Manufacturing an Airfoil Capable of Handling a Micro-Pillar Array to make Large Scale Measurements of Wall Shear Stress

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Introduction

- The goal of this project is to manufacture an airfoil that is capable of housing an array of Micro-Pillars to make measurements of wall shear stress
  - Design and construct an Airfoil with a slot for the Micro-Pillar Array capable of being wind tunnel tested
  - Utilize CNC Machining to manufacture Micro-Pillar arrays in the order of microns
  - Perform wind tunnel testing at low Reynold's numbers
  - Employ high speed cameras to track the tip deflection of the Micro-Pillar array
  - Determine the Wall Shear Stress using the velocity profile gained from the tip deflection

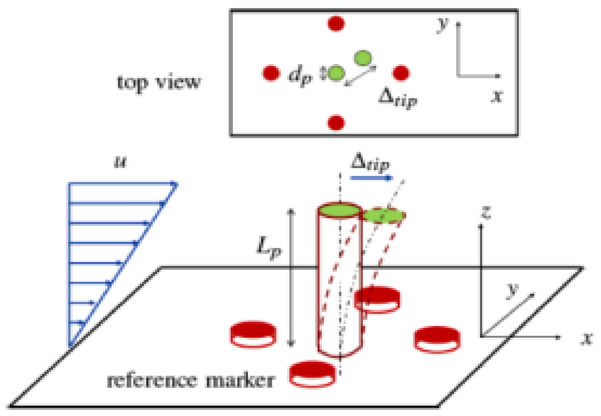

Figure 1. Schematic of the Micro-Pillar concept. From Gnanamanickam et al., 2013 © IOPScience

Objectives

- Manufacture an Airfoil that can hold a Micro-Pillar array to make large scale measurements of wall shear stress
  - With the wall shear stress measurements, determine the skin friction drag on the airfoil
  - Compare results of this method to previous methods

Methods and Materials

- Chose a NACA-0012 airfoil due to the symmetry and the extensive amount of research done on this airfoil
  - Designed the Airfoil in CATIA V-5 using NACA-0012 coordinates gained from the UIUC Airfoil Coordinates Database with a chord of 1 ft and a span of 2 ft
  - Performed a Finite Element Analysis of the Airfoil wind tunnel mount with a margin of safety of 1.2
  - 3D printed the airfoil in two sections
  - Strengthened the airfoil with West System 105 Epoxy Resin and Carbon Fiber composites
  - Cleaned the airfoil with 80, 220, and 400 grit sandpaper
  - Fixed any discrepancies with bondo body filler
  - Combined the two prints using Cyanoacrylate glue and 2 inch steel dowel pins
- Handled a CNC machine to create the Micro-Pillar arrays of dimensions 100 µm tall with a radius of 10 µm with a total array length of 6.5 inches
  - Used CNC machining to drill holes into wax sheets to be a mold for the Micro-Pillar arrays
  - Silicone Rubber poured into the mold, and vacuum sealed for two days to remove any air pockets

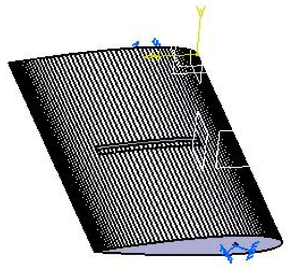

Figure 2 (above). Catia model of airfoil with mounts shown.

Figure 3 (below). Both sections of the airfoil after all carbon fiber layups

Discussion

- Wall Shear Stress can be seen in a multitude of billion dollar industries, including but not limited to: Aerospace, Medical, and Industrial
- In the Aerospace industry, wall shear stress results in finding the skin friction drag on an airplane in flight
  - Skin Friction drag accounts for roughly half the drag on an airplane in flight
  - Any reduction in this drag can save millions in fuel costs in the commercial aviation industry
- Current methods of measuring wall shear stress are either expensive, intrusive to the flow, time consuming, or destroy the surface that is being measured
  - Current methods include: Oil film interferometry, MEMS, Liquid Crystal Based Systems, Laser Doppler Velocimetry & Particle Image Velocimetry
- Micro-Pillars cover all the disadvantages that previous methods have
  - Can make large scale exact measurements
  - Highly inexpensive
  - Can be used repeatedly on the surface it is implemented on
  - Unintrusive to the flow as they operate in the viscous sublayer

Table 1. Table summarizing the two velocities and Reynolds numbers that will be seen in the wind tunnel testing

Wind Tunnel Test Parameters		
Velocity of Freestream	15 m/s	20 m/s
Reynolds	$3.08 * 10^6$	$4.11 * 10^6$

What's Next?

- The next steps to complete this project are as follows:
  - Spray a thin layer of paint on the airfoil and sand with 800 grit
  - Complete the manufacturing of the Micro-Pillars avoiding any discrepancies caused by the CNC machine
  - Fit the Array into the Airfoil and begin wind tunnel testing
  - Collect and analyze data from testing

References

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[2] Gnanamanickam, Ebenezer. Et. Al. *Image Based Sensor for Distributed Wall Shear Stress Measurement.* Purdue University, West Lafayette, IN 47906.https://arc.aiaa.org/doi/pdf/10.2514/6.2008-270. Accessed 20 May 2022.