ICSV13 - Vienna

The Thirteenth International Congress on Sound and Vibration

Vienna, Austria, July 2-6, 2006

PSYCHOACOUSTIC CHARACTERISATION OF LAWNMOWERS VERSUS STANDARD A-WEIGHTED SOUND POWER AND COMPARISON WITH VIRTUAL PROTOTYPING RESULTS

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Abstract

In the framework of the R&D project LaMoNoV (LawnMower Noise and Vibration) dealing with noise sources ranking and characterisation in lawnmower machines [1], this paper presents a psychoacoustic approach based on jury assessments using, in particular, binaural audio-conform recordings under ISO-11094 standard measurement condition.

The relationship between conventionally measured objective lawnmower noise and the general acoustic impression is derived from juries of experts, drivers and “neighbours”. A comparison is made between A-weighted ISO-11094 standard ratings and perceptive judgements. The obtained relationship is then tested against synthesised noise calculated through virtual acoustic prototyping, and specifically on the NST methodology (Noise Synthesis Technology).

The prediction of the radiated noise, and related noise control recommendations, is achieved by means of a software tool which is fed by input data obtained from the components and their interaction. Two types of output data are available: synthesis noise in the form of spectra, and noise waveform reproduction. The NST does not work as an absolute predictive process, and thus requires experimental validation. Components are taken into account in a deterministic way, by establishing their detailed vibro-acoustic characteristics via measurement. In the present work on lawnmowers, selected components are the blade(s), the motor, its exhaust, the deck, the transmission system, ...

INTRODUCTION

In the project LaMoNoV, the Work Package Two was devoted to psycho-acoustic topics and covered 32 lawnmower machines of all size and usage (personal, professional, cutting and bagging or mulching…).

Audio-conform recordings

They were taken under standard ISO-11094 static running condition: maximum blade speed, 3cm or minimum cutting height if higher, recordings after 30 min of engine pre-run and check for at least 30 seconds of "clean" signal.

All the above audio-conform recordings have been processed into a commercial psychoacoustic software and analysed in terms of general existing criteria.

Jury evaluations

Preliminary jury evaluations limited to a panel of few experts (Maximum 8 among Manufacturers and acousticians) and also to a few selected machines. These first evaluations were intended to ease the preparation of the full jury evaluations in:

- Validating the most significant criteria.
- Selecting the proper noise recorded sequences to be used for re-listening (only short duration records are usable for jury evaluation),
- Determining the appropriate type of jury evaluation method (pair comparison, differential semantic …).

After the selection done in the previous work, three machine types were defined: “Deck and Huge”, “Ride-on” and “Walk-Behind”. A short representative part of the audio-conform recordings from WP2-A were selected, processed and used for jury evaluation.
Three types of jury testing have been carried out:

- Experts (Manufacturers, Acousticians),
- Users (private, professional),
- Neighbours (owning a lawn field or not).

At the writing time, the number of jurors is respectively: 24, 14 and 14 persons.

NST

NST is an acronym for Noise Synthesis Technology [2]. It stands for a mixture of different approaches structuring together well established experimental techniques (as masking, uncoupling, sub-structuring, transfer path analysis…), empirical modelling (i.e. ASHRAE, for fan and blade noise…) and computational vibro-acoustic methods (as SEA, FEM…). The aim is not only to provide reasonable noise predictions but also to build a robust virtual prototyping tool [3]. As NST masters component sources and transfer paths, it eventually produces synthetic noise. This gives a virtual vibro-acoustic model that can be rebuilt and “tortured” again before making final choice in mechanical design, part sourcing… and before going for real hard prototyping.

AUDIOCONFORM RECORDINGS AND PSYCHOACOUSTICS ASSESSMENT

All the 32 lawnmower machines were recorded through a dummy head and a pilot head-set equipped with high quality microphones.

