Theoretical Modeling and Experimental Analysis of the Flight Mechanics of Lepidoptera

By Tyler Wilson
Candidate for Master of Science in Mechanical Engineering

Abstract

Development of micro air vehicles has led to a strong interest in the biomechanics of flapping fliers such as bats, birds, and insects, due to their ability to perform extreme unsteady maneuvers and fly in confined spaces. Determining the methods and mechanisms used by these fliers is a valuable source of bio-inspiration with many potential applications to micro air vehicles and elsewhere. This thesis presents an analysis of Lepidoptera flight, including the development of a numerical model of a flapping Tree Nymph butterfly, as well as the analysis of experimental data from live flight recordings of butterflies.

A numerical model of the Tree Nymph Idea leuconoe was developed to examine the effects of different motion parameters on the longitudinal stability of flight. Independent kinematic parameters were used as inputs to describe the motion of the butterfly's wings and abdomen. The model would then solve for the position and pitch history over the duration of a flight and output all relevant forces and moments. A genetic algorithm was used to find kinematic parameter solutions that achieved the desired flight characteristics.

Experimental data from recordings of live butterfly flights was processed and analyzed to examine the motion of the butterfly's wings and abdomen, and how it related to the insect's flight mechanics. Butterflies were recorded both in free flight conditions, as well as in an open-jet wind tunnel, simulating cross-wind conditions. Two cameras were used in a stereoscopic vision configuration to record the insects' flights, allowing for estimation of 3D position of points on the butterfly in space using tracking software. Postprocessing was used to estimate the position time derivatives in a fixed inertial frame as well as a moving body frame. The experimental data was used to examine the kinematics of butterfly flight, as well as validation of the numerical model.

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