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CHARACTERIZING THE SOURCES OF NOISE AND VIBRATION ON A SMALL AUTONOMOUS SUBMERSIBLE

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ABSTRACT
In this paper a Finite Element and Boundary Element approach is developed to characterize the AUV sources that generate the self-noise (vibration and radiated sound pressure) of a simplified FAU Ocean Explorer AUV. Mechanical excitation from the "podule", which contains the motors for the propulsion and motion control, is assumed. The low frequency (less than 1 Khz) results are dominated by two types of modes. One type associated with the motion of the "podule" as a rigid body on the vibration isolation supports that connects it to the rest of the AUV structure. The second type is associated with local structural deformations of the "podule", support frame, and AUV hull. Modifying the stiffness of the supports reduces the frequency of the rigid body modes of the "podule", but does not influence the frequencies of the local structural deformations of the "podule" and the rest of the AUV. Decreasing the stiffness of the supports results in a reduced AUV acoustic signature (work sponsored by ONR).

1 - INTRODUCTION

This paper describes work in progress [1] to model and measure the radiated noise from an OEX (Ocean EXplorer) class AUV (Autonomous Underwater Vehicle). The modeling is based on a finite element (FE) / boundary element (BE) approach. This upper frequency of the analysis is 1 KHz. While this may be considered low, understanding the mechanism by which the vibration is propagated through the AUV structure does not require analysis across the whole of the frequency range.

2 - DESCRIPTION OF THE SOURCES

An AUV has several sources of noise: flow-induced vibrations and noise, propeller noise, hull vibrations and noise, etc. In this paper, the emphasis is on the noise generated due to mechanical vibrations, induced in the AUV structure by on-board mechanical equipment. The AUV has five motors, one used for propulsion and four servomotors that control the rudder and dive planes. All five motors are contained in an aluminum and PVC cylindrical shell referred to as the "podule". The vibration generated by the "podule" is transmitted to the hull through neoprene isolator mounts. The general configuration of the AUV is shown in figure (1).

The present effort is concentrated on modifications of the vibration transmission paths. The AUV is free-flooded between the podule and the hull, therefore the transmission path through the vibration isolation mounts is not the only path for the vibrational energy. Vibrational energy can also be transmitted through the water and through the shaft, fins and propeller supports. These paths are shown in figure (2). A bulkhead ring connects the podule to the rest of the AUV structure, through vibration isolation mounts. The stiffness of these mounts can be optimally selected to minimize the transmitted vibrational energy from the podule to the AUV hull.

3 - FE MESH

The FE model is created from CAD drawings figure (3).

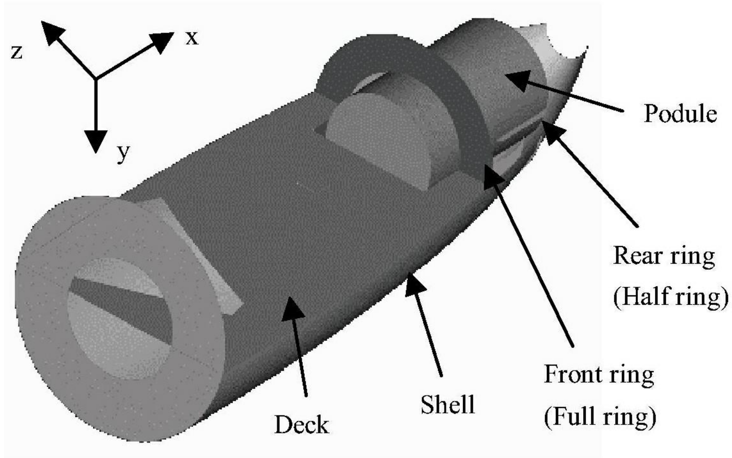

Figure 1: OEX ProE drawing, top shell removed.

