Analysis of a Flapping Blade in Two-Phase Flow

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Abstract: When bees fly close to water, they sometimes fall in. They then can no longer fly, but use a different mechanism (hydrofoiling) to propel them forwards so that they can reach the water's edge, where they can then climb out, allow their wings to dry and again fly off. The hydrofoiling involves a flapping of their wings in such a way as to keep only their ventral side wetted, generating ripples on the water surface that propel them forward. In this paper, we demonstrate a similar mechanism numerically by analyzing a flapping blade at the air-water interface using the commercial code ANSYS Fluent on overset meshes.

Keywords: Flapping Wings, hydrofoiling, Two Phase Flow, Thrust, ANSYS, overset

1 Introduction

Biomimicry is described as the application of features, systems or processes, that are found in nature, in engineering design. Recently insect flapping wing motion has also been used recently for the development in micro air vehicles (MAVs). This was only done for motion in air (single phase). In 2019 Roh and Gharib [1] published an in-depth study of bee wing motion on a water surface (two phase). Measurements were done to determine the body and wing kinematics, the wave patterns around the bee as well as flow patterns just below the water surface around the bee. A mechanical model was also constructed to accurately determine the flow field under the wing. If this motion can be fully understood, it can be used for the development of Autonomous Surface Vehicles (ASVs) as well as Energy extraction devices.

2 Problem Statement

The aim of this paper is to create an accurate CFD model of the mechanical model used by Roh and Gharib. Validation will be done by the experimental data collected by Roh and Gharib. A 2D model has been built using ANSYS Fluent where the wing is modelled as a rigid blade. The turbulence model selected is the RANS k-ω SST. LES will also be attempted in future to obtain more details of the flow field. For the mesh motion, an overset mesh approach was selected for possible large scale motion. The two-phase flow model selected is that of Volume of Fluid (VOF) which is very good for open, flat water simulations.

The kinematics applied in the 2D CFD model have been taken from the Roh and Gharib's mechanical model – the published data was digitized and then curve-fitted. The digitization software used was WebPlotDigitizer. The curve-fitting was done using MATLAB's curve fitting tool. A Fourier series with 5 terms was fitted with an R-square value of 0.9993, showing a very good fit. The kinematics are entered as ANSYS Expressions in the Cell Zone Conditions input field in Fluent using translational velocity components as well as rotational velocity. The equations for the leading edge y-displacement as well as for the rotation motion is shown below:

$\mathbf{y_{LE}(t) =}$

$$2.961e\text{-}04 - 2.271e\text{-}04*\cos(189.2t) + 1.901e\text{-}04*\sin(189.2t) - 3.282e\text{-}05*\cos(2*189.2t) + 9.849e\text{-}06*\sin(2*189.2t) - 1.375e\text{-}05*\cos(3*189.2t) - 2.112e\text{-}05*\sin(3*189.2t) - 5.901e\text{-}06*\cos(4*189.2t) - 4.489e\text{-}06*\sin(4*189.2t) + 5.292e\text{-}06*\cos(5*189.2t) + 3.461e\text{-}07*\sin(5*189.2t)$$

$\boldsymbol{\theta_1(t) =}$

$$1.933e\text{-}01 - 5.314e\text{-}02*\cos(187t) + 1.094e\text{-}01*\sin(187t) - 1.376e\text{-}02*\cos(2*187t) + 6.215e\text{-}04*\sin(2*187t) - 4.992e\text{-}05*\cos(3*187t) - 3.869e\text{-}03*\sin(3*187t) - 1.102e\text{-}03*\cos(4*187t) + 6.501e\text{-}04*\sin(4*187t) + 3.033e\text{-}03*\cos(5*187t) - 4.536e\text{-}04*\sin(5*187t)$$

3 Results and Verification

Verification of the model is done using the leading edge positional plot as well as the rotation angle plot of the rigid blade and comparing these to the original data in Roh and Gharib. Velocity field plots under the wing are also used for comparison of flow effects. These are done for all six plots in one cycle in Roh and Gharib at time values of 0.0 ms, 6.7 ms, 13.3 ms, 20 ms (plot shown in Figure 1), 26.7 ms and 33.3 ms. Finally, a plot of the thrust force generated by the rigid blade is compared to a calculated acceleration value from the velocity field plots in Roh and Gharib.

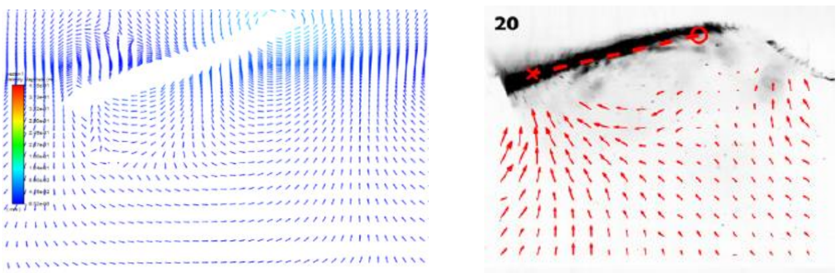

Figure 1: Velocity Plot results from (a) ANSYS Fluent and (b) experiments[1]

Contour plots of the two-phase fractions at four different angular positions are shown in Figure 2. These plots have been extracted within one cycle of motion. The red represents liquid water while the blue represents air. It is evident that the bottom of the rigid blade is always in contact with the water, no matter what the angle of the rigid blade is at, as also observed by Roh & Gharib (2019) during their measurements.

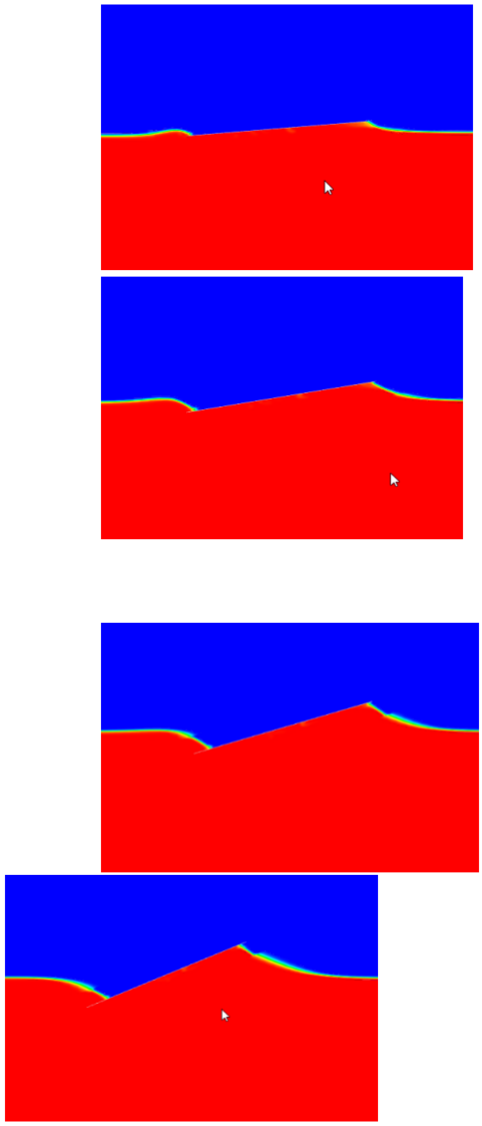

Figure 2: Two phase contours – water (red) and air (blue)

References

[1] Roh, C., Gharib, M. Honeybees use their wings for surface locomotion. *Proceedings of the National Academy of Sciences*, 116:49, 2019.