Wing transmission for a micromechanical flying insect

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Abstract—Flapping wings provide unmatched maneuverability for flying micro-robots. Recent advances in modelling insect aerodynamics show that adequate wing rotation at the end of the stroke is essential for generating adequate flight forces. A thorax structure has been developed utilizing planar 4-bar frames combined with a spherical 5-bar differential to provide adequate wing stroke and rotation. Calculations using a simple resonant mechanical circuit model show that piezoelectric actuators generate sufficient power, force and stroke to drive the wings at 150 Hz.

Keywords: Micro aerial vehicle; insect flight; piezoelectric actuation; thorax design; unsteady aerodynamics.

1. INTRODUCTION

The micromechanical flying insect (MFI) project entails the development of a centimeter-scale robot capable of flying using flapping wings. Commercial and military applications for micro aerial vehicles such as this have been identified including operations in hazardous environments (e.g. search-and-rescue within collapsed buildings, nuclear plant exploration during a radiation leak, etc.) and defense-related missions (e.g. reconnaissance and surveillance).

Flapping flight for micro-robots is not only an intriguing mode of locomotion, but provides maneuverability not achievable with fixed or rotary wing aircraft. Biological insects can fly with a payload equal to their body mass and have peak accelerations approaching 10 m/s² [14]. Although they require relatively still
air, flying micro-robots could fly over terrain which would be impassable for a legged micro-robot. Following the initial vision of Flynn [7], pioneering work in micro-robotic flight was started by Shimoyama (see [20], [12], and [16]) and more recently, milli-robotic flapping flight by Cox et al. [2]. Previous work on the MFI has been documented in several areas by Fearing et al. [6], Schenato et al. [18], Sitti et al. [21] and Yan et al. [25].

This paper considers the kinematic and power requirements for the MFI and presents the current thorax design for the device. The design, shown in Fig. 1, utilizes planar flexural 4-bar elements to amplify small piezoelectric actuator displacements and a 5-bar spherical differential mechanism to map the motions into flapping and rotational movements.

The design target for the MFI is the blowfly Calliphora, which has a mass of 100 mg, wing length of 11 mm, wing beat frequency of 150 Hz, and actuator power of roughly 8 mW. At this size scale, the current best understanding of non-steady state aerodynamics comes from experimental observations of real insects and kinematically similar mockups, most notably, work by Dickinson et al. [3] and Ellington et al. [5].

Figure 1a illustrates the proposed components of the MFI. A photo of a mock-up, fabricated to scale (but without actuation), is shown in Fig. 1c. Table 1 summarizes the size and mass specifications of some MFI thorax components.