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HEATHROW DEPARTURES NOISE STUDY

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1. INTRODUCTION

During aircraft departure operations, the available power after overcoming drag has to be converted into kinetic energy to accelerate to cruising speed and into potential energy to climb to cruising altitude. Putting more energy into accelerating the aircraft leaves less available for the climb and vice versa. The high lift devices (flaps) fitted to the wing leading and trailing edges allow the aircraft to climb away from the runway at relatively low speeds but they also increase drag. It is important to withdraw the flaps as soon as possible to minimise energy wasted in overcoming drag, but this cannot be done until the airspeed is high enough to allow the aircraft to continue to climb without them. Unfortunately, the additional drag associated with the flaps limits the ability of the aircraft to accelerate to a speed at which the flaps can be withdrawn. On top of all this, the engines must be cut-back from the take-off power setting to climb power at some appropriate stage during the climb out. This further limits operational flexibility to trade acceleration for rate of climb.

Noise on the ground at different distances away from the airport depends both on the noise at source and on the height reached when the aircraft passes over the receiver point. Noise at source can be reduced by cutting back from take-off power to climb power at some appropriate safe height. Directly beneath the point of cut-back, noise levels on the ground will be correspondingly reduced. Moving further out, there will eventually arise a point at which the reduction in noise level at source is cancelled out by the effects of the aircraft climbing at a slower rate. In addition, choosing between acceleration and rate of climb will also affect the height achieved at different distances along the route and the amount of time and fuel needed to reach the optimum cruising speed and altitude.

There are standard departures procedures agreed between the operators, aircraft manufacturers and airport authorities designed to optimise noise levels on the ground. Manufacturers are able to carry out theoretical calculations of the likely costs and benefits of adopting different departures procedures, but as far as we are aware, this is the first time that a large scale empirical trial has been carried out under normal operational conditions using current large aircraft types such as the B747 series.

2. DEPARTURES PROCEDURES TESTED

The current B747 departures procedure (designated C in these trials) adopted by British Airways at Heathrow has been adapted from the ICAO B procedure to maximise aerodynamic efficiency independently of noise considerations. Following consultation with the Boeing Airplane Company, two alternative departure procedures (A and B) were selected by British Airways for comparison against the standard procedure to investigate the potential for improvements in noise levels at increasing distances from the start of roll position on the ground.

Procedure A - 1000 ft cut-back
Climb to 1000 ft at take-off thrust and flaps at V2 + 10-25 knots.
At 1000 ft, cut-back to climb thrust, reduce rate of climb and accelerate to flaps 10.
Continue climb to 4000 ft at Vflap10 + 10 knots.
At 4000 ft cut-back further to lower climb thrust, further reduce rate of climb and accelerate to flaps 0.
Continue climb to cruising altitude.

Procedure B - 1500 ft cut-back (ICAO A)
Climb to 1500 ft at take-off thrust and flaps at V2 + 10-25 knots.
At 1500 ft cut-back to climb thrust, but maintain take-off flaps.
At 3000 ft reduce rate of climb and accelerate to flaps 0.
When cleaned up, cut-back to lower climb thrust and continue to cruising altitude.

Procedure C - current (modified ICAO B)
Climb to 1000 ft at take-off thrust and flaps at V2 + 10-5 knots.
At 1000 ft, reduce rate of climb and accelerate to flaps 5.
At flaps 5 (between 1500 ft and 2000 ft), cut-back to lower climb thrust.
On cut-back, reduce rate of climb further and accelerate to flaps 0.
Continue climb to cruising altitude.

Under the current procedure based on a modified ICAO B (designated C in these trials), the first thrust cut-back occurs at between 1500 ft and 2000 ft, by which time the aircraft has already gained significant height and speed. V2 is the design take-off safety speed and is defined as the lowest steady flight speed which the aircraft is required to maintain to be able to climb safely from 35 ft after a single engine failure. Under the ICAO A procedure (designated B in these trials), the first thrust cut-back occurs at 1500 ft, which is mostly earlier than under the current procedure designated C in these trials. The flaps are maintained at the take-off setting up to 3000 ft. This means that the rate of climb is increased compared to the current procedure but the airspeed remains quite low and the amount of energy wasted in overcoming drag is quite high until the aircraft can be cleaned up above 3000 ft. Under the 1000 ft cut-back procedure (designated A in these trials), the main engine noise generated at source is cut-back earlier still, but the subsequent rate of climb is maintained at the cost of keeping the speed down right up until the aircraft can be cleaned up above 4000 ft.

