Environmental Research and Consultancy Department

CS REPORT 9539 Supplement

Review of the Departure Noise Limits at Heathrow, Gatwick and Stansted Airports: Additional Study of Boeing 747 Departures

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CS REPORT 9539 SUPPLEMENT

ERRATUM SHEET

The following errors have come to our attention since the publication of the above document:-

Page 11, paragraph 4.16: the computed step-function increments for the -100s and -200s should be reversed, i.e. the indent should read:-

-100 7.4dB
-200 3.2dB
(-400 0dB)

Appendix A Figures A1 and A2: the numbers on the 'Lmax' axes referred to the proposed new daytime limit, not the current limit. A replacement page is attached giving revised figures which show the axes labelled with the correct numbers relative to the current daytime limit. The "infringement" rates given in paragraphs A.15 and A.17 can be read from Figures A1 and A2 respectively on the '-3dB' vertical line, i.e. 3dB below the present daytime limit.

DORA
29th October 1996

FIGURE A1

Lmax DISTRIBUTIONS AT HEATHROW MONITOR 6: 6.6KM FROM START OF ROLL

B747 DEPARTURES FROM RUNWAY 27L THAT PASS WITHIN 300m TO SIDE OF MONITOR

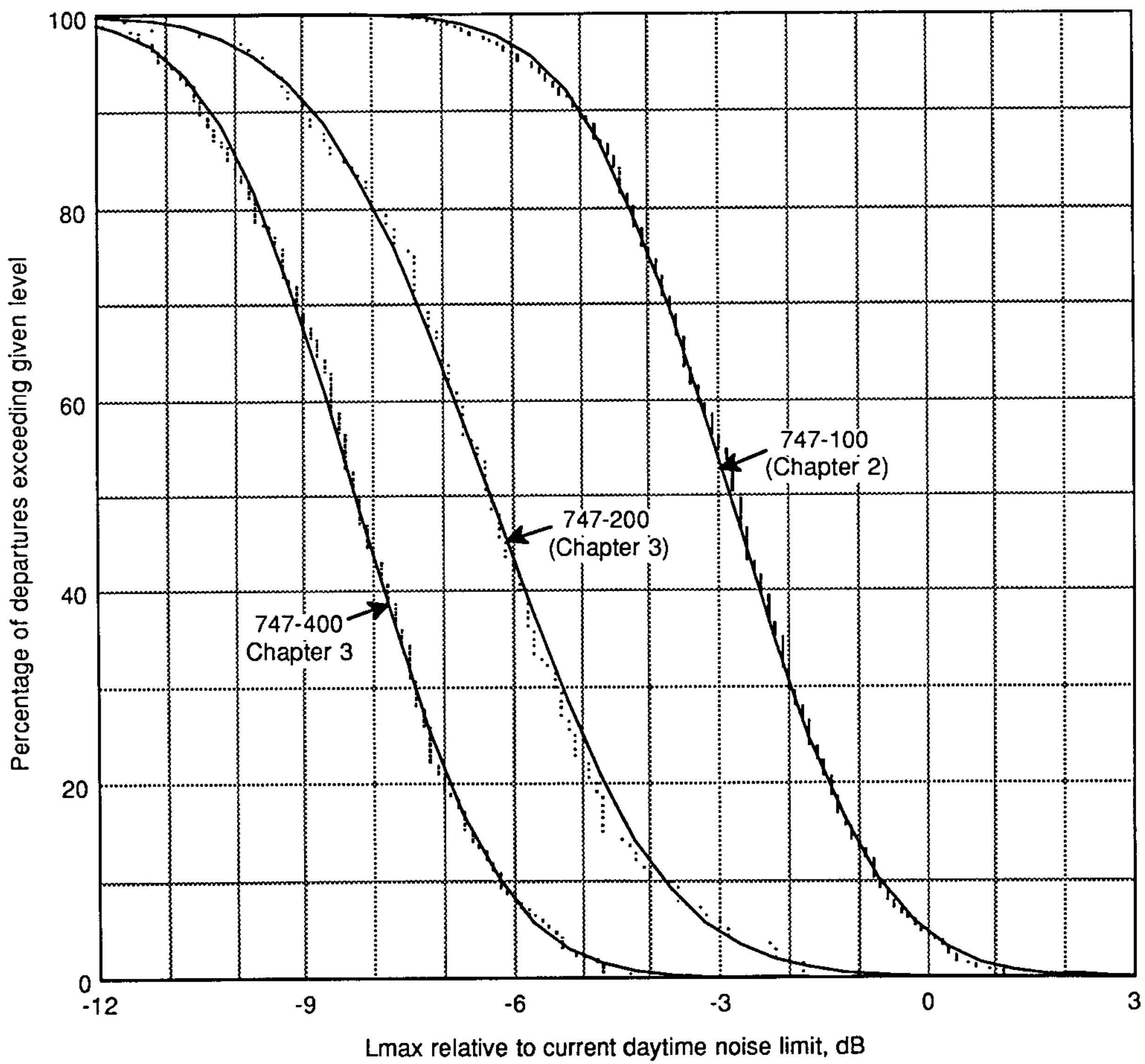
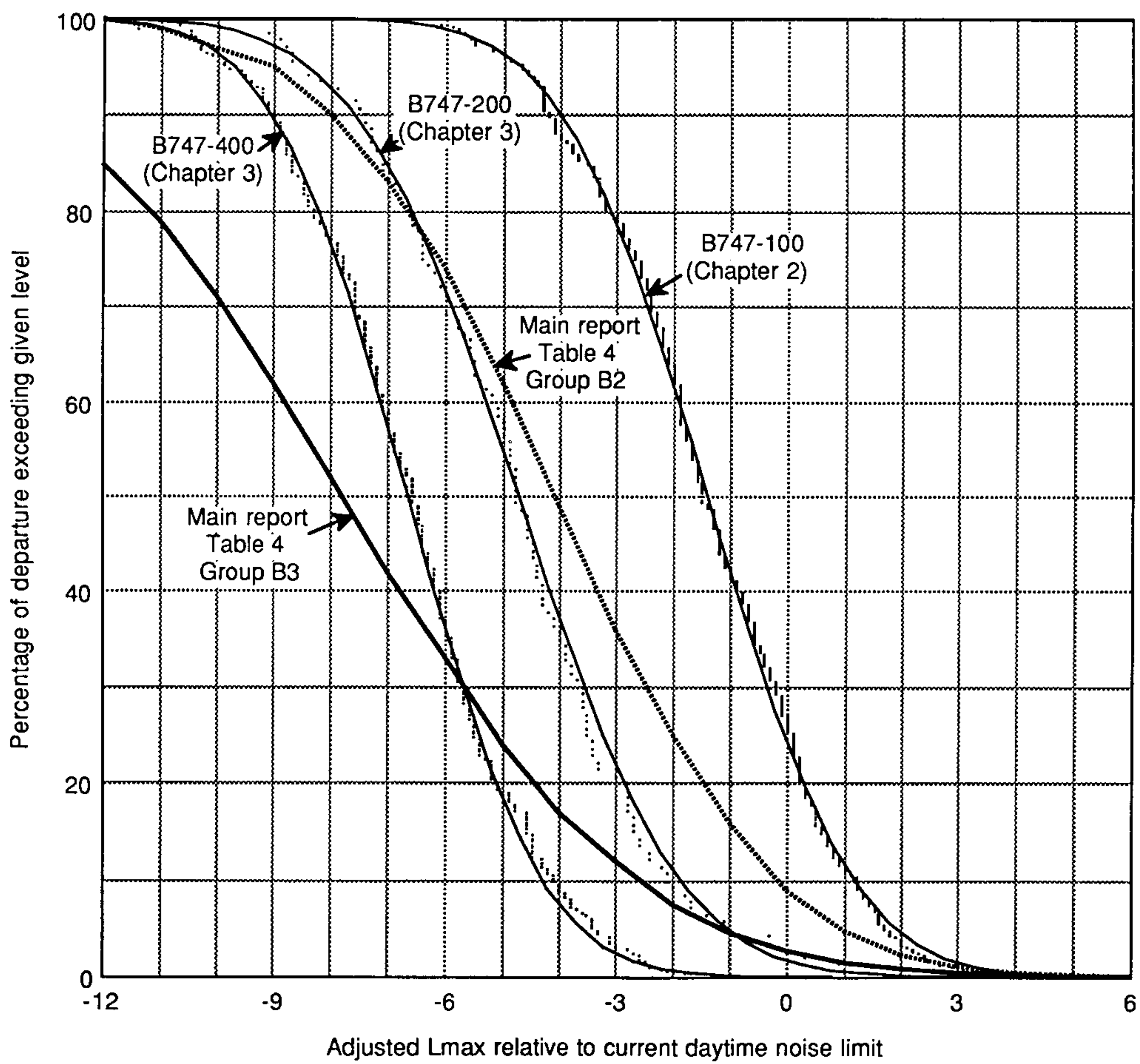


FIGURE A2

COMPARISON OF ADJUSTED NOISE LEVEL DISTRIBUTIONS WITH MAIN REPORT



Research and Development Directorate
National Air Traffic Services Ltd

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R E Cadoux
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SUMMARY

This supplement describes analyses of Boeing 747 take-off noise, performance and weight data, undertaken to assess particular points raised in responses to the consultation on the review of noise limits at Heathrow, Gatwick and Stansted airports. The main topics addressed are Boeing 747 climb performance, seasonal variations in aircraft heights and noise levels, and noise abatement procedures. The accuracy of the model which was used to estimate numbers of infringements is also considered, and estimates are given of infringement rates under the proposed new monitoring regime.

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Department of Operational Research & Analysis,
National Air Traffic Services Ltd, London, October 1996

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CONTENTS

GLOSSARY OF TERMS

(Additional terms not listed in the Glossary to the main report CS9539)

aal	Aircraft height above the airfield level (all heights are aal unless stated otherwise).
agl	Aircraft height above the local ground level.
HAL	Heathrow Airport Ltd (who are responsible for the operation of the NTK system at Heathrow Airport).
L_{max}	The maximum noise level of an aircraft noise event: experienced when a single aircraft passes by.
Minimum slant distance	The distance between a noise monitor and the closest point on an aircraft's flight track.
n	Number of samples.
Present noise limits	The prescribed daytime and night-time limits are 97 and 89dBA respectively (Ref 3).
SOR	Start-of-roll: the average position on a runway where aircraft commence their take-off runs.
TOW	Take-off weight (N.B. this has been used in preference to the more correct phraseology "take-off mass" as this expression remains in common usage). All "weights" are given in tonnes (1 tonne = 1,000kg).
Vw	Headwind speed: the component of the surface wind (i.e. wind at airfield ground level) in the direction 180° from the heading of the runway in use. The selection of the runway in use is decided on the basis of the surface headwind, although the wind speed, and its direction, change with altitude.

1. INTRODUCTION

1.1 The main report, CS Report 9539, described a technical study of the present noise monitoring arrangements at Heathrow, Gatwick and Stansted Airports performed to assist ANMAC in its review of the departure limits. The outcome of the ANMAC review was a proposal to lower the limits, by 3dB during the day and 2dB at night, and also to increase the number of monitors in order to increase the efficiency of the system, i.e. "monitoring efficiency", the percentage of offenders that are recorded as infringements at one or more of the monitors in the array. These proposals were the subject of a public consultation process (Ref 1).

1.2 This paper reports a limited supplementary study performed at the request of the Department of Transport to investigate some specific technical questions raised by the consultation. These were:

- Actual infringement rates have varied from month to month and have tended to be relatively low during April and May, the months during which the study data were collected in 1994. Is this the result of predictable seasonal effects, and did the study underestimate the true effects on infringements of lowering the noise limits for this or any other reason?

- Are some Boeing 747 aircraft, operating normally but at high take-off weights, unable to reach a height of 1000ft at a distance of 6.5km from start-of-roll, and are they consequently unable to cut back engine power in order to reduce noise beyond that point?

1.3 Many factors influence the noise level that a departing aircraft generates at a noise monitor, mainly through their effects upon its height above and displacement to the side of the monitor and its engine power setting at the time. Specific factors considered in this additional study include:-

(i) monitor position (i.e. its distance from start-of-roll),
(ii) aircraft trajectory,
(iii) aircraft take-off weight,
(iv) the operating procedure (especially the take-off thrust and the point and depth of cutback after the initial climb), and
(v) atmospheric conditions (especially air temperature and headwind).

1.4 The study described in the main report involved detailed analyses of noise and flight path data collected during April and May 1994 at all three airports. The main influences of factors (i) and (ii) above were taken into account by normalising each monitored level to a reference position, under the flight path, 6.5km from start-of-roll, and at airfield elevation. Only flights that passed 'over' a monitor, i.e. within ±30° of the vertical, were included, in order to eliminate lateral attenuation effects. The effects of factors (iii), (iv) and (v), explained below, were not analysed specifically; their effects were 'averaged out' as far as possible by analysing a large quantity of departure data. However, this data had to be collected in a limited time period; April/May conditions were taken as representative, being midway between winter and summer extremes.

Take-off weight

1.5 Other things being equal, the take-off climb gradient is decreased as the take-off weight *TO W*[1] is increased; thus more heavily loaded aircraft generate higher noise levels at the monitors because of lower height. It has been suggested that load factors can exhibit seasonal trends, e.g. arising from vacation traffic. This may be true for particular routes at particular times of the year but the question was raised whether these would result in any consistent trends in noise infringement rates.

Operating procedure

1.6 Detailed aircraft operating procedures can vary quite significantly between operators and for different conditions, partly to allow for weight and weather conditions but also to reduce engine wear, noise and in some cases fuel consumption and exhaust emissions. Important factors are the engine thrust and flap settings during take-off, initial climb and after power cutback, which together control the aircraft height and noise emission over the monitor. Two generalised noise abatement take-off procedures are recommended by ICAO in Ref 2 ("PANS-OPS"). Procedure A, in which thrust is cut back at 1500ft *aal,* is designed to reduce noise levels some distance from the airport (at the expense of higher noise closer in). Procedure B is balanced in the opposite way by initiating action at 1000ft.

1.7 It also has to be recognised that turns, again assuming unchanged thrust and flap settings, may cause a reduction of climb rate because of increased drag. Alternatively, to maintain the same climb gradient, thrust may be increased during a turn. Either way, depending on the rate of turn, noise on the ground below turning aircraft will tend to be somewhat higher than below non-turning aircraft at the same distance from start-of-roll.

Meteorological conditions

1.8 To some extent, ambient air conditions affect engine performance and both the generation and propagation of noise, but their principal influence in relation to noise infringements is upon aircraft climb gradient. In high temperatures, air density is less; this causes reduced wing lift at a given speed and flap setting, and consequently lower heights over the noise monitors. As specific climb

[1] Terms defined or explained in the Glossary are shown in italics where they are introduced.

gradient capabilities relate to still air, movement of the air - wind - changes gradients as measured relative to the ground. Thus aircraft climb at steeper angles into headwinds than into still air. Tailwinds of course have the opposite effect. A factor of importance at Heathrow is a declared preference for westerly operations. To minimise the number of departures over the more highly populated areas to the east of the airport, departures are made to the west whenever possible - always into headwinds but also in tailwind components of up to 5kt. It is also relevant if difficult to take into account, that wind speed and direction can vary markedly with height above the ground.

The supplementary study

1.9 The supplementary study concentrated on operations at Heathrow, because at present there are more B747 operations and more noise monitors there than at the other two London airports. Figure 1 shows the present fixed noise monitor positions at Heathrow (defined in Ref 3), and the locations used for mobile monitors in the original study (main report) which were used as the technical basis for the proposals in Ref 1.

1.10 There are many variants of the Boeing 747, the heaviest aircraft in common operation, and the one likely to be most affected by any changes to the departure noise limits. The particular versions considered were the B747-100, the earliest and lightest model, which is generally noise-certificated to ICAO Chapter 2 standards; the B747-200, a later, somewhat heavier and higher performance model certificated under either Chapter 2 or Chapter 3, and the B747-400 which has a higher maximum TOW than the earlier models, and is certificated under Chapter 3. The -400 is the current production standard of the B747 and is likely to remain in service for many more years than the earlier variants. Operations by other less common variants (such as -300, SP and SR, which are almost entirely Chapter 3) have not been considered in most of this supplementary study, except where ‘all B747’ data has been used or where B747s have been analysed by certification Chapter number. The older -100 and -200 versions are the most critical in terms of noise and climb performance.

1.11 A direct way of answering the questions in paragraph 1.2 would have been to repeat in full the analysis of the main report using NTK data collected at different times of year. Such extensive analysis was agreed by the DoT to be disproportionate to the need; instead a more limited sensitivity study of NTK-measured flight paths and noise data has been undertaken to assess the possible magnitude of seasonal variations. As very few B747s depart during the period when the night-time noise limit applies, 2300-0700 local (see main report paragraph 7.8), only daytime limits and departures have been analysed.

2. ACCURACY OF INFRINGEMENT MODELLING METHODOLOGY

2.1 The reliability of the methodology used in the main report to assess the performance of noise monitoring options can be assessed directly by testing it against actual infringement records and NTK data that have become available since the original study was completed. Although the NTK system was commissioned in 1993, its analytical capabilities were not then fully operational and, in 1994, a great deal of manual intervention was necessary to assemble and validate the original study data. Continuing development has since improved the system to the point where large quantities of reasonably reliable data are now collected and stored routinely.

2.2 An important initial check on the accuracy of the infringement model described in the main report is to compare expectations with actual experience. The table below summarises an analysis which compares (1) calculations based on information taken from the main report, where results were based on data acquired in April/May 1994, with actual average numbers of daytime infringements of the *present noise limits* recorded by Heathrow Airport Ltd *(HAL) (2)* annually, and (3) in the months of April and May. Most of these infringements were by B747s.

	Chapter 2	Chapter 3
(1) Estimation based on main report		
a) Average monthly B747 departures, 0700-2300 local (1995/6[1] actual figures from BAA):	535	1445
b) Percentage of departures expected to exceed effective base limit (from Table 4):	9%	2.7%
c) Average monitoring efficiency[2] (estimated from Table 8):	9.6%	5.6%
d) Infringement rate = (b) x (c):	0.86%	0.15%
Expected monthly infringements = (a) x (d):	4.6	2.2
- total:	6.8	
(2) Actual Annual average 1993-1996[3]:	8.4	
(3) Actual April /May average 1993-1996[3]:	5.3	

[1] July 1995 to June 1996 inclusive

[2] Based on a 50/50 runway split (1995/6 actual split was 48%E/52%W)

[3] A subdivision by Chapter was not available.

2.3 Thus the semi-empirical calculation method of the main study underestimates the actual annual average numbers and overestimates the April/May figures. However, given the simplistic nature of the prediction process and the fact that infringements have represented a very small proportion of total annual B747 departures (0.4%), the agreement is considered to be reasonable.

3. LIKELY INFRINGEMENTS OF NOISE LIMITS UNDER PROPOSED NEW MONITORING ARRANGEMENTS

3.1 Infringements of the departure noise limits in the future will of course depend not only upon the monitoring arrangements - the numbers and dispositions of noise monitors and the limits set at each monitor - but also upon the departure traffic, in terms of the types and variants of aircraft and the manner in which they are flown. For the limited purposes of this study, possible infringement rates were assessed by considering what the existing situation would be if the proposed new arrangements were already in place. The most recent data available before the completion of this study was for June 1996; the 12-month period from 1 July 1995 to 30 June 1996 was therefore selected for study.

3.2 Expected rates of infringement (numbers of infringements expressed as a percentage of numbers of departures) by B747s that would have occurred during 1995/6 under the new arrangements have been estimated in three ways:-

(a) from generalised information provided in the main report,
(b) by extrapolating noise level exceedance statistics calculated from the complete 1995/6 Heathrow NTK database, and
(c) by inference from more detailed analysis of a special subset of Heathrow NTK departure data.

Each of the methods has strengths and weaknesses and an overall judgement has to take account of all results.

3.3 The detailed analyses are presented in Appendix A. The results are summarised below:-

Estimation method	B747 variant	Chapter 2 models	Chapter 3 models
(a) Prediction based on Main report	All	21.5%	5.4%
(b) Extrapolation from 1995/6 rates	All	42%	4.6%
Extrapolation (b) plus detailed analysis (c)*	-100	50%	-
(b) Extrapolation from 1995/6 rates	-200	33%	-
Extrapolation (b) plus detailed analysis (c)*	-200	†	11%
Extrapolation (b) plus detailed analysis (c)*	-400	-	0.9%

* (c) = analyses of special data subset: see Appendix A.

† The special data subset included no Chapter 2 versions of the -200.

These indicate that for the Chapter 3 variants, which comprised over 70% of Heathrow B747 departures, 1995/6 infringement rates under the new arrangements would have been predicted quite closely by using information from the main report. Of the Chapter 3 infringements, the great majority would have been by -200s.

3.4 However this analysis suggests that infringements by Chapter 2 B747s would have occurred at nearly twice the rate predicted by the main report. Within this Chapter 2 group, the B747-100 was the worst offender with an estimated infringement rate of 50%. For the -200s it was 33%. Appendix A shows that this underestimation is partly explainable by the fact that 1995/6 data from NTK for Chapter 2 B747s included a higher proportion of -100 variants than the original April/May 1994 sample. However, the principal reason appears to be that the 1994 sample encompassed data from all three London airports, not just Heathrow. Table C4 of the main report indicates that the Chapter 3 B747-100s at Gatwick in the main study were significantly less noisy than the similarly certificated aircraft at Heathrow - Reference Mean Levels for these were 3.8dBA lower at Gatwick. The main study sample also included departures covering markedly wider ranges of climb rate and noise level, particularly among -200 operations. Whether this is due to a sampling deficiency or to differences or changes in operating conditions and procedures - between April/May and the rest of the year or between 1994 and 1995/6 - is not clear from the analysis in Appendix A, although it is possible that the faster-climbing B747s were relatively lightly loaded aircraft. Possible seasonal factors are considered in the following section.

4. ANALYSIS OF FACTORS CONTRIBUTING TO INFRINGEMENTS

Seasonal Effects

4.1 The methodology used in the main study to calculate expected infringement rates was based on data collected in April/May 1994. The breakdown of the 1995/6 B747 "infringement" rates by quarter was:

		% exceeding limits at any existing monitor			
Quarter	B747 Departures	Present limit Ch. 2	Present limit Ch. 3	Present limit - 3dB Ch. 2	Present limit - 3dB Ch. 3
Jul-Sep 1995 - Q3	5,459	2.36	0.21	18.64	1.34
Oct-Dec 1995 - Q4	4,785	1.79	0.14	9.56	0.89
Jan-Mar 1996 - Q 1	5,288	1.41	0.079	8.08	0.87
Apr-Jun 1996 - Q2	5,794	0.80	0.024	10.58	0.34
1995/6	21,326	1.59	0.11	11.95	0.84

This confirms that there is some seasonal variation in "infringement" rates and that the 1995-Q3 figures are particularly high.

4.2 Figure 2, which gives a graphical breakdown of the actual numbers of daytime infringements recorded by HAL during 1993-6, shows marked variations from month to month. Infringements were mostly by variants of the Boeing 747 (in 1995, 96% of the total). In addition to the effects of factors identified in paragraphs 1.3 to 1.8, the numbers of infringements vary because of different east-west splits and runway usage, which, under the existing arrangements, are relevant because of the differing monitor distances applicable to each runway. (Under the new arrangements, the adjustments that will be applied to the limits to correct for different monitor distances will eliminate such variations.) The unusually high peak in July 1995 was principally due to maintenance work on Runway 27R, which meant that Runway 27L (which gives higher noise levels at Monitor 6, the most critical monitor for westerly departures) was used for nearly all departures in this direction.

4.3 Figure 3 averages the monthly results given in Figure 2 (the unrepresentative July 1995 figure being excluded). This illustrates that average infringement rates during April and May have been relatively low (only December's average is lower). The highest numbers (July, September, October) are around 14 per month. The annual average is about 9 per month, i.e. 50% higher than during April/May. The remainder of this supplement considers the possible causes of this seasonal variation, focussing on the factors identified in Section 1.

Boeing performance calculations

4.4 Boeing provided DORA with performance calculations for the B747-400, and the computed flight profiles have been analysed to determine predicted effects of TOW, air temperature, and headwind on climb performance. Figure 4 illustrates two climb profiles calculated by Boeing for take-offs of the B747-400 with RB211-524G engines at 100% and 91.4% of maximum TOW (398 and 364 tonnes respectively) assuming an air temperature of 25°C, zero headwind and the same thrust levels. In each case, reduced engine thrust is selected at 1000ft - note that the gradient does not reduce instantly as it takes some time for the engines to 'spin down'. Between the two weights the difference in heights at 6.5km from start-of-roll is more than 250ft.

