THE INITIATIVE OF LIFT FORCE MEASUREMENT OF AN ORNITHOPTER FORMATION

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ABSTRACT

According to Lissaman and Shollenberger's article published in *Science* in 1970, birds fly in formation to reduce the overall energy expenditure for flight. Thus this work adopted the same principle of flight formation to ornithopters to save energy. Two experiments are described herein. Firstly, a rigid frame housing three ornithopters was made and a tethered flight of it around a fixed suspension point was performed to evaluate the cruise performance of the ornithopter formation and check for energy saving by monitoring the endurance against a known reference value. In the second experiment, a jig housing three ornithopters was subject to a wind tunnel test at the Wind Engineering Center of Tamkang University. The aerodynamic force evaluation of the formation was done. From the preliminary examination, it is found that at 3 m/s, 10˚ angle of attack was the best case to generate largest lift and thrust. When compared to the real birds flying in a formation, the energy saving of ornithopters may be further improved by replicating the dynamic adjustments of frequency, phase change and separation among neighboring ornithopters, to obtain best energy-saving results in the future.

KEYWORDS: WIND TUNNEL, FORMATION FLIGHT, ORNITHOPTER

Introduction

From the development of flapping micro air vehicles (MAVs) or ornithopters in the past decade, the flight endurance of ornithopters is still limited much less than 1 hour [Yang *at al.* (2009) and Keennon *at al.* (2012)]. The short flight time of ornithopters in Figure 1(a) confined the degree of freedom of their real applications very much, and needs to prolong in the next generation of ornithopters of improvement. Referred to natural birds' long-range migration, they adopted the formation flight to save their flight power during cruising [Lissaman and Shollenberger (1970)]. This previous article also addressed that the Vee-formation is the best one for birds. Therefore the prior art from natural birds inspire us to apply the formation flight concept into the artificial ornithopters as Figure 1(b).

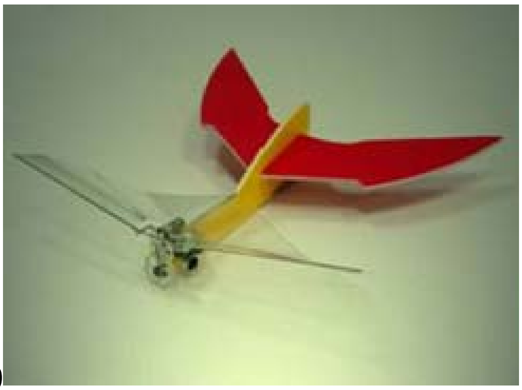
(a)  (b) 

Figure 1: Mini Ornithopters (a) ”Tamkang’s Golden Snitch”; (b) Formation of Ornithopters.

There are two parts of experiments initiative done in this paper.

1. Tethered flight test

During cruising, the power consumption is due to overcoming the air drag on the aircraft body. It is also true for ornithopter formation. Without the real remote flight control for ornithopter formation, we firstly did the tethered flight test as Figure 2. In other words, the formation flight and the mono-ornithopter flight are done via a level-turning with keeping a constant-flight altitude and cruising velocity by their manual remote controller. After running out all electricity in a Lithium battery on board, we record the total flight time and summarize the test result in Table 1.

From Table 1, the power consumption of a tri-flapper formation is found to be larger than the mono-ornithopter case and contradict the conclusion of Lissaman and Shollenberger’s work (1970). Due to the intrinsic instabilities of the MAVs, lack of data consistency about in power saving in formation flight concludes less promising results from this 1st experiment.The reason may be also due to the improper manipulaiton of the tri-flapper formation flight. The testing field in Figure 2 is too small to provide an ideal air domain for formation cruising. Without making sure the perfect flight gesture for all the ornithopters in a formation all the time, the measured flight time is not a reliable evidence to verify the global flight performance about the formation flight.

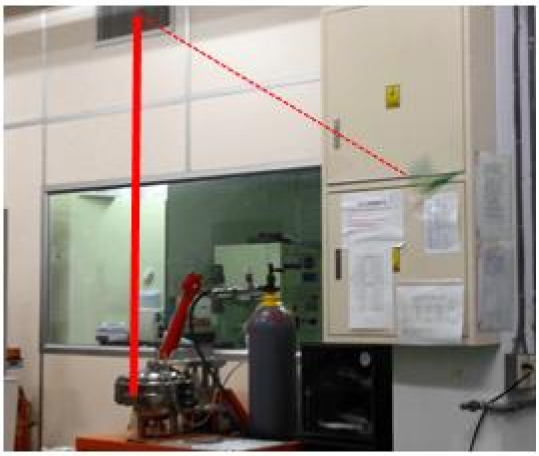
	
1	2

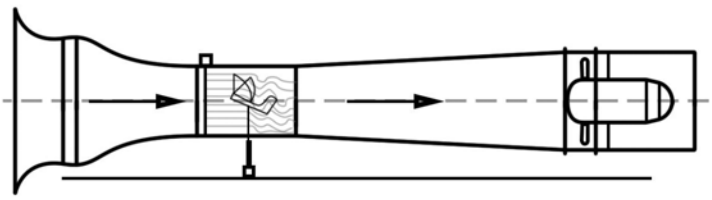
Figure 2: Tethered Flight of an Ornithopter (1) To the Left; (2) To the Right.

