CETIM_VENTIL: A SOFTWARE TO PREDICT THE NOISE OF A COOLING FAN UNDER A HOOD

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SUMMARY

This paper presents a numerical tool allowing computing the sound power radiated by an air cooled engine hood. This tool uses known techniques to model the interactions between the aero-thermal and acoustics phenomenon, improved by some empiric models. It is intended to be use at first steps of design or redesign, and use of a small amount of input data.

INTRODUCTION

One of the main acoustic sources under the engine hood of agricultural and building machines is the fan associated with the cooling system. In this case, an acoustic optimization of the system cannot be dissociated from a thermal optimisation.

In a technological context where the power of the machines tends to increase in a space which cannot evolve any more, and where the cooling system is increasingly complex, the global optimization of the system on intuitive bases becomes difficult. The numerical modelling tools then become essential.

Upstream of the generic computational aeroacoustics software, very powerful but also very expensive in use, remains a place for simpler modelling tools, with limitations in the configurations which they can handle, but easier to use. This paper presents such a numerical tool, elaborated by associating already existing software elements, and by integrating some of the experimental results obtained on former research. This software has been defined to be usable by industrial design departments, and to allow to take into account the system and aero-thermal effects on the acoustic performances of a cooling fan confined under a hood.

SOFTWARE DESCRIPTION

General points

The model includes the following elements:

- a hood of parallelepipedic shape, with possible openings in the faces. Each face is defined by a material and a thickness. It can be covered with an acoustic treatment material,
- an acoustic source of parallelepipedic shape, defined by its sound power spectrum. The noise source can be defined at different levels of precision: for the whole structure or by faces, global level or third octave band spectrum. Whatever the level of definition of the acoustic source at the interface level, the computations are done with a source in third octave bands distributed on the source faces, with an interpolation of the input data when necessary,
- Heat exchangers. Each exchanger is connected to a thermal source,
- Air blocking parts. These parts are thermal passive components that are used in the calculation of the pressure losses,
- A fan, of axial or centrifugal type.

The components can be saved in individual files in xml format. This allows the creation of a data base and their re-use in other simulations.

The performance of the fan and the heat exchangers are computed starting from the performance curves given by the manufacturers:

- pressure – flow curves for the fan,
- thermal power – flow and pressure loss – flow for the heat exchangers.

These curves being established under specific conditions, the software re-compute them under the effective conditions of the simulation.

All the performance curves of the components and the airflow network pressure loss curves are interpolated using cubic splines. In this way, all mathematical treatments rely on the same bases.

Software structure

In order to be able to use the computer code under different user interfaces, the code is divided in two parts: a calculation core and a user interface. The exchange of data between the two parts is done via files in xml format. This code has its own interface, and can be interfaced, for example, with the noise synthesis software EQUIP+.

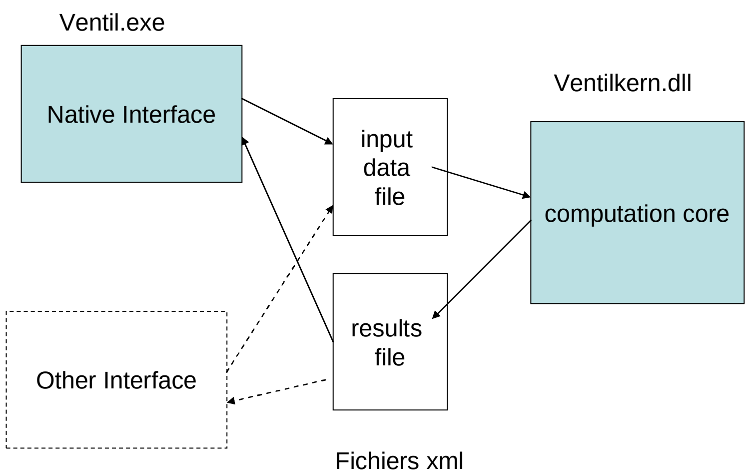

Figure 1: software structure.

Implementation

The software has been implemented using the Delphi language.

The Graphical User Interface shows a hierarchical tree allowing accessing to the design parameters of each component, and three superposed panels showings the results (figure 2).

