Aircraft noise and sleep disturbance - summary of Government sponsored research

Table of contents

A summary of government sponsored research

Important Note

This page is designed to give an introduction to UK Government sponsored research into aircraft noise and sleep disturbance. Although there are brief references to various research studies, only by reading the reports themselves can their findings be fully appreciated.

In particular, the precise definitions of terms such as ’disturbance’, ’arousal’ and ’awakening’ are crucial in interpreting the research findings. It is therefore important that the interested reader should check the exact definitions used in each case.

Reports reflect the views of the authors and not necessarily those of the Government.

Past Research

1. It has been long-standing Government practice that policy on night noise should be based on research into the relationship between aircraft noise and sleep disturbance. Research in the 1980s was based primarily on social surveys of people living around Heathrow and Gatwick. The sites chosen for the surveys covered a very wide range of aircraft noise exposure. Laboratory studies of sleep disturbance had suggested that the probability of an awakening depended on the peak noise level of a single noise event. The social survey research, on the other hand, focused on the combination of all the aircraft noise events occurring over an 8 hour night, as measured by Leq (the equivalent continuous sound level, which takes account of the average noisiness and number of events).

2. Earlier reports include:

i. *Aircraft Noise and Sleep Disturbance: Final Report* DORA Report 8008 August 1980. (Â£3.50).

ii. *Noise Disturbance at Night near Heathrow and Gatwick Airports: 1984 Check Study* DR Report 8513 February 1986. (Â£2.50).

iii. *Noise Disturbance at Night near Heathrow and Gatwick Airports: Critique of the Technical Issues Raised by Consultees during the 1986 public consultation* DORA Report 8715 October 1987. (Â£3.00).

iv. *Night Noise Contours: A Feasibility Study* Porter et al, National Physical Laboratory, 1997.

(i)-(iii) are available from http://www.tsoshop.co.uk/bookstore.asp . (iv) is available free of charge from the National Physical Laboratory, Teddington, Middlesex, TW11 OLW.

3. A more detailed list of research publications concerning aircraft noise and sleep (and aircraft noise more generally) may be found on the website of the Environmental Research and Consultancy Department of the Civil Aviation Authority at http://www.caa.co.uk/default.aspx?categoryid=68

4. In 1992 the Department of Transport published the results of a major sleep study. The main purpose of the study was to provide objective measurements of disturbance of people's sleep. Scientific measurements of disturbance were obtained from people while they were sleeping in their homes near Heathrow, Gatwick, Stansted and Manchester airports. The study also included a social survey element and the results of that were related to those from the earlier research.

Report of a Field Study of Aircraft Noise and Sleep Disturbance (1992): Executive Summary is reproduced in the following section.

5. The full title of the report is *Report of a Field Study of Aircraft Noise and Sleep Disturbance: A study commissioned by the Department of Transport from the Department of Safety, Environment and Engineering, Civil Aviation Authority* December 1992.(Â£10.00) A summary of the report in paper form is available from the Department free of charge at the contact address at paragraph 15). The full report is available from The Stationery Office (telephone orders/general enquiries 0870 600 5522, fax orders 0870 600 5533). Website: www.tso-online.co.uk

6. The report concluded that high aircraft noise levels could awaken people, but that the likelihood of the average person having his or her sleep noticeably disturbed due to an individual aircraft noise event was relatively low. However the Government acknowledged that there are differing views, among those who suffer noise, as to whether a single loud noise event or the accumulation of smaller noise events causes more disturbances. It is clear that disturbance is different from annoyance and also from sleep deprivation, which relates to lengthy periods without sleep. It was also acknowledged that a small minority of people is much more sensitive to noise, and to sleep disturbance from aircraft noise, than most others.

7. In 2003 a supplementary report to the 1992 report was published. The full title of the report is *Effects of Aircraft Noise on Sleep: EEG-Based Measurements* (K I Hume, F Van & A Watson, Department of Biological Sciences, Manchester Metropolitan University, June 2003). The report is a further analysis of the raw material derived from the fieldwork and to see what could be learned about the possible effects of noise in preventing sleep onset at the beginning of the night, or delaying return to sleep after awakening during the night or in the early morning. The report may be found on the following web site:
http://www.search.mmu.ac.uk/search?q=Effects%20of%20aircraft%20noise%20on%20sleep:%20EEG-Based%20Measurements&sort=date%3AD%3AL%3Ad1&output=xml_no_dtd&ie=UTF-8&oe=UTF-8&client=mmumain&proxystylesheet=mmumain&site=default_collection

Recent Research

8. In 1998 further research was commissioned to include:

- a review of existing research in the UK and abroad; and
- a trial to assess methodology and analytical techniques, to determine whether to proceed to a full scale study of either sleep prevention or total sleep loss.

