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Rating of helicopter noise with respect to annoyance

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CONTENTS

EXECUTIVE SUMMARY

This report presents an analysis of data from the literature related to annoyance due to helicopter noise exposure. The analysis has been carried out with the following aims:

- to specify those aspects of military and civil helicopter noise which are relevant with regard to annoyance;
- to combine these results with the results of a more general study (Miedema, 1993) on noise measures to rate aircraft noise, in which conclusions with respect to fixed-wing aircraft have been formulated.

Extent of and annoyance from helicopter noise exposure in the Netherlands

Helicopter noise is observed by many persons in the Netherlands in their living environment although usually rather sporadically. Investigations carried out in the past on representative samples of the Netherlands population showed that in 1977 55% of the respondents did observe helicopters in their living environment, while 6% and 1%, respectively, were annoyed and severely annoyed by helicopter noise. In 1987 these percentages were 56, 18 and 6 and in 1993 54, 24 and 6. A comparison of the 1993 data on annoyance due to noise from also other types of aircraft shows percentages of (very) annoyed people due to helicopter noise to be about equal to those due to fixed-wing civil aircraft and both take up the second place, following military fixed-wing aircraft noise.

Helicopter operations: noise, vibration and rattle

A flying helicopter may produce a typical impulsive type of noise (blade slap). Blade slap originates from the rotating blades. One type of impulsive noise (blade-vortex interaction noise (BVI)) is due to the rotor blades crossing the vortices that did originate from the preceding blades. The other type of impulsive noise (high-speed impulsive noise (HSI)) is originated when the velocity of the air flowing around the advancing blade tip locally exceeds that of the velocity of sound, thus inducing a pressure wave which resembles a shock wave as in sonic booms.
Apart from the noise originating from the main rotor, also tail rotor noise, engine noise and air-frame noise can be observed during helicopter operations.
Apart from noise, helicopter operations may also produce vibrations of buildings and rattling of windows, ceiling tiles and objects in buildings, due to the presence of low frequencies in helicopter noise. The levels of rattle and vibrations are dependent upon the slant distance (distance of closest approach between the helicopter and the location on the ground). For an impulsive type of

helicopter, such as the UH-1H Huey helicopter, the 'high' rattle zone covers the points where slant distances are less than 1000 ft (330 m). At slant distances larger than 1500 ft (500 m) for level flyovers and take-offs and 2000 ft (700 m) for landings, rattles and vibrations are virtually absent. These slant distances are expected to differ with type of helicopter.

Special characteristics of helicopter noise exposure

In the report special characteristics of helicopter noise exposure which may have an impact on experienced annoyance have been considered. These are:

<u>Impulsivity and tonality of helicopter noise</u>

Psycho-acoustic field and laboratory tests have shown on average only minor differences in annoyance ratings of more or less impulsive helicopter noise with the same noise levels: impulsive helicopter noise events are on average equally annoying as non-impulsive helicopter noise events which have a 1 dB(A) higher SEL value. Most data, however, show an increased inter-individual variability in annoyance score in the case of impulsive helicopter noise compared to non-impulsive helicopter and fixed-wing aircraft noise.

Applying a tone correction, such as specified in ISO 3891-1978, to helicopter noise gives a small increase in the inter-individual variability in annoyance score and it is therefore advisable not to apply such a correction.

<u>Multi-bladed versus two-bladed helicopters</u>

Also only minor differences have been observed between annoyance due to noise from multi-bladed helicopters and noise from two-bladed helicopters.

<u>Onset rate of helicopter noise during approach</u>

Taking into account the maximal speed of helicopters, indicative calculations show that onset rates of approaching helicopters will not exceed 10 dB/s. This value is below the lowest value for which a penalty for onset rate is applicable. Therefore additional impact on experienced annoyance by helicopter noise due to high onset rates is very unlikely.

<u>Directionality of helicopter noise during approach</u>

It is not unlikely that the very long attention-arresting sound of an approaching helicopter is a particular source of aggravation. The long period during which an approaching helicopter may be heard is related to the directionality of helicopter noise. In front of an approaching helicopter, the impulsive helicopter sound can be heard before its sound level reaches the ambient sound level. However, the sound levels during only the last part of the approaching period will substantially contribute to the time-integrated value of the noise levels during a helicopter noise event. Since the directionality during approach of fixed-wing aircraft noise is less and the speed of fixed-wing aircraft is usually higher, such an effect occurs to a lesser extent when fixed-wing aircraft noise is observed. This is a reason why helicopter noise events might be longer (more) disturbing than fixed-wing aircraft noise events with the same time-integrated value of the noise levels during such events. On the other hand, a fixed-wing aircraft also produces substantial noise to the rear, which means that such an aircraft is heard for a longer time after the direct overflight. This effect may well compensate for the possible extra effect described with respect to helicopter noise during approach. These assumptions, however, have not been verified by research.

Sporadicity of occurrence of overflights in residential areas

Usually, helicopter noise exposure will occur in residential areas only occasionally. In a survey carried out in the Netherlands in 1993 it was found that 74% of the respondents that experienced helicopter noise in their living environment did so only a few times or less a month. Unfortunately, no research data exist from which annoyance due to sporadic helicopter noise events can be evaluated. Research carried out with respect to annoyance from 'sporadic' military fixed-wing aircraft training operations showed no statistically significant differences between average annoyance scores from more and less sporadic flights, nor from regular or irregular flights, if exposure was expressed in equivalent sound level over 24 hours. However, these noise events were considered 'sporadic' even when they occurred once a day. Since sporadicity with respect to helicopter noise in the Netherlands falls into another range, it is questionable whether these results are applicable to sporadic helicopter noise.

Frequency spectrum of helicopter noise

The frequency spectra of helicopter noises during overflight are quite comparable to those of fixed-wing aircraft noise. Usually, both sets of frequency spectra have A-weighted octave-band sound pressure levels that are maximal at the midfrequency of 500 Hz. Only in the low-frequency range (octave-bands with midfrequencies of 16, 31 and 63 Hz) helicopter noise has relatively higher octave-band sound pressure levels than fixed-wing aircraft noise. This does especially have an effect on the production of vibrations and rattling of objects in buildings.

Differences between outside and inside sound levels

In specifying relations between annoyance and environmental noise, usually noise exposure is expressed in values representative of outdoors levels. However, the sound-insulation of dwellings is usually lower for predominant low-frequency noise and therefore indoor sound levels may be relatively higher and may therefore increase annoyance scores. Despite the higher low-frequency components of helicopter noise compared to fixed-wing aircraft noise, this effect does not seem to be relevant due to the presence of the higher frequency components in helicopter noise.

Differences between most and least exposed sides of dwellings

Community surveys have shown that residents take action to avoid regular noise exposure, one such action being moving to the quieter side of the house. This may also occur with respect to dwellings in residential areas around heliports with prescribed helicopter flight paths used for approaching and leaving the heliport. In other circumstances, however, flight paths of helicopters are less predictable and residents are less able to take appropriate action to avoid annoyance. This might well have an effect on annoyance resulting from such helicopter operations. This has, however, not been verified in investigations.

<u>Attitude of the population towards helicopters</u>

In areas where helicopters are considered a 'rich man's toy', where the public questions the benefit of helicopter operations and where the behaviour of pilots is criticized annoyance ratings are much higher than in areas where the necessity of the use of helicopters to the general public is accepted. Also, fear of helicopter crashes has a large impact on annoyance scores.

<u>Duration of the presence of helicopters above residential areas</u>

It seems reasonable to assume that feelings of fear and feelings of deprived privacy increase with the duration of helicopter operations above residential areas.In that respect hovering of helicopters above these areas might be of special importance with respect to resulting annoyance. However, no direct evidence from research data is available to support this assumption.

A model to rate aircraft noise exposure

In a study (Miedema, 1993) on noise measures to rate aircraft noise, a mathematical model is presented in which the theory of hierarchical power summation is applied to the specification of noise measures in order to enable them to be related to annoyance. In the present report, this model has been applied to the data in the literature related to helicopter noise. The model takes a noise event as a basis and it gives four steps to be taken to specify a noise measure which can be related to annoyance. The four steps concern one 'frequency'-step and three 'time'-steps. In the first step, the frequency-dependent sound pressure levels, present at a given moment during a noise event, are combined into one momentary value. Frequency-weighting may be carried out according to the standardized frequency-characteristics of sound level meters (A-, B-, C- and D-weighting) or according to other frequency-weightings such as in perceived noise level (L_{PN}) and tone-corrected perceived noise level (L_{TPN}) (see Annex).

The first time-step combines the instantaneous frequency-weighted values of one noise event into a value representative for that noise event. Examples are SEL (in dB(A)) and $L_{A,max}$, when in the frequency-step A-weighting has been applied, and L_{EPN} and $L_{PN,max}$ in the case of the frequency-weighting related to perceived noise level. SEL and L_{EPN} concern time-integrated values, the time-

integrations of L_A and L_{PN} applied in exactly the same way. $L_{A,max}$ and $L_{PN,max}$ are the maximum of the instantaneous frequency-weighted values of a noise event averaged over 1 s.
The second time-step combines the various noise events occurring during a specified period of time by combining the values obtained in the first time-step per noise event into one value, representative for the noise exposure during that period of time. Examples are $L_{Aeq,T}$ and L_{PNeq} over period T. Usually this combination involves a trade-off which can be represented by a simple rule if all events have the same level. The rule for the trade-off between level (L) and number of noise events (n) is then: $L + k_n \log n$, in which k_n is the trade-off factor. For $L_{Aeq,24h}$, L_{dn}, BKL and L_{etm} the trade-off factor k_n is equal to 10. For B and also for the noise measure NNI, formerly used in Great Britain, k_n is equal to 15.
The third time-step combines the various values determined in the second time-step over specific periods of time into one value, representative for the noise exposure during a period of 24 hours.
In the Miedema report the combination rules used at each step are specified for five noise measures: $L_{Aeq,24h}$, L_{dn}, BKL, B and L_{etm}. With respect to $L_{Aeq,24h}$ the results of the second time-step at any period of the 24 hours have equal weight. For L_{dn} first 10 dB(A) is added to the night-time levels, and then the results of the day and the night are combined into one value. For BKL first 5 and 10 dB(A) are added to the evening- and night-time levels, after which the results are combined into one value. For B, various values (ranging from 0 to 10 dB(A), see annex A) are added dependent upon the period of the 24 hours day, and the results are combined. L_{etm} is the maximum of three values representing the results for day-time, that for evening-time plus 5 dB(A) and that for night-time plus 10 dB(A).
To determine a value representative for long-term noise exposure, such as for one year, a fourth time-step would be necessary to determine a value representative for that period. This step should combine the values representative for the noise exposures during all 24 hour periods during that long-term period. Regulations in the Netherlands specify combination rules for environmental noise exposure with regard to BKL, B and L_{etm} on a yearly basis. However, information on which such a combination-rule for helicopter noise exposure could be based is virtually absent. Therefore, this aspect is not considered in this report.

Application of the model to helicopter noise exposure

Only a very limited number of publications dealing with psycho-acoustical and epidemiological investigations into the annoying and disturbing effects of helicopter noise were available. The conclusions with respect to the rating of helicopter noise with respect to annoyance as given below are based on scientific aspects only; factors of importance in policy making, such as feasibility, social/economical aspects of introducing new measures, and compatibility with measures for environmental noise sources other than helicopters, have not been taken into account. In the following, a noise measure is preferred over other noise measures, if it allows an estimation of annoyance with a smaller inter-individual variability in annoyance scores than would be the case if these other noise measures were taken to characterize the noise exposure. The results of the analysis with respect to helicopter noise are as follows:

- there is a slight preference for frequency-weighting according to perceived noise level, as specified in ISO 3891-1978, over A-weighting;
- time-integrated values of frequency-weighted sound pressure levels have preference over maximum values with respect to rating annoyance from a helicopter noise event;
- a trade-off factor of 10 between sound level and log number of noise events fits the experimental data quite well; a factor equal to 15 has a probability which is below 0.01. A trade-off factor equal to 10 implies that equivalent sound levels during specific parts of the 24 hour period constitute a proper basis for a description of helicopter noise exposure;
- a night-time penalty of 10 dB for helicopter noise is close to the experimental results. Possible evening-time penalties have not been considered in the literature to such an extent that a conclusion is allowed.

These results have been applied to noise measures which are used in regulations in the Netherlands and abroad in the rating of environmental noise exposures, such as L_{PNeq}, $L_{Aeq,24h}$, L_{dn}, BKL (a L_{den} determined in a specific way), L_{etm} and B. It then turns out that L_{PNeq}, with a night-time penalty of 10 dB, is the measure in which the relatively most preferred frequency- and time-weightings are incorporated. Therefore, L_{PNeq} is expected to rate annoyance from 24 hours helicopter noise exposure with a smaller inter-individual variation in annoyance than other noise measures. When helicopter noise exposure is expressed in L_{PNeq}, the total range within which individuals of a population consider helicopter noise equally annoying might be about 2 dB smaller than such a range when helicopter noise exposure is characterised by L_{dn} (the measure which differs from L_{PNeq} only in frequency-weighting).

If the A-weighting is chosen as the frequency weighting, then L_{Aeq}-related measures ($L_{dn,}$ BKL, L_{etm}) - including time-integration over each separate noise event - should be preferred over measures such as B and NNI. A tentative estimate gives an increase in the total range of inter-individual variation in annoyance which may correspond to 5 dB(A) due to the choice of $L_{A,max}$ over SEL and another 5 dB(A) due to the choice of the trade-off factor between L and log number of events equal to 15.

Since for helicopter noise exposure possible evening penalties have not been considered substantially in the literature, it is not possible to indicate a preference of L_{dn} over L_{etm} or over L_{den} (or more specifically BKL).

Exposure-effect relations for helicopter noise

The very limited amount of quantitative data available on the relation between helicopter noise exposure and resulting annoyance do not give an indication that exposure-effect relations for frequent helicopter noise exposure around heliports differ significantly from those of fixed-wing aircraft in the exposure range considered. This exposure range was limited to lower exposures, at most up to a L_{dn} value of 50 dB(A).

However, in the case of high levels of rattle and vibration, increased annoyance due to helicopter operations has been clearly established. Helicopter operations producing noise and high levels of rattle are as annoying as helicopter operations with noise only that have a SEL value which is on average 10 dB(A) higher.

Notwithstanding the results of the quantitative analysis for frequent helicopter flights in the vicinity of heliports, other data on sporadic occurrences of helicopters showed that whenever helicopter noise is observed, a relatively higher percentage of residents indicate (severe) annoyance than in the case of a similar exposure to fixed-wing aircraft noise. This observation, however, could not be further quantified.

1. INTRODUCTION

This introduction first presents the background and the aims of this study. Then the procedure used in the study is outlined and the structure of the report is presented.

1.1 Background and aims of the study

In the Netherlands various noise measures exist to rate community noise with respect to annoyance: B in Kosten Units for aircraft noise (including helicopter noise) and L_{etm} for road and rail road traffic and industrial noise, and also for noise from engine ground-running during maintenance of aircraft (including helicopters). For general aviation BKL was developed in the Netherlands. Readers of this report not familiar with acoustical terms are referred to annex A, which specifies terms and definitions used throughout this report.

To determine which noise measure is to be preferred for rating aircraft noise with regard to annoyance, our Institute carried out the study 'Noise measures to rate aircraft noise', by order of the Ministry of Housing, Spatial Planning and the Environment (VROM). This study has been reported in the Dutch TNO-report 'Geluidmaten voor vliegverkeer' (Noise measures for air traffic) (Miedema, 1993). The conclusions in the report are mainly restricted to fixed-wing aircraft noise.

At the moment the use of helicopters in the Netherlands for civil and military purposes is relatively small compared to the use of fixed-wing aircraft. There are helicopter operations performed from two airfields (mainly) designated for fixed-wing aircraft operations and there are two (military) airfields mainly for helicopter operations. However, it is foreseen that the use of helicopters will increase with the establishment of the military Air Mobile Force. Therefore VROM requested our Institute to carry out a literature study with the following goals:

- to specify those aspects of military and civil helicopter noise which are relevant with regard to annoyance;
- to combine these results with the results of the already mentioned study 'Noise measures to rate aircraft noise'.

Already before the start of the study there have been contacts concerning the rating of helicopter noise between VROM, the National Physical Laboratories (NPL) and the Institute of Community and Occupational Medicine (ICOM) of the RAF, both situated in Great Britain. Both these organizations have been engaged so far only in noise emission studies of helicopters, without evaluation of community reactions. It was agreed with NPL and RAF-ICOM to exchange data and opinions. Therefore, this report has been written in English.

1.2 Procedure

The study started with a literature search for relevant publications in English, French and German, using superbase 'Environmental Medicine and Protection' of DIMDI. This superbase contains the databases AGRIS, ELFIS, MEDLINE, BALTIC, SOMED, TOXLINE, AGRICOLA, ASFA, BIOLIS, ENVIRONLINE, PSTA, BIOSIS - PREVIEWS, SCI SEARCH, CAB-ABSTRACTS, EMBASE and TOXLIT. Database PSYCHINFO was also consulted as well as publications already available at the Institute, such as the Proceedings of the Congresses of the International Commission on Noise as a Public Health Problem. Further, data from references given in the publications were verified if necessary. Only a part of the available publications are referred to in the report. These publications are included in the list of references. Publications not referred to in the report are listed separately.
The publications have been analyzed and the results of the analysis are presented in this report. During the study, the author visited dr B.F. Berry of NPL and discussed several topics with regard to helicopter noise. A draft report has been discussed with dr B.F. Berry, dr J.B. Ollerhead (Civil Aviation Authority, UK) and dr. P.D. Schomer (Construction Engineering Research Laboratory, USA). Their cooperation is highly appreciated.

1.3 Contents of the report

Chapter 2 presents estimates of annoyance in the Netherlands due to exposure to helicopter noise in the living environment. It also considers whether other adverse health effects, apart from annoyance, may be induced by the present helicopter noise exposure in the Netherlands. Helicopter operations in the vicinity of residential areas not only produce noise experienced by residents, but may also produce vibrations of dwellings and rattling of objects in dwellings. This subject is also treated in chapter 2, as well as some explanation of the aerodynamic background of the characteristic impulsive noise, 'blade slap', produced by flying helicopters. Also other characteristics of helicopter noise exposure which might affect annoyance are described.

Chapter 3 deals with the model, presented by Miedema (1993), to rate environmental noise exposure, and more specifically aircraft noise exposure, with respect to annoyance.

In chapter 4 summaries of epidemiological investigations and psycho-acoustical laboratory studies into the effects of helicopter noise exposure on annoyance and disturbance are presented. Emphasis is on those aspects relevant to rate helicopter noise exposure and to determine exposure-effect relations. The overview in chapter 4 is restricted to studies published in 1979 and later.

In chapter 5 special aspects of helicopter noise which may affect annoyance are considered.

In chapter 6 the method given in chapter 3 is applied to the data presented in chapter 4, to determine which noise measure(s) rates helicopter noise exposure most reliably and exposure-effect relations are considered as far as research data are available.

