PRELIMINARY INSIGHT INTO AERODYNAMICS OF FLAPPING WING MICRO AIR VEHICLES (MAV) FOR INDOOR RECONNAISSANSE

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Abstract. In this paper scaled up wings of a fly are used with representative wing kinematics to analyse steady-state, inviscid flow in forward flight. The small (approximately 6 inches, or hand-held) reconnaissance micro air vehicles (MAVs) will fly inside buildings, and require hover for observation, and agility at low speeds to move in confined spaces. For this flight envelope insect-like flapping wings seems to be an optimal mode of flying. The investigation of the aerodynamics of flapping wing MAVs is very challenging. The problem involves complex unsteady, viscous flow (mainly laminar) with the moving wing generating vortices, and interacting with them. At this early stage of research only a preliminary insight into the nature of the little known aerodynamics of MAVs was obtained.

INTRODUCTION

The development of small (approximately 6 inches, or hand-held) autonomous flying vehicles is driven by a need for intelligent reconnaissance robots, capable of discreetly penetrating confined spaces, and manoeuvring in them without the assistance of a human telepilot [1,2]. This is particularly relevant to military operations in urban terrain (MOUT) [3].

Flight inside buildings, stairwells, shafts and tunnels has significant military and civilian value, and requires agility at low speeds to avoid obstacles and move in confined spaces. The vehicles can be used in dull, dirty or dangerous (D^3) environments, where direct or remote human assistance is not practical. Non-military uses will include law enforcement and rescue operations. The ability to explore D^3 environments without human involvement will be of interest for many industries, for example, allowing air sampling in inaccessible areas, and examination of confined spaces in buildings, installations and large machines. The flight envelope of MAVs requires high agility (including hover) at low speeds (1-2ms^{-1}) and silent flight, which is not easily met by scaled-down fixed or rotary wing aircraft. However, insect-like wing-flapping flight would appear to be very suitable for such applications requiring highly manoeuvrable flight through confined spaces [1,2].

INSECT-LIKE FLAPPING

The unconventional aerodynamic concept associated with MAVs deserves a more detailed explanation. Insects fly by oscillating (frequency range: 5–200Hz) and rotating their wings through large angles, which is possible because their wing articulation is not limited by an internal skeleton. The wing beat cycle can be divided into two distinct phases, the downstroke and the upstroke.

At the beginning of downstroke the wing (as seen from the front of the insect) is in the uppermost position with the leading edge pointing forward. The wing is then pushed downwards and rotated continuously resulting in large changes to the angle of attack. At the end of downstroke the wing is twisted rapidly so that the leading edge points backwards, and the upstroke begins.

During the upstroke the wing is pushed upwards and rotated again, changing the angle of attack throughout this phase. At the highest point the wing is twisted, so that the leading edge is pointing forwards again, and the next downstroke begins.

In forward flight the downstroke lasts longer than the upstroke, because of the need to generate thrust in addition to lift. In the hover, where lift only is required, the two strokes are of equal duration.

This mode of flying relies on unsteady aerodynamics [4], producing high lift coefficients (peak C_L of the order of 3 is typical [5]), and excellent manoeuvrability. The unsteady mechanism varies with different insects, the most important being a bound leading edge vortex [6]. The high lift is a major factor in high efficiency of the mechanism: a typical power requirement for insects is 30W/kg [7], whereas small, electrically-powered, propeller-driven, fixed wing aircraft require about 150W/kg. Insect wing flapping occurs in a stroke plane that generally remains at the same orientation to the body, and may be horizontal or inclined. Rapid rotations occur at each end of the flapping half-stroke. To a first approximation kinematic control of insect flight manoeuvres is provided by changes in the tilt of the stroke plane, which is analogous to helicopter control. Precise control is achieved by including inter-wing differences in the magnitude of the force produced, the timing of the downstroke-to-upstroke wing rotation, and the geometric position of the wings when the rotation occurs.

NUMERICAL MODELLING

Sample calculations providing a preliminary insight into the aerodynamic behaviour of flapping wings have been performed for a low speed (7ms^{-1}) forward flight. These calculations used an in-house Euler finite volume code based on an artificial compressibility concept. Only quasi-steady calculations were conducted. At this stage the choice of the wing planform, the shape of aerofoils forming the wing, and the prescribed kinematics of movement, are still open questions. The aerodynamic design, and a thorough understanding of the physics involved, will be a subject of a long-term detailed study. In the presented calculations the choice of the planform has been inspired by the geometry of the wing of a Bibio fly. The potential choice of the generic geometry of the planform is illustrated in Figure 1(a). The actual geometry used in the calculations was simplified, and the corresponding computational mesh is shown in Figure 1(b). Semi-span is 126mm long.