9. The review of existing research was carried out on the Department's behalf by the then Department of Operational Research and Analysis (DORA) of National Air Traffic Services Ltd (now Environmental Research and Consultancy Department (ERCD) of the Civil Aviation Authority *Adverse Effects of Night-Time Aircraft Noise (2000): Executive Summary*

The full title of the report is *Adverse Effects of Night-Time Aircraft Noise*DORA R&D Report 9964, March 2000. A copy is available on the Civil Aviation Authority's website at http://www.caa.co.uk/application.aspx?categoryid=33&pagetype=65&applicationid=11&mode=detail&id=753

10. The **methodology trial** had been commissioned because the earlier research highlighted the need for further investigation into the overall question of whether aircraft noise causes harmful loss of sleep throughout the night and especially the effect of sleep delay and disturbance at the beginning and end of the night. Its aim was to decide whether to proceed to a full scale study of the effects of aircraft noise on either sleep loss or sleep prevention at the beginning of the night, or on premature awakening towards the end of the night. It was subsequently decided to complement the methodology trial with a **social survey** to help explore the marked difference between objectively measured and publicly perceived disturbance due to night-time aircraft noise.

11. Both the **methodology trial** and **social survey** were managed for the Department by the Department of Operational Research and Analysis (DORA) at National Air Traffic Services (now Environmental Research and Consultancy Department (ERCD) at the Civil Aviation Authority). Two consortiums undertook the detailed research work.

12. The **methodology trial** was carried out in two parts. The first was a field trial based in residential areas in the vicinity of Manchester Airport involving measurements of people sleeping in their homes using electroencephalography (EEG) equipment, and covered 'high noise' and 'lower noise' areas. The second was a laboratory trial in a sleep laboratory at the Centre for Human Sciences at Farnborough involving subjects from the Farnborough area having similar socio-economic characteristics to the Manchester areas.

The report is entitled *Aircraft Noise and Sleep - 1999 UK Trial Methodology Study*27 November 2000. (Ian Flindell & Andrew Bullmore, Institute of Sound and Vibration Research Consultancy Services, University of Southampton; Karen A Robertson, Nicky A Wright, Claire Turner & Claire Birch, Centre for Human Sciences, Defence Evaluation and Research Agency; Mark Jiggins & Bernard Berry, Centre for Mechanical and Acoustical Metrology, National Physical Laboratory; Martin Davison & Martin Dix, MVA Consultancy).

The Report (which includes an executive summary) may be found on the following web site: www.isvr.co.uk/environm/sleep.htm

13. The **social survey** comprised four parts:

i. a qualitative study involving focus group discussions with residents in areas around Heathrow and Manchester airports;

ii. a secondary analysis of data from a previous survey in Bristol about aircraft noise at night;

iii. an interview survey of respondents in areas around Heathrow, Manchester, Gatwick, East Midlands and Stansted airports; and

iv. a postal survey of respondents in areas around Heathrow, Manchester, East Midlands and Coventry airports.

In the case of (iii) and (iv), two sites were chosen for each survey to represent areas exposed to relatively high and low levels of noise at night.

The report is entitled *Perceptions of Aircraft Noise, Sleep and Health*. December 2000. (Ian Diamond, Rob Stephenson & Zoe Sheppard, University of Southampton; Andrew Smith, Sheila Hayward & Sue Heatherley, Cardiff University; Gary Raw, Building Research Establishment; Stephen Stansfeld, Queen Mary and Westfield College.)

The report (which includes an executive summary) may be downloaded from:

http://www.dft.gov.uk/pgr/aviation/environment/perceptionsofaircraftnoisesl2945 (PDF, 511KB)

Please note that the report was formerly published on Southampton University's website at: http://www.socstats.so ton.ac.uk/r esearch/noisereport.doc

Future Research

14. The Government announced on 8 May 2001 that a new full-scale objective sleep study would be unlikely to add significantly to existing knowledge; it is to concentrate instead on further research into subjective responses to aircraft during both day and night.

