15th World Congress on Computational Mechanics (WCCM-XV)
8th Asian Pacific Congress on Computational Mechanics (APCOM-VIII)
31 July – 5 August 2022, Yokohama, Japan

Modeling Freely Flying Monarch Butterflies Using a Strongly Coupled High Fidelity Numerical Framework

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Key Words: *Butterfly, Unsteady Aerodynamics, Flight Dynamics, Fluid Structure Interaction*

Insects are impressive creatures due in part to their small size and agile flight maneuvers [1]. Additionally, butterflies can be highly efficient fliers, as evidenced by monarchs having the longest migration amongst insects [2]. To begin uncovering the complex mechanisms enabling monarchs to migrate roughly 80 million times their average body length, high-fidelity modeling tools must be developed. These tools must consider the distinguishing features of monarchs – their low flapping frequency, high Reynolds number (amongst insects), large wings relative to their body, low wing loading, flexibility of their wings, and the highly coupled interplay between the instantaneous wing aerodynamics and dynamic body response.

Many high-fidelity models have been used for the study of butterfly flight to date [3–5]. However, most have neglected the passive wing pitching arising from butterfly's flexible wings. Here, we propose a framework that tightly couples the effects of all three physics solvers using a dynamic relaxation scheme. As such, the highly nonlinear interplay between fluid, body, and passive wing dynamics is efficiently accounted for in each time step. We apply the model to the free flight of monarch butterflies, resulting in stable motion for many periods without any controller. Analysis of the vortex dynamics resulting from the unsteady aerodynamics coupled to the large rotations and undulations of the body will be presented.

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