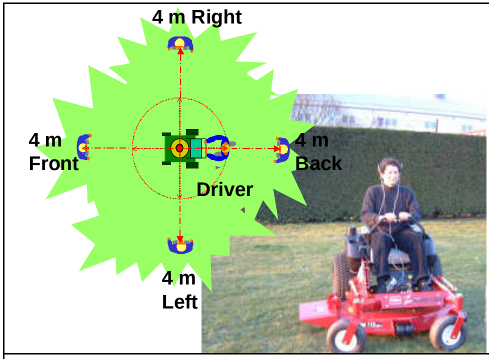


Fig.1: static conditions:
- *operator position,*
- *surrounding position.*

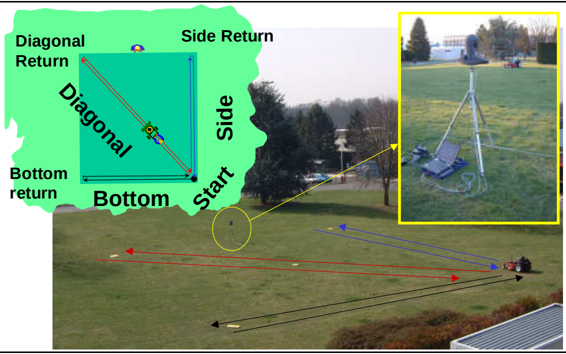


Fig.2: dynamic conditions (lawn=20x20m):
- *operator position,*
- *edge of field (neighbour's position).*

The standard ISO-11094 defines six measuring microphones distributed over a hemisphere of radius 4 or 10m (according to the cutting width of the lawnmower) but, here, two additional measurement points are examined in priority:

- Driver's position – "on" or "behind" the machine (left and right ears),
- Neighbour's position – at the edge of the "field" (left and right ears).

The recordings gathered at these positions were then post-processed to correct the head diffraction effect and provide microphone like measurement for comparison with classical methods (dB Lin, dB A…). In parallel, pieces of 5 seconds were selected and cut out from each original audioconform recordings. Direct re-listening of these sounds proved very harsh due to their usually high levels. In order for the jurors to be able to judge the machine noise and not only the striking transition from silence to operating noise, these sounds were linearly faded in and out on half a second long, leaving a central untouched 4 seconds for jury assessment. Original and faded sounds were processed with a psychoacoustic software providing all desired metrics (or perceptive criteria) for future analyses and comparisons.

Fig.3: some examples of the three different lawnmower types.
From left to right, back: 1 RO, 2 D&H, 3 RO, front: 3 WB.

JURY EVALUATIONS

Both "paired comparison" and "semantic differential" tests were performed on the 32 lawnmower sounds with differences due to the procedures attached to each method:

Paired comparison evaluations

In a "paired comparison" test, all the sounds to be assessed are combined into pairs that are presented in turn to the jurors. They are asked to choose one of the two sounds of each pair, according to a specific feature (the more pleasant, for instance). In our case, jurors were asked to listen to sound A, sound B then to vote if they preferred sound A, sound B or neither A nor B (unforced choice, see Fig.4).

Fig.4: paired comparison voting key-pad.

If we have N different sounds, the presented pairs is a subset of the N*N matrix of possible pairs. One can discard the diagonal because normally there is no point comparing a sound to itself. One can also discard the inferior matrix triangle as pairs (n,m) and (m,n) should be judged the opposite way. Nevertheless a little number K of reversed pairs is added to the test for jurors' repeatability checking. Whatever the value of K, jurors' consistency is checked by testing triads of sounds: if sound "a" is preferred to sound "b" and "b" to "c", "a" should be preferred to "c" otherwise a cyclic inconsistency is declared.

