AerE 344: Undergraduate Aerodynamics and Propulsion Laboratory

Lab Instructions

Lab #13: Aerodynamic force measurement on an icing airfoil

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Lab #13: **Aerodynamic force measurement on an icing airfoil**

Objective:

The objective of this lab is to measure the aerodynamic forces acting on an airfoil in a wind tunnel using a direct force balance. The forces will be measured on an airfoil before and after the accretion of ice to illustrate the effect of icing on the performance of aerodynamic bodies.

The experiment components:

The experiments will be performed in the ISU-UTAS Icing Research Tunnel, a closed-circuit refrigerated wind tunnel located in the Aerospace Engineering Department of Iowa State University. The tunnel has a test section with a 16 in × 16 in cross section and all the walls of the test section optically transparent. The wind tunnel has a contraction section upstream the test section with a spray system that produces water droplets with the 10–100 um mean droplet diameters and water mass concentrations of 0–10 g/m^3. The tunnel is refrigerated by a Vilter 340 system capable of achieving operating air temperatures below -20 C. The freestream velocity of the tunnel can set up to ~50 m/s. Figure 1 shows the calibration information for the tunnel, relating the freestream velocity to the motor frequency setting.

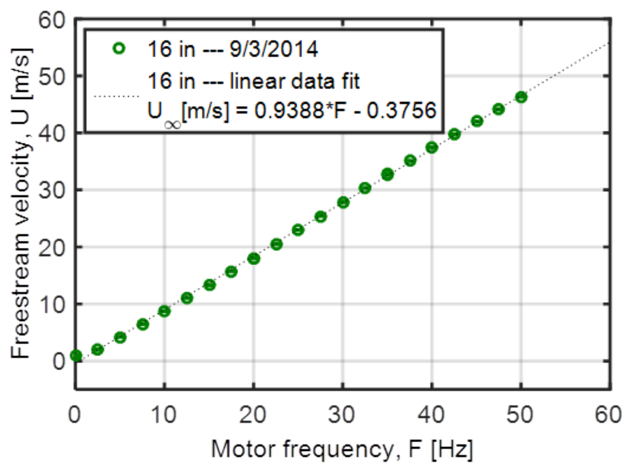

Figure 1. Wind tunnel air speed versus motor frequency setting.

The airfoil model for the lab is a finite wing NACA 0012 with a chord length of 6 inches and a span of 14.5 inches. The model is supported by spanwise rods that are centered at the ¼ chord location. The wing supports are connected to two 6-axis force/torque transducer (ATI-IA mini45) which measures all 3 force components and all 3 moment components on the airfoil. Figure 2 illustrates the configuration of the model relative to the force transducer. During the experiment, while the No 1 force transducer was attached to the airfoil model that would rotate with it as the AOA change, the No 2 force transducer was fixed on the wind tunnel panel. **The positive y axis in No 1 points to the Axis force direction of airfoil, and the negative x is the Normal force direction. As for the No2 force transducer, negative y and negative x represent the Lift and Drag direction of the airfoil.** Therefore, the final lift and drag should be the sum of individual lift and drag components from the two force transducers, namely, $Lift = lift_1 + lift_2$, $Drag = drag_1 + drag_2$. Note that, since the No 1 force transducer is fixed relative to the wing's frame of reference, the force components will need to be rotated into a frame of reference relative to the freestream velocity to determine the lift and drag components as the angle of attack is adjusted.

