MANEUVERING WITH RIGID FLAPPING FINS

FIRST D. N. BEAL* AND SECOND P. R. BANDYOPADHYAY* AND THIRD A. MANGALAM †

* Naval Undersea Warfare Center
Newport, Rhode Island 02841, USA
BandyopadhyayPR@npt.nuwc.navy.mil

† Tao of Systems Integration, Inc.
144 Research Drive, Hampton, VA 23666

Many swimming and flying animals use flapping fins for maneuvering, hovering, and cruising. These fins lie along a spectrum from low-aspect ratio highly-flexible fins with exceptional control over the instantaneous fin surface shape, such as the sunfish pectoral fin, to higher aspect ratio rigid fins with constant shape, like those of penguins. This study investigates one extreme of that spectrum: a rigid foil with minimal actuation. Seen as a canonical form for flapping propulsion, this allows study and understanding of the basic principles and provides a bound for the hydrodynamic performance of swimming animals.

We performed a series of experiments with a rigid foil sinusoidally flapping in roll and pitch within an otherwise still fluid (i.e. the only fluid motion was induced by the flapping fin itself, such as would occur during hovering). Additional tests were performed in a towing tank at constant forward velocity in order to study the creation of maneuvering and propulsive forces during cruise. The foil actuators were mounted to the carriage via a six-axis load cell, and instantaneous torques and velocities from the roll and pitch motors were used to calculate the hydrodynamic power into the fluid (which is independent of the actuation method used). Regions of separated flow relative to the flapping cycle were measured using thermal anemometers mounted flush with the surface of the fin, illustrating the timing of leading edge separation as an indicator of the instantaneous forces produced by the foil.

The mean forces generated during the hovering experiments lay exclusively in the plane perpendicular to the zero-position of the fin shaft axis. Mean thrust, lift, and power are functions of the pitch amplitude and bias when normalized by the dynamic head defined using the wing flapping velocity. Additionally, the direction of the thrust jet generated is a function of pitch bias alone. Such simplicity eases the creation of an engineering controller.

This elegant simplicity was complicated when a uniform flow was introduced using the tow tank carriage. As speed increases, the flapping frequency and pitch amplitude both must change in order to maintain thrust levels generated during hover. Within the uniform flow mean lift forces are more easily generated and higher efficiencies of thrust development in the downstream direction are possible (reaching a maximum of 55%).

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