# University of Genoa (UNIGE)

**"EMSHIP"**
**Erasmus Mundus Master Course**
**in "Integrated Advanced Ship Design"**

## Prediction of Noise Propagation on Board a Motor Yacht Using Statistical Energy Analysis (SEA)


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# OBJECTIVE OF THE STUDY

- To understand the basis of the noise propagation mechanisms
- To get familiar with the simplified methods and associated software for the analysis
- To emphasize the underlying theories mainly based on statistical energy analysis (SEA)
- To evaluate the advantages and difficulties of the applied method and software

**Total noise in analyzed compartment**

Depends on -

1. Ship structure
2. Power and structure of mechanisms
3. The foundation
4. Distance between noise source and analyzed compartment

**Airborne noise** + **Structure borne noise**

**Airborne noise**

- Influences mainly in the compartments where the noise sources are installed
- Noise transmitted by way of the air

**Structure borne noise**

- Influences in compartments located at some distance from noise sources
- Noise generated by the vibrations induced in the structure causing them to radiate noise

## Statistical Energy Analysis (SEA)

Numerical analysis method, developed for the purpose of studying the diffusion of acoustic and vibrational energy in a system (analyzed yacht)

Statistical means that the variables are extracted from statistical population and all the results are expected values.

Based on numerical model in which the analysis of both the structural elements and acoustic spaces can be performed.

Subsystem with higher modal energy → Energy transferred → Subsystem with lower modal energy

## Advantage of S…

…at is …stem?

T… …ms

The struct… …al cavities involv… …nted by general g… material data fr… …perties like average modal densities, average modal damping and average coupling data may be derived. Also the dynamic field variables are represented by simple spatial and temporal averages, corresponding to the total vibratory energy of the subsystems

## Main Disadvantage of SEA

The energy levels obtained for different subsystem are statistical estimates of the true levels, and therefore afflicted with some degree of uncertainty.

Nevertheless this disadvantage, the level of uncertainty will be less pronounced when the subsystems have sufficient modal density at a given frequency

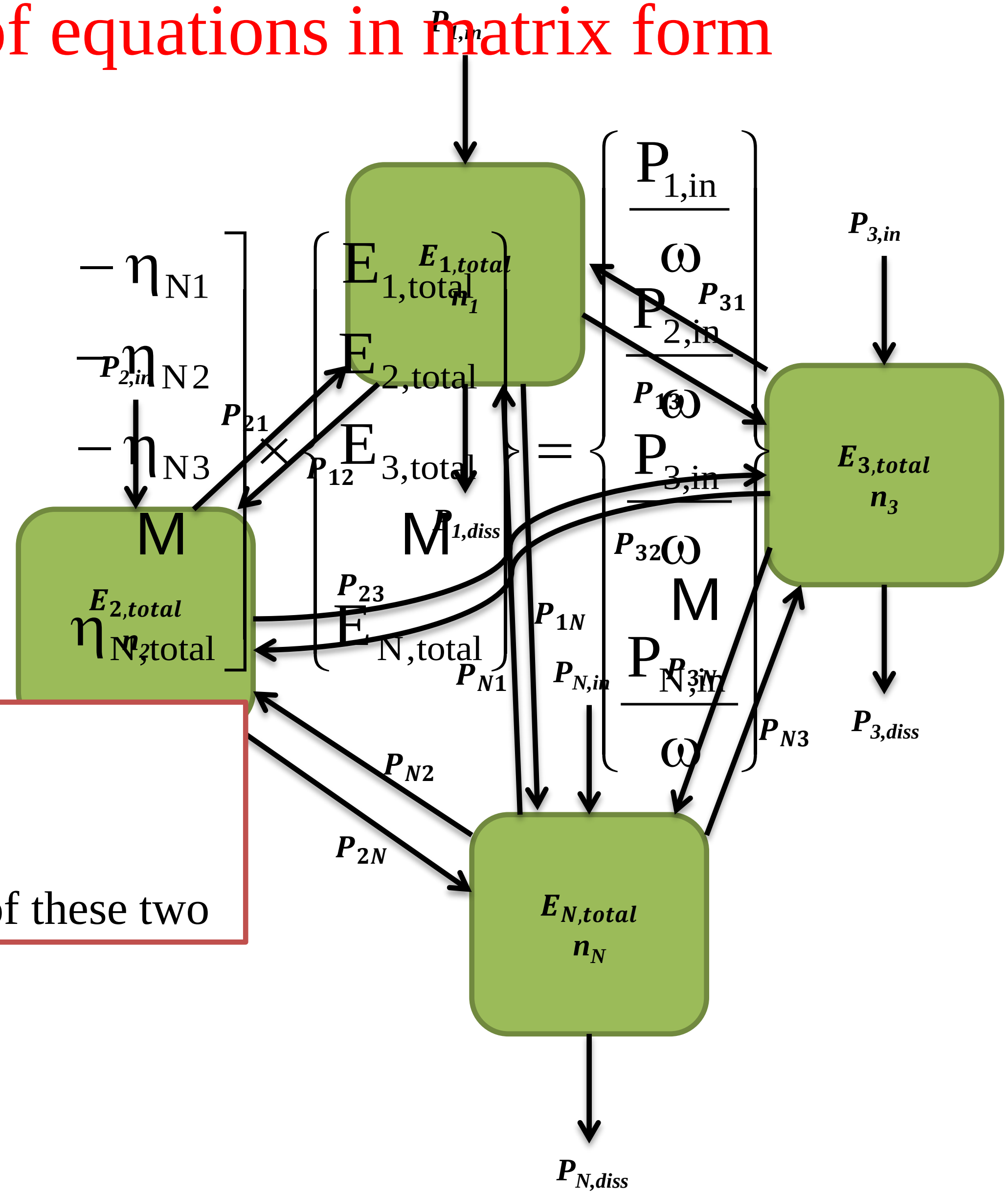
# N-Subsystem SEA Model

# Implementing systems of equations in matrix form

For each subsystem, there are:

- Stored vibrational energy,
- Modal density,
- Input power from external source,
- Dissipated power due to the damping of the subsystem and
- Transferred power due to coupling between subsystems

$$\begin{bmatrix} \eta_{1,total} & -\eta_{21} & -\eta_{31} & \cdots & -\eta_{N1} \\ -\eta_{12} & \eta_{2,total} & -\eta_{32} & \cdots & -\eta_{N2} \\ -\eta_{13} & -\eta_{23} & \eta_{3,total} & \cdots & -\eta_{N3} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ -\eta_{1N} & -\eta_{2N} & -\eta_{3N} & \cdots & \eta_{N,total} \end{bmatrix} \begin{Bmatrix} E_{1,total} \\ E_{2,total} \\ E_{3,total} \\ \vdots \\ E_{N,total} \end{Bmatrix} = \begin{Bmatrix} \frac{P_{1,in}}{\omega} \\ \frac{P_{2,in}}{\omega} \\ \frac{P_{3,in}}{\omega} \\ \vdots \\ \frac{P_{N,in}}{\omega} \end{Bmatrix}$$




Type of loss factors –
Damping loss factor
Coupling loss factor
Total loss factor – combination of these two

# Modal Density, *n(f)*

- Modal density is an important SEA parameter used to check the reliability for the created SEA yacht model noise analysis.
- It is recommended for each subsystem in the whole yacht to have sufficient modal density. (suggested to have at least 2)
- Therefore, it is suggested not to have very small plate panels and acoustic cavities when creating the model.

