ACOUSTIC COMPARATIVE ANALYSIS FOR TRACTORS
/
ANALIZA ACUSTICĂ COMPARATIVĂ PENTRU TRACTOARE

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ABSTRACT
This article presents results on the comparison of the noise produced by the operation of two tractors of different types and generations. The results of gross measurements using the same measurement point network, but also by interpolating in terms of the equivalent noise level, are compared. The results apply to simulation problems of disturbing acoustic fields generated by tractors or multiple tractors in simultaneous action.

REZUMAT
Acest articol prezintă rezultatele comparării zgomotului produs de funcționarea a două tractoare de diferite tipuri și generații. Se compară rezultatele măsurătorilor brute utilizând aceeași rețea de puncte de măsurare, dar și prin interpolarea în ceea ce privește nivelul echivalent de zgomot. Rezultatele se aplică problemelor de simulare a câmpurilor acustice perturbatoare generate de tractoare sau tractoare multiple în acțiune simultană.

INTRODUCTION
Acoustic pollution of the environment is also manifested in agriculture because, for example, the degree of mechanization of agricultural works has increased. Engine acoustic pollution is accompanied by pollutants and exhaust emissions. Agricultural workers involved in working processes near tractors in operation or other power sources are affected by the pollution produced by these sources. Estimating the polluting effects of these sources is a first step towards their control. By evaluating noise sources of the same type, comparisons can be made and can give an idea of what the evolution of the sources in time is, both in terms of fabrication and wear. The results of the measurement experiments *(Rainio et al., 2018)* and their interpolation for the purpose of the prognosis of the effects are steps in obtaining advanced results, for the time being in research, thus exceeding the usual testing standards. The effects of accumulating acoustic pollution over time on the human body or estimating, at least partially, the degree of wear and tear of an engine, are only prime orientations in this regard.

MATERIALS AND METHODS
Steps of investigation and modelling
The results presented in this paper are obtained in the frame of an international collaboration.

The experimental data was obtained at the Angel Kancev University in Ruse and data processing was done at the National Agricultural Machinery Institute in Bucharest. The conclusions belong to both parties.

The scheme of the metering system is shown in fig. 1. This includes the position of the tractor, the reference system and the position of the points where the characteristics of the acoustic field are measured.

Sequence of data recorded and stored in the Excel database **Table 1**

P11	Octave bands, Hz											Weighted
	No	31.5	63	125	250	500	1000	2000	4000	8000	16000	A
	1	48.1	65.7	78.6	78.1	90.3	93.4	91.6	88	81.1	77.1	97.5
	2	48.3	66.4	78.6	78.5	90.2	93.5	91.4	88.2	81.1	76.7	97.5
	3	49.4	66.7	78.9	78	90.1	93.5	91.1	87.6	80.9	76.7	97.3
	4	48	66.9	78.9	78	90.2	94.2	91.4	88	81.1	76.9	97.7
	5	48.9	67.8	78.7	78.3	89.6	94	91.3	87.7	80.8	76.8	97.4

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The characteristics of the acoustic field of each tractor were measured for two engine revs. A typical sequence of data recorded and stored in the Excel database is shown in Table 1.

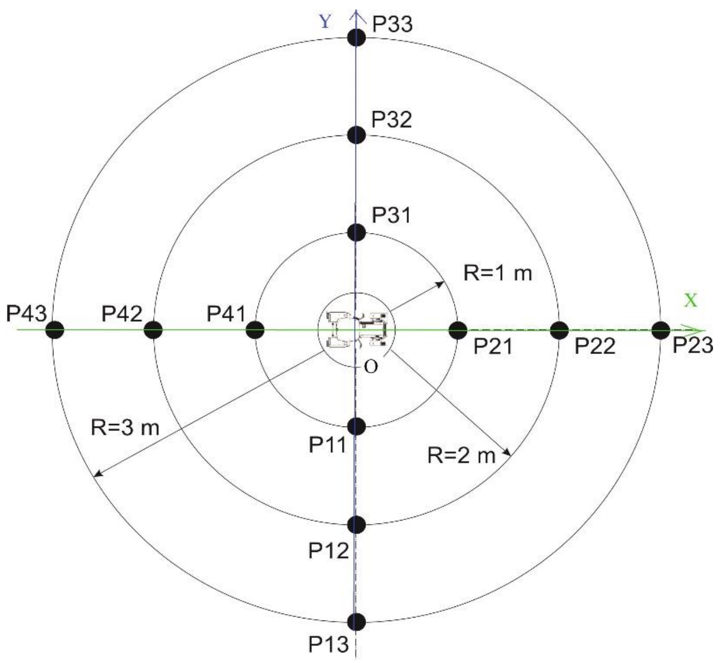

Fig. 1 - The scheme of the acoustic field measurement system generated by the operation of the tractor engine

The orientation of the tractor in measurement operation is given in fig. 1. Therefore, there is a pronounced asymmetry to the axis Ox, marked by maximum of two measuring points P11 and P31. The distance of the two maximums of the noise field from the Ox axis is the same, but the intensity is different. It is possible that, in reality, the two maximum points do not exist. It is possible to have a single point of maximum longitudinal axis of the tractor axle, maximum of two points that appear in the graphic representations of fig. 2-5.

