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TNO-rapport

SLEEP DISTURBANCE DUE TO NIGHTTIME AIRCRAFT NOISE

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CONTENTS

SUMMARY

In the Netherlands nighttime aircraft noise is rated by its equivalent sound level during the 'night' determined in the bedroom of residents. 'Night' is specified as a period of seven consecutive hours between 23.00 and 7.00 hours. With regard to Schiphol International Airport this seven hours period is chosen as the period from 23.00 to 6.00 hours. In 1993 a nighttime equivalent sound level of 27 dB(A), calculated on a yearly basis has been proposed as exposure limit. After the Dutch version of this report became available a nighttime equivalent sound level of 26 dB(A) has been accepted as exposure limit. Nevertheless, calculations in this English version of the report still have an equivalent sound level of 27 dB(A) as a starting point. With respect to the number of awakenings and sleep stage changes, these numbers are at a nighttime equivalent sound level of 26 dB(A) 0.79 times the numbers applicable to a nighttime equivalent sound level of 27 dB(A).
The report gives an estimate of the number of awakenings and sleep stage changes due to nighttime aircraft noise events, with the noise exposure rated according to the nighttime equivalent sound level, measured indoors, on a yearly basis.
The estimations have been based on a tentative model, which specifies an exposure-effectrelation derived from results of field investigations. In the model the percentage noise-induced awakenings and the percentage noise-induced sleep stage changes during a night with aircraft noise events is a linear function of the number of noise events and the SEL values of these noise events, measured indoors.
First, it is supposed that the aircraft noise situation is the same during each night of the year. Then it can be mathematically shown that the percentage awakenings and sleep stage changes at a given equivalent sound level during the night are increasing functions of n from n equal to zero up to a certain value of n, after which they decrease as a function of n. This means that at a given equivalent sound level during the night the percentages awakenings and sleep stage changes are maximal at a certain value of n. With respect to awakenings the percentage awakenings at a nighttime equivalent sound level of 27 dB(A) during 7 hours is maximal at n equal to 5. The SEL values of these 5 aircraft noise events are then 64 dB(A), measured indoors. For that situation the number of awakenings during a year is equal to 13 in an average population and the number of sleep stage changes equal to 380 a year. It is estimated that at nighttime equivalent sound levels below 16 dB(A) no noise-induced awakenings occur. At a nighttime equivalent sound level of 32 and 37 dB(A) the maximal number of awakenings in an average population is 42 and 131 respectively.
After the calculations related to the situation with each night of the year the same aircraft noise exposure, for several other scenario's calculations have been carried out. In these scenario's noisier nights and quieter nights have been distinguished, with the equivalent sound levels of the noisier nights

10. 20 and 25 dB(A) above the equivalent sound level on a yearly basis. It is shown in the report that the maximal number of noise-induced awakenings during a year in an average population is independent of the distribution of the noise events over the nights and that it is only a function of the nighttime equivalent sound level on a yearly basis.

It has been shown that many people in the Netherlands have a sleep period that is longer than 7 hours. Taking a sleep period of 8 hours a night, also during the eighth hour noise-induced awakenings and sleep stage changes may occur. The number of these awakenings and sleep stage changes depend completely upon the extend of the aircraft noise events. In the report a reasonable estimate of these aircraft noise exposures during the eighth sleep hour is given. Due to these aircraft noise events the number of awakenings is twice as large as the number of awakenings for a sleep period of 7 hours.

In the Netherlands nighttime aircraft noise regulations the equivalent sound levels measured in the bedrooms of residents is taken as a basis. In calculating from the measured outdoors equivalent sound levels the indoors equivalent sound levels the sound-insulation of the dwellings, determined with the windows in ventilation-position, is taken into account. With windows opened the sound-insulation is less. If the bedroom window is opened each night of the year, then the number of noise-induced awakenings and the number of sleep stage changes are 3.2 times as large as with windows in ventilation-position. With windows opened 4 months a year, these numbers increase by a factor 1.8.

Due to both modifying factors - windows opened 4 months a year and a sleep period of 8 hours - the maximal number of awakenings in an average population exposed to a nighttime equivalent sound level of 27 dB(A) increases from 13 to 50 times a year.

There does exist an inter-individual variation in the percentage awakenings due to nighttime aircraft noise events. A field study has shown that 2.5% of a group of residents in a specified situation has a percentage of noise-induced awakenings which is at least twice as large as the average value and another 2.5% has at most half this percentage awakenings. A 'worst case' calculation, based on this inter-individual variation shows that it is very likely that there is no interaction between noise-induced awakenings for nighttime equivalent sound levels up to at least 27 dB(A). With respect to noise-induced sleep stage changes such an interaction may occur, especially at equivalent sound levels over 27 dB(A). Whether the estimate according to the model results in an over- or underestimate of the actual number of noise-induced sleep stage changes cannot be deduced from the available information.

The tentative model has been based upon data from field investigations. In the report it is indicated that uncertainties in the model will induce deviations from the actual number of awakenings and sleep stage changes which are at most a factor 4. Whether it concerns an over- or underestimate is unknown.

1. INTRODUCTION

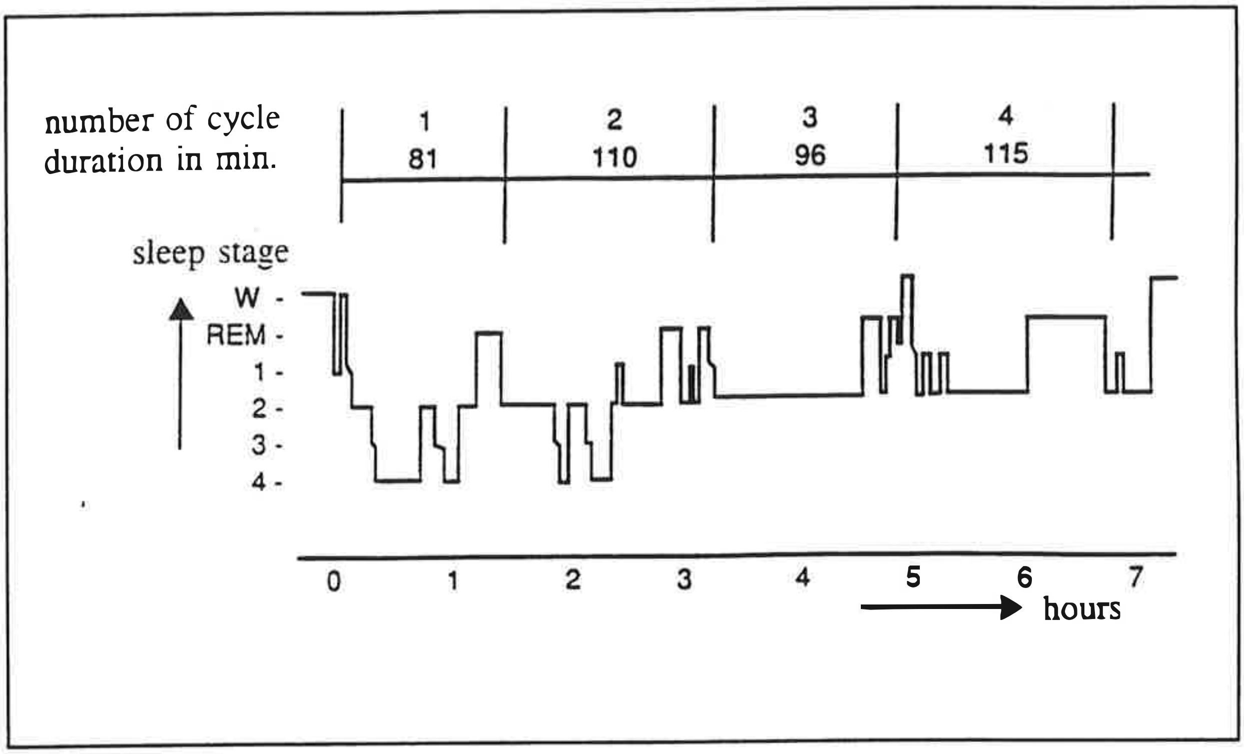
In a letter to parliament, dated 26-08-1993, the cabinet council of the Netherlands announced that they had chosen to rate nighttime aircraft noise by its equivalent sound level during the 'night' as determined in the bedroom of residents. 'Night' is specified as a period of seven consecutive hours between 23.00 and 7.00 hours. With regard to Schiphol International Airport this seven hours period is chosen as the period from 23.00 to 6.00 hours (PMMS, 1993). An equivalent sound level ($L_{Aeq,7h,ind}$) of 27 dB(A)*, calculated on a yearly basis has been proposed as exposure limit.
Which adverse effects on sleep should be expected at such an exposure limit? Sleep disturbance by external factors, such as noise, manifests itself according to the advisory report of the Health Council on aircraft noise and sleep (GR91) as an influence on sleep quality and an influence on mood and on functioning the following day.
Parameters of sleep quality are (Passchier-Vermeer, 1993a,b):

- awakenings during the sleep period
- changes in sleep stages, from deeper sleep to a lighter stage
- changes in sleep pattern
- changes in heart rate
- changes in hormone levels
- changes in the immune system
- changes in subjective assessment of sleep quality.

This report deals with the two first mentioned parameters: awakenings and sleep stage changes. These (physiological) parameters are measurable by means of electro-encephalograms (EEG), determined while falling asleep and during sleep. The EEG is a continuous recording of electrical potential differences between several parts of the brain cortex. Eye movements also are recorded by means of the EOG (electro-oculogram) and the EMG (electro-myogram) is sometimes also recorded. The EEG and EOG indicate the sleep stages. The following sleep stages can be distinguished: W (waking), 1, 2, 3, 4, REM (Rapid Eye Movements). Stage 4, and usually stage 3 also, are termed deep sleep, stages 1 and 2, light sleep and the REM stage dream sleep. The several stages occur as a more or less regular pattern in the course of the sleep period, as shown in figure 1. Sleep stages 3 and 4 occur mainly at

*In reality, an equivalent sound level of 26 dB(A) has been accepted as exposure limit after this report became available. Calculations in this English version of the Dutch report therefore have still an equivalent sound level of 27 dB(A) as a starting point. With respect to the calculation of the number of awakenings and sleep stage changes, these numbers are at an equivalent sound level of 26 dB(A) 0.79 times these numbers at 27 dB(A).

Figure 1 Sleep pattern of an adult, with a cyclic occurrence of sleep stages.



the beginning of the sleep period and the REM stage in the course of the second part of the sleep period.

