Noise and Vibration: Comparison between prediction and measurements on yachts

Elisa Fassola[a,1] and Lorenzo Kustermann[a]
[a] *RINA Services S.p.A., Genoa, Italy*

Abstract: Nowadays, yachts can reach very high performances and the discovery of new technologies will allow to achieve even better ones. Therefore, building quiet yachts with the lowest possible vibration levels has become the new challenge. To propose the most cost-effective solutions to its clients, RINA predicts noise and vibration levels onboard. Using simulation software allows to detect in advance the most critical areas of the ships, thus reducing the need of costly countermeasures late in the design phase. Finally, RINA evaluates the noise and vibration levels onboard to certify that the yacht is compliant with the specified limits. The work presents a test case in which RINA performed a full study on a yacht.

Keywords: Noise, vibration, prediction, Finite Element Analysis (FEA), Statistical Energy Analysis (SEA)

1. Introduction

The design of large yachts has been driven in the last years by an increasing demand of comfort on board. Boat owners want to enjoy the sea in a quiet environment on board of their yachts. Consequently, shipyards have been focusing on the development of strategies to reduce noise and vibration and to certify the comfort level of their product.

In the last decades, the growing need to reduce costs has been driving every aspect of the design phase. Thus, relying solely on late-stage test procedures to identify vibro-acoustic performance can have a negative impact on profit. Thanks to advanced computer technology, RINA engineers perform an extensive amount of work early in the project simulating the boat environment to detect possible vibroacoustic issues. Being able to count on accurate predictions, they evaluate improvements made by shipyards to their yachts' structure or materials used. Working alongside shipyards allows to achieve an optimized design towards noise and vibration control.

In order to meet contract specifications and certify the comfort levels onboard, RINA assesses the yachts through measurement campaigns of vibration and sound pressure levels at all relevant points. This dataset, which is obtained using an array of microphones and accelerometers, is post-processed to confirm the validity of the work that was done during the previous stages of design and construction of the yacht.

In this work, following an overview of the tools used to predict noise and vibration levels onboard and a description of the instrumentation that surveyors use to measure them, a test case is proposed.

---

[1] Elisa Fassola, RINA Services S.p.A., Marine Environmental & Safety Innovation, Via Corsica 12, 16128 Genoa, Italy; E-mail: elisa.fassola@rina.org.

2. Noise and Vibration prediction

The prediction of the behavior of a yacht from a noise and vibration perspective cannot be studied using one single analysis. As per [1] and [2], RINA uses the following applied to ship building:

- Statistical Energy Analysis (SEA) for noise levels estimation
- Finite Element Analysis (FEA) for vibration levels estimation

To provide easily accessible data to its clients, RINA makes use of widely spread commercial software. The focus of this section is to present an overview of the two methods that are used early in the design cycle for noise and vibration levels prediction respectively. To meet product performance objectives of the clients, it is of paramount importance to act soon to drive down the cost of countermeasures.

2.1. Statistical Energy Analysis (SEA)

RINA engineers perform accurate noise predictions onboard of yachts to assess possible issues at an early stage. The commercial software used for the vibro-acoustics analysis is based on SEA, which is a method for studying the diffusion of acoustical and vibrational energy in a system.

To perform such analysis, the system is partitioned into components (plates, beams and acoustic cavities) that are coupled together at various junctions. Thus, the three-dimensional model of the boat is used to perform automatic calculations of coupling loss factors based on full-wave transmission theory (and advanced radiation efficiency algorithms). In Figure 1 a model of a yacht modeled using the software is shown.

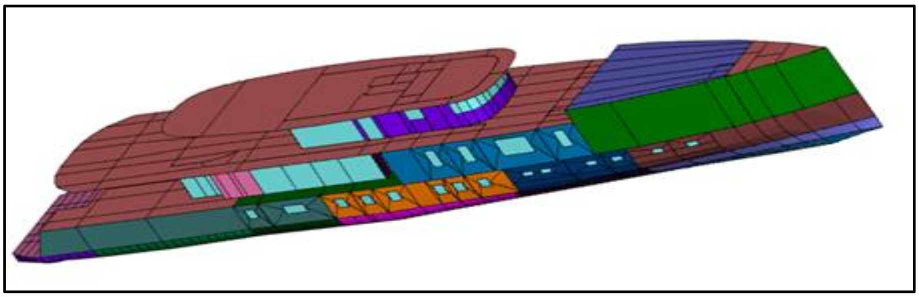

Figure 1. Noise prediction. Model of a yacht.