The first graphical representations of the noise level averaged over all octaves are show in the fig. 2 and 3.

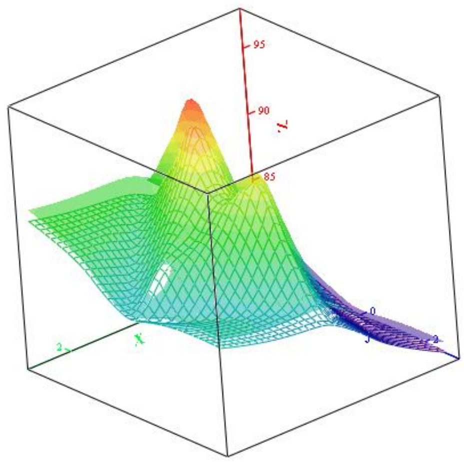

Fig. 2 - Noise distributions in the measurement plane for the Bulgarian tractor

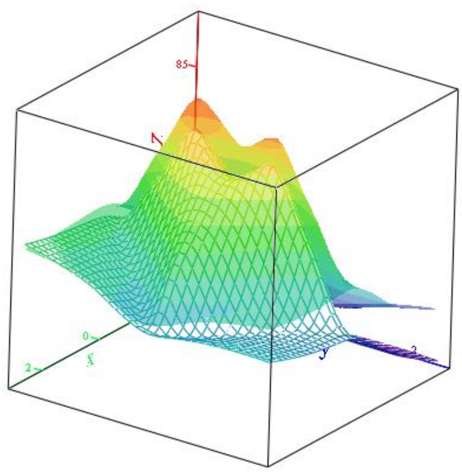

Fig. 3 - Noise distributions in the measurement plane for the Case tractor

In each of the fig. 2 and 3, the noise distribution is represented at engine speed of 1500 RPM and 2000 RPM.

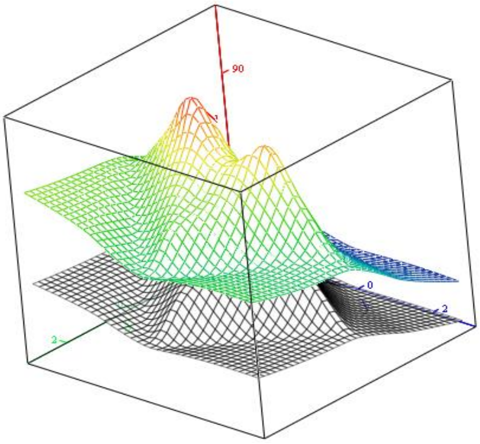

Fig. 4 - Noise distribution in the measurement plane: colour - Bulgarian tractor; Black and white - Case tractor. Engine speed 1500 RPM

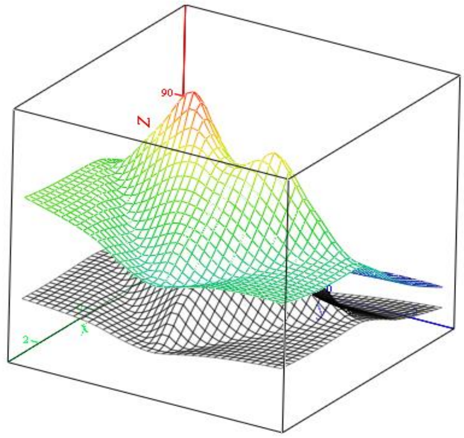

Fig. 5 - Noise distribution in the measurement plane: colour - Bulgarian tractor; Black and white - Case tractor. Engine speed 2000 RPM

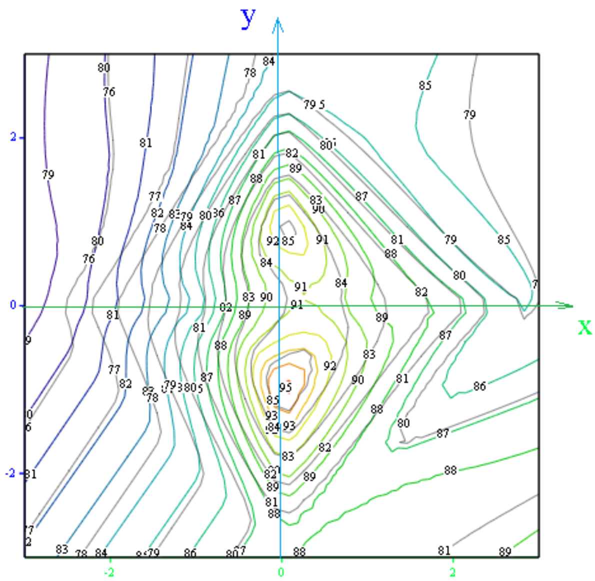

Fig. 6 - Noise distribution in the measurement plane: colour - Bulgarian tractor; Black and white – Case tractor. Engine speed 1500 RPM

