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Noise Emission from Snowmobiles

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Four different snowmobiles have been tested using different methods. The operating conditions have been accelerating, cruising and stationary and two different measurement distances and two different microphone heights have been used. The maximum pass-by sound pressure levels were measured in both 24 km/h and 50 km/h using both time-weighting F and S. In addition the acoustic impedance of the snow and grass covered ground was determined. The measurements were also carried out in frequency bands and these results were used to put up an acoustic source model of the snowmobile, which was then used to calculate the acoustic ground effect for propagation over different distances and ground surfaces. The most important conclusions of the measurements and theoretical calculations are: • All snowmobiles tested failed to meet the American requirements for maximum pass-by sound pressure level during acceleration;

- time weighting S used by SAE-standards yields around 2 dB lower measurement values than time-weighting F normally used for road vehicle testing;
- type approval measurements should be carried out on snow. The snow depth is not very critical as long as it exceeds 7,5 cm;
- selection of measurement distance and time-weighting is not very critical as long as the limit values are adjusted accordingly;
- grassland may influence the operating conditions and should not be used for type approval measurements;
- operating conditions should be both cruising and accelerating. The reference speed for acceleration is not critical. However, when cruising, 50 km/h makes much more noise than 24 km/h;
- subtraction of two dB from the measured value as in SAE J192 is not compatible with the European Directive on noise emission from equipment for use outdoors.

1 Introduction

This paper is a summary of [11] and the work has been financed by the Swedish Road Administration.

At present snowmobiles are not included in the directive 2000/14/EC, [1], on noise emission from equipment used outdoors. Sweden wishes to have snowmobiles included and SP was given the task to analyse some of the problems to be dealt with.

The largest and commercially most important market for snowmobiles is in the USA and Canada. In USA alone it is estimated to be about 1,5 million snowmobiles. In Europe the major market is in Sweden, Finland, Norway and Russia. with about 456000 registered snowmobiles in 2008. There are 4 major manufacturers, three from North-America and one from Japan with 5 different brands.

Since 1975 there is a voluntary limit value in North-America for snowmobiles of 78 dB measured during acceleration according to SAE J192, [2]. Later this requirement has been supplemented by a 73 dB requirement when measured during cruising according to SAE J1161. In several states/provinces these values are also used for regulations. Sweden used to have a corresponding limit value but this requirement was removed in 2001 as a consequence of the membership in the European Union. The American limit value has remained unchanged since 1975. In the meantime the engine power has increased substantially and the test method has also changed from acceleration from stationary to acceleration from 24 km/h and, not to be forgotten, the time weighting has changed from F (fast) to S (slow) making the manufacturers gain 2 to 3 dB without having to make any extra effort.

This project has had the aims of comparing different measurement methods, establishing state-of-the-art of noise emission from snowmobiles and finally to analyse the future technical and economical potential of further lowering of limit values.

2 Measurement methods

2.1 SAE J192 Maximum Exterior Sound Level

This is the most commonly used method for snowmobile measurements. It was last revised in 2003. It is used voluntarily and for regulatory purposes in USA and Canada. It is a pass-by test under acceleration starting at 24 km/h 22,8 m before the normal from the snowmobile path to the microphone. The measurement distance, measured from the centre line of the snowmobile, is 15 m and the microphone height is at 1,2 m. It is primarily used on snow but may also be used on dry grassland with maximum grass length 75 mm. There must be a minimum of 50 mm compacted snow under the track and a maximum of 75 mm loose snow between the drive path and the microphone. The measure of the measurement is the maximum instantaneous A-weighted sound pressure level using time-weighting S, L_{pASmax}, during pass-by. Older versions of the standard used time-weighting F. The measurements are carried out on each side of the snow mobile. The result for each side is the average of 3 measurements differing less than 2,0 dB rounded to the nearest integer. The final result is the highest value of the two sides.

The method has the following weaknesses in relation to similar methods (i.e. ISO 362, [4]) used for road vehicles:

- It measures L_{pASmax} with time-weighting S instead of time-weighting F, L_{pAFmax}. The motivation for this choice is to achieve a better reproducibility. However, as can be seen in figure 1 and in the measurement results this leads to a *systematic underestimate* in relation to L_{pAFmax}. The reason for this is that the meter simply is too slow to catch the maximum during a pass-by of a fast vehicle at a short distance. The figure is based on a speed of 50 km/h at the North American pass-by distance (15 m). The real speed after acceleration may be different from this assumption. The higher the real speed the higher the difference.
- The measurement distance is 15 m instead of 7,5 m. This longer distance makes the procedure more sensitive to variations in snow depth, snow conditions and background noise. The measurement site is also more sensitive to reflections from nearby vertical objects when the measurement distance increases. The only advantage with a longer distance is that the measurement result is less sensitive to variations in the distance to the path of the snowmobile to be tested. 0,2 m change in path distance at 7,5 m will yield an error of about 0,2 dB whereas the same change at 15 m will diminish this error to about 0,1 dB. However, this little difference is, from the practical point of view, negligible compared to the extra uncertainties in excess ground attenuation due to the increased distance.
- It starts the acceleration from 24 km/h instead of from 50 km/h. This increases the acceleration, the spin of the track and the tear on the drive path on snow or grass.

