Axial Propulsion with Flapping and Rotating Wings

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ABSTRACT

Interest in biological locomotion, and what advantages the principles governing it might offer in the design of manmade vehicles, prompts one to consider the power requirements of flapping relative to rotary propulsion. The amount of work performed on the fluid surrounding a thrusting surface (wing or blade) is reflected in the kinetic energy of the wake. Consideration of the energy in the wake is sufficient to define absolute minimum limitations on the power requirement to generate a particular thrust. This work applies wake solutions to compare the minimum inviscid propulsive power requirement of wings flapping and in rotation from hover through a state of lightly-loaded cruise. It demonstrates that hovering flapping flight is less efficient than rotary wing propulsion except for the most extreme flap amplitude strokes (Θ > 160°) while operating at large wake wavelength. In cruise, a larger range of flap amplitude kinematics (Θ > 140°) can be aerodynamically more energy efficient for wake wavelengths reflective of biological propulsion. These results imply, based on the observed wing kinematics of continuous steady flight, that flapping in animals is unlikely to be more efficient than rotary propulsion.

Christopher Kroninger is a researcher and team leader of the Microsystem Mechanics Team of the Autonomous Systems Division within the Army Research Laboratory's (ARL) Vehicle Technology Directorate and the Technical Area Lead for the Micromechanics Center of the Micro Autonomous Systems and Technology Collaborative Technology Alliance. Kroninger's research has focused primarily on experimental and analytic characterization of the aerodynamic and dynamics performance of rotary and flapping wing MAV components. His work pertains to the design and assessment of insect-scale wings and understanding of the aerodynamic limits of MAV flight performance. Early work with ARL included conducting wind tunnel tests in a subsonic tunnel at NASA Langley in support of some of the DARPA Nano Air Vehicle program. Prior to working at ARL, Kroninger performed research exploring optimal circulation distributions for rotorcraft at Penn State. He has a Masters degree in aerospace engineering from the Pennsylvania State University.