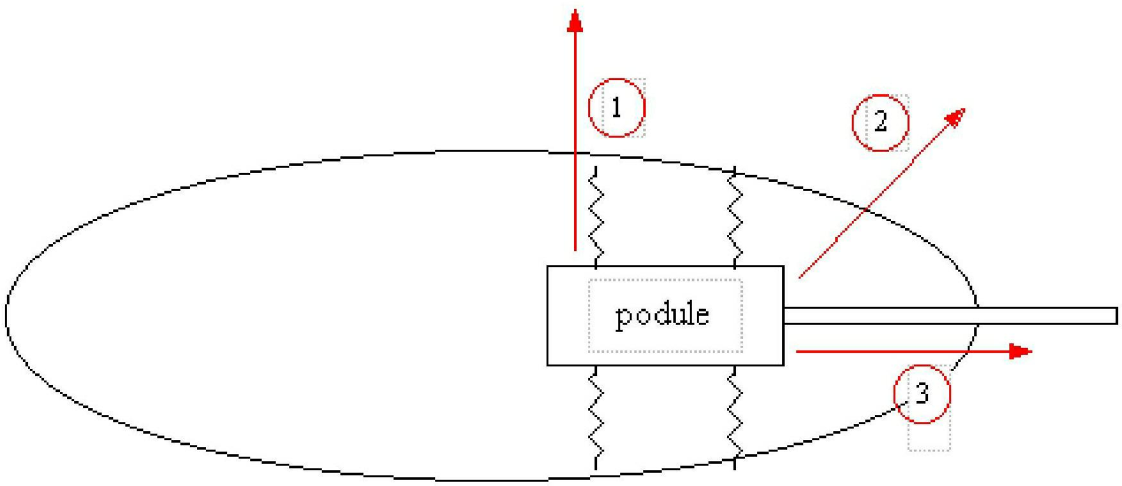

Figure 2: The three paths of transmission.

3.1 - Shell hull (yellow elements)
Since the AUV is free-flooded, the AUV hull does not have to withstand any pressure differential, and thus it is made out of a thin fiberglass shell, 5 mm thick. The hull is modeled for the FE analysis by thin shell elements. The element used is the ANSYS [2] Shell63 element. Each node has six degrees of freedom that are the displacements and rotations along the three orthogonal directions.

3.2 - Podule (pink elements)
The podule is a watertight cylinder filled with oil. The presence of the oil eliminates the requirements of designing this cylinder to withstand the external water pressure when the AUV is submerged. The podule aluminum cylinder is thus not subjected to high stresses and is therefore made from 5 mm thick aluminum shell. The FE model of the podule also consists of Shell63 elements.

3.3 - Deck and support rings (gray elements)
The deck and support rings are made from high-density polyethylene. As for the previous components, these plastic elements are thin enough to be considered as shell elements.
The use of shell elements is an important advantage in FE modeling. The models created with 2D elements (like shells) have a significant reduction of the number of nodes compared with regular 3D elements. The benefit of this scaled down model is a reduction in computation time.

3.4 - Isolation mounts
Neoprene isolation mounts are located between the podule and the supporting ring bulkheads as shown in figure (4). They are modeled as spring/damper elements with two coefficients, stiffness, and damping. The element used to model these mounts is a two-node line element that can carry a load along its axial

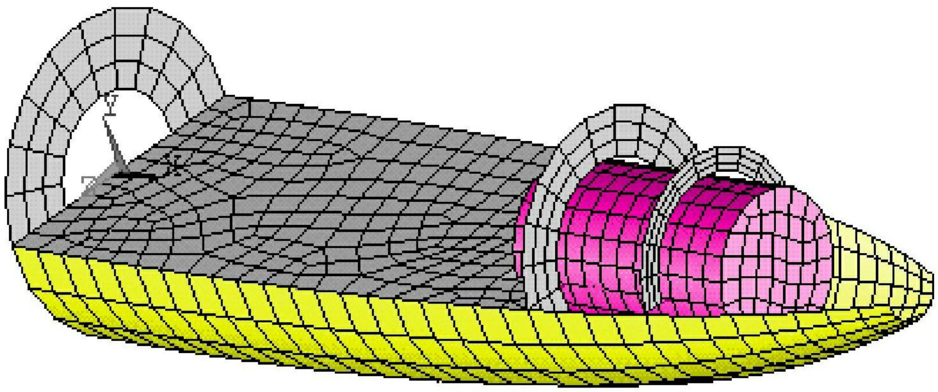

Figure 3: OEX FE model (top half of hull removed).

direction. The element used is the ANSYS Combin14 element. The degrees of freedom at each node are the three displacements.

