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Comparison of Sea and PFFEA Predictions of Radiated Noise from a Stiffened Box Structure

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COMPARISON OF SEA AND PFFEA PREDICTIONS OF RADIATED NOISE FROM A STIFFENED BOX STRUCTURE

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INTRODUCTION

Power Flow Finite Element Analysis (PFFEA) [1-7] has been under development in the Structural Acoustics and Strength group of the Defence Research Establishment Atlantic (DREA) to provide DND with the expertise and tools necessary to solve current structures-related noise problems on CF vessels and to develop future reductions in underwater acoustic signatures. PFFEA (also known as the Power Flow Finite Element Method, PFFEM) is an analysis method for predicting high frequency structural acoustic and vibration response. PFFEM is based on a vibrational conductivity approach in which the flow of vibrational energy is modelled in a similar fashion to heat conduction with convective losses. Statistical Energy Analysis (SEA) [8-9] is a more mature method for the examination of high frequency structural vibrations and radiated noise. SEA is a method based on energy balance between substructures and has been used to evaluate structure-borne sound transmission in a variety of structures including ship structure components or scale models of ships. DREA has recently performed investigations to both validate the PFFEA software produced in-house and to compare it against commercially available SEA software, in particular, SEAM [10], a product from Cambridge Collaborative, Inc.

The PFFEM is not a mature technology and the bulk of the work at DREA has been focussed on the development of the methodology with initial work being directed towards the prediction of vibrational energy flow in beam and plate networks. As the method is developmental, relatively little work has been done to date to validate the computer codes against actual structural experiments [11-13]. In light of this, DREA decided to perform a series of experiments involving test structures used previously in low frequency structurally radiated noise experiments [14,15]. This report discusses experiments performed with DREA's ship tank test model and the results of the PFFEA and SEA calculations based on this model.

NUMERICAL CODES

Power Flow Finite Element Method PFFEA uses a vibrational conductivity model of structural components in which the flow of vibration energy is treated in a way analogous to the flow of thermal energy in steady state. This comes about by applying time-averaged and local space-averaged expressions for energy density and power flow to a unit volume of a structural component. This results in a second-order conductivity equation governing the distribution of vibration energy. The basic equations for PFFEA are obtained by spatial discretization of the differential equation. Energy in each vibration type (e.g. flexural, torsional, etc.) can be modelled separately with PFFEA, with coupling occurring at junctions of components.

PFFEA is in a sense an interdisciplinary method. It utilises many of the physical concepts already accepted in the realm of structural acoustics, while applying the equation solving power of the finite element method. The development of PFFEA has progressed to a stage at which relatively complex structural models can now be evaluated. The PFFEA system, embodied as the software suite SNAP [7], which is owned by DREA, consists of a PFFEA translator program, which converts a VAST finite element model to a PFFEA model, and the field equation solver VASTF [16], which performs the PFFEA analysis.

Statistical Energy Method Cambridge Collaborative's SEAM software provides a method of analysis that is particularly well suited for studying the dynamic response of complex structures at high frequencies. SEAM was developed in 1980 to study structure-borne noise in submarines, and was made commercially available in 1983. Since that time SEAM has become an accepted analysis procedure by major shipyards, Navy research establishments, and vehicle and aircraft manufacturers.

SEAM includes a complete implementation of SEA. The complex dynamic system being analyzed is divided into a set of substructures and acoustic elements. The modes of each substructure and acoustic element form the SEA subsystems. The flow of energy between the different subsystems is proportional to the modal energies of the subsystems and the coupling factors. The SEAM program calculates all required coupling factors and performs a power balance for each subsystem. The resulting equations are solved for the modal energy and response of each subsystem.

EXPERIMENTAL PROCEDURES

DREA's ship tank test model was used as the test platform for comparison between the two methods. This model is intended to be a simplistic ship bottom model for both low and high frequency radiated noise prediction validations. In a preliminary set of tests, the model was tested in-air on a wooden test frame. For the underwater radiated noise measurements, the model was taken to the DREA Acoustic Calibration Barge [17] and tested while both suspended from a crane (for input mobility) and while floating in sea water.

