Development of an Insect-Inspired Micro Air Vehicle

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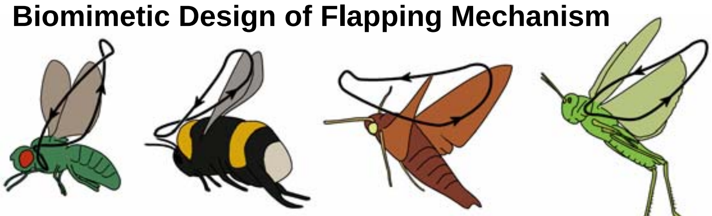
Abstract

A novel micro air vehicle (MAV) flapping mechanism for replicating insect wing kinematics is presented. Unlike most existing flapping mechanisms, the parallel crank-rocker (PCR) mechanism has an integrated flapping and pitching output motion which is not constrained. This allows the wing angle of attack, a key kinematic parameter, to be adjusted and enables manoeuvres. A PCR prototype was measured to produce a mean lift force of 3.35g in a hovering orientation at a wing beat frequency of 7.15Hz. Wind tunnel flow visualisation confirmed lift production benefited from the presence of a leading edge vortex.

Introduction

- The development of micro air vehicles (MAVs) is necessary for various military and civil applications, such as indoor reconnaissance and search-and-rescue.
- The difficulty in producing sub-15cm craft capable of agile manoeuvres and hovering in a confined space has led to solutions from nature being considered.
- An insect-inspired MAV can have improved lift production and manoeuvrability by successfully replicating insect wing kinematics.

Biomimetic Design of Flapping Mechanism

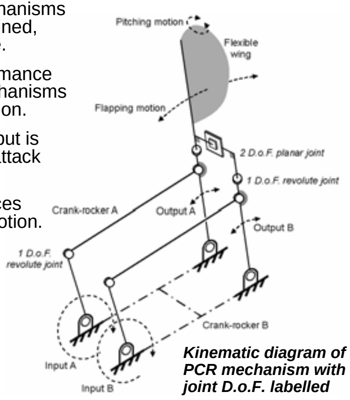


Example wing tip trajectories for blow fly, bumblebee, hawkmoth and locust (L-R)

- Flying insects augment steady-state "airfoil" lift with a variety of **unsteady aerodynamic mechanisms**.
- The optimum wing kinematics required to enact these aerodynamic mechanisms are unknown so **mimicking values of the main kinematic parameters** of suitable insects was used as a design starting point for a flapping mechanism.
- Identifying which kinematic parameters are adjusted for manoeuvres and flight stability is critical to this approach.
- Also, copying insects' use of **elastic storage** during wing strokes and **resonant wing beat frequency** is beneficial to optimising the MAV's energy efficiency.

Parallel Crank-Rocker (PCR) Mechanism

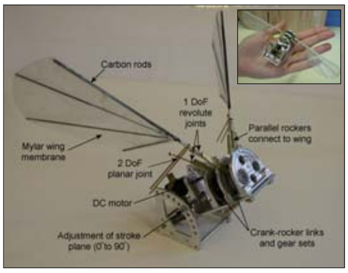
- In theory linear actuator-driven flapping mechanisms are optimal since they can be under-constrained, highly adjustable and operated at resonance.
- However, limitations in linear actuator performance means the majority of existing flapping mechanisms have been rotary-input with fixed output motion.
- Unlike previous mechanisms, the PCR's output is partially-constrained, meaning the angle of attack can be adjusted dynamically.
- The PCR mechanism is compact and produces an integrated flapping and pitching output motion.
- PCR is driven through the cranks (labelled as inputs A and B, *right*), with a phase lag between them to control the angle of attack.



Kinematic diagram of PCR mechanism with joint D.o.F. labelled

PCR Prototype Development and Testing

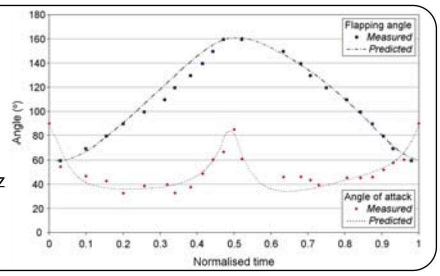
- PCR mechanism developed into a non-airborne experimental test-rig.
- Driven by 0.75W DC motor with angle of attack currently manually adjustable.
- Near-MAV scale with 75mm long wings and dimensions of 60 x 25 x 25mm.
- Total mass of 46g (moving parts = 10g).
- Three stages of testing so far:
  - *(1) Wing kinematics verification*
  - *(2) Lift force measurement*
  - *(3) Wind tunnel flow visualisation*



Assembled experimental PCR prototype

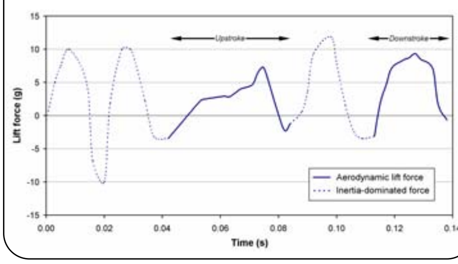
(1) Wing kinematics

- Motion analysed using high-speed camera.
- Measured wing kinematics matched predicted values (*see right*).
- Observed frequency of 7.15Hz lower than expected, due to non-optimised elastic storage causing speed fluctuations.



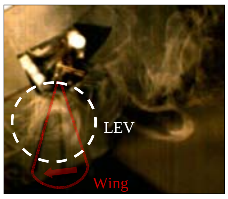
(2) Lift force measurement

- Single-axis load cell used to measure lift in hovering configuration (i.e. in stagnant air).
- High-frequency noise removed with 4th order Butterworth filter.
- Mean lift of 3.35g measured (flapping at 7.15Hz).
- Large force oscillations at stroke reversal caused by wing inertia shaking mechanism (*see below*).



(3) Wind tunnel testing

- Flow visualisation around wing using high-speed camera and smoke trails.
- $Re_{wing} = 26000$
- Attached leading edge vortex (LEV) observed (*see below*).



LEV formation on wing (red outline) in wind tunnel

Conclusions and Future Research

- A novel flapping mechanism has been presented that allows control of wing angle of attack, a key kinematic parameter for manoeuvring and flight stability.
- Prototype produced 3.35g of lift in hovering configuration.
- Wing beat frequency lower than expected so optimised elastic storage to be implemented to increase motor speed and hence lift.
- Particle Image Velocimetry to be used to quantify flow fields around wings.
- Large strain Electro-Active Polymer actuators being developed for a highly adjustable, under-constrained flapping mechanism.