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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 (=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 $0.2 \leq \mathrm{St} \leq 0.4$. 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 $A^*(=A/L)$, 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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