Parallel Optimization of Fish Shape and Swim Mode by Genetic Algorithm

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ABSTRACT

Aquatic animals, like fish and dolphin, swim much faster and more efficiently than expected from their muscle power. Scientists have been trying to employ the fish propulsion system for vessels, and in reality, several types of robot fish have been already developed. However, it would be impossible, in terms of time and finances, to develop all the possible types of robots and adjust each parameter for the best performance. Due to recent advances in computer and numerical technique, computer-aided modeling of fish and optimization methods have become potent in searching the superior sample efficiently. In the present study, the authors aim to analyze the flow field around a single 2-D fish with fine resolution including the boundary layer and the far-field, and to optimize fish shape and maneuver with Genetic Algorithm (GA). The authors apply time-dependent body-fitted coordinate system to replicate a deforming and traveling fish in a fluid, and Arbitrary Lagrangian-Eulerian method is employed to solve the flow around the fish. An implicit method is employed for time marching of motion of gravity center and rotation around the center. The fish is modeled with the following characteristic five parameters: thickness, amplitude, frequency, length of peduncle and phase-lag between the motions of tail and body displacement. This optimization process by GA involves large scale computation for flow field interacting with fish body with the above control parameters. In the present study, the GA procedure is carried out efficiently with multiple processors interconnected by the MPI library. Optimization of fish quality and surrounding flow field with the present advanced coupling method has never been attempted at this large scale of computation.

Our preliminary study shows a tendency that fish with a big amplitude consumes a lot of energy to generate vortices in the slipstream, while the vortices induce a current in the direction opposite to the vortex shedding from the fish trailing edge, resulting in propulsion of fish. On the other hand, a smaller amplitude generates only a meandering flow behind the fish, which is generally hard to convert for propulsion energy. Figure 1 shows a snapshot of the flow field behind the fish.

Also, our GA results show that fish exhibits different ideal shapes and maneuvers for different desired fitnesses. For example, fish showing the best efficiency among the whole GA solutions has a phase-lag between tail pitch and heave, and deforms only small part of the body to move like a real fish. This result agrees with the prediction by Lighthill[1]. On the other hand, to swim as fast as possible with no consideration for efficiency, the best-performing fish does not have a phase-lag and uses entire body to move. That optimized fish swims approximately 15 times as far as the best efficient fish in the same period, while consumes approximately 15 times energy. Figure 2 demonstrates this results. Also a trend of body shape depending on the fitnesses will be discussed.

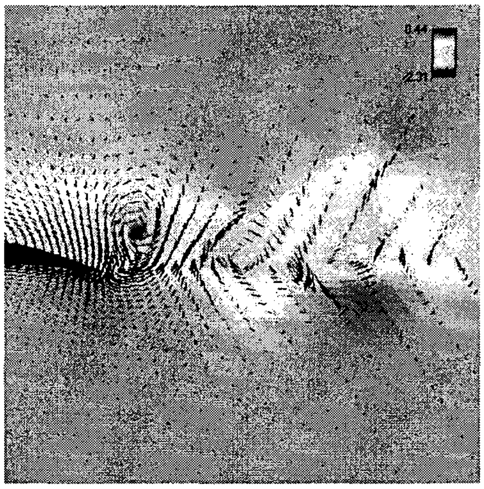
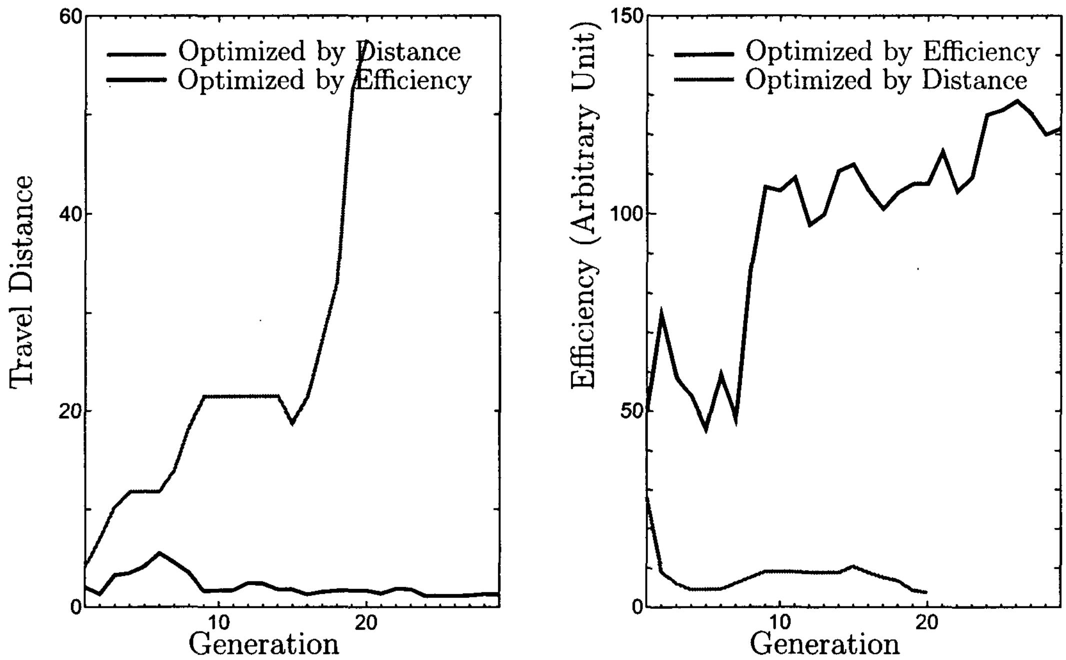


Figure 1: Pressure distribution and velocity field in the slip stream



(a) Chronicle of Travel Distance

(b) Chronicle of Efficiency

Figure 2: Comparison of two GA cases with different optimization targets

This result suggests that a solution for one objective is not always suited for another objective, and our method effectively demonstrated the capability of solving this type of optimization problem including the flow field surrounding the object. Also, our results suggest possibilities that GA is applicable for designing optimized undersea vessels.

[1]M. J. Lighthill, "Note on the swimming of slender fish", J. Fluid Mech., vol.**9**, pp.305-317, 1960