This report first presents a description of nighttime exposure to aircraft noise: some noise measures are presented, mathematical formula's being given in annex A. Next, a tentative model is discussed that allows the description of awakenings and sleep stage changes. With this model as a basis calculations have been carried out in annex B. These calculations aim at estimating the consequences of the present nighttime regulations in the Netherlands. In the main text of this report the results together with an interpretation are given. At last some conclusions have been formulated.

2. DESCRIPTION OF NOISE EXPOSURE TO AIRCRAFT NOISE

Many noise measures have been developed and used. In this report, only those noise measures are described which have been included in Netherlands regulations (Noise Nuisance Act and Aircraft Act and their Decrees) and that are therefore used to express environmental noise exposure in the Netherlands.
Sound can be characterised by its sound level in dB(A). 'A' indicates that the frequency sensitivity of the human ear has been taken into account. During approach of an aircraft, its sound level observed on the ground rises steadily and after direct overflight or flyby it decreases again steadily. This is illustrated schematically in figure 2.
The maximal sound level ($L_{A,max}$) as well as the sound exposure level (SEL) of an aircraft noise event are noise measures which specify such an event. In principle, $L_{A,max}$ 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) and 35 ms (I: impuls). For the situations described in this report there is on average only a small, negligible, difference between the maximal sound level of an aircraft noise event determined with the measuring equipment using F or S.
SEL is a measure of the time-integrated sound energy of a noise event. The mathematical definition is given in annex A. The total time-integrated sound energy of a noise event is in the SEL value converted to a one-second value. Figure 3 shows in which way time-varying sound levels of a number of noise events can be represented by SEL values.

Figure 2 Schematic representation of the sound levels observed on the ground during an aircraft overflight.

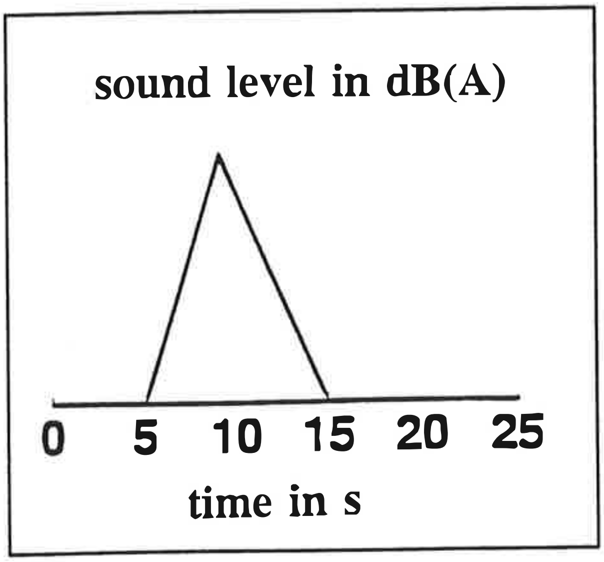
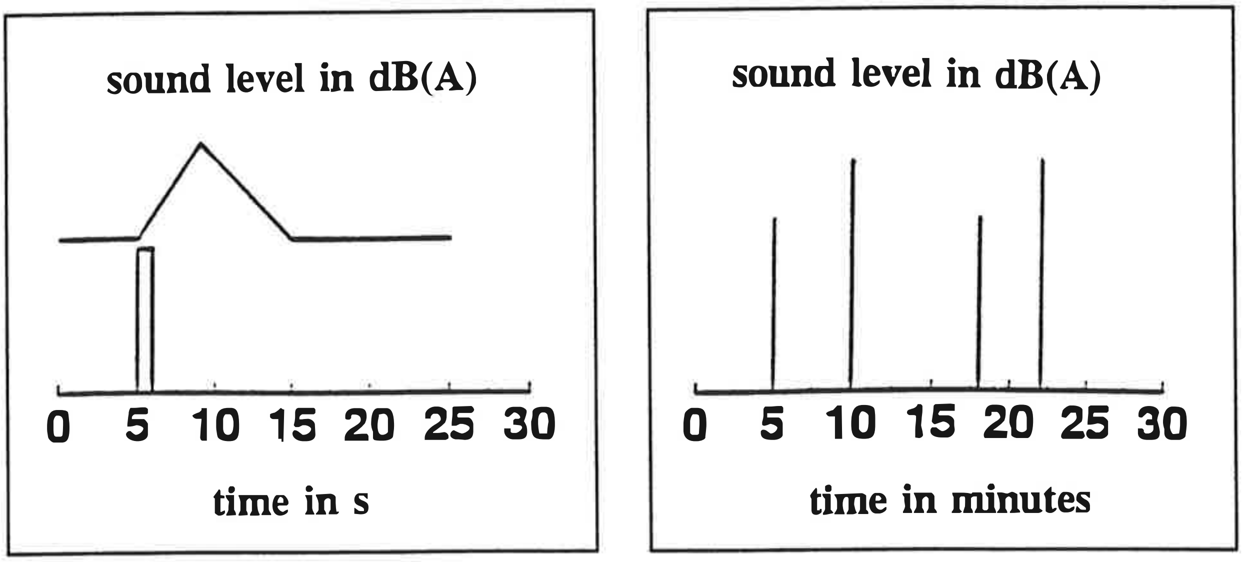


Figure 3 Characterization of the time-varying sound levels of a noise event into one SEL value (left figure) and representation of several SEL values as a function of time (right figure).



The description of the noise exposure of residents living in the vicinity of an airport concerns a judgement of many aircraft noise events during a longer period of time. In this respect, the following noise measures are used in the Netherlands for characterising long-term exposure of residents to environmental noise sources:

- quantity B in Kosten Units (Kosten eenheden). B is determined by the total number of aircraft noise events a year, with $L_{A,max}$ values of at least 65 dB(A), the $L_{A,max}$ values of each of these events, with varying penalties for night- and evening flights. E.g., for nighttime aircraft noise events, a penalty of 10 dB(A) is applicable.
- L_{etm} value in dB(A) ('etm' is the abbreviation of 'etmaal', the 24-hour period of the day). This value is determined from the equivalent sound levels during three parts of the 24 hour period. It is the maximum of the following three values: the equivalent sound level during the day (07.00-19.00 h), the equivalent sound level during the evening (19.00-23.00 h) plus 5 dB(A) and the equivalent sound level during the night (23.00-07.00 h) plus 10 dB(A).
- The equivalent sound level determined indoors during a period of seven consecutive hours within the nighttime period of 23.00-07.00 hours, determined on a yearly basis ($L_{Aeq,7h,ind}$).
- BKL in dB(A). This is a measure specified in the Netherlands for small aircraft noise exposure. It is a day-evening-night level, determined by specific rules dependent upon the two busiest days per week during the busiest 26 weeks of a year.

With respect to the residential areas around Schiphol International Airport there is a relation between L_{etm} and B. This relation is:

$$L_{etm} \approx 0{,}5B + 45 \ (dB(A))$$

3. TENTATIVE MODEL FOR SLEEP DISTURBANCE DUE TO AIRCRAFT NOISE

As specified in the introduction, this report deals with awakenings and sleep stage changes. Lukas (1975) published dose-effect relations, based on published data then available. The effects concerned average percentage of awakenings and sleep stage changes in reaction to an acoustic stimulus. Noise exposure was expressed as $L_{A,max}$ of the noise event. The analysis by Lukas was based on 13 laboratory studies regarding mostly traffic noise (road traffic, aircraft, sonic booms), all with an intermittent pattern.

Griefahn published her analysis about sleep disturbance in 1976. Of the 76 available references, ten were useful for her analysis, that mainly dealt with laboratory research. Effects considered were awakening and sleep stage changes and the noise parameter taken was $L_{A,max}$ of the noise events. Acoustic signals studied were aircraft (including sonic booms), rail road and road traffic noise, impulse noises and white noise.

At the end of 1989, Pearsons published his analysis of sleep disturbance, based on 21 publications. In addition to the studies analyzed by Lukas and Griefahn, he also took into account more recent studies. He distinguishes between field and laboratory investigations. Field studies mean studies in which the subjects are in their normal living situation with the usual nighttime noises in their bedroom. The percentages of awakenings and of sleep stage changes were plotted as a function of $L_{A,max}$ of a noise event. Pearsons also presents his results as a function of SEL. SEL was sometimes not measured, but estimated from a combination of $L_{A,max}$ and the duration of a noise event.

In this report, in the determination of an exposure-effectrelation, preference is given to the results of field studies over those of laboratory studies, since the real world situation in field studies is more representative for the situation in which the model should be applicable than a laboratory situation. The results from both types of investigations differ mostly with respect to the degree of habituation of the test persons to nighttime noises.

Figure 4 and 5 show the exposure-effectrelations determined by Pearsons from field investigations. The percentage awakenings and sleep stage changes have been plotted as a function of the maximal sound level of a noise event. The percentage awakenings is for n nighttime noise events to which p persons are exposed equal to 100 times the total number of awakenings (by p persons exposed to n noise events) divided by n x p. It therefore concerns an average value. The percentage sleep stage changes is determined accordingly.

Figure 4 The percentage noise-induced awakenings as s function of the maximal sound level, measured in the bedroom, during a noise event as determined from field investigations. The straight line is the best-fitting straight line according to the method of least squares, the dashed lines represent the 95%-confidence interval (Source: Pearsons, 1989).

