that this should be accompanied by an increase in stringency. BAA and DORA were therefore asked to consider further the most cost-effective monitor layout for each runway that might achieve such an efficiency, and to identify and evaluate practical sites for the monitors.

6.12 Detailed negotiations and arrangements are required before any new fixed monitor site can be commissioned. Landowners' permission, planning permission, access for servicing, and provision of power and telephone services (which in some cases may require poles and cables over, or excavation under, third party-owned land) all need to be considered. All site positions described are therefore provisional.

[17] 'Monitoring Efficiency' in the remainder of this report, unless otherwise stated, is the percentage of those Chapter 2 Boeing 747 departures from the runway in question with noise levels greater than 97 dBA at runway elevation at any point on the Reference Arc which are recorded as infringements at one or more of the monitors.

6.13 The results in Table 6 indicated that the following ‘optimum’ monitor arrays would give around 50% monitoring efficiency - in every case a very large improvement on the efficiency of the present array. The site numbers refer to the maps in Figures 11-16.

MONITORING EFFICIENCY OF OPTIMUM ARRAYS: DAYTIME

Airport	Runway	‘Optimum’ site numbers	Present Arrays	Optimum Arrays
Heathrow	09R	14, 15, 16, 17	8%	55%
Heathrow	27L/R	6, 10, 11, 12, 13, 25	11%	50%
Gatwick	08R	80, 81	20%	51%
Gatwick	26L	20, 21	16%	50%
Stansted	05	42, 43, 44, 46	4%	56%
Stansted	23	31, 32, 33, 34	5%	52%

6.14 At each airport a search was made to locate a possible practical position for each monitor, as close as possible to the ‘optimum’ locations listed above, and suitable from an acoustic viewpoint. The initial area of search was within ±100 m longitudinally and ±50 m laterally, but in some cases these tolerances had to be increased. These ‘optimum’ and provisional practical sites are shown in Figures 11 to 16, which also show a sample of departure tracks from the appropriate runway(s) to illustrate the relative positions of the proposed noise monitors to the routes.

Heathrow

6.15 The four sites on the Reference Arc to the east of Heathrow (Runway 09R) numbered 14 to 17 are largely in accessible parts of built-up areas (Figure 11) and have therefore been assumed workable for present purposes. The monitoring efficiency for this array is estimated at 49%.

6.16 The composite ‘Reference Arc’ to the west of Heathrow (Figure 12) relates to both Runways 27R and 27L. To the south, this is distorted by the presence of the Wraysbury Reservoir - the southerly Reference Points are at somewhat greater distances from start-of-roll than 6.5 km because they have to be placed beyond the reservoir embankment.

6.17 The array of six reference monitors shown (including present monitor number 6) is estimated to give a monitoring efficiency of 50%. Practical locations have been found at or reasonably close to each of the reference positions apart from Sites 10 and 12. Site 10 is in a large open farmed area, and at least 0.5 km from any power/telephone services. The field in which the site is situated, being adjacent to the River Colne, is susceptible to flooding, and there are large unfenced ploughed fields west and south of the site. A possible practical alternative is location number 61. Site 12 is in a public space; Site 62 is a possible alternative. The monitoring efficiency for this practical array of six monitors including numbers 61 and 62 is estimated at 43%.

Gatwick

6.18 For monitoring departures from Runway 26L, Gatwick Airport Ltd wished to retain the present monitor, number 1 (Russ Hill), which is inside the Reference Arc at 6.2 km from start-of-roll. To reach 50% monitoring efficiency with Site 1 retained, it is necessary to have two further monitors, either side of the runway centreline. Optimum efficiency would be achieved with a lateral spacing between adjacent monitors of 290 m - these theoretical sites are shown in Figure 13 as Sites 22 and 23. An array consisting of 1, 22 and 23 would give a monitoring efficiency of 65%. Site 23, however, is in the middle of a fairly dense woodland area, which would not be suitable for noise measurements, and 22 is in an open field. Practical sites identified close to existing power supplies are shown as Sites 50 and 53, which together with monitor 1 are estimated to give a monitoring efficiency of 50%.

6.19 Gatwick Airport Ltd also considered retaining the present monitor number 2 to the east of Gatwick (Runway 08R), but, as it is a considerable distance beyond the Reference Arc, and displaced to the side of the runway centreline, the operational benefit of retaining it is small. The theoretically optimum positions for two new monitors, spaced 200 m either side of the runway centreline, are 80 and 81 (Figure 14). Possible practical positions, close to existing power supplies, are shown as Sites 41 and 42. The monitoring efficiency for these two locations is estimated at 48%.

Stansted

6.20 The four ideal sites for Runway 05 are shown on Figure 15. All of these are in open cultivated fields. Provisional practical sites close to existing power supplies are shown as 52, 53, 54 and 56; Site 52 is the furthest from the Reference Arc, but there would appear to be little prospect of obtaining a site any closer. Monitors at these four practical sites would give an estimated monitoring efficiency of 40%. To improve on this it would be necessary to concentrate the monitors towards the southern end of the array, and/or install a fifth monitor south of Site 44. Either of these options would require costly installation of power and telephone lines for long distances over (or under) cultivated fields.

6.21 Figure 16 shows theoretically optimum sites for Runway 23 numbered 31, 32, 33 and 34. Site 31 is in an open cultivated field and, in addition, motorway noise levels make it impracticable. A more practical alternative is shown as

Site 41. Site 32 is also in an open field, and the existing monitor number 3 is sufficiently close to this theoretical site that a move is not warranted. 43 and 44 are in the grounds of private houses. The estimated efficiency of an array consisting of Sites 41, 3, 43 and 44 is 51%.

Evaluation of Practical Sites

6.22 The full results for the possible practical arrays identified above are presented in Tables 8 and 9 (for day and night respectively). As for the theoretical monitor arrays, these are based on large slow-climbing aircraft - specifically Boeing 747s. For comparison, the tables also show the results for the present monitor arrays and the theoretical 'optimum' arrays. For the practical arrays the effect of lowering the Base Limit, in steps of 1 dB from the present values of the day and night limits, is also shown. Results are again given for Chapter 2 and Chapter 3 Boeing 747s, the latter being the aircraft most affected after the phase-out of the Chapter 2 versions.

6.23 The estimated monitoring efficiencies for each of the proposed practical arrays (with a Base Limit equal to the present daytime limit) are summarised below:-

PRACTICAL ARRAYS: DAYTIME MONITORING EFFICIENCY

Airport	Runway	Practical Site Numbers	Present	Ideal	Practical
Heathrow	09R	14, 15, 16, 17	8%	55%	49%
Heathrow	27L/R	6, 11, 13, 25, 61, 62	11%	50%	43%
Gatwick	08R	41, 42	20%	51%	48%
Gatwick	26L	1, 50, 53	16%	66%	51%
Stansted	05	52, 53, 54, 56	4%	56%	40%
Stansted	23	3, 41, 43, 44	5%	52%	51%

6.24 It can be seen that the practical arrays considered would give a monitoring efficiency between 40% and 51% (compared with between 4 and 20% at present). The least efficient proposed new arrays are those for Stansted Runway 05 (40%) and Heathrow 27L/R (43%), due to the lack of suitable sites near one or more optimum positions. There appears to be very little that could be done to improve on the proposed Heathrow 27L/R array. Additional monitors would be of little help unless there were very many of them. For Stansted Runway 05 efficiency could be improved by installing an additional monitor to the south, although this may be difficult to arrange in practice.

6.25 The adjustments required at each proposed monitor position to allow for track distance and ground elevation are given in Table 10. (Under the present system the only such adjustment is the 2 dB applied to noise levels monitored at Russ Hill, Gatwick.) Although many of the adjustments shown are small (where the sites are close to 6.5 km from start-of-roll and close to runway elevation), it is proposed that for consistency the adjustments should be applied at all sites. The NTK software would require minimal modification to allow reports to be produced automatically listing flights exceeding the different Infringement Levels at each monitor.

6.26 It must be emphasised that this analysis, although supported by extensive measured data collected by the NTK system, relies on a number of theoretical - but probably reasonable - assumptions. The accuracy of the estimated results is considered adequate for the purposes of selecting and evaluating noise monitor placements, but it would be advisable to review the Infringement Levels in the light of results from prolonged monitoring, and if necessary to make minor adjustments after an initial period of say two years.

7 FACTORS AFFECTING CHOICE OF LIMITS

7.1 ANMAC decided to recommend that the new limits should reflect what is operationally achievable at the present time and have a sound empirical basis. The number of operational infringements should be a realistic proportion of the total number of departures, so that operators are encouraged to make greater use of better noise abatement operating practices - without making it so difficult that operators lose the impetus to avoid infringements. In addition to infringement rates, a number of other factors need to be considered, including the phase-out of Chapter 2 aircraft, the impact of the noisiest common aircraft type, the Boeing 747[18], and the relationship between the night limit and the night restrictions regime.

7.2 The requirement that any new limits are consistent and uniform from airport to airport can be met by setting Base Limits on the Reference Arc. When comparing any new proposals, it is important to remember that the current limits of 97 dBA by day and 89 dBA by night apply at each of the present individual monitor positions. Appendix A, Table A1 lists the individual adjustments that are necessary to compare these directly with the Base Limit. Disregarding Monitor 1 at Heathrow (Cranford), and Monitor 1 at Gatwick (Russ Hill), these vary from -0.4 dB to -2.1 dB. Thus, simply setting the Base Limits equal to the present day and night limits, without extending the monitor array, would effectively increase the system stringency, and increase the infringement rate - as noted in paragraphs 5.11 and 6.4.

7.3 The consequences for aircraft in the various type groups of reducing the Base Limits can be quantified by reference to the nominal exceedance rates given in Table 4. These are the same for all airports, and are summarised separately for

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[18] As noted previously, taking the three airports as a whole, movements of other 'noisier' types are comparatively infrequent.

day and night below. (In these and subsequent tables in the text, percentages less than 0.005% are shown by '*'.)

ESTIMATED DAYTIME OFFENDERS:
PERCENTAGE OF DEPARTURES OF GROUP EXCEEDING BASE LIMIT

Aircraft group	Approx. Present[19]	Base Limit (dBA) 97	96	95	94	93	92
B2	4.7	8.9	16	25	36	49	62
B3	1.5	2.7	4.6	7.5	12	17	24
C	7.3	9.9	13	17	22	27	33
D	*	*	*	*	0.01	0.02	0.06
E	0.14	0.31	0.65	1.3	2.4	4.2	7.0
F	*	*	*	*	*	*	*
G	*	*	*	*	*	*	0.01
H	*	*	0.01	0.01	0.02	0.05	0.09

ESTIMATED NIGHT-TIME OFFENDERS:
PERCENTAGE OF DEPARTURES OF GROUP EXCEEDING BASE LIMIT

Aircraft group[20]	Approx. Present[19]	Base Limit (dBA) 89	88	87	86	85	84
B2	83	90	95	>96	>96	>96	>96
B3	42	52	62	71	79	85	90
C	45	52	59	65	71	76	81
D	0.36	0.79	1.6	3.1	5.5	9.2	15
E	16	23	32	41	51	61	70
F	*	*	*	*	0.01	0.05	0.18
G	0.03	0.07	0.14	0.27	0.50	0.89	1.5
H	0.28	0.49	0.81	1.3	2.1	3.2	4.7

7.4 When comparing these group exceedance rates it must be remembered that the overall exceedance rates (i.e. fraction of total departures classed as offenders)

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19 As noted in paragraph 7.2, Base Limits of 97 dBA (daytime) and 89 dBA (night-time) are generally somewhat more stringent than the current limits, because of the present positions of the monitors. To specify Base Limits equivalent to the current limits, the monitor adjustments in Appendix A Table Al need to be applied: the average adjustment (excluding Cranford and Russ Hill) is approximately 1 dB, so that in Table 4 Base Limits of 98 dBA (day) and 90 dBA (night) might give an indication of the present situation.

20 Although night-time results are shown for Group B2 in this table and elsewhere, in practice there are very few departures at night by any aircraft in this group due to night restrictions. (Under the present night restrictions regime aircraft classified as QC/8 may not take off between 2300 and 0600, those classified as QC/1 6 may not take off between 2300 and 0700. Delayed departures by QC/8 and QC/16 aircraft may be permitted between 2300 and 2330.)

depend upon the mix of aircraft types in operation at each airport. As an example, the following table gives the estimated situation (aggregated for all three airports) assuming Base Limits are equal to the current daytime and night-time limits:-

PERCENTAGE OF TOTAL DEPARTURES EXCEEDING
BASE LIMITS OF 97 dBA DAY/89 dBA NIGHT

Aircraft group	% of total departures (derived from Table 2)		% of group over Base Limit (From Table 4)		Offenders as % of total traffic	
	Day	Night	Day	Night	Day	Night
B2†	2.6	1.2	8.9	90	0.23	1.1
B3†	5.8	2.8	2.7	52	0.16	1.5
C	0.8	1.1	9.9	52	0.08	0.58
D	15	14	*	0.79	*	0.11
E	17	9.1	0.31	23	0.05	2.1
F	48	43	*	*	*	*
G	8.3	26	*	0.07	*	0.02
H	2.0	2.2	*	0.49	*	0.01
All	100	100			0.52	5.4

† B747 traffic data from Table 2 split using proportions of Chapter 2 and Chapter 3 departures derived from Appendix C Table C4.

It must be stressed that the determination of exceedance rates such as those shown above is based purely on statistical estimates. The percentages in Table 4 are simply estimates of the distributions of the Reference Levels that would occur over long periods of time, assuming that aircraft continue to be operated as they were, on average, during the period of this investigation. Greater use of better noise abatement operating procedures would of course result in lower exceedance rates.

Chapter 2 Phase-Out and Classification of Boeing 747 Aircraft

7.5 The above comparisons highlight how substantial the differences are between noisier and quieter aircraft. Any limit exceeded by small fractions of the noisier aircraft (groups B, C and E) would have negligible impact upon the quieter ones (I), F, G and H). At present a relatively small but significant number of heavy Chapter 2 aircraft remain in service. It is apparent from Table 4 that any effective noise limit will penalise aircraft in groups B and C to a much greater extent than the remainder. Of the present fleet, Concorde excepted, departures of Chapter 2 B747s are the most significant in terms of daytime noise exposure. Group C is composed of aircraft such as hush-kitted B707 and DC8 aircraft which operate in relatively small numbers and which will be phased out of service along with the other Chapter 2 aircraft in Group E.

7.6 B747 aircraft exist in both Chapter 2 and Chapter 3 versions; these sub-categories were examined separately (see Appendix C Table C4). The Reference Mean Level for Chapter 2 B747s was 92.3 dBA, compared to 89.2 dBA for the Chapter 3 variants.

7.7 When the Chapter 2 aircraft have been retired by 2002, Figure 7 shows that there will be a gap of some 9 dB between the average noise levels of the Chapter 3 B747s and almost all other aircraft, although it is possible this may eventually be filled to some extent by future new large aircraft. In the intermediate term, therefore, it is mainly B747s that will dominate the exceedance rates of any overall noise limit. Aircraft in groups F, G and H have much lower noise levels and are unlikely to be a significant fraction of offenders in the presence of the noisier aircraft.

Night Limits and the Night Restrictions

7.8 Under the present night restrictions arrangements at the London airports (Ref 3), night quotas are linked to the certificated noise levels of individual aircraft. The take-off Quota Count (QC) rating of any aircraft is determined from the arithmetic average of its certificated EPNLs at the flyover and sideline measurement points[21]. As aircraft with QC ratings of 8 and 16 may not be scheduled to depart at night[22], it might be considered logical to link the night-time limit to the QC/8 threshold.

7.9 Unfortunately, there is no unique relationship between certificated and monitored noise levels, even for ‘flyover’ levels at the 6.5 km point to which the latter have been adjusted in this study. Sideline levels were not monitored for the purposes of this study[23]. Certification test conditions are generally aimed at worst case situations; i.e. maximum weights and engine power settings. Noise levels generated in normal operations differ due to variations in operating weights, flight procedures and weather conditions. The microphone heights used for noise monitoring differ from that used in certification testing. Different noise metrics are involved: EPNL for certification and L_{Amax} for monitoring, and there is no single transformation from one scale to the other. Only by making certain assumptions can a broad comparison be made.

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[21] For Chapter 2 aircraft 1.75 EPNdB is added to the flyover and sideline average, to allow for the use of different lateral displacements of the sideline measurement points in the Chapter 2 and Chapter 3 tests.

[22] Except that QC/8 aircraft may depart between 0600 and 0700 LT and, if unavoidably delayed from an earlier scheduled departure time, QC/8 and QC/16 aircraft may depart between 2300 and 2330 LT.

[23] Monitoring of sideline noise would involve severe practical problems; it is intended to investigate this as part of the ANMAC study on the monitoring of the QC classification of aircraft.

7.10 In order to relate monitored ‘flyover’ noise levels to aircraft QC classifications, the broad assumptions can be made that, first, sideline and flyover levels are similar on average, and second, that L_{Amax} is approximately EPNL - 15 dB[24]. On this basis an L_{Amax} equivalent to the QC/8 threshold of 99 EPNdB would be around 84 dBA at the Reference Point. Individual departure noise levels of aircraft meeting this certification standard would of course vary; for about five percent of events perhaps the level could differ by more than 5 dB. This would indicate that a suitable Base Limit to penalise noise events well in excess of the norm would be in the vicinity of 89 dBA.

7.11 What cannot be judged from the results is to what extent the use of ‘best’ noise abatement procedures at operating take-off weights at night would improve upon the levels typified by noise certification. However, the above logic suggests that the current night-time limits - and possibly some small reductions of them - are broadly in line with the aims of the present night restrictions arrangements.

Effect of Lowering the Base Limit

Chapter 2 Boeing 747s

7.12 The theoretical effects of lowering the Base Limits on (a) the percentage of offenders, (b) the monitoring efficiency and (c) the percentage of infringements, for each of the practical extended monitor arrays can be extracted for the current daytime ‘critical’ aircraft, the Chapter 2 Boeing 747, from Table 8.

7.13 The stringency of the system is purely a function of the Base Limit:-

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[24] L_{Amax} and EPNL are different measures of noise; unlike L_{Amax}, EPNL makes special allowance for the presence of tones in the noise, and for the way in which 'instantaneous level' varies with time during the event - i.e. its duration. The differences between L_{Amax} and EPNL therefore vary from event to event over a substantial range. Even average differences vary - between aircraft types, between operating modes (especially landing and take-off) and between measurement locations. A difference of 15 dB must be viewed as just one of a range of values that could apply in different circumstances. The practical validity of the assumption and, more specifically, the statistical relationships between the different metrics in various circumstances, will be determined from the results of a related monitoring study also being conducted on behalf of ANMAC. That study will additionally provide important information on the relationships between certificated and operational noise levels.

PERCENTAGE OF CH 2 B747 DEPARTURES OFFENDING
(EXCEEDING THE BASE LIMIT)

DAY Base Limit dBA	DAY Exceedance rate %	NIGHT Base Limit dBA	NIGHT Exceedance rate %
97	8.9	89	90
96	16	88	95
95	25	87	>96
94	36	86	>96
93	49	85	>96
92	62	84	>96

7.14 The monitoring efficiencies for each of the runways (from Table 8) are:-

DAYTIME MONITORING EFFICIENCY, %

	Heathrow Runway		Gatwick Runway		Stansted Runway	
	09R	27	08R	26L	05	23
Present array*	8.0	11	20	16	4.2	5.0
- adjusted limits	19	21	26	19	7.5	16
Extended array	49	43	48	51	40	51
-ldB	53	47	52	53	43	56
-2dB	57	51	55	55	46	60
-3dB	62	56	59	58	50	65
-4dB	67	61	63	61	53	69
-5dB	71	66	67	65	57	74

* Figures for the present system are notional: the first row assumes the Base Limit is equal to the present limit, while the second row additionally includes allowance for the individual monitor adjustments to achieve balanced Infringement Levels. The net effects of extending the arrays to the practical arrays listed in paragraph 6.23 are thus obtained by comparing the second and third rows.

7.15 As the Base Limit is lowered, the rate of infringement increases due to increases in both numbers of offenders and monitoring efficiency:-

DAYTIME CH 2 B747 INFRINGEMENT RATES, %

	Heathrow Runway 09R	Heathrow Runway 27	Gatwick Runway 08R	Gatwick Runway 26L	Stansted Runway 05	Stansted Runway 23
Present array	0.7	1.0	1.8	1.4	0.4	0.5
Extended array	4.4	3.9	4.3	4.5	3.6	4.6
-ldB	8.4	7.4	8.1	8.2	6.8	8.7
-2dB	14	13	14	14	11	15
-3dB	23	20	21	21	18	24
-4dB	33	30	31	30	26	34
-5dB	44	41	42	40	35	46

7.16 For the lower Base Limits at night, the theoretical infringement rates are, of course, markedly higher. The full results for night-time are given in Table 9.

Chapter 3 Boeing 747s

7.17 When all Chapter 2 aircraft have been phased out, the Chapter 3 B747 will probably become the critical aircraft. The corresponding figures are:-

PERCENTAGE OF CH 3 B747 DEPARTURES OFFENDING
(EXCEEDING THE BASE LIMIT)

DAY Base Limit dBA	DAY Exceedance rate %	NIGHT Base Limit dBA	NIGHT Exceedance rate %
97	2.7	89	52
96	4.6	88	62
95	7.5	87	71
94	12	86	79
93	17	85	85
92	24	84	90

DAYTIME CH 3 B747 INFRINGEMENT RATES, %

	Heathrow Runway 09R	Heathrow Runway 27	Gatwick Runway 08R	Gatwick Runway 26L	Stansted Runway 05	Stansted Runway 23
Present array	0.1	0.2	0.4	0.2	0.1	0.1
- adjusted limits	0.4	0.4	0.5	0.5	0.1	0.3
Extended array	1.0	0.9	1.0	1.3	0.8	1.0
-1dB	2.0	1.7	1.9	2.3	1.6	2.0
-2dB	3.5	3.0	3.5	3.8	2.9	3.6
-3dB	5.8	5.0	5.6	5.9	4.7	6.0
-4dB	9.3	8.2	9.0	9.1	7.5	9.7
-5dB	14	13	13	13	11	15

NIGHT-TIME CH 3 B747 INFRINGEMENT RATES, %

	Heathrow Runway 09R	Heathrow Runway 27	Gatwick Runway 08R	Gatwick Runway 26L	Stansted Runway 05	Stansted Runway 23
Present array	11	14	19	18	5.0	7.4
- adjusted limits	18	19	22	16	6.9	14
Extended array	37	34	35	34	29	38
-1dB	47	44	44	42	37	48
-2dB	57	54	53	51	45	58
-3dB	67	64	62	60	53	67
-4dB	76	74	70	69	60	75
-5dB	83	81	77	76	67	82

8. ANMAC CONCLUSIONS AND RECOMMENDATIONS

8.1 Through its review of the departure noise limits at the London airports, ANMAC identified the needs for both an increase in stringency and improvements in the monitoring efficiency of the present NTK system. A further requirement was for similar levels of monitoring efficiency to be achieved at the three airports. Stringency defines the fraction of departures that fail to meet the limits; efficiency is expressed as the percentage of departing offenders that are actually registered as infringements.

8.2 Uniform performance can best be achieved by monitoring at a fixed track distance or by adjusting the set limits to allow for individual monitors displacements. It is recommended that standard Base Limits be set at a Reference Point at runway elevation, 6.5 km from start-of-roll; this is the distance to the flyover measurement point used for international noise certification. Infringement Levels set at individual monitors can then be adjusted from the Base Limit to account for monitor elevation and along-track displacement from the Reference Point.

8.3 Monitoring efficiency depends primarily upon the numbers and spacings of monitors deployed, but also upon the aircraft noise levels and the set limits. For the currently critical aircraft, the Chapter 2 Boeing 747, daytime efficiencies of the present monitor positions are estimated to vary between 4% and 20% for different airports and runways, whilst at night the range is 16% - 53%. However, relatively few Chapter 2 B747s depart at night; for Chapter 3 B747s, the night-time efficiency range is 10 - 37%.

8.4 High monitoring efficiency can only be achieved by deploying a large number of monitors - sufficiently closely spaced that most aircraft pass close to at least one of them. Mindful of the need to balance performance and costs, ANMAC recommended a new daytime target of 50% efficiency for the Chapter 2 B747. A range of monitoring options has been considered; practical monitor arrays have been identified (subject to permissions and provision of services) that should achieve efficiencies in the approximate range 40% - 50% with an increase from 12 to 23 fixed monitors. The corresponding range for Chapter 3 B747s at night would be 56% - 75%.

8.5 ANMAC concluded that the limits should be expressed in L_{Amax}, continue to be enforced only at fixed monitor positions, and reflect what is operationally practicable. The overall stringency of the system is set by the choice of Base Limit. Because the present limits of 97 dBA (day) and 89 dBA (night) apply to individual monitors which are mostly located at distances greater than the 6.5 km Reference Distance, numerically equal Base Limits (with adjusted monitor Infringement Levels) would effectively lower the overall limit by approximately 1dB. The corresponding levels of stringency are reflected by the following estimated exceedance rates (percentage of departures classified as offenders):-

	Day (97 dBA)	*Night (89 dBA)*
Chapter 2 B747	8.9%	90%
Chapter 3 B747	2.7%	52%

8.6 After consideration of all the analyses, ANMAC decided to recommend that future daytime and night-time Base Limits be set at 94 dBA and 87 dBA, nominally 3 dB and 2 dB lower than the present limits. The corresponding exceedance rates would be:-

	Day (94 dBA)	*Night (87 dBA)*
Chapter 2 B747	36%	>96%
Chapter 3 B747	12%	71%

8.7 Because they automatically increase as the Base Limits are lowered, corresponding monitoring efficiencies would be higher: 50% - 65% by day for the Chapter 2 B747; 63% - 82% at night for the Chapter 3 B747. The suggested night-time limit is broadly compatible with the aims of the current night restrictions. These proposed ‘transitional’ reductions in the limits which, for the reasons given in paragraph 8.5, are effectively 4 dBA for daytime and 3 dBA for night-time, were accompanied by the recommendation that a further review of the limits be conducted before the phase out of Chapter 2 aircraft is completed in 2002.

8.8 All the above estimates of monitor performance for both day and night are based on the pooled distributions of measured noise levels. Although night-time data samples were generally too small for statistically reliable conclusions, they show that, in most aircraft groups, levels were somewhat lower at night, indicating that the corresponding exceedance rates might be lower than the estimates. Also, they would be further lowered by greater use of better noise abatement operating procedures.

REFERENCES

1. UK Aeronautical Information Publication (sections AGA 2-23-2, 2-24-3, 2-25-2).

2 International Civil Aviation Organisation: International Standards and Recommended Practices - Environmental Protection - Annex 16 to the Convention on Civil Aviation Volume 1 Aircraft Noise Third Edition: July 1993

3. UK NOTAM: Supplement to the United Kingdom AIP 837/1995: September 1995

4. Ollerhead J B: The CAA Aircraft Noise Contour Model: ANCON Version 1: DORA Report 9120: November 1992.

TABLE 1

AIRCRAFT TYPE GROUPS FOR AIRCRAFT IN MEASURED SAMPLE

A	CONCORDE	Concorde
B	BOEING 747 (Note 1)	Boeing 747* (- 100, -200, -300, -400, SP, SR)
C	HEAVY CHAPTER 2 (Note 2)	Antonov AN-124 Boeing 707* Ilyushin IL-62, IL-76, IL-86 Douglas DC8-60, -70*
D	HEAVY CHAPTER 3	Boeing 767 Airbus A300*, A310, A330, A340 Lockheed L 10 11 TriStar McDonnell Douglas DC 10*, MD 11
E	LIGHT CHAPTER 2 (Note 3)	Aerospatiale S210 Caravelle Boeing 727*, 737-100,-200 BAC 1-11 Douglas DC9 Fokker F28 Tupolev TU-134, TU-154 McDonnell Douglas MD81/82/83/87/88
F	LIGHT CHAPTER 3	Boeing 737-300, -400, -500 Boeing 757 British Aerospace 146/RJ Airbus A320/321 Fokker 100
G	PROPELLER AIRCRAFT	Avions de Transport Regional ATR42, ATR72 Beechcraft 1900, Super King Air 200 British Aerospace (HS) 748, ATP/Jetstream, 61 British Aerospace Jetstream 31/41 Cessna 404 de Havilland Canada Dash7, Dash 8 Embraer E 110, E 120 Fokker F27, 50 Gulfstream 1/159 Handley Page Herald Lockheed C130 Hercules Saab-Fairchild 340 Shorts 330, 360 Vickers Viscount, Vanguard
H	EXECUTIVE JETS	Cessna 500/501/550 Citation Falcon 10, 20, 50, 90 Gulfstream G-II, G-III, G-IV British Aerospace (HS) 125 Astra/Westwind Learjet 35, 55, 60 Canadair CL-600/601

* Variants could be either Chapter 2 or Chapter 3 - determination requires detailed aircraft type information (which is not always available via NTK). Aircraft have been placed in the group shown regardless of Chapter number.

(Note 1) For most purposes in this study, Boeing 747s have been subdivided into groups B2 and B3, according to their certificated Chapter number.

(Note 2) Although there are a few Chapter 2 A300s and DC10s in operation, these types have been included in Group D rather than C because they are much quieter than the other types in Group C. Inclusion of them in Group C would have led to a ‘bi-modal’ distribution of noise levels, particularly at Heathrow.

(Note 3) Similarly, MD80s were included in Group E because, although certificated to Chapter 3 standards for take-off, their departure noise levels are closer to those of Group E aircraft than to the other types in Group F.

TABLE 2

NUMBER OF DEPARTURES ON AVERAGE 1994 24-HOUR DAY

		Number of departures per average 24-hour day					
		Heathrow		Gatwick		Stansted	
Group		Day	Night	Day	Night	Day	Night
A	Concorde	2.4	0.0	0.1	0.0	0.0	0.0
B	B747	68.9	2.1	12.8	0.0	0.1	0.0
C	Other heavy Chapter 2	3.0	0.0	2.4	0.3	2.4	0.3
D	Other heavy Chapter 3	102.8	2.9	41.8	4.2	3.9	0.5
E	Light Chapter 2	82.8	0.8	61.1	3.7	22.5	0.4
F	Light Chapter 3	306.3	3.5	113.6	15.0	42.1	4.8
G	Propeller	13.1	0.4	43.5	4.5	23.5	9.1
H	Executive Jets	11.9	0.9	3.0	0.1	4.4	0.2
	TOTAL	591.2	10.6	278.3	27.8	98.9	15.3

Day = 0700-2300, Night = 2300-0700 BST; mid-June to mid-September.

Night-time figures are based on a sample of data.

TABLE 3
SUMMARY OF MEASURED DATA

Airport	Mon. No.	Rwy Dirn	Data available for analysis (1994)	No. of identified noise measurements	No. of flights with track data and overhead monitor*	No. of "overhead" flights with an associated noise level †								
						A Conc	B B747	C Heavy Ch2	D Heavy Ch3	E Light Ch2	F Light Ch3	G Prop	H Exec Jets	TOTAL: All aircraft
LHR	2	E	1/4 - 25/5	8650	1989	0	173	5	189	253	1075	6	31	1732
LHR	6	W	1/4 - 2515	13776	4048	21	365	15	791	518	1834	60	60	3664
LHR	53	W	1/4 - 25/5	10172	1507	0	106	5	335	299	483	20	19	1267
LHR	55	W	1/4 - 25/5	12885	3594	2	222	12	435	421	1479	19	23	2613
LHR	56	W	1/4 - 25/5	10515	3165	0	174	5	286	353	1578	25	40	2461
LHR	57	W	19/4 - 25/5	8507	3456	0	109	2	225	242	1120	18	26	1742
LGW	1	W	1/4-7/4, 21/4-30/5	3834	3557	0	30	9	255	615	1051	49	6	2015
LGW	2	E	1/4 - 30/5	5180	5296	0	129	17	599	885	2020	220	24	3894
LGW	29	W	1/4 - 30/5	3680	2292	0	25	12	119	488	590	95	8	1337
STN	1	E	1/4 - 30/5	1328	493	0	0	5	38	166	177	21	9	416
STN	2	W	1/4 - 30/5	987	677	0	1	7	21	159	158	40	5	391
STN	3	W	1/4 - 30/5	1355	459	0	0	6	5	51	189	10	3	264
STN	36	W	27/4 - 25/5	694	695	0	2	6	4	45	115	10	2	184
STN	37	W	4/5 - 30/5	350	37	0	0	2	1	2	1	2	1	9
TOTALS:														
Heathrow				64505	17759	23	1149	44	2261	2086	7569	148	199	13479
Gatwick				12694	11145	0	184	38	973	1988	3661	364	38	7246
Stansted				4714	2361	0	3	26	69	423	640	83	20	1264
POOLED DATA				81913	31265	23	1336	108	3303	4497	11870	595	257	21989

LHR = Heathrow
LGW = Gatwick
STN = Stansted

* ie within ± 30 deg of vertical. Note that some of these flights did not have a noise event associated with them.

