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CALCULATION OF RADIATION EFFICIENCY OF COMPLEX STRUCTURES USING FINITE AND INFINITE ELEMENTS

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1. INTRODUCTION

In designing a structure for reduced radiated noise characteristics it is useful to know its modal radiation efficiency given by

$$\sigma = \frac{\Pi}{\rho\, c\, A <V^2>}$$

where the radiated power Π is normalized by the product of mass density ρ, sound speed c, area A and mean square velocity V. The radiated power needed in this equation can be determined from the Helmholtz equation once the mode shapes of the structure are available. However, for complex three-dimensional structures this calculation has to be performed numerically and could result in considerable computational expense, especially at higher frequencies. We present a method that uses finite and infinite elements to model the acoustic medium and results in a solution that has proven to be more efficient than the traditional boundary element method. We briefly describe the method as implemented in the SARA computer program and its specialization to the calculation of modal radiation efficiencies. To demonstrate the accuracy of the method we compare the SARA solution to classical simply supported plate results. Finally, we solve a more practical problem of a stiffened machinery cover structure.

2. THE FINITE AND INFINITE ELEMENT METHOD IN STRUCTURAL ACOUSTICS

The software we are using to calculate the radiated power is the SARA structural acoustics program [1] which has been in use for over a decade in the solution of radiation and scattering problems of underwater structures. In general SARA solves the coupled set of time harmonic structure-fluid interaction equations written in terms of the complex structural displacements u and the scalar fluid pressures p as

$$\begin{bmatrix} \mathbf{K}-\omega^2\mathbf{M} & -\mathbf{L} \\ -\mathbf{L}^T & \frac{1}{\rho\omega^2}(\mathbf{H}-\omega^2\mathbf{Q}) \end{bmatrix} \begin{Bmatrix} \mathbf{u} \\ \mathbf{p} \end{Bmatrix} = \begin{Bmatrix} \mathbf{F}_s \\ \mathbf{F}_f \end{Bmatrix} \tag{1}$$

where in the top row **K**, **M**, $\mathbf{F}_s$ represent the usual structural stiffness, mass, and forces, ω is the circular frequency and **L** provides the coupling to the fluid. In the lower row **H**, **Q**, $\mathbf{F}_f$, and **L** are analogous quantities for the fluid resulting from the discretization of the wave equation. We use standard polynomial shape functions in the acoustic finite elements to model the nearfield and to fill any irregularities due to structural geometry. Infinite elements with special shape functions are then attached to the convex nearfield/farfield boundary to satisfy the radiation condition at infinity.

We use infinite elements of the 'decay-function type originally used by Bettess and Zienkiewicz [2] for surface wave problems. The shape functions of these elements are complex since they contain terms that describe an outward traveling and decaying wave. Since this method provides only an approximate solution for farfield pressures we use the calculated pressures and normal velocities at the structure-fluid interface in the Helmholtz integral equation to evaluate field pressures. Radiated power is calculated from these same quantities as

$$\Pi = \frac{1}{2}\,\mathrm{Re}\int p\,V^{*}\,da \tag{2}$$

The efficiency of the method derives from the symmetric and banded set of equations that need to be solved. Although some of the exterior fluid needs to be modeled this is kept to a minimum by varying the mesh dimensions radially outward from the structure with frequency. In this way 3 to 6 layers of elements generally suffices over all frequencies. Modeling of the exterior fluid is automated in SARA to ease the analyst's burden. In the underwater structures community the infinite element method is now generally recognized as being more cost effective than the more traditional boundary element method for representing the fluid, especially as problem size gets large. This is mainly due to the expense of solving fully coupled unsymmetric (although smaller in number) equations. In addition, the non-uniqueness of the solution at certain wavenumbers causes difficulties.

To a large extent these efficiencies should carry over to the modal efficiency calculation. Of course, we need not solve the coupled equations since the structural displacements are assumed known, i.e. the mode shapes have been determined elsewhere. The set of equations that need to be solved reduces to

$$(\mathbf{H}-\omega^2\mathbf{Q})\mathbf{p} = \rho\omega^2\mathbf{L}^T\mathbf{u} \tag{3}$$

where **u** represents the known nodal displacements. Power is calculated from Eq.(2) using the computed pressures and velocities derived from the known displacements **u**.

3. VERIFICATION AND RESULTS

The SARA program has an interface to the ANSYS finite element code for importing models as well as selected results. Although the following problems could have been solved entirely in SARA we deliberately chose to perform the eigenvalue analysis in ANSYS. In that way models created for stress or vibration analyses can also be used for acoustic studies. In order to demonstrate the accuracy of the infinite element- finite element method of calculating radiation efficiency we first solved the problem of a simply-supported square plate in a plane infinite rigid baffle [3]. The plate was modeled in ANSYS where natural frequencies and modeshapes were computed. The surface pressures and modal radiated power are calculated in SARA using an acoustic fluid model consisting of a few air finite element layers plus an infinite element layer. Results of the radiation efficiency calculation for three symmetric modes are compared to the exact solution in Fig.1 and clearly indicate the accuracy of the method.

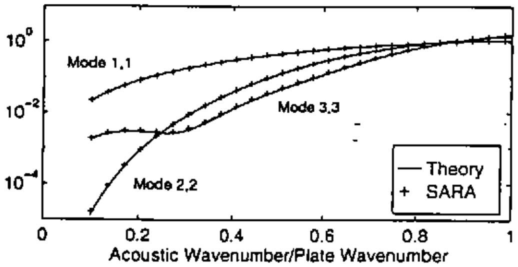

Figure 1 Radiation Efficiency for a Simply-Supported Plate

Fig.2 shows a portion of a complex stiffened plate, machinery cover structure originally modeled in ANSYS. Also shown is a partial acoustic model from SARA that models the surrounding air. Results of the radiation efficiency calculation are shown in Fig.3 for the first three modes of vibration.

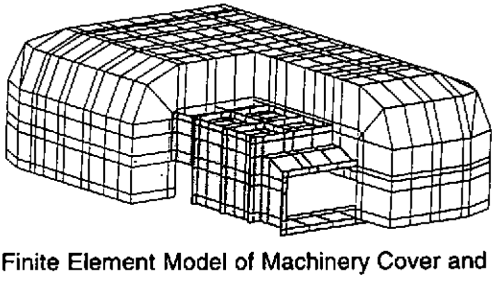

Figure 2. Finite Element Model of Machinery Cover and Fluid

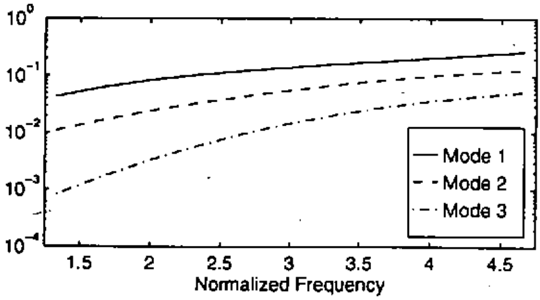

Figure 3. Radiation Efficiency for Machinery Cover

4. CONCLUSION

A finite element infinite element method for calculating the radiation efficiency of complex three-dimensional structures has been demonstrated. This method should prove to be more cost effective than the boundary element method due to the efficiencies derived from solving banded rather than full sets equations.

5. ACKNOWLEDGMENT

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