Swedish Aircraft Noise Calculation Model

This model is based on the Nordic Method, Air Traffic Noise Calculation-Nordic Guidelines, Nord 1993:38, which defines the technical demands that air-traffic noise calculation models must fulfil in order that the calculation results can be accepted by the environmental authorities of the Nordic countries. The segmentation method is used. The calculation of noise from each segment is dependent on actual speed and power setting in each segment. The method is intended for computer implementation.

1. Principles for Preparation of Calculation Assumptions

Air-traffic noise calculations cannot be made until the necessary information determining the individual calculation task has been provided.

The calculation assumptions are divided into four groups:

1.1 Traffic Assumptions

- The calculation situation which can be characterised by the existing (perhaps previous) or a future traffic
- The number of operations, perhaps distributed on a number of traffic categories
- Time-of-day traffic distribution
- Distribution of traffic on aircraft types.

1.2 Operational Assumptions

- Runway configuration with indication of directions, lengths, surfaces, plans for extension, etc.
- Runway use, which is dependent on local wind conditions combined with air traffic destination and places of origin. The runway use might also be affected by environmental restrictions. Eventually, the runway use might depend on the wind sensitivity of the individual aircraft.
- The flight track system which is the horizontal projection of the flight paths used by the air traffic. The flight track system is defined by flight tracks or flight sectors. For both flight tracks and flight sectors horizontal dispersion of the traffic must be defined.
- Traffic distribution on the specific flight tracks or flight sectors.

1.3 Noise and Performance Data

Determination of the noise exposure requires that the following information is available for each of the aircraft types used:

- The sound exposure level L_{AE} and the maximum A-weighted sound pressure level L_{Amax} as a function of the shortest distance to the aircraft during fly-over and as a function of the engine power setting
- Flight profiles during take-off and departure at typical take-off weights, indicating the altitude, speed, and engine power setting as a function of distance to start of take-off roll
- The flight profile during arrival and landing

Formats of noise and performance data are defined in Section 3.

For civil aviation airports and military air bases calculation of noise exposure is in general made for each individual aircraft type.

For general aviation airfields the number of aircraft types is often considerable, and a simplification is necessary. The principles used to simplify the calculations, described in Danish Miljöstyrelsen Report 1992:5, are based on a noise and performance classification. All propeller-driven aircraft types with an MTOM of 5700 kg or lower are divided into 4 "noise classes", each 5 dB wide. The noise classification is based on the L_{Amax}-value measured during noise certification. All types are further divided into 3 "profile classes" depending on the take-off profile gradient. Any propeller aircraft traffic mix can subsequently be simplified to a maximum of three "average types" with a take-off profile each.

If an air traffic noise exposure calculation includes helicopter operations, these must be treated separately. The flight track will often diverge from fixed-wing aircraft tracks, and the take-off procedures are mostly specific for the operator. Normally, the calculation assumptions need to be established in co-operation with the operator.

1.4 Calculation Principles

The calculation principles shall comply with the principles of the model described in Sections 4 and 5. In general the same principles are used for calculation of noise exposure for civil airports, general aviation airfields, and military air bases. The principles include assumptions concerning e.g.:

- Air attenuation factors for sound propagation (included in the NPD data, see chapter 3.1)
- Lateral attenuation model
- Directivity pattern of noise source
- Forward speed effects on noise emission (flight effect)

2. Calculation Result

The model is made for calculation of the equivalent A-weighted sound pressure level (L_{Aeq}) as well as for calculation of the maximum A-weighted sound pressure level (L_{Amax}).

The model concerns only the calculation methodology, whereas the method for rating aircraft noise (FBN) is not included. The rating method include guidelines for how the single noise events have to be weighted depending on the time of day they occur.

3. Input Data Formats

3.1 Noise Power Distance data, NPD

Depending on whether the calculation result shall be expressed as FBN (L_{Aeq}) or L_{Amax}, the input noise data for each individual aircraft are the sound exposure level L_{AE} or the maximum A-weighted sound pressure level L_{Amax}.

For each individual aircraft the noise data are given in a format showing the noise level as a function of distance to the aircraft and engine power setting. The format which is identical for L_{AE} and L_{Amax} is shown in Table 1. Distance and engine power are given in ascending order.

In general the noise data are taken from the Nordic Noise and Performance Data Base which also contains a method for estimation of L_{Amax} from L_{AE} (and vice versa). The Nordic Noise and Performance Data Base consists of data from the largest operators in the Nordic countries. For other aircraft reference is made to the database in FAA Integrated Noise Model.

Distance	Engine power setting				
	P_1	P_2	P_3	...	P_n
d_1	L_{11}	L_{12}	L_{13}	...	L_{1n}
d_2	L_{21}	L_{22}	L_{23}	...	L_{2n}
d_3	L_{31}	L_{32}	L_{33}	...	L_{3n}
.	.	.	.		.
.	.	.	.		.
					.
d_m	L_{m1}	L_{m2}	L_{m3}	...	L_{mn}

Table 1.
Noise data format: L_{AE} or L_{Amax} as a function of the closest distance d and engine power setting P.

The noise levels in the format correspond to the noise level measured during a fly-over. During the fly-over the aircraft is assumed, within the time period which determines the noise metric, to follow a straight path with constant speed and power setting. The distance in the format is the closest between aircraft and measurement position during the fly-over. The engine power is expressed in the unit of relevance to each individual aircraft. This is for jet aircraft normally thrust in lbs per engine. The noise level in the format is corrected to comply with the atmospheric attenuation factors described in ECAC Doc 29, ICAO Cir 205 and SAE Air 1845. The validity range is: air temperatures less than 30°C, product of air temperature (°C) and relative humidity (%) larger than 500, wind speed less than 8 m/s. For L_{AE} the reference speed corresponding to the values in the format shall also be stated.