4.5 Figure 5 shows (for the same aircraft type) the variation with TOW of height at 6.5km (25°C, zero wind, constant take-off thrust), assuming cutback at 1000ft. From these heights, which change with TOW at approximately -7ft/tonne, the approximate mean noise level for each weight has been estimated - these are included in Figure 5 to illustrate the predicted effect of TOW variations on noise level. The similarly calculated effects of headwind and air temperature on climb profiles may be seen in Figures 6 and 7 (these both apply to the B747-400 with PW4056 engines, as this was the only version for which profiles for which different headwind and temperature conditions were provided. Climb profiles in tailwinds were not provided.). The height changes shown in those figures have been converted to noise level differences using the standard relationship in Appendix A paragraph A.16, i.e. 8dB per doubling of distance. The independent effects of these profile changes on noise levels, Lmax, at the 6.5km point are estimated to be, approximately:-

TOW	~ +0.08dB per tonne
Headwind	~ -0.1dB per kt
Air temperature	~ +0.04dB per °C

4.6 Similar calculations for the B747-200 or -100 were not supplied, but it is understood from Boeing that the climb performance of these variants could be more susceptible to temperature changes than the B747-400.

NTK height data

4.7 The Boeing performance estimates above are, of course, based upon particular operating procedures and specified atmospheric conditions. To assess the magnitude of actual operational variations in aircraft height through the year, at a distance representative of a typical noise monitoring position, NTK was used to identify the positions of B747-400 aircraft departing from Heathrow Runway

27L on the Compton (CPT), Southampton (SAM) and Midhurst (MID) departure routeings, at their closest points to Monitor 6 (see Figure 1). This monitor is at a distance of approximately 6.6km from start-of-roll and therefore in the position most comparable to the proposed new monitor arrays. Figure 8 shows typical 27L departure tracks, together with the positions of the monitor and the analysis 'gate', the vertical surface in which the heights and lateral displacements were determined.

4.8 Figure 9 shows the monthly average heights at Monitor 6 for B747 departures between April 1995 and March 1996[2]. April 1995 and July 1995 are the months with the highest and lowest average heights. For these two months, the corresponding distribution of heights and lateral displacement from the centre of the gate are shown in Figures 10 and 11.

4.9 Corresponding results for B747-100s and -200s combined are given in Figure 12 which shows the monthly average heights[3] at Monitor 6, and Figure 13 which shows the distribution of heights in the month with the lowest average height, July 1995. Climb performance generally appears worse than for the heavier B747-400 (Figure 10) - the B747-100/200 departures were on average about 100ft lower at Monitor 6 than the -400. (Differences between the annual average heights for the -400 and for the - 100/-200 versions are statistically significant at the 5% level.)

4.10 The long-standing instructions to pilots departing from Heathrow, Gatwick and Stansted Airports (Ref 3) state that an "aircraft shall be operated in such a way that it is at a height of not less than 1000ft *agl* when it is at the point nearest to the [relevant] noise monitoring terminal". Boeing stated in their response to the consultation that "many 747 configurations would not reach a height of 1000ft agl ... until after passing ... 6.5km". The measured data (Figures 10 and 13) indicate that in practice this can happen in the worst summer months - according to NTK 18% of B747-100/-200s and 2% of B747-400s were below 1000ft aal[4] at Monitor 6 in July 1995 - although it should be noted that average heights at this distance are in the range 1200ft to 1400ft for the B747-100/-200, and about 100ft higher for the -400.

4.11 For the B747-400, the range of NTK-measured average monthly heights at Monitor 6 (1250 to 1500ft - see Figure 9) is consistent with the heights given by Boeing for the RB211-524G and PW4056 engined versions of the B747-400 at a TOW of 364 tonnes at 25°C and 5 kt headwind (see for example the heights at 6.6km in Figure 6). However, in an attempt to understand the height

[2] Sample sizes ranged between 30 and 191 flights per month.

[3] Sample sizes ranged between 37 and 264 flights per month.

[4] The ground elevation at Heathrow Monitor 6 is about 40ft below airfield level (i.e. aal = agl - 40ft).

variations apparent in Figures 9 to 13, and the effect of these variations on noise levels, a special sample of 930 B747 departures from Heathrow Runway 27L (see Appendix A paragraphs A.12 to A.14) has been analysed in more detail.

Multivariate analysis

4.12 The data analysed included radar flight paths, L_{max} at Monitor 6, TOWs, surface wind speed and direction, and air temperature. In order to avoid complications introduced by the effects of lateral attenuation, the sample was restricted to departures that passed less than 300m to the side of the monitor (see Appendix A paragraph A.14).

4.13 TOWs were determined by matching operators' data to NTK records by date and destination. Figure 14 shows noise level L_{max}, plotted against TOW for each of the three different models of the B747 included in this analysis: the -100 (Chapter 2 versions only), -200 (Chapter 3 versions only) and -400 (all Chapter 3). Linear regression lines show mean trends of the relationships between L_{max} and TOW; these have slopes of:-

-100: 0.078 dB/tonne
-200: 0.070 dB/tonne
-400: 0.044 dB/tonne.

These suggest that TOW may be more critical in its effect on noise level for the -100s and -200s than for the -400.

4.14 Although the figures for the -100 and -200 are close to the result derived from the Boeing data of 0.08 dB/tonne (paragraph 4.5), the Boeing calculations relate to the -400 for which the agreement is poor. However, the scatter of the data about the trend lines is high. This may be attributed to the effects of variable weather conditions, operating procedures and lateral deviations from the monitor. In order to make a more valid comparison with the Boeing performance estimates, such effects have to be taken into account. This has been done in two ways using linear multiple regression 'prediction models'.

4.15 In the first regression analysis, lateral deviations have been accommodated simply by making the dependent variable the noise level that would have been recorded had the monitor been directly beneath the aircraft, i.e. the level beneath the aircraft at airfield height and monitor distance from start-of-roll. The distributions of these adjusted levels, and the way in which they have been derived, is explained in Appendix A.

4.16 The independent variables were TOW (tonnes), headwind Vw (kt) and air temperature, T (°C). The regression coefficients were calculated separately for each B747 model. Also, in order to calculate an overall relationship, data for the three B747 models were merged by including 'step-function' terms to account for mean differences between the noise levels of the three types (relative to that of the -400). The computed step-function increments were as follows:-

-100	3.2dB
-200	7.4dB
(-400	0dB)

That is, compared with those of the Chapter 3 B747-400s, operational noise levels (close to the monitor at 6.6km from start-of-roll) of the Chapter 2 B747-100s and Chapter 3 B747-200s were found to be, on average, 7.4dB and 3.2dB greater respectively.

4.17 The regression coefficients, which statistically were all highly significant, are compared below with the estimates derived from the Boeing data (the standard error indicates how much of the data scatter - expressed as its standard deviation - remains unexplained by the regression model).

B747 version:	-100	-200	-400	All	*-400 (Boeing)*
TOW (dB/tonne):	0.075	0.083	0.052	0.061	*0.08*
Vw (dB/kt):	-0.201	-0.156	-0.151	-0.175	*-0.1*
T (dB/°C):	0.071	0.025	0.025	0.057	*0.04*
Standard error:	1.66	1.62	1.20	1.37	

The regression coefficients reflect the mean effects of weight, headwind and air temperature on monitored noise levels at Heathrow; the “Boeing” figures are based on design performance calculations for a particular B747-400 model (see paragraphs 4.4 and 4.5).

4.18 For the -400, the effect of TOW and temperature on operational noise levels appears less than the Boeing estimate, the effect of headwind greater. But differences between the aircraft variants are apparent. Weight effects for the -100 and -200 models were rather closer to the Boeing -400 estimate. Headwind and temperature effects were greatest for the -100.

4.19 The second method used to account for variations in lateral dispersion was not to adjust the dependent variable L_{max}, but to include slant distance (or rather its logarithm - to the base 10) among the independent variables. The coefficients given by this second regression are:-

B747 version:	-100	-200	-400	All	*-400 (Boeing)*
TOW (dB/tonne):	0.058	0.057	0.037	0.044	0.08
Vw (dB/kt):	-0.068	-0.064	-0.045	-0.056	-0.1
T (dB/°C):	0.044	0.009*	0.003*	0.030	*0.04*
Coefficient of log of slant distance:	-10.6	-10.5	-10.5	-10.6	
Standard error:	1.28	1.38	1.01	1.23	

*Not statistically significant

4.20 This second approach clearly produces rather different results from the first, given in paragraph 4.17 above. It is very significant that the regression coefficients of the slant distance terms are substantially less than the 26.6 (corresponding to 8dB per doubling of distance) normally adopted in DORA studies of this kind (see Appendix A paragraph A.16). The effect of allowing the attenuation rate to 'float freely' in this way has been to reduce the apparent dependency of L_{max} on all three factors, TOW, Vw and T. Also, the predictions are 'better' in the sense that more of the variance has been explained (the standard errors are smaller). The relationship between predicted and measured L_{max} for the merged data set is illustrated in Figure 15.

4.21 This apparent disparity between the two analyses can be explained in terms of aircraft operating procedures. The fact that, on average, sound level was observed to fall more slowly with distance than expected indicates that, after allowance has been made for TOW and weather effects, the more distant aircraft were emitting more noise than the nearer ones. Among the flights included, i.e. those within ±300m to the side of the monitor, 'more distant' generally means higher and more noise emission means higher thrust settings. This is likely to be an effect of 'thrust derate' - the practice of reducing take-off thrust at lower take-off weights in order to reduce stress and wear on the engines - which results in longer ground roll distances and lower climb rates.

4.22 To relate the magnitude of this apparent slant distance effect to an equivalent change of thrust setting requires information about the thrust/noise relationships for the B747 engines. The information most readily available was the INM[5] database (Ref 4) which provides 'NPD' curves (noise-power-distance) for various models. At high thrust levels the slopes of these curves are typically 0.2dB for each % thrust change. As most minimum slant distances in this sample lay within a range covering a ratio of about 1.7 (i.e. of the longest to shortest), the fact that the average 'fitted' attenuation coefficient

[5] The Integrated Noise Model (INM) is the US Federal Aviation Administration's official noise model. The noise and performance data contained in its database is derived from manufacturers' data.

was 10.6 instead of 26.6, i.e. around 16 less, suggests that lower aircraft were typically generating 16 log (1.7) = 3.7dB less noise than higher aircraft. Based on the INM NPD slope of 0.2dB for each percent change of thrust, this equates to the lower aircraft operating with around 18% lower thrust than the higher ones - again after allowing for separate effects of variations in TOW and weather.

4.23 It is concluded that the second multiple regression showed less dependency of noise upon weight, headwind and air temperature than the first because of the statistically confounding effects of compensating adjustments made to engine thrust settings. The dependencies obtained from the first analysis describe the gross effects of operational factors - weight, headwind and temperature - on monitored noise. They take implicit account of the effects of thrust changes made to compensate for those same operational factors. The results of the second analysis indicate the net effects of weight headwind and temperature, that is after making allowance for operational thrust adjustments.

4.24 A question beyond the scope of this study, and which could not be addressed without more information (on actual thrust settings and the height and degree of thrust cutback after initial climb), is to what extent the trade-off between noise emission and height affects noise at the monitor position. What can be stated is that if thrust were not reduced, the aircraft would initially climb more rapidly, although generating additional noise nearer to the airport. If thrust can then be reduced before the monitor is reached, less noise will be recorded at the monitor. Of course the implementation of such noise reduction 'cutbacks' involves safety considerations of paramount importance, but higher take-off thrust would lead to lower flyover noise at the monitors, even if cutback thrust is no lower than current derate levels. Less critical than safety, but of considerable concern to the operators, is that use of higher take-off thrust affects engine maintenance requirements, fuel bum and engine emissions.

4.25 To summarise, the net effects on B747 departure noise levels of take-off weight (TOW), headwind (Vw) and air temperature (T) under operational conditions are estimated to be, on average:-

B747 version:	-100	-200	-400	All	*-400 (Boeing)*
TOW (dB/tonne):	0.058	0.057	0.037	0.044	*0.08*
Vw (dB/kt):	-0.068	-0.064	-0.045	-0.056	*-0.1*
T (dB/°C):	0.044	0.009	0.003	0.030	*0.04*

4.26 Effectively, these describe the magnitude of the effects if thrust were held constant. The average gross effects, including those of compensatory engine thrust adjustments made in practice, are estimated to be:-

B747 version:	-100	-200	-400	All	*-400 (Boeing)*
TOW (dB/tonne):	0.075	0.083	0.052	0.061	0.08
Vw (dB/kt):	-0.201	-0.156	-0.151	-0.175	-0.1
T (dB/°C):	0.071	0.025	0.025	0.057	*0.04*

In both tables, the "Boeing" figures are based on the manufacturer's performance calculations for a particular model of B747-400 operating at constant take-off thrust. It is evident from a comparison of the net and gross results that thrust derate effectively increases the susceptibility of noise to all effects.

4.27 These are statistical results derived from available NTK data and therefore subject to a degree of uncertainty. However, the net effects of TOW and headwind (essentially having removed the effects of thrust variation) are rather smaller than indicated by the Boeing performance estimates and no significant effect of temperature was observed. However, the gross effects of TOW, headwind and temperature (i.e. disregarding the confounding influence of thrust variation) are rather closer, especially those of wind and temperature. The older B747 versions, the -200 and particularly the -100 models appear more susceptible to both weight and weather effects, as indicated by Boeing. In the following section, the larger gross effects are used to estimate the possible magnitude of consequent seasonal variations; i.e. assuming that thrust derate is used consistently.

5. EXPECTED EFFECTS OF SEASONAL FACTORS ON INFRINGEMENT RATES

5.1 It is evident that infringements will be most probable under combinations of high weight, high temperature, low headwinds (or high tailwinds), overflight of a monitor and operating procedures that are not optimised for low noise. In order to assess the effects of seasonal variations of those factors, available data have been aggregated by quarters of the year (see paragraph 4.1). As available NTK data samples are unevenly distributed between the quarters, and different data sources covered slightly different periods, the representativeness of the quarterly statistics may vary slightly in the following analysis.

Take-off weights

5.2 Figures 16 to 18 shows the distributions of operational B747 take off weights for a large sample of Heathrow departures during the period June 1995 to May 1996. For the B747-400 (Figure 16), TOW percentiles varied between quarters by over 10 tonnes in mid range and by 5-10 tonnes between the 10th and 20th percentiles; with 2nd quarter weights being lowest and 3rd quarter highest. In each quarter, including April-June, more than 5% are at maximum TOW. With present operating procedures, an annual infringement rate of around 1% might be expected for -400s under the proposed new monitoring arrangements (Appendix A paragraph A.18). Assuming that heavier departures include those most likely to infringe the noise limits, TOW itself is thus unlikely to cause the highest summer levels (Q3) to exceed highest spring levels (Q2) to any marked degree. Relative to Q2, the margin at 10th percentile attributable to TOW variation can be estimated as (reading approximate TOW differences from Figure 16):-

Change of noise level with TOW x change of weight = Increase in noise level

Q1:	up to 0.052 dB/tonne x up to 1 tonne	= up to ~ 0.05dB
Q3:	up to 0.052 dB/tonne x up to 5 tonnes	= up to ~ 0.25dB
Q4:	up to 0.052 dB/tonne x up to 3 tonnes	= up to ~ 0.15dB

5.3 For the B747-200 (Figure 17), the quarterly distributions overlap; over about 80% of the range, 2nd quarter weights were intermediate. Between the 15th and 30th percentile, 2nd quarter weights are lowest, the highest (Q1) being 5-8 tonnes greater than in Q2. The Q4 increment was smaller; about 3 tonnes. In the highest 10% of the range, Q2 weights were again intermediate, Q1 weights were higher by 0-5 tonnes whilst Q3 and Q4 weights were lower. Thus, for B747-200 departures, weight-related noise changes in the 10-30th percentile range (where mean infringement rates might be expected) would be, relative to Q2 (reading approximate TOW differences from Figure 17):-

Q1:	up to 0.083 dB/tonne x up to 8 tonnes	= up to ~ 0.66dB
Q3:		Nil
Q4:	up to 0.083 dB/tonne x up to 5 tonnes	= up to ~ 0.4dB

5.4 Finally, for the B747- 100 (Figure 18), TOW distributions are very similar for quarters 1, 3 and 4 especially at the highest percentiles. During the summer, Q3, weights are higher, by about 5 tonnes at mid range, 1 or 2 tonnes at highest levels. Thus weight related noise increases in the 40-50th percentile range may be expected to be, relative to Q2 (reading approximate TOW differences from Figure 18):-

Q1:		Nil
Q3:	up to 0.075 dB/tonne x up to 6 tonnes	= up to ~ 0.48dB
Q4:	up to 0.075 dB/tonne x up to 2 tonnes	= up to ~ 0.15dB

Headwinds and tailwinds

5.5 Figure 19 shows quarterly distributions of NTK-measured surface headwind speed for 13,771 B747 departures in the period April 1995 to March 1996. Figure 20 is a bar chart showing a monthly breakdown. Negative speeds define tailwinds, which arise as a result of westerly preference at Heathrow. With regard to noise infringements, it may be assumed that tailwinds are critical; these occur for between about 3% and 22% of departures. Indeed, it is interesting that the monthly incidence of tailwinds tends to mirror the pattern of infringements shown in Figure 3. The highest quarterly total, during spring (Q2), is about 18%; during summer (Q3) 14% of departures are in tailwinds, during autumn 12% and winter, 10%. However, as average tailwind and low headwind speeds vary seasonally by about 0.5kt only (Figure 19), associated variations of mean noise levels would be small:-

		Q 1	Q2	Q3	Q4
	Headwind:	0	0	-0.5kt	-0.5kt
B747-400	-0.151 dB/kt	0	0	+0.076	+0.076dB
B747-200	-0.156 dB/kt	0	0	+0.078	+0.078dB
B747-100	-0.201 dB/kt	0	0	+0.10	+0.10dB

Of more practical significance is the potential effect upon infringements of the westerly preference at Heathrow. These results indicate that up to 20% of departures could be affected, a few by adverse tailwinds up to 5kt (i.e. an overall headwind component difference of 10kt relative to the reverse runway direction), which would increase noise levels by:-

up to 0.201 dB/kt x up to 10kt = up to 2dB relative to the reverse departure direction.

Air temperature

5.6 Figure 21 shows typical variations in air temperature through the day for a period in July 1995 (each point represents the temperature taken from NTK at Monitor 6 at Heathrow at the time of a noise event). The daily peak levels are consistent with the July value from the following Meteorological Office data on 1995 monthly average daily peak temperatures (°C):-

January	8.8°	February	10.6°	March	11.2°
April	15.0°	May	19.0°	June	20.7°
July	26.3°	August	27.0°	September	19.2°
October	18.3°	November	12.0°	December	5.8°

5.7 Summer 1995 was considerably warmer than average: for every month except December, the daily maximum temperature was higher than the Heathrow long-term average: these are reproduced below from Ref 3 (°C):-

January	6°	February	7°	March	10°
April	12°	May	16°	June	19°
July	21°	August	21°	September	19°
October	17°	November	9°	December	7°

5.8 Thus, during an exceptional year, differences in mean high temperatures relative to the April/May values would change upper percentile noise levels (dB) as indicated below:

		Q1	Q2	Q3	Q4
Temperature difference °C:	1995 *(Average year*	-8 *-6*	+2 *+3*	+8 *+5*	-1 *+ 1)*
B747-400	0.025 dB/°C	-0.2	+0.05	+0.2	-0.03
B747-200	0.025 dB/°C	-0.2	+0.05	+0.2	-0.03
B747-100	0.071 dB/°C	-0.6	+0.14	+0.6	-0.07

In average years, the variations would generally be less. In both cases, summer increases would tend to be balanced by winter decreases.

5.9 In summary, the effects of variations in weight, wind and temperature on monitored noise levels, at the upper end of the ranges, would typically be as follows (in dB relative to the level in Q2):-

	Winter (Q 1)	Spring (Q2)	Summer (Q3)	Autumn (Q4)
TOW:-				
B747-400	up to +0.05	0	up to +0.25	up to +0.15
B747-200	up to +0.65	0	0	up to +0.4
B747- 100	0	0	up to +0.5	up to +0.15
Wind:-				
B747-400	0	0	up to +0.08	up to +0.08
B747-200	0	0	up to +0.08	up to +0.08
B747-100	0	0	up to +0.1	up to +0.1
Temperature:-				
B747-400	down to -0.2	up to +0.05	up to +0.2	down to -0.03
B747-200	down to -0.2	up to +0.05	up to +0.2	down to -0.03
B747-100	down to -0.6	up to +0.14	up to +0.6	down to -0.07
Aggregate (rounding to nearest 0.05dB):-				
B747-400	-0.2 to +0.05	up to +0.05	up to +0.8	-0.05 to +0.25
B747-200	-0.2 to +0.65	up to +0.05	up to +0.3	-0.5 to +0.5
B747-100	down to -0.6	up to +0.15	up to +1.2	-0.05 to +0.25

5.10 This crude assessment suggests that predictable seasonal effects might typically cause noise levels around the infringement point to differ from the April/May values by as much as -0.6dB in winter to +1.2dB in summer. Despite the considerable uncertainties of predicting infringement rates, these results are sufficient to confirm that seasonal variations are inevitable. However, the likely variations of noise level are relatively small; the following section indicates that observed increases could readily be countered by the use of effective noise abatement operating procedures. This does not mean that seasonal variations would be eliminated; round-the year implementation of noise abatement procedures would simply lower the overall infringement rate.

6. OPERATING PROCEDURES

6.1 As explained in paragraph 3.3 of the main report, a distance of 6.5km from start-of-roll is the ‘flyover’ reference position defined in international aircraft noise certification procedures. By the time they reach this distance in normal operation, many jet aircraft have completed their high power initial take-off climb and have cut back to a lower climb setting. In this case, noise levels monitored at the 6.5km point reflect the noise of continuing climb which often tends to dominate the departure noise footprint. Noisier aircraft may cut back thrust levels to an even lower ‘noise abatement’ setting. Paragraph 3.4 of the main report explained that noise abatement operating procedures for departures involve choosing a balance between rate of climb and power cutback; aircraft height (determined by rate of climb) and noise emission (determined by engine power setting) both contribute to the noise on the ground under the aircraft.

6.2 In Ref 2, ICAO currently recommends a choice between two specific noise abatement take-off procedures, A and B, one of which “should be applied routinely for all take-offs”. In procedure A, which “results in noise relief during the latter part of the procedures”, the initial high-power climb is maintained to 1500ft before cutting back. Procedure B, which “provides relief during that part of the procedure close to the airport”, ends the initial climb at 1000ft; thereafter, flaps are retracted while the aircraft accelerates to a higher climb speed - then power is reduced. In December 1995, the ICAO Committee on Aviation Environmental Protection (CAEP) recommended that Procedures A and B should be replaced by new ones defined specifically as ‘close in’ and ‘distant’ procedures, which allow operators more flexibility (Ref 5). Both permit thrust cutback at heights down to 800 feet. Although the CAEP recommendations, including associated operational and safety issues, are subject to detailed review by ICAO’s Air Navigation Commission and Council before they can be ratified, similar procedures have already been approved for use in the USA (but not yet by some other member states). Whether or not specific authorised procedures are implemented at particular airports is a matter for the aircraft operator.

6.3 It has recently become possible to make some comparisons of aircraft noise measurements made under operational and certification conditions. This is because the NTK fixed noise monitors incorporate facilities to measure EPNdB, the noise certification unit, as well as dBA. Difficulties caused by background noise interference have so far prevented their use for measuring EPNLs of quieter events but they do provide accurate measurements at higher noise levels, i.e. around the daytime noise limits. Figures 22 to 24 show the operational noise levels of the special subset of B747 departures measured in EPNdB. For each of the three B747 variants studied, two graphs are shown: for example, Figures 22a and 22b relate to the -100. Figure 22a is a scatter diagram relating EPNL to L_{max}; Figure 22b compares the measured flyover EPNL levels (at Monitor 6) with (i) the appropriate certification limit, (ii) the certificated noise levels of various B747-100s for different maximum TOWs and (iii) the approximate equivalent EPNL departure noise limits, present and proposed - read from the regression line fitted to the EPNL-L_{max} scatter diagram (Figure 22a). Figures 23 and 24 show similar results for the B747-200 and -400 variants.[6]

6.4 Figure 22b shows that, allowing for inevitable data scatter, the operational flyover noise levels of the -100 variants lie close to the certificated values, which in turn lie close to the applicable Chapter 2 limits. This confluence of measured and certificated noise levels is probably indicative of how little scope there was with the -100 to achieve low flyover noise levels through expeditious use of cutback, because of its engines' relatively low thrust ratings and consequent poor climb performance. In this case therefore operational take-off procedures probably differ little from those that were used in -100 certification testing. Figures 23b and 24b show that by contrast, operational flyover noise levels of the higher performance -200 and, more especially, -400 aircraft are somewhat higher than their certificated levels. This reflects the surplus thrust available to achieve low certification flyover noise by the use of high take-off thrust and (relatively) low cutback thrust.