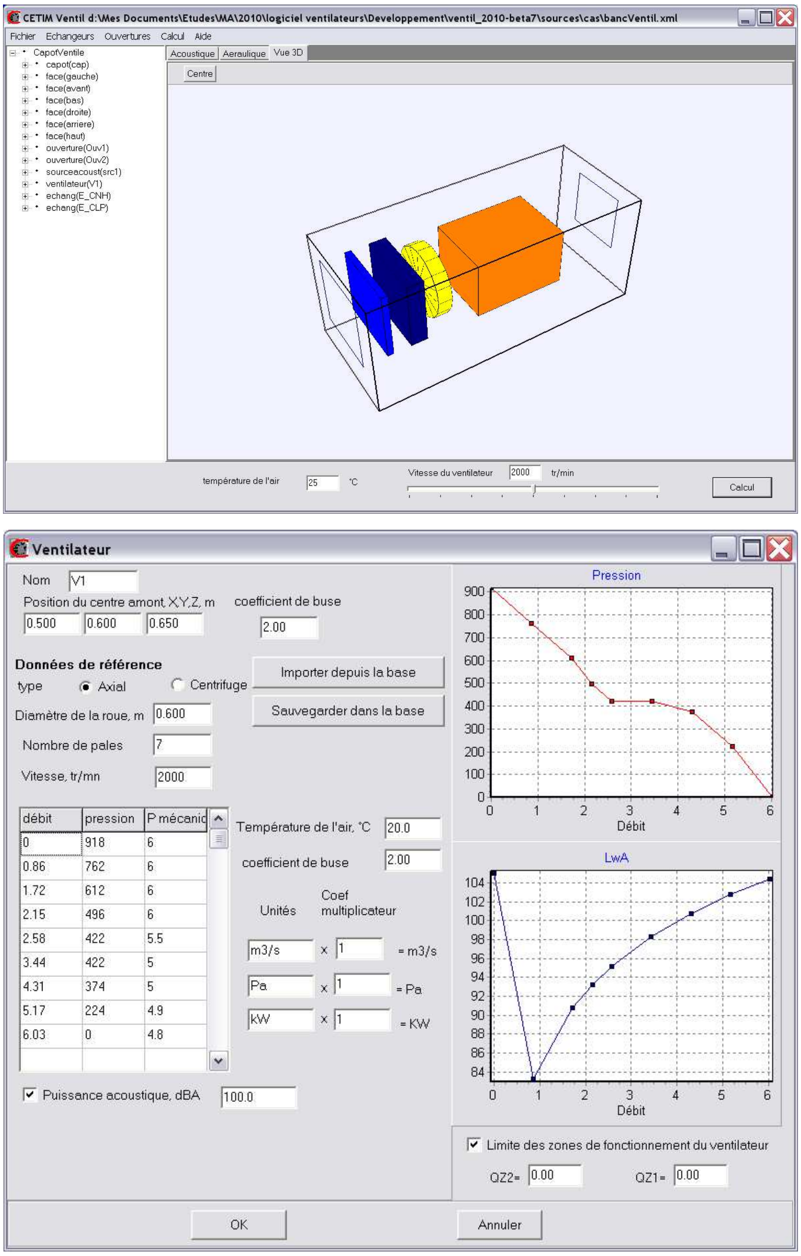

Figure 2: Software interface –3D control view (top) and fan properties dialog box (bottom).

MODELS FOR COMPONENTS

The goal of the software is mainly to compute the acoustic response of the system. However, any relevant acoustic comparison between different configurations must be done for the fan giving the same service, i.e. same cooling efficiency. Then a thermal and aerodynamic model must be provided. The bases of this model are classical basic assumptions used in the domain.

The fan acoustic model relies on the well known model ASHARE, that have been improved using experimental data collected at Cetim, or resulting from a synthesis of the literature.

Air flow

The air flow is computed, in a usual way, by finding the intersection between the system pressure loss curve and the fan pressure – flow curve.

The system pressure loss curve is build by associating the individual pressure loss coefficients of each item: inlet grid, heat exchangers block, air gap between the internal source and the walls, and outlet grid.

