CORRECTIVE MEASURES FOR AIRCRAFT NOISE MODELS, NEW ALGORITHMS FOR LATERAL ATTENUATION

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ABSTRACT

New equations for lateral attenuation of aircraft noise have been developed and implemented in the Norwegian aircraft noise model NORTIM. The new routines differentiate between ground and engine installation effects. Ground effect is based on Nord2000 algorithms. Engine installation effects are depending on aircraft type and equations have been developed for two essentially different types so far, aircraft with engines mounted under the wings and aircraft with engines mounted on the sides of the rear fuselage. These equations are based on measurements performed at Oslo airport in 2001.

Implementation of the routines into NORTIM is ahead of standardization, a decision taken to minimize the differences between calculated noise levels and results from noise monitoring systems. It is also a conservative step, since the new routines ends the overestimation of lateral attenuation in the existing standard.

1. INTRODUCTION

Several studies undertaken in recent years have revealed that today's aircraft noise models have a tendency to underestimate noise levels around airports. It has been acknowledged that standards and recommendations for the computation of aircraft noise must be reviewed. The major contributor to the miscalculation is believed to be the SAE AIR 1751 [1] on lateral attenuation. Several studies have focused on the effects that this recommendation is set up to account for. It should be noted that SAE subgroup A-21 is undertaking a revision of the recommendation [2]. In parallel, ANCAT Sub-Group on Aircraft Noise Modeling (ANCAT-AIRMOD) of the European Civil Aviation Conference (ECAC) is updating ECAC-CEAC Doc 29 [3], which has its methodology based on AIR 1751.

A measurement study was performed in 2001 at Oslo airport Gardermoen [4] to investigate the deviations between measurements from the permanent monitoring system around the airport and calculated noise levels for the same traffic scene. Unique for the measurement program was the possibility, generously offered by SAS, to acquire flight recorder data for each measured flight. This resulted in the best possible control of the source characteristics, position and attitude. A total number of 155 flights were accepted for further analysis from two weeks of measurements.

The main result from the study was a confirmation of the long term recorded deviation between measured and calculated noise levels. Analysis of the measurements pointed to lateral attenuation as being one of the main contributors to the deviation. One other finding that will be important for future models is that the aircraft should not be treated as a cylindrical symmetric noise source.

The measurements gave the possibility to establish noise source directivity hemispheres in 1/3-octave bands for some specific aircraft types. Further investigations were based on these descriptions of the sources.

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2. THEORY

The noise database for aircraft represents the noise from an aircraft flying an indefinitely long straight line directly above the observer at steady conditions. When calculations are performed the noise data are modified for observer positions to the sides of the flight path to account for several physical phenomena. The main phenomena are normally referred to as ground effect and engine installation effects. Ground effect counts for the influence from the ground on sound propagation between source and receiver. Engine installation effects include interactions between the generated sound and the airplane wings, body, and the flow fields surrounding these.

SAE AIR 1751, which is the basis for most aircraft noise models around the world, defines a lateral attenuation to account for these effects. The recommendation was based on measurements of 1960/70 airplanes mainly with engines mounted on the rear part of the fuselage. The lateral attenuation is defined by two regression equations – one for the ground to ground situation, one for the air to ground situation. The ground to ground situation is dependant on the source receiver distance only. The air to ground situation is dependant on source elevation angle as seen from the receiver. The result from these two equations combines to a total lateral attenuation given in dBA.

3. METHOD

For the development of the new ground attenuation and engine installation effect routines, a large number of simulations were done using MATLAB®. The simulations were performed as virtual flights, with parameters lateral distance l and elevation angle φ, as seen from an observer 1.5 m above the ground. The sound pressure level at the observer was calculated for each of the aircraft positions during the virtual flight. The aircraft positions were spaced 20 m apart. For each virtual flight A-weighted SEL levels were calculated. Corresponding A-weighted SEL levels were also calculated for the same slant distances, but with the observer directly below the virtual flight path.

