

Environmental Research and Consultancy Department



R&D REPORT 9964

Adverse Effects of Night-Time Aircraft Noise

**N D Porter
A D Kershaw
J B Ollerhead**

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Enquiries regarding the content of this publication should be addressed to:
Environmental Research and Consultancy Department, Directorate of Airspace Policy, Civil Aviation Authority, CAA House, 45-59 Kingsway, London, WC2B 6TE.

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Department of Operational Research and Analysis
National Air Traffic Services Ltd

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Adverse effects of night-time aircraft noise

N D Porter
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Prepared by DORA on behalf of the Department of the Environment, Transport and the Regions, London, March 2000

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EXECUTIVE SUMMARY

1. This report considers the potentially adverse effects of night-time aircraft noise on people and identifies a number of issues for possible further research. The report is part of continuing research supported by the UK Government, and is intended as background to any future UK studies of night-time aircraft noise.
2. Aircraft noise can adversely affect people living near airports in many ways and concern that night-time noise is detrimental to public welfare is understandable. Employing the broad WHO definition of health, it is evident that night-time environmental noise adversely affects health by causing chronic subjective reactions. However, as yet, there appears to be no hard scientific evidence of clinically significant health impairment, i.e. chronic objective effects. Nevertheless, the possible existence of cause-effect relationships cannot be rejected and it seems that two fundamental questions need to be addressed in the longer term:
 - Can night-time aircraft noise cause clinically significant health impairment directly through physiological effects?
 - Accepting that night-time environmental noise adversely affects health by causing chronic subjective reactions, can these reactions also give rise to objective effects and thus impair health indirectly?
3. A number of possible responses and effects due to night-time aircraft noise have been identified. A model framework is postulated which shows effects developing in four stages:
 1. acute responses that include immediate or direct disturbances caused by noise events,
 2. total night effects that are aggregations of (1) over the whole night,
 3. next day effects that are a result of (1) and (2), and
 4. chronic effects that are pervasive long-term consequences of (1), (2) and (3).
4. It is acknowledged that the model is a simplification of a complex web of interactions that also contains a large number of modifying factors which intervene at every stage of the model. Modifying factors (such as attitude to the noise source) have a strong influence on reaction to night-time aircraft noise, often more influence than the noise exposure itself. However, the relative and combined influence of these factors is not well understood.

5. Key findings of DORA studies on night-time aircraft noise are found to be comparable with those of other similar studies performed elsewhere.
6. The research evidence suggests a disparity between subjective perceptions of noise-induced disturbance (and consequent annoyance) and objectively measured disturbance. Subjective reactions are strong whereas noise has a relatively small effect on the incidence of physiological disturbance. High levels of aircraft noise can waken people but at current levels of exposure near airports, aircraft noise is just one of very many causes of sleep disturbance.
7. This raises the question of whether previous UK studies have focused too strongly on sleep disturbance, especially noise-induced awakenings during the night, as this is only one of many effects of night-time aircraft noise.
8. Gaps in knowledge have been identified. It is acknowledged that the present understanding of the cause-effect web represented by the model framework is fragmentary and, although no decision has yet been taken, the DETR is considering whether there is a case for a further full scale study on the adverse effects of night-time aircraft noise. Three advisory groups were convened to consider future work options. After considering advice from DORA and the advisory groups, the Department decided to commission two short research studies to investigate the options further.

GLOSSARY OF TERMS

Actimeter	Instrument for measuring wrist movements, worn like a wrist watch.
Actimetry	Measurement of arousals from sleep using an actimeter.
Arousals	Used generally in the scientific literature to mean various perturbations or disturbances to sleep. (Specifically used in the 1992 UK field study to describe the onset of sleep disturbance as measured by an actimeter.)
Awaken(ing)	Generally, the process of changing from a state of sleep to wakefulness. However, the term is sometimes used to describe particular responses; for example, for the special purposes of the 1992 Field Study (Oll92), it was defined as the start of at least 15 seconds of 'wakefulness' or 10 seconds of 'movement time'.
CAA	UK Civil Aviation Authority.
dB	Decibels, units of sound level, or relative sound level, calculated as 10 times the log (base 10) of a sound energy ratio.
dba	Levels on a decibel scale of noise measured using a frequency dependent weighting which approximates the characteristics of human hearing. These are referred to as A-weighted sound levels; and are very widely used for noise assessment purposes.
DETR	UK Department of Environment, Transport and the Regions.
DORA	Department of Operational Research and Analysis; NATS.
Dose-response	A relationship between the noise exposure dose received and the response arising from it.
EEG	Electroencephalography: the measurement of very small electrical signals generated within the brain using small electrodes attached to the head - used to determine sleep stages.

Hypertension	Abnormally high blood pressure.
Ischaemic heart disease	Disease of blood vessels supplying the heart leading to heart attacks and associated with increased mortality risk.
Leq	A measurement of long-term average noise exposure; for aircraft noise it is the level of a steady sound which, if heard continuously over the same period of time, would contain the same total sound energy as all the aircraft noise events.
NATS	National Air Traffic Services Ltd
Negative affectivity	The propensity to regard everything in a negative light. It is an important trait found to explain the level of responses and types of behaviour in a number of different areas of life. Negative affectivity is often measured using neuroticism scales.
Neurosis	A mild mental disorder characterised by anxiety, depression, or obsessional behaviour.
Rebound effect	Natural recovery of sleep following sleep disturbance.
REM	Rapid Eye Movement; a stage of sleep usually accompanied by dreaming.
Reverse causality	An observed correlation between two variables may have a cause in the opposite direction to that expected. E.g. We expect a change in X to cause a change in Y but in reality, changes in Y cause changes in X.
SEL	Sound Event (Exposure) Level is effectively a 1 second Leq. SEL is used to compare different transient events for total noise energy content. Like EPNL, this scale accounts for both the duration and the intensity of the noise event.
Shoulder hours	Notionally, the period of transition between ‘most people awake’ and ‘most people asleep’ at the beginning and end of the night (so called because they span the ‘shoulders’ of a graph of percentage of people awake versus time). The term is sometimes used in the UK to refer specifically to the periods 2300-2330 and 0600-0700 local, to which distinct rules apply for the purposes of night restrictions at the London airports, or to comparable administratively defined periods elsewhere.

Sleep disturbance	All types of disturbance to the sleeping process.
Sleep fragmentation	Multiple arousals. The frequency of arousals determines the extent of fragmentation.
Sleep onset latency (SOL)	The time between 'lights out' and falling asleep.
Sleep onset	The time of first falling asleep.
Sleep stage	State of sleep as measured by sleep-EEG. Sleep stages include wakefulness, movement time, and REM as well as stages 1 to 4, the latter relating to depth of sleep.
Sleepiness	The propensity to fall asleep
Tiredness	Distinct from sleepiness, it is a feeling of lethargy, difficulty in getting going, 'heavy limbs' and loss of interest.
Wellbeing	Generally used to describe the condition of being contented, healthy, or successful. Used here to describe positive state-of-mind and perceived good health.
WHO	World Health Organisation

1 INTRODUCTION

- 1.1 This report, prepared for the DETR, considers the potentially adverse effects of night-time aircraft noise on people and identifies a number of issues for possible further research. It benefits from the help of three advisory groups that were established to help consider the issues and provides a record of the thinking that led to the commissioning of two exploratory research projects that are now underway.

Background

- 1.2 Aircraft noise can adversely affect people living near airports in many ways and concern that night-time noise is detrimental to public wellbeing is understandable. Aircraft noise can disturb sleep and it is generally acknowledged that good quality sleep is important for health and wellbeing.
- 1.3 It is important to clarify what is meant by 'health' and to consider its relationship to wellbeing. In 1968, the World Health Organisation (WHO) defined health as '*a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity*' (WHO68). In 1990 WHO stated that '*good health and well being require a clean and harmonious environment in which physical, physiological, social and aesthetic factors are all given their due importance*' (WHO90).
- 1.4 Health impairment can be assessed objectively in terms of physical and mental states of clinical significance which, for the purposes of this report, are termed **chronic objective effects**. Health impairment can also be assessed subjectively in terms of wellbeing, quality of life and perceived state of health, which, for the purposes of this report, are termed **chronic subjective reactions**. More detailed interpretations of the meaning of health can be found elsewhere (Por97, HCN99).
- 1.5 Employing the broad WHO definition, it is clear that night-time environmental noise adversely affects health by causing chronic subjective reactions which effect quality of life. As yet, there appears to be no hard scientific evidence of clinically significant health impairment, i.e. chronic objective effects. Nevertheless, the possible existence of cause-effect relationships cannot be rejected and it seems that two fundamental questions need to be addressed in the longer term:
- 1) Can night-time aircraft noise cause clinically significant health impairment directly through physiological effects?