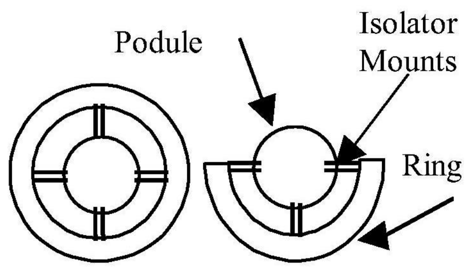

Figure 4: Front and rear ring and their connections with the podule.

4 - BEM MESH

A Boundary Element Model [3] consists of two different components. One component is the mesh on the boundary of the model, and the second component is the Data Recovery Mesh (DRM), which is a surface in the 3D space where the far field acoustic pressure and velocity is calculated.

The envelope mesh of the FE model is used to create the BE mesh. It consists of triangle elements with an average size of 5 cm. Two different DRM meshes are used. The first DRM is a cylinder, and this mesh is used to obtain a surface contour of the acoustic pressure around the AUV. Since the AUV is cylindrically shaped, a cylindrical DRM is the most appropriate surface to represent the radiated pressure around the AUV. The second DRM is a sphere and is used to compute the radiated acoustic power. Unlike the cylindrical DRM used for determining the scattered pressure, this DRM has to be closed. The power is an integration of the intensity over a complete enclosing surface.

5 - RADIATED PRESSURE

Using the FE and BE model, the radiated sound power is calculated. From this sound power the source level of the AUV (that is the radiated sound pressure level at a distance of 1 meter) is obtained. Figure (5) shows the narrow band source level.

From the narrow band source levels, the source levels in one-third octave frequency bands can be obtained. These are compared to the measured source levels in open water experiments [4] (figure (6)). It can be observed that the calculated levels generally match the measured source levels. One can also observe that there are two peaks in the measured source level at 400 Hz and 800 Hz. The calculated source levels also shows two peaks but these peaks are shifted to 300 Hz and 700 Hz. The frequency offset that exists between the measured and the computed source levels can be attributed to the simplifications of the model. Components that are neglected in the computation influence the mass and/or stiffness resulting in a shift in the frequencies.

6 - DIRECTIVITY

The directivity pattern of the radiated pressure from the AUV is computed for a selection of modes. The two first rigid body modes represent rotations around the z and y-axis respectively. The first mode

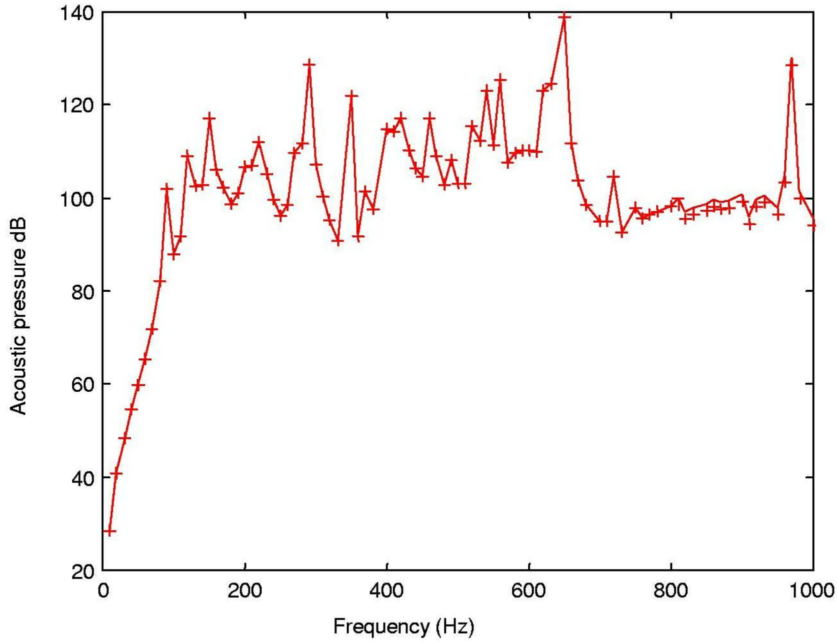

Figure 5: Radiated acoustic pressure, computed in the far field.

is therefore a displacement of the podule in the x-y plane, the pressure will be maximum in that plane as seen in figure (7). The second set of two modes represents translational motion. The pressure is a maximum where there is a maximum velocity of the shell. Here the maximum velocity occurs in the direction of the displacement (figure (8)).

