Sonar Dome Vibration Analysis

Scientists at INSEAN, The Italian Ship Model Basin, have developed a way to calculate the effects of turbulent boundary layer flow on a bulbous bow housing sonar system with an easy-to-use simulation model to reduce self-noise.

BY JENNIFER HAND

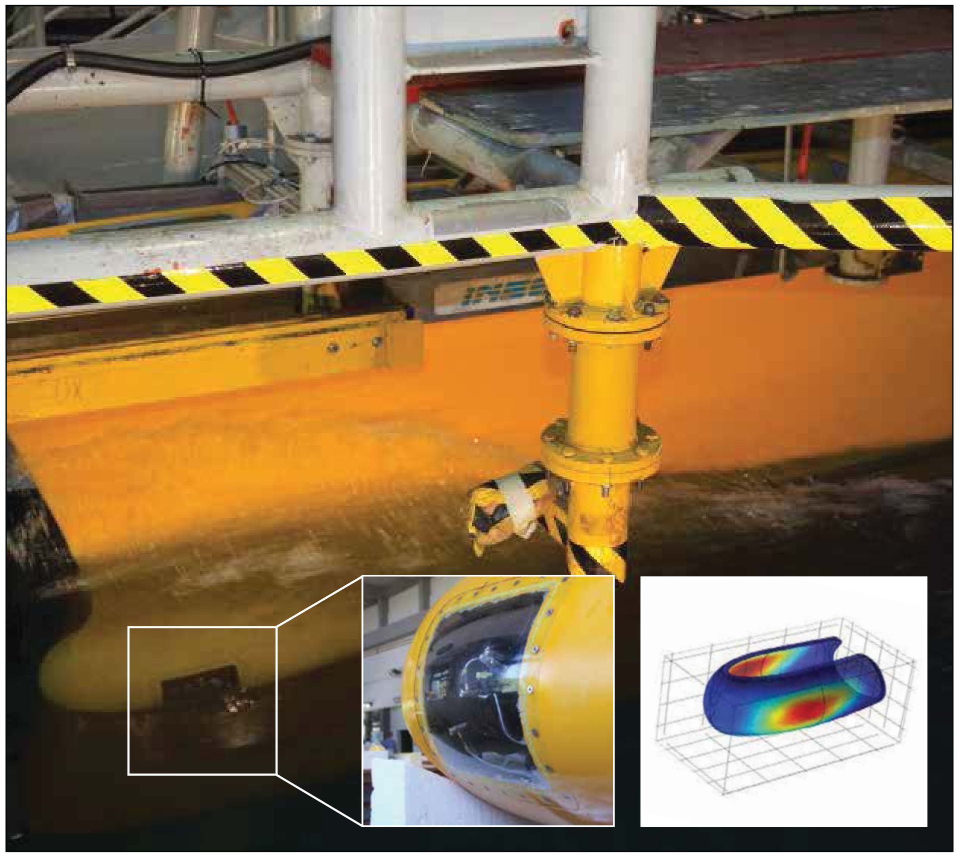

FIGURE 1: Experimental campaign on a 1:8 scaled model of the bulbous bow. A section of the bulbous bow has been substituted with a transparent material on which accelerometers have been placed (bottom middle). The simulation shows the system's structural response (bottom right).

A bulbous bow, the protruding bulb that sits below the waterline at the front of a vessel, has become a standard design feature in large ships. It significantly reduces wave resistance when traveling long distances at a speed near to maximum capacity, resulting in more stability and fuel efficiency.

In recent years there has been a move towards utilizing the bulbous bow to house different types of sonar system but there are questions about the extent to which structural vibration interferes with the functioning of the transducer array inside such a sonar dome. In particular, the pressure fluctuation that arises from the turbulent boundary layer (TBL), a thin layer of fluid where gradient of velocity and the resulting shear stress magnitudes are much higher than in the laminar case, is thought to be one of the major causes of self-noise for on-board sensors. A team from INSEAN therefore set out to investigate.

Testing a Scale Model

Francesca Magionesi, a researcher at INSEAN, explains: "Most existing research on wall pressure fluctuation has been done using simple geometries and ideal flow conditions that do not take into account the free flow of water over a complex curvature. So our first aim was to understand the frequency spectra of wall pressure fluctuations induced by the turbulent boundary layer acting on a bulbous bow."

This was done by building a large-scale model bulbous bow that was rigid and conducting an experiment to characterize wall pressure fluctuations within one of the two towing tanks at INSEAN. "This was tricky not only because of the effects of structural curvature and fluid loads but also because we had to capture the higher frequency component of pressure fluctuations using miniaturized pressure transducers," reports Magionesi. Despite this, the team managed to measure wall pressure fluctuations at different locations along the bulbous bow and model these loads in terms of auto and cross spectral densities.

In a second experiment the researchers substituted a section of the bulbous bow with an elastic linear material (a transparent polymethyl methacrylate, PMMA, thermoplastic) and obtained its structural response (see Figure 1).

The team then turned to simulation to replicate the results of the physical testing.