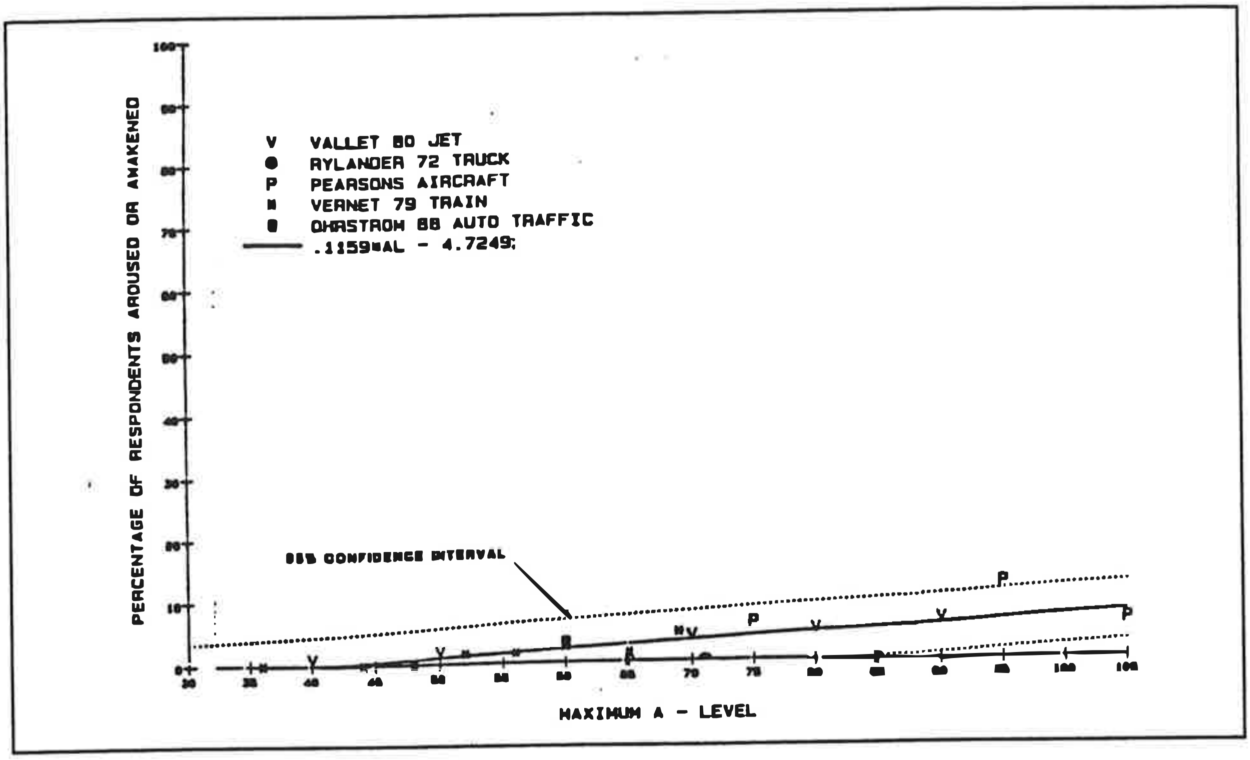


Figure 5 The percentage noise-induced sleep stage changes as s function of the maximal sound level, measured in the bedroom, during a noise event as determined from field investigations. The straight line is the best-fitting straight line according to the method of least squares, the dashed lines represent the 95%-confidence interval (Source: Pearsons, 1989).

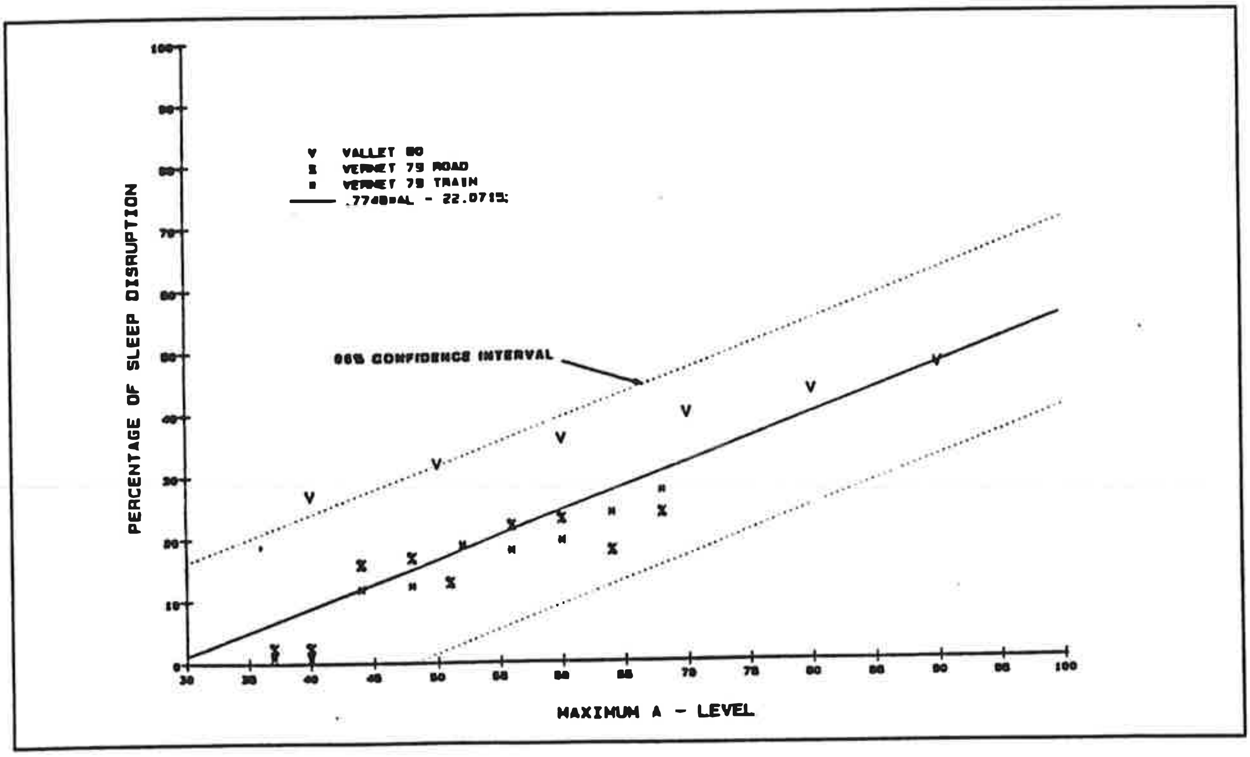
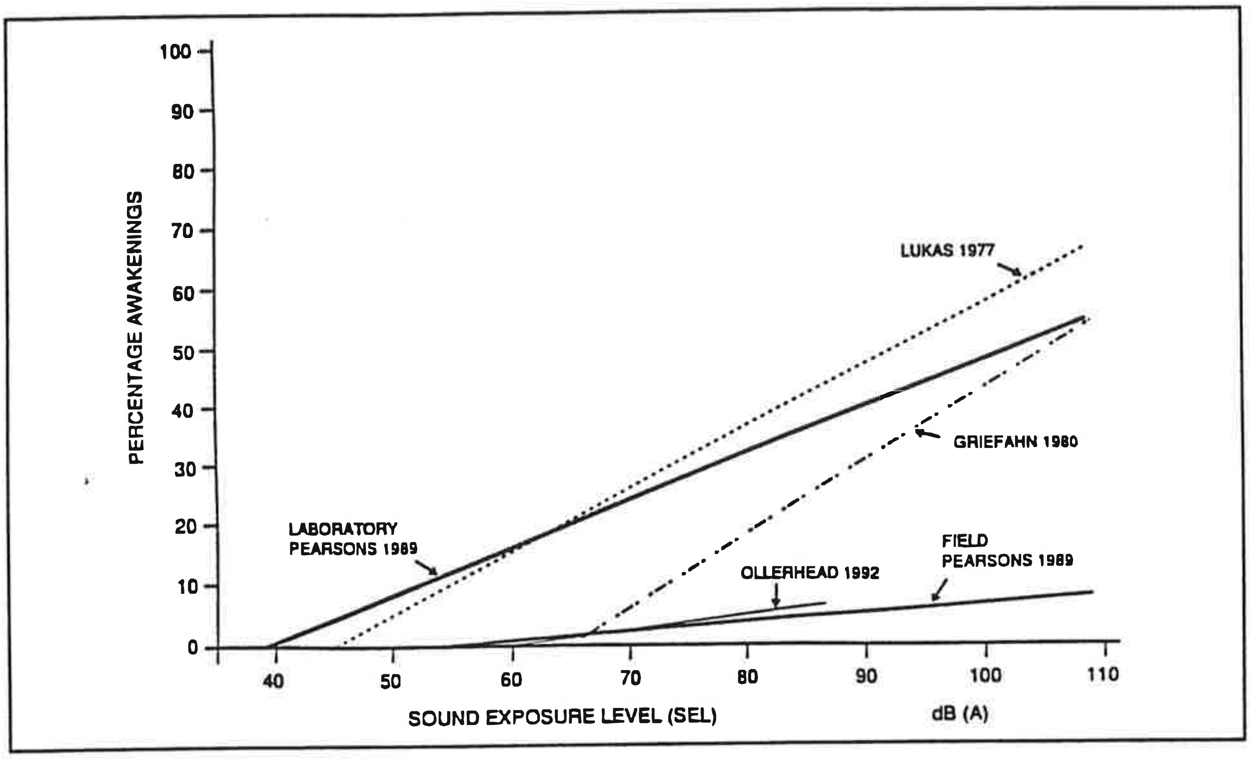


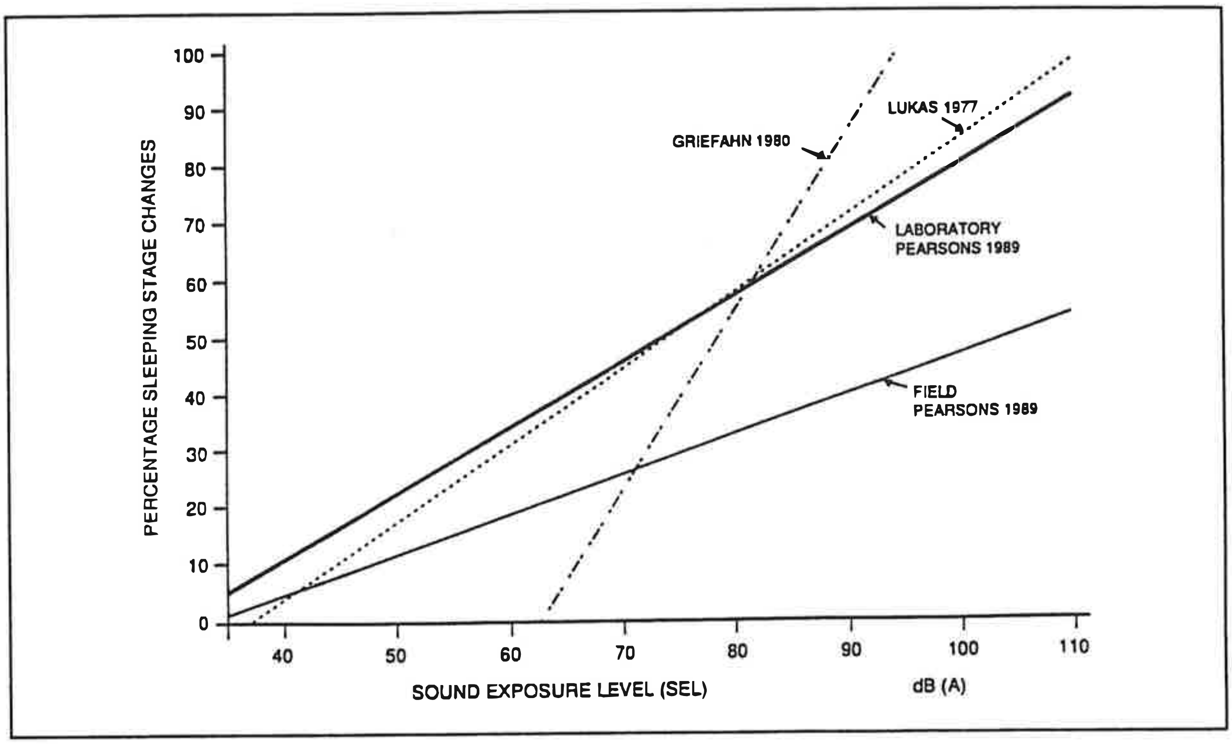
Figure 6 Comparison of exposure-effectrelations determined by Lukas, Griefahn, Pearsons ('laboratory' and 'field') and the exposure-effectrelation which has been derived from the Ollerhead investigation (1992).