† under acceptable weather conditions

TABLE 4

EQUIVALENT CUMULATIVE NORMAL DISTRIBUTIONS
OF POOLED REFERENCE LEVELS

Base Limit	Percentage of aircraft in Group exceeding Base Limit							
dBA	B2	B3	C	D	E	F	G	H
65	100	100	100	100	100	100	96	96
66	100	100	100	100	100	100	93	95
67	100	100	100	100	100	100	90	92
68	100	100	100	100	100	100	87	89
69	100	100	100	100	100	100	82	85
70	100	100	100	100	100	99	76	81
71	100	100	100	99	100	97	69	76
72	100	100	100	99	100	94	61	69
73	100	100	100	97	100	88	53	63
74	100	100	99	95	100	79	45	56
75	100	100	99	92	100	67	37	49
76	100	100	99	87	99	53	30	41
77	100	100	98	80	99	38	23	34
78	100	100	97	72	98	25	17	28
79	100	99	96	62	96	15	13	22
80	100	99	94	51	94	7.8	8.9	17
81	100	98	92	40	90	3.7	6.0	13
82	100	96	89	30	85	1.5	3.9	9.5
83	100	94	85	22	78	0.57	2.5	6.8
84	100	90	81	15	70	0.18	1.5	4.7
85	100	85	76	9.2	61	0.05	0.89	3.2
86	99	79	71	5.5	51	0.01	0.50	2.1
87	97	71	65	3.1	41	0.00	0.27	1.3
88	95	62	59	1.6	32	0.00	0.14	0.81
89	90	52	52	0.79	23	0.00	0.07	0.49
90	83	42	45	0.36	16	0.00	0.03	0.28
91	74	33	39	0.16	11	0.00	0.02	0.16
92	62	24	33	0.06	7.0	0.00	0.01	0.09
93	49	17	27	0.02	4.2	0.00	0.00	0.05
94	36	12	22	0.01	2.4	0.00	0.00	0.02
95	25	7.5	17	0.00	1.3	0.00	0.00	0.01
96	16	4.6	13	0.00	0.65	0.00	0.00	0.01
97	8.9	2.7	9.9	0.00	0.31	0.00	0.00	0.00
98	4.7	1.5	7.3	0.00	0.14	0.00	0.00	0.00
99	2.2	0.76	5.3	0.00	0.06	0.00	0.00	0.00
100	0.98	0.37	3.7	0.00	0.02	0.00	0.00	0.00
101	0.38	0.17	2.5	0.00	0.01	0.00	0.00	0.00
102	0.14	0.08	1.7	0.00	0.00	0.00	0.00	0.00
103	0.04	0.03	1.1	0.00	0.00	0.00	0.00	0.00
104	0.01	0.01	0.71	0.00	0.00	0.00	0.00	0.00
105	0.00	0.00	0.44	0.00	0.00	0.00	0.00	0.00
106	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00
107	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00
108	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00
109	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
110	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00

Equivalent cumulative Normal distributions from pooled (all airports, day+night) measured data.

TABLE 5

PERCENTAGE TRAFFIC SPLIT BY AIRCRAFT GROUP
- COMPARISON OF STUDY DATA AND 1994 24-HOUR AVERAGE SUMMER DAY

	Heathrow		Gatwick		Stansted	
Group	Study data	Average 24-hr day	Study data	Average 24-hr day	Study data	Average 24-hr day
A	0.2	0.4	0.0	0.0	0.0	0.0
B	8.5	11.8	2.5	4.2	0.2	0.1
C	0.3	0.5	0.5	0.9	2.1	2.4
D	16.8	17.6	13.4	15.0	5.5	3.8
E	15.5	13.9	27.4	21.2	33.5	20.0
F	56.2	51.5	50.5	42.0	50.6	41.1
G	1.1	2.2	5.1	15.7	6.6	28.5
H	1.5	2.1	0.5	1.0	1.6	4.0

TABLE 6
ASSESSMENT OF THEORETICAL MONITORING OPTIONS - DAY

Runway(s)	Monitors			Infr'mt	Est.	% of Chapter 2 B747 departures					Mon	% of Chapter 3 B747 departures					Mon
	No.	Position	Locations	Level	Cost	Offen-	Infringements		Missed		eff'y	Offen-	Infringements		Missed		eff'y
					£000	ders	Total	>3dB	Total	>3dB	%	ders	Total	>3dB	Total	>3dB	%
LHR09R	3	Present	2/3/4	Unadj		8.9	0.7	04	8.2	1.1	8.0	2.7	0.1	0.1	2.5	0.2	4.5
	3	Present	2/3/4	Adj	0	8.9	1.7	0.6	7.2	0.9	19	2.7	0.4	0.1	2.3	0.2	13
	3	Ref	11/16/17		63	8.9	4.1	1.1	4.9	0.5	46	2.7	0.9	0.2	1.7	0.1	36
	4	Ref	14/15/16/17		74	8.9	5.0	1.3	4.0	0.3	55	2.7	1.2	0.2	1.5	0.1	43
	5	Ref	14/15/18/19/20		100	8.9	6.0	1.4	2.9	01	67	2.7	1.5	0.2	1.2	0.0	55
	6	Ref	12/13/14/15/18/21		126	8.9	6.2	1.4	2.7	0.1	69	2.7	1.5	0.2	1.0	0.0	58
	7	Ref	10/12/13/15/18/21/22		152	8.9	6.6	1.5	2.4	0.0	73	2.7	1.6	0.2	1.0	0.0	61
	7	Ref	10/12/13/15/18/21/22	-1	152	16	12	3.1	3.5	0.1	77	4.6	3.1	0.5	1.5	0.0	66
	7	Ref	10/12/13/15/18/21/22	-2	152	25	20	5.9	4.9	0.1	80	7.7	5.4	1.0	2.3	0.0	70
	7	Ref	10/12/13/15/18/21/22	-3	152	36	30	10.5	5.9	0.1	83	12	8.6	1.9	3.1	0.1	73
	7	Ref	10/12/13/15/18/21/22	-4	152	49	43	17.1	6.5	0.1	87	17	13	3.4	4.0	0.1	76
	7	Ref	10/12/13/15/18/21/22	-5	152	62	55	25.7	6.6	0.2	89	24	20	5.8	4.9	0.1	80
LHR27	3	Present	5/6/7	Unadj		8.9	1.0	0.6	7.9	1.0	11	2.7	0 2	0.1	2.5	0.2	6.7
	3	Present	5/6/7	Adj	0	8.9	1.9	0.7	7.1	0.9	21	2.7	0.4	0.1	2.3	0.2	14
	3	Ref*	6/10/12		46	8.9	3.3	1.0	5.7	0.6	36	2.7	0.7	0.1	1.9	0.1	27
	4	Ref*	6/10/11/12		72	8.9	4.0	1.2	5.0	0.4	44	2.7	0.9	0.2	1.8	0.1	32
	5	Ref*	6/10/12/13/25		98	8.9	4.3	1.3	4.6	0.3	48	2.7	1.0	0.2	1.7	0.1	35
	6	Ref*	6/10/11/12/13/25		124	8.9	4.5	1.3	4.5	0.2	50	2.7	1.0	0.2	1.7	0.1	37
	8	Ref*	6/11/12/13/14/16/17/18		176	8.9	5.0	1.4	4.0	0.1	55	2.7	1.1	0.2	1.5	0.0	41
	8	Ref*	6/11/12/13/14/16/17/18	-1	176	16	9.4	3.0	6.1	0.2	60	4.6	2.2	0.5	2.4	0.1	46
	8	Ref*	6/11/12/13/14/16/17/18	-2	176	25	16	5.8	8.6	0.2	65	7.7	3.9	1.0	3.7	0.1	51
	8	Ref*	6/11/12/13/14/16/17/18	-3	176	36	25	10	11	0.3	70	12	6.5	1.9	5.2	0.1	55
	8	Ref*	6/11/12/13/14/16/17/18	-4	176	49	37	17	12	0.3	75	17	10	3.3	6.9	0.2	60
	8	Ref*	6/11/12/13/14/16/17/18	-5	176	62	49	26	13	0.3	79	24	16	5.6	8.6	0.2	64
LGW08R	1	Present	2	Unadj		8.9	1.8	0.7	7.1	0.9	20	2.7	0.4	0.1	2.3	0.2	14
	1	Present	2	Adj	0	8.9	2.3	0.7	6.6	0.8	26	2.7	0.5	0.1	2.2	0.2	19
	1	Ref	19		25	8.9	2.8	0.8	6.2	0.8	31	2.7	0.6	0.1	2.0	0.2	24
	2	Ref	80/81		54	8.9	4.6	1.2	4.3	0.4	51	2.7	1.1	0.2	1.6	0.1	41
	3	Ref	19/22/23		83	8.9	5.8	1.3	3.1	0.2	65	2.7	1.5	0.2	1.2	0.0	55
	4	Ref	24/25/26/27		112	8.9	6.6	1.4	2.4	0.1	73	2.7	1.7	0.2	1.0	0.0	64
	4	Ref	24/25/26/27	- 1	112	16	12	2.9	3.6	0.2	76	4.6	3.1	0.5	1.5	0.0	68
	4	Ref	24/25/26/27	-2	112	25	20	56	5.2	0.4	79	7.7	5.5	1.0	2.2	0.1	71
	4	Ref	24/25/26/27	-3	112	36	30	10	6.7	0.7	81	12	8.6	1.8	3.1	0.2	73
	4	Ref	24/25/26/27	-4	112	49	41	16	7.7	1.0	84	17	13	3.2	4.1	0.3	76
	4	Ref	24/25/26/27	-5	112	62	54	25	8.5	1.4	86	24	19	5.4	5.2	0.4	79
LGW26L	1	Present	1 (Infr. Level=99)	Unadj		8.9	1.4	0.2	7.5	6.2	16	2.7	0.2	0.0	2.3	2.0	9.6
	1	Present	1	Adj	0	8.9	1.7	0.6	7.2	0.9	19	2.7	0.5	0.1	2.2	0.2	17
	1	Ref	19		25	8.9	2.6	0.7	6.3	0.9	29	2.7	0.7	0.1	2.0	0.2	26
	2	Ref	20/21		54	8.9	4.5	1.1	4.4	0.4	50	2.7	1.2	0.2	1.4	0.1	45
	3	Ref	19/22/23		83	8.9	5.9	1.3	3.1	0.3	66	2.7	1.6	0.2	1.0	0.0	62
	4	Ref	24/25/26/27		112	8.9	6.4	1,4	2.5	0.1	72	2.7	1.8	0.2	0.8	0.0	69
	4	Ref	24/25/26/27	-1	112	16	11	2.9	4.2	0,3	73	4.6	3.2	0.5	1.4	0.1	70
	4	Ref	24/25/26/27	-2	112	25	18	5.5	6.3	0.5	75	7.7	5.5	1,0	2.2	0.1	72
	4	Ref	24/25/26/27	-3	112	36	28	9.9	8.5	0.8	76	12	8.4	1.8	3.3	0.2	72
	4	Ref	24/25/26/27	-4	112	49	39	16	10	1.2	79	17	13	3.2	4.7	0.3	73
	4	Ref	24/25/26/27	-5	112	62	50	24	12	1.7	81	24	18	5.4	6.2	0.5	74
STN05	1	Present	1	Unadj		8.9	0.4	0.2	8.6	1.3	4.2	2.7	0.1	0.0	2.6	0.2	2.5
	1	Present	1	Adj	0	8.9	0.7	0.2	8.3	1.3	7.5	2.7	0.1	0.0	2.5	0.2	5.2
	1	Ref	42		39	8.9	1.5	0.4	7.4	1.2	17	2.7	0.3	0.1	2.3	0.2	13
	2	Ref	43/44		65	8.9	2.8	0.8	6.2	0.8	31	2.7	0.6	0.1	2.0	0.2	23
	3	Ref	42/43/44		91	8.9	4.1	1.1	4.8	0.5	46	2.7	1.0	0.2	1.7	0.1	36
	6	Ref	42/43/44/45/46/47		169	8.9	6.5	1.5	2.4	0.0	72	2-7	1.6	0.3	1.1	0.0	59
	6	Ref	42/43/44/45/46/47	-1	169	16	12	3.1	3,6	0.0	76	4.6	3.0	0.5	1.6	0.0	64
	6	Ref	42/43/44/45/46/47	-2	169	25	20	6.0	4.9	0.1	80	7.7	5.3	1.1	2.4	0.0	69
	6	Ref	42/43/44/45/46/47	-3	169	36	30	11	5.9	0.1	83	12	8.5	2.0	3.2	0.0	72
	6	Ref	42/43/44/45/46/47	-4	169	49	43	17	6.4	0.1	87	17	13	3.4	4.1	0.1	76
	6	Ref	42/43/44/45/46/47	-5	169	62	56	26	6.4	0.2	89	24	19	5.8	4.9	0.1	79
STN23	2	Present	2/3	Unadj		8.9	0.5	0.3	85	1.3	5.0	2.7	*01*	0.0	2.6	0.2	2.4
	2	Present	2/3	Adj	0	8.9	1.4	0.5	7.5	1.1	16	2.7	0.3	0.1	2.4	0.2	10
	2	Ref	31/33		53	8.9	2.6	1.0	6.3	0.8	29	2.7	0.5	0.1	2.2	0.1	19
	3	Ref	2/3/37		51	8.9	2.6	0.9	6.3	0.7	29	2.7	0.5	0.1	2.1	0.1	19
	4	Ref	31/32/33/34		105	8.9	4.7	1.3	4.2	0.3	53	2.7	1.2	0.2	1.5	0.1	45
	4	Ref	31/32/33/34	-1	105	16	8.9	2.8	6.6	0.5	57	4.6	2.3	0.5	2.3	0.2	50
	4	Ref	31/32/33/34	-2	105	25	15	5.3	9.7	0.8	61	7.7	3.9	0.9	3.8	0.2	51
	4	Ref	31/32/33/34	-3	105	36	24	10	12	1.3	66	12	6.5	1.8	5.2	0.4	55
	4	Ref	31/32/33/34	-4	105	49	35	16	14	1.9	72	17	11	3.2	6.7	0.5	62
	4	Ref	31/32/33/34	-5	105	62	49	25	14	2.6	78	24	16	5.4	8.4	0.8	65

Notes: 'Adj': Infringement level adjusted for monitor track distance and height. 'Ref*': placed as close as practicable to Reference Arc. **: Preliminary selection of practical sites, not on Reference Arc (see Appendix D Figure D6). '-1', '-2', '-3, '-4', '-5': results for lowering present limits in 1 dB steps.

TABLE 7
ASSESSMENT OF THEORETICAL MONITORING OPTIONS - NIGHT

Runway(s)	Monitors			Infr'mt	Est.	% of Chapter 2 B747 departures					Mon	% of Chapter 3 B747 departures					Mon
	No.	Position	Locations	Level	Cost	Offen-	Infringements		Missed		eff'y	Offen-	Infringements		Missed		eff'y
					£000	ders	Total	>3dB	Total	>3dB	%	ders	Total	>3dB	Total	>3dB	%
LHR09R	3	Present	2/3/4	Unadj		90	33	30	58	29	36	52	11	8.7	41	13	20
	3	Present	2/3/4	Adj	0	90	46	38	44	21	51	52	18	11	34	9.9	35
	3	Ref	11/16/17		63	90	71	52	19	6.7	79	52	34	18	18	3.7	65
	4	Ref	14/15/16/17		74	90	79	56	11	2.8	88	52	40	20	13	1.6	76
	5	Ref	14/15/18/19/20		100	90	83	57	7.6	2.2	92	52	44	20	8.5	1.1	84
	6	Ref	12/13/14/15/18/21		126	90	84	57	6.5	t_6	93	52	44	20	7.7	0.9	85
	7	Ref	10/12/13/15/18/21/22		152	90	87	59	3.7	0.2	96	52	46	21	5.7	0.1	89
	7	Ref	10/12/13/15/18/21/22	-1	152	95	92	70	2.6	0.2	97	62	57	30	5.2	0.2	92
	7	Ref	10/12/13/15/18/21/22	-2	152							71	66	39	4.3	0.2	94
	7	Ref	10/12/13/15/18/21/22	-3	152							79	75	51	3.4	0.2	96
	7	Ref	10/12/13/15/18/21/22	-4	152							85	83	62	2.4	0.2	97
	7	Ref	10/12/13/15/18/21/22	-5	152							90	89	72	1.6	0.1	98
LHR27	3	Present	5/6/7	Unadj		90	38	33	53	26	42	52	13	10	39	11	26
	3	Present	5/6/7	Adj		90	47	37	44	22	51	52	19	12	33	9.6	37
	3	Ref*	6/10/12		46	90	63	47	27	12	70	52	29	16	23	5.5	56
	4	Ref*	6/10/11/12		72	90	73	54	18	5.5	80	52	34	19	18	2.8	66
	5	Ref*	6/10/12/13/25		98	90	76	55	14	3.5	84	52	37	20	15	1.8	70
	6	Ref*	6/10/11/12/13/25		124	90	79	57	11	1.5	88	52	38	20	14	1.0	73
	8	Ref*	6/11/12/13/14/16/17/18		176	90	82	59	7.9	0.3	91	52	41	21	11	0.3	79
	8	Ref*	6/11/12/13/14/16/17/18	-1	176	95	89	69	5.6	0.2	94	62	52	30	10	0.3	83
	8	Ref*	6/11/12/13/14/16/17/18	-2	176							71	62	39	8.9	0.3	87
	8	Ref*	6/11/12/13/14/16/17/18	-3	176							79	72	50	7.1	0.2	91
	8	Ref*	6/11/12/13/14/16/17/18	-4	176							85	80	62	5.2	0.2	94
	8	Ref*	6/11/12/13/14/16/17/18	-5	176							90	87	72	3.6	0.2	96
LGW08R	1	Present	2	Unadj		90	47	38	43	21	53	52	19	12	33	9.3	37
	1	Present	2	Adj	0	90	51	40	39	19	56	52	22	13	30	8.8	42
	1	Ref	19		25	90	54	41	36	18	60	52	24	13	28	8.2	46
	2	Ref	80/81		54	90	73	52	18	7.2	80	52	36	18	16	3.5	69
	3	Ref	19/22/23		83	90	79	55	11	4.2	88	52	41	19	11	2.1	79
	4	Ref	24/25/26/27		112	90	83	57	6.8	2.2	92	52	45	20	7.2	1.1	86
	4	Ref	24/25/26/27	-1	112	95	89	67	5.6	2.2	94	62	55	28	7.2	1.4	88
	4	Ref	24/25/26/27	-2	112							1	64	38	6.8	1.7	90
	4	Ref	24/25/26/27	-3	112							79	73	49	6.1	1.9	92
	4	Ref	24/25/26/27	-4	112							85	80	60	5.2	2.0	94
	4	Ref	24/25/26/27	-5	112							90	86	70	4.2	2.0	95
LGW26L	1	Present	1 (Infr. Level=99)	Unadj		90	48	26	42	28	53	52	18	6.0	34	24	35
	1	Present	1	Adj	0	90	40	34	51	25	44	52	16	11	36	11	30
	1	Ref	19		25	90	47	37	43	22	52	52	21	12	31	9.7	40
	2	Ref	20/21		54	90	67	50	23	9.4	74	52	53	1-7	19	4.3	63
	3	Ref	19/22/23		83	90	76	54	15	5.4	84	52	39	19	13	2.5	75
	4	Ref	24/25/26/27		112	90	80	56	10	2.9	88	52	42	20	10	1.4	81
	4	Ref	24/25/26/27	-1	112	95	86	67	8.8	3.0	91	62	51	28	11	1.8	83
	4	Ref	24/25/26/27	-2	112							71	61	37	10	2.2	85
	4	Ref	24/25/26/27	-3	112							79	69	48	9.4	2.5	88
	4	Ref	24/25/26/27	-4	112							85	77	59	8.1	2.7	91
	4	Ref	24/25/26/27	-5	112							90	84	70	6.6	27	93
STN05	1	Present	1	Unadj		90	14	12	76	47	16	52	5.0	3.7	47	18	9.6
	1	Present	1	Adj	0	90	17	14	73	45	19	52	6.9	4.2	45	17	13
	1	Ref	42		39	90	31	24	59	35	34	52	13	7.2	39	14	25
	2	Ref	43/44		65	90	56	43	34	16	62	52	25	13	27	7.9	47
	3	Ref	42/43/44		91	90	68	50	22	9.5	76	52	33	17	19	4.6	64
	6	Ref	42/43/44/45/46/47		169	90	87	59	3.6	0.3	96	52	47	21	5.5	0.2	89
	6	Ref	42/43/44/45/46/47	- 1	169	95	92	69	2.5	0.3	97	62	57	30	5.0	0.2	92
	6	Ref	42/43/44/45/46/47	-2	169							71	67	39	4.2	0.2	94
	6	Ref	42/43/44/45/46/47	-3	169							79	75	50	3.3	0.2	96
	6	Ref	42/43/44/45/46/47	-4	169							85	83	62	2.3	0.2	97
	6	Ref	42/43/44/45/46/47	-5	169							90	89	72	1.6	0.2	98
STN23	2	Present	2/3	Unadj		90	23	21	67	38	26	52	7.4	6.0	45	15	14
	2	Present	2/3	Adj	0	90	34	26	57	33	37	52	14	8.2	38	13	27
	2	Ref	31/33		53	90	56	42	34	16	62	52	24	13	28	80	46
	3	Ref	2/3/37		51	90	63	49	27	10	70	52	27	16	25	5.7	51
	4	Ref	31/32/33/34		105	90	76	54	14	5.5	84	52	38	19	14	2.7	73
	4	Ref	31/32/33/34	1	105	95	84	66	11	4.1	89	62	50	28	12	3,5	81
	4	Ref	31/32/33/34	-2								71	60	37	11	3.4	85
	4	Ref	31/32/33/34	-3	105							79	69	49	9.7	3.6	88
	4	Ref	31/32/33/34	-4	105							85	77	60	8.2	3,6	90
	4	Ref	31/32/33/34	-5	105							90	84	70	6.2	3.5	93

Notes: 'Adj': Infringement Level adjusted for monitor track distance and height. 'Ref*': placed as close as practicable to Reference Arc. **: Preliminary selection of practical sites, not on Reference Arc (see Appendix D Figure D6). '-1', '-2', '-3', '-4', '-5': results for lowering Present limits in 1 dB steps.

TABLE 8
ASSESSMENT OF PRACTICAL MONITORING OPTIONS - DAY

Runway(s)	Monitors			Infr'mt	Est.	% of Chapter 2 B747 departures					Mon	% of Chapter 3 B747 departures					Mon
	No.	Position	Locations	Level	Cost	Offen-	Infringements		Missed		eff'y	Offen-	Infringements		Missed		eff'y
					£000	ders	Total	>3dB	Total	>3dB	%	ders	Total	>3dB	Total	>3dB	%
LHR09R	3	Present	2/3/4	Unadj		8.9	0.7	0.4	8.2	1.1	8.0	2.7	0.1	0.1	2.5	0.2	4.5
	4	Ref	14/15/16/17		74	8.9	5.0	1.3	4.0	0.3	55	2.7	1.2	0.2	1.5	0.1	43
	4	Practical	14/15/16/17		74	8.9	4.4	1.2	4.5	0.3	49	2.7	1.0	0.2	1.6	0.1	38
	4	Practical	14/15/16/17	-1	74	16	8.4	2.6	7.2	0.6	53	4.6	2.0	0.4	2.6	0.2	42
	4	Practical	14/15/16/17	-2	74	25	14	5.1	10	0.9	57	7.7	3.5	0.8	4.1	0.3	46
	4	Practical	14/15/16/17	-3	74	36	23	9.3	14	1.4	62	12	5.8	1.6	5.9	0.4	49
	4	Practical	14/15/16/17	-4	74	49	33	15	16	1.9	67	17	9.3	2.8	8.1	0.6	53
	4	Practical	14/15/16/17	-5	74	62	44	24	18	2.4	71	24	14	4.9	10	0.9	57
LHR27	3	Present	5/6/7	Unadj		8.9	1.0	0.6	7.9	1.0	11	2.7	0.2	0.1	2.5	0.2	6.7
	6	Ref*	6/10/11/12/13/25		124	8.9	4.5	1.3	4.5	0.2	50	2.7	1.0	0.2	1.7	0.1	37
	6	Practical	25/61/62/6/13/11		124	8.9	3.9	1.2	5.1	0.4	43	2.7	0.9	0.2	1.8	0.1	31
	6	Practical	25/61/62/6/13/11	- 1	124	16	7.4	2.5	8.2	0.7	47	4.6	1.7	0.4	2.9	0.2	35
	6	Practical	25/61/62/6/13/11	-2	124	25	13	4.9	12	1.1	51	7.7	3.0	0.8	4.6	0.3	39
	6	Practical	25/61/62/6/13/11	-3	124	36	20	9.0	16	1.7	56	12	5.0	1.5	6.7	0.5	42
	6	Practical	25/61/62/6/13/11	-4	124	49	30	15	19	2.4	61	17	8.2	2.7	9.2	0.8	47
	6	Practical	25/61/62/6/13/11	-5	124	62	41	23	21	3.0	66	24	13	4.8	12	1.1	51
LGW08R	1	Present	2	Unadj		8.9	1.8	0.7	7.1	0.9	20	2.7	0.4	0.1	2.3	0.2	13
	2	Ref	80/81		54	8.9	4.6	1.2	4.3	0.4	51	2.7	1.1	0.2	1.6	0.1	41
	2	Practical	41/42		54	8.9	4.3	1.2	4.6	0.4	48	2.7	1.0	0.2	1.7	0,1	38
	2	Practical	41/42	-1	54	16	8.1	2.4	7.4	0.7	52	4.6	1.9	0.4	2.7	0.2	41
	2	Practical	41/42	-2	54	25	14	4.7	11	1.3	55	7.7	3.5	0.8	4.2	0.3	45
	2	Practical	41/42	-3	54	36	21	8.5	15	2.2	59	12	5.6	1.5	6.1	0.5	48
	2	Practical	41/42	-4	54	49	31	14	18	3.2	63	17	9.0	2.7	8.4	0.8	51
	2	Practical	41/42	-5	54	62	42	21	20	4.5	67	24	13	4.6	11	1.3	55
LGW26L	1	Present	1 (Infr. Level=99)	Unadj		8.9	1.4	0.2	7.5	6.2	16	2.7	0.2	0.0	2.3	2.0	9.6
	2	Ref	20/21		54	8.9	4.5	1.1	4.4	0.4	so	2.7	1.2	0.2	1.4	0.1	45
	3	Ref	19/22/23		83	8.9	5.9	1.3	3.1	0.3	66	2.7	1.6	0.2	1.0	0.0	62
	3	Practical	1/50/53		66	8.9	4.5	1.2	4.4	0.3	51	2.7	1.3	0.2	1.4	0.1	47
	3	Practical	1/50/53	-1	66	16	8.2	2.6	7.3	0.6	53	4.6	2.3	0.4	2.3	0.1	49
	3	Practical	1/50/53	-2	66	25	14	5.0	11	1.0	55	7.7	3.8	0.9	3.8	0.2	50
	3	Practical	1/50/53	-3	66	36	21	8.9	15	1.7	58	12	5.9	1.6	5.8	0.4	50
	3	Practical	1/50/53	-4	66	49	30	is	19	2.6	61	17	9.1	2.8	8.2	0.6	52
	3	Practical	1/50/53	-5	66	62	40	22	22	3.7	65	24	13	4.8	11	1.0	55
STN05	1	Present	1	Unadj		8.9	0.4	0.2	8.6	1.3	4.2	2.7	0.1	0.0	2.6	0.2	2.5
	4	Ref	42/43/44/46		117	8.9	5.0	1.1	4.0	0.4	56	2.7	1.2	0.2	1.5	0.2	41
	4	Practical	52/53/54/56		117	8.9	3.6	1.0	5.3	0.6	40	2-7	0.8	0.2	1.8	0.1	31
	4	Practical	52/53/54/56	-1	117	16	6.8	2.0	8.8	1.1	43	4.6	1.6	0.3	3.0	0.2	34
	4	Practical	52/53/54/56	-2	117	25	11	3.9	13	2.1	46	7.7	2.9	0.6	4.8	0.4	37
	4	Practical	52/53/54/56	-3	117	36	18	7.2	18	3.5	so	12	4.7	1.2	7.0	0.8	40
	4	Practical	52/53/54/56	-4	117	49	26	12	23	5.4	53	17	7.5	2.2	9.9	1.3	43
	4	Practical	52/53/54/56	-5	117	62	35	18	27	7.8	57	24	11	3.8	13	2.0	46
STN23	2	Present	2/3	Unadj		8.9	0.5	0.3	8.5	1.3	5.0	2.7	0.1	0.0	2.6	0.2	2.4
	4	Ref	31/32/33/34		105	8.9	4.7	1.2	4.2	0.3	52	2.7	1.0	0.2	1.6	0.1	38
	4	Practical	3/41/43/44		91	8.9	4.6	1.2	4.3	0.3	51	2.7	1.0	0.2	1.7	0.1	37
	4	Practical	3/41/43/44	-1	91	16	8.7	2.6	6.8	0.5	56	4.6	2.0	0.4	2.6	0.1	42
	4	Practical	3/41/43/44	-2	91	25	15	5.1	9.8	0.9	60	7.7	3.6	0.8	4.0	0.2	47
	4	Practical	3/41/43/44	-3	91	36	24	9.2	13	1.4	65	12	6.0	1.6	5.7	0.4	51
	4	Practical	3/41/43/44	-4	91	49	34	15	15	2.0	69	17	9.7	2.9	7.7	0.6	55
	4	Practical	3/41/43/44	-5	91	62	46	23	16	2.7	74	24	15	5.0	9.8	0.9	60

NOTES: 'Unadj' - Infringement Level not adjusted for monitor track distance and height; 'Ref*' - placed as close as practicable to Reference Arc;
-1, -2, -3, -4, -5: results for lowering present limits in 1 dB steps

TABLE 9
ASSESSMENT OF PRACTICAL MONITORING OPTIONS - NIGHT

Runway(s)	Monitors			Infr'mt	Est.	% of Chapter 2 B747 departures					Mon	% of Chapter 3 B747 departures					Mon
	No.	Position	Locations	Level	Cost	Offen-	Infringements		Missed		eff'y	Offen-	Infringements		Missed		eff'y
					£000	ders	Total	>3dB	Total	>3dB	%	ders	Total	>3dB	Total	>3dB	%
LHR09R	3	Present	2/3/4	Unadj		90	33	30	58	29	36	52	11	8.7	41	13	20
	4	Ref	14/15/16/17		74	90	79	56	11	2.8	88	52	40	20	13	1.6	76
	4	Practical	14/15/16/17		74	90	77	56	13	3.0	85	52	37	19	15	2.0	71
	4	Practical	14/15/16/17	-1	74	95	84	67	10	2.8	89	62	47	28	15	2.3	76
	4	Practical	14/15/16/17	-2	74							71	57	37	14	2.5	80
	4	Practical	14/15/16/17	-3	74							79	67	48	12	2.6	85
	4	Practical	14/15/16/17	-4	74							85	76	59	10	2.5	89
	4	Practical	14/15/16/17	-5	74							90	83	70	7	2.3	92
LHR27	3	Present	5/6/7	Unadj		90	38	33	53	26	42	52	14	10	39	11	26
	6	Ref*	6/10/11/12/13/25		124	90	79	58	11	1.5	88	52	38	20	14	1.0	73
	6	Practical	25/61/62/6/13/11		124	90	74	55	16	3.8	82	52	34	19	18	2.5	66
	6	Practical	25/61/62/6/13/11	-1	124	95	82	66	13	3.5	86	62	44	27	18	3.0	71
	6	Practical	25/61/62/6/13/11	-2	124							71	54	37	17	3.2	76
	6	Practical	25/61/62/6/13/11	-3	124							79	64	48	15	3.3	81
	6	Practical	25/61/62/6/13/11	-4	124							85	74	59	12	3.2	86
	6	Practical	25/61/62/6/13/11	-5	124							90	81	70	9.0	2.9	90
LGW08R	1	Present	2	Unadj		90	47	38	43	21	53	52	19	12	33	9.3	37
	2	Ref	80/81		54	90	73	52	18	7.2	80	52	36	18	16	3.5	69
	2	Practical	41/42		54	90	71	51	19	7.8	79	52	35	18	17	3.8	66
	2	Practical	41/42	-1	54	95	78	62	17	8.2	82	62	44	25	18	4.8	70
	2	Practical	41/42	-2	54							71	53	34	18	5.8	74
	2	Practical	41/42	-3	54							79	62	44	17	6.8	78
	2	Practical	41/42	-4	54							85	70	55	15	7.3	82
	2	Practical	41/42	-5	54							90	77	65	13	7.5	85
LGW26L	1	Present	1 (Infr. Level=91)	Unadj		90	48	26	42	28	53	52	18	6.0	34	24	35
	2	Ref	20/21		54	90	67	50	23	9.4	74	52	33	17	19	4.3	63
	3	Ref	19/22/23		83	90	76	54	15	5.4	84	52	39	19	13	2.5	75
	3	Practical	1/50/53		66	90	70	52	21	6.7	77	52	34	18	19	3.1	64
	3	Practical	1/50/53	-1	66	95	77	63	18	7.1	81	62	42	26	20	4.0	68
	3	Practical	1/50/53	-2	66							71	51	35	20	5.0	72
	3	Practical	1/50/53	-3	66							79	60	45	18	5.8	77
	3	Practical	1/50/53	-4	66							85	69	56	16	6.4	81
	3	Practical	1/50/53	-5	66							90	76	66	14	6.6	85
STN05	1	Present	1	Unadj		90	14	12	76	47	16	52	5.0	3.7	47	18	10
	4	Ref	42/43/44/46		117	90	71	50	19	9.4	78	52	36	17	16	4.3	70
	4	Practical	52/53/54/56		117	90	61	44	29	15	67	52	29	15	23	6.4	56
	4	Practical	52/53/54/56	-1	117	95	67	54	27	16	71	62	37	21	25	8.5	60
	4	Practical	52/53/54/56	-2	117							71	45	29	26	11	63
	4	Practical	52/53/54/56	-3	117							79	53	38	26	13	67
	4	Practical	52/53/54/56	-4	117							85	60	47	25	15	71
	4	Practical	52/53/54/56	-5	117							90	67	57	23	16	74
STN23	2	Present	2/3	Unadj		90	23	21	67	38	26	52	7.4	6.0	45	1 15	14
	4	Ref	31/32/33/34		105	90	76	53	14	5.5	84	52	38	19	14	2.7	73
	4	Practical	3/41/43/44		91	90	77	55	13	4.0	86	52	38	19	14	2.2	73
	4	Practical	3/41/43/44	-1	91	95	84	66	11	4.1	89	62	48	27	14	2.7	77
	4	Practical	3/41/43/44	-2	91							71	58	37	13	3.1	82
	4	Practical	3/41/43/44	-3	91							79	67	47	12	3.5	85
	4	Practical	3/41/43/44	-4	91							85	75	58	9.8	3.7	88
	4	Practical	3/41/43/44	-5								90	82	69	7.9	3.6	91

NOTES: 'Unadj' - Infringement Level not adjusted for monitor track distance and height; 'Ref` - placed as close as practicable to Reference Arc;
-1, -2, -3, -4, -5: results for lowering present limits in 1 dB steps
Values have not been calculated where the proportion of offenders would exceed 96%.