3.1. Development of new ground attenuation routines

For the development of new ground attenuation routines, 209 virtual flights were performed[1]. The Nord2000 [5] method was used to calculate the ground attenuation from the aircraft to the two observers for each point of the virtual flights. Ground flow resistivity 250.000 Rayl, corresponding to soft grass covered ground, was assumed. The Nord2000 turbulence parameters for wind and temperature have a high influence on the attenuation for small elevation angles. Results from the Gardermoen measurements [4] showed best agreement with Nord2000 predictions if these parameters were set to 0.5 and 0.0, respectively. For standard conditions (used in benchmark testing of Nord2000), the following values were selected:

Wind turbulence parameter: Cv2 = 0.12 [$m^{4/3}/s^2$]
Temperature turbulence parameter: Ct2 = 0.008 [K/s^2]

The source spectrum was a mean of the SEL spectra measured at site 1 and 2 (directly below the flight path) during the Gardermoen measurements [4].

The ground attenuation was calculated as the difference between the simulated level observed below the flight path and the simulated level observed at the given (l, φ) combination. For $\varphi \geq 60$ the attenuation was assumed to be zero.

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[1] The distances were 50, 75, 100, 150, 200, 300, 400, 500, 600, 700 and 1000 m, and the angles were 0, 0.1, 0.5, 1, 2, 3, 4, 5, 6, 8, 10, 15, 20, 25, 30, 40, 50, 80 and 90 degrees.

3.2. Development of new engine installation effect routines

For the development of new engine installation effect routines, 506 virtual flights were performed[1]. The source spectra used in the simulations were based on the spectral source directivities obtained during the post processing of the Gardermoen measurement data. These spectral source directivities were obtained from measurement data by backward propagation using Nord2000 [3]. The source directivities have a 10° horizontal and vertical resolution. The source spectra of B736 and B737 were averaged. Similarly, the spectra of MD81 and MD82 were averaged. Both of the averaged spectra were truncated to the interval 50 – 5000 Hz.

The engine installation effect was calculated as the difference between the simulated level observed below the flight path and the simulated level observed at the given (l, φ) combination. The calculated engine installation effects were then modeled by approximate formulae.

4. RESULTS

4.1. New ground attenuation routines

The simulated ground attenuation can be represented by the surface shown in Figure 1.

