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DREA ACOUSTIC CALIBRATION BARGE NATURAL FREQUENCY MEASUREMENTS AND PREDICTIONS

L.E. Gilroy – T.R. MacFarlane – A. Ritchie

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by

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TECHNICAL MEMORANDUM

Prepared by

Defence Research Establishment Atlantic

Centre de Recherches pour la Défense Atlantique

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Abstract

C++ classes for representing sparse matrices are described. The matrices use one of four profile storage schemes: compressed row storage, skyline storage, sparse skyline storage (similar to skyline storage but with compressed arrays above and below the diagonal), and S2dBlock storage (a special purpose storage scheme for matrices arising from partial differential equations on two-dimensional structured blocks).

C++ classes are also provided for iterative solution methods for linear systems of equations. The Conjugate Gradient, Conjugate Gradient Squared, Quasi-Minimum Residual, and Generalized Minimum Residual (GMRES) methods have been implemented. Element re-ordering and preconditioning using the diagonal (Jacobi) or incomplete LU factorization of order zero (ILU0) methods are also provided.

Résumé

Description des classes d'objets C++ pour représenter des matrices d'analyse. Les matrices utilisent l'un des quatre systèmes de stockage des profils: par rangées comprimées, par horizon d'analyse (similaire à l'horizon, mais avec des tableaux comprimés au-dessus et au dessous de la diagonale) et par bloc S2d (système de stockage à but spécial pour des matrices provenant d'équations différentielles partielles sur blocs structurés bidimensionels).

Les classes d'objects C++ sont également fournies pour des méthodes de solution itérative pour les systèmes linéaires d'équations. Les méthodes du gradient conjugé, du gradient congugé au carré, de la valeur résiduelle quasi-minimum (QMR) et de la valeur résiduelle minimum généralisée (GMRES) ont été mises en oeuvre. La remise en ordre et le préconditionnement des éléments en utilisant les méthodes de la diagonale (Jacobi) ou de la factorisation LU incomplète de l'ordre zéro (ILU0) sont également donnés.

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Executive Summary

Introduction

In support of both the Ship Noise and Ship Structures programs, DREA conducted a series of experiments to determine the natural frequencies of the DREA barge. These experiments were done to examine the performance of DREA's finite element structural analysis software, VAST, for large naval structures and to provide a validated numerical model of the barge for future structural radiated noise predictions to validate DREA's acoustic prediction software. Accelerometer measurements of the barge hull vibrations were obtained by setting the equipment to record the hull accelerations overnight with only the wave energy providing the excitation. Resonant peaks were taken from these accelerometer measurements and the first few mode shapes of the barge hull were deduced.

Principal Results

The predicted natural frequencies of the barge (in water) compared very well with the measured values. The first two predicted modes were accurate within 15% with subsequent modes being somewhat more accurate. The first four modes include the first and second hull torsion and hull longitudinal (bending) modes. The frequencies were also calculated *in vacuo* and the comparison with the floating barge showed a 60% decrease in the first four hull modes due to the fluid added mass. The floating barge also exhibited deckhouse resonances with very similar frequencies to the *in vacuo* case, as expected.

Difficulties were encountered in measuring any superstructure or deckhouse modes for the barge, due to insufficient structural excitation, and in establishing the correct displacement in the finite element model. The addition of 40 tonnes of point masses and 60 tonnes of mass due to anchor cables resulted in an acceptable displacement for the numerical model.

Significance of Results

In general, the results indicate the model was a reasonably accurate representation of the barge on a global scale and that the assumed distribution of additional masses was acceptable. These results give confidence that the model can be used to predict the radiated noise from the DREA barge under a given loading for comparison to planned experimental measurements of radiated noise.

Future Plans

The use of this barge model for comparison to planned radiated noise measurements would be a valuable step towards validation of AVAST's capability for predicting radiated noise from a CF ship or submarine. Should the opportunity arise, additional measurements of the barge superstructure natural frequencies may be attempted to further validate the model. As well, other prediction methods, such as AVAST or the finite element ship analysis software, MAESTRO, may be used for comparison to the measured results.

