Andres Esteve Santos

**MSc Research Project – FEEG 6012**

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# Reducing Noise and Vibrations in Offshore Racing Yachts

*Scoping Study*

"*Sometimes I like to hear the screaming of the foil because it sounds fast, and you are happy about it but then it can get too much, and you just try to avoid it with ear plugs"* [1]

*-Boris Herrmann*

*Skipper Team Malizia Vendée Globe 2020/21*

# Introduction

The International Monohull Open Class Association IMOCA is the governing body behind a series of 60ft offshore racing sailboat designs which follow a "Box Rule" or the IMOCA Class rules which limit geometrical features of the sailing yachts, specify safety requirements, and provide certain components which must be identical across the fleet [2]. This class is used for major ocean racing events such as the non-stop singlehanded round the world race; *Vendée Globe* among other regattas. Their popularity has been growing since its conception in 1991 because they provide fair offshore racing at the highest level whilst allowing flexibility for designers to innovate and create competitive, safe designs yet ensure build budgets remain relatively even.

With recent technological improvements in lightweight materials and fluid dynamic analysis packages boats are increasing speeds significantly compared to the first generations. With the addition of hydrofoils for the previous class rules the achieved speeds by IMOCA's has even further increased with boats now typically exceeding 20kts average speeds, 40kts instantaneous speeds are not a rare sight. The combination of higher speeds, notorious sea states, sail flutter, and hydrofoil/appendage induced vibrations has led to unprecedented noise levels inside the cockpit. It has been reported by multiple IMOCA skippers that the noise and vibrations are compromising their comfort affecting both performance and safety [1].

As an effort to decrease the boats environmental footprint the class has implemented incentives for naval architects to choose sustainable building materials [3]. A new boat for 2022, Team Malizia is featuring non-structural flax components figure 1.

*Figure 1: Flax Hatch on an IMOCA 60. Courtesey of Greenboats*

Flax fibres, a natural alternative to traditional fibres in composite materials are gaining popularity across the automotive, aerospace, and marine industries given its reduced manufacturing CO2 emissions. The mechanical properties of flax epoxy laminates are similar to traditional glass fibre epoxy laminates however experimental tests have shown improved vibration dampening properties when compared to glass or carbon fibres making them an ideal material choice for composite boat building [4]. Natural fibres also set new technical challenges that engineers should consider, flax tends to absorb water and has poor bonding characteristics between fibre and matrix leading to a higher risk of delamination [5].

It is widely known that audible noise is the physical propagation of airwaves proportionally related to the amplitude of the emitting solids vibrations. It will be key to determine key sound emitting areas of the boat as well as the noise transmission path and potential sound absorbing components present in modern IMOCA arrangements [6].

Given the previous discussion, Greenboats a flax fibre boat builder and sustainable composites consultant is interested in reducing noise and vibration onboard IMOCA's by incorporating hybridized flax carbon laminates in future boats. This research paper is a result of their interest in collaborating with the universities MSc Research Project programme.

## Literature Review

Mitigating noise and vibration requires a noise control strategy as illustrated in figure 2 two main areas to investigate are the noise source and the transmission path. For the case of an Open 60 the noise sources are predominantly driven by slamming events and continuous appendage induced vibrations. Noise will be transmitted by the composite structure dynamic properties (flax-carbon) and internal air. Existing literature regarding noise source and transmission will be discussed separately.