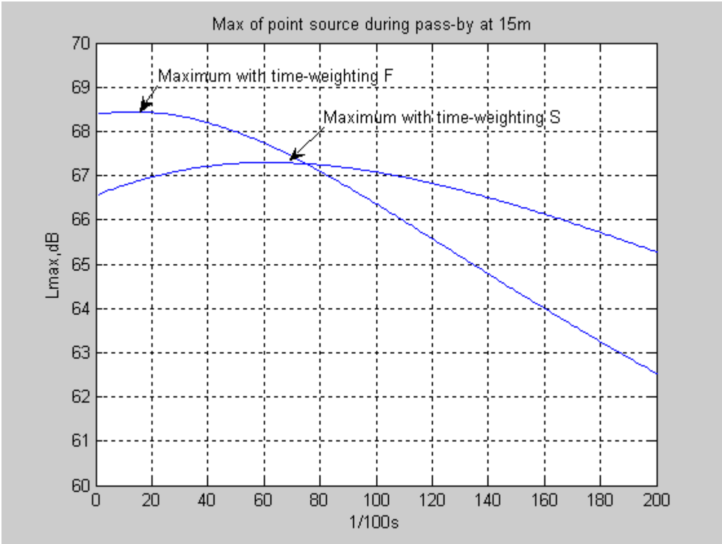

Figure 1 Calculated instantaneous sound pressure level with different time-weightings during a pass-by of a point source at 15 m at 50 km/h. The difference in the figure is 1,2 dB but the measured difference is often larger, see table 2.

2.2 SAE J1161 Operational Sound Level Measurement Procedure

This method is in principle identical to SAE J192 with the exception of the operating conditions of the snowmobile. Instead of accelerating it cruises at the constant speed of 24 ± 3 km/h.

2.3 SP proposal from 1995

1995 SP proposed a method, [5], more adapted to the ISO standards for road vehicles. The main differences to SAE J192 were to use time-weighting F, to change the measurement distance from 15 m to 7,5 m, to increase the start speed for acceleration from 24 km/h to 50 km/h and finally to start the acceleration 10,0 m before the normal instead of 22,8 m. It should be noted that at that time the SAE standard started the acceleration from stationary and not from 24 km/h causing the drive path to show a lot of tear already after a few runs.

2.4 NT ACOU 104 for ground impedance

In modern prediction methods the attenuation of sound when propagating over ground is calculated using exact sound propagation theory. Such calculations require knowledge about the acoustic properties of the ground, which are described by its acoustic impedance. For most types of ground this impedance can be modelled using the flow resistivity in either a one parameter or a two parameter model. The two parameter model includes the depth of the ground layer whereas the one parameter model assumes an equivalent infinitely thick layer. These two models yield the impedance as a function of frequency and they are both used in the NORDTEST-method NT ACOU 104, [6].

The sound pressure level is measured at two different heights, 0,2 and 0,5 m respectively, above the ground at 1,75 m from a loudspeaker at 0,5 m above the ground emitting broadband noise. The measured data are used to obtain a best fit to one of a number of precalculated curves. The result is the flow resistivity class. The frequency range used is the one third octave bands between 200 Hz and 2500 Hz. The difference $\Delta L_{M,j}$ for each frequency band j between the high and the low microphone is determined and the error E is determined from

$$E = \sum_{j=1}^{12} \left| \Delta L_{M,j} - \Delta L_{C,j} \right| \qquad (1)$$

where $\Delta L_{C,j}$ is the corresponding calculated difference using the proper impedance and propagation model. The most correct impedance class is obtained when the error E has its minimum. For a result to be perfectly valid according to the Nordtest model E has to be ≤ 15 dB.

The one-parameter model uses σ, the effective specific flow resistivity, as a parameter.

$$Z_\infty = 1 + 9{,}08(\frac{1000f}{\sigma})^{-0{,}75} + i11{,}9(\frac{1000f}{\sigma})^{-0{,}73} \quad (2)$$

As a rough guideline, σ is between 10 kPas/m^2 (soft snow) and 20 000 kPas/m^2 (old asphalt). Note that σ is just a parameter, but it is usually said to have the same unit (Pas/m^2) as the physical quantity flow resistivity. The one-parameter model can be expanded to a situation where the porous material is backed by a very hard surface, and then we get a two-parameter model and the following formula should be used:

$$Z_L = Z_\infty i \cot(Lk) \quad (3)$$

$$k = \frac{2\pi f}{c}\left[1 + 10{,}8(\frac{1000f}{\sigma})^{-0{,}70} + i10{,}3(\frac{1000f}{\sigma})^{-0{,}59}\right] \quad (4)$$

L is the depth of the porous material.

3 Noise from snowmobiles

3.1 Regulatory limit values

In North America most snowmobiles will meet the requirements given in table 1, although it is common to accept up to 2 dB higher values when tested in order to take the measurement accuracy into account. The requirement in the national parks is enforced for most but not all snowmobiles travelling there. In practice this requirement is only met by 4-stroke engines supplied with best available technology (BAT).

Table 1 Limit values in general use in North America

Measurement method	Requirement
Acceleration according to SAE J192	$L_{pASmax} \leq 78$ dB
Cruising according to SAE J1161	$L_{pASmax} \leq 73$ dB
Stationary according to SAE J2567	$L_{pAS} \leq 88$ dB
Special requirements on snowmobiles used in Yellowstone and Grand Teton NPs	
Acceleration according to SAE J192	$L_{pASmax} \leq 73$ dB

Before joining the European Union Sweden had the limit value 85 dB measured according to the SP-method, see 2.4, which roughly corresponds to the American 78 dB value. However, in 1995 the Swedish limit value, was exceeded by 9 out of 14 tested snowmobiles reported in [5].