TABLE 10

POSITIONAL ADJUSTMENTS AND INFRINGEMENT LEVELS FOR PRACTICAL SITES

AIRPORT	RUNWAY	SITE	Track Distance km	Elevation above runway m	Provisional Adjustment dB	Infringement Level Examples	
						Base Limit = 94 dBA	Base Limit = 87 dBA
HEATHROW	09R	14	6.63	-1	-0.2	93.8	86.8
		15	6.57	-2	-0.2	93.8	86.8
		16	6.52	-3	-0.1	93.9	86.9
		17	6.50	-4	-0.2	93.8	86.8
	27L/R	6	6.66	-5	-0.4	93.6	86.6
		11	7.12	-7	-1.1	92.9	85.9
		13	6.80	-6	-0.7	93.3	86.3
		61	6.21	-5	0.7	94.7	87.7
		62	6.65	-5	-0.4	93.6	86.6
		25	6.43	-4	0.1	94.1	87.1
GATWICK	08R	41	6.67	-1	-0.3	93.7	86.7
		42	6.68	0	-0.3	93.7	86.7
	26L	1	6.21	50	3.2	97.2	90.2
		50	6.70	48	1.6	95.6	88.6
		53	6.83	46	1.3	95.3	88.3
STANSTED	05	52	6.95	-23	-1.5	92.5	85.5
		53	6.56	0	-0.1	93.9	86.9
		54	6.74	-16	-0.9	93.1	86.1
		56	6.70	-5	-0.5	93.5	86.5
	23	3	6.68	-20	-1.0	93.0	86.0
		41	6.97	-27	-1.6	92.4	85.4
		43	6.68	-19	-1.0	93.0	86.0
		44	6.50	-20	-0.7	93.3	86.3

FIGURE 1

AIRCRAFT NOISE FOOTPRINT AND CERTIFICATION MEASUREMENT POINTS

Not to Scale

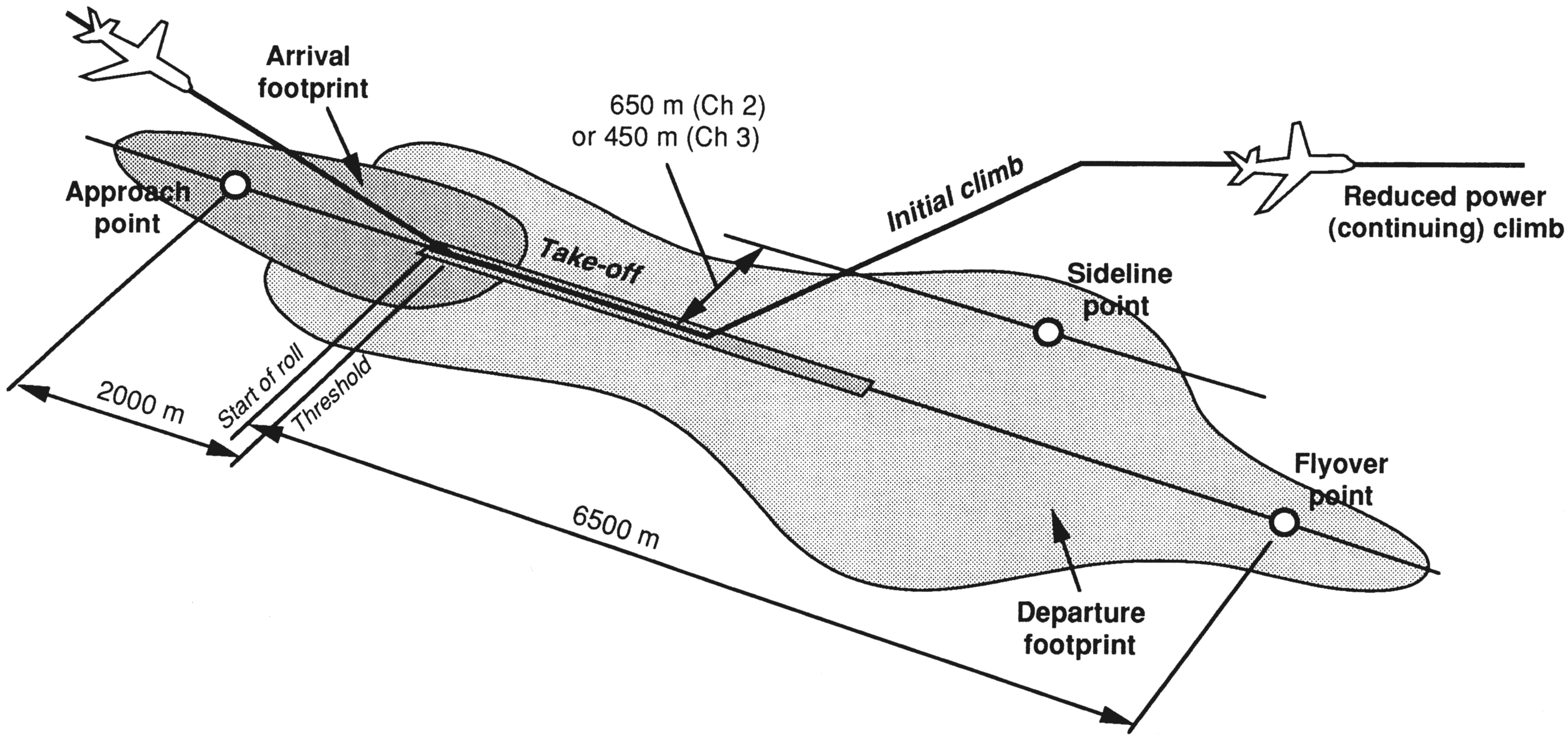


FIGURE 2

DISPERSION OF FLIGHT PATHS

Section through swathe

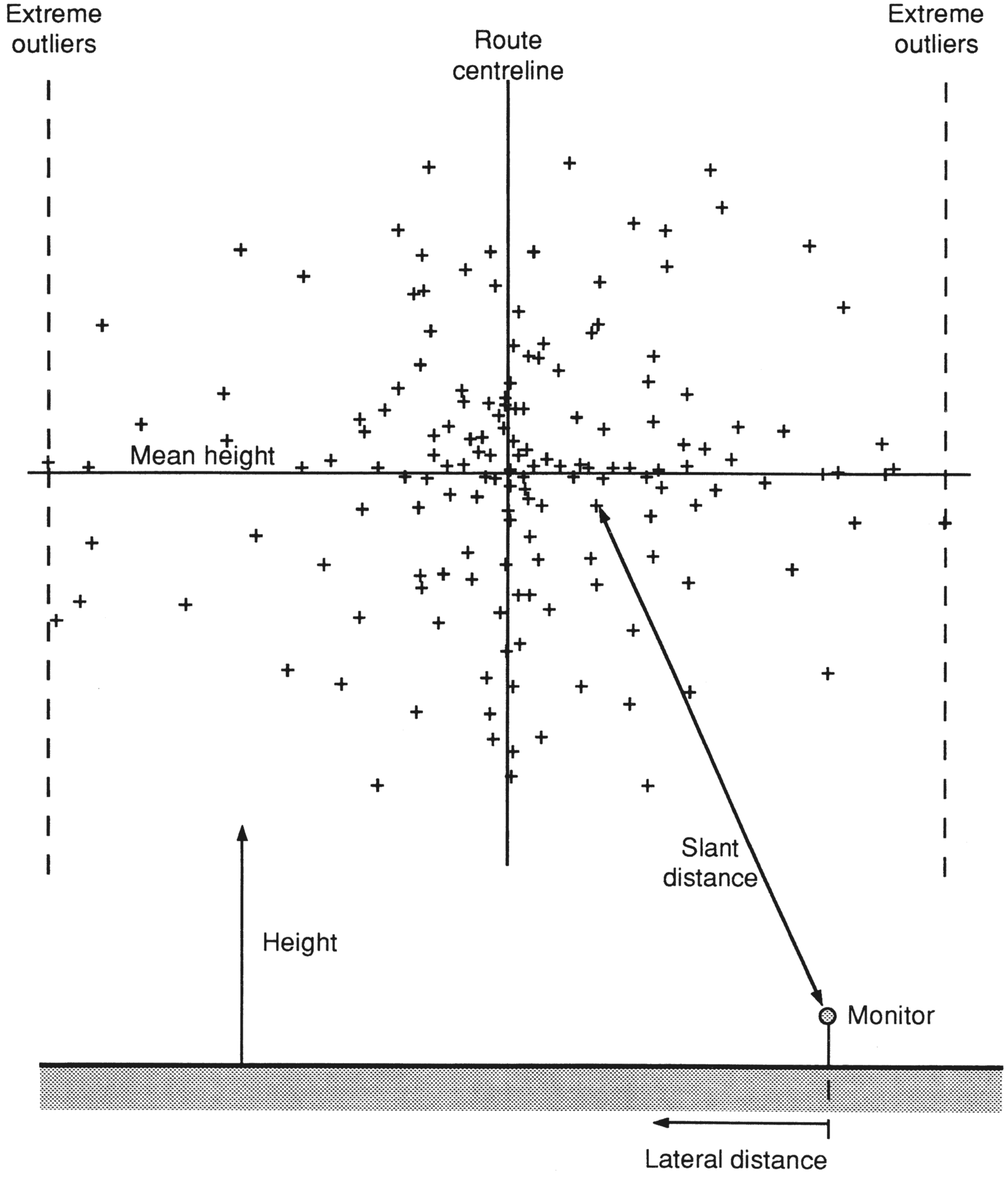
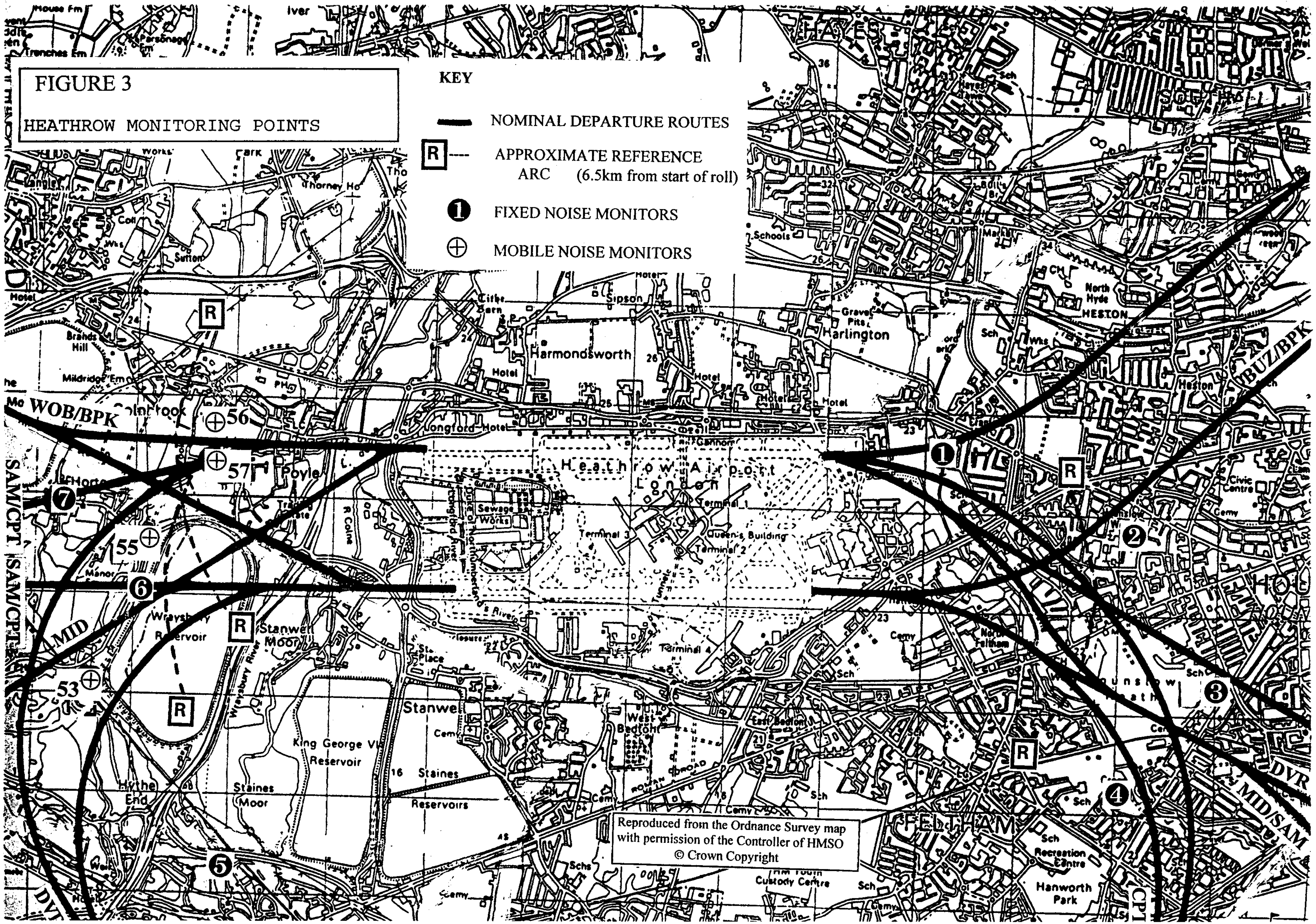


FIGURE 3

HEATHROW MONITORING POINTS



Reproduced from the Ordnance Survey map with permission of the Controller of HMSO

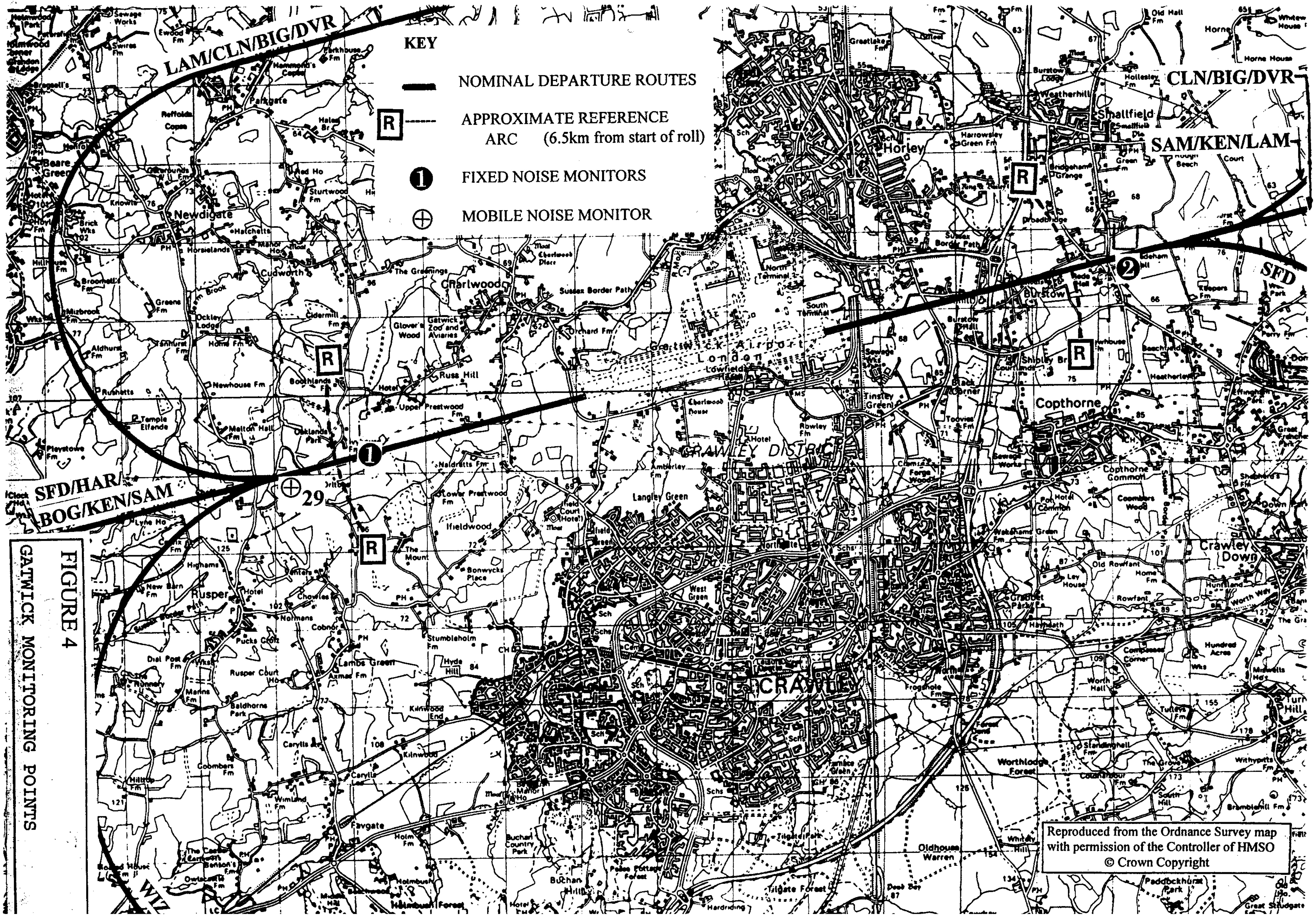


FIGURE 4

GATWICK MONITORING POINTS

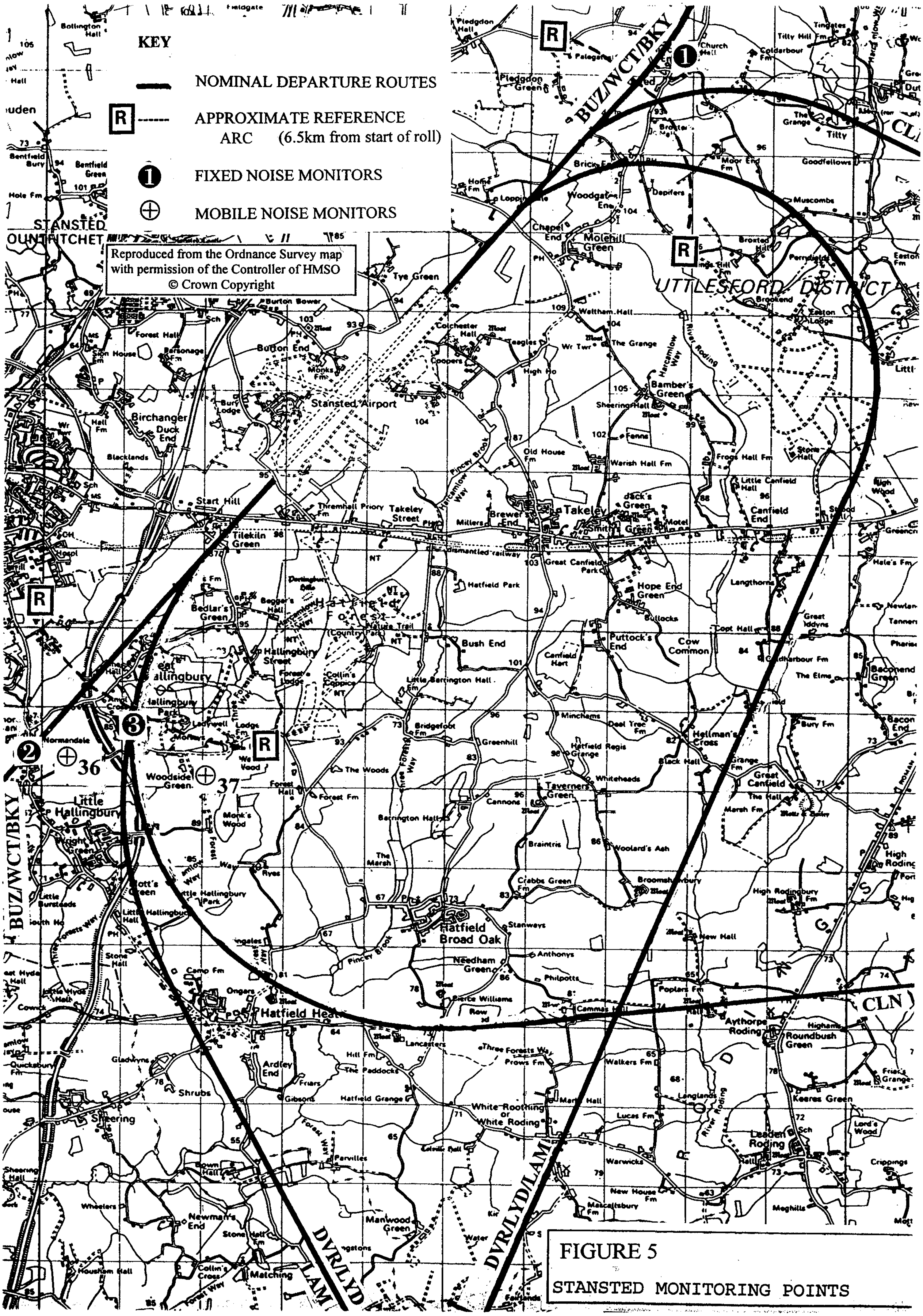


FIGURE 5

STANSTED MONITORING POINTS

FIGURE 6

ESTIMATION OF REFERENCE LEVEL

Reference Level L_r = Estimated L_{Amax} at Reference Point

$$L_r = L_m - 26.6 \log_{10} (s/h)$$

where L_m is the noise level measured at the monitor

('8dB per doubling of distance' rule applies - see para 4.9)

