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Characteristics of daily aircraft noise near Heathrow Airport, the Reduced Noise Impacts of Short-Term Aircraft Noise (RISTANCO) project

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ABSTRACT

Daily aircraft noise exposure levels in 2014-2018 at ~155,000 postcodes in the vicinity of Heathrow airport with combined population ~6.3 million was modelled, using version 3b of the Aviation Environmental Design Tool (AEDT). This provided a comprehensive set of average 'A' frequency weighted daily noise estimates (2014-2018) at eight time-bands corresponding to airport activity, and number of noisy flight events exceeding a maximum sound level (65 decibels (A) N65 in daytime, 60 decibels (A) N60 at night, 2018 only). The morning shoulder period (06:00-07:00) had the highest mean noise (50.92 dB) per day per postcode and an average of 3 noisy flight events during the hour. During daytime hours (07:00-15:00), the average aircraft noise level was 49.87 dB, with an average of one noisy flight event per hour. The mean noise levels during the late night (23:00-24:00) and early morning (24:00-04:30) were 41.06 dB and 29.81 dB respectively. The results of the pairwise correlation analysis showed high correlation (Coefficient range: 0.68-0.90) between commonly used metrics including Lday, Laeq24, Leve and Lnight. However, when looking at correlations between noise levels in the eight time bands, correlations were generally weak. Aircraft noise exposure levels during night-time (04:30-06:00h, 23:00-24:00h and 24:00-04:30h) had a larger coefficient of variation (38.08-74.16) compared to daytime levels. This finding suggests that nighttime noise may have greater day-to-day variability than daytime noise. Our results suggest non-standard noise metrics and noisy event metrics may provide important characteristics of noise exposure, with potential relevance for impacts on biological systems.

Keywords: Daily aircraft noise, LAeq, N60/N65, Metrics, Heathrow airport,

Introduction

London Heathrow Airport is located on the outskirts of west London, a densely populated area meaning that several million people are exposed to aircraft noise. The UK Civil Aviation Administration (CAA) models population exposures to aircraft noise, using the UK Civil Aircraft Noise Contour Model ANCON [1, 2]. The model provides standard metrics, such as Lnight and Lden, which quantify the yearly average noise levels experienced over specific periods (e.g., 23:00-07:00h for Lnight and a 24-hour period for Lden). Numerous studies have employed these metrics to investigate the relationship between chronic aircraft noise exposure and various health outcomes [3-10].

However, there are limited data on non-standard metrics, such as daily aircraft noise exposure, daily aircraft noise events, and temporal variation in aircraft noise near Heathrow airport. These non-standard metrics may provide important insights into the acute impacts of noise exposure on health, which could be overlooked when using standard metrics.

As a part of the Reduced Noise Impacts of Short-Term Aircraft Noise (RISTANCO) project, which is evaluating the association between short-term aircraft noise and health outcomes, the daily aircraft noise exposures at different times of day were modelled from January 1st, 2014, to December 31st, 2018, for approximately 155,000 postcodes within the outer bounds of the CAA's annual-average aircraft noise contours in 2011. This provided us with a very large and detailed dataset on daily noise exposure at postcode level (an average of 53 inhabitants and 22 occupied households based on 2011 census data) near Heathrow airport.

The objective of this paper is to characterise non-standard metrics, with the aim of improving our understanding of noise exposure near Heathrow airport and informing policy decisions to reduce the health impact of noise exposure on the population. By comparing both standard and non-standard metrics, we hope to broaden our comprehension of their use in future health analyses, enabling more accurate evaluations of the underlying mechanisms with the most suitable noise metrics.