The ship tank test model is 1.83m long, 1.22m wide, and 0.61m deep. It comprises an outer box with an internal tank-like structure equal in depth to the main box. All vertical surfaces are stiffened horizontally with 6.4mm x 50.8mm flat bar stiffeners at their top edges and midheight. The box is constructed entirely of 6.4mm mild steel with the exception of the bottom of the centre tank which is a 3.2mm mild steel plate. The test model is of welded construction and has been heat-treated in an attempt to remove any residual stresses. A photograph of the ship tank model on its in-air test frame is shown in Figure 1. Using welded studs, multiple 19mm x 19mm mounting blocks were attached to the test model at various locations to facilitate the mounting of accelerometers and force tranducers.

For the original in-air tests, a B&K electromechanical shaker was used to provide the loading on the test model. The shaker was installed so that it rested on a layer of viscoelastic damping material on the floor of the lab and the stinger was attached to the force transducer located on the mounting block attached to the test model. Trials were performed with the shaker in each of four positions. A schematic of the test setup with the shaker in the first position is shown in Figure 2. The four shaker positions are also shown in Figure 2 as seen from above. The shaker was always placed so that it was driving the test model from below in the vertical direction. The first location was at the centre of the thin plate at the bottom of the centre tank. The second location was at the intersection of one of the internal walls with the centre plate at the midpoint in the transverse direction. This formed an unsymmetric T-plate junction as the centre plate is thinner than the

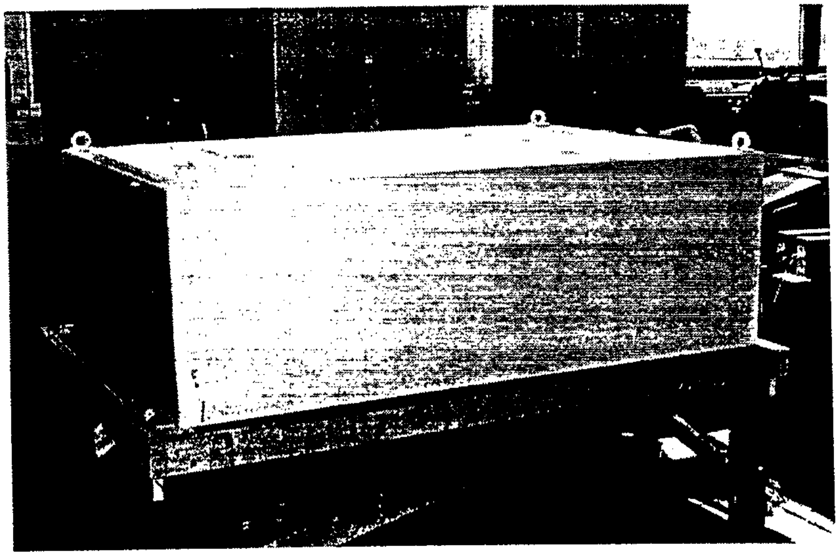


Figure 1: Ship Tank Test Model

others. The third location was at an intersection of three plates of the same thickness forming a symmetric T-plate junction. The final location was at the outside edge of the test model at the midpoint in the transverse direction forming an L-plate junction.

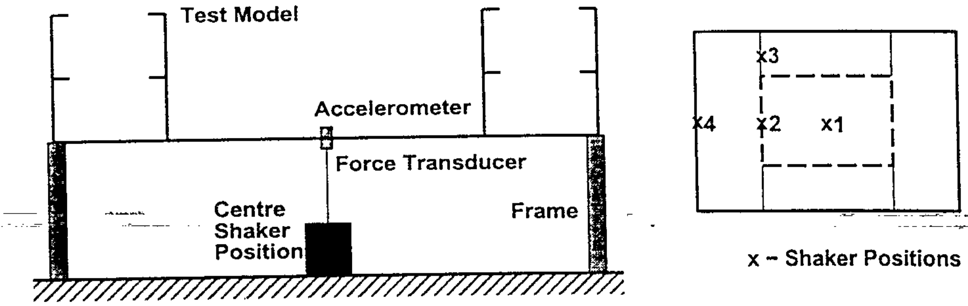


Figure 2: Schematic of Test Setup

A stinger was connected from the shaker to a force transducer mounted on a block on the test model. The test model response was measured using B&K Model 4333 accelerometers attached to B&K Model 2635 charge amplifiers. The response was viewed using an HP35670A Signal Analyzer which was also used to provide the excitation voltage to the shaker. For each shaker location, the narrow band input mobility was recorded over a 12 kHz span and the transfer mobility for each panel in the model (there are 37 in total) was recorded over an 8 kHz frequency span. The numbering used to identify the panels is shown in Figure 3.

