Fluid–Structure Interaction of a Triple-Wingsail System

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Key conclusions

- The upstream wingsail experiences the largest deformation due to aerodynamic interaction within the sail array.
- Wake interaction reduces aerodynamic loads on downstream sails.
- Structural oscillation frequency is close to the natural frequency of the wingsail, indicating strong aeroelastic coupling.
- Aeroelastic deformation slightly affects lift but has stronger influence on drag and spanwise load distribution.
- Downstream sails are more sensitive to unsteady wake-induced aerodynamic fluctuations.

Background & Aim

Rigid wingsails are promising for wind-assisted ship propulsion, but practical applications often require multiple sails. In such systems, wake interaction and structural flexibility are coupled.

This study investigates how aerodynamic interaction in a triple-wingsail system affects deformation, oscillation, and aerodynamic loads.

Study case

Three apparent wind angles were examined: β = 60°, 90°, and 120° (**Fig. 1**).

The freestream velocity was fixed at 8 m/s, and the angle of attack was fixed at the operating condition corresponding to high thrust generation.

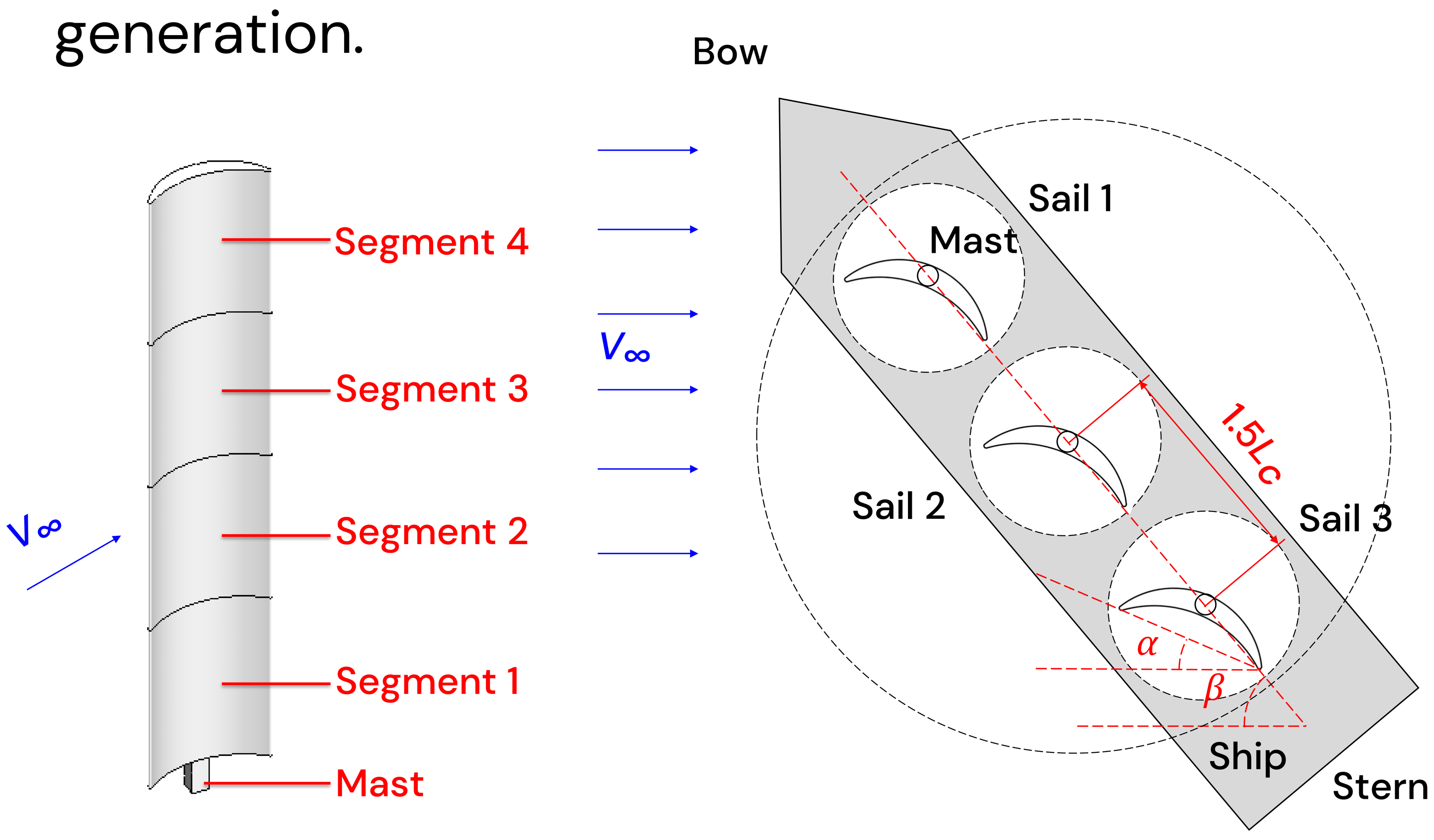


Fig 1. Wingsail structure and triple-wingsail arrangement

Methods

The triple-wingsail system was simulated using a two-way coupled FSI framework.

- **Fluid**: three-dimensional CFD simulations with the IDDES turbulence model.
- **Structure**: dynamic finite element analysis.