The pressure loss coefficient of the heat exchangers block is computed in the following way:

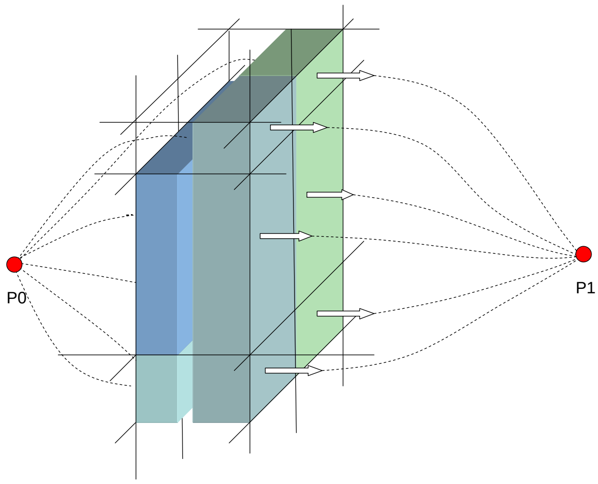

Figure 3: Heat exchangers air network.

One postulates that the air flow is mainly axial. The heat exchangers bloc is cut in homogenous zones for which a dedicated pressure loss coefficient is computed (figure 3). The global pressure loss coefficient is computed by associating the individual coefficients in parallel.

Heat transfer

As for pressure loss, the thermal performances of the heat exchangers are computed for each homogenous zone, and then associated to compute the overall heat transfer coefficient of each component. Then the equilibrium temperature of the thermal source associated to each heat exchanger is computed, given the power generated by the source. This temperature is assimilated to the temperature of the fluid entering the exchanger.

Fan – heat exchangers interaction

The interaction effect between the fan and the heat exchangers is taken into account by applying a corrective factor on the heat exchanger pressure loss curve. This factor is a function of the ratio between the distance from the last heat exchanger to the fan and the fan diameter. Figure 4 shows an example of corrective factor used for axial fans.

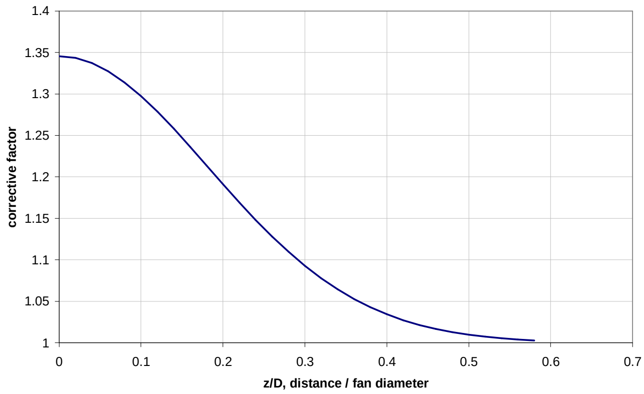

Figure 4: Corrective factor for fan – heat exchanger interaction, axial fan.

This corrective coefficient has been defined from experimental data obtained on the CETIM fan test bench [1]. While given in a non-dimensional form for convenience, it relies on a limited set of fans and heat exchangers associations, with a typical width close to 600 mm, so its convenience for different sizes should be verified before use.

Fan noise

The computation of fan noise relies on a set of specific curves established by the ASHRAE, on experimental bases. These curves provide octave band spectra for a given technology of fan, allowing to compute the fan noise at its nominal aerodynamic point, when the flow and pressure of this nominal point is known. This approach is described in ref [2].

In the software, the acoustic power generated by the fan is computed in the following way:

The acoustic power at the nominal point is computed using the ASHRAE method, with these two modifications:

- the octave spectra are interpolated on one-third octave band spectra,
- when an overall noise power is given by the user, the ASHRAE curves are shifted to match it,
- ASHRAE method gives an extra contribution in the octave band containing the blade passing frequency (BPF). Another extra contribution is added on the band containing second harmonic of BPF, as the experiments made in CETIM have shown that this contribution could be significant, specially on A-weighted scale. This contribution is equal to the third (in dB) of the contribution given at BPF.