The maps in fig. 2-6 don't show symmetry axes, not even reported to the longitudinal axis of the tractor. Such measurements and graphical results were also obtained in previous works (*Postelnicu et al., 2013; Cârdei, Muraru, Sfîru, 2018; Cârdei, Sorica, Vladut et al. 2019).*

Interpolation by classical distribution functions

Computer Programs noise distribution formulas use incremental decreases of the noise wrapped source proportionally with the logarithm of distance (*Cârdei, Muraru, Sfîru, 2018*). For a single-source programs use a formula of the form:

$$L_{eq} = L_w - 20\lg r - 11 \quad (1)$$

where L_{eq} is the equivalent noise level, L_w is the source power, and r is the distance to the source.

For Bulgarian tractor speed of 1500 RPM, we found the following formula:

$$L_{eq} = 104.792 - 20\lg r - 11 \quad (2)$$

Because the noise distribution has no symmetry, the radial coordinate with the following formula is considered:

$$r = \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2} \quad (3)$$

where x_0, y_0, z_0, are the coordinates of the source. By the method of least square, it results: L_w=104.792, x_0=0.621, y_0=-0.883, z_0=0.406 (coordinates of the source centre).

With (3), the formula (2) became:

$$L_{eq} = 104.792 - 20\lg\sqrt{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2} - 11 \quad (4)$$

In fig. 7 is shown only the interpolated noise level for the Bulgarian tractor at the speed of 1500 rot/min, from two points of view.

Similarly, in fig. 8 and 9 are plotted noise distributions of the Bulgarian tractor at the engine speed corresponding to the value of 2000 RPM. The noise level interpolated formula for this case is:

$$L_{eq} = 105.261 - 20\lg\sqrt{(x-0.599)^2+(y+0.999)^2+(z-0.701)^2} - 11 \quad (5)$$

It is obvious that the single source interpolation formula (1) leads to distributions of noise that have a unique point of maximum.

Note: In the formulas (1), (2), (4) and (5), the radial coordinate became null for the source location (r = 0, or $x = x_0$, $y = y_0$, $z = z_0$). The logarithms have no sense for the null argument or infinite value to zero, i.e. these terms tending to infinity, if one takes into account the minus sign in front of these terms.

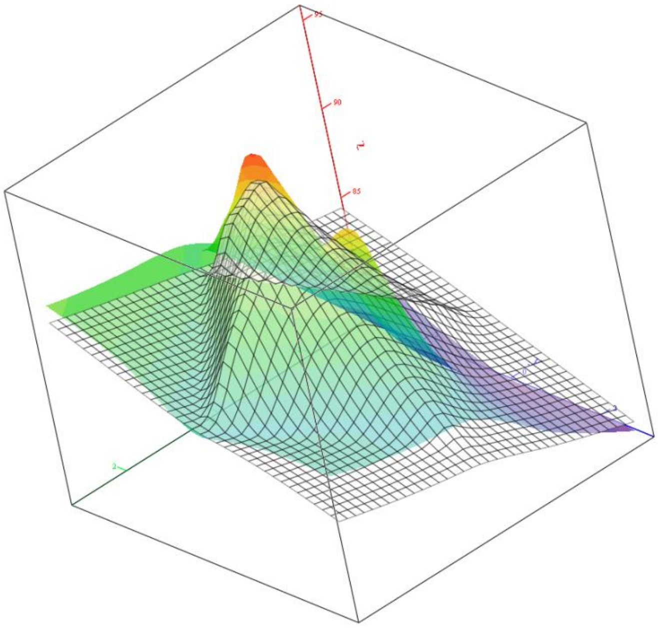

Fig. 7- Noise level distribution around the Bulgarian tractor at 1500 RPM: colour – experimental distribution, black and white – interpolated distribution (formula (4)) at the measuring height of 1.2 m from the ground of the Sound Level Meter