Chapter 7 gives a conclusion and chapter 8 a list of references used in the report, together with a list of references not suitable to be used in the report, but related to helicopter noise (e.g. emission data and data relevant for noise contours).

Annex A contains definitions and terms. As already stipulated, those readers not familiar with acoustical terms, are advised to take notice of this annex before reading the following chapters of this report. In contrast to 'sound' 'noise' is not given a description in annex A. It is not unusual to define noise as unwanted sound, but this description raises more questions than it answers. There is a certain transition from sound to noise. According to Kristensen (1989) this transition concerns controllability, predictability, content, noise level, other acoustic properties, disharmony, and appreciation of the acoustic event. The transition from sound to noise can, however, be described only globally. This report uses both terms, sound and noise. Noise is usually taking as a collective term, as in environmental noise. When a specific source is meant, the term sound will mainly be used: the sound of a helicopter.

In annex B a relation is given between SEL and $L_{A,max}$ of helicopter noise events in a specific situation, which can be described as close to a heliport. The correspondence between this relation and such a relation for fixed-wing aircraft noise is also considered in annex B.

2. HELICOPTER OPERATIONS

2.1 Noise-induced effects on health

Prolonged exposure to environmental noise of sufficient intensity may have the following effects on health (Passchier-Vermeer, 1993, Gezondheidsraad, 1994):

- annoyance
- sleep disturbance
- stress-related health effects: hypertension and ischaemic heart disease
- effects on performance
- permanent hearing loss.

For road- and air traffic noise, severe annoyance has been observed in epidemiological studies to start on average from a L_{dn} value of 42 dB(A), measured outdoors. For impulsive environmental noise, this level is 20 dB(A) lower (Miedema, 1992).
Subjective sleep quality starts to decrease from $L_{Aeq,night}$ values equal to about 40 dB(A) also measured outdoors (Miedema, 1992).
The stress-related noise-induced effects on health occur in an average population above L_{dn} values of about 70 dB(A) for road- and air traffic noise, measured outdoors.
Effects on the performance of schoolchildren occur at equivalent sound levels of at least 70 dB(A), measured during school-time, outside the school. It is unknown at which equivalent sound levels performance of adults is adversely affected.
Permanent hearing loss as a result of environmental noise occurs due to exposure of people to equivalent sound levels over 24 hours of at least 70 dB(A).
Usually, the epidemiological investigations from which the values above which noise-induced health effects occur have been derived, did not mention helicopters as a noise source. Therefore it can only be assumed that these values are also applicable to helicopter noise.

Any night-time helicopter operations in the Netherlands, apart from flights for rescue operations, are presently very limited in number. Therefore, any substantial sleep disturbance from night-time helicopter noise in the Netherlands is at this time not to be expected.
Only for some specific situations, which are estimated to be among the areas having the highest helicopter noise exposures in the Netherlands at the moment, data on day- and evening-time

helicopter noise exposure are available (e.g. in the vicinity of the heliports Deelen and de Kooy, and around the Eder- en Ginkelse Heide, where military helicopter operations take place). On a long term basis, these helicopter noise exposures are estimated to be in residential areas (very) much not over an equivalent sound level of 55 dB(A) during the day and evening. On a national level, however, it is unknown to which levels of helicopter noise the Netherlands population is exposed during day- and evening-time.

In the UK, in 1982 a number of areas were considered for the UK helicopter disturbance study (Atkins, 1983 a,b). The areas having the highest noise exposure in the UK due to civil helicopters turned out to have equivalent sound levels during the day and evening in the range of 40 to 50 dB(A). According to an estimate by Simson (1992) the number of helicopters in the UK has nearly doubled from 1985 to 1992. Taking into account also a possible increase in the number of flights per helicopter, then it is estimated that in the UK daily equivalent sound levels due to civil helicopters will nowhere exceed 55 dB(A), when averaged over prolonged observation times, e.g. one year.

In the USA, Edwards (1980) evaluated the environmental noise impact of civil helicopters in areas along the Gulf Coast of Louisiana and Texas, these areas having been identified as having the 'heaviest of civil helicopter activities' in the USA. During very busy helicopter hours, equivalent sound levels did not exceed 51 dB(A) (10 flyovers an hour) in residential areas in the vicinity of the heliports. Measurements adjacent to heliports and below narrow corridors for take-off and landing activities (about 300 m from the heliports) showed equivalent sound levels during the hours of heaviest helicopter activity of 63 dB(A) (34 noise events per hour). Schomer (1981 a,b) presents L_{dn} values of helicopter noise in residential areas in the vicinity of an Army Base. Exposure to helicopter noise was divided into two categories: L_{dn} values between 65 and 70 dB(A) and L_{dn} values over 70 dB(A). However, only in a relatively very few cases (139 dwellings) the exposure fell into the last category.

Taking into account this information on helicopter noise exposure in the Netherlands and abroad, the L_{dn} value of 70 dB(A) above which noise-induced effects (with the exception of annoyance and sleep disturbance) occur and the assumption that this value is also applicable to helicopter noise exposure, it seems reasonable to suppose that at present helicopter noise exposure in the Netherlands will not induce these health effects to any significant extent.

Apart from exposure effects from only helicopter noise, it should not be excluded that helicopter noise in combination with noise from other environmental noise sources such as road traffic, contributes to adverse health effects, such as ischaemic heart disease and hypertension. There is, however, as yet no method to predict such effects of combined exposures.

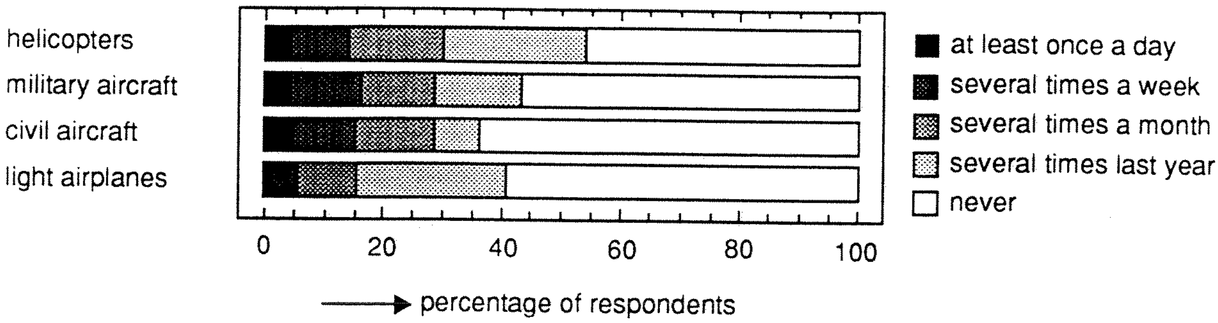
With respect to annoyance due to helicopter noise in the living environment three investigations have been carried out allowing an estimation of the extent of helicopter noise annoyance in the Netherlands (de Jong, 1981, 1988 and 1994). In the first investigation, carried out in 1977, a representative sample of the Netherlands population has been questioned about annoyance from many noise sources in the living environment, helicopters being one of them. The investigation was repeated in 1987 and again in 1993. It was shown that in 1977 55% of the respondents did hear helicopters in their living environment and 6% and 1% were annoyed and severely annoyed, respectively, by helicopter noise. In 1987 these percentages were 56, 18 and 6 and in 1993 54, 24 and 6 (de Jong, 1994). Of those annoyed by helicopter noise, 55% supposed the noise to be produced by military aircrafts and 45% considered the noise to come from civil helicopters. More detailed information is given in figure 1 and table 1. A comparison is made with other types of aircraft. The figure shows helicopter noise to be observed by larger percentages of the respondents in the Netherlands than any other source of air traffic noise. However, most of the respondents observe helicopter noise only sporadically. About 75% of the respondents that observe helicopters do so only at most several times a month. Only 4% of the respondents observe helicopters on a daily basis.

The upper and lower part of table 1 show that the percentages of (severely) annoyed respondents specified for helicopters and for fixed-wing civil aircraft are about equal. All in all, helicopters take up, following military fixed-wing aircraft and together with civil aircraft, the second place in annoying aircraft noise sources in the Netherlands.

Table 1 Annoyance due to aircraft noise in the Netherlands in 1993. Upper part of the table: percentages refer to those respondents observing a noise source. Lower part of the table: percentages refer to the total number of respondents (Source: de Jong, 1994).

	percentage annoyed	percentage severely annoyed
helicopters	24	6
military aircraft	40	21
civil aircraft	25	8
light airplanes	18	4
helicopters	13	3
military aircraft	17	9
civil aircraft	9	3
light airplanes	8	2

Figure 1 Percentage of respondents which do observe air traffic noise for several types of air traffic noise in 1993 (Source: de Jong, 1994).



2.2 Vibration and rattle due to helicopter operations

Apart from noise, helicopter operations may also produce vibrations and rattle. Schomer (1985, 1987) tried to answer the question whether the sound of windows, ceiling tiles or objects in the room rattling and the general perception of building vibration does increase the adverse response to helicopter noise. He performed a study, in which test participants were placed in a wood-frame home, a mobile home or in a tent. An Army UH-1H Huey helicopter made a series of flyby's over the test area to produce the noise and rattle stimulus. The researchers subjectively evaluated the vibrations and rattles induced in the homes during a flyby. Slant distance (distance of closest approach between the helicopter and the location on the ground) offers the best correlation with high levels of rattle in the homes. For an impulsive type of helicopter such as the UH-1H Huey helicopter, the 'high' rattle zone is at slant distances of up to 1000 ft (330 m). Annoyance ratings from helicopter flyby's producing noise and high levels of rattles correspond to those from helicopter operations producing noise only, which have a SEL value that is about 10 dB(A) higher. At slant distances larger than 1500 ft (500 m) for take-offs and level flyovers and 2000 ft (700 m) for landings, rattles and vibrations in homes are virtually absent. These slant distances are expected to differ with type of helicopter.

In other literature related to annoyance from helicopter operations, no mention is made of rattle and vibration. Therefore, no further information is available with respect to this aspect of helicopter operations.

2.3 Helicopter noise emission

There are three main sources of noise emitted by a flying helicopter:

. noise originated by the main rotor

. noise originated by the tail rotor

. engine noise.

In case of noise originating from the rotors (blade slap), the processes of noise emissions are best described by aerodynamic processes. Two types of blade slap can be distinguished:

a blade-vortex interaction (BVI) noise

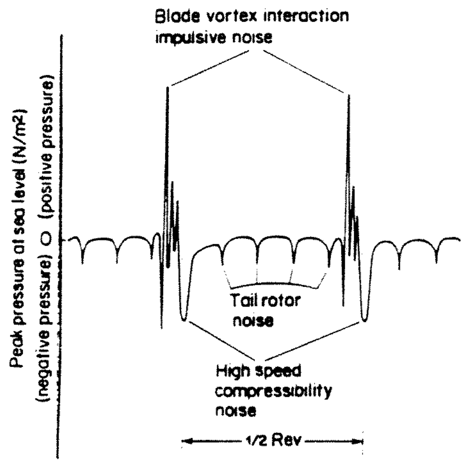
b high-speed impulsive (HSI) noise.

Ad a. When a rotor (with blades) rotates, the shape of the blades is such that a decrease in air pressure is developed at the upper side of the blades. To equalize the difference in the air pressures at the upper and lower side of the blade, turbulent air containing vortices will flow from the lower to the upper side of a rotating blade. Blade-vortex interaction impulsive noise is due to a succession of impulses, each generated by a rotor blade crossing the vortices originated from the preceding blade tips. In forward horizontal flight, the vortices are somewhat beneath the rotor blades. In that instance, blade-vortex interaction is weak. In forward descending flight and during a descending steep curve, the rotor blades are in the plane of the vortices, thus inducing a strong interaction.

Ad b. High speed impulsive noise is related to compressibility effects occurring in the air flowing around the advancing blade tip. Locally, near this blade tip, the air flow velocity may exceed the velocity of sound thus inducing a shock wave (as in sonic booms). This shock wave propagates in front of the helicopter. As the name indicates, high speed impulsive noise occurs when the helicopter is having a high speed. It is clearly observable as a strong impulsive noise. There is also a (left-right) difference in the impulses originated at both sides of the helicopter: at the side where the blade tips are moving in the same direction as the helicopter, the impulses are stronger than at the other side where the blade tips move in the direction opposite to that of the helicopter.

Figure 2 shows characteristics of both blade-vortex interaction impulsive noises and high-speed impulsive noises for the two bladed UH-1H Huey helicopter (Schmitz, 1986). The figure gives the instantaneous sound pressure as a function of time, at a position located 30° below the tip-path-plane of the rotor of a descending helicopter. The time between the two blade-vortex interaction impulsive noises is equal to the time of one-half revolution of the rotor (one blade passage). The wide negative-pressure pulse is indicative of high-speed impulsive noise and the positive pressure pulses depict impulsive noise resulting from blade-tip vortex interactions. Tail-rotor high-speed

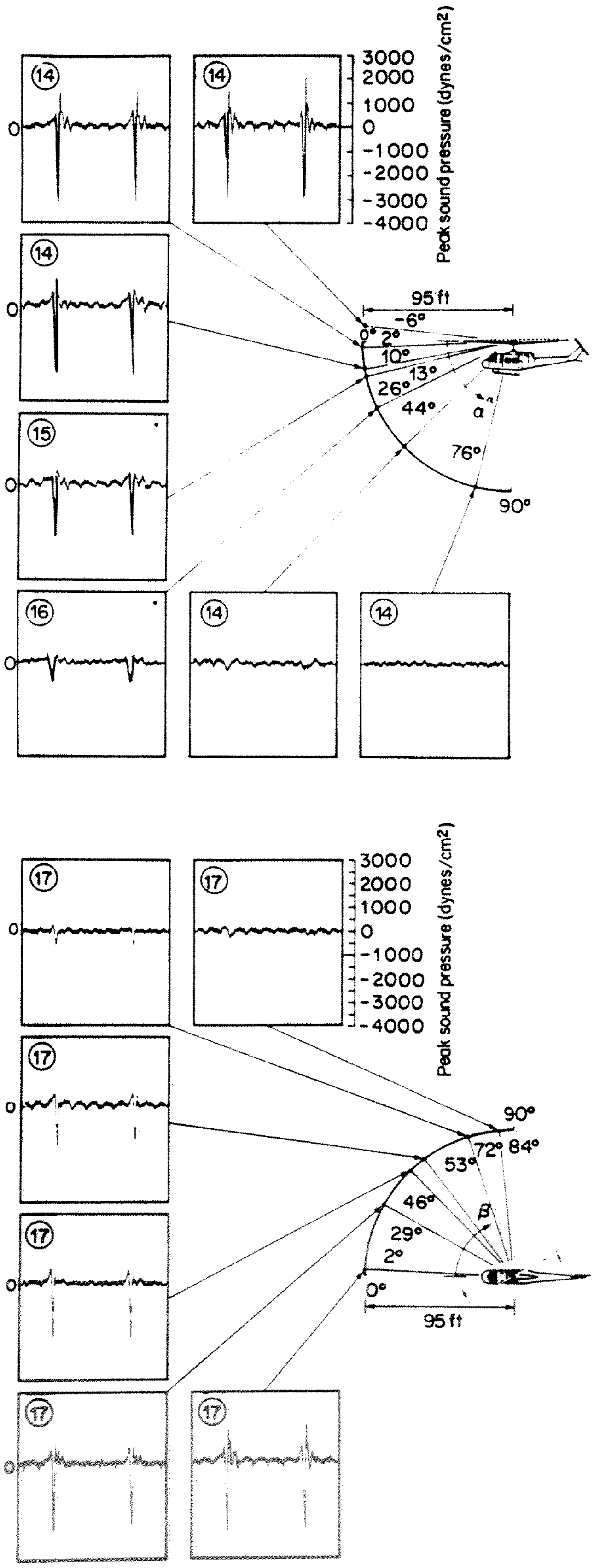
Figure 2 Composite figure showing blade-vortex interaction and high speed impulsive noise. Instantaneous pressure levels as a function of time (Source: Schmitz, 1986).



impulsive noise is also depicted in the same figure by the higher-frequency, smaller-amplitude negative-going pulses.

The impulsive helicopter noise emissions are very directional as is illustrated in figure 3 for high-speed impulses. The UH-1H helicopter is in horizontal flight with a speed of 115 knots. Impulses are most pronounced in the horizontal plane through the helicopter (upper part of the figure) and in front of the helicopter (lower part of the figure). Another example of the directionality of helicopter noise is given in Siegersma (1992) (adapted from Prouty, 1982). Noise contours (lines of equal maximal sound level) presented for a helicopter in horizontal forward flight, show that at about two miles in front of the helicopter the maximal sound level is equal to that at about 0.3 miles at the side of the helicopter. This means that a helicopter is heard much earlier and during a longer time in its flying direction than in other directions.

Figure 3 Directionality of high-speed impulsive helicopter noise. Upper part of the figure: vertical directionality, lower part of the figure: lateral directionality (Source: Schmitz, 1986).



2.4 Helicopter noise exposure

The operations of a helicopter can be divided into:

- ground running operations, inclusive those with engine idle
- take-off
- hover
- overflight and flyby, including ascending, horizontal and descending flights
- landing.

The available literature does not mention ground running operations in a quantitative way. Only Simson (1992) states that 'Lack of manoeuvring space can often mean that ground running - required to satisfy the run-up and run-down needs of the engines for safety purposes - and hover taxi manoeuvres must take place on the landing site. In dense urban areas the contribution to total equivalent sound level from the ground running phase can be dominant in the overall noise burden'.

Noise exposure of a population as a result of a helicopter operation is usually described by maximal sound level during an operation, such as $L_{A,max}$, or by a time-integrated level, such as SEL. In general, $L_{A,max}$ depends upon the time constant of the measuring equipment. Standardized time constants for the exponential averaging circuits of sound level meters are: 1 s (S: slow), 125 ms (F: fast), 35 ms (I: impulse)*. In Siegersma (1992) a comparison has been made of the maximal sound levels, measured with F, S or I time constant, during helicopter overflights. It concerned 17 overflights; the measurement locations were from directly under the flight path up to 500 m away from this path. The average of the maximal sound levels using time constant S was 77.9 dB(A). This average sound level was 2.3 and 3.8 dB(A) lower than the average values using F and I, respectively.

According to ISO 3891-1978 time constant S is preferred to determine the maximum levels of an aircraft noise event. Presumably, this recommendation stems from its easy applicability to measurements carried out in the seventies with a conventional analogue indicator. With present digital indicators, measurements on F and I are as reliable as on S and contain a more accurate reflection of the integration time of the human ear. Nevertheless, unless specified otherwise, in this report $L_{A,max}$ is assumed to be determined with time constant S.

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* The signal from this exponential circuit is fed into a peak detector circuit with decay time constant of 1500 ms (IEC, 651).

