An experimental mechanism of a tandem flapping wing for micro aerial vehicle

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Abstract. Micro Aerial Vehicles, otherwise known as MAVs, is defined as an aerial vehicle that has a 15cm or less wingspan with a take off weight of less than 200g. Its miniature size and manoeuvrability allows it to fly in confined space at low Reynolds number flight conditions (100 – 100,000). In this study, an entothopter design inspired by dragonfly wings was investigated using a subsonic wind tunnel to see the effect of tandem wing configuration on the lift generation. The study was done at different flapping frequency (5-11Hz) and at different flight speed (5m/s, 7m/s, and 9m/s). It was observed that in phase flapping configuration produces better lift for all flapping frequency and all flight speed.

1. Introduction

Due to their large potential in both military and civilian application, the study of Micro Aerial Vehicles (or MAVs) have seen a recent increase in quantity [1]. One of the reason for its potential is its ability to fly in an enclosed area that makes them perfect for reconnaissance and surveying operations. MAVs is defined by its small size where the wingspan is limited to 15 cm, the gross take-off weight (GTOW) is limited to 200g, and have a flight speed of 15m/s or less [2-3]. There are four types of MAVs; rotary, fixed and flapping wings. For a wider areas and outdoor missions, fixed are generally used while rotary wings are used while rotary wings are used for indoor or tighter space missions [4]. Flapping wings however can fly in both conditions due to the fact that flapping wings have a higher aerodynamic efficiency than both fixed or rotary wing when scaled down in size [5]. Due to its miniature size, MAVs have a moderate speed of flight where the flight conditions is limited to 100 to 100,000 Reynolds number, which is the reason why flapping wings have a better performance than fixed wings. This is because fixed wings have a diminished lift, increased drag and lowered stall angle at this flying condition [6].

This shows the potential of flapping wings being the preferred choice for MAV design. Flapping wings can be categorised in to two types; ornithopter and entothopter. Ornithopter are flapping wings that is based on bird wings and entothopter are flapping wings that is based on insect wings. Entothopter are have an advantage over ornithopter because they are known to have a better manoeuvrability and significantly simpler as they do not require active control along the wingspan [7]. Entothopter’s better manoeuvrability can be attributed to its ability to hover by using a phenomenon known as clap and fling where the wings clap and greatly changing their pitch angles and generating additional lifts at the leading and trailing edge and thus allows for sustained lift even with slow forward flight.
While there are several works done in different entothropther design, there is still limitation in terms of designs that are based on Dragonfly wings. The uniqueness of dragonflies lies in the tandem wing. This is the focus of this study, where the main objective of the study is to investigate the effect of a tandem flapping wing configuration on lift performance.

2. Methodology
The aim of this study is to investigate the effect of tandem wing configuration on lift generation. This is done using a open tunnel sub-sonic wind tunnel that is located at the Aerodynamics Laboratory, School of Aerospace Engineering, University Sains Malaysia. The lift forces of the was measured using a digital strain gauge that is attached to a Kyowa PCD-300A Data Acquisition System (DAQ). The DAQ unit transfers the measured data to a personal computer where the measured data was processed and recorded.

In terms of the tested wing design, a previously designed wing model made by H. Takahashi [8] was used as a base design for this study. In that study, microelectromechanical systems (MEMS) with pressure sensors was used to create the difference in phase angles. In this study, the original design was modified and simplified using a slider-crank mechanism where a brushless DC motor was used along with reducing gears to produce a flapping motion for the forewing. A shaft was used to connect the slider crank of the hindwing to the motor frame. The location where the shaft is connected to the motor frame will determine the flapping motion of the hindwing to be either to move parallel to the forewing or unparalleled to the hindwing. The design of the system was made using a computer aided design (CAD) software, Solidworks. The 3D CAD drawing of the flapper design is shown in figure 1.

![Figure 1. The combined slider crank mechanism.](image)

The design was tested at a fixed angle of attack (AoA) of 100 and the only changing variables that was change was the flapping frequency, the flight speed, and the flapping frequency. The flapping frequency that was tested was 5Hz to 11Hz and the flight speed that was tested was 5m/s (Re = 14000), 7m/s (Re = 19000), and 9m/s (Re = 24000). The flapping configuration that was tested were in phase (parallel) flapping motion and out of phase (unparalleled) flapping motion.
3. Results and discussion
From the recorded data, it can be seen that as the flight speed increases, the generated lift slightly decreases for in phase flapping motion (figure 2) and for the out of phase flapping motion (figure 3), the decrease in lift with increasing flight speed seems to be greater. In terms of the effect of flapping frequency, it can be seen that as the flapping frequency increases, the generated lift also increases. This is true for all flight speed and for all flapping configuration. However, figure 3 shows that for out of phase flapping configuration the difference in generated lift with increasing flapping frequency seems to be more at low flight speed (at 5m/s or Re= 14000) and decreases as the flight speed increases.

The result also shows that the different in flapping configuration effects how the lift generation decays with changing flight speed and flapping frequency, where out of phase flap produces a more lift decay with increasing flight speed for 11Hz, 10Hz, and 9Hz but the lift decay slower for 5-8Hz flapping frequency. However, the lift for the in-phase configuration decays at around the same rate as the flight speed increases.

Figure 2 and figure 3 also shows the difference between in phase and out of phase flapping motion, where it is clearly shows that in phase flapping configuration produces greater lift. This is true for all flapping frequency and all flight speed. This is due to the upwash that is produced by the hindwing that effect the lift generation of the forewing when the wing flaps in phase which the helps to produce better lift even during downstroke [9].

![Figure 2. CL Vs Reynolds number for different frequency at 10° AoA for in phase flapping configuration.](image-url)
Figure 3. CL Vs Reynolds number for different frequency at 10° AoA for the out of phase flapping wing configuration.

4. Conclusion

The aim of this study is to investigate the effect of flapping configuration (in phase and out of phase) on the aerodynamic performance, particularly in terms of lift generation, of a tandem wing that is inspired by dragonfly wings. It was observed that in phase flapping configuration produce the best lift performance over the out of phase performance in all flight speed and flapping frequency. This is due to the presence of hindwing upwash that helps in lift generation.

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