3.2 State-of-the-art

The most comprehensive list of noise from snowmobiles which we managed to find on internet was for snowmobiles with 4-stroke engines complying with the Yellowstone Best Available Technology requirements. Here L_{pASmax} was in the range 70-75 dB but please note that all these measurements were carried out at high altitude tending to yield lower noise levels.

4 Measurement sites

Two different measurement sites were used for the measurements on snow. One site was used for the measurements at constant speed but as the snow quickly deteriorated the acceleration measurements on the following day were moved to another open space. The temperature of both sites was a few degrees above 0º C and the snow was coarse and wet. The snow depth of site 1 was 100-150 mm and of site 2 200-300 mm. On two of the snowmobiles tested on snow some further tests were carried out four weeks later on grassland. The grass length was 50-70 mm.

5 Snowmobiles tested

Four different snowmobiles, two with 2-stroke and two with 4-stroke engines were borrowed from two agents, a dealer and a private machine owner and tested on snow. Two of them were later tested on grassland as well. The different snowmobiles were: Ski-doo GTX SE manufactured 11/2008, 311 kg, 92 kW 4-stroke engine, Polaris Trail Touring manufactured 3/2008, 281 kg, 44 kW 2-stroke engine; Lynx Adventure Grand Tourer 600 SDI manufactured 11/2008, 323 kg, 85 kW 2-stroke engine, Arctic Cat TZI Turbo LXR manufactured 10/2008, 370 kg, 130 kW 4-stroke engine.

6 Measurements

6.1 Determination of impedance class

NT ACOU 104 was applied using both the one parameter and the 2-parameter impedance models as outlined in clause 2.4. However, it was not possible to get a good fit to the impedance models chosen. The minimum relative error E obtained was around 35 dB both for the one and the 2-parameter model which is far from the Nordtest method requirement $E \leq 15$ dB. The best fit using the one parameter model was obtained with the flow resistivity class 10 - 16 kPas/m^2. Due to the large error this value is not very reliable but at the same time it is well in line with earlier findings in the literature, see e.g. [7].

6.2 Measurement procedures for pass-by noise

The pass-by measurements were carried out simultaneously according to the method proposed by SP and the relevant SAE standard. Two additional microphone positions at the height 3,5 m were used both at 7,5 m and 15 m distance. By adding positions more data become available for the development of source and propagation models. SP measured on one side using a 4-channel dB01 Harmonie measurement system and SMP measured on the other side using a 3-channel Brüel & Kjær Pulse system. SP measured with time-weighting S and F simultaneously whereas SMP measured with time-weighting S only. In some cases the SMP measurements with time-weighting S have been converted to time-weighting F using the difference recorded by SP during the same measurement. The operating conditions for the snowmobiles were both according to the SAE-standards and the SP-proposal, that is cruising at 24 and 50 km/h and accelerations starting from the same speeds but from different distances. When measuring on grassland only cruising at 24 and 50 km/h respectively were used as the acceleration tests destroyed the underlayer for the land owner and risked damaging the snowmobiles.

7 Measurement results

7.1 Difference between time-weighting F and S

In table 2 the differences between time-weightings F and S for the 4 different microphone positions used by SP are given together with the difference between L_{pAFmax} in position 7,5m/1,2m and L_{pASmax} in 15m/1,2m. The mean indicates the arithmetic average of the 4 different snowmobiles tested.

Table 2 Measured difference between time-weighting F and S, in dB.

		7,5/1,2	7,5/3,5	15/1,2	15/3,5	SP-SAE
50 km/h	Mean	2,6	2,4	1,8	1,8	9,0
(ISO)	stdav	0,44	1,11	0,26	0,27	0,69
24 km/h	Mean	1,5	1,6	1,2	1,2	7,8
(SAE)	stdav	0,14	0,42	0,30	0,15	0,50
50 acc	Mean	3,5	3,3	2,8	2,8	9,9
(ISO)	stdav	0,52	0,17	0,79	0,39	0,66
24 acc	Mean	3,3	3,1	2,2	2,2	9,4
(SAE)	stdav	0,32	0,04	0,49	0,18	0,74

The most interesting results of table 2 are the following:

- Time-weighting S in the SAE position 15m/1,2m yields 2,2 dB lower values than was obtained using time-weighting F in standard editions prior to the latest 2003 version.
- The difference 1,8 dB between time-weighting F and S at 15 m obtained at constant speed of 50 km/h is about 0,5 dB higher than the theoretically calculated difference 1,3 dB shown in figure 2.1
- The difference between the SP-proposal at 7,5m/1,2m and time weighting F and the SAE-method at 15 m using time-weighting S is, on average, 9,0 dB.

7.2 SAE results in relation to North American requirements

In table 3 the measurement results according to the SAE standards are shown. All vehicles tested comply with the limit values for cruising and stationary vehicles respectively. However, not one single vehicle meets the limit values for the acceleration test even if we, as is normally done in North America, subtract 2 dB to take the measurement uncertainty into account.

Table 3 Measurement results (without subtraction of 2 dB) according to SAE methods, in dB.

