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Author: Mr. Nathan Widdup
University of New South Wales, Australia

Dr. Li Wang
Australian National University (ANU), Australia
Dr. John Young
UNSW Australia, Australia
Prof. Fang-Bao Tian
University of New South Wales, Australia

BIO-INSPIRED FLIGHT FOR MARTIAN EXPLORATION

Abstract

Recently, bio-inspired flight mechanisms (such as flapping wings) have been identified as a candidate for Martian aircraft design due to their high lift and efficiency in low Reynolds number environments. The low atmospheric density on Mars leads to low Reynolds numbers and moderate-high Mach number (due to the operational speeds required to achieve sufficient lift). While natural flyers fit the low Reynolds number criteria, they also travel at low speeds corresponding to an incompressible flow regime. This research aims to identify the effects of compressibility on the aerodynamic force and acoustic profiles of flapping wing vehicles and their corresponding unsteady flow structures to inform future Martian UAV design.

This study is conducted numerically utilising an in-house FSI solver consisting of three distinct components: the finite difference method for laminar aerodynamics, the finite element method for the structure dynamics and the feedback immersed boundary method for FSI coupling. This study considers a dual wing bumblebee-inspired configuration with rigid flapping wings in the hovering flight condition. The wings undergo symmetrical flapping motion in the horizontal stroke plane and pitching motion occurs about the wing's leading edges. The stroke and pitch angle amplitudes are fixed at $A_\phi = 100^o$ and $\alpha = 45^o$. A Reynolds number of $Re = 200$ is considered in this study and the average leading edge Mach number is incrementally increased over the range $Ma = 0.4 - 1.4$.

The average lift coefficient was observed to decrease with increasing Mach number and the temporal force behaviour was repeated periodically (rather than every half period as was observed for a single flapping wing). This was due to the pressure distribution over the body and its asymmetry through the vertical plane. The decrease in lift coefficient was attributed to unsteady vortex decay with increasing Mach number. The presence of a shock wave at sufficiently high Mach number resulted in an increase of leading-edge vortex average pressure and a reduction in its size. The acoustic profile was observed to vary significantly with Mach number in both amplitude and directionality. In particular, the secondary fundamental frequency was observed to increase from a 4-pole to 6-pole sound source with increasing Mach number.

This study provides a basis for flapping wing flight mechanisms in Martian UAV design by considering compressibility effects on aerodynamic force generation and acoustic wave propagation.