

Performance Optimization of a Whale-Inspired Oscillating Foil for Auxiliary Cargo Ship Propulsion

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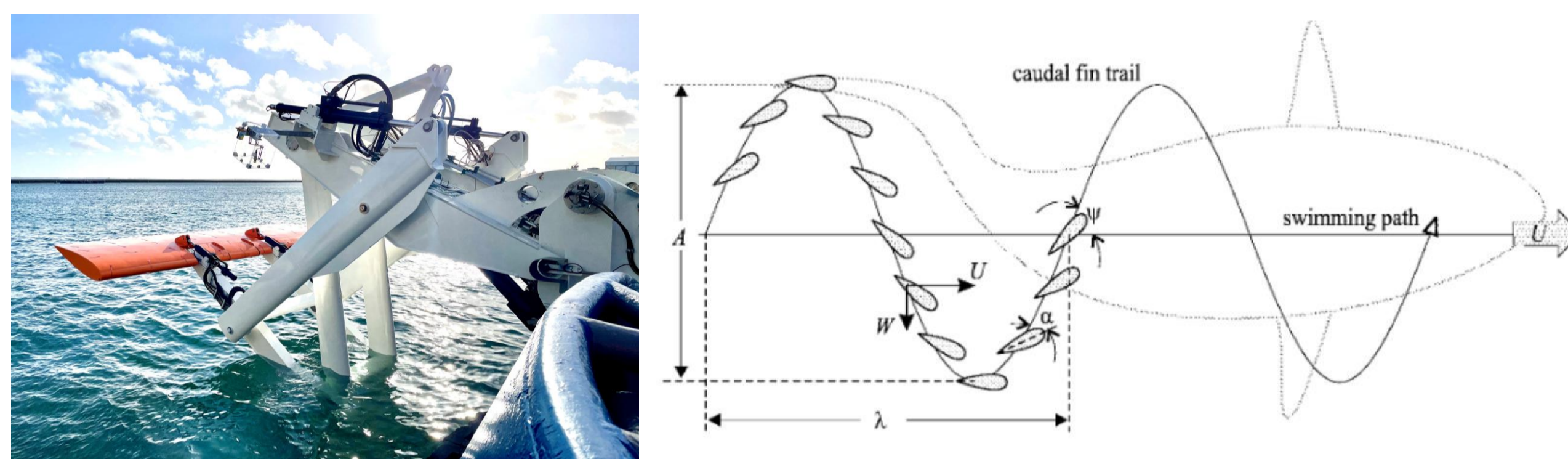


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Bio-Inspired Foils for Auxiliary Ship

Reducing fuel consumption and emissions in cargo shipping requires auxiliary propulsion systems capable of adapting to diverse ships, routes and operational conditions. Whale-inspired oscillating foils provide a promising bio-inspired solution, but large-scale deployment demands tailored geometry and control strategies for each individual ship and route. This work investigates a hybrid passive and active oscillating foil system that harnesses ship and wave-induced motions while actively controlling its kinematics. A dedicated optimization framework is proposed to simultaneously optimize foil geometry and motion control, maximizing propulsion performance for each operational scenario.



(a) First sea deployment of the Bluefins system (2025)

(b) Oscillatory movement of the whale's caudal fin for propulsion (Sfakiotakis, Lane and Davies, 1999)