	SAE J192	SAE J1161
	Acceleration	Cruising
1. Ski-Doo	81,0	67,0
2. Polaris	80,9	72,7
3. Lynx	83,6	67,4
4. Arctic Cat	84,6	65,2
Limit value[1)]	78	73

[1)] Voluntary and often also legal limit value applied in North America

[2)] For technical reasons the Polaris was not tested stationary

7.3 Difference between SP proposed method and SAE

When studying the difference between the method proposed by SP in 1995 and the SAE tests we have in principle two differences to take into account. One is the difference with respect to the difference in distance and time-weighting and the other is the difference in operating conditions. SAE accelerates from 24 km/h 22,8 m before the normal from the snowmobile path to the microphone whereas SP starts from 50 km/h 10 m before the normal. The constant speeds are 24 km/h and 50 km/h for SAE and SP respectively. The results are shown in table 4. The average difference for the acceleration test is 9,3 dB. This is in good agreement between the 1991 result reported in [8] which was 7,3 dB. The 2,0 dB difference is due to the switch from time-weighting F to time-weighting S in the SAE method. For constant speed the average difference is 13,1 dB.

Table 4 Difference between the SP and the SAE method (only one side of the snowmobile), in dB.

	Acceleration			Constant speed		
	SAE J192	SP	Difference SP - SAE	SAE J1161 24 km/h	SP 50 km/h	Difference SP-SAE
1. Ski-Doo	77,9	87,8	9,9	66,0	79,2	13,2
2. Polaris	77,2	85,9	8,7	69,1	80,0	10,9
3. Lynx	82,9	90,7	7,8	67,2	81,0	13,8
4. Arctic Cat	83,4	94,0	10,6	64,8	79,2	14.4
Average			9,3			13,1

Note. The values in table 4 differ from those of table 3 because they refer to measurements on only one side of the snowmobile (We were only able to measure simultaneously with time-weighting S and F on one side)

7.4 Difference between grass and snow

The Ski-Doo and the Arctic Cat were tested at constant speed on both snow and about four weeks later on grass. The results are summarized in table 5.

Table 5 Measurement results for Ski-Doo and Arctic Cat on snow and grass, in dB.

	L_{pAF} at 50 km/h			L_{pAS} at 24 km/h		
	Snow	Grass	Difference Grass-snow	Snow	Grass	Difference Grass-snow
1. Ski-Doo						
7,5 m/1,2 m	79,2[2)]	83,9[2)]	4,7	74,7[1)]	78,0[1)]	3,3
7,5 m/3,5 m	80,2[2)]	82,8[2)]	2,6	74,0[1)]	78,4[1)]	4,4
15 m/1,2 m	71,5[2)]	77,0[2)]	5,5	67,0[1)]	71,3[1)]	4,3
15 m/3,5 m	73,1[2)]	76,8[2)]	3,7		72,9[1)]	
4. Arctic Cat						
7,5 m/1,2 m	79,2[2)]	84,5[2)]	5,3	72,4[1)]	75,3[1)]	2,9
7,5 m/3,5 m	81,9[2)]	85,1[2)]	4,2	72,8[1)]	75,8[1)]	3,0
15 m/1,2 m	71,9[2)]	76,7[2)]	4,8	65,2[1)]	68,5[1)]	3,3
15 m/3,5 m	74,9[2)]	77,3[2)]	2,4		70,5[1)]	
Averages						
7,5 m/1,2 m			5,0			3,1
15 m/1,2 m			5,2			3,8
7,5 m/3,5 m			3,4			3,7
15 m/3,5 m			3,1			

[1)] Highest mean value of both sides

[2)] Mean value of left side

7.5 Difference between 7,5 m and 15 m

On snow 16 different measurements were carried out simultaneously at 7,5 m and 15 m. For time-weighting F the mean difference between 7,5 m and 15 m at the height 1,2 m was 7,1 dB with a standard deviation of 0,5 dB. For time-weighting S the corresponding results were 6,4 dB and 0,9 dB respectively.

8 Creating a source model

Assuming that the sound source is modelled by two point sources *i*= 1, 2 and that we measure the sound pressure level L_j at j= 1,2,..*N* microphone positions and that each source – microphone transfer function is described by C_{ij} we get the following equations:

$$C_{11}W_1 + C_{21}W_2 = L_1 \quad (5)$$

$$C_{12}W_1 + C_{22}W_2 = L_2 \quad (6)$$

$$C_{1N}W_1 + C_{2N}W_N = L_N \quad (7)$$

or written in matrix form

$$CW=L \quad (8)$$

or

$$W=C\backslash L \quad (9)$$

The method can easily be expanded to 3, 4 or more source positions. This method is described in [9]. Of course, the modelling by point sources is an approximation. In real life there are few, if any, point sources. Sources are extended and in this model an extended source is modelled as a number of point sources with different strengths.

It is recommended to average over a great number of vehicle pass-bys. The method has several limitations and the results have to be handled with care. At low frequencies the resolution is not sufficient to distinguish between different source heights. The transfer functions are not 100% correct as they assume a certain distribution in height which may be different from that of the actual test case. To perform an exact calculation the impedance of the ground also have to be known. In figure 2 – 3 some of the results are shown when adapted to the propagation measurements across snow. The four different microphone positions used by SP have been used and it has been assumed that the ground impedance follows the one parameter model with the specific flow resistivity equals to 10 kPas/m2 (or, in one case, 16 kPas/m^2). As this impedance model did not fit very well in our case a certain amount of extra uncertainty is introduced into our source modelling.