- 2) Accepting that night-time environmental noise adversely affects wellbeing by causing chronic subjective reactions, can these reactions also give rise to objective effects and thus impair health indirectly?
- 1.6 The UK Government continues to support research into the effects of aircraft noise. The Department of the Environment, Transport and the Regions (DETR) has commissioned much research to inform policy decisions. With respect to restrictions on night-time aircraft movements at the designated UK airports, Heathrow, Gatwick and Stansted, it has commissioned several studies of sleep disturbance from DORA. The most extensive of these, the ‘1992 UK field study’ of sleep disturbance in the home (Oll92), is considered in this report.
- 1.7 This report is intended to be a ‘snapshot’ of current knowledge with emphasis on night-time aircraft noise, not a comprehensive review of effects of noise on health in general. Many excellent and extensive reviews of that kind have already been reported (HCN94, Job96, Mor97, Tho96, IEH97, Sta97). It must be borne in mind that reference is made here to selected work from sources of varying status, from non-refereed technical reports and conference proceedings to peer-reviewed papers from archived journals. The quality and reliability of the references might therefore vary with status.
- 1.8 No attempt is made to identify noise acceptability limits. People react differently to noise. Some people living close to airports are not troubled by night-time aircraft noise whilst others living very many miles away are badly affected. Policy judgements have to take account of such variability – and many other factors. Scientific research can only help to inform decisions.

Report Structure

- 1.9 Section 2 reviews the problem of night-time aircraft noise in relation to a hypothetical ‘model framework’ of effects. Section 3 summarises past work carried out by DORA with particular emphasis on the UK field study of sleep disturbance. Its results are compared with more recent findings and with current guidelines on noise-induced sleep disturbance. Section 4 considers specific future research options that were considered by the advisory groups and concludes the report with an outline of the exploratory studies that have been commissioned.

2 EFFECTS OF NIGHT-TIME AIRCRAFT NOISE

Model framework

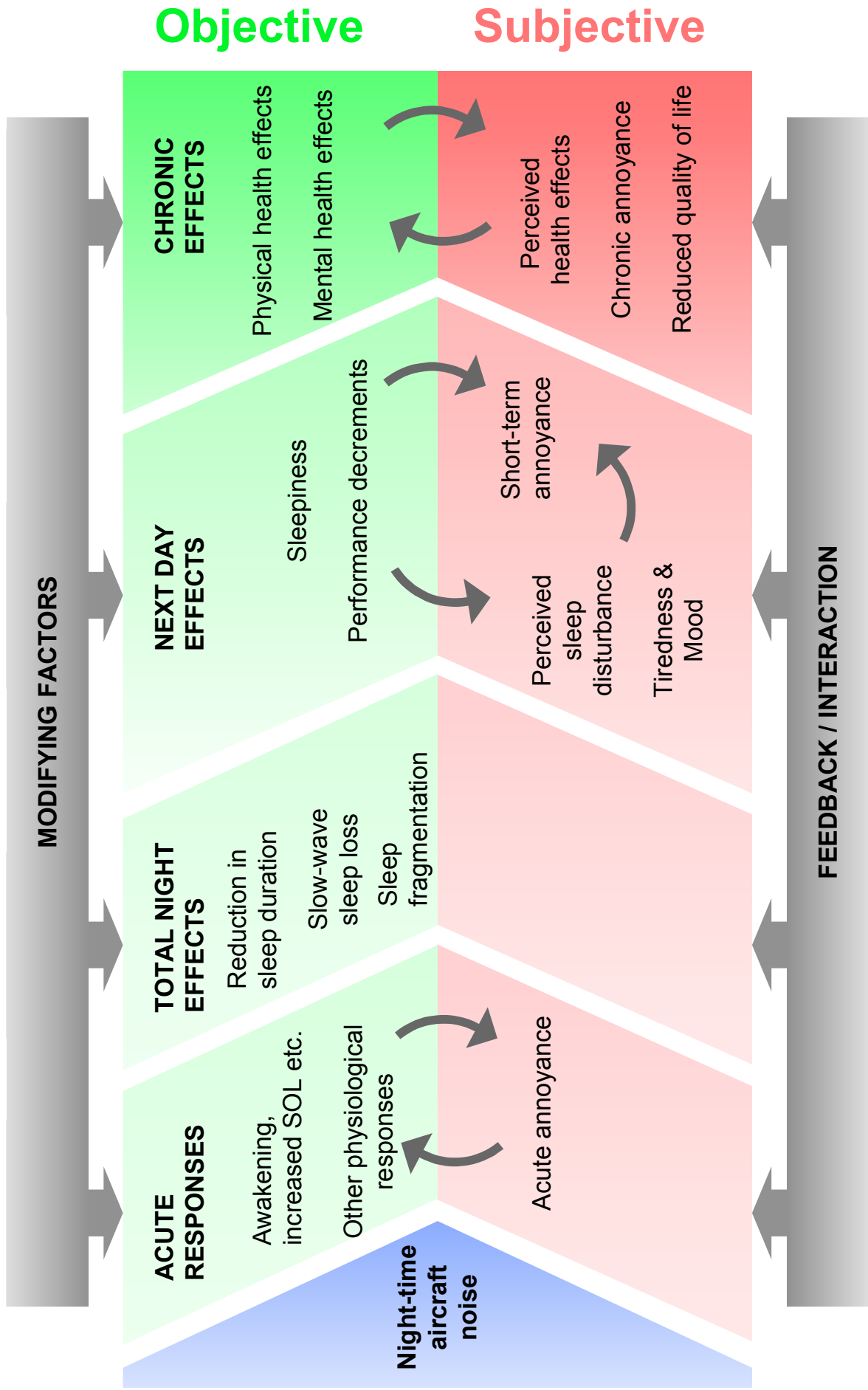
2.1 **Figure 1** links various causes and effects of night-time aircraft noise on people living near airports in a conceptual ‘model framework’. This is a considerable simplification of what in reality is a complex web of interactions; it shows what are thought to be the principal elements and connections. It recognises four levels of effect:

1. acute responses that include immediate or direct disturbances caused by noise events,
2. total night effects that are aggregations of (1) over the whole night,
3. next day effects that are a result of (1) and (2), and
4. chronic effects that are pervasive long-term consequences of (1), (2) and (3).

Effects which are objectively measurable are shown in green; subjective reactions in red. The model recognises that all of these effects are dependent on many modifying factors - demographic, behavioural, sociological, situational and so on. Modifying factors have a substantial, sometimes dominant influence.

2.2 The elements of this model are interdependent and overlap; their boundaries are somewhat blurred. Although the principal cause-effect sequence is noise \Rightarrow acute \Rightarrow total night \Rightarrow next day \Rightarrow chronic, noise can cause next day and chronic effects directly and there is substantial potential for feedback, interaction and reverse causality. Thus, for example, a person suffering chronic annoyance might be more susceptible to acute disturbance. A key question is whether an indirect route from noise to health impairment is more significant than the possible consequences of sleep disruption upon which so much past research has focused.

Figure 1 Potential impact of night-time aircraft noise: Model framework



Acute responses

Sleep disturbance

- 2.3 Acute responses, both physiological and psychological, are immediate disturbances attributable to the noise. A major acute response is sleep disturbance. Disturbances include changes to the depth of sleep, wakening from sleep and prevention from getting to sleep. 'Depth of sleep' can be measured by EEG; sleep stages 1 and 2 are recognised as shallow sleep; stages 3 and 4, also known as slow wave sleep (SWS), are deep sleep. Dreaming sleep is termed REM sleep (because it is accompanied by rapid eye movement). SWS, with an element of REM, has been described as 'core sleep' which may be essential for brain restitution (Hor88). Other possible functions of sleep include regulation of the cardiovascular and immune systems.
- 2.4 The threshold for noise-induced awakening has been quoted as lying between 55 and 60 dBA SEL indoors (Ber95, HCN94). However, research indicates that, above this threshold, the probability of awakening increases slowly with noise level (Oll92, Fid94, Fid95, Fid98). Aircraft noise can also induce sleep stage changes, at levels significantly lower than awakening thresholds (HCN97, Ber95).

Other Physiological responses

- 2.5 Other acute responses to noise include changes in the body's cardiovascular and immune systems. The former include increases in blood pressure and heart rate (Muz80). Such responses may occur when a person is sleeping or awake. In themselves these responses may not be symptomatic of a clinical condition; however, there is concern that they may lead to permanent increases in blood pressure (Car96). Sleep is a state of reduced activity that might be cardio-protective; it has therefore been hypothesised that chronic reduction of this respite by noise could have implications for long-term cardiovascular health (Car98). In one field study of volunteers with mild forms of cardiac arrhythmia¹ it was speculated that there is a slightly increased risk of this condition occurring in the presence of environmental noise during sleep (Car94). However, at present, evidence for chronic effects of environmental noise on cardiovascular health is inconclusive (Por97, IEH97, Sta97).
- 2.6 Research evidence that noise exposure may be related to impaired functioning of the immune system is also inconclusive. Bly and co-workers reviewed nine laboratory studies on noise-induced effects of the

¹ Variation in the normal rhythm in the heartbeat.

immune system (Bly93). Some of the studies suggested that noise-induced stress caused moderate suppression of the immune system and others suggested that immune system stimulation occurred with exposure to noise. However, it was noted that some of the findings were contradictory.

- 2.7 It has been speculated that reduction in slow-wave sleep may impact on the immune system and since SWS may be reduced by intermittent noise, the possibility exists that the immune system may be affected by aircraft noise indirectly in this way (Car96).

