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Evaluation of Dolphin Swimming Speed and Thrust Based on CFD

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For many years, the maximum swimming speeds of dolphins have been reported almost entirely through observations. The objective of this paper is to estimate the swimming speed of dolphins using a theoretical analysis and numerical method. The FLUENT software solver and User Defined Function (UDF) dynamic mesh method were used to simulate the dolphin kicking during its swimming. Three peak-to-peak tail motion amplitudes and frequencies were chosen to study. The simulation results of the resistance of dolphin were compared with experimental results. The thrusts generated by dolphin fluke motion were compared with available data from the references. In conclusion, the dolphin can reach a very high speed because of its large thrust generated by its fluke motion and high propulsive efficiency.

INTRODUCTION

For a long time, dolphins have been considered good swimmers with extremely high thrust efficiency and minimum resistance. Swimming encompasses the transfer of kinetic energy and momentum from the animal's propulsive movements to the water. High speeds allow increased foraging and active pursuit but require large energy expenditures because thrust power is directly related to the cube of velocity. Low swimming speeds have been observed for cetaceans while foraging and migrating (Lang, 1975; Webb, 1975; Fish, 1998). A dolphin swimming at a constant speed balances forces and moments acting on it by the principle of momentum conservation. The total thrust produced by the action of the caudal flukes balances the total resistance (i.e., drag) that the animal's body encounters moving forward (Fish and Rohr, 1999). It is uncertain whether special properties of the dolphin's skin itself contribute to the drag reduction or whether it is simply due to the maintaining of an attached turbulent boundary layer (Fish, 1993).

In the wild, dolphins swim over a wide range of speeds. The highest swimming speeds recorded were those of captive dolphins, ranging from 8.0 to 8.2 m/s and typically lasting for a few seconds (Rohr et al., 1998). Estimations of thrust based on the motion of the flukes can be used to assess independently the drag due to body form and swimming motions (Triantafyllou et al., 1993). Many studies of dolphin swimming have used the rigid model; this model assumes that the thrust generated by a swimming dolphin is equal to the estimation of drag from a gliding dolphin. Measurements of hydrodynamic force generated by swimming dolphins have been made using bubble digital particle image velocimetry (DPIV), where the movement of the bubbles was tracked with a high-speed video camera. Dolphins swam at speeds of 0.7 to 3.4 m/s within the bubble sheet oriented along the midsagittal plane of the animal (Fish et al., 2014).

According to observations, dolphins also have mechanical bases on the vortex control, which can extract vortex energy generated by the tail or caudal fin, and can create a vortex ring during the extension kick, which is associated with most of the thrust generation (Triantafyllou et al., 1993). This vortex could been used as the power of propulsion and motion control (Schouveiler et al., 2005). The characterization of an animal's swimming motion is typically made through the Strouhal number (S_t), $S_t = fA/u_\infty$, where f is the frequency of stokes, A is the stroke peak-to-peak amplitude, and u_∞ is the bulk animal speed. An average S_t in the range of 0.2 to 0.4 for maximum propulsive efficiency in dolphins and aquatic animals has been predicted by Eloy (2012).

In this paper, the rigid model resistance of a common bottlenose dolphin (*Tursiops truncatus*) in calm water for different speeds is studied using a numerical method. The data comparisons between the numerical results and experimental test show a good match with each other. An analysis of kicking kinematics is conducted for a dolphin. And the purpose of this study is to obtain the thrust and to estimate the maximum speed of dolphin swimming. Furthermore, vortex formation and the propulsive S_t were investigated.

NUMERICAL METHOD

Dolphin Model for Numerical Simulation

Based on the data from van Oossanen (1988), the dolphin modeled with 3D software in Fig. 1 does not have the pectoral fin. The main size and shape of the dolphin model is the same as van Oossanen's data, as this approach would make the simulation and test results more comparable. Table 1 gives the main dimensions of dolphin.

Numerical Method and Turbulence Model

Water is assumed to be an incompressible and isothermal Newtonian fluid. Flow is three-dimensional and turbulent. The con-

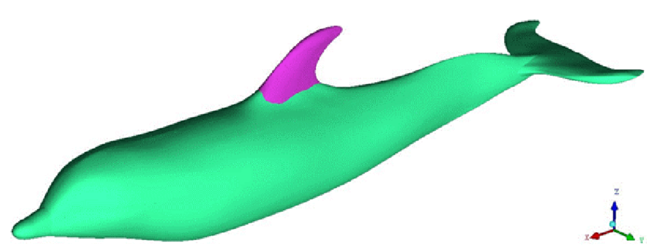

Fig. 1 3D model of dolphin

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KEY WORDS: Bottlenose dolphin, swimming speed, thrust, CFD, efficiency.