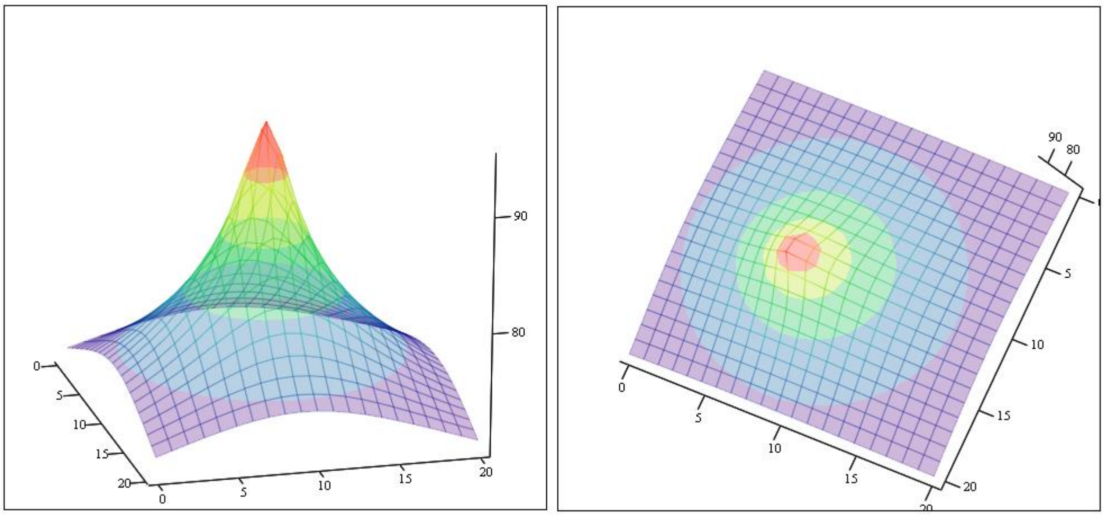

Fig. 8 - Interpolated noise level distribution for Bulgarian tractor at 2000 RPM (two projections) at the measuring height of 1.2 m from the ground of the Sound Level Meter

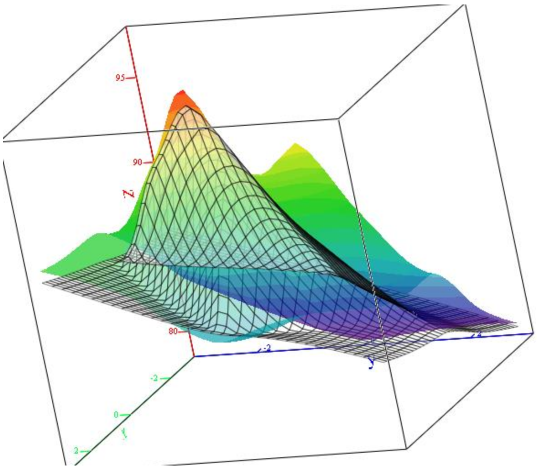

Fig. 9 - Noise level distribution around the Bulgarian tractor at 2000 RPM: colour – experimental distribution, black and white – interpolated distribution (formula (5)) at the measuring height of 1.2 m from the ground of the Sound Level Meter

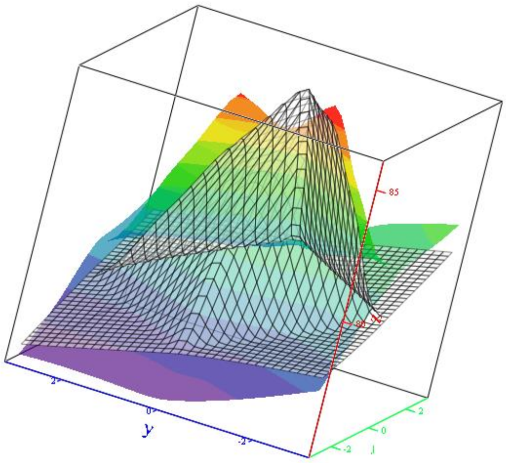

Fig. 10 - Noise level distribution around the Case tractor at 1500 RPM: colour – experimental distribution, black and white – interpolated distribution (formula (6)), at the measuring height of 1.2 m from the ground of the Sound Level Meter