Psychological responses

- 2.8 Acute psychological responses include annoyance, and the perception that aircraft noise is disturbing sleep *at the time of the noise event*.
- 2.9 ‘*Acute annoyance*’ is an immediate subjective response to a noise event which might be accompanied by physiological responses such as acute increases in blood pressure. Annoyance reactions have been studied extensively by psychoacoustic researchers using, for example, scales to quantify responses to such questions as “when you are disturbed by noise, how annoyed do you feel”. This research has shown that the incidence of noise annoyance is strongly influenced by many modifying factors such as sensitivity, attitude to the source, past experience and expectations. A long term feeling of annoyance accumulated over time is described here as chronic annoyance. This and the role of modifying factors are discussed more fully later under the heading of *chronic effects* (see 2.32-2.52).
- 2.10 It is notable that airport neighbours often cite sleep disturbance at the beginning and end of the night as the most objectionable and annoying aspect of night-time aircraft noise (HAC98).

Total night effects

- 2.11 The cumulative effects of repeated disturbances over a whole night might be characterised as:
- *Reduction in sleep duration* - a reduction in the time asleep;
 - *Slow-wave sleep (SWS) loss* - a reduction in the time spent in deep sleep; and
 - *Sleep fragmentation* – frequent disturbances breaking up the general sleep pattern.
- 2.12 Sleep duration and the proportion of deep sleep stages have been shown to decrease with age. Old people are more likely to be disturbed by

noise (Hor88). Studies have also found women to be more responsive to noise stimuli than men (Luk75, Ber95) although other studies have found the opposite (Oll92, Fid95).

Reduction in sleep duration

- 2.13 Reductions in sleep duration might be caused by increased sleep onset latency (SOL). SOL is the time between intending to sleep ('lights out') and falling asleep. Öhrström (Ohr93) reported that when peak noise levels reach 45 dBA and above, intermittent noise increases the time for falling asleep by about 5-20 minutes. From additional analysis of the 1992 UK field study data (Hum00) it was not possible to conclude whether aircraft noise increased SOL.
- 2.14 The time asleep might also be shortened by premature awakening, wakening earlier than usual in the morning. In the early morning, sleep typically cycles between REM and stage 2 sleep with occasional spontaneous arousals that increase towards the end of the night. Experimentally it is difficult to ascertain whether or not specific awakenings are caused by aircraft noise events or just happen to coincide. From additional analysis of the 1992 UK field study data it was not possible to conclude whether aircraft noise has a significant effect on premature awakenings (Hum00).

Slow-wave sleep loss

- 2.15 If SWS is the most restorative component of sleep, any induced *slow-wave sleep loss* during the normal sleeping period is likely to be particularly detrimental.
- 2.16 A review by Carter indicated that SWS in young adults may be reduced by intermittent noise (such as that from aircraft) (Car96). The field studies reviewed were of subjects who had lived at their homes for at least one year, and therefore had sufficient time to habituate to the noise.
- 2.17 If, over a period of time, sleep is disturbed excessively, an increase in the amount of deep sleep can occur subsequently. This process, often called the 'rebound effect', may be a protective mechanism that can, to some extent, reverse the effects of sleep disturbance.

Sleep fragmentation

- 2.18 Sleep fragmentation involves the breaking up of sleep by frequent arousals. It has been argued that the benefits of sleep accumulate over time and that frequent awakenings can slow or stop that process, thereby reducing those benefits (Bon89).

Next day effects

- 2.19 Next day effects are essentially short-term and may occur following a night of disturbed sleep. Some are directly measurable and include sleepiness, disturbance to functioning or performance. Others are subjective; effects perceived or reported the next day including annoyance, recollections of sleep disturbance, tiredness and changes of mood.

Sleepiness

- 2.20 Sleepiness is the propensity of an individual to fall asleep. When it occurs during the day it can be a secondary symptom of a disturbed night's sleep. It can be measured using a *Multiple Sleep Latency Test*, MSLT. One study, of young adults, revealed no sleepiness when sleep periods were restricted to 5 hours until this regime had been maintained for 4 nights (Car81). No information has been found on the relationship between sleepiness as measured by MSLT and aircraft noise.

Performance decrements

- 2.21 Generally, studies have shown that sleep deprivation (experimentally enforced disturbance of sleep) can result in next day performance and functioning decrements (Hor88, Bon94). Methods of measuring performance include vigilance and reaction time tests as well as complex tests of IQ performance and decision-making. It has been suggested that 'divergent' thinking skills such as creativity, novelty and flexibility of behaviour should also be tested (Hor88).
- 2.22 It has been found in some studies that performance and alertness decrements accumulate when the time allowed for sleeping each night is 5.5 hours or less but not for longer periods (Hor85, Web74). In these studies, the length of time spent in slow-wave sleep (SWS) was maintained. These results suggest that young adults who sleep for 7-8 hours could physically tolerate up to 2 hours chronic reduction in their daily sleep without any significant reduction in performance. However, aged people may not be able to tolerate such chronic reductions in daily sleep (Hor88).
- 2.23 Even if two hours chronic sleep loss does not result in measurable reductions in performance, other responses and effects may be significant. In one study the time allowed for sleeping was shortened in 30-minute steps over several weeks (Fre77). Subjects began to complain of discomfort, fatigue and difficulty remaining vigilant while driving, yet no significant performance reduction was measured.

- 2.24 Studies have indicated that repeated arousals during sleep, even if brief, systematically reduce daytime alertness by an amount which depends on the frequency of arousals and age of the subject. The critical arousal interval is thought to be about 20 minutes. No effects were observed for greater intervals; below that limit the effect increased with frequency (Bon94).
- 2.25 This appears to be an illustration of the effects of fragmentation. But it suggests that although aircraft noise might be a cause, at exposure levels around airports, the rate of fragmentation is unlikely to result in health effects of clinical significance.²
- 2.26 To date, there appears to be no evidence that sleep losses comparable to those experienced in these studies of sleep deprivation are likely to be caused by aircraft noise, even at night-time aircraft traffic levels currently experienced at busy airports. Nevertheless, the possibility of noise-induced sleep loss cannot be ruled out in the case of especially sensitive people. Where noise events are sufficiently intense and sufficiently frequent, some delayed sleep onset and premature awakening might occur, even if SWS remains unaffected and sleep is not fragmented. However, whether the resulting sleep loss would be sufficient to lead directly to chronic health effects is another question.

Perceived sleep disturbance, tiredness & mood

- 2.27 Whether or not it has actually happened, individuals may perceive that aircraft noise has disturbed their sleep and caused effects such as tiredness, bad mood and lack of concentration. In turn, such perceptions might induce annoyance and worry about health effects. If so, it would be quite possible for such subjective reactions to be just as detrimental, if not more so, than any objective next day effects.
- 2.28 There is evidence that such perceptions are prevalent. A DORA study found reported sleep disturbance to be widespread, regardless of aircraft noise exposure (DOR80). In a community study of exposure to road traffic noise, perceived sleep quality and mood were decreased following sleep disturbance by road traffic noise (Ohr89).

Short-term annoyance

- 2.29 The expression *short-term annoyance* is used here to describe that felt the day after a disturbed night. It may be an accumulation of annoyance felt during the night or it may arise separately as a result of

² The high frequency of sleep fragmentation required to produce direct health effects is only typically found in people with the breathing disorder apnoea (Whi94).

the perception that sleep has been disturbed. Annoyance responses due to night-time aircraft noise all aggregate into chronic annoyance which is discussed later (paragraphs 2.44-2.48).

2.30 What appear to be the main determinants of annoyance due to noise at night are depicted in **Figure 2** adapted from Porter (Por97). These include (in addition to the acoustic energy of the noise itself) the following:

- Increased noticeability (of the noise) - Generally outdoor ambient noise during the night is around 10 dB less than during the day (Von93, Nel87). In addition, noise-generating activities in the home are reduced. Even without considering increased sensitivity to noise at night, these two effects mean that the same noise heard at night will be more intrusive and noticeable than during the day. Hazard (Haz68) reported that the main predictor of annoyance due to aircraft noise was the awareness of the aircraft between midnight and 6 am (particularly between 12 and 3am).
- Sleep disturbance - Noise may be more annoying during the night-time period due to heightened noise sensitivity. People can become annoyed if they feel that their sleep has been interrupted. It has been reported that sleep disturbance in the early part of the night and the hours before usual awakening is more annoying than in other hours (Nel87, Ohr93, Fid80, Fie86, Nem81).
- Expectation of lower noise levels – Many people expect their homes to be restful havens, particularly after busy (and possibly noisy) days at work (Fie86, Fid80).
- Noise heard during the preceding hours - It has been argued that the response to noise during a particular time period is dependent on the noise heard during other periods; night noise might be more annoying to a person who had experienced noise during the preceding evening or day (Val83, Ber93).
- Attitudes and perceptions - There is much evidence that people generally consider noise to be worse at night than during the day. Fields attributes this ‘conventional wisdom’ to a belief that ‘noise is worse at night because being kept awake by a noise is worse than anything noise can do during the day’ (Fid80, Fie86).
- Negative affectivity - This is the propensity to regard everything in a negative light. It is an important trait found to explain the level of responses and types of behaviour in a number of different areas of life. Negative affectivity is also used in determining annoyance during the day. Negative affectivity is often measured using neuroticism scales.