Taking into account the various possible helicopter operations and the strong directionality of helicopter impulse noise, it is quite unlikely that a high correlation does exist between a noise measure which takes into account only the maximal value during a helicopter operation and a noise measure which takes into account all sound levels during a helicopter operation, such as SEL. This seems especially valid for helicopters hovering above the ground. Since hovering may last any time, a correlation between $L_{A,max}$ and SEL may be virtually absent.
However, in annex B it is shown that for the specific situation of direct overflights of helicopters in the vicinity of heliports, the correlation between SEL and $L_{A,max}$ is quite high: a correlation coefficient of 0.94 is appropriate. In annex B it is also shown that the relation between these two noise measures of a noise event determined for fixed-wing aircraft noise in residential areas in the vicinity of airports (Ollerhead, 1992) is the same as the relation for helicopter noise, in the case of direct overflights of helicopters in the vicinity of heliports. This implies that it is very likely that for situations in the direct vicinity of heliports and of airports, the time-aspects of a helicopter noise event and of a fixed-wing aircraft noise event will not contribute to differences between exposure-effect relations for helicopter noise exposure and those for fixed-wing aircraft noise exposure.

There are several aspects which might in principal affect annoyance from helicopter noise. The following special features related to helicopter noise and helicopter noise exposure might be relevant for the distinction between helicopter and other environmental traffic noise sources:

- impulsivity of helicopter noise
- onset rate of helicopter noise during approach
- tonality of helicopter noise
- directionality of helicopter noise
- frequency spectrum of helicopter noise
- sporadicity of occurrence of overflights in residential areas
- differences between outside and inside sound levels of dwellings of residents
- differences between most and least exposed sides of dwellings in residential areas
- duration of the presence of helicopters above residential areas
- attitude of the population towards helicopters.

The possible effects of these special characteristics of helicopter noise will be discussed in chapter 5.

3. THE STUDY: NOISE MEASURES TO RATE AIRCRAFT NOISE

The report (Miedema, 1993) deals with relations of aircraft noise exposure with annoyance and with sleep disturbance. In this report, only aspects in the Miedema report related to annoyance will be referred to.

In the report a mathematical model is discussed to describe in which way noise measures should be specified in order to enable them to be related to annoyance. The mathematical model is based on a theory about the trade-offs between basic attributes of noise, which, in a number of hierarchically organised steps, determine annoyance caused by noise. A summary of this mathematical modelling is given in annex C. In this report, the results of the model will be specified in a format which more closely conforms to the contents of the literature related to helicopter noise.

The model specifies four steps to be taken to specify a noise measure which can be related to annoyance. The four steps concern one 'frequency'-step and three 'time'-steps. These four steps are in the Miedema report quantitatively specified with respect to the following five noise measures: $L_{Aeq,24h,}$ L_{dn}, BKL, L_{etm} and B. The model takes one noise event as a basis. In the first step, the frequency-dependent sound pressure levels present at a given moment during a noise event are combined into one momentary value. For all the five noise measures specified in the report, frequency-weighting occurs according to the standardized A-characteristic of sound level meters (IEC 651). Also other frequency-weightings (B, C, D) have been specified in IEC documents (IEC 651, IEC 537). In the literature with respect to helicopter noise, also perceived noise level (L_{PN}) and tone-corrected perceived noise level (L_{TPN}) are used (see Annex). Frequency-weighting with respect to (tone-corrected) perceived noise level is specified in ISO 3891-1978. L_{PN} and L_{TPN} of a sound at a given instant are derived from its noisiness, in noys, at that instant.

The first time-step combines the instantaneous frequency-weighted values of one noise event into a value representative for that noise event. Examples are SEL and $L_{A,max}$, when in the frequency-step A-weighting has been applied, and L_{EPN} and $L_{PN,max}$ in the case of the frequency-weighting related to noys. SEL and L_{EPN} concern time-integrated values, these time-integrations of L_A, L_{TPN} and L_{PN} occurring in exactly the same way. $L_{A,max}$ and $L_{PN,max}$ both are the maximum of the values occurring during 1 s.

The second time-step combines the various noise events occurring during a specified period of time by combining the values obtained in the first time-step per noise event into one value, representative for the noise exposure during that period of time. Examples are $L_{Aeq,T}$ and L_{PNeq} over period T. In all five noise measures specified in the Miedema report this combination involves a trade-off which can be represented by a simple rule if all events have the same level. The rule for the trade-off between level (L) and number of noise events (n) is then: L + k_n log n, in which k_n is the trade-off factor. For $L_{Aeq,24h}$, L_{dn}, BKL and L_{etm} the trade-off factor k_n is equal to 10. This implies that a doubling of the number of noise events during a period T is equivalent to a level increase of 3 dB. For B, and also for the formerly in Great Britain used noise measure NNI, k_n is equal to 15. A doubling of the number of noise events during a period T then is equivalent to a level increase of 4.5 dB. Also for L_{PNeq} the trade-off factor is equal to 10.

The third time-step combines the various values determined in the second time-step over specific periods of time into one value, representative for the noise exposure during a period of 24 hours. For the five noise measures specified in the Miedema report specific rules for these combinations are given. With respect to $L_{Aeq,24h}$, the results of the second time-step at any period of the 24 hours have equal weight. For L_{dn}, first 10 dB(A) is added to the night-time level and then the results of the day and the night are combined into one value. For BKL, first 5 and 10 dB(A) are added to the evening- and night-time levels, after which the results are combined into one value. For B, various values are added dependent upon the period of the 24 hours day, and the results are combined. L_{etm} is the maximum of three values representing the result for day-time, that for evening-time plus 5 dB(A) and that for night-time plus 10 dB(A).

Miedema states that a fourth time-step would be necessary to determine a value representative for a long-term period, such as a year. This step should combine the values representative for the noise exposures during all 24 hour periods of a year. Only in BKL the results of the third time-step for various periods of a year have been combined by putting emphasis to specific periods, such as the 26 busiest weeks of a year or the two busiest days during a week. In the other noise measures, the results of the third step have equal weight.

In the Miedema report, also specific aspects of aircraft noise and aircraft noise exposure are discussed. It concerns aspects such as loudness, noisiness, frequency weighting, tonality, impulsiveness, also in relation to the integration time of the human hearing organ, onset rate and aspects related to the noise exposure of residents, such as differences between most and least exposed sides of dwellings and differences between sound levels outside and inside dwellings due to aircraft noise. Partly, the specific aspects of helicopter noise (exposure) specified in 2.4 of this report have been taken from the Miedema report. In chapter 5 of this report, where the specific helicopter noise characteristics will be discussed, the analysis in the Miedema report will be taken as a basis.

4. HELICOPTER NOISE DISTURBANCE STUDIES

Berry et al. (1979)

Berry describes the contributions of the National Physical Laboratories to the work of ISO/TC43/SC1/WG 2 with respect to a possible modification to the scale of effective perceived noise level (L_{EPN}) to account for the subjective effects of impulsive helicopter noise. In a preliminary experiment twenty test subjects made judgements by the method of paired comparison on the annoyance of field recordings of helicopter noise: five of helicopters hovering and six flyovers. Annoyance turned out not to be related to the degree of impulsiveness (as determined by listening or by objective rating with an impulse factor I, specified in the report), as is shown in Table 2.

Further experiments in the NPL study used generated test signals. Attention of the 31 test subjects was focused on level and impulsiveness, since other factors were held constant. The experiments showed a trade-off between level and impulsiveness, suggesting an impulsiveness correction of the order of 5 dB. However, as Berry puts forward, the importance of this effect in the overall perception of real helicopter noises is unknown. In real life other factors such as a growth and decay in loudness, cues about the altitude of the helicopter, spectral irregularities and extraneous background noises may interact with impulsiveness, as is suggested by the results of the preliminary experiment.

From the results of the NPL study and of other studies, ISO/TC43/SC1/WG 2 concluded that sufficient evidence was available of the need for an impulse correction in rating helicopter noise with respect to annoyance. Research was undertaken to define a description for impulsiveness, resulting in 1978 in a draft proposal for an Addendum to ISO 3891-1978. The proposed impulse correction ranged from zero up to 6 dB.

At about the same time, however, as Berry reports, a report (Powell, 1978) was published with the results of a specially commissioned program of psycho-acoustic tests conducted under real-life flyover conditions. The investigators concluded that the temporal and spectral characteristics of the impulsive helicopter noise were adequately represented by L_{EPN}, primarily through an increase in the duration component. The addition of an impulsive correction in fact degraded the correlations between the objective noise measures and the subjective responses obtained in these tests. Unfortunately the Powell report could not be obtained (in time) to be included in this study.

Table 2 Results of initial NPL subjective experiment: rank ordering of annoyance judgements of helicopter operations with the same noise levels.

	Noise ref*	Subjective rank order	Degree of Impulsiveness
Hover Noises	6	1 (Most annoying)	Moderate
	11	2	Slight
	3	3	High
	2	4	High
	7	5 (Least annoying)	Moderate
Flyover Noises	1	1 (Most annoying)	High
	5	2	Moderate
	10	3	Slight
	9	4	Slight
	8	5	Slight
	4	6 (Least annoying)	High

* The noise reference numbers are in rank order of descending impulsiveness.

Schomer (1979, 1981 a,b, 1982, 1983 a)

All publications deal with one community survey into the attitudes towards noise in the vicinity of a large army base. The survey sought to compare blast noise and helicopter noise in the context of other noises, such as from fixed-wing aircraft, wheeled traffic and children. In all, 2348 persons participated in the study. In the survey use was made of a face to face questionnaire. The respondents rated the subjectively perceived loudness of noise events relative to conversational level. A portion of the questionnaire contained questions related to activity interference. For each of the activities respondents were asked what noises caused the previously stated interference and how often this occurred. Finally, each respondent was asked about their degree of annoyance due to the sources they mentioned. Five answers were possible ranging in steps from extremely annoyed to not at all annoyed. The number of extremely annoyed people plus half the number of respondents giving the second answer has been taken as the number of highly annoyed persons.

In table 3 a comparison has been made between the results for helicopters and for fixed-wing aircraft. Percentages of highly annoyed people are given per subgroup of respondents, subgroups being determined by the number of events observed by the respondents and the loudness subjectively experienced by the respondents. In the table the number of subjects within each cell has been presented in classes.

Table 3 Percentage of respondents highly annoyed by helicopter and by fixed-wing aircraft noise in subgroups, determined by number of experienced noise events and experienced loudness relative to conversation level (much more: fixed-wing aircraft and helicopter noise much more louder than conversation; other headings defined in an analogous way).

Loudness relative to conversation level										
	much more		more		same		less		much less	
Number of events	fixed wing	helicopter	fixed wing	helicopter	fixed wing	helicopter	fixed wing	helicopter	fixed wing	helicopter
daily	30	36	10	12	9*	9*	2*	2**	-	-
several per week	23*	31	5	5	2*	2	2*	2*	0**	-
several per month	31**	22**	6*	6*	2*	0*	0**	0**	-	-
once every few months	-	-	0**	-	0**	0**	-	0**	-	-
less often	-	-	-	-	-	-	-	-	-	-

Without: subgroup of more than 100 respondents
*: subgroup of 36-100 respondents
**: subgroup of 11-35 respondents
-: subgroup of at most 10 respondents

The table shows that when fixed-wing aircraft and helicopters are equal in perceived loudness and in perceived frequency of occurrence, there is usually no difference in percentage highly annoyed respondents. Only a small difference is apparent for the most frequently experienced loudest helicopters and airplanes. In that case, helicopters seem to be more annoying than fixed-wing airplanes.

The analysis of the data showed that there are at least two factors which contribute to increased annoyance during a time period of the 24 hour day. One factor is the annoyance per individual event during a time period. The second is the number of events noticed during a period of time. The analysis shows that single noticed events are more or less equally annoying during all periods of the 24 hour day. There is only a small growth in intrinsic annoyance during the night and this growth occurs primarily with the more impulsive sources, such as artillery and helicopters. The results indicate that the second factor, the number of events noticed per period, is more important in contributing to a night- and evening-time difference and to a difference between weekends and weekdays.

The night-time adjustment, calculated by taking into account the actual occurrences of noise events and the numbers of persons noticing a noise event, is for fixed-wing aircraft noise equal to 5 dB(A) and for helicopter noise 8 dB(A). Splitted up into weekdays and weekends, night-time adjustments are 5 and 7 dB(A) for fixed-wing aircraft noise and 7 and 9 dB(A) for helicopters.

Ollerhead (1982)

Ollerhead (1982) reports on an extensive laboratory study for rating helicopter noise annoyance. A large sample of recordings of 89 helicopters and 30 fixed-wing aircraft flyover sounds (conventional take-off and landing: CTOL) were rated with respect to annoyance by groups of approximately 40 subjects. These subjects were undergraduate students in the age range of 19 to 23 years with roughly equal numbers of males and females.

The 89 helicopter noise events, recorded during helicopter operations, concerned 73 less impulsive and 16 more impulsive helicopters, the 30 CTOL's were 12 approaches and 18 take-offs. The impulsiveness of helicopter noise is determined by its I value. This I value is the difference between L_{EPNi} and L_{EPN}. When this difference is 4 dB or more, Ollerhead considers the helicopter noise impulsive.

In order to probe the role of long approach phases associated with some helicopter flyover sounds, a pilot experiment was carried out with three helicopter sounds in which the approach components were modified. On the basis of this pilot experiment it was concluded that even in a very extreme case (a 3.5 minute long recording of the approach of a very impulsive helicopter, the Bell 205 helicopter) the approach component makes no measurable contribution to judged annoyance or noisiness. The approach component concerns the period between the moment the helicopter starts to be heard and the moment the noise of the helicopter reaches for the first time a level equal to $L_{A,max}$ minus 10 dB. In the main experiments, therefore the approach component was cut off from recordings of the helicopter noise. However, in the conclusion of the report, Ollerhead states 'In particular, it is disconcerting that the very long attention-arresting sound of an approaching, highly impulsive helicopter did not effect annoyance judgements in the pilot experiments. Yet the "hearsay" evidence of complaints indicates that the characteristically long audible duration of much helicopter noise is a particular source of aggravation. If this can be established as fact, perhaps by field survey research, the case will be made to develop improved techniques for laboratory study, and ultimately perhaps, to formulate a better concept for helicopter noise certification standards'.

Ollerhead considers as noise metrics various maximum levels (such as $L_{A,max}$) during overflights and various time-integrated levels (such as SEL). He determines (for all 119 sounds together, for the subgroups of 89 helicopter noises and 30 CTOL's and for the sub-subgroups of 73 less impulsive helicopter noises, 16 more impulsive helicopter noises, 12 approaches and 18 take-offs) the best-fitting straight lines of unit slope (i.e. the unit slope line about which the variance in the y-direction is minimized), where the annoyance level is the independent variable on the x-axis and the noise measure is the dependent variable on the y-axis. Ollerhead denotes the intercept of such a straight line with the y-axis annoyance prediction error. These annoyance prediction errors are given in table 4 for several noise measures. Also given is the standard deviation taken from the variance of the data points in the y-direction relative to the best-fitting straight line. The noise measure with the smallest differences in the mean annoyance prediction errors of the various subgroups and sub-subgroups and with the smallest standard deviation related to the variance of the data points in the y-direction is to be preferred as noise measure to rate helicopter noise with respect to annoyance.

On the basis of a broad comparison of the differences in mean annoyance prediction errors and of the standard deviations for the maximum levels and for the time-integrated levels it is clear that with time-integrated levels the consistency with which scales predict annoyance level is improved. The improvement is significant at the 1 percent level in the cases of $L_{A,}$ $L_{D,}$ and L_{TPN} and at the 5 percent level for L_{PN}.

Table 4 shows that on average the helicopter sounds were judged to be equally annoying as CTOL sounds with the time-integrated levels of the CTOL sounds approximately 2 dB higher. However, all scales predict the annoyance levels of helicopter noise significantly less consistently than those of CTOL noise, a finding which according to Ollerhead may be attributed to the widely differing acoustical characteristics of different helicopter types. The table shows that the time-integrated scales predict annoyance of the more impulsive helicopters less accurate than annoyance of less impulsive helicopters. The variance in annoyance due to the more impulsive helicopters is statistically greater than it is due to the less impulsive sample at the 1 percent level.

Multiple regression analysis indicated that, provided the difference of about 2 dB between helicopter and CTOL level is taken into account, the particular linear combination of level, time-integration and tone-correction inherent in effective perceived noise level is close to optimum**. The results revealed no general requirement for special effective perceived noise level correction terms to penalize helicopter sounds which are particularly impulsive; apparently, impulsiveness causes spectral and temporal changes which themselves adequately amplify conventionally measured sound levels. SEL (in dB(A)) performs only slightly less than L_{EPN}, as can be observed in table 4. The standard deviation increases from 1.6 dB in the case of L_{EPN} to 1.9 dB in the case of SEL, when all helicopters are considered together. For the more impulsive helicopters the standard deviation is for SEL 2.7 dB, whereas it is 2.5 dB in the case of L_{EPN}.

** Ollerhead estimates that his experiments would induce variations which correspond to standard deviations of not less than 1.5 dB in the case of a perfect noise rating scale. Time-integrated L_{TPN} shows a standard deviation of 1.7 dB.

Table 4 Annoyance prediction errors (in dB). Mean values for sub-samples are relative to the overall mean value, listed for all the 119 sounds. Standard deviation (in dB) in parentheses (Source: Ollerhead, 1982)

	Maximum levels			Time-integrated levels		
scale	All 119 sounds	89 heli's 30 CTOL's	73 less imp. 16 more imp. 12 approaches 18 take-offs	All 119 sounds	89 heli's 30 CTOL's	73 less imp. 16 more imp. 12 approaches 18 take-offs
L_A	- 4.6 (2.5)	- 0.2 (2.6) + 0.3 (1.9)	+ 0.2 (2.4) - 1.8 (3.2) + 1.0 (1.8) - 0.1 (1.9)	- 16.6 (2.0)	+ 0.5 (1.9) - 1.6 (2.0)	+ 0.7 (1.7) - 0.1 (2.7) - 2.4 (1.0) - 1.0 (1.5)
L_D	+ 2.3 (2.3)	- 0.2 (2.3) + 0.7 (2.6)	+ 0.1 (2.1) - 1.6 (3.0) + 2.6 (2.1) - 0.6 (2.1)	- 9.8 (1.8)	+ 0.5 (1.8) - 1.3 (1.0)	+ 0.6 (1.5) + 0.2 (2.6) - 1.0 (1.1) - 1.3 (0.9)
L_{PN}	+ 8.6 (2.2)	- 0.1 (2.2) + 0.3 (2.1)	+ 0.2 (2.0) - 1.3 (2.8) + 1.6 (1.8) - 0.6 (1.9)	- 3.3 (1.8)	+ 0.6 (1.7) - 1.7 (1.0)	+ 0.9 (1.4) + 0.4 (2.4) - 2.0 (1.0) - 1.5 (0.9)
L_{TPN}	+ 10.5 (2.6)	- 0.2 (2.6) + 0.4 (2.8)	+ 0.1 (2.3) - 1.9 (3.2) + 2.5 (1.7) - 0.9 (2.6)	- 1.7 (1.7)	+ 0.5 (1.6) - 1.5 (1.0)	+ 0.6 (1.3) - 0.1 (2.5) - 1.3 (1.2) - 1.6 (0.9)
L_{TPNC} *	+ 13.1 (2.3)	- 0.2 (2.6) + 0.4 (2.3)	+ 0.3 (2.3) + 0.0 (2.4) + 0.9 (1.9) - 1.6 (2.0)	+ 0.1 (2.2)	+ 0.8 (1.8) - 2.4 (1.2)	+ 0.5 (1.6) + 2.1 (2.0) - 2.4 (1.4) - 2.5 (1.0)
L_{AC}	- 1.9 (2.4)	+ 0.3 (2.5) - 0.7 (2.0)	+ 0.3 (2.5) + 0.2 (2.5) - 0.4 (2.4) - 0.8 (2.4)	- 14.8 (2.5)	+ 0.9 (2.1) - 2.5 (1.7)	+ 0.6 (2.0) + 1.9 (2.3) - 3.4 (1.3) - 1.9 (1.7)

* $L_{TPNC} = L_{TPN} + C - 12$; $L_{AC} = L_A + C - 12$. For C, see appendix

Schomer (1983 b)

Schomer describes a community attitudinal noise survey carried out in the vicinity of a smaller sized general aviation airport Decatur. L_{dn} ranged from 44 to 66 dB(A). It is an otherwise quiet and residential area. Each week one helicopter (UH - 1H Huey) lands and takes off from the airport. The number of respondents was 231, the survey was mainly administered by telephone. The respondents have been divided into four categories, dependent upon the L_{dn} value of their aircraft noise exposure. In table 5 the total number of respondents per noise zone is given, together with the L_{dn} values. Also given are the percentages of respondents highly annoyed by aircraft and helicopter noise, and the percentages of respondents who spontaneously mentioned airplanes and helicopters as a source of annoyance.