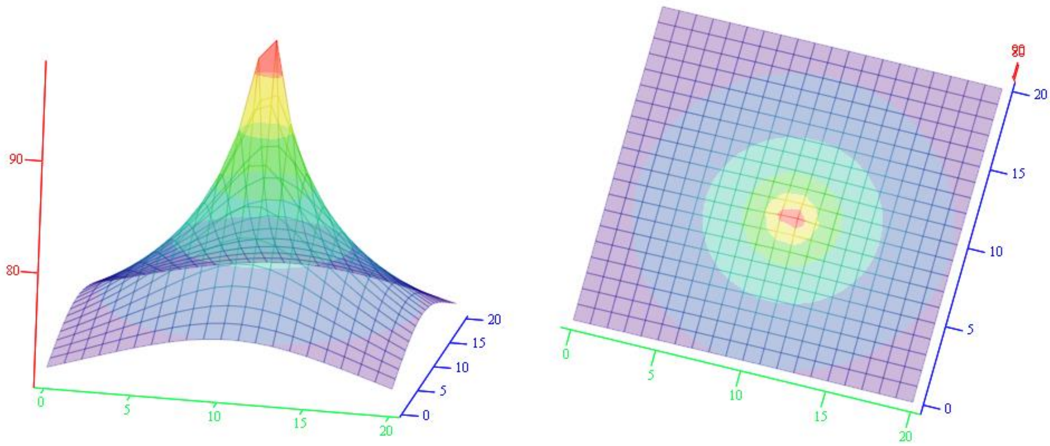

Fig. 11 - Interpolated noise level distribution for Bulgarian tractor at 2000 RPM (two projections) at the measuring height of 1.2 m from the ground of the Sound Level Meter

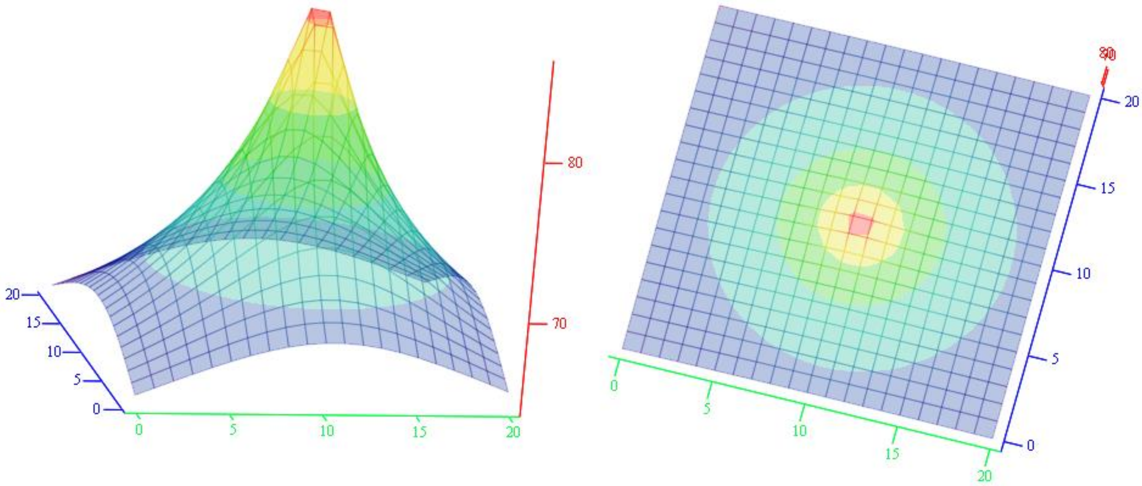

Fig. 12 - Interpolated noise level distribution for Case tractor at 1500 RPM (two projections) at the measuring height of 1.2 m from the ground of the Sound Level Meter

The formula for interpolated noise level tractor at 1500 RPM is the following:

$$L_{eq} = 99.224 - 20\lg\sqrt{(x-0.458)^2 + (y+0.355)^2 + (z-0.000)^2} - 11 \qquad (6)$$

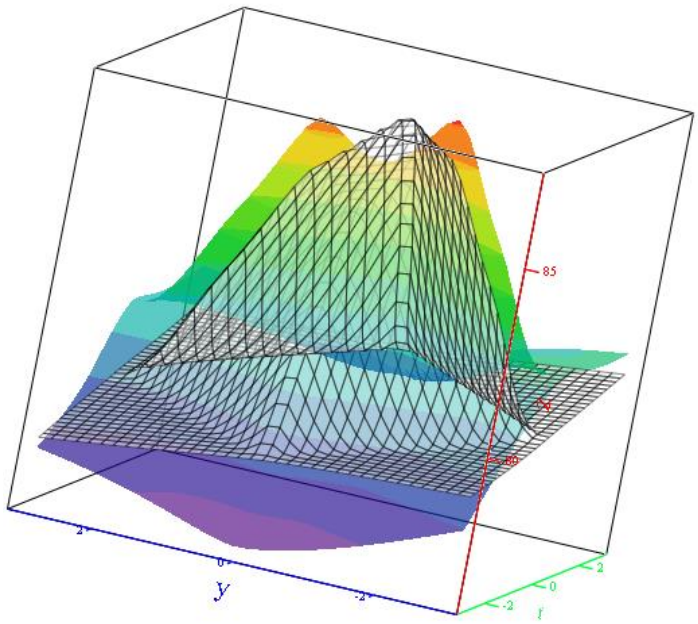

Fig. 13 - Noise level distribution around the Case tractor at 2000 RPM: colour – experimental distribution, black and white – interpolated distribution (formula (7)), at the measuring height of 1.2 m from the ground of the Sound Level Meter