## Yacht's Principal Dimensions

| | | |
|---|---|---|
| Length overall | LOA | 40.86m |
| Length on waterline | LWL | 39.26m |
| Maximum beam | B | 9.4m |
| Beam on waterline | BWL | 8.9m |
| Depth moulded | D | 6.1m |
| Draft | T | 2.75m |
| M[illegible] | | 2.79m |

## Cerri 40m KN Explorer

**Built by**

## Propeller Characteristic

| | |
|---|---|
| Diameter | 1.4 m |
| Number of blades | 5 |

## Engine Characteristics

| | |
|---|---|
| Main engine type | CAT C32 ACERT |
| Max[illegible] power | 1081kW |
| Nominal revolution | 2300rpm |

The transmission of airborne noise and structure borne noise due to vibration within a vibroacoustic system depends on the way in which the system components are joined together and the dynamic properties of the individual components.

In order to let the energy propagate throughout the yacht model, this yacht model consists of three main objects.

**Subsystems (plate panels and acoustic cavities, etc)**

Used to model the various structural and acoustic components that transmit energy through the vibroacoustic system.

**Junctions**

Used to model the connections between the various subsystems in a system. They are also used to describe the way in which the energy is transmitted between the different subsystems in a system.

**Noise generating sources**

Used to model the various sources that inject energy into the subsystems in a vibroacoustic system.

# Creating the SEA 3D Model

**Creation of subsystems**

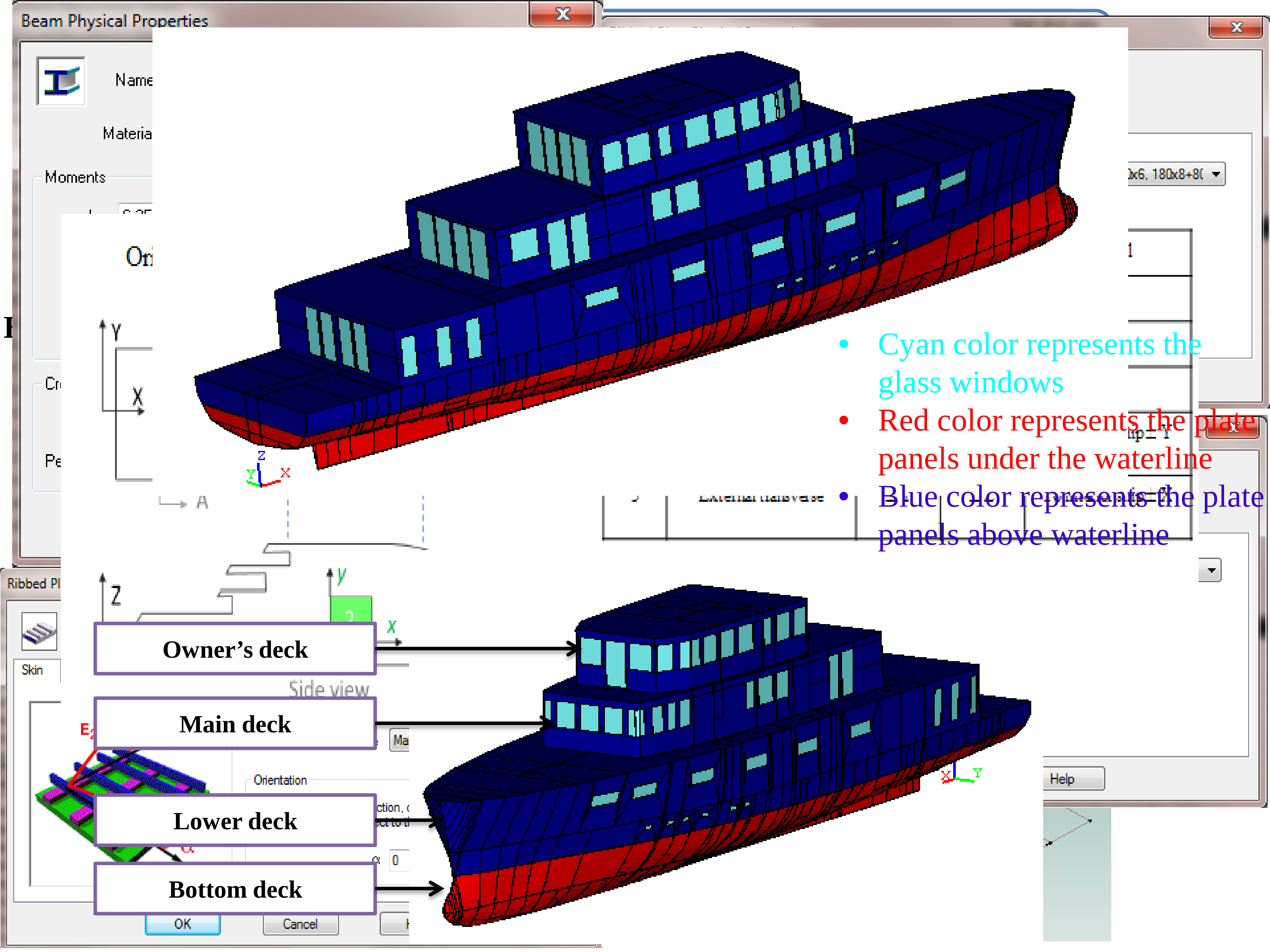
- Assigning body and floor acoustic lines to form SEA 3D model
- Assigning beam and plate physical properties
- Assigning noise control treatment (NCT - insulations)
- Assigning damping of the panels and insulations
- Creation of SEA acoustic cavities
- Applying fluid loading and underwater SIF

**Junctions**

- Creation of corresponding SEA subsystem (point, line or area) junctions

**Noise generating sources**

- Assigning airborne and structure borne noise generating sources onboard the yacht


Beam Physical Properties
Owner's deck
Main deck
Lower deck
Bottom deck
Side view
Cyan color represents the glass windows
Red color represents the plate panels under the waterline
Blue color represents the plate panels above waterline

# Assigning damping of the panels and insulations

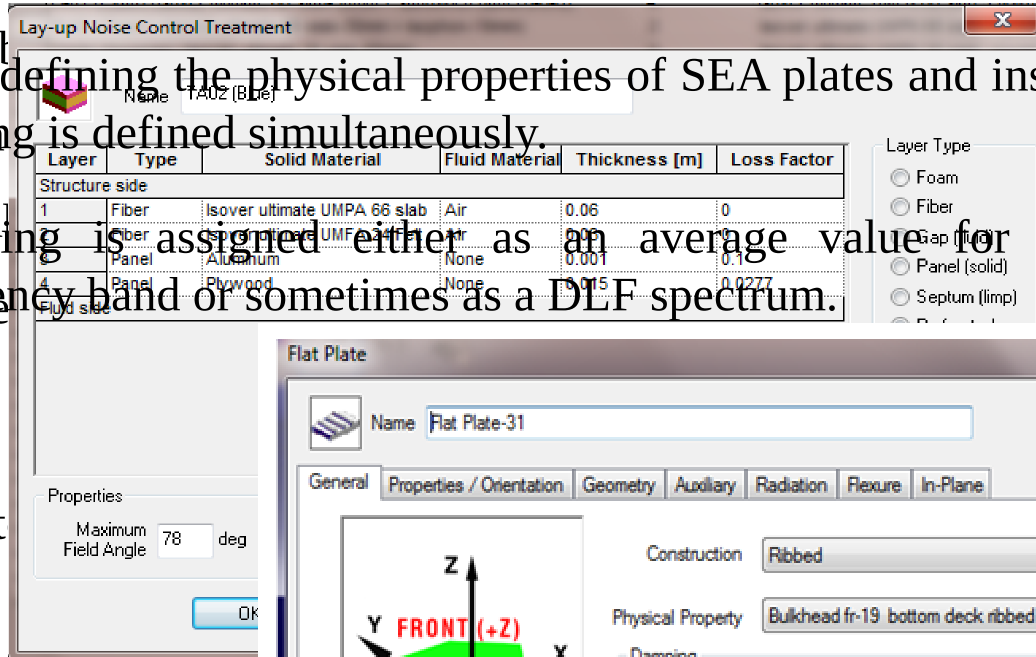
While defining the physical properties of SEA plates and insulations, the damping is defined simultaneously.