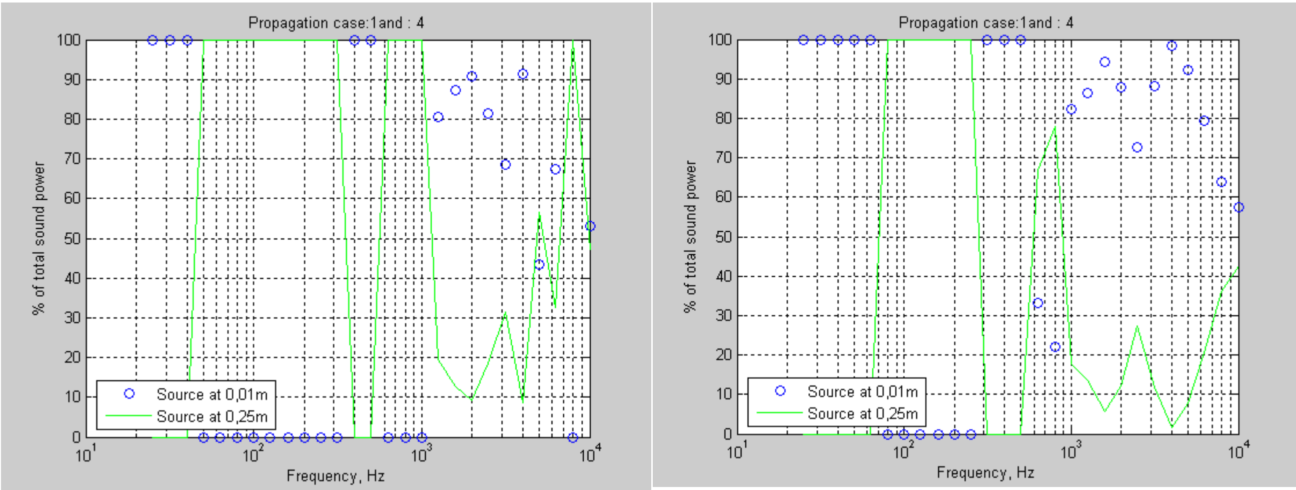

Figure 2 Distribution between 2 different source heights, 10 kPas/m² (left) and 16 kPas/m² (right)

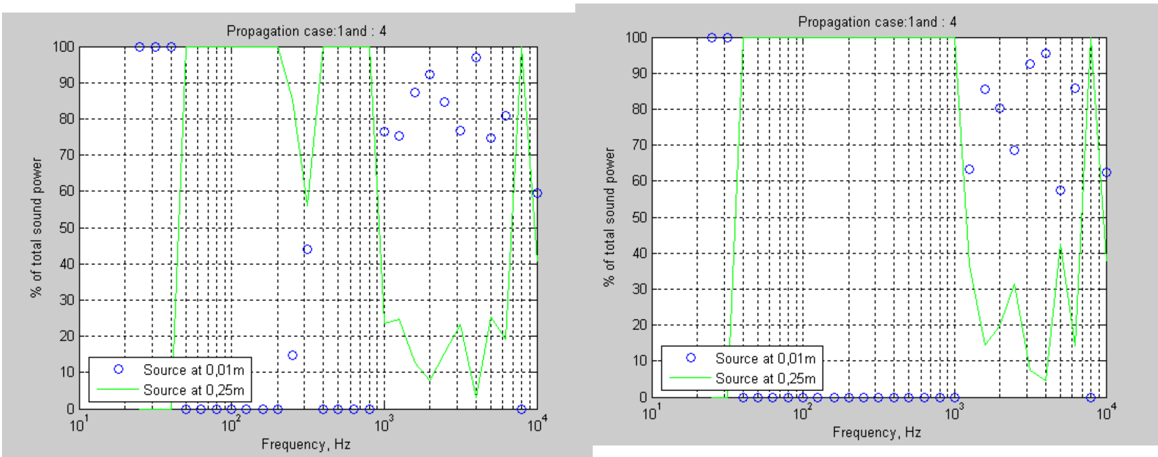

Figure 3. Snowmobile towed after another snowmobile (left) and with acceleration from 24 km/h (right).

Assuming that we model the snowmobile using two source heights, h_1 and h_2, each with the predetermined ratio p_1 and p_2 respectively of the total sound power W the sources will yield the sound pressure levels L_1 and L_2 respectively given by

$$L_1 = L_W + 10 \cdot \lg(p_1) - 10 \cdot \lg(4\pi \cdot r^2) + \Delta L_1 \qquad (10)$$

$$L_2 = L_W + 10 \cdot \lg(p2) - 10 \cdot \lg(4\pi \cdot r^2) + \Delta L_2 \qquad (11)$$

which can be added up to

$$L = L_W - 10 \cdot \lg(4\pi \cdot r^2) + 10 \cdot \lg\left(p_1 \cdot 10^{0,1\Delta L_1} + p_2 \cdot 10^{0,1 \cdot \Delta L_2}\right) \qquad (12)$$

where r is the distance to the receiver and ΔL the excess ground attenuation (ranging from + 6 dB to - ∞) for the propagation from the source to the receiver, which will be calculated according to Nord2000.