6.5 It is evident that to produce a noise benefit at 6.5km, thrust must be cutback before the aircraft reaches that point. Whether this can be achieved in practice depends on the initial climb gradient of the aircraft, i.e. whether it has reached sufficient height. In their response to the consultation, Boeing stated that "virtually all Chapter 2 B747s will still be at full power at 6.5km" so that they would not be able to take advantage of cutback which, for that aircraft, was stated by Boeing to be worth about 5dB (all noise levels in the remainder of this report are in A-weighted decibels, dBA).

6.6 To investigate this further, data acquired from NTK during the main study have been re-examined. Data were taken from four measurement sites to the west of Heathrow, positioned as follows (see Figure 1):-

[6] It should be noted that certificated flyover noise levels slightly in excess of the certification limits are permissible under the certification rules, because limited trade-off is allowed between noise levels at the three measurement points (flyover, sideline and approach).

Site	Distance from. Start-of-Roll (m)
56	6060
57	6050
55	6600
6	6660

Monitors 56 and 57 cover departures from Runway 27R; Monitors 6 and 55 apply to Runway 27L. According to the Boeing view, power settings typically change little between 6050m and 6600m from start-of-roll, and thus noise levels produced by B747-200s at the closer monitors 56 and 57 would be similar to those at the more distant monitors 55 and 6 - only the difference in height, which would result in a noise level difference of about 1dB, would be of consequence.

6.7 To assess the possible operational use of cutback, 10th percentile noise levels at the closer and more distant monitors were compared, for both the -200 and -400 departures. (10th percentiles were taken to represent aircraft flying closest to the monitors, which are the most likely to infringe.) For both variants, the differences were less than 2dB. Although this test was a very crude one (not the least because it compared aircraft on different tracks) it provided no evidence of significant operational thrust reductions before the monitor positions.

6.8 The above results strongly support the conclusion drawn from the regression analyses in Section 4 that a principal factor governing operational B747 flyover noise levels is the practice of derating thrust for take-off and initial climb (paragraphs 4.21 to 4.24). Taken together, these results indicate that, at least for the -200 and -400 variants, typical departure procedures involve initial climb rates markedly lower than maximum and little thrust reduction before passing the 6.5km monitor positions. It is probable that lower noise levels could often be achieved at the 6.5 km monitors by increasing take-off thrust and thus initial climb gradients. The practicality of doing so has not been assessed as part of this study. Also, this alternative would of course lead to higher noise levels and exhaust emissions prior to the cutback point, i.e. in the immediate vicinity of the airport.

Comparison of ICAO Type A and B operating procedures

6.9 Boeing have calculated flight profiles for the B747-200 (with JT9D-7F engines) at 364 tonnes TOW, 25°C, zero wind, comparing the ICAO A and B noise abatement procedures (Ref 2). In this case, procedure A involved a power reduction at 1500ft, and commencement of 'clean-up' at 3000ft; procedure B commenced clean-up at 1000ft, and power reduction at the flap 5° speed (which in the case provided occurs just before 1500ft). In both cases, cutback occurs well past the 6.5km point (which is passed at full power at a height of about 600ft), so at the proposed monitor positions there would be no difference in noise level for the B747-200 between the two procedures. However an aircraft passing over a 6.5km noise monitor at Heathrow at 600ft would clearly be failing to meet the AIP 1000ft agl requirement (see paragraph 4.10).

6.10 Figures 12 and 13 indicated that, in practice, few if any B747-100s and -200s are at heights as low as 600ft, suggesting that, ignoring possible wind effects, operational TOWs are generally rather lower than 364 tonnes. This was confirmed to be the case by Figures 22b and 23b. However, among the departures illustrated in Figure 13, some 18% had not reached 1000ft by 6.5km. It therefore appears that for the earlier B747 models, the changes to the ICAO noise abatement procedures proposed by CAEP (see paragraph 6.2) would be of some advantage in complying with requirements to reduce noise.

6.11 For the B747-400, Boeing have suggested a modified ICAO B procedure for 'close-in' cutback at 1000ft (Ref 6). For the B747-400 with RB211-524G engines at maximum TOW (398 tonnes), zero wind and 25°C, they estimate a height at 6.5km of 1170ft, with noise levels of 92dBA for this modified procedure B, or 94dBA for procedure A or the 'true' procedure B.

6.12 No quantitative analysis of noise abatement operating procedures has been made in this supplementary study but the observations described in this section clearly indicate that flyover noise levels could be reduced more than enough to cover the increases of around 1dB attributable to seasonal effects.

7. CONCLUSIONS

Summary

7.1 This study addressed some of the technical questions raised during the DoT consultation on the review of departure noise limits concerning the validity of the assessment procedures used in the main report and the abilities of B747 aircraft to comply with the proposed new arrangements. The study, which was confined to daytime infringements at Heathrow, made use of NTK data that were not available at the time of the original study. The principal conclusions are outlined below.

7.2 Because of the number of variables affecting noise levels, and the proposed changes to the numbers and dispositions of monitors, it is not possible to make precise predictions of infringement rates. Nevertheless, **the relatively simplistic methodology employed in the main report was found to provide reasonable estimates of average April/May daytime infringement rates actually experienced at Heathrow since the new NTK system was commissioned.**

7.3 Available records confirm that during the last four years, **overall infringement rates at Heathrow have varied from month to month and that during April and May, the months during which data for the main report study were collected, they have tended to be lower than average, by about 50%, while highest monthly rates have been about 50% higher than average.**

7.4 The likely effects of the proposed new departure noise monitoring arrangements on B747 infringement rates have been assessed (i) by applying the empirical methodology of the main report, (ii) by extrapolating from a large amount of information for the period July 1995 to June 1996 extracted from the NTK database, and (iii) by inference from a detailed analysis of a special subset of B747 departures. The results indicate that, **had the proposed new monitor arrays been in place in 1995/96, about 5% of Chapter 3 B747 departures would have been recorded as having infringed limits 3dB lower than at present. This is close to what would have been expected on the basis of the main report.**

7.5 **The 1995/6 results indicate that corresponding infringement rates for Chapter 2 B747s would have been about 42%. This rate is twice what would have been predicted on the basis of the main report.** There are at least four reasons for this disparity, the first being the seasonal variation already noted, which can be attributed to changes in TOW and atmospheric conditions (see paragraph 7.8 below). Second, the sample of Chapter 2 B747s obtained in April/May 1994, from which conclusions were drawn in the main study, covered Gatwick and Stansted airports as well as Heathrow, and included large proportions that were at significantly greater heights and less noisy than the 1995/6 sample averages. Third, the Chapter 2 B747 sub-group in the main study data sample contained a smaller proportion of the noisiest variants, the B747-100. Fourth, a closure of Heathrow Runway 27R to departures in July 1995 resulted in an exceptionally high infringement rate at Monitor 6, the most critical of existing monitors (effectively this increased the overall monitoring efficiency of the present system).

7.6 B747s grouped by ‘noise chapter’ include a variety of models with rather different noise characteristics. For 1995/6 departures of specific B747 models, it is estimated the following percentages would have infringed daytime noise limits had the proposed new arrangements been in place:-

B747-100, Chapter 2:	50%
B747-200, Chapter 2:	33%
B747-200, Chapter 3:	11%
B747-400, Chapter 3	0.9%

The B747-400 is the current production standard of the B747 and is likely to remain in service for many more years than the earlier variants.

7.7 Factors considered most likely to affect departure noise levels include:-

- Take-off weight
- Headwind component
- Air temperature
- Operating procedure

Seasonal effects

7.8 The first three of these factors are subject to relatively small seasonal variations. To assess their possible effects on infringement rates, analyses of operational data obtained from the Heathrow NTK system have been compared with B747 performance calculations supplied by Boeing Commercial Airplane Group. These were found to be in broad agreement; differences could be related to variations in operating procedures.

7.9 A multiple regression analysis of the special data subset showed that L_{max} levels monitored at a distance of 6.6km from start-of-roll could be predicted to within ±1dB (standard deviation) by accounting for operational variations in TOW, headwind component, air temperature, and slant distance - although other factors not considered may also be of some importance. The results confirmed Boeing's prediction of the temperature effect, while the effects of headwind were estimated to be somewhat greater that predicted. The fact that L_{max} appeared less sensitive to TOW than Boeing calculated may be attributed to operational weight-dependant variations in engine thrust (Boeing had necessarily assumed standardised thrust settings).

Westerly preference

7.10 **A finding of particular importance is that the 'westerly preference' at Heathrow results in a significant proportion of westerly departures being made in tailwind conditions, between 10 and 20% for B747s in the period studied. It is estimated that this could cause L_{max} increases of up to 2dB at the monitoring points relative to the reverse runway direction.**

Operating Procedures

7.11 **Perhaps the most important factor governing departure noise levels is the operating procedure, that is the variation of engine thrust and flap settings along the flight track. Together with TOW and meteorological conditions, it is these that control the height of the aircraft over the monitor as well as the level of noise emitted.** Greater height and/or lower thrust lead to lower noise at the monitor; traditional noise abatement procedures involve high take-off thrust to gain altitude rapidly followed by a shallower climb at reduced ('cutback') thrust over the monitor. In overall noise terms these two climb components are tradeable - use of higher take-off thrust to reduce 'flyover noise' generates more noise close to the airport; the noise certification procedure defines the latter in terms of 'lateral noise'. The standard certification test involves maximum take-off thrust to establish maximum lateral noise and permits optimum cutback to determine minimum flyover noise.

7.12 **The results of the study confirm that operational flyover noise levels are generally higher than certificated values. This is due to both reduced (derated) thrust at take-off and less cutback at the flyover reference distance.** Any reversal of this balance, that is towards higher take-off thrust and deeper cutback, would reduce noise at the monitors - but cause greater noise prior to the monitors. **An objective of the review of the departure noise limits was "... to encourage the use of ... best noise abatement operating practice". It was not the purpose of this analysis to study the practicality of noise abatement operating procedures but, with regard to monitored noise levels, it can only be concluded that there is scope for obtaining more advantage from their use.** They would not eliminate seasonal variations (assuming the procedures were applied uniformly around the year) but they should yield reductions in infringement rates.

Specific questions raised in the consultation

7.13 **The supplementary study provided the following answers to two specific questions raised by the consultation:-**

7.14 *Actual infringement rates have varied from month to month and have tended to be relatively low during April and May, the months during which the study data were collected in 1994. Is this the result of predictable seasonal effects and did the study underestimate the true effects on infringements of lowering the noise limits for this or any other reasons?*

Observed seasonal differences in B747 infringement rates may be attributed to variations of take-off weight, headwind and temperature variations. However, their effects are relatively small. Overall, the main study provided reliable assessments of infringements by Chapter 3 variants but for Chapter 2 variants, 1995/6 infringement rates were markedly higher than would have been expected. Four principal reasons have been identified - (i) the above seasonal factors (to which Chapter 2 variants are more susceptible); (ii) the presence of fast climbing B747s in the April/May 1994 data sample upon which the main report was based and which covered Gatwick and Stansted Airports as well as Heathrow; (iii) a higher proportion of the noisiest (-100) B747 variants in the 1995/6 Chapter 2 B747 fleet at Heathrow, and (iv) the distorting effect on infringements in July 1995 of runway maintenance work.

7.15 *Are some Boeing 747 aircraft, operating normally but at high take-off weights, unable to reach a height of 1000ft at a distance of 6.5km from start-of-roll, and are they consequently unable to* *cut back engine power in order to reduce noise beyond that point?*

The oldest and noisiest of the B747s are the -100 models which have poor climb performance and often fail to meet the existing minimum height criteria at the London airports. Although noise abatement operating procedures might help to reduce their infringement rate to a limited extent, these variants may be expected to exceed the revised daytime noise limits frequently. B747-200 aircraft also fail to meet the minimum height requirements on occasions, despite having better climb performance and, at least for Chapter 2 versions, many noise infringements are inevitable. However, noise abatement operating procedures are likely to be more effective in reducing their infringement rates, especially for Chapter 3 variants. The results of the study indicate that most B747-400s, the most modem variants, pass the monitors at heights well above 1000ft and could therefore derive benefit from conventional noise abatement thrust cutbacks. These versions are the least likely to infringe in any case; the use of very modest noise abatement actions should ensure that the daytime noise limits are rarely exceeded by B747-400s.

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

4. Integrated Noise Model (INM) Version 5.0 User's Guide: FAA-AEE-95-01: August 1995

5. Recommendations of the Third Meeting of the Committee on Aviation Environmental Protection for Amendment of Annex 16 and PANS-OPS, Doc 8168, Volume 1 - Flight Procedures: ICAO: June 1996

6. Private Communication: Boeing: April 1996

FIGURE 1

HEATHROW MONITOR POSITIONS

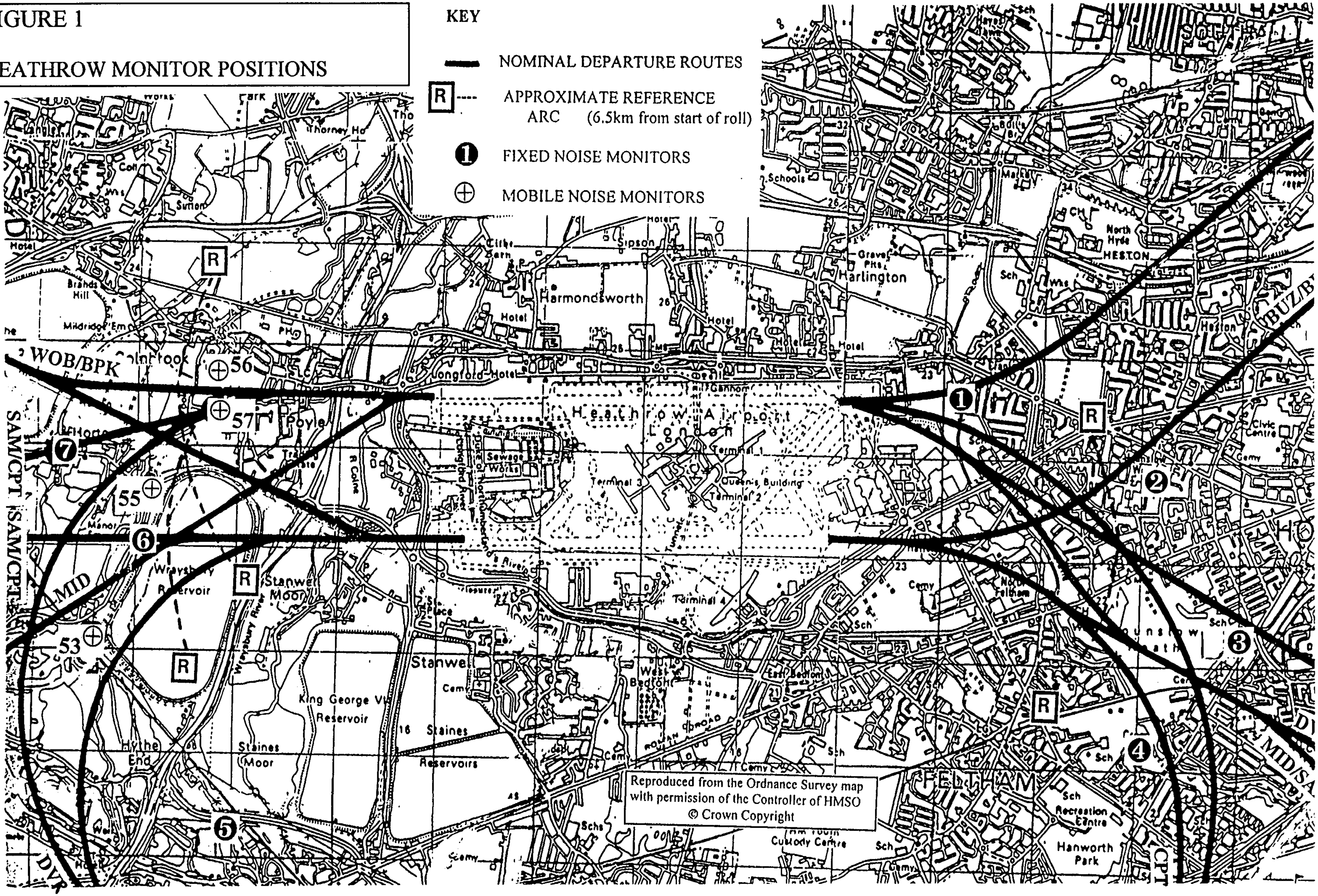


FIGURE 2

HEATHROW DAYTIME INFRINGEMENTS APRIL 1993 - JUNE 1996

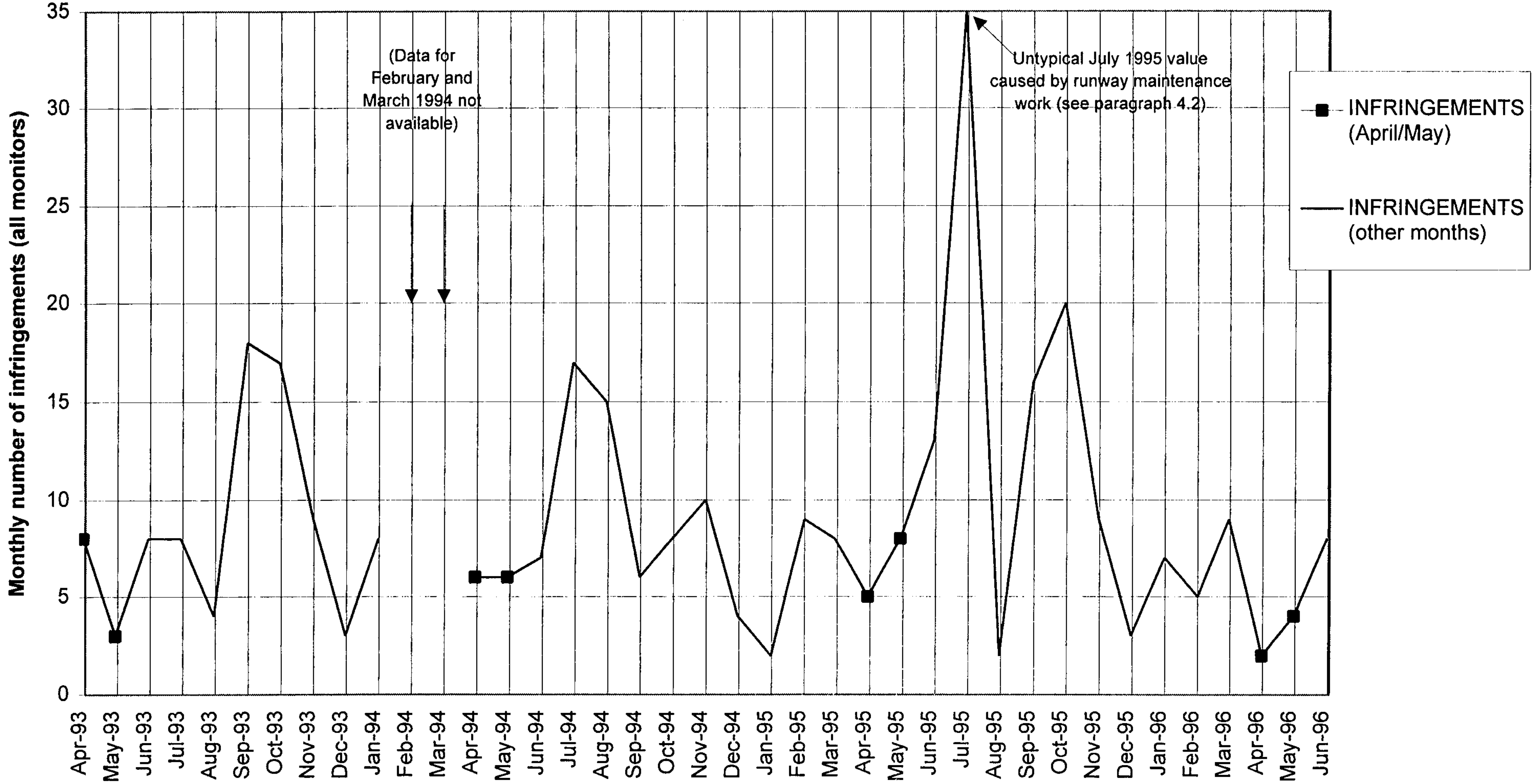


FIGURE 3

MONTHLY AVERAGE NUMBERS OF DAYTIME INFRINGEMENTS

(April 1993 - June 1996)