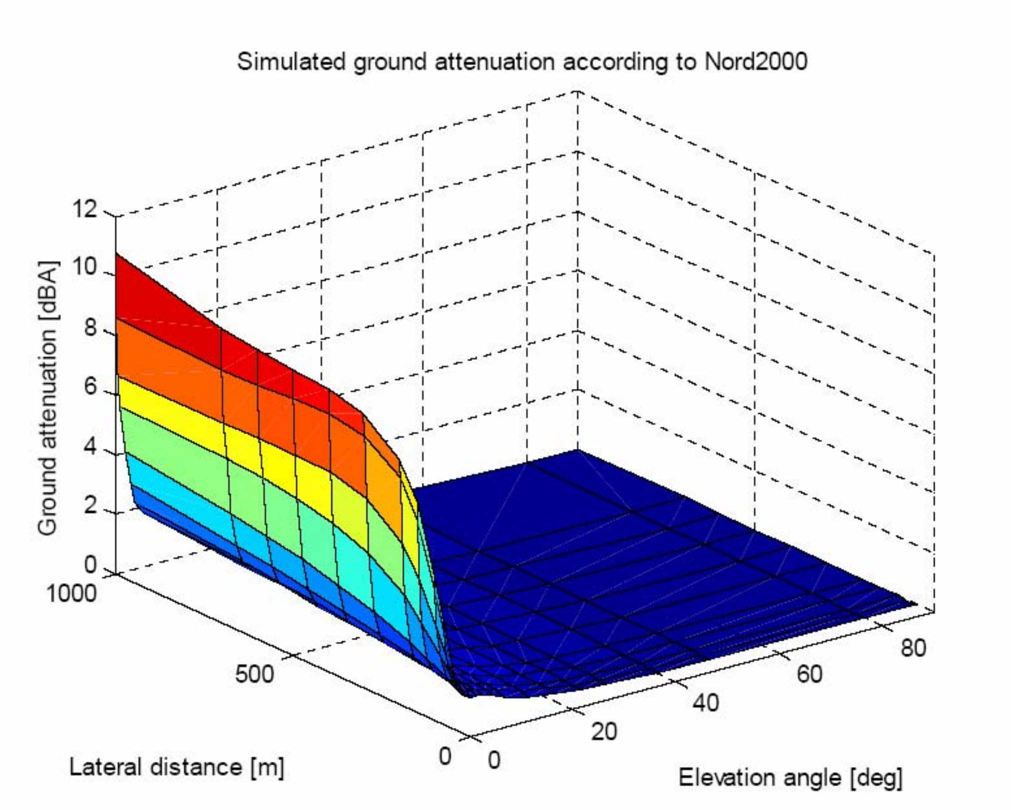

Figure 1. *Ground attenuation simulated by Nord2000, as function of lateral distance l and elevation angle* φ*.*

It was assumed that the data could be modeled by expressions similar to the formulae for lateral attenuation in SAE AIR 1751, with some minor modifications, and with all the coefficients fitted to the simulation data.

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[1] The distances were 75, 100, 150, 200, 300, 400, 500, 600, 800, 1000 and 1200 m, and the angles were every other degree between (and including) 0 and 90 degrees.

The ground attenuation can be written as:

$$\mathrm{ATN}\,(l,\varphi)=\begin{cases}\dfrac{\left[a_0+a_1\varphi^{a_2}+a_3\exp(a_4\varphi)\right]\cdot\left[a_5l^{a_6}+\left(1-\exp(a_7l)\right)\right]}{a_8}, & \varphi<46.6\wedge l\geq 23.4\\ 0 & \varphi\geq 46.6\vee l<23.4\end{cases}\qquad(1)$$

The coefficients $a_0..a_8$ were fitted to the simulated ground attenuation by non-linear least squares fitting in MATLAB®. The coefficients are given in Table 1. Figure 2 shows the modeled ground attenuation compared to the simulation data. Note that for lateral distances above 1000 m, a lateral distance of l = 1000 m is assumed in the above formula. Thus, for φ = 0 degrees, the maximum ground attenuation is 10.19 dBA.

a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
15.7782	-5.8654	0.2576	31.3516	-0.8068	-0.3597	-0.2063	-0.0089	4.2241

Table 1 *Coefficients of the approximate ground attenuation formula ATN(l,φ)*

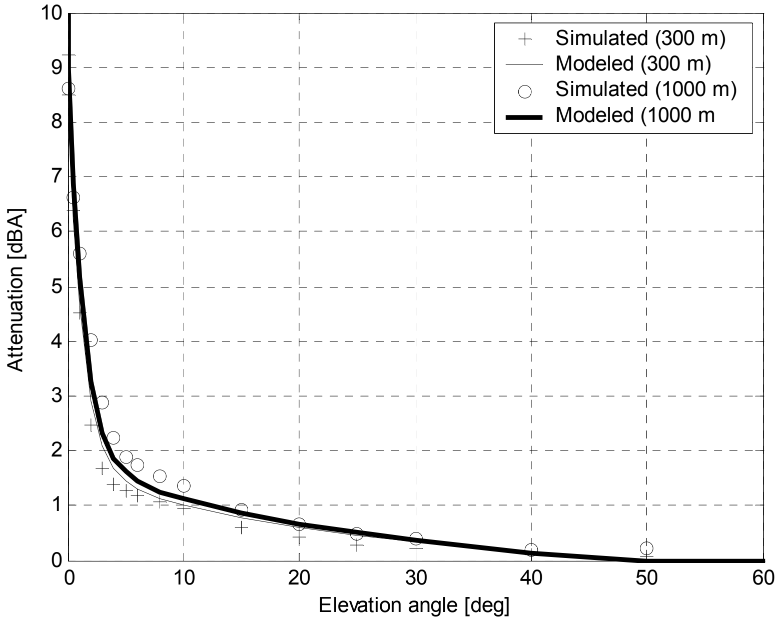

Figure 2 *Simulated and modeled ground attenuation as function of elevation angle φ for lateral distances l = 300 m and l = 1000 m*

