

AERODYNAMIC CHARACTERISTICS ANALYSIS OF BIO-INSPIRED FLYING FISH MEMBRANE WINGS CONSIDERING STATIC AEROELASTIC EFFECTS

Minghao Zhou, Zhigang Wu and Chao Yang*

*School of Aeronautic Science and Engineering, Beihang University
Beijing, 100191
China*

ABSTRACT

With the development of small unmanned air vehicles, demands for high manoeuvrability and adaptability to unstable flow fields have progressively increased. However, rigid wings often suffer from significantly reduced aerodynamic efficiency due to flow separation over their upper surface. In response to this issue, membrane wings, which can passively adapt to the flow, have attracted increasing attention [1]. Research on membrane wings is motivated by the wings of natural creatures, such as insects and bats. Among them, the flying fish, a species capable of locomotion in both aquatic and aerial environments, can utilize its expanded membranous pectoral fins to glide over considerable distances in the air. This capability provides significant inspiration for the membrane wing design of fixed-wing aircraft.

For membrane wings, the configuration and structural stiffness of the support skeleton exert a significant influence on aerodynamic characteristics. While previous theoretical and experimental studies have revealed numerous factors influencing the aerodynamic characteristics of membranes, the majority of the relevant research has concentrated on two-dimensional (2D) models or three-dimensional (3D) models featuring simple geometries. Research on 3D membrane wings that comprehensively considers both the supporting structure and membrane elasticity remains relatively scarce.

Therefore, this study focuses on the 3D membrane wing, bio-inspired by the flying fish pectoral fin, which features a thin elastic membrane supported by a flexible skeleton. To enhance numerical stability and accuracy in analysing this large-deformation fluid-structure interaction (FSI) problem, a strongly coupled algorithm based on a predictor-corrector method is established, as illustrated in Figure 1. The FSI analysis framework is developed by extending the methodology established by Luo et al [2]. Specifically, the coupling problem is solved implicitly using Block Gauss-Seidel iteration and Aitken's under-relaxation is used to improve the robustness of the simulations. The fluid solver employs the open-source software OpenFOAM, whilst the membrane structure utilises the degraded shell method proposed by Yang et al. [3]. The accuracy of the present FSI method is validated against wind tunnel experimental data for the membrane wings reported by Song et al [4].

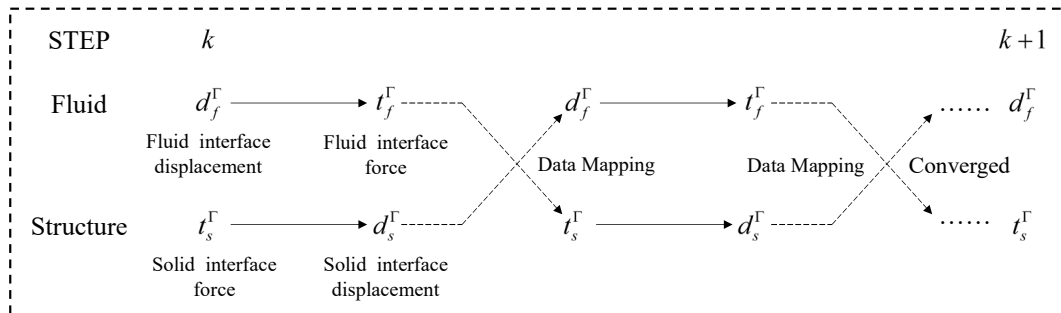


Figure 1: Schematic diagram of FSI scheme.

Subsequently, drawing inspiration from the morphology of the flying fish pectoral fins, simplified membrane wing models with different supporting skeletons are developed, alongside a rigid model established as a control, as illustrated in Figure 2. These models are then analyzed using FSI simulations to investigate the effects of support configuration and structural stiffness on their aerodynamic characteristics and deformation responses. Based on the findings, potential supporting structure forms for improving the aerodynamic performance of the membrane wing are investigated.

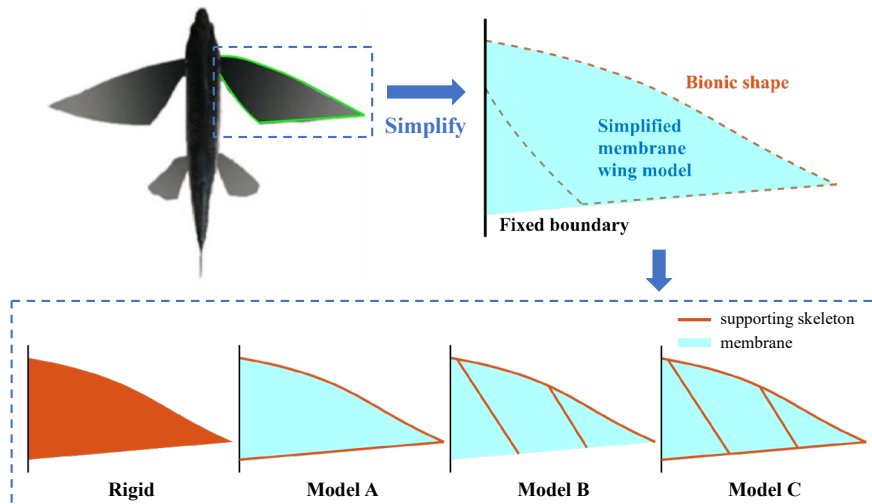


Figure 2: Schematic diagram of membrane wings with different supporting skeletons. The flying fish morphology is derived from reference [5]

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