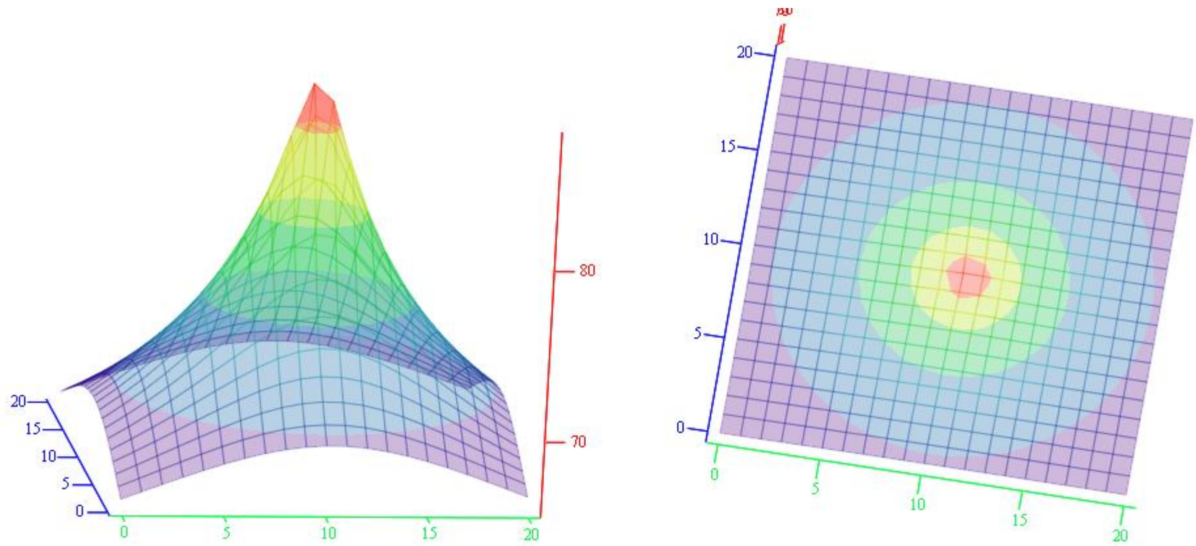

Fig. 14 - Interpolated noise level distribution for Case tractor at 2000 RPM (two projections) at the measuring height of 1.2 m from the ground of the Sound Level Meter

The formula for interpolated noise level of the Case tractor at 2000 RPM is the following:

$$L_{eq} = 100.443 - 20\lg\sqrt{(x-0.293)^2 + (y+0.169)^2 + (z-0.000)^2} - 11 \qquad (7)$$

RESULTS

Noise field created by two Bulgarian tractors

This application shows how to use interpolation formulas for the noise intensity of a source in order to simulate the noise field generated by several sources. The papers (*Cârdei, Muraru, Sfîru, 2018; Cârdei, Muraru, Vladut et al., 2008*), for example, give the formula for calculating the sound field caused by several sources, composition which is not linear:

$$L_{eq} = 10\lg\left[\sum_i 10^{\frac{L_i}{10}}\right] \tag{8}$$

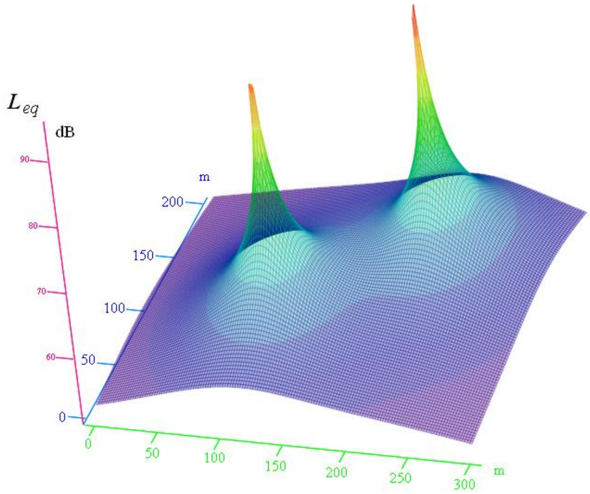

Fig. 15 - The noise field generated by two working Bulgarian tractors in a field of 200 x 300 m size
The first (right) tractor works at 2000 RPM, and the second (left) at 1500 RPM

