Interior noise prediction in cargo ship

Arnaud Caillet[1], Oussema Fatmi[1], Kazunobu Fujita[2], Noriko Hirukawa[2]

[1] *ESI GmbH, 85609 Munchen, Germany, arnaud.caillet@esi-group.com*

[2] *MIJAC, Tokyo, Japan*

Abstract

Noise in cargo ships has become an important topic as international regulations are increasing the constraints. Predicting the sound pressure level in crew cabins for a new ship and diagnose the effect of design changes (construction, sound package…) is now part of the standard design process. The marine industry needs tools to face this challenge. SEA can help during the design phase to predict interior noise.
This paper will present a method to create efficiently a SEA model of a ship starting from 2D drawings cabin arrangement and all the physical properties descriptions (construction, sound package, excitation…).
A validation of a cargo ship SEA model excited by combined structureborne and airborne noise sources will be presented.

Introduction

Ships are large structure. FEM simulations are difficult because of the size of the models. To compute noise up to a reasonable and usable frequency, the amount of computation power requested to compute FEM models are huge. For example, up to 50Hz, 5000 modes are identified for a medium size ship. At very low frequency, modes are local. They fast start to become local modes within the different bulkheads or deck panels. This is the perfect example where the SEA method can be used. Figure 1 is illustrating the typical response of a mechanical system to an excitation. At low frequency, the modal density is low and the modes are global, it is perfect for FEM method, at higher frequency, the modal density is high and the modes are local, which is perfect for SEA.

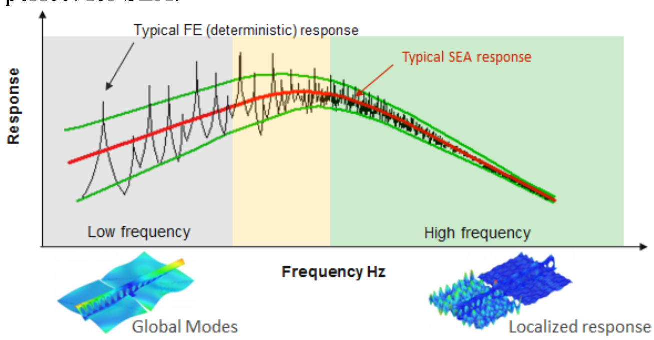
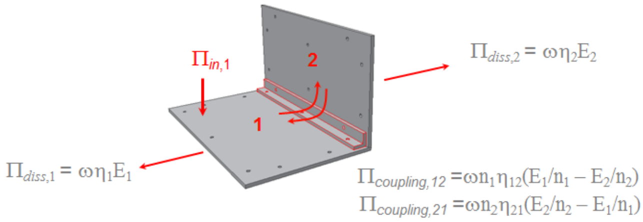


Figure 1: Typical Vibro-acoustics response of a mechanical system, validity zones of the FEM and SEA methods.

The SEA method [1] consists in describing a mechanical in a serie of subsystems which contains the information related to the physical properties of each (mechanical construction, material property, damping). The subsystems are connected together and the coupling will be automatically computed from analytical formulas. For each subsystems, the power balance equation is identified and all power balance equations are assembled within a system of equation which will be resolved in order to obtain the energy levels at each subsystems. Figure 2 illustrate the power balance equations for a mechanical system containing 2 panels and the power balance equation system to be resolve to compute the energy (velocity of each plates in this case).



$$\begin{bmatrix} \Pi_{in,1} \\ 0 \end{bmatrix} = \omega \begin{bmatrix} n_1(\eta_1+\eta_{12}) & -n_1\eta_{12} \\ -n_2\eta_{21} & n_2(\eta_2+\eta_{21}) \end{bmatrix} \begin{bmatrix} E_1/n_1 \\ E_2/n_2 \end{bmatrix}$$

Figure 2: SEA equation system for a 2 panel mechanical system

The same principle will be applied on a larger scale to a ship. The process and the results obtained in that case are described in the following sections.

Model creation process

Overview

In ESI Group VA One software [2,3] is integrated a module which provide the marine industry engineer an efficient tool to build the SEA models of ships. This module is called “Marine Modeller”. The process described by the diagram in Figure 3 is followed to create the SEA model of a ship. From the cabin arrangement to the 3D SEA model.

