DOLPHIN FLUKES AS PASSIVELY SELF-ADJUSTING FLEXIBLE PROPULSORS FOR HIGH EFFICIENCY TRANSPORT

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Dolphins and other cetaceans (whales) are able to swim at high speeds. The caudal flukes are the primary locomotor structure in cetaceans, which produce hydrodynamic thrust as the tail is oscillated vertically [1]. Effective thrust generation is a function of the kinematics of the flukes, the angle of attack between the flukes and the incident water flow, and the shape of the flukes. Hydrodynamic models, which were used to estimate thrust production and efficiency, considered the flukes as rigid hydrofoils or flat plates. However, flukes are not rigid but are flexible. Flexibility across the chord of an oscillating hydrofoil can increase propulsive efficiency [2, 3].

Flukes were examined to determine if flexibility allowed for passive shape changes. High-speed video of dolphins freely swimming and statically pushing against a load cell showed chordwise and spanwise flexibility of the flukes. The amount of fluke bending was correlated with swimming effort. Spanwise bending was restricted to the fluke tips. Fluke chord was maximally bent as the fluke changed vertical direction during the oscillatory cycle with a chord reduction of 31.6-35.1%. Shape changes of bent flukes were examined with X-ray Computer Tomography. Flukes were removed from deceased cetaceans of five species, and bent on an adjustable support at 0, 45, and 90^{o}. At 0^{o}, cross-sections of the flukes displayed a symmetrical profile. Cross-sections of bent flukes (45^{o}, 90^{o}) were asymmetrical and showed a cambered profile. Cambering was facilitated passively due to the position of the fluke insertion on the tail with respect to the major bending axis.

Cambering could increase hydrodynamic force production during swimming, particularly during direction reversal in the oscillatory cycle. In addition, bending at the fluke tips would act like winglets to control tip vortices, enhance thrust production and increase hydrodynamic efficiency.

References

[1] F.E. Fish, “Biomechanical perspective on the origin of cetacean flukes,” pp. 303-324, in: *The Emergence of Whales: Evolutionary Patterns in the Origin of Cetacea*, (J.G.M. Thewissen), Plenum Press, New York. 1998.
[2] J. Katz and D. Weihs, “Hydrodynamic propulsion by large amplitude oscillation of an airfoil with chordwise flexibility,” *J. Fluid Mech*. **88**, 485-497, 1978.
[3] N. Bose, “Performance of chordwise flexible oscillating propulsors using a time-domain panel method,” *Int. Shipbuild. Progr*. **42**, 281-294, 1995.

Keywords: flexibility, dolphins, flukes