A report published in 1992 describes an extensive English epidemiological investigation into sleep disturbance from aircraft noise (Ollerhead 1992). The investigation concerned eight locations around four airports (Heathrow, Gatwick, Stansted and Manchester). In each location 50 residents took part in the investigation for 14 to 15 nights. The subjects wore an actometer around their wrist from the time of going to sleep until awakening; 6 of the 50 residents also had a sleep EEG taken for four of the nights. The report gives data for awakenings; much emphasis is placed on the relation between results from EEG and those from actometer measurements.

An exposure-effectrelation has been derived from the data presented by Ollerhead (Passchier-Vermeer 1993a,b) giving the percentage awakenings as a function of SEL, measured in the bedroom. This exposure-effectrelation is in figure 6 compared with those specified in the other publications mentioned above. The figure shows that there is a very good agreement between the exposure-effectrelation given by Pearsons for field investigations and that derived from the Ollerhead data. Figure 7 shows the comparison by Pearsons of the results of the analyses by Lukas, Griefahn and himself with respect to sleep stage changes, the percentages sleep stage changes in the figure having been plotted as a function of SEL in the bedroom.

Figure 7 Exposure-effectrelations determined by Lukas, Griefahn, Pearsons ('laboratory' and 'field'). The percentage noise-induced sleep stage changes have been given as a function of SEL, measured indoors (Source: Pearsons, 1989).



Ollerhead also determined an estimated relation between the outdoors measured maximal sound level of an aircraft noise event and SEL. This relation is for the situations considered:

$$SEL_{out} \approx 0{,}8\ L_{A,max,out} + 25\ (dB(A))$$

Figure 8 SEL_{ind} as a function of the number of aircraft noise events a night, in which it is assumed that all noise events have the same SEL value and that $L_{Aeq,7h,ind}$ is equal to 27 dB(A).

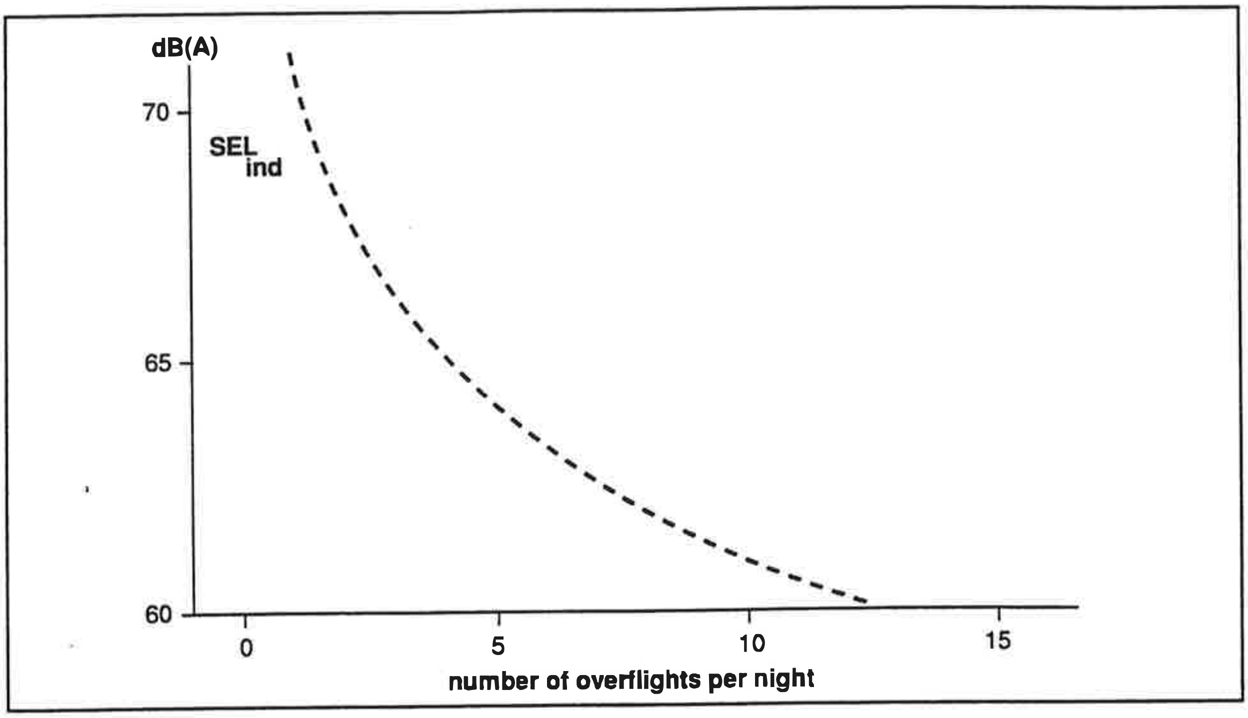
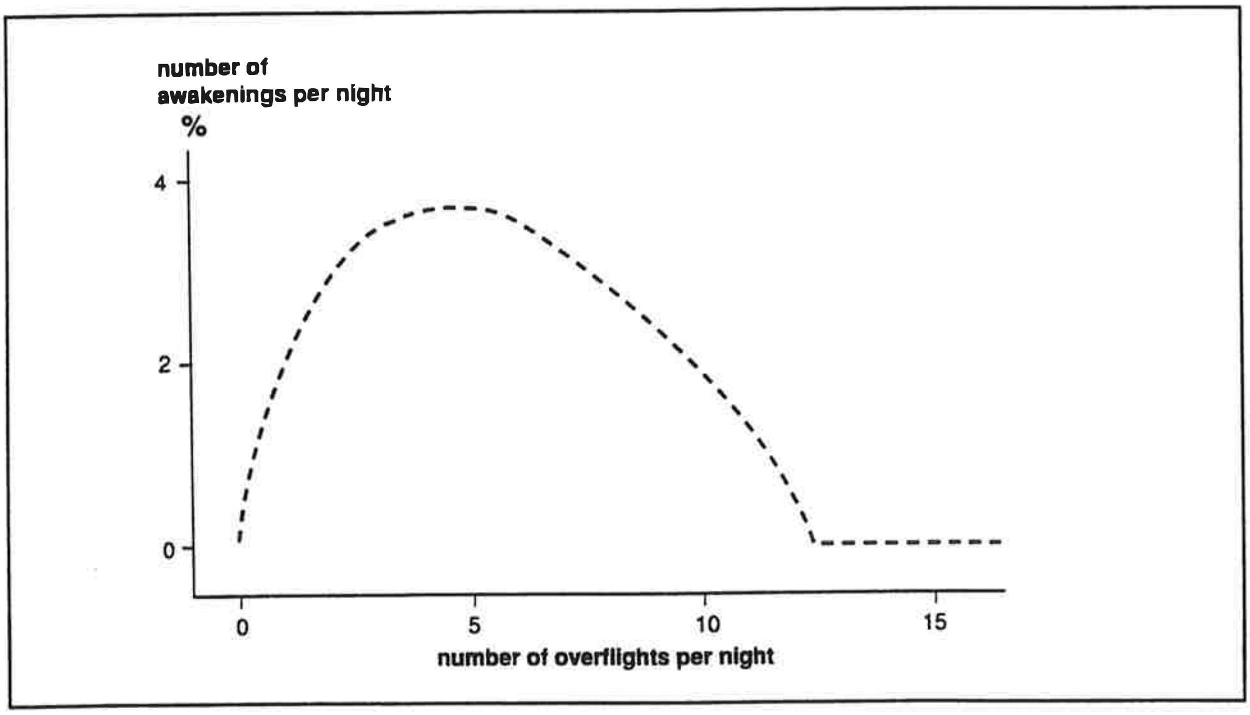


Figure 9 The percentage of awakenings per night as a function of the number of aircraft noise events a night, in which it is assumed that all noise events have the same SEL value and that LAeq,7h,ind is equal to 27 dB(A).



The model is based on the exposure-effectrelation tentatively determined from field investigations. In the estimation of this relation the chance to awaken during the night by n noise events is taken equal to n times the chance of being awakened by one noise event. This assumption has also been applied to sleep stage changes. It is a tentative model, since the available information does not yet allow possible variables and interactions to be taken into account.

The percentage awakenings of a person (P_w) depends upon $SEL_{i,ind}$ and n as follows:

$$P_w = 0.18\ \Sigma_i n_i\ (SEL_{i,ind} - 60) \qquad \text{for } SEL_{i,ind} > 60\ dB(A)$$

$$P_w = 0 \qquad \text{for } SEL_{i,ind} < 60\ dB(A)$$

in which:

P_w: percentage awakenings due to n aircraft noise events a night

n_i: number of nighttime aircraft noise events with a SEL value equal to $SEL_{i,ind}$; $n = \Sigma_i n_i$

$SEL_{i,ind}$: SEL value of the i-th noise event, determined in the bedroom.