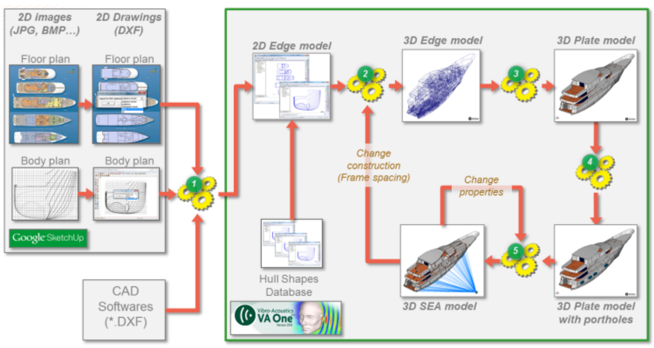


Figure 3: VA One Marine Modeller process to create SEA ship model

Input data needed

In order to create a realistic model of a ship, the following input data are needed:
-To create the structure: cabin arrangement, body plan, girder and frame spacing
-To create the physical properties: panel thicknesses, beam properties for frames and girders, non-structural panel properties and locations and damping loss factors.

-To create the acoustic treatments: material properties (Biot if porous materials are used), layup description (material and thicknesses) and location
-To create the sources: excitation location, spectra of pressure or velocity at the given location

Creation of the geometry

To create the geometry, as described in the previous section, the cabin arrangement and the body plan are the 2 main inputs needed. From these 2 inputs, the user can generate 2D plans of the decks and body plans. This information will be loaded in VA One in order to generate edges which will be used to build the panel 3D structure of the ship SEA model. Figure 4 illustrates the decks and body plan edges model converted to 3D SEA structure of the ship.

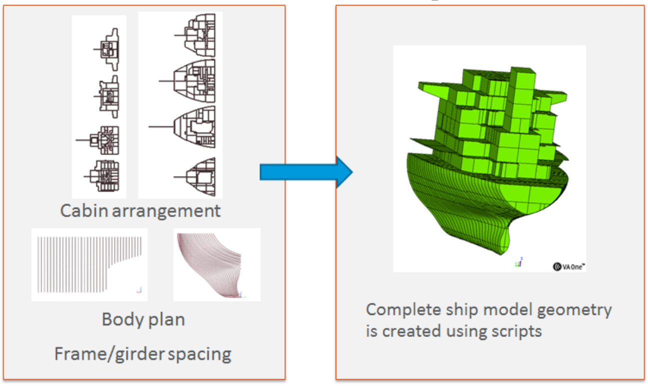


Figure 4: From 2D to 3D, creation of the ship SEA model geometry

Panel physical properties

In usual ships, the structure is made of thick ribbed panels. The SEA model must also contain these properties. This can be identified from the ship construction drawings. From them, different regions are identified using different skin panel thickness and frame/girders properties and spacing. The ribbed panel property available in VA One is suitable to model this property.

The non-structural bulkheads are usually made of a sandwich construction with 2 skins of aluminium or steel and a mineral wool core. The location of these sandwich panels can be done from the cabin arrangement.

For both these type of properties, a damping loss factor spectrum must be assigned. This spectrum is obtained from measurements.

Acoustic treatments

The location of the acoustic treatments can be obtained from the insulation plans. They can be located on decks (visco-elastic material glued on the panel deck) or on the walls and ceiling.
The visco-elastic treatments are directly glued on the structure and are changing the properties of the steel panel (higher damping, higher mass). These properties will change the modal density of the panel. They cannot be just included into the model using the transfer matrix method. A modified panel property must be used [4].
The walls and ceiling panels are usually build on top of the main bulkhead and made of a first layer of mineral wool, and airgap and a panel (same construction as the non-structural panels. The transfer matrix method using the Biot parameter theory to model the porous materials [5] is perfect to model the insulation and absorption effects of the treatments. For each treatment types, an insertion loss and added damping will be computed and will modify the coupling loss factors between the main panel and the cabin connected to it.
In order to model the absorption due to the furniture (bed, chairs, couch…) contained within the cabin, a measured representative absorption within the given cabin is used.

Effect of fluid loading

The ship is partially immerged in the water when it is travelling on the ocean [6]. The water will have an effect on the modal density and the radiation efficiency of each immerged panels. It is important to include this within the model. Figure 5 illustrates the effect of the fluid loading on a ribbed panel. The effect is high at low frequency and is reduced when the frequencies are increasing.
Figure 6 illustrates the effect of the fluid loading on the radiation efficiency of a ribbed panel. The radiation efficiency is much higher for a non-wetted panel.

