CFD Simulation of Piston-cylinder Jet Flows in Marine Propulsion

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As a result of natural selection, fast moving marine animals choose impulsive modes to swim. Examples are: a squid generates an impulsive jet for thrust through its body muscle contraction, and a fish, through a control of the flapping of its caudal fin, is able to create an impulsive jet with a feature of thrust vectoring. A great amount of experimental work has been carried out to study impulsive jets and the associated vortex rings through the starting flows generated from a piston-cylinder apparatus. The research showed the efficiency advantage of an impulsive jet for propulsion lies in the utilization of the largest possible isolated vortex ring an impulsive jet can generate before its pinch-off from the trailing jet. With growing interests for a practical use of impulsive jet in marine propulsion, numerical simulation capabilities for impulsive jet flows become of obvious importance. Numerical simulation capabilities are challenged by the highly transient and vortical nature in the impulsive jet flows. Most of studies in the numerical simulations for the impulsive jet flows, especially the starting flows from a piston-cylinder apparatus, were for low Reynolds numbers in the scale of marine animals. Few numerical simulations were found for impulsive jetting into a background flow.

CFD solver based on OpenFOAM was applied to simulate the starting flows by a piston-cylinder apparatus at Reynolds numbers from low to high covering marine animals and practical marine propulsors, and with various background flows. Numerical aspects such as numerical schemes, grid sensitivity and convergence quality in terms of the accuracy in capturing the flow vortical structures in the transient flow fields were studied. The numerical simulations were first validated and verified against those from the experimental and numerical studies found in the literature in the low Reynolds number range with and without background flows. The simulation tool was then applied to the predictions of the impulsive jet flows in the high Reynolds number range in practical marine propulsion with background flows.