Contents

1 Introduction

In support of both the Ship Noise and Ship Structures programs, Defence Research Establishment Atlantic (DREA) conducted a series of experiments to determine the natural frequencies of the DREA Acoustic Calibration Barge [1, 2] located in Bedford Basin, Halifax, Nova Scotia (Figure 1). The results of this investigation are to be used to examine the performance of DREA's finite element structural analysis software, VAST [3], for large naval structures and to provide a validated numerical model of the barge for future structural radiated noise predictions to validate DREA's acoustic prediction software.

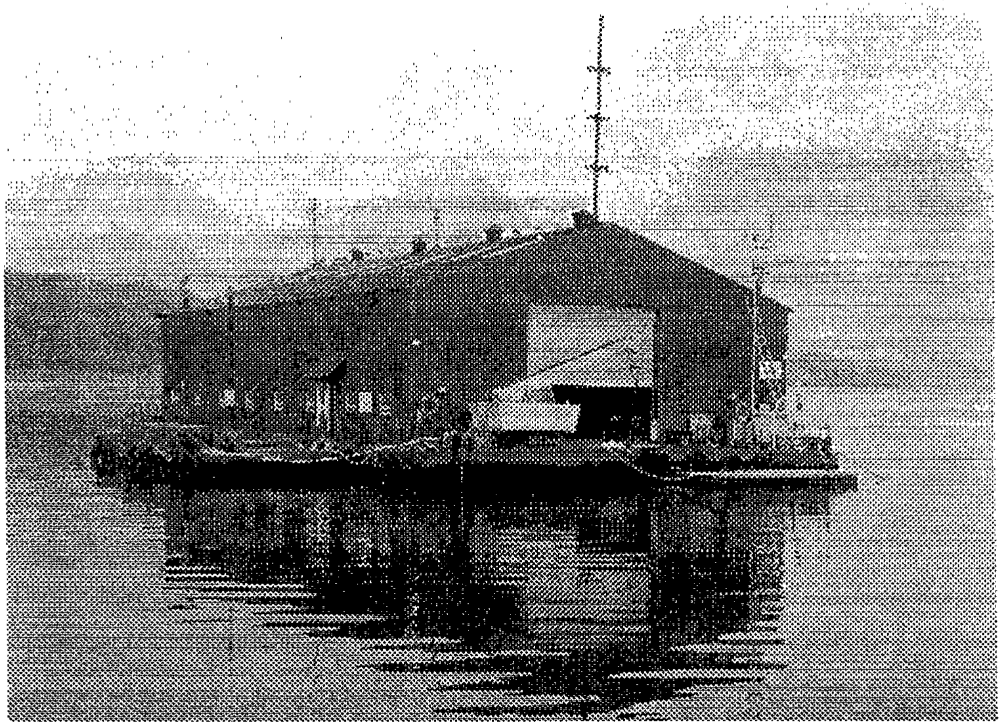


Figure 1: DREA Acoustic Calibration Barge

While the VAST software has been in successful use for some period of time, its capability for predicting the natural frequencies of very large models has rarely been tested. The numerical model of the DREA barge is one of the largest models yet created by DREA for dynamic analysis using VAST, particularly the sections of VAST involving fluid added mass. Furthermore, the DREA acoustic prediction computer code, AVAST [4, 5, 6, 7], which is based on the boundary element method, has yet to be verified using such large structural models. The AVAST software is also capable of predicting the natural frequencies including added mass, but its primary use involves predicting the radiating noise from a vibrating structure. Trials to measure the radiated noise from the DREA barge are planned and this barge model, if validated, will be used as a basis for the predicted radiated noise against which the measured data will be compared.

Various attempts were made to obtain accelerometer measurements of the barge hull vibrations under different forms of excitation. The most useful data were obtained by setting the equipment to record the hull accelerations overnight with only the wave energy providing the excitation. Difficulties were also encountered in verifying whether the numerical model matched the real structure with a reasonable degree of accuracy. This technical memorandum discusses the procedure used to record the acceleration data, the construction and verification of the finite element model, and the comparison between the measured and predicted frequencies.

