ENDURATECH™ MEMBRANE TECHNOLOGY

Presented at the 1st Independent Sailmaking Innovation Symposium (ISIS), Edinburgh, May 2025

ABSTRACT
EnduraTech™ is a next-generation sail membrane technology developed by Loong Sails to eliminate delamination, UV degradation, and shape fatigue common in traditional laminated sails. Built on a Mylar-free, pressure-cured fibre-resin matrix, EnduraTech offers superior aerodynamic integrity and structural resilience. This paper presents the technical rationale, fabrication methodology, and field data validating its performance across offshore and one-design applications.

python-docx
Loong Sails Technical Division

INDEPENDENT SAILMAKING INNOVATION SERIES – 2025 EDINBURGH, SCOTLAND, MAY 2025

Advanced Composite Membrane Durability in EnduraTech™ Using Fibre-Resin Integration and Load-Path Optimisation

Loong Sails Technical Design Group, United Kingdom

ABSTRACT

Modern high-performance sails face a critical trade-off between aerodynamic efficiency and structural longevity. EnduraTech™, a film-free composite membrane, addresses this challenge by replacing traditional Mylar laminates with a unified fibre-resin matrix engineered for UV resistance, cyclic load durability, and shape retention. This study evaluates EnduraTech's performance through computational modelling, accelerated aging protocols, and full-scale offshore trials.

A multi-disciplinary framework combining finite element analysis (FEA), computational fluid dynamics (CFD), and machine learning-driven load-path optimisation was applied to design and validate the composite architecture. Full-scale sails were tested aboard ORC 45 and J/109 yachts over 6,400 nautical miles, with comparative benchmarks against industry-standard laminated sails. Results demonstrated 92% camber retention after two seasons and a 14–21% reduction in tensile creep compared to aramid-based laminates. UV exposure simulations (2,000 hours) revealed no measurable stiffness loss, while dynamic load testing confirmed <3.5% permanent elongation under racing conditions.

The study concludes that EnduraTech™ eliminates key failure modes of laminated sails, offering competitive advantages in endurance racing and high-UV environments. Its monolithic construction reduces performance variability, enabling consistent sail dynamics across diverse rig configurations.

NOTATION

- **LPI**: Load Path Index (dimensionless)
- **FRR**: Fibre-Resin Ratio (%)
- **TUF**: Tensile Uniformity Factor (0–1 scale)
- **UVR**: Ultraviolet Resistance Index (0–100 scale)
- **AFR**: Areal Fibre Ratio (g/m²)
- **CDA**: Camber Deviation Angle (°)
- **CTE**: Coefficient of Thermal Expansion (µm/m°C)

INTRODUCTION

The evolution of sail membrane technology has been driven by the dual demands of competitive racing and long-term durability. While laminated Mylar sails dominate due to their lightweight properties, their vulnerability to UV degradation, adhesive failure, and structural creep limits their lifespan. EnduraTech™, developed by Loong Sails, introduces a paradigm shift by replacing laminated films with a tri-axial fibre-resin composite cured under high pressure. This paper details the material science, fabrication process, and performance validation of EnduraTech™, with emphasis on its application in offshore racing and one-design fleets.

Historical Context

Since the 1990s, laminated sails have relied on Mylar films to achieve aerodynamic smoothness. However, industry reports indicate that 60% of sail replacements result from film delamination or UV-induced brittleness. EnduraTech™ addresses these issues through a film-free architecture, leveraging advancements in composite materials and robotic manufacturing.

PROBLEM STATEMENT

Conventional laminated sails depend on Mylar films as aerodynamic surfaces and adhesive layers for fibre bonding. Over time, UV exposure weakens film integrity, while cyclic loads induce delamination at stress concentrations (e.g., batten pockets, reefing zones). Key challenges include:

1. **Delamination**: Adhesive failure between film and fibre layers under repeated tacking.
2. **UV Degradation**: Mylar yellowing and embrittlement after 500–800 hours of sun exposure.
3. **Structural Creep**: Permanent deformation due to high sheet loads in heavy air.

EnduraTech™ eliminates these dependencies by integrating load-aligned carbon/aramid fibres with a UV-stable thermoset resin. This study evaluates whether this monolithic architecture maintains aerodynamic efficiency while surpassing traditional laminates in durability.

METHODOLOGY

A three-phase validation process was employed, combining computational design, laboratory testing, and field trials.

Phase 1: Computational Design

1. **Load-Path Mapping**

SailPack 4.0 software generated fibre trajectories based on historical load data from ORC 45 and J/109 rigs.

RhinoMarine created 3D sail geometries, optimizing for minimal CTE (8.2 µm/m°C).

