Influence of porous materials on structure-borne sound in aircraft application

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Introduction

Porous surfaces are used to influence the flow noise and the excitation of the structure-borne noise. Within the project *Sonderforschungsbereich 880* Fundamentals of High Lift for Future Civil Aircraft, the aim is to reduce sound produced by aircraft propeller drives and trailing edges. The influence of porous layer on the surface of airfoil is evaluated, specifically on the upper surface of a channel wing. A sensitivity analysis is carried out in order to study the behaviour of the structure-borne sound with the implementation of porous material layers. Microperforated plates, sintered fibre felts and metal foam materials are considered. To perform this study a simple structure representing an airfoil segment is used. Some results showing the influence of a porous layer applied on a generic channel wing geometry are presented as well.

Modelling of structure-borne sound

To build a structure-borne sound model, coupling methods algorithms including different subdomains are implemented in our research code *elPaSo* using the Finite Element Method [3]. The coupled system is constituted by a free flow, a porous material layer, an elastic structure and an acoustic fluid [4][5]. The porous layer is represented by Biot's model using the u-p Formulation, to simulate the solid and the fluid phase of the porous material and the interaction between them [1]. The fluid phase is described by the flow resistivity, the porosity, the tortuosity and the viscous and thermal characteristic length. The solid phase is described by the density, Young's modulus and Poisson's ratio. For the flow-porous material interaction, the coupling conditions at the interface must be satisfied (1), giving continuity to the pressure, stress and velocity [2].

$$\begin{aligned} ((\sigma_{ij}^t)^c \cdot n_j)\, n_i &= -p^f, \\ (\sigma_{ij}^t)^c\, n_j &= (\sigma_{ij}^t)^p\, n_j, \\ v_i^c n_i &= (v_i^s + \phi(v_i^f - v_i^s))\, n_i, \end{aligned} \tag{1}$$

where the index c denotes quantities belonging to the free flow, p to the porous material and f and s to the fluid and solid phases of the porous material, respectively. σ_{ij} represents the global stress tensor, v the velocity and p the pressure. The Beavers-Joseph-Saffman condition must be fulfilled as well (2). This condition states that the size of the velocity jump at the interface is directly proportional to the shear stress.

$$((\sigma_{ij}^t)^c \cdot n_j)\, t_i = \frac{\alpha \cdot \mu}{\sqrt{K}}(v_i^c - v_i^s)\, t_i. \tag{2}$$

K is the permeability of the porous media, μ the dynamic viscosity and α the coefficient slip rate that describes the material-dependent surface characteristics.

Sensitivity analysis

To carry out the sensitivity analysis a simple structure that resembles an airfoil is used. This structure consists of two plates, representing the the top and bottom wing skin. They are connected by two ribs and a spar. In Figure 1 the structure and its dimensions are shown. The

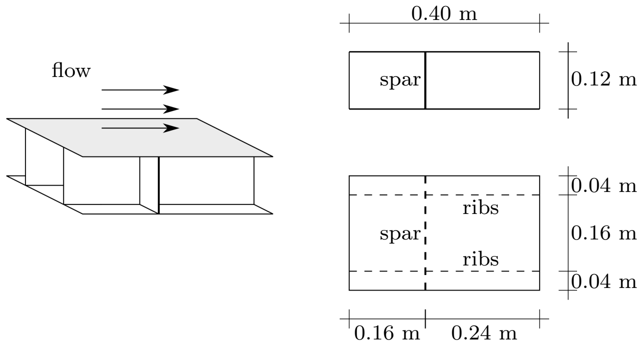

Figure 1: Airfoil segment. Structure and dimensions

thickness of the plates upper and lower and of the ribs is 0.0005 m. The thickness of the spar is 0.001 m. The structure is simple supported on its shorter sides. The geometry is discretized using Mindlin plate elements. A layer of porous material can be applied on the upper plate. The incompressible flow simulation is carried out using the commercial software ANSYS. The results of the sensitivity analysis are expressed as an improvement index (II) (3), considering the velocities with and without using porous material layer (4).

$$II[dB] = v_{withoutporo}[dB] - v_{withporo}[dB] \tag{3}$$

$$v[dB] = 20 \log \frac{v[m/s]}{v_0[m/s]} \quad \text{with} \quad v_0 = 5 \cdot 10^{-8} m/s \tag{4}$$

