Proceedings of SMASIS08
ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems
October 28-30, 2008, Ellicott City, Maryland, USA

SMASIS08-613

DRAWING INSIGHT FROM NATURE: A BAT WING FOR MORPHING AIRCRAFT

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ABSTRACT

Being the only flying mammal, bats have evolved unique flight devices affording them high maneuverability and efficiency despite their low flight speeds. By selecting bats of three different ecological niches – a highly efficient fishing bat, a nimble insectivorous forager, and a large soaring bat of the 'flying fox' family - passive wing shapes can be demonstrated as capable of attaining very different aerodynamic performance characteristics. The aerodynamics of man-made equivalents to these wing shapes, using thin airfoils rather than skeleton and membrane construction, are studied both computationally through a lifting-line approach and experimentally with quasi-static wind tunnel data of 'morphed' and 'unmorphed' wing shapes. Results confirm that shape inspired by the larger soaring bat has higher lift-to-drag ratios, while that of the foraging bat maintains lift at higher angles of attack than the other wings. The advantages are more pronounced by morphing, increasing both lift coefficient and lift-to-drag ratios by up to 50% for certain wings. This is validated both numerically and in the Cornell University 4'x4' wind tunnel.

Analysis of these shapes provides the first phase of wing design for use on a morphing aircraft vehicle. In order to take greater advantage of vehicle morphing, wing shapes with camber and twist distributions unique from those found in nature will evolve to suit a man-made structure. In this way, a wing shape intended for cruise may extend its practicality into highly maneuverable operations through the use of wing morphing. Starting from the bat planform shapes, a series of optimizations determines the best camber and twist distributions for effective morphing. Given a fixed degree of shape change at any point along an airfoil based on mechanism constraints, improved morphing performance can be found compared to initial assumptions of the natural shape change. Heuristic optimization employing simulated annealing determines the required morphing shapes for increased performance, broadening the abilities of each wing shape by increasing parameters such as lift, rolling moment, and endurance.

INTRODUCTION

Bats are extremely agile flyers capable of generating high roll moments, creating very high lift at low speeds, and even flying upside-down (Norberg et al., 2000; Neuweiler, 2000). Being one of only three classes of vertebrate fliers and the only flying mammal, they have evolved with a lightweight skeletal structure with a thin, flexible aerodynamic membrane as the lifting surface. In addition, bats have a few unique shape change characteristics unlike any of their flying cousins. Unlike the bird's span change capabilities, the bat's primary shape change is a variation of wing shape by manipulation of an elongated fifth finger digit, which functions as an active camber change mechanism to enhance lift coefficient at slow speeds. In addition, bats can make use of a leading edge flap by lowering their thumb digit and thereby moving the propatagium membrane, increasing lift without flow separation and akin to Krueger flaps found on aircraft (Norberg, 1972; Abbott and von Doenhoff, 1949). The ability to fly with great agility at low speeds makes them attractive for inspiration on unmanned aerial vehicles (UAVs) with a wingspan on the order of 12-36 inches, specifically those which are considered morphing aircraft vehicles (MAVs) capable of large-scale shape change while in flight (Wlezien et al., 1998).

While the aforementioned shape change mechanisms are common to all bats, there are many different classifications of bat morphology by ecological niche, as different food sources and environments dictate unique aerodynamic requirements. In-depth studies by experimental biologists have already classified bats by a number of geometric factors, including wingtip shape index, the ratio of hand-wing area to total surface area, and overall aspect ratio (Norberg and Rayner, 1987). When considered as a morphing flier, a bat can have either one or two flight regimes – many will need to be highly agile at low speeds for catching various types of prey, and some will need an additional flight mode for high efficiency soaring, increased payload capacity, or long range flight. Since all of these parameters are specific to a particular environmental