Damping is assigned either as an average value for the analyzed frequency band or sometimes as a DLF spectrum.

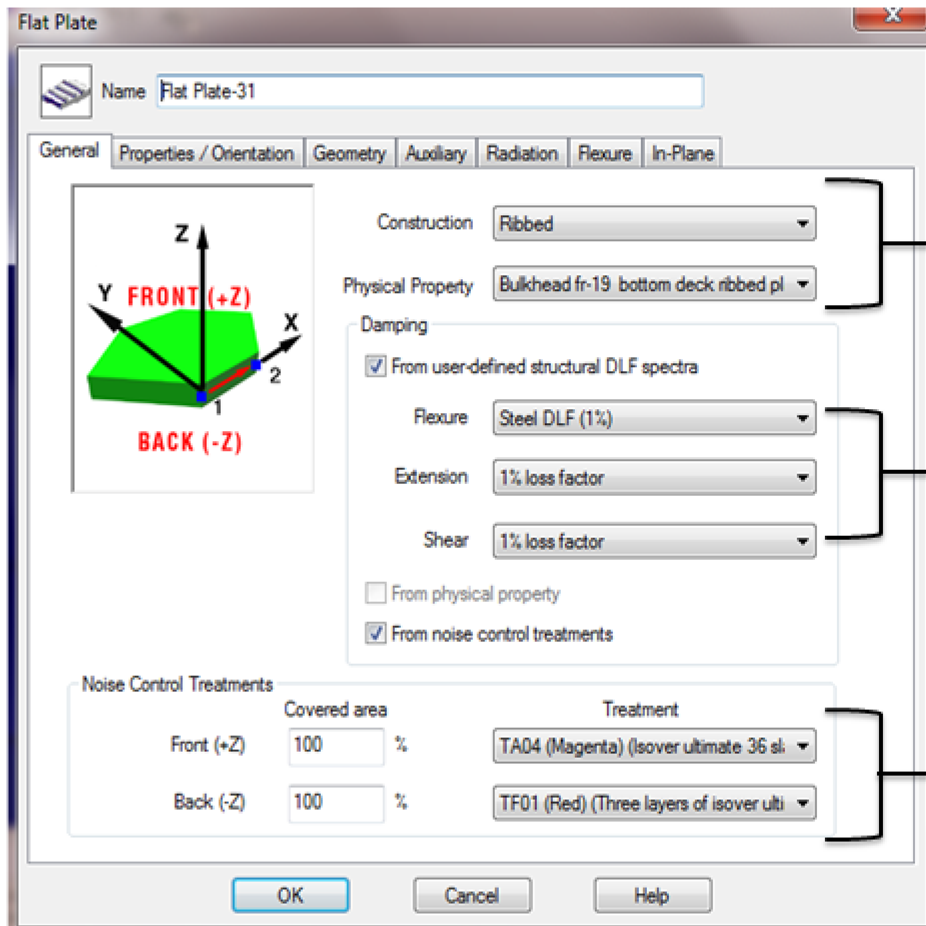
- Applied ... e yacht.
- Affecting ... adjacent acoustic cavity su...
- Dissipate ... ic cavity.

Four ways t...

Three locations to assign DLF.








Assign type of plate and material

Assign damping

Assign the type of insulation

# Applying fluid loading and underwater SIF

SIF: Semi-infinite Fluid – To take into account the sea water around the hull. For the purpose to model the exterior acoustic impedance for SEA subsystems – an energy dissipating sink – the acoustic waves radiated by the subsystem connected to it are not reflected back into the subsystem.

SEA Acoustic cavities are subsystems used to predict the sound pressure level in a model and consist of a set of faces that form a valid enclosed volume of acoustic fluid.

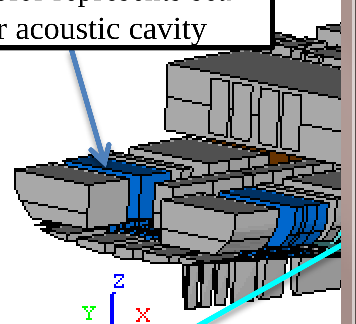
**According to capacity plan of yacht** → **Altogether 5 types of fluid**

Apply fluid loading to the plates under draft line of 2.79m.

Due to this sea water loading:

- The mass of the plates of ship hull under the waterline increases
- The number of modes in band and wave number increases
- The effect (response) decreases as the frequency increases

**Yacht Model in shrunk view**




Grey color represents air acoustic cavity

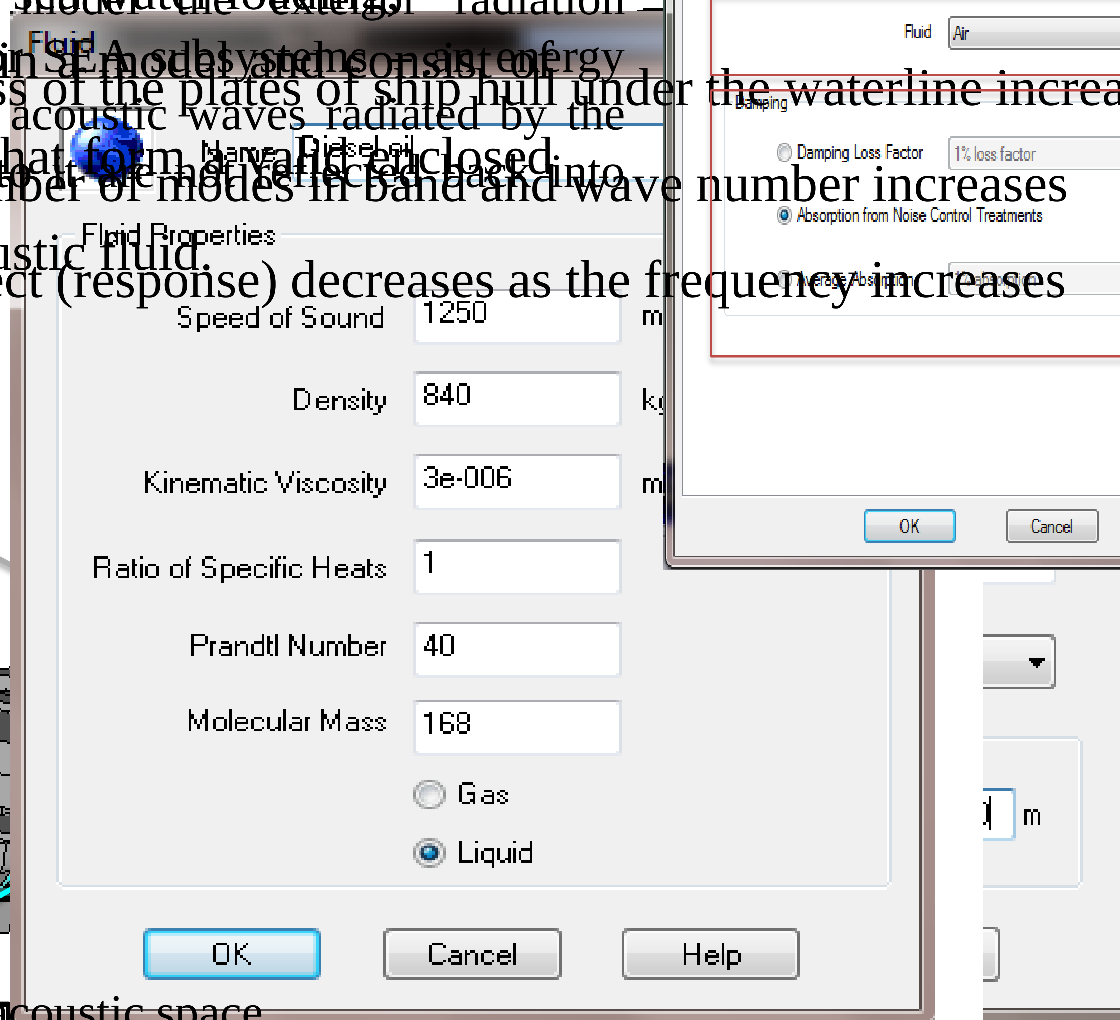
Blue color represents sea water acoustic cavity