The computation of fan noise for all the flow range is based on the following model: The pressure-flow curve allows defining 3 zones (figure 5):

- zone 1, where the fan runs in good conditions, for the higher flows,
- zone 3, stall flow conditions with high drag, for the lower flows,
- zone 2, intermediate.

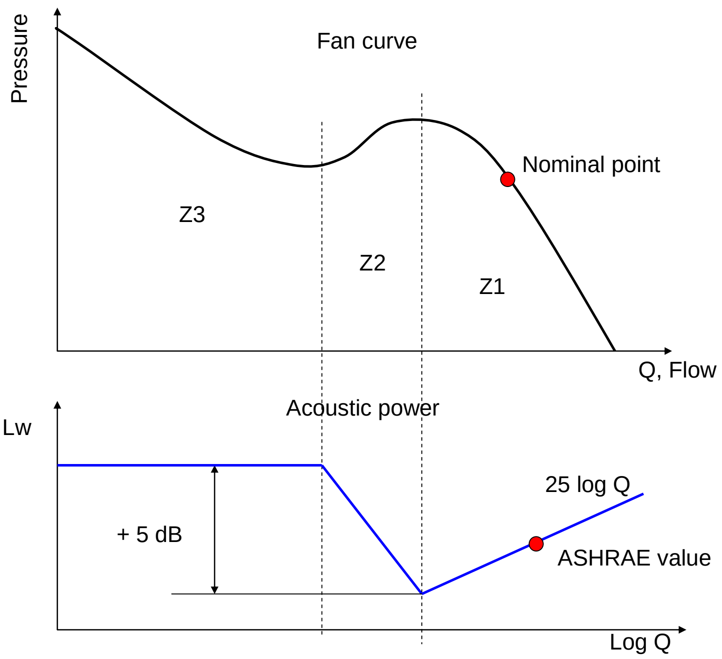

Figure 5: fan noise model.

In zone 1, the sound power varies around the nominal point according to the law

$$Lw = Lw_N + 25\log(Q/Q_N)$$

where Lw_N and Q_N are the sound power level and flow at nominal point. This scaling law results from experimental results [1].

In zone 3, as a consequence of the bad flow conditions, an increase of 5 dB of the noise power level is set. In zone 2, the curves from zone 1 and zone 3 are connected by a linear part (in dB). This 5 dB value is a typical value taken from literature. An example of such data is given in figure 6.

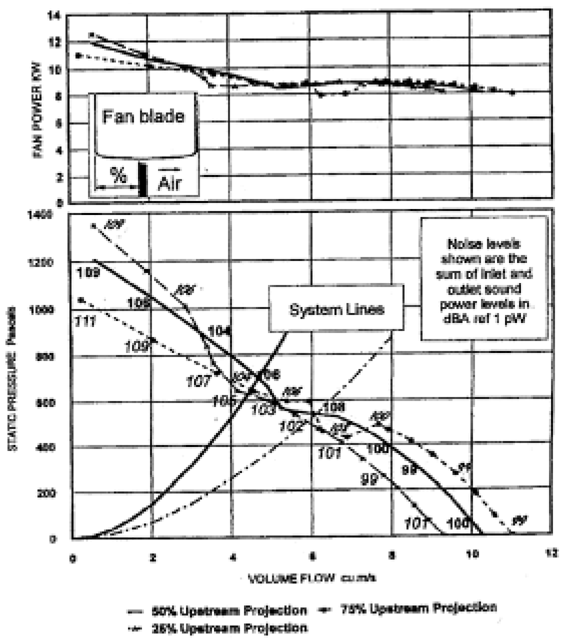

Figure 6: evolution of fan noise in function of the flow (ref [3]).

Regarding the directivity, the model makes the assumption that the sound power is equally shared between the front and back face for an axial fan, while the power on the back is around 7 dB higher then the power on the front for a centrifugal fan.

Noise model of the hood

The transmission loss of the hood is computed using the CETIM software ‘Cetim-Capot’, integrated to this environment. This software was formerly created by J.C. Pascal [4]. The structural scheme of the software is given in figure 7 (Only the airborne paths are taken into accounts in ‘cetim-ventil’).