2 The VAST Software

VAST (Vibration And STrength) is a general purpose, finite element computer code for the analysis of complex structures. It has been developed both in-house at DREA and through contracted research since the early 1970's. Over the twenty years of development, many general purpose and special features for naval structural analysis have been implemented in VAST. These include specialized pre- and post-processors, as well as links to commercial model generators, a substantial library of element types, and a wide range of analysis options consisting of the usual linear static, dynamic and eigenvalue solutions. More recent additions to VAST include: large displacement nonlinearity; random response to sea spectra loading; stochastic Finite Element Analysis (FEA); elasto-acoustic analysis; complex eigenvalue solutions for vibration isolation; and component mode synthesis.

3 Measurements

The DREA Acoustic Calibration Barge has a length of 36.0m, width of 17.1m, and a draft of about 1.04m. The barge is anchored (from each of its four corners) in Bedford Basin, Halifax, Nova Scotia. The barge is primarily used for the calibration of acoustic transducers and possesses specialized facilities for this purpose. The hull is of steel construction with longitudinal stiffeners and deep transverse frames. The barge has a steel- and aluminum-framed corrugated steel superstructure or deckhouse covering the majority of the main deck. The barge also has an internal moon pool which measures 18.3m by 6.1m. The main deck of the barge also has a 12mm-thick coating of a cement-like substance over the steelwork. A photo of the interior of the barge may be seen in Figure 2.

Two B&K Model 4370P accelerometers attached to B&K Model 2635 charge amplifiers were used to measure the barge vibrations. The accelerometers were connected through the charge amps to an HP35670A Signal Analyzer. The accelerometers were placed at various locations throughout the barge selected so as to give an indication of the mode shape as well as the frequency of a detected peak.

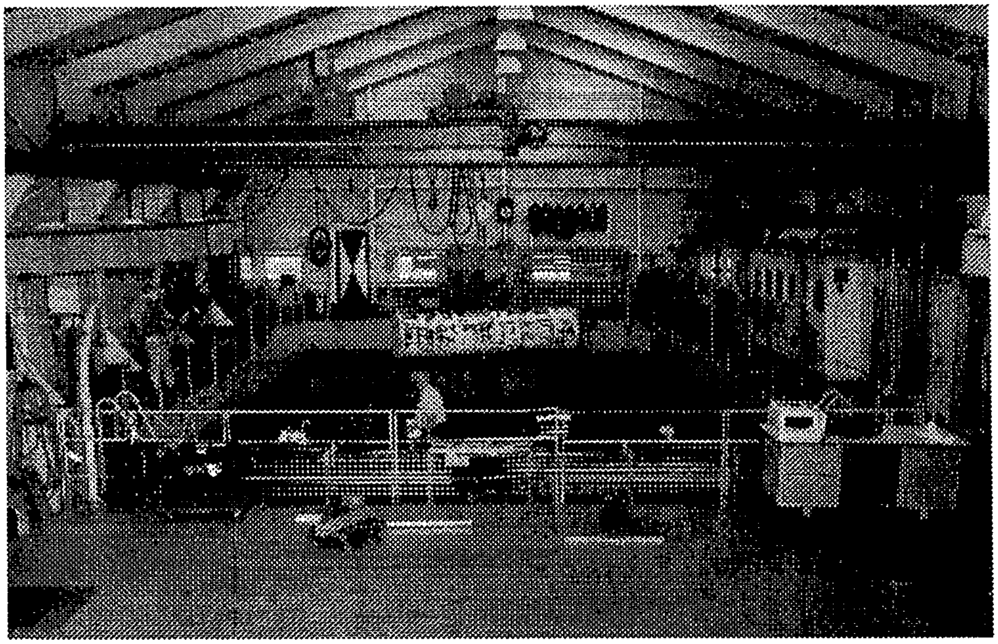


Figure 2: DREA Acoustic Calibration Barge Interior

To examine the dynamic behaviour of a structure, typically an impact hammer or a shaker is used to excite the structure. In this case, no large impact hammers were available and the best shaker available was a nominal 450 N combination electromechanical-piezoelectric shaker. At the lower frequency ranges of interest (less than 50 Hz), this shaker only puts out a fraction of the 450 N. This level of applied force was insufficient to register on the accelerometers. A larger 2200 N electromechanical shaker was also tried with similar results. Various other methods were used to attempt to excite the barge structure including running the backup diesel engine, running the external diesel crane, and running the large overhead crane into its end stops. None of these methods proved sufficient. Finally, it was decided to wait for sufficiently rough weather and use the ocean waves as the excitation mechanism.