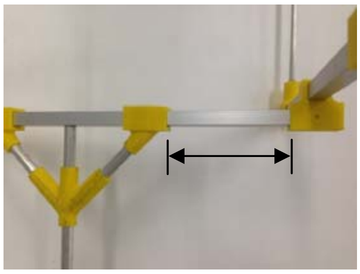
Table 1: Flight Endurance of an Ornithopter Subject to Figure 2 (Lithium battery: 75 mAH, cruising speed=2.22 m/s)

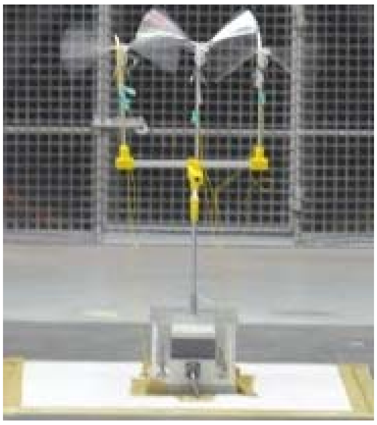
item	Mono-flapper	Tri-flapper (formation)
The 1st (s)	814	474
The 2nd (s)	792	490
The 3rd (s)	856	485
The 4th (s)	826	473
The 5th (s)	808	492
Averaged endurance (s)	819±6.7%	482±7.8%
Driving current (A)	0.33±6.7%	0.56±7.8%
Driving voltage (V)	1.9-3.7 (2.5 V in average)	
Power per ornithopter (W)	0.8±6.7%	1.4±7.8%

2. Wind tunnel test:

The 2nd experiment is the aerodynamic force measurement of the formation cruising of ornithopters installed in a wind tunnel. This suction type wind tunnel has a test section of 22 m long, and the cross section is 2.2 m wide and 1.8 m high. The wind speed ranged from 1~28 m/s. The extraction ratio of the entrance is 3.92:1. Honeycomb tube array and damping networking were mounted at the entrance to make sure the turbulence strength as small as 0.5%~1%. A 6-axis force gauge (Bertech, OH, USA) is accessed to take the aerodynamic forces. The measure range of lift/thrust forces are 200 gf and 100 gf respectively. The error due to nonlinearity and hysteresis is 0.2% FSO. Figure 3 shows the schematic of the wind tunnel, the truss for holding the ornithopter formation, tri-flapping setup (three-flapping) and bi-flapper setup (two-flapping).

(a) 

(b) 

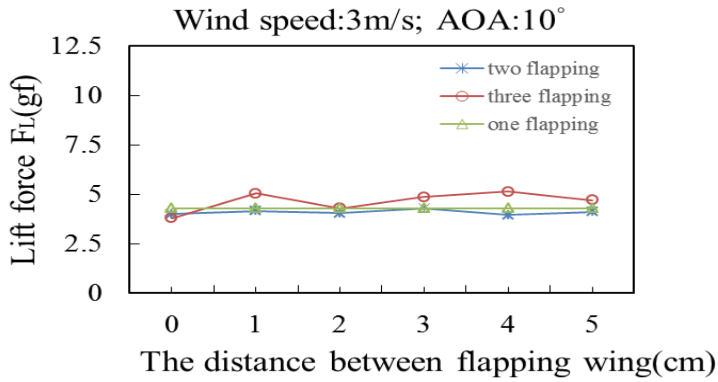
(b) 

(c) 

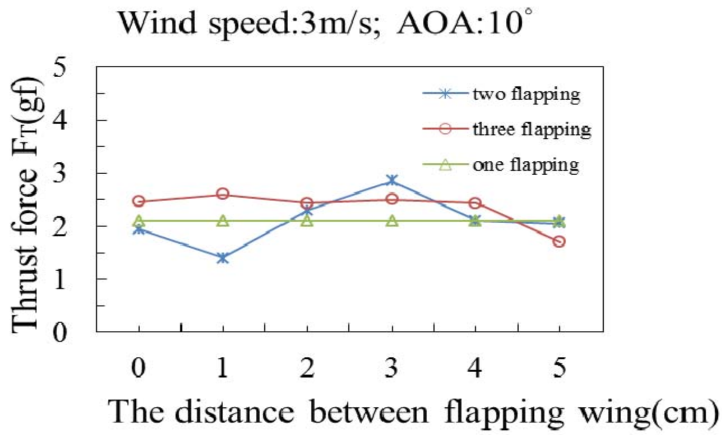
Figure 3: Setup of the Wind Tunnel Test (a) Schematic; (b) Definition of Distance between Ornithopters; (c) Tri-flapper Case; (d) Bi-flapper Case

The authors changed several testing parameters including wind speed (1~4 m), angle of attack (AOA=10~30°), distance between ornithopters (1~5 cm). The flapping frequency is fixed as 13~14 Hz so far. Figure 4 show the best case (U=3m/s; AOA=10°) of these testing subject to the 20 cm-span ornithopter. Due to the mechanical vibrations from the jig itself and the wind tunnel structure, interpretation of the complicated lift/thrust data was processed by the help of Fast Fourier Transform (FFT).

The lift force measurement in Figure 4 demonstrated that the tri-flapper is the best one compared to mono-flapper and bi-flapper. The net thrust force also has the best performance unless the high speed (5 m/s) point.



(a)



(b)

Figure 4: The Best Case of Wind Tunnel Test (U=3m/s;AOA=10°) (a) Lift; (b) Net Thrust vs. distance between ornithopters

Conclusions

The aerodynamic force measurement of the ornithopter formation was done in this work. It is found that at 3 m/s and 10° angle of attack was the best case to generate largest lift and thrust. When compared to the real birds flying in a formation, the energy saving of ornithopters may be further improved by replicating the dynamic adjustments of frequency, phase change and separation among neighboring ornithopters, to obtain best energy-saving results in the future [Portugal *et al.* (2014)].

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