A comparison of the percentage of all respondents highly annoyed by helicopter noise (6.5%) with the various percentages highly annoyed by fixed-wing aircraft noise, shows that this percentage for helicopter noise is equal to that for fixed-wing found at a L_{dn} value of about 61 dB(A). This percentage of highly annoyed respondents seems amazingly high for only two helicopter operations a week.

Table 5 Percentage highly annoyed (HA) and percentage of respondents spontaneous mentioning (spont) airplanes and helicopters (Source: Schomer, 1983 b).

Zone	L_{dn} in dB(A)	Number	Airplanes		Helicopters	
			% HA	% spont	% HA	% spont
1	66	29	24	72	7	17
2	63	57	11	53	11	12
3	61	99	6	35	3	5
4	55	46	2	24	9	2
All		231	8.7	42.0	6.5	7.4

Atkins (1983 a), Atkins et al. (1983 b), Prescott-Clarke (1983)

The main report of the UK 1982 Helicopter Disturbance Study gives the results of an epidemiological investigation of annoyance caused by aircraft noise, including helicopter noise. The study was carried out because of the need for better information on helicopter noise and its effect on communities, and because of doubts about the application of NNI to measure annoyance due to helicopter operations. Purpose of the investigation was to determine whether NNI or L_{Aeq} are adequate for describing disturbance due to helicopter operations, and, if not, to devise appropriate modifications to these measures.

The noise measurements and social surveys have been carried out at five locations, which can be described as follows:

Balmedie: a residential area in the vicinity of Aberdeen Airport, not affected by rail road noise nor to a great extent by road traffic noise. No fixed-wing aircraft, only helicopter noise with NNI equal to 28.5 dB. Helicopters are used to serve oil rigs in the North Sea.

Sheddocksley: a residential area in the vicinity of Aberdeen, not affected by rail and road traffic noise. Only fixed-wing aircraft, no helicopter noise.

Lower Feltham: some suburban railway noise, a main road passes through the area. Helicopter noise, from the Gatwick-Heathrow Airlink: NNI equal to 28.2 dB, fixed-wing aircraft noise: NNI equal to 29.4 dB.

West End, Esher: not affected by railway noise, some houses affected by road traffic noise. Helicopter noise from the Gatwick-Heathrow Airlink: NNI equal to 26.2 dB and fixed-wing aircraft noise with NNI equal to 35.2 dB.

Woodcote Park, Epsom: no railroad noise, some parts are slightly affected by traffic noise. Helicopter noise from the Gatwick-Heathrow Airlink with NNI equal to 17.0 dB and fixed-wing aircraft noise with NNI equal to 24.8 dB.

In total 438 persons participated in the study.

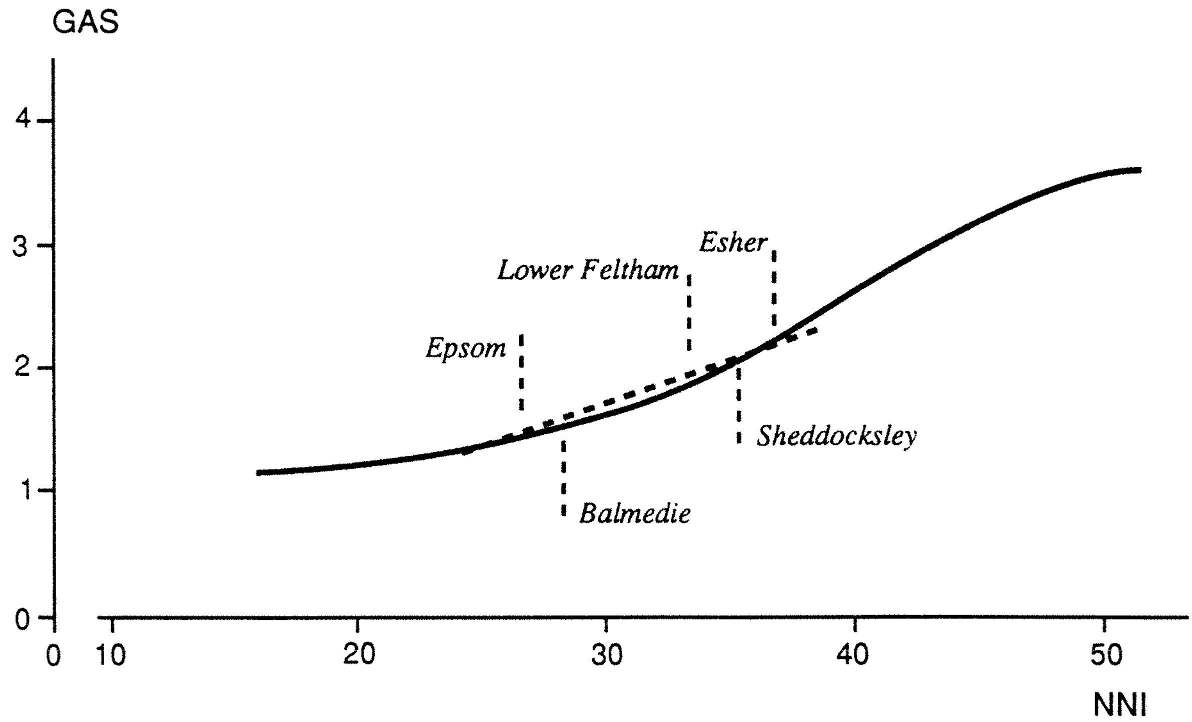
Disturbance was assessed by means of the Guttman Annoyance Scale (GAS), which has been derived from a series of questions about the annoyance reported when aircraft noise disturbs or interferes with various everyday activities. The scale was developed in the 1967 Heathrow Study.

Disturbance was also assessed on the Aircraft Noise Annoyance Scale (ANAS) and Helicopter Noise Annoyance Scale (HENAS). Because the relationships involving HENAS were so statistically weak they were not considered in any detail in the report of Atkins.

Exposure-effect relations in the report are expressed in terms of average GAS against NNI[***] The result is given in figure 4. The curve in the figure summarizes the responses obtained in previous surveys around Heathrow and Gatwick.

[***] The calculation of NNI requires the determination of L_{PN} for each noise event. However, in the calculations presented in the study (Atkins, 1983) L_{PN} has been estimated from $L_{A,max}$ by adding 13 dB to $L_{A,max}$. This is the standard ICAO correction (ICAO, Environmental Protection: volume 1 - Aircraft Noise. Annex 16 to the Convention on International Civil Aviation).

Figure 4 GAS scores as a function of NNI. Vertical lines are the 95% confidence bands on the mean GAS scores. The straight line (dashed) is the least square fit to the mean GAS scores at the five areas surveyed. The curve is taken from earlier studies on fixed-wing aircraft noise at Heathrow and Gatwick (Source: Atkins, 1983).



The statistical analyses showed that the socio-economic grouping of the respondent and a respondent's fear that aircraft might crash have an important bearing on the annoyance scores. In figure 5 GAS scores in which allowance is made for the first factor are plotted. The NNI-measure as defined and as presented in figures 7 and 8 does not take into account any aircraft noise event with a $L_{A,max}$ lower than 67 dB(A). If also noise events with $L_{A,max}$ values between 62 and 67 dB(A) are taken into account, the relation between GAS and the NNI (indicated by NNI62) is given in figure 6. There is apparently a better fit than in figure 5. Atkins concludes in his report that the reported disturbance occurring as a result of aircraft noise is consistent with previous studies over the same range of (relatively low) noise exposures. This concerns the relation of annoyance with noise exposure. There are indications that the variation of the data around the average exposure-effect functions is somewhat larger than fluctuations occurring with fixed-wing aircraft noise exposure only.

Figure 5 GAS scores as a function of NNI. The GAS scores for the survey areas are adjusted to remove the effects of socio-economic grouping. The vertical lines are the 95% confidence bands on the mean GAS scores. The curve is the same as shown in figure 4 (Source: Atkins, 1983).

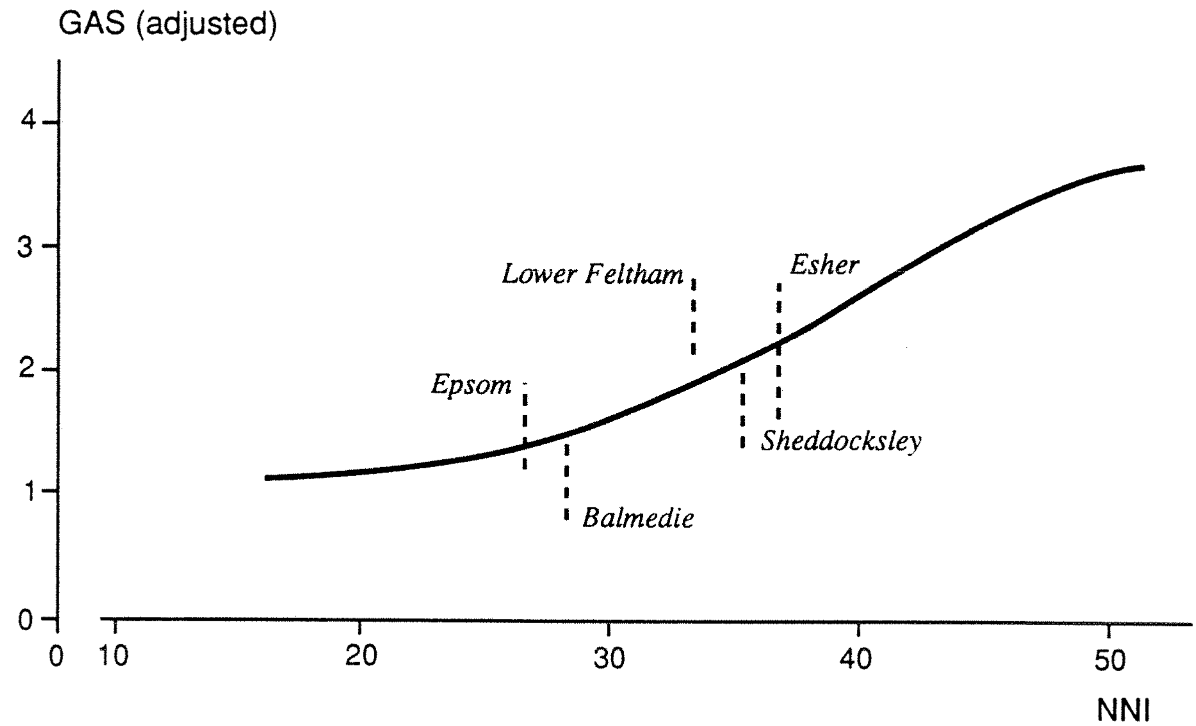


Figure 6 GAS score as a function of NNI62 (NNI which includes aircraft operations with $L_{A,max}$ values exceeding 62 dB(A)). The GAS scores are adjusted as in figure 5. The straight line is the least square fit to the data (Source: Atkins, 1983).

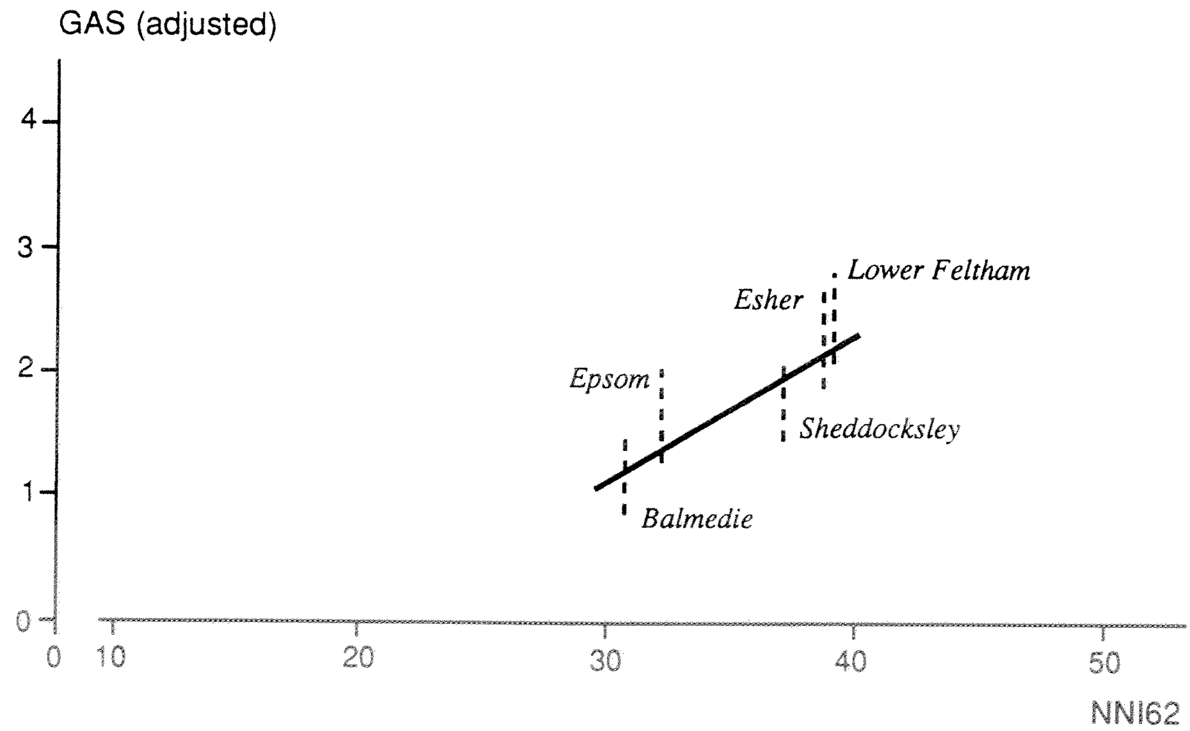


Table 6 Relative disturbance due to helicopter and fixed-wing aircraft noise in mixed areas (Source: Atkins, 1983)

Percentage of people considering helicopters more or less disturbing than fixed-wing	Lower Feltham	West End, Esher	Woodcoke Park, Epsom
1. much more and more	52.3	44.9	50.7
2. same	22.1	37.2	29.6
3. less and much less	25.6	17.9	19.7
quotient*	2.0	2.5	2.6
Characterization of noise exposure			
NNI helicopters	28.2	26.2	17.0
NNI fixed-wing	29.4	35.2	24.8
number** of helicopters	22	22	21
number** of fixed-wing	167	48	31
average L_{Amax} helicopters	76	74	71
average L_{Amax} fixed-wing	74	79	76
$L_{Aeq,07\text{-}19h}$ helicopters	51	50	44
$L_{Aeq,07\text{-}19h}$ fixed-wing	53	57	51

* quotient of percentages of 1 and 3

** number with L_{Amax} of at least 57 dB(A) on an average day (07.00 - 19.00 hours local time).

In the areas with 'mixed' aircraft noise exposure, helicopter operations are generally felt to be more annoying than fixed-wing aircraft operations. This is shown in table 6. The upper part of the table concerns the answer to the question: do you find the noise of helicopters more or less disturbing than that of other aircraft? The phrasing of the question is such that it does not exclusively refer to the situation of the respondent. Therefore, the relative number of disturbing helicopters and fixed-wing aircrafts in their own situation may not have been important in their answers. The table shows that the percentages of people who consider helicopters more and much more disturbing than fixed-wing aircraft are 2 to 2.5 as large as the percentages who consider helicopters less and much less disturbing. It should be pointed out that at Lower Feltham, the values of the noise measures of helicopters and of fixed-wing aircraft are about the same (compare the values at the lower part of the table), only the number of aircraft noise events is about 7 times as large as the number of helicopter noise events. In Esher and Epsom, the number of helicopters and of fixed-wing aircrafts are in both situations more or less about the same, with fixed-wing aircrafts being on average 5 dB(A) louder. Nevertheless, the disturbance due to helicopter noise is 2.5 times as large as that due to aircraft noise.

A multiple regression analysis was also carried out with GAS and ANAS as dependent variables and several noise measures, noise exposure characteristics and social and attitudinal features as independent variables. When a noise measure was entered as independent variable in the first step of the analysis, only a few of all possible independent variables added significantly in the explanation of the magnitude of the dependent variable: fear of aircraft crashing, socio-economic group, the difference between $L_{Aeq,07\text{-}19h}$ and $L_{Aeq,\ 19\text{-}23h}$ and the average value of $L_{A,max}$ of helicopters. Of these, fear of aircraft crashing showed by far the most effect. In particular, the variable representing a respondent's fear of crashes has a much higher correlation coefficient with GAS than NNI or other noise measures.

NNI and $L_{Aeq,07\text{-}19h}$ appeared to perform about equally well in rating annoyance. When NNI was determined including noise events with $L_{A,max}$ values from 62 dB(A), instead of only values from 67 dB(A) as is usually done in calculating NNI, then performance of NNI to predict annoyance increased and in this respect turned out to be slightly, but statistically insignificant, better than $L_{Aeq,07\text{-}19h}$.