Estimation of noise levels at distances and power settings between the values in the format is made by interpolation. Linear interpolation is used between two power settings whereas logarithmic interpolation is used between two distances according to Equation 1.

$$L(d) = L(d_1) + (L(d_2) - L(d_1)) \frac{\log d - \log d_1}{\log d_2 - \log d_1} \qquad \textbf{(Equation 1)}$$

where L(d) is the noise level at the distance d,
$L(d_1)$ is the noise level at distance d_1 in the format immediately below d,
$L(d_2)$ is the noise level at distance d_2 in the format immediately above d.

The interpolations used are illustrated in Figure 1. where P is the power setting and P_1 and P_2 are the power settings in the format immediately below and above P.

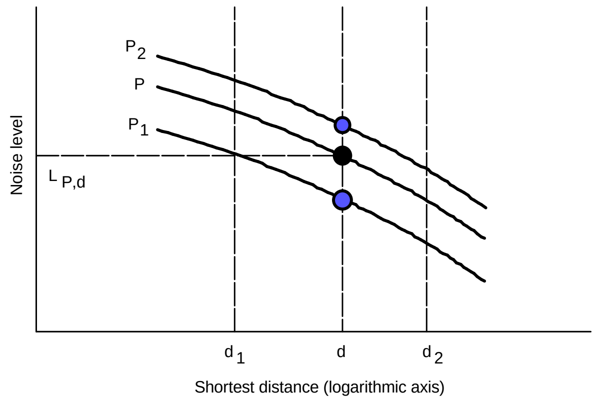

Figure 1.
Interpolation in the noise data format.

The noise data should preferably cover all distances and power settings of relevance to the noise calculations. Most data bases cover the distance range approx. 60-7600 m (200-25000 ft). If not so, it is necessary to extrapolate the data. Extrapolation is made by the same principles as interpolation.

3.2 Performance data

Performance data for each individual aircraft type and take-off and landing procedure are given in a format showing the height of the aircraft relative to the runway, the speed relative to the ground (ground speed), and the engine power setting as a function of the distance from start-of-roll when brakes are released (take-offs) or end-of-roll (landings). In this way there is no fundamental difference between take-off and landings, as a landing may be regarded as a take-off performed backwards. The performance data format is shown in Table 2. The distances x must be in ascending order. By calculation of L_{Amax} the information on ground speed is not used except for calculating flight effect during take off roll.

Between the heights and the engine power settings in the format linear interpolation is used. Between the speeds an interpolation is used assuming constant acceleration.

This interpolation principle is defined in Equation 2.

$$V = \sqrt{V_1^2 + \left(V_2^2 - V_1^2\right)\frac{x - x_1}{x_2 - x_1}} \qquad \textbf{(Equation 2)}$$

where x is the distance from start-of-roll/end-of-roll,
V is the speed at the distance x, (ref section 4.2)
V_1 is the speed at distance x_1 in the format immediately below x,
V_2 is the speed at distance x_2 in the format immediately above x.

Distance from start-of-roll/ end-of-roll	Height	Speed	Engine power setting*
x_0	h_0	V_0	P_0
x_1	h_1	V_1	P_1
x_2	h_2	V_2	P_2
x_3	h_3	V_3	P_3
. . .	. . .	. . .	. . .
x_n	h_n	V_n	P_n

* P is the engine power set at a point. The power is maintained through the segment to the next point.

Table 2.
Performance data format: Height, speed, and engine power setting as function of the distance from start-of-roll/end-of-roll.

The reference conditions for the performance data are:

- ISA atmospheric (15°C, 70% relative humidity)
- 4.1 m/s (8 kts) headwind, no wind gradient
- No runway slope
- Airport at sea level

In general the performance data are taken from the Nordic Noise and Performance Data Base and INM as a complement.

4. Calculation Model for a Single Event

The calculation model outlined in this section is adapted to the requirements concerning calculation result metrics (Section 2) and input data formats (Section 3).

The conditions for using the noise and performance data to calculate L_{AE} or L_{Amax} in a calculation point without any corrections are (see Section 3):

- The calculation point is placed on the flight track (beneath the flight path).
- The path (and therefore the flight track) must be straight on the section which determines the noise metric (L_{AE} or L_{Amax}).
- The speed (only for L_{AE}) and power setting have to be constant on the section which determines the noise metric.
- The speed has to be equal to the reference speed (only for L_{AE}).

These conditions are in practice, not fulfilled, the single event noise level has to be corrected. The basic model for calculation of the noise level without any corrections are described in Section 4.1. The corrections are described in Sections 4.2-4.7.

<u>Segmentation</u>

The flight path is divided into segments. The basic segmentation is dependent on the structure of the performance data. In addition to that basic segmentation, the take-off run and turns are divided into several segments. When calculating the dose (FBN) the noise energy from each segment is added, taking account of:

- The proportion which depends on the angle from the observation point to the start and end points of the segment
- The thrust used within the segment
- The speed in the midpoint of the segment

The lateral attenuation is dependent on the noise emission angle. When calculating noise from a flight the same lateral attenuation is applied for all segments.

4.1 Basic Calculation for each segment before Corrections

For a given flight track and flight profile the point on the path for which the distance to the calculation point is shortest is determined. This is illustrated in Figure 2. In the figure the closest point is denoted P and calculation point B.

