Efficient hybrid FE-TMM modeling of the vibroacoustic response of structures with attached sound packages

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Oral presentation, no special requirements. Nowdays, poroelastic materials are widely used as a passive treatment in single and double wall systems to obtain a reduction of the interior noise level in aeronautic and automotive industries. Moreover, efficient and accurate prediction tools are demanded for design purposes. Unfortunately, for complex systems, such as aicraft fuselages, simple analytical methods cannot be used, while numerical approaches are computationally expensive.

Typical engineering applications consist of two semi-infinite fluids (emission and receiver sides) divided by a complex multilayer system. In aeronautic applications, such system typically includes a main structure wetted by the fluid on the emission side, and, sometimes, a trim panel in contact with the fluid on the receiver side. Between these two subsystems, a sound package is designed in order to minimize the acoustic energy transmission. The excitation on the emission side can be either mechanical (i.e. loads applied on the master structure) or acoustical (e.g. plane wave, diffuse acoustic field, turbulent boundary layer, etc...). Typical configurations of the sound package may include an air gap and one or more poroelastic materials assembled in a multilayer fashion. Modeling this problem efficiently and accurately is still an open issue.

Finite Element (FE) formulations have been developed during the last twenty years to account for poroelastic materials. For the general case of multilayer systems and for a broad range of excitation frequencies, sophisticated approaches must be taken into account to obtain a good accuracy. In this case, the Biot's theory is the most classical and accurate way to describe the coupling between solid and fluid phases in poroelastic media. Even if several formulations of the Biot's theory have been developed, the mixed pressure-displacement (u, p) formulation [1] still remains the most used and efficient for FE applications.

Unfortunately, modeling complex systems using FE based methods can be, even if accurate, computationally expensive. The greatest part of the computational burden is due to the FE model of the poroelastic subsystem, mainly because of the following reasons. Firstly, the poroelastic FE matrices must be evaluated at each frequency due to the frequency dependency of the material properties. Secondly, the (u, p) formulation, even if it is more efficient compared to other formulations (i.e. displacement based formulation), it still needs four unknowns per node, leading to large FE matrices. Finally, classical mesh criteria, i.e. six linear or four quadratic elements per wavelenght, do not provide a sufficient condition to get reliable results, due to the coupling between the two phases and because of the dissipation mechanisms. Therefore, a large number of elements are always needed in order to capture the solution.

To alleviate these drawbacks, several attempts have been made. Firstly, the FE formulation has been improved using hierarchical elements [5] [8], but computational issues still remain. Then, substructuring approaches based on modal analysis have been investigated [3] [2]. However, it is evident that poroelastic materials do not exhibit a clear modal behavior, mainly because of their intrinsic dissipative nature. Recently, the Wave Based Method (WBM), which considers a superposition of travelling waves in a convex envelop of the computational domain, has been applied to poroelastic

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materials [6]. Still, these methods remain computationally expensive or limited to simple configurations. An alternative to these numerical approaches is the Tranfer Matrix Method (TMM), which account basically for wave propagation in infinitely extended flat multilayered systems. Despite these apparently constraining hypotesis, some of these limitations have been removed by developing a finite size correction and accounting for coupling between the transfer matrix formulation of the sound package and a modal description of the master structure [7]. However, the approach is limited to flat configurations, even if it is often used to model curved systems, such as aircraft panels. Moreover, attempts have been also made to couple a FE model for the master structure and a TMM for the sound package [9]. Such approach is still based on simple assumptions, considering locally reacting materials and limiting the interface conditions to normal displacement and stress (i.e. pressure).

The aim of this work is to present a FE methodology for the structure which can account for a fast treatment of the poroelastic subsystem through the TMM, in order to obtain accurate and efficient prediction of the vibroacoustic indicators over the widest possible frequency range. A structure representative of aircraft applications with attached sound package is used to illustrate the efficiency of the presented method in comparison to some of the above cited methods. Namely, a fully coupled FE-BE model of the entire system, a modal approach based on the modal synthesis of the master structure [4] and a classical Statistical Energy Analysis (SEA) model are considered for comparison purposes, in order to identify advantages and limitations of the proposed method over a wide frequency range. Moreover, a comparison with the classical FE-TMM approach [9] is also presented to assess its limitations. Special attention is paid to the efficiency of the proposed technique, comparing computational time and accuracy level among the considered models. Finally, the ability of the considered methods in predicting energetic based parameters, such as the equivalent damping effect of the poroelastic treatment on the master structure, is assessed.

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