Comparing figures (7) and (8), two differences can be observed. First, for mode 1, the pressure decreases rapidly along the x-axis as one moves away from the podule. Second, the level of mode 3 is higher than for mode 1 by about 10 dB. The reason for the difference in levels can be explained from consideration of the podule vibration. Mode 1 has a dipole type motion, while mode 3 is more like a monopole, (figure (9)).

For other modes of vibration, especially those associated with the hull, the scattered pressure is dependent on the mode shape of the hull

These low frequency radiated pressure directivity patterns (figures (7) and (8)) are very strongly dominated by the mode shapes of vibration of the podule and the hull. This is expected since one is dealing with very low frequency modes.

7 - CONCLUSION

Presented in this paper is the work performed in modeling the acoustic signature of an Ocean Explorer AUV. Numerically computed results for the radiated acoustic power and sound source levels are presented. The computed results are compared to measurement data and the agreement is generally good, especially in terms of overall levels. These are some discrepancies between the computed and measured data and these are generally attributed to simplifications in the numerical model, which were required to keep the computation within reasonable bounds.

An Autonomous Underwater Vehicle (AUV) is very complex with a number of interconnected elements. The model of the AUV used in this paper has been generated and built using CAD drawings of the AUV. However, many simplifications are implemented. Some components and elements of the AUV have been removed for simplicity. Additionally, the model does not include the details of parts inside the pressure vessels. The parts inside the podule consisting of the motors, linkages, etc., are not included in the numerical model. These parts also contribute to the overall response of the AUV. Finally, the Ocean Explorer AUV is hand built, and in the process of fabrication and tailoring to fit specific sensors, structural modifications, some minor and some not so minor, are implemented without necessarily including these changes in the CAD drawings. For example the deck of an actual AUV is different from that found in the CAD drawings in that there are a number of cutouts, hand made during assembly to fit specific sensors and components. The contribution of all these modifications can create differences in the signature between the computed signature and the measured data.

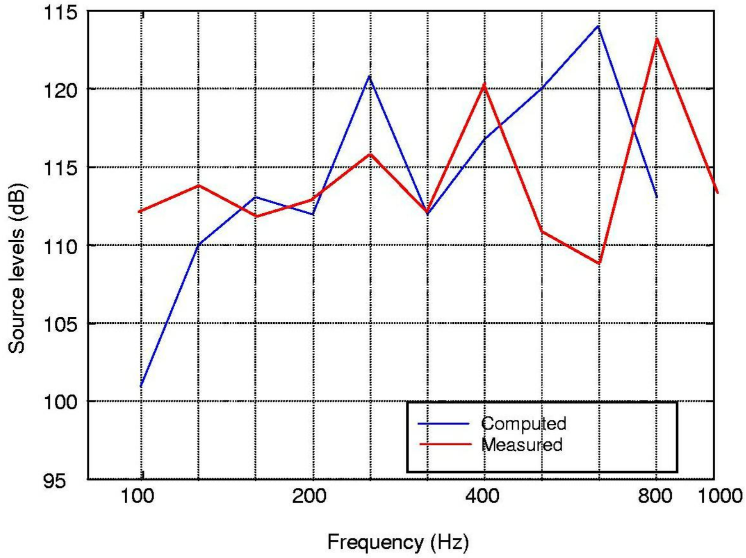

Figure 6: Measured and calculated source levels.