Other factors, such as differences between weekend and weekday noise exposure, and regional differences in attitude to aircraft noise, seem to contribute to the variability in the response-relationship to a lower extent. However, Atkins considered the scope of his study too limited to establish a quantitative relationship with regard to these factors. Atkins points at the possibility that some of these aspects would be considered as part of a more general study of noise indices, the United Kingdom Aircraft Noise Index Study (ANIS). This study has been reported in 1985 (Brooker, 1985). The ANIS-study confirms that the Guttman Annoyance Scale is a good measure of disturbance and that it agrees well with other scales, such as the proportion of 'very much annoyed' people in the community. The 'trade-off' factor of 15 in the NNI is according to the ANIS-study not substantiated: it places too much weight on the number of aircrafts. A value of 9 to 10 would be better. Noise events with perceived noise levels below 80 dB, the noise level cut-off in the NNI, should according to the ANIS-study be included in the calculation for an index. Also, according to the ANIS-study, aircraft movements outside day-time hours (07-19h) should be included in an index, but <u>not</u> weighted to be more severe in their relative effect than the day-time movements. A good fit to disturbance responses is given by $L_{Aeq,24h}$, the equivalent sound level over the 24 hour period, without applying any penalties to night- and evening-time noise events.

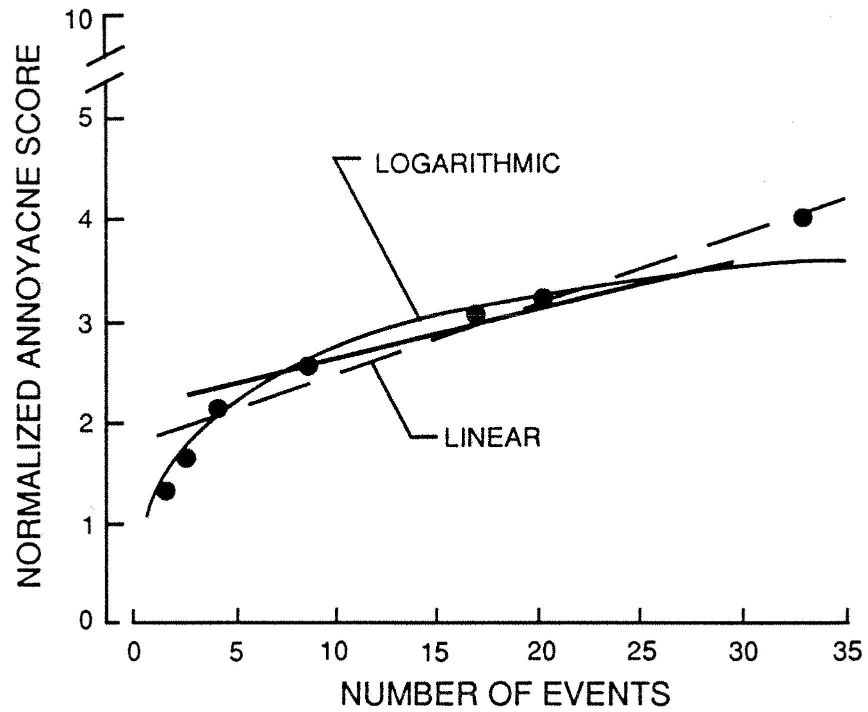
Fields and Powell (1985, 1987)

The study was designed to investigate the reactions of community residents to noise from low numbers of helicopter operations (at most 35 per day). The design combined features found in both laboratory and field studies: community residents were interviewed, but helicopter operations were carefully controlled (without the knowledge of the residents). The study was conducted in a suburban area normally exposed to military helicopter operations. After one initial face to face interview, telephone interviews were repeated with the same respondents during the evening on 22 additional days. These telephone interviews measured annoyance due to noise during the day-time on that day. The helicopter noise levels were controlled in 17 of 22 repeated interview days. A total of 338 respondents, 84% of those eligible, participated in the initial interview and 330 completed the program with a concluding interview. Fields considers a major issue in this study the applicability of the equivalent energy assumptions about the relative importance of noise level and number of noise events. An interview was included in the data analysis only if it was held on the 17 noise exposure days and only from the respondents who were home during scheduled noise events.

The number of scheduled helicopter overflights was 1, 2, 4, 8, 16 or 32 per day. Two helicopter types were included: the relatively impulsive UH-1H Huey and the less impulsive UH-60A Black-hawk. Large numbers of UH-60A helicopter overflights could not be realised so that 16 and 32 helicopters per day were limited to days with UH-1H helicopters. Apart from the planned helicopter overflights, also other helicopter operations took place. These operations have also been taken into account in the analysis.

In order to examine the pattern of reactions to different noise levels and number of noise events, the daily annoyance scores were averaged within number of event and noise level categories. The resulting annoyance scores that are normalized to a SEL value of 87 dB(A), are plotted by number of noise events in figure 7. The figure also includes lines that are predicted from regression analysis in which number is entered as either the untransformed number of events or as log number of events. The logarithmic transformation provides a better fit than the untransformed representation. The same pattern persisted when helicopter type was entered into both regression equations.

Figure 7 Normalized annoyance score as a function of number of events (Source: Fields, 1985, 1987).



Fields determined trade-off factors (k_n) taking four noise metrics as independent variables: SEL, $L_{A,max}$, L_{EPN} and L_{PN}. The result is presented in table 7 for the planned flights only and for all flights, including the other helicopter operations. For those operations, L_{EPN} and L_{PN} could not be calculated. For each noise metric the upper row gives k_n when helicopter type has not been taken into account. If helicopter type is entered into the equations, represented by the difference Δ_H between both types of planned helicopters, the best estimate of k_n is given in the lower row for each noise metric. The standard deviations of k_n and Δ_H are also given in the table. The lower this standard deviation, the better the noise metric predicts annoyance.

The two noise metrics that account for the duration of the flyovers, SEL and L_{EPN}, give very similar estimates of k_n. When helicopter type is taken into account, the values of k_n are only slightly changed for the SEL estimate and not changed at all for the L_{EPN} estimate. This means that L_{EPN} rates these two types of helicopters equal.

Table 7 The best estimate of k_n and ΔH for several noise measures. The standard deviations of k_n and Δ_H between brackets (Source: Fields, 1985, 1987).

Noise metric		Trade-off factor	Helicopter type
	k_n^{*} (σk_n)	k_n^{**} (σk_n)	Δ_H in dB ($\sigma\Delta_H$)
All flights:			
SEL	8.1 (3.1)		
		7.8 (2.8)	1.2 (1.5)
$L_{A,max}$	14.5 (8.4)		
		10.6 (4.1)	4.5 (2.2)
Planned fights			
SEL	8.5 (3.0)		
		7.9 (2.4)	1.8 (1.6)
L_{EPN}	8.3 (2.2)		
		8.3 (2.3)	0.0 (1.4)
$L_{A,max}$	15.8 (30.2)		
		10.6 (12.5)	5.8 (2.5)
$L_{PN,max}$	12.5 (5.0)		
		10.9 (3.4)	3.3 (2.1)

* helicopter type not taken into account
** helicopter type taken into account

SEL should be given preference to $L_{A,max}$, since the standard deviations are much lower. The same applies to L_{EPN} and $L_{PN,max}$.

The table shows that the best estimates for k_n are equal to 8 when SEL and L_{EPN} are taken as noise metrics. Fields showed that $k_n = 10$ can not be rejected and that the probability that $k_n = 15$ is less than 0.01. This means that in measures such as NNI and B the trade-off factor in the case of helicopter noise exposure is too high.

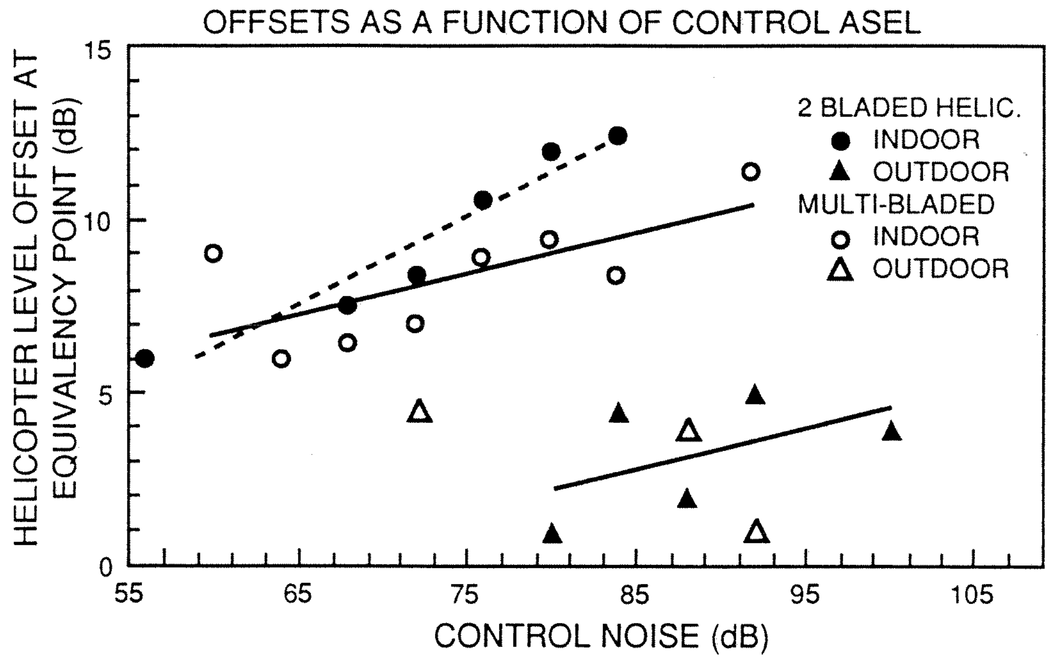
Being indoors during a flyover reduces annoyance significantly, though by less than the difference in the indoor and outdoor noise levels would suggest (a 4.6 dB reduction in annoyance for a 15 to 20 dB reduction in noise level).

The study sample differed from the general population in age, sex, employment status and military employment. The reactions, however, of people in the sample who differed in these characteristics were found to be not statistically significant different.
The short-term helicopter annoyance was found to be associated with each of the four following attitudes:
- fear that a helicopter might crash nearby
- belief that helicopter noise could be prevented
- feeling that helicopter flights are important
- individual susceptibility in annoyance.

Schomer and Neathammer (1985, 1987), Schomer et al. (1991)

The first study (1985, 1987), which has already been mentioned in chapter 2.2, was performed with 20 test subjects placed in a wood-frame home, a mobile home or tent. A Huey helicopter made series of flyovers and flyby's to produce the noise, vibration and rattle. Subjects were unaware of the reason of the study, i.e. to examine changes in responses related to rattle and vibration. The researchers subjectively evaluated rattles and vibrations. SEL-values of the overflights were in the range of 80 to 108 dB(A), measured outdoors. Slant distances (distance of closest approach between the helicopter and the location on the ground) varied from 100 to 2000 ft. In the study test subjects carried out paired comparison tests. They were asked to choose which of each pair of noise events was more annoying or bothersome. The control noises were 500 Hz octave band noises with a gradual onset, a constant level and a gradual decay.
The results of the study suggest helicopter noise without vibration or rattle to be in the order of 10 dB(A) more annoying than the control noises. Adding high levels of rattle and vibration to helicopter noise does increase annoyance with at least another 10 dB(A). In the study slant distance offered the best correlation with high levels of rattle. For the helicopter used in the experiment high levels of rattle and vibration occurred during each operation at slant distance shorter than 500 ft, whereas slant distances in excess of 1000 ft virtually ensured the absence of high levels of vibration and rattles.
In 1991 Schomer presents a follow-up study, in which tests were carried out with six different types of helicopters. The same procedure was followed as in the earlier study. Helicopter operations were all without any high levels of rattle and vibrations. One of the helicopters used in the second experiment was the two-bladed type of helicopter (Huey) also used in the earlier study. Of the other helicopters, two were of the two-bladed and three of the multi-bladed type. In the case

Figure 8. Difference between the SEL values of helicopter noise and of control noise being equally annoying, as a function of the SEL value of control noise.



of indoor noise exposure, helicopter noise again appeared to be about 10 dB(A) more annoying than the control noises. Small differences in annoyance-rating were observed between the two- and multi-bladed helicopters, as is shown in figure 8. Schomer assumes the average difference to be 2 dB(A) between the SEL value of equally annoying two-bladed and multi-bladed helicopters. Whether this difference is statistically significant is not mentioned in the study. Results from the exposure to Huey helicopter noise in the second study were in agreement with those of the first study, when little rattle and vibrations were produced during helicopter flyover. The figure also shows helicopter noise experienced outdoors to be relatively less annoying than helicopter noise observed indoors.

Gjestland (1991,1994)

In the laboratory study carried out by Gjestland with 20 test subjects the method of comparative judgements was used. Test signals were recordings of operations of four types of helicopters (Super Puma AS322, Sea King S61, Bell 205, Westland Lynx) and reference signals were recordings of fixed-wing aircraft operations, all of a 7 seconds duration. The reference stimuli had SEL-values equal to the SEL values of the test signals and 5 dB(A) above and below these values. The results of the experiments showed that the large helicopters like Super Puma AS322 and Sea King S61 are judged to be somewhat more quiet than the smaller types like Bell 205 and Westland Lynx. On average, the larger helicopters were considered as annoying as fixed-wing aircraft with a 1 dB(A) lower SEL value. The smaller helicopters were equally annoying as fixed-wing aircraft with a 3.5 dB(A) higher SEL value. The author concludes that the results of his experiment combined with the findings from other studies indicate that a possible correction factor for helicopter noise relative to fixed-wing aircraft noise will be relatively small and that it will hardly contribute to the accuracy of any method aimed at predicting community reactions to noise from helicopter operations.

Schomer (1994)

The study by Schomer (1994) deals with experimental field tests of four types of noises from real sources: small arms, a 25 mm cannon, blasts and helicopters. In the study subjects carried out paired-comparisons. The signals to be compared with the test noises were also coming from real sources (wheeled-vehicles): a tank retrieval truck, a 2.5 ton military type cargo truck, a 5 ton civilian type cargo truck, a HUMM-V utility vehicle, a 4 wheel drive pick-up truck and a small rental car. The helicopter used as noise source was the UH-1H Huey helicopter. It is described as a type of helicopter with much blade slap.

The tests were carried out during two sessions by 350 test subjects. According to Schomer, test subjects presented a reasonable cross-section of the general public in terms of age and gender. Subjects were not screened for perfect listening. Only subjects who could not communicate over the telephone because of their hearing capacities were excluded.

Tests were carried out outdoors (in a large tent) and inside two real houses, with two test conditions: windows of the listening rooms opened and closed. The helicopter flew past the houses at two distances (at about 60 and 150 meters), thus giving an average SEL value of 88 dB(A) for the 'near' helicopter and of 78 dB(A) for the 'far' helicopter, measured outdoors. These SEL values, measured indoors, were 65 and 54 dB(A) with windows closed, and 69 and 62 dB(A) with windows opened.

The subjects were requested to indicate which of two signals, such as that from a helicopter flyover and that from a passing wheeled-vehicle, was more annoying or to indicate that they were equally annoying. Responses of the test subjects were analyzed to determine the SEL value at which 50 percent of the test subjects felt that the test sound was more annoying than the control sound.

The results for the helicopter noises compared to wheeled-vehicle noises are given in table 8. Tests were also carried out using pink noise as control sound. The results of those tests correspond with

Table 8 Results from tests using UH 1H Huey helicopter noise as test signal and wheeled-vehicle noise as control signal (Source: Schomer, 1994). The table gives differences in the median SEL values between helicopter noise and control noise, which are judged by test subjects to be equally annoying.

Situation of test subjects	Difference in SEL-value in dB(A)	
	helicopter at near distance (60 m)	helicopter at far distance (150 m)
Out of doors (tent)		
first session	2.5	1
second session	2	5
average	2.3	3
Indoors, windows closed	-7	-1
Indoors, windows opened		
first session	2	-3.5
second session	2	1.5
average	2	-1

the results of the tests with wheeled-vehicle noises, taking into account a difference of about 10 dB(A) in annoyance from pink noise and wheeled-vehicle noise. The results show helicopter noise to be somewhat more annoying than wheeled-vehicle noise (2 to 3 dB(A)) when experienced out of doors, about equally annoying indoors with windows opened and less annoying with windows closed, particularly for the helicopter at the short distance of about 60 m, resulting in an indoor SEL-value of 69 dB(A). A comparison of the results for helicopter noise observed indoors with those obtained for outdoors listening, shows indoors noise exposure to be relatively less annoying than outdoors noise exposure. This result contradicts that of the earlier investigation by Schomer (1991).

For the other types of test noises, such as those from the small arms and the cannon, it was found that they were much more annoying than the wheeled-vehicle noises: penalties of 10 to 15 dB(A) turned out to be appropriate.

Ollerhead (prepublication extract, 1994)

The epidemiological investigation was carried out with the objective to obtain data additional to those of the 1982 UK helicopter disturbance study to test the hypothesis that at the same equivalent sound level fixed-wing aircraft and helicopters are equally annoying. At the time the present report was issued, only a prepublication summary was available to refer to. This summary was discussed in London on 24-11-1994 by dr. J.B. Ollerhead and mrs. dr. C.J. Jones and the author of the present report.

The field work was performed in three areas in the vicinity of Battersea Heliport, mainly used by helicopters serving the Gatwick-Heathrow Airlink. At these study sites also fixed-wing aircraft was noticeable. Also two sites with fixed-wing aircraft only were included in the investigation. In all, the study comprised about 700 face-to-face interviews. Helicopter noise exposure was defined as low. No long term representative noise measurements have been made. A rough estimate was based on the relatively high average daily helicopter traffic levels experienced during the week of the Farnborough Airshow. Representative equivalent sound levels would have been substantially lower than the values obtained during that special week. These values all were below 50 dB(A).

Preparations for the field work included in-depth interviews and focus group discussions. From these interviews and discussions it became apparent that present attitudes towards helicopters in the study area differ substantially from those towards fixed-wing aircraft, helicopters usually being considered as a 'rich man's toy'.

The analysis of the 700 interviews showed that at the lower noise exposures considered, helicopter noise causes more annoyance than fixed-wing aircraft noise. It was also shown that it is possible to explain this difference purely in 'socio-psychological' or attitudinal terms. Respondent's opinions, which together were sufficient to explain the difference in fixed-wing aircraft and helicopter noise responses, concerned the following:

- ability to get used to the noise
- sufficiency of information about operations
- cause of vibrations
- low flying
- pilots minimise nuisance
- operator's concern for the environment
- operators try to minimise noise.

Together with the previous findings in Balmedie in the Aberdeen area (Atkins, 1982), Ollerhead concludes that the helicopter differential is not universal and that its magnitude is very susceptible to the state of relations between the public and the operators.

5. SPECIAL ASPECTS OF HELICOPTER NOISE

5.1 Introduction

In paragraph 2.4 special aspects of helicopter noise have been listed. Some of these aspects, such as impulsiveness and tonality of helicopter noise, may have an impact on resulting annoyance only for some helicopter types and thus increase the variance in annoyance due to helicopter noise. Other features, such as fear of residents for crashes of helicopters, may increase annoyance due to all types of helicopter noise compared to annoyance due to other environmental noise sources and may therefore have an impact on exposure-effect relations for helicopter noise compared with these relations for other environmental noise sources.
First, the helicopter type dependent aspects (impulsivity and tonality of helicopter noise and number of blades of the rotor) will be discussed and then the other aspects applying to all helicopters, irrespective of type.

