

Aircraft noise and sleep – 1999 UK Trial Methodology Study

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SUMMARY

Introduction

- 1.1 In February 1998, the Department of the Environment, Transport, and the Regions announced a Government commitment to carry out "a research trial on sleep disturbance. Its aim will be to assess methodology and analytical techniques, to determine whether to proceed to a full scale study of either sleep prevention or total sleep loss". Following further DETR announcements and extensive consultations, NATS Ltd (now Environmental Research and Consultancy Department, CAA) were instructed by the DETR to invite tenders for a research study with the following objectives;

"To evaluate the research options A-C (as set out below and described in section 5 of Annex 2 (NOTE: this annex refers to a review of existing research carried out by Porter, Kershaw, and Ollerhead of NATS Ltd in 1999) and to recommend the best way to proceed for any future full scale study of sleep disturbance and other effects of night-time aircraft noise

- A. To 'extend' the 1992 UK Field Study to the shoulder hours
- B. To compare sleep patterns in 'high noise' and 'low noise' communities
- C. To study sleep disturbance among noise sensitive people"

- 1.2 A consortium comprising the Institute of Sound and Vibration Research (ISVR) at the University of Southampton, the Centre for Human Sciences (CHS) at DERA Farnborough, the Centre for Mechanical and Acoustical Metrology (CMAM) at the National Physical Laboratory and the MVA Consultancy at Woking were contracted to carry out the study described in this report.

Background

- 1.3 A large scale field study of aircraft noise and sleep disturbance around major UK airports was carried out by a consortium led by the CAA for the Department of Transport in 1991. This study was reported in December 1992 [Ollerhead et al, 1992], and is usually referred to as the 1992 UK Field Study. This study found a low incidence of objectively measurable sleep disturbance (both minor arousals and brief awakenings from persistent sleep) attributable to individual aircraft events. There was no detectable increase in the probability of minor arousals or brief awakenings for individual outdoor aircraft noise event levels below 80 dB(A) L_{Amax} . For individual outdoor aircraft noise event levels above 80 dB(A) L_{Amax} , the probability of a minor arousal was around 1 in 30 and the probability of a brief awakening was around 1 in 75 (Note: these probabilities are additional to the probability of a minor arousal or a brief awakening occurring anyway at around the same time as but not caused by the aircraft noise event).
- 1.4 Notwithstanding these findings of a relatively low incidence of objectively measurable disturbance caused by individual aircraft noise events, aircraft noise at night remains an issue of public concern around major UK airports. Because of this, the findings of the 1992 UK Field Study have been described as being counter-

intuitive. In addition, research studies carried out in laboratories have generally found higher sensitivity to noise at night than was observed in the 1992 UK Field Study. The most recent international guidance on noise levels to avoid sleep disturbance [WHO, 2000] recommends a guideline value of 45 dB(A) L_{Amax} measured indoors, with lower values preferred where the background noise levels are low or to protect the most noise sensitive persons. The outdoor aircraft noise event threshold of 80 dB(A) L_{Amax} found in the 1992 UK Field Study can be roughly equated to anything from 45 to 60 dB(A) L_{Amax} indoors depending on outdoor to indoor attenuation which varies with different house constructions and orientations, with different types of windows and whether the windows are open or closed.