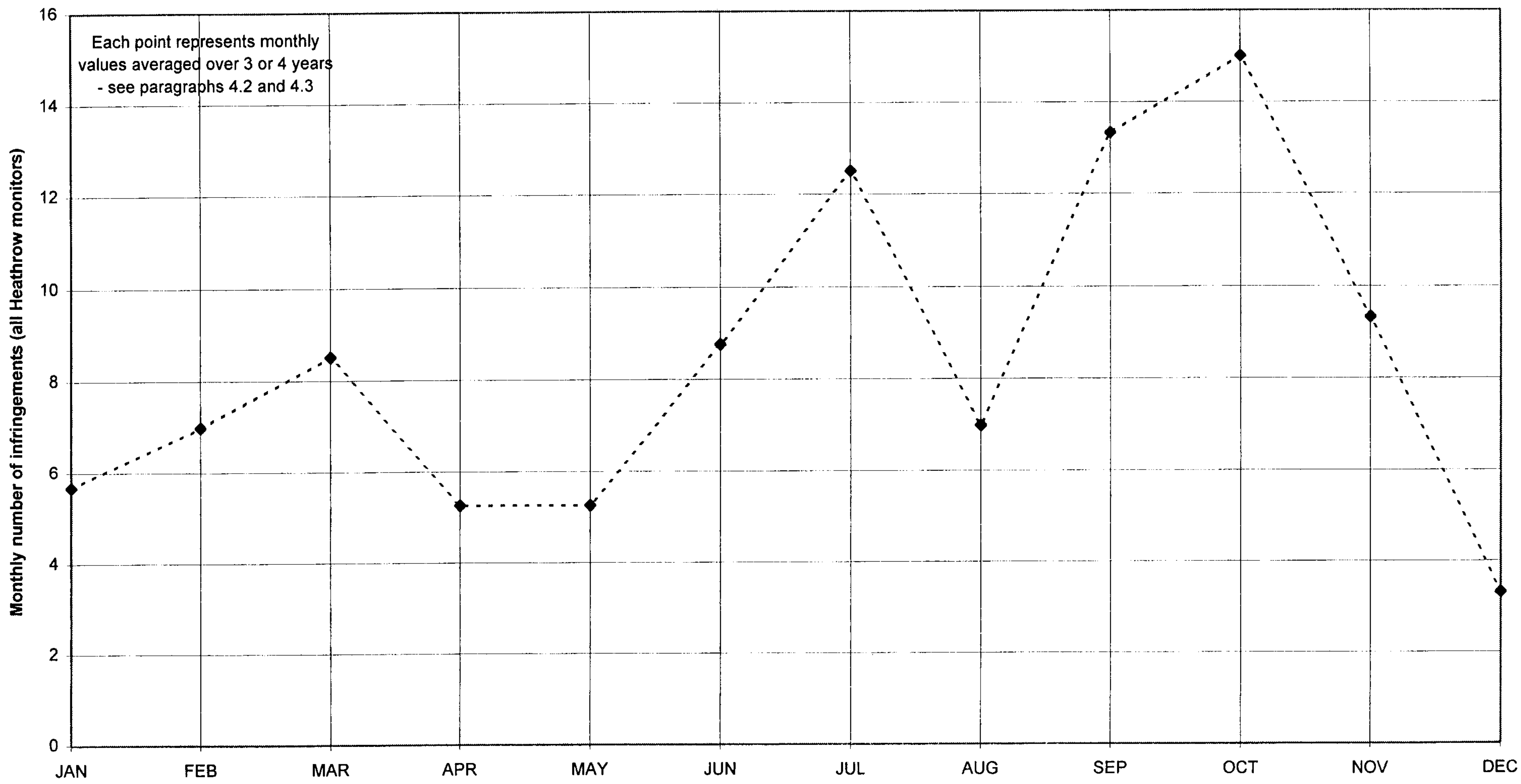


FIGURE 4

EFFECT OF TAKE-OFF WEIGHT ON CLIMB PROFILE
BOEING 747-400 Zero Wind, 25°C

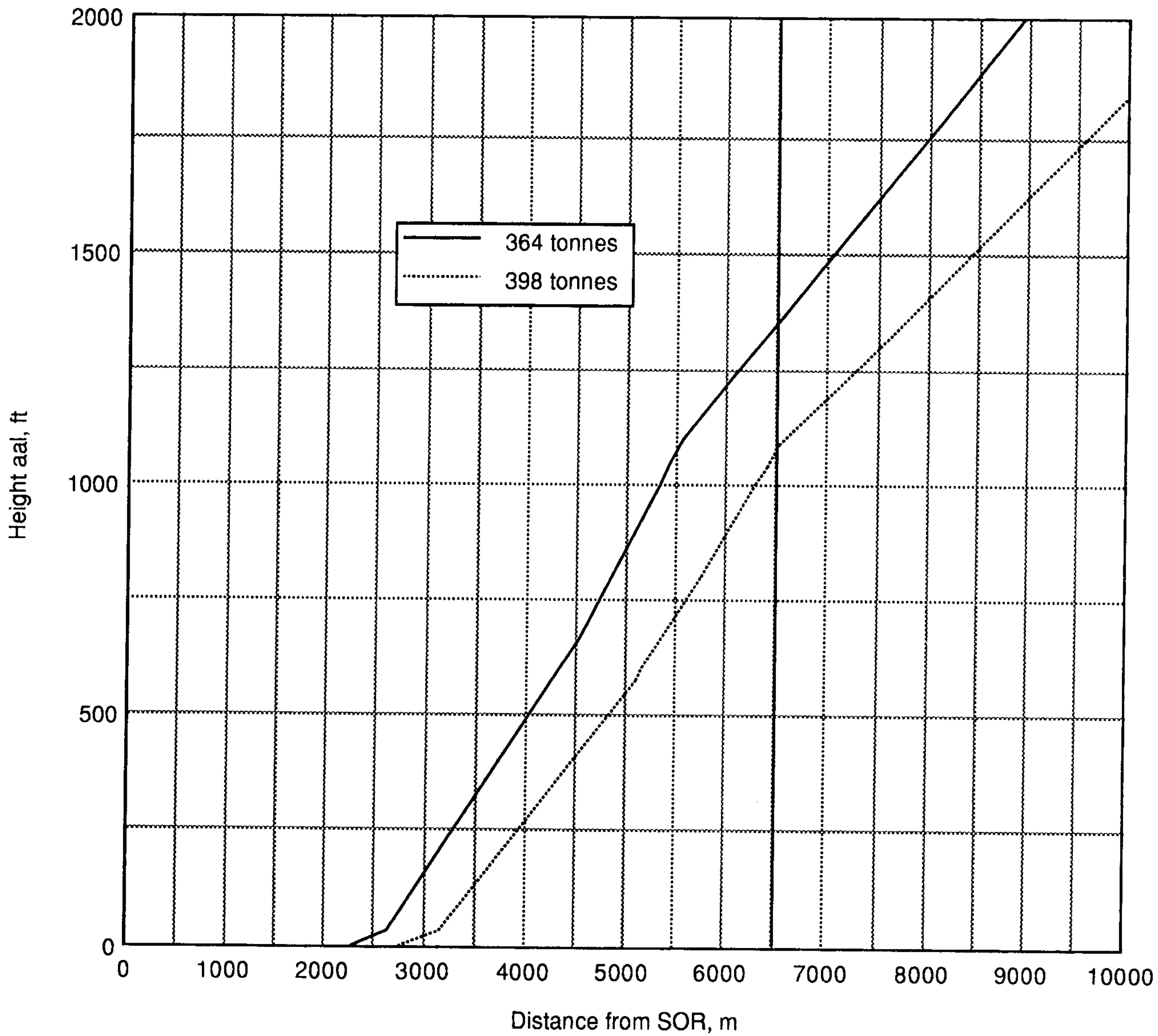


FIGURE 5

EFFECT OF TAKE-OFF WEIGHT ON HEIGHT AND NOISE LEVEL AT 6.5km

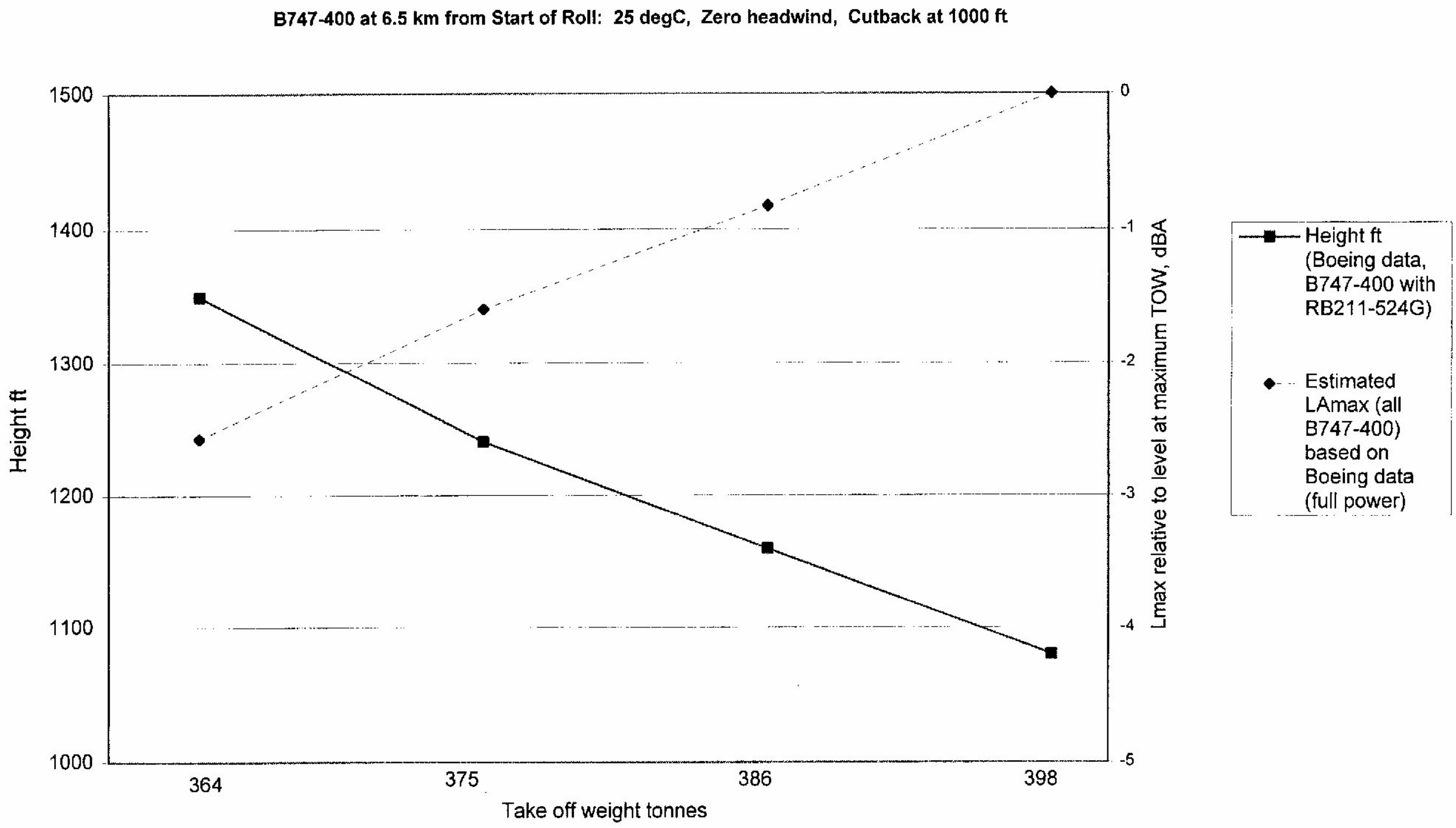


FIGURE 6

EFFECT OF HEADWIND ON CLIMB PROFILE

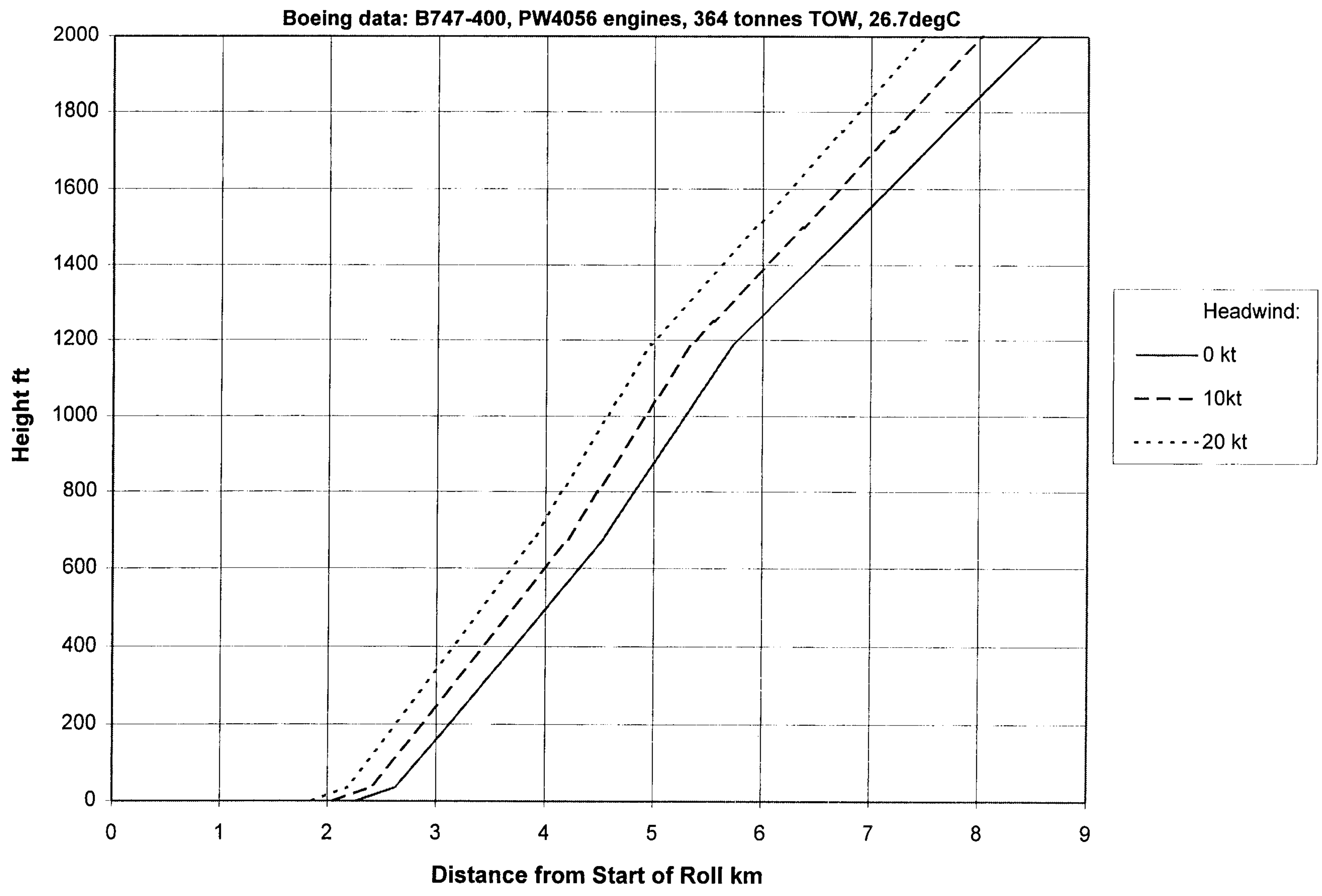
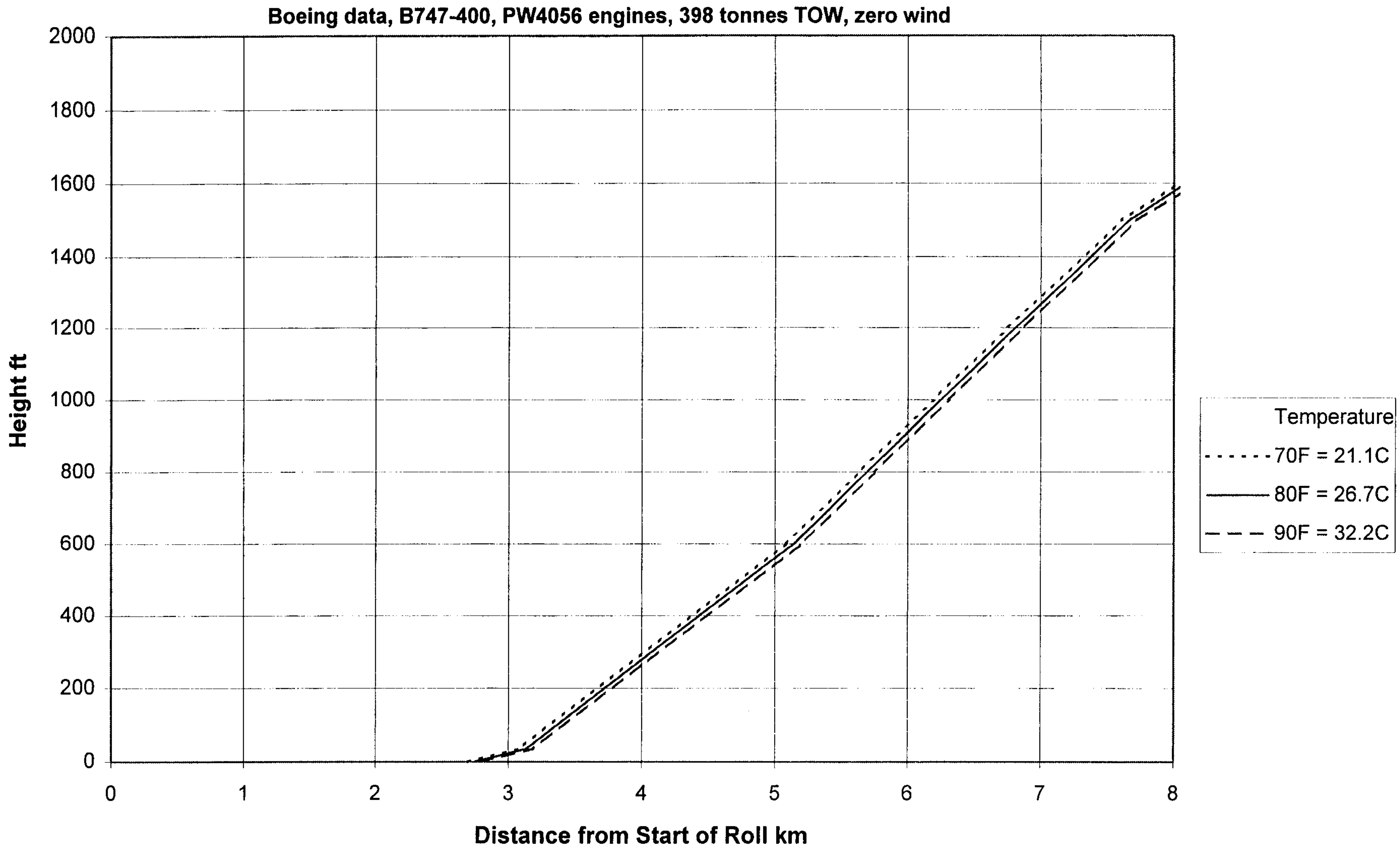


FIGURE 7

EFFECT OF AIR TEMPERATURE ON CLIMB PROFILE



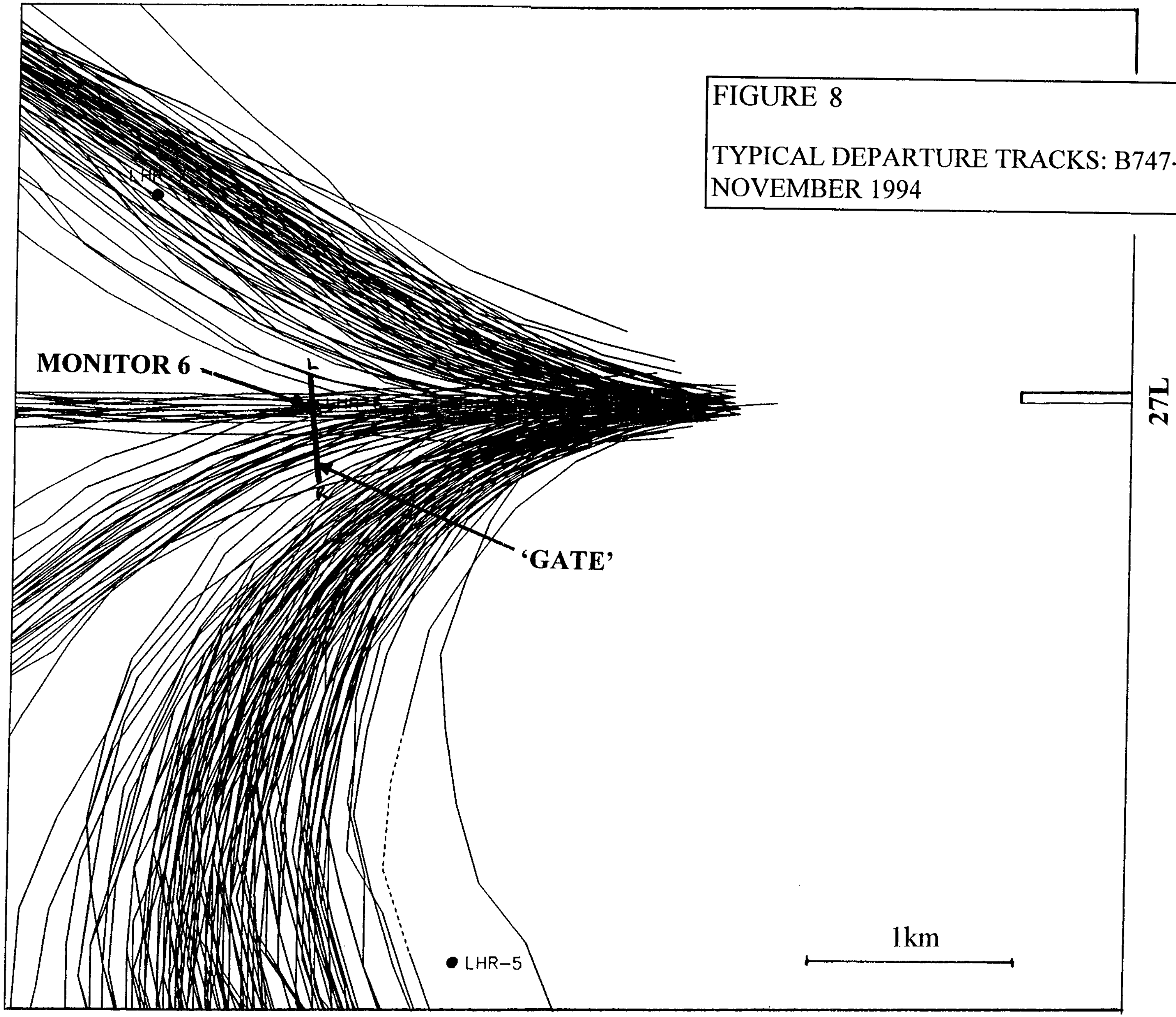
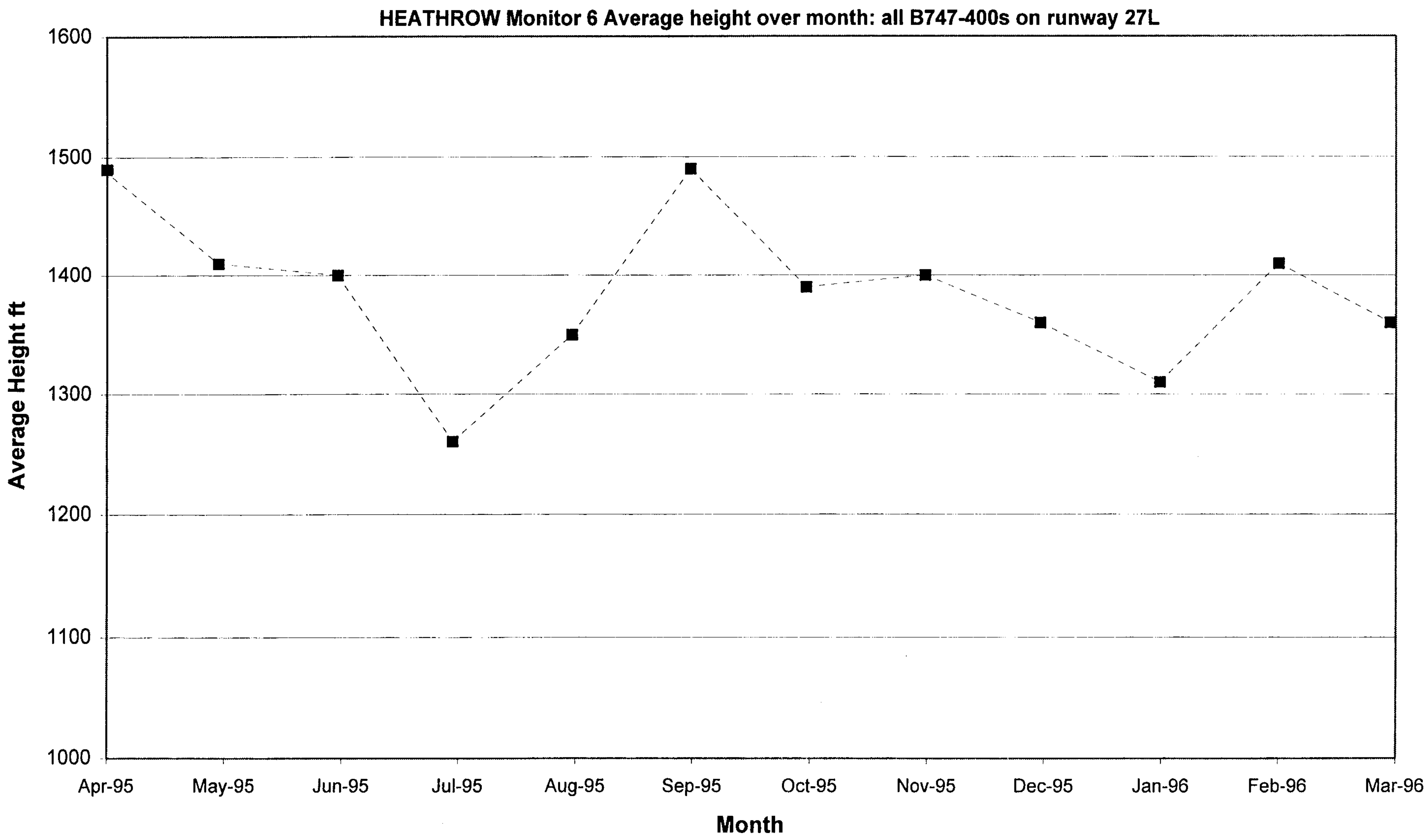


