Building SEA Predictive Models to Support Vibro-Acoustic Ship Design

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Abstract

In the past, the shipping industry has used empirical models extensively to predict vibro-acoutic responses aboard ships. This method has proven effective for reasonable ship size, shapes and typical materials. However, empirical approaches offer little flexibility and are limited to known construction types and materials. Nowadays, ships are getter larger and use more sophisticated material such as composite. Regulation and ship owners impose more stringent vibro-acoustic performance of their vessels and the luxury yacht segment is no exception. In addition, the timeframe available to design the vibro-acouctics package aboard a ship is shrinking forcing designers to seek industrially efficient methods to build ship models and perform design analysis.

This paper presents an efficient method for quickly building a detailed predictive vibro-acoustic model from 2D or 3D data. This model includes all SEA structural subsystems of the hull, superstructure, interior bulkhead, etc. It also includes SEA acoustic subsystems of all cabins and other living areas. Structureborne and airborne sources are defined for all types of excitation encountered in a ship such as engine, gearbox, generator, HVAC, bow thrusters, propeller…. Vibration, SPL and Power inputs are available at any locations of the vessel and serve as the basis for vibro-acoustic design analysis.

Introduction

Statistical Energy Analysis (SEA) is a proven methodology to predict airborne and structureborne sound inside a ship. The large panels and relatively simple geometry of the panels and their connection are ideal attributes for SEA prediction. New superyachts are built using new materials. They are stiff and lightweight structures with more complex geometry. They exhibit a higher power to weight ratio, higher specification trim and tighter noise specifications from demanding customers [1]. SEA is a high frequency method and when applied to ships it can cover a wide frequency range starting well under 100 Hz.

Building large yacht SEA models involves creating thousands of subsystems. This task can be very tedious if not automated. Furthermore, there is no return on investment (ROI) from building an SEA model, the benefits only come once the model is completed and iteration on design changes can take place. This paper proposes an automated way to build SEA models using the commercial software VA One [2].

Modelling the Structure

VA One allows users to import 3D CAD data in different formats such as CATIA, PRO-E, IGES, SAT and STEP.

An automatic quality mesher is included to help create a geometry mesh that can readily be used for automatic creation of SEA subsystems (see Figure 1).

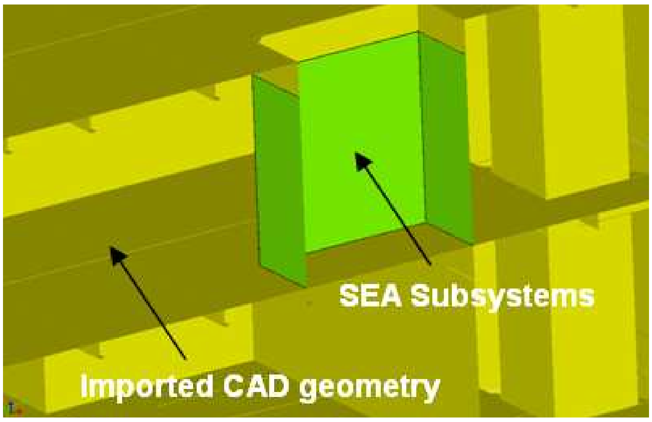

Figure 1: Creation of SEA subsystems from an imported 3D CAD geometry. Automatically meshing of CAD data and creation of SEA plates.

Recent developments allow the creation of SEA subsystems from a 2D image. This feature uses a scripted HTML file that allows the user to click on a 2D image, creating nodes for the SEA plate to be created (see Figure 2). Once the nodes are created, the SEA subsystem is automatically created in the VA One environment. This is particularly useful when 3D data is not available.

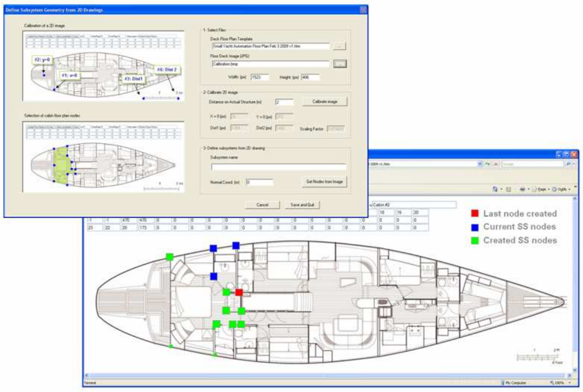

Figure 2: An HTML file is used to gather geometry from a 2D drawing image. User clicks on the drawing to create nodes. Panels are automatically created in VA One

Physical properties are created into the database and then associated to the different structural flat or curved SEA panels. Typical panel cross-sections modelled are ribbed panels, composite layups, damping treated panels, internal bulkheads made of different layers, portholes…

Once all panels are created, an automatic junction algorithm creates all point and line junctions assuming that the plates have proper node connectivity (see Figure 3). Therefore, all coupling loss factors are computed automatically following rigorous theoretical formulations [3][4]. Many utility tools also available to split, merge and heal geometry.