- 1.5 The main motivation behind the 1999 UK Trial Methodology Study was to explore the feasibility of being able to resolve some of these outstanding issues. Following extensive consultation, the three research options A-C were defined by NATS Ltd. Option A – to ‘extend’ the 1992 UK Field Study to the shoulder hours refers to the possibility of aircraft noise at the beginning and end of the night period (commonly known as the night shoulder hours) contributing to delayed sleep onset and premature awakening. These two possibilities were not specifically addressed by the design of the 1992 UK Field Study, which mainly investigated arousals and awakenings in response to individual aircraft noise events whilst asleep. Option B – to compare sleep patterns in ‘high noise’ and ‘low noise’ communities refers to a requirement for some overall measure of sleep quality or loss of sleep which could be related to objectively measurable next day effects and which might show differences between ‘high noise’ and ‘low noise’ communities. The main focus of the 1992 UK Field Study was on disturbance caused by separate events and not on overall sleep measures. Option C – to study sleep disturbance among noise sensitive people arose from previous findings that there is a wide range of individual sensitivities to noise at night. In terms of research feasibility, it was considered important to be able to deal with individual differences in noise sensitivity as a separate issue. Individuals might vary both in terms of their sensitivity to disturbance attributable to separate events, and the effect that such disturbance might have on whole night or next day measures.
- 1.6 NATS Ltd also identified a fourth issue which was not separately listed in the invitation to tender. This was the question of to what extent, if any, observed sleep disturbance might contribute to longer term health effects in exposed populations. There are many possible indicators of different types of sleep disturbance ranging from minor arousals and brief awakenings in response to separate events through various whole night effects through to next day effects. Normal sleep cycles involve a sequence of minor arousals and brief awakenings in between periods of deeper sleep and there is no reason to believe that minor arousals and brief awakenings are intrinsically harmful unless they occur more than some presently unknown number of times through the night. To determine the threshold at which long term health effects start to occur (if there is such a threshold) would involve significant methodological difficulties, not the least of which would be finding experimental and control groups of residents with different long term health outcomes who are matched for all other health effect variables except for aircraft noise exposure. The 1999 UK Trial Methodology Study was not directly addressed to the problem of identifying experimental and control groups, although the findings are highly relevant to the general problem of identifying health effects thresholds.

- 1.7 The consortium proposed that research options A, B, and C be investigated by a combined laboratory and field approach. The chief advantage of the laboratory method is that all exposure variables can be precisely controlled in accordance with a rigid experimental design. Also, additional procedures and measurements are feasible in the laboratory which would not be practicable under field conditions. The main potential disadvantage is that subjects might not behave in the same way in the laboratory as they do in their own homes. The laboratory is to some extent artificial and subjects might not have time to habituate either to the unusual environment or to the noise exposure. The validity of using this methodology needed to be established by direct comparison of laboratory findings against data obtained in-situ in people's own homes.

Procedures

- 1.8 The research was carried out in two parts; the first part being a field trial in residential areas around Manchester Airport; with the second part being a laboratory trial in the sleep laboratory at the CHS DERA Farnborough with the noise exposures being closely matched to those measured in Manchester. During both parts, sleep electroencephalography (EEG), actigraphy (using similar devices to those used in the 1992 UK Field Study) and other physiological measurements were taken, together with a battery of subjective reports and next day performance tests. For the field trial, simultaneous indoor and outdoor noise measurements were taken. The indoor acoustic measurements were also recorded onto a spare channel of the physiological measurement recorders. In the laboratory it was also possible to apply the multiple sleep latency test (MSLT) at regular intervals the following day as an objective measure of day-time sleepiness. It was not practical to use the MSLT under field conditions. Trained interviewers recruited all subjects using a structured questionnaire in accordance with agreed constraints. Subjects were restricted to the 30-40 age group to minimise variability due to age in what was necessarily a small scale pilot study. Following research option C, only those subjects who reported themselves as 'more sensitive to aircraft noise at night than the average person' were invited to take part.
- 1.9 For the field trial, 9 subjects were recruited from a predefined 'high noise' area and a further 9 subjects were recruited from a similarly predefined 'lower noise' area, both near to Manchester Airport (i.e. 18 subjects in total). The high noise area was defined by named streets in Moss Nook and Heald Green at distances from 500 m to 2500 m from the landing runway threshold and was therefore representative of the higher levels of residential aircraft noise exposure around Manchester Airport. The lower noise area was defined by named streets in Cheadle and Edgeley at distances from 4000 m to 7000 m from the landing runway threshold. The lower noise area streets were selected because outdoor aircraft noise exposure was expected to be significantly lower than in the defined high noise area, while still being high enough above other background noise sources to allow for reliable measurements. It should be noted that as a trial methodology study, the 1999 study was not intended to derive definitive noise dose-effect relationships.
- 1.10 In the field trial, each subject participated over five consecutive nights from Sunday night until Friday morning. The first night (Sunday night to Monday morning) for each subject was considered to be an adaptation night. Each subject was collected and taken to a temporary laboratory at the Manchester Airport Post House Hotel to be