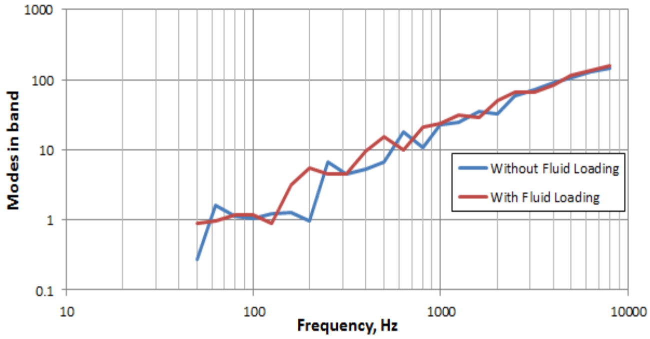


Figure 5: Effect of fluid loading on modal density of a ribbed panel

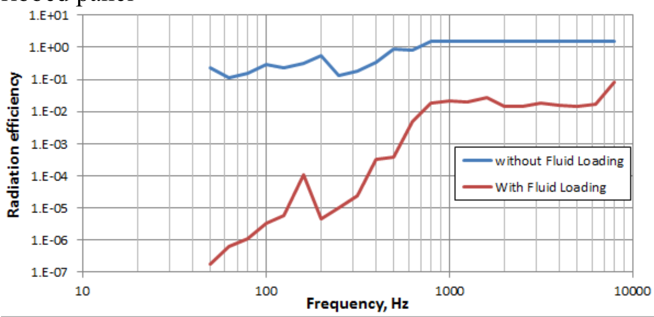


Figure 6: Effect of fluid loading on radiation efficiency of a ribbed panel

Sources

Several sources can generate noise within the ship. The main ones are: the main engine, the generators and the HVAC system. To illustrate how to obtain and apply the sources to the model, the example of the main engine source will be used.
The sources applied to the model are extracted from measurements. Accelerometers located close by the engine foundations are giving the excitation spectra of a representative panel. Microphones are located around the engine and the average measured pressure is used to model the engine noise. The structureborne and airborne sources are applied as velocities and pressure constrains within the SEA model in subsystems representative of the measurement locations. Figure 7 illustrates how the excitation is set to the ship SEA model.

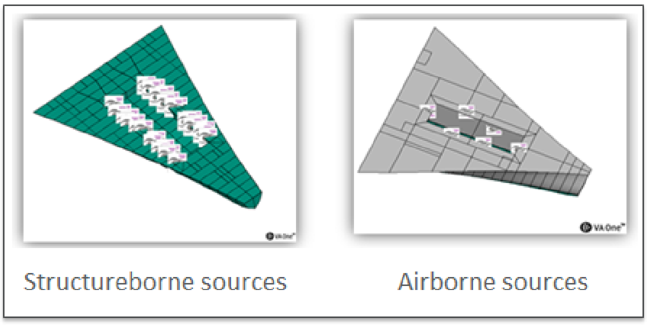


Figure 6: Engine airborne and structureborne sources

Results

The ship modelled during the analysis made for MIJAC was a typical medium size cargo ship. For this ship, the excitations used are representing the engine and the electricity generators located in the hull. The model was build according to the guidelines explained within the previous sections. This section will show the correlation of the simulation results with measurements. Figure 6 shows the correlation between the measurements and the simulation for some representative cabins. The difference between the simulation and the measurements is between 2 and 3dB which is a very acceptable correlation. The model is providing simulations results which are representing the measurements.

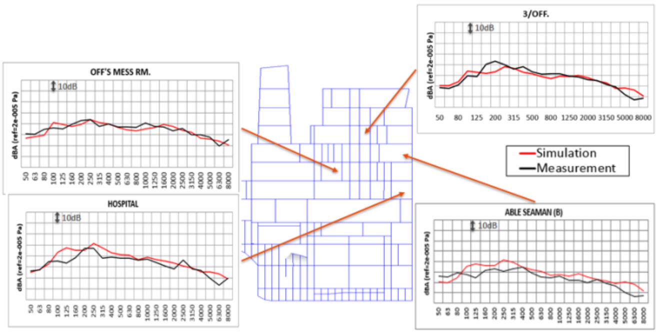


Figure 6: Interior noise ship simulation, comparison with measurements

Model usage, design change analysis

The main objective of building a model is to analyse the energy flow within the ship and test design changes. This section will present example for both cases.

Energy flow analysis

It is possible using the SEA model to visualize the energy flow within the structure and the different cabins. Figure 7 illustrates the overall sound pressure levels within the different cavities on the left side and the overall velocity levels on the right side. The energy is flowing from the main sources which are located at the bottom of the ship to the top. It can be observed that when the energy can freely be airbonely transmitted, it flows more easily. This is clearly obvious in the funnel region which is directly connected to the engine room.