Eventually the test is composed of N*(N-1)/2 + K pairs. For each pair, the test lasts about 18 seconds: 10 seconds for sounds presentation, 8 seconds for slide transitions and voting. If we had to build a paired comparison with 32 sounds we would end with about 500 pairs i.e. almost 2 hours and half in a row! The only possible answer is to divide the sound corpus into smaller sets. Three lawnmower types already existed among the machines under study:

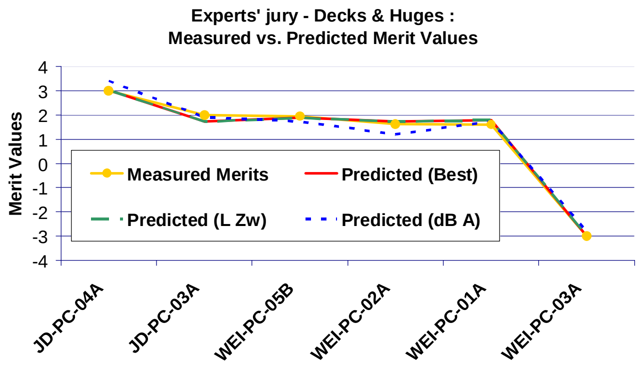
- "deck and huge" (6 D&H machines),
- "Ride-On" (10 RO machines),
- "Walk-Behind" (16 WB machines).

For practical reasons, and based on the results of preliminary tests, this late type was in turn divided into "Loud" and "Quiet" machines (8 "WBL and 8 "WBQ" machines). Thus, four groups of machines were tested separately by paired comparison. In each group, the jurors' votes, for or against every sound, were compiled to give the corresponding machine measured merits. Prediction laws were built by linear regression, the measured merits being the "response variable" and different selection of psychoacoustic criteria being the "explanatory variables":

- Best fit: multiple regression with the best combination of criteria,
- Regression with only the Zwicker Loudness (in Sones),
- Regression with only the A-weighted SPL (in dBA).

Lawnmower noise assessment done by “paired comparison”; example of results obtained with experts’ jury.

Fig.5: decks and Huge: sound ranking from the most pleasant (-3) to the most annoying (+3).



Groups	Analysis	Merit prediction law	R^2
D&H	Best fit	7.472 - 0.065*Zwicker Loudness (Sones)	0.994
	Zwicker Loudness (Sones)	7.472 - 0.065*Zwicker Loudness (Sones)	0.994
	A-weighted SPL (dBA)	40.932 - 0.440*A-weighted SPL (dBA)	0.980
RO	Best fit	6.701 -0.072*Transient Loudness (Sones)	0.671
	Zwicker Loudness (Sones)	6.621 - 0.071*Zwicker Loudness (Sones)	0.652
	A-weighted SPL (dBA)	42.251 - 0.467*A-weighted SPL (dBA)	0.638
WBL	Best fit	66.335 - 0.710*Speech Interference (dB) - 29.138*Fluctuation Strength (vacil) - 0.089*Transient Loudness (Sones)	0.986
	Zwicker Loudness (Sones)	22.000 -0.266*Zwicker Loudness (Sones)	0.901
	A-weighted SPL (dBA)	93.423 - 1.023*A-weighted SPL (dBA)	0.732
WBQ	Best fit	118.276 - 1.200*D-weighted SPL (dBD) - 0.388*Intelligibility (%) - 2.732*Frame Kurtosis)	0. 976
	Zwicker Loudness (Sones)	15.143 -0.248*Zwicker Loudness (Sones)	0. 790
	A-weighted SPL (dBA)	46.997 - 0.555*A-weighted SPL (dBA)	0. 885

Table 1: merit prediction laws derived from “paired comparison” with experts’ jury.

For D&H, RO and WBL, the regression coefficient R^2 is better with the forced regression with the Zwicker Loudness (in Sones) than with the A-weighted SPL (in dBA). For WBQ, dBA gives a better fit than Zwicker Loudness.

As expected, different lawnmower noise assessment and thus different merit prediction laws are obtained from drivers’ jury.

Semantic differential evaluations

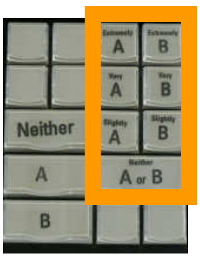


Fig.6: semantic differential voting key-pad.