4.2. New installation effect routines

4.2.1. Under wing mounted engines (B73x)

The engine installation effect for aircraft with under wing mounted engines can be modeled by

$$ENG(l,\varphi)=\begin{cases} 1.0032\cdot GRD(l)-0.0795\cdot AIR(l,\varphi) & \varphi\le 64 \\ \text{Linearly interpolated between } \varphi=64 \text{ and } \varphi=72 & 64<\varphi\le 72 \\ 0 & \varphi>72 \end{cases} \tag{2}$$

where

$$GRD(l)=-15.5120+13.7655\cdot l^{0.0193} \tag{3}$$

and

$$AIR(l,\varphi)=\begin{cases} 48.0678+A(l,\varphi)\sin(-0.0277\cdot\varphi-1.2869) & \varphi\le 29 \\ 4.7395+1.8780\cdot\sin(0.2779\cdot\varphi+3.8270) & 29<\varphi\le 48.5 \\ -8.6393+0.2349\cdot\varphi & 48.5<\varphi\le 64 \end{cases} \tag{4}$$

The amplitude of the first **sin** function in equation (4) is given by

$$A(l,\varphi)=51.2693+\frac{(29-\varphi)}{29}\cdot\frac{\log(l)-\log(400)}{\log(400)}\cdot\frac{51.2693}{2} \tag{5}$$

The maximum error of this formula compared to the calculated engine installation effect is ±0.3 dBA. The average error is ±0.1 dBA. Note that for lateral distances above 1000 m, a lateral distance of $l = 1000$ m is assumed in the above formulae.

4.2.2. Rear fuselage mounted engines (MD8x)

The engine installation effect for aircraft with engines mounted on the rear fuselage can be modeled by:

$$ENG(\varphi)=\begin{cases} 2.1853 & \varphi\le 12 \\ 1.3693-0.8478\cdot\sin(-0.1512\cdot\varphi+0.0637) & 12<\varphi\le 32 \\ 0.6716+0.3300\cdot\sin(-0.2990\cdot\varphi+2.8287) & 32<\varphi\le 53.5 \\ -0.9760+\dfrac{78.1738}{\varphi} & 53.5<\varphi\le 80 \\ 0 & 80<\varphi \end{cases} \tag{6}$$

Note that the engine installation effect for this aircraft type is independent of lateral distance. The maximum error of this formula compared to the calculated engine installation effect is +0.55 and -0.38 dBA. The average error is ±0.08 dBA

4.3. Lateral attenuation

The lateral attenuation is the sum of the ground attenuation and the engine installation effect. Figure 3 and Figure 4 compare the lateral attenuation of SAE AIR 1751 with the lateral attenuation obtained when the engine installation formulae for the two aircraft types B73x and MD8x is added to the new ground attenuation.