2.31 Some of these factors are acoustic in nature, others fall under the heading of modifying factors which are addressed in paragraphs 2.51 – 2.52. Porter (Por97) has summarised:

- the extent of an effect of noise is mediated by modifying factors such as familiarity with the noise (Fie86),
- the role of sleep disturbance in chronic night-time annoyance depends on defining the time period of interest, how much sleep disturbance is recalled, and how the person feels about the aircraft (Fie85),
- sleep interruption has been shown to be one of the strongest direct effects on individual annoyance towards aircraft noise (Tay84), and
- getting to sleep and awakenings were shown to be significant factors (at 5% level) in determining an annoyance response (Hal85).

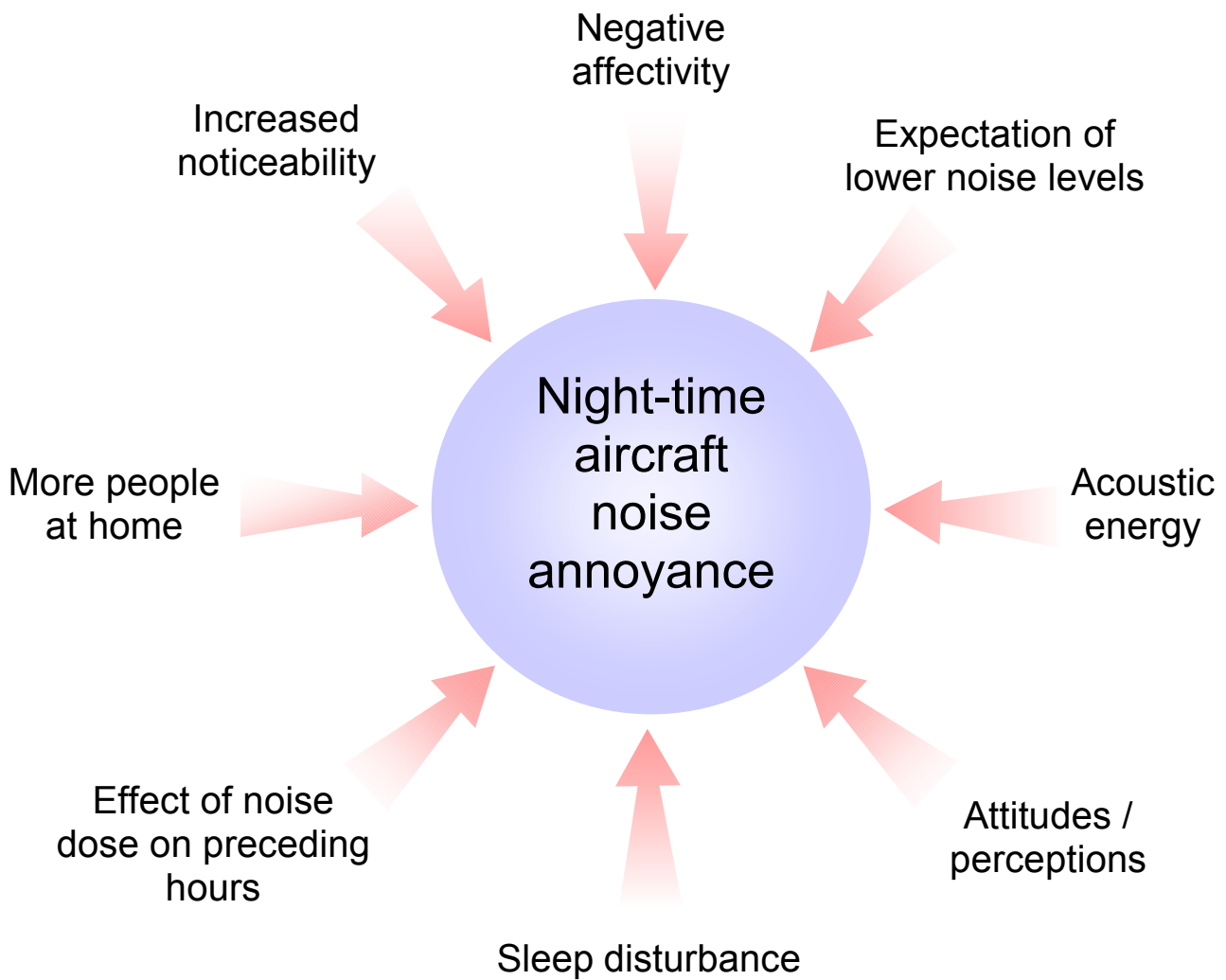


Figure 2 Main determinants of an annoyance response during the night-time period

Chronic effects

- 2.32 These are the possible long-term effects of aircraft noise upon human health and wellbeing. According to a definition of health that embraces wellbeing in general, there can be no question that high levels of aircraft noise near airports have some effect. One crucial question considered in this report is whether night-time aircraft noise leads directly or indirectly to objectively measurable impairment of health, mental as well as physical, that has clinical significance. These are termed *chronic objective effects*.
- 2.33 Perceptions of wellbeing and quality of life, i.e. dissatisfaction with the environment, worries about health, and general adverse reaction to the noise which may be termed chronic annoyance, are termed *chronic subjective effects*. Expressions of chronic annoyance are usually obtained through public opinion surveys via questions such as ‘in general, how annoyed or bothered are you by noise around here’.
- 2.34 Because it has proved to be a general and robust indicator of public antipathy, chronic annoyance caused by noise from many sources has been the subject of a great deal of research and is well documented. Other chronic effects of night-time aircraft noise are less well defined and not easily divided into discrete areas. Of particular concern is whether severe subjective reactions can themselves lead to physical and mental health impairment.

Chronic objective effects

Physical Health Effects

- 2.35 Chronic physical health effects such as hypertension, heart disease and diseases resulting from suppression of the immune system, may be long-term consequences of persistent objective acute and next day effects. They may also arise from chronic annoyance and stress.
- 2.36 Persistently high blood pressure is considered to be harmful. Studies of occupational noise impact have uncovered evidence of a relationship between noise and raised blood pressure, but not a consistent relationship. Evidence of an increased risk of raised blood pressure as a result of exposure to environmental noise is even more limited (Bab98, IEH97).
- 2.37 On the basis of some limited evidence that aircraft noise may contribute to cardiovascular disease (Por98, IEH97), a report by the Health Council of the Netherlands concluded that it was necessary to identify the

possibility of noise-induced ischaemic heart disease and hypertension above 70dBA Leq (HCN94).

- 2.38 Some relationships have been found between aircraft noise exposure and the use of medication. In a study near Amsterdam Schiphol airport, purchases, over 4 years, of prescription drugs used to treat sleep disturbances, psychological and psychosomatic complaints, cardiovascular and hypertensive disease were examined. In high noise areas the number of purchases varied with aircraft noise exposure, but purchases remained static in a low noise (control) area (Kni77).
- 2.39 Although it seems scientifically plausible that a minority of the population exposed at the highest noise levels might be susceptible, the evidence for night-time aircraft noise contributing to increased morbidity is, so far, fragmentary. Some studies of environmental noise exposure and chronic physical health effects have been criticised on methodological grounds, not least with regard to the treatment of confounding factors.

Mental health effects

- 2.40 Some studies have yielded indications that mental health effects might result from aircraft noise exposure (Sta97). For example, higher rates of mental hospital admission, depression, susceptibility to minor accidents and reliance on sedatives and sleeping pills have been found among people living near to airports than among those with less noise exposure. However, some inconsistencies preclude firm conclusions in this area (Job96). It has been suggested that noise is not a direct cause of mental illness but that it might accelerate and intensify the development of latent neurosis (Her72).
- 2.41 If impairment in mental wellbeing is included among mental health effects, the research evidence is more definitive. These effects have been found to be caused by aircraft noise, hence Morrell and co-workers state that '*Using the World Health Organization definition of health, which includes positive mental and social wellbeing, aircraft noise is responsible for considerable ill-health.*' (Mor97).

Chronic subjective effects

Perceived health effects

- 2.42 It is possible for a perception of health impairment to cause annoyance and stress. Hence an individual whose health is not directly affected by aircraft noise but perceives that it is, might come to exhibit symptoms of ill health as a result.

- 2.43 Examples of perceived health effects due to aircraft noise were obtained from a complaints hotline set up to monitor community reaction to the opening of a new airport runway in Sydney, Australia. About 1700 health-related complaints were received: 20% concerned sleeping difficulties, 20% increased (mental) tension, 15% increased anxiety and 10% increased fatigue (ADS95).

