XI International Conference on Computational Methods in Marine Engineering

High Efficiency Swimming using Hydrodynamic Eigenmode Decomposition

Jack Preuveneers[1,*], Amanda Smyth[2] and Luca Di Mare[1]

[1] Oxford Thermofluids Institute, Department of Engineering Science,
University of Oxford, Osney Mead, Oxford OX2 0ES

[2] Oxford Environmental Fluid Mechanics Group, Department of Engineering Science,
University of Oxford, Parks Road, Oxford OX1 3PJ
[*] jack.preuveneers@eng.ox.ac.uk

ABSTRACT

Underwater swimming can exhibit remarkable efficiency, as evidenced by adept aquatic animals. This study introduces a novel approach for systematically uncovering high-efficiency motion patterns in flexible three-dimensional rectangular bodies via hydrodynamic eigenmode decomposition.

By formulating and solving a generalised eigenvalue problem from the governing hydrodynamic equations, we show that the resulting complex eigenvalues cluster into distinct families defined by chordwise and spanwise wavenumbers. The chordwise wave manifests as a travelling wave, whereas the spanwise is a standing wave. The imaginary and real components of these hydrodynamic eigenmodes respectively capture the oscillatory and growth/decay characteristics of the flow, enabling us to pinpoint modes that generate thrust with minimal input.

We further examine how varying the plate's aspect ratio significantly affects the clustering and spacing of these eigenvalue families. oderate combinations of chordwise and spanwise wavenumbers yield especially high propulsive efficiency. Moderate combinations of chordwise and spanwise wavenumbers yield especially high propulsive efficiency, while higher chordwise wave numbers correspond to shorter wavelengths and larger imaginary eigenvalues. An inverse relationship also emerges between reduced frequency and spatial growth rate. These findings underscore a direct link between eigenvalue characteristics and optimal kinematic strategies. By bridging the gap between hydrodynamic theory and biologically informed design, this hydrodynamic eigenmode based framework offers a powerful route for selecting and tuning modes in biomimetic or engineered systems. By focusing solely on the hydrodynamic response - without introducing structural complexities - this approach provides a promising route toward advanced, energy efficient designs for autonomous underwater vehicles and marine robotics.

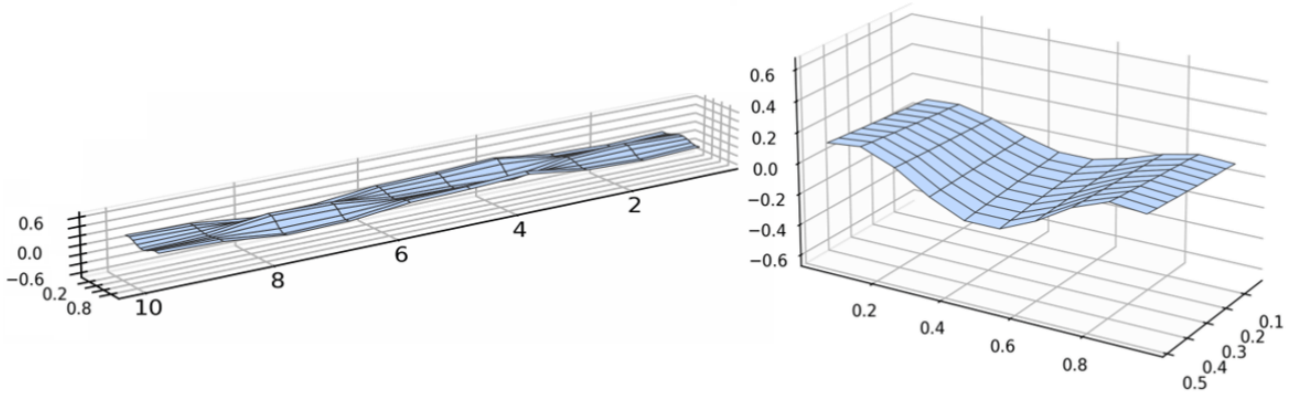

Figure 1: Example of an eigenvector motion patterns, representing variations in aspect ratio