The jurors were asked to quote the sound according to four groups of opposite pairs (A / B) of semantics (here in English and in French):

Pleasant / Annoying	***Agréable / Désagréable***
Smooth / Rough	***Doux / Rude***
High quality / Low quality	***Haute qualité / Basse qualité***
Powerful / Weak	***Puissant / Faible***

The vote consisted in scaling the sound on a seven step scale (see Fig.6 and Table 2):

Extremely A	Very A	Slightly A	Neither A or B	Slightly B	Very B	Extremely B

Table 2: seven step scale for semantic differential voting.

This time, for all 32 machines, each semantic pairs were tested in 32*10 seconds (less than 6 minutes). With a little pause in between each semantic pairs, the 4 semantic differential tests lasted a bit less than half an hour.

Pleasant vs. All Other Semantics		Smooth vs. All Other Semantics	
Smooth	0.827	Pleasant	0.827
High quality	0.704	High quality	0.883
Powerful	-0.683	Powerful	-0.410
High quality vs. All Other Semantics		**Powerful vs. All Other Semantics**	
Pleasant	0.704	Pleasant	-0.683
Smooth	0.883	Smooth	-0.410
Powerful	-0.180	High quality	-0.180

Table 3: jury of "experts"; correlation coefficients among the four groups (Here, only the first semantic is used to label its group).

Among the four groups, "Pleasant/Annoying", "Smooth/Rough" and "High quality/Low quality" are positively well correlated together while "Powerful/Weak" is negatively correlated to all the others.

Not surprisingly the tightest links are between: "Smooth/Rough" and "High quality/Low quality", "Pleasant/Annoying" and "Smooth/Rough" and between "Pleasant/Annoying" and "High quality/Low quality". The strongest opposition arises between "Pleasant/Annoying" and "Powerful/Weak".

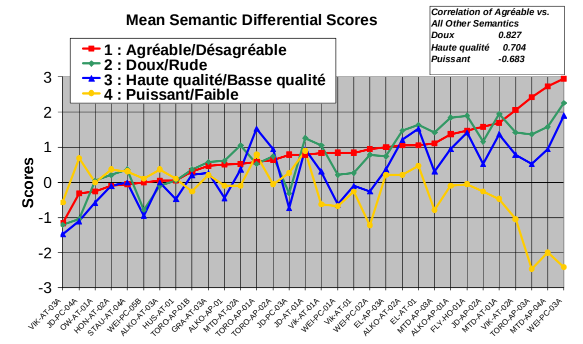


Fig.7: example of sound ranking for all the machines and for the four semantic groups

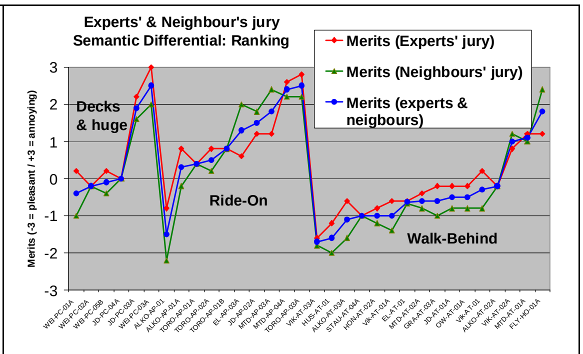


Fig.8: sounds ranking for each of the three types of machines (D&H, RO, WB).

PSYCHOACOUSTIC AND NST

Through the machine NST model it is possible not only to apply psychoacoustic criteria on the global noise (useful for checking the synthesis validity) but also to assess the perceptive contribution of any individual noise source to the overall machine noise. If by "removing" the investigated source from the global machine noise, the resulting noise can still be recognised as a lawnmower noise, if we can considered that the prediction laws derived from jury evaluations are valid, then we can compare the predicted merits to the merits obtained by the original machine. It would be a mistake to apply prediction laws on individual noise source unless it is highly dominant in the global machine noise. Nevertheless it is always interesting to process the various psychoacoustic criteria of the individual noise sources and check how they compare to their global machine noise counterpart.