5.2 Special aspects

Impulsivity and tonality of helicopter noise

Older publications, not referred to in chapter 4 of this report, have been considered by Berry (1979). He states that Leverton (1972), Wright (1977) and Southwood (1976) carried out psycho-acoustical laboratory tests on the effects of impulsive helicopter noise on annoyance. In all three publications, helicopter noise with heavy blade slap turned out to be more annoying than helicopter noise without blade slap. Also Munch (1974) came to this conclusion. His tentative boundary for blade slap existence is a crest factor of 13 dB. For helicopter noise with higher crest factors 'penalties' of about 10 dB(A) might be applicable. However, as he pointed out, much work needed to be done to clearly define the presence of blade slap and the penalty to be associated to SEL. In an experiment carried out by Man, Acoustics and Noise Inc (1976) 24 simulated and recorded helicopter noises were used in listening tests of 24 test subjects. In the report it is concluded that L_{EPN} reliably reflects annoyance due to helicopter noise, no extra correction/penalty for blade slap or tones being required. However, they also state that heavy blade slap produces an increase in annoyance equivalent to an increase in level of up to 3 dB. A more recent experiment carried out by Karamcheti (1982) with 10 test subjects judging fabricated impulse noise, with characteristics corresponding to those of helicopter noise, showed that impulsivity had no effect on annoyance.

Other psycho-acoustical tests on the disturbing effects of recorded helicopter noise or noise from real overflights, such as those carried out by Powell (1978), Klumpp (1978) and Berry (1979) showed impulsiveness not to be related to annoyance. On the other hand, systematic experiments with fabricated test signals showed a trade-off between level and impulsiveness, suggesting a penalty of the order of 5 dB. Barry concludes that the presence of confounding factors in trying to judge (recordings of) real helicopter flyover noises has been clearly demonstrated. There seem to be so many uncontrolled variables with real or recorded helicopter noises that tests based upon them can only provide information on the dominant characteristics, such as the perceived helicopter speed and distance, and these are liable to vary from case to case.

Also the publications by Ollerhead (1982), Fields (1985, 1987) and Gjestland (1991, 1994) show only small differences in annoyance ratings of more or of less impulsive helicopter noises. Table 4 shows that the differences in annoyance corresponds to an increase between 0.5 and 0.8 dB of time-integrated noise measures. Table 7 indicates that differences in helicopter type (impulsive or not) result in differences in time-integrated values of 1.2 dB(A) when all flights are considered, and 1.8 dB(A) and 0.0 dB when only the planned flights are taken into account.

With respect to a tone-correction, Table 4 shows that applying such a correction as specified in ISO 3891-1978 to helicopter noise gives results which are somewhat inferior to those in which such tone-correction has not been applied.

However, although present research may not have been able to identify significant differences in annoyance from impulsive helicopter noise compared with non-impulsive helicopter noise, most data show an increased inter-individual variability in annoyance score for impulsive helicopter noise. This is shown in table 4 (standard deviations of the sub-subgroups of impulsive helicopters being larger than those for less impulsive helicopters and those for fixed-wing aircraft noise). Ollerhead considers this to be attributable to the widely differing acoustical characteristics of different helicopter types. According to Atkins, there are indications that the inter-individual variation in annoyance scores for helicopter noise is larger than for fixed-wing aircraft noise exposure.

Two-bladed helicopters versus multi-bladed helicopters

The data of four investigations allow a comparison between annoyance due to two-bladed helicopter noise and multi-bladed helicopter noise (Ollerhead, 1982; Fields 1985, 1987; Schomer, 1991; Gjestland, 1991, 1994). All four investigations do show no differences in annoyance at all or only small differences. The Schomer study shows the largest differences between both types of helicopters. However, this observed difference of 2 dB(A) does not seem to be important.

Onset rate of helicopter noise during approach

The phenomenon of a high onset rate during approach of an aircraft is known to occur for low-flying military fighter jets. Due to these high onset rates and high maximal sound levels during overflight, annoyance from these fighter jets is much larger than from common fixed-wing aircraft noise. Fighter jet noise exposure with a 10 dB(A) lower equivalent sound level are estimated to cause approximately the same percentage of severely annoyed persons as common fixed-wing aircraft noise (Passchier-Vermeer, 1993).

At NPL (Teddingdon) a software model (AIRNOISE) has been developed which is able to predict the time-history of fixed-wing aircraft noise, onset rates for common fixed-wing and low-flying aircrafts inclusive (Berry, 1992). Data have been gathered during operation Keevel on noise emission from helicopter operations to be able to extend AIRNOISE to helicopter noise (Berry, 1993). Taking into account the maximal speed of helicopters, an indicative calculation of the onset rate of an approaching helicopter shows this onset rate not to exceed 10 dB/s (Berry, 1994, personal communication). This value is below the lowest onset rate for which a penalty is applicable. McKinley (1994) recently showed this onset rate penalty to be zero up to onset rates of 15 dB/s, to be equal to 11 log (onset-rate) - 12.9 dB for onset rates between 15 and 150 dB/s and for onset rates higher than 150 dB/s to be equal to 11 dB. Therefore an extra effect on annoyance by helicopter noise due to high onset rates is quite improbable. It is, on the contrary not unlikely that the very long attention-arresting sound of an approaching helicopter is a particular source of aggravation (Ollerhead, 1982).

Directionality of helicopter noise during approach

The long period during which an approaching helicopter is heard is related to the directionality of helicopter noise (see figure 3). In front of an approaching helicopter, the impulsive helicopter sound can be heard before its sound level reaches the ambient sound level, which might in rural areas be below 40 dB(A). From this moment on, the helicopter noise will gradually reach its maximal sound level (during flyover), after which the sound level will more quickly decrease. However, the sound levels during only the last part of the approaching period will substantially contribute to the SEL value of the helicopter noise event. E.g., the contribution to the SEL value of a helicopter overflight of all sound levels of more than 10 dB(A) below $L_{A,max}$, occurring in the first part of the approach, will be less than 0.5 dB(A). Since the directionality during approach of fixed-wing aircraft noise is less and the speed of fixed-wing aircrafts is usually higher, such an effect occurs to a lesser extent in fixed-wing aircraft noise observations. Therefore, due to the directionality of helicopter noise during approach, helicopter noise events might be longer (more) disturbing than fixed-wing aircraft events with the same SEL value. On the other hand, a fixed-wing aircraft also produces substantial noise to the rear, which means that such an aircraft is heard during a longer time after the direct overflight. This effect may well compensate for the possible extra effect described with respect to helicopter noise during approach.

Sporadicity of occurrence of overflights in residential areas

Helicopter noise exposure may occur in residential areas only occasionally. Due to the specific capabilities of helicopters, flight paths are usually less strict compared with those of fixed-wing aircrafts. Helicopters may therefore pass residential areas occasionally at low attitude or even hover for some time above these areas. Apart from the Schomer study (1983 b) in the vicinity of Decatur airport, no investigation exists in which annoyance due to sporadic helicopter noise events has been determined. In the vicinity of that airport, severe annoyance due to two helicopter operations a week (one landing and one take-off) was amazingly high compared to severe annoyance from fixed-wing aircraft noise in that surrounding.

Some research has been carried out with respect to annoyance from sporadic military fixed-wing aircraft training operations (McKinley, 1994; Bradley, 1994). McKinley refers to two psycho-acoustic studies of high-speed flyovers. These tests have been performed to validate a noise metric to assess the impact of noise from military missions on the civilian population. In this metric L_{dn} is determined from the L_{dn} values during the calender month with the highest number of operations.

Bradley carried out an epidemiologically investigation into annoyance from sporadic military training operations; the study was conducted in 24 homes for a period of one month in each home. With respect to sporadicity, exposures have been split up into 6 or fewer events per 24 hours, 7 to 12 events and 13 or more events. Irregularity was also assessed. There turned out to be no statistically significant differences between average annoyance scores from regular and from irregular flights nor from more and less sporadic flights, when the exposure was expressed in equivalent sound level over 24 hours. Whether these results are also applicable to helicopter noise exposure is not quite certain. At the same time, 'sporadic noise event' in the Bradley study is different from 'sporadicity of helicopter noise events' in the Netherlands. In the survey carried out by de Jong (1994) on Netherlands respondents observing and annoyed by environmental noises, it turned out that 74% of the respondents that observed helicopter noise did this only several times or less a month. Therefore, sporadicity with respect to helicopter noise in the Netherlands population falls into another range than specified in the investigation by Bradley.

Frequency spectrum of helicopter noise

The frequency spectra of helicopter noises during overflight are quite comparable to those of fixed-wing aircraft noise. Only in the low-frequency range (octave-bands with midfrequencies of 16, 31 and 63 Hz) helicopter noise has relatively higher octave-band sound pressure levels than fixed-wing aircraft noise (Magliozzi, 1975). This does especially have an effect in producing vibrations and rattling of objects in buildings.

Differences between outside and inside sound levels of dwellings.

Relatively more low-frequency noise may also have an impact on the sound-insulation of dwellings. Usually, low-frequency noise is transmitted through partitions with less transmission loss than does high frequency noise. Therefore, sound insulation of dwellings expressed in dB(A) may be less for noises with predominantly low frequency components. This effect, however, does not seem to be relevant with respect to helicopter noise, since the A-weighted octave-band sound pressure level of helicopter noise is usually maximal at the midfrequency of 500 Hz and much lower at the octave-bands in the low frequency region.

Differences between most and least exposed sides of dwellings

Community surveys on environmental noise exposure have shown that residents take appropriate action to avoid noise exposure. One such action is moving to the quieter side of the house, if possible. This may also occur in dwellings in residential areas around heliports with prescribed helicopter flight paths used for approaching and leaving the heliport. In other circumstances, however, flight paths of helicopters are less predictable and residents are less able to take appropriate action to avoid annoyance. This might well have an effect on annoyance resulting from such helicopter operations.

Attitude of the population towards helicopters

Both UK helicopter disturbance studies showed attitudes towards helicopters to have a large impact on annoyance scores. In areas where helicopters are considered a 'rich man's toy', where the public questions the benefit of helicopter operations and where the manipulations of pilots are criticized annoyance ratings are relatively much higher than in areas where the benefits and necessity of the use of helicopters is not questioned by the public. Also, both the epidemiological investigation of Atkins (1983 a,b) and Fields (1985, 1987) showed fear of helicopter crashing to have a large impact on annoyance scores. In case of the first UK helicopter disturbance study this impact turned out to be more important than any noise measure in the multiple regression analyses. Also Fields reports short-term helicopter annoyance to be associated with fear that a helicopter might crash nearby.

Duration of the presence of helicopters above residential areas

It seems reasonable to assume that feelings of fear and feelings of deprived privacy increase with the duration of the presence of helicopters above residential areas. In that respect hovering of helicopters above these areas might be of special importance and hovering might have an impact on exposure-effect relations.

6. A NOISE MEASURE TO RATE HELICOPTER NOISE EXPOSURE

6.1 Introduction

In this chapter the four steps specified in chapter 3 will be considered. The data in the publications outlined in chapter 4 will serve as a basis. Aspects as feasibility and compatibility with noise measures to rate environmental noise sources other than helicopters are not taken into account here. They may, however be of importance for political decisions.
As far as the data permit, also exposure-effect relations of helicopter noise will be discussed. In that respect, considerations are limited to a comparison with exposure-effect relations for other environmental noise sources, mainly fixed-wing aircraft noise.

6.2 Frequency-weighting and time-weighting

Step 1 - frequency weighting

Two publications referenced in chapter 4 analyze their data with respect to frequency-weighting: Ollerhead (1982) a laboratory study with recorded helicopter flyover noises and Fields (1985, 1987) a field study. Table 4 shows for helicopter noise L_{PN} to be preferred when maximum levels are considered and L_{TPN} for time-integrated levels. This follows from a comparison of the standard deviations for the 89 helicopters together and the differences, observed between annoyance prediction errors of the subgroup of more and less impulsive helicopter noises. In the case of maximum levels, the standard deviation in L_{PN} is equal to 2.2 dB, for L_D 2.3 and for L_A and L_{TPN} 2.6 dB. For time-integrated levels, the standard deviation is smallest in case of L_{TPN} (1.6 dB) and largest for L_A (1.9 dB). Also the difference in mean annoyance prediction errors of more and less impulsive helicopters is somewhat larger in A-weighting (+ 0.8 dB) than in PN- and TPN-weighting (0.5 and 0.7 dB, respectively).
Table 7 with results of the Fields investigation also shows a slight preference for PN-weighting over A-weighting. With PN-weighting the mean differences with respect to helicopter type and the standard deviations in these differences are smaller than with A-weighting, irrespective whether maximal levels or time-integrated levels are considered. According to the table, with PN-weighting

for time-integrated levels the mean annoyance rating is equal for both types of helicopters used in the investigation.

Step 2 - first time step, within one noise event

In three investigations data have been analyzed with respect to rating instantaneous frequency-weighted sound pressure levels occurring within noise events: Ollerhead (1982), Atkins (1983) and Fields (1985, 1987). All compare the maximal sound level during a noise event with time-integrated levels as specified in SEL and L_{EPN}. (It has already been remarked that in both noise measures time-integration occurs in exactly the same way).
Table 4 (Source: Ollerhead) shows time-integrated levels to be much preferred over maximum levels, since standard deviations and differences between mean annoyance prediction errors are smaller for time-integrated levels than for maximum levels.
Following Atkins, time-integrated A-weighted sound levels perform about equally well as maximum A-weighted sound levels. However, in both cases the multiple regression analysis only showed a weak correlation between individual rating of annoyance due to aircraft (fixed-wing and helicopter) noise and noise measure (multiple regression coefficients ranged from 0.15 to 0.16; when fear of aircraft crashes was taken into account, the coefficients rose to over 0.40). Therefore, the results of the study by Atkins do not allow a determination of the most preferred measure in this respect.
Table 7 (Source: Fields) shows for the planned flights as well as for all flights that time-integrated values are to be preferred over maximum values. This can be observed by comparing the average values of Δ_H and the standard deviations.

Step 3 - second time step, combining noise events

Schomer (1979, 1981 a.b, 1982, 1983 a) and Fields (1985, 1987) both determined trade-off factors k_n, specifying the trade-off between number and level of events. Fields showed the relation between the log number of events to provide a better fit to his results than the untransformed representation. Schomer gives as the best estimate of k_n a value of 8.1 in the equation $L + k_n \log n$. Fields (see table 8) also shows that the best estimate for k_n is equal to 8 when a combination of time-integrated levels are considered. His statistical analysis showed that $k_n = 10$ can not be rejected and that the probability that $k_n = 15$ is less than 0.01.

Step 4 - third time step, combining periods during 24 hours

The epidemiological investigation carried out by Schomer (1979, 1981 a,b, 1982, 1983 a) showed night-time helicopter noise to be equally annoying as day-time helicopter noise with a day-time equivalent sound level which is on average 8 dB(A) higher. His night-time penalty for helicopter noise is therefore about equal as usually supplied to fixed-wing aircraft noise. Compared with weekend night-time helicopter noise, night-time helicopter noise during weekdays is about 2 dB(A) less annoying.

Summary of the four steps

In the following, a noise measure is to be preferred over other noise measures, if it allows an estimation of annoyance with a smaller inter-individual variability in annoyance score than would occur if these other measures were taken to characterize the noise exposure. Taking into account the limited number of publications dealing with experimental and epidemiological investigations into the annoying and disturbing effects of helicopter noise, the results of the four steps can be summarized as follows:

- there is a slight preference for frequency-weighting according to perceived noise level, as specified in ISO 3891-1978, over A-weighting;
- time-integrated values of frequency-weighted sound pressure levels have preference over maximum values with respect to annoyance from a helicopter noise event;
- a trade-off factor of 10 between sound level and log number of noise events fits the experimental data quite well; a factor equal to 15, as is used in B and NNI, has a probability of less than 0.01. A trade-off factor equal to 10 implies the equal energy concept to be applicable to helicopter noise exposure;
- a night-time penalty of 10 dB for helicopter noise is close to the experimental results. Possible evening-time penalties have not been considered in the literature to an extent which allows a conclusion.

Applying these results to noise measures which are used to specify environmental noise exposures - such as L_{PNeq}, $L_{Aeq,24h}$, L_{dn}, B, BKL and NNI - then L_{PNeq}, with a night-time penalty of 10 dB, rates annoyance from 24 hours helicopter noise exposure with a smaller inter-individual variation in annoyance than the A-weighted noise measures. This statement is based on the fact that in L_{PNeq}, with a night-time penalty of 10 dB, the relatively most preferred frequency- and time-weightings are applied. The extent, in which L_{PNeq} estimates annoyance due to helicopter noise more reliable than L_{dn} cannot be completely deduced from the available data. An indication can be obtained from table 4 (Ollerhead, 1982) and table 7 (Fields, 1985, 1987). Table 4 shows, taking a noise event as a basis, the variation in the noise measure for equal annoying helicopter noises. This variation is given as standard deviation. If the total range of variations is taken equal to four times the standard deviation (+ and - two times the standard deviation), table 4 shows, when SEL is taken as noise measure, this range to be 7.6 dB for all helicopter noises together and 6.4 dB when L_{EPN} is taken as noise measure. From table 7 it can be deduced with respect to the results of the planned helicopter flights that in case of SEL the range is 8.5 dB(A), and 5.6 dB in case of L_{EPN}. Therefore, there is an indication that L_{PNeq} results in an individual annoyance rating with a total range in individual variation which is 2 dB smaller than in the case of L_{dn}.

When the A-weighting is chosen as the frequency-weighting, then the time-integrated and L_{Aeq}-related measures L_{dn} and BKL should be preferred over the measures B or NNI, in which maximum sound levels during noise events are used and the trade-off factor is 15. Table 4 and 7 show the total range of individual variations to be 10.4 and 15.8 dB(A) when $L_{A,max}$ is taken as noise measure and 7.6 and 8.2 dB(A) in case of SEL. With respect to the trade-off factor, for a combination of noise events, it was shown that k_n = 8 is the best estimate of the trade-off factor between sound level and log number of noise events. In B and NNI this trade-off factor is equal to 15 and for the L_{Aeq}-related measures k_n is equal to 10. For a number of helicopter operations equal to 10, differences between the best estimate of k_n and the estimate of k_n chosen, induce variations in sound levels of 2 dB(A) in case of k_n = 10 and 7 dB(A) for k_n = 15, i.e. a difference in variation of 5 dB(A). For 100 helicopter operations this difference in variation is equal to 10 dB(A). When B is taken as noise measure, both variations mentioned above have to be taken into account, since B is based on $L_{A,max}$ and on a trade-off factor of 15. Even if it is realised that both variations should not be simply added to determine the total effect, the use of B as noise measure to rate helicopter noise results in much larger inter-individual variation in annoyance at a specific B-value than when a specific value of L_{Aeq} is used.