The percentage sleep stage changes (P_v) during a night can be expressed as follows:

$$P_v = 0.65\ \Sigma_i\ n_i\ (SEL_{i,ind} - 32) \qquad \text{for } SEL_{i,ind} > 32\ dB(A)$$

$$P_v = 0 \qquad \text{for } SEL_{i,ind} < 32\ dB(A)$$

If each of the noise events during a night have the same SEL value, then the following formula is applicable:

$$L_{Aeq,7h,ind} = SEL_{ind} + 10 \log n - 44\ \ dB(A)$$

By inserting $SEL_{i,ind}$ in the formula's of P_w and P_v , P_w and P_v are expressed in n and $L_{Aeq,7h,\ ind}$. The formula's then become:

$$P_w = 0.18\ n\ (L_{Aeq,\ 7h,ind} - 10 \log n - 16)$$

$$P_v = 0.65\ n\ (L_{Aeq,\ 7h,ind} - 10 \log n + 12)$$

Mathematically it can be shown that for a fixed $L_{Aeq,7h,ind}$ P_w and P_v are increasing functions of n from 0 up to a certain value, after which they decrease with increasing value of n. In other words, P_w and P_v are functions with a maximum at a certain value of n, where n also depends upon $L_{Aeq,\ 7h,ind}$. In annex B and C it is shown that P_w and P_v are maximal at a value of n which is in the case of P_w :

$$\log n = \frac{L_{Aeq,7h,ind} - 16}{10} - 0.43$$

and for P_v:

$$\log n = \frac{L_{Aeq,7h,ind} + 12}{10} - 0.43$$

In the figures 8 and 9 some results are shown for $L_{Aeq,7h,ind}$ equal to 27 dB(A). If all SEL values are equal, then for that situation the following formula is applicable:

$$SEL_{ind} + 10 \log n = 71 \quad dB(A)$$

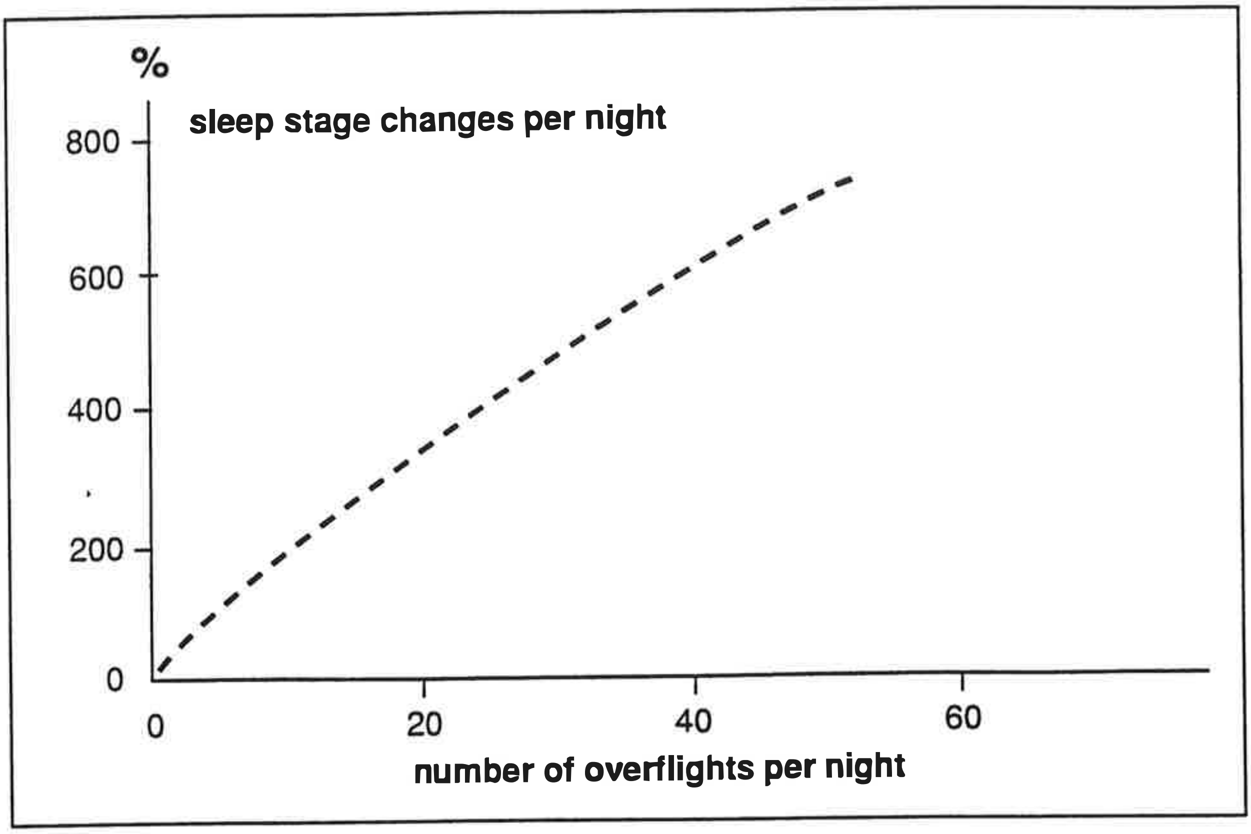
This formula implies that for one noise event (n=1) SEL_{ind} should not exceed 71 dB(A) in order to limit nighttime noise exposure to an equivalent sound level of 27 dB(A) and for 10 noise events (n=10) each of the SEL_{ind} values should not exceed 61 dB(A). The relation between SEL_{ind} and n is graphically shown in figure 8 for an equivalent sound level during the night of 27 dB(A).
Figure 9 shows the percentage awakenings per night as a function of the number of noise events per night, under the condition that the resulting aircraft noise-induced equivalent sound level (over 7 hours) is equal to 27 dB(A).
With respect to sleep stage changes the following remark. It is also for P_v correct that it has a maximal value at a certain value of n for a given $L_{Aeq,7h,ind}$. If $L_{Aeq,7h,ind}$ is taken equal to 27 dB(A), then P_v is maximal at a value of n equal to 2951. This value will in practice never be reached. Therefore, in the range to be considered, the percentage sleep stage changes is an increasing function of n at a $L_{Aeq,7h,ind}$ of 27 dB(A). This function is given in figure 10.

Still two other terms have been defined: W and V. W is the total number of awakenings a year due to nighttime aircraft noise and V is the total number of sleep stage changes a year. If Pw and P_v have the same value each night of the year, then:

$$W = 3.65\ P_w$$

$$V = 3.65\ P_v$$

Figure 10 Percentage sleep stage changes per night as a function of the number of aircraft noise events during the night, in which it is assumed that all noise events have the same SEL value and that $L_{Aeq,7h,ind}$ is equal to 27 dB(A).



4. RESULTS AND INTERPRETATION

Annex B gives a number of calculations, of which the results are presented in this chapter.

4.1 The same aircraft noise situation during each night of the year

With the same aircraft noise situation during each night of the year as a basis, the total number of awakenings a year has been calculated for the situation in which P_w is maximal. Figure 9 showed already that this is for an equivalent sound level of 27 dB(A) at n = 5. The maximal number of awakenings has been given as a function of $L_{Aeq,7h,ind}$ in figure 11. Figure 12 presents the number of sleep stage changes as a function of $L_{Aeq,7h,ind}$ for those situations in which the total number of awakenings is maximal.

At and below a value of $L_{Aeq,7h,ind}$ equal to 16 dB(A) the number of awakenings per year due to aircraft noise events is estimated to be zero. In order not to surpass an equivalent sound level during the night of 16 dB(A), even if one noise event occurs it should have a SEL value of less than 60 dB(A) and according to the model awakenings start to occur at SEL values of at least 60 dB(A). The number of awakenings a year at an equivalent sound level of 27 dB(A) is equal to 13 and the number of sleep stage changes equal to 380.

Figure 11 Number of awakenings a year as a function of the equivalent sound level during the night (7 hours), for those situations in which the number of noise events (n) is such that the number of awakenings is maximal. Each night of the year has the same noise situation.

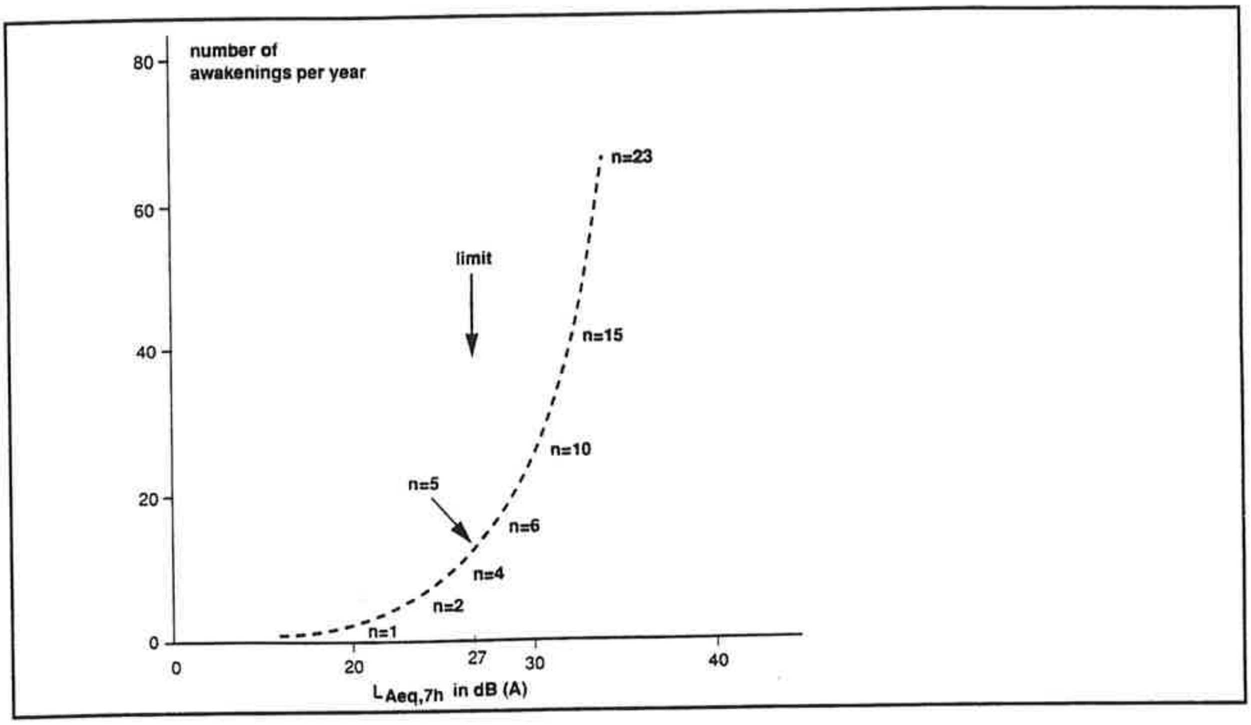
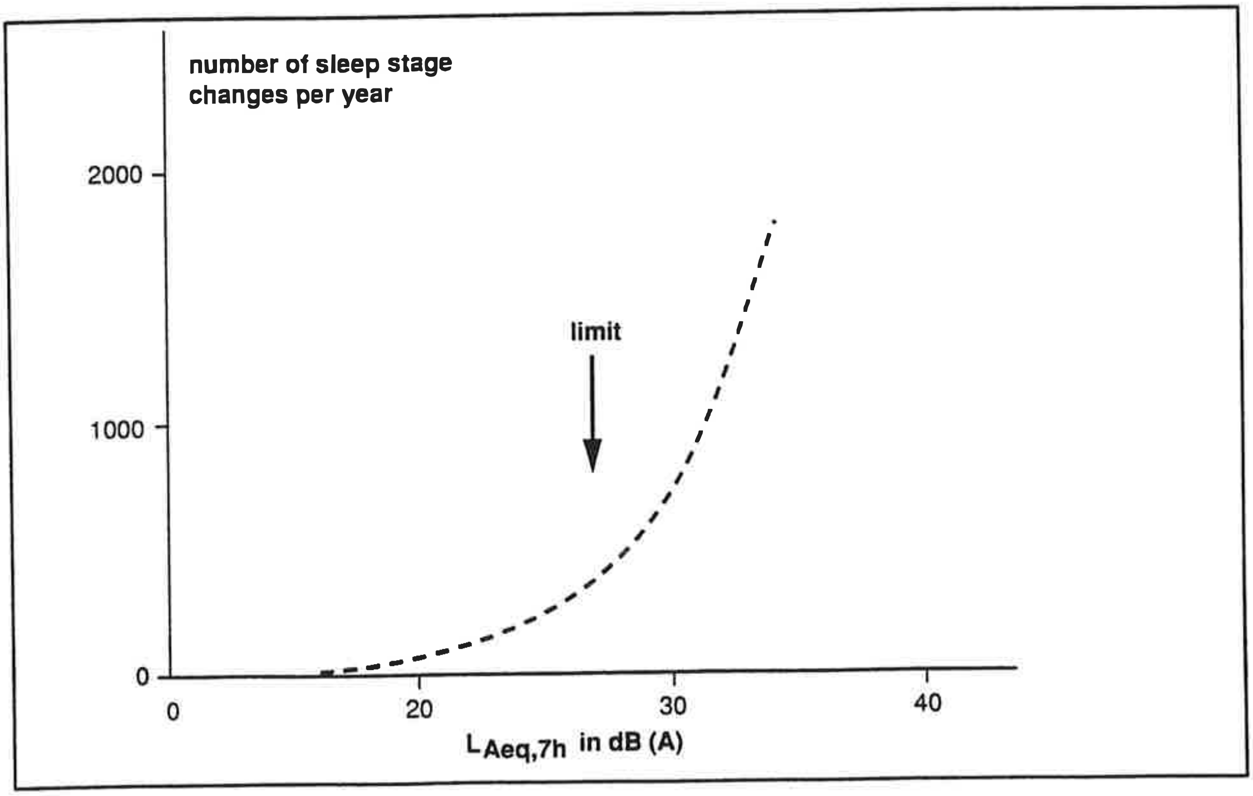


