ME – PhD Thesis Colloquium

An experimental and computational investigation of pulse-jet propulsion using a clapping body

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ABSTRACT

This work investigates pulse-jet propulsion using a self-propelling clapping body, inspired by the locomotion of animals such as squids and jellyfish. The clapping body consists of two flat plates hinged at the leading edge by a torsion spring. Clapping and subsequent forward propulsion are initiated by the sudden release of the plates, which are initially held apart at an angle ($2\theta_o$). Twenty-four cases have been studied by varying the depth-to-length ratio (d^*= 1.5, 1.0, 0.5), spring stiffness per unit depth, body mass, and initial separation angle ($2\theta_o = 45^{\circ}, 60^{\circ}$). The body motion consists of two phases: an initial rapid acceleration during the clapping motion and a gradual deceleration to rest after the plates have come together. The acceleration phase involves strong coupling between plate and fluid motions, while the deceleration is dominated by the drag force. The wake consists of either a single axis-switching elliptical vortex loop (for d^*= 1.0, 1.5) or multiple connected loops (for d^*= 0.5). In contrast, the body motion is nearly independent of $d^*$and is most sensitive to variations in spring stiffness and θ_o. A relation between translation velocity and these parameters was obtained from linear-momentum balance and conversion of the initial strain energy in the spring to kinetic energies in the body and the fluid. Roughly 80 % of the initial stored energy is transferred to the fluid and 20 % to the body. The experimentally obtained cost of transport lies between 2 and 8 J kg^{-1} m^{-1}, similar to that observed in squids.

To examine how body translation influences the flow field, a comparative study was conducted between the self-propelling body (dynamic) and one that is forward-motion-constrained (stationary). There are large and unexpected differences between the two, including faster clapping and lower thrust coefficients for the dynamic case, emphasizing that results from studies of pulsed propulsion with stationary bodies need careful interpretation.

Finally, three-dimensional simulations were performed using plate-motion data from the experiments. The results show that forward motion lowers the interplate pressure relative to the stationary cases and significantly alters the vortex patterns. A notable finding is an energy deficit between the work done on the fluid by the rotating plates and the kinetic energy in the wake. A similar deficit was found from CFD simulations of axisymmetric vortex rings. In both cases, the energy deficit was equal to a ‘potential pressure energy’ in the vortex cores. This identification of core potential energy provides a new physical term missing from classical vortex-ring energetics.

ABOUT THE SPEAKER

Suyog Mahulkar is a PhD student in the Department of Mechanical Engineering. He works under the guidance of Prof. Jaywant Arakeri and Prof. Raghuram Govardhan. His primary research area is bio-inspired propulsion. He has also worked on several other topics, including a patented drone-spraying nozzle, a patented microfluidic device for oscillatory bidirectional shear stress, gust tunnel development, evaporation on leaf-mimicking surfaces, and a patented jet-assisted vacuum cleaner.