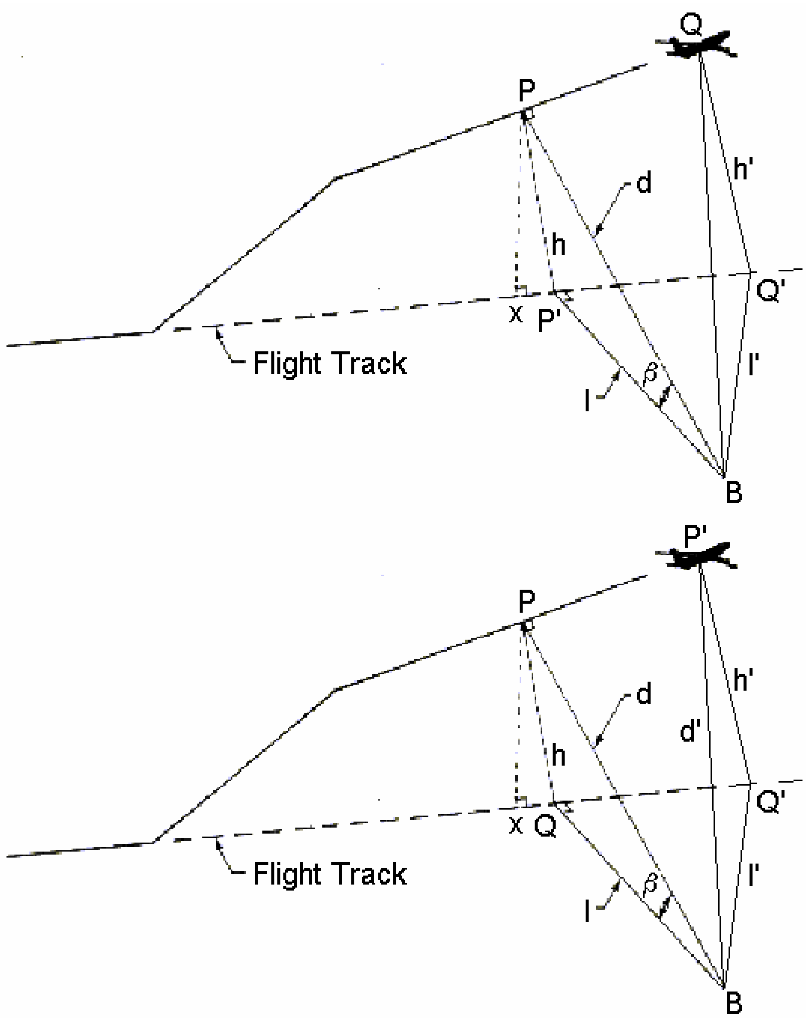

Figure 2.
Definition of geometrical parameters.

From the performance data format the height at point P is determined. The distance from P to B denoted d is calculated. Based on the distance d and the engine power setting the uncorrected noise level for each segment can be determined from the noise data format. Distance d is computed according to Figure 2 even if point P lies beyond the ends of the segment.

Since the speed in a segment normally deviates from the reference speed for the noise levels in the format (only for L_{AE}), it is necessary to make a correction for the change in duration of the noise event caused by the change in speed. The correction is described in Section 4.2.

If the calculation point is not placed beneath the flight path, but laterally, a correction has to be added for the excess lateral attenuation as described in Section 4.3. The lateral attenuation is basically a function of the elevation angle β between the line segments BQ and BP and of the distance *l* from B to Q. Q is as shown in Figure 2 defined as the point on the flight track for which PQ is perpendicular to the flight path. The flight path segment which includes P becomes hereby the normal to the plane defined by the point P, Q, and B. Since the noise emission angle for jet aircraft is directed backwards, the Swedish model requires an adjustment described in Section 4.3. Point P' in Figure 2 represents the aircraft at a position where the angle between BP' and the flight path is the noise emission angle.

The calculation of the proportion of noise energy from each segment is described in Section 4.4.

Methods for calculations of the noise from ground roll are described in Sections 4.5 and 4.6 for take-offs and landings, respectively.

If the flight track is not straight, but includes one or more turns, a correction has to be added due to the change in duration caused by the track geometry (only for L_{AE}). Correction for track geometry is described in Section 4.7.

4.2 Correction for Duration

If the speed of the aircraft changes, the duration of the noise event will change also. Therefore, if the speed of the aircraft deviates from the reference speed for L_{AE} in the format, it is necessary to make a correction for the change in duration within each segment. The speed in the midpoint of each segment is used for the calculation. Interpolation is performed according to Equation 2. The correction for duration is calculated by Equation 3.

$$\Delta L_V = 10 \log \frac{V_{ref}}{V} \qquad \textbf{(Equation 3)}$$

where V_{ref} is the reference speed for the noise data in the format,
V is the current speed given in the same units as V_{ref}.

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The duration correction is of no relevance when calculating maximum levels.

4.3 Correction for Lateral Attenuation

If the calculation point is not placed beneath the flight path, but in a lateral position, a correction has to be added for the excess attenuation by the terrain surface. In connection with aircraft sound propagation this attenuation is called lateral attenuation. Often the term ground attenuation is used instead of lateral attenuation. However, this may lead to misunderstandings, as ground attenuation normally is defined as the excess attenuation relative to the free-field level (no ground is present) whereas the lateral attenuation is the excess attenuation relative to the overflight level.

The lateral attenuation model, described in SAE AIR 1751, is combined with equations for the downwind conditions. SAE AIR 1751 assumes a flat terrain surface covered by short-cut grass.

Lateral attenuation is based on the elevation angle of the segment, and the distance to the segment. Lateral attenuation is calculated separately for each segment.

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Referring to Figure 2, the elevation angle used for calculation of lateral attenuation of noise from propeller aircraft, or from jet aircraft whose maximum directivity angle is 90 degrees, is the angle β indicated between P'B and PB.

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Most jet aircraft have directivity toward the rear. In Figure 2, Point Q represents the aircraft at a position such that the angle between PB and PQ is the complement of the directivity angle. When calculating lateral attenuation of noise from jet aircraft the angle β is based on the maximum noise emission position. The following distances are defined in Figure 2:

h is the aircraft height at P, the point closest to the calculation point.

l is the closest distance between the calculation point and the projection of the flight track on ground, point Q.

h' is the height at P', the point where maximum noise is generated when measured at the observation point, and depends on the angle of directivity. Point Q' is the corresponding projection of this onto the flight track on the ground, analogous to Q.

l' is the distance between the point Q' and the calculation point.

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Two elevation angles may be defined: β_1 = ARCTAN (*h*/*l*) (indicated as β in Figure 2), and β_2 = ARCTAN (*h'*/*l'*) (analogous angle for maximum emission point). Each of these angles has a corresponding distance, *l* with β_1 and *l'* with β_2. Attenuation will be computed for both β, *l* pairs, and the smaller attenuation used in the model.

