Designing flapping wings as oscillating structures

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Abstract

Micro air vehicles propelled by flapping wings are gaining interest for certain applications because flapping can provide more agility and maneuverability at low speeds. Flapping wings must deform in certain shapes to produce maximum lift and thrust. In this paper, we show that one can tailor the flapping wing's forced response to match a desired response. When the desired flapping motion is a harmonic oscillation, the desired response can be described by the shape of the steady state response. For non-harmonic forced response we need displacements, at least at a few locations on the wing, as a function of time. In both cases, we want to optimize the structural parameters and input base excitation to minimize the error in forced response from the desired response. High speed video of hummingbird wings is used as reference to specify desired response. For harmonic oscillations the steady state response desired was defined by deforming the wing to mimic the shape of the humming bird wing during flapping. For a more realistic non-harmonic response the motion at points along the wing was obtained from references. We assume that the wings are made of graphite/epoxy laminated composite and shaped like humming bird wings with a maximal dimension of 15 cm and flight speeds upto 12m/s. When the wing is flapping in a harmonic motion, it can be designed to oscillate in a desired fashion using both the base excitation parameters and structural parameters. Base excitation parameters can be the amplitude of flapping, heaving and pitching motions as well as frequency. Several structural parameters could be optimized including ply orientations, number of layers, distribution of point masses and the shape of the wing and its attached stiffeners. In this work we only use ply orientation for the optimization.

For non-harmonic flapping of the wing, the desired response is defined by motion at points along the wing as a function of time. Data is available in references for the motion of the tip and wrist of the humming bird wing as it flaps. The motion at the tip and wrist of the wing at two different flying speeds, 12m/s and 0m/s (hovering), are used as the desired motion. Fourier transform of this motion reveals the frequencies of interest. The base excitation is assumed to be a combination of flapping motion and forward-backward motion. These input base motions are functions of time and must be optimized to obtain the desired response. To parameterize these input motions, it is convenient to express them as a truncated Fourier series. The amplitudes in the Fourier series are then the design variables / parameters to be optimized. The structural dynamics of the wing is optimized to match the desired motion using ply orientation as a design variable to minimize the difference between the desired and the computed response. The forced response of the wing is computed using finite element analysis.