Predicting Very Low Frequency Underwater Radiated Noise from Full-Scale Ships

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Introduction

Methods for predicting fluid-structure interaction and underwater radiated noise have been under development for a number of years. For very low frequencies, a combined finite element (FE) and boundary element (BE) technique is often used and such a system (AVAST [1]) is available at DRDC Atlantic. While a variety of structures have been examined, the complete analysis of a full-scale vessel is still relatively rare. There is also a renewed concern to minimize the underwater radiated noise from commercial vessels and, in particular, fisheries research vessels. The International Council for the Exploration of the Sea (ICES) has issued recommendations [2] for maximum radiated noise levels over a broad spectrum. This includes very low frequency (less than 50 Hz) narrowband noise, which is not amenable to prediction with energy-based or empirical methods. This paper will outline the procedure for predicting the very low frequency radiated noise from a generic ship model with excitation provided by sample vibrations measured on engine mounts. The analysis will proceed from a coarse MAESTRO [3] model of the vessel, through to a finite element model where the loads will be applied and the natural frequencies calculated, to a radiated noise prediction using the AVAST software. The resulting prediction will be compared to the ICES recommendations up to a frequency of about 20 Hz. The paper will also discuss the difficulties encountered in such analyses and make recommendations as to an appropriate way ahead.

Numerical Modelling

The first step in examining the radiated noise is the production of a finite element model. A generic ship model based on a fisheries research vessel was created using the MAESTRO software, which allows for the rapid generation of a coarse FE model of a vessel. The 2200-tonne vessel has a length of 58m (BP), a beam of 15m, and a draft of 6m. The FE model is shown below in Figure 1 and contains 6516 nodes and 13715 elements.

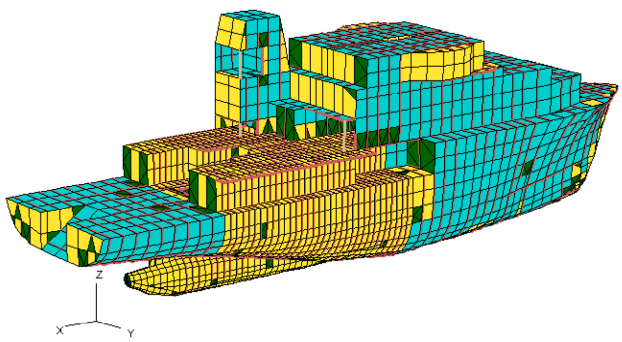

Figure 1: Structural Finite Element Model.

The MAESTRO formulation involved a lumped mass approximation where the structure is assumed to have stiffness, but to be massless in the model. To model the ship's mass, the overall weight curve for the ship (light ship) is divided up by longitudinal stations, then distributed equally to all nodes closest to that station. Thus, the weight from some heavier equipment might be distributed throughout a section to structure not necessarily intended to bear such weights. This is standard practice for a preliminary static analysis of a ship. Tankage loads and a few selected large masses were added separately.

This specialized MAESTRO model can be converted to a standard FE model (which would look identical to Figure 1) using available translators. This FE model can then be further refined for other analyses if required. An in-air dynamic analysis of the model was performed to determine the dry natural frequencies of the ship which are required input for the AVAST analysis. Dynamic loads were applied to the FE model to simulate three (of four) diesel generators and one electric motor running. In this case, acceleration measurements were available for the motor and for a diesel generator or representative values may be obtained from the literature [4,5]. Figure 2 shows the vertical component of the loads and their points of application. To determine the appropriate load levels, unit loads were applied, a modal frequency response analysis performed, and the resulting accelerations of the engine mounts (with the ship in water) were compared. The applied loads were scaled to correct for the differences between the predicted and measured amounts. This procedure was iterated until convergence. The resulting loads were then available for the radiated noise analysis. For the purposes of this analysis, the loads were assumed to be constant with respect to frequency. Modal damping factors were assumed to be a consistent value of 0.002 based in part on data measured on a scientific research vessel of similar displacement.

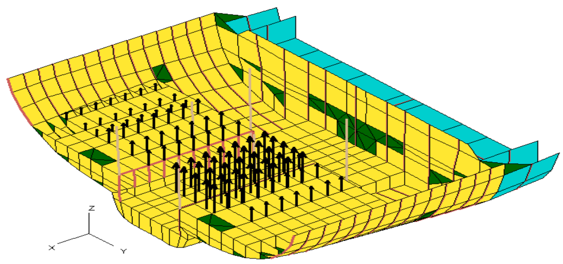

Figure 2: Applied Motor And Generator Loads**.**

Given a description of the dry natural frequencies and a load file, the boundary element based AVAST code can be used to predict low frequency radiated noise. The program requires only a model of the wetted surface of the vessel and the required model (containing 2235 panels) is shown in Figure 3.

