Unifying Rules for Aquatic Locomotion MEHDI SAADAT, Harvard University / University of South Carolina, AUGUST DOMEL, VALENTINA DI SANTO, GEORGE LAUDER, Harvard University, HOSSEIN HAJ-HARIRI, University of South Carolina — Strouhal number, $St = \frac{fA}{U}$, a scaling parameter that relates speed, $U$, to the tail-beat frequency, $f$, and tail-beat amplitude, $A$, has been used many times to describe animal locomotion. It has been observed that swimming animals cruise at $0.2 \leq St \leq 0.4$. Using simple dimensional and scaling analyses supported by new experimental evidence of a self-propelled fish-like swimmer, we show that when cruising at minimum hydrodynamic input power, $St$ is predetermined, and is only a function of the shape, i.e. drag coefficient and area. The narrow range for $St$, 0.2-0.4, has been previously associated with optimal propulsive efficiency. However, $St$ alone is insufficient for deciding optimal motion. We show that hydrodynamic input power (energy usage to propel over a unit distance) in fish locomotion is minimized at all cruising speeds when $A^* (= \frac{A}{L})$, a scaling parameter that relates tail-beat amplitude, $A$, to the length of the swimmer, $L$, is constrained to a narrow range of 0.15-0.25. Our analysis proposes a constraint on $A^*$, in addition to the previously found constraint on $St$, to fully describe the optimal swimming gait for fast swimmers. A survey of kinematics for dolphin, as well as new data for trout, show that the range of $St$ and $A^*$ for fast swimmers indeed are constrained to 0.2-0.4 and 0.15-0.25, respectively. Our findings provide physical explanation as to why fast aquatic swimmers cruise with relatively constant tail-beat amplitude at approximately 20 percent of body length, while their swimming speed is linearly correlated with their tail-beat frequency.

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