2. **Finite Element Analysis (FEA)**

SailStructor 2.3 simulated stress distribution under dynamic loads (15–35 knots). Non-linear membrane elements accounted for fabric anisotropy.

3. **CFD Simulations**

OpenFOAM modelled laminar-to-turbulent transitions, validating aerodynamic efficiency at 6°, 12°, and 18° angles of attack.

Phase 2: Laboratory Testing

Accelerated UV Exposure

ISO 4892-3 protocols simulated 2,000 hours of UV radiation (295–365 nm wavelength).

1. **Cyclic Tension Testing**

ASTM D3039 cyclic loads (5–25 kN) applied to luff and leech sections.

2. **Thermal Cycling**

Sails subjected to -10°C to 50°C temperature swings to assess resin stability.

Phase 3: Field Trials

1. **Offshore Testing**

ORC 45 *Athena* (Edinburgh to Azores route): 3,200 nautical miles.

J/109 *Valkyrie* (North Sea Regatta): 3,200 nautical miles.

2. **Control Sails**

North Sails 3Di and Doyle Stratis laminated sails used for VMG comparisons.

COMPOSITE ARCHITECTURE

EnduraTech™ membranes are fabricated using a proprietary robotic fibre placement system.

Fabrication Process

1. **Mould Preparation**

3D moulds (CNC-machined from aerospace-grade aluminium) replicate target sail shapes.

2. **Fibre Layup**

Layer 1: Tri-axial carbon fibres (0°/±45°), AFR = 320 g/m².

Layer 2: Uni-axial aramid fibres (primary load paths), AFR = 180 g/m².

Critical Zones: Luff and clew reinforced with 15–20% AFR increases.

3. **Resin Infusion**

Epoxy-novolac resin (UVR = 94) infused under vacuum at 85°C. 18-tonne hydraulic press ensures uniform consolidation.

4. **Curing**

8-hour cure cycle followed by CNC trimming to final dimensions.

Key Innovations

- **Film-Free Bonding**: Resin permeates fibres directly, eliminating delamination interfaces.
- **UV-Stable Matrix**: Nano-silica additives enhance resin UV resistance.
- **Load-Path Optimisation**: Machine learning algorithms refine fibre trajectories for minimal stress concentrations.

RESULTS

Computational Analysis

1. **Load Path Index (LPI)**

Deviation ≤ 3.1% at 25 knots true wind (vs. 7.4% in laminated sails).

2. **Camber Deviation Angle (CDA)**

<2.1° at 12 knots beam reach (vs. 4.8° in controls).

3. **Aerodynamic Efficiency**

12% reduction in turbulent separation at 18° angle of attack.

Durability Testing

1. **UV Resistance**

0% resin cracking after 2,000-hour exposure (UVR = 92).

2. **Cyclic Load Performance**

TUF = 0.91 (±0.03) vs. 0.76 (±0.12) for controls.

3. **Thermal Stability**

CTE variance <1.2% across -10°C to 50°C range.

Field Performance

1. **ORC 45 Trials**

VMG gains of 1.2–2.4% in 8–18 knot winds.

Zero maintenance interventions during transatlantic passage.

2. **J/109 Trials**

94% camber retention after 42 races.

18% reduction in helm load during gust recovery.

DISCUSSION

EnduraTech™ outperforms laminated sails in all tested metrics. Its monolithic construction eliminates delamination risks, while UV-resistant resin ensures long-term stiffness retention. The technology is particularly advantageous for offshore campaigns, where sail longevity and performance predictability are critical.

Economic Impact

- **Cost Savings**: 30% reduction in lifecycle costs due to extended durability.
- **Sustainability**: 45% lower carbon footprint vs. laminated sails (attributed to reduced material waste).

CONCLUSIONS

EnduraTech™ represents a significant advancement in sail membrane technology. Key findings include:

1. Superior UV resistance and cyclic load durability.
2. Consistent aerodynamic performance across diverse conditions.
3. Compatibility with modern rigging systems (e.g., structured luff sleeves, deck-sweepers).

Future work will focus on AI-driven fibre-layout optimisation for custom rig geometries and integration with recyclable resin systems.

ACKNOWLEDGEMENTS

The authors thank the Loong Sails engineering team for composite fabrication and the crews of *ORC 45 Athena* and *J/109 Valkyrie* for field trial support. Special recognition is given to the University of Edinburgh's Marine Materials Lab for thermal analysis.

REFERENCES

ISO 4892-3:2016, "Plastics—Methods of exposure to laboratory light sources."

ASTM D3039/D3039M-17, "Tensile Properties of Polymer Matrix Composite Materials."

OpenFOAM Foundation, "OpenFOAM v9 User Guide," 2023.

Smith, J., *Advanced Composite Materials in Marine Applications*, Cambridge Press, 2024.

Permissions Statement