The structural elements, whose geometry, configuration and stiffness represent the actual structure of the boat, are of the following three types:

- 3D beam elements, to which can be assigned both axial and bi-directional shear and torsional and bending stiffnesses
- Plating-shell elements, to which can be assigned a value for thickness
- Volume elements that represent the yacht's enclosed spaces (such as cabins, corridors, etc.)

2.2. Finite Element Analysis (FEA)

The scope of RINA engineers is to perform accurate vibration predictions through frequency analysis of the yachts. This is to assess potential critical areas early in the design that could decrease the comfort on board. The commercial software used for the pre- and post-processing is based on FEA.

This software is utilized to study the diffusion of vibrational energy in a system. The free and forced vibration analysis are solved to obtain both natural modes and harmonic vibration triggered by the dynamic loads applied to the boat structure. In Figure 2 a model of a yacht developed using the software is shown.

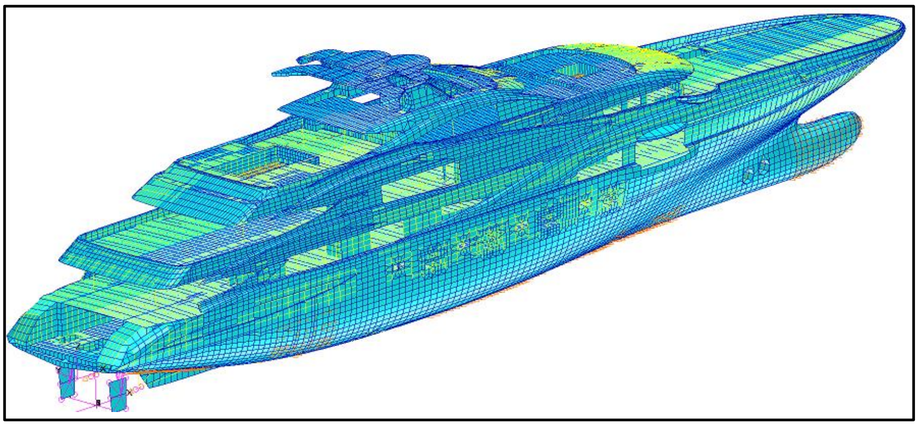

Figure 2. Vibration prediction. Model of a yacht.

The structural elements, whose geometry and properties represent the actual structure of the ship, are divided into three categories:

- Shell elements, used to model decks, bulkheads and shell plating
- Beam elements, used to describe girders, web frames, stiffeners and pillars
- Rigid link elements, used to replicate axial and bending stiffness

3. Noise and Vibration measurements and processing

RINA's Noise & Vibration team is focused on the certification of the comfort levels onboard. Therefore, measuring the actual levels of noise and vibration onboard is an essential part to certify that the yacht is under the limits agreed with the client. The acquisition of data is performed by means of accelerometers and microphones. Specifically, the following types are used:

- Prepolarized microphones coupled with a preamplifier
- Tri-axial accelerometers

RINA performs noise and vibration measurements according to ISO 6954:1984 [3] and ISO 2923:1996 [4] respectively. If agreed by all parties and specified in the terms of the offer, the final position of any of the microphones and accelerometers can differ from the stipulations of the norms.

Finally, the analysis of the noise and vibration data collected is performed by means of a commercially available software. Such post-processing tool is commonly used by RINA and an overview of the graphics of the software is shown in Figure 3 and Figure 4 for noise and vibration analysis respectively.

As a final step to provide clients with useable and clear data, the processing phase of the measurements is completed using a RINA in-house developed Excel file.