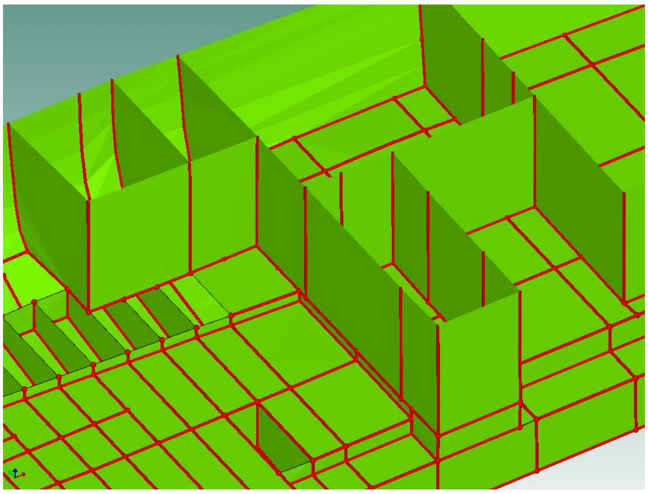

Figure 3: SEA plates used to represent the vessel structural and non-structural panels (in red, point and line junctions)

Modelling the acoustic fluid

The air in each cabin as well as the sea water, fuel and other fluids in tanks are modelled using SEA cavities. These are created automatically from the panels' geometry (see Figure 4). Appropriate fluids are assigned to each cavity to represent the proper storage and transmission of energy. The absorption spectra associated with each cavity are computed from Sabine room acoustics equations with each cabin fully trimmed.

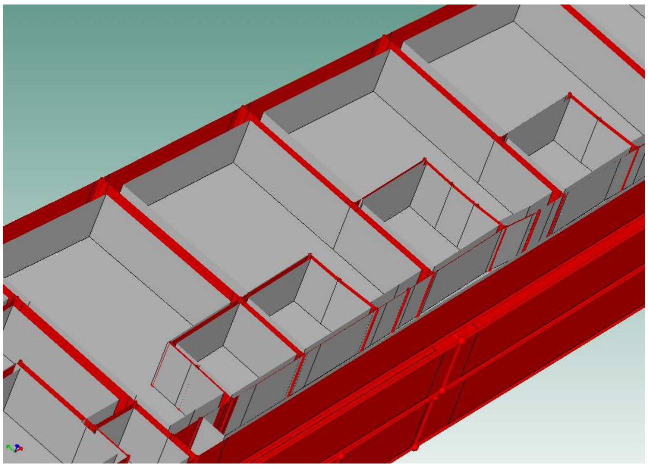

Figure 4: Cabins and tank cavities are created automatically following panel geometry and naming convention. GRAY: cavities (shrinked for vizualization), RED: Point, Line and Area junctions [5]

Modelling the trim

To minimize the actual number of SEA panels to create, a condensation method was developed. The objective is to condense a "complex trim" into a User-Defined Noise Control Treatment (UDNCT) that can be applied on either sides of a single SEA base panel. A "complex trim" can be a combination of foam, fiber, elastic panel, air gap or mass layer combined with structural panels, beams, double wall construction connected with rigid or flexible junctions (see Figure 5). This condensation approach is suitable for complex systems such as floating floors, isolated internal walls and structural bulkheads…

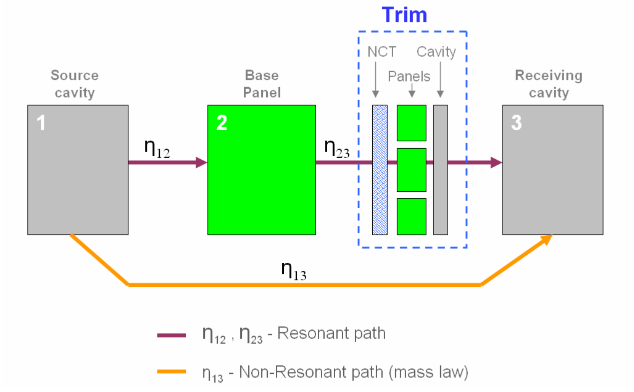

Figure 5: The condensation method replaces the complex trim (foam, fiber, elastic panel, air gap or mass layer combined with structural panels, beams, double wall construction connected with rigid or flexible junctions) by two IL and one damping spectrum.