"To evaluate the dynamical response of an elastic structure to the turbulent boundary layer load it would normally be necessary to use direct numerical simulation of the fluid flow coupled with a structural code," explains Magionesi. "But the high Reynolds number typical of a real naval application makes this approach impossible because of the tremendous computational time and

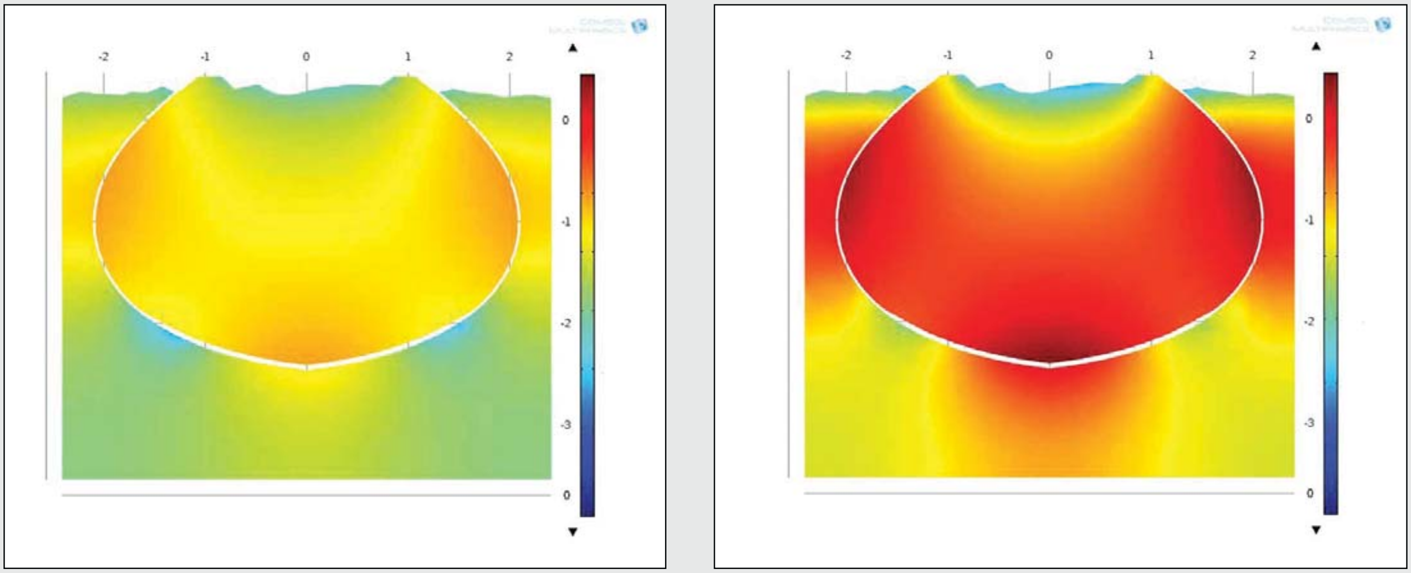

FIGURE 2: Sound pressure level at a cross section of the 3D bulbous bow simulation for a cruise velocity of 15 knots (left) and 30 knots (right).

memory requirement. We therefore developed a simplified expression of the fluid load, based on a weak coupling between fluid and structure, which assumes that structural vibration would not affect fluid excitation, and a simplified fluid load expression. In this way we validated the experimental-numerical procedure at scale model level.”

> “In order to predict the noise and vibration caused by the flow of water interacting with the structure of the bow, we tested at different velocities using the structural, fluid and acoustic domains.”

Simulating at Full Size

The next stage was to create a full-scale model within COMSOL Multiphysics, which would take into account the complexity of the composite material used for the bulbous bow. The results of an in-house program, a code that solves the Reynolds Averaged Navier-Stokes (RANS) equations, allowed the team to rescale the wall pressure fluctuations measured on the small model and obtain full-scale excitation data at relatively low computational cost. These data were used as input for COMSOL Multiphysics and inserted as a pressure load in the numerical model (see Figure 2).

“Livelink™ *for* Pro/ENGINEER® enabled us to bring CAD data for the different parts of the bulbous bow into COMSOL Multiphysics,” explains Magionesi. “Because this data had not been developed for finite element analysis we had to improve the quality in certain places, particularly with regard to the different thicknesses of the bow wall. We really appreciated the flexibility to carry out these small changes directly within COMSOL Multiphysics. Another reason we like the software is the capacity to analyze any number of physics in one unified package. In order to predict the noise and vibration caused by the flow of water interacting with the structure of the bow, we tested at different velocities using the structural, fluid and acoustic domains. That was really important because it gave us the opportunity to insert governing equations directly.”

The team later used COMSOL Multiphysics LiveLink™ *for* MATLAB® to move their homemade code over to MATLAB®.

An Easy-to-Use Tool for Complex Systems

According to Magionesi the most important achievement is an easy-to-use tool with which to evaluate the noise and vibration level induced by turbulent boundary layer load at full scale, i.e. with a high Reynolds number. “Yet we only had to perform the experiment with a small model scale that captured turbulent boundary layer excitation,” she reflects.

“We also used COMSOL Multiphysics to ascertain the parametric qualities of materials. By varying the characteristics of these, we extended the scope of our tool beyond sonar sensors to the design of the bulbous bow itself so that we could address drag as well as vibration levels. Our research led us to create a multi–disciplinary tool for achieving global optimization of the bulbous bow sonar system at the design stage. Our aim now is to integrate this tool with other aspects of analysis and make it available for others to use.” ■

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