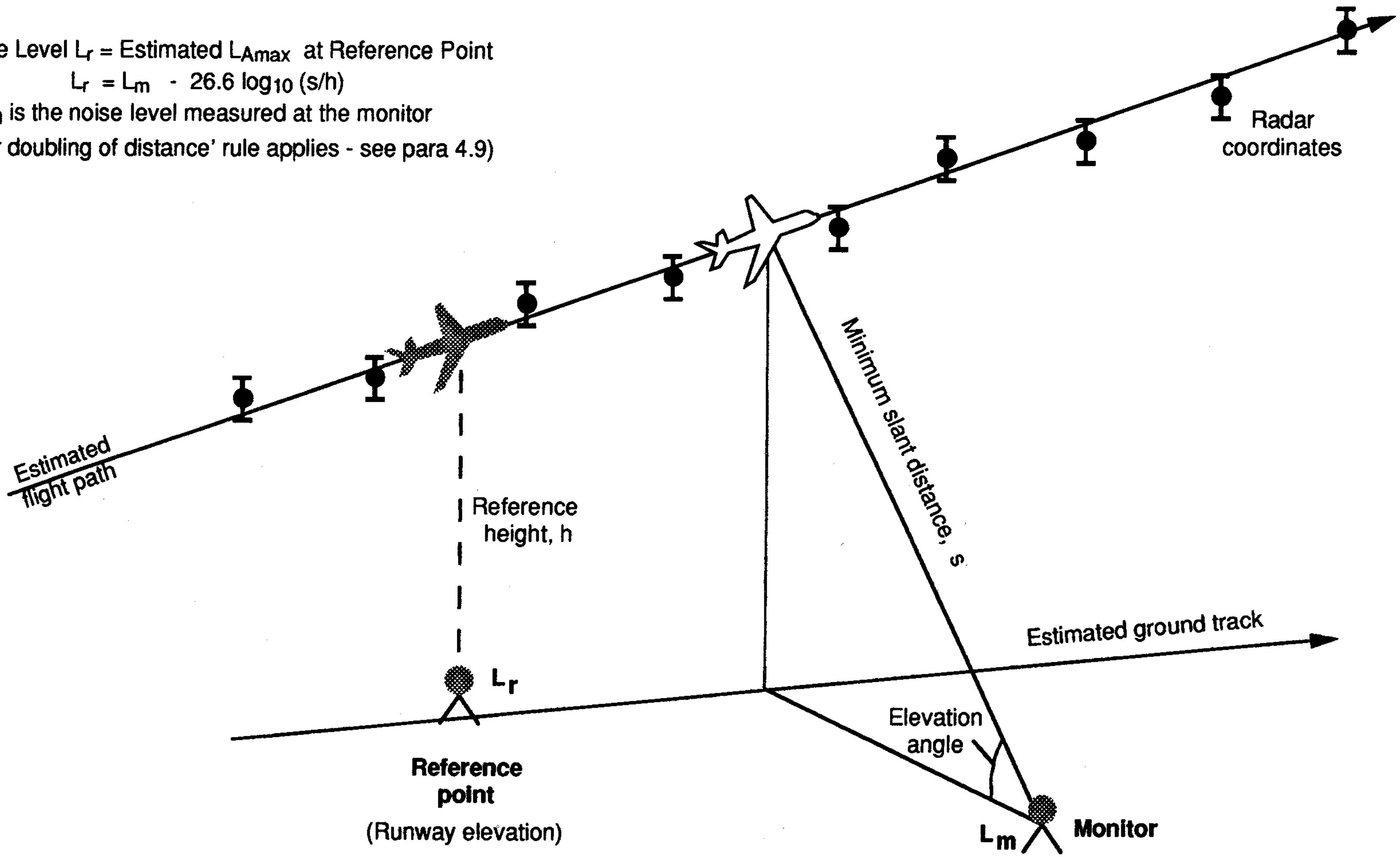


FIGURE 7

CUMULATIVE DISTRIBUTIONS OF REFERENCE LEVEL BY GROUP, ALL AIRPORTS, DAY+NIGHT

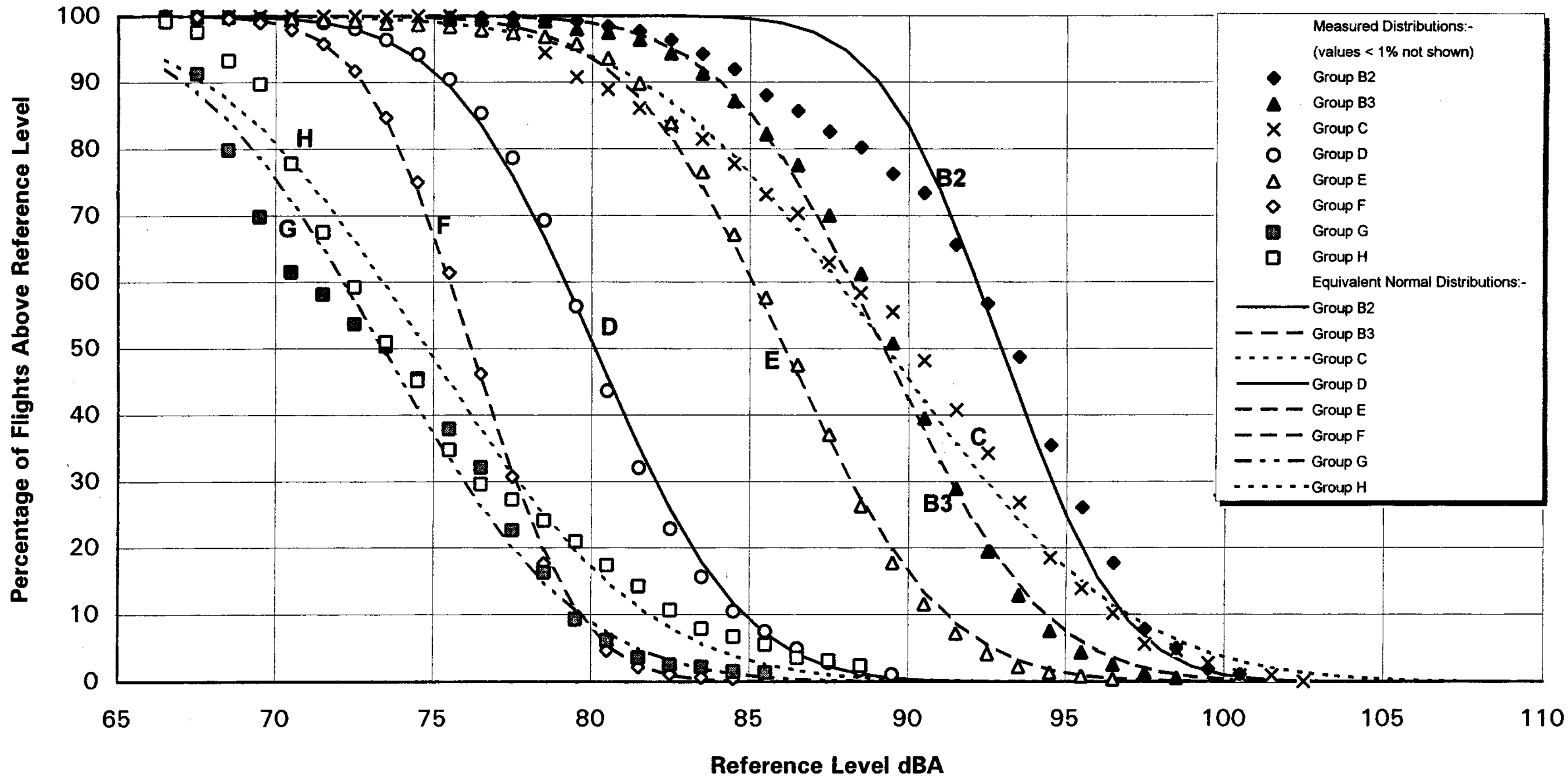


FIGURE 8a

CUMULATIVE DISTRIBUTIONS OF REFERENCE LEVEL: ALL GROUPS, ALL AIRPORTS, DAY AND NIGHT

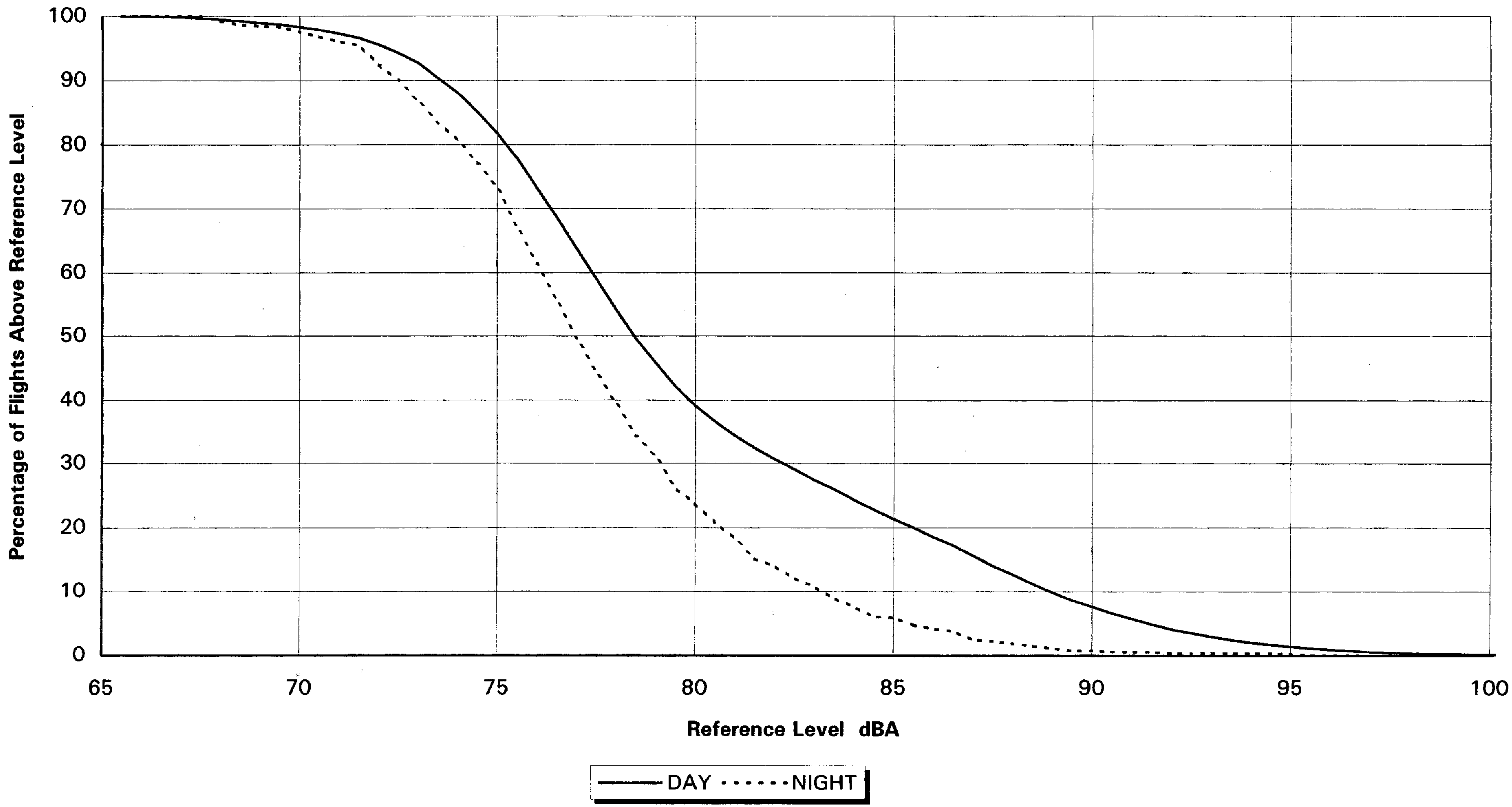


FIGURE 8b

CUMULATIVE DISTRIBUTIONS OF REFERENCE LEVEL: ALL GROUPS, ALL AIRPORTS, DAY AND NIGHT

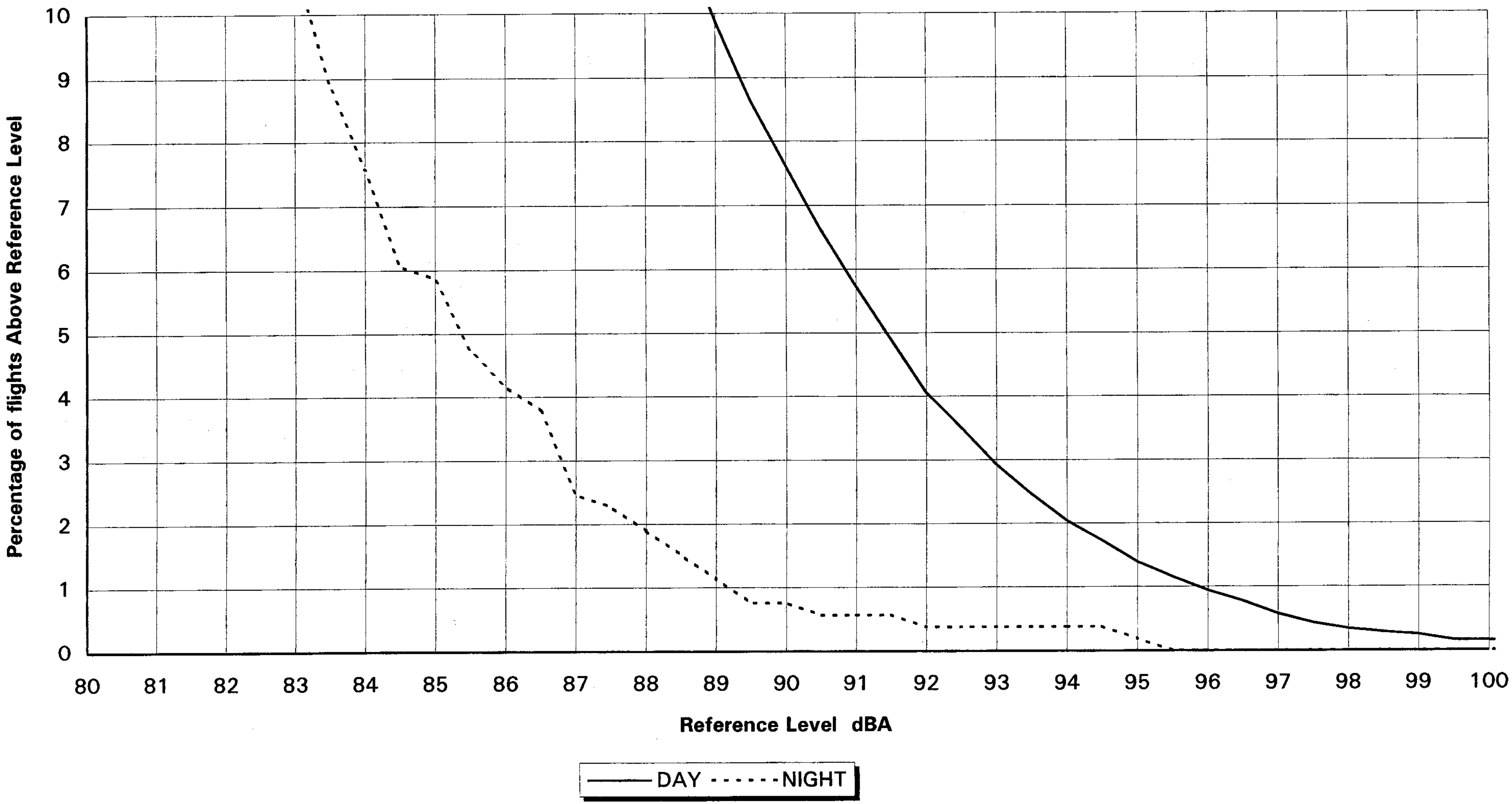
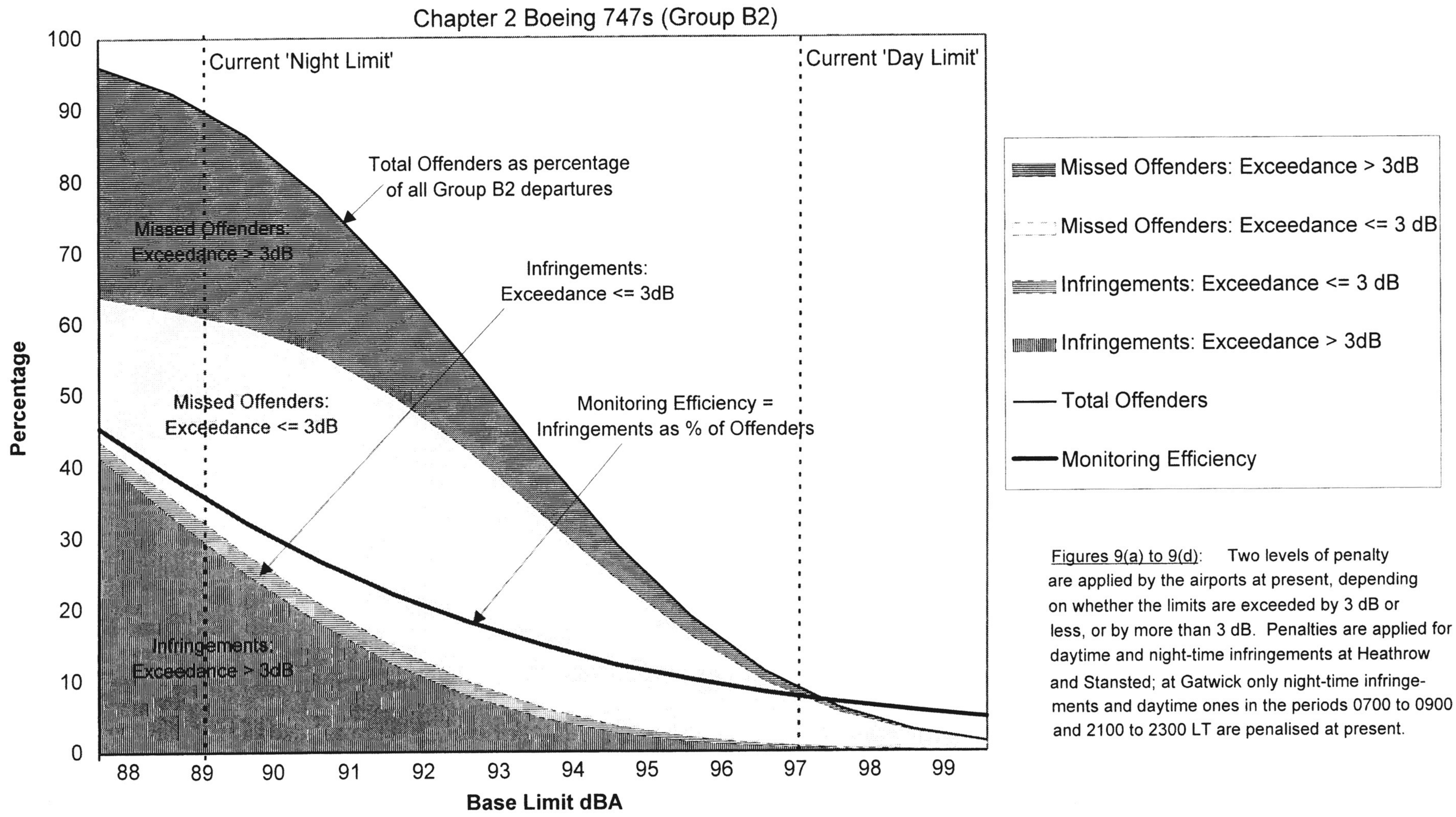


FIGURE 9

RELATIONSHIP BETWEEN BASE LIMIT AND PERFORMANCE OF MONITOR ARRAY

(a) Heathrow Runway 09R: Present 3 monitors: Unadjusted Fixed Limit



<u>Figures 9(a) to 9(d)</u>: Two levels of penalty are applied by the airports at present, depending on whether the limits are exceeded by 3 dB or less, or by more than 3 dB. Penalties are applied for daytime and night-time infringements at Heathrow and Stansted; at Gatwick only night-time infringements and daytime ones in the periods 0700 to 0900 and 2100 to 2300 LT are penalised at present.

FIGURE 9

RELATIONSHIP BETWEEN BASE LIMIT AND PERFORMANCE OF MONITOR ARRAY

(b) Heathrow Runway 09R: Present 3 monitors: Adjusted Limits

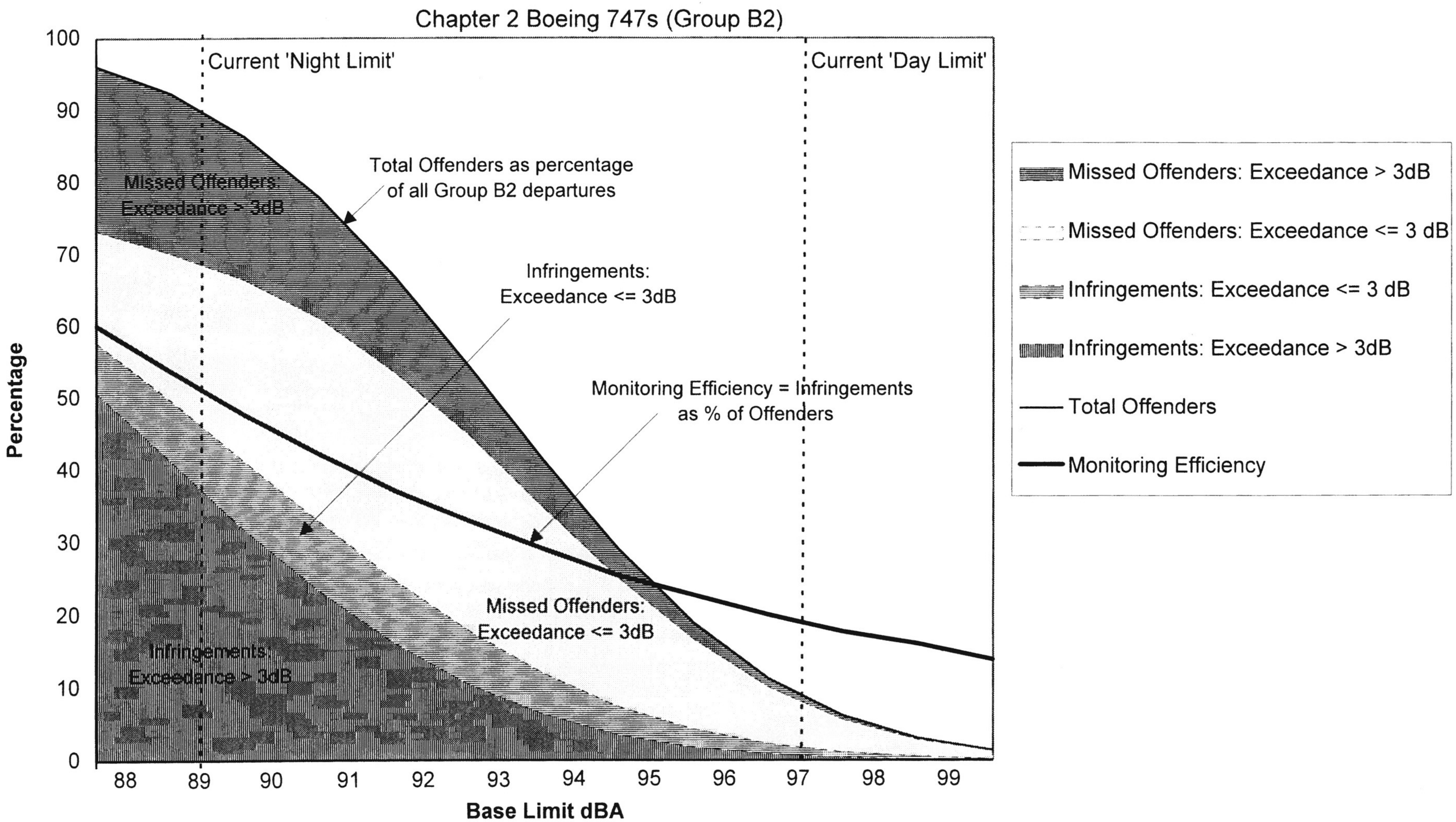


FIGURE 9

RELATIONSHIP BETWEEN BASE LIMIT AND PERFORMANCE OF MONITOR ARRAY

(c) Heathrow Runway 09R: 3 monitors at Reference Distance: Adjusted Limits

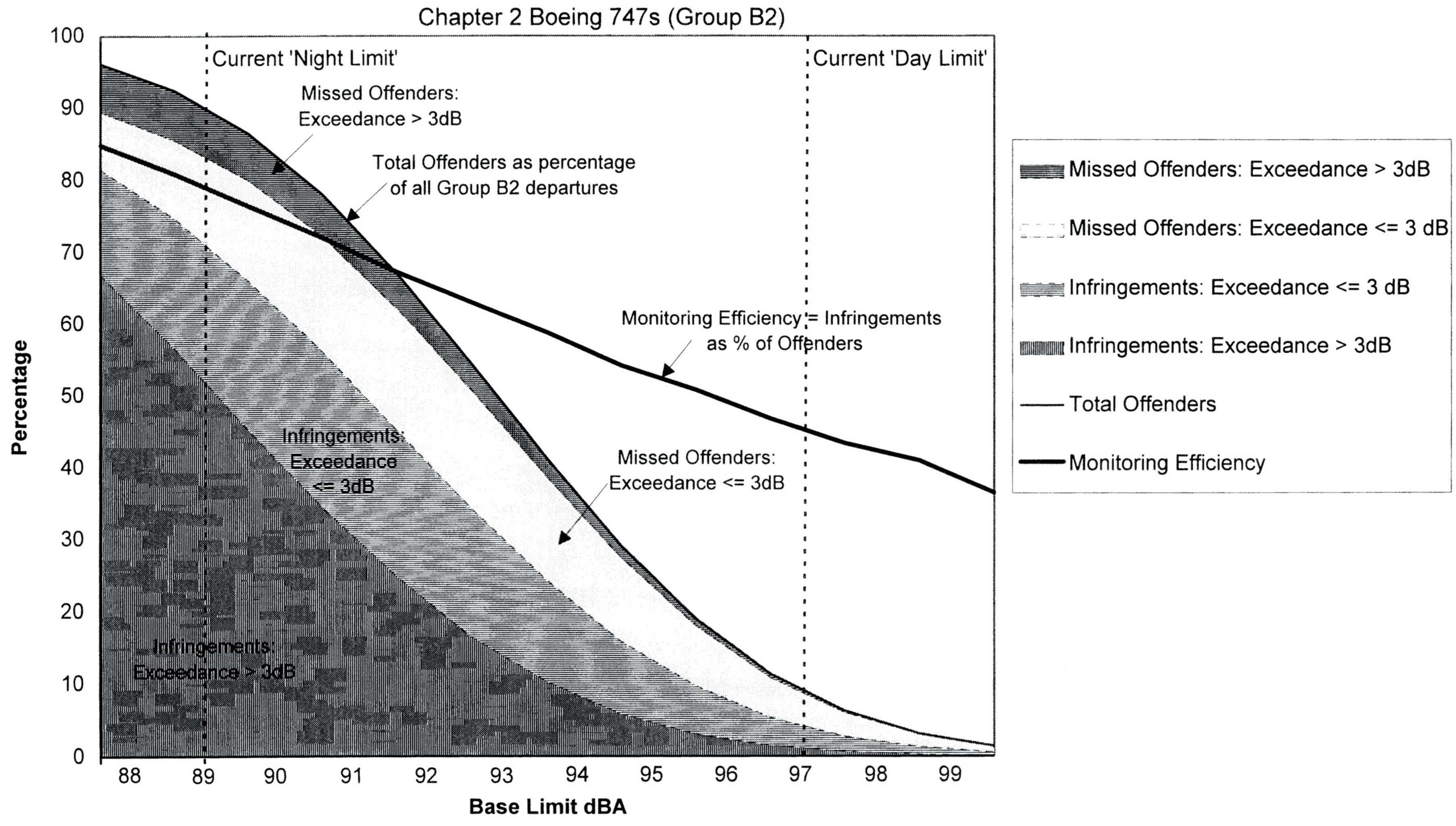


FIGURE 9

RELATIONSHIP BETWEEN BASE LIMIT AND PERFORMANCE OF MONITOR ARRAY

(d) Heathrow Runway 09R: 7 monitors at Reference Distance: Adjusted Limits

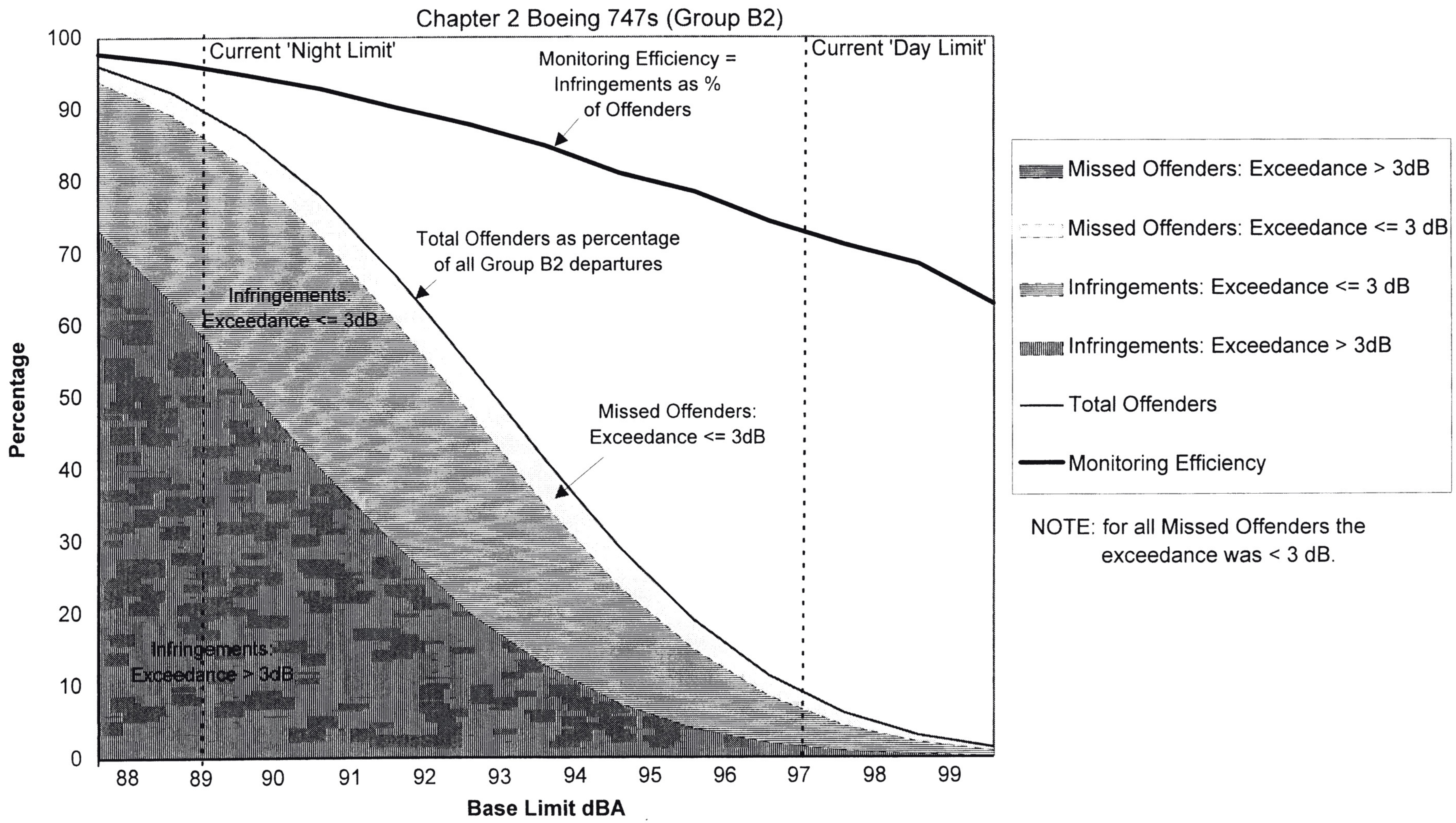
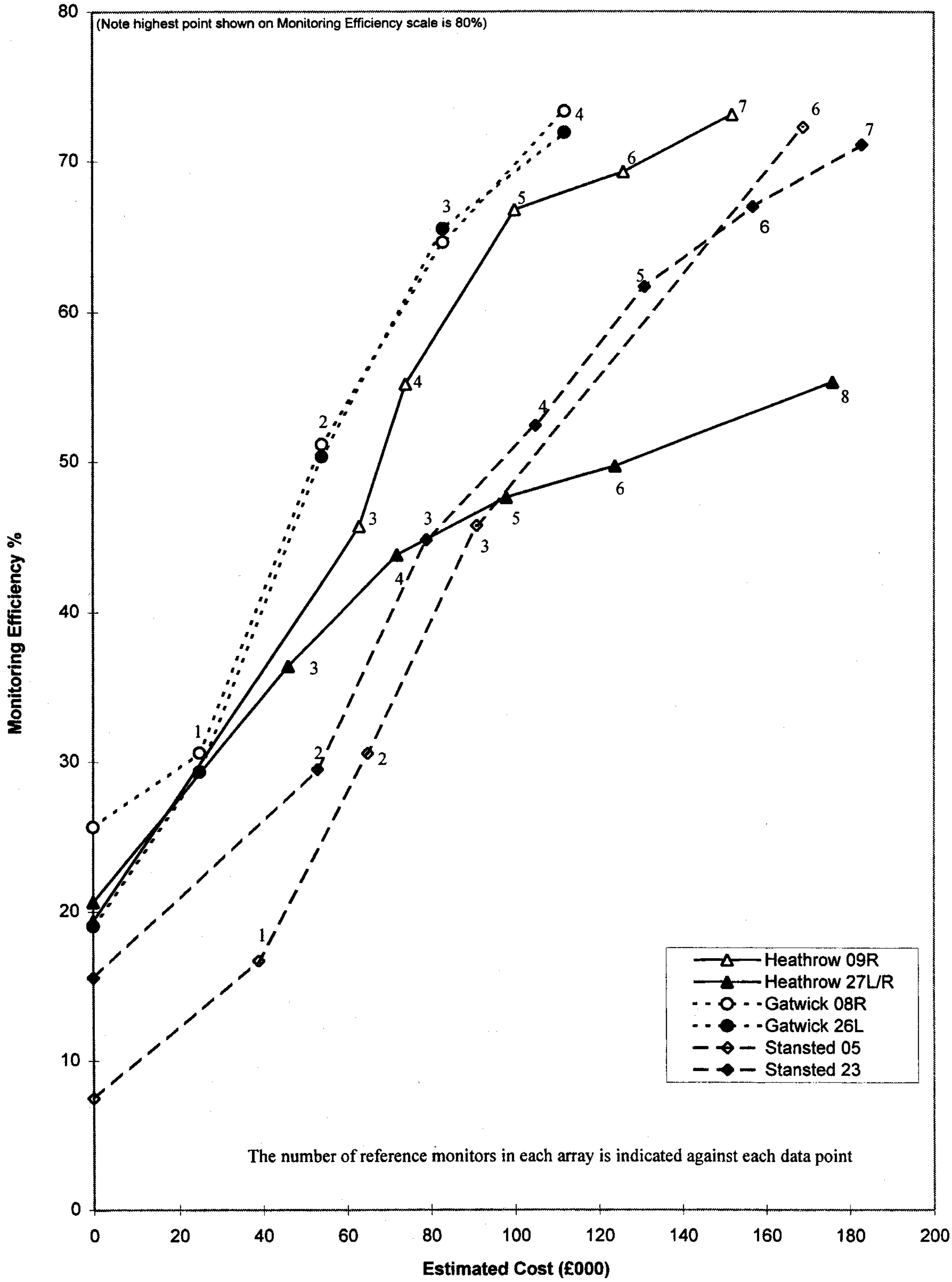


FIGURE 10

COST EFFECTIVENESS OF MONITORING OPTIONS



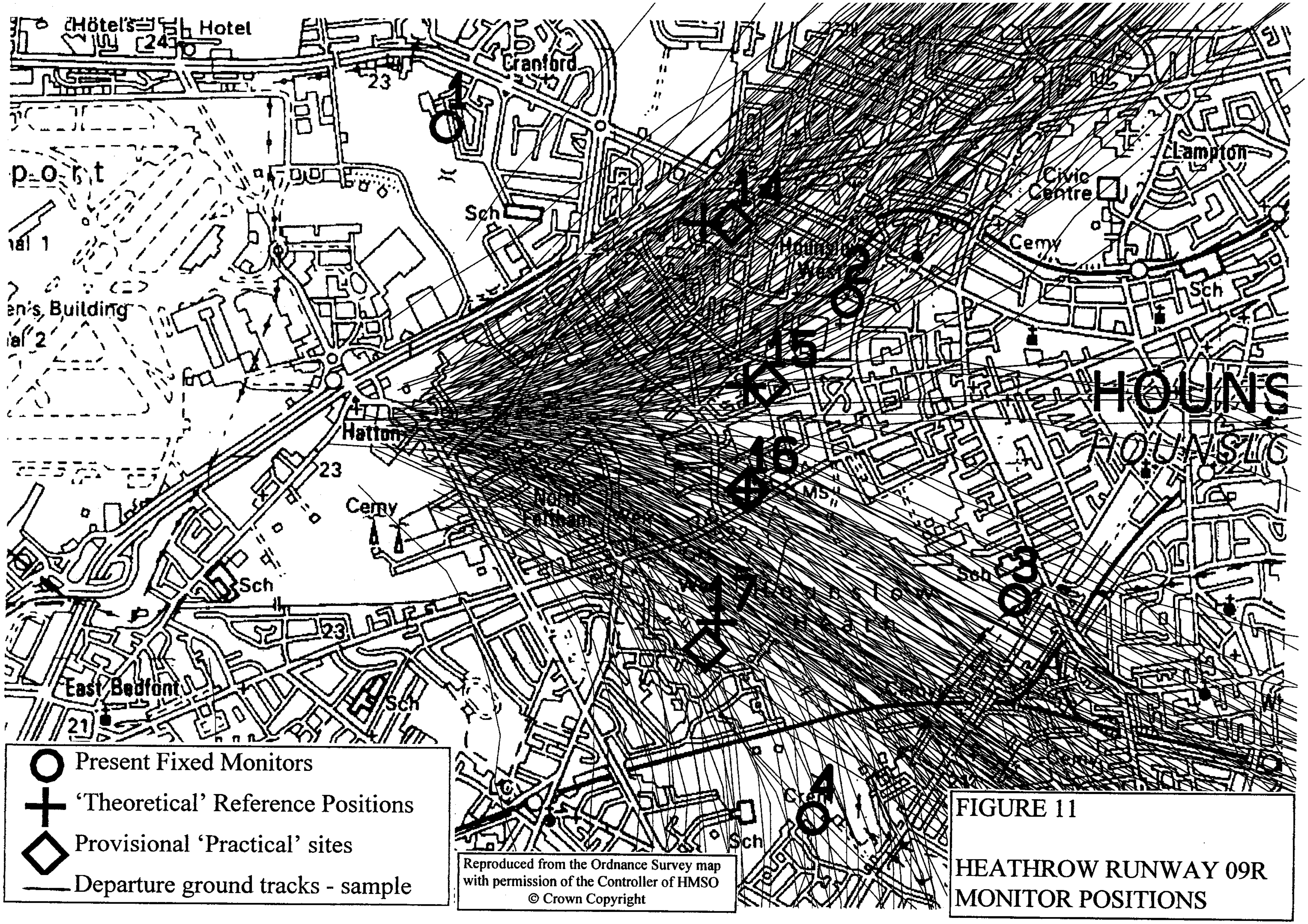
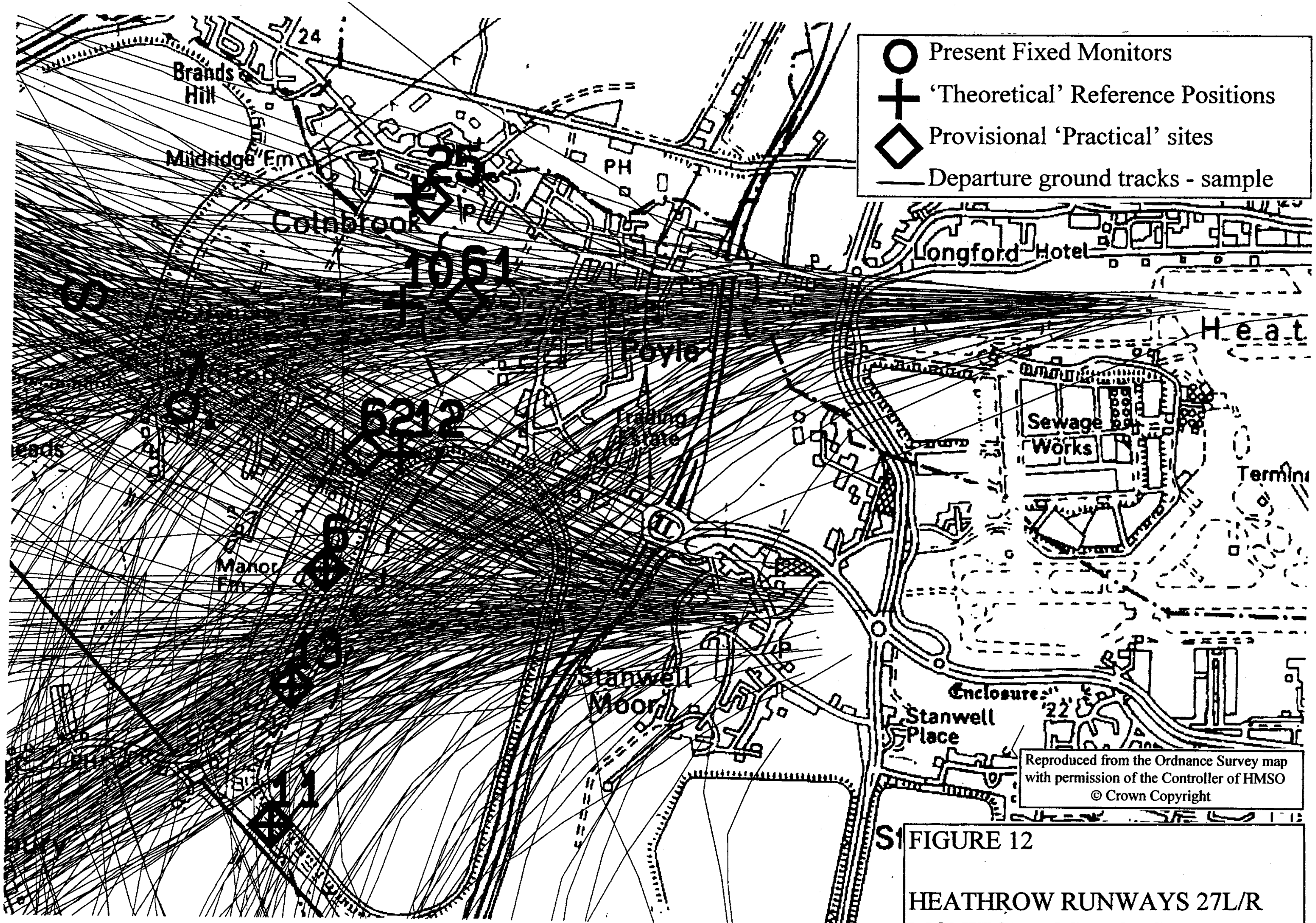