To be accurate, the condensation method must fulfil the following constraints: For a given excitation in the source cavity i) the SPL in the receiver cavity is unchanged compared to explicit model ii) the velocity level of the base panel is unchanged compared to explicit model

These constraints will ensure that even though a condensation method is used, it yields similar results as a fully explicit model. It also ensures that the proper energy paths will be represented in the model.

To condense the trim, an Insertion Loss (IL) approach is used. Two side models are built (see Figure 6). For the computation of the structureborne IL, only the force exciting the base panel is enabled and when computing the airborne IL only the diffuse acoustic field exciting the source cavity is used. The structureborne and airborne ILs are computed using equation (1).

$$IL = -10\,Log_{10}\left(\frac{\Pi_t}{\Pi_b}\right) \qquad [\text{dB}] \qquad (1)$$

Where:

- Π_t is the resonant or non-resonant power input in receiver cavity for the trimmed model
- Π_b is the resonant or non-resonant power input in receiver cavity for the bare model

The resonant power input is used to compute the structureborne IL and the non-resonant power input is used to compute the airborne IL. The added damping to the base panel is computed directly by VA One.

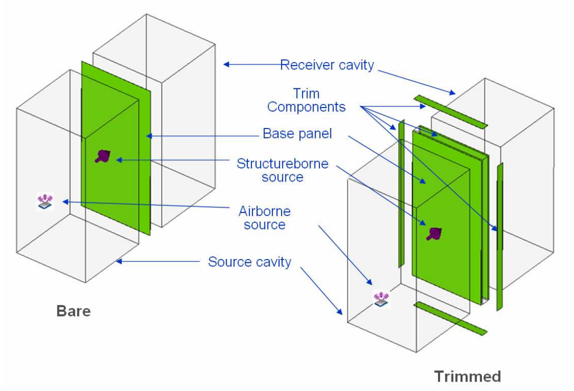

Figure 6: The condensation method uses Insertion Loss (IL) and damping spectra that are associated to the condensed based panel. A side model is built to derive these quantities. User can therefore build a database of trim to be reused in different vessel models

To validate that the condensation method works, the Structureborne IL, airborne IL and added damping are assigned to the bare base panel. This is efficiently done in VA One by using the UDNCT functionality. The models are solved and compared to the trimmed case. Validation results of this approach are presented in Figure 7. Variation between condensed and trimmed models are less than 2 dB.

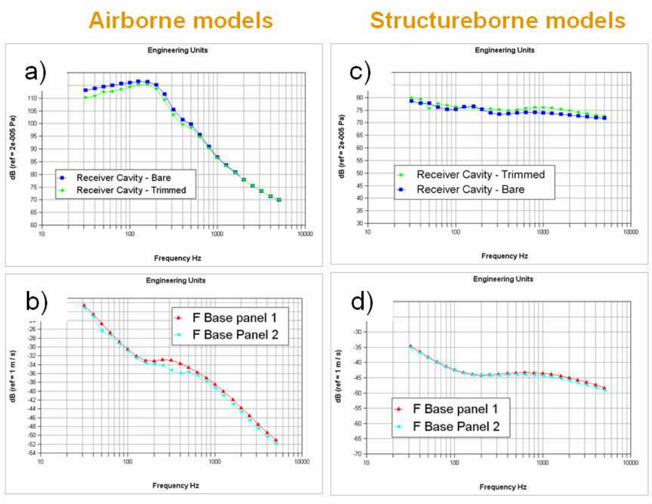

Figure 7: Validation of the condensation method. Comparisons are between condensed and trimmed models. Upper graphs are SPL in receiver cavity, lower graphs are the velocity of the base panel. Left graphs are for airborne condensation and right graphs for structureborne.