At the DREA barge, a Wilcoxon combination electromechanical/piezoelectric shaker (mass about 3.5kg) was used to provide the excitation to the the ship tank test model. This shaker uses a single point mount system and includes an integral impedance head. The transfer mobilities were again measured using the B&K accelerometers and the shaker's integral impedance head. For the measurements at the barge, the shaker was mounted in one of two locations, either in the centre plate of the tank bottom or opposite a bar stiffener on an internal tank wall (see Figure 4). In

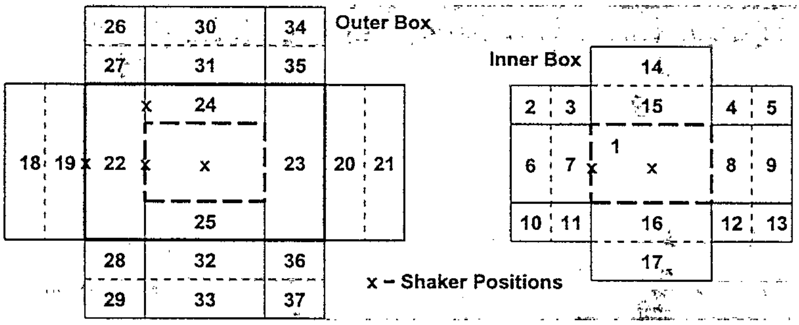


Figure 3: Ship Tank Test Model Plate Numbering

both cases, input mobilities were measured over a 12 kHz span both in-air and with the box floating (with a draft of roughly 30cm).

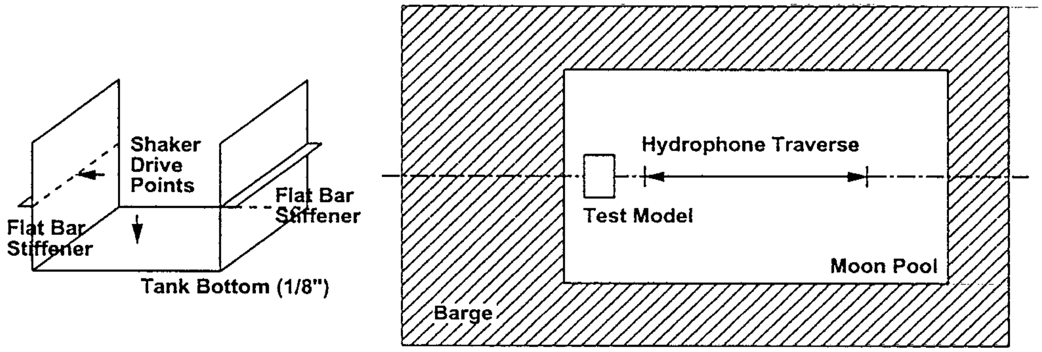


Figure 4: Cutaway of Test Model Internal Tank & Schematic of Radiated Noise Measurements

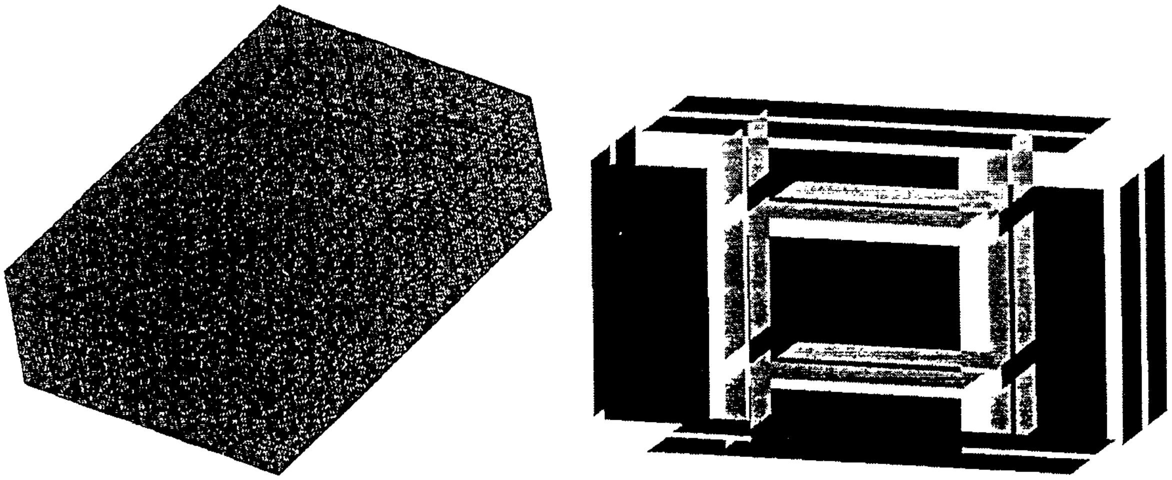
For the underwater radiated noise tests performed at the DREA barge, the hydrophone used was a B&K model 8106. With the shaker on the tank bottom, narrow band radiated noise measurements were made every 1m as the hydrophone was traversed starting 2m and finishing 10m from the centre of the tank (see Figure 4). Two trials were done with the hydrophone at depths of 4.6m and 9.2m.

