A Proposal to Study the Effect of Butterfly-scale Inspired Patterning on the Leading-edge Vortex Growth

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Motivation

Nature has created many solutions to its own problems, and those solutions have been an inspiration for common engineering problems. By examining the evolutionary characteristics that insects use for flight, we can better understand how they work and how they can be applied to solve our own problems. The Monarch butterfly (*Danaus plexippus*) makes a great example of evolutionary development of exceptional flight capabilities. Like many insects, the butterfly uses its wing kinematics and wing shape to create thrust and lift for flight, but one of the characteristics that set the butterfly apart is its use of surface patterning (scales), which may be used for several different purposes.

It is hypothesized that the scales on the wing serve an aerodynamic purpose of altering the leading edge vortex that forms during flapping flight in a manner that is favorable for efficiently producing thrust and lift. This hypothesis will be investigated using time resolved digital particle image velocimetry (TR-DPIV) to study the flow field and vortex that forms under a flapping plate. The surface patterning of the flat flapping plate will be varied between a smooth surface and two types of rapid-prototyped grooves, one set being chordwise and the other being spanwise. The effect of angle of attack on the vortex formation and flow field will also be investigated. A flow field will be generated at three Reynolds numbers that are similar to the regime in which the butterfly flies. Flow fields of same Reynolds number will be compared to determine the effect of surface patterning on the formation of the leading edge vortex.

Deliverables

Data has already been collected and processed and I am currently in the analysis stage. For this project I am looking at how the surface patterning affects the vortex formed underneath the flat plate. To do this, a comparison will be made between the three types of surfaces using the smooth surface as a control. Since I am examining vortices, circulation and vorticity are important parameters to use when describing a vortex. Plots of these two types of data will be used when comparing the vortices. When examining the vorticity plots, I am especially interested in the interaction of vorticity between the vortex and the boundary layer of the flat plate. The movement and location of the vortex relative to the plate during certain formation times will be examined.

Timeline
I began this project back in May of 2014 when Dr. Lang and I first discussed my involvement in her research project. Work started off slowly as my only job was to read the literature associated with the project (included in the references section) so that I understand what I am doing and why I am doing it. I then progressed to working with Dr. Wahidi, a post-doc under Dr. Lang at the time. Dr. Wahidi assisted in the modification of LabVIEW software that had been previously used on other projects needed to be modified for control of the setup and camera for data acquisition. We also had to tamper with the settings of the camera and laser to achieve the optimal settings for data collect. This was a tedious process, but once completed, data collection followed swiftly. As soon as data collection began, I simultaneously began processing the data. The processing software Insight 3G, like the data acquisition software, had to be tinkered with to achieve the optimal settings. Once this was done, the processing of large chunks of data began. I am currently in the stage of analyzing data, which requires a large quantity of time due to the amount of information collected. Analyzing of data also requires manual observation of plots and graphs so that the data can be interpreted and understood. From the analyzed data, a presentation will need to be created and presented at the American Physical Society conference in San Francisco. Findings will also be reported in a technical presentation that is due December 5, 2014. Work for this report began around the beginning of November and will continue until the beginning of December when the paper will be revised and proofread.

**Figure 1. Gantt chart showing a timeline for the completion of research and for the creation of a technical paper**

**Literature Review**

Literature has been selected based on the goals of this project and the background needed to lay the framework for computations and knowledge concerning this area. The area of study for this experiment is in fluid mechanics so all resources chosen are related to fluid mechanics in some way, whether it be experimental, computational, or observation of fluid phenomenon. For this research, we are interested in the effect of surface patterning on the leading-edge vortex (LEV) formation and specifically how the vortex interacts with the boundary layer of the surface. In the
article “Unconventional lift-generating mechanisms in free-flying butterflies,” Srygley et al. visually describe the flow fields that occur over the wing of a butterfly using free-flying butterflies in a smoke wire wind tunnel. This research confirms that a leading-edge vortex (LEV) occurs over the wing of the butterfly and reveals that there are many other complicated wing kinematics that the butterfly uses to generate lift and maneuver itself.\footnote{Srygley, R. B., and Thomas, A. L. R., “Unconventional lift-generating mechanisms in free-flying butterflies,” NATURE, Vol. 420, December 2002, pp. 660-664.} For this project, we are simplifying the complex motion of butterfly wings to simple flapping, or plunging, of a plate through quiescent water at several Reynolds numbers and angles of attack. Birch et al. reported that for LEVs formed by insect wings do not shed energy through the core of the vortex like those of delta wings.\footnote{Birch, James M., and Dickinson, Michael H., “Spanwise flow and the attachment of the leading-edge vortex on insect wings,” NATURE, Vol. 412, August 2001, pp. 729-733.} Since this is the case, something else must be used by the butterfly to control the growth of its LEV. This information is important for our study since we are only examining 2D flow beneath the plate and along the chord; this will eliminate the concern of spanwise flow. Other sources study the effect of vorticity dynamics and wing tip vortices on the lift of a flat plate.\footnote{Milano, M., and Gharib, M., “Uncovering the physics of flapping flat plates with artificial evolution,” Journal of Fluid Mechanics, Vol. 534, 2005, pp. 403-409.} Rausch et al. conducted an experiment very similar to the one we have planned. They focused on parameters like circulation and vorticity of a plunging plate. We are observing the same phenomenon in addition to the secondary vorticity that occurs at the boundary; we are also observing the effect of surface patterning on the LEV. Finally, since we are interested in the interaction between the vortex vorticity and the secondary vorticity created by the boundary layer, we can refer to sources that computationally and experimentally examine vortex interactions with free-slip and no slip boundaries.\footnote{Shyy, W., Trizilia, P., Kang, C., and Aono, H. “Can Tip Vortices Enhance Lift of a Flapping Wing?,” AIAA Journal, Vol. 47, No. 2, 2009, pp. 289-293.}

**Team Members**

For this project, there are a few team members. Jacob Wilroy, a senior in Aerospace Engineering and Mechanics at the University of Alabama, is responsible for running the experiments, collecting data, and analyzing and processing the data. Dr. Lang, an associate professor at the University of Alabama and my advisor, is overseeing the project and has provided valuable insight and direction. Dr. Wahidi provided a jump start by introducing me to the project and assisting me initially with software setup and settings. He has also provided direction and advice for data processing and analyzing.

**References**