Looking at figure 2 – 4 and considering the uncertainties in the impedance model it is not simple to create a reliable source model. However, there seems to be some clear trends. For frequencies at and below 1000 Hz most of the acoustic energy seems to come from a source around 0,25 m which is not unreasonable as this fits both parts of the engine and the exhaust. This is quite clear in figure 4 where the right figure shows the case with full acceleration, that is with a likely engine noise domination. Above 1000 Hz there seems to be significant contributions from a lower source, probably the track. Thus in our calculations in clause 9 we will use the following model:

$$f \leq 1000 \text{ Hz: } h_1 = 0{,}01;\ p_1 = 0{,}2;\ h_2 = 0{,}25;\ p_2 = 0{,}8 \quad (13)$$

$$f > 1000 \text{ Hz: } h_1 = 0{,}01;\ p_1 = 0{,}8;\ h_2 = 0{,}25;\ p_2 = 0{,}2 \quad (14)$$

9 Theoretical analysis of test methods

9.1 Verification of the calculation method

Equation (12) with data as described in clause 8 has been used do determine the sound power level of the Lynx snowmobile cruising at 50 km/h. The result is shown in figure 5. Input data for the calculations were taken from measurement position 7,5m/3,5m as this position has the lowest influence of ground attenuation. This sound power level was then used to determine the sound pressure levels at the positions 7,5m/1,2m and 15m/1,2m respectively for propagation over snow (flow resistivity 10 kPas/m^2) and grass land with flow resistivity 250 and 500 kPas/m^2 respectively. The calculated ΔL-values are shown in figure 6. The results are given in table 6 for A-weighted values. All calculations were carried out in 1/3 octave bands.

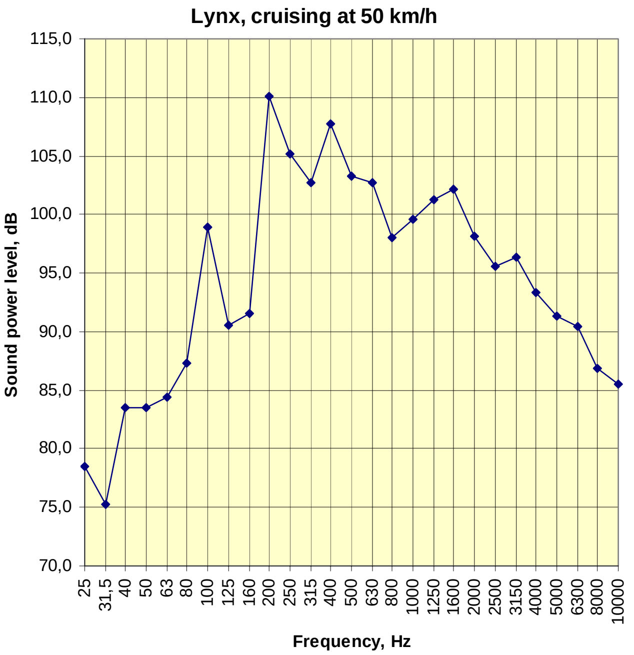

Figure 5 Estimated sound power level of the Lynx snowmobile when cruising at 50 km/h

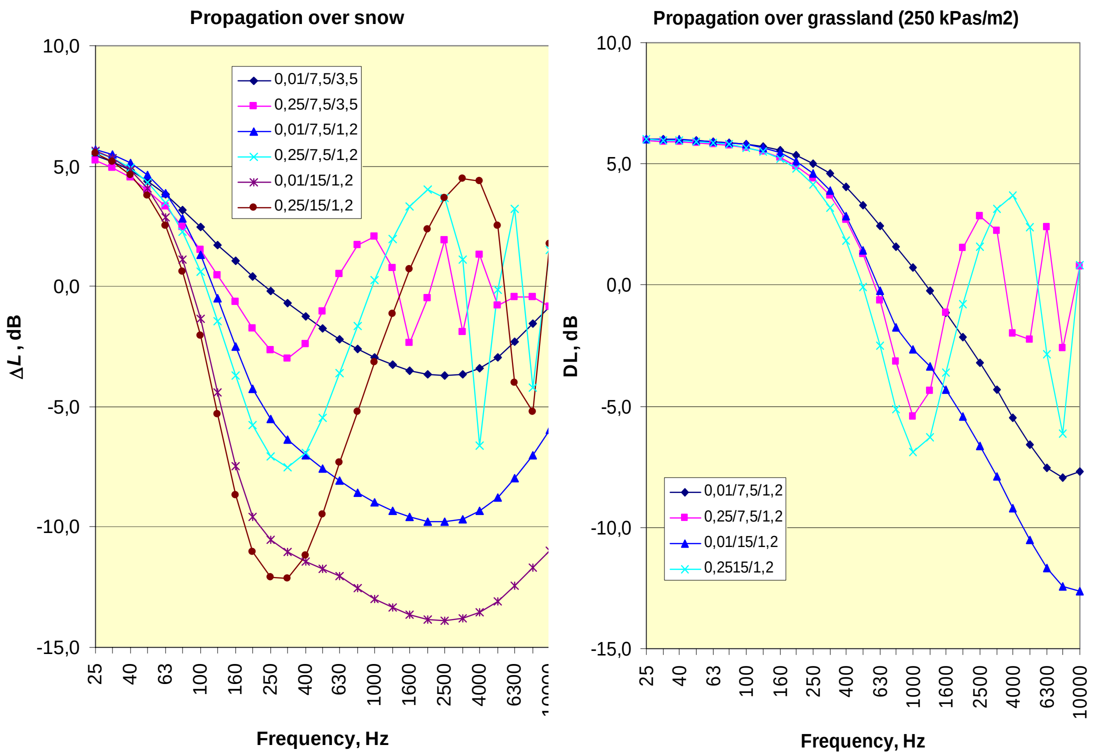

Figure 6 Calculated ground effect relative to free-field sound propagation for the point source heights 0,01 m and 0,25 m for the different microphone positions used on snow (10 kPas/m², left) and for grassland (250 kPas/m², right)

Table 6 Comparison between calculations and measurements, in dB.