British Airways allocated the three procedures alternately on successive days to selected B747-100, -200, and -400 series aircraft where previous experience had shown that aircraft would be generally heavier. A total of 2214 Aircraft Communications, Addressing and Reporting System (ACARS) reports transmitted to BA Aircraft Performance Engineering relating to departures between 1st June and 30th September 1997 were examined to extract data for 524 departures flying along the noise monitored routes and conforming to the parameters set for the study. The detailed management of the trials involved some additional training and a considerable amount of organisation by British Airways staff.

3. NOISE MONITORING

Four noise monitors were deployed under the Brookmans Park and Wobun departure routes off the 27L runway at Heathrow at the following distances from the start of roll point. Unfortunately, the data collected at a fifth noise monitoring position could not be used because of technical problems. Noise monitor 17 is one of the permanent positions specified by the DETR to monitor the departure noise limits. The other noise monitors, 101 to 103 are portable instruments which were temporarily positioned at the distances shown for the purposes of this study.

NTK number	Site	Distance (approx)
101	Horton Road, Stanwell Moor	4.6 km
17	Horton Depot, Horton	6.7 km
102	Churchmead School, Dachet	10.5 km
103	Cricket Pavilion, Agars Plough playing field	12.3 km

Individual noise event records obtained for each noise monitor position via the BAA Heathrow Noise and Track Keeping (NTK) system were matched by date and flight number against the BA ACARS data to obtain a total sample of 478 departures for which complete records exist. The reason for obtaining such a large sample size was simply to increase the statistical precision of the results, particularly in the light of expected variability due to other factors and of the small differences in average noise level expected.

4. RESULTS

The mean L_{Amax} noise levels for each aircraft type variant, procedure and noise monitor position are given below. A is the special trial procedure (cut-back at 1000 ft), B is the standard ICAO A procedure (cut-back at 1500 ft), and C is the current, modified ICAO B procedure (cut-back at flap 5 selection at between 1500 ft and 2000 ft), all as described above.

Mean L_{Amax} noise levels by aircraft type variant, procedure, and noise monitor

Type	Procedure	Sample	4.6 km	6.7 km	10.5 km	12.3 km
747-100	A	17	104.6	90.2	86.2	85.4
747-100	B	12	104.5	92.8	85.4	84.9
747-100	C	27	103.9	92.9	84.5	84.2
747-200	A	18	100.1	87.8	85.0	83.7
747-200	B	20	100.1	90.5	83.3	83.3
747-200	C	22	99.6	90.1	84.2	83.0
747-400	A	136	99.8	89.6	84.2	82.8
747-400	B	100	99.5	91.1	82.3	81.7
747-400	C	126	99.3	90.8	83.9	83.1

The standard deviations within each cell of the above table vary between around 1 to 2 dB for the B747-400 and between around 1 to 3 dB for the older B747-100 and B747-200. Taking into account the much smaller overall sample sizes for the B747-100 and B747-200, this means that differences between procedures of around half a decibel can be considered to be statistically significant for the B747-400 and that differences between procedures of around one decibel can be considered to be statistically significant for the B747-100 and B747-200.

For the B747-400 a more comprehensive statistical analysis was carried out using all available additional variables such as take-off weight, take-off EPR (engine pressure ratio - used as an indicator of the main engine thrust setting), cross wind, head wind, cross wind and head wind at 1000 ft, time of day, height over the monitor, and lateral deviation to either side of the monitor position. Interestingly, individual L_{Amax} noise levels at the 6.7 km monitoring position in particular were found to be positively correlated with the time of day, but this may well have had something to do with an observed tendency for the take-off weight, and consequently, take-off EPR, to increase during the day. The individual L_{Amax} noise levels were found to be strongly negatively correlated with the height over the monitor at 4.6 km, 10.5 km and 12.3 km, but at the 6.7 km monitoring position the lateral deviation seemed to be more important. The first turn to the north west has to be completed just before reaching this monitor position and this probably contributed to larger than average lateral deviations here. Individual L_{Amax} noise levels were highly correlated with individual SEL noise levels as would be expected.

