VELOCITY FIELD AROUND A RIGID WING IN MECHANICAL MAIN FLAPPING MOTION

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Abstract The natural flyers flap there wings for its flight. When the wings flap, flow field around the wings would be reoriented and flyers make use of it to sustain its flight. In the present study, particle image velocimetry measurements are used to capture the flow field around the rigid wings attached to a mechanical main flapping mechanism. The experiments are conducted for a kinematic asymmetry flapping of the wing with aspect ratio 1.0 and flapping frequency of 2.0 Hz in quiescent water medium. The dimensions of the wing are 40mm in chord, 40mm in span and thickness of 1.5mm. The Reynolds number is of the order of 10^4. The results revealed the formation of wingtip vortices, flow along the span, added mass and residual flow.

Introduction

The advantages of flapping wing are well known as addressed in ref. [1], the best examples are the natural flyers. Flow field around a flapping wing is responsible for generating the necessary forces/moments [2] and helps attain sustainable flight. Force measurements on a flapping wing were discussed for different frequencies, aspect ratio (AR) and materials [3-6]. Hong & Altman [7, 8] have used similar kinematics to that used in the present study and have concentrated on force measurements and some of the results cover velocity and vorticity distribution. Some previous works [1, 9-11] used identical kinematics to that reported in the present paper and compared the flow field for rigid and flexible wings at various flapping frequencies and aspect ratio. In the present study, the velocity field for AR 1.0 and frequency 2.0 Hz are discussed which were not detailed in ref. [11].

Experimental set up

The details of main flapping four bar mechanism and its dimensions were reported in Goli et al. [1]. Figure 1 shows the mode of flapping motion in which the asymmetry in kinematics has been used, the angular amplitude from the horizontal line is maintained as 3:1 ratio on the upper side to lower side. The experiments have been carried out in a water tank with dimensions of 0.9m×0.6m×0.79m. The flapping mechanism has been fully immersed inside the water tank with the walls and free surfaces at sufficiently large distances so that the near wing flow field would not be perturbed by boundary proximity effects.

The water is initially maintained in quiescent condition. The dimensions of the flapping wing are 40 mm in span and 40 mm in chord. The wing is made of Perspex® acrylic and it has 1.5 mm thickness. The flapping frequency is 2.0 Hz.

The test has been conducted by illuminating the flow along the span of the wing, with the laser sheet aligned to the mid chord position of the wing. The greater details in this regard were mentioned in ref. [9]. At each discrete flapping angle, ϕ, three instantaneous velocity vector fields are obtained and mean of these fields has been calculated to find the phase locked average velocity vector field. The results are 95% accurate considering various uncertainties. The details regarding the PIV system were mentioned in ref. [9, 10]. Figure 2 show the complete experimental setup.

Results and Discussion

The velocity vector field during downstroke and upstroke are shown in figures 3 and 4 respectively.

During the downstroke or upstroke a wing-tip vortex forms which is counter-clockwise (CCW) or clockwise (CW) in nature respectively. The wing-tip vortices generated at the beginning of downstroke and upstroke are represented as WTV1 and WTV2 respectively. It is a well-established fact that these vortices would contribute to generation of fluid dynamic forces which would act on the wing.

It has been observed that there is a certain extent of flow in the immediate vicinity of the wing which tends to follow it or gets dragged by it, which is known as added mass. In the present study the added mass flow starts developing during the course of downstroke or upstroke and residual flow bifurcates at the end of each stroke to form counter signed vortex (FACW or FACCW) at the end of upstroke or downstroke respectively. The two vortices comprising of a wing tip vortex and a counter signed vortex (WTV1 or WTV2 and FACW or FACCW) forms counter rotating vortex pair which is visible at the beginning of downstroke or upstroke. This counter rotating vortex pair is caused by the residual flow generated during the previous stroke. The counter rotating vortex (FACCW or FACW) generated during upstroke moves in a nearly horizontal direction whereas for downstroke it moves in a nearly vertical direction. This is because of the effect of kinematic asymmetry in the flapping mechanism. Kim & Gharib [2] reported that the counter rotating vortex which they referred as stopping vortex (in the present case FACW and FACCW) has effect on force generation.

Conclusion

The two vortices comprising of a wing tip vortex and a counter signed vortex forms at the beginning of each stroke making it a counter rotating vortex pair. This counter rotating vortex pair is caused by the residual flow generated during the previous stroke. It was found that added mass plays an important role in determining the flow field.

