2D Quasi-Steady Flow Investigation of a Flexible Flapping Wing

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A 2D quasi-steady flow simulation of a flapping wing with given moving boundary fed from stereo-photography measurement is firstly conducted in this paper. The whole research framework used the software Surfer, and Gambit to slice a quarter-span cross section from the previous 3D trajectory. It's then regarded as a 2D solid boundary for the quasi-steady CFD simulation by Fluent. The upwind direction changing of the flapping flow field has also been novelly considered herein. The computed time-varying outputs include the 2D flow fields and the corresponding lift coefficient. The one cycle history of lift coefficient subjected to 14 Hz flapping shows the qualitative similarity to the corresponding wind tunnel data.

I. Introduction

The research group of flapping micro-air-vehicles (MAVs) has devoted to the development of palm-size MAVs for many years [1-5]. Electrical-discharge-wire-cutting (EDWC) tech is first used to fabricate the 4-bar linkage flapping mechanism of a palm-size biomimetic MAV "Golden Snitch" with the total mass of 6g in 2009 [1]. In 2012, the fabrication of a polymeric "Golden Snitch" is successful implemented, and the precision injection molding technique shows its feasibility in commercial realization and mass production of this MAV [2]. With studying the effects of wing configuration and stiffness on the aerodynamic performance of "Golden Snitch" via wind-tunnel testing, a well-designed flapping wing foil made by PET is proposed [3]. So the modified MAV "Golden Snitch" prolongs its flight endurance record to 8 min.

In 2012, the figure-8 trajectories of the MAVs' wing tips were confirmed by their proper function of the carbon-fiber wing frames and the parylene wing skin [4]. The authors moreover constructed the research framework in Fig. 1. It shows that the comparison of the wind tunnel data and the CFD numerical computation is necessary for the furthermore investigation of the unsteady flapping flow field. The time-varying lift data of 15.4Hz flapping from computational fluid dynamics (CFD) results seems to have the similar changing trend with the wind tunnel data [5]. But the unsteady lift coefficient in ref. [5] is actually not correct in qualitative manner. They didn't consider the upwind direction changing effect during their numerical simulation. Hence in this work we tried to modify this problem, and setup the foundation of an unsteady CFD process for flapping MAVs based on the quasi-steady assumption.

II. Results

The details of the stereo photography to capture the time-varying, discrete 3D coordinates of the flapping wing foil are fully depicted in [5]. The focus of this paper is described the improved procedure to transfer the discrete 3D coordinates into the well-posed moving boundaries for quasi-steady CFD, and therefore shows its promising feature.

As the 1st step, Fig. 2 shows the deforming profiles of the flapping membrane wing corresponding to every 60° phase angle of a wing beating cycle and by the driving voltage of 3.7V. The curved surface fitting is obtained from the 3D discrete coordinates by software Surfer. The modified Sheppard's method is assigned as the interpolation method in Surfer.

The second step is to generate the grid mesh and setup the boundary conditions for the CFD simulation. We design a local circle around the plugging aerofoil. Inside the circle, the mesh is dense; outside the circle the mesh is far less dense. Such method can save some computation time.

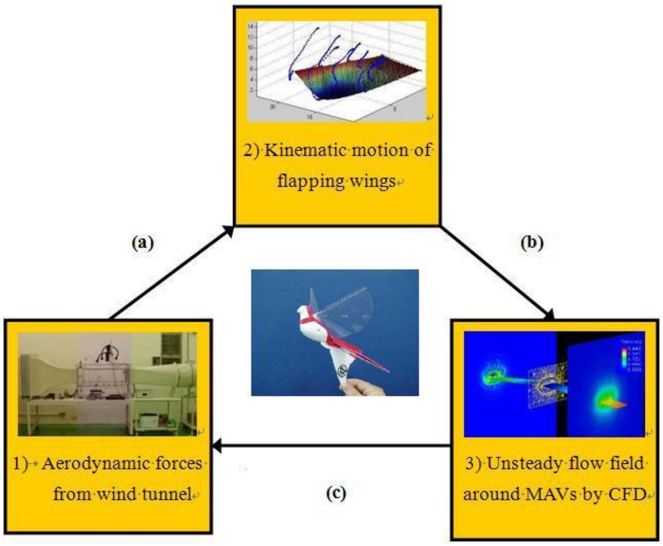


Fig. 1. The triangle research framework of flapping MAVs "Golden Snitch" at Tamkang University [4]: (a) Comparing the theoretical trajectory with the stereo image trajectory; (b) Providing the dynamic wing boundary for CFD simulation; (c) Comparing the lift/thrust with the wind tunnel data.