15. All of the reports referred to may be inspected free of charge at the Ashdown House Library and Information Centre. The address is Ashdown House, 123 Victoria Street, London SW1E 6DE. An appointment can be made by telephoning the enquiry desk on 020 7944 3039.

16. Further enquiries may be made to:

Mr Roy Strapp
DfT
Aviation Environmental Division 4
Zone 1/33
Great Minster House
76 Marsham Street
London SW1P 4DR
Tel: 020 7944 4856
Fax: 020 7944 2189
E-mail: aed@dft.gsi.gov.uk

Report of a Field Study of Aircraft Noise and Sleep Disturbance (1992): Executive Summary

Objectives

1. Current night restrictions at Heathrow and Gatwick Airports are based, in part, on the results of studies of the effects of noise on sleep carried out more than ten years ago. As these policies were due to be reviewed, the Department of Transport asked the Civil Aviation Authority to undertake further studies of aircraft noise and sleep disturbance, with emphasis on objective measurements. The study has been conducted by the CAA in conjunction with research teams from the Universities of Loughborough, Manchester Metropolitan and Southampton.

2. The objectives of the study were to determine:

a. the relationships between outdoor aircraft noise levels [1] and the probability of sleep disturbance;

b. the variation of these relationships with time of night.

To meet these, it was also necessary to investigate the influence of non-acoustical factors upon disturbance of people’s sleep including their age, sex and personal characteristics, their general views about the neighbourhood, their perceptions about sleep quality and the ways in which this might be affected by aircraft noise.

3. It may be postulated that sleep disturbance involves three different kinds of effects, (1) interference with the sleep process itself, (2) short-term after-effects which include, for example, daytime sleepiness and annoyance, and (3) possible long-term health effects. As the latter effects are consequent upon the first, a major aim of this study was to observe the sleeping patterns of people in homes which are affected by aircraft noise.

Background

4. The traditional method for monitoring sleep is electroencephalography or 'sleep-EEG' in which brainwaves are measured by electrodes attached to the scalp. A hypnogram is a record of sleep stage changes during the night obtained from EEG data. Sleep stages in the hypnogram include light, deep and REM (rapid eye movement - indicative of dreaming) as well as wakefulness. However, the method is complex and expensive and, partly for these reasons, most EEG work has been performed in laboratory situations using relatively small numbers of subjects. In order to avoid the statistical constraints of such limited studies and because of a strong possibility that laboratory results are not representative of the way people react in their homes, this study made use of actimeters to gather a large quantity of field data. Actimeters are used to measure fine limb movements, usually of the wrist, which are indicative of sleep disturbance. Actimeters are small, relatively inexpensive devices, worn like a wrist watch, and easily used in the home without supervision. They log and store data for many nights which is subsequently transferred to a computer for conversion to *actigrams*, the graphical records of limb movements.

5. Actimetry is widely used in sleep research, but an important part of the study was to validate its use for measuring the effects of aircraft noise on sleep. This was done by direct comparison of EEG and actimeter measured disturbance, both in the main study itself and in a preliminary pilot investigation.

Definition of Sleep Disturbance

6. In order to establish a working definition of 'sleep disturbance' within the context of this study, views were sought from a number of eminent sleep experts both at the outset and when the initial experimental results became available. Opinions differed on precise definitions, particularly with regard to effects which might in any way be regarded as injurious to health. However, there was broad agreement on three points:

a. Any identified period of EEG-measured wakefulness is definitely indicative of sleep disturbance.

b. Lesser EEG responses, such as sleep stage changes, may be considered as minor perturbations.

c. Brief awakenings, of less than about 30 seconds, are most unlikely to result in daytime sleepiness or otherwise impair health unless, in sum, they occur more than about six times an hour through the night. Longer awakenings, depending on their duration and number, can be increasingly more harmful. Awakenings are not usually remembered the next day unless they last beyond 1 to 2 minutes. A high proportion of awakenings are very brief with durations measured in seconds rather than minutes.