Underwater Radiation

An automatic algorithm detects the panels under a user-defined waterline level and loads the exterior side of the hull panels with sea water. In VA One, fluid loading adds a frequency-dependent fluid mass loading. Each underwater hull panel is also automatically connected to a free field propagation model called a Semi-Infinite Fluid (SIF) (see Figure 8) . Radiation from rib and radiation from rib scattering is included in the underwater radiation.

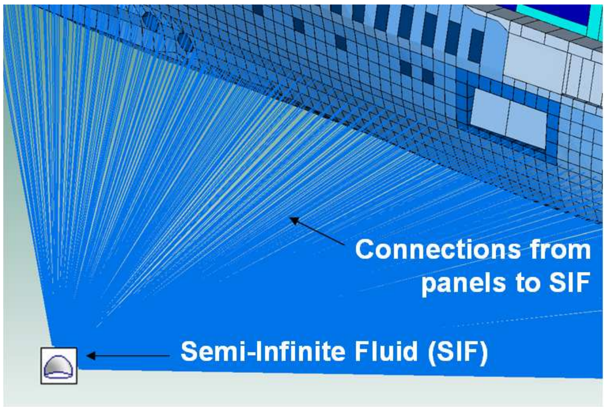

Figure 8: Underwater panels are loaded with sea water and connected to a free field underwater propagation element (SIF: Semi-Infinite Fluid)

Sources

Typical sources are of 3 types: airborne, structureborne and waterborne. Main sources of noise and vibrations are engines, gearbox, generators, HVAC, bow thrusters and propellers. To keep the ship model as simple as possible, a side model is built in finite element (FE) to compute the structure input mobility at the source location (see Figure 9).

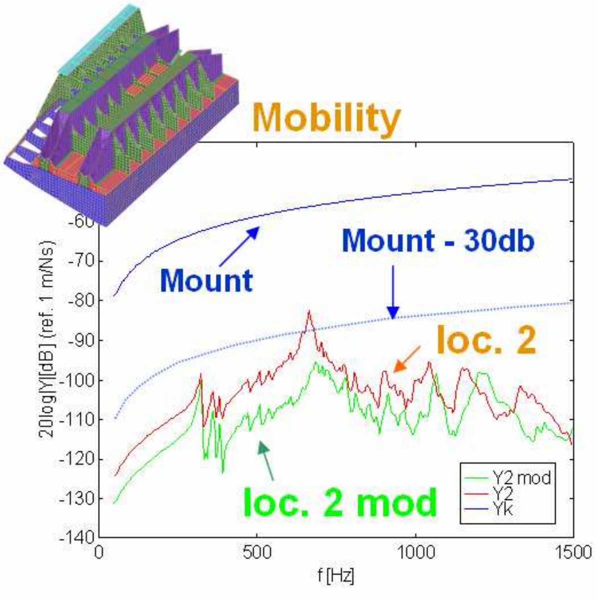

Figure 9: An FE model of the source structural foundation is used to compute input mobility at attachment points. Resilient mount mobilities are compared with structural ones. At least 30 db difference is required to ensure low level of energy being transmitted to rest of the structure.

These mobilities are compared with idealized mount mobilities. Structural design changes are recommended if i) less than 30dB between mount and structure ii) structural mobility is higher than -100 dB or iii) resonance peaks occur. From force and input mobility, a power input is computed. It is then applied to the appropriate subsystems in the SEA model. When no power input is available, a force spectrum or an acceleration constraint is used (see Figure 10).

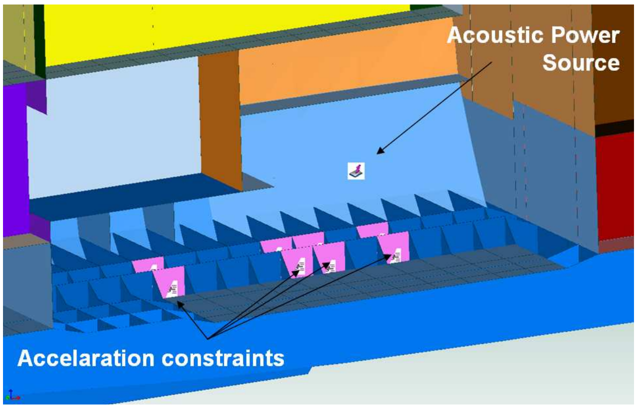

Figure 10: Examples of sources used to represent the engine structureborne (Acc. constraints) and airborne (Acoustic power) excitations.

In addition to these sources, the HVAC systems power input can be assigned in the location of the HVAC unit and additional HVAC power sources added to individual cabin to represent flow noise.