As the first few modes of the barge were expected to be very low in frequency, the analyzer was typically set to record in a frequency band from 0 Hz to 12.5 Hz with a 400-line (0.03125 Hz) resolution or 0 Hz to 25 Hz with a 800-line resolution. A Hanning window was used for the spectral analysis and 1000 spectra were averaged (using RMS averaging) for each measurement. This resulted in run times on the order of eight hours and necessitated leaving the equipment running overnight to perform a complete measurement. Thus, on days when there was sufficient wind and/or waves, the equipment was set up to run overnight and the results were examined the next morning. This method proved to result in accelerometer measurements with sufficient signal to noise to determine the lowest resonant frequencies of the barge hull. While this method was useful for determining the first few hull modes of the barge, there proved to be insufficient excitation of the barge superstructure to determine any of the modes associated predominantly with the superstructure.

Several sets of data were taken to attempt to determine the longitudinal, lateral, and torsional modes of the barge hull. The data were collected and the resonant peaks were examined to determine the resonant frequencies and mode shapes.

4 Numerical Model

The finite element (FE) model of the barge was constructed at DREA using construction drawings of the barge and performing measurements where data was missing from the drawings (the barge was constructed in 1960). The model was assembled using a format suitable for a VAST analysis. The model contained 7684 nodes and 151 element groups containing 13,699 elements consisting of 4-noded and 3-noded shell elements and the 2-noded general beam element. The axis system chosen has the x-z plane parallel to the water surface with y being positive upwards and the origin located at the forward perpendicular of the barge. The finished model is shown in Figure 3 (with one half the superstructure removed for viewing purposes).

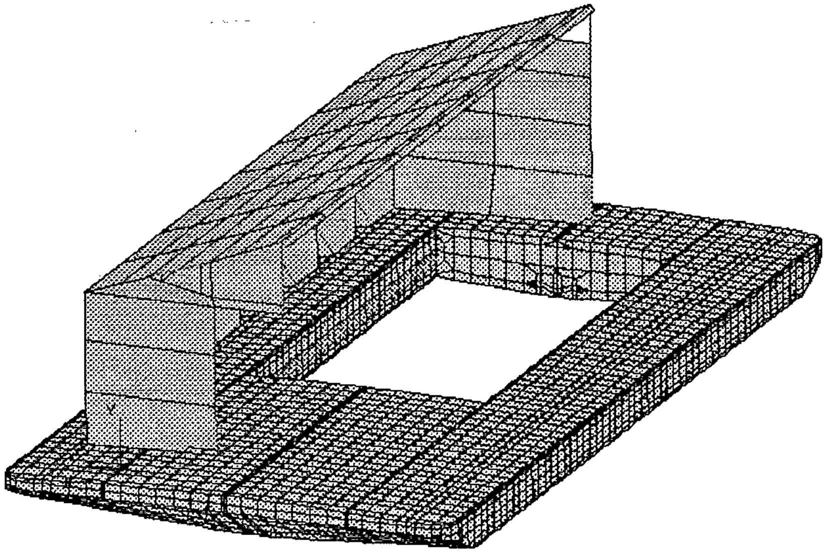


Figure 3: Finite Element Model of Barge

As it was not possible to obtain reasonable measurement data for the superstructure, the superstructure (or deckhouse) was not modelled in as great a detail as the barge hull. This resulted in fewer overall nodes and elements in the numerical model with a minor reduction in the accuracy of the deckhouse model. The internal office and compartment bulkheads were modelled with reasonable accuracy and the thickness and material properties of the deck plating were adjusted to include the cement-like material covering the steel. Material properties used for the steel in the barge were those of mild steel with Young's Modulus of 200 GPa, Poisson's ratio of 0.3, and density of 7800 kg/m^3.