One of the differences in L_{dn} and BKL or L_{etm} concerns an evening penalty. The data in the publications do not allow any judgement about a preference with respect to this aspect of L_{dn} over L_{etm} and BKL, since possible evening penalties for helicopter noise exposure have hardly been considered in the literature.

6.3 Exposure-effect relations for helicopter noise

First, the question has to be considered whether helicopters should be regarded different from fixed-wing aircrafts. If residents would consider helicopters not being different from other aircraft, then exposure-effect relations applicable to fixed-wing aircraft noise would also apply to helicopter noise and a combination of helicopter and fixed-wing aircraft noise.
To my opinion, several surveys have shown helicopters to be a different phenomenon than fixed-wing aircraft. In the investigations by de Jong (1981, 1988, 1994) it was shown that respondents are able to distinguish between helicopter and fixed-wing aircraft noise. This is also applicable to the various studies by Schomer, Ollerhead, Atkins and Fields. Therefore, in the following, helicopter noise will be considered as a specific environmental noise source.

Taking into account the very limited data about the effects of helicopter noise on annoyance, only a comparison is made of helicopter noise annoyance relative to annoyance due to other environmental noise sources. For these noise sources, exposure-effect relations exist (Miedema, 1992). At the lower environmental noise exposure levels, exposure-effect relations for fixed-wing aircraft noise and those for highway road traffic correspond to a large degree and to a lesser degree also to other road traffic and rail road traffic. Stationary environmental impulse noise sources, however, are much more annoying at the lower noise exposure levels than the traffic noise sources mentioned. E.g., at an L_{dn} value of 45 dB(A), the percentage severely annoyed persons due to air, highway road, other road and rail road noise are between 1 to 5 and due to impulse noise exposure this percentage is 18.
Taking into consideration all quantitative data of the publications with respect to annoyance due to helicopter noise, the conclusion is that annoyance and disturbance is not systematically different from annoyance and disturbance from other traffic noise sources in the exposure ranges considered. This will be discussed below. However, qualitative data not in a format to be included in exposure-effect relations show increased annoyance due to helicopter noise compared to fixed-wing aircraft noise.
De Jong (1981, 1988, 1994) shows the percentages annoyed and severely annoyed residents and the average annoyance score of those residents observing a specific noise source to be about equal for helicopter noise and for large civil fixed-wing aircraft noise. However, among those residents, exposure to fixed-wing aircraft noise is more frequent than to helicopter noise: about twice as many residents observe fixed-wing aircraft noise at least once a day compared to those observing helicopters at least once a day. Therefore, as a whole fixed-wing aircraft noise exposure may have

higher equivalent sound levels over longer periods (e.g. a year) than helicopter noise exposure for those residents observing these environmental noises. However, since ratings of annoyance due to both types of environmental noise sources are about the same, this may be indicative for an increase in annoyance due to helicopter noise exposure compared to exposure to fixed-wing aircraft.

Schomer (1979, 1981 a,b, 1982, 1983 a) shows in his epidemiological study that daily observed loudest perceived helicopters are more annoying than fixed-wing aircrafts: 36% of the residents which perceive helicopters much louder than conversation level are highly annoyed compared to 30% in case of fixed-wing aircraft. However, this concerns subjectively experienced loudness. Therefore, exposure-effect relations can not be derived from these results, since the results do not allow statements with respect to objectively determined noise exposure levels.

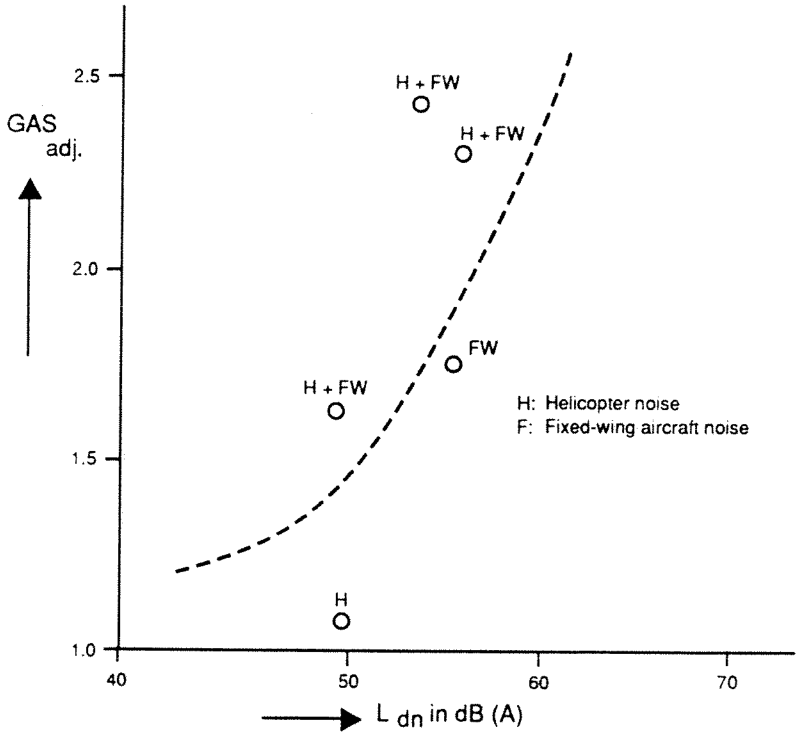
The results of the psycho-acoustic tests by Ollerhead (1982) show fixed-wing aircraft noise events to be more annoying than helicopter noise events: on average, helicopter noise events with time-integrated values (SEL, L_{EPN}) 2 dB above those of fixed-wing noise events are equally annoying to these fixed-wing noise events.

The community noise survey by Schomer (1983 b) does show a relatively large percentage of highly annoyed residents due to sporadic helicopter noise events. However, since the amount of helicopter noise exposure expressed in a noise measure is unknown, this outcome cannot contribute to the establishment of exposure-effect relations.

The UK Helicopter Disturbance Study (Atkins 1983 a,b) shows no systematic difference in mean annoyance score from exposure to helicopter noise, a combination of helicopter and fixed-wing aircraft noise and fixed-wing aircraft noise. It should be realised however that in only one of the five situations studied, helicopter noise was the prominent noise exposure source. In one of the other four situations it concerned fixed-wing aircraft noise exposure only; in the other three situations exposure to fixed-wing aircraft had equivalent sound levels during day-time which were 7, 7 and 2 dB(A) higher than those due to helicopter noise. Since annoyance from the combined noise exposures have been related to a noise measure which takes into account both noise sources, in fact annoyance has been related to predominantly the fixed-wing aircraft noise component. Effects from helicopter noise exposure in these three situations may thus have been largely obscured by fixed-wing aircraft noise exposure.

The results of the study are again presented in figure 9, in which the average annoyance score, adjusted for social grouping, have been plotted as a function of L_{dn} for the five situations considered. L_{dn} has been calculated from the data in the Atkins report. The figure also presents an assumed relation between average annoyance score and L_{dn} which has been derived from

Figure 9 GAS scores as a function of L_{dn} (Source: Atkins, 1983). The curve is taken from earlier studies on fixed-wing aircraft noise and adjustments from NNI to L_{dn} have tentatively been made. It is not pretended that this curve specifies the definite relation between GAS score and L_{dn}.



Brooker (1984) (UK Aircraft Noise Index Study). In that respect the $L_{Aeq,24h}$ values in the Brooker report have been estimated to be 2 dB(A) lower than the L_{dn} values (Miedema, 1992). It should be stressed that it is not pretended that the curve in figure 9 gives a definite relationship between L_{dn} of fixed-wing aircraft noise exposure and resulting average annoyance. The curve has been plotted to serve as a comparison for the data-points in the figure. This comparison shows all three areas with mixed noise exposures to fall above the curve, while the data-points representing helicopter noise exposure only and fixed-wing aircraft noise exposure only are below the curve. All in all, the conclusion seems justified that the study does not show a substantial difference in mean annoyance scores from helicopter and fixed-wing aircraft noise exposure.

However, much higher percentages of people in the mixed areas consider helicopters (much) more disturbing than fixed-wing aircrafts. Helicopter noise is considered (much) more disturbing than fixed-wing aircraft noise by 2 to 2.5 times as many residents, although the fixed-wing aircraft noise exposures were 2 to 7 dB(A) higher than the helicopter noise exposures.

The experimental field study by Fields (1985, 1987) concerns helicopter noise exposure only and it does not present any data relevant to the establishment of exposure-effect relations. He does

specify, however, a difference of 2 dB(A) with respect to the annoying effect of different types of helicopters.
The only experimental field study showing large differences in annoying possibilities of helicopter noise concerns the study by Schomer (1985, 1987, 1991) on vibration and rattle from helicopters. At small slant distance (shorter than 500 ft) helicopters may produce high levels of vibration and rattles, which results in an increase in annoyance equivalent to a noise level increase of at least 10 dB(A).
The recent study by Schomer (1994) shows on average outdoors exposure to helicopter noise at a SEL value 2 to 3 dB(A) lower than that of exposure to wheeled-vehicle noise to be equally disturbing; indoors helicopter noise exposure with windows closed turned out to be on average less disturbing than wheeled-vehicle noise exposure by the equivalence of 1 to 7 dB(A) and for the situation with windows opened disturbance was on average about equal. Therefore, all in all, this study did not show a substantial difference in annoying capacity of helicopter noise compared to wheeled-vehicle noise.
In summary, the three publications which allow a quantitative comparison of helicopter noise annoyance, as a function of a noise measure, with other environmental traffic noise annoyance, as a function of the same noise measure, all do not show a systematic difference between the average annoyance effects of helicopters and of other noise sources. Only when helicopter operations induce high levels of rattle and vibration, annoyance is increased by an amount which corresponds to a level difference of 10 dB(A). However, it is also apparent from the other data which are not in a format to be included in exposure-effect-relations, that when helicopter noise is observed it causes higher percentages of (severely) annoyed residents than does fixed-wing aircraft noise.

7. CONCLUSIONS

The conclusions with respect to helicopter noise annoyance given below are based on scientific aspects only; factors of importance in policy making, such as feasibility and mutual compatibility with noise measures to rate environmental noise other than helicopter noise, have not been taken into account.

Only a very limited number of publications dealing with psycho-acoustical and epidemiological investigations into the annoying and disturbing effects of helicopter noise were available. The results of an analysis of these publications can be summarized as follows:

- there is a slight preference for frequency-weighting according to perceived noise level, as specified in ISO 3891-1978, over A-weighting;
- time-integrated values of frequency-weighted sound pressure levels have preference over maximum values with respect to the prediction of annoyance due to a helicopter noise event;
- a trade-off factor of 10 between sound level and log number of noise events fits the experimental data quite well; a factor equal to 15, as is used in B and NNI, has a probability of less than 0.01. A trade-off factor equal to 10 implies the equivalent sound level during a specific part of the 24 hour period to be an appropriate descriptor of helicopter noise exposure;
- a night-time penalty of 10 dB for helicopter noise is close to the experimental results. Possible evening-time penalties have not been considered in the literature to an extent which allows a conclusion.

These results imply that of those noise measures used for rating environmental noise exposures, L_{PNeq}, with a night-time penalty of 10 dB, incorporates the relatively most preferred frequency- and time-weightings. It is not unlikely that L_{PNeq} rates annoyance from 24 hours helicopter noise exposure with a smaller inter-individual variation in annoyance than other noise measures. There are indications that, when helicopter noise exposure is expressed in L_{PNeq}, that the total range in which individuals of a population consider helicopter noise equally annoying is about 2 dB smaller than such a range when helicopter noise exposure is characterised by L_{dn} (the measure which differs from L_{PNeq} only in frequency-weighting).

If the A-weighting is chosen as the frequency weighting, then L_{Aeq}-related measures (L_{dn}, BKL, L_{etm}) - including time-integration over each separate noise event - should be preferred over measures such as B and NNI. A tentative estimate gives an increase in the total range of inter-individual variation in annoyance which is larger than estimated above for the frequency-weighting and which may correspond to 5 dB(A) due to the choice of $L_{A,max}$ over SEL and another 5 dB(A) due to the choice of the trade-off factor between L and log number of events equal to 15.

Since for helicopter noise exposure possible evening penalties have hardly been considered in the literature, it is not possible to indicate a preference of L_{dn} over L_{etm} and over L_{den}.

Taking into consideration the very limited amount of quantitative data on helicopter noise exposure and average values of resulting annoyance, there are no indications that exposure-effect relations for frequent helicopter noise exposure around heliports differ significantly from those of fixed-wing aircraft in the exposure range considered. This exposure range was limited to exposures with a L_{dn} value of at most 50 dB(A). However, in the case of high levels of rattle and vibration, annoyance is on average substantially increased with an equivalence in SEL of 10 dB(A). For the helicopter sample studied, high levels of rattle and vibration occurred at slant distances less than 1000 ft (330 m), whereas slant distances in excess of 1500 ft (500 m) for level flyovers and take-offs and 2000 ft (700 m) virtually ensured little or no such high levels of vibration and rattles. These slant distances may, however, vary with type of helicopter. Notwithstanding the results of the quantitative analysis for frequent helicopter operations in the vicinity of heliports, other data on sporadic occurrences of helicopters show that whenever helicopter noise is observed, a relatively higher percentage of residents indicate (severe) annoyance than in the case of a similar exposure to fixed-wing aircraft noise. This observation, however, could not be incorporated in quantitative exposure-effect relations since the data concerning this observation did not include quantitative noise measure values.

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ANNEX A

Terms and definitions

1. Sound

Sound is a phenomenon with alternating compression and expansion of air which propagate from a noise source in all directions. At a given location these compressions and expansions represent pressure variations around atmospheric pressure. These pressure variations can be described mathematically as the sum of one or more sines. The sound pressure variations of a pure tone are described by one sinus as a function of time.

2. Frequency

The number of pressure variations per second is the frequency of a sound and is expressed in hertz (Hz). The frequency determines the pitch of a sound: a high pitched one (e.g. 4000 Hz) has a squeaking sound, a low pitched tone (e.g. 200 Hz) a humming sound.

3. Sound pressure level

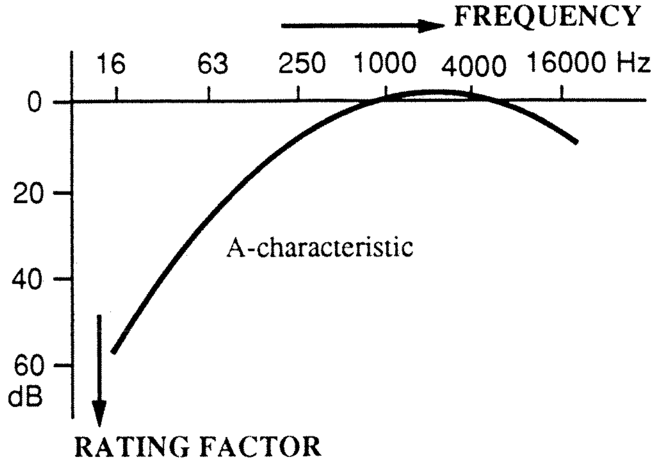
A sound has not only a frequency, but also a level (L). The level is related to the sound pressure (p). In practice, sound pressures range from less than 20 μPa up to more than 200 Pa, a range of 1 to 10 million. Therefore, in acoustics, the logarithm of the sound pressure relative to a reference sound pressure (p_o) is usually taken as a basis for the noise measure. A reference sound pressure of 20 μPa was chosen. It usually represents an average tone just audible at 1000 Hz for someone with normal hearing. The sound pressure level is expressed in decibels (dB) and can be calculated from:

$$L = 10 \log \frac{p^2}{p_o^2} \quad dB \ (p_0 = 20 \mu Pa)$$

4. Sound level

The human hearing organ is not equally sensitive to sounds with the same sound pressure level but with different frequencies. Therefore, to take this sensitivity into account, it is common practice

Figure A1 Frequency weighting of noise.



when noise is measured, to use a noise filter which rates the sound pressure levels at the different frequencies. There are several noise filters with a so-called A, B, C or D characteristic. In figure A1 the A-characteristic is plotted as a function of frequency. When the sound pressure levels of a sound are measured, using the A-filter, the result is the A-weighted sound pressure level. In this report the A-weighted sound pressure level is shortly indicated by sound level.

5. Equivalent sound level

When the sound level fluctuates with time, the equivalent sound level over a period of time is determined for a number of acoustic applications. This equivalent sound level can be expressed as follows:

$$L_{Aeq,T} = 10 \log \frac{1}{T} \int_{o}^{T} \frac{p_A^2(t)}{p_0^2} dt \quad dB(A)$$

in which:

. p_A (t): the A-weighted sound pressure at time t

. T: duration of the period considered.

6. Equivalent sound level over 24 hours ($L_{Aeq,24h}$)

The equivalent sound level over 24 hours is the equivalent sound level due to an exposure of 24 consecutive hours.

7. Day-night level (L_{dn})

$$L_{dn}=10\log[\frac{15}{24}\,10^{L_{Aeq,d}/10}+\frac{9}{24}10^{(10+L_{Aeq,n})/10}]\quad dB(A)$$

in which:

. d (day-time) is the period from 07.00-22.00 h

. n (night-time) is the period from 22.00-07.00 h

The day-night level is the equivalent sound level over 24 hours, with the sound levels during the night increased by 10 dB(A).

8. Day-evening-night level (L_{den})

$$L_{den}=10\log[\frac{12}{24}10^{L_{Aeq,d}/10}+\frac{3}{24}10^{(5+L_{Aeq,ev})/10}+\frac{9}{24}10^{(10+L_{Aeq,n})/10}]\quad dB(A)$$

in which:

. d(day-time) is the period from 0700-19.00 h

. ev(evening) is the period from 19.00-22.00 h

. n(night-time) is the period from 22.00-07.00 h

The day-evening-night level is the equivalent sound level over 24 hours, with the sound levels during the evening increased by 5 dB(A) and during the night by 10 dB(A).

9. Etmaalwaarde (24-hours value)

$$L_{etm}=\max(L_{Aeq,d}\ ,\ L_{Aeq,ev}+5,\ L_{Aeq,n}+10)\quad dB(A)$$

in which:

. d(day-time) is the period from 0700-19.00 h
. ev(evening-time) is the period from 19.00-23.00 h
. n(night-time) is the period from 23.00-07.00 h

The etmaalwaarde ('24-hour value') is the maximum of one of three equivalent sound levels during certain parts of the 24-hour period, with the sound levels during the night increased by 10 dB(A) and those during the evening by 5 dB(A).

10. Aircraft noise exposure measure B

$$B=20\log\sum_{i=1}^{N}(n_{ti}\ x\ 10^{L_i/15})-157\quad Ke(Kosten Units)$$

in which:

. N: number of overflights a year with $L_{A,max}$ at least 65 dB(A)
. L_i: the maximum level during an overflight i
. n_{ti} a weighting factor, dependent upon the part of the 24-hour period:

time in hours	n_{ti}	time in hours	n_{ti}
0 - 6	10	19 - 20	3
6 - 7	8	20 - 21	4
7 - 8	4	21 - 22	6
8 - 18	1	22 - 23	8
18 - 19	2	23 - 24	10

11. Small aircraft noise exposure measure BKL

BKL is a L_{den} level, for legal requirements determined by specific rules related to the busiest aircraft days per week during the busiest period of a year (Peeters, 1981).