Figure 1. From nature to technology: inspired by whale tails

Gaussian Process-Based Optimization

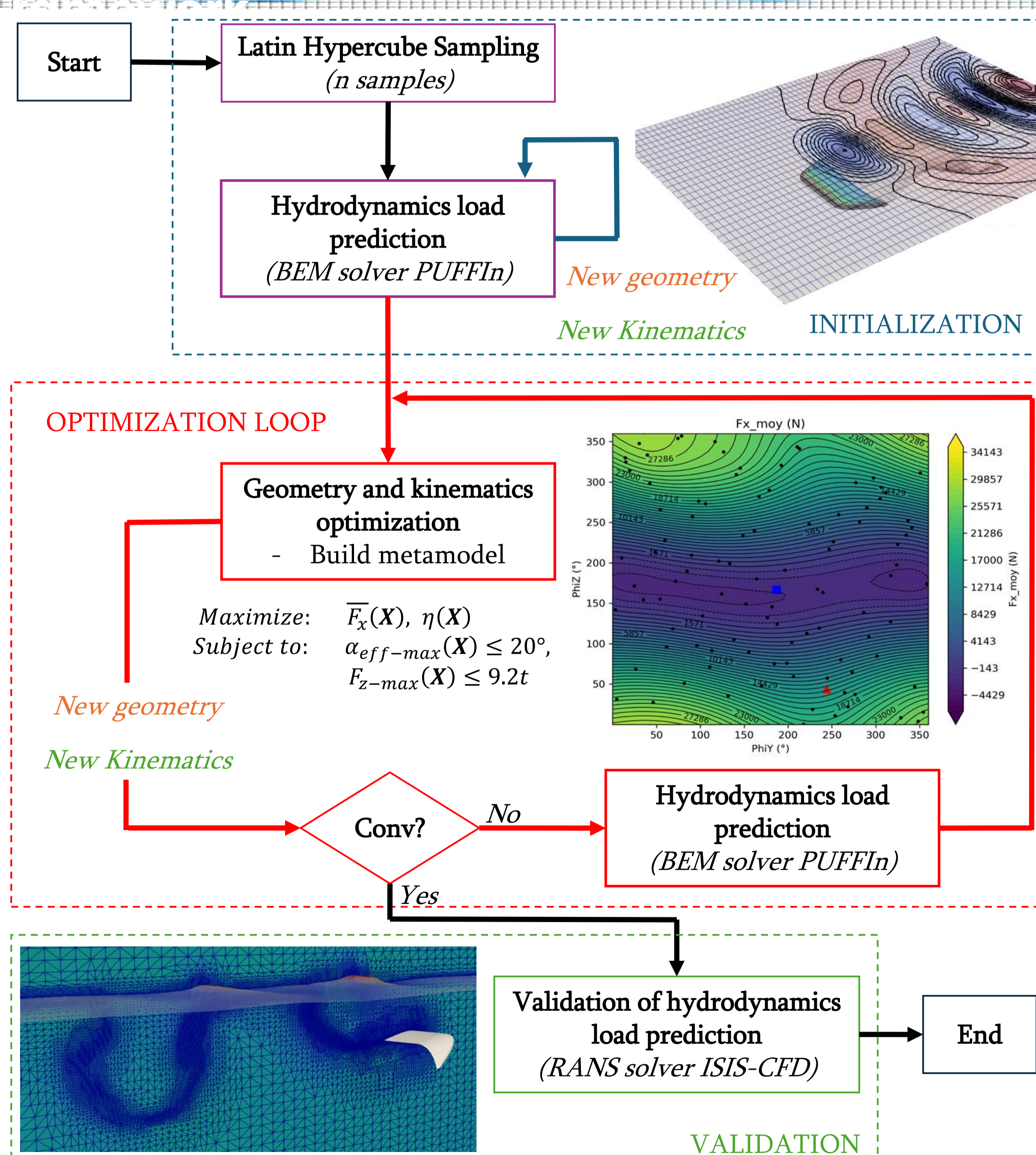


Figure 2. Surrogate-based optimization strategy

Industrial-Scale Foil Optimization for Sea

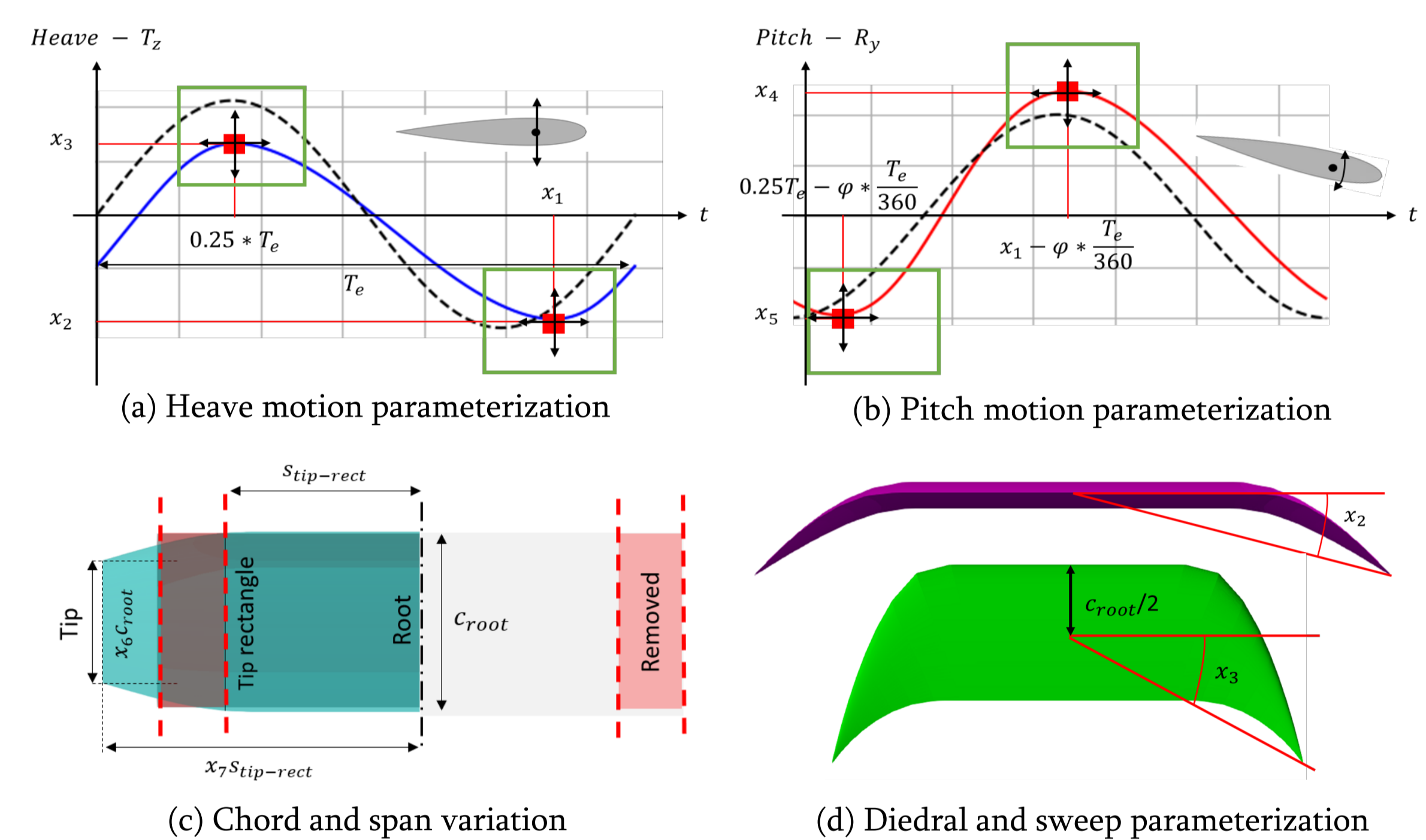


Figure 3. Foil geometry and kinematics parameterization

The developed optimization tool enables rapid prediction of the optimal foil geometry and kinematics under simplified operating conditions. Foil motion is defined by two degrees of freedom: heave and pitch. Both classical sinusoidal trajectories and more general spline-based trajectories are tested, while geometry variations include span, chord distribution, dihedral and sweep angle. The objective is to maximize average thrust and hydrodynamic efficiency while respecting constraints from the real industrial system.