Boundary conditions for the structure were selected to simulate as closely as possible the floating, anchored characteristics of the barge. As such, the four corners of the barge were restricted from moving in the plane of the water surface, i.e., the x and z directions. This results in the model having three rigid body degrees of freedom; vertical translation and rotation about the x and z axes.

One difficulty in assessing the accuracy of the FE model was that there was some confusion over the actual displacement of the barge. Various documentation sources showed the launch weight to be on the order of 190 tonnes, but there were no references to any modern measurements of the weight of the current structure. Using draft measurements made during the experiments and the geometry of the barge hull, the barge's displacement was determined to be 287 tonnes. The finite element analysis showed a total of 186 tonnes for the weight of the structure. This left a discrepancy of roughly 100 tonnes. After a careful survey of the attachments and embarked equipment of the barge, a total of 40 tonnes of additional mass were identified which included items from individual tire fenders up to the auxiliary diesel set. The resulting weight was still 60 tonnes short of the measured displacement. Finally, it was determined that, when installed, the anchor cables are placed under considerable strain, requiring the services of a crane barge and a powerful tug to set the cables. As it would not be feasible to determine the actual strain on the cables, it was decided (after discussion with the crew responsible for rigging the cables) to assume the remaining 60 tonnes of displacement would be due to the vertical downward forces exerted by the anchor cables. This additional mass was distributed equally to groups of elements located at the four corners of the barge.

Given this structural model, the boundary conditions, and the indicated additional masses, the VAST program calculates both the *in vacuo* and 'wet' natural frequencies of the barge. In determining natural frequencies of structures in water, it is necessary to include the 'added mass' effect of the surrounding or entrained fluid which is accelerated with the structure. This additional effective mass can be on the order of 50% to 100% of the dry mass of the structure. The added mass of the water for the model is accounted for by using a surface panel added mass method developed at DREA for general finite element analyses of ships and other hydrodynamic structures [8]. This surface panel model is shown in Figure 4. The surrounding fluid was salt water with an assumed density of 1025 kg/m^3. The resulting predicted frequencies are shown in the following section.

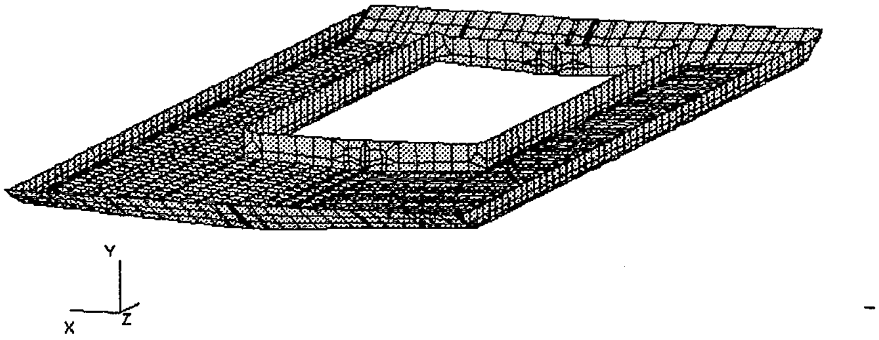


Figure 4: Wetted Surface Panel Model of Barge

5 Results

Table 1 shows the first eight *in vacuo* calculated, non-zero, natural frequencies (i.e., non rigid-body) for the DREA Acoustic Calibration Barge. While there are no measured values against which these can be compared, the results are useful for later comparison of the added mass effects. The deckhouse modes can also be used to partially validate the floating model as they should remain essentially unchanged with the addition of the fluid added mass. This table shows the first resonant mode being the torsional mode of the barge hull and the second mode being the first longitudinal mode of the hull.