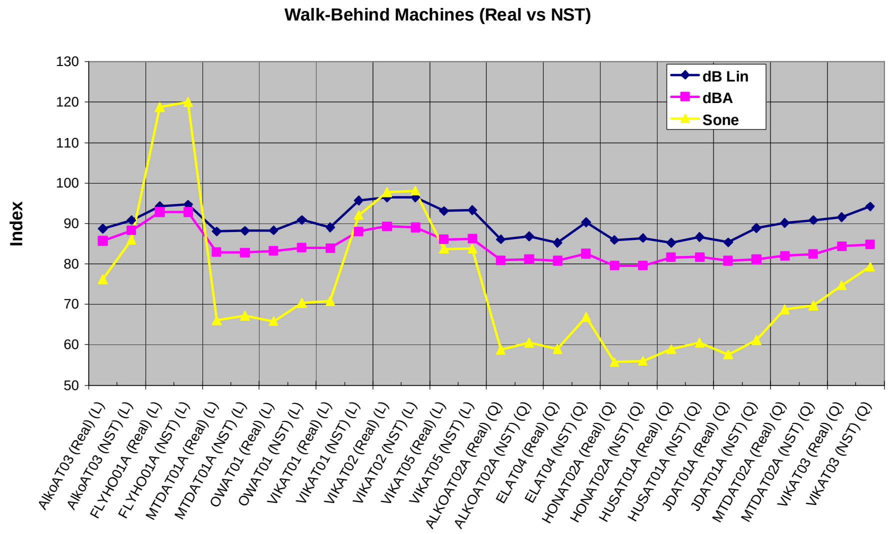


Fig.9: comparison Real vs NST index levels for WB machines.

Zwicker Loudness appears more sensitive to differences among the various machines but also to pick-up NST model defaults.

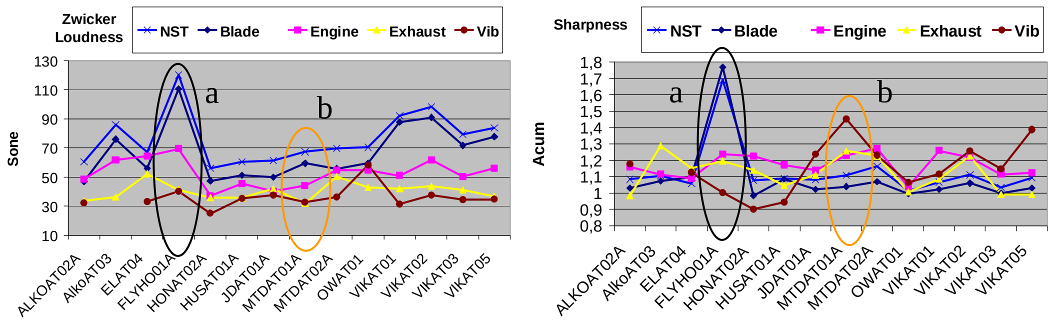


Fig.10: comparison of Zwicker Loudness(left) and Sharpness (right) levels for WB machines for the global noise and for the individual noise sources.

Here we can track the intrinsic individual noise source characters and rank their influence on the global machine noise. We verified that the sound character of the global noise is imposed by the strongest individual noise source (see machine “a”). On the contrary, and as expected, we can see on the above example that the strong sharpness of a weak individual noise source does not influence the global noise sharpness (see machine “b”).

CONCLUSIONS

It has been possible to assess perceptive noise from lawnmower machines of any type and size and to rank the machines according to perceptive criteria. Jury testing gave keys for building predictive laws that can be used directly on new real machines but also on virtual machines modeled by the NST approach. The resulting tool is promising to be a virtual prototyping method providing both physical and perceptive indications of what will sound an assembly of components not yet prototyped for real.

ACKNOWLEDGEMENT

This work is part of the LaMoNoV project supported by a consortium of lawnmowers European based companies, members of the European Garden machinery industry Manufacturers Federation (EGMF) [4].

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