Method

Study time, area, and population

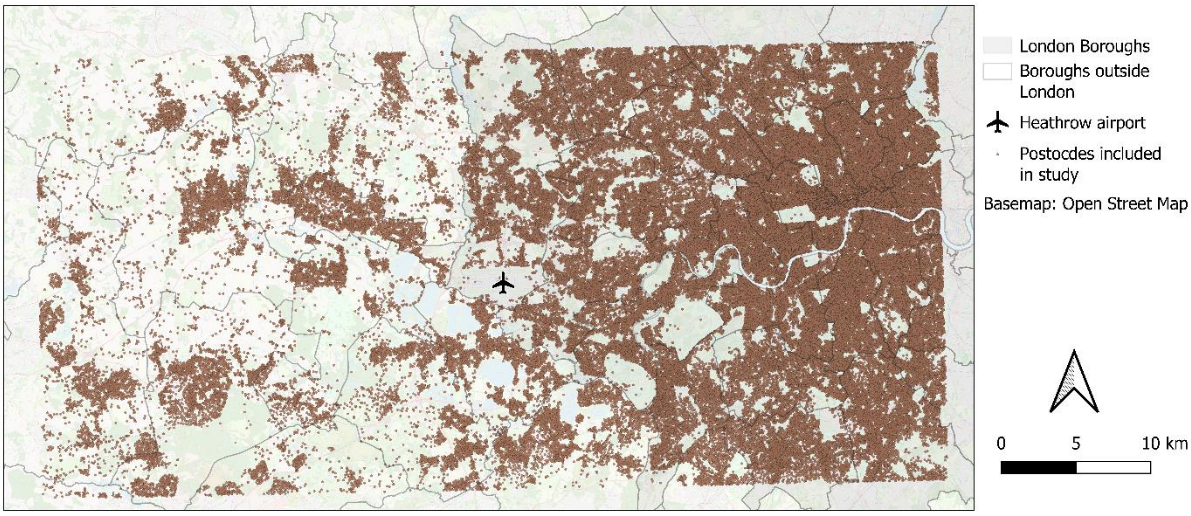

Figure 1 Geography of the targeted postcodes.

The study period was 1st January 2014 to 31st December 2018. The centroid of the study area falls on Heathrow Airport and covers a region defined by a bounding box, as depicted in Figure 1. The whole region spans approximately 97 km from east to west and 47 km from north to south. The study area was specifically designed to capture the outer boundaries of the Civil Aviation Authority's (CAA) annual average aircraft noise contours in 2011.

We used postcodes as our unit of analysis because they represent the smallest geographical area in the United Kingdom. There were approximately 1.75 million live postcodes within the country in 2016 [11]. We identified a total of 164,012 postcodes within the boundary box, with a combined population of approximately 6.3 million in 2011. On average, each postcode within the study area had 53 residents (SD = 44) and 22 occupied households (SD = 17), based on headcount data from the Office for National Statistics NOMIS service [12].

Postcodes in the study area changed every year, as new postal delivery postcodes were created, and old postcodes became redundant from increases in and redistributions of the population over time. The total number of postcodes in each year is as follows:

Year	Postcodes
2014	156,324
2015	155,960
2016	155,558
2017	155,448
2018	155,671

Table 1: The number of postcodes per year

Exposure Data

Spatiotemporal aircraft noise sources originating from Heathrow were modelled in version 3b of the Aviation Environmental Design Tool (AEDT) [13] by the environmental consultancy firm, Anderson Acoustics, with external guidance from the University of Leicester.

Radar tracks of individual flights were provided by Heathrow airport, with a unique set of aircraft footprints constructed for each of the modelled periods on a sub-daily basis. The created AEDT surfaces cover 1,826 days across the five years of 2014-18.

The noise surface estimates accounted for terrain features and meteorological parameters, following standard AEDT model protocols:

1. Atmospheric pressure, relative humidity and wind speed were set as meteorological constants, which reflect the 30-year average at the airport. These simplifications are a limitation of existing modelling practices, when estimating sub-annual average aircraft noise exposures.
2. The headwind speed is maintained at 8 knots, during the entire period of each operation. This may result in inaccurate aircraft performance parameters such as climb and speed, which are related to the location and intensity of noise.
3. Wind speed or direction are not used by the AEDT sound propagation calculations, with sound assumed to propagate in a uniform manner at all times.
4. The AEDT terrain model only accounts for natural landscapes, and not manmade features, therefore, containment and sheltering effects in urban locations are ignored. The Ordnance Survey (OS) digital terrain model (DTM) of Great Britain, which has a 50m horizontal resolution, was used to describe terrain influences.

