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Interactive Multidimensional Optimization of Motion of Flapping Wing with Fluid-Structure Interaction Analysis

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Summary

Flapping flight mechanisms of birds and insects are well known to have excellent flight performances such as VTOL ability, high energy efficiency, rapid turning ability and so on. Thus the Micro Air Vehicles (MAV), which are inch-size flying robots and imitate the flight motion of insects are expected to play an important role in environmental monitoring and life-saving activities in narrow space with complex obstacles. On the other hand, flapping flight itself is accompanied by a very complex phenomenon with highly unsteady fluid-structure interaction. It is very difficult to measure the phenonema as well as to simulate the phenomenon presicely. Full scale 3D simulations of the actual flapping flight of birds and insects are grand challenge problems for multiphysics computational mechanics. In addition, to realize flapping flight with artificil MAV, it is also critical to know how to move the wing appropriately, depending on desired flight motion. This is a kind of multi-optimization problems for shape and structure design of wing as well as control of wing motion. To tackle on such complex and challenging multiphysics problems, we have been performing several studies on computational mechanics. In this presentation, we first describe an efficient partitioned coupling algorithm for FSI problems, which offers the ability to achieve almost identical results as the monolithic algorithms in a robust and more flexible manner. In the proposed approach, non-linearity of FSI problems is mainly treated on the interface between solid and fluid portions using the line search method by minimizing non-equilibrated displacements on the interface in each fixed point iteration. A structural predictor also plays a major role even in the iterative partitioned approach for improvement of convergence performance. Next we present an intensive parametric study on the motion of flapping wing. In the analyses, we employ the dimensional parameters of a hawkmoth model, and perform the parametric study varying amplitude and frequency of flapping, timing of wing rotation, body angle and so on. For each motion determined by the combination of the above motion parameters, we perform a 2D unsteady incompressible fluid flow around flapping wing and calculate magnitude and efficiency of the generated forces in lifting as well as propulsive directions. In each simulation, we perform 2D finite element FSI analysis around several wing sections are performed, and quasi 3D force is estimated by integrating the 2D results instead of performing fully 3D simulation. A number of multidimensional results for different parameters of hawkmoth wing model are provided to an interactive visualization tool of multidimensional solutions. Analyzing the solutions with the interactive tool, we obtain an optimum solution of motion of the flapping

wing in some flight mode. Through comparing the obtained optimum solution with the motion parameters of real hawkmoth in nature, we discuss quantitative properties between motion parameters and flight performance. Such knowledge will be some reference of the design of MAV with flapping wing.