Figures 2 and 3 show the results obtained using sintered fibre felt as porous layer [6]. The improvement for different frequencies is presented in decibels. In Figure 2 the variation of the thickness of the porous layer on top of the structure is presented. The thickness varies between 0.4 and 1.5 cm and it shows a positive effect on the structural sound. With increasing layer thickness, the improvement index rises as well. In Figure 3 the variation of the porosity of the porous layer on top of the structure is presented. The original porosity is changed from 0.92 to 0.96 and 0.80. The highest porosity value is also combined with half value of the flow resistivity of the porous layer. The results show that higher porosity

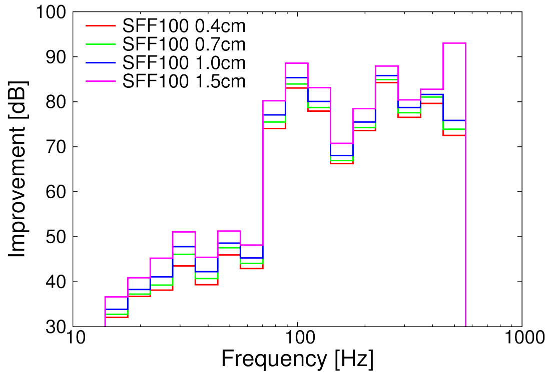

Figure 2: Sintered fiber felt. Results of the sensitivity analysis changing the thickness of the porous material layer

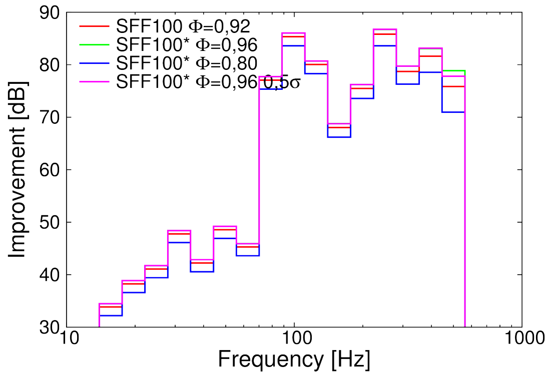

Figure 3: Sintered fiber felt. Results of the sensitivity analysis changing the porosity values of the porous material layer

values lead to higher improvement indices. To evaluate the influence of the mass, the density of the upper elastic plate of the structure is increased to contain the mass of the porous layer. The results show that the improvement indices due to the use of a porous layer is significantly higher than those obtained by increasing the density of the elastic plate. Also the variation of the flow resistivity is evaluated. It is changed to half and double of the original value, but the obtained results do not show a significant effect.

Generic channel wing geometry

A generic channel wing geometry is studied. The mean

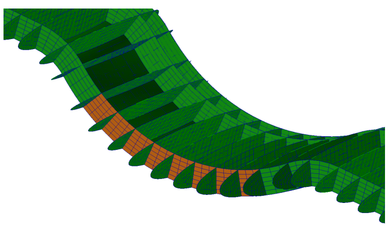

Figure 4: Generic channel wing geometry

vibration velocities of the front spar (orange area in Figure 4) with and without a liner placed on the upper wing skin of the channel wing are shown in Figure 5. The evaluation shows that a positive influence of the structure-borne sound can be achieved.

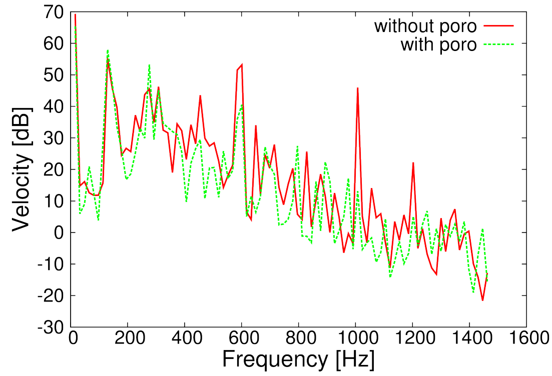

Figure 5: Velocities with and without using porous layer

Summary

An approach that models the flow-induced structure-borne sound has been implemented. To mitigate the noise emissions of aircraft structures, porous material layers have been used. A sensitivity analysis of the porous material parameters has been performed, changing thickness, mass, porosity and flow resistivity. The effect of a porous layer on the upper surface of a channel wing generic geometry has been presented.

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