Chronic annoyance

- 2.44 Annoyance has been defined as a feeling of depression, resentment, anger, displeasure, agitation, discomfort, dissatisfaction, distraction, helplessness or offence which occurs when an environmental factor interferes with a person's thoughts, feelings or activities (HCN99, Ber95). Annoyance reactions are sensitive to non-acoustical factors such as those of social, psychological or economic nature.
- 2.45 Annoyance has short, intermediate and long time dimensions; these explain the presence of annoyance at the three levels of response: acute, next day (short-term) and chronic (long-term). It is logical to think of the higher levels of annoyance as accumulations of the lower ones: acute responses to a noise event, short-term reactions the day after a disturbed night's sleep and chronic feelings pent-up over periods of weeks, months or years. Despite the different orders of time, all three levels of annoyance share the same causes and characteristics. Most of what is stated here applies also to acute and short-term annoyance reactions.
- 2.46 Annoyance is a principal cause of psychological stress reactions which include fear, depression and frustration. Noise may also cause stress directly. The direction of causality may be reversible in that stress could lead to annoyance reactions, just as annoyance can lead to stress reactions. Stress has been suggested as the major mechanism through which noise can affect mental and physical health (Kry85, HCN99).
- 2.47 Noise annoyance has been related to increased blood pressure³, antihypertensive treatment, psychiatric disorder and psychological wellbeing. (IEH97, Job96).
- 2.48 There have been attempts to isolate the extent of night-time annoyance responses from daytime annoyance or general annoyance responses for the purposes of general noise impact assessment (Fie86, Por97). Porter concluded that the present understanding of the relationship between

³ After adjusting for age, body mass index, sex, education, smoking and occupational risk factors (IEH97).

night-time noise and annoyance was not such as to provide meaningful interpretation of night noise contour maps (Por97).

Reduced quality of life

- 2.49 People cite a multitude of factors when rating the quality of their living environment. Desirable factors range from having a private parking space to sports facilities. Undesirable factors range from vermin to traffic jams. In areas near to airports, aircraft noise annoyance is often cited as a negative aspect of quality of life (Hol97). The specific contribution of night-time aircraft noise in reducing quality of life is not clear, but if reported sleep disturbance, perceived health effects and chronic annoyance (due to night-time aircraft noise) are prevalent then reduced quality of life could be inferred. A common complaint about transportation noise in general is the feeling of helplessness that it engenders – being trapped in a hostile environment with a total lack of control.
- 2.50 In the past, chronic subjective effects have not been regarded as of primary importance when assessing health impairment. It is likely that such effects occur at levels of noise that are lower than that required to directly cause clinically significant health effects. There was a consensus view in the advisory groups that in the future, health should be viewed more holistically and all the factors including quality of life issues be taken into account when considering adverse impacts of noise with associated developments in airports and operational conditions.

Modifying factors

- 2.51 There are many factors other than noise exposure which can profoundly affect, mask or modify the adverse consequences that are attributed to night-time aircraft operations; indeed these factors may be of overriding significance. Even where an association between, say, noise and sleep disturbance can be identified, the details of any relationship can be obscured by factors that serve to ‘scatter’ data points around a dose-response curve.
- 2.52 An inventory of modifying factors recently prepared by a Dutch led symposium group (Fli99) includes:
- perceived predictability (perceived likelihood of future noise level changes)
 - perceived control (either by individual or by others)
 - trust and recognition (the latter referring to perceptions that impacts are recognised by authorities)

- voice (the extent to which people are able to speak to and be listened by authorities)
- general attitudes (such as awareness of economic and social benefits of the undertaking generating the noise of an airport, awareness of noise control actions, fear of crashes etc)
- personal benefits (employment at the airport, regular use of the airport etc.)
- compensation (noise insulation or house purchase schemes etc)
- sensitivity to noise (individual differences)
- home ownership (home owners might be concerned about the effects on the value of their property)
- accessibility to information (this can influence general attitudes and the extent to which authorities are perceived to be taking an interest in the noise exposed community)
- understanding (referring to all the relevant issues since it is quite possible that general attitudes can be based on irrelevant or incorrect information).

Sensitivity and habituation are considered further below.

Sensitive People

- 2.53 Certain people are more sensitive to noise than others and are more likely to suffer from its effects. Ill people, old people and people with sleeping difficulties show more noise-induced sleep disturbance, especially with respect to the inability to fall asleep after being awakened, than do other adults. Other groups with a particular sensitivity to noise include shiftworkers, those with high stress or anxiety levels and those with tendency to neurosis. 'Light sleepers' and people who are exceptionally annoyed by noise might also be classed among the more susceptible to the adverse effects of night-time noise.
- 2.54 Although research data indicate that the incidence of noise-induced effects is small, on average, the existence of a few exceptionally sensitive people is a matter of concern. The 1992 UK field study found that a small proportion of the population is 60% more sensitive to aircraft noise induced sleep disturbance than the 'average' population. Griefahn (Gri80) suggested that personality factors such as neuroticism lead to higher sensitivity to noise and that these people may be the only ones seriously affected.

Habituation

- 2.55 Habituation is the process by which one becomes accustomed to one's environment. Some degree of habituation to noise has been shown to occur, at least for awakenings from sleep (Val82, Gri80, Ric82).

- 2.56 Perhaps the most significant evidence supporting a habituation effect is a substantial difference between the exposure-effect relationships derived from field and laboratory sleep studies; far fewer awakening reactions occur in the home where habituation will generally be largely complete. This seems less true for changes between different stages of sleep (Pea95). However, it is important to recognise that large differences can exist between field and laboratory studies due to many factors including different experimental procedures, conditions and noise exposures.
- 2.57 Heart rate responses to noise appear to have a much lower propensity to habituate than the awakening response. A study of residents living near Roissy (Paris) airport found no habituation of the acute heart rate response to aircraft flyovers after seven years (Val83). A study of children found that although awakening responses habituated, there was no change in heart rate response (Muz80). However, not clear at this time is the extent to which changes in heart rate responses are natural - without actually presenting increased risks to health.
- 2.58 Griefahn has suggested that if people do not habituate completely to their acoustic environment, health disorders can be expected in the long term (Gri91). Conducting experiments on noise-induced sleep disturbance where changes in the source noise have been fairly recent may not give a true longer-term response. Care must therefore be taken in conducting and interpreting the results from such studies. Longitudinal studies encompassing changes in noise exposure would best describe these effects. Consideration must be given to how far research can take into account habituation to noise, and the role of habituation in determining the relationship between noise and sleep disturbance.

3 DORA STUDIES OF NIGHT-TIME AIRCRAFT NOISE

Findings of DORA studies

- 3.1 Since 1977 DORA has carried out several studies of aircraft noise-induced sleep disturbance on behalf of the DETR. A research review in 1977 (Bro78) examined what was then known about the effects of noise on sleep and what uncertainties remained. As this revealed that available knowledge was based mainly on the results of laboratory research whose applicability to ‘real life’ was uncertain, a social survey of noise and sleep disturbance was recommended.
- 3.2 Between 1977 and 1979 a major social survey was undertaken around Heathrow and Gatwick (DOR80). An important conclusion was that sleep disturbance attributed to aircraft noise increased more markedly with night noise (Leq_{8hr}) than did total reported sleep disturbance. This may be seen in **Figure 3** where the percentage of ‘yes’ responses to the question ‘are you ever wakened?’ hardly varies with aircraft noise Leq whereas the percentage reporting being ever awakened by aircraft noise shows a strong dependency.

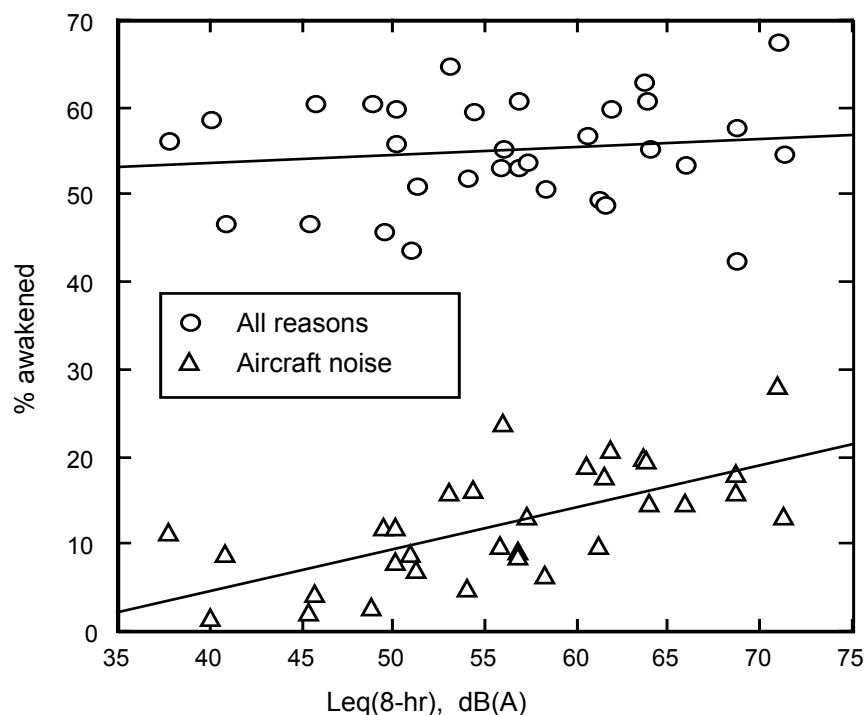


Figure 3 Results from 1980 CAA social survey

- 3.3 In 1990, DORA was asked to carry out a major new study on aircraft noise and sleep disturbance to inform UK government decisions on aircraft night operations. In planning this work, a major concern was that laboratory results were of uncertain relevance to ‘real life’

situations: available evidence showed that, for the same level of noise, people were much less likely to be awakened at home than in the laboratory. That evidence was subsequently published (Pea95) (see **Figure 4**). It was concluded that “*published findings on noise-induced sleep disturbance revealed large discrepancies between those of laboratory studies and those of field studies*”. Limitations were also recognised in the subjective data on which earlier studies relied, in particular the difficulty of securing reliable estimates of the quality and quantity of sleep, as well as how often subjects were disturbed. Therefore the study focused on in-home measurements of noise-induced awakenings using EEG and limb movement monitoring.