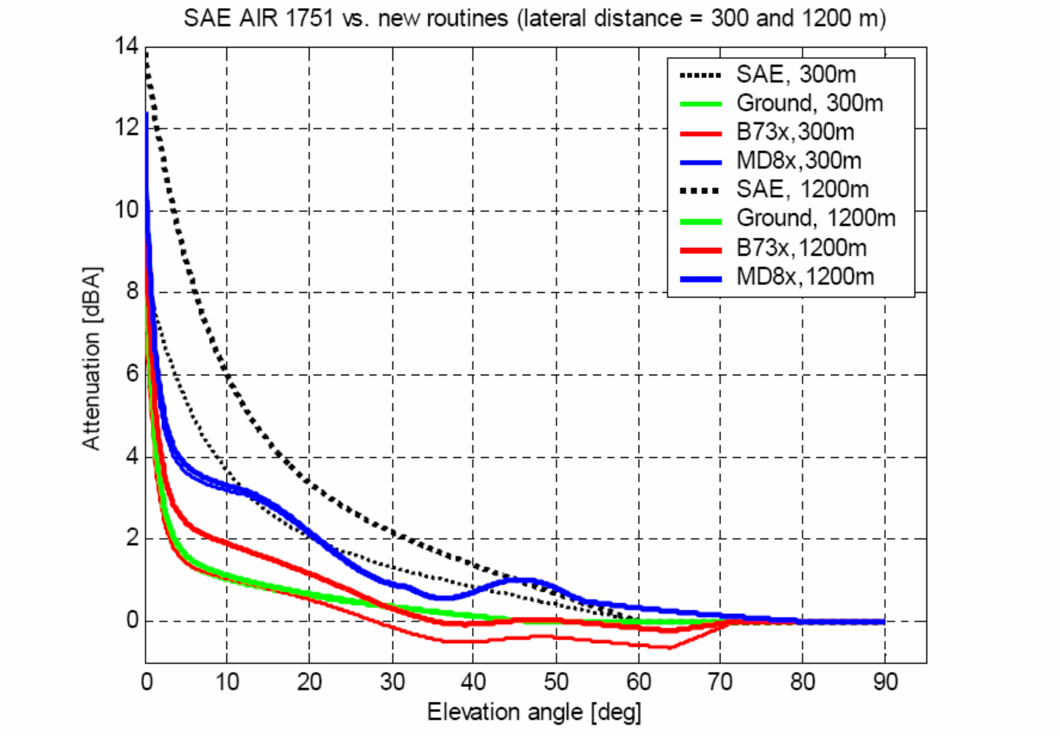

Figure 3 *Lateral attenuation as function of elevation angle φ for lateral distances l = 300 m and l = 1000 m. Original attenuation given by SAE AIR 1751 compared to lateral attenuation for aircraft with under wing mounted engines (B73x) and rear fuselage mounted engines (MD8x)*