	Position	Snow, 10 kPas/m²	Grass, 250 kPas/m²	Grass, 500 kPas/m²	Difference grass (250 kPas/m²) - snow	Difference Grass (500 kPas/m²) - snow
Calculated	7,5m/1,2m	78,8	83,7	85,0	4,9	6,2
	15m/1,2m	70,4	76,5	78,2	6,1	7,8
	Difference	8,4	7,2	6,8		
Measured	7,5m/1,2m				5,0	
	15m/1,2m				5,2	
	Difference	7,5[1)]				

[1)] Only the difference is given as the calculations have been made based on the spectrum of another snowmobile. Thus the individual values are not fully comparable. It is, however, assumed that the difference does not vary much from one snowmobile to another.

Table 6 indicates that the prediction method used can predict the difference between different measurement conditions with a reasonably good accuracy, at least as long the operating conditions remain the same. In our case we cannot be 100% sure that the operating conditions on snow and grass are identical.

9.2 Effect of different snow depths and distances

The same model as before but using the two-parameter model for the acoustic impedance of snow has been used to estimate the effect of different snow depths. The result is shown in table 7.

Table 7 Calculated sound pressure level at the snow depths 0,075 m, 0,15 m, 0,30 m and 0,45 m respectively.

Geometry	7,5/0,075	7,5/0,15	7,5/0,30	7,5/0,45	15/0,075	15/0,15	15/0,30	15/0,45
LpA	79,0	78,7	78,8	78,8	70,4	70,3	70,4	70,4

Table 7 indicates that the snow depth is not critical as long as it exceeds 0,075 m. It also shows that the difference between 7,5 m measurement distance and 15 m distance is around 8,5 dB if only the difference in propagation conditions is considered. This can be compared with the 7.1 dB with standard deviation 0,5 dB reported in 7.5.

10 Future potential for lower noise emission

The sound emission from snowmobiles has remained fairly constant during the last 15 years when measured according to the acceleration test in SAE J192. During the same time period the engine power level has almost tripled! To achieve this the introduction of 4-stroke engines in snowmobiles has been a major factor.

Manufacturers have tested several new technical modifications and designs in order to produce quieter snowmobiles. Examples are engines with more cylinders, lower engine speed, a more quiet track, more parts made of plastic, fewer and smaller openings in the hood, more efficient silencers (both intake and exhaust) and vibration insulation of the engine.

At our measurements we noted that at the cruising speed 24 km/h the maximum sound pressure level increased 2-3 dB when the snowmobile passed the normal and exposed the rear of the machine to the microphone for the last 10-22,8 m of the test path. This indicates that the air intake and the transmission/suspension are major noise sources. Some significant noise also finds its way out at the foot rests.

A simple test to find out how much noise the transmission and bogie suspension causes was made on snow. Two snowmobiles were connected by a 40 m long rope. The first snowmobile towed the other which had the engine switched off through the measuring zone at a cruising speed of 24 km/h. At 7,5 m/1,2 m the A-weighted sound pressure level, using time-weighting F, from the snowmobile with the engine shut off was 70 dB. At 15 m/1,2 m the sound pressure level was 62,1 dB(A). The sound pressure level of the towing snowmobile was at least 10 dB below that of the towed snowmobile at the shortest pass-by distance.

An earlier study [10] made by SMP on stationary snowmobiles showed that the sound pressure level differs in different directions around a snowmobile. The difference was approx. 3 dB for a 2-stroke snowmobile and approx. 4 dB for a 4-stroke snowmobile.

It can be verified that a lot of the noise from the snowmobile is generated by the transmission and suspension. There is a potential for improvement concerning noise. A more enclosed engine compartment and air intake with noise trap could be possible areas for improvement.

Like the car industry different software in the snowmobile's electronic control unit (ECU) can change the characteristics of the engine dramatically with the corresponding effect on the sound pressure level. It has been shown that more engine power and more aggressive acceleration result in higher values on the sound level emission.

Earlier tests in Sweden by SMP in accordance with the SP proposal from 1995 showed that even used snowmobiles with engine displacement up to 440 cc easily met the 85 dB requirement. A 340 cc snowmobile could also meet the requirement on grass.

The easiest way to lower the sound level from a snowmobile is to reduce the rated engine power and to limit the maximum acceleration like some of the BAT classified snowmobiles. To produce snowmobiles for Europe with the same specification as the snowmobiles that meets the North American requirements is one way to lower the sound level on several models. The benefit would be a global specification for each model.

11 Discussion, conclusions and recommendations

11.1 Test methods

The SAE-methods seem to be designed to yield lowest possible measurement values. They use longer distances than corresponding ISO-standards for other types of vehicles and they use time-weighting S instead of time-weighting F for the pass-by measurements. Finally they allow for a 2 dB subtraction from the measured sound pressure level to make the manufacturer and not the consumer get all benefits from the measurement uncertainty. However, as long as the legislators are aware of these facts it is not really any problem. It is possible to correct for distance and time-weighting with a fairly high degree of accuracy.

As to the different operating conditions there does not seem to be any major difference during acceleration between 24 and 50 km/h. Including difference in time weighting the difference between 7,5 m and 50 km/h and 15 m and 24 km/h is around 9,5 dB. As the distance effect is around 7,5 dB and the time weighting effect 2 - 3 dB the two operating conditions seem to be rather equivalent. However, when cruising at constant speed, this difference increases by 4 dB, that is you make 4 dB more noise cruising at 50 km/h than you make cruising at 24 km/h.