The protocol was enhanced through the use of dynamic rather than static dry air temperature profiles, which account for variations by season (n=4) and time-of-day (n=8) in the hourly meteorological data at Heathrow airport.

To reduce the computation demands of AEDT, each day was split into eight time-bands, and a variable grid resolution was used. In total, 14,608 flight-activity informed noise surfaces were constructed with a resolution of 100x100m near to Heathrow and a resolution of 200x200m at distant locales. The inner grid with a 100m resolution covers the area from Datchet to Osterley Park (approximately 25km east-to-west) and West Drayton to Ashford (approximately 15km north-to-south).

The short-term ‘A’ frequency weighted noise surfaces cover eight bands of time in each day, defined by the diurnal variations in temperature and operational activity at Heathrow: 24:00-04:30h, 04:30-06:00h, 06:00-07:00h, 07:00-15:00h, 15:00-19:00h, 19:00-22:00h, 22:00-23:00h, and 23:00-24:00h. Daily noise metrics of Lday, Leve, Lnight Lden and LAeq24 were then calculated from these surfaces. These time periods were chosen in discussion with the study advisory board and industry representatives to capture conventional time periods, together with timings that are aligned with Heathrow operations. The 'A' Weighting is standard weighting of the audible frequencies designed to reflect the response of the human ear to noise.

In addition, the number of flight events exceeding a maximum sound level of 65 decibels (A) in the daytime and 60 decibels (A) at night, were estimated at each modelled location (N-Above) from 01/01/2018 to 31/12/2018. For further context, if any of the 1/8th second periods from an aircraft noise event (generated by a single aircraft operation) exceeds the specified threshold, then that event is counted as one.

Statistical analysis

We used the daily aircraft noise levels during the eight time-bands (04:30-06:00h, 06:00-07:00h, 07:00-15:00h, 15:00-19:00h, 19:00-22:00h, 22:00-23:00h, 23:00-24:00h, 24:00-04:30h), as well as the four metrics LAeq24, Lday (07:00-19:00h), Leve (19:00-23:00h), and Lnight (23:00-07:00h).

We calculated means, standard deviations, and the 90th percentile. Since sound intensity is measured on a logarithmic base 10 scale, we applied a log-10 logarithmic transformation to the data before conducting descriptive analysis. We then applied an anti-log-10 transformation after the calculation, so the results were once again expressed in decibels.

We also presented arithmetic means, standard deviations, and the 90th percentile of number of flight events per time band (N65: number of flights > 65 dB in daytime; N60: number of flights >60 dB in night-time) in the same table.

To explore whether the different noise metrics exhibit similar distributions, we conducted a pairwise correlation analysis.

CoV is a measure of day-to-day variation in noise per postcode. We provided a descriptive summary of the coefficient of variation (CoV = standard deviation / mean * 100) for noise during each of the eight time bands across each postcode between 2014-2018.

Results

Table 2 summarises noise metrics, with the study area comprising 155,448 to 156,324 postcodes from 2014 to 2018. The highest noise levels were during the morning shoulder period (06:00-07:00h; mean: 50.92 dB), followed by daytime (07:00-15:00h; mean: 49.87 dB). Late night-time periods (24:00-04:30h; mean: 29.81 dB) were the quietest on average, with the latter having the lowest mean noise level (29.81 dB). Aircraft noise level during the time period of 23:00-24:00h still impacted nearly all postcodes, with an average value of 41.06. 07:00-15:00h had the noisiest flight events, with an average of 8, and the top 10% of postcodes experiencing 10 events. The morning shoulder (06:00-07:00h) had the third highest mean noise level (mean: 3), but the highest average number of noisy events per hour compared to all other periods.