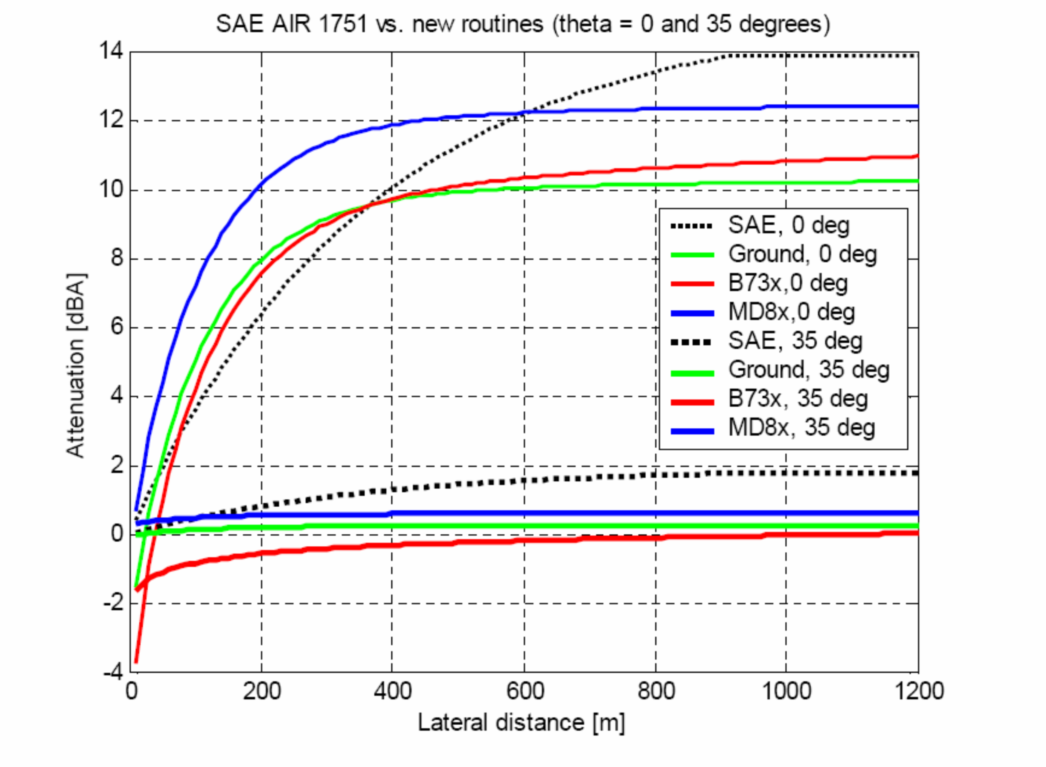

Figure 4 *Lateral attenuation as function of lateral distance l for elevation angles φ = 0 degrees and φ = 35 degrees. Original attenuation given by SAE AIR 1751 compared to lateral attenuation for aircraft with under wing mounted engines (B73x) and rear fuselage mounted engines (MD8x)*

5. DISCUSSION

There are several differences between the new equations and those of SAE AIR 1751. It is acknowledged that the empirical equations from SAE were to a large extent based on aircraft with engines mounted on the rear fuselage. Comparison in Figure 3 between lateral attenuation for MD80 and the SAE curve also shows that, at least for short distances, the difference is small, and much smaller than for aircraft with wing mounted engines.

Another clear difference is seen in Figure 4 for the ground to ground situation, where the new routines give higher lateral attenuation in the region up 600 meters for rear fuselage engines type and from 50 to 350 meters for under wing engines type. This is strongly dependant of the ground attenuation equation and is correlated to the turbulence factors mentioned in chapter 3.1. The choice of values for these corresponds to standard meteorology conditions and has been used in benchmark testing of the Nord2000 model.

Comparison has also been made with the existing proposals for new equations both from the SAE A-21 committee and ANCAT-AIRMOD. Both proposals divide lateral attenuation into ground and installation effect, and both distinguish between aircraft types with wing mounted and aft body mounted engines. At this stage, it seems these two groups will come up with different proposals to both ground attenuation and engine installation effects. Figures 5 and 6 illustrate some of the differences in a comparison between the old SAE routines, routines developed by SINTEF, and the current A-21 and AIRMOD proposals.

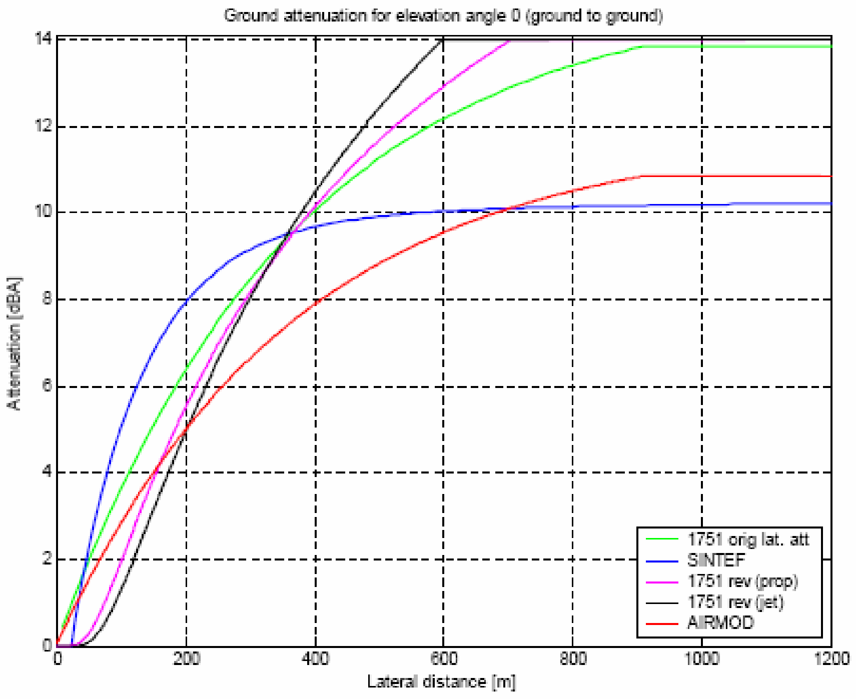

Figure 5 *Comparison of proposals for ground attenuation for the ground to ground situation.*

Comparison between the equations presented herein and the two proposals show that our solution will be very close (within 1 dB) to the A-21 committee proposal for the air to ground situation for both aircraft types. For the ground to ground situation A-21 committee has a different approach to turbulence and the differences mentioned in the paragraph above will increase.