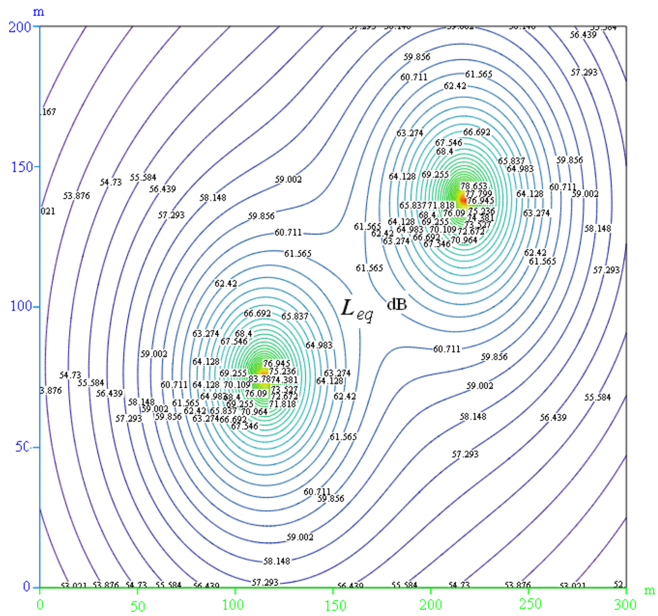

Fig. 16 - The noise field (lines level map) generated by two working Bulgarian tractors in a field of 200 x 300 m size. The first (right) tractor work at 2000 RPM, and the second (left) at 1500 RPM

On the plot of land sized 200 x 300 m, two Bulgarian tractors are considered, one operating at 1,500 RPM speed, the other at the speed of 2,000 RPM. We intend to determine the noise field generated by two sources working within in the same agricultural field. To obtain the noise field in fig. 15 and 16 the formulas of the noise fields generated by individual sources, given by the formulas (4) and (5), are composed according to the formula (9).

The difference between the two sources intensity is observed in fig. 15, but is small compared to the maximum.

It can be observed that at the edge of the plot, the noise intensity created by the two sources reaches the normal level for working in an office or the level of a telephone talk or radio (50–60 dB). (http://www.dezumidificare.ro/nivelul-de-zgomot; http://www.viaclab.utcluj.ro/FEA13_14_p1_Experimente.pdf; *Popescu et al., 2003*), and (*Cârdei, 2008*). The maxim value of the noise level is 94.887 dB, and the minim value is 51.32 dB.

In Fig. 17 is shown similar to Fig. 15 and 16, the noise field generated by the same Bulgarian tractors, working at the speed of 2000 RPM.

The difference in intensity is visible in the two graphical representations.

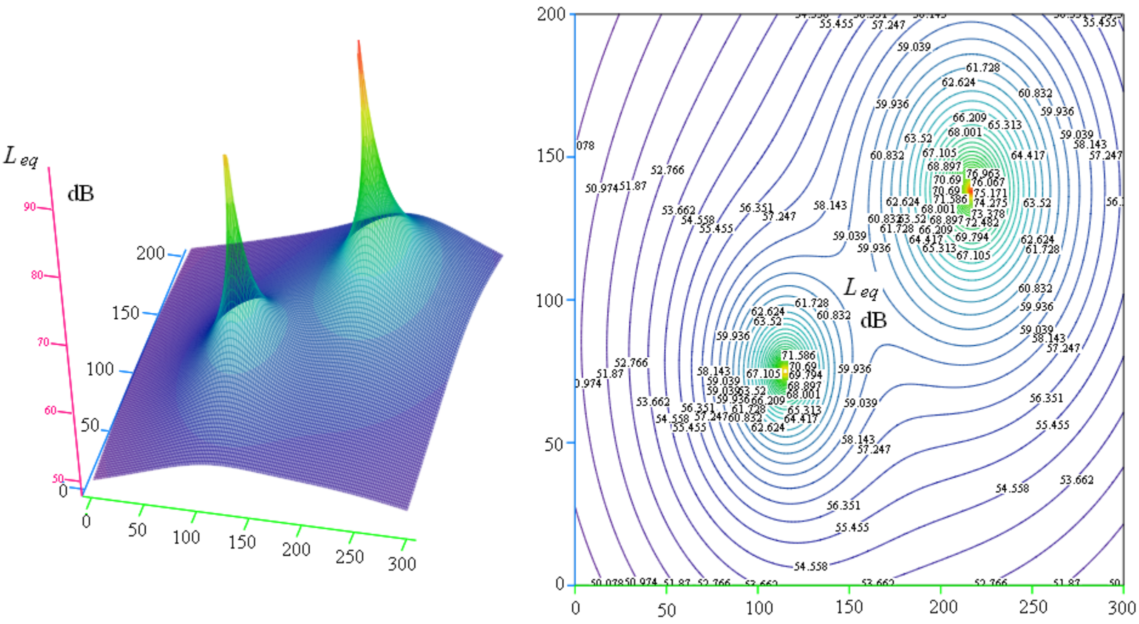

Fig. 17 - Noise field generated by two tractors: left – Case tractor and –right Bulgarian tractor, both working at 2000 RPM

Alternative formulas

In the paper *Cârdei (2008*) is used for the interpolation of the harvesting machine sound level, the following formula of noise level:

$$L_{eq} = L_w - 20 \cdot \lg r - 8 \tag{9}$$

But the difference in the precision is negligible. An improved calculation formula is, (*Cârdei, 2008*):

$$L_{eq} = A - B \cdot \lg\left(r + r_0\right) \tag{10}$$

Or, even a better version, with dimensionless argument:

$$L_{eq} = A - B \cdot \lg\left(\frac{r}{r_0} + 1\right) \tag{11}$$

For now, these alternative formulas have not been tested enough and we recommend to the young specialists to try applying or developing other formulas. In fig. 18 and 19 are given graphical representations for noise fields generated by tractors, which use mathematical models obtained using interpolation functions without singularities in origin (in the sources location), and having asymptotic behaviour at large distances. At large distances, the average noise level tends towards the background noise (which is to be determined).