As to measurements on grass it is possible to make quite accurate corrections for the different sound propagation effects. There is good agreement between calculated and measured ground effects. However, there is an uncertainty in the operating conditions. Engine load, problems with overheating, excitation of track and track radiation may differ between snow and grass and more tests are necessary in order to be able to come up with any recommendation. For the time being it is difficult to recommend grass measurements for type approval measurements. Besides it is quite feasible to save some artificial snow from the winter season and to carry out snow measurements during the summer. In Sweden it has become a tradition to have some cross-country skiing competitions in the summer or early autumn on snow saved from the previous winter season.

As the differences between the different test methods are quite consistent it does not matter very much which method is used as long as the limit values are adapted accordingly. Differences in sound propagation and time-weighting can be explained quite well theoretically. The snow depth is not very critical as long as it exceeds 7,5 cm.

In summary our recommendations are:

- Type approval measurements should be carried out on snow as described in SAE J192;
- grassland may influence the operating conditions and should not be used for type approval measurements;
- selection of measurement distance and time-weighting is not very critical as long as the limit values are adjusted accordingly;
- operating conditions should be both cruising and accelerating, see limit values below. The reference speed for acceleration is not critical. However, when cruising, 50 km/h makes much more noise than 24 km/h.

11.2 Limit values

None of the tested snowmobiles, even after subtraction of 2 dB from the measured value, complied with the North American requirements during acceleration whereas all complied with the requirements during cruising. The non-compliance during acceleration is in line with previous tests carried out in 1995. As snowmobiles seem to be verified regularly in North America one could conclude that snowmobiles exported to Sweden are different from those sold in North America either with respect to the electronic regulation of the engines or the silencers. Models sold in Europe often have unique configuration and model numbers. However, the manufacturers strongly deny that snowmobiles intended for the European market are different. An alternative explanation could be that the operating conditions depend strongly on the snow conditions and that the more experienced testers in North America are clever to select conditions minimizing the noise emission. Whatever the reason, the conclusion is that it is necessary to reintroduce limit values in Europe and to enforce these values by regular testing of imported snowmobiles.

The acceleration test is a rather extreme test and the operating conditions are not always representative for normal driving. It should be considered either to introduce two limit values, one for acceleration and one for cruising, or a new type of limit value consisting of some kind of weighted average of cruising and acceleration. An example of this way of thinking is given in eq. (15) and table 8. The starting point of this example has been the American limit values and giving them equal weight.

$$L = 10 \cdot \lg\left(10^{0,1 \cdot L_a} + 10^{0,1(L_c + L_{al} - L_{cl})}\right) - 3 \qquad (15)$$

where L_a and L_c are the measured values during accelerating and cruising respectively. The extra index l indicates the limit values, in our example 78 and 73 dB respectively.

Table 8 Example using weighted average including both cruising and acceleration, in dB.

	SAE J192 Acceleration	SAE J1161 Cruising	Weighted average
1. Ski-Doo	81,0	67,0	78,5
2. Polaris	80,9	72,7	79,6
3. Lynx	83,6	67,4	80,9
4. Arctic Cat	84,6	65,2	81,8
Average	82,5	68,1	80,0
Limit value	78	73	78,0

As to selection of limit values considerations should be given to the following facts:

- The former Swedish requirements on 85 dB was referred to time-weighting F, a change to time-weighting S would change this limit to approximately 87,5 dB if measured with the same test method (acceleration from 50 km/h at 7,5 m);
- in Yellowstone and Grand Teton national parks it has been shown to be achievable to implement 5 dB lower limit values in their BAT requirements, that is 73 dB in stead of 78 dB commonly used for other state regulations, when measured according to SAE J192;
- when putting up a limit value one can either require it never (that is with a given, often 95%, probability) to be exceeded, which means that the measurement uncertainty is added to the measured value, or, one can do as required by the SAE standards, subtract it from the measured value to make sure that no snowmobile is ever (that is with a given probability) rejected just because of the measurement uncertainty. In the former case the consumer is protected and in the latter case the manufacturer benefits. Whatever method is chosen it should be clearly stated. The European directive on outdoor machinery, [1], works with guaranteed levels, that is the measurement uncertainty is added to the measured levels. The 2 dB subtraction of the SAE-methods is not compatible with this approach.

12 References

[1] European Directive 2000/14/EC on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors

[2] SAE J192:2003 Maximum Exterior Sound Level for Snowmobiles

[3] SAE J1161:2004 Operational Sound Level Measurement Procedure for Snowmobiles

[4] ISO 362-1:2007, Measurement of noise emitted by accelerating road vehicles – Engineering method – Part 1: M and N categories, Part 2: L category

[5] Anders Stenhoff, Terrängskotrar - Förslag till bullernorm, SP RAPPORT 1995:35

[6] NT ACOU 104 Ground surfaces: Determination of the acoustic impedance (http://www.nordicinnovation.net/article.cfm?id=1-834-435)

[7] Mikael Ögren & Hans Jonasson, Measurement of the Acoustic Impedance of Ground, SP Report 1998:28

[8] Anders Stenhoff, Kartläggning av buller från terrängskotrar, SP RAPPORT 1991:18

[9] Gunnar Taraldsen, Noise Emission from Road Vehicles, Nordtest technical report 557, SINTEF Report STF90 AO4002, 2004

[10] Stefan Frisk, Ljudeffektnivå för snöskoter baserat på mätning enligt standard ISO 362:1998, SMP RAPPORT F700413, 2007

[11] Hans Jonasson & Stefan Frisk, Noise Emission from Snowmobiles, SP Report 2009:24