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Downwind conditions should be assumed when calculating lateral attenuation. The downwind conditions are calculated by modification of the elevation angle. The modified elevation angle β' is calculated according to Equations 4 and 5.

$$\beta' = \beta + \Delta\beta(\ell) \qquad \textbf{(Equation 4)}$$

where

$$\Delta\beta(\ell) = 1.13\log\left(\ell^2 + 525\right) - 3.03 \quad \ell < 914\ \text{m}$$
$$\Delta\beta(\ell) = 3.66 \quad \ell \geq 914\ \text{m} \qquad \textbf{(Equation 5)}$$

The hypothetical lateral attenuation G(l) in dB for aircraft on the ground under calm conditions is calculated based on the horizontal distance l (in meters) according to Equation 6.

(Equation 6)

$$G(\ell) = 15.09\left(1 - e^{-0.00274\ell}\right) \text{for } 0 < \ell < 914\ \text{m}$$
$$G(\ell) = 13.86 \quad \ell \geq 914\ \text{m}$$

If the the horizontal distance is larger than 914 m, the lateral attenuation G(β) is calculated based on the modified elevation angle β’(in °) according to Equation 7.

(Equation 7)

$$G(\beta') = 3.96 - 0.066\beta' + 9.9\,e^{-0.13\beta'} \text{ for } 0° \leq \beta' \leq 60°$$
$$G(\beta') = 0 \quad \beta' > 60°$$

When the aircraft is airborne and the horizontal distance is less than 914 m, the lateral attenuation G(β’,l) is predicted by a transition equation as shown in Equation 8.

$$G(\beta', \ell) = \frac{G(\ell)\,G(\beta')}{13.86} \qquad \textbf{(Equation 8)}$$

Equations 6 and 7 are illustrated in Figures 3 and 4.

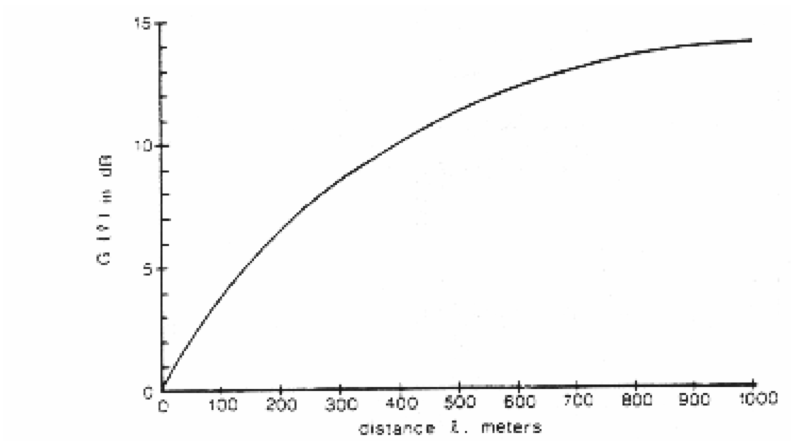

Figure 3.
SAE AIR 1751. Recommended prediction curve for $\beta = 0$.

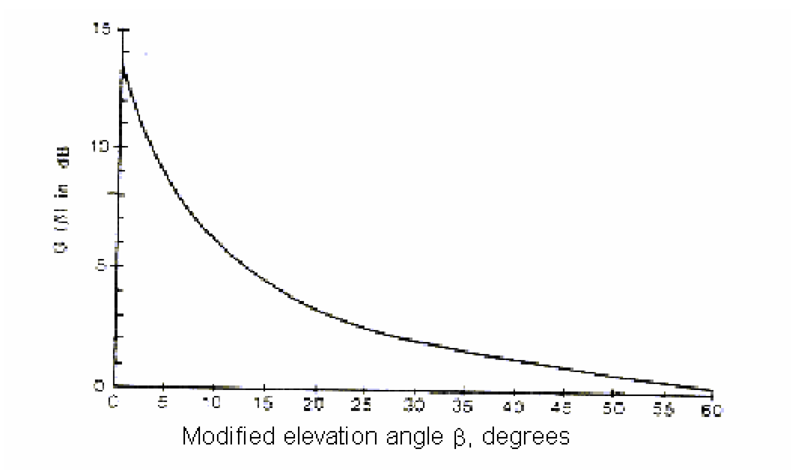

Figure 4
SAE AIR 1751. Recommended prediction curve for $\beta' > 0$ and $l > 914$ m.

4.4 Proportion of Noise Energy from Each Segment

The following methods shall be used for determination of the effect of power changes on L_{Amax} and the determination of proportion of noise energy from each segment for the calculation of L_{AE}. If directivity data is not available the maximum noise emission angle is set to 50° from the tail for jet aircraft and 90° for propeller aircraft.

4.4.1 Energy Proportions from Two Segments

This section describes the principle for adding noise energy from two segments for calculation of L_{AE}.

Knowing on the one hand, the shortest distance between the calculation point B and the aircraft path d, and on the other hand, the directivity angle α, **the first step** is to determine the point P_d which is the position of the aircraft on the line from the aircraft along the maximum directivity direction to the calculation point B as shown in Figure 5.

The second step is to find the imaginary calculation point B′ perpendicular to the direction of the aircraft on the distance d from the point P_d.

The third step is to determine the angle θ_m (in °) between the direction of the aircraft and the direction P_mB'. P_m is the point where the power setting is changed from M_1 to M_2.

If P_mB is more than three times P_dB, the effect of changes in power setting may usually be ignored when calculating L_{AE} whereas twice is usually enough when calculating L_{Amax}.

