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A reduction method for structure-acoustic and poroelastic-acoustic problems using interface-dependent Lanczos vectors

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Abstract

A reduction method is proposed for analysing structure-acoustic and poroelastic-acoustic problems within a finite element framework. This includes systems consisting of an acoustic fluid domain coupled to a flexible structural domain and/or a porous sound absorbing material domain. The studied problem is reduced by dividing the system into a number of physical subdomains. A set of basis vectors is derived for each of these subdomains, including both normal modes and interface-dependent vectors that take account of the influence of connecting subdomains.

The method is verified in two numerical examples using the proposed method for both solving the structure-acoustic eigenvalue problem and performing a frequency response analysis in an acoustic cavity with one wall covered by porous material.

Keywords: Structure-acoustic; Poroelastic; Biot's theory; Component mode synthesis

1. Introduction

This paper investigates the sound pressure distribution in enclosed acoustic cavities using finite element analysis. The studied system is typically a vehicle structure with an interior passenger compartment, illustrated in Fig. 1. As vehicles develop towards being more fuel efficient and with a greater focus on stiffness in the interest of crashworthiness, lighter and stiffer construction can introduce the problem of interior noise. Therefore, the need to conduct detailed analysis of acoustic comfort is increasing.

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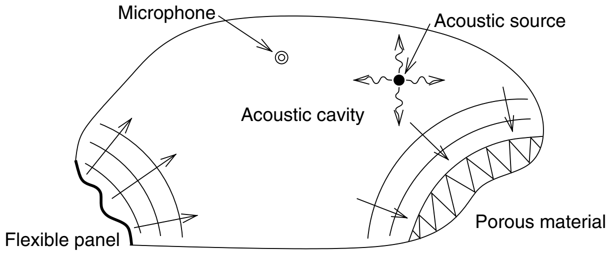

Fig. 1. Problem description: The vibrating panels generate noise inside the enclosed cavity where the noise can be reduced by the use of porous material. The noise, measured by a microphone at some point in the cavity, can also be generated by an acoustic source.

In the finite element analysis of acoustic problems, the increase of the frequency limit of interest, the need to resolve the details of complex geometries in the finite element model and the inclusion of advanced material descriptions to model, for example, porous sound absorption material, lead to a rapid increase in the number of degrees of freedom in the model. Efficient techniques for solving such large equation systems are thus of great importance.

This structure-acoustic problem has been studied by several authors using the finite element method, and several different formulations have been proposed [1–3]. The difference between these formulations lies in the way the fluid domain is described. The fluid can be described by a displacement formulation which, due to the lack of shear stiffness, introduces spurious modes. Using reduced integration [4] and control of the hourglass modes [5], all pure rotational modes have the eigenvalue zero. This procedure is adopted in this paper when studying the fluid partition of the porous material. The most straightforward and compact method for describing the fluid in structure-acoustic systems is to start with the acoustic wave equation using a potential description, for example, of pressure, with only one degree of freedom in each node [6]. The drawback is that the system matrices of this two-field formalisation become unsymmetric. If one instead uses both pressure and velocity potential to describe the fluid, symmetric system matrices are generated; however, this three-field formulation uses two degrees of freedom in each node, thereby increasing the total number of degrees of freedom of the system [7].

The dominant method for model reduction is the component mode synthesis method [8,9]. The studied physical domain is divided into a number of components and a set of basis vectors is derived for each component to be included in the description of the entire system. This procedure is also adopted in the model reduction of structure-acoustic problems starting with the unsymmetric two-field formulation [3,10–14]. The eigenvalue problems of the structural and fluid domains are first solved separately. The coupled system is then reduced by the calculated normal modes. The reduced unsymmetric system can, by using some matrix manipulations, be written as a symmetric standard eigenvalue problem [15]. A large number of eigenmodes must be included in the reduction to describe the coupled problem correctly, and only the most important of these modes can be chosen to be included in the reduction to decrease the problem size [16], Paper 1.

The Lanczos procedure, described in, for example, [17], can be used when deriving the normal modes for each component. It has also been used to derive load-dependent Lanczos vectors, achieving a very efficient basis for each excitation of the studied system, which has been applied to a symmetric three-field formulation of a structure-acoustic system in [2].

In modelling porous sound absorption material, Biot's theory can be adopted in order to include both the flexible frame material and the fluid in the open pores in the description [18,19]. This is necessary when the flexibility of the frame material is important to the behaviour of the system. Both domains are then described by the equations of continuum mechanics. This theory has been implemented in the finite element environment using a $\langle \mathbf{u}_s, \mathbf{u}_f \rangle$ formulation [20–22], i.e. both the structural and fluid partitions are described