NUMERICAL MODEL

Input Mobility The numerical model used to obtain the theoretical PFFEA input mobility involved idealizing the ship tank test model as either an infinite flat plate, in the case of excitation of the centre plate, or as a semi-infinite plate junction, in the case of excitation at the second through the fourth locations. Modelling a finite system by its infinite equivalent is discussed in [18]. For the SEAM software, the input mobility was determined from the conductance, which is a standard output from the software.

For the tests involving the shaker on the centre plate, it was necessary to model the mounting blocks for the shaker or shaker stinger. For the PFFEA model, it was necessary to include the masses of the mounting blocks in the impedance calculations for the input mobility. For the SEAM model, it was necessary to model an additional small plate at which the input force was applied. For inputs involving the other shaker locations, the blocks were not modelled as their inclusion appeared to have negligible effect. For both models, the input was assumed to be random noise with an amplitude of 1 N.

Response The numerical model used in the PFFEM analysis was formulated [6] from a simple finite element model and is shown in Figure 5 (due to limitations in the imaging software, the stiffeners are not shown). For this analysis, this model consists of 53 components (37 plates and 16 beams) and 56 junctions (16 L-plate, 24 T-plate, and 16 beam-plate junctions). The material properties used are those of mild steel (Young's modulus of 200 GPa, Poisson's ratio of 0.3, density of 7600 kg/m^3, and a loss factor of 0.005).



PFFEA Model

Hypermesh Representation of SEAM Model

Figure 5: Numerical Models (beam stiffeners not shown)

The SEAM model used was derived from the Hypermesh model shown in Figure 5 with the stiffeners modelled as plate elements (not shown for clarity). This model consists of 26 structural elements and 37 structural connections and used similar material properties to the PFFEA model. For the floating box, fluid loading was added to the submerged portions of the models.

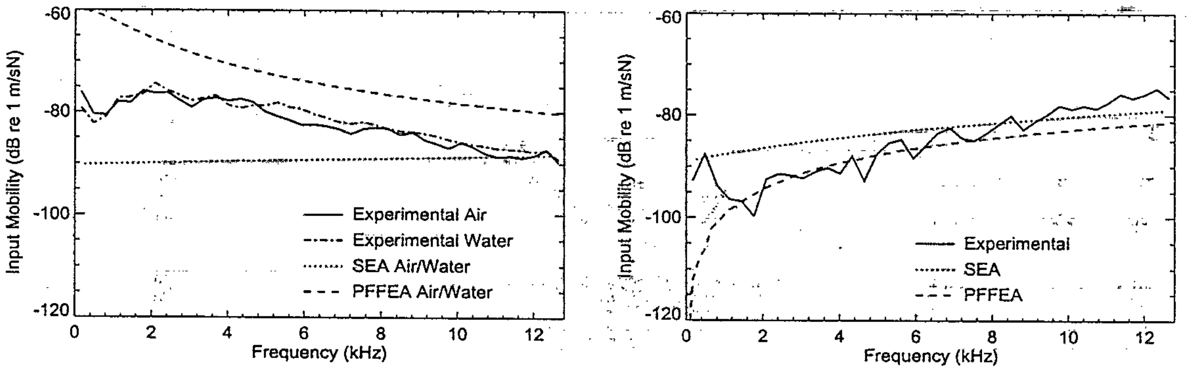
Radiated Noise At present, the PFFEA software does not incorporate a radiated noise prediction capability, although one has been formulated [6]. For these tests, this capability was modelled using MATLAB.

For the SEAM model, an acoustic space element was added to the structural model along with 9 additional structural-acoustic connections. As the software does not explicitly support radiated noise predictions that vary with distance from the source, corrections were made to the acoustic space element at each distance to predict an appropriate sound pressure level.