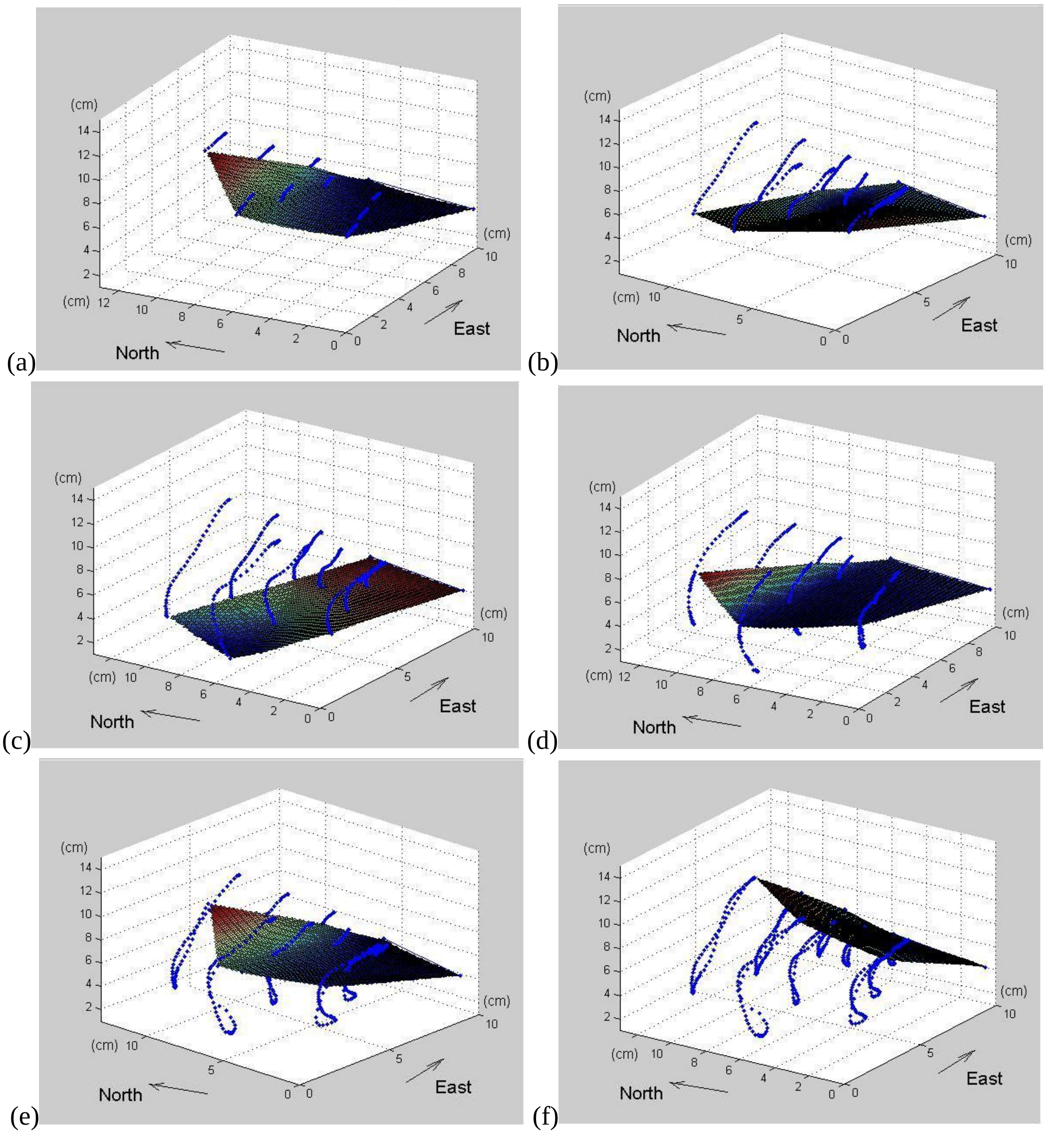


Fig. 2. The deforming profiles of the flapping membrane wing corresponding to every 60° phase angle of a wing beating cycle; driving voltage=3.7V [5]: (a) 60°; (b) 120°; (c) 180°; (d) 240°; (e) 300°; (f) 360°.