A subsequent multiple linear regression analysis demonstrated a complex pattern of apparent relationships between the different variables. There was no effect of the departures procedure at the 4.6 km monitor position, as expected, but the statistical significance of the observed differences in mean L_{Amax} and SEL noise levels at the noise monitors further out appeared to have been partially confounded by co-variation in other variables, such as the tendency for take-off weight to increase during the day. On the other hand, it should be borne in mind that what was being tested here was the effect of alternative departure procedures over which British Airways have some control (and which were applied effectively randomly in the study), and not the effect of all the many other variables such as atmospheric conditions over which they have no control whatsoever. Given the fact that none of these other variables were (or even could have been) controlled or even systematically varied during the study, then there is no reason to doubt the general tendency of the results as shown in the table above. However, it is certainly relevant that the effect of day-to-day and hour-by-hour variation in meteorological and other factors appears to be at least as important as the precise departure procedure adopted.

The results can be summarised as follows;

Cut-back at 1000 ft - Procedure A

4.6 km	No differences between procedures.
6.7 km	A significant reduction in noise level as compared to the current procedure.
10.5 km	A significant increase in noise level for the B747-100 as compared to the current procedure. A smaller (marginally significant) increase in noise level for the B747-200 as compared to the current procedure. No difference in noise level for the B747-400 as compared to the current procedure.
12.3 km	A significant increase in noise level for the B747-100 as compared to the current procedure. A smaller (marginally significant) increase in noise level for the B747-200 as compared to the current procedure. No difference in noise level for the B747-400 as compared to the current procedure.

Cut-back at 1500 ft - Procedure B

4.6 km No differences between procedures.

6.7 km No differences between procedures.

10.5 km A small (marginally significant) increase in noise level for the B747-100 as compared to the current procedure. A small (marginally significant) reduction in noise level for the B747-200 as compared to the current procedure. A significant reduction in noise level for the B747-400 as compared to the current procedure.

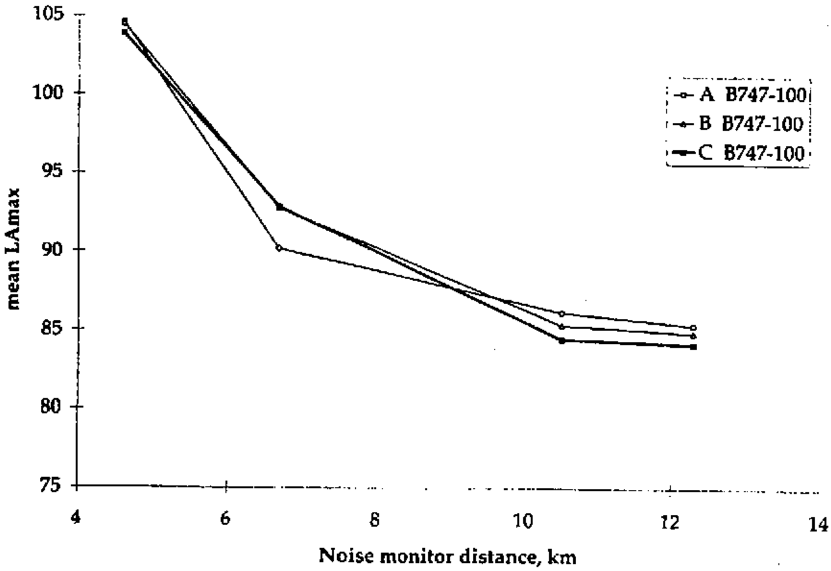
12.3 km A small (marginally significant) increase in noise level for the B747-100 as compared to the current procedure. No difference in noise level for the B747-200 as compared to the current procedure. A significant reduction in noise level for the B747-400 as compared to the current procedure.