Figure 12 Number of sleep stage changes a year as a function of the equivalent sound level during the night (7 hours) for the same situations as taken in figure 11.



4.2 Different noise situations during various nights of the year

Annex B shows calculations for several scenario's, with in each scenario a distinction between noisier and quieter nights. First, these calculations have been carried out for an equivalent sound level of 27 dB(A) on a yearly basis. The following scenario's have been chosen:

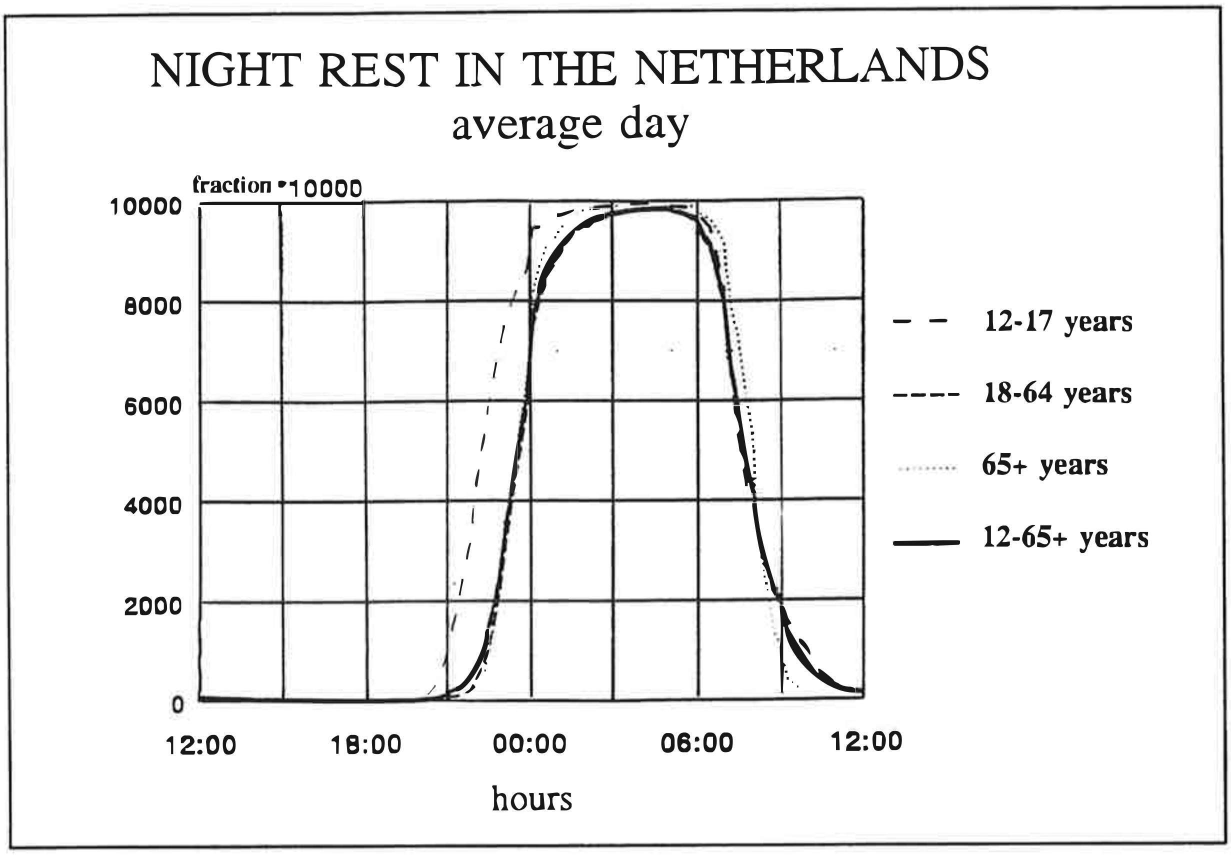
- 27 dB(A) during 365 nights
- 32 dB(A) during 1, 12, 36 and 115 nights. In order not to surpass 27 dB(A) on a yearly basis, only 115 nights with an equivalent sound level of 32 dB(A) are allowed.
- 37 dB(A) during 1, 12 and 36 nights (not more than 36 nights possible)
- 47 dB(A) during 1, 2 and 3 nights (not more than 3 nights possible)
- 52.6 dB(A) during 1 night (only one night possible).

Annex B shows the maximal number of awakenings not to be dependent upon the distribution of the noise events over the year! In that respect, the line is taken that there are no systematic differences between noisier and quieter nights apart from differences in aircraft noisiness. Such a systematic difference might be applicable if residents sleep more often with the windows of their bedroom opened during noisier nights than during more quiet nights.
Next it is shown in annex B that also for other equivalent sound levels than 27 dB(A) on a yearly basis, the number of awakenings does not depend upon the scenario chosen. This is, however, without any restriction only applicable for equivalent sound levels over about 20 dB(A). At lower sound levels disparities may be introduced when during the quieter nights awakenings due to aircraft noise are absent. The scenario's with the smallest number of noisier nights then result in less awakenings a year than calculated for the scenario with the same noise situation during each night of the year.
Also, the number of sleep stage changes is independent of the scenario chosen. Only for the scenario with the noisiest nights (47 dB(A)) V is 13% larger than for the scenario with the same noise situation during each night.

4.3 Longer sleep period than 7 hours

In the Netherlands nighttime aircraft noise regulation a sleep period of 7 hours has been chosen as a basis. Only for that period restrictions with respect to nighttime aircraft noise are appropriate. For Schiphol International Airport it has been proposed to specify the nighttime period as from 23.00 to 06.00 hours. Many people in the Netherlands have, however, a sleep period which lasts after 6 hours (Gezondheidsraad, 1991). Figure 13 shows the night's rest of the Netherlands population, aged 12 years and over. At 6 hours in the morning only a few percent of the population got up. At 7 hours on average 28% of the population got up during weekdays and 7% on weekends (Saturday and Sunday morning). At 8 hours on weekdays more than a quarter of the population over 12 years of age is still in bed and during weekends even more than three quarters of them. Therefore, it can be concluded that the night rest of the Netherlands population lasts longer than 6 hours in the morning. Since no detailed data are available about the noise levels of early morning aircraft noise events, only calculations can be carried out in which the noise exposure is reasonably estimated. In this estimation it is supposed that during one hour after the nighttime period specified in the regulations, 5 aircraft noise events occur each with a SEL value of 64 dB(A). The equivalent sound level during that hour is then 35 dB(A) and the equivalent sound level during the 8 hours is 29 dB(A) (7 hours 27 dB(A) and one hour 35 dB(A) is equivalent to 8 hours 29 dB(A)). With this extended sleep period, the total number of awakenings is twice as large as for the 27 dB(A) calculations, i.e. 26 per year. Also the number of sleep stage changes is doubled.

Figure 13 Fraction of the respondents to an investigation into the activities of people, indicating to have night's rest during a given time of the 24 hour period. The curve shows an average value over all days of the week (Source: Gezondheidsraad, 1991).



4.4 Windows opened during the night

The Netherlands aircraft nighttime noise regulations specify the equivalent sound level occurring indoors in the bedroom as a basis. In calculating from the measured outdoors equivalent sound levels the indoors equivalent sound level the sound-insulation of the dwelling has to be taken into account. This sound-insulation is determined according to the specifications with windows in ventilation-position (partly opened to allow some ventilation). In calculating indoors noise levels from outdoors measurements, different values of sound-insulation are to be taken into account for different types of dwellings and for different aircraft operations. E.g., for Schiphol International Airport, dwellings in apartment blocks are taken as the representative type of housing and a sound-insulation of 22 dB(A) is taken for landings and 20.5 dB(A) for take-offs. With windows completely opened, the sound-insulation is estimated to be 5 dB(A) lower than with windows in ventilation-position. This implies the indoors equivalent sound levels to be 5 dB(A) higher with windows opened than with windows in ventilation-position. If an equivalent sound level of 27 dB(A) has been calculated for a given situation with windows in ventilation-position, then the actual equivalent sound level to which residents are exposed with their windows in the bedroom opened would be 32 dB(A) and this implies according to the figures 11 and 12 an increase in W and V with a factor 3.2. When the windows are opened during 4 months a year, W and V increase by a factor 1.8.

4.5 Combination of windows opened and a sleep period longer than 7 hours

Suppose, windows are opened during 4 months a year and during the eighth sleep hour there are 5 noise events, each having a SEL value equal to 64 dB(A). Then the number of awakenings is in this situation 48 a year. This is a factor 3.7 larger than would be calculated for a situation with a value of $L_{Aeq,7h,ind}$ equal to 27 dB(A.