Additionally, also the most important part of this work, is how to assign the correct upwind direction and the magnitude of the uniform flow. Since we have the precise aerofoil geometries for every two moments (; the total wing flapping cycle is divided into 70 segments.) So by the differentiation of the x-y coordinate there's no difficulty to know the instantaneous flapping velocity of the aerofoil leading edge due to the flapping motion. Combining the original uniform flow of 3 m/s and the instantaneous flapping velocity, we can have the correct upwind uniform flow velocity vector including the correct angle and the correct magnitude as the input boundary condition of software Fluent. Herein we at least repeated 71 times of the process mentioned above and iterate each steady computation until it converges.

Fig. 3 shows the computed flow fields for the flapping case with wingbeat frequency of 15Hz and the freestream velocity of 3m/s. From the time-varying flow patterns we could see the up and down flapping phenomena. The upstream uniform flow is actually bended up and down accordingly.

We also output the lift coefficient with respect to time in a wingbeat cycle as Fig. 4(a). Even though there is somewhat fluctuation in the lift data, the fundamental trend is matched with the wind tunnel data [3]. We believed that the data fluctuation comes from the differentiation process of the x-y coordinates of every two moments.

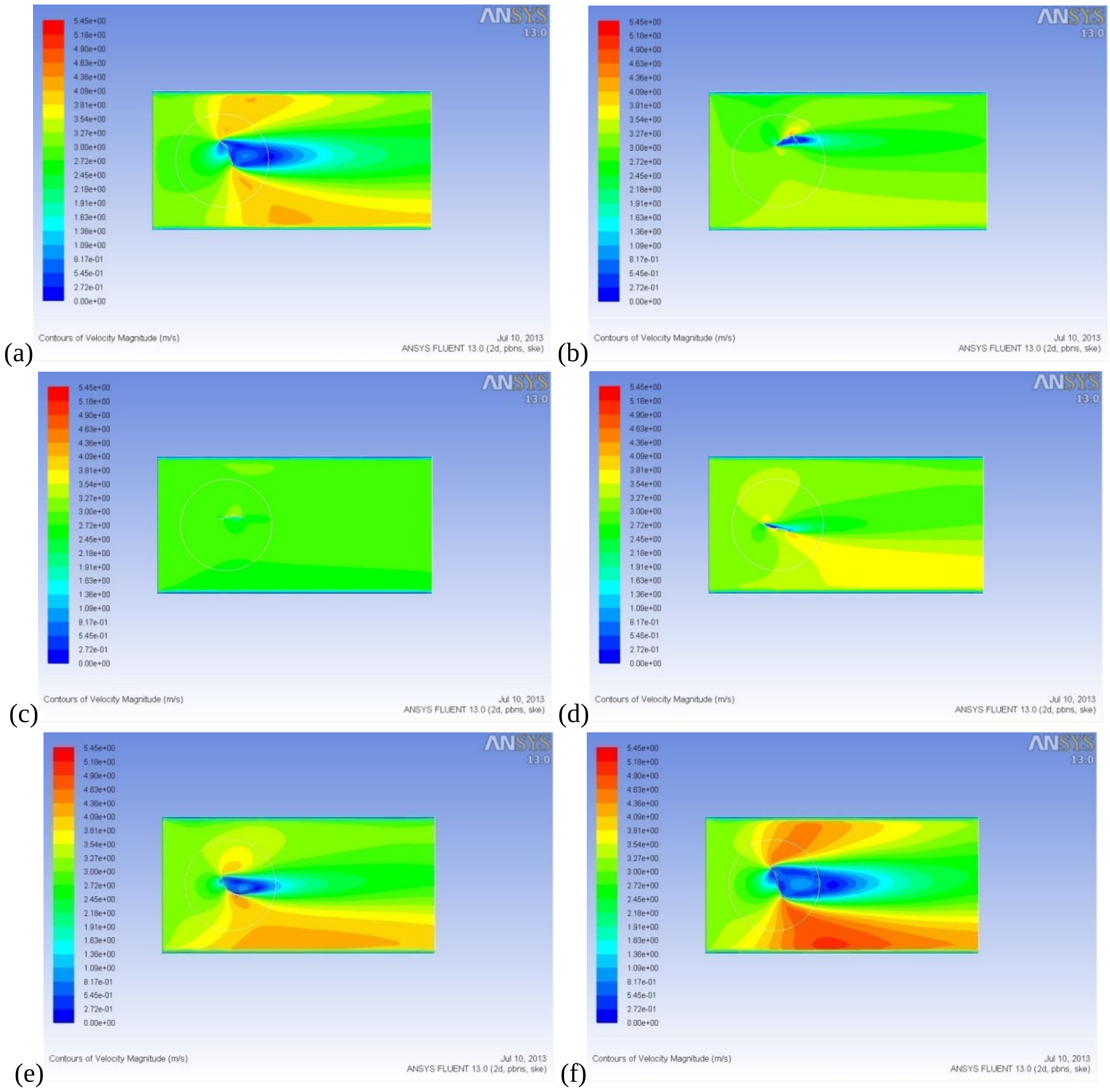
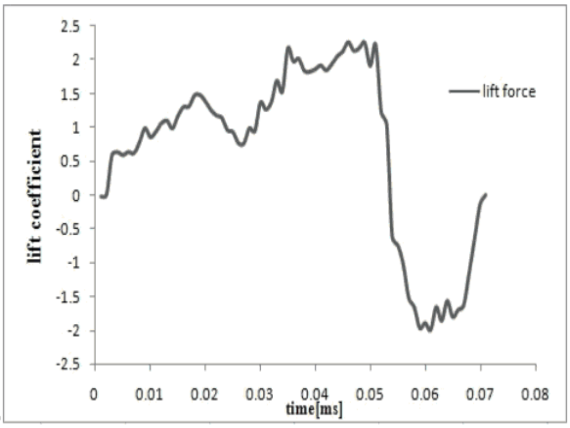