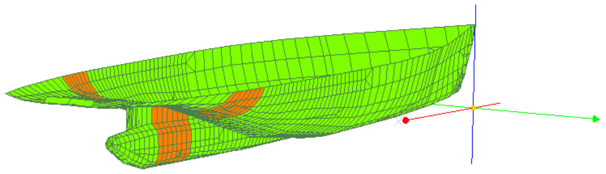

Figure 3: Wetted Surface Boundary Element Model.

Once the model is read, and the modes and forces input, the user must generate a set of field points for the radiated noise prediction. For this analysis, the field points were located at a depth of 10m from the surface and a range of 100m from the approximate centre of the fluid model. The user indicates that there is a reflecting surface (located at the draft line) and also inputs the fluid properties and the frequency for this analysis. As the fluid matrix properties vary with frequency, multiple analyses were run with a frequency increment of roughly 2 Hz.

Results & Discussion

The predicted radiated noise level (dB re 1 μPa) at the 100m distance is plotted versus frequency in Figure 4. The three curves show the sound level for the broadside and bow aspects, as well as the maximum at each frequency. The strongly radiating resonances can clearly be seen as can the variation of the maximum with respect to aspect (no single aspect dominates). The first large resonant peaks correspond to the primary hull bending modes of the vessel.

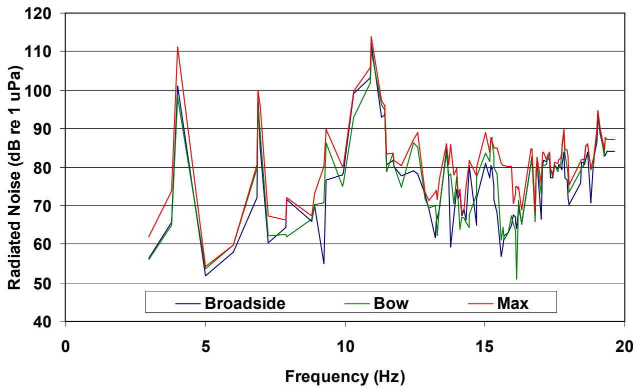

Figure 4: Radiated Noise at 100m.

An important use of this type of analysis is to compare the ship's signature with that recommended by ICES. In the frequency range used here, the recommended ICES source level limit (SL) in dB is given in [2] as SL = 135–1.66 log(f) where f is the frequency in Hz. Using a simplified approximation involving a source in an infinite half-space to determine the transfer function between the radiated noise level and a source level and, using the maximum values from Figure 4, the source level (in dB re 1 μPa at 1m) was estimated and is shown in Figure 5 compared with the ICES level for this frequency band. It can be seen that only the first three resonant peaks exceed the ICES level, but as the curve approaches 20 Hz, it appears there may be some danger of the source level completely exceeding the recommended level. Clearly, in this case, there are issues to address at the primary hull modes and there may be more broadband concerns at frequencies above 20 Hz. Obviously, this type of analysis can show where problems might occur and possible solutions could be examined at the design stage.

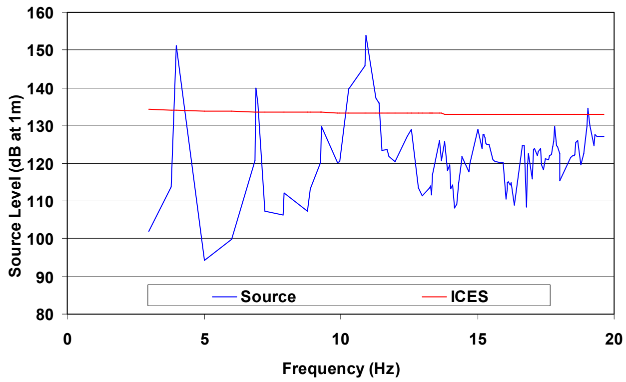

Figure 5: Approximate Source Level Due to Engine Noise.

The choice of how to create the FE model has a significant impact on this type of dynamic analysis. As these models are often initially created for static strength calculations, issues such as the lumped mass approximation (with weight curve) cause problems, such as those encountered here, with low frequency internal modes which may not be realistic, thus limiting the analysis to 20 Hz. Similar problems were encountered with a container ship model, in which even the whip antennae were originally modelled. On the other hand, the radiated noise of a small generic ship, which was modelled with a dynamic analysis in mind, was predicted to a frequency of 50 Hz [6]. As well, this vessel was relatively small and even relatively coarse models of tankers can have in excess of 70,000 elements, which may be an issue for some types of dynamic analysis and for some BE codes.

References

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