The results for the B747-100 and B747-200 are less significant overall than for the B747-400 because of the very much smaller measurement sample sizes.

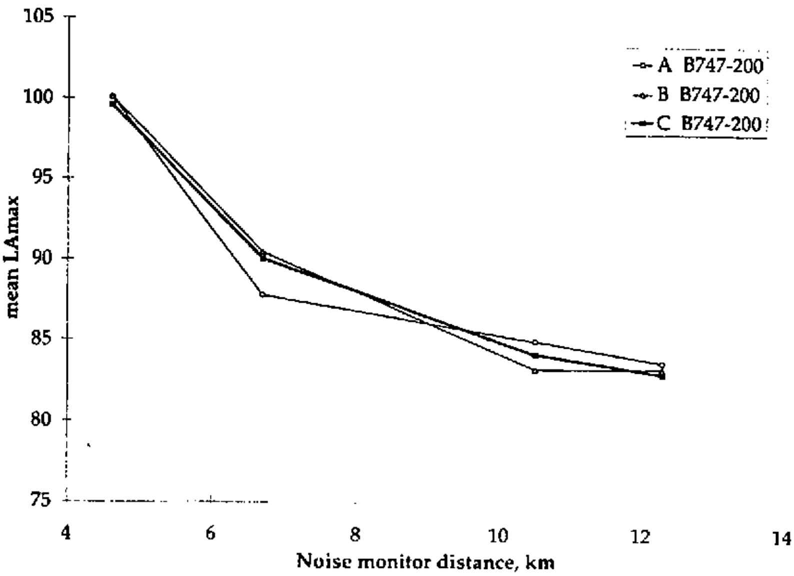
5. CONCLUSIONS

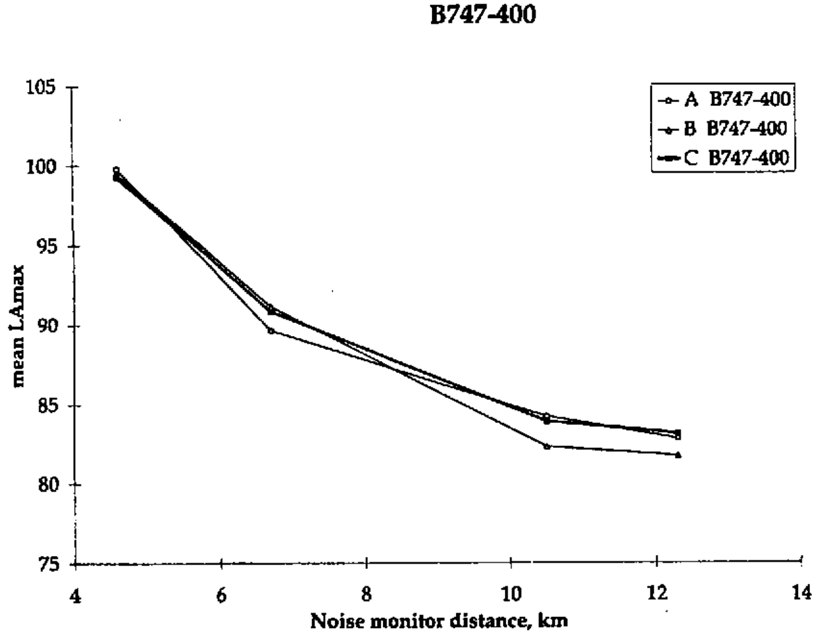
The analysis of the data shows that an early cut-back at 1000 ft can give significant reductions in average noise level at the 6.7 km noise monitor position for all B747 type variants. However, this improvement is not maintained further out and can even lead to higher noise levels for the B747-100 and B747-200 at 10.5 km and 12.3 km. A later cu-back at 1500 ft has no effect at the 6.7 km noise monitor position but shows clear benefits for the B747-400 at 10.5 km and 12.3 km.

B747-100



B747-200




B747-400
A B747-400
B B747-400
C B747-400
105
100
95
90
85
80
75
mean LAmax
4
6
8
10
12
14
Noise monitor distance, km