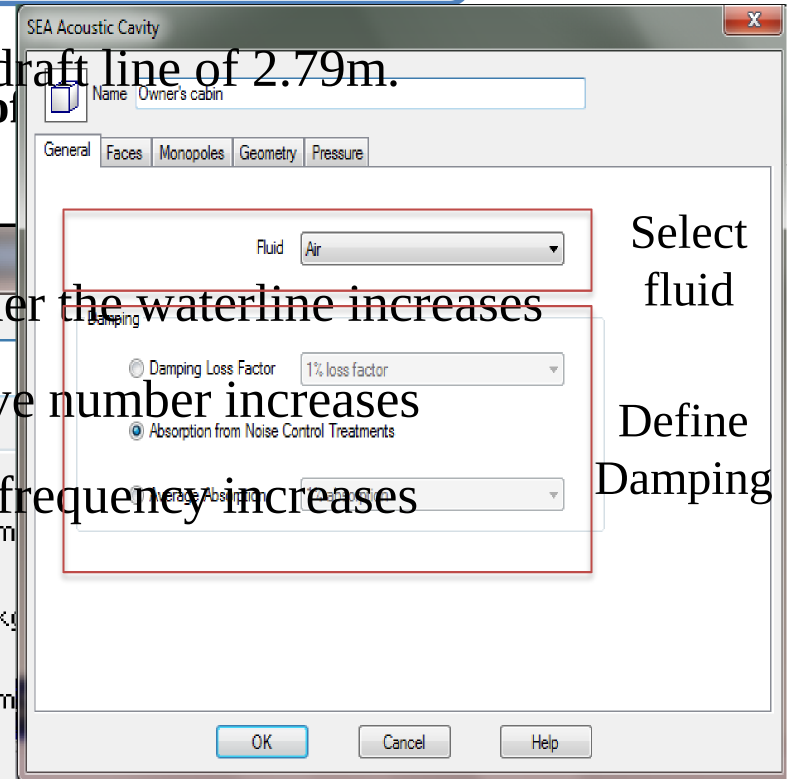
Cyan color represents fresh water acoustic cavity

Black color represents lube oil acoustic cavity

Brown color represents diesel oil acoustic cavity

An unbounded exterior acoustic space



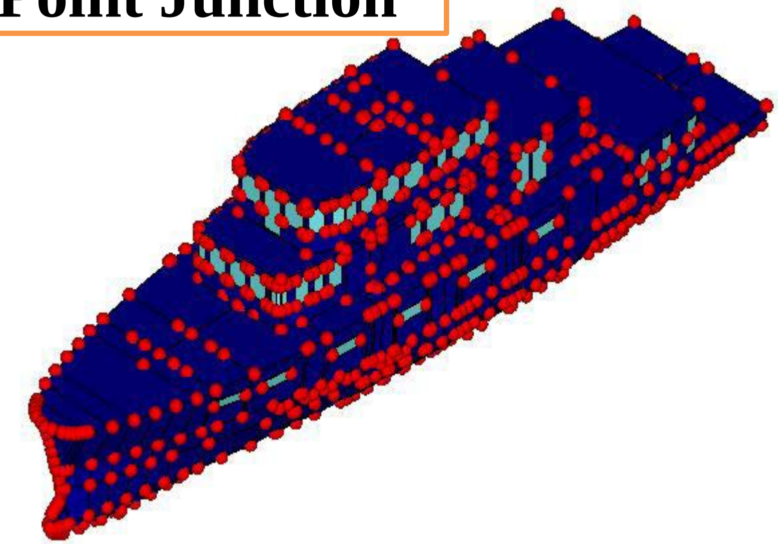

Select fluid

Define Damping

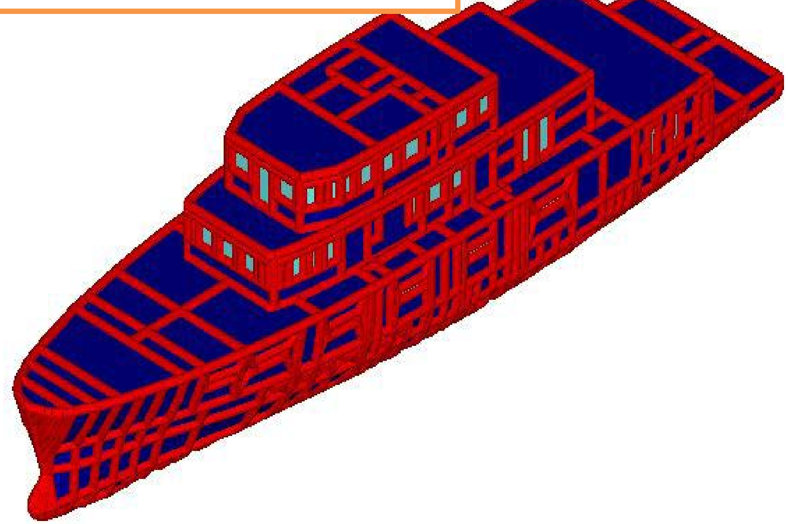
# Creation of SEA subsystem junctions

Corresponding junctions are created to let the software calculate the coupling loss factors (CLF) from which the energy transfer between subsystems are calculated.