RESULTS

The following section compares the results of the PFFEA and SEAM analyses to measurements taken with the ship tank test model. While all the measurements were narrow band, the plotted results have been smoothed for clarity.

Input Mobility The input mobilities (magnitude) measured at two of the locations are shown in Figure 6. With the shaker on the centre plate, there was no substantial difference between the in-air and floating measured data. For this case, the PFFEA results, while showing the correct trend, overpredicted the response by about 7 dB. On the other hand, the SEAM results underpredicted the measurements over much of the frequency range, only converging at the highest end. With the shaker on the stiffener, as shown in Figure 4, both PFFEA and SEAM accurately predicted the measured input mobility.



Centre Plate Input

Symmetric-T Junction Input

Figure 6: Input Mobility, In Air and Water

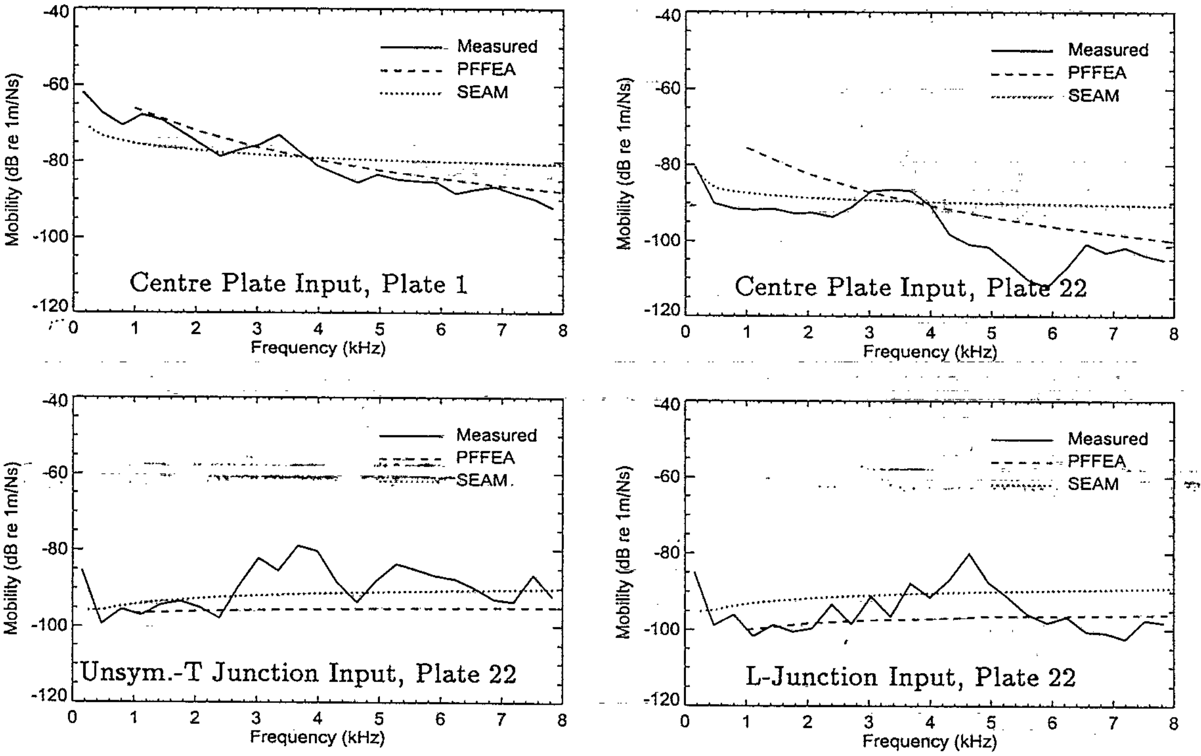


Figure 7: Transfer Mobility, In Air

Response In Air Transfer mobilities (magnitude) were measured in air with the shaker at a variety of locations. Selected results are shown in Figure 7. There was some variation in the overall shape of the measured curves and, as such, for some panels, PFFEA provided a better prediction and, for others, SEAM provided a better prediction. Overall, both codes predicted the response with reasonable accuracy.

Radiated Noise In Water Underwater radiated noise mesaurements were made with the tank floating in sea water. The results, and the predictions made by PFFEA and SEAM, are shown in Figure 8. Neither method accurately predicted the response over the entire frequency range and, although both methods predicted roughly the same response, the predicted curves did not show the same shape between the two methods. Both methods were reasonably accurate at the 9.2m depth with PFFEA overpredicting above 8 kHz. At the 4.6m depth, PFFEA was slightly more accurate below 3 kHz and SEAM was more accurate from 3 to 6 kHz. Both methods overpredicted the noise above 6 kHz with SEAM being closer to the data by roughly 10 dB.