FIGURE 8

TYPICAL DEPARTURE TRACKS: B747-400
NOVEMBER 1994

FIGURE 9

MONTHLY AVERAGE HEIGHTS: B747-400



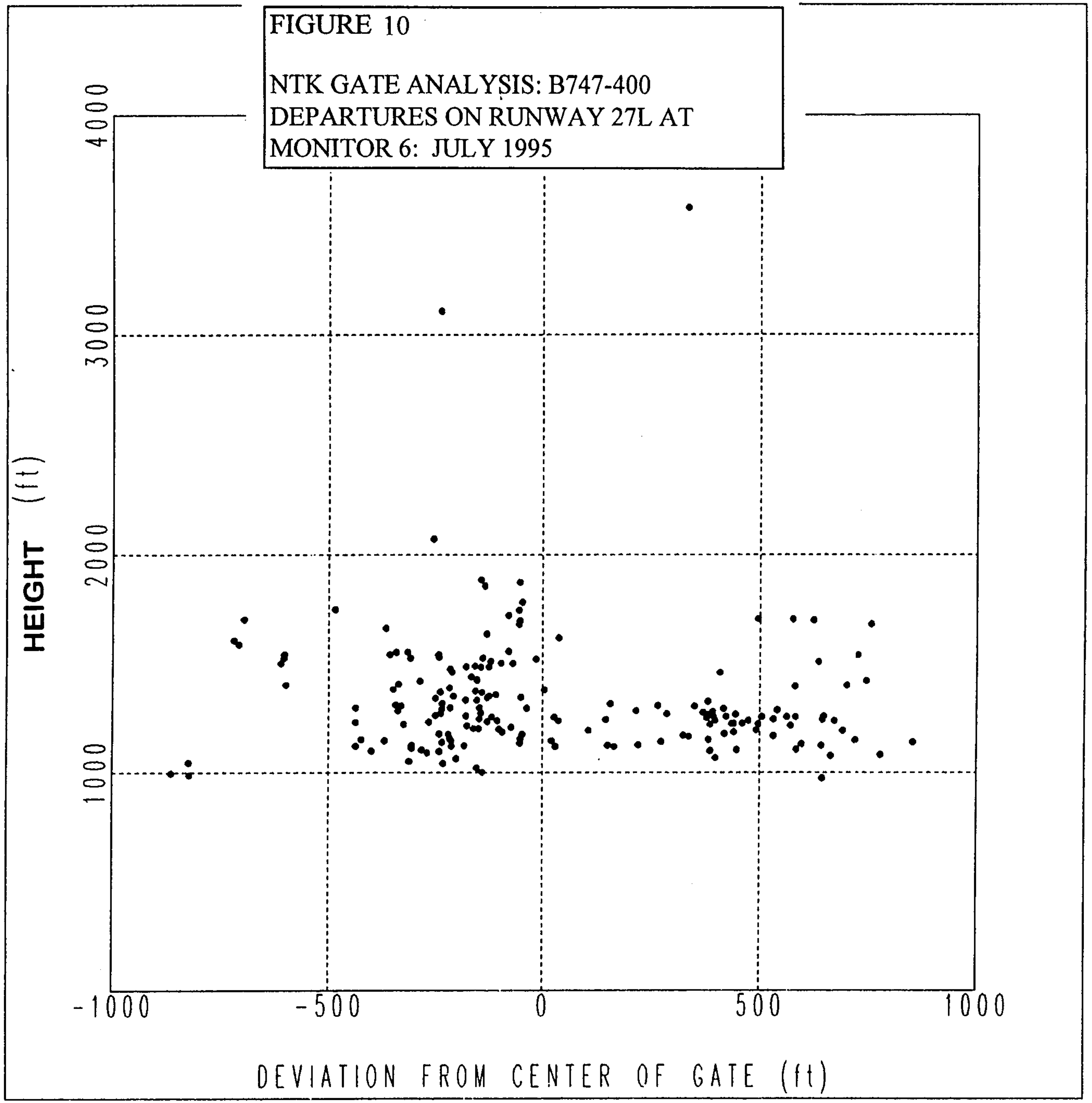


FIGURE 10

NTK GATE ANALYSIS: B747-400
DEPARTURES ON RUNWAY 27L AT
MONITOR 6: JULY 1995

FIGURE 11

NTK GATE ANALYSIS: B747-400
DEPARTURES ON RUNWAY 27L AT
MONITOR 6: APRIL 1995

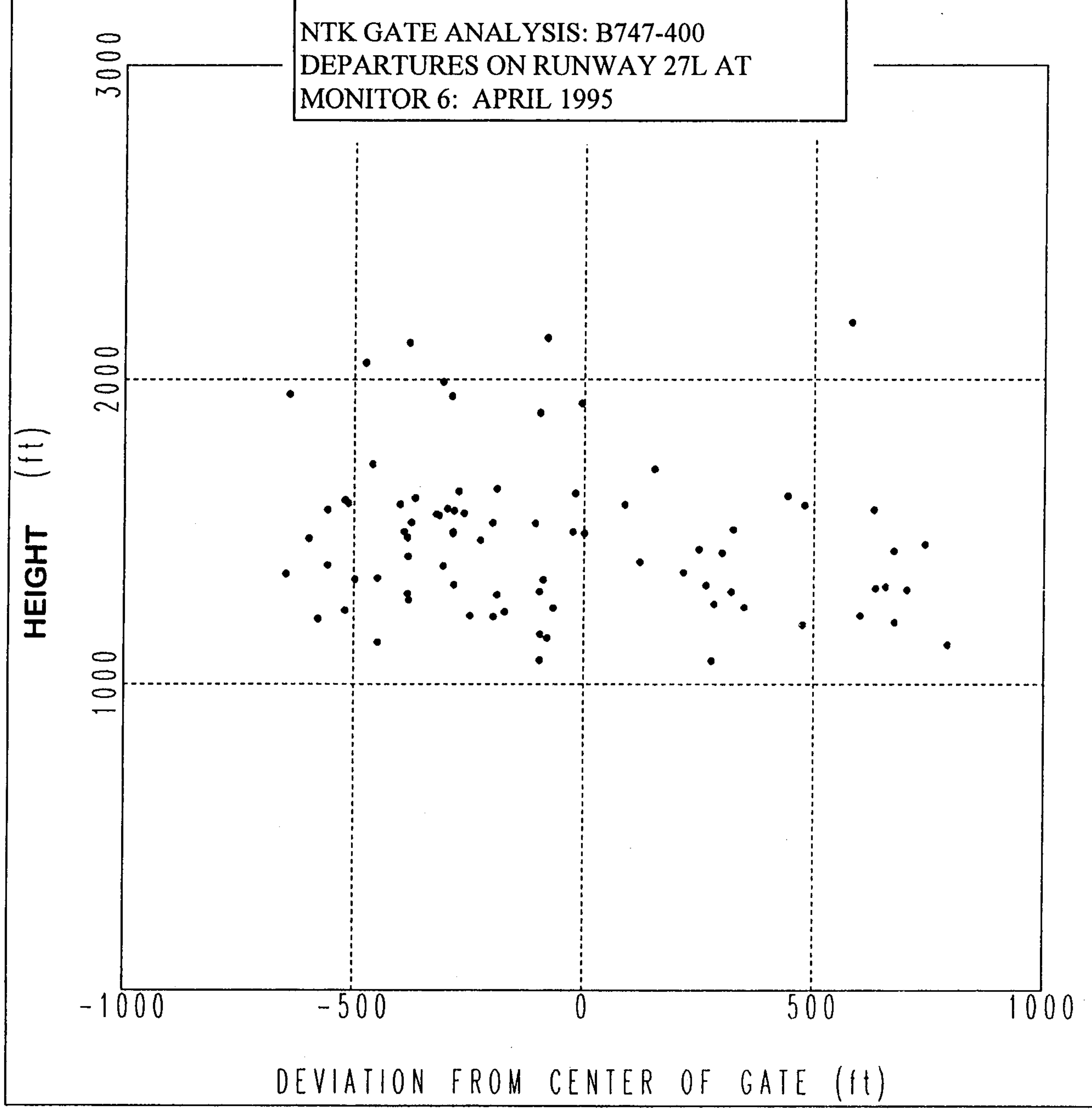


FIGURE 12

MONTHLY AVERAGE HEIGHTS: B747-100/-200

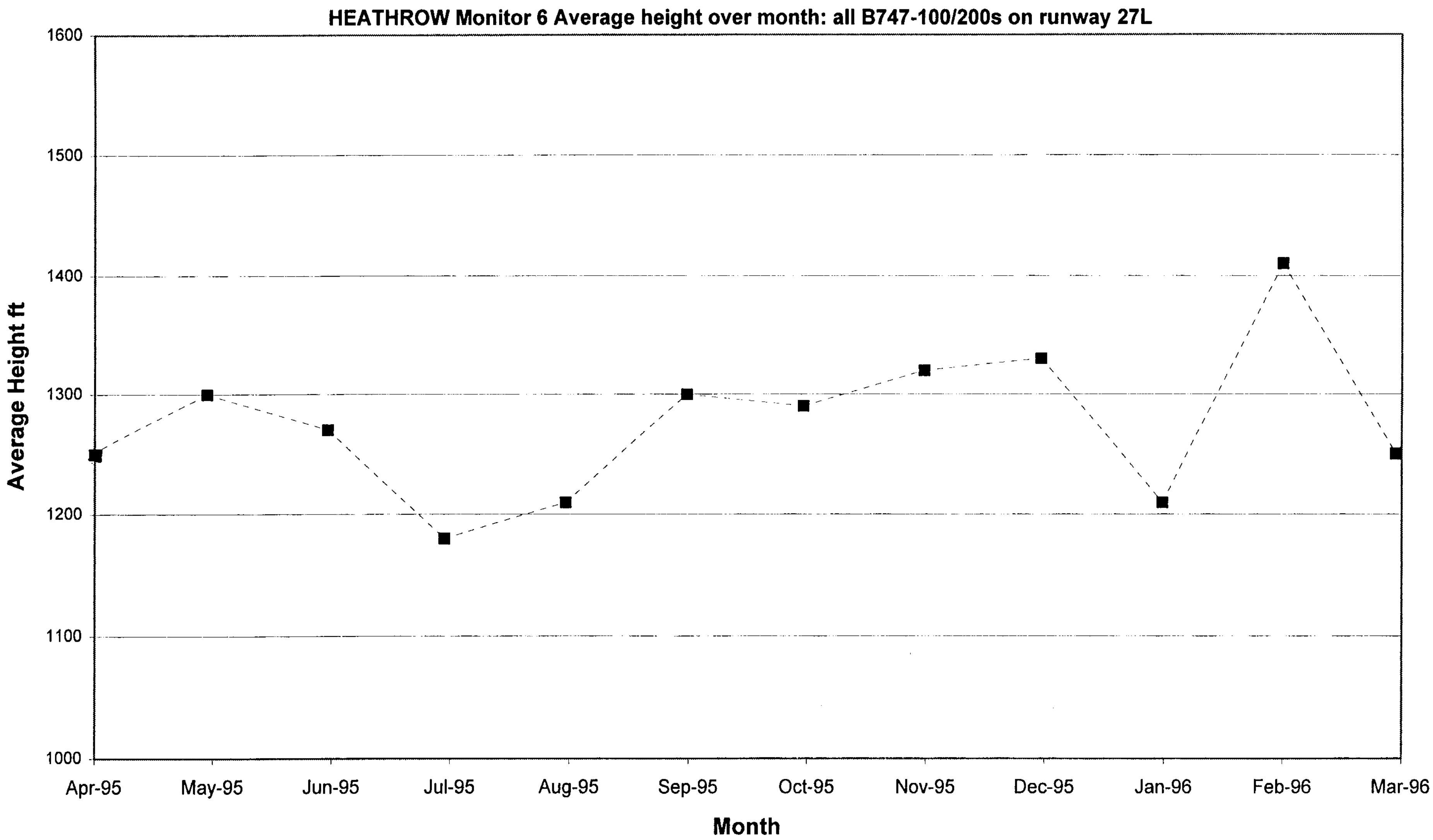


FIGURE 13

NTK GATE ANALYSIS: B747-100/-200
DEPARTURES ON RUNWAY 27L AT
MONITOR 6: JULY 1995

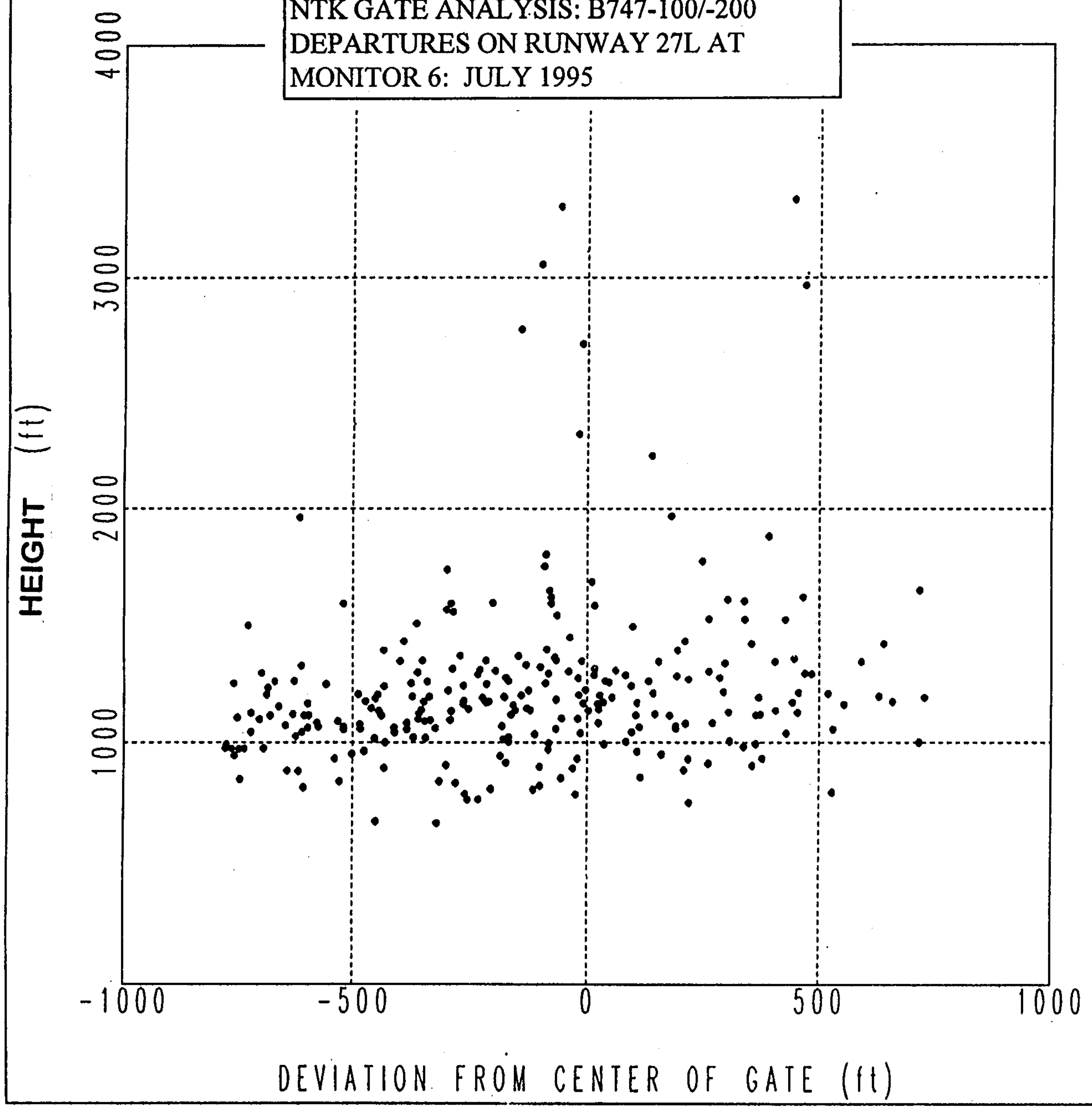


FIGURE 14

RELATIONSHIP BETWEEN MEASURED NOISE LEVEL AND TAKE-OFF WEIGHT

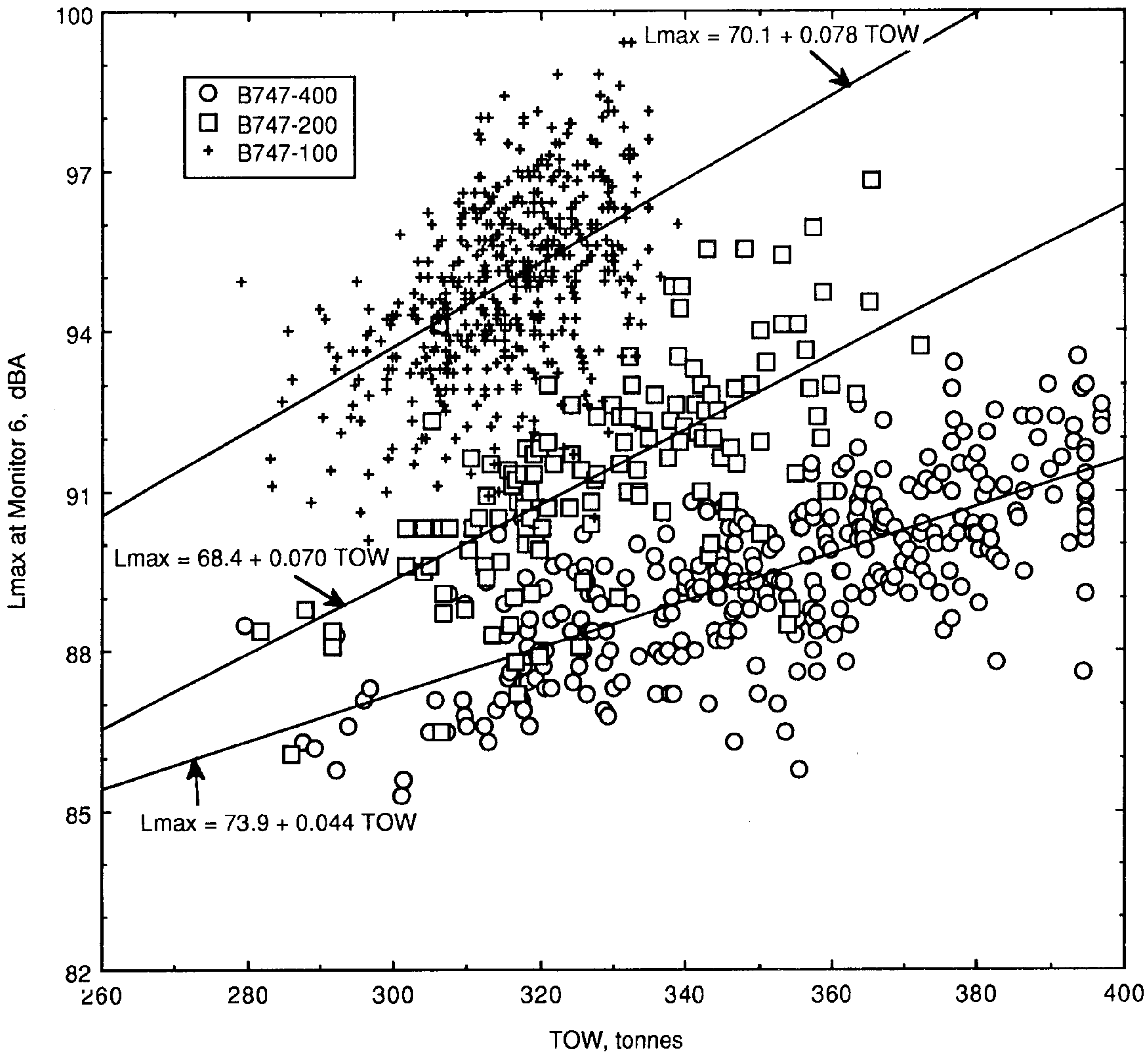


FIGURE 15

BOEING B747-100, -200 AND -400 DEPARTURES
RELATIONSHIP BETWEEN MEASURED AND PREDICTED NOISE LEVELS

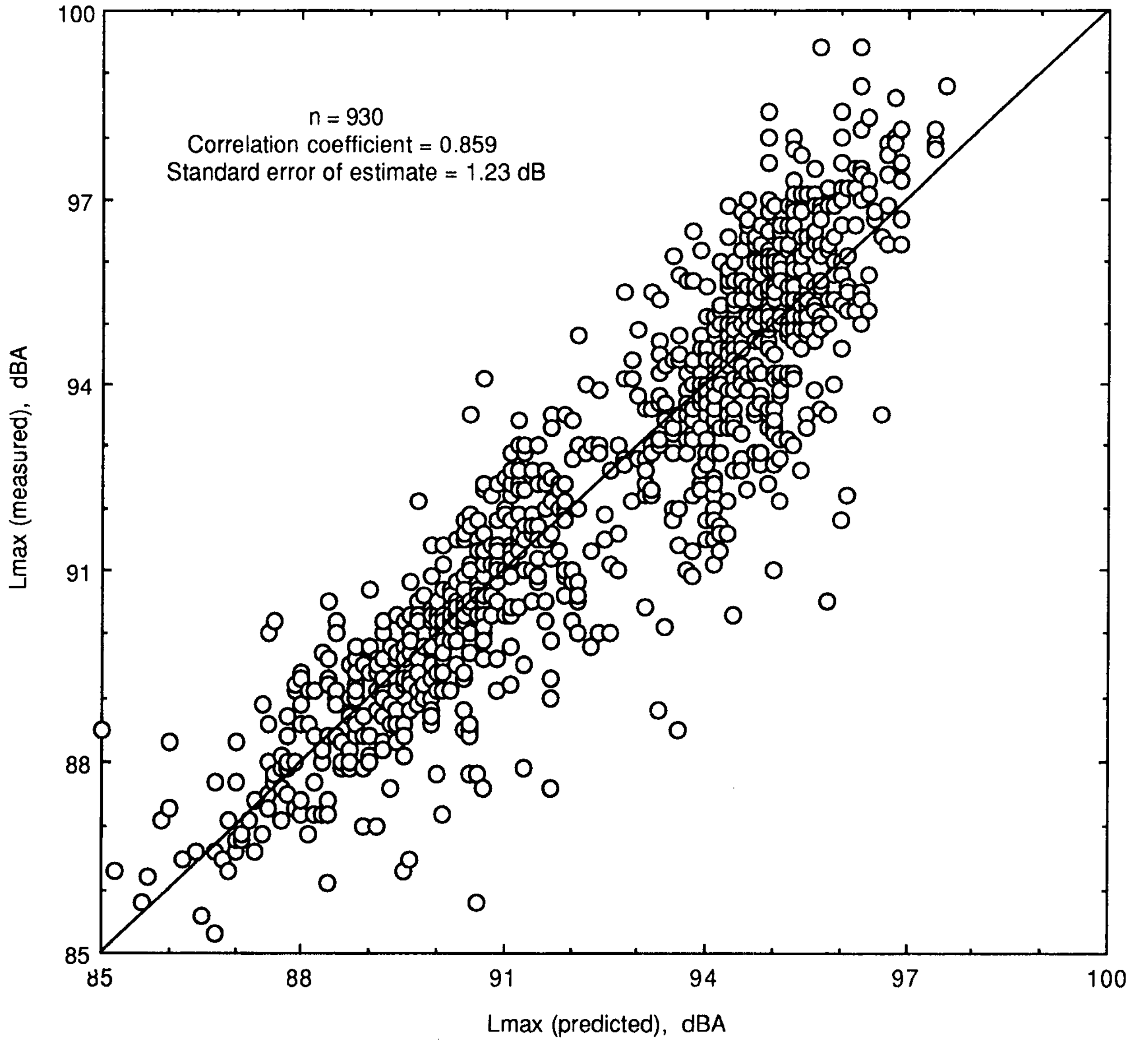


FIGURE 16

QUARTERLY DISTRIBUTION OF TOW : B747-400 DEPARTURES HEATHROW