Table 3 presents a descriptive summary of the coefficient of variation for noise during each of the eight time bands across each postcode. The coefficient of variation was highest for night-time periods, with 24:00-04:30h having the highest mean CoVs (67.33 to 74.16). The time period from 24:00-04:30h had the highest mean CoVs (mean: 72.13) compared to all other time bands, followed by 23:00-24:00h (mean: 45.64) and 04:30-06:00h (mean: 44.80). Daytime aircraft noise was found to be less variable than night-time noise.

In Table 4, the pairwise Pearson correlation coefficients showed high to very high correlations (Coefficient: 0.68-0.90) between each pair of the four standard noise metrics (Lday, Lnight, Leve, and LAeq24). In comparison, daily aircraft noise during early morning (0430 to 0600h) and late night (2400 to 0430h), had a much weaker correlation (Coefficient: <0.4) with noise levels during any other time bands. There were moderate to high correlations (Coefficient: 0.52-

0.87) between each pair of daily aircraft noise levels during the day (0700 to 1500h), the afternoon (1500 to 1900h), and the early evening (1900 to 2200h and 2200 to 2300h). There were weak to moderate correlations (Coefficient: 0.07-0.48) between the number of flight events and the actual noise levels during the eight time bands, with the exception of N60 0600-0700h. Moreover, there were relatively weak correlations between each pair of noisy flight events except for N60 0600-0700h and N60 0430-0600h (Coefficient: 0.73), N65 1900-2200h and N65 1500-1900h (Coefficient: 0.96), N65 2200-2300h and N65 1500-1900h (Coefficient: 0.71), N65 2200-2300h and N65 2200-2300h (Coefficient: 0.55).

Noise metrics	N	Mean	SD	Min	Max	P90
LAeq 043:0-06:00h	283,706,122	43.75	53.22	0	77.69	44.72
LAeq 06:00-07:00h	284,476,323	50.92	58.44	7.04	80.33	52.93
LAeq 07:00-15:00h	284,476,323	49.87	58.06	22.96	78.83	51.5
LAeq 15:00-19:00h	284,165,204	49.44	57.67	19.84	78.9	51.09
LAeq 19:00-22:00h	271,590,174	49.12	57.3	17.04	78.84	50.95
LAeq 22:00-23:00h	284,476,323	47.48	56.69	9.19	81.07	49.24
LAeq 23:00-24:00h	279,444,325	41.06	51.54	0	79.52	42.15
LAeq 24:00-04:30h	87,705,638	29.81	42.3	0	76.34	30.04
Lday	284,165,204	49.73	57.17	22.79	78.29	51.76
Leve	271,590,174	48.8	56.97	16.33	78.86	51.2
Lnight	86,618,974	44.19	51.39	4.23	74.13	46.49
LAeq24	83,220,954	48.92	55.98	22.87	76.88	50.72
N60 04:30-06:00h	56,819,915	1	2.62	0	33	1
N60 06:00-07:00h	56,819,915	3	7.39	0	58	9
N65 07:00-15:00h	56,664,244	8	32.91	0	388	10
N65 15:00-19:00h	56,819,915	4	16.47	0	199	5
N65 19:00-22:00h	56,819,915	3	11.87	0	146	3
N65 22:00-23:00h	56,819,915	1	2.83	0	47	1
N60 23:00-24:00h	56,352,902	0	1.34	0	43	1
N60 24:00-04:30h	21,171,256	0	0.67	0	23	1