4.6 Variations in the model

The model, on which the calculations have been based, specifies a linear relation between P_w and SEL_{ind} (see figure 6) and between P_v and SEL_{ind} (see figure 7). Two variations in the model will be discussed below. First, the angle of the straight line representing the relation between P_w and SEL_{ind} may vary (rotation of the line) and second the lowest value at which P_w starts to increase (the intercept of the line with the horizontal axis) may vary (shifting of the line). If the angle is increased by a factor 2, P_w and therefore also W increases by a factor 2. The number of noise events at which P_w is maximal is independent of the angle mentioned. (In general, when the angle is increased by a factor α, then W is also increased by a factor α).

P_w can be expressed as a function of the lowest value (60 - ΔL) at which P_w starts to increase by:

$$P_w = 0.18\, n\, (SEL_{ind} - 60 + \Delta L)$$

This formula shows that the curve in figure 11 shifts by ΔL to lower equivalent sound levels. The value of n at which the maximum of P_w occurs is dependent upon ΔL and is to be calculated from:

$$\log n/n' = \frac{\Delta L}{10}$$

(When ΔL is taken equal to 5 dB(A), then n/n′ is equal to 3.16).

The same considerations are applicable to sleep stage changes.

4.7 Inter-individual variations in awakenings

All foregoing considerations have been based on the relation between the average percentage awakenings as a function of a noise exposure measure. In individual subjects this percentage may be smaller or larger than the average value. Ollerhead (1992) gives information about the inter-individual variation in percentage noise-induced awakenings. Table C2 of the Ollerhead report specifies that 2.5% of a group of residents in a specified situation has a percentage of noise-induced awakenings which is at least two times as large as the average value and another 2.5% has at most half this percentage awakenings. This factor 2 corresponds with a change in equivalent sound level of 3 dB(A). Therefore, the Ollerhead data indicate that 2.5% of the residents awakes due to aircraft noise events a number of times which corresponds with the average number of noise-induced awakenings due to an at least 3 dB(A) higher equivalent sound level and for another 2.5% of the residents this value corresponds to an at least 3 dB(A) lower equivalent sound level.

5. CONCLUSION

The model presented in this report is based on the assumption that noise-induced awakenings during one night do not depend upon each other. At an equivalent sound level of 27 dB(A) on a yearly basis the average number of awakenings is estimated to be 13 a year. This is an average value and applicable only for a seven hours sleep time and windows in ventilation-position. In calculating the 'worst case' for an equivalent sound level of 27 dB(A) on a yearly basis the following aspects have to be taken into account:

- possible deviations of the model from reality
- longer sleep period than 7 hours a night (this report also considers a sleep period of 8 hours)
- windows opened during a part of the year (in this report taken as 4 months a year)
- inter-individual differences in sensitivity to noise-induced awakenings.

With respect to the first factor, a doubling of the angle of the straight line, representing the relation between percentage awakenings and SEL_{ind}, corresponds to a doubling of W and a shift of this straight line over 5 dB(A) corresponds with a multiplication of W with 3.2. Assuming that it is not likely that these two possibilities both occur at the same time, and this seems a reasonable assumption, and taking these two possibilities as independent, then it may be assumed that W will increase by a factor $\sqrt{[2^2 + (3.2)^2]} = 3.8$.

A sleep period of 8 instead of 7 hours, with during the eighth hour an exposure to aircraft noise as specified before, and windows opened during 4 months a year result together in a multiplication of W with a factor 3.8. It has also already been stipulated that in 2.5% of the people W is at least two times the average value. Multiplication of all these factors with each other results in the conclusion that 2.5% of the residents for which the aircraft noise exposure is described by a nighttime equivalent sound level of 27 dB(A) will awake due to aircraft noise events maximal 28.8 x 13 times a year. This is 375 awakenings a year, which means maximal on average once a night. It should be stressed that this occurs only in situations in which the combination of SEL and n is such that this maximum is reached. Many other combinations of SEL and n cause on average (much) less noise-induced awakenings and there may be on average even zero noise-induced awakenings at a nighttime equivalent sound level of 27 dB(A). This, e.g., occurs if the SEL values of all noise events are below 60 dB(A).

Taking into account the average number (13) of noise-induced awakenings at a nighttime equivalent sound level of 27 dB(A) and the number (373) of noise-induced awakenings in the worst case, it seems very likely that at this equivalent sound level these awakenings have no interaction with each other. Therefore the basis of the tentative model seems to be correct at this equivalent sound level. At (much) higher nighttime equivalent sound levels such an interaction might happen. For instance, at a nighttime equivalent sound level of 37 dB(A) (on a yearly basis) the numbers of noise-induced awakenings are 10 times these numbers at 27 dB(A): on average maximal 131 times a year and in the worst case on average 10 times a night. An interaction should then not be excluded; it is then even most probable. With regard to sleep stage changes, calculations showed that a nighttime equivalent sound level of 27 dB(A) on a yearly basis induces on average 381 of these changes a year in those situations in which the number of awakenings is maximal. This is on average somewhat over once a night. Calculations for the worst case show the number of noise-induced sleep stage changes to be on average 30 per night. Probably, these sleep stage changes should not be considered to be independent of each other. However, in which way this interaction acts on changes in sleep stages is unknown: the number of sleep stage changes may be lower or higher than according to the model. At nighttime equivalent sound levels (much) higher than 27 dB(A) on a yearly basis it should for sure be expected that interactions between sleep stage changes do occur.

In conclusion: it has been shown that noise-induced awakenings should be expected due to nighttime aircraft noise exposure with a nighttime equivalent sound level of 27 dB(A) on a yearly basis. According to the model this is in an average population 13 times a year during a sleep time of 7 hours with windows in ventilation-position. Due to modifying factors - windows opened during 4 months a year and a sleep time of 8 hours - the maximal number of awakenings increases in an average population to 50 times a year . The number of noise-induced awakenings in 2.5% of the residents is estimated to be maximal 375 times a year at a nighttime equivalent sound level of 27 dB(A). According to the tentative model, on average 380 noise-induced sleep stage changes a year occur at 27 dB(A) and in the worst case this number is about 30 times a night. Since it is unlikely that there is no interaction between sleep stage changes when they occur 30 times a night, it should be concluded that the tentative model may not give an accurate estimation of the number of noise-induced sleep stage changes for the worst case. Whether the estimate according to the model results in an over- or under-estimate of the actual number of noise-induced sleep stage changes cannot be deduced from the available data.

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ANNEXES

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 mor sine functions. 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

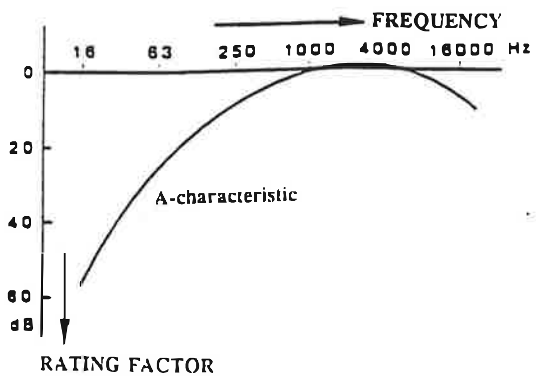
A sound has not only a frequency, but also a level (L). The level is related to the sound pressure (p). In practice, sound pressures range from less than 20 μPa up to more than 200 Pa, a range of 1 to 10 million. Therefore, in acoustics, the logarithm of the sound pressure relative to a reference sound 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 when noise is measured, to use a noise filter which rates the sound pressure levels at the different

Figure A1. Frequency weighting of sound.



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:

$$L_{Aeq,T}=10\log\frac{1}{T}\int_{0}^{T}\frac{p_A^2(t)}{p_0^2}dt \quad dB(A)$$

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})

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

in which:

- d (daytime) is the period from 07.00-22.00 h
- n (nighttime) 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})

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

in which:

- d(daytime) is the period from 0700-19.00 h
- ev(evening) is the period from 19.00-22.00 h
- n(nighttime) 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. Small aircraft noise exposure measure BKL

BKL is a L_{den} level, for legal requirements determined by specific rules dependent upon the two busiest aircraft days per week during the busiest 26 weeks of a year.

10. Etmaalwaarde (24-hours value)

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

in which:

- d(daytime) is the period from 07.00-19.00 h
- ev(evening) is the period from 19.00-23.00 h
- n(nighttime) 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).

11. Aircraft noise exposure measure B

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

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 (at most 10: during the night, at least 1: during the day)

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. Relation between SEL and $L_{Aeq,T}$:

$$\mathbf{L_{Aeq,T} = SEL - 35.6 + 10 \log n/T \quad (dB(A))}$$

in which:

. n is the number of noise events, all with the same SEL value, during T hours.

Annex B Calculations

1. AWAKENINGS

Exposure-effectrelation used:

$P_w = 0.18\ n\ (SEL_{ind} - 60)$.

If each noise event has the same SEL value, then:

$L_{Aeq,7h,ind} = SEL_{ind} + 10 \log n - 44$ dB(A).

From this it follows:

$P_w = 0.18\ n\ (L_{Aeq,7h,ind} - 10 \log n - 16)$, in which n is the number of noise events.

P_w is maximal, as a function of n, for that value of n with which the afgeleide of P_w to n is equal to zero. Then:

$$\log n = \frac{L_{Aeq,7h,ind} - 16}{10} - 0.43$$

The term 0.43 is equal to log e.

1.1 Determination of the number of awakenings at several values of $L_{Aeq,7h,ind}$

Suppose $L_{Aeq,7h,ind}$ is the same for each night of the year.

Then: W= 3.65 P_w.Table B1 gives W for values of $L_{Aeq,7h,ind}$ from 16 to 40 dB(A). At each of the $L_{Aeq,7h,ind}$ values, first it has been calculated at which n P_w is maximal and then P_w has been calculated at the nearest whole number of n, since in practice n should be a whole number.

Table B1 The total number of awakenings a year (W) at several values of $L_{Aeq,7h,ind}$. Also given the number of noise events and the values of SEL_{ind} with P_w and W maximal.

$L_{Aeq,7h,ind}$ in dB(A)	SEL_{ind} in dB(A)	n	P_w in %	W
16	>60.0	0	0	0
18	62.0	1	0.4	1.3
20	64.0	1	0.7	2.6
22	63.0	1 of 2	1.1	4.2
24	65.0	2	1.8	6.6
26	64.0	4	2.9	10.5
27	64.2	5	3.6	13.1
28	64.2	6	4.5	16.6
30	64.0	10	7.2	26.3
32	64.2	15	11.5	41.8
34	64.4	23	18.2	66.2
36	64.3	37	28.8	105.0
38	64.3	59	45.6	166.4
40	64.3	93	72.2	263.7

1.2 Determination of number of awakenings for $L_{Aeq,7h,ind}$ equal to 27 dB(A)

1.2.1 Each night the same noise situation

If each night the same situation occurs, then the nighttime noise exposure during each night is equal to the average value applicable for a year. Therefore, for each night the following equation is applicable:

$SEL_{ind} + 10 \log n = 71.$

In table B2 P_w has been calculated from SEL_{ind} and n, while SEL_{ind} and n satisfy the relation given above.