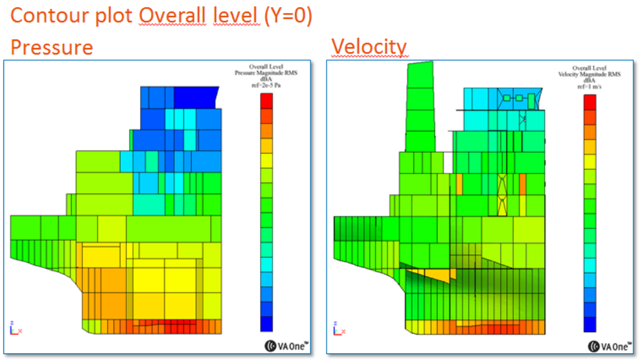


Figure 7: Contour plot of overall SPL and overall velocities within the ship at Y=0m

Design change analysis

Design changes can be implemented within the model. For example, the objective is to lower the overall sound pressure level within the officer's mess. First of all, a contribution analysis will be run in order to identify from which panel is transmitted the most of the energy to the selected cabin. This is illustrated within figure 8. Most of the energy here is coming from the floor (57%). From this observation, it has been decided to test a design change which will be located on the floor panel. This design change consists in gluing a high damping visco-elastic material and adding a carpet on the floor. Figure 9 is showing the effect of this design change. After the design change, the SPL has been reduced of 2.6dB in comparison to the initially simulated one. This design change is having a beneficial influence on the SPL of the selected cabin and could be implemented with the real ship.

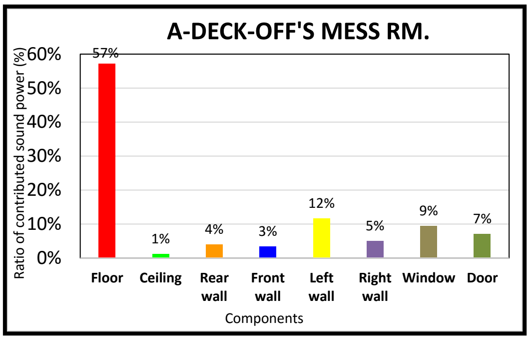


Figure 8: Main contributors to the overall sound pressure level within the A Deck officer's mess cabin

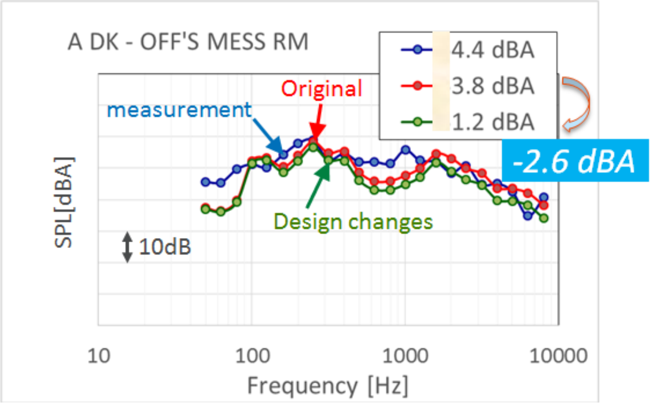


Figure 9: Effect of design change on the SPL within the officier's mess

Conclusion and perspectives

This paper has presented guidelines to create a predictive SEA model of a ship. Despite some uncertainties in the definition of the physical properties, the correlation between the measurements and the simulation are reasonable. It is possible to make efficiently design changes using the model which would not be possible on the real ship. The SEA method is providing an efficient tool to simulate realistically the interior noise of a ship and test the influence of design changes.

Reference

[1] R. Lyon and R. DeJong, "Theory and Application of Statistical Energy Analysis", Butterworth-Heinemann, 1995.

[2] VA One, ESI Group, www.esi-group.com

[3] D. Blanchet, S. Matla, Building SEA Predictive Models to Support Vibro-Acoustic Ship Design, DAGA 2009

[4] P.J. Shorter, "Wave propagation and damping in linear viscoelastic laminates", in *J. Acoust. Soc. Am.* **115 (5)**, pp. 1917–1925, (2004).

[5] J.F. Allard, "Propagation of Sound in Porous Media: Modeling Sound Absorbing Materials", Elsevier Applied Science, New York, 1993.

[6]D. Blanchet, A. Caillet, "Predicting underwater sound radiation and directivity pattern of vibrating structures in deep and shallow water", ECUA Edinburg, 2012

Acknowledgements

The authors would like to thank Taiki Tsukada and Yuuji Ikeda from ESI Nihon for their collaboration and contribution during the project.