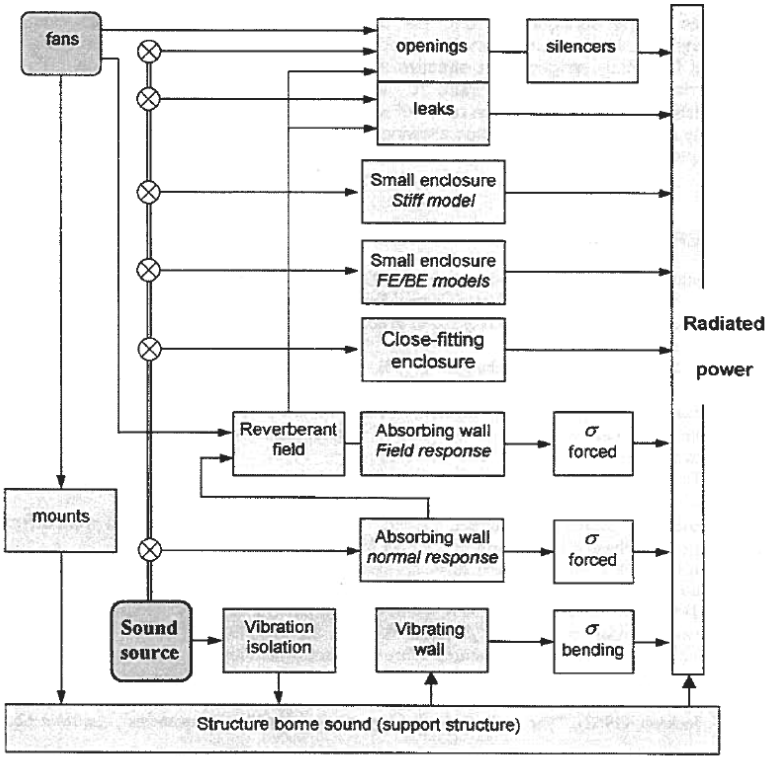

Figure 7: ’Cetim Capot’ structure (ref [4]).

The noise abatement takes into account the transparency of the wall of the hood, the influence of an internal noise treatment, and the influence of openings. Two asymptotic noise models are used: when the size on the internal acoustic source is of the same order of magnitude as the size of the cavity, a wall to wall model is used, with possible resonance when the distance between the walls is a multiple of half a wavelength (‘close fitting’ model); When the size of the source is small compared to the size of the cavity, a diffuse field model is used.

OUTPUTS

Thermal and aerodynamic results

On example of result panel for the thermal and aerodynamic results is shown in figure 8.

One can see:

- A graphic showing the fan pressure –flow curve computed for the given fan speed, and the overall pressure loss curve of the system.
- The fan sound power source spectrum, and the front and back repartition of that source.

- An histogram giving the repartition of the pressure loss on the entrance, the heat exchanger bloc, the surrounding of the noise source, and the exit.
- An histogram showing the temperature of each thermal source,
- A table giving the air temperature at the entrance, after the heat exchangers, and at the exit.

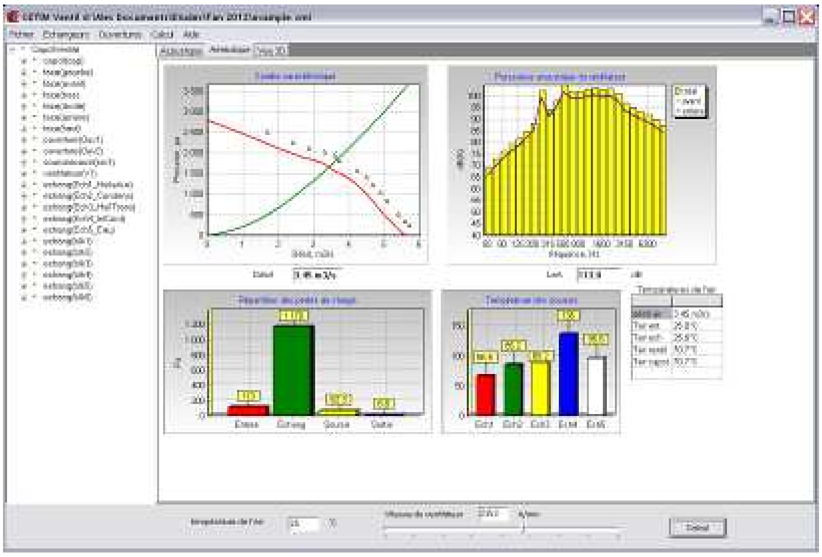

Figure 8: Thermal and aerodynamic results screen.