The interpolation indicates the location of the source and its local sphere of action in relation to the background noise. The model applies interpolation used in dimensional terms.

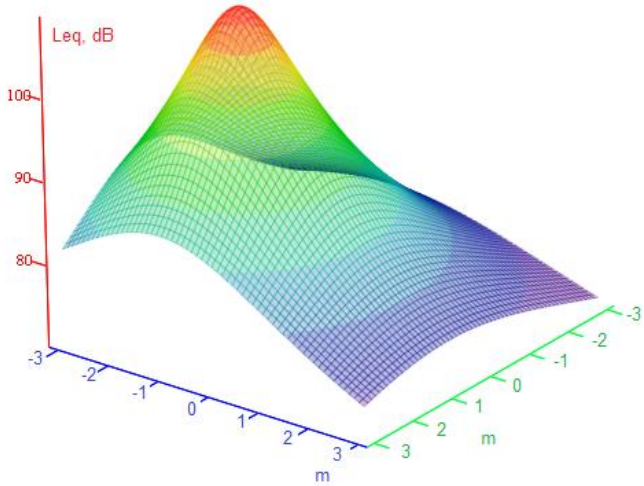

Fig. 18 - The variation with distance of a noise level function without singularity in noise source

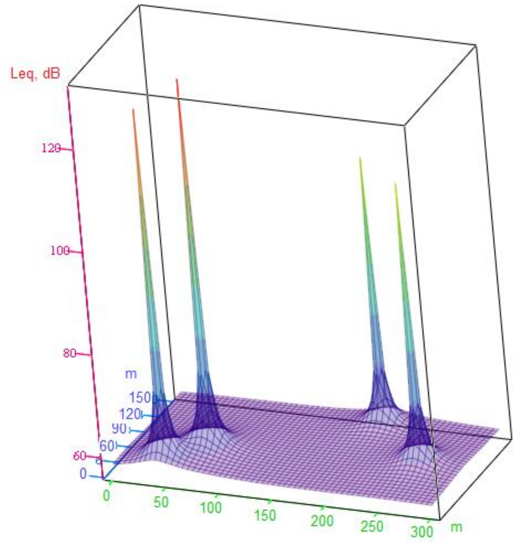

Fig. 19 - Noise field for four tractors (Bulgarian tractors at 1500 rpm and 2000 - left side of the plot and Case tractors, at 1500 and 2000 rpm - right side of the plot).

For simulation (fig. 19) were used interpolation function without singularity in origin and asymptotic behaviour at infinity.

Interpolation formulas defined for each of the tractors can be used for:

- Simulation of complex noise fields (tractors and other agricultural machines and other sources);
- Study of the wear status of tractors;
- Study of the road traffic effects.

CONCLUSIONS

The conclusions are the following:

- For both types of tractors, noise level at the speed of 1500 RPM, is lower than that at the speed of 2000 RPM;
- For each speed (1,500 and 2,000 RPM), noise is appreciably higher for Bulgarian tractor towards tractor Case (see fig. 4 and 5, 6.9% at 1500 RPM, 6.4% at 2000 RPM);
- The noise maps don't show symmetry axes, not even reported to the longitudinal axis of the tractor;
- For the interpolation stage and the identification of the noise sources from the tractor (it seems that there are two sources), it would be useful to know the longitudinal axis of each tractor during the measurement, reported to the Ox and Oy axes;
- The orientation of the tractor during measurement operation is given in Fig.1 and shows that there is a pronounced asymmetry to the axis Ox, marked by maximum of two measuring points P11 and P31.

The distance of the two maximums of the noise field from the Ox axis is the same, but the intensity is different. It is also possible to have a single point of maximum of the noise field, located on the tractor longitudinal axis, at the intersection with the axis of the two maximums of noise field, that appear in the graphic representations in fig. 2-5.

- The single source interpolation formula (1) leads to distributions of noise that have a unique point of maximum.
- Interpolation formulas defined for each of the tractors can be used for:
  - Simulation of complex noise fields (tractors and other agricultural machines and other sources);
  - Study of the wear status of tractors;
  - Study of the road traffic effects.

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