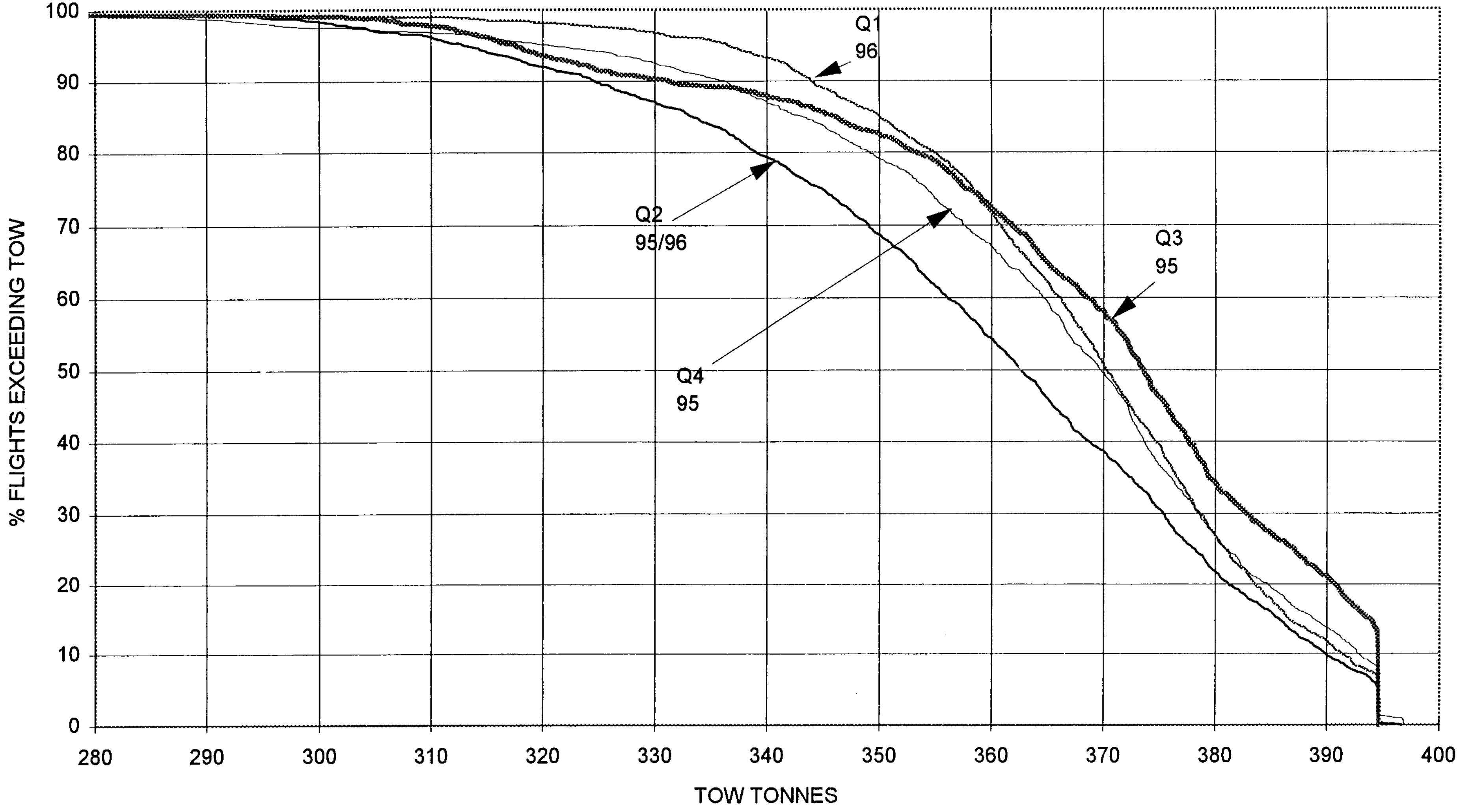


FIGURE 17

QUARTERLY DISTRIBUTION OF TOW : B747-200 DEPARTURES HEATHROW

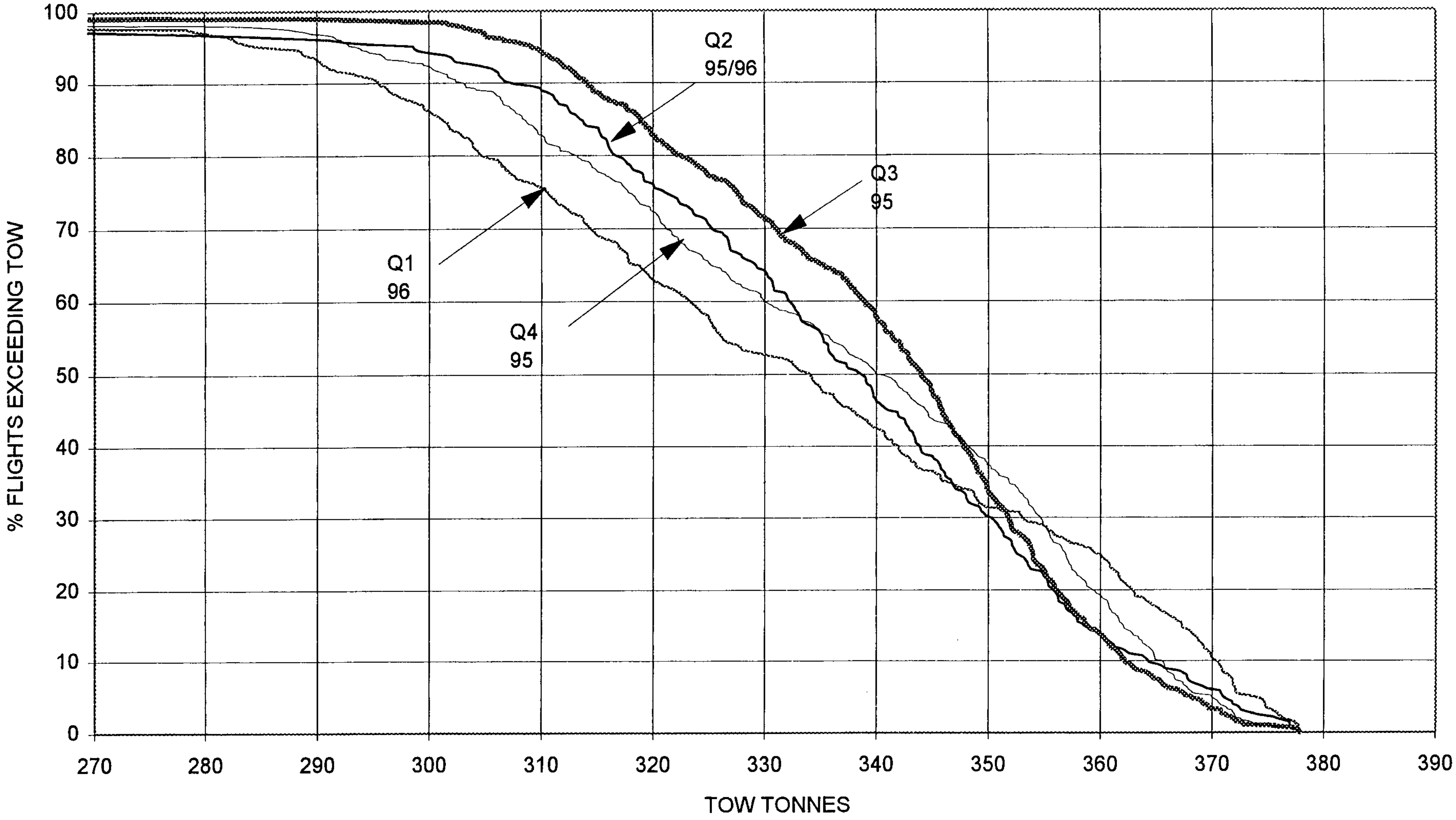


FIGURE 18

QUARTERLY DISTRIBUTION OF TOW : B747-100 DEPARTURES HEATHROW

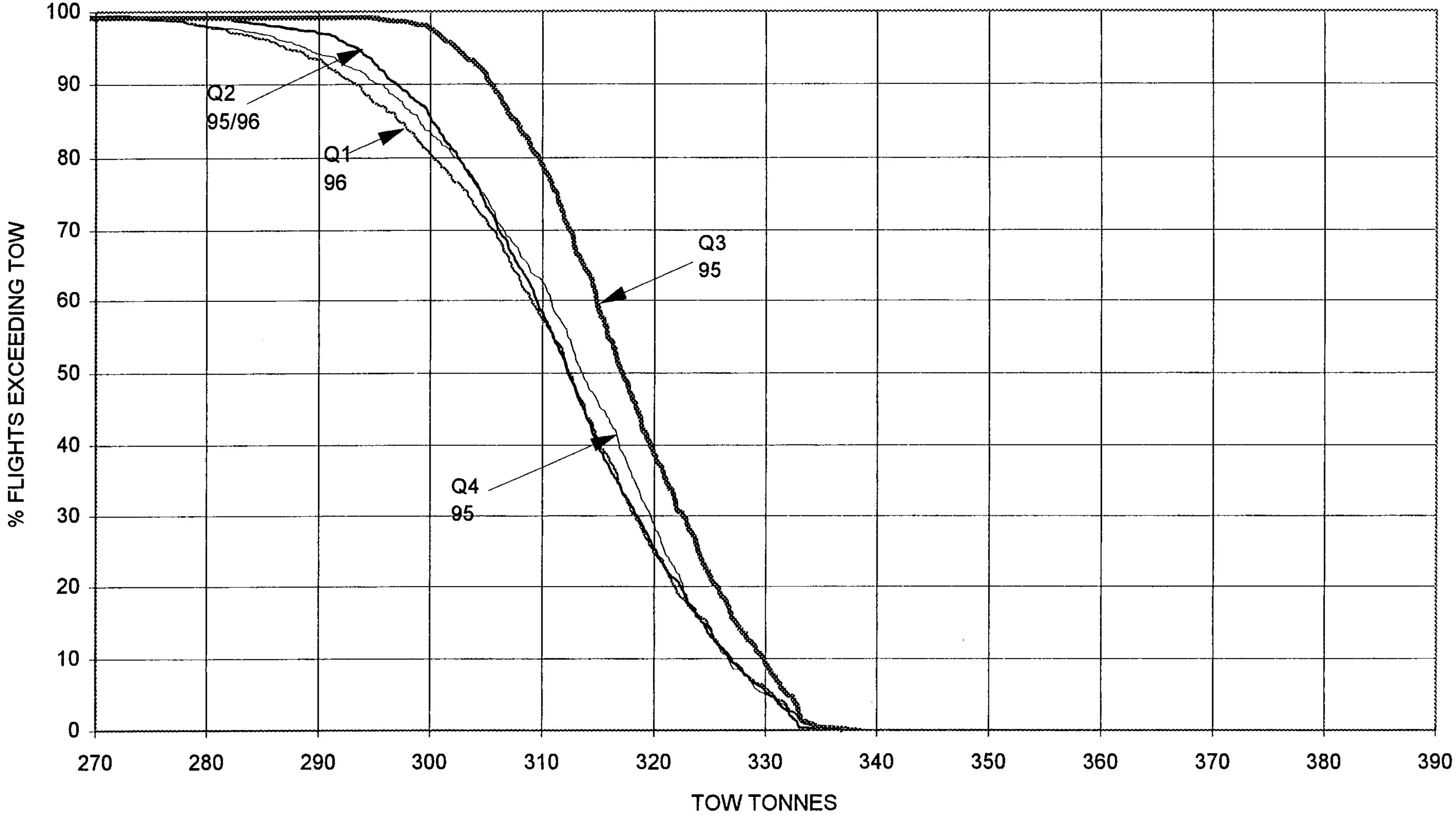


FIGURE 19

HEATHROW RUNWAY 27L: DISTRIBUTION OF HEADWIND COMPONENT BY QUARTER

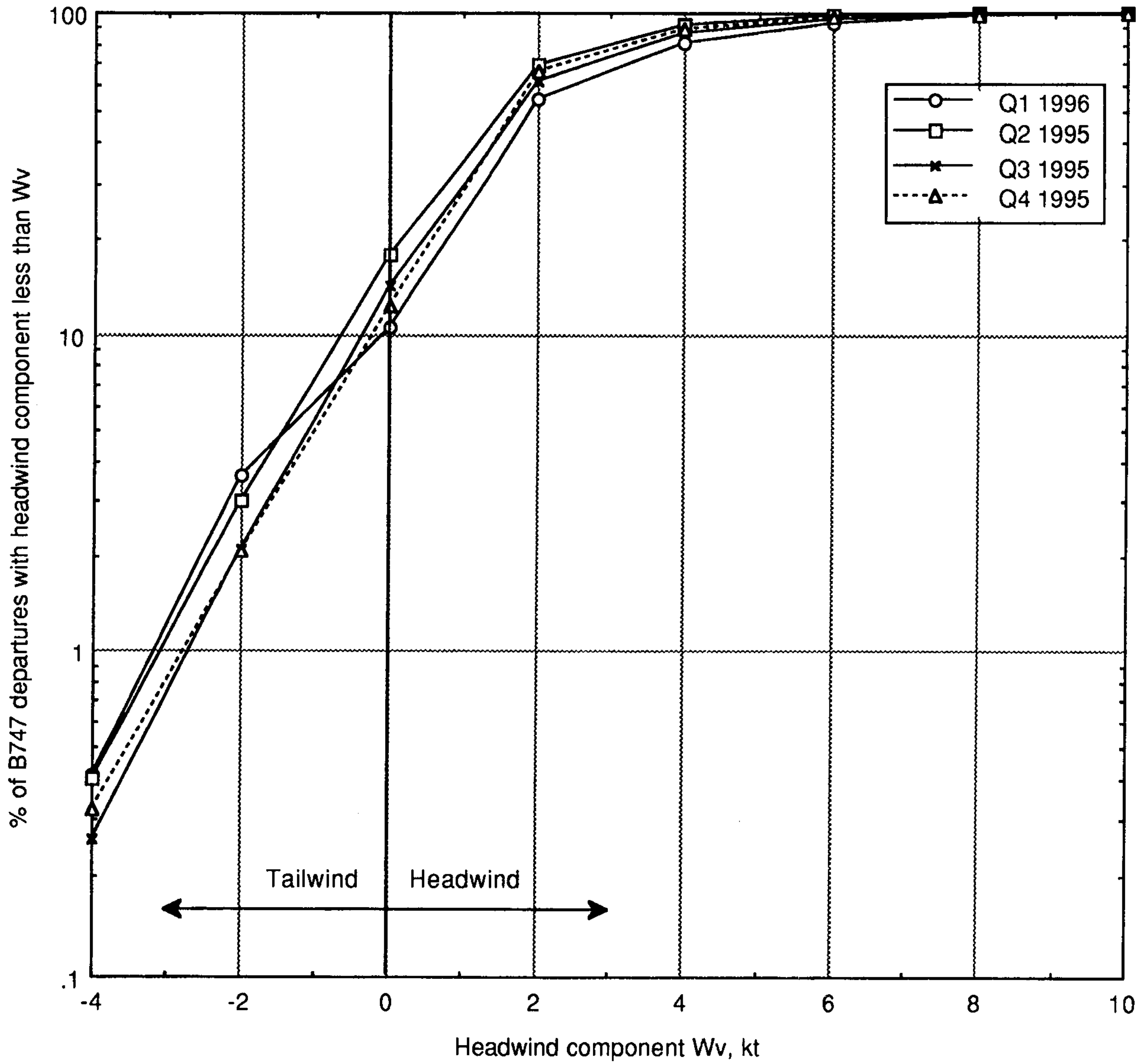


FIGURE 20

MONTHLY DISTRIBUTION OF HEADWIND/TAILWIND COMPONENTS:
ALL B747 DEPARTURES FROM RUNWAY 27L, HEATHROW

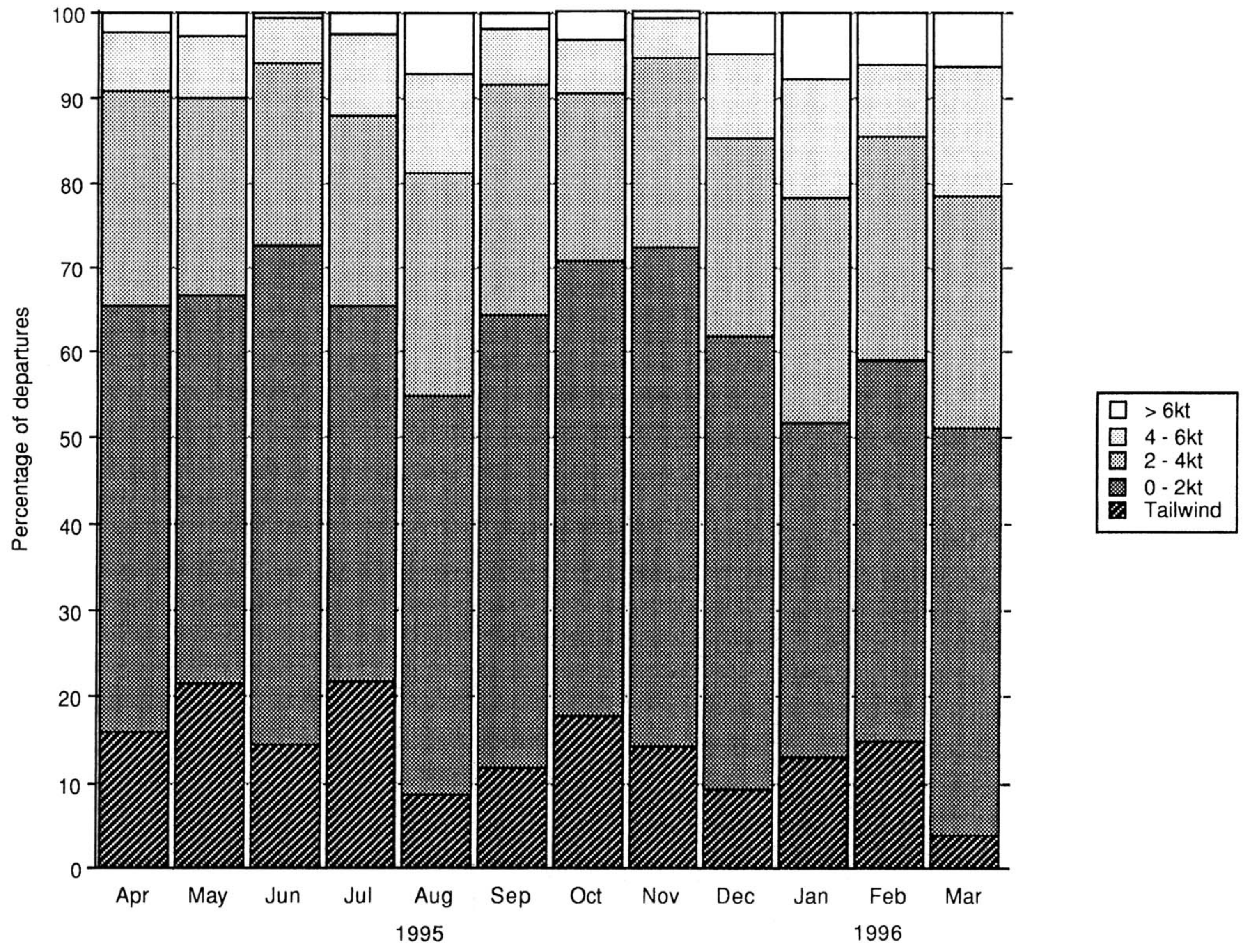


FIGURE 21

MEASURED VARIATIONS IN TEMPERATURE THROUGH DAY - JULY 1995

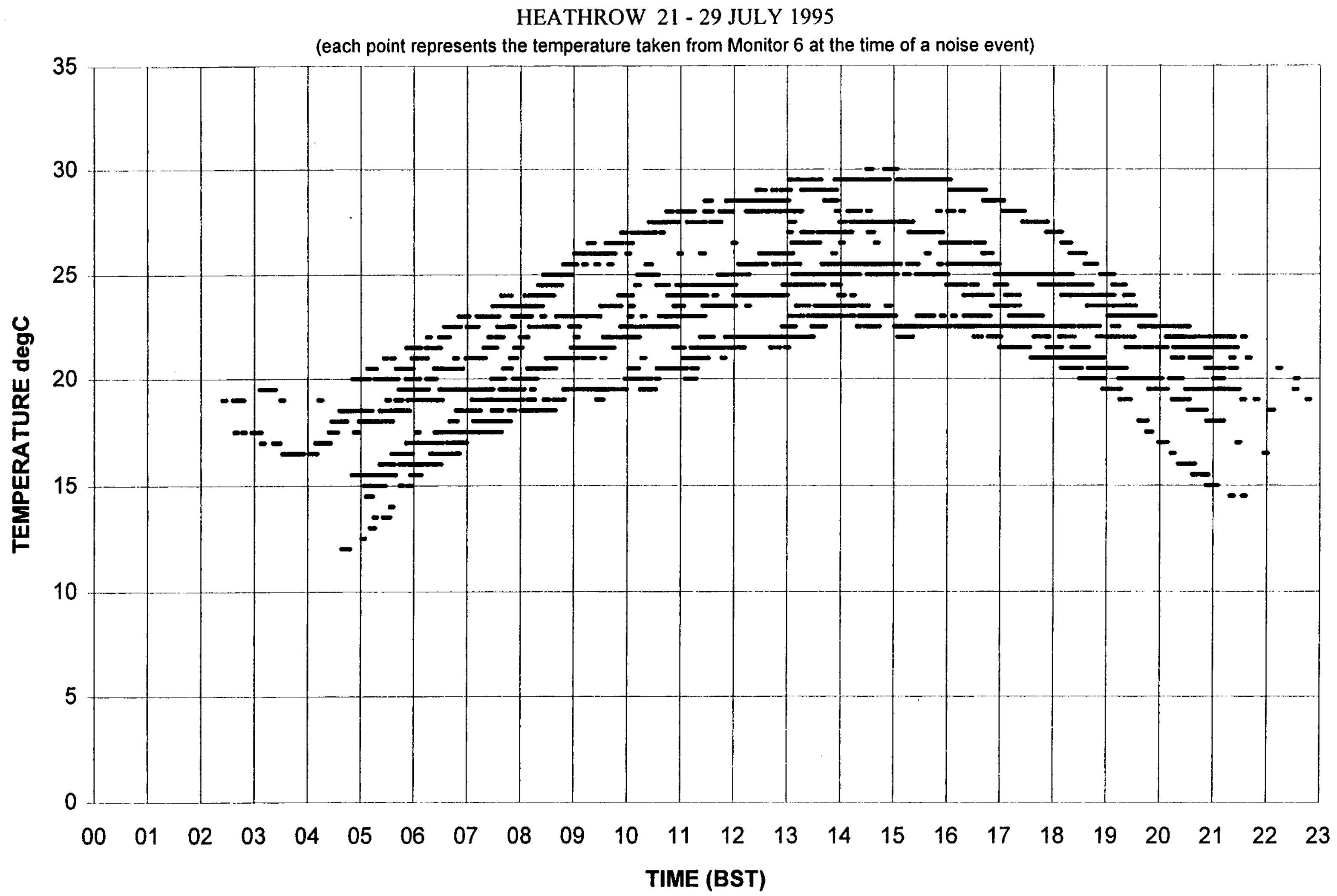


FIGURE 22a

B747-100: RELATIONSHIP BETWEEN EPNL AND Lmax(A)

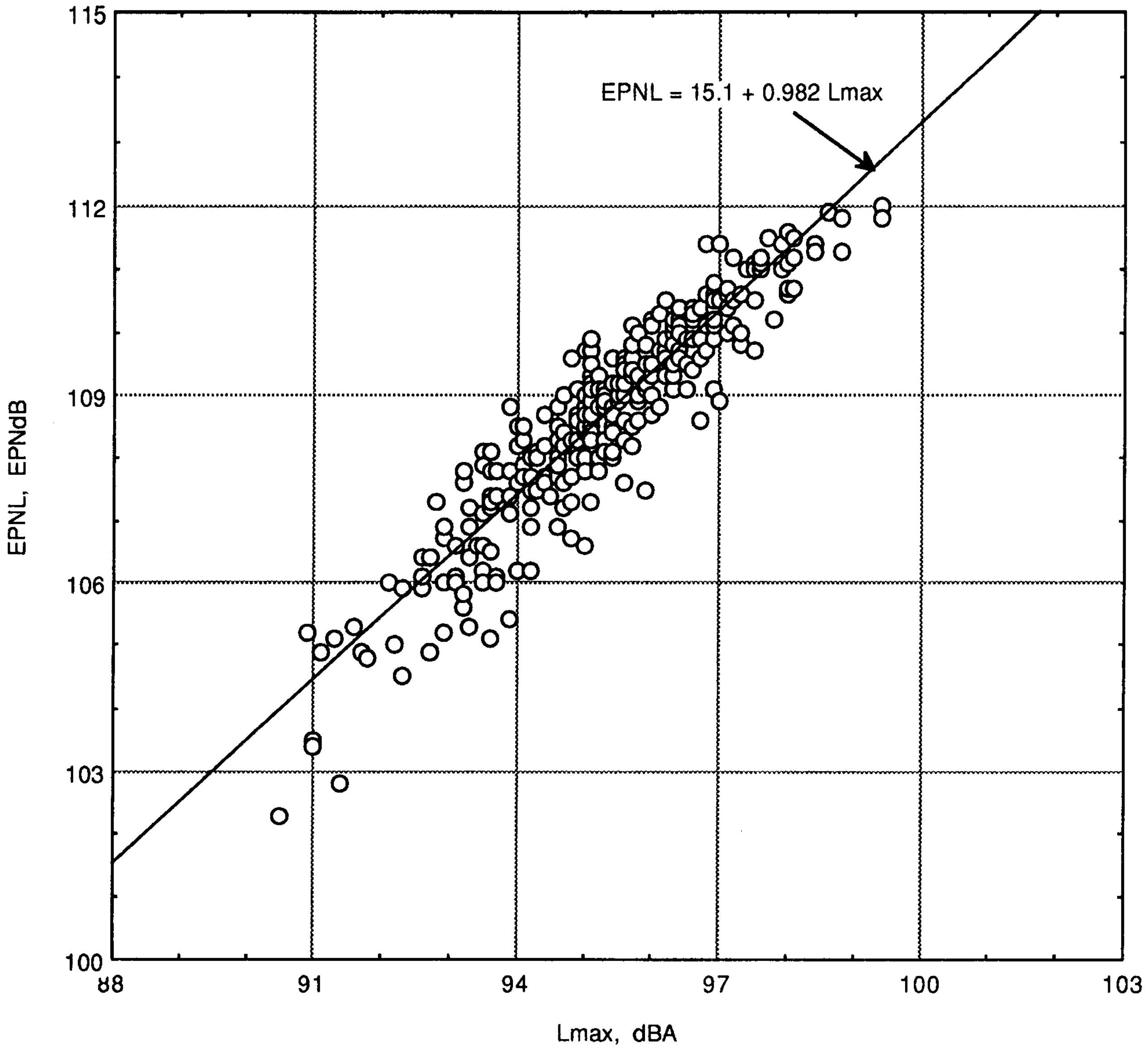


FIGURE 22b

B747-100 DEPARTURES
COMPARISON OF CERTIFICATION NOISE LEVELS AND DAYTIME LIMITS

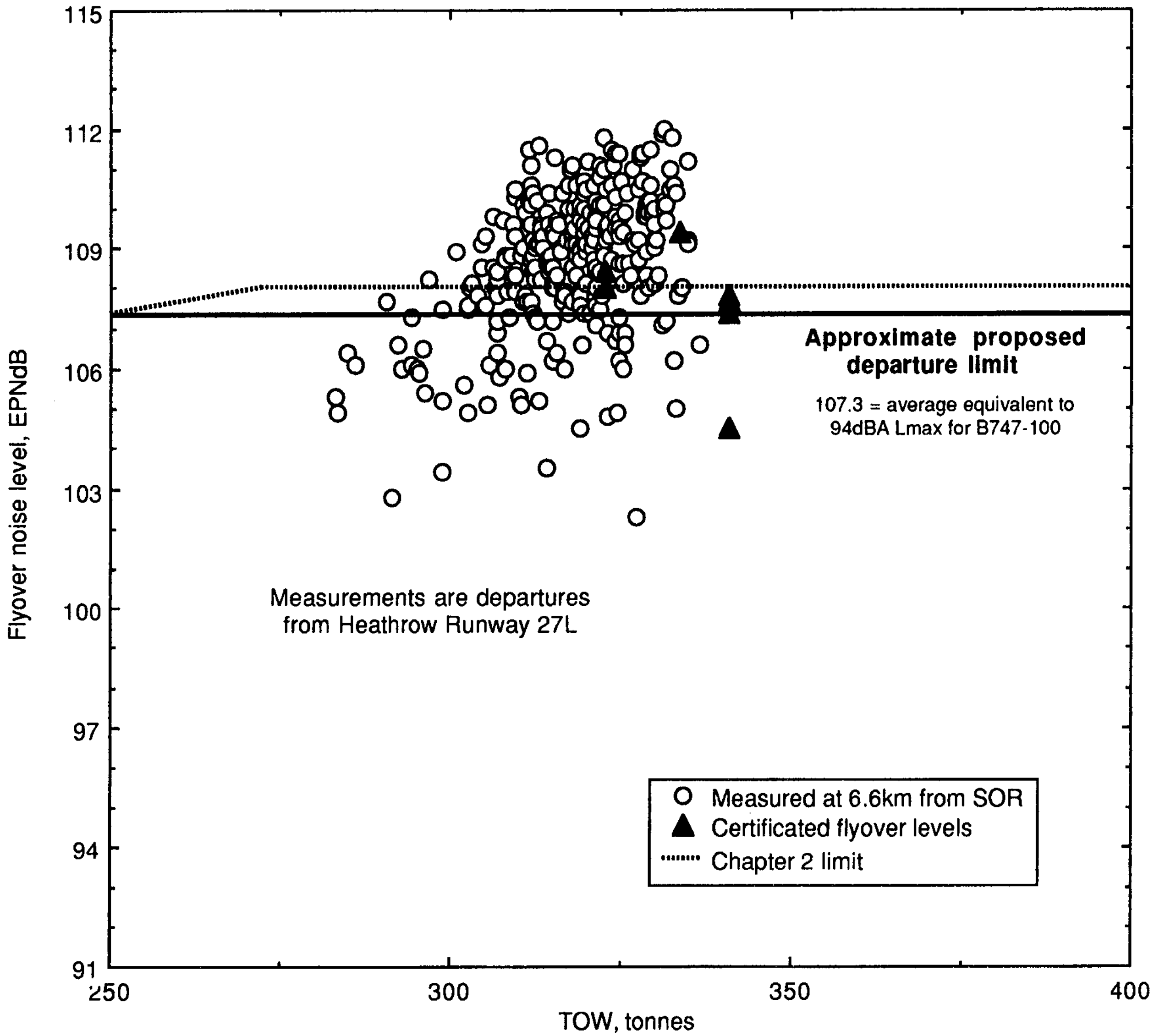


FIGURE 23a

B747-200: RELATIONSHIP BETWEEN EPNL AND Lmax(A)