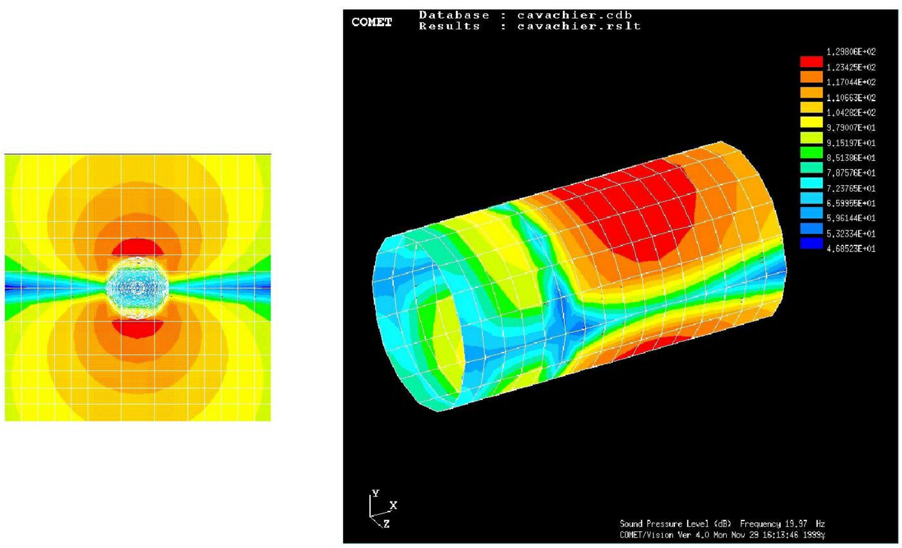

Figure 7: Directivity of the first mode.

The numerical model developed in this thesis still has is usefulness. It provides insight into the sources from which vibrational energy is transferred from the podule, which contains most of the mechanical components to the rest of the AUV structure and the hull. Furthermore, the model can be used to obtain a better handle on how the hull interacts with the surrounding water. The numerical models provide a tool that can be used to investigate different options for mitigating the acoustic signature. That is, while it may not provide absolute levels, it can provide expected level changes for alternative modifications of the AUV structure or mounting options.

ACKNOWLEDGEMENTS

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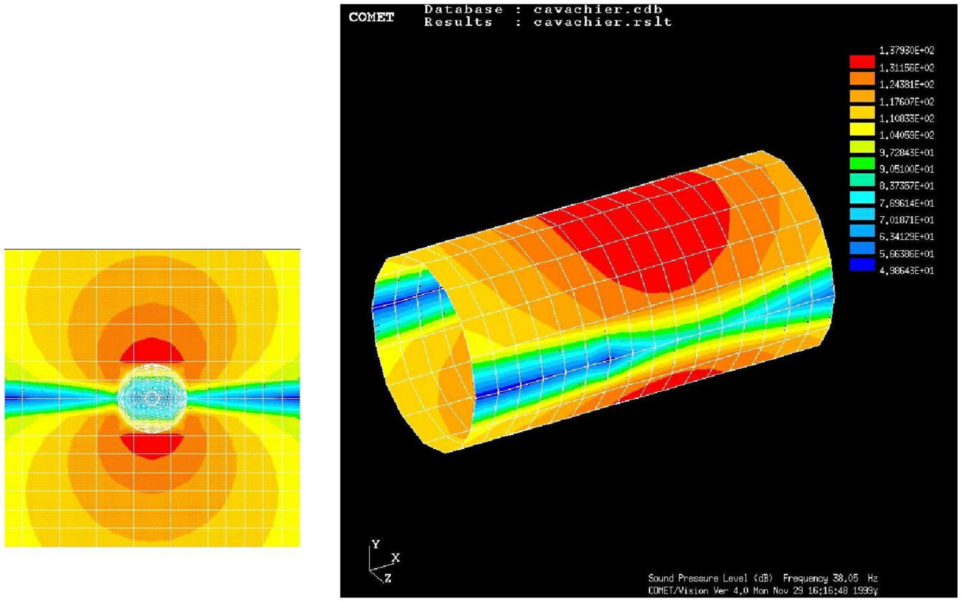

Figure 8: Directivity of the third mode.

Figure 9: Schematic representation of the podule rigid body displacements for (a) mode 1 (rotation) and (b) mode 3 (translation).

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