Table B2: The percentage awakenings a night as a function of the number of noise events, with $L_{Aeq,7h,ind}$ equal to 27 dB(A)

n	SEL_{ind} in dB(A)	P_w in %
1	71.0	1.98
2	68.0	2.87
3	66.2	3.36
4	65.0	3.59
5	64.0	3.61
6	63.2	3.48
8	62.0	2.84
10	61.0	1.80
12	60.2	0.45
12.5	60.0	0.00

1.2.2 Several scenario's

In this annex calculations have been made for several scenario's, with in each scenario a distinction between noisier and quieter nights. First, these calculations have been carried out for a nighttime equivalent sound level of 27 dB(A) on a yearly basis. The following scenario's have been chosen:

- 27 dB(A) during 365 nights
- 32 dB(A) during 1, 12, 36 and 115 nights. In order not to surpass 27 dB(A) on a yearly basis, only 115 nights with an equivalent sound level of 32 dB(A) are allowed.
- 37 dB(A) during 1, 12 and 36 nights (not more than 36 nights possible)
- 47 dB(A) during 1, 2 and 3 nights (not more than 3 nights possible)
- 52.6 dB(A) during 1 night (only one night possible).

First, for each of the noisier nights the number of noise events and their SEL_{ind} values have been calculated for the situation in which P_w is maximal. Then, the maximal permissible value of $L_{Aeq,7h,ind}$ for each of the quieter nights has been calculated in order to obtain a value of $L_{Aeq,7h,ind}$ equal to 27 dB(A) on a yearly basis. From this equivalent sound level during the quieter nights SEL_{ind} and n have again been calculated for the situation in which P_w is maximal. At last, W has been calculated by adding all noise-induced awakenings in the noisier nights to all noise-induced awakenings in the quieter nights. The result is presented in table B3. For the scenario with $L_{Aeq,7h,ind}$ equal to 52.6 dB(A) during one night a year W has also been calculated for the situation in which the noise exposure is to only one noise event. Such a (theoretical) noise event should produce a SEL_{ind} value equal to 96.6 dB(A).

It is obvious from the last column of table B3 that W is independent of the scenario chosen.

Table B3: The maximal number of awakenings a year for several scenario's which all have a $L_{Aeq,7h,ind}$ value of 27 dB(A) on a yearly basis.

Description situation				Situation in which W is maximal				
Noisier night(s)		Quieter nights		Noisier night(s)		Quieter nights		W
$L_{Aeq,7h,ind}$	number	$L_{Aeq,7h,ind}$	number	SEL_{ind}	number	SEL_{ind}	number	
27		27		64.0	5	64.0	5	13.1
32	1	26.97	364	64.2	15	64.0	5	13.2
32	12	26.7	353	64.2	15	64.7	4	12.1
32	36	25.8	329	64.2	15	63.1	4	13.2
32	115*	<16	250	64.2	15	>60	0	13.2
37	1	26.89	364	64.3	47	63.9	5	13.1
37	12	25.4	353	64.3	47	64.6	3	13.1
37	36*	<16	329	64.3	47	>60	0	13.1
47	1	25.6	355	64.8	468	64.3	3	13.1
47	2	23.6	354	64.3	468	64.6	2	13.2
47	3	<16	353	64.3	468	>60	0	10.9
52.6	1	<16	355	64.3	1698**	>60	0	13.1
(52.6)	(1)	(<16)	(355)	(96.6)	(1)	(>60)	(0)	(0.1)

* maximal number of nights, in order not to surpass 27 dB(A) on a yearly basis.
** 4 noise events a minute.

1.3 Number of awakenings at values of $L_{Aeq,7h,ind}$ other than 27 dB(A)

P_w depends upon $L_{Aeq,7h,ind}$:

$P_w = 0.18\, n\, (L_{Aeq,7h,ind} - 10 \log n - 16)$.

Let P_w be the percentage awakenings due to a value of $L_{Aeq,7h,ind}$ equal to 27 dB(A) and let P'_w correspond to another equivalent sound level:

$P'_w = 0.18\, n'\, (L_{Aeq,7h,ind} - 10 \log n' - 16)$.

If both P_w and P'_w are maximal then:

$$\log n - \log n' = \frac{L_{Aeq,7h,ind} - L_{Aeq,7h,ind}}{10}$$

From this it follows:

$$\log n/n' = \frac{\Delta L}{10} \quad met \quad \Delta L = L_{Aeq,7h,ind} - L_{Aeq,7h,ind}$$

Also applicable is: $P_w/P'_w = n/n'$ if P_w and P'_w are maximal.

Thus: $P'_w = P_w\ n'/n = P_w\ 10^{-\Delta L/10}$.

This equation shows that if another equivalent sound level than 27 dB(A) on a yearly basis is chosen IN table B3 W has to be multiplied by a factor $10^{-\Delta L/10}$. For instance, if ΔL is chosen equal to -5 dB(A) ($L_{Aeq,7h,ind}$ is then equal to 32 dB(A)) then W has to be multiplied for all scenario's with a factor 3.16. For a $L_{Aeq,7h,ind}$ value of 26 dB(A) W has to be multiplied by a factor 0.79.

1.4 Number of awakenings for sleep periods longer than 7 hours

The tentative model has the following formula with respect to noise-induced awakenings as a basis: $P_w = 0.18\ n\ (SEL_{ind} - 60)$. That implies that P_w is independent of the duration of the period in which the noise events occur, since this period does not enter into the equation. However, keeping the SEL_{ind} values and n constant and changing the duration of the nighttime period to be taken into account does change the equivalent sound level over that period. Apparently, noise events which result in an equivalent sound level of 27 dB(A) over 7 hours, will result in an equivalent sound level over 8 hours of 27.0 - 10 log 8/7 = 26.4 dB(A). The difference is therefore 0.6 dB(A).

In the Netherlands nighttime aircraft noise regulation a sleep period of 7 hours has been chosen. Only for that period restrictions with respect to nighttime aircraft noise are appropriate. For Schiphol International Airport it has been proposed to specify the nighttime period as from 23.00 to 06.00 hours. As has been shown in paragraph 4.3, many people in the Netherlands have a sleep period which lasts after 6 hours (Gezondheidsraad, 1991). Unfortunately, no detailed information is available about the noise levels of early morning aircraft noise events. Therefore, only calculations can be carried out in which the noise exposure and the extension of the sleep period is reasonably estimated. Suppose people do sleep another hour after the nighttime period specified in the regulations, and suppose that during the eighth hour 5 aircraft noise events occur each with a SEL value of 64 dB(A). The equivalent sound level during that hour is then 35 dB(A) and the equivalent sound level during the 8 hours is 29 dB(A) (7 hours 27 dB(A) and one hour 35 dB(A) is equivalent to 8 hours 29 dB(A)). With this extended sleep period, the total number of awakenings is twice as large as for the 27 dB(A) calculations, i.e. 26 per year. Also the number of sleep stage changes is doubled.

2 SLEEP STAGE CHANGES

Exposure-effectrelation to be used:

$P_v = 0.65\ n\ (SEL_{ind} - 32)$.

P_v is maximal at an n value for which $\log n = (L_{Aeq,7h,ind} + 12)/10 - 0.43$,

that is to say for $\log n = L_{Aeq,7h,ind}/10 + 0.77$.

For a value of $L_{Aeq,7h,ind}$ above 16 dB(A) P_v is maximal above at least 234 noise events a night. Therefore, in practical situations P_v is an increasing function of n and there does not exist a maximum such as with P_w.

2.1 Determination of the number of sleep stage changes at several values of $L_{Aeq,7h,ind}$

Suppose $L_{Aeq,7h,ind}$ is the same for each night. Then:

$V = 3.65\ P_v$

Table B4 specifies V for values of $L_{Aeq,7h,ind}$ from 16 to 34 dB(A) for those situations in which W is maximal (see table B1).

Table B4: Number of sleep stage changes a year as a function of $L_{Aeq,7h,ind}$, for those situations in which W is maximal

$L_{Aeq,7h,ind}$ in dB(A)	V
16	0
18	71
20	76
22	115
24	187
26	304
27	381
28	458
30	759
32	1146
34	1768

2.2 Determination of number of sleep stage changes for $L_{Aeq,7h,ind}$ equal to 27 dB(A)

2.2.1 Each night the same noise situation

Table B5 specifies P_v for SEL_{ind} + 10 log n = 71 and P_v = 0.18 n (11-10 log n).

Table B5: The percentage sleep stage changes as a function of the number of noise events for the situation in which $L_{Aeq,7h,ind}$ is equal to 27 dB(A)

n	SEL_{ind} dB(A)	P_v in %
1	71	25
2	68	47
3	66.2	67
4	65	86
5	64	104
6	63.2	121
8	62	156
10	61	189
12	60.2	220
25	57	407
50	54	715

2.2.2 Several scenario's

For the scenario's mentioned in paragraph 1.2.2 the total number of sleep stage changes a year (V) have been calculated. The result is given in table B6.

Table B6: The total number (V) of sleep stage changes a year according to several scenario's with a value of $L_{Aeq,7h,ind}$ equal to 27 dB(A)

Scenario with the following situation in the noisier night(s) (see table B3)		number of sleep stage changes a year V
$L_{Aeq,7h,ind}$ in dB(A)	n	
27	5	380
32	1	382
32	12	338
32	36	379
32	115	361
37	1	387
37	12	343
37	36	355
47	1	329
47	2	429
47	3	428
52.6	1	362
(52.6)	(1)	(0.4)

The total number of sleep stage changes is rather independent of the scenario chosen. For the scenario's with the noisiest nights V is about 13% higher than for the scenario with $L_{Aeq,7h,ind}$ equal to 27 dB(A) during each night.

2.3 Number of sleep stage changes at values of $L_{Aeq,7h,ind}$ other than 27 dB(A)

The same reasoning is applicable as presented in paragraph 1.3 of this annex with respect to awakenings. In table B6 V has to be multiplied by a factor $10^{-\Delta L/10}$ if an equivalent sound level of 27 - ΔL dB(A) is taken as a yearly basis.

2.4 Number of sleep stage changes for sleep periods longer than 7 hours

Here again the same reasoning is applicable as presented in paragraph 1.4 of this annex with respect to awakenings.

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