FIGURE 11

HEATHROW RUNWAY 09R MONITOR POSITIONS

SCALE 1: 25000



SCALE 1: 25000

FIGURE 12

HEATHROW RUNWAYS 27L/R MONITOR POSITIONS

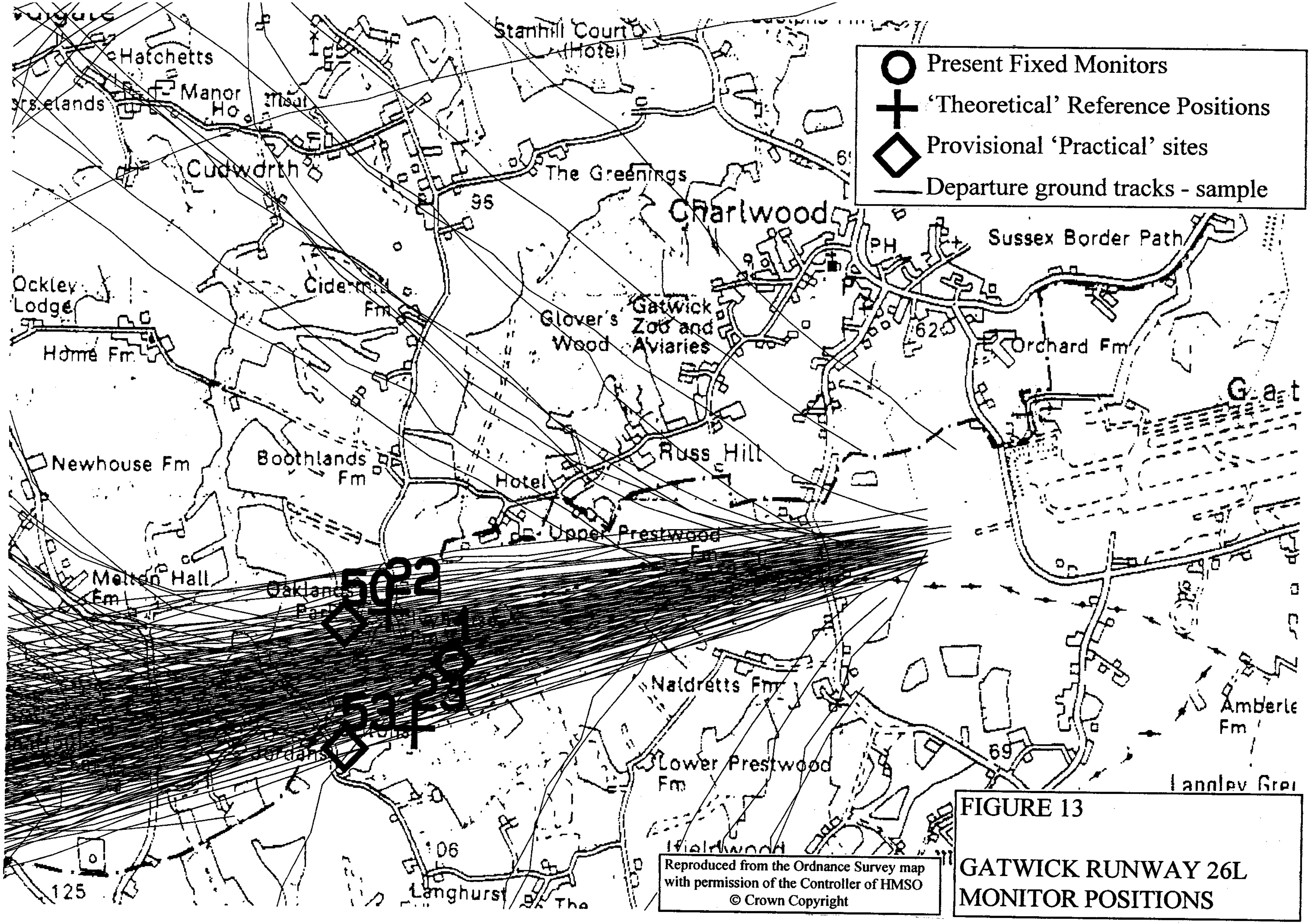
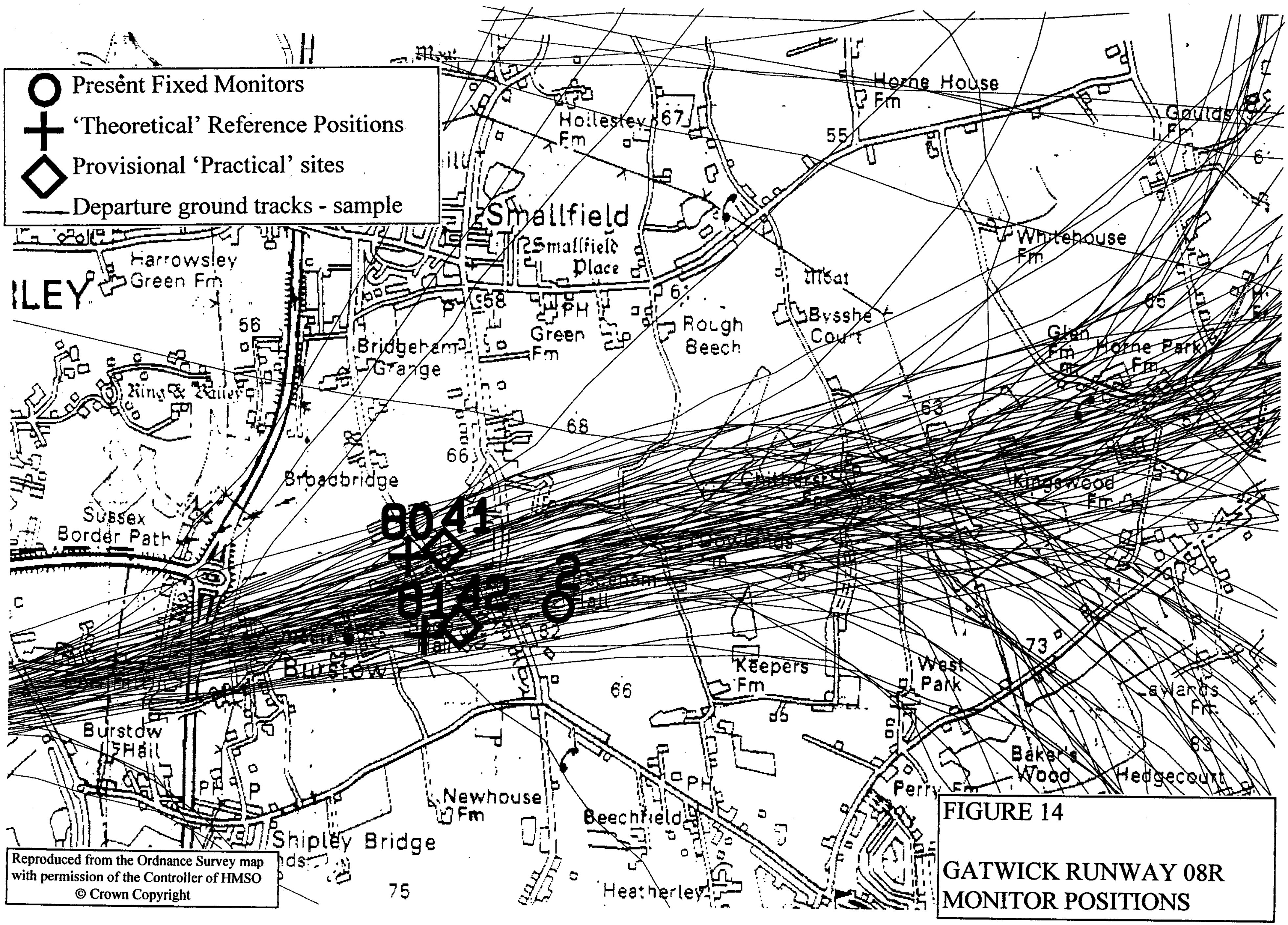


FIGURE 13

GATWICK RUNWAY 26L MONITOR POSITIONS

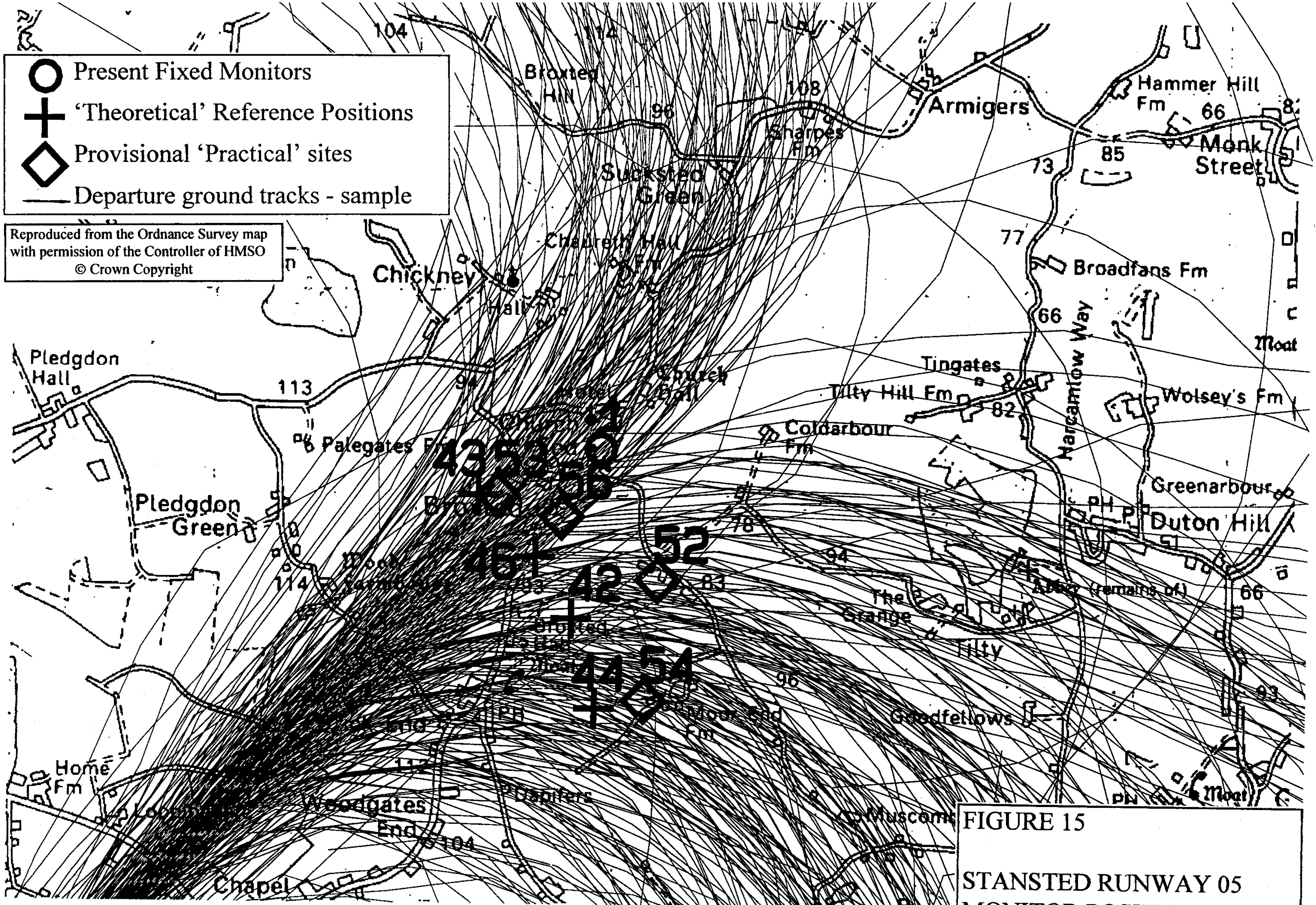
SCALE 1: 25000



SCALE 1: 25000

FIGURE 14

GATWICK RUNWAY 08R MONITOR POSITIONS



SCALE 1: 25000

FIGURE 15

STANSTED RUNWAY 05 MONITOR POSITIONS

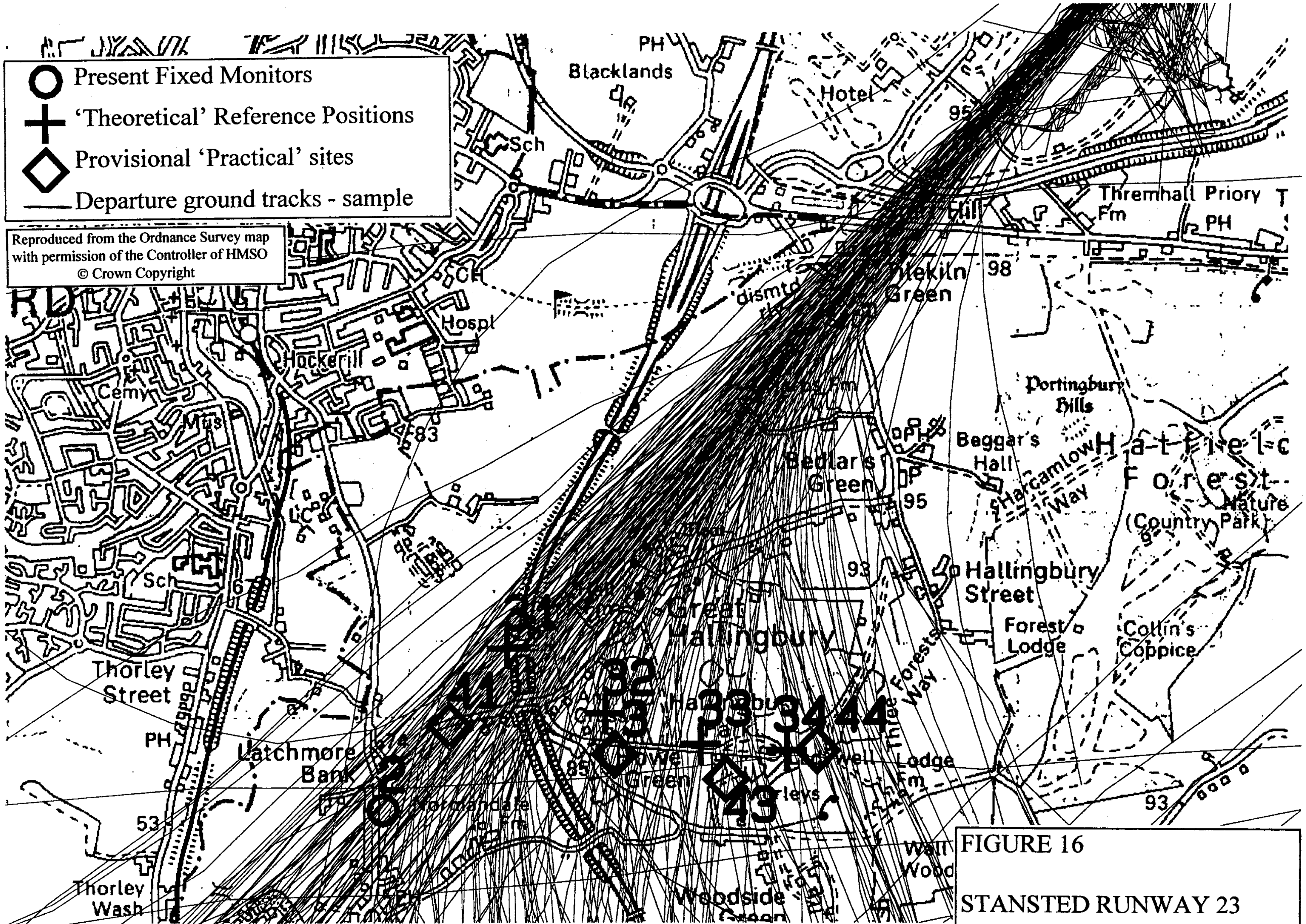


FIGURE 16

STANSTED RUNWAY 23 MONITOR POSITIONS

SCALE 1: 25000

APPENDIX A

COMPARISON OF ORIGINAL AND CURRENT MONITOR POSITIONS AT GATWICK AND HEATHROW

Introduction

A. 1 In 1992, the four original noise monitors at Gatwick were replaced by the two fixed monitors of the present NTK system, one at each end of the runway, both at positions closer to the flight tracks. The positions of old and current monitors are shown in relation to the nominal departure routes in Figure Al. At Heathrow, use of seven of the original thirteen monitor sites was discontinued and one new fixed monitor site was added. The new site number 6 effectively replaced the two original monitors at Sunnymeads and Wraysbury (Figure A2).

A.2 The reasons why the monitoring arrangements at Gatwick were in need of improvement in order to provide comparable coverage to that at Heathrow can be illustrated by means of a simple assessment of the effects of repositioning these monitors on the overall system performance.

A.3 Monitoring system changes which increase the number of infringements detected include:-

(1) Moving monitors closer to start-of-roll
(2) Lowering the limits
(3) Moving monitors closer to flight tracks
(4) Adding monitors

A.4 The effect of (1) and (2) is mainly to increase the *stringency* of the system; (3) and (4) increase its *efficiency*. In this context, 'stringency' relates to the infringement threshold, i.e. whether or not an aircraft will be penalised if it flies over the monitor. 'Efficiency' relates to whether or not the aircraft will fly close to a monitor. When assessing the effects of system changes, it is very important to separate these two performance measures.

A.5 Key dimensions of the monitor layouts are summarised in Table A1 (where Stansted has been included for comparison). The original Heathrow monitor numbers are shown in Roman numerals to avoid confusion with the current convention. The 'shortest track distances' are minimum straight line values from start-of-roll to the monitor position, via the end of the runways. The aircraft heights relate to the most critical aircraft in terms of noise, i.e. those with minimal climb performance that pass 6.5 km from start-of-roll at 1000 ft above runway elevation and climb thereafter at a gradient of 4%. The final column gives, for this climb-critical aircraft, the difference in LAmax between the monitor position and the Reference Point - estimated on the assumption that L_{Amax} changes by 8 dB per doubling of distance. Thus, for example, for the same overflying aircraft, the level L_{Amax} recorded by the old Gatwick monitor at Rusper would be 2.1 dB lower than the level at the Reference Point. (These estimates disregard flight-to-flight variations that would be caused by unpredictable sound propagation effects etc.) For monitors with track distances less than 6.5 km, a nominal 'before cutback' climb gradient of 8% is assumed. The increment for the Gatwick Russ Hill monitor supersedes the 2 dB tolerance presently permitted.

Gatwick

A.6 The original four monitors were arranged in two 'gateway pairs' aimed primarily at aircraft which deviated excessively from the nominal routes. The lateral displacements of all the monitors from the nominal routes were substantial, from about 1 km at Rusper to about 2.5 km at Copthorne (Figure Al). The two easterly monitors were located at similar track distances (7.1 km. and 8.2 km.) to that of the present monitor 2 (7.2 km). However, the westerly units were at rather greater track distances than Russ Hill (number 1), approximately 2.4 km greater at Rusper and 4.5 km at Capel.

A.7 It is evident that, because of their great width, the monitoring efficiencies of both gateways were very low. For aircraft flying directly over the individual monitors (i.e. those most likely to be recorded as infringing the limits) the levels measured at Rusper would have been 4.5 dB lower than at Russ Hill (after taking account of the 2 dB allowance for the high Russ Hill monitor elevation). At Capel, the difference would be nearly 7 dB.

A.8 To the east, there would be rather less difference in the readings at the original and current monitor positions for overhead aircraft (0. 1 dB and 1. 5 dB). However, most aircraft passed well to the side of the old positions so that detection rates would have been very low.

A.9 No suitable data from the old system are available to provide a check on these theoretical conclusions. However, during Spring 1994, a mobile monitor was deployed at Site 21, approximately 1 km further along the nearest route to the old Capel site - see Figure Al. Among the data collected were 565 cases for which departure noise events were recorded at the two monitors, number 21 and number 1 (Russ Hill). The flight paths of these aircraft encompassed a wide range of slant distances from the monitor; very few would have been directly overhead.

A.10 It is not surprising therefore that the differences between the levels recorded at monitors 1 and 21 covered a wide range as indicated below (after allowing for a 2 dB adjustment at Russ Hill):-

Level difference, dB	% of departures
< 3	4
3-6	9
6-9	11
9-12	17
12-15	16
15-18	16
> 18	27

These figures indicate that relatively few aircraft overflew Site 2 1; most passed well to the side.

A.11 It follows that the infringement rates would have been very much lower for the old monitor sites. On the basis of the 565 measurements from the two single monitors 1 and 2 1, the rates for those particular departures would have been as follows:-

Monitor	Infringement Rates (% of noise events)	
	Daytime	Night-time
Site 21	0.0%	0.0%
Russ Hill	1.3%	3.1%

It is not possible to estimate the overall performance of the old gateway pair but it would have been rare for any infringements to have been recorded at either Capel or Rusper. It should be noted that the above percentages relate to numbers of noise events recorded, not total departures. Many event levels would have been too low to trigger the monitors.

Heathrow

A.12 No measured data are available for the old monitor positions at Sunnymeads and Wraysbury but flight path considerations (Table Al) indicate that, again for overflying aircraft, levels at the current monitor 6 adjacent to Wraysbury Reservoir would typically be more than 2 dB higher than at either of the old positions. Since variations in slant distance between aircraft and the original monitors would be similar to those at the old Gatwick monitors, their single monitor efficiencies for particular routes would also have been similar.

Conclusions

A.13 It is evident that the monitor sites currently retained at Heathrow are among the most stringent of the original sites. Of those that were decommissioned, only the monitors at Colnbrook (XIII), Hounslow (III) and South Hounslow Heath (V) would have had a beneficial effect upon overall system efficiency (small in the case of III and V). However, as much benefit may have been gained by the addition of monitor 6 to the west. Old monitor VII (Stanwell) and the Cranford monitor I (now 1) only covered departures from the little used Runways 23 and 09L.

A.14 For the current six effective fixed monitors at Heathrow (numbers 2 to 7), the average L_{Amax} relative to the Reference Point is - 1.3 dB. For the old gateway pairs at Gatwick they were -3.3 dB to the west and - 1. 1 dB to the east. Thus the western gate was effectively 2 dB less stringent than the Heathrow system for overflying aircraft whilst the eastern gate was about the same. That 2 dB would alone reduce the Gatwick infringement rate by about three quarters relative to Heathrow.

A.15 However, a far more significant limitation of the old Gatwick arrangements was the very wide spacing of the gateway monitors which meant that they would generally only have detected the noise of aircraft which turned very sharply to the north or south. As a consequence, the overall monitoring efficiency was very low indeed and was the principal reason why very few infringements were registered by the original system towards the end of its life. This weakness was readily eliminated by positioning the current monitors under the flight paths before they disperse too much.

A.16 Nevertheless, Table A1 shows that, because of the high ground and its distance of 6.2 km from start-of-roll, the Russ Hill monitor is not in an ideal position. Without adjustment, the relative L_{Amax} there is +4.4 dB, i.e. 5-6 dB more stringent than the current Heathrow monitors.

TABLE A1

MONITOR GEOMETRIES AT HEATHROW, GATWICK AND STANSTED

Airport	Original monitor	Original I/D no.	Present monitor no.	Shortest track distance, km	Monitor elevation, m*	Min aircraft height**, m Above runway	Above monitor	LAmax at Monitor - LAmax at Ref Point
HEATHROW		I	1	5.1	-8	193	201	4.8
		II	2	7.0	-8	325	333	-1.0
	Hounslow	III		7.6	-3	349	352	-1.7
		IV	3	7.7	-11	353	364	-2.0
	S H'low Heath	v		7.5	-4	345	349	-1.6
		VI	4	7.1	-15	329	344	-1.4
	Stanwell	VII		3.7	-4	81	85	14.8
		VIII	5	7.0	-10	325	3 5	-1.1
	Hythe end	IX		7.8	-9	357	366	-2.1
	Wraysbury	X		8.3	-7	377	384	-2.7
	Sunnymeads	XI		8.5	-7	385	392	-2.9
		XII	7	7.5	-11	345	356	-1.8
	Colnbrook	XIII		6.7	-2	313	315	-0.4
	-	-	6	6.6	-12	309	321	-0.6
GATWICK	Rusper			8.4	15	381	366	-2.1
	Capel			10.5	15	465	450	-4.5
	Smallfields			7.1	15	329	314	-0.3
	Copthorne			8.2	15	373	358	-1.9
			1	6.0	56	265	209	2.4†
			2	7.2	18	333	315	-0.4
STANSTED			1	7.4	10	341	331	-0.9
			2	7.5	-21	345	366	-2.1
			3	6.7	-7	313	320	-0.6

* Elevations for original monitors are approximate † The relative LAmax at Gatwick monitor 1 (Russ Hill) has been adjusted by -2dB

** Based on minimum permissable climb performance: 1000ft (305m) over Reference Point; 4% gradient after; 8% gradient before

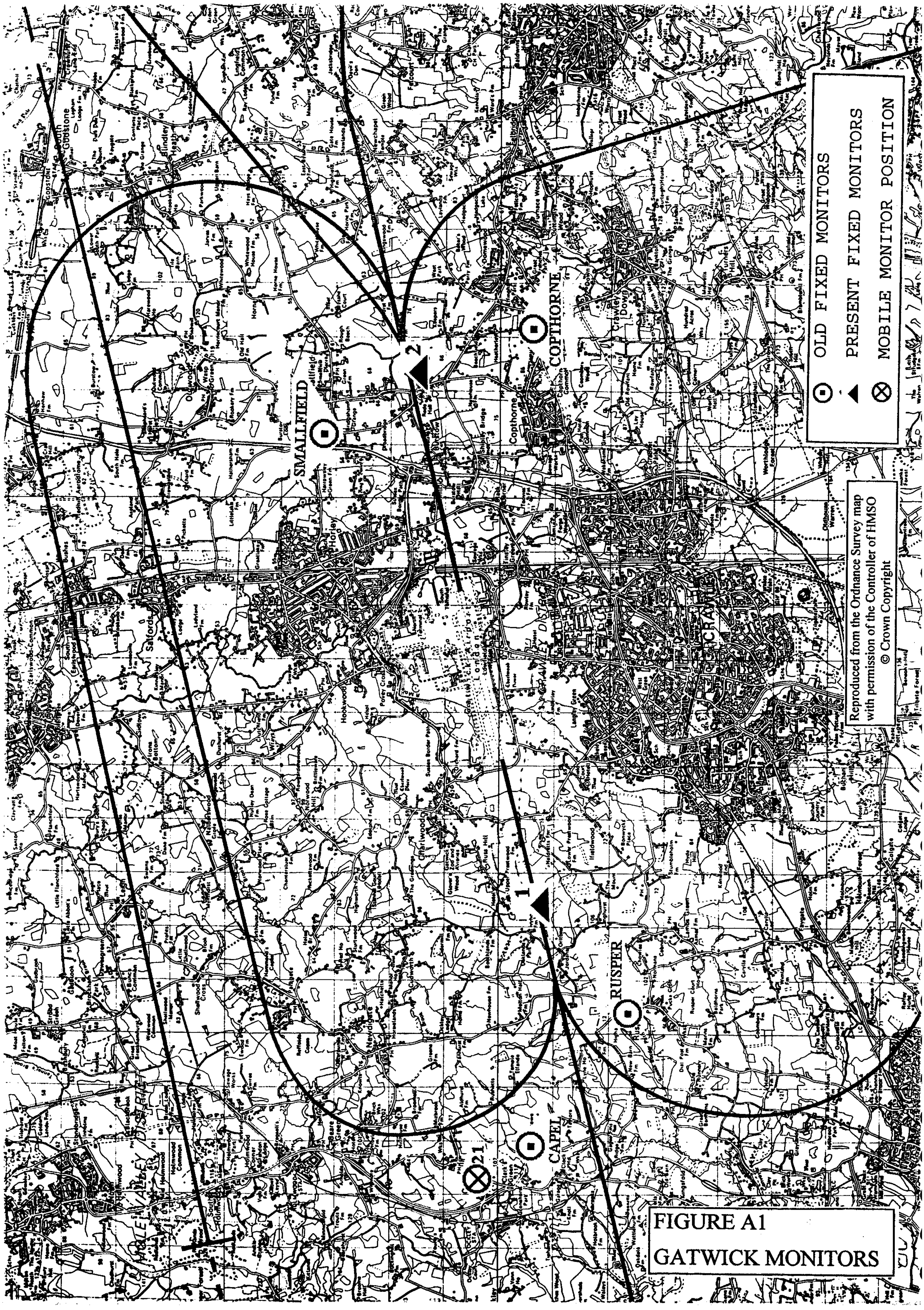


FIGURE A1
GATWICK MONITORS

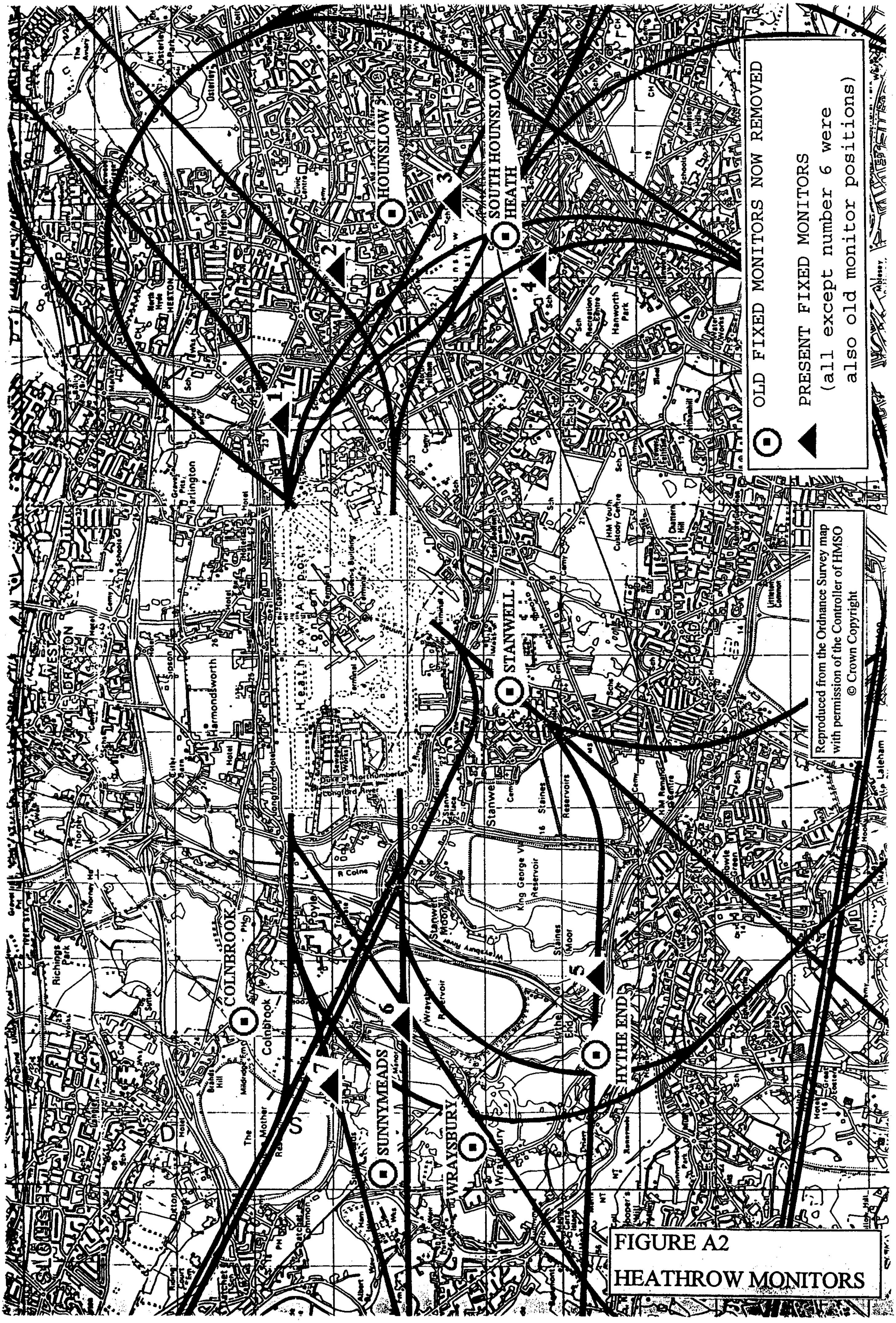


FIGURE A2

HEATHROW MONITORS

NOISE LEVEL EXCEEDANCE RATES: STATISTICAL CONSIDERATIONS

B.1 A primary aim of this study was to define the noise levels generated by different types of aircraft, as classified into different monitoring categories. For this purpose, the noise levels generated by a number of movements of each aircraft type were measured at several measurement sites and normalised to a standard reference position. Each event noise level can be influenced by a number of factors which vary from flight to flight. Some are connected with the aircraft operation - eg the aircraft type, its distance from the monitor and angle of elevation above the horizon, its weight, speed and engine power settings, and some with the atmospheric conditions (particularly the wind speed and direction, temperature, humidity and turbulence, and the way these vary with height above the ground).

