Measurement and Numerical Simulation of a Flapping Butterfly

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1. Introduction

The objective of this study is to clarify the principle of stabilization of motion in living animals. A prospective target may be applications of the principle to intelligent motion control of robots. Concretely, this study considers a flapping-of-wings flight of a butterfly, which is a rhythmical periodic motion, and tries to clarify the principle that enables the flight.

2. Mathematical Model of Butterfly

A butterfly is considered as a rigid multi-body system, and a dynamics model is developed by Lagrange's method. For aerodynamic forces, fundamental computation methods, i.e., a simple method and a vortex method, are introduced to build a simulator.

3. Experiments of Flapping-of-Wings

An experimental system with a low-speed wind tunnel is constructed for fundamental data acquisition of flapping-of-wings motion, where the system measures aerodynamic force and motion simultaneously by a balance and a optical measurement system. The experimental results show the characteristic aerodynamics at wingbeat phase and peeling phase. There exist strong wing tip vortex wakes that might have an effect on aerodynamics (Fig. 1).

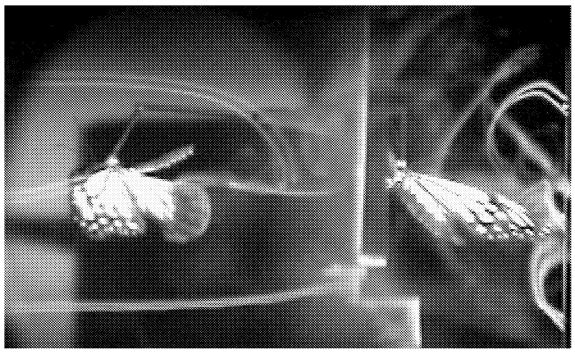

Figure 1: Strong wing tip vortex wakes

4. Effects of Flapping-of-Wings

The above fundamental computation methods are not sufficiently accurate for aerodynamic modeling of the flapping-of-wings. The aerodynamics is reviewed and modified. The following effects are modeled and contained in the vortex method: the interaction of right-and-left wings, the sdmming effect, the downwash induced by wing tip vortices, and the peel mechanism. Numerical simulation shows that the obtained model is considerably accurate.

5. Flapping Trajectory Search

By using the simple method model, a flapping trajectory is searched to realize the steady flapping-of-wings flight. Though it is not a perfect steady flapping-of-wings flight, the obtained flapping trajectory (Fig. 2) is remarkably similar to the trajectory of the experiment.

6. Concluding Remarks

This study has performed the modeling of the butterfly, the experiment for the quantitative data acquisition and the qualitative observation, the simulator construction, and the comparison between the actual and the modeled butterfly. Stability of flight has not shown in simulations yet. Some other effects, e.g., a feedback control, might be essential.

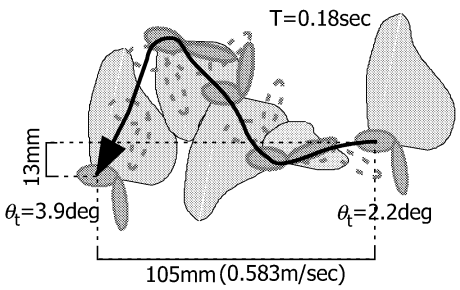

Figure 2: Flapping-of-wings flight of simple method model