Mode	Frequency (Hz)	Description
1	5.79	1st torsion
2	7.40	1st longitudinal hull
3	9.23	deckhouse lateral
4	10.4	fwd wall deckhouse
5	10.8	2nd torsion
6	12.0	2nd long. hull and fwd wall dh.
7	12.3	deckhouse roof
8	12.9	fwd wall deckhouse

Table 1: In-Air Natural Frequencies of the DREA Acoustic Calibration Barge

Table 2 shows both the calculated and measured natural frequencies for the barge. The measured values were determined from the peaks of the acceleration spectra. The first ten non-zero natural frequencies are shown here. Note that, as indicated above, measured values were not obtained for the deckhouse or superstructure related modes.

The calculated mode shapes for several of the hull resonant frequencies are shown in Figure 5. As can be seen from the table, the predicted hull frequencies are within about 15% of the measured values. This indicates that the model and the software provide a reasonable representation of the actual structure. The added mass of the ocean water decreased the first four hull resonant frequencies to an average of about 60% of their in-air value (differences ranged from 54% to 62%). It is also apparent that the modes involving the deckhouse were essentially unaffected by the fluid added mass, as expected. The calculated mode shapes for two of the deckhouse resonant frequencies are shown in Figure 6.

Mode	Measured (Hz)	Predicted (Hz)	Difference (%)	Description
1	3.16	3.59	+13.6	1st torsion
2	3.50	4.03	+15.1	1st longitudinal hull
3	6.44	6.60	+2.5	2nd torsion
4	6.66	7.25	+8.9	2nd longitudinal hull
5		8.72		deckhouse lateral
6	10.2	9.77	-4.2	3rd torsion
7		10.3		fwd wall deckhouse
8		10.7		fwd wall deckhouse
9		11.7		fwd wall deckhouse
10		12.3		deckhouse roof

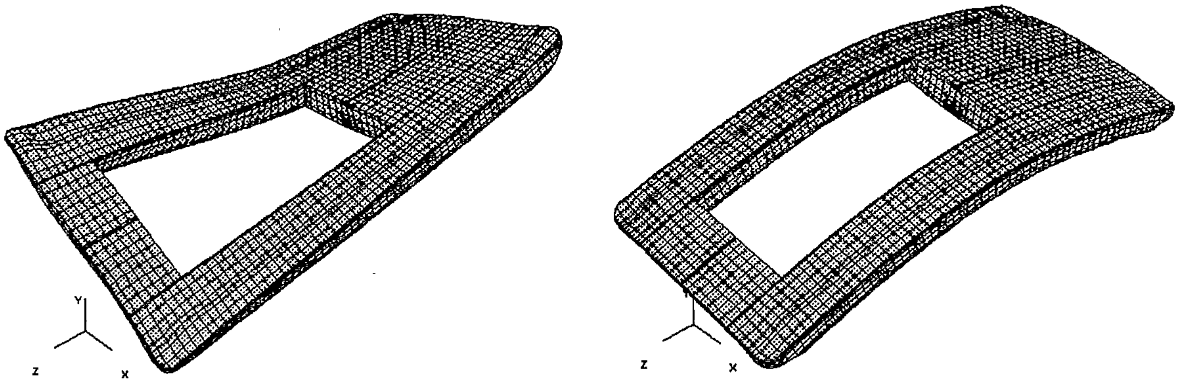
Table 2: Natural Frequencies of the DREA Acoustic Calibration Barge in Water

6 Conclusions

These experiments have largely validated DREA's finite element structural analysis software for the prediction of natural frequencies of large naval structures.