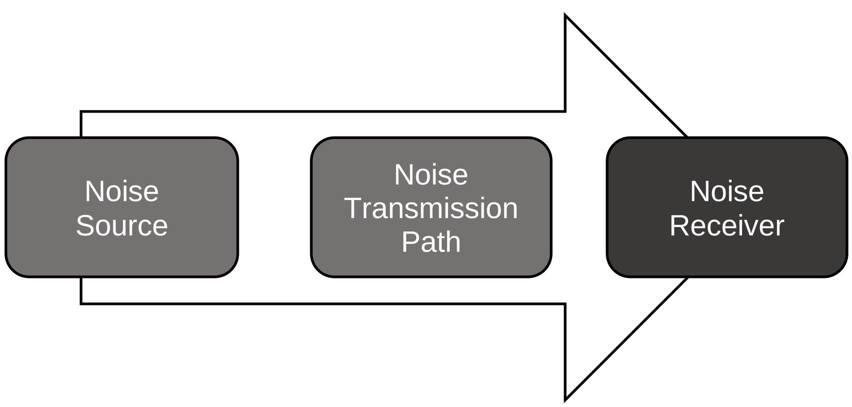



*Figure 2: Noise Control Strategy "adopted from [14]"*

## *Flax-Carbon Dynamic Properties*

Flax fibres have been widely studied on its own, specifically their mechanical properties as a textile without composite lamination. There is a wide interest from the marine, aerospace, sports, rail, wind, and automotive industries to accelerate their development as an alternative to traditional composites specially in structural applications. Studies regarding noise and vibration dampening are on the rise, the automotive industry in particular has studied natural fibre applications for noise control in car interiors mostly with thermoplastic natural fibre composites. Necessary information to conduct this study will be the vibration dampening properties of hybridized carbon and flax epoxy composites for specific use in racing yachts.

The principal characteristic that is likely to reduce noise onboard IMOCA's and other noise constrained structures using flax fibres are its viscoelastic properties. Figure 3 shows the typical viscoelastic behavior of flax composites. In contrast with synthetic fibres, natural fibres with organic impurities inherently transfer kinetic energy into heat when vibrated due to their cellulose content thus having better damping ratios, this effect is most notable at low frequencies, thus the viscoelasticity of flax is frequency dependent [7].

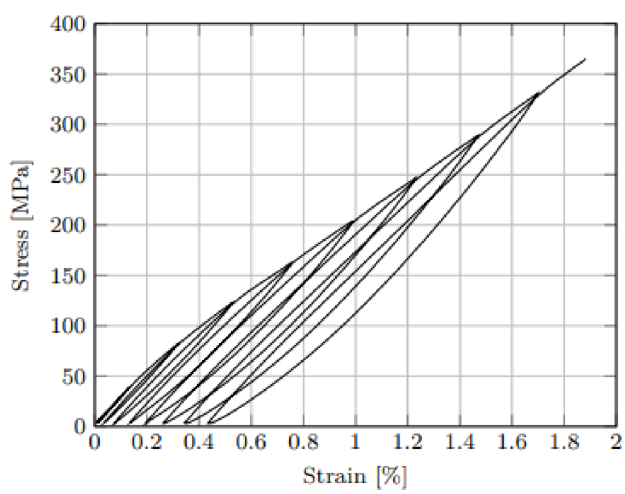



*Figure 3: Typical stress Strain Curves and Relaxation of Viscoelastic Flax Epoxy [8]*

Hybridized Flax Carbon laminates have limited exposure to academia and to practical applications however there are certain studies will be very valuable to this research project. A key parameter to determine a material's vibration properties the damping ratio in this case we are interested in carbon flax composites. Assarar et al, where able to experimentally determine the specific damping ratios of different carbon flax plates by a free-free impact hammer test from which dynamics and strain data in each laminate direction (11,22,66) could be converted into in-plane strain energy. The study then derived the damping ratio from in plane strain energy and compared the results to a finite element analysis study where results showed good agreements for specific damping ratios across a frequency range. It was also concluded that even at high frequencies (dampening of significantly reduces for composites) flax has improved damping properties over carbon dominant hybrid laminates. Dampening coefficients are independent of vibration amplitude however Highly dependent on laminate stack configuration with a [C/F/C/C/F/C] providing 15% improved dampening over non hybrid carbon and minimal loss in bending modulus [7]. When practical work begins it will be important to investigate in detail the aforementioned studies method and inputs for final element analysis.

Unlike isentropic materials there are a number of properties associated with dampening characteristics of composite structures including, fibre, matrix and core mechanical properties, fibre orientation, volume fibre ratio, laminate stack configuration, laminate type (twill, UD, etc..), void content, interlaminar shear, component geometry and frequency of vibration among others. The difficult in analysis imposed by the complexity of composites is also an opportunity to tailor lightweight structures specifically to absorb vibrations from specified directions whilst retaining structural reliability. Given the amount of dependent variables needed to accurately determine the damping ratio of a structure a simplified approach is likely to be a better approach given the scope of this project. A novel approach to estimate damping ratios has been proposed by Hashin further studies by Yim and Jang implemented a correction factor α to Hashin’s equation the resultant equation to for estimating the damping ratio is describe in equation 1 [9].

$$\psi_c = \frac{\psi_m(V_m)}{V_m + (\frac{E_c}{E_m})^{\alpha}} \qquad (1)$$

If adequately adopted Yim and Jang’s approach would yield al necessary inputs for the FEA simulation of more complex geometries. Performing modal analysis and harmonic acoustic studies could result in a quantitative method of estimating noise levels of racing yachts.