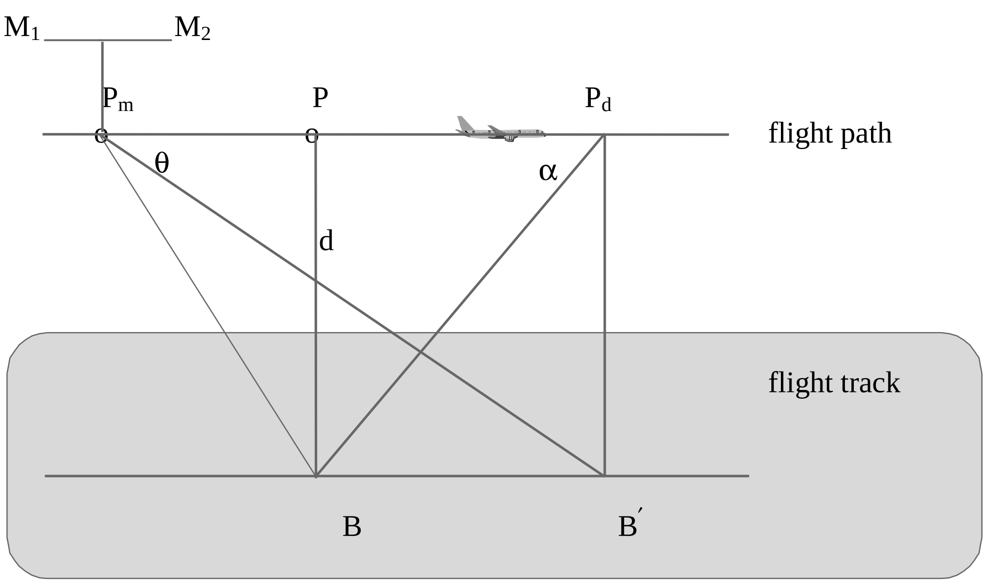

Figure 5
Definition of geometrical parameters for prediction of a change in power setting

The effect of a change in power setting on the sound exposure level L_{AE} is calculated according to Equation 9.

$$L_{AE}(d) = 10\log\left(F(\theta_m)10^{\frac{L_{AE,1}(d)}{10}} + (1 - F(\theta_m))10^{\frac{L_{AE,2}(d)}{10}}\right) \quad \textbf{(Equation 9)}$$

where $L_{AE,1}(d)$ is the sound exposure level in distance d at the power setting before P_m,
$L_{AE,2}(d)$ is the sound exposure level in distance d at the power setting after P_m,
$F(\theta_m)$ is the proportion of the sound energy from $\theta = 0°$ to $\theta = \theta_m$.

If the speed is different between the two segments, then $L_{AE,1}$ and $L_{AE,2}$ should be adjusted according to the duration correction, Equation 3.

The proportion of the sound energy $F(\theta)$ from 0° to θ is calculated according to Equation 10.

$$F(\theta) = \frac{\theta}{180} - \frac{\sin(\theta)\cos(\theta)}{\pi} \quad \textbf{(Equation 10)}$$

4.4.2 Energy Proportions from Three or More Segments

The principle is easily extended to cover three or more segments as the proportion of the energy from θ_{m1} to θ_{m2} is equal to $F(\theta_{m2})-F(\theta_{m1})$. Figure 6 illustrates a situation where there are three segments. The angles θ_{m1} and θ_{m2} are indicated.

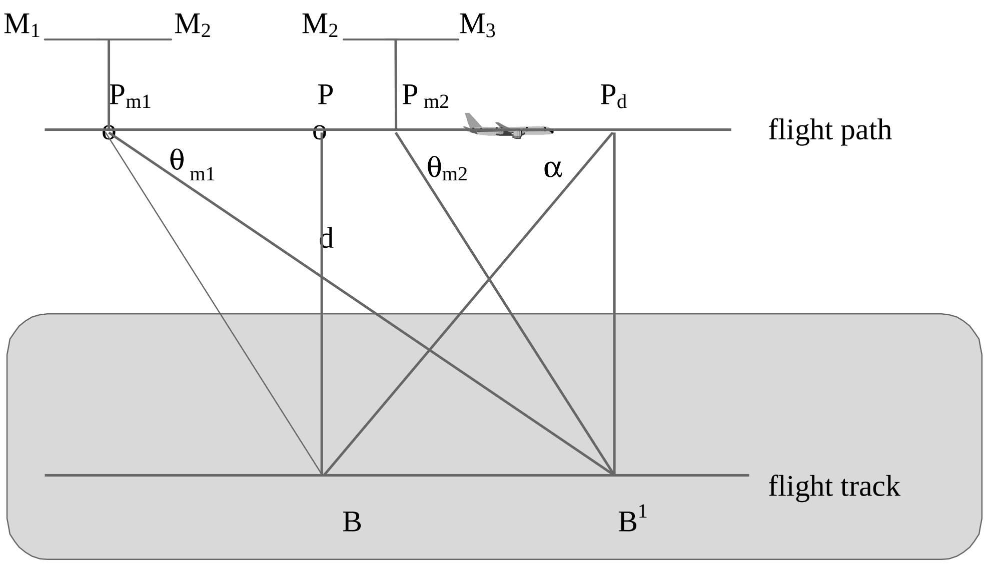

Figure 6
Definition of geometrical parameters for prediction of two changes in power setting

The proportion of sound energy between P_{m1} and P_{m2} is given by Equation 11.

$$F(\theta_{m2}) - F(\theta_{m1}) = \frac{\theta_{m2} - \theta_{m1}}{180} - \frac{\sin(\theta_{m2})\cos(\theta_{m2}) - \sin(\theta_{m1})\cos(\theta_{m1})}{\pi} \quad \textbf{(Equation 11)}$$

If the three segments sketched in Figure 6 have significant contributions to the noise, then Equation 9 would be modified to Equation 12.

$$L_{AE}(d) = 10\log\left(F(\theta_{m1})10^{\frac{L_{AE,1}(d)}{10}} + \left(F(\theta_{m2}) - F(\theta_{m1})\right)10^{\frac{L_{AE,2}(d)}{10}} + \left(1 - F(\theta_{m2})\right)10^{\frac{L_{AE,3}(d)}{10}} \right)$$

(Equation 12)

It is straightforward to extend Equation 12 to an arbitrary number of segments:

$$L_{AE}(d) = 10\log\sum_{N}\left(F(\theta_{m,i+1}) - F(\theta_{m,i})\right)10^{\frac{L_{AE,i}(d)}{10}} \quad \textbf{(Equation 13)}$$

4.4.3 Correction to L_{Amax} for Change in Power Setting

The effect of changes in power setting on the maximum L_{Amax} is calculated according to Equation 14. The highest of the two alternative values in Equation 14 is used.