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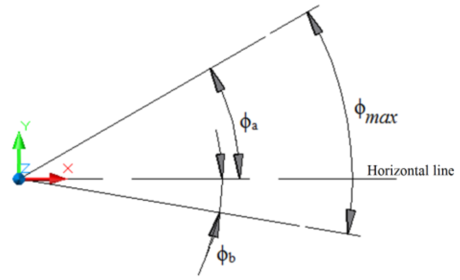

Fig. 1 Schematic of main flapping motion

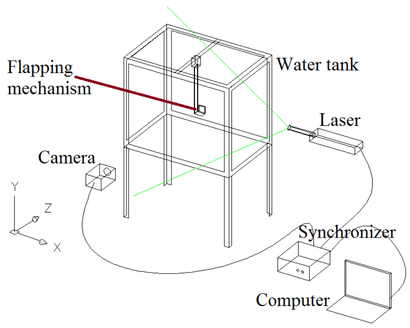

Fig. 2 Schematic of experimental setup.

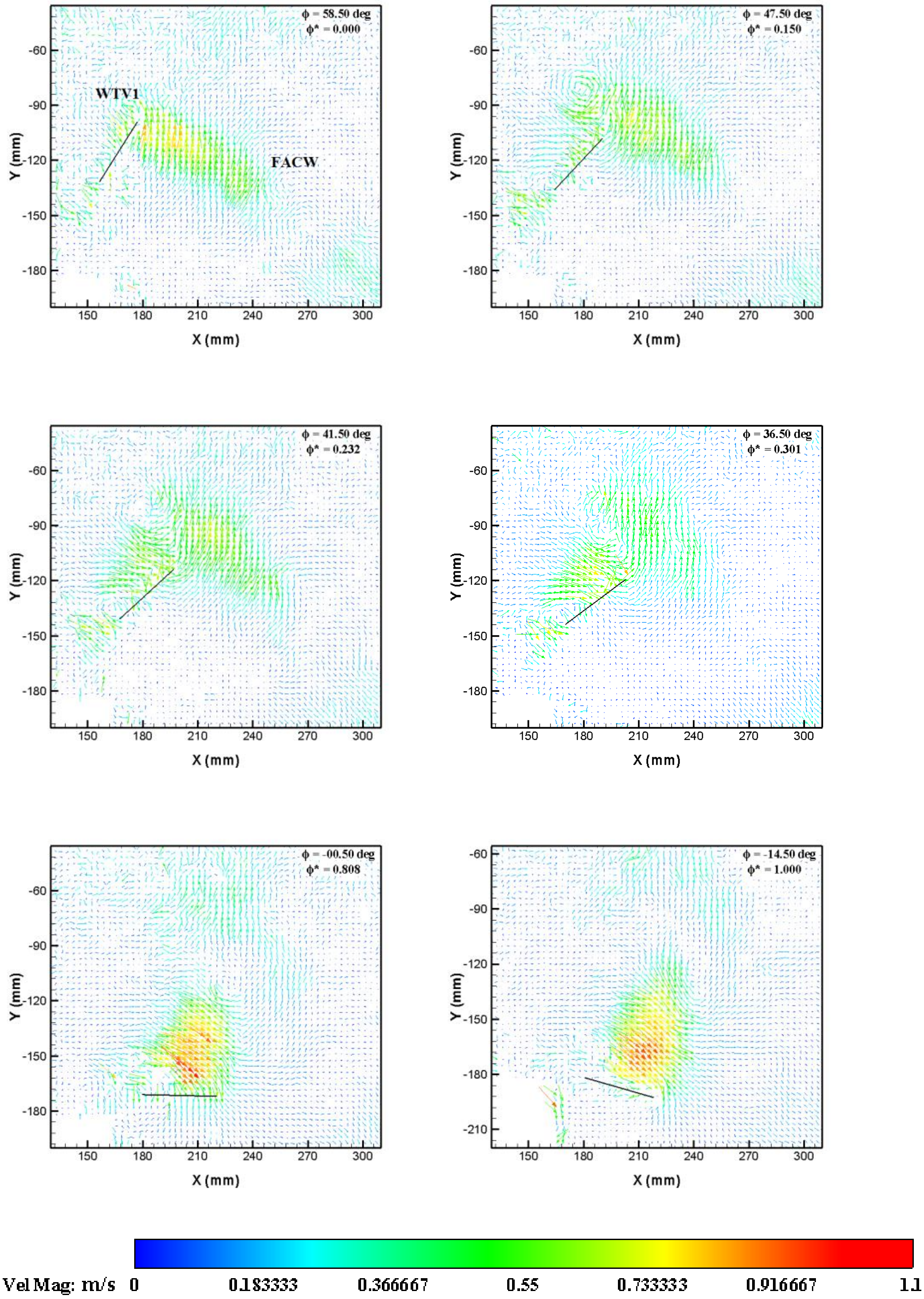

Fig. 3 Velocity field during downstroke of flapping cycle

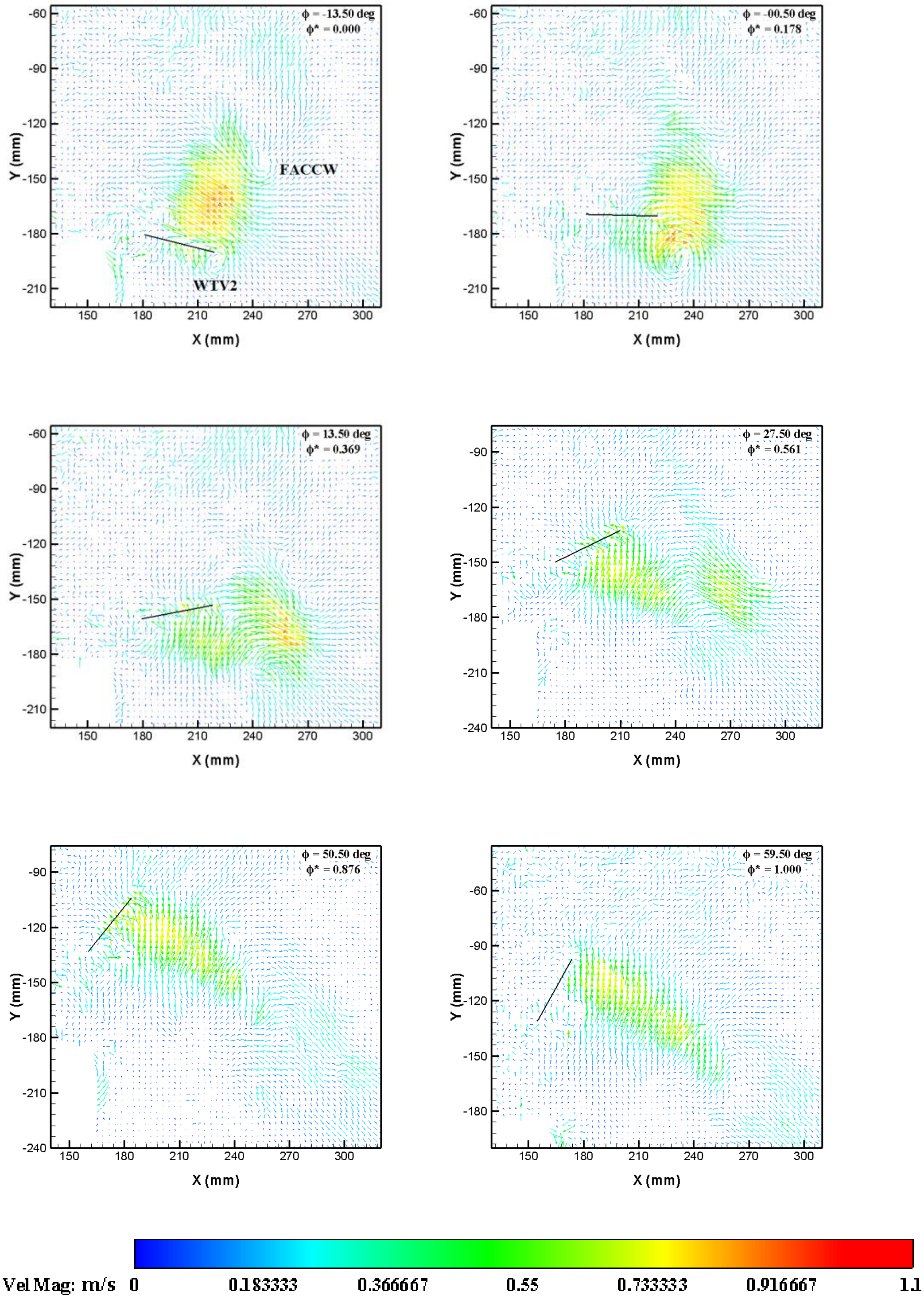

Fig. 4 Velocity field during upstroke of flapping cycle