The current proposal from AIRMOD shows higher lateral attenuation for the air to ground compared to our equations for elevation angles below 20°. For aft body mounted engines the AIRMOD proposal is even closer to the original SAE routines.

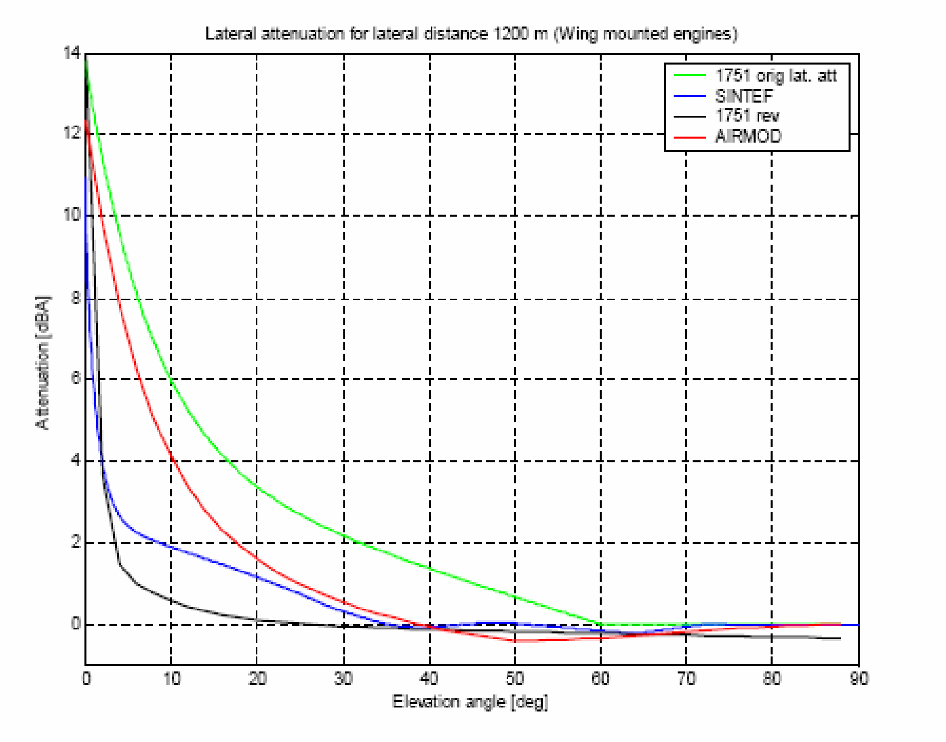

Figure 6 *Comparison of proposals for lateral attenuation for the air to ground situation for aircraft with under wing mounted engines.*

6. CONCLUSIONS

The new routines developed by SINTEF for lateral attenuation of aircraft noise divides the phenomena into ground effect and engine installation effect (source directivity). Implementation into NORTIM is ahead of standardization, but gives a more correct calculated result than the existing recommendation.

7. REFERENCES

[1] Society of Automotive Engineers, Inc. *Prediction Model for Lateral Attenuation of Airplane Noise during Takeoff and Landing,* AIR 1751, 1981.
[2] Society of Automotive Engineers (SAE) A-21 Committee on Aircraft Noise, *Proposed Draft Replacement to AIR 1751,* Draft 11, April 10, 2003.
[3] ECAC.CEAC Doc 29, *Report on Standard Method of Computing Noise Contours around Civil Airports,* Second Edition 1997.
[4] S. Å. Storeheier et al, *Aircraft Noise Measurements at Gardermoen Airport, 2001 (part 1 &2),* SINTEF Reports STF40 A02032 and STF40 A02033, Trondheim 2002.
[5] B. Plovsing, J. Kragh, *Nord2000. Comprehensive Outdoor Sound Propagation Model,* Lyngby 2001.