B.2 In theory, if all aircraft were the same and all departures were made under identical conditions, any particular monitor would register either 0% or 100% infringements depending on the limit. In reality, noise levels vary substantially from flight to flight so that actual infringement rates fall between these two extremes; the lower the limit, the higher the rate.

B.3 To anticipate how the choice of noise limit would affect the overall infringement rate over a long period of time, it is necessary to know exactly how the levels of all noise events will be distributed. In this context ‘all noise events’ are referred to as the ‘population’. As the entire population cannot be measured, it is necessary to estimate its characteristics from just a sample of measurements.

B.4 This process of ‘statistical inference’ is largely based on the general observation that variables subject to random perturbation follow a bell-shaped ‘*Normal’* (or ‘*Gaussian’) distribution.* The characteristics of this distribution are well documented in mathematical terms and provide the theory that explains to what extent the characteristics of data samples (ie statistics such as mean value, standard deviation, 95th percentile etc.) may be expected to differ from those of the whole population. The starting point in most statistical analyses is to assume 'Normality' of the data unless there is clear and reliable evidence to the contrary.

B.5 Some of the measured variation of noise level is predictable and can be ‘removed’ from the data. For example, the event Reference Levels were calculated by accounting for the expected effects of monitor displacement from the Reference Point and for the lateral displacements of the flight tracks from the monitor.

B.6 Figures B1 and B2 show the distributions of all the Reference Levels determined from the Gatwick and Stansted data. These are in the form of histograms; the vertical bars show the numbers of values falling within each 1dB interval (i.e. at the stated levels ±0.5 dB). Superimposed on each histogram is the equivalent Normal distribution - that which has the same mean value and standard deviation as the measurements. It is apparent that the shapes of these histograms do not match those of the Normal distributions; indeed, in both cases, the measured distributions exhibit two 'humps' rather than one. This is clear evidence of the presence of two distinctly different classes of aircraft.

B.7 In fact, assuming an evenly distributed range of take-off weights, there are no particular reasons why the departure noise levels of a *single aircraft type* should not approximately follow a Normal distribution, as the causes of variation from flight to flight are mainly random in nature - and data from airport noise monitoring systems generally confirms this to be the case. Furthermore, different aircraft types with similar size and performance have sufficiently similar noise distributions that they may be grouped together for statistical purposes. For example, Figures B3 and B4 show histograms of Reference Level for samples of aircraft in particular monitoring categories - groups E and F - for Heathrow departures. These resemble more closely the theoretical Normal distributions although the match is by no means exact.

B.8 Indeed, even if the population distribution were exactly Normal, a close match could not be expected unless the data sample were very large. Different samples from the same population will show somewhat different distributions; the magnitude of the differences depends upon the size of the sample. Figure B5 shows that histograms for four different but large samples, of 1000 Reference Levels selected randomly from the Heathrow group F data, are very similar in shape. However, noticeable differences arise when the samples are smaller; Figures B6 and B7, for samples of 200 and 50 respectively, show that the smaller the sample the greater the differences. These are examples of so-called 'sampling fluctuations'.

B.9 A visual comparison of any two histograms, with each other and with their equivalent Normal distributions, may reveal no marked differences, i.e. that might be greater that those caused by sampling fluctuations. However, such observations might be unreliable and it is necessary to invoke mathematical tests based on Normal probability theory. The differences are deemed to be 'statistically insignificant' if the tests show that, to an acceptable level of confidence, both samples (a) exhibit Normality and (b) probably come from the same population.

B.10 The main statistical questions that arose in this study were:-

- Which aircraft types can be grouped together for the purposes of noise classification?
- Are the group noise characteristics similar at the three airports, and for night and day?
- What are the probable long term relationships between noise limits and exceedance rates?

The tests applied took into account the sample sizes, the shapes of the distributions (including their symmetry), the mean values, and the variance of the measurements about the means[1]. It is usual to perform such tests ‘at the 95% confidence level’, i.e. such that there is only a 5% probability of the wrong inference being made.

B.1 1 The question of exceedance rates becomes problematical in cases where they are small, i.e. in the ‘tails’ of the distributions where the actual numbers of measurements may be relatively small. Essentially, accurate inferences about this region can only be made on the basis of very large samples. Looked at another way, inferences based on the more limited samples that are possible in any practical study may be less reliable.

B. 12 In order to ensure that conclusions about the probable effects of revising the noise limits are as sensible as possible, i.e. not too sensitive to sampling limitations at the extremes of the distributions, it was recommended to ANMAC that these be based upon the equivalent or ‘best fit’ Normal distributions described in para B.6 and illustrated in Figures B3 and B4. Essentially, these are estimates of the shapes of the ‘population’ distributions. Figure 7 of the text shows the equivalent Normal distributions for the different aircraft groups; Appendix C gives further detailed results.

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[1] The tests used included two-sample T-tests, Levene’s test for equality of variances, the Chi-squared test for Normality and some procedures specially derived by Southampton University for assessing differences based on percentile values.

FIGURE B1
GATWICK: ALL AIRCRAFT

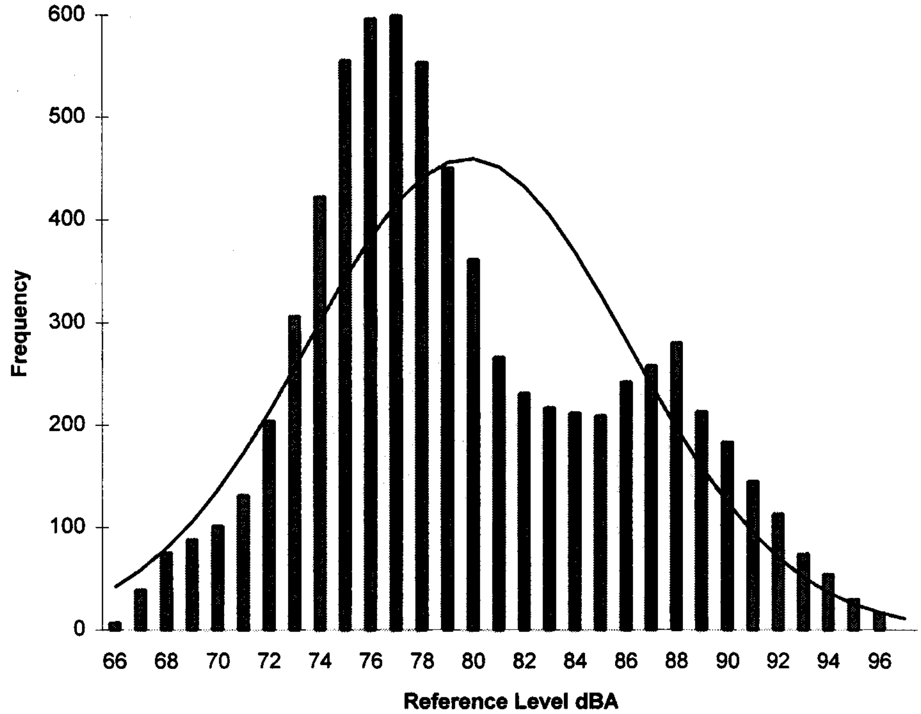


FIGURE B2
STANSTED: ALL AIRCRAFT

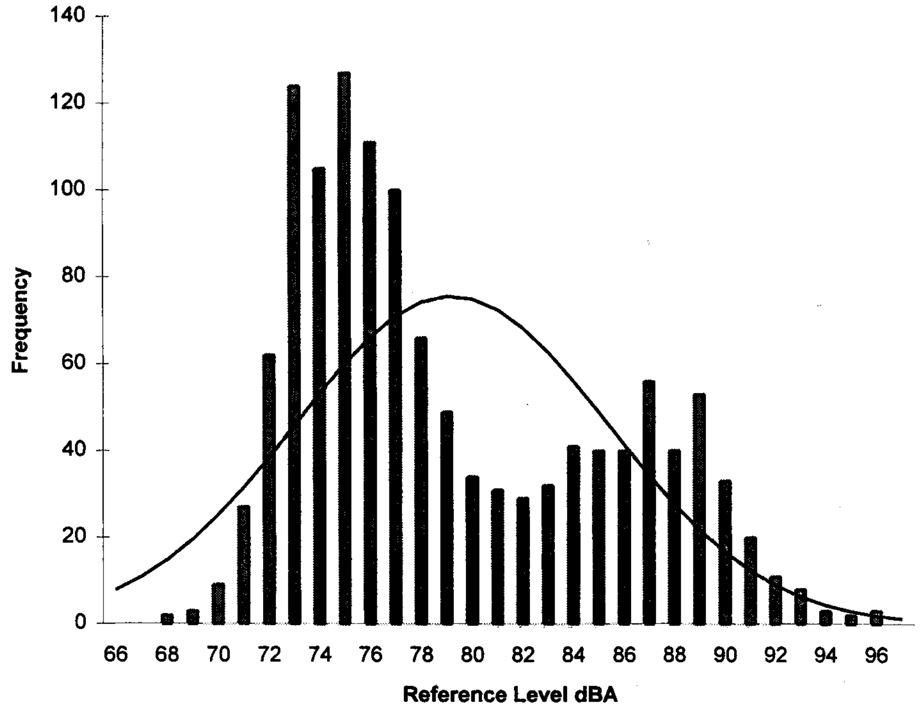


FIGURE B3
HEATHROW GROUP E

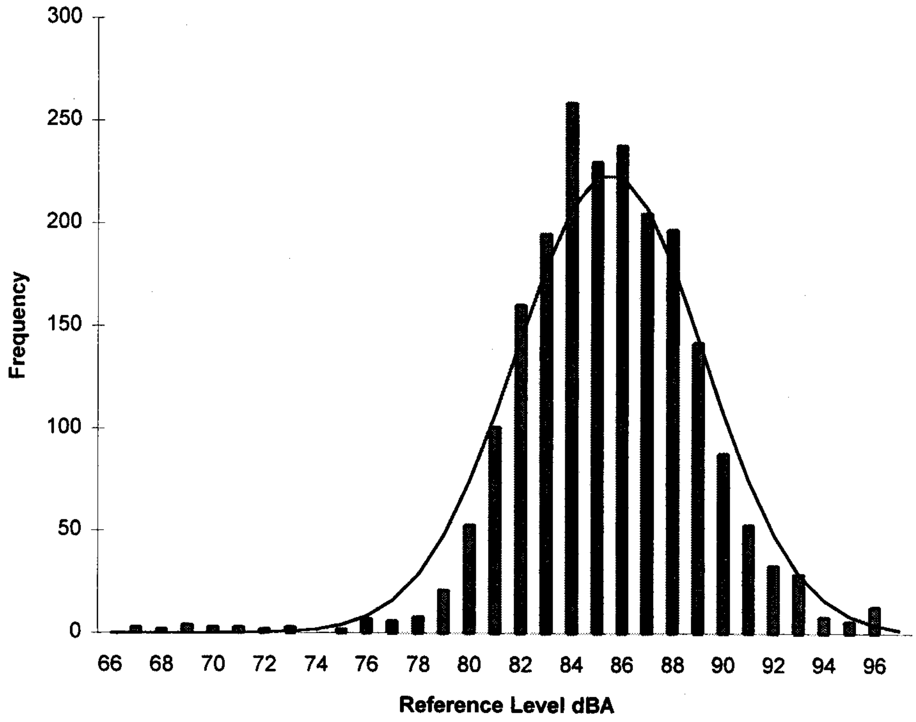


FIGURE B4
HEATHROW GROUP F

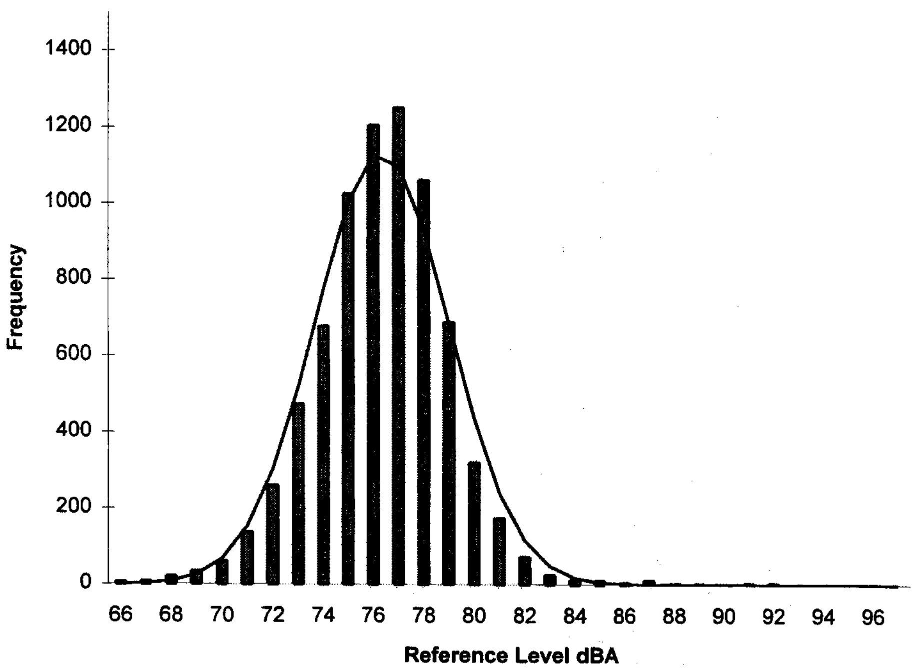
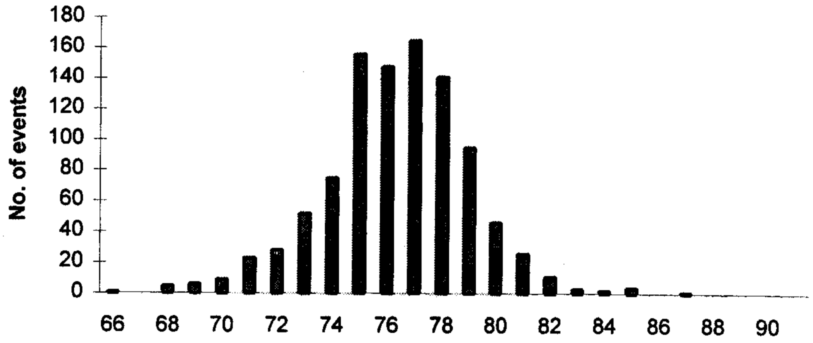
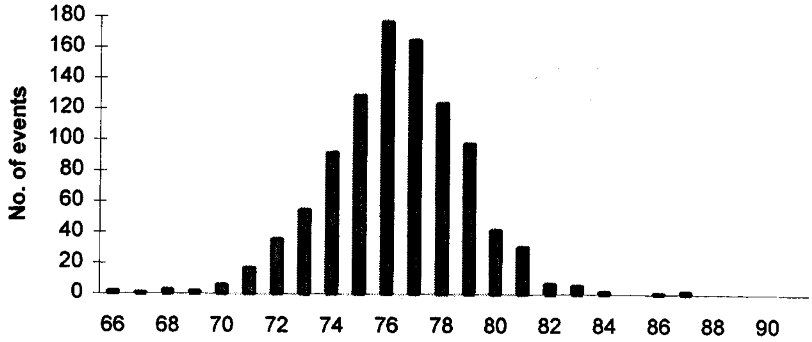


FIGURE B5
RANDOM SAMPLES OF 1000 FROM HEATHROW GROUP F DATA

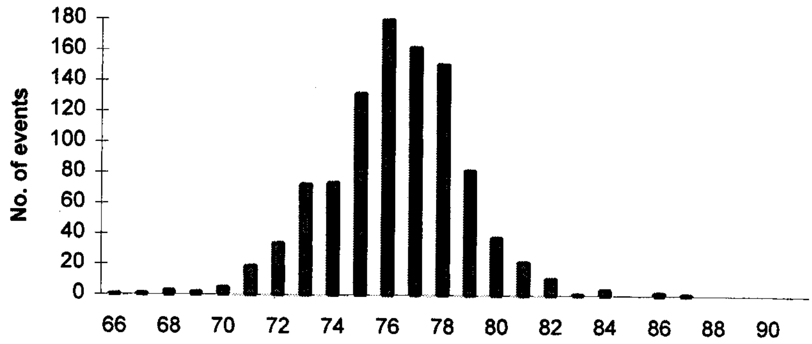
(i)



(ii)



(iii)



(iv)

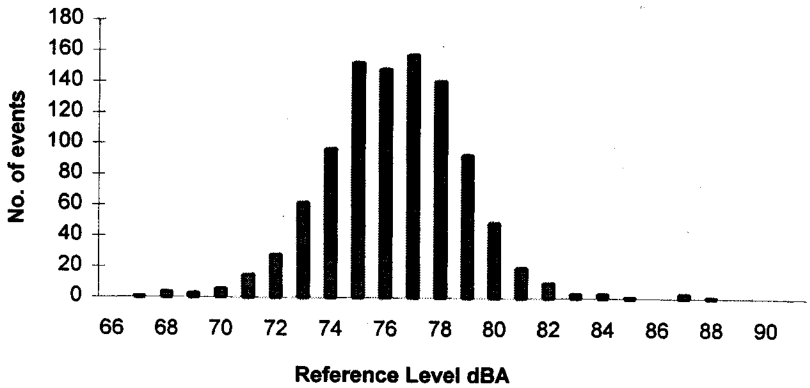


FIGURE B6
RANDOM SAMPLES OF 200 FROM HEATHROW GROUP F DATA

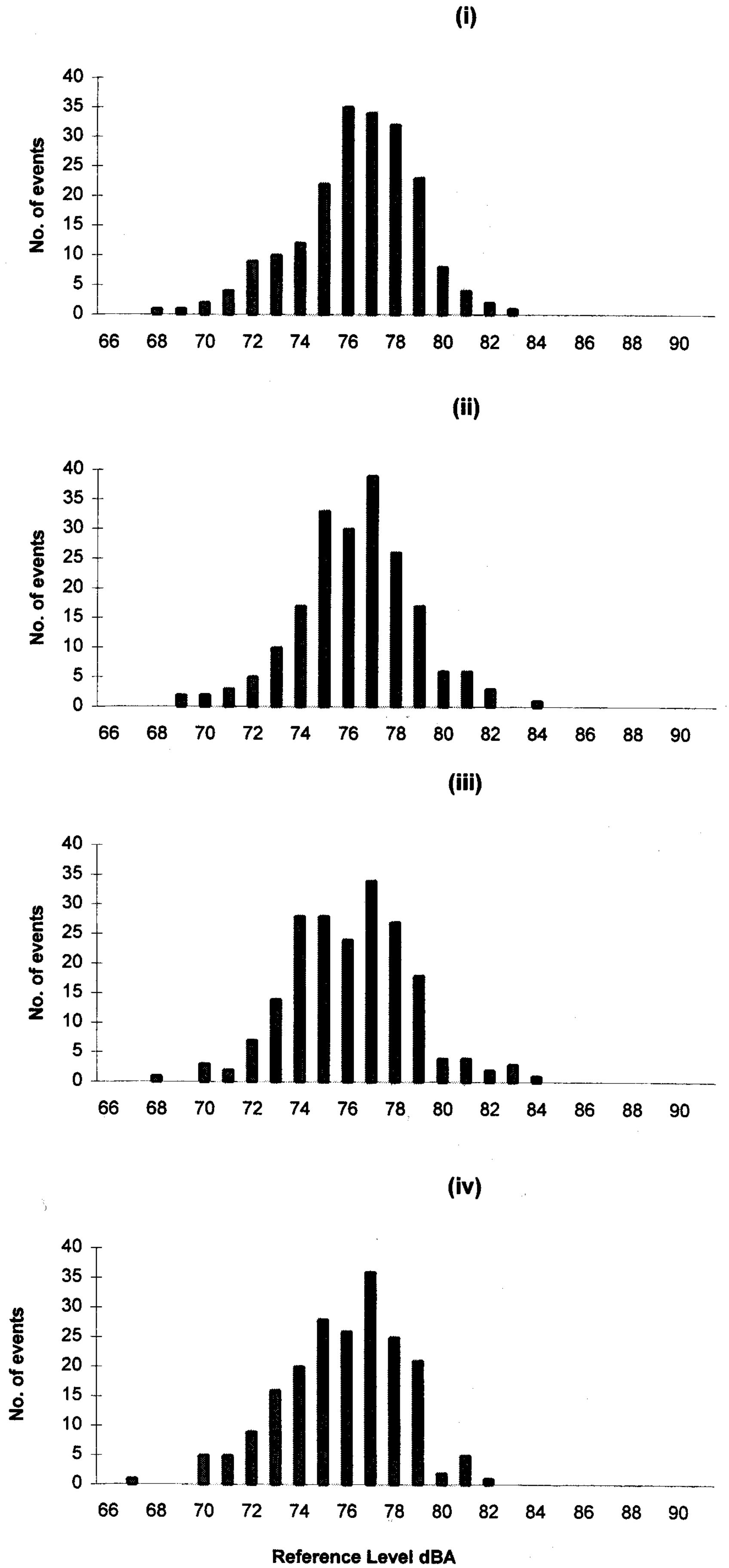
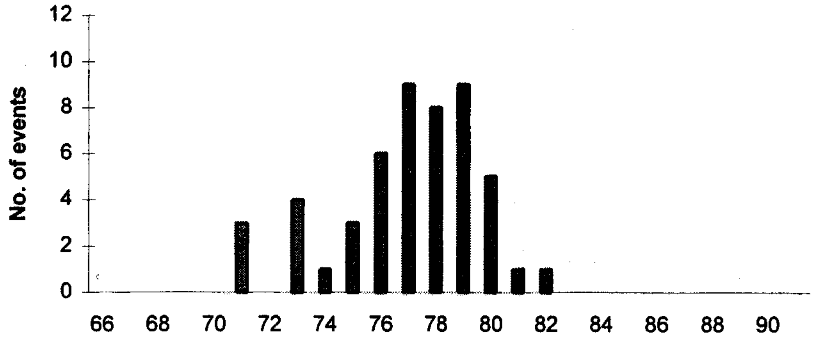
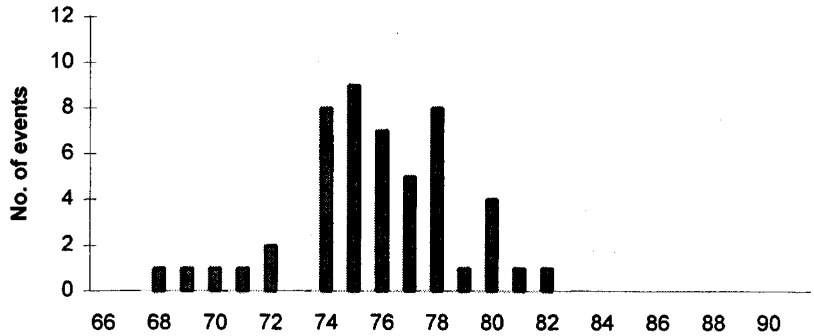


FIGURE B7
RANDOM SAMPLES OF 50 FROM HEATHROW GROUP F DATA

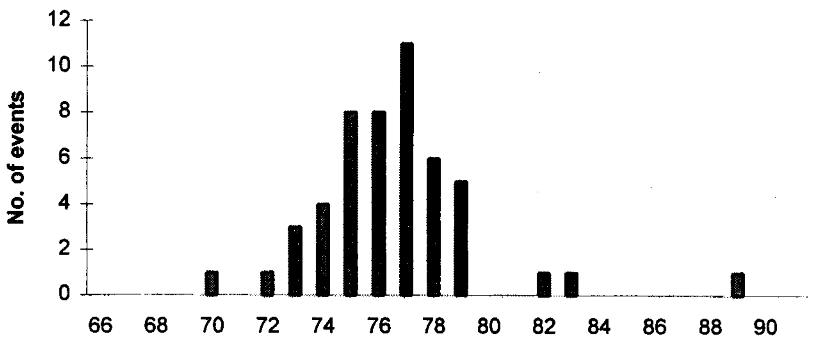
(i)



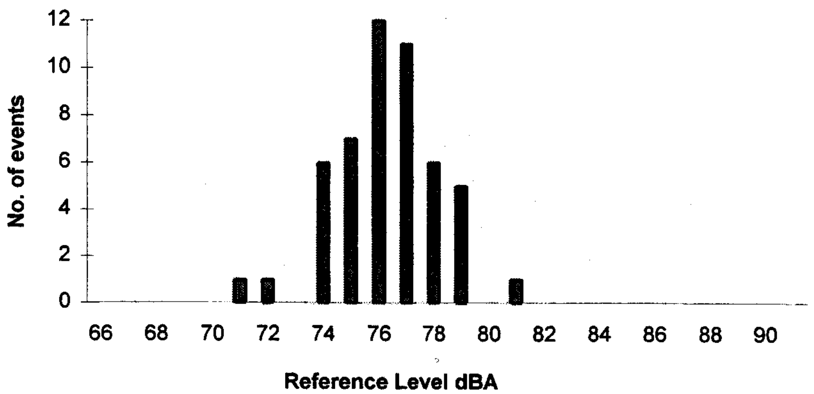
(ii)



(iii)



(iv)



CLASSIFICATION OF AIRCRAFT

C. 1 Figures C1 to C8 show the cumulative distributions[1] of the estimated reference levels within each of the aircraft groups. Up to six sets of data are plotted in each diagram: these are daytime (0700-2300 LT) and night-time (2300-0700 LT) measurements at each of the three airports[2]. Results are omitted in cases where the data set was too small (less than 15 values) to compute meaningful percentiles.

C.2 Table C1 presents associated summary statistics broken down by airport and aircraft group:- Reference Mean Levels and standard deviations, and the Reference Levels exceeded by 50%, 90%, 95% and 99% of the actual flights in each group. Table C2 shows similar results for the 'pooled' (all-airport) data.[3]

C.3 The distributions show some variations between airports and between day and night. These are attributable to both natural scatter in noise event levels (see Appendix B), to different proportions of individual aircraft types within the different data sets and to different aircraft versions and take-off weights used by different operators. In order to estimate the overall effects of varying the noise limits, the data were pooled by group and represented by equivalent normal distributions, i.e. distributions with the same mean values and standard deviations. These curves smooth out the ‘small sample’ irregularities at the extremes of the distributions where limits are likely to be set. These curves, which are overlaid on Figures C1 to C8, provide the basis for Table 4 of the main text.

C.4 Table C3 shows the breakdown by airport of each aircraft type with the B747s split by certification Chapter number[4]. The Table sets out the mix of types within each group at all three airports, and also shows the Reference Mean Level for each aircraft type. This table illustrates the reasons for the (generally small) airport to airport variations shown in Table C1.

C.5 Table C4 shows the detailed breakdown by airport of each Boeing 747 variant (identified by the IATA aircraft type code), split by certification Chapter

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1 Cumulative distributions show what fractions or percentages of measurements exceed different values, rather than, as in Appendix B Figures B1 to B7, the numbers lying within particular intervals.

2 The standard codes for the airports been used in places in this Appendix: LHR = Heathrow, LGW = Gatwick, STN = Stansted.

3 The ‘All Aircraft’ data in Tables C1 and C2 include the ‘Chapter not known’ Boeing 747s (see para C.4), which are not counted in the individual aircraft type groups.

4 Chapter number is not a variable which is currently handled by the NTK software. The Chapter number for each aircraft was therefore obtained from the ‘BUCHair’ database (JP Airline Fleets International, 1994). The database did not however provide Chapter number for 7% of the Boeing 747s. As this 'Chapter not known' sub-group was small and contained a mixture of Chapter 2 and 3 aircraft in unknown proportions, it was excluded from the analyses based on groups B2 and B3.

number. For each case the numbers of measurements obtained and the Reference Mean Levels are shown. For comparison, the pooled results for Groups C and D are also shown.

C.6 The results show why it would not have been appropriate to include the ‘noisier’ Chapter 2 B747s with Group C (other heavy Chapter 2 aircraft). The pooled results in Table C4 show that the Reference Mean Level for Chapter 2 B747s was 92.3 dBA, compared to 89.2 dBA for the Chapter 3 variants. The Group C RML was 89.3 dBA - much closer in fact to that of the Chapter 3 B747s than the Chapter 2’s.

TABLE C1
SUMMARY OF STATISTICS FOR REFERENCE LEVELS

AIRCRAFT TYPE GROUP			DAY + NIGHT			DAY			NIGHT		
			Heathrow	**Gatwick**	**Stansted**	**Heathrow**	**Gatwick**	**Stansted**	**Heathrow**	**Gatwick**	**Stansted**
A	Concorde	N	23	0	0	23	0	0	0	0	0
		SD	3.4			3.4					
		Mean	110.5			110.5					
		50%	110.0			110.0					
		90%	116.5			116.5					
		95%	117.3			117.3					
		99%									
B2	Ch2 Boeing 747	N	350	34	0	348	34	0	2	0	0
		SD	4.8	5.3		4.7	5.3		0.6		
		Mean	92.3	92.5		92.3	92.5		81.2		
		50%	93.2	94.0		93.2	94.0		81.2		
		90%	97.3	96.9		97.3	96.9				
		95%	98.6	97.8		98.6	97.8				
		99%	100.6			100.6					
B3	Ch 3 Boeing 747	N	745	123	0	736	123	0	9	0	0
		SD	3.9	4.7		3.9	4.7		7.2		
		Mean	89.2	89.2		89.3	89.2		86.3		
		50%	89.6	90.0		89.6	90.0		87.9		
		90%	93.9	94.5		93.9	94.5				
		95%	95.1	95.6		95.1	95.6				
		99%	98.2	98.6		98.2	98.6				
C	Heavy Chapter 2	N	44	38	26	44	38	21		0	5
		SD	4.2	6.1	6.9	4.2	6.1	7.2			5.2
		Mean	89.9	91.1	85.5	89.9	91.1	86.2			82.7
		50%	90.0	92.7	85.7	90.0	92.7	87.2			81.2
		90%	96.4	97.3	95.9	96.4	97.3	96.4			
		95%	98.5	100.4	97.3	98.5	100.4	97.5			
		99%									
D	Heavy Chapter 3	N	2261	973	69	2241	924	62	20	49	7
		SD	3.3	4.4	4.6	3.3	4.4	4.8	3.3	3.8	2.5
		Mean	80.0	80.5	79.7	80.0	80.6	79.5	80.3	77.7	81.5
		50%	79.9	80.3	79.4	79.9	80.4	79.1	80.3	77.9	82.2
		90%	83.8	86.5	85.6	83.8	86.6	85.6	84.0	83.0	
		95%	85.3	87.8	87.3	85.3	87.8	87.4	86.2	83.8	
		99%	88.4	90.6		88.5	90.8				
E	Light Chapter 2	N	2086	1988	423	2083	1949	419	3	39	4
		SD	3.7	4.0	4.9	3.7	4.0	4.9	1.3	2.6	4.2
		Mean	85.5	86.8	85.5	85.5	86.8	85.5	82.6	83.8	85.0
		50%	85.4	87.2	86.6	85.4	87.2	86.5	82.2	83.7	86.7
		90%	89.8	91.5	90.5	89.8	91.5	90.5		87.9	
		95%	91.5	92.7	91.6	91.5	92.7	91.7		88.4	
		99%	95.8	94.7	95.1	95.8	94.7	95.2			
F	Light Chapter 3	N	7569	3661	640	7512	3495	580	57	166	60
		SD	2.7	2.8	2.4	2.7	2.9	2.4	3.1	2.6	2.5
		Mean	76.3	76.1	75.1	76.3	76.1	75.1	76.2	76.2	75.2
		50%	76.4	76.2	74.9	76.4	76.2	74.9	76.3	76.1	75.5
		90%	79.3	79.7	78.1	79.3	79.7	78.0	80.0	79.6	78.3
		95%	80.3	80.6	79.3	80.3	80.6	79.3	81.2	80.5	80.0
		99%	82.6	82.8	81.7	82.6	82.8	82.1		82.1	
G	Propeller aircraft	N	148	364	83	142	327	37	6	37	46
		SD	5.4	4.4	3.7	5.4	4.5	4.1	4.6	3.8	3.4
		Mean	74.6	72.1	77.1	74.5	71.9	77.1	76.9	73.7	77.1
		50%	75.2	70.3	76.6	75.1	70.0	75.9	77.5	73.2	76.6
		90%	80.1	78.8	82.5	80.0	78.8	83.9		79	81.9
		95%	81.8	79.9	84.3	81.6	80.0	84.9		79.5	84.9
		99%	92.8	81.2		93.0	81.3				
H	Executive jets	N	199	38	20	185	36	20	14	2	0
		SD	5.5	6.0	3.2	5.7	6.1	3.2	3.1	4.4	
		Mean	74.3	77.0	75.7	74.3	77.2	75.7	73.9	73.2	
		50%	72.8	75.0	75.2	72.6	75.0	75.2	73.9	73.2	
		90%	82.5	88.9	80.4	82.7	89.1	80.4	78.5		
		95%	86.2	91.4	82.7	86.3	91.4	82.7			
		99%	89.7			89.9					
ALL	All aircraft	N	13479	7246	1264	13367	6952	1142	112	294	122
		SD	5.8	6.3	6.1	5.8	6.3	6.3	4.9	4.1	3.9
		Mean	79.6	79.8	79.2	79.6	79.9	79.4	77.8	77.1	76.9
		50%	78.1	78.4	77.1	78.1	78.5	77.2	77.6	76.9	76.3
		90%	88.2	89.0	88.7	88.2	89.2	88.9	83.6	83.1	82.2
		95%	91.1	91.0	90.0	91.2	91.1	90.3	86.9	85.0	86.4
		99%	96.4	94.2	93.4	96.5	94.3	93.7	95.0	88.3	88.7

KEY:

N	Number of samples
SD	Standard Deviation (dBA)
Mean	Arithmetic Average Level (LAmax dBA)
x%	Percentile values of LAmax (dBA) (ie x% of sample having LAmax less than value shown). Not given if sample size prevents calculation.