3.4 The work, referred to as the ‘1992 UK field study’, involved field measurements at 8 sites, 2 each around Heathrow, Gatwick, Stansted and Manchester Airports. Subjects were selected by social survey. The selected subjects (50 per site) wore actimeters for 15 nights and also completed ‘sleep diaries’ covering both the night and any daytime sleepiness. In addition, 6 of the 50 subjects were also monitored using EEG for 4 of their actimetry nights; the EEG data were required to calibrate the actimetry results. Throughout the survey period, a concurrent programme of outdoor noise measurement provided synchronous aircraft noise event data. Descriptions of the research methodology, data collection, analysis, and results are to be found in Oll92 and Hor94.

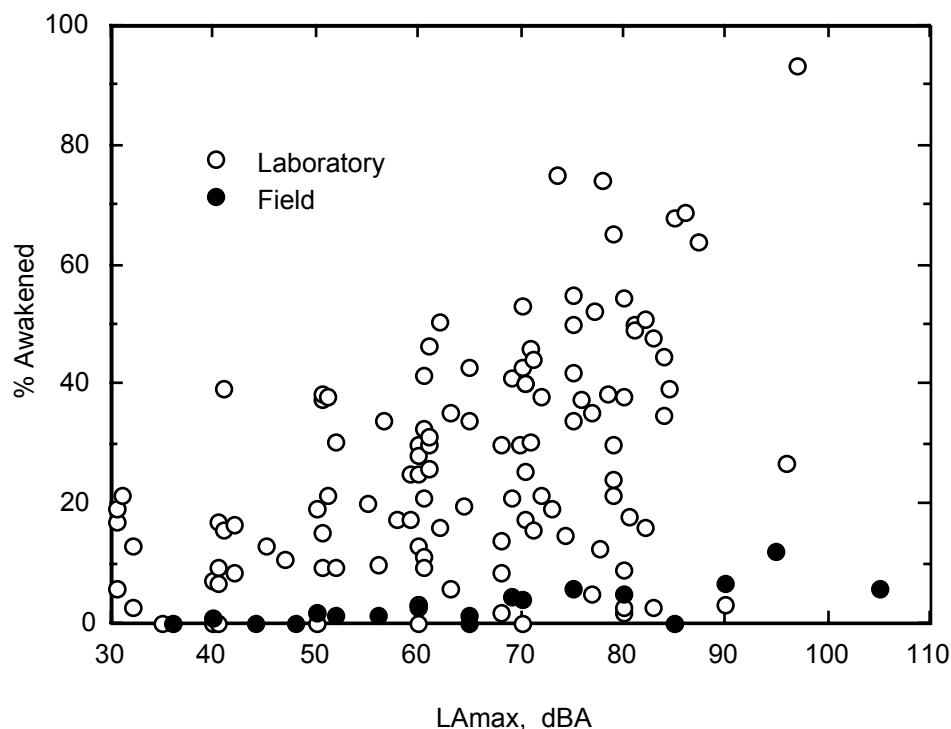


Figure 4 Noise-induced sleep disturbance data from laboratory and field studies

3.5 The key finding was that at outdoor noise events below 90 dBA SEL (approximately 80 dBA L_{max}), average sleep disturbance rates were unlikely to be affected and, at higher noise event levels (mostly in the range 90 - 100 dBA SEL), the chance of the average person being wakened by an aircraft noise event was about 1 in 75. **Figure 5** shows the estimated average disturbance rate (based on actimetric arousals) as a function of outdoor aircraft noise event level (SEL). The risk of arousal due to aircraft noise was compared with an average of 18 nightly awakenings from all causes; thus it was considered that even large numbers of night movements would be likely to cause very little increase in the average person's nightly awakenings.

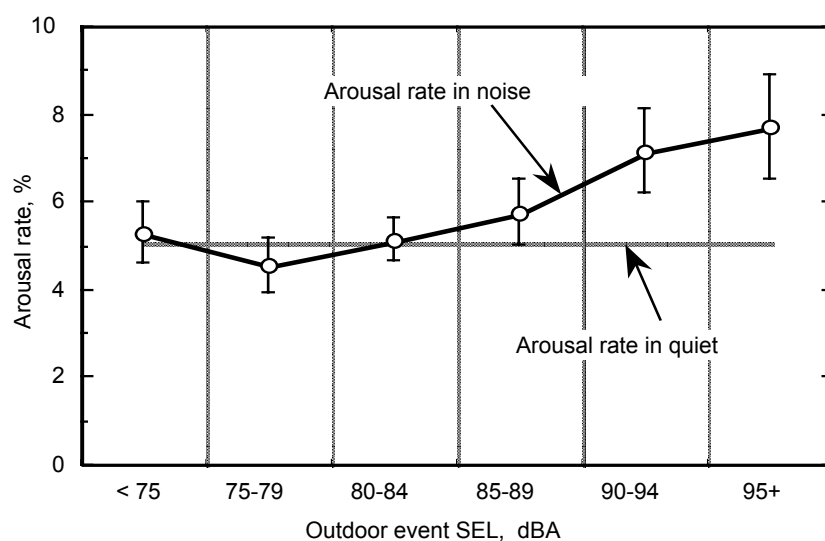


Figure 5 Relationship between actimetrically measured sleep disturbance and noise in 1992 UK field study

- 3.6 It was acknowledged that that this key finding related to awakenings once asleep. The field study gave little information about effects on sleep onset latency (time taken to fall asleep) and premature awakenings in the early morning periods referred to as the 'shoulder hours'.
- 3.7 'Aircraft' were assessed as a relatively minor cause of disturbance (less than 4% of reported awakenings); 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. Susceptibility to noise-induced sleep disturbance varied considerably: the 2-3% most sensitive individuals were disturbed over 60% more than average.

- 3.8 A limited social survey conducted at the time of the 1992 field study found that more than 20% of the residents at sites near Heathrow and more than 30% at one site near Manchester were ‘very much annoyed’ by night-time aircraft noise (Oll92). There appeared to be no simple relationship between the proportion of people very much annoyed and noise exposure level Leq - either in general, or specifically at night. However, it was clear that aircraft noise did disturb the study residents in a number of ways. The reported levels of annoyance were in line with those found in previous surveys: although total sleep disturbance showed only a minor dependence on aircraft noise exposure level, disturbance attributed to aircraft noise was strongly correlated with Leq. The level of annoyance was higher than might have been expected considering the relatively low rates of sleep disturbance physically measured in the main study.

Validity of Field Study findings

- 3.9 It is now possible to re-examine the key findings of the 1992 UK field study in light of additional analysis of the data and the results of more recent independent field studies.
- 3.10 A quantity of EEG data was collected during the 1992 field study. The primary purpose was to validate and calibrate the principal measurement technique of actimetry (Oll92). This provided a source of additional information on sleep disturbance, albeit limited, that actimetry could not obtain. A total of 178 nights of EEG data were obtained from 46 subjects living around the airports and the data were synchronised with simultaneous measurements of outdoor aircraft noise levels made at each site. Subsequent to the publication of the 1992 UK field study report, the EEG data were analysed in further detail (Hum99). The results gave support to the main actimetry-based finding that very few people living near airports are at risk of substantial sleep disturbance due to aircraft noise.
- 3.11 Recently, following further development of computer-based statistical analysis procedures, it has been possible to perform simultaneous multi-variate analysis of a larger set of the 1992 actimetry data. This involved approximately 85,000 observations, about 60% more than the original data set. This reanalysis confirmed that the key findings of the 1992 UK field study (Dia00).
- 3.12 Since the 1992 UK field study, a number of similar studies have been conducted in the USA (Fid94, Fid95, Fid98). Like the 1992 UK study, these studies involved in-home measurements of sleep disturbance in areas near airports. However the methodologies were not identical. A

principal difference was that in the 1992 UK study, awakenings were inferred from limb movements whereas, in the US studies, awakenings were ‘behaviourally confirmed’; test subjects pressed buttons when they awakened. The UK and US results are compared with each other and with other data previously reviewed by Pearsons and co-workers (Pea95) in **Figure 6**.

