A NEW NON-LINEAR IMPEDANCE MODEL FOR LINERS

Touchais A, Atalla N, and Panneton R
Dept. of mechanical engineering, University of Sherbrooke, Québec, Canada, J1K2R1.

1. INTRODUCTION

Acoustic treatments are extensively used in commercial gas turbine engine nacelle system to reduce aircraft noise in flight. The liners usually consist of a single degree of freedom resonator made up of a cavity filled by honeycomb construction on which a perforated sheet is bonded. These kinds of liners exhibit nonlinear impedance characteristics that depend on sound pressure level (SPL) [1]. At high sound pressure levels (starting at 120 dB), the resistance and reactance are modified to account for nonlinear effects. Classical nonlinear models such as Hersh's model [2] and Crandall's model [3] are respectively too empirical and not applicable for a thickness- diameter ratio over 0.80. A more accurate model is still needed for single degree of freedom non linear liners. In this paper, an attempt to develop such a model is presented. It uses Maa's [4] model for the linear component of the impedance and Melling's [5] model for the nonlinear effects on the resistance. It takes also into account a frequency shift toward high frequencies when sound pressure level increases. This phenomenon is especially visible on absorptions curves and the imaginary part of the impedance. The model considers only the effects of resonator geometry and incident sound pressure amplitude according to frequency. Normal incidence impedance measurements, in a high intensity impedance tube, are presented to corroborate the validity of the developed model.

2. IMPEDANCE MODEL

2.1 Model without frequency shift

Maa's impedance model [4] is given by

$$\zeta = R + j\omega m,$$

with ζ , R and ω are respectively impedance, resistance and reactance and

$$R = \frac{32\eta t}{\phi\rho_0 c_0 d^2} * \left[\sqrt{1+\frac{x^2}{32}} + \sqrt{\frac{2xd}{8t}}\right],$$

With d, t, ϕ , ρ_0 , c_0 , and η are respectively the diameter, thickness, porosity, density, speed of sound and cinematic viscosity; and

$$\omega m = \left[\frac{\omega y}{\phi c_0}\right] * \left[1 + \frac{1}{\sqrt{9+\frac{x^2}{2}}} + 0.85\frac{2\varepsilon}{t}\right],$$

where $x = d\sqrt{\frac{\omega\rho_0}{4\eta}}$, and the length correction ε is

$$\varepsilon = 0.48 * \sqrt{\pi * \left(\frac{d}{2}\right)^2}.$$

To account for non linear effects, a nonlinear resistance component is added. Melling's nonlinear resistance model is used [5]. It is given by the expression

$$R_{NL} = 1.2\frac{\left(1-\phi^2\right)}{2c_0\left(\phi C_D\right)}V_a,$$

with C_D is the discharge coefficient given by:

$$C_D = 0.80695 * \sqrt{\frac{\phi^{0.1}}{e^{-0.5072*\frac{t}{d}}}},$$

and V_a is the acoustic particle velocity.

2.2 Frequency shift

When sound pressure levels increase, a frequency shift of the zero of the imaginary part of impedance (or maximum of the absorption) is observed experimentally. This phenomenon is visible in both the imaginary part of impedance and the absorption coefficient. An example is shown in Fig.1 for a single degree of freedom resonator made up of cavity construction on which a perforate sheet is bonded. The perforated plate has perforation diameter of 1mm, a porosity of 4.5%, a thickness of 2mm and a cavity depth of 25mm. It is clearly seen that the absorption's maxima increases with SPL and shifts towards high frequency.

To account for this frequency shift, the radius and thickness of the perforations are modified as a function of the acoustical Mach number. The latter is used for homogeneity reasons. The proposed modifications are based on an experimental parameters study. It resulted in the following expressions:

$$\Delta r = -6{,}15.10^{-3} * M_a + 20 * M_a^2 - 2660 * M_a^3,$$

$$\Delta t = 0.301 * M_a - 97.50 * M_a^2 + 11400 * M_a^3.$$

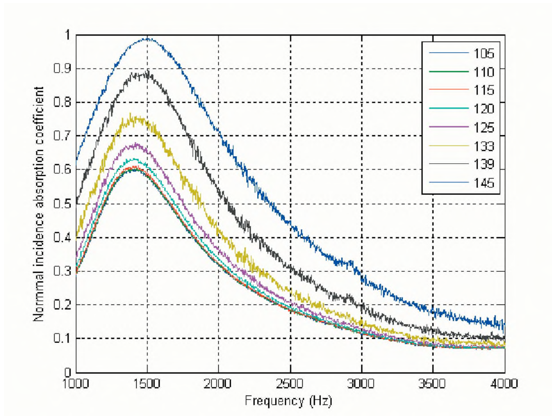

Fig.1 Absorption coefficients at different SPL with normal incidence impedance tube for a single degree of freedom resonator

According to these expressions, the effective radius and thickness of the perforations decrease at high SPL [6]. These corrections are added to Maa's model for the linear component of the impedance and Melling's model for the nonlinear effects on the resistance.

3. RESULTS

The complete model gives good approximation versus measurements, as shown in Fig. 2 for the absorption, in Fig. 3 for the resistance and in Fig. 4 for the reactance. On the other hand, the classical models of Hersh and Crandall fail to predict the results of the presented example.

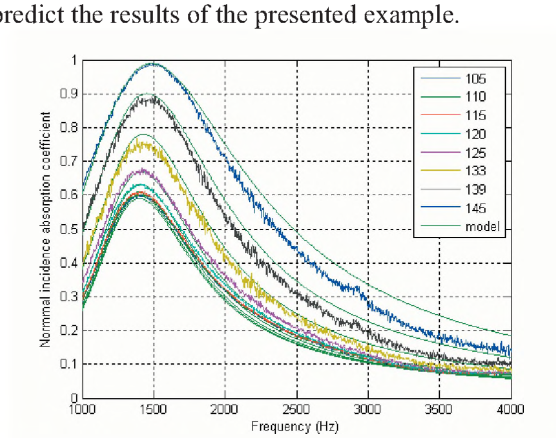

Fig. 2 Comparison experiments versus model for the absorption coefficient.

4. CONCLUSION

Thanks to Maa's model for the linear part and the proposed nonlinear resistance, including the frequency shift effects, the proposed model allows for simulations of various perforated plates configurations, such as microperforated plates at high SPL. This is an enhancement over classical models. However, its full validity is still to be confirmed using an experimental study on various SDOF liners configurations.

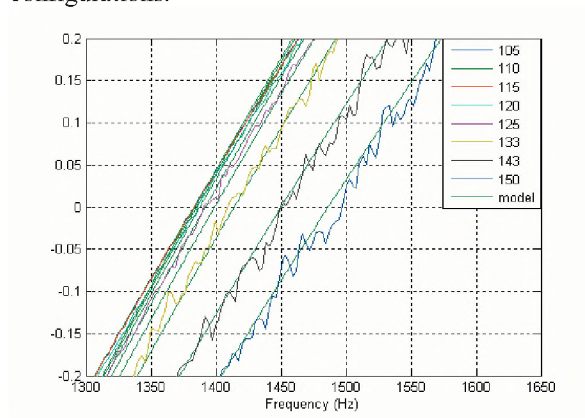

Fig. 3 Imaginary part of normal impedance at different SPL. When SPL increase, imaginary part of impedance decrease.

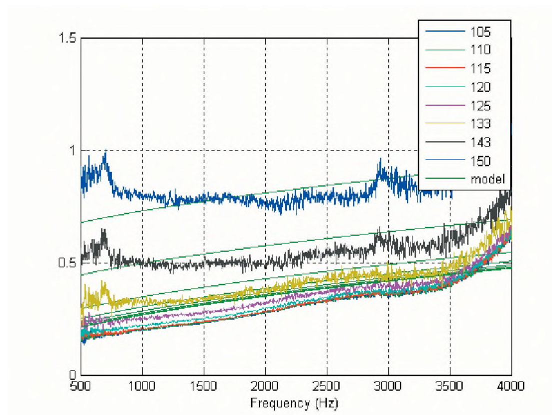

Fig. 4. Real part of normal impedance at different SPL. When SPL increase, real part of impedance increases too.

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