TABLE C2
SUMMARY STATISTICS FOR REFERENCE LEVELS - POOLED DATA

AIRCRAFT TYPE GROUP			ALL AIRPORTS		
			DAY + NIGHT	DAY	NIGHT
A	Concorde	N	23	23	0
		SD	3.4	3.4	
		Mean	110.5	110.5	
		50%	110.0	110.0	
		90%	116.5	116.5	
		95%	117.3	117.3	
		99%			
B2	Ch 2 Boeing 747	N	384	382	2
		SD	4.8	4.7	0.6
		Mean	92.3	92.3	81.2
		50%	93.4	93.4	81.2
		90%	97.3	97.3	
		95%	98.5	98.6	
		99%	100.6	100.6	
B3	Ch 3 Boeing 747	N	868	859	9
		SD	4.0	4.0	7.2
		Mean	89.2	89.2	86.3
		50%	89.6	89.6	87.9
		90%	94.0	94.0	
		95%	95.3	95.3	
		99%	98.2	98.2	
C	Heavy Chapter 2	N	108	103	5
		SD	6.0	5.9	5.2
		Mean	89.3	89.6	82.7
		50%	90.3	90.5	81.2
		90%	96.6	96.6	
		95%	98.4	98.8	
		99%	101.7	101.8	
D	Heavy Chapter 3	N	3303	3227	76
		SD	3.7	3.7	3.8
		Mean	80.1	80.1	78.8
		50%	80.0	80.0	78.9
		90%	84.6	84.7	83.6
		95%	86.4	86.5	84.3
		99%	89.8	89.8	
E	Light Chapter 2	N	4497	4451	46
		SD	4.0	4.0	2.7
		Mean	86.1	86.1	83.8
		50%	86.2	86.3	83.9
		90%	90.8	90.8	87.8
		95%	92.2	92.2	88.4
		99%	95.2	95.2	
F	Light Chapter 3	N	11870	11587	283
		SD	2.7	2.7	2.7
		Mean	76.2	76.2	76.0
		50%	76.3	76.3	76.1
		90%	79.4	79.4	79.5
		95%	80.4	80.4	80.6
		99%	82.7	82.6	82.9
G	Propeller aircraft	N	595	506	89
		SD	4.9	5.0	4.0
		Mean	73.4	73.0	75.7
		50%	73.4	72.3	76.1
		90%	79.4	79.2	80.6
		95%	80.9	80.7	82.6
		99%	87.0	88.5	
H	Executive jets	N	257	241	16
		SD	5.5	5.7	3.1
		Mean	74.8	74.8	73.8
		50%	73.6	73.6	73.9
		90%	82.6	82.7	78.3
		95%	86.3	86.4	
		99%	91.3	91.3	
ALL	All aircraft	N	21989	21461	528
		SD	6.0	6.0	4.3
		Mean	79.6	79.7	77.2
		50%	78.2	78.2	76.7
		90%	88.5	88.6	83.0
		95%	91.0	91.1	85.1
		99%	95.6	95.6	89.2

'Day' and 'Day+Night' results obtained from a random sample of 80% of total data to enable computation.

KEY:

N	Number of samples
SD	Standard Deviation (dBA)
Mean	Arithmetic Average Level (LAmax dBA)
x%	Percentile values of LAmax (dBA) (ie x% of sample having LAmax less than value shown). Not given if sample size prevents calculation.

TABLE C3
TRAFFIC MIX WITHIN AIRCRAFT GROUPS: PERCENTAGE BY TYPE
DATA FROM FULL STUDY SAMPLE: DAY+NIGHT

		Reference	Percentage of departures of aircraft type group			
GROUP	TYPE	Mean Level	HEATHROW	GATWICK	STANSTED	ALL
A	CONC	110.5	100.0	0.0	0.0	100.0
B	B747-100/200 Ch 2	92.6	29.7	19.6	0.0	28.4
	B747-100/200 Ch 3	90.8	14.7	59.2	0.0	20.6
	B747-400 (all Ch 3)	88.5	444	21.2	100.0	41.3
	B747-300 (all Ch 3)	88.2	3.8	0.0	0.0	3.3
	B747SP Ch 3	85.1	5.6	0.0	0.0	4.8
	B747SP Ch 2	83.6	1 8	0.0	0.0	1.6
C	IL86	93.0	22.7	0.0	0.0	9.3
	IL76	92.8	0.0	0.0	34.6	8.3
	B707	89.3	47.7	63.2	7.7	43.5
	AN24	89.1	0.0	0.0	11.5	2.8
	IL62	88.5	15.9	0.0	0.0	6.5
	DC8	87.2	13.6	36.8	46.2	29.6
D	DC10	84.4	2.9	15.5	36.2	7.3
	L101	84.2	1.5	14.2	0.0	5.2
	EA34	82.5	0.4	1.6	0.0	0.8
	MD11	82.4	4.9	0.7	0.0	3.5
	B767	79.8	48.6	49.9	0.0	48.0
	EA30	79.5	21.7	14.9	17.4	19.6
	EA31	77.7	20.0	3.1	2.9	14.7
	EA33	75.7	0.0	0.0	43.5	0.9
E	B727	90.9	2.0	2.6	1.9	2.2
	BA11	87.9	1.1	0.6	22.9	2.9
	TU34	87.6	0.0	0.6	0.2	0.3
	B737	86.9	22.7	70.3	57.7	47.0
	DC9	86.9	27.4	2.0	2.8	13.9
	FK28	86.0	4.1	8.9	0.0	5.8
	TU54	85.4	2.4	0.4	1.4	1.4
	MD80	83.9	40.4	14.6	13.0	26.4
	Other		0.0	0.1	0.0	0.0
F	B73F	77.1	32.8	37.4	3.8	32.6
	BA46	76.3	2.2	12.6	27.2	6.7
	B73S	76.2	19.3	11.4	1.4	15.9
	B757	75.7	26.4	23.2	5.9	24.3
	EA32	75.5	17.8	11.2	8.6	15.3
	FK10	74.6	1.6	4.3	53.1	5.2
G	VC8	79.8	0.0	0.0	18.1	2.5
	FK27	77.1	41.9	21.2	4.8	24.0
	G159	77.0	0.0	0.3	10.8	1.7
	HP7	76.7	0.0	16.2	25.3	13.4
	L188	76.5	0.0	0.0	13.3	1.8
	DH8	73.6	6.8	0.0	0.0	1.7
	BEK	71.8	7.4	1.4	2.4	2.4
	AT72	70.6	0.0	3.6	0.0	2.2
	SH36	69.6	0.0	11.0	1.2	6.9
	SF34	69.5	0.0	4.1	1.2	3.0
	FK50	69.4	10.1	0.3	0.0	2.7
	DH7	68.7	15.5	0.0	0.0	3.9
	AT42	68.4	0.0	37.4	0.0	22.9
	Other		18.2	4.7	22.9	10.9
H	EXEC	74.4	100.0	100.0	100.0	100.0

TABLE C4
BOEING 747 DATA

Airport	Type	Number of measurements				Reference Mean Level		
		CH 2	CH 3	not known	TOTAL	CH 2	CH 3	ALL
LHR	741	199	17		216	93.8	94.1	93.9
	742	112	130	8	250	91.0	91.2	91.2
	74F/C	24	20		44	90.5	88.2	89.5
	-100/200	335	167	8	510	92.6	91.1	92.1
	74L	15	49	21	85	83.6	85.1	85.0
	743	0	44		44	-	88.2	88.2
	744	0	485	25	510	-	89.1	89.0
	GROUP B	350	745	54	1149	92.3	89.2	90.1
LGW	741	12	5		17	94.1	90.3	93.0
	742	22	96	10	128	91.7	90.3	90.1
	-100/200	34	101	10	145	92.5	90.3	90.5
	744	0	22	17	39	-	83.7	82.4
	GROUP B	34	123	27	184	92.5	89.2	88.7
STN	744	0	0	3	3	-	-	78.5
	GROUP B	0	0	3	3	-	-	78.5
Pooled data:								
	741	211	22	0	233	93.9	93.2	93.8
	742	134	226	18	378	91.1	90.8	90.8
	-100/200	369	268	18	655	92.6	90.8	91.8
	74L	15	49	21	85	83.6	85.1	85.0
	743	0	44	0	44	-	88.2	88.2
	744	0	507	45	552	-	88.8	88.5
	GROUP B	384	868	84	1336	92.3	89.2	89.9
	GROUP C				108			
	GROUP D				3303			80.1

<u>Notes</u>

(i) IATA B747 type codes:

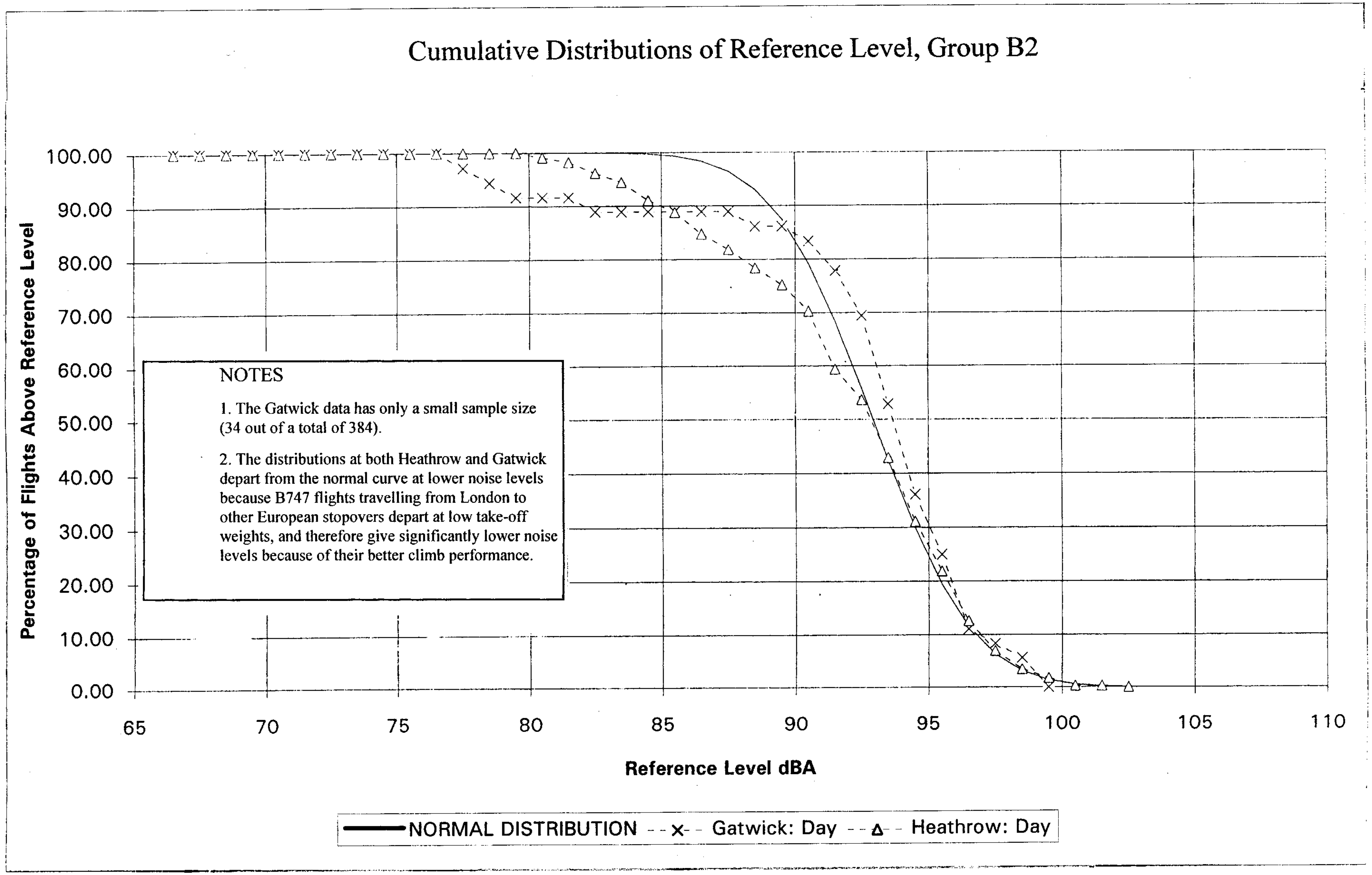
741	Boeing 747-100	74C	Boeing 747 Convertible
742	Boeing 747-200	74F	Boeing 747 Freighter
743	Boeing 747-300	74L	Boeing 747SP
744	Boeing 747-400		

(ii) At Heathrow some Chapter 3 variants appear to be slightly noisier than the corresponding Chapter 2 aircraft. No particular reason has been found for this, although noise certification data does indeed show certain Chapter 3 variants have higher flyover noise levels than some of the Chapter 2 aircraft. (They are allowable under provisions to 'trade-off' against lower sideline/approach levels.)

(iii) Although there is an apparent anomaly in the overall Group B Reference Mean levels for Gatwick (88.7 dBA compared with 92.5 for Chapter 2 and 89.2 for Chapter 3), this is in fact correct as the RML for the 27 ‘Chapter not known’ Gatwick B747s was 82.1 dBA.

(iv) The three Stansted B747-400s appear very much quieter than those at Heathrow and Gatwick. These flights have been investigated and the heights at 6.5 km were found to be almost twice those of typical B747-400s at Heathrow. It is likely therefore that these aircraft were operating unloaded and/or over a very short range.

FIGURE C1



Cumulative Distributions of Reference Level, Group B2
Percentage of Flights Above Reference Level
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
65
70
75
80
85
90
95
100
105
110
Reference Level dBA
NORMAL DISTRIBUTION
Gatwick: Day
Heathrow: Day
NOTES
1. The Gatwick data has only a small sample size (34 out of a total of 384).
2. The distributions at both Heathrow and Gatwick depart from the normal curve at lower noise levels because B747 flights travelling from London to other European stopovers depart at low take-off weights, and therefore give significantly lower noise levels because of their better climb performance.

FIGURE C2

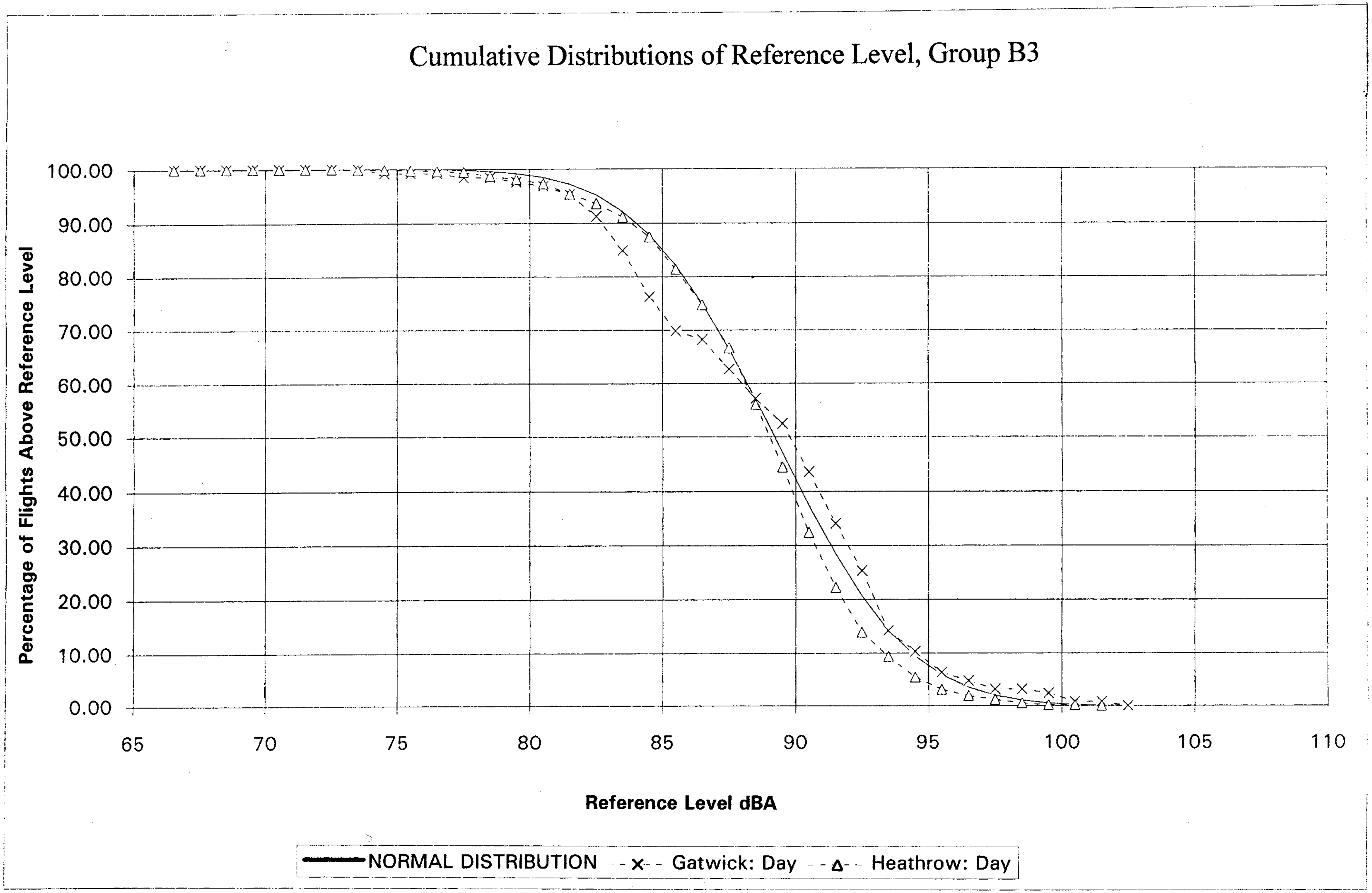

Cumulative Distributions of Reference Level, Group B3
Percentage of Flights Above Reference Level
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
65
70
75
80
85
90
95
100
105
110
Reference Level dBA
NORMAL DISTRIBUTION
Gatwick: Day
Heathrow: Day

FIGURE C3

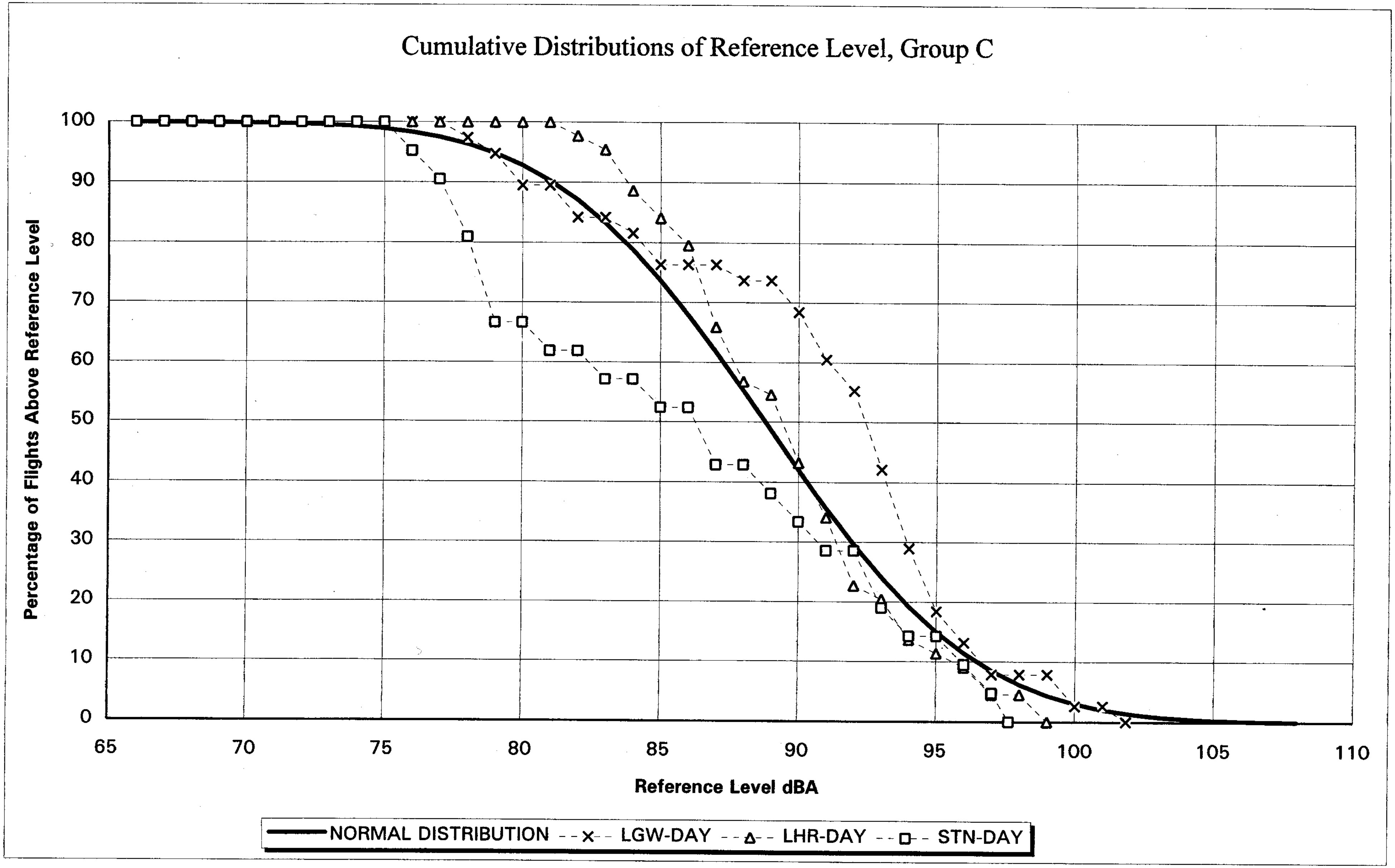

Cumulative Distributions of Reference Level, Group C
Percentage of Flights Above Reference Level
100
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
90
95
100
105
110
Reference Level dBA
NORMAL DISTRIBUTION
LGW-DAY
LHR-DAY
STN-DAY

FIGURE C4

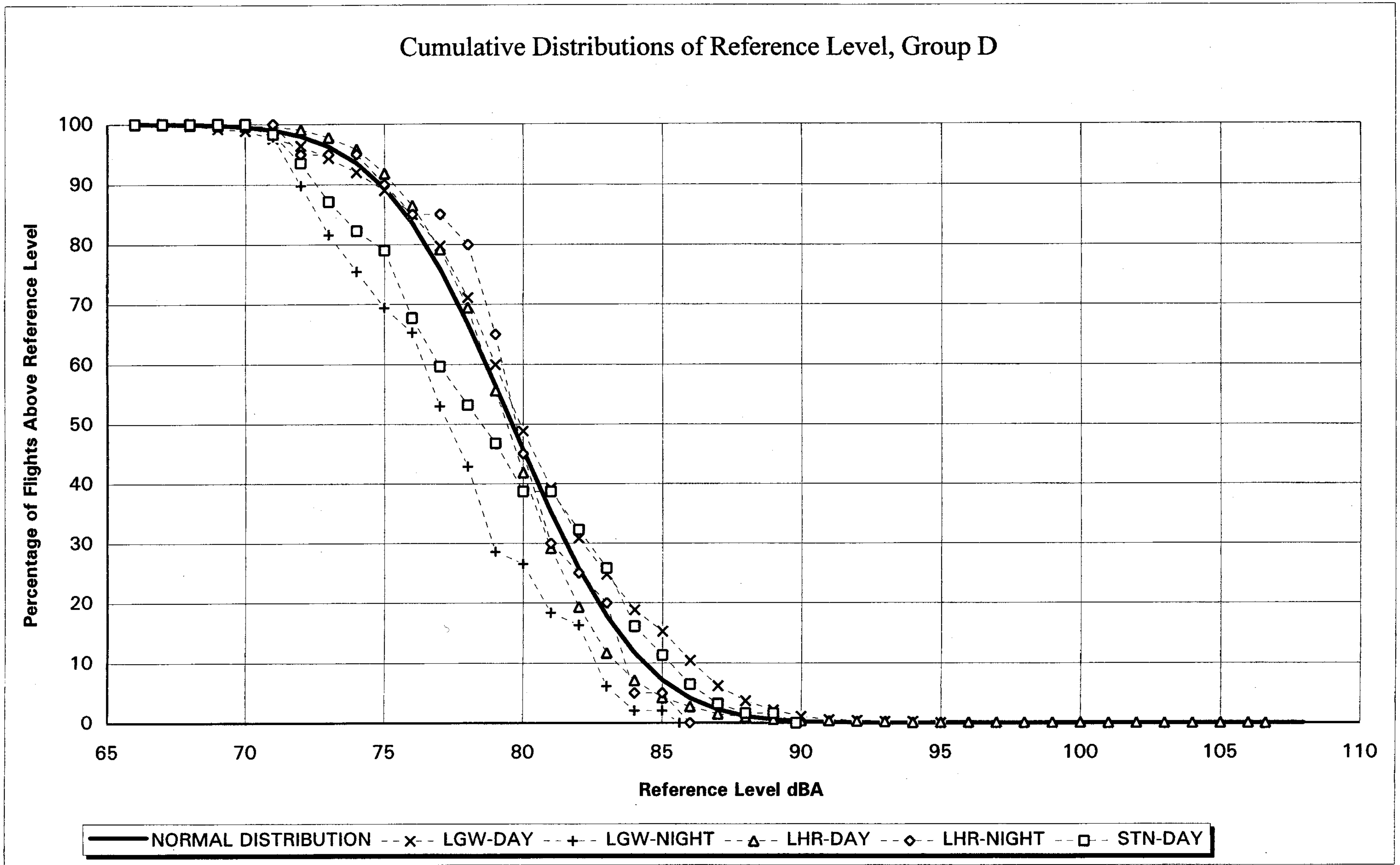
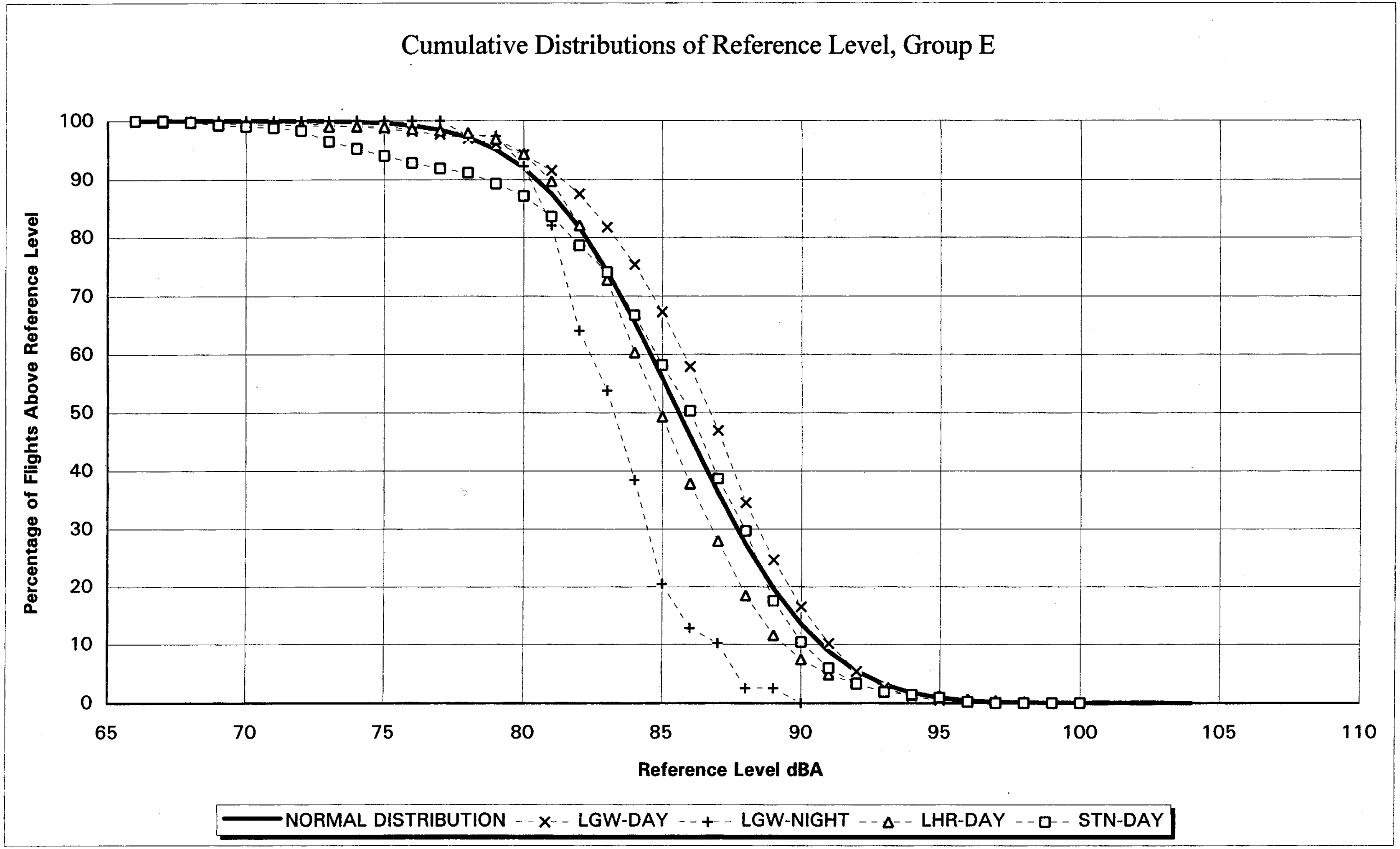
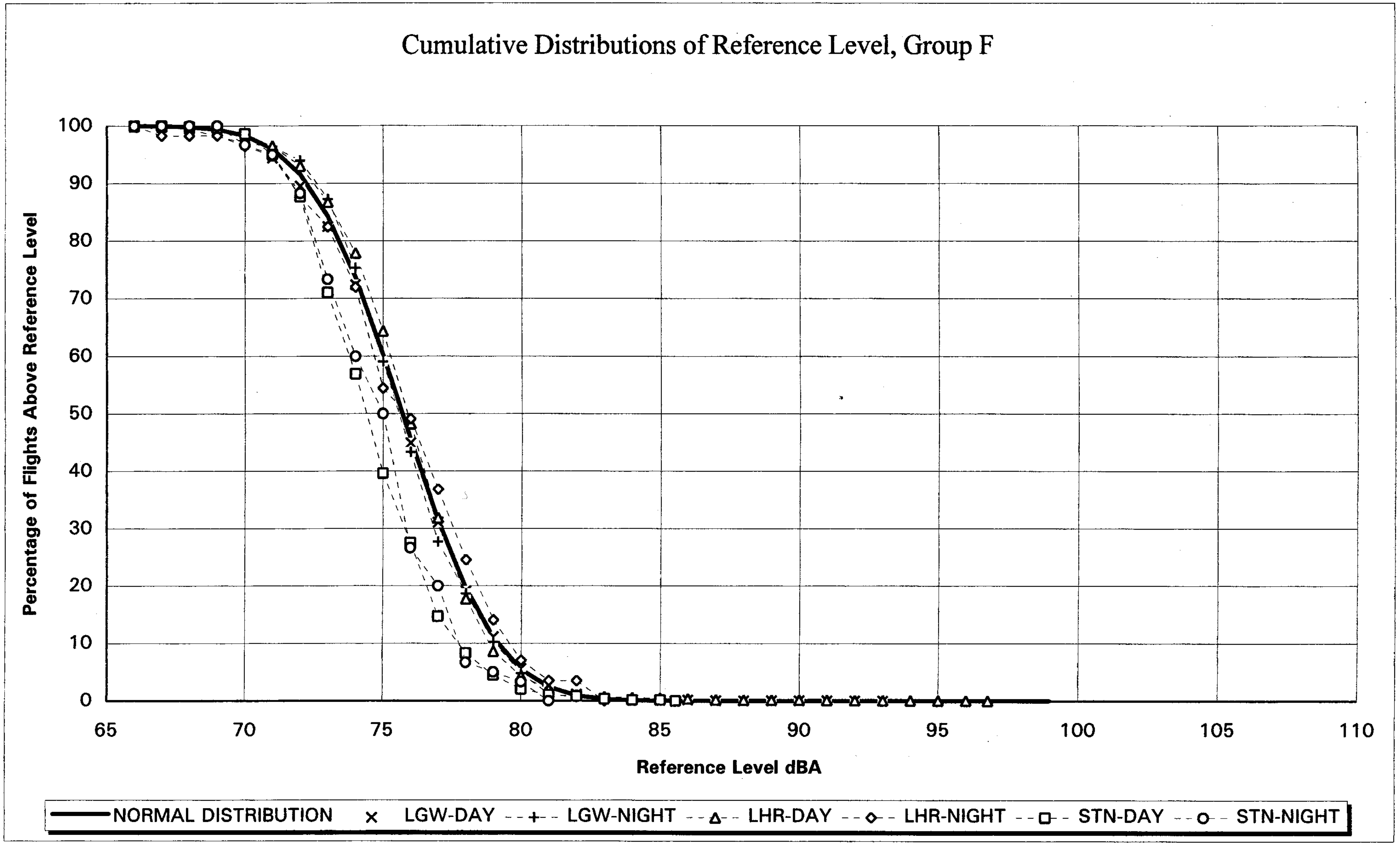