fitted with EEG electrodes and then returned to their own houses with instructions to go to bed at the normal time. The recording equipment was collected from their houses the next morning, the data downloaded and preparations made for recording again the following night. There were two test weeks in September 1999, with 9 subjects participating in each week.

- 1.11 For the laboratory trial, an additional 9 subjects were recruited from residential areas in and around Farnborough with generally similar socio-economic characteristics to the Manchester areas. Night-time aircraft noise exposure in the Farnborough area was very much less than in either of the Manchester high noise and lower noise areas. Each subject attended the laboratory on 5 nights at one night per week over a 5 week period in October and November 1999. The first night was treated as an adaptation night for familiarisation with the recording equipment and the laboratory bedrooms. On the 4 subsequent test nights subjects were exposed in a balanced order to the following 4 test conditions; a zero aircraft noise baseline control condition, a Manchester 'high noise' simulation night with recorded aircraft flyover events reproduced using loudspeakers, and two further experimental nights with the numbers of aircraft noise events doubled in either the evening or early morning shoulder hours (specifically to address research option A). (Note: to increase the likelihood of obtaining statistically significant differences in sleep outcome measures, the shoulder hours periods were doubled from the standard definitions, i.e. the evening shoulder hour was defined for this study as extending from 2300 to 2400 and the early morning shoulder hours were defined for this study as extending from 0500 to 0700).

Findings

Methodology

- 1.12 As a trial methodology study, one of the primary objectives of the study was to identify any problems with instruments and techniques that could not be overcome within the scope of any future main study. A few initial difficulties caused some data to be lost, particularly during the first week of testing in Manchester, but all problems arising were successfully overcome during the second test week. Most if not all of the initial difficulties occurred because there was insufficient preparation time (around 3 weeks) between the final instructions being given to proceed with the study and the deadline imposed by NATS Ltd for starting work in Manchester. Given a bit more time for preparation, it is unlikely that there would have been any problems at all.

Airport traffic and average noise levels during the field trial

- 1.13 As far as is known, all aircraft movements over the field trial areas during the period of the study were arrivals from the north east. Due to the prevailing wind direction, this is the predominant operating pattern at Manchester Airport although aircraft depart over the field study areas whenever there are north easterly winds. The average numbers of arrivals reduced from around 10 per hour between 2200 to 2300 hrs down to around 2 to 3 per hour during the quietest part of the night from 2400 hrs to around 0400 hrs. After 0400 hrs the average numbers of arrivals built up again reaching morning peaks of around 8 per hour between 0600 to 0700 hrs and around 14 per hour between 0700 to 0800 hrs. The daytime peaks of up to around 24 arrivals per hour

were between 0800 to 0900 hrs and again between 1700 to 1800 hrs. Measured over the field trial nights, the average number of arrivals during the 2300 to 0700 hrs night period was 36.6 but there was considerable variation from one night to the next ranging from 27 up to 45 arrivals.