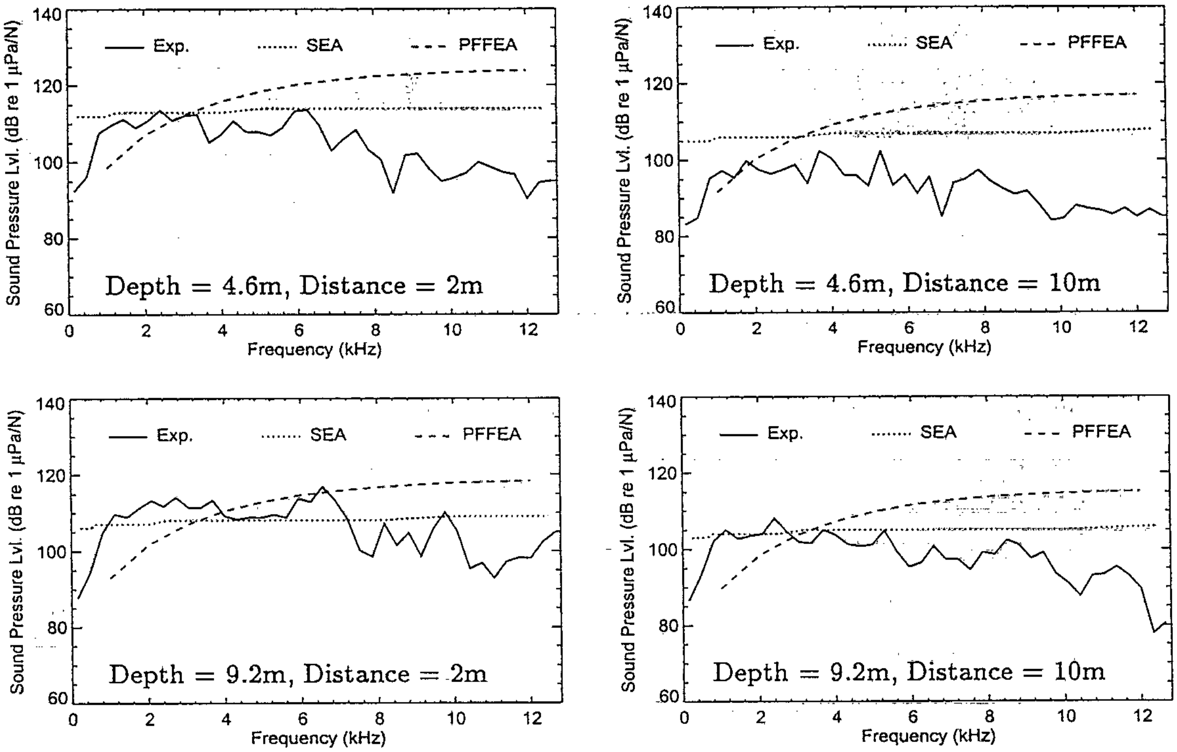


Figure 8: Radiated Noise

CONCLUSIONS

Experiments were performed with DREA's ship tank test model to assist in the validation of the PFFEA software (SNAP) for high frequency structural vibrations and to compare SNAP with a commercial SEA code, SEAM. Input mobility, transfer mobility (response), and underwater radiated noise were measured with the test model in air and also floating in sea water.

Both SNAP and SEAM accurately predicted the input mobility to the test model when the input force was applied at a plate junction. Both methods were somewhat less accurate when applied to the thin bottom plate, but still provided values within about 7 dB. The response of the structure was measured over an 8 kHz span at each of the 37 'panels' in the model and, while their relative accuracy varied from panel to panel, both methods predicted the response to a reasonable degree of accuracy. Finally, with the test model floating in sea water, underwater radiated noise measurements were made at a variety of free-field locations. Both PFFEA and SEAM gave reasonable estimates of the radiated noise for the 9.2m depth, but both methods overpredicted the noise for the 4.6m depth, particularly above 6 kHz. In general, SEAM slightly outperformed PFFEA for radiated noise; however, neither method seemed to accurately predict the trend for the radiated noise to decrease with increasing frequency. Neither computer code has an explicit formulation for predicting free-field radiated noise and further work is necessary with both codes to improve their abilities in this area.

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