Table 2 descriptive summary of noise metrics

(1)	(2)	(3)	(4)	(5)	(6)
Time band	N	Mean	SD	Min	max
04:30-06:00h	164,012	44.80	16.85	3.301	112.9
06:00-07:00h	164,012	16.59	7.980	1.655	53.11
07:00-15:00h	164,012	10.43	4.798	1.194	22.31
15:00-19:00h	164,012	10.62	4.849	1.315	23.44
19:00-22:00h	155,951	10.29	4.155	1.388	23.56
22:00-23:00h	164,012	24.07	37.24	2.126	210.9
23:00-24:00h	164,012	45.64	35.95	8.104	255.4
24:00-04:30h	164,012	72.13	17.84	20.16	238.4

Table 3 descriptive summary of the coefficient of variation for daily noise levels by postcode level

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
(1) LAeq 0430-0600h	1.000																			
(2) LAeq 0600-0700h	0.680	1.000																		
(3) LAeq 0700-1500h	0.425	0.725	1.000																	
(4) LAeq 1500-1900h	0.343	0.632	0.845	1.000																
(5) LAeq 1900-2200h	0.309	0.574	0.764	0.868	1.000															
(6) LAeq 2200-2300h	0.090	0.299	0.520	0.562	0.664	1.000														
(7) LAeq 2300-2400h	-0.062	0.109	0.269	0.279	0.353	0.600	1.000													
(8) LAeq 2400-0430h	0.075	0.157	0.276	0.262	0.283	0.373	0.357	1.000												
(9) Lday	0.415	0.723	0.974	0.928	0.831	0.555	0.286	0.284	1.000											
(10) Leve	0.275	0.546	0.755	0.855	0.977	0.771	0.417	0.315	0.820	1.000										
(11) LAeq24	0.445	0.744	0.950	0.924	0.901	0.665	0.366	0.306	0.980	0.901	1.000									
(12) Lnight	0.682	0.912	0.769	0.698	0.682	0.495	0.310	0.289	0.778	0.680	0.818	1.000								
(13) N60 0430-0600h	*0.296*	*0.440*	*0.421*	*0.377*	*0.385*	*0.229*	*0.066*	*0.114*	*0.431*	*0.369*	*0.465*	*0.497*	*1.000*							
(14) N60 0600-0700h	*0.339*	*0.620*	*0.596*	*0.519*	*0.513*	*0.309*	*0.113*	*0.163*	*0.601*	*0.496*	*0.631*	*0.661*	*0.733*	*1.000*						
(15) N65 0700-1500h	*0.190*	*0.344*	*0.519*	*0.390*	*0.370*	*0.328*	*0.206*	*0.209*	*0.503*	*0.393*	*0.500*	*0.413*	*0.331*	*0.497*	*1.000*					
(16) N65 1500-1900h	*0.176*	*0.308*	*0.390*	*0.484*	*0.400*	*0.410*	*0.229*	*0.201*	*0.449*	*0.433*	*0.477*	*0.394*	*0.293*	*0.400*	*0.433*	*1.000*				
(17) N65 1900-2200h	*0.169*	*0.295*	*0.373*	*0.462*	*0.403*	*0.431*	*0.243*	*0.211*	*0.430*	*0.445*	*0.465*	*0.385*	*0.273*	*0.378*	*0.410*	*0.959*	*1.000*			
(18) N65 2200-2300h	*0.124*	*0.233*	*0.379*	*0.400*	*0.336*	*0.452*	*0.283*	*0.225*	*0.407*	*0.410*	*0.423*	*0.325*	*0.139*	*0.242*	*0.448*	*0.708*	*0.737*	*1.000*		
(19) N60 2300-2400h	*0.096*	*0.185*	*0.333*	*0.335*	*0.304*	*0.394*	*0.374*	*0.236*	*0.348*	*0.349*	*0.384*	*0.323*	*0.130*	*0.219*	*0.333*	*0.372*	*0.385*	*0.550*	*1.000*	
(20) N60 2400-0430h	*0.117*	*0.161*	*0.238*	*0.238*	*0.204*	*0.281*	*0.239*	*0.317*	*0.250*	*0.244*	*0.256*	*0.239*	*0.088*	*0.147*	*0.264*	*0.295*	*0.306*	*0.318*	*0.335*	*1.000*

Table 4 pairwise Pearson correlation coefficients (r) between daily aircraft noise levels at eight specified time bands and standard four noise metrics (LAeq24, Lday, Lnight and Leve), and the daily number of flight events at eight time periods.

