The role of wing geometry on batoid gait selection

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Abstract

A dynamic model of batoid swimming is developed and analyzed for three specific species: the Atlantic, Butterfly, and Cownose rays. These species are chosen for their close biological relationship and variety of observed swimming gaits, from undulation (passing waves down the fin) to oscillation (bird-like flapping). Each species is modeled using biological parameters, such as wing size and shape, approximate fluid forces, observed frequency of wing oscillation, and swim velocity. Optimal swimming gaits with respect to various criteria, including energy efficiency, muscle tension, and wing curvature, are calculated for each case and compared. A general trend is observed where undulatory gaits result for lower aspect ratio, elliptic wing shapes and oscillatory gaits result for higher aspect ratio. Triangular wing shapes, which agree with biology. Gait transitions are also observed as oscillation frequency is changed, from symmetric gaits with pitching of the body at higher frequencies to anti-symmetric gaits with rolling of the body at lower frequencies, both of which are observed in batoid swimming.

Body: Batoid Mechanical Model

Wing Discretization

Actuation: Torque Approximation

Small Amplitude Approximation: Bilinear Equations of Motion

Low Velocity: Symmetric with Pitching

High Velocity: Asymmetric with Rolling

Conclusions

We have shown lower aspect ratio, elliptic wing shapes result in more undulatory gaits for all cost functions (and the converse). Similarly, the cost functions also influence the resulting gait, with energy efficiency being the most undulatory, muscle tension being the most oscillatory, and wing curvature in the middle. Gait transitions were also observed as the locomotion velocity to frequency ratio changed, from symmetric gaits with pitching of the body at lower velocities (or higher frequencies) to anti-symmetric gaits with rolling of the body at higher velocities (or lower frequencies), with an accompanying drop in amplitude. This is observed in batoid swimming during sudden acceleration, when the maximum thrust with minimal motion is required.