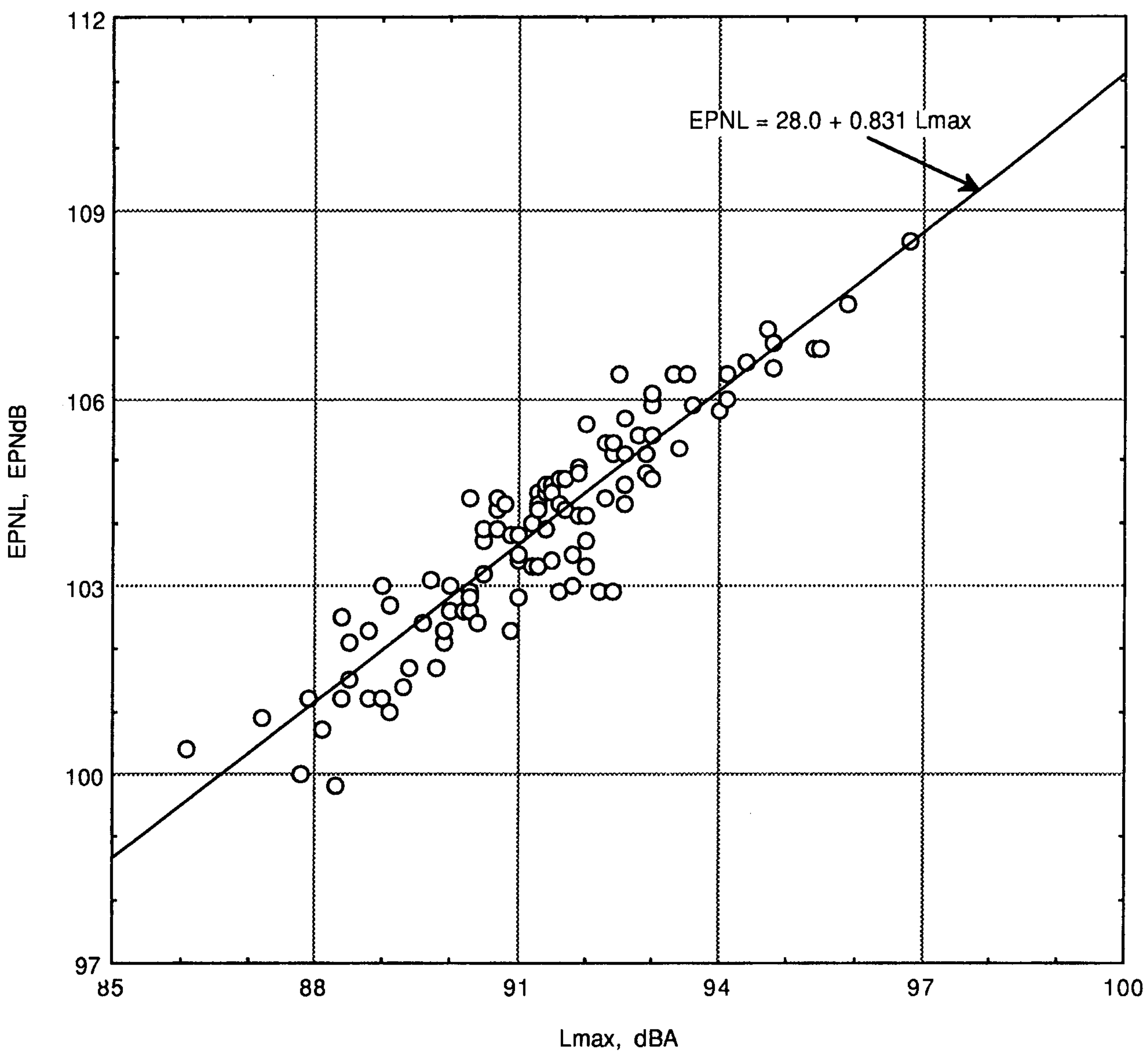


FIGURE 23b

CHAPTER 3 B747-200 DEPARTURES
COMPARISON OF CERTIFICATION NOISE LEVELS AND DAYTIME LIMITS

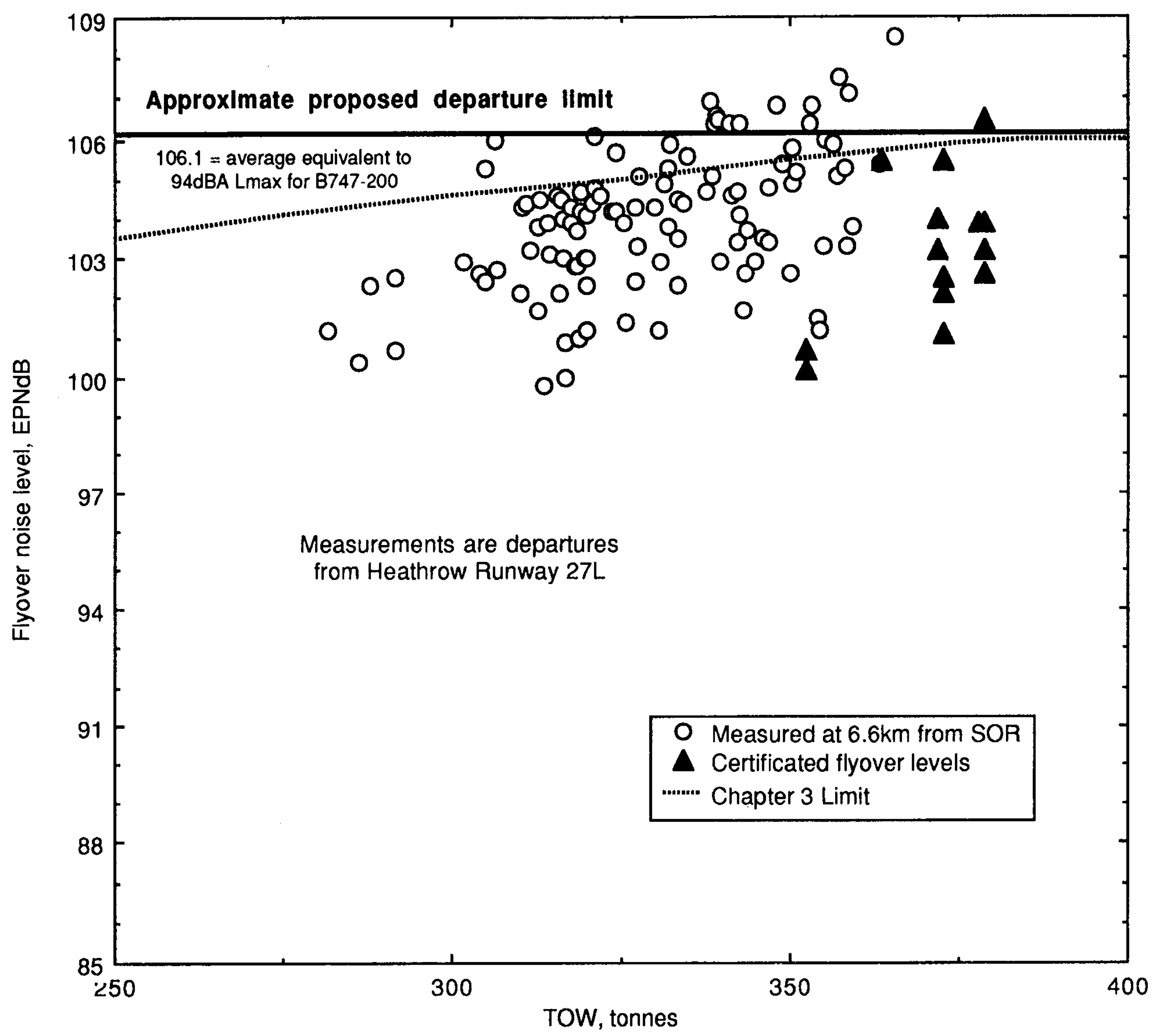


FIGURE 24a

B747-400: RELATIONSHIP BETWEEN EPNL AND Lmax(A)

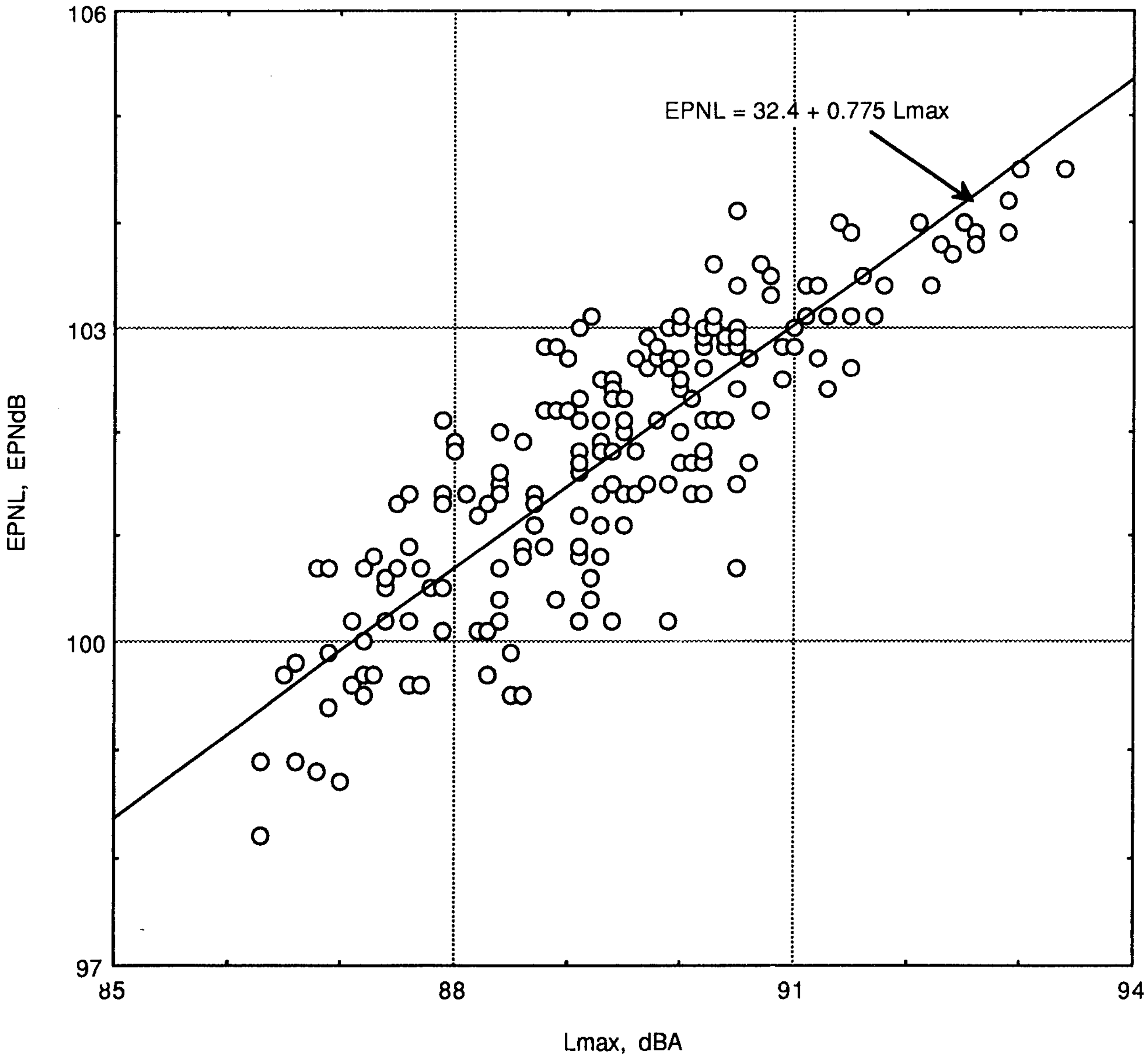
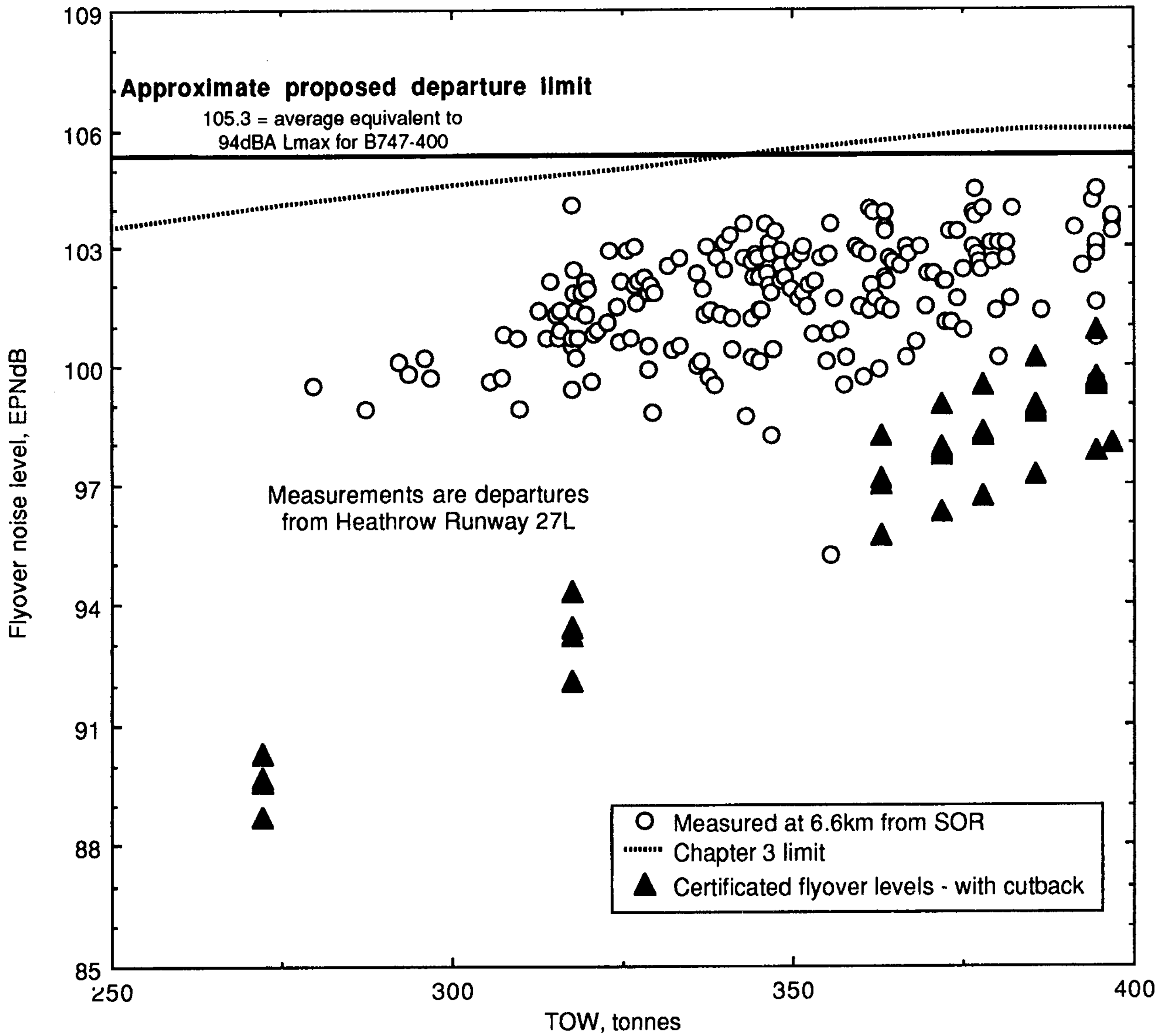


FIGURE 24b

B747-400 DEPARTURES
COMPARISON OF CERTIFICATION NOISE LEVELS AND DAYTIME LIMITS



APPENDIX A

ESTIMATION OF INFRINGEMENT RATES UNDER PROPOSED NEW MONITORING ARRANGEMENTS

A.1 Three different methods have been used in this supplementary study to estimate what rates of infringement B747 aircraft would have incurred during the 1995/6 study period had the enhanced monitoring arrangements been in place.

(a) Estimation based on main report

A.2 Table 4 of the main report (CS9539) indicated that 36% of Group B2 aircraft (Chapter 2 B747s) and 12% of Group B3 (Chapter 3 B747s) aircraft may be expected to exceed the proposed daytime Base Limit of 94dBA. The expected B747 infringement rates given below are taken from Table 8 of the main report which allows also for the estimated monitoring efficiencies of the various monitor arrays (see 'practical' arrays, -3dB):-

	Chapter 2 (Group B2)	Chapter 3 (Group B3)
Easterly operations (Runway 09R):	23%	5.8%
Westerly departures (Runways 27L and 27R):	20%	5.0%
Average*:	21.5%	5.4%

* The 1995/6 B747 departures were divided 48% easterly and 52% westerly; a simple arithmetic average is used here and elsewhere in this study

(b) Extrapolations from 1995/6 NTK data

A.3 The NTK database is not yet fully error free and considerable care is required when evaluating information extracted. The process that is most error-prone is the merging of noise, radar and flight information obtained from three different sources. This is done in two stages. The first is performed automatically by computer; this achieves a match for a large majority of aircraft movements. The second stage requires manual scrutiny to detect unmatched data and wrongly matched events; in most cases this identifies the reason for the failures, which can then be remedied. However, a small proportion of flights are not logged by the system and some records are incomplete, for example on occasions when the radar data are missing.

A.4 BAA monitor adherence to the noise limits by recording all noise events at all monitors and identifying those which exceed the limits[7]. Each record for a potential infringement is then checked against associated NTK data, and, if necessary, information from other sources in order to confirm that the event was due to an aircraft movement and to assure correct identification of the offending flight. This individual scrutiny is necessary to guard against errors due to missing or erroneous data or interference from non-aircraft noise. In this study, such detailed scrutiny has not been possible; apart from the exclusion of highly inconsistent data which are most likely to be erroneous, NTK data has been taken at face value (after it has been checked as described in paragraph A.3).

A.5 In what follows, "infringements" (in quotes) refer to potential rather than actual registered infringements, i.e. levels that exceed specified thresholds whether they refer to statistics taken from tables in the main report or data extracted from the NTK system.

A.6 In order to determine B747 "infringement" rates, detailed information on B747 departure numbers is required. For the specified 1995/6 period. BAA traffic data show that a total of 24,192 B747 departures occurred during daytime hours, 0700 to 2300 local time. For the same period, the NTK database was found to contain a total of 21,326 records identified as B747 departures, i.e. 88% of all B747 departures.

A.7 Table A1 gives the percentages of the 21,326 B747 departures in the 1995/6 data extracted from the NTK that exceeded (i) the present daytime noise limit, and (ii) a level 3dB below the current limit, at one or more of the existing fixed monitors, broken down by specific B747 models. The overall exceedance rates were:-

	Chapter 2	Chapter 3
Present monitors and limit:	1.59%	0.11%
Present monitors and 3dB lower limit:	11.95%	0.84%
Increase in "infringement" rate caused by lowering limit by 3dB:	x7.5	x7.6

These show that, proportionately, the effects of reducing the present limits by 3dB at the current monitors would have been to increase infringements by very similar factors for both Chapter 2 and Chapter 3 Boeing 747s.

A.8 The main report does not provide figures that can be directly compared with these NTK-measured "infringement" statistics because Tables 6 and 8 do not cover straightforward reductions of the noise limits at the existing monitor positions - only the combined effects of enhancing the monitor arrays

7 A measurement tolerance of 0.7dB is allowed by BAA before recording an infringement.

(including adjustments to individual limits to account for monitor displacements from the 6.5km reference arc) and lowering the limits. Table 8 of the main report gives the following expected infringement rates :-

	Chapter 2		Chapter 3	
Runway direction:	East	West	East	West
(a) Present monitors and limits:	0.7%	1.0%	0.1%	0.2%
(b) Enhanced arrays, 3dB lower limits*:	23%	20%	5.8%	5.0%

* adjusted to apply uniform limits at the 6.5km reference distance.

In view of the various simplifying assumptions underpinning the empirical methodology of the main report, the agreement between these expected "infringement" rates (a) and the observed rates of 1.59% (Chapter 2) and 0.11% (Chapter 3) for the 1995/6 period (paragraph A.7) is considered to be reasonable.

A.9 The above results can be expressed in terms of multiplicative factors, i.e. as increases over current B747 infringement rates that would be expected as a result of changes to the monitoring arrangements:

	Chapter 2			Chapter 3		
Runway direction:	East	West	Average	East	West	Average
(a) Present monitors and limits:	x1	x1	x1	x1	x1	x1
(b) Enhanced array, adjusted lower limits:	x33	x20	x26.5	x58*	x25*	x41.5*

*Less certain due to the limited resolution of the present infringement rate figures.

A.10 Thus, assuming they are separable from the effects of lowering the limits, which were estimated in paragraph A.7 to raise infringement rates by factors of 7.5 (Chapter 2) and 7.6 (Chapter 3), the corresponding effects of moving and adding monitors (and adjusting limits to 6.5km) can be expressed by average factors of 26.5/7.5 = 3.5 and 41.5/7.6 = 5.5 respectively. These can then be used to estimate what the B747 infringement rates would have been under the enhanced monitoring arrangements:-

	Chapter 2	Chapter 3
Present monitors and limit:	1.59%	0.11%
Present monitors and 3dB lower limit:	11.95%	0.84%
Enhanced array, 3dB lower limit adjusted to 6.5km:	11.95% x 3.5 = 42%	0. 84% x 5.5 = 4.6%

A.11 Table A1 also lists "infringement" rates for specific B747 models. The same enhancement factors are applied below to determine corresponding estimates of "infringement" rates for the more common variants:

	Chapter 2	Chapter 3
B747-100:	13.47 x 3.5 ~ 47%	-
B747-200:	9.33 x 3.5 ~ 33%	3.22 x 5.5 ~ 18%
B747-400:	-	0.25 x 5.5 ~ 1.4%

Note that all -100s have been assumed to be Chapter 2 (see paragraph A. 22), and all -400s are Chapter 3.

(c) Analysis of subset of 1995/6 data
c1: Measured Lmax distributions

A.12 This alternative method of analysing the 1995/6 data was to extract noise measurements that were representative of the proposed new arrangements. This required aircraft position to be determined from the NTK data. A subset of the 1995/6 NTK data, comprising more than 2,000 B747 departures for which matched weight data was also available, was extracted. These departures covered all months of the year and representative times of day.

A.13 Of the existing fixed units at Heathrow, and specifically for departures from Runway 27L, Monitor 6 is closest to the standard reference distance of 6.5km from start-of-roll (6.6km) and close to the extended runway centreline (see Figure 1 of the text). As the enhanced arrays will ensure that very few departures pass more than 300m to the side of a monitor, Monitor 6 noise measurements of aircraft departing from Runway 27L may be considered representative of data from the new system, provided more distant flight tracks are excluded.