7. Accordingly, for the purposes of this work, an EEG-disturbance was defined as an episode of wakefulness lasting 15 seconds or more, or 'movement time' (a distorted EEG response usually related to wakefulness) lasting 10 seconds or more. Onsets of such disturbances, identified from EEG records or hypnograms, were defined as *awakenings*.

8. Disturbances identified from actigrams, ie any onsets of wrist movement following still periods, were termed *arousals*. These arousals often coincide with EEG-awakenings or movement time (nearly 90% of these are detected) but they also include minor perturbations such as twitches of the kind that commonly occur during dreaming (REM) sleep.

Measurements

9. In the main study, volunteer subjects were recruited from homes in 8 study areas, two near to each of four major UK airports - London-Heathrow, London-Gatwick, London-Stansted and Manchester. The sites were chosen (a) to cover a wide range of night-time aircraft noise exposures (Leq) and widely different combinations of event noise levels and numbers, (b) to be large enough to provide statistically adequate samples of residents but small enough to limit the variation in outdoor noise exposure, ideally to within 3 dB, and (c) to be free of excessive noise from non-aircraft sources.

10. At each site, at least 200 people were interviewed in a preliminary social survey. Each sample was chosen to match the wider local population with respect to sex and age distribution. As well as providing a pool of potential subjects, the social survey was designed to yield information on factors other than noise which affect sleep patterns. These included personal characteristics, general views about the neighbourhood, perceptions of sleep quality and the ways in which that might be affected by aircraft noise.

11. From the survey respondents at each site, 50 participants were selected who met various sampling and test criteria. People who said they were deaf, that they suffered from serious sleep-disturbing ailments, that they were taking medications that affect sleep or that they were shift workers were excluded. At each site, all 50 subjects wore actimeters for a fifteen night monitoring period; 6 of them also underwent simultaneous EEG monitoring on four sequential nights.

12. The fieldwork was conducted during the summer of 1991. In all, 400 subjects were monitored for a total of 5742 subject-nights. Sleep-EEG were obtained from 46 subjects for 178 subject-nights (the 'EEG sample' - 3% of the total; data from two subjects were lost). In total, some 40,000 subject-hours of sleep data were analysed, broken down into more than 4.5 million 30-second *epochs*. Outdoor aircraft noise levels (Lmax and SEL) were measured at up to three positions at each site using noise monitors set to record all levels in excess of 60dBA (use of a lower threshold would have increased the difficulty of identifying and measuring aircraft noise events due to interference from non-aircraft noise sources). Aircraft movements causing noise events were identified from airport runway logs; the events were accurately timed for synchronisation with the sleep measurements. A total of 4823 aircraft noise events were logged during the 120 measurement nights at outdoor noise levels from 60dBA to more than 100dBA Lmax. Accompanying data from pre-test and debrief interviews, sleep logs and diaries comprised another 100,000 items of data.

13. The data were analysed to determine the relationships between sleep disturbance and aircraft noise taking into account the effects of other relevant factors including time of night and the age and sex of the subjects. Because the main results, such as overall disturbance rates, are based on analyses of large data samples, there is a high level of statistical confidence that they are reliable estimates of true 'population' values. However, when the data were divided into subsamples to determine the effects of the other factors, confidence intervals inevitably widened and considerable care was necessary to ensure that the conclusions are statistically valid. Wherever possible, a procedure known as *random effects logistic*

regression analysis was used to take proper account of the combined effects of the various factors of importance. This technique also overcomes a limitation inherent in measured data of this kind: that although each individual subject provides an independent set of disturbance data, the many measurements from one individual are not statistically independent of each other.

Validity of Actimetry

14. Actimetry was shown to be a convenient and valid technique for investigating sleep disturbance in the home. For the EEG-sample, the agreement between actimetrically determined arousals and EEG-measured awakenings was very good: 88% of all awakenings coincide with actimetric arousals. For the noisiest site, the agreement was 92%. The agreement in the case of undisturbed epochs is even higher, 97% overall. This is important support for the actimetry method, given that undisturbed epochs were 95% of the total.

Overall Disturbance

15. The mean arousal rate (ie the proportion of epochs with movement arousals) for all subjects, all causes, all nights, all epochs, was 5.3%. For the average sleeping period of 7.25 hours, this is equivalent to about 45 arousals per night. Of these, some 40%, ie about 18 per night, are likely to be awakenings of 10-15 seconds or more, the remainder being minor perturbations [2] .