- 1.14 Average outdoor aircraft noise event sound levels were 82.3 dB(A) L_{Amax} in Moss Nook, 78.3 dB(A) L_{Amax} in Heald Green and 76.7 dB(A) L_{Amax} in Cheadle/Edgeley. The corresponding average indoor aircraft noise event sound levels were 51.9 dB(A) L_{Amax} in Moss Nook, 52.1 dB(A) L_{Amax} in Heald Green and 52.1 dB(A) L_{Amax} in Cheadle/Edgeley. The differences in average outdoor noise levels between Moss Nook and Heald Green were consistent with the differences in relative distances from the runway threshold, but the differences between Heald Green and Cheadle and Edgeley were much less than expected on the basis of distance alone.
- 1.15 The average outdoor to indoor sound level differences were 32.2 dB with the windows closed (9 subjects) and 27.3 dB with the windows open (9 subjects). It should be noted that while the average outdoor to indoor sound level difference of 27.3 dB with the windows open was somewhat higher than might have been expected on the basis of published guidance, there was no reason to doubt these findings for this particular case. In addition, while the average outdoor aircraft noise event sound levels were not particularly high when compared against the 80 dB(A) L_{Amax} threshold identified in the 1992 UK Field Study, there was considerable variation above and below the averages with some outdoor aircraft noise events at much higher (and lower) sound levels.

Field trial sleep data

- 1.16 Overall, no major differences were observed between sleep variables from participants in the high noise and lower noise areas. There were some minor differences in general noise sensitivity ratings, in self reported anxiety ratings and in some detailed EEG measures. No differences were observed in next day performance measures. However, it should be noted that there were no significant differences between the average indoor aircraft event noise levels as measured in the high noise and lower noise areas. This was partly because the average outdoor to indoor attenuation in the high noise area was greater than in the lower noise area and also because the differences in average outdoor aircraft noise event levels were unexpectedly small. If there had been a significant difference in indoor aircraft noise event levels then significant differences in sleep outcome measures might well have occurred.
- 1.17 There were increases in the number of awakenings, total durations of stage 1 sleep, number of rapid eye movement (REM) sleep periods and changes in the frequency content of the EEG associated with higher numbers of aircraft noise events occurring during the 'lights out' period. It was not possible within the limitations of a small scale trial methodology study to determine the underlying importance of these findings. It should be noted that the 1999 UK Trial Methodology Study was not designed to obtain statistically definitive results representative of the population as a whole. The findings relating to the number of aircraft noise events could have been indicative of some important effect. Alternatively, some subjects who stayed in bed

longer in the mornings would have been exposed to much higher numbers of aircraft noise events and this could also have influenced the quality of sleep.

Laboratory trial sleep data

- 1.18 The average noise sensitivity ratings were in the same range as for the field trial. There was generally good agreement between the laboratory and field results. The numbers of awakenings detected by standard visual analysis of the EEG records was very similar to the numbers observed in the field. Both sets of data were also consistent with the 1992 UK Field Study results. Although the numbers of actual awakenings in the laboratory and in the field were generally similar, the numbers of reported awakenings (measured using a next day questionnaire) were much greater in the laboratory (between 4 and 8 per night, depending on test condition) than in the field (around 2 per night and not significantly different between the high noise and lower noise areas). These are key findings and imply that while objective data from laboratory studies can be related to the field situation, there may be differences in terms of subjectively reported data.
- 1.19 Comparing the four aircraft noise event conditions tested in the laboratory, there were no differences in next day effects. However, differences in sleep measures between the four aircraft noise event conditions were observed. There were reduced sleep latencies and latencies to stage 4 sleep (deep sleep) which were associated with increased numbers of aircraft noise events in the evening shoulder hours, and increased REM sleep in the early mornings associated with increased numbers of aircraft noise events in the early morning shoulder hours, together with changes in the frequency content of the EEG associated with each of the noise event conditions. These findings imply that people may have some awareness in terms of next day subjective reports of aircraft noise events occurring while they are asleep. Perhaps surprisingly, the findings imply that increased numbers of aircraft noise events in the evening shoulder hours may help individuals to get to sleep quicker. This last finding could have been associated with indications that subjects attended the laboratory with differing degrees of prior sleep loss from the previous night. There was no evidence of delayed sleep onset or premature awakening associated with increased shoulder hours aircraft noise events.
- 1.20 There were no differences in movement activity levels during sleep measured using actigraphy, although this finding was not unexpected due to the small numbers of subjects tested.