A.14 The track of each aircraft was determined from the NTK data after 'smoothing' the positional coordinates to minimise the effects of random radar errors, as discussed in paragraph 4.9 of the main report, but using an alternative procedure described in Ref Al. Departures with a minimum horizontal distance from the monitor greater than 300m were discarded. Figure A1 shows distributions of L_{max} (relative to the current daytime limit) for the resulting sample of 930 B747 departures comprising 481 B747-100s (Chapter 2), 140 B747-200s (Chapter 3) and 309 B747-400s (Chapter 3). (Note that this sample did not contain any Chapter 2 B747-200s.) The solid lines through each set of data indicates a best-fit normal distribution.

A.15 The following "infringement" rates for this sample of 930 departures can be read directly from Figure A1:-

	Chapter 2	Chapter 3
B747-100:	55%	-
B747-200:	†	6%
B747-400:	-	0.06%*

* No events exceeded the limit; this estimate was made by fitting a normal distribution curve to the data following the method used to generate Table 4 of the main report.
† The special data subset included no Chapter 2 versions of the -200.

c2: Adjusted Lmax distributions

A.16 Figure A2 illustrates corresponding distributions of the estimated noise level L_{max} at ground level immediately beneath the aircraft (again relative to the current daytime limit). An estimate of this level has been calculated from the noise and radar data by adjusting the measured L_{max} for the difference between the minimum slant distance r and height h at the closest point of approach to Monitor 6 (see Figure A3), using the relationship:

$$L_{max}(adj) = L_{max} + 26.6 \log (r/h)$$

where the coefficient 26.6 gives a sound attenuation rate of 8dB per doubling of distance. This relationship is standard in DORA noise models and was used in the main study to normalise measured levels to the standard reference point.

A.17 The distributions in Figure A2 are directly comparable with the data in Table 4 of the main report (see paragraph A.24). The distributions of the 1995/6 data give Base Limit exceedance rates close to the standard reference point of :-

B747-100:	79%
B747-200:	22%
B747-400:	2.5%

To estimate "infringement" rates from these, the following average monitoring efficiencies are applied; these are taken from Table 8 of the main report (see 'practical' arrays, limit = -3dB):-

	Chapter 2	Chapter 3
Easterly departures	62%	49%
Westerly departures	56%	42%
Average	59%	46%

These give the following estimated "infringement" rates:-

	Chapter 2	Chapter 3
B747-100:	79 x 59% ~ 47%	-
B747-200:	-	22 x 46% ~ 10%
B747-400:	-	2.5 x 46% ~ 1.2%

Summary

A.18 The various estimates derived above using approaches (a), (b) and (c) (see paragraph 3.2 of the text) are summarised below. The disparities between the various estimates can be attributed to uncertainties inherent in the modelling procedures. It is not possible to attach weights to the different estimates of "infringement" rates; simple averages of (b), (c1) and (c2) are shown.

B747 model	Estimation method	Chapter 2 models	Chapter 3 models
All	(a)	21.5%	5.4%
All	(b)	42%	4.6%
-100	(b)	47%	-
	(c1)	55%	-
	(c2)	47%	-
	Average	*50%*	-
-200	(b)	33%	18%
	(c1)	-	6%
	(c2)	-	10%
	Average	*33%*	*11%*
-400	(b)	-	1.4%
	(c1)	-	0.06%
	(c2)	-	1.2%
	Average	-	*0.9%*

A.19 It is evident that, for all Chapter 3 B747s as a group, predictions (a) based on the main report methodology are in good agreement with extrapolations (b) based on 1995/6 NTK statistics. The breakdown of Chapter 3 "infringements" by B747 model shows that most Chapter 3 infringements would be by -200s. For Chapter 2 B747s, the predicted "infringements" (a) are about half of those expected on the basis of 1995/6 extrapolations (b). Of the Chapter 2 infringers, the - 100 model is the worst with an average estimated "infringement" rate of 50% compared with 33% for the Chapter 2 -200s.

A.20 The possibility that use of the results of the main report CS9539 underestimates Chapter 2 "infringement" rates is due to seasonal factors, i.e. the main study's reliance on April/May data, is considered in Sections 4 and 5 of the report. However it is also important to examine whether it may result, in part, from differences between the mixes of B747 types in the 1995/6 NTK database and in the main study sample.

B747 traffic mixes

A.21 The analysis in the main report was by broad aircraft type categories and combined data for all three airports. For the purposes of this supplementary study, a more detailed breakdown into B747 variants has been undertaken. The noise certification categories (Chapter 2 or 3) are shown separately for the 1995/6 traffic in Table A1. Of the eight B747 models identified, four include variants certificated to either Chapter 2 or Chapter 3 standards. These are the -100, -200, -200 Freighter and - 100/200 Combi (although there are very few Chapter 3 model -100s operating at Heathrow). The other models, the -300, -400, SP and -400 Freighter are Chapter 3 only. The noise categories have been identified from airframe and engine information stored in the NTK database. The same information has been used to update equivalent information given for the study sample in the main report. The results are summarised in the table below, which shows percentages of B747 departures:-

B747 Type	1995/6 NTK database (n = 21,326) Chapter 2	1995/6 NTK database (n = 21,326) Chapter 3	Main report study sample (n = 1,336) Chapter 2	Main report study sample (n = 1,336) Chapter 3
-100	17.8	15.8	1.6	-
-200	7.0	9.8	11.4	16.9
-300	-	3.0	-	3.3
-400	-	55.5	-	41.3
-1/200 Combi/ -200 Freighter	3.5	1.4	1.8	1.5
SP	-	1.8	-	6.4
-400 Freighter	-	0.2	-	-
All	28.3	71.7	29.0	71.0

A.22 Overall, the principal difference is the increase in the proportion of B747-400 departures, from 41.3% in the April/May 1994 sample to 55.5% in 1995/6, doubtlessly reflecting continuing replacement of older, noisier versions - mainly the -200. The proportions of -100s are very similar; the fact that a few Chapter 3 variants were present in the 1994 Heathrow sample had little bearing on the noise contributions of the -100s as there was no appreciable difference in the mean noise levels of the Chapter 2 and Chapter 3 versions (see main report, Table C4). It is noteworthy however that at Gatwick the Chapter 3 B747-100s were noticeably quieter than the Chapter 2 variants - by 3.8dB. These quieter -100s in the main study sample study were not matched by similar aircraft in the 1995/6 sample, which was restricted to Heathrow.

A.23 Within the Chapter 2 groupings, the distributions were as follows:-

B747 Type	1995/6 NTK database (n = 6,041) Number	%	Main report study sample[8] (n = 369) Number	%
-100	3,801	62.9	211	57.2
-200	1,500	24.8	134	36.3
-200 Freighter	740	12.3	24	6.5
All	6,041	100.0	369	100.0

This shows that although the proportions of Chapter 2 B747s in the two samples are very similar (paragraph A.21), the 1995/6 Chapter 2 traffic actually contained a higher proportions of the substantially noisier -100 models. However, although this would certainly lead to a higher percentage of infringements by Chapter 2 variants, it is unlikely that this difference alone explains the marked underestimation of the 1995/6 rate. It is therefore necessary to compare flight paths and noise levels within the two data sets.

A.24 Overlaid on Figure A2, which shows the distributions of the adjusted noise levels of the special subset of 930 B747 departures from Heathrow Runway 27L, are the generalised curves for B747 groups B2 and B3 from Table 4 of the main report. These are comparable as they relate to noise levels beneath the aircraft at the 6.5km reference distance (Monitor 6 is at 6.6km from start-of-roll). Immediately apparent is that the shapes of the B2 and B3 curves are markedly different from those for the individual B747 variants.

A.25 The different shapes are a reflection of the substantially higher variances of the main study data. This is partly because they each combined data from a

[8] Excluding 15 B747SPs indicated as Chapter 2: these aircraft have noise characteristics much more typical of the Chapter 3 B747s.

number of different B747 models at Heathrow, Gatwick and Stansted. However, assuming that the -100 and -400 models typify the most and least noisy versions of the B747, it is apparent that factors other than the mix of types influenced the B2 and B3 curves (the distribution for any mix of B747-100, -200 and -400 departures would fall between the -400 and -100 curves).

A.26 There are probably many reasons, the most significant of which is the fact that the main study sample was gathered from 11 different monitors at three airports and thus encompassed a wider range of B747 types and operating procedures. The differences between the two study samples for the B747 -100s and -200s are evident in Figure A4 which shows the vertical and lateral displacements of the aircraft as they pass the monitor and Figure A5 which shows the measured Lmax plotted against the minimum slant distance to the aircraft. It is evident that the original sample included many faster climbing departures, particularly among B747-200s.

REFERENCE

A1 RAP (Radar Analysis Program) - An Interactive Computer Program for Radar Based Flight Path Reconstruction and Analysis: S Roberts et al: ISASI Forum Seminar Proceedings: 1994

TABLE A1 - B747 DEPARTURES RECORDED AT HEATHROW FIXED MONITORS JULY 1995 - JUNE 1996

Type	Chapter	Departures	Number exceeding:		Percentage exceeding:	
			Present Limit	Present Limit - 3dB	Present Limit	Present Limit - 3dB
B747-100	2	3,801	48	512	1.26%	13.47%
B747-200	2	1,500	41	140	2.73%	9.33%
	3	2,083	10	67	0.48%	3.22%
B747-300	3	643	2	30	0.31%	4.67%
B747-400	3	11,842	5	30	0.04%	0.25%
B747	2	405	4	45	0.99%	11.11%
-1/200 Combi	3	56	0	0	0.00%	0.00%
B747	2	335	3	25	0.90%	7.46%
-200 Freighter	3	223	0	1	0.00%	0.45%
B747SP	3	389	0	1	0.00%	0.26%
-400 Freighter	3	49	0	0	0.00%	0.00%
All	100.00%	21,326	113	851	0.53%	3.99%
All Chapter 2	28.33%	6041	96	722	1.59%	11.95%
All Chapter 3	71.67%	15285	17	129	0.11%	0.84%

FIGURE A1

Lmax DISTRIBUTIONS AT HEATHROW MONITOR 6: 6.6KM FROM START OF ROLL

B747 DEPARTURES FROM RUNWAY 27L THAT PASS WITHIN 300m TO SIDE OF MONITOR

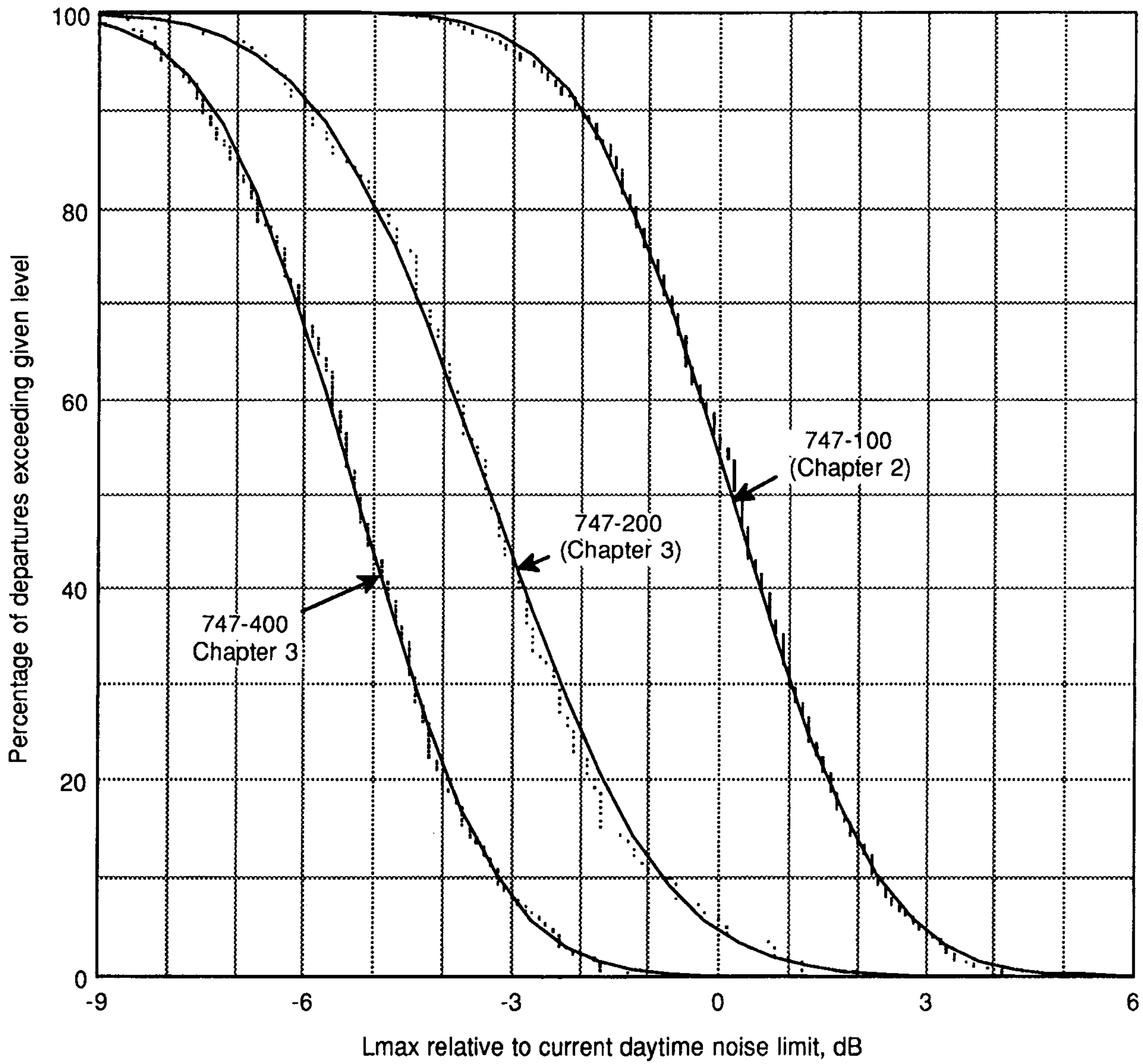


FIGURE A2

COMPARISON OF ADJUSTED NOISE LEVEL DISTRIBUTIONS WITH MAIN REPORT

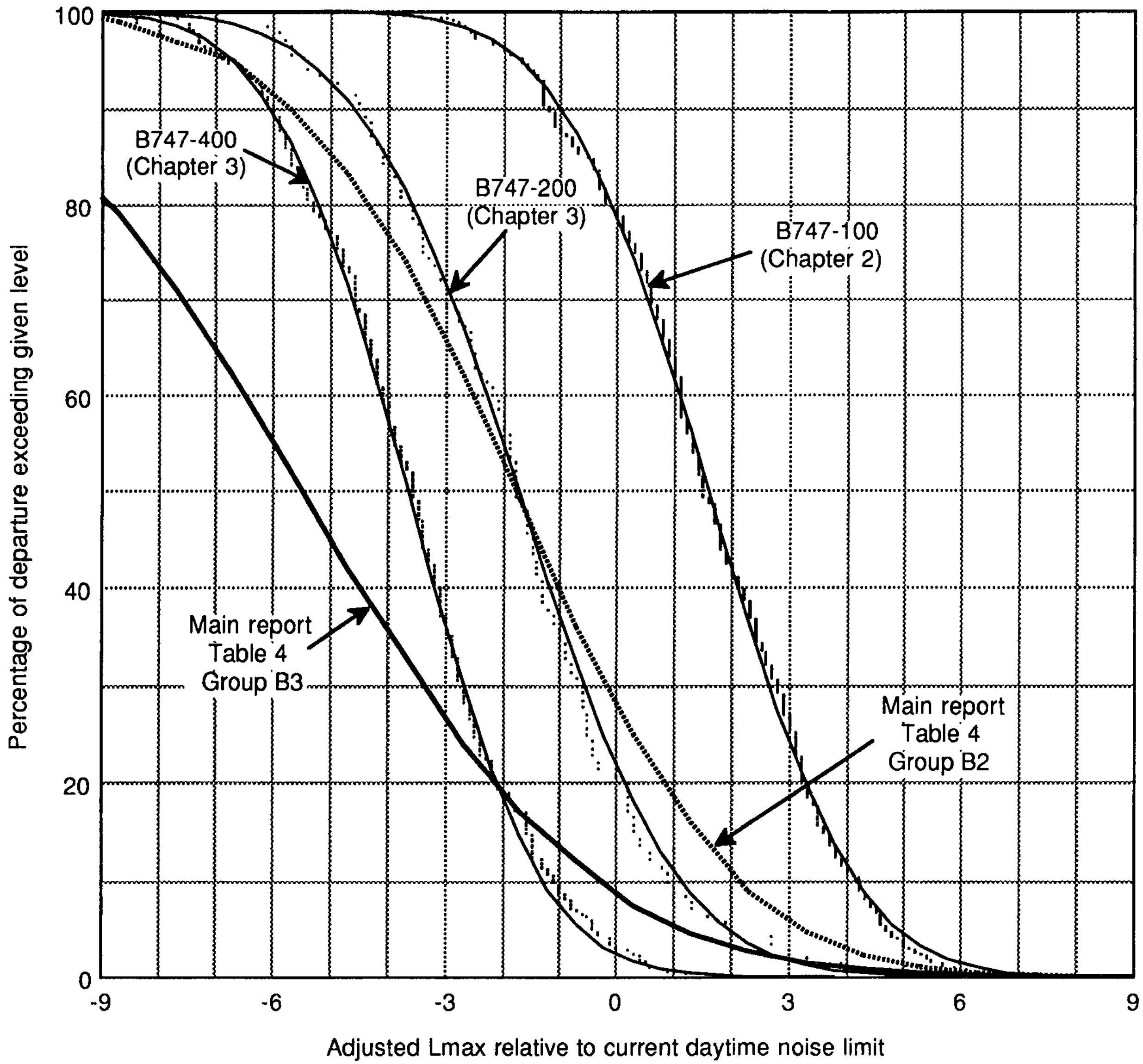


FIGURE A3

CALCULATION OF ADJUSTED L_{max}

L_{max} (adjusted) = L_{max} (measured) + 26.6 log (r/h)

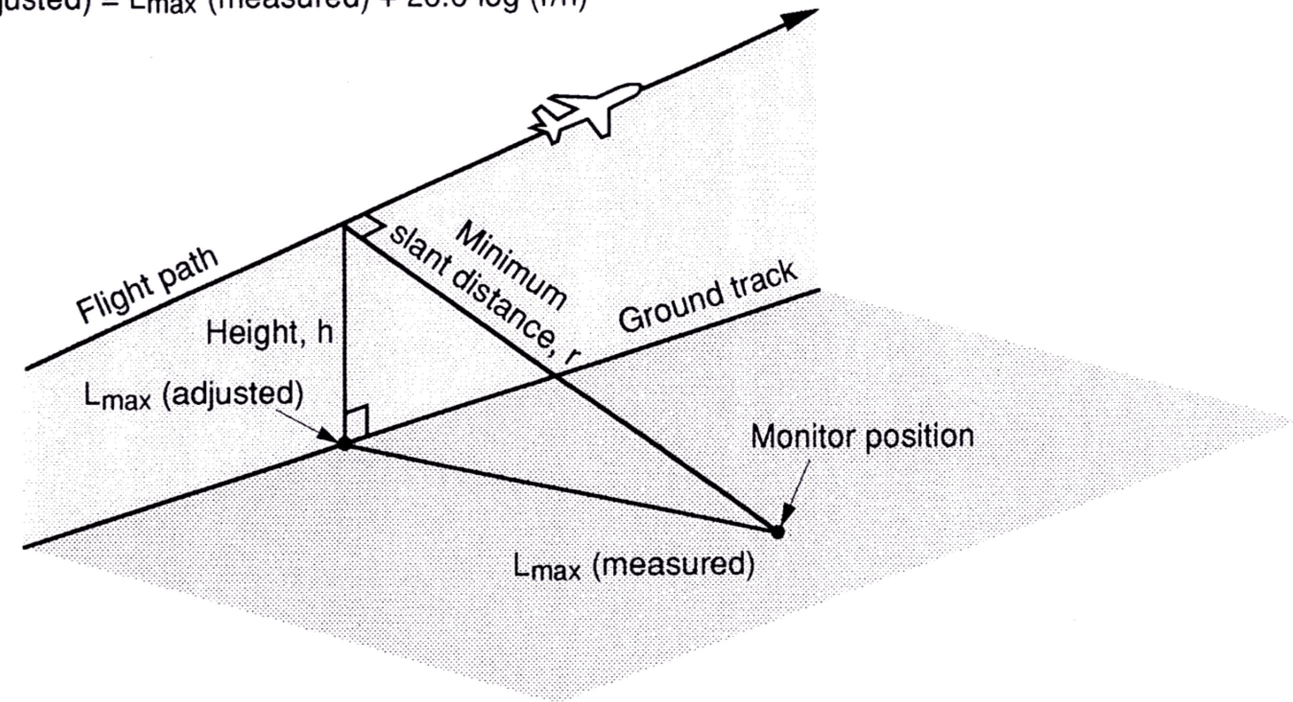


FIGURE A4

COMPARISON OF MAIN STUDY AND 1995/6 NTK B747-100 AND B747-200 SAMPLES: AIRCRAFT HEIGHT v LATERAL DISPLACEMENT

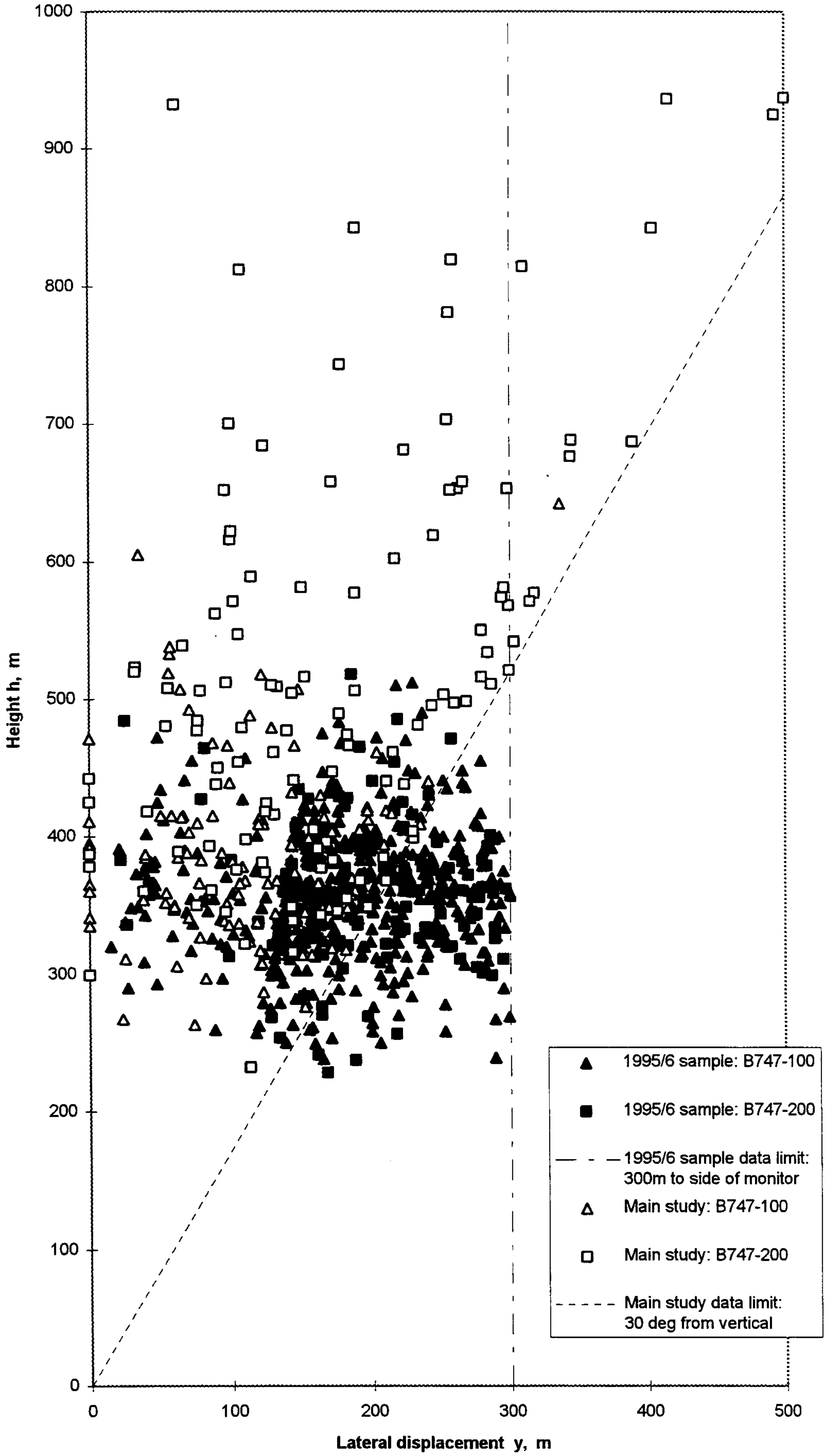


FIGURE A5

COMPARISON OF MAIN STUDY AND 1995/6 NTK B747-100 AND B747-200 SAMPLES: LAmax v MINIMUM SLANT DISTANCE