- 3.13 **Figure 6** shows ‘prevalence of awakening’ plotted against indoor event noise level SEL. For the purposes of this comparison, 25dB has been subtracted from the DORA noise levels to allow for the attenuation of sound transmitted from outdoors to indoors. Actual attenuations for individual homes would of course have varied markedly.
- 3.14 Several features of **Figure 6** are striking. First, although there is an obvious positive association between noise event level and awakening, the data indicate that where indoor noise event levels are less than 80-90 dBA SEL, i.e. except close to the flight paths of the very noisiest civil jet aircraft, incidences of awakening are typically less than about 5%. Second, within the wide range of noise levels, the probability of awakening increases very slowly with noise level - around 1% for each 10 dB increase in noise (which broadly corresponds with a doubling of perceived loudness). Third, the US data exhibits substantial scatter, especially between studies. Fourth, notwithstanding this scatter and despite being derived by different methodologies, the US and UK results, and indeed the results from the ‘previous’ studies, all convey the same message - that, in the home, awakenings are infrequent and only weakly correlated with noise. This is in marked contrast to the findings of laboratory work.
- 3.15 But in **Figure 6** there is one conspicuous disparity that raises a question concerning cause and effect. The noise-awakening relationship inferred from the UK study levels out as indoor SEL falls below 65 dBA, while no such trend is obvious in the US data. This is related to the principal conclusion drawn from the UK study; that below 90 dBA SEL outdoors (equivalent to above about 65 dBA indoors), aircraft noise would be unlikely to disturb sleep. This followed from the observation that, in the absence of aircraft noise, the probability of awakening - due to all other causes - remained at around 2%. The question this raises is whether the 1992 UK field study data should be adjusted to account for this residue before comparing it with the US results. The effect of doing so – the ‘Oll92 Adjusted’ data in **Figure 6** – is to move the UK mean wakening rates towards the lower end of the range.
- 3.16 Overlaid on **Figure 6** are some currently quoted criteria regarding noise and sleep disturbance. These include ‘guideline threshold values’, suggested by the Health Council of the Netherlands (HCN94) and the

Community Noise Report (Ber95). In the Community Noise Report a limit of 45 dBA L_{max} indoors (about 55 dB(A) SEL) [as shown in **Figure 6**] is recommended where noise exposure is intermittent. The report of the Health Council of the Netherlands (HCN94) concluded that existing evidence supports the existence of causal relationships between night-time noise exposure and changes in sleep pattern, changes in sleep stages and awakening, and subjective sleep quality. The level below which no response is observed, the observation threshold for awakenings, was defined as 60 dBA SEL indoors. Included for comparison is the awakening threshold identified in the UK 1992 study (65dBA SEL indoors ~ 90 dBA outdoors). Also shown is a dose-response curve intended to replace a curve previously recommended by FICAN, the US Federal Interagency Committee on Aviation Noise (Eli99), labelled 'Elias and Finegold'.

- 3.17 The various guidelines are in broad accordance with the observations; the evidence suggests they are sufficiently conservative that adherence to the guidelines should ensure little or no noise-induced awakening from sleep.
- 3.18 Thus there appears to be reasonable agreement between the 1992 UK field study results and other comparable evidence that relates to aircraft noise and sleep in the home. There is also no change in the findings from reanalysis work of the UK 1992 field study suggesting the findings are still valid today.

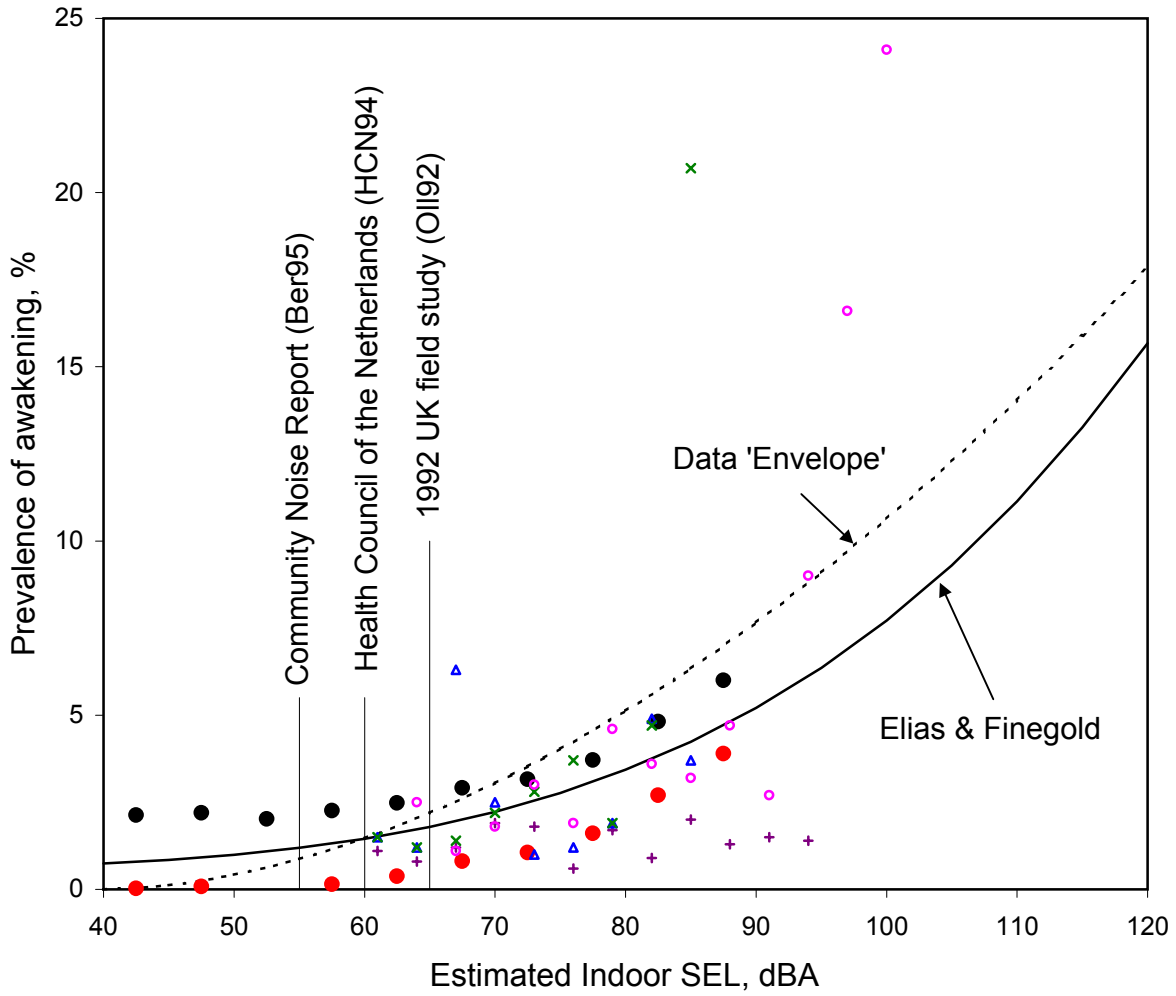


Figure 6 Comparison of 1992 field study findings with similar field studies and currently quoted criteria

Interpretation of Field Study findings

- 3.19 The principal finding of the 1992 study has been widely misinterpreted as an affirmation that aircraft noise does not disturb sleep. In fact, even though the likelihood of an individual being awakened by one individual aircraft noise event appears to be relatively low, it does not necessarily follow that the total incidence of sleep disturbance in a densely populated neighbourhood overflown by night-time aircraft is likely to be insignificant.
- 3.20 Calculations of total disturbance were made to inform a recent DETR consultation on night restrictions on aircraft movements at Heathrow, Gatwick and Stansted Airports (DET98). Applying the findings of the UK field study directly to aircraft movements at Heathrow airport during a typical 1997 summer night (11.00pm to 7.00am), the estimated number of aircraft noise induced awakenings was around 8,700 per night. It was acknowledged that the analysis was a simplistic one. It did not consider sleep prevention at the beginning of the night or following an awakening during the night, that some people are more likely to be awakened than others, and that the analysis excluded movements before 11.00pm and after 7.00am when some people may be trying to sleep and when the aircraft movement rate is higher.
- 3.21 It also has to be remembered that the 1992 UK field study indicated that, on average, a person experiences between 14 and 22 nightly awakenings from all causes⁴. It should not be inferred from the findings that few people are woken by aircraft noise during the night; rather that the number of awakenings attributable to aircraft noise remains a small proportion of nightly awakenings from all causes.
- 3.22 Results of the UK studies on night-time aircraft noise are relevant to the fundamental question of whether night-time aircraft noise can lead to health impairment, both in objective and subjective terms. The relationships between aircraft noise and sleep disturbance, and specifically noise-induced awakenings during the night, have been examined in detail. The findings are in broad agreement with similar studies from elsewhere.
- 3.23 Nevertheless, as Section 2 has made clear, awakening from sleep is but one effect in the complex web of interactions that are depicted in **Figure 1**. The existence of various pathways between aircraft noise and

⁴ Most of these awakenings are very short and will not be remembered the next day. In the 1992 study, no awakenings were reported by subjects on days following 57% of the measurement nights. In the remaining 43% of cases, subjects recalled an average of three awakenings during the previous night.

'chronic effects' points to the possibility that it is time to change the focus of attention from actual sleep disturbance to other effects.