Factors and Affecting Sleep Disturbance

Individual Sensitivity

16. Individual rates of sleep disturbance varied markedly; after statistically controlling for the effects of aircraft noise, sex and time of night, the 2-3% most sensitive individuals were disturbed over 60% more than average. There appear to be no strong personal factors contributing to this sensitivity; a large number of possible variables have been specifically ruled out, although further analysis is being undertaken.

Aircraft Noise

17. The results indicate that, below outdoor event levels of 90 dBA SEL (80 dBA Lmax), aircraft noise events (ANEs) are most unlikely to cause any measurable increase in the overall rates of sleep disturbance experienced during normal sleep. For outdoor event levels in the range 90-100 dBA SEL (80-95 dBA Lmax) the chance of the average person being wakened is about 1 in 75. Again, individual deviations from the average are substantial. It is possible that, for aircraft noise related disturbance, the variability is even greater; compared with the average, the 2-3% most sensitive people could be over twice as likely to be disturbed and the 2-3% least sensitive less than half as likely.

Sex and Age

18. The results indicate that, overall, men are disturbed from sleep about 15% more frequently than women and that this is true for all causes of disturbance, not especially aircraft noise. No statistically significant effects of age were found.

Time of Night

19. Statistically, time of night and time from sleep onset are significant factors. When the data are broken down by time of night, people appear to be most resistant to disturbance, from any cause, after first falling asleep. Then, starting with a pronounced fluctuation having a cycle time of about 90 minutes, the overall disturbance rate increases steadily, from the equivalent of about two awakenings an hour at the beginning of the night to about three per hour at the end of the night.

20. Arousals related to aircraft noise seem to follow a stronger cyclic pattern. After the first 45 minutes of sleep, which appears to be insensitive to the noise, noise-related disturbances repeatedly rise and fall in a way that cannot be explained by the rates at which aircraft noise events occur. Although difficult to verify statistically, natural biological rhythms of sleep may be the reason. The possibility that people are most sensitive to disturbance by noise when sleep lightens, and less vulnerable when sleep deepens, is the subject of continuing analysis.

21. As well as being minimal during the first hour of sleep, sensitivity to aircraft noise seems to diminish at the end of the night's sleep. However, this may be due to greater overall rates of awakening from all causes and, consequently, a diminishing proportion of people asleep from 0600 onwards. Further analysis is continuing in an attempt to shed more light upon this important but difficult question.

Non Significant Effects

Site

22. There were no statistically significant differences between the average arousal rates over the night at the different study sites.

Window State

23. The reported 'window state' each night, ie open, single glazing shut or double glazing shut, was included in the analysis but, although increased noise insulation was accompanied by reduced arousal rates, this has not been found statistically significant.

Aircraft Type

24. *Allowing for noise level*, ie comparing their effects at the same event noise levels, no significant differences were found between the average noise-related arousal rates for large jets, small Chapter 2 jets, small Chapter 3 jets [3] and propeller aircraft types.

Length of Residence

25. No subjects were selected who had lived locally for less than one month. With this proviso, there is no significant effect of length of residence on arousal rates, ie there appear to be no adaptation effects after the first month of residence.

Other Noise Variables

26. Because of the predominance of approach noise in this study (which rightly reflects the high proportion of arrivals in nighttime aircraft movements) as well as the generally weak effect of aircraft noise level, it is impossible to distinguish between the performance of Lmax and SEL as indicators of sleep disturbance.

Recollections of Sleep Disturbance

27. The secondary or after effects of sleep disturbance include subjects' recollections of being wakened and adverse perceptions of their sleep quality. For 57% of subject-nights, no awakenings were reported the next day. On the remaining 43% of occasions, at least one awakening was reported (all causes), the average number being three per night. In 26% of reported awakenings, the reason was given as 'not known'. For the remainder, the most frequently reported cause was 'toilet' (16%). The next most common was 'children' (13%) mainly among women in the lower age groups. 'Illness' was also mentioned frequently (>9%), again mostly by women. 'Aircraft' was a relatively a minor cause (<4%); about one quarter of all actimetry subjects specifically reported being disturbed by aircraft noise during the study - on average by these subjects, once every five nights.