(Equation 14)

$$L_{Amax}(d) = L_{Amax,1}(d)$$
$$L_{Amax}(d) = L_{Amax,2}(d) + 10 \log\left(\sin^4(\theta_m)\right)$$

where $L_{Amax,1}(d)$ is the maximum level in distance d at the power setting corresponding to the segment which contains P,

$L_{Amax,2}(d)$ is the maximum level in distance d at the power setting corresponding to the adjoining segment.

Also in the case of maximum levels the principle may easily be extended to cover two or more changes in engine power settings as the second alternative in Equation 14 is repeated for each power setting

4.5 Noise during Take-Off Ground Roll

Prediction of the noise exposure in a calculation point located along the runway or behind the start-of-roll is a very complicated matter. As mentioned above, the conditions for using the noise data from the format without corrections are a straight infinite flight path and constant speed and power setting. During the acceleration of an aircraft from start-of-roll to lift-off neither of the conditions are fulfilled. Furthermore, the noise emission from the engine jet stream, which is normally the main noise source for jet engines, is highly affected by the speed of the aircraft even if the power setting is kept constant. This effect, which is most often called the "flight effect," causes an attenuation in the noise emission of approximately 0,036 dB for every knot (kts) the speed is increased. This effect is especially important during take-off ground roll where the noise emission in most cases is 5 or 6 dB higher at start-of-roll compared to lift-off.

In the new version of the Swedish model, segmentation is used, with procedures similar to those used in the Integrated Noise Model and Noisemap. The takeoff roll is divided into ten segments.

The geometrical parameters of the method are defined in Figure 7. The angle α is the noise directivity angle, typically 50 degrees for jets aircraft and 90 degrees for propeller aircraft. “Forward of start of takeoff roll” refers to positions to the right of the dashed lines at angle α to the start of roll (left end of Figure 7), while “behind start of takeoff roll” refers to positions to the left.

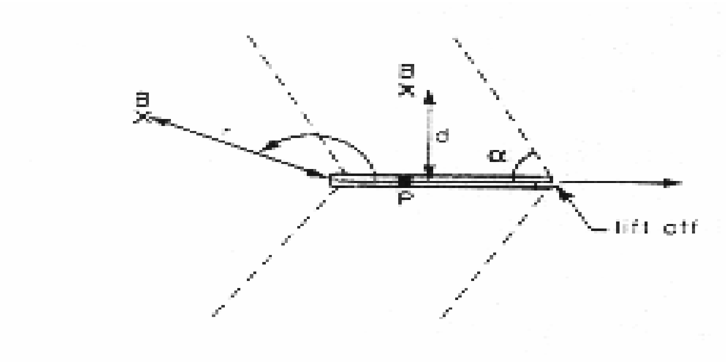

Figure 7
Definition of geometrical parameters during take-off ground roll.

The speed of the aircraft at point P along the runway is given by Equation 15.

$$V = \sqrt{V_0^2 + \left(V_L^2 - V_0^2\right) \frac{x}{x_L}} \qquad \textbf{(Equation 15)}$$

where V_0 is the speed at start-of-roll,
V_L is the speed at lift-off,
x is the distance from start-of-roll to midpoint of segment,
x_L is the ground roll distance in the same unit as x.

At a receiver point B, adjacent to runway position P and distance d from it, the Minimum Method specifies that the sound exposure level is calculated according to Equation 16.

$$L_{AE}(x,y) = L_{AE,TO}(d) + \Delta L_V - G(0,d) \qquad \textbf{(Equation 16)}$$

where $L_{AE,TO}(d)$ is L_{AE} at the reference speed, distance d and power setting corresponding to lift-off,
ΔL_V is the duration correction calculated as described in Section 4.2.
$G(0,d)$ is the lateral attenuation as described in Section 4.3

Equation 16 is valid at distance d small compared to the length of takeoff roll. Distance d must actually be small compared to the length of a section of takeoff roll over which the speed V does not change substantially. A criterion similar to P_mB being more than three times P_dB, discussed earlier, is applicable. When d is larger, segmentation as described in Section 4.4 must be used. In view of this issue, it is more practical to always use segmentation and never use Equation 16. Calculation of L_{AE} for takeoff roll, forward of the start of roll, is thus performed according to segmentation as described in Section 4.4.2. To ensure continuity of results, the contribution of the first segment is computed with $\theta_1 = 0°$, i.e., the first segment is modelled as if it continued to minus infinity at a speed of 16 knots.

The speed V_0 at start-of-roll is specified to be 16 kts. The speed has not been chosen as representative of a typical speed, but rather to ensure that the predicted noise levels correspond to the measured noise levels after having added the correction ΔL_V. In this way the correction includes changes in duration as well as the flight effect. For a lift-off speed of 160 kts the 16 kts correspond to corrections of +10 dB at the start-of-roll relative to lift-off. In the Nordic Noise and Performance Data Base, which is mainly based on Data Base 10 of the calculation program INM 3, 16 kts is used.

The maximum level L_{Amax} is also predicted by segmentation, but using $L_{Amax,TO}(d)$ for the closest segment, and applying ΔL_V calculated from Equation 17.

$$\Delta L_V = 0.036\,(V_L - V) \text{ in dB} \qquad \textbf{(Equation 17)}$$

where V_L and V in kts are as defined above. In this case ΔL_V is a correction for flight effect only, as duration is not taken into account for maximum levels. V must correspond to a point P on the runway such that the receiver position B is on a line at directivity angle α from the runway. To ensure that the appropriate position and speed are used, the L_{Amax} calculation also divides the takeoff ground roll into ten segments. Only the closest segment is considered, and (unlike the L_{AE} calculation) there is no rearward extension of the first segment.