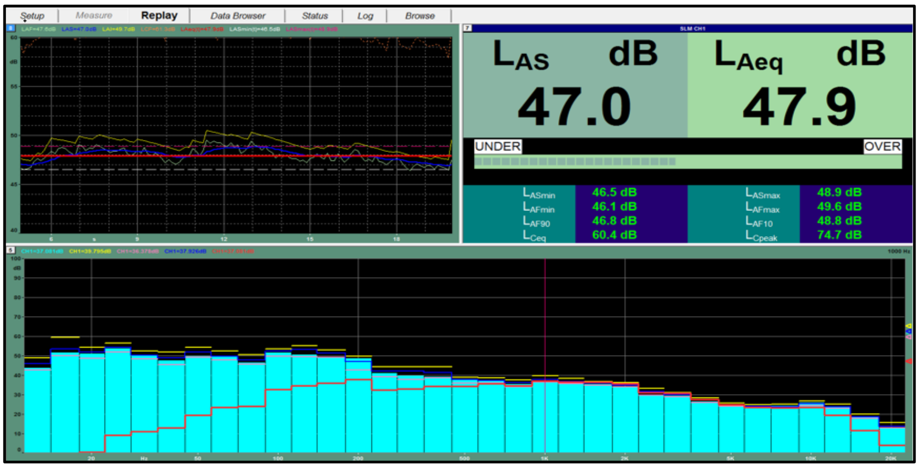

Figure 3. Graphics of the processing software for noise measurements.

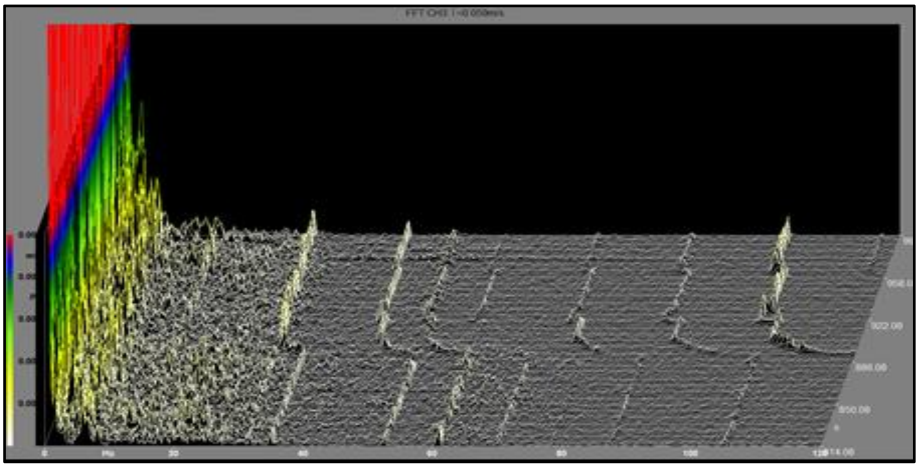

Figure 4. Graphics of the processing software for vibration measurements.

4. Test case on a 50m yacht

For the chosen test case object of this section, the client requested RINA to provide a full simulation of noise and vibration levels to characterize the yacht. In addition, the client commissioned a full set of measurements onboard to be assigned the RINA comfort class COMF(Y) as specified by internal Rules [5]. These requests offered an opportunity to produce a comparison between the simulated environment and the real levels onboard.

While an extensive FEA study and a full set of measurements was taken to assess the vibration levels of the yacht, the focus of this paper will be on airborne and structure-borne noises.

4.1. Investigation process

In order to satisfy the requests of the client, the full assessment of the noise inside the yacht was completed in three main steps: prediction using SEA to identify critical areas, evaluation of design changes made by the shipyard and final validation through measurements on board.

Forecast of sound pressure levels in the different spaces (such as cabins, corridors, wheelhouse, etc.), was performed according to input data provided by shipyard and different suppliers. In case of missing inputs, RINA engineers proceeded with the simulations extracting data from an extensive internal database available from previous measurements collected on similar yachts. To correctly describe the yacht environment, the following airborne and structure-borne noise sources were considered:

- Main engines
- Engine room fans noise
- Propellers
- Air handling units
- Stabilizers
- Diesel generators

After running simulations and obtaining preliminary results, the shipyard began the iterative process to propose and implement changes. In this phase, it was still relatively time and cost-effective to make variations from the original design. For each change made by the shipyard with progresses in the design of the yacht, RINA modified inputs to the software and run the simulations again, thus achieving more reliable data and better predictions.

After the design was consolidated, the shipyard started the building phase of the yacht. In preparation for the measurements on board, engineers from RINA overviewed the construction of the boat to make sure all the relevant design features were assembled correctly from a noise and vibration point of view.

4.2. Analysis of results

Although RINA simulated both harbor and cruising condition, this work focuses on the main issues investigated at continuous service rate (CSR).