28. The agreement between individuals' measured arousal rates and their general self-ratings of sleep quality (recorded during the prior social survey interview) is poor. However, there is better agreement between the measured arousal rates and next-day reports of sleep quality obtained from the daily sleep logs. This suggests that when social survey methods are used for investigating sleep disturbance, emphasis should be placed on collecting data about disturbance experienced during the previous night.

29. The measurements of sleep disturbance, which were the main subject of this study, are quite distinct from those of annoyance, which must be counted among secondary effects. The relationship between measured disturbance and annoyance reports as well as the question of daytime sleepiness, are the subject of continuing study.

Conclusions

30. All subjective reactions to noise vary greatly from person to person and from time to time and sleep disturbance is no exception; deviations from the average can be very large. Even so, this study indicates that, once asleep, very few people living near airports are at risk of any substantial sleep disturbance due to aircraft noise, even at the highest event noise levels.

31. At outdoor event levels below 90 dBA SEL (80 dBA Lmax), average sleep disturbance rates are unlikely to be affected by aircraft noise. At higher levels, and most of the events upon which these conclusions are based were in the range 90 to 100 dBA SEL (80 to 95 dBA Lmax), the chance of the average person being wakened is about 1 in 75. Compared with the overall average of about 18 nightly awakenings, this probability indicates that even large numbers of noisy nighttime aircraft movements will cause very little increase in the average person's nightly awakenings. Therefore, based on expert opinion on the consequences of sleep disturbance, the results of this study provide no evidence to suggest that aircraft noise is likely to cause harmful after effects.

32. At the same time, it must be emphasised that these are estimates of *average* effects; clearly more susceptible people exist. At one extreme, 2-3% of people are over 60% more sensitive than average; some may be twice as sensitive to noise disturbance. There may also be particular times of the night, perhaps during periods of sleep lightening, when individuals could be more sensitive to noise. Although the relationship cannot be verified statistically, the data do indicate that aircraft events with noise levels greater than 100 dBA SEL (95 dBA Lmax) out of doors, will have a greater chance of disturbing sleep. The most sensitive people may also react to aircraft noise events with levels below 90 dBA SEL (80 dBA Lmax) (approximating to 95 EPNdB on the noise scale used internationally for the noise certification of aircraft).

33. These conclusions are based on actimetric measurements of arousals from sleep supported by EEG data.

34. Work is continuing on a number of detailed points to supplement the findings in this report including further analysis of the possible effects of noise in preventing sleep onset at the beginning of the night, or delaying return to sleep after awakening during the night or in the early morning. This will not change the conclusions about aircraft noise presented here but additional results will be published subsequently.

The full title of the report is **Report of a Field Study of Aircraft Noise and Sleep Disturbance: A study commissioned by the Department of Transport from the Department of Safety, Environment and Engineering, Civil Aviation Authority December 1992. (Â£10.00)**. A summary of the report in paper form is available from the Department free of charge by telephoning 020 7944 5462. The full report is available from The Stationery Office (telephone orders/general enquiries 0870 600 5522, fax orders 0870 600 5533). Website: www.tso-online.co.uk

A copy may be inspected free of charge at the Ashdown House Library and Information Centre. The address is Ashdown House, 123 Victoria Street, London SW1E 6DE. An appointment can be made by telephoning the enquiry desk on 020 7944 3039.

[1] Although people in bed hear aircraft noise as attenuated by the walls, windows and furnishings of their bedrooms, indoor noise levels naturally vary very widely from room to room and from ear to ear. These variations cannot be accounted for in planning or policymaking; only outdoor levels are known or can be estimated with any degree of confidence. Noise level measurement inside subjects' bedrooms was not practicable. The unknown variability is viewed simply as one of the many uncontrollable factors affecting sleep disturbance.

[2] The awakening-to-arousal ratio of 40% is an example of a statistic which is subject to a sampling uncertainty, in this case of perhaps plus or minus 10%. Thus, although the average number of nightly awakenings (all causes) is likely to be *about* 18, it would be more accurate to state that it probably lies in the range 18 plus or minus 4.

[3] These 'Chapters' refer to international aircraft noise certification standards; at comparable weights, Chapter 3 aircraft are quieter than (earlier) Chapter 2 aircraft.