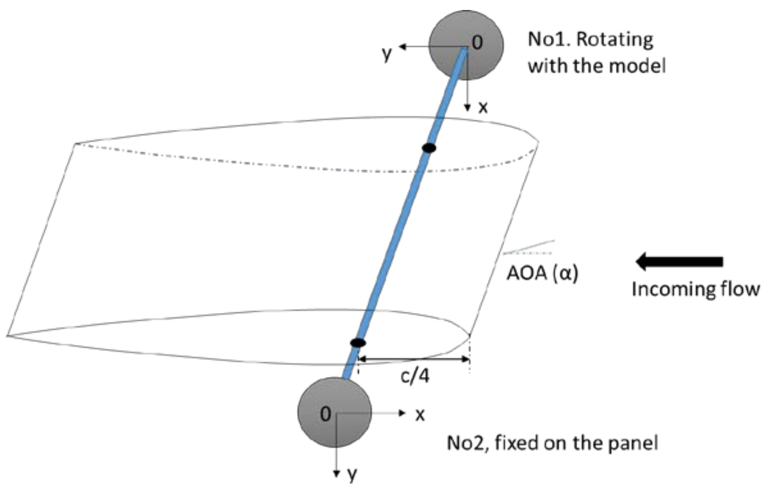

Figure 2: Configuration of the wing model in the wind tunnel relative to the force transducer. The force transducer origin is denoted by *0*.

The force transducers produce analog voltages related to the applied forces—6 voltages that are required to specify 3 forces + 3 moments. The voltages are scanned by a 16-bit data acquisition system (NI USB-6218), which are read into the computer by a MATLAB script and stored. The transducer's decoupling matrix (**M**) is used to compute the forces and moments from the voltages, where we can find the **M** matrix from the transducer manuals.

Equation 1: $$\begin{Bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{Bmatrix} = M * \begin{Bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{Bmatrix}$$

Here, if the voltages are given with units of volts, then the forces given by equation 1 have units of Newtons, and the moments have units of Newton-meters.

Experiment procedure

1. The forces acting on the airfoil before ice accretion must first be referenced to the unloaded state of the airfoil. This is accomplished by taking a tare measurement on an unloaded airfoil for each angle of attack, to account for the weight of the model and any residual offset signal in the force transducer.

   Make sure the tunnel is off. Using the digital inclinometer to set the angle of attack for each angle that will be tested, and record the forces using the MATLAB script.

2. Now that reference measurements have been obtained to tare the force transducer, the aerodynamic forces acting on a clean airfoil can be acquired.

   Set the wind tunnel speed to the desired setting. Using the digital inclinometer, set the angle of attack to each test angle, recording the forces in the MATLAB script.

3. Now that the forces acting on the clean airfoil have been measured, the airfoil can be subjected to icing conditions.

   Using the digital inclinometer, set the angle of attack to the desired test angle for the ice accretion. Turn on the water spray system and watch the ice accretion process over airfoil. After certain time, stop the water spray and prepare for the iced wing lift/drag/moment vs angle of attack measurements.

4. Finally, now that ice has formed on the airfoil, the effect of ice on the performance over a range of angles of attack can be observed. Repeat the same procedures as indicated in procedure 1 and 2 to quantify the aerodynamic forces acting on an iced airfoil.

What you will be given for your experiment:

- Icing wind tunnel
- A NACA 0012 airfoil model
- Two force/torque transducer
- A data acquisition system
- A digital inclinometer

What you need to know before you came to the lab:

- You should review and understand the concepts of airfoil lift and drag.
- You should review and understand the concepts of forces and moments in static equilibrium.

- You should review and understand the concepts of icing on aerodynamic structures.

What your experiment needs to produce:

1. Lift, drag, and moment measurements vs angle of attack (α = -2° – 20°) without icing.
2. Lift, drag, and moment measurements vs angle of attack (α = -2° – 20°) after the airfoil has accumulated ice.

What results you will produce from the experiment data:

a. The lift, drag, and moment coefficients vs angle of attack for the NACA 0012 airfoil with uncertainty bounds for the <u>uniced conditions</u>.

b. The lift, drag, and moment coefficients vs angle of attack for the NACA 0012 airfoil with uncertainty bounds for the <u>iced conditions.</u>

Requirements for the Lab Report

1. **You are required to prepare a formal lab report with following results included:**

   a. Plots of the lift, drag, and moment coefficients vs angle of attack for the NACA 0012 airfoil with uncertainty bounds for both the uniced and iced conditions.

   b. Plot of the Lift-to-Drag ratio vs angle of attack for both the clean and iced airfoils.

2. **Report requirement:**

   a. Discuss the uncertainty in the force coefficients derived from the force transducer readings and wing geometry.

   b. Discuss how the accretion of ice on the wing affects the performance of the airfoil. How was L/D affected? How was stall affected? What implications might this have for the operation of aircraft in cold weather?