Cumulative Distributions of Reference Level, Group D
Percentage of Flights Above Reference Level
100
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
90
95
100
105
110
Reference Level dBA
NORMAL DISTRIBUTION
LGW-DAY
LGW-NIGHT
LHR-DAY
LHR-NIGHT
STN-DAY

FIGURE C5



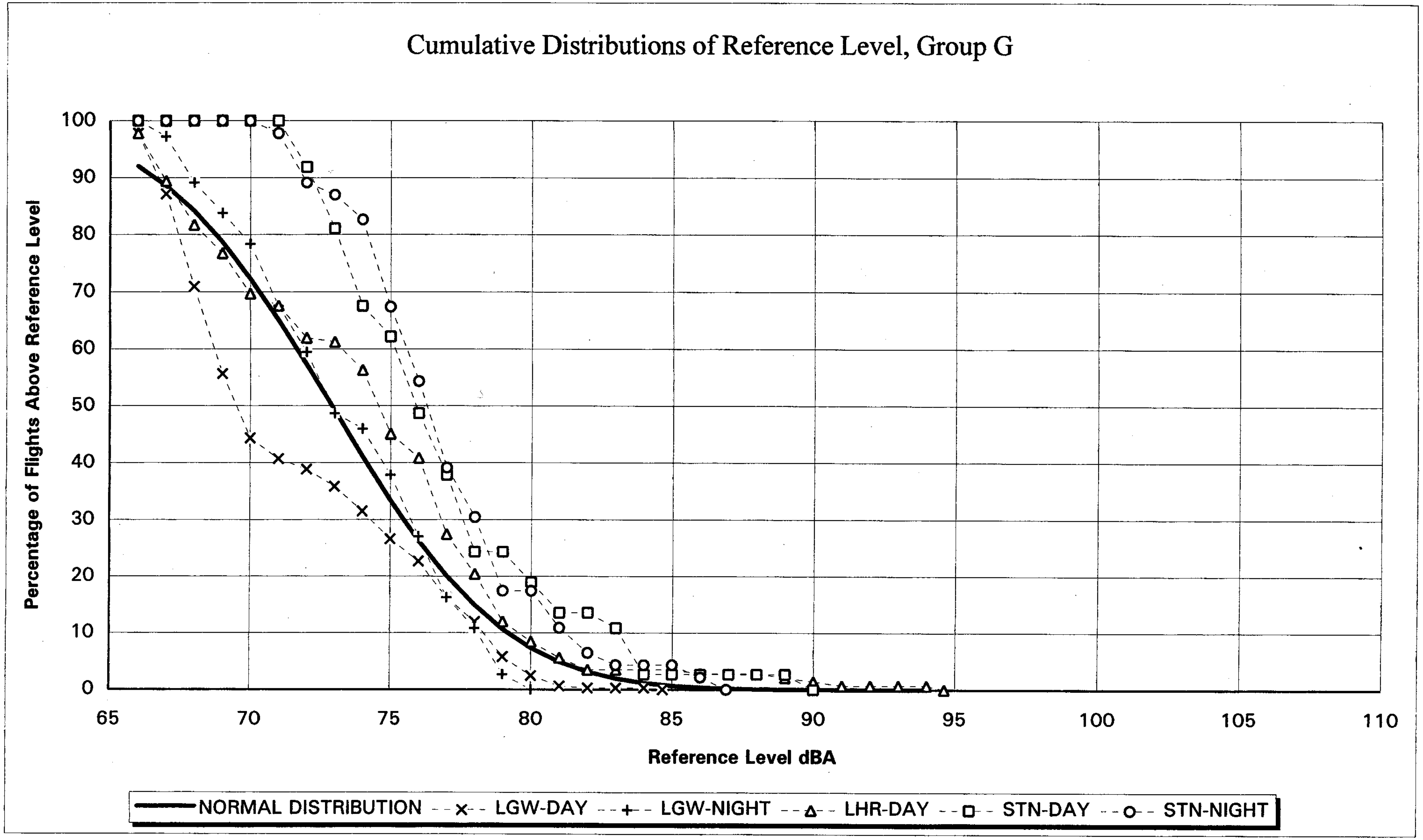
Cumulative Distributions of Reference Level, Group E
Percentage of Flights Above Reference Level
100
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
90
95
100
105
110
Reference Level dBA
NORMAL DISTRIBUTION
LGW-DAY
LGW-NIGHT
LHR-DAY
STN-DAY

FIGURE C6



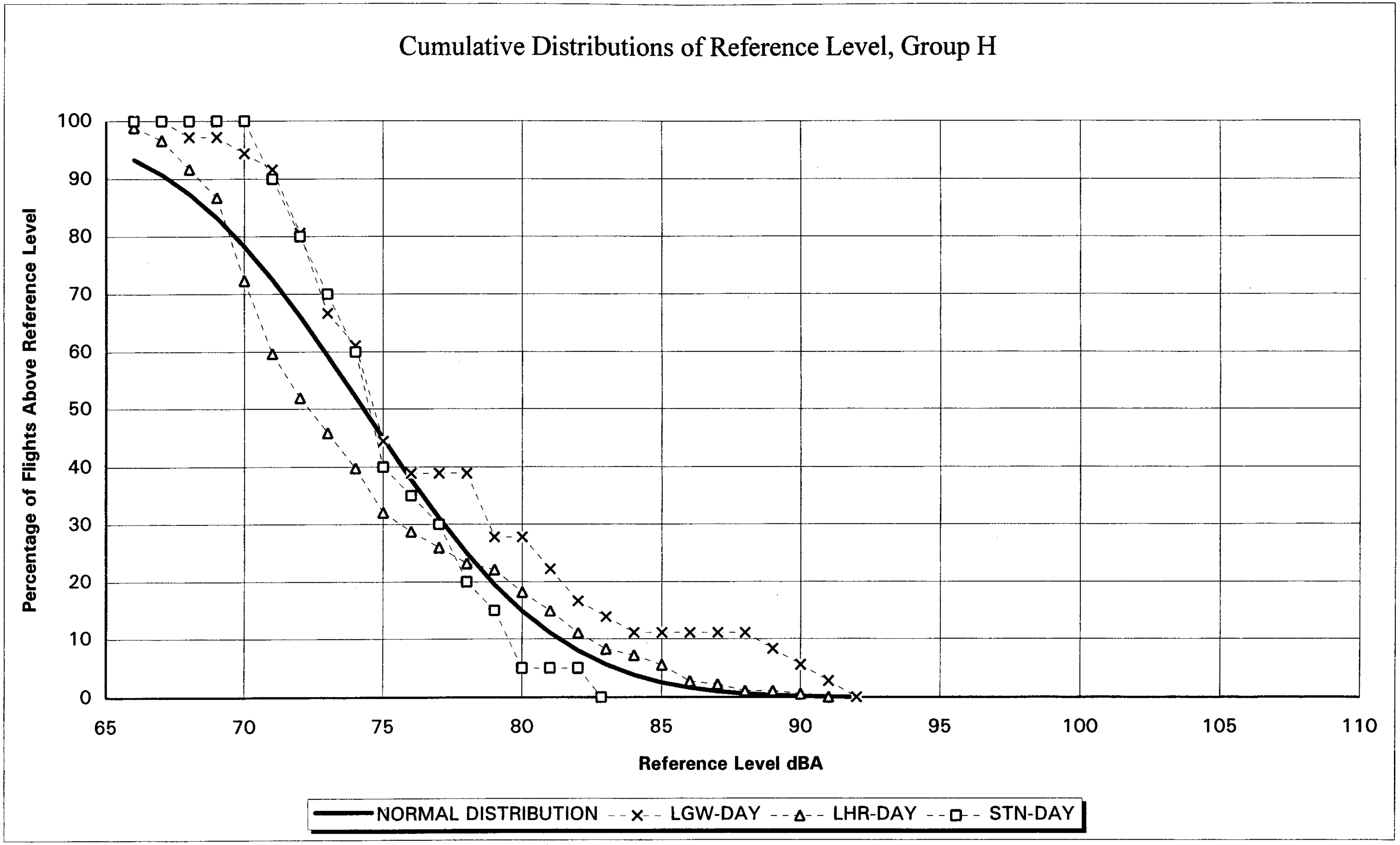
Cumulative Distributions of Reference Level, Group F
Percentage of Flights Above Reference Level
100
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
90
95
100
105
110
Reference Level dBA
NORMAL DISTRIBUTION
LGW-DAY
LGW-NIGHT
LHR-DAY
LHR-NIGHT
STN-DAY
STN-NIGHT

FIGURE C7



Cumulative Distributions of Reference Level, Group G
Percentage of Flights Above Reference Level
100
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
90
95
100
105
110
Reference Level dBA
NORMAL DISTRIBUTION
LGW-DAY
LGW-NIGHT
LHR-DAY
STN-DAY
STN-NIGHT

FIGURE C8


Cumulative Distributions of Reference Level, Group H
Percentage of Flights Above Reference Level
100
90
80
70
60
50
40
30
20
10
0
65
70
75
80
85
90
95
100
105
110
Reference Level dBA
NORMAL DISTRIBUTION
LGW-DAY
LHR-DAY
STN-DAY

APPENDIX D

MONITOR POSITIONS

Figures D1 to D6 show for each runway the positions of the current fixed monitors, the Reference Arcs and all the theoretical reference positions used in the analysis to determine optimum spacings.

LIST OF FIGURES

<u>Current Fixed Monitors and Reference Arcs:</u>

Figure D1	Heathrow 09R
Figure D2	Heathrow 27L/R
Figure D3	Gatwick 08R
Figure D4	Gatwick 26L
Figure D5	Stansted 05
Figure D6	Stansted 23

KEY TO FIGURES

———	Reference Arc
⦿	Reference Sites
⊠	Fixed Monitors

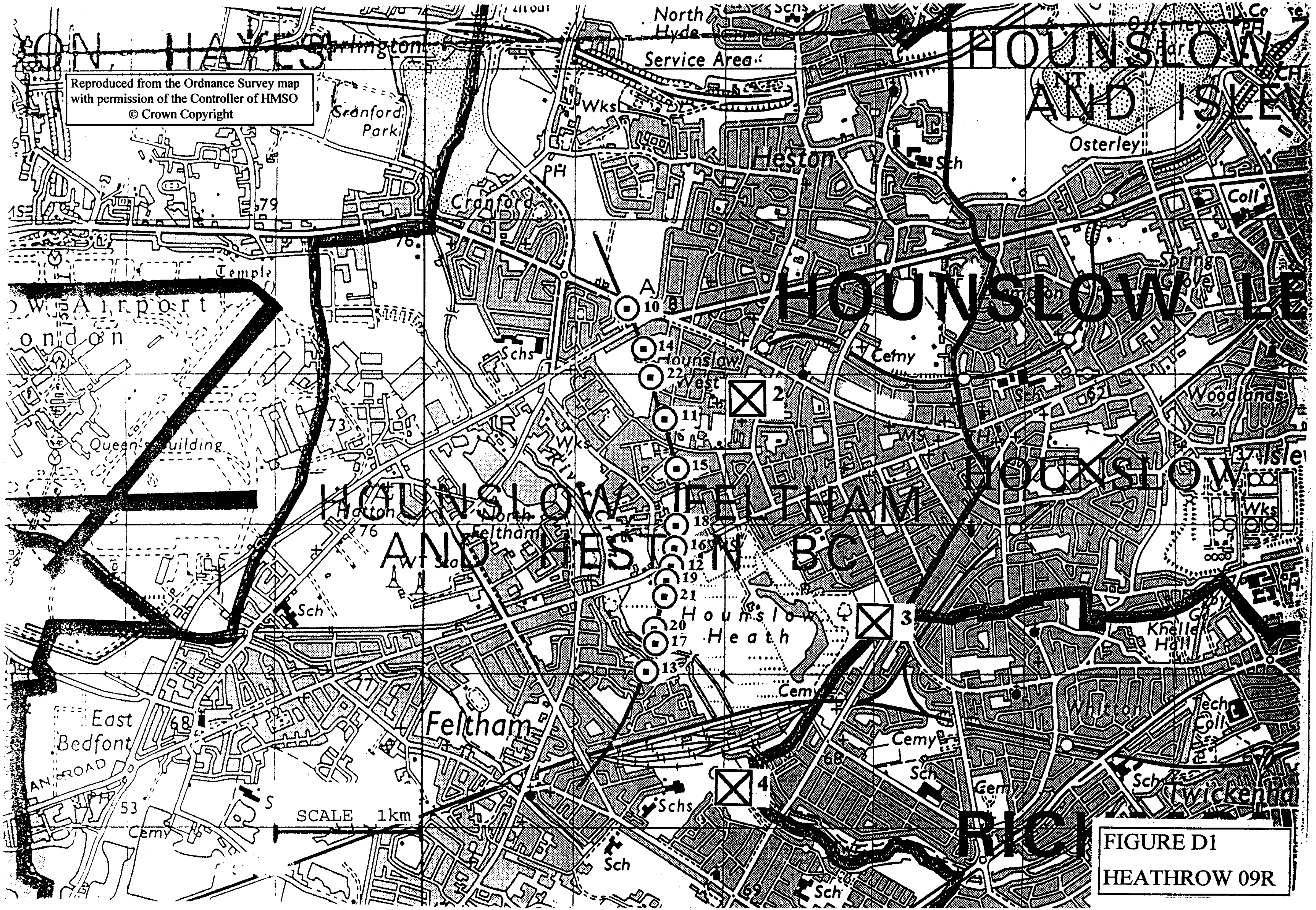


FIGURE D1
HEATHROW 09R

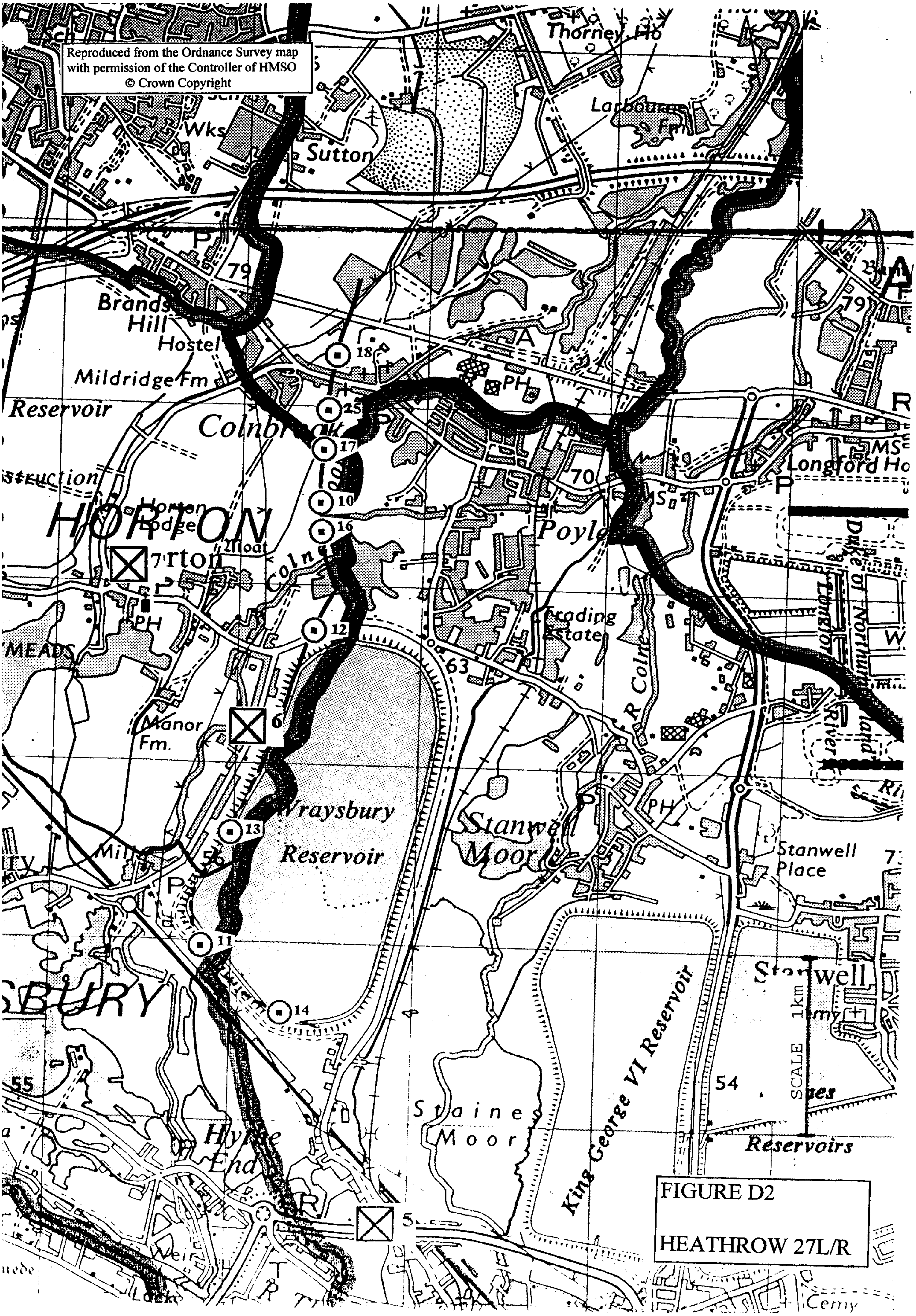


FIGURE D2

HEATHROW 27L/R

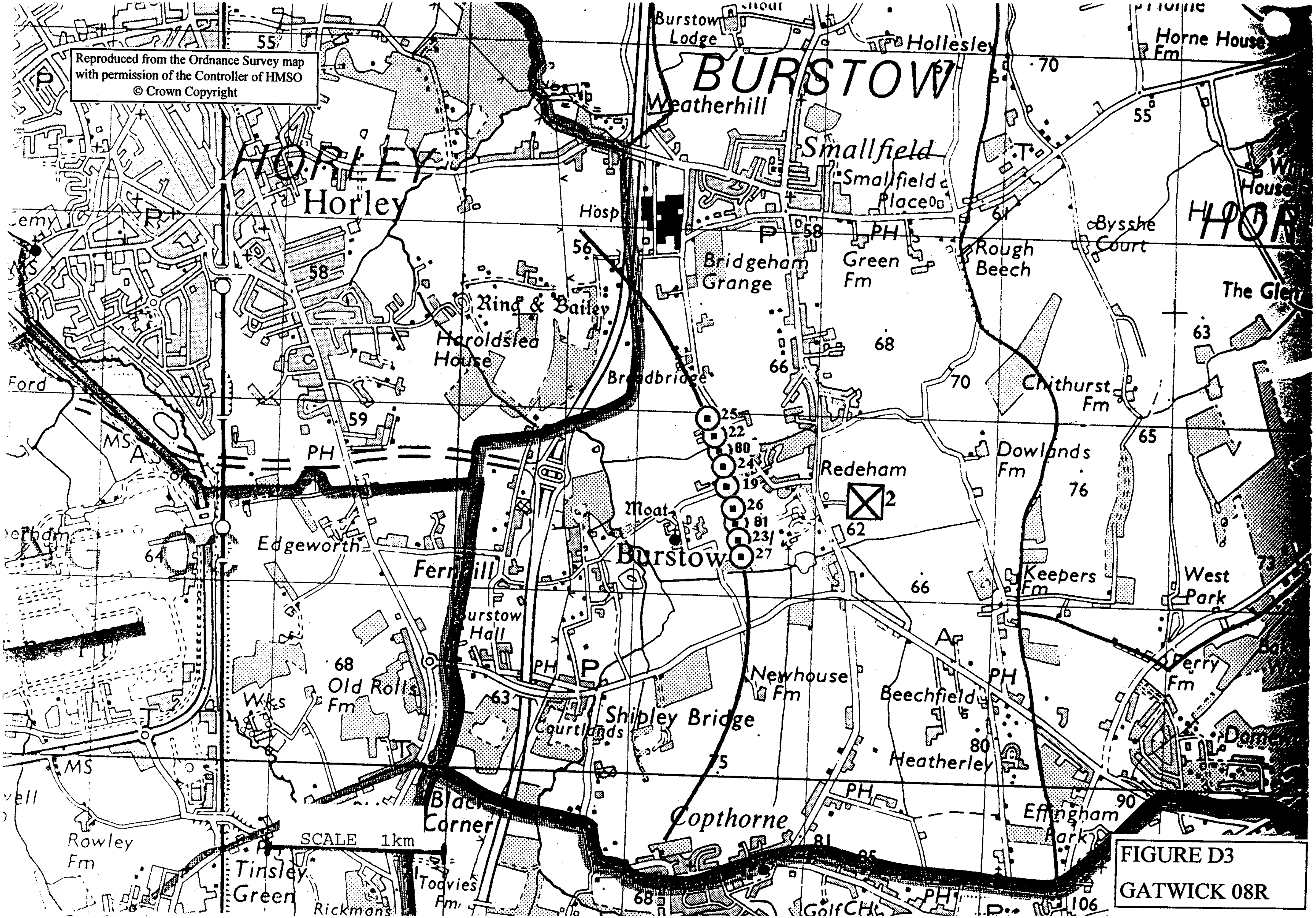


FIGURE D3
GATWICK 08R

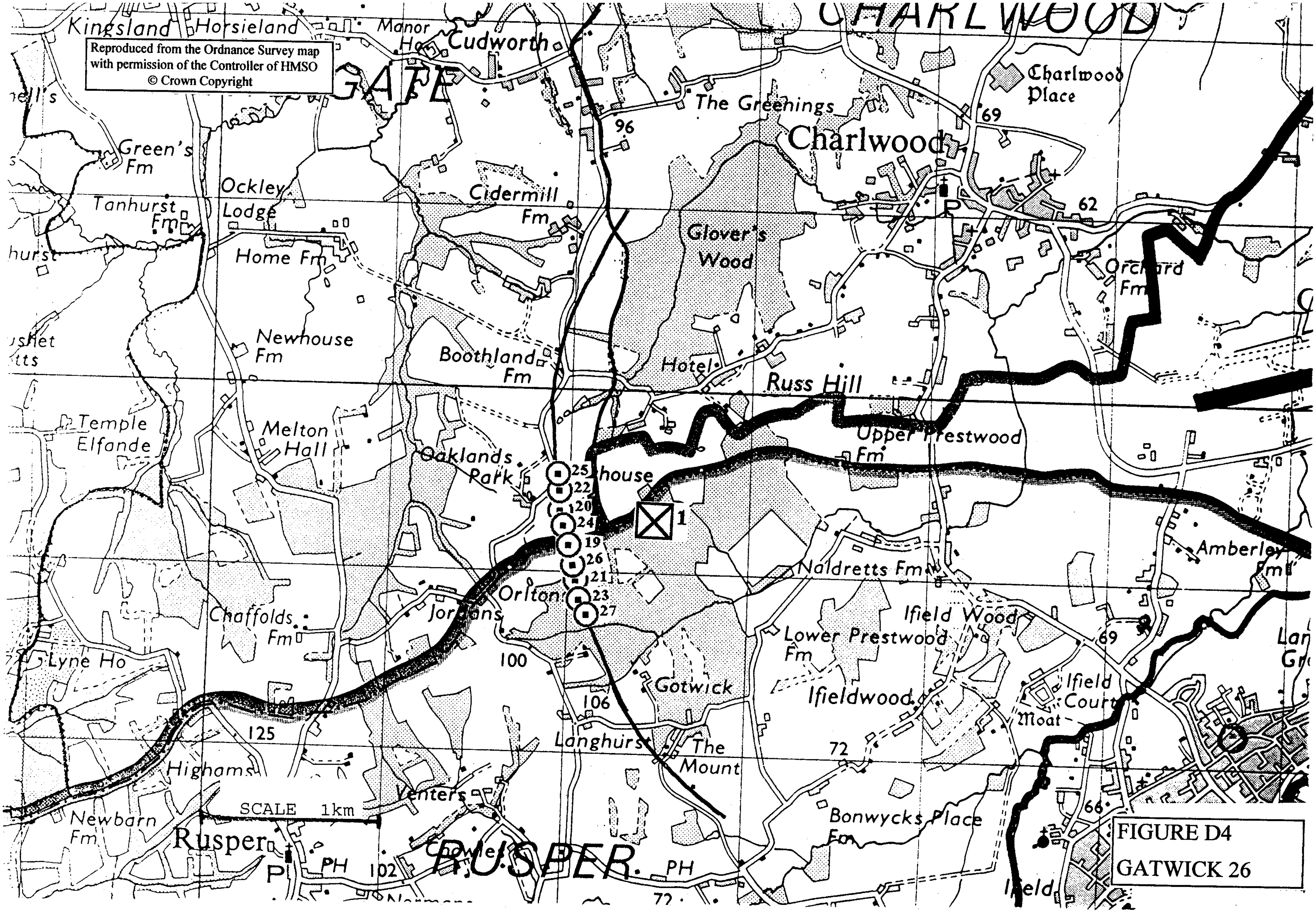


FIGURE D4
GATWICK 26

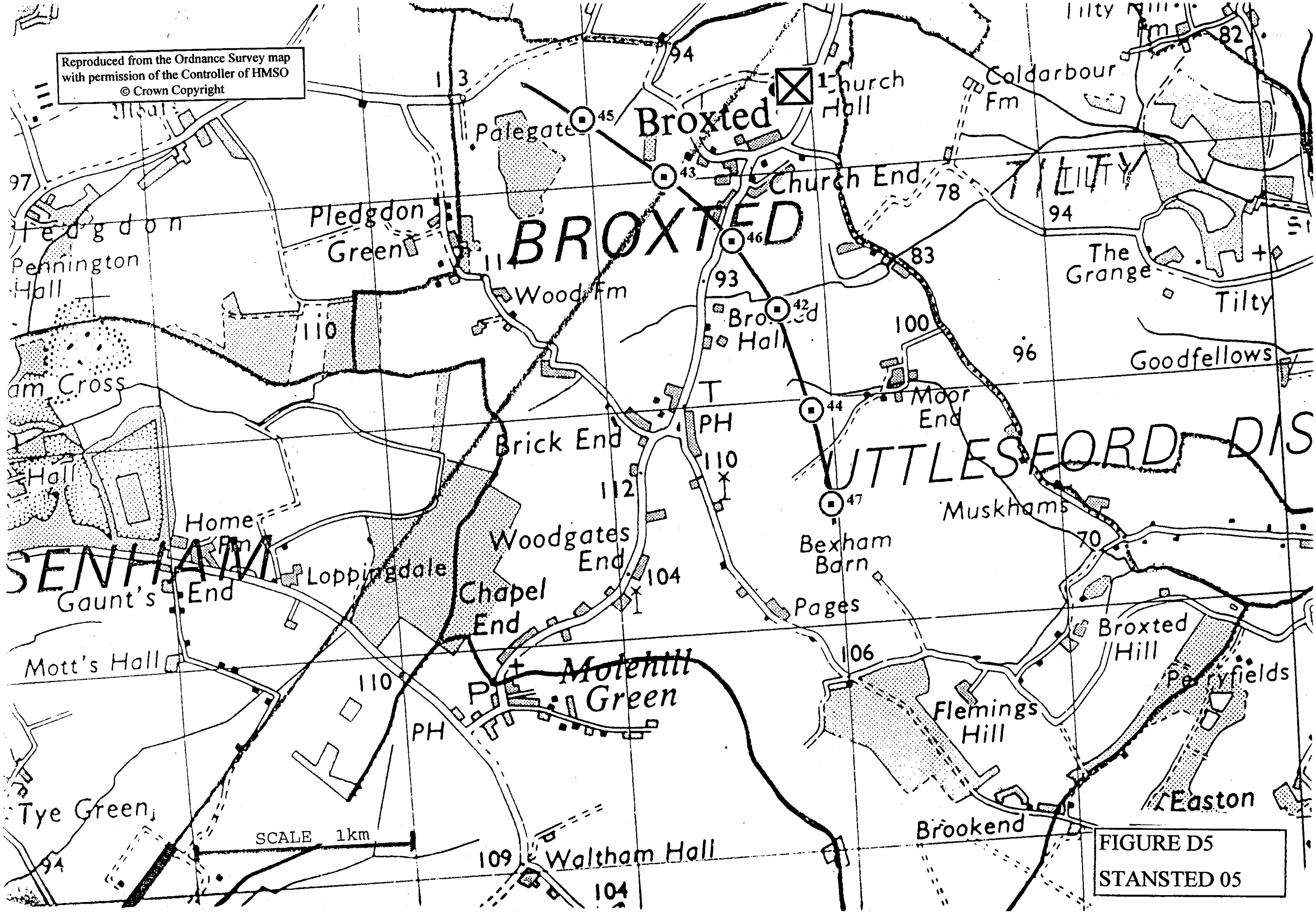


FIGURE D5
STANSTED 05

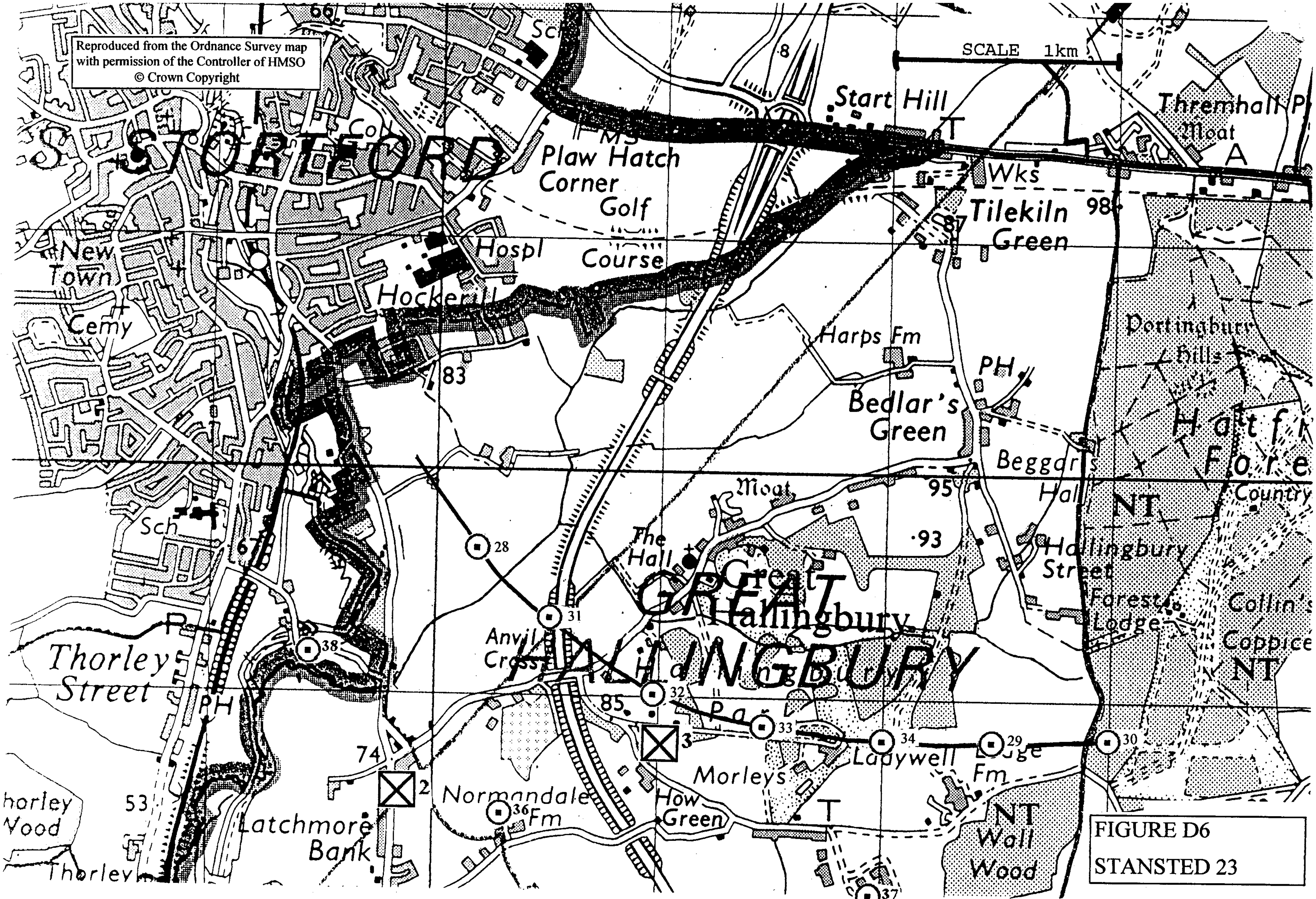


FIGURE D6
STANSTED 23