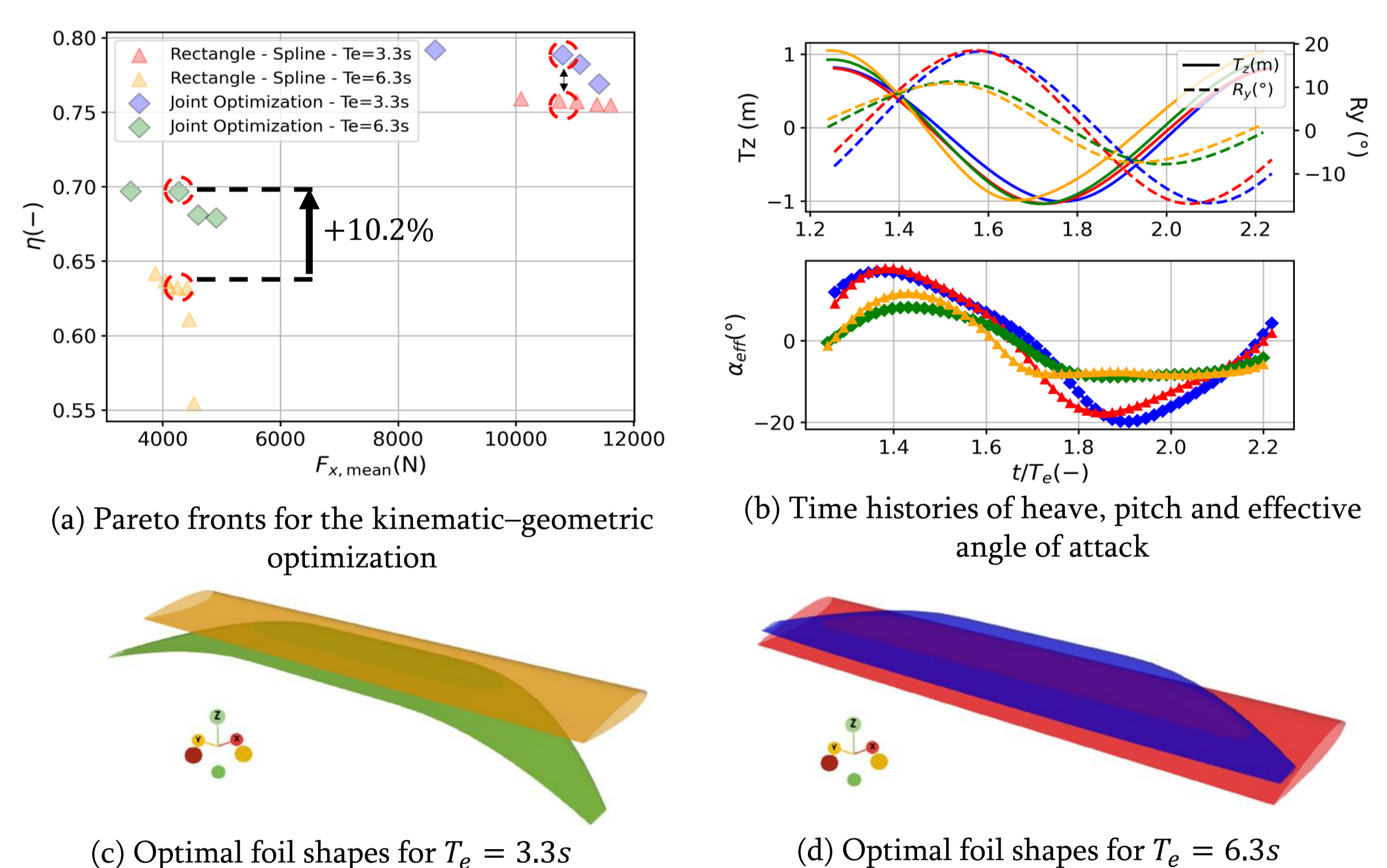


Figure 4. Optimization results for two oscillation periods

Key results

- Bio-inspired geometries and spline-based kinematics **improve propulsion efficiency by up to 10.2%** at fixed mean thrust, while remaining computationally efficient (2 days per optimization, 10 variables, 8 CPUs).
- The resulting optimized foil has been selected for upcoming Bluefins sea trials.



Figure 5. Optimized foil shape for 2026 sea trials