ME 552 Measurements in Fluid Mechanics and Heat Transfer
Lab 2-Hot-Film Anemometry
Location: Rogers 334
Due date: At the start of your respective laboratory experience during week 6

Introduction

This lab exercise introduces you to a point based flow measurements device that is commonly used to determine mean flow and turbulence intensity, the hot-film probe. We discussed the working principle of a hot-wire anemometer in class. Also provided on Canvas are **materials from the manual of the anemometer that you will be using as reference material.** Please consult Chapter 1 in particular to help with the laboratory assignment. This handout provides a basic outline of the calibration, jet flow facility, and the lab procedures.

A picture of the calibration and the jet flow facility is shown in Fig. 1. The facility is assembled such as to permit ease of movement of the probe between calibration and jet flow testing. A person only needs to reposition the probe from the calibration position to the jet flow analysis. The calibration experiment is described first followed by the jet flow experiment. Note that the approach you will use is similar for both a hot-wire and hot-film.

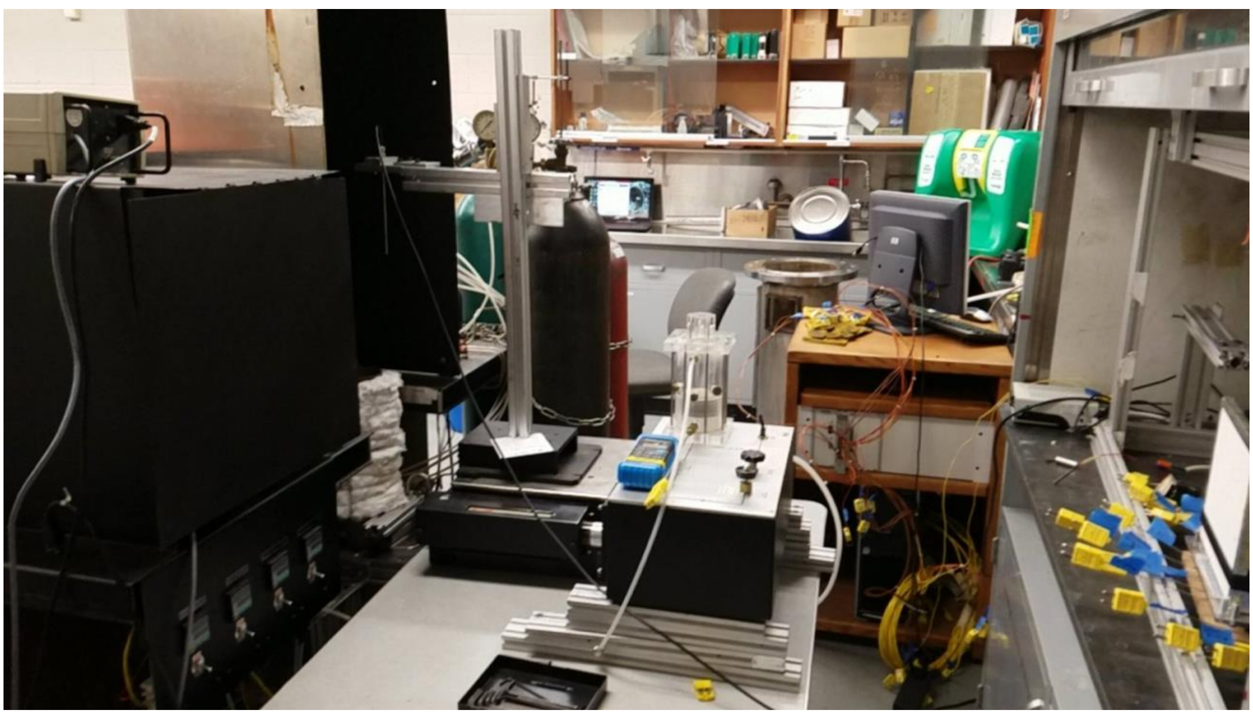

Fig. 1. Picture of the hot film calibration and jet flow facility. Calibration is the unit on the left, and the jet flow facility will take place over the burner exit as shown above.

Note: Be **extremely gentle** while using the HWA system and calibrator. Sudden movements and vibration can break the probe (which are very expensive).

Hot-film instrumentation and calibration facility

The hot wire anemometer consists of an IFA 300 unit that houses the electronics of the system (such as the Wheatstone circuitry, feedback amplifier to maintain constant temperature, filters, signal amplifiers, variable resistance, for the bridges arms, etc.). This unit *talks* with the computer via a serial port. A dedicated program is used to communicate with the anemometer via the serial port. Communications include commands such as measuring cable resistance, cold wire resistance, setting the overheat ratio, gain, and offset, and turning on or off the anemometer circuitry. The data from the channel to which the hot-wire is connected (**channel 1**) is relayed into the computer through USB (National Instruments USB 6009) data acquisition card (**analog channel 2**). The output voltage from the hot wire is related to the bridge voltage output as:

$$E_{out} = \left(E_{bridge} - E_{offset}\right) \times E_{gain}$$

This equation is primarily going to be used in determining the calibration equation for the hot-wire probe. This relationship should have been discussed in class and outlined in the handouts; it is a function of the velocity, probe power output, wire resistances, and wire temperatures. This equation can also be useful in setting gain and offset limits for the probe. The hot wire probe is to be inserted into the probe holder carefully. A BNC cable connects the probe holder with the IFA unit.

Hot-wire calibration facility

Figure 2 shows a simplified schematic of the hot-wire facility set up for calibration. The calibration facility consists of a plenum chamber followed by a nozzle at the exit of which the hot-wire is to be placed. By measuring the pressure differential between the plenum chamber and ambient, the velocity of the jet at its exit can be determined using Bernoulli's equation. By varying the pressure and/or flow valves of the calibration facility, a plot of velocity as a function of voltage output of the anemometer can be generated during the post-processing. Note that one should expect U^n relationship with voltage output, as we discussed in class. Once such a relationship is determined, the calibrated hot-wire can now be used to determine the mean velocity and turbulence intensity of an unknown jet flow.

