Comparative Kinematics and Hydrodynamics of Mysticete Cetaceans: Morphological and Ecological Correlates with Swimming Performance

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Abstract:

The scale-dependence of locomotor performance has long been studied in comparative biomechanics, but how animals move in their natural environment remains poorly understood. At the upper extreme of body mass, baleen whales (Mysteci) are predictably among the most efficient swimmers in terms of cost of transport through a combination of low mass-specific metabolic rate and high hydrodynamic efficiency. Such efficiency enables these oceanic giants to migrate vast distances and thus underlies a major component of their life history and functional ecology. However, we lack even basic kinematic data for most species. Here we combine morphometric data from flyover drone photography, whale-borne inertial sensing tag data, and computational fluid dynamics (CFD) to study the locomotion of four rorqual species. Focusing on fundamental kinematic parameters such as tailbeat frequency and forward speed, we quantified spatial and temporal changes in swimming performance for individual whales and compared these metrics across a wide body mass range. We also calculated thrust and drag using lunate tail hydrodynamic modeling (Fish 1993), and compared these values against those from CFD simulations carried out with realistic rigid-body models. Differences in excess of 100% between the two approaches point to the significant contributions of tail and head heaving to overall drag, and thus the need to account for them in rigid-body CFD simulations. Together these kinematic data and CFD modeling inform a new parametric factor designed at multiplying the rigid-body drag equation to predict the contribution of body heaving unsteady hydrodynamics in cetaceans.