Result examples

The following are result examples obtained on a luxury yacht for different running conditions and at anchor. Many different result types are available such as SPL in any cavity or underwater SIF (see Figure 11), vibration level on all plates, power input to any SEA subsystem including path contribution (structureborne vs airborne). Source ranking is also available for any subsystem in the model.

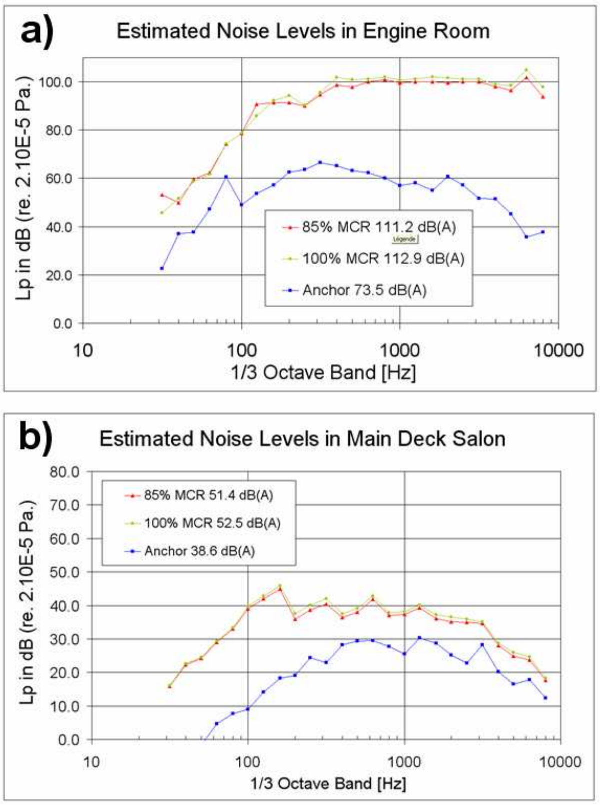

Figure 11: Model predicts the SPL in any cabin of the vessel.

Finally, thermograms allows user to view the propagation of energy throughout the vessel (Figure 12). Thermograms are ideal to diagnose a model and understand how the energy flows from one subsystem to the other.

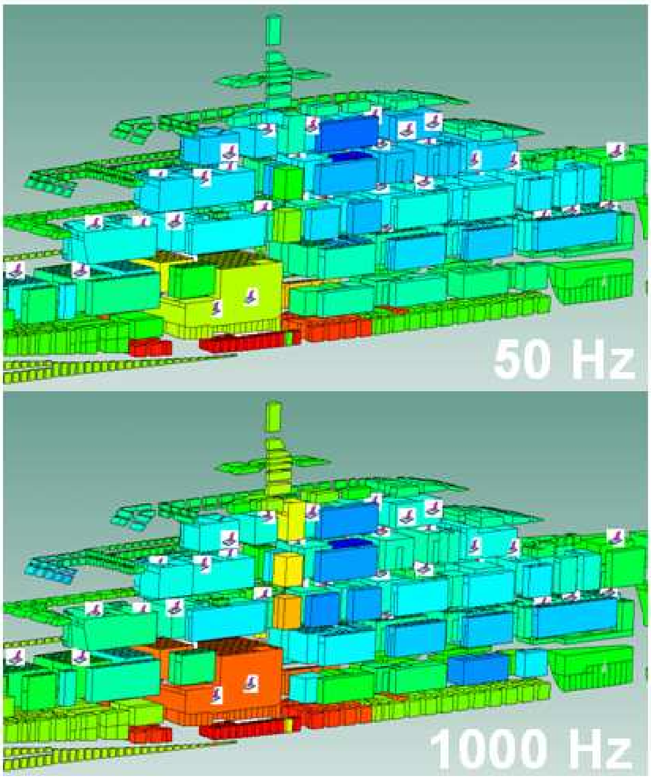

Figure 12: Thermogram showing propagation of energy from sources to rest of vessel. A) 50 Hz and b) 1000 Hz. Small squares represent acoustic power source of HVAC system.

Conclusion

This paper has shown that building an SEA model of several thousands of subsystems can be done efficiently. It has been shown that using condensation, a trim can be represented as insertion loss and added damping. Finally that many types of results can be retrieved from such a model making design changes efficient and accurate. Comparison with empirical model of typical vessels has shown acceptable accuracy.

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