Discussion

Our study identified two periods of higher noise levels than expected: the morning shoulder period (06:00-07:00h) and 23:00-24:00h time frame. The morning shoulder period had the highest mean and number of noisy events per hour among all periods, and the 23:00-24:00h period had an average mean of 41.06, closer to the World Health Organization-recommended threshold of 42 dB, which could cause sleep disturbance [14]. These two periods were loud because of a combination of meteorological, operational, and logistic reasons, including the first flights of the day departing early in the morning, long-haul flights (with larger planes) landing early in the morning and flights scheduled before the night quota period.

These periods of high noise levels may have health implications, particularly for sleep disturbance. 06:00-07:00h and 23:00-24:00h may still be within people's sleep time [15]. This may suggest that the night quota period might be insufficient to protect residents' 8-hour sleep. Moreover, the loud aircraft noise during the morning shoulder period contrasts significantly with the relatively quiet night quota periods. Abrupt short-term increases in aircraft noise has been linked to an increase in cortisol and catecholamine release [16], and may induce beat-by-beat variations in blood pressure [14, 17]. The timing and intensity of aircraft noise coincides with an observed sharp increase in blood pressure 1–2 hours after awakening among the elderly [18]. This implies that aircraft noise occurred during morning shoulder may pose a particular health risk, especially among the elderly, for several hours following the noise event.

We also found that non-standard metrics can be useful to capture unique noise exposure characteristics that standard metrics may miss. The correlations between non-standard metrics, especially between 23:00-24:00h and 24:00-04:30h, were generally low. The lower correlations of non-standard and noisy event metrics, compared with high correlations between the standard metrics (Lday, Lnight, Leve, and LAeq24) raises the possibility that standard metrics may miss important characteristics of noise exposure, with potential relevance for impacts on biological systems.

Several studies have examined high noise events as a potential indicator of the link between noise exposure and sleep quality [19, 20]. One study found that the number of high noise events could impact sleep quality, as measured by motility [19]. Our study found a weak association between high noise events and actual noise levels, suggesting that high noise events may provide unique information. However, we only assessed high noise events for one year (2018) using certain noise thresholds, so further research exploring lower cut-points and additional years would be helpful to understand the relationship between noise events and health outcomes.

We used the coefficient of variation to examine the day-to-day variability in noise exposure levels per postcode. Night-time noise tended to vary more greatly than daytime periods, highlighting the uniqueness of night-time aircraft noise and its potential health implications, particularly for sleep disturbance and increased blood pressure among the elderly.

We identified several limitations in the use of the AEDT model when estimating average aircraft noise exposures within a single day, including simplifications in input parameters. These limitations may lead to exposure misclassification bias, but our study used several approaches to develop and enhance the existing approach to create sub-annual exposure surfaces.

However, several studies have validated the accuracy of noise estimates generated by the AEDT model. Meister [21] modelled close-range stationary noise monitoring against AEDT at Zurich and Geneva airports and found that approaches were generally overestimated while departures were underestimated, but with a standard deviation of 2.5 dB, similar to FDR data. Gabrielian [22] also used AEDT version 3c to model departing and three arriving flights at San

Francisco International Airport (KSFO) and suggested that differences between AEDT and measurements were within 2.5 dB.

Conclusion

We characterized daily aircraft noise levels and the number of noise events for approximately 150,000 postcodes near Heathrow airport during eight daily time bands from 2014-2018, corresponding to airport activity periods. Our dataset provides rich and detailed information on noise exposure near the airport and evaluates non-standard noise metrics. The resuts will be used in health studies to extend investigations of noise impacts on health, to explore impact of time of day on observed associations.

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