Fig. 3. Equi-velocity contour (unit: m/s) of the flapping flow field operated at 3.7V; wingbeat frequency is 15Hz; freestream velocity is 3m/s.

(a) 

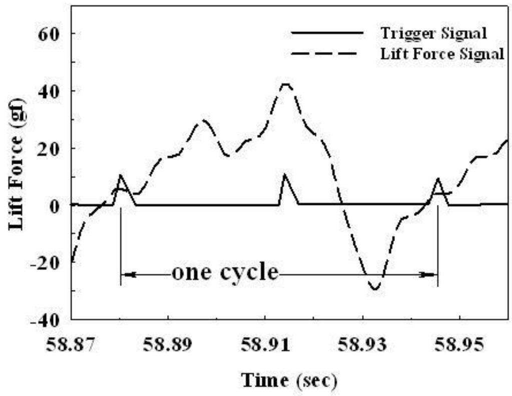
(b) 

Fig. 4. The unsteady lift force information: (a) the lift coefficient history of a flapping cycle predicted by this work; (b) the experimental lift data of the "Golden Snitch" in a wind tunnel [3].

The future work of this investigation includes the lift data error correction, the extension to 3D case, and modification of this quasi-steady computation to predict the thrust force accordingly.

III. Conclusion

With a correct upwind uniform flow velocity composing the original uniform flow and the flapping velocity extracted from the real 3D trajectory measurement, the quasi-steady assumption of 2D CFD simulation produces a qualitatively correct result compared to the real wind tunnel test. We believed this is the first time in the world of this methodology applied to the real flapping MAV (Golden Snitch). The more advanced modification of this unsteady flow simulation framework is promisingly looked forward to in the future.

Acknowledgments

We give our heartfelt thanks for the financial support of the National Science Council of Taiwan (project numbers NSC-101-2632-E-032-001-MY3 and NSC 102-2923-E-032-001-MY3.)

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