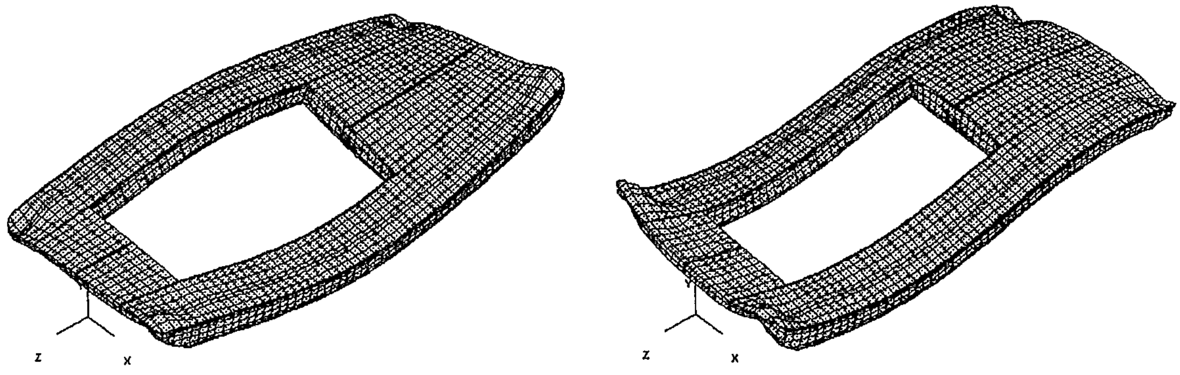
Difficulties were encountered in measuring any superstructure or deckhouse modes for the barge, due to insufficient structural excitation, and in establishing the correct displacement (or overall mass) of the finite element model. The addition of 40 tonnes of point masses and 60 tonnes of mass due to anchor cable tension resulted in an acceptable displacement for the numerical model.

The predicted natural frequencies of the barge (in water) compared very well with the measured values. The first two modes were accurate within 15% with subsequent modes being somewhat more accurate. The first four modes include the first and second hull torsion and hull longitudinal (bending) modes. The frequencies were also calculated *in vacuo* and the comparison with the floating barge showed a 60% decrease in the first four hull natural frequencies due to



First Torsion Mode

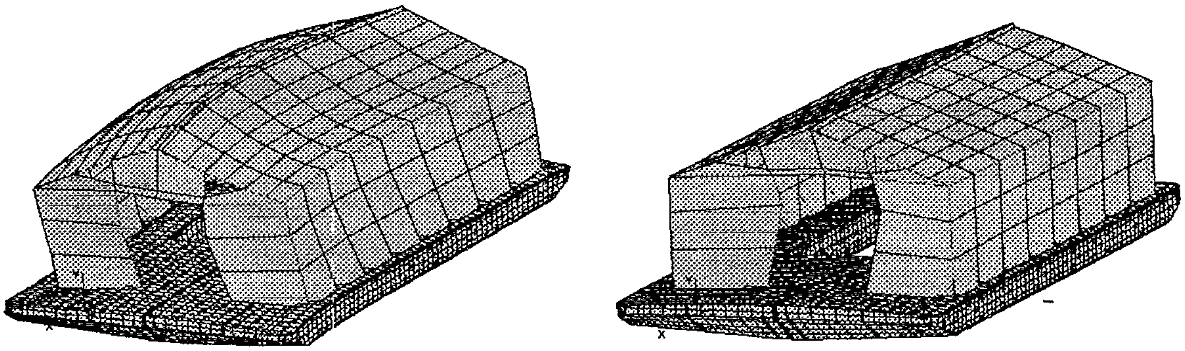
First Longitudinal Hull Mode



Second Torsion Mode

Second Longitudinal Hull Mode

Figure 5: Predicted Hull Mode Shapes



Lateral Deckhouse Mode Fwd. Wall Deckhouse Mode

Figure 6: Predicted Deckhouse Mode Shapes

the fluid added mass. The floating barge also exhibited deckhouse resonances with very similar frequencies to the *in vacuo* case, as expected.

In general, the results indicate the model was a reasonably accurate representation of the barge on a global scale and that the assumed distribution of additional masses was acceptable. These results give confidence that the model can be used to predict the radiated noise from the DREA barge under a given loading for comparison to planned experimental measurements of radiated noise. The use of the barge in this regard would be a valuable step towards validation of AVAST's capability for predicting radiated noise from a CF ship or submarine. Should the opportunity arise, additional measurements of the barge superstructure natural frequencies may be attempted to further validate the model. As well, other prediction methods, such as AVAST or the finite element ship analysis software, MAESTRO [9], may be used for comparison to the measured results. Further experiments involving measuring the radiated noise from the barge are planned.

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[9] "MAESTRO (Method for Analysis Evaluation and STRuctural Optimization) User's Manual - Version 7.1," Proteus Engineering, Stevensville, Maryland, 1996.

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