The software proved useful to analyze potential issues of the yacht by returning a very clear picture of the sound pressure levels of each area. In Figure 5 the overview of the latest simulation of the yacht is shown.

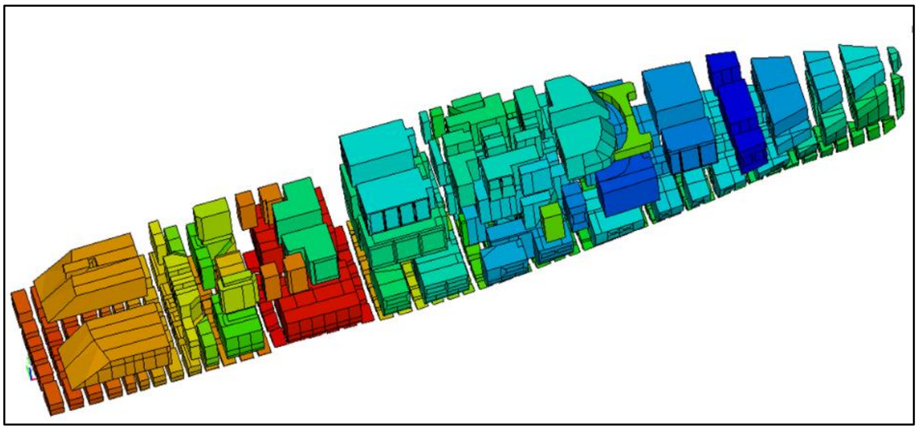

Figure 5. Noise levels of the yacht predicted using SEA.

From the SEA analysis, the predicted overall sound pressure levels complied with the specifications. As a matter of fact, all spaces subject of the analysis were predicted to be below the limits specified by RINA Rules [5] for the COMF(Y) notation. Thus, the shipyard started the construction of the yacht.

Table 1 reports the delta between the predicted sound pressure levels values and the measurements during the sea trial of the yacht (at a cruising speed of 14 knots). Positive deltas mean that a higher level of noise was expected than the actual one and vice versa.

Table 1. SEA prediction vs measurements. Cruising speed 14 knots.

Accommodation spaces	Delta SEA Prediction vs Measured Noise [dB(A)]
LD VIP Bathroom	+1
LD VIP Cabins	-3
LD Guest Cabins	-4
MD Owner’s Cabin	-3.5
MD Main Saloon	+5
UD Sky Lounge	+3.5
UD Wheelhouse	0

The actual measurements onboard were close to the forecast levels of noise. However, unexpected negative discrepancies were discovered in three cabins:

- VIP cabins at the Lower Deck
- Guest cabins at the Lower Deck
- Owner’s cabin at the Main Deck

In this paper, a detailed discussion of the countermeasures is given for the issue on the Main Deck (Owner’s cabin).

4.3. Countermeasures

This chapter describes the noise issue concerning the Owner cabin. When the software is given the correct input data for SEA, it performs extremely reliable simulation that match sound pressure levels onboard closely. In fact, the unexpected presence of leakages in the balcony windows seals explained the excessive airborne noise near the hull side and the discrepancy with the prediction. As a countermeasure, the client proposed to RINA a design that involved the use of pneumatic seals to reduce noise transmission through windows.

To prove that the software would have been capable to correctly identify the issue, a new simulation was run to account for the balcony windows leakages. In addition, the measured noise on the balcony was given as input to the software to better reflect the real environment. Figure 6 shows the result.

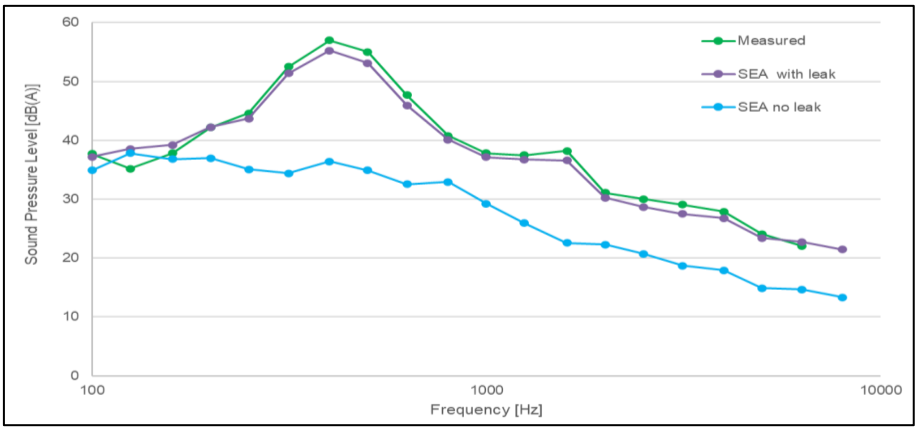

Figure 6. Comparison between measured and SEA predicted noise levels in different conditions.