The procedures described above are employed only for points forward of the start of takeoff roll. For points in the half-plane behind the start of takeoff roll, directivity of the jet engine noise field is important. The procedure described in ECAC Doc 29, Nord 1993:38 and SAE 1845 is used. The radial distance r from start-of-roll to B and the angle θ in degrees between the direction to B and the direction of the runway are determined. The noise level is calculated according to Equation 18. The same method is used for L_{AE} and L_{Amax}.

$$L(x,y) = L(0,r) + \Delta L_{\theta} \qquad \textbf{(Equation 18)}$$

where L means L_{AE} or L_{Amax}, L(0,r) is calculated by segmentation (including all segments in the takeoff roll) and (for L_{Amax}) Equation 17 at x = 0, y = r. ΔL_{θ} is calculated according to Equations 19 or 20.

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For $90° \leq \theta \leq 148.4°$

$$\Delta L_{\theta} = 51.44 - 1.553\theta + 0.015147\theta^2 - 0.000047173\theta^3 \qquad \textbf{(Equation 19)}$$

For $148.4° < \theta \leq 180°$

$$\Delta L_{\theta} = 339.18 - 2.5802\theta - 0.0045545\theta^2 + 0.000044193\theta^3 \qquad \textbf{(Equation 20)}$$

For propeller aircraft and other aircraft with a directivity pattern that is approximately omni-directional, ΔL_{θ} is 0. Also, the "flight effect" is of relevance only to jet aircraft. It is estimated that a start-of-roll speed approximately 1/3 the lift-off speed is appropriate for non-jet aircraft.

Note that the procedures described in this section apply only to segments on the ground during takeoff roll. In-flight segments are always accounted for by the method described in 4.4.

4.6 Noise during Landing Ground Roll

Noise from landing ground roll is not as important to the total noise exposure as noise from take-off ground roll.

If thrust reversal is not used, the engines are normally running at idle power during ground roll, and the noise will therefore be insignificant. There are two possible approaches for this part of a landing. Ground roll can be ignored or the same equations can be used as for a take-off. In the latter case $L_{AE,TO}$ and $L_{Amax,TO}$ are replaced by values corresponding to low power setting, normally idle power, and ΔL_{θ} is assumed to be 0 (the contour is ended by a half circle).

If thrust reversal is used for the braking action, the significance to the noise exposure depends very much on the power setting. The main difference between a landing, in which thrust reversal is applied, and a take-off is that jet aircraft (as well as propeller aircraft) are approximately omni-directional and the noise emission is decreasing with decreasing speed (assuming constant power setting).

When the thrust reverses are activated, the aerodynamics are changed resulting in increased noise even for an unchanged power setting. For Chapter 2 aircraft a suitable average value will be 8 dB whereas it is recommended to use 5 dB for Chapter 3 aircraft. For aircraft with internal trust reversers the increase of the noise due to the aerodynamics is less important, and it is recommended not to make any correction in this case. It must be emphasised that these estimations are rough and based on a very limited number of data.

For propeller aircraft which are able to use the propellers for reversal, it has not been possible to make similar simple principles. The effect of propeller reversal has to be estimated in each individual case. If the traffic is a mix of jet and propeller aircraft in which the jet aircraft are dominating the noise exposure, it is possible to ignore propeller reversal.

Furthermore, in connection with thrust or propeller reversal it is recommended that ΔL_V and ΔL_θ are set to 0, in which case the contours become parallel to the runway and are closed by half circles behind end-of-roll.

Because landing ground roll is modelled by the same equations used for takeoff, the same considerations of segment length and receive distance apply. Full segmentation of is used. Because of the lesser importance of landing ground roll, three segments are used.

4.7 Correction for Track Geometry

If a flight track includes a turn, the sound exposure level will increase inside the turn and decrease outside the turn. This is due to the change in duration of the noise event compared to a straight flight track. Depending on the size of the turn the maximum correction inside the turn will typically be in the range from +2 to +4 dB whereas the correction on the outside in most cases will be less than -1 to -2 dB.

No correction for track geometry is performed when calculating maximum levels.

The Swedish model requires that the turn is divided into a sequence of straight segments, each representing a small portion of the turn. Segmentation usually involves more calculations than the method described in ECAC Doc 29, but is simpler to program and can also be used in general situations such as sequences of turns with no straight segments.

When dividing the turn into a series of equal-length straight segments, each segment should represent no more than 10° of the turn. No more segments will be used than the minimum number necessary to attain that limit.

5 Calculation Model for the Total Traffic

5.1 Calculation Grid

The result of a calculation of noise exposure from air traffic is normally noise contours drawn on a map. A noise contour is a line through points having the same noise exposure. The noise contours are determined on the basis of calculated noise exposures in single points, but two different methods may be used: calculations in a fixed grid or contour searching.

In the grid method calculations of the noise exposure are made in a suitable number of calculation points arranged in a grid. A regular grid is normally used with a suitable grid spacing, but irregular grids may be used also. When the calculations of the noise exposure in the grid points have been made, the contours are determined. Most often linear interpolation is used between the grid points, possibly combined with some kind of smoothing of the contours.

A regular grid is recommended with linear interpolation between the grid points and no contour smoothing. The grid should have a grid fine enough so that a resolution of 1 dB is obtained. That is enough to draw accurate contours, and is enough to interpolate the level at any position to within 0.5 dB.

5.2 Lateral Dispersion

For actual departures and arrivals the flight tracks will more or less deviate from the nominal tracks. This is denoted lateral (or horizontal) dispersion. When the aircraft aim for a nominal track, the dispersion can in general be described by a normal (Gaussian) distribution. Departures and arrivals with a normally distributed dispersion occur e.g. for instrument flights (IFR).