Recommendations

- 1.21 The differences observed in the laboratory trial between the four aircraft noise event conditions tested and the general comparability of the laboratory and field data demonstrated that it is feasible to 'extend' the 1992 UK Field Study to the shoulder hours (research option A) by using the combined laboratory and field study methodology. Any such 'extension' should include an emphasis on whole night and next day effects (see research option B below) while varying shoulder hours noise events in a way that is only really possible in the laboratory. It is not generally

possible to vary shoulder hours noise events independently of whole night noise events in the field.

- 1.22 Research option B (compare ‘high noise’ and ‘low noise’ communities) could also be followed up by using the combined laboratory and field study methodology, particularly because it is difficult to control indoor aircraft noise exposure in the field within desired experimental parameters. The possibility of identifying some overall measure of sleep quality or sleep loss that could be related to objectively measurable next day effects depends on finding significant differences in those next day effects. To obtain differences in next day effects of a size which might be considered as precursors of longer term health effects would probably require much larger differences in indoor aircraft noise exposure than were observed in this study. To obtain significant next day effects in an experimental situation, it may be necessary to increase the number of night-time Aircraft Noise Events above that which might easily be found in real field situations, and this could only be done in the laboratory. Alternatively, it would be possible to compare individuals living in areas with high night time aircraft noise against other individuals living in areas with zero or negligible aircraft noise but unless the ‘high’ aircraft noise condition was of sufficient magnitude to result in significant next day effects, this design would not be able to address the fundamental health effects issues underlying research option B. In addition, it would be necessary for all other potentially relevant factors to be matched as closely as possible, and this might be difficult. A further potentially promising alternative could be to determine the aircraft noise event parameters that produce effects on next day performance; such effects could be related to efficiency and performance at work, which in turn could have long term economic impacts.
- 1.23 If there was sufficient interest, research option C could be followed up by comparing self-reported noise sensitive and noise insensitive people under controlled laboratory test conditions as well as in their own homes where indoor aircraft noise exposure cannot be controlled. In the 1999 UK Trial Methodology Study, the findings suggested that self-reported noise sensitivity might not be particularly well correlated with objective sensitivity, meaning that other measuring instruments might have to be developed. In addition, any differences between individual sensitivities (measured either objectively or subjectively) to separate events and the effects that any resulting sleep disturbances might have on whole night and next day measures could raise important issues.
- 1.24 Finally, in relation to the possibility of investigating the hypothetical relationship between sleep disturbance and long term health effects, it is recommended that future studies should concentrate on understanding the precise mechanisms of sleep disturbance first – before progressing to large scale prevalence studies of what are presently only conjectured effects without any sound theoretical basis. The findings of the 1999 UK Trial Methodology Study should be followed up by more detailed studies, particularly in relation to the possibility of differential sensitivities to sleep disturbance at different times of the night, where the possible effects of different numbers of events per hour appear to be important.
- 1.25 Notwithstanding the small numbers of subjects tested in the 1999 UK Trial Methodology Study, a considerable amount of data was collected. Further analysis of these data to test for differential sensitivity at different times of the night would be

worthwhile. Depending on the results of this further analysis, an appropriate next step could be a series of titration experiments carried out in the laboratory to find the thresholds at which next day effects might start to become detectable. The results of the further analysis of the existing data would be used in optimising the noise exposure conditions for the titration experiments. The results of the titration experiments could then be used to develop combined indicators of Aircraft Noise Event level and/or the number of Aircraft Noise Events at different times of the night most relevant to sleep loss. Prevalence studies could then concentrate on comparing aggregate sleep loss in residential areas exposed at above and below these level and number thresholds, but only if sufficiently large sample sizes can be found with exposures exceeding the identified thresholds.