Acoustic results

On example of result panel for the acoustic results is shown in figure 9.

The results given are:

- a graphic showing the sound power spectrum radiated outside of the hood, on which is superposed the spectra of the noise power emitted by faces, or of the internal sources (given acoustic source and fan),
- the overall and by faces transmission losses of the hood, in graphical or tabulated form.

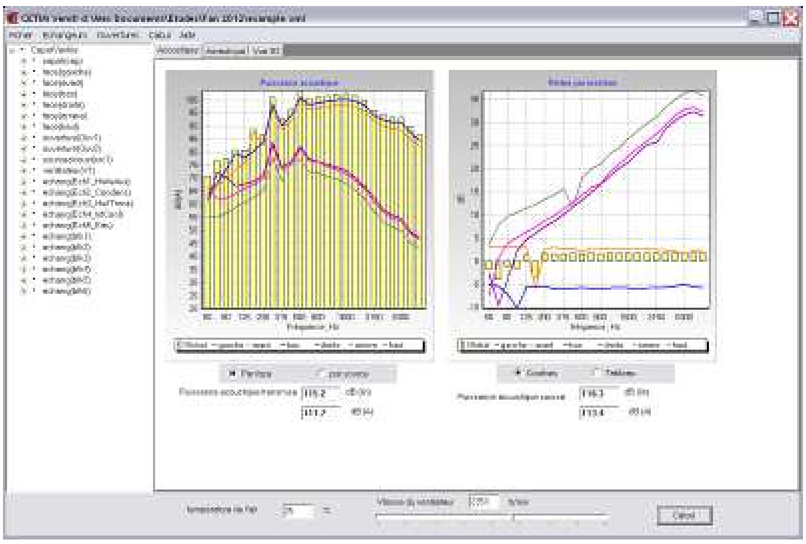

Figure 9: Acoustic results screen.

TESTS AND APPLICATION CASES

The software components that have been assembled here have been test individually from several years.

Aerodynamic tests made on a test bench comprising a 600 mm fan, heat exchangers, and configurable inlet and outlet, have shown that the error on the prediction of the flow in various configuration was of the order of 25% when no interaction coefficients was taken into account, and was kept in a few percents when the fan-heat exchanger interaction coefficient was taken into account [5].

The application cases covers different applications where a noisy machine under a hood has to be cooled by a heat exchanger: air compressor [6], earth moving machines[7], and tractors [8].

A typical use for that software is to calibrate the models on a known configuration, and to compute the influence of changing some parts of the systems. Used that way, this software has shown that it was able to give the right tendencies and order of magnitude on the resulting flow, temperatures and noise, thus being a useful tool for design.

CONCLUSIONS

The numerical tool 'Cetim-Ventil' has been created to make the synthesis of existing pieces of software, each one dedicated to a different aspect of aero-acoustic behavior of an air cooled engine hood.

It relies on manufacturers data and standard aero-thermal and acoustic models, improved by empiric correction factors when the data where available.

Its scope is to allow taking into accounts, at first steps of design or redesign, the thermal and acoustics phenomenon that coupled the components under the hoods.

Some aspects of the model should be improved: the experimental data set use to define the fan-heat exchanger coupling parameter is small, the axial flow model for the heat exchangers is over simple… Nevertheless, any proposed improvement should try to preserve the 'fast and simple' aspect of this kind of software, especially in the amount of input data that is required.

The progress made by CAA software will probably in the future render this kind of approach obsolete. At this time, it stays useful as an integration tool, especially for small and medium size companies.

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