Departures and arrivals may also take place within a sector. A sector is an area, inside which the flight may occur. As the aircraft do not aim for a specific track but only for flying within the limitations of the sector, the dispersion is in this case more likely to follow a uniform distribution. Departures and arrivals in sectors occur most often in connection with visual flights (VFR).

In order to achieve the highest possible accuracy in the noise exposure calculations it is recommended to determine flight tracks and lateral dispersion by radar-tracking.

However, in the absence of such measurements nominal or estimated "average" tracks may be used instead. In the case of calculation of the equivalent sound level (FBN) the model in ECAC Doc 29 for lateral dispersion described below for IFR-flights may be used. It is assumed that the dispersion is normally distributed with the mean value located on the flight track. The standard deviation of the distribution is estimated according to Equations 21 and 22.

a) Routes involving turns of less than 45°:

(Equation 21)

$$s(x) = 0.055\,x - 0.150, \text{ for } 5 \text{ km} \le x \le 30 \text{ km}$$
$$= 1.5 \text{ km, for } x > 30 \text{ km}$$

b) Routes involving turns of more than 45°:

(Equation 22)

$$s(x) = 0.128\,x - 0.42, \text{ for } 5 \text{ km} \le x \le 15 \text{ km}$$
$$= 1.5 \text{ km, for } x > 15 \text{ km}$$

In Equations 21 and 22 s(x) is the standard deviation and x the distance from start-of-roll in km. Between lift-off where s(x) = 0 and x = 5 km linear interpolation is used in both equations according to the original method in ECAC Doc 29. This method is, however, not very applicable if lateral dispersion is taken into account by dividing the traffic on dispersion tracks. In this case it will be necessary to use individual dispersion tracks for each aircraft type. A more applicable approach is to extend the application range of Equations 21 and 22 down to the x-value where s(x) becomes 0. This takes place at x = 2.7 km in Equation 21 and at x = 3.3 km in Equation 22. Below these values of x s(x) is assumed to be 0. As the lateral dispersion is limited for distances below 5 km, this approximation is satisfactory. Standard deviation for flight tracks with more than one turn is calculated by Equation 22.

For IFR-arrivals lateral dispersion can normally be neglected within 6 km of touch-down. Otherwise, dispersion depends upon each individual runway and aircraft type.

If substantial vectoring by air traffic control occurs for departures and arrivals, much larger dispersions should be assumed. For vectored departing aircraft, standard deviations are typically twice those for non-vectored aircraft.

It is assumed that the lateral dispersion follows a normal distribution, and the continuous distribution can be approximated by a discrete distribution. Using a discrete distribution is physically equivalent to dividing the traffic on dispersion tracks. As a minimum a 5-point discrete approximation should be used. Table 3 shows the lateral distance from the mean track to each individual dispersion track and the corresponding proportion of traffic. The accuracy of the 5-point discrete approximation given in Table 3 is generally within 1 dB of the continuous distribution.

Distance from mean track	Proportion
- 2.0 s(x)	0.065
- 1.0 s(x)	0.24
0	0.39
+ 1.0 s(x)	0.24
+ 2.0 s(x)	0.065

Table 3
5-point discrete approximation for normal distribution.

A similar standard model for lateral dispersion of VFR-flights cannot be elaborated.

In the case of a uniform distribution the continuous distribution also has to be approximated by a discrete distribution. The same principle is used as shown in Table 3, but in this case the distance to the mean track is expressed on the basis of the width of the sector, and the proportion of the traffic is the same for all dispersion tracks.

If the lateral dispersion model outlined above for equivalent sound levels is used for calculation of maximum levels, too, it may have a considerable influence on the calculation result as the outer dispersion tracks which are only carrying a minor proportion of the traffic will be determinant to the noise contours. Conversely, if the calculation is based on the mean flight track, the contours will be "narrower" than if lateral dispersion is taken into account.

5.3 Vertical Dispersion

In excess of dispersion laterally the traffic will also be dispersed vertically. This is due to variations in take-off weight, headwind (or tailwind) component, take-off procedure, and how the pilot is executing the procedure. A headwind component of 8 kts is assumed as mentioned in Section 3. The vertical dispersion is mainly due to the variation in take-off weight, and the dispersion will therefore be different for short-range aircraft compared to long- range. It is not possible to elaborate a model for vertical dispersion as it will be strongly dependent of the aircraft type. Furthermore, the vertical dispersion does not influence the calculation result to the same extent as the lateral dispersion. It is in general sufficient to choose a typical flight profile which is normally the average profile when calculating equivalent sound levels and the flight profile corresponding to largest take-off weight in the case of maximum levels. If the vertical dispersion is very large due to large differences in take-off weight, it may be necessary when calculating equivalent sound levels to divide the traffic on two or more take-off profiles corresponding to different stage lengths.

5.4 Summation of Noise Levels

Before the noise exposure in a calculation point from the total traffic can be determined, the sound exposure level or maximum level has to be calculated for each individual aircraft operation.

If the purpose is to determine the maximum level from the total traffic, this value is simply equal to the maximum level calculated for each single type of operation.

If the purpose is to determine the time weighted equivalent sound pressure level FBN, the sound exposure levels for each individual operation in a year are added on an energy basis. The sound exposure level for each operation is weighted for the time-of-day in accordance with the model. The summation is defined in Equation 23.

$$FBN = 10 \log \left(\frac{1}{T} \sum_{j=1}^{N} W \, 10^{\frac{L_{AE,j}}{10}} \right) \qquad \textbf{(Equation 23)}$$

where $L_{AE,j}$ is the sound exposure level from the j'th aircraft operation out of N,

W is the weighting factor depending on the time-of-day
W= 1 during daytime (0700-1900) local time)
W= 3 during evening (1900-2200 local time)
W= 10 during night (2200-0700 local time)

T is the reference time for L_{Aeq} in seconds.
The reference time is one year corresponding to 31 536 000 sec.