As can be deduced by the image, the SEA simulation that considered the effect of leakages through the windows predicted a trend of sound pressure levels that closely matched the measured ones.

Comparing these curves with the original SEA model, which did not account for leakages, the introduction of pneumatic seals was estimated to give a noise reduction of about 10dB close to the balcony of the cabin.

5. Conclusions

This paper assesses the work performed by the engineers of the RINA Noise & Vibration team in predicting and measuring the vibration and sound pressure levels onboard of yachts. Firstly, they start by modeling the boat and assessing each potential issue in a virtual environment. Secondly, they simulate early in the project the design changes proposed by the shipyards to assess the different improvements from a comfort point of view. This practice is extremely valuable for clients as it allows them to reduce countermeasures costs late in the development of the yacht. Finally, RINA completes its work by certifying the comfort level of the yacht through a measurement campaign onboard.

The illustrated test case showed that simulation software based on Statistical Energy Analysis and Finite Element Analysis are an accurate tool to predict the levels of noise and vibration on a yacht. They provided a realistic characterization of the yacht before the sea trials giving confidence that there were no weak spots in the design. Due to the complexity of such analyses, it is not always possible to accurately predict the noise levels onboard. In this work, some discrepancies were found and the most relevant addressed suggesting countermeasures to the shipyard.

As proven in the present work, these software provide a dynamic environment for the analysis of noise and vibration issues allowing to quickly test different solutions to implement on the physical yachts. When the proper inputs are given to the system, there is an extraordinary correlation between the simulated environment and the real world. Thus, the future of noise and vibration prevention on board of yachts is directly linked to the correct use of simulations to avoid issues in the real environment altogether.

References

[1] Blanchet D, Caillet A. Design of acoustic insulation in ships based on predictive vibro-acoustic models. ESI-group. 2013.

[2] Basu R, Kirkhope K, Srinivasan J. Assuring quality and reliability of ship structure Finite Element Analysis. Ship Structure Symposium. 1996.

[3] ISO 2923 (1996) “Acoustics - Measurement of Noise on Board Vessels”

[4] ISO 6954 (1984) “Mechanical Vibration and shock – Guidelines for the overall evaluation of vibration in merchant ships”

[5] RINA Services S.p.A. Rules for Pleasure Yachts. 2022 Jan. Part E. Section 4.

[6] ESI Group VA One. Official website. <https://www.esi-group.com/products/vibro-acoustics>

[7] MSC PATRAN. Official website. <https://www.mscsoftware.com/product/patran>

[8] SOUNDBOOK SINUS Messtechnik GmbH. Official website < https://sinus-leipzig.de/en/>

[9] SOUNDBOOK SINUS Messtechnik GmbH. Official website. Products section <https://sinus-leipzig.de/en/produkte/sensoren>

[10] SOUNDBOOK SINUS Messtechnik GmbH. Official website. Products section <https://sinus-leipzig.de/en/produkte/sensoren>

[11] SOUNDBOOK SINUS Messtechnik GmbH. SAMURAI Official website <https://sinus-leipzig.de/en/produkte/software/samurai>

[12] IMO Resolution MSC.337(91) “Adoption of the code on noise levels on board ships” Annex 1. 2012.

[13] Tonelli A, Torre D, Vergassola G, Boote D. Numerical tools and experimental activities for the prediction of noise propagation on board superyachts. Design and Construction of Super & Mega Yachts. 2017.

[14] Vergassola G. The prediction of noise propagation onboard pleasure crafts in the early design stage, Journal of Ocean Engineering and Marine Energy. 2020.

[15] Vergassola G, Boote D. Numerical and experimental comparison of the dynamic behaviour of superyacht structure. Ships and offshore structures. 2018.