4 CONCLUSIONS AND FUTURE RESEARCH OPTIONS

- 4.1 This report has reviewed available evidence on the effects of night-time aircraft noise on people. A summary of the findings below highlights areas of uncertainty and raises various questions at which future research might be aimed. This is followed by descriptions of two specific research options that were identified for detailed consideration.
- 4.2 Effective noise limitation and understanding of how best to specify controls requires reliable ‘dose-response relationships’. The pathways linking noise exposure and its effects are complex and subject to many extraneous influences; previous sections have identified some of the key elements and noted the research carried out by DORA and others aimed at quantifying some of the links.
- 4.3 Various effects that might be attributable to night-time aircraft noise have been categorised as acute, total night, next day or chronic (**Figure 1**). Acute responses include immediate or direct disturbances caused by noise events - awakenings, sleep stage changes or other physiological changes - e.g. to heart rate or blood pressure - that can be measured and that are observed to coincide with the noise events. Total night effects are aggregations of acute responses over a total night, such as sleep loss. Next day effects are short-term effects of the acute responses and total night effects. Thus a loud aircraft noise might cause instant annoyance; repetitions might prevent sleep, causing prolonged wakefulness during the night; and loss of sleep might lead to next day tiredness, sleepiness and degradation of task performance.
- 4.4 Chronic effects are pervasive long-term consequences of continuing acute responses and next day effects. They have been split here into objective and subjective effects. Under the latter heading, ‘chronic annoyance’ is a general adverse reaction embracing, for example, dissatisfaction, resentment, anger and even worries about state of health. Under the former, manifestations of stress, psychological and physiological, would represent more severe levels of chronic reaction and worse still would be clinical symptoms of health impairment, mental or physical. Research into the latter has involved studies of the incidence of sickness, drug taking, and hospital admissions.
- 4.5 Of course, at a detailed level, there is a multitude of possible chronic effects: complainants attribute many kinds of adverse consequences to aircraft noise. The problem, depicted in **Figure 1**, is that such effects have many causes, of which noise disturbance is only one. In practice it is very difficult to identify the many cause-effect links, let alone disentangle them. **Figure 1** indicates how the ‘modifying factors’, of which there are a large number, intervene at each stage. A consequence

is that, moving from left to right in the diagram, the relationships between noise and its effects are increasingly ‘scrambled’ and therefore difficult to determine by simply correlating the effects with some measure of noise exposure. For example, a graph of an acute effect against noise level, e.g. the probability of being awakened by a particular noise event in a laboratory situation (where modifying factors can be minimised), will normally exhibit a higher degree of statistical correlation than a similar plot of a chronic effect such as chronic annoyance against average noise exposure level.

- 4.6 A further diagnostic problem is that of putting the effect itself into a proper context. Social survey respondents selected from different neighbourhoods might express similar levels of overall satisfaction with their general living conditions, despite the fact that local noise exposures vary markedly. A graph of ‘general satisfaction’, an indicator of quality of life, against Leq might reveal no dependency to noise exposure. Yet the same residents might report very divergent degrees of noise annoyance such that a graph of noise annoyance against Leq would show a strong dependency. This kind of a difference is evident in the social survey results plotted in **Figure 3** which compares general awakening (all reasons) with awakening attributable to aircraft noise against Leq. General awakening shows very little dependency to noise exposure whilst aircraft related awakenings show a strong dependency. As the trend lines are not parallel, these results suggest at face value that other causes of disturbance diminish as aircraft noise increases. Alternatively, it may be speculated that the divergence is subjective and indicates an increasing tendency for people to assume that aircraft noise awakens them if the actual cause is unknown.
- 4.7 A goal of continuing research is to establish whether night-time aircraft noise can lead to clinically significant impairment of health either directly, or indirectly as a result of chronic subjective reactions. Given that present understanding of the cause-effect web of night noise impact is fragmentary, it is evident that achievement of this goal remains some way off. It can only be viewed as a long-term objective; first, it is necessary to disentangle some of the intermediate relationships. This raises the question of measurement; to establish any relationship, both cause and effect must be quantifiable in reliable terms. Some effects such as awakenings from sleep are physically measurable whilst others, like annoyance, can only be quantified in subjective terms, e.g. on a self-rating scale of some kind.
- 4.8 Although there is a tendency to assume that physical measurement is more reliable than subjective rating, it is important to recognise that perceptions of harm may be just as important to health and wellbeing as physical disturbances. Anxiety that night noise significantly reduces the

benefits derived from sleep may be just as harmful, through stress, as any actual loss of sleep. Thus further research to build on existing studies such as the 1992 UK field study should balance and match as far as possible both objective and subjective measurements. But what specific questions should future work address?

- 4.9 The 1992 UK field study indicated that aircraft noise, even at high levels, has a relatively small effect on awakening from within sleep during the night. This appears to have been corroborated by subsequent studies in the USA. But uncertainties remain about the shoulder hours: would similar conclusions apply to the beginning and end of the night? Could aircraft noise during these periods delay sleep onset and/or hasten final awakening - in other words, shorten the duration of sleep? And, if so, are there compensatory biological mechanisms which would, on average, change the sleep pattern in order to maintain the same quantity (e.g. product of depth and duration) of sleep? Can residual loss of sleep be determined and, if so, how and to what extent could this directly impair health?
- 4.10 The 1992 UK field study focused mainly on sleep disturbance. Acknowledging the importance of annoyance as a significant effect that could separately affect health and wellbeing, is this independent of sleep disturbance or primarily a consequence of it? How do other effects compare as potential health risks?
- 4.11 Most field studies of environmental noise impact have highlighted the profound significance of the 'intervening factors' that modify individual reactions and responses to mask the underlying noise-effect relationships. Can these be successfully identified, quantified and 'controlled' to allow those relationships to be isolated reliably?
- 4.12 These were among many questions that DORA put to advisory groups convened to assess two possible UK research studies, referred to as Options A and B, that are summarised below.

Option A: Extend the 1992 UK field study to the shoulder hours

- 4.13 The key objective would be to answer the question: could aircraft noise delay sleep onset and hasten final awakening and thus reduce quantity of sleep? The study would involve measurement of the acute effects but these could be related to next day and chronic effects. Although the main focus would be the shoulder hours at the beginning and end of the night's sleep, subjects would be instrumented for whole nights so that the existence of compensation mechanisms could be investigated. Chronic effects would be determined during the subject selection process, as would chronic annoyance and numerous intervening

personal, sociological and demographic variables. Next day effects would be probed using next-day sleep logs/diaries. Consideration could be given to some measurement of daytime sleepiness and performance degradation although this requires complex techniques that are not easily applied in field research.

Option B: Compare sleep patterns in communities with high and low levels of noise exposure

- 4.14 This study would be designed to test the null hypothesis that aircraft noise does not cause harmful loss of sleep or, expressed in a different way, a degree of sleep disturbance that, in the longer term, could be directly detrimental to health (in terms of objectively measurable health effects as shown in **Figure 1**). A basic requirement for this study would be a measure of total sleep quantity (or of sleep loss). Can the aggregate effects of sleep disturbance be expressed in sleep loss terms? Assuming sleep loss can be determined from EEG data, many details of this study would mirror those of option A. However, an alternative or supplementary approach might include daytime measures of sleepiness. The study core could be a comparison of sleeping patterns among two groups of subjects: one from high night-noise areas adjacent to busy airports, the other from areas where aircraft noise was absent or minimal. A crucial need would be that the two groups of subjects were closely matched with respect to all intervening factors of principal importance. This would present the main research challenge. Noise from other sources would need to be considered in the study design.
- 4.15 It may be regarded as axiomatic that if this study led to an acceptance of the null hypothesis with an adequate margin of safety, then subsequent research would be more effectively directed at other pathways between noise exposure and possible health impairment, particularly on those involving annoyance
- 4.16 The deliberations of the advisory groups led to the consideration of two additional research options C and D.

Option C: Study sleep disturbance among noise sensitive people.

- 4.17 Research has revealed the importance of individual sensitivity among the modifying factors; in the 1992 UK field study it was found that people of high susceptibility were 2.5 times more likely to be disturbed than those with low susceptibility. In view of the relatively low incidence of noise-induced disturbance, it was suggested that any study along the lines of options A or B might be focused on highly sensitive individuals in order to maximise the chance of detecting significant

noise effect relationships. A practical difficulty foreseen was that of identifying sensitive people prior to a study.

Option D: Survey opinions of airport neighbours

- 4.18 It was accepted that, within any long term effort to determine whether night-time aircraft noise can lead to health impairment, directly or indirectly, there is a clear need to disentangle the web of interactions depicted in Figure 1.
- 4.19 In particular, this report has highlighted the drawbacks of continuing to focus attention on objectively measurable sleep disturbance. Subjective perceptions of night-time aircraft noise effects may be equally important, if not more so. Accordingly, a need was seen to look more closely at the subjective aspects of Figure 1, especially the interrelationships and the role of the modifying factors. It was considered that the most effective way to do this is through a social survey. Lessons learned from previous DORA survey studies should be taken into account, but the advantages of powerful statistical analysis tools available to modern computers would allow very substantial advances to be incorporated; in particular there would be no computational limitation on the number of modifying factors considered. The only restrictions would be those upon the structure and choice of questions imposed by the length of the questionnaire.

Preliminary studies

- 4.20 After considering advice from DORA and the advisory groups, the Department decided to commission two short research studies investigate the options further under a programme managed by DORA. The first is concerned with methodology, to evaluate options A to C. The second is a public attitude survey to explore the public's perceptions of the effects of aircraft noise at night. It is recognised that either study (or both) might point to further research options. After considering the results, the DETR will decide whether there is a case for a full scale study on the adverse effects of night-time aircraft noise (no decision has yet been taken).

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