12. Sound exposure level of a noise event

$$\mathbf{SEL = L_{Ax} = L_{Aeq,t} + 10 \log t \quad dB(A)}$$

in which:

t is the exposure time in seconds.

13. Effective duration of a noise event

The effective duration is specified in the following equation:

$$\mathbf{SEL = L_{A,max} + 10 \log \tau \quad dB(A)}$$

in which:

τ is the effective duration in seconds.

14. Perceived noise level (L_{PN})

In ISO 3891-1978 procedures are given to describe noise, from all kinds of aircraft operations, heard on the ground. At any instant during a specific aircraft operation, the sound is expressed in perceived noise level when the noise spectrum of the sound is without pronounced irregularities. Perceived noise level at a given instant is derived from the noisiness, in noys, at that instant in a way specified in ISO 3891-1978.

15. Tone-corrected perceived noise level (L_{TPN})

For a sound having tonal components or other pronounced irregularities in its noise spectrum, tone-corrected perceived noise level at any instant is obtained by adding a correction to its perceived noise level. The tone-correction factor is specified in ISO 3891-1978. For tones in the 1/3 octave bands between 500 and 5000 Hz the tone-correction is between 0 and 6.7 dB; for tones in the 1/3 octave bands in the range between 50 and 10.000 Hz, but outside the range 500 to 5000 Hz, the tone-correction is between 0 and 3.3 dB.

16. Effective perceived noise level (L_{EPN})

The total subjective effect of an aircraft operation is defined by

$$L_{EPN}=10\log\frac{1}{T_0}\int_{-\infty}^{+\infty}10^{L_{TPN}/10}\,dt$$

in which:

. T_o is equal to 10 s.

According to ISO 3891-1978 L_{TPN} may be integrated over the total time-interval t_2- t_1 during which the instantaneous value of L_{TPN} is within a specified value (not less than 10 dB) of the maximum value of L_{TPN} (L_{TPNmax}). In a note ISO 3891-1978 specifies that the time-interval t_2-t_1 shall be taken as the total time between the instants t_1, when the noise level (for a single event) first rises to the specified level (for example L_{TPNmax} - 10 dB) and t_2, when the level last decreases to the specified level.

17. Equivalent perceived noise level (L_{PNeq})

To characterize exposure to noise from a succession of aircraft operations, the equivalent perceived noise level is obtained from the effective perceived noise levels of these operations as follows:

$$L_{PNeq}=10\log\frac{\tau_{ref}}{T}\sum_k 10^{L_{EPNk}/10}$$

. τ_{ref} = 10 s and T is the total period of time under consideration, in seconds

. L_{EPNk} is the effective perceived noise level for the kth event

18. Noise and Number Index (NNI)

$$NNI = 10\log \frac{1}{N}\sum_i 10^{L_{PNmax,i}/10} + 15 \log N - 80$$

in which:

- $L_{PNmax,i}$ is the maximum value of L_{PN} during the i-th overflight
- N is the number of overflights with L_{PNmax} of at least 80 dB, occurring in the period from 7.00 - 19.00 h

19. Crest factor

To characterize the variation in sound pressure levels occurring during a noise event, the crest factor may be used as defined by

$$f_c = \frac{p_{peak}}{p_{rms}}$$

in which:

- p_{peak} is the peak sound pressure
- p_{rms} is the root mean square value of the sound pressure during a specified time.

Usually the crest factor is specified by its logarithmic value C in which

$$C = 20 \log f_c \text{ (dB)}$$

For broadband random noise C is equal to 12 dB.

20. ISO impulsiveness correction

The ISO impulsiveness correction, specified in Draft Addendum ISO 3891/DAD1 'Measurement of Noise from Helicopters for certification Purposes' (1979) is computed from the A-weighted sound pressure time history which is low-pass filtered at 2000 Hz and digitized at 5000 Hz. For each half-second time period, a quantity is computed where

$$X = 10\log\left[\frac{1}{N}\sum_{i=1}^{N}\left(\frac{p_{A,i}-s}{s}\right)\right.$$

$$s = \frac{1}{N}\sum_{i=1}^{N} p_{A,i}^{2}$$

where $p_{A,i}$ is the i-th sampled value of p_A.

The half-second impulsiveness correction is given as follows:

if < 5.5	$\Delta = 0$
if $5.5 \le x \le 10.5$	$\Delta = 0.8\ (x-3)$ dB
if $x > 10.5$	$\Delta = 6$ dB

ANNEX B

Relations between SEL and $L_{A,max}$

Data presented by Newman (1980, 1982) allow the determination of the relation between $L_{A,max}$ and SEL for measurements carried out at one specific location: within 100 ft under the flight paths, at a specified distance from the take-off point. Newman presents a large amount of $L_{A,max}$ and SEL values for mainly horizontal level flyovers, and fewer data for take-off and approach operations. Several aspects were varied: helicopter speed, distance, main rotor speed, take-off power and type of helicopter. In total, the average values of SEL and of $L_{A,max}$ could be obtained for 61 different situations; averaging being based on up to 10 individual helicopter operations. In figure B1 the average $L_{A,max}$ values have been plotted as a function of the average SEL values. The correlation coefficient is 0.94. The best-fitting straight line (according to the method of least squares) has the formula: $L_{A,max} = 1.20\ SEL - 26.54$.

In figure B2 a comparison is made of the linear relationship between SEL and $L_{A,max}$ for helicopter noise at the location specified above with such a relationship determined for fixed-wing aircraft noise (Ollerhead, 1992), over the ranges considered in the publications by Ollerhead and by Newman. The straight line for helicopter noise is again determined from the Newman data (formula: $SEL = 30.3 + 0.728\ L_{A,max}$; this formula has been determined since Ollerhead gives his formula in this format only). According to Ollerhead, the best-fitting straight line for fixed-wing aircraft noise has the following equation : $SEL = 23.9 + 0.810\ L_{A,max}$. The measurements to determine the relation for fixed-wing aircraft have been made in residential areas around airports, not necessarily directly below flight paths of fixed-wing aircrafts. There is a striking correspondence between both straight lines. This implies that it is to be expected that for situations in the direct vicinity of heliports and of airports, in this respect time-aspects of helicopter noise events and of fixed-wing aircraft noise events will not contribute to differences in exposure-effect relations for helicopter noise exposure and those for fixed-wing aircraft noise exposure.

Figure B1 $L_{A,max}$ of helicopter operations as a function of SEL at a location within 100 ft under the flight paths (data points taken from Newman, 1980). The straight line represents the best fitting straight line according to the method of least squares.

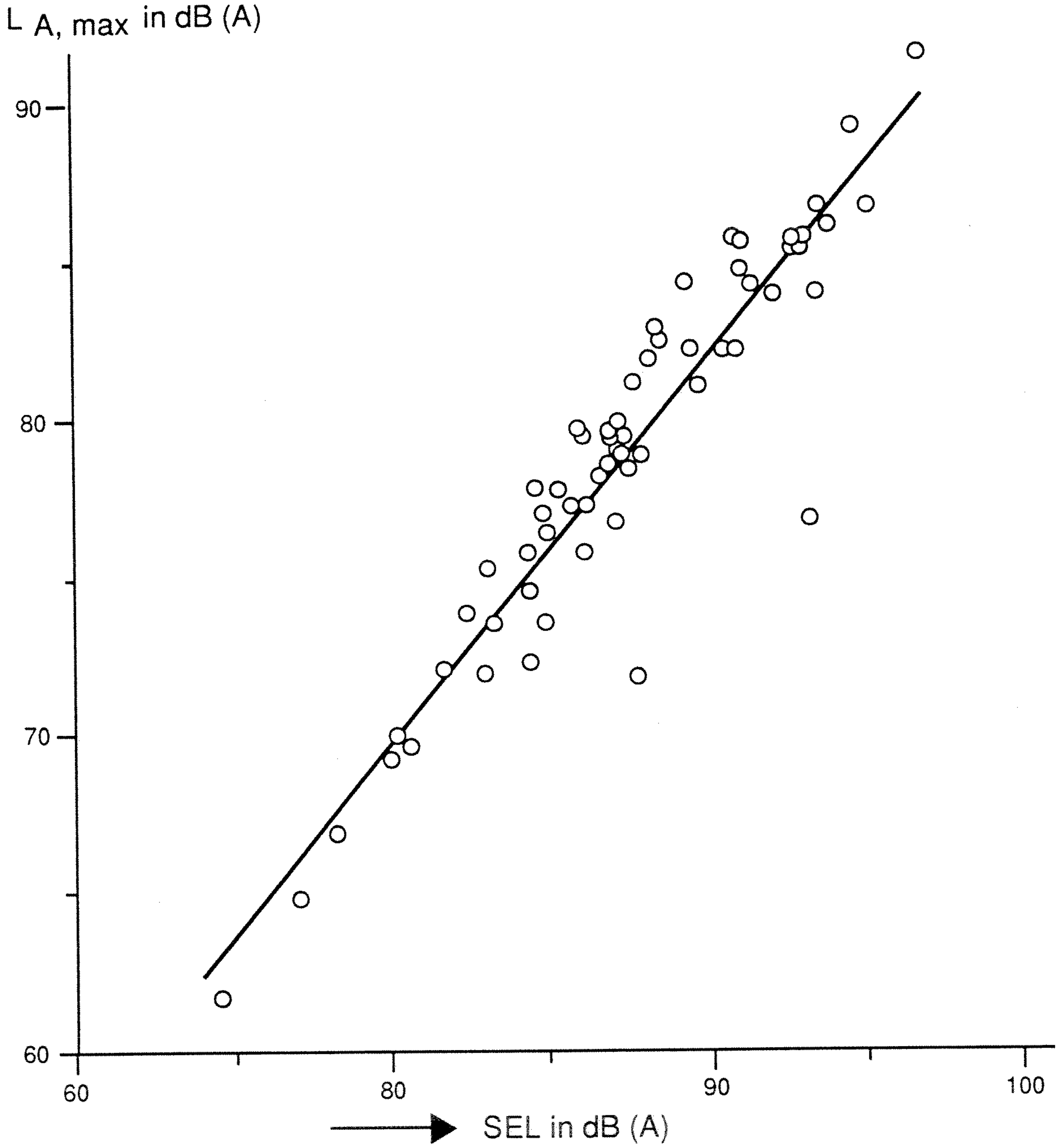
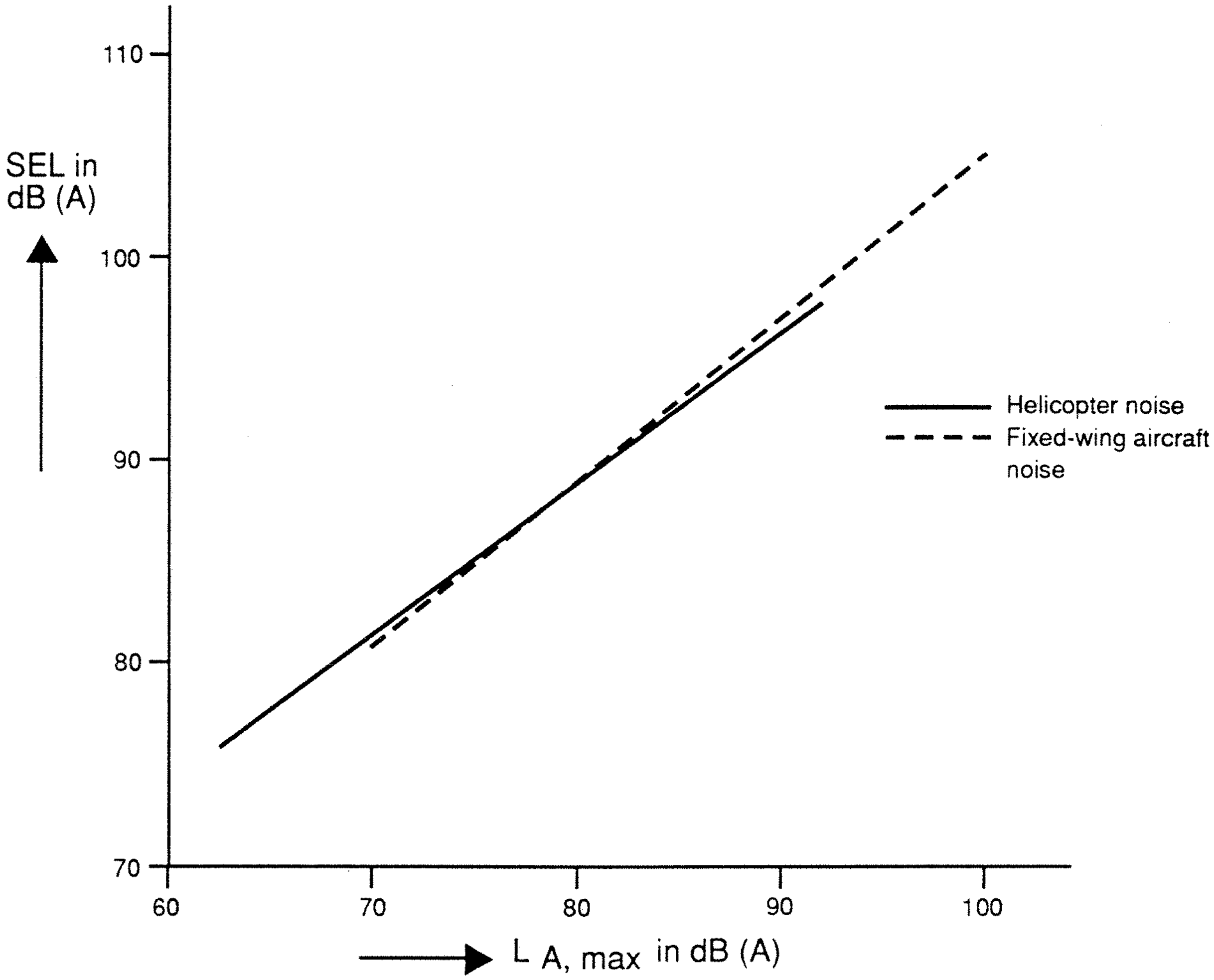


Figure B2 Comparison of best fitting straight lines of SEL as a function of $L_{A,max}$ for helicopter noise (data points taken from Newman, 1980; location specified in legend to figure 4) and for fixed-wing aircraft noise in residential areas (Source: Ollerhead, 1992).



ANNEX C

The theory of hierarchical power summation applied to noise measures

The model presented by Miedema (1993) with respect to annoyance describes how the trade-off between more basic attributes (intensities per frequency band per event moment) determines the annoyance caused by noise. According to that model, a quantification of annoyance is a hierarchical power sum of quantifications of these basic attributes. This hierarchical power sum is obtained by the repeated application of the power sum rule:

$$[\Sigma_k (b_k x_k)^{ak}]^{1/a}.$$

The hierarchical power sum rule is more general than a weighted addition.

All measures considered in the model are based on the sound intensities as the quantification per frequency-time combination. Per point of time a frequency-weighted sound intensity, I_F is determined. This quantity is defined as follows

$$I_F = \Sigma_j F_j I_j,$$

where the I_j are the one-third octave band intensities at a certain moment.

Two different quantifications of sound events are used. Let $I_F(t)$ denote the I_F value at point of time t. Then a sound event may be quantified by the maximum of the I_F values that occur during an event:

$$I_{Fmax} = \max_t I_F(t).$$

This maximum is the limit of a power sum of the I_F values that occur during an event. With respect to helicopter noise this quantification is used with frequency-weighting according to the A- and PN-weighting. For B, the A-weighting is applicable (F=A) and for NNI the weighting according to perceived loudness (F=PN).

For BKL, L_{Aeq}(24h), L_{dn} and L_{etm} , for which A-weighting is applied, a sound event is quantified by the sum of the I_A values that occur during the event:

$$I_{AX} = \Sigma_t I_A(t).$$

Although it is not required for the determination of the noise measures, it is convenient for the discussion in the sequel to distinguish the sound events from different noise sources, such as highway traffic, other road traffic, rail traffic, aircraft, non-impulsive stationary sources and impulsive stationary sources. The overall loudness of these events is quantified as described above, by I_{Amax} for B and by I_{AX} for the other measures.

Two different ways are used to quantify the noise caused by a single source during a period of time (e.g., day, evening, night). Let $I_{Amax}(i)$ denote the I_{Amax} value for event i and let $I_{AX}(i)$ denote the I_{AX} value for event i.

Then for B the noise caused by a single source during a period of time is quantified by the following power sum of the I_{Amax} values for that source during that period:

$$I_p = \Sigma_i [I_{Amax}(i)]^{2/3}.$$

For $L_{Aeq}(24h)$, L_{dn} and L_{etm} the noise caused by a single source during a period of time is quantified by the sum of the I_{AX} values:

$$I_{Aeq} = \Sigma_i I_{AX}(i).$$

All measures quantify the noise during a 24 hours' period in a different way. Let $I_p(j,k)$ symbolize the value of I_p for period k due to source j and let $I_{Aeq}(j,k)$ symbolize the value of I_{Aeq} for period k due to source j. Furthermore, let T be the length of a 24 hours' period in seconds and let T_k be the length of a period of the day in seconds.

B is a logarithmic transformation of a weighted sum of the I_p values:

$$B = 20 \log \Sigma_k \Sigma_j w_k I_p(j,k)/T - 7.$$

The definitions of the periods and of the weights w_k are not essential here. The weighting system for B roughly can be characterized as a refinement of the weighting system for L_{etm}, which is given below.

L_{Aeq} is a logarithmic transformation of the sum of the I_{Aeq} values:

$$L_{Aeq} = 10 \log \Sigma_k \Sigma_j I_{Aeq}(j,k)/T.$$

Note that the value of $L_{Aeq}(24h)$ does not depend on which periods are distinguished.

L_{dn} is defined as a logarithmic transformation of a weighted sum of the I_{Aeq} values:

$$L_{dn} = 10 \log \Sigma_k \Sigma_j w_k I_{Aeq}(j,k)/T.$$

L_{dn} only distinguishes two periods, a day-time period (7 h-22 h) for which the weight is 1 and a night-time period (22 h-7 h) for which the weight is 10.

L_{etm} is defined as a logarithmic transformation of the maximum of weighted I_{Aeq} values:

$$L_{etm} = 10 \log \max_k [\Sigma_j w_k I_{Aeq}(j,k)/T_k],$$

or, with $D_{jk} = w_k I_{Aeq}(j,k)/T_k$,

$$L_{etm} = 10 \log \max_k [\Sigma_j D_{jk}].$$

L_{etm} distinguishes three periods, a day-time period (7h-19h) for which the weight is 1, an evening period (19h-23h) for which the weight is 3.16 and a night-time period (23h-7h) for which the weight is 10.

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