Selected results

- **Aerodynamic loads (Fig. 2).** Flexibility slightly changes mean lift but has a stronger effect on drag and load fluctuations, especially downstream.
- **Structural response.** Crossflow deformation dominates. Sail 1 deforms most, while Sail 3 deforms least due to reduced inflow and wake effects.
- **Aeroelastic oscillation (Fig. 3).** All sails show periodic oscillations near the natural frequency, indicating strong aeroelastic coupling.
- **Spanwise load distribution.** Sail 1 produces the highest lift. Middle segments carry higher loads than root and tip regions.

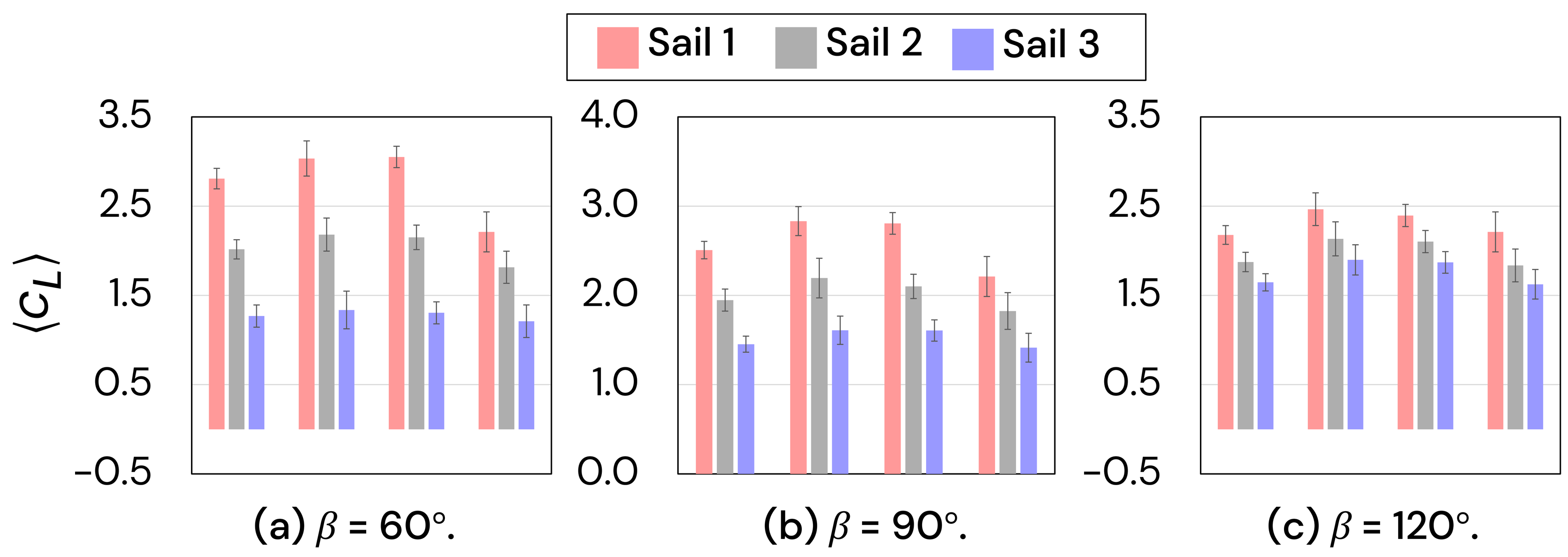
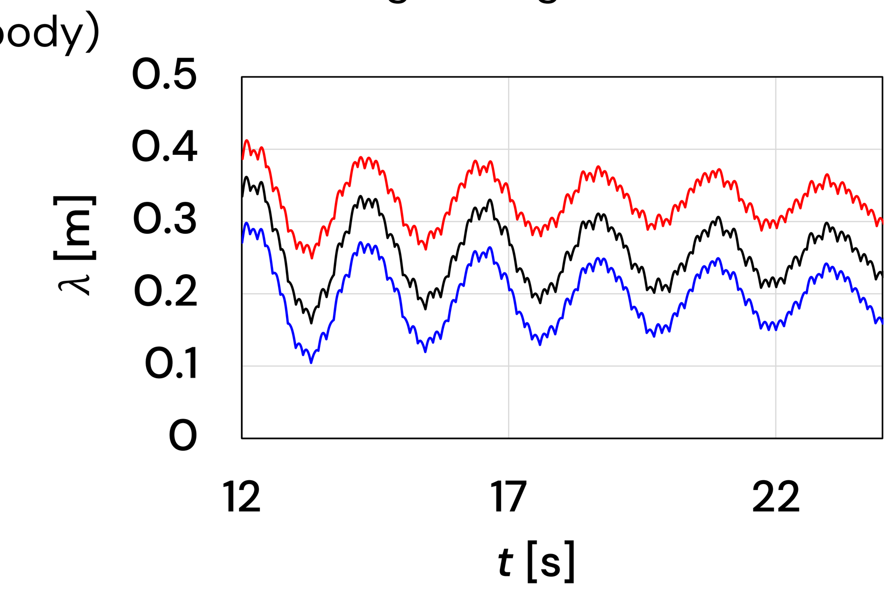


Fig 2. Time-averaged lift force coefficients of each wingsail segment according to FSI analyses (flexible body)

Fig 3. Time history of the total tip displacement β = 60°.



Future direction

Future work will examine aeroelastic effects under realistic sail spacing, wind speeds, and ship motions to support stable and efficient large-scale wingsail design..

Full text is available via:

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