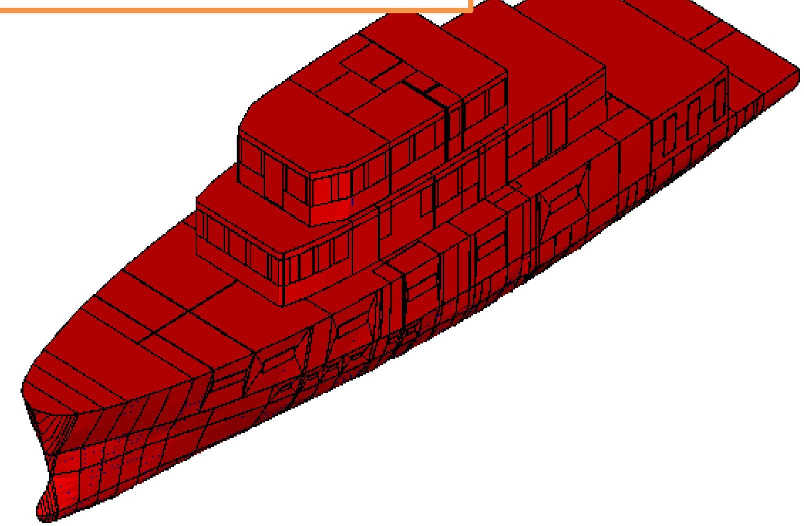
**Point Junction**



**Line Junction**



**Area Junction**



Among the analyzed frequency range, the highest sound pressure levels are extracted for each cavities and checked for comfort.

# Loudness chart dB(A) relative to human ears in reality

# Contour Plot (Results of SEA Analysis) for

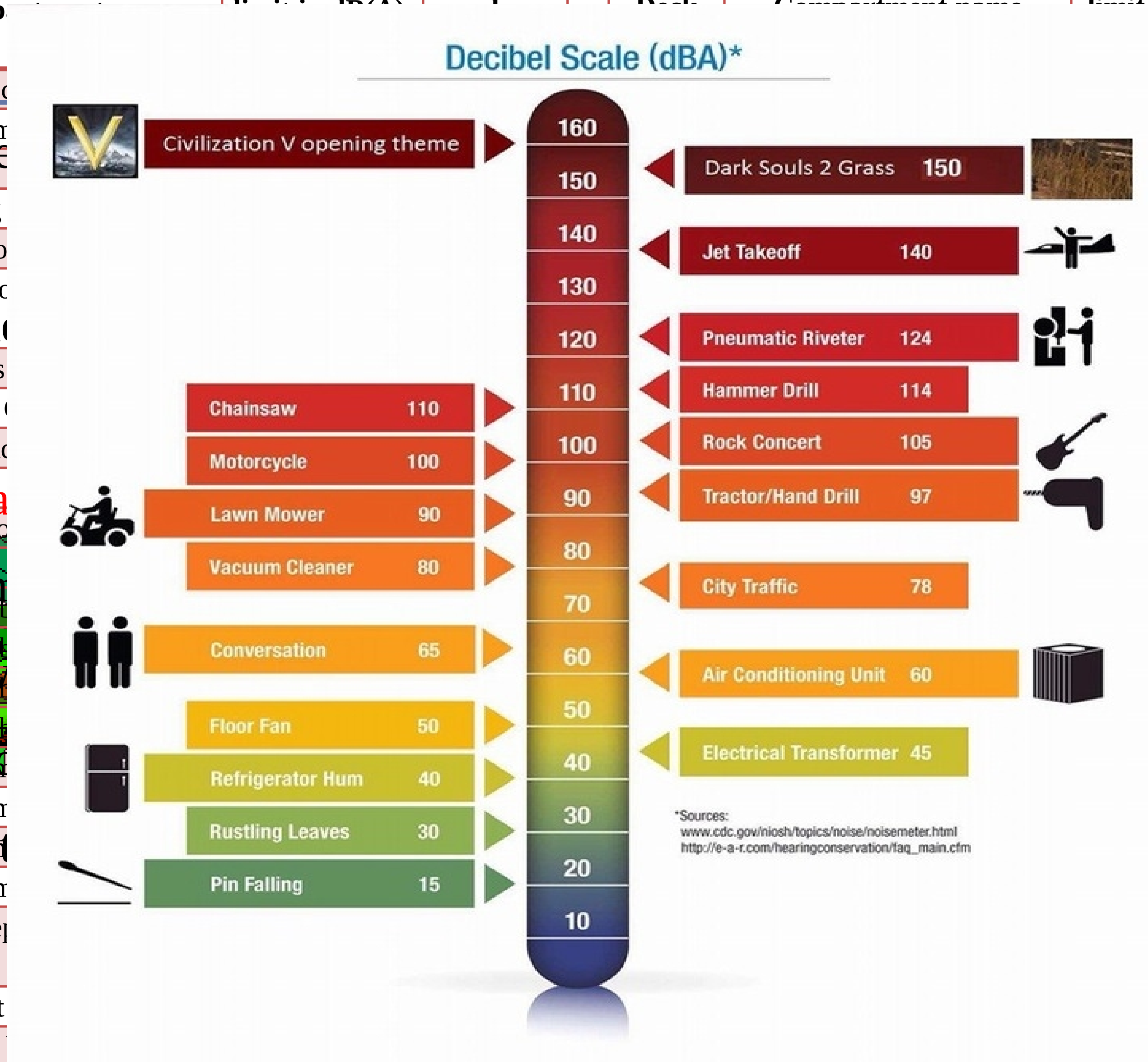
Since the

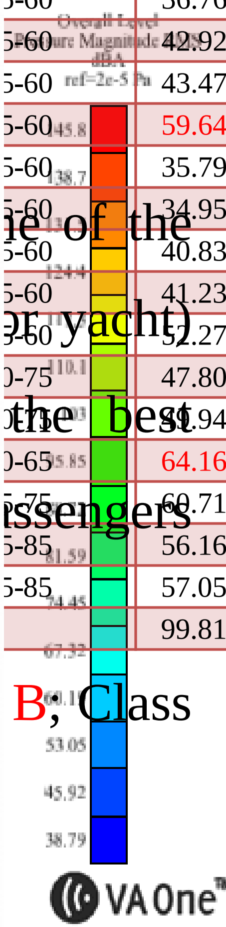
The gene... ...e of the comfort ... (for yacht) from Ita... ...the best compromi... ...ssengers and crew

In this ... B, Class A being t...

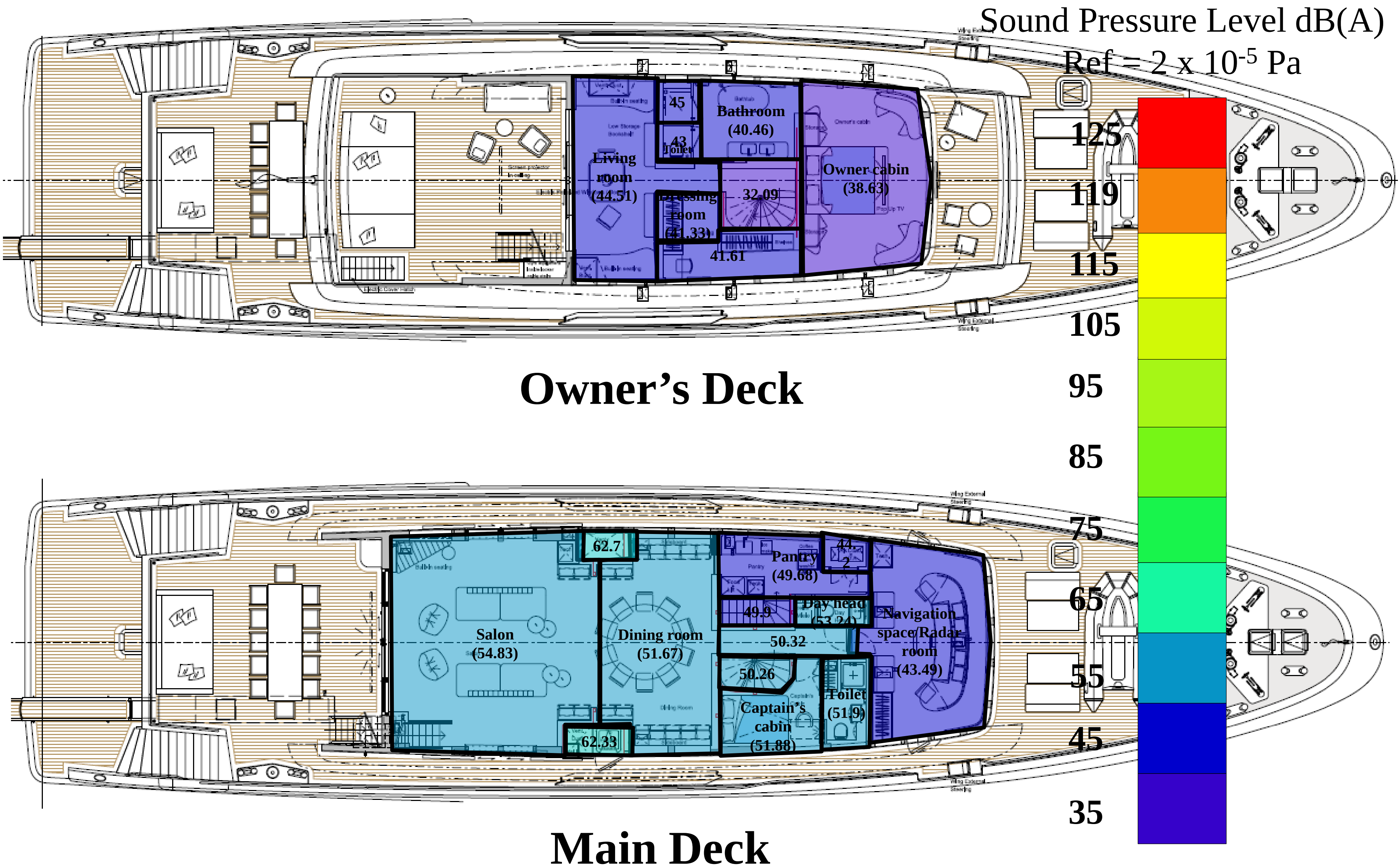
| Deck | Compartment name | Acceptable limit in dB(A) | Peak value |
|---|---|---|---|
| Owner's deck | Owner's c... | | |
| | Bathroom | | |
| | Toilet | | |
| | Dressing | | |
| | Living ro... | | |
| Main deck | Navigatio... room | | |
| | Captain's | | |
| | Toilet in ... | | |
| | Day Head | | |
| | Pantry | | |
| | Dining ro... | | |
| | Salon | | |
| Lower deck | Guest cab... | | |
| | Guest cab... | | |
| | Guest cab... | | |
| | Guest cab... | | |
| | Bathroom | | |
| | Bathroom | | |
| | Bathroom | | |
| | Bathroom | | |
| | Food prep... galley | | |
| | Life boat | | |
| | Corridor | | |
| | Cinema/Lounge | 55-60 | 59.49 |
| | Bar | 55-60 | 59.44 |

| Deck | Compartment name | Acceptable limit in dB(A), class A-B | Peak value dB(A) |
|---|---|---|---|
| | | ...5-60 | 36.60 |
| | | ...5-60 | 36.76 |
| | | ...5-60 | 42.92 |
| | | ...5-60 | 43.47 |
| | | ...5-60 | 59.64 |
| | | ...5-60 | 35.79 |
| | | ...5-60 | 34.95 |
| | | ...5-60 | 40.83 |
| | | ...5-60 | 41.23 |
| | | ...5-60 | 52.27 |
| | | ...0-75 | 47.80 |
| | | ...0-75 | 49.94 |
| | | ...0-65 | 64.16 |
| | | ...5-75 | 60.71 |
| | | ...5-85 | 56.16 |
| | | ...5-85 | 57.05 |
| | | | 99.81 |

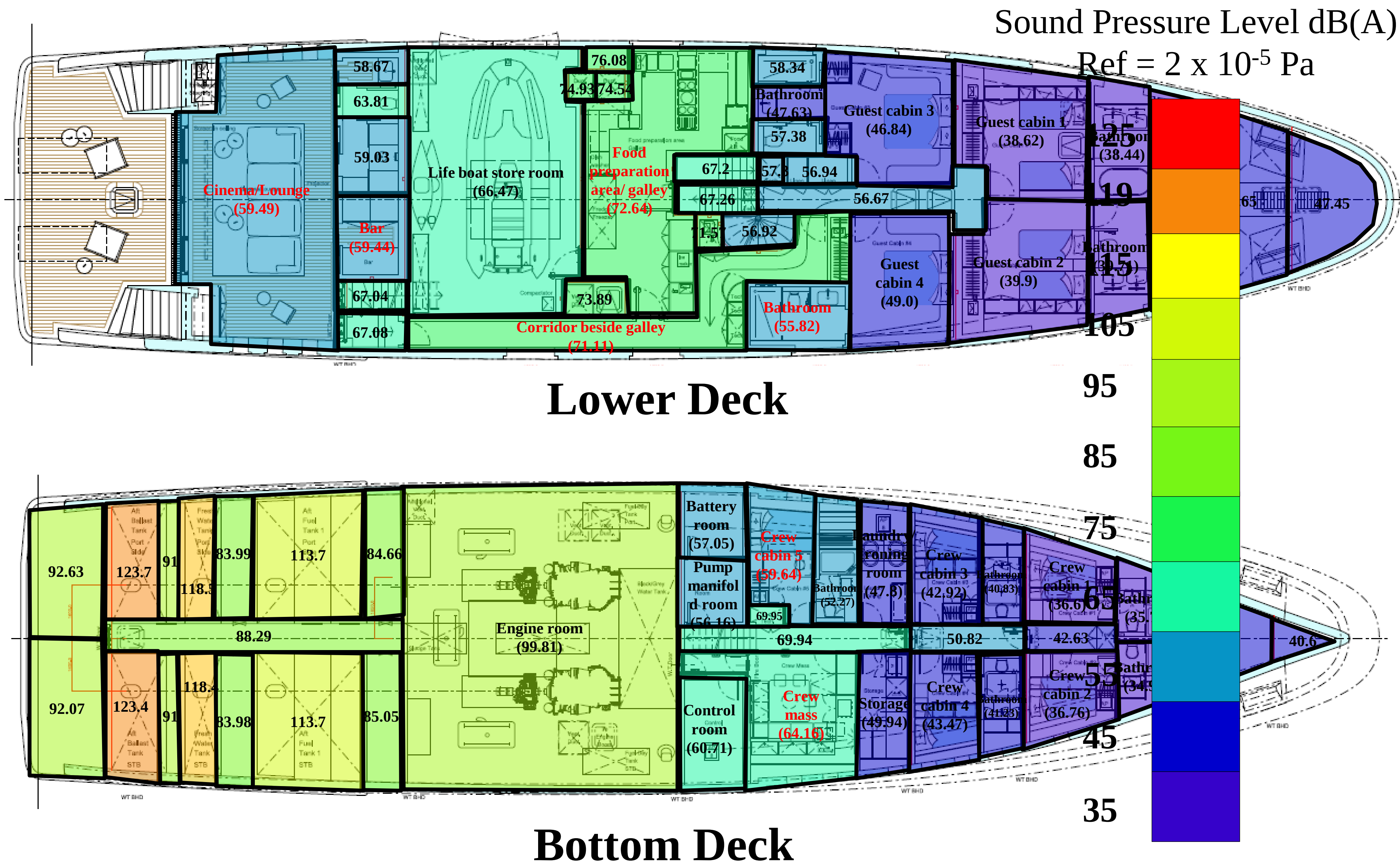


# Highest Sound Pressure Level dB(A)

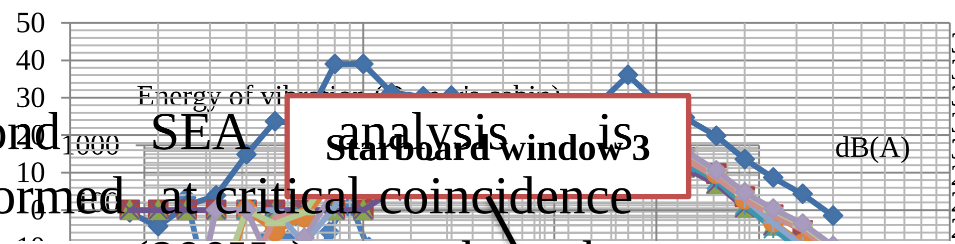


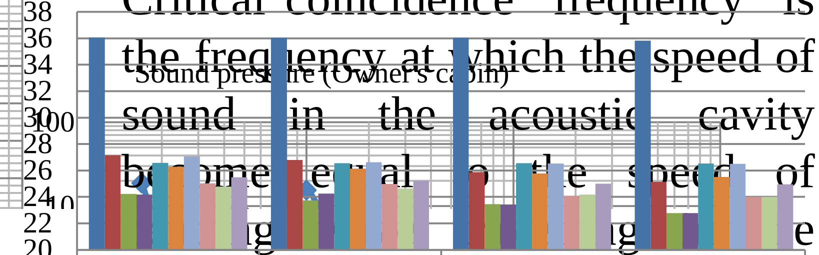
# Highest Sound Pressure Level dB(A)




Main purpose of this thesis finished here

# Owner's Cabin Cavity




Second SEA analysis is performed at critical coincidence frequency (800Hz) to see how the sound pressure level changes (drops) as a function of the structural thickness of these glass windows and door.

Critical coincidence frequency is the frequency at which the speed of sound in the acoustic cavity becomes equal to the speed of bending waves in the structure.

**Owner's cabin cavity**

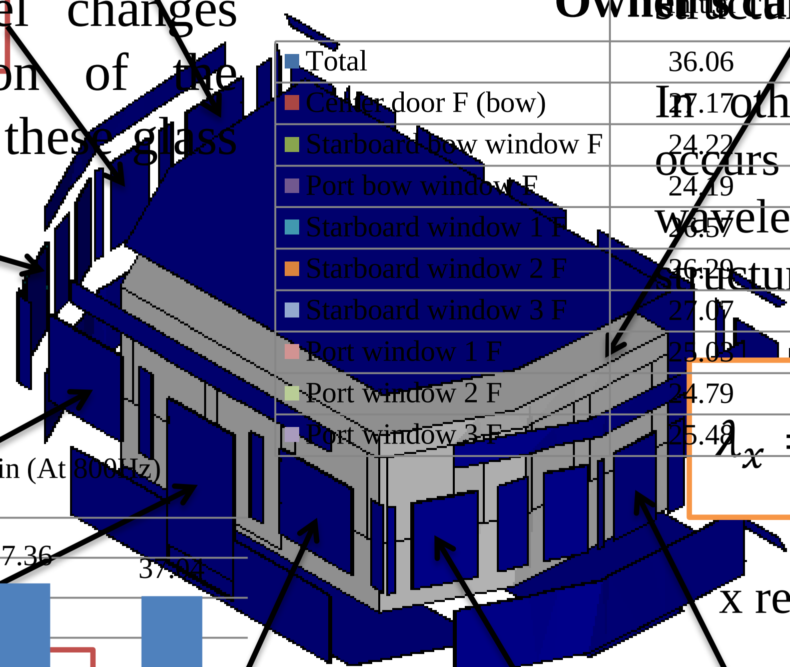
| Structural | Initial | Increased by 10% | Increased by 20% | Increased by 30% |
|---|---|---|---|---|
| Total | 36.06 | 36.05 | 36.04 | 35.84 |
| Center door F (bow) | 27.17 | 26.79 | 25.87 | 25.14 |
| Starboard bow window F | 24.22 | 23.75 | 23.45 | 22.78 |
| Port bow window F | 24.19 | 24.25 | 23.42 | 22.77 |
| Starboard window 1 F | 26.57 | 26.56 | 26.55 | 26.54 |
| Starboard window 2 F | 26.29 | 26.14 | 25.77 | 25.50 |
| Starboard window 3 F | 27.07 | 26.62 | 26.52 | 26.50 |
| Port window 1 F | 25.03 | 24.99 | 24.08 | 24.01 |
| Port window 2 F | 24.79 | 24.63 | 24.17 | 24.01 |
| Port window 3 F | 25.48 | 25.22 | 25.01 | 24.97 |

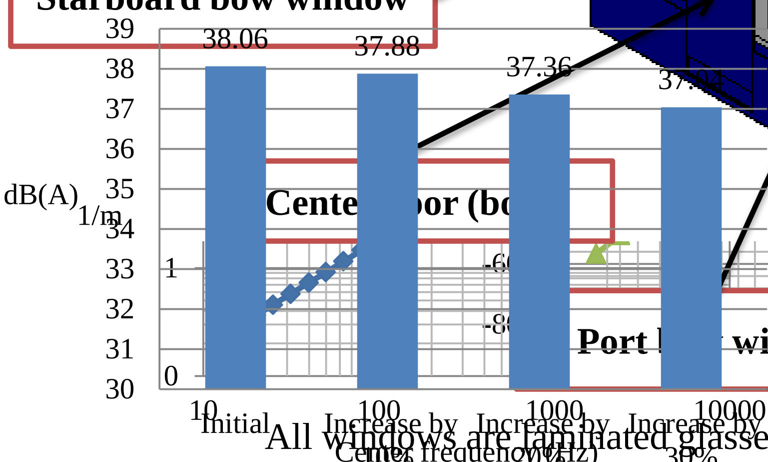
In other words, the coincidence occurs when the acoustic wavelength is equal to the structural flexural wavelength.

$$\lambda_x = \lambda_0; k_x = k_0; c_x = c_0$$

x refers to of structure and 0 refers to of acoustic

Peak (38.63dB(A)) at 100 Hz – Hi-fi/refrigerator … human ears'




All windows are laminated glasses

Sound reduction is dramatically decreased.

Sound transmission loss (TL) is significantly decreased around this frequency.

VA One also allows us to see the sound transmission loss behavior of plate panel between two cavities.

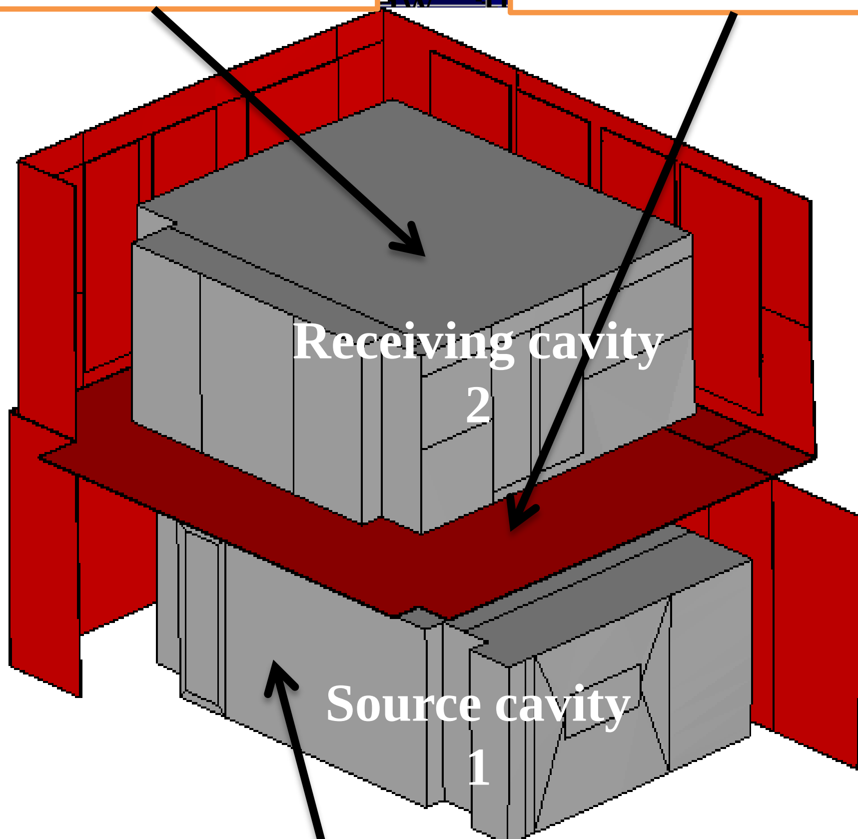
$$STL\ or\ TL = 10\ log(\frac{P_{incident}}{P_{transmitted}})$$

$$STL\ or\ TL = 10\ log_{10}(\frac{A\omega}{8\pi^2\ c_1^2 n_1 \eta_2}(\frac{E_1}{E_2} - \frac{n_1}{n_2}))$$

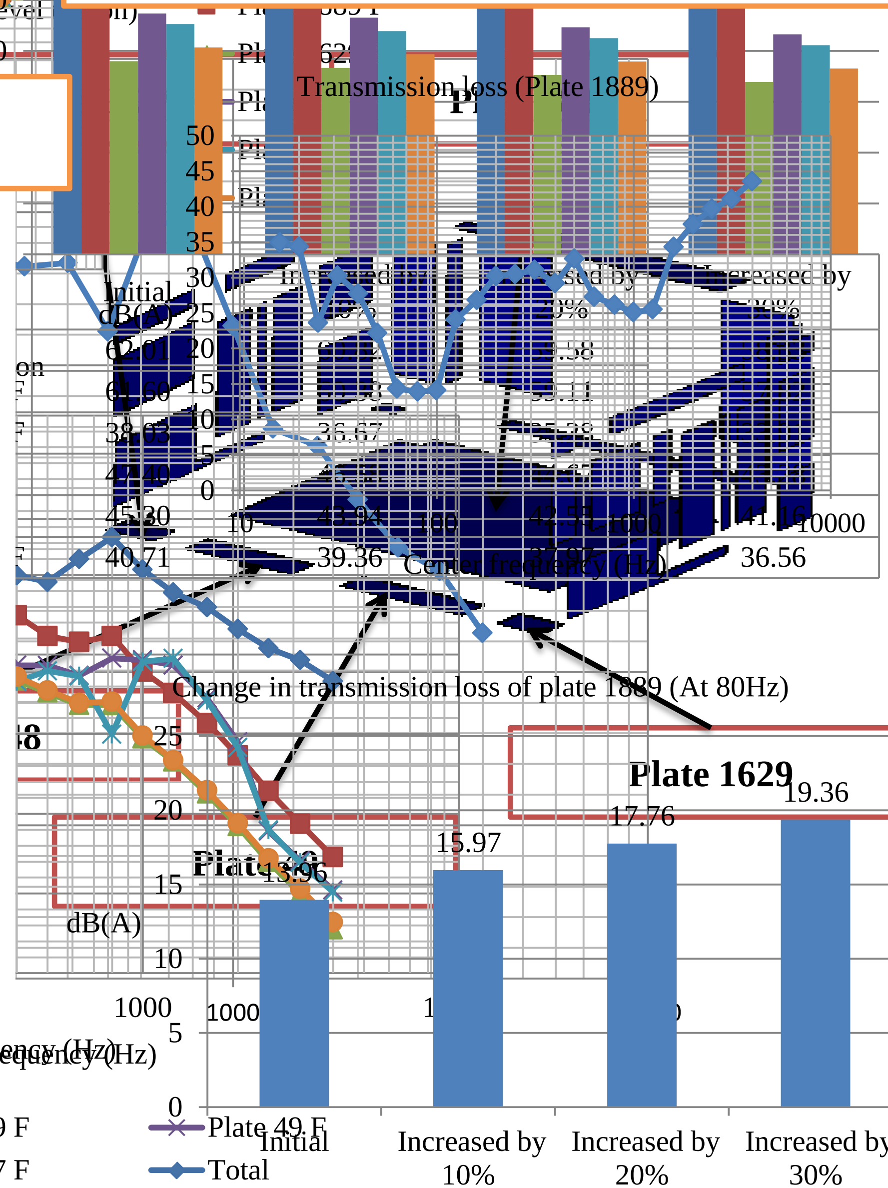
Third SEA analysis is performed at

**Salon (Main deck)**

**Plate 1889**




**Life boat store room (Lower deck)**



## Conclusion

The noise level predicted in each acoustic cavity in this thesis will be even decreased because when modeling the yacht, the noise absorption in the acoustic cavity is considered and calculated only from the noise control treatment. In real condition, there will be some sound absorbing objects inside the room such as furniture, decorative items, floor carpet, etc.

Some of the uncertainties will emerge when referring to damping because the DLF defined here are only the average values from the corresponding damping tests of the material used in the yacht. Uncertainty also comes from the noise spectrum of noise generating sources because the spectra used here are RINA averaged measurement which can be applied for the yachts ranging from 40 to 50m in length.

Fortunately, the influence of damping does not have much effect in the statistical energy analysis and therefore, if one is willing to make only a prediction, SEA is apparently reliable with the advantage of decreasing cost and time consuming.

## Recommendation

- It is recommended to have the actual noise spectrum of noise generating sources on the yacht.
- In order to have the more precise sound pressure level, other noise generating sources apart from main engines and propellers should be added in the analysis if possible.
- Particular damping test of some subsystems which contribute the highest sound pressure levels should be performed in order to obtain better accuracy.
- If possible and if there is enough time, it is suggested to use the hybrid model instead of whole SEA model.

THANK YOU FOR YOUR ATTENTION AND NOW IT'S TIME FOR QUESTIONS AND DISCUSSIONS