## *Yacht Noise and Vibration Sources*

Vibration, and dynamic response of ships is a subject area of it’s own, modern racing yachts are no exemption. Specifically, literature has address keel flutter and seakeeping behavior of Open 60’s and Volvo Ocean 65’s. [10] [11] [12] [13]. Recent information regarding foiling IMOCA’s is not publicly available given the recent developments in hydrofoil assisted monohulls (no later than 2015) and competitiveness of designs. Keel flutter is a phenomenon that occurs at low frequencies hence they are not the principal source of noise on modern IMOCAS. Additionally, keels have simpler dynamic modal shapes compared to hydrofoils were high noise levels have been reported by skippers [1]. Audio signal processing of videos documenting the sound problem on IMOCA’s could provide information to artificially reproduce vibrations seen whilst sailing.

## Aims & Objectives

This research project will aim to develop a method of quantifying noise and vibration reduction on IMOCA boats by simulating the dynamic behavior of a specific area in the yachts. From literature informed decisions optimal configurations of hybrid carbon-flax laminates will be implemented in key areas to reduce vibrations and perceived noise levels for the skippers. A finite element study will simulate the sound levels inside the IMOCA cockpit comparing current hull lamination noise with a novel hybrid flax structure.

- Develop a fundamental understanding of noise and vibration characteristics and sources on IMOCA 60 sailboats. Figure 4 shows areas with high noise levels, a specific component will be picked to study its specific effects.
- Propose a literature informed hybrid carbon flax layup for noise reduction.
- Establish a methodology to quantify noise reduction levels with FEA
- Validate FEA methodology with comparison to experiments or previous literature.
- Evaluate results of current boats and proposed changes with sound pressure level graphics.

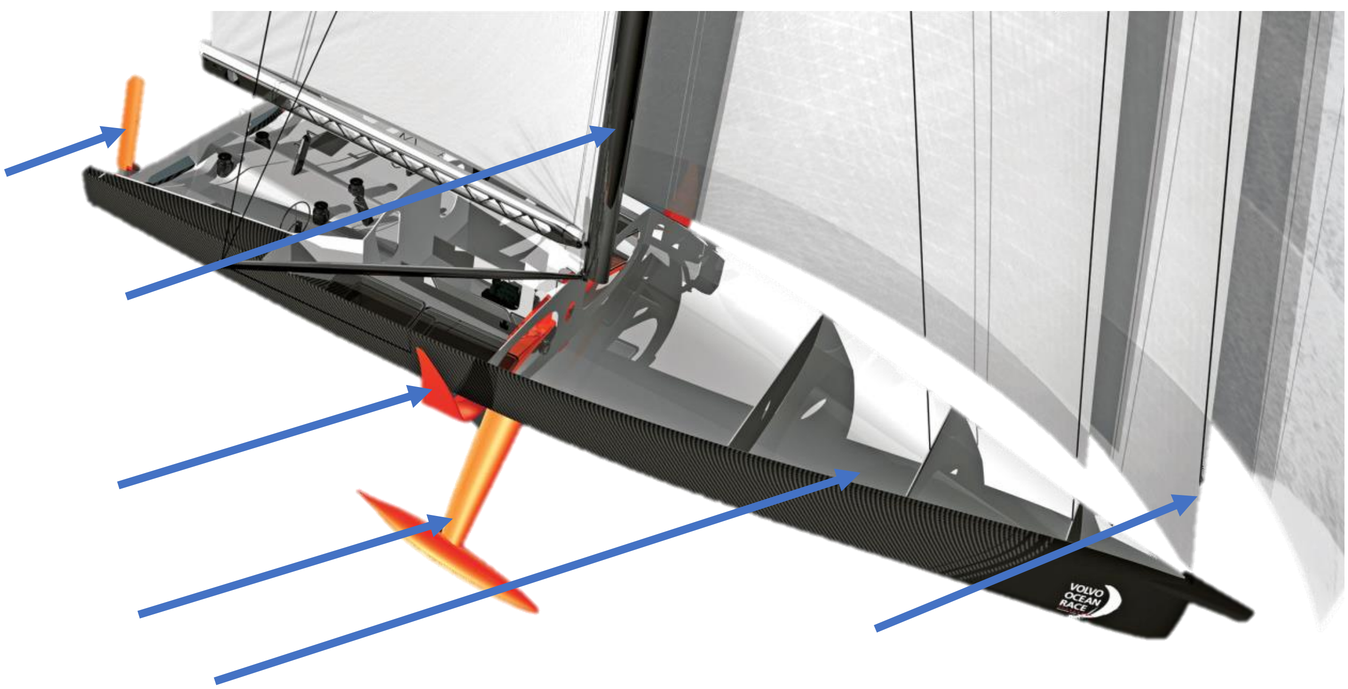
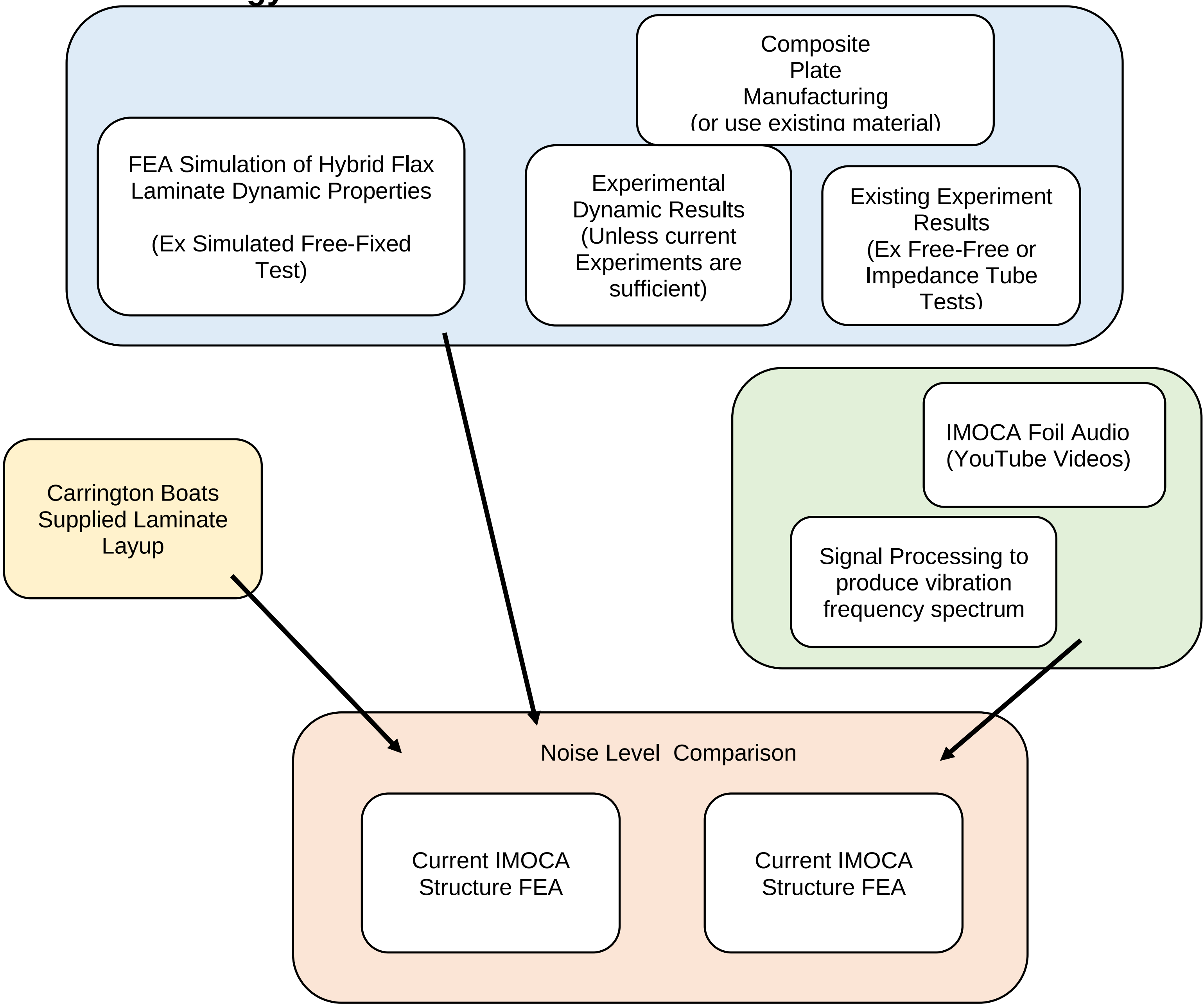


*Figure 4: High Noise Emission Components Onboard IMOCA boats*

## Methodology




### *FEA Sound Quantification Methodology*

1. Model a simplified IMOCA section geometry with current composite layup in ANSYS ACP
2. Static Structural Analysis: Generate pre-stress on components
3. Modal Analysis. Obtain Modal Shapes
4. Random Vibration: From known data and pre evaluated acceleration spectrum (Acceleration spectrum determined from Youtube Videos)
5. Harmonic Acoustics: Sinusoidal excitation source from Random Vibration: Obtain expected Sound Pressure Level Graphs

## References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# MSc Research: Reducing Noise and Vibrations in Offshore Racing Yachts with Natural Fibre Composites

**Andres Esteve: MSc Maritime Engineering Science**
**Supervisor: James Blake**

| 1/31/2022 | 1/28/2021 | 4/22/2022 |
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| START DATE | END DATE | LAST UPDATE DATE |

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| | 8-Apr | 15-Apr | 22-Apr | 29-Apr | 6-May | 13-May | 20-May | 27-May | 3-Jun | 10-Jun | 17-Jun | 24-Jun | 1-Jul | 8-Jul | 15-Jul | 22-Jul | 29-Jul | 5-Aug | 12-Aug | 19-Aug | 26-Aug | 2-Sep | 9-Sep | 16-Sep | 22-Sep |
| | | V | Scoping Study | | | | | Exam Weeks | | | | | | Poster Progress | V | V | | | | | 1st Draft | | Present | | Final Paper |
| **Scoping** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Preliminary Lit Review | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | |
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| Risk Assesment | | | ■ | | | | | | | | | | | | | | | | | | | | | | |
| **Simplified FEA Model** | | | | | | | | | | | | | | | | | | | | | | | | | |
| FEA Practice | | | | ■ | ■ | ■ | ■ | | ■ | | ■ | | | | | | | | | | | | | | |
| FEA Dampng Correltions | | | | | | | | | | | | | ■ | ■ | | | | | | | | | | | |
| **Simplified Composite** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Composite Lamination* | | | | | | | | | | | | ■ | | | | | | | | | | | | | |
| Dynamic Experiments** | | | | | | | | | | | | | ■ | | | | | | | | | | | | |
| External Property Data Collection | | | | | | | | | | | ■ | ■ | | | | | | | | | | | | | |
| **Full FEA Model** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Implement new flax-carbon layup | | | | | | | | | | | | | | | | | ■ | ■ | | | | | | | |
| Current IMOCA layup | | | | | | | | | | | | | | | | | ■ | ■ | | | | | | | |
| FEA Validation | | | | | | | | | | | | | | | | | | ■ | ■ | | | | | | |
| FEA Results comparison | | | | | | | | | | | | | | | | | | | | ■ | ■ | | | | |
| **Documentation** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Re- Visit Scoping Methodology | | | | | | ■ | | | | ■ | ■ | | | | | | | | | | | | | | |
| Simplified FEA write up | | | | | | | | | | | | ■ | ■ | | | | | | | | | | | | |
| Physical Modeling Write up*, ** | | | | | | | | | | | | | | ■ | | | ■ | | | | | | | | |
| Final FEA Results Comparison | | | | | | | | | | | | | | | | | | | | ■ | ■ | | | | |
| Poster Creation | | | | | | | | | | | | | ■ | ■ | | | | | | | | ■ | ■ | | |
| Final Draft Edits | | | | | | | | | | | | | | | | | | | | | | | | ■ | ■ |

Notes: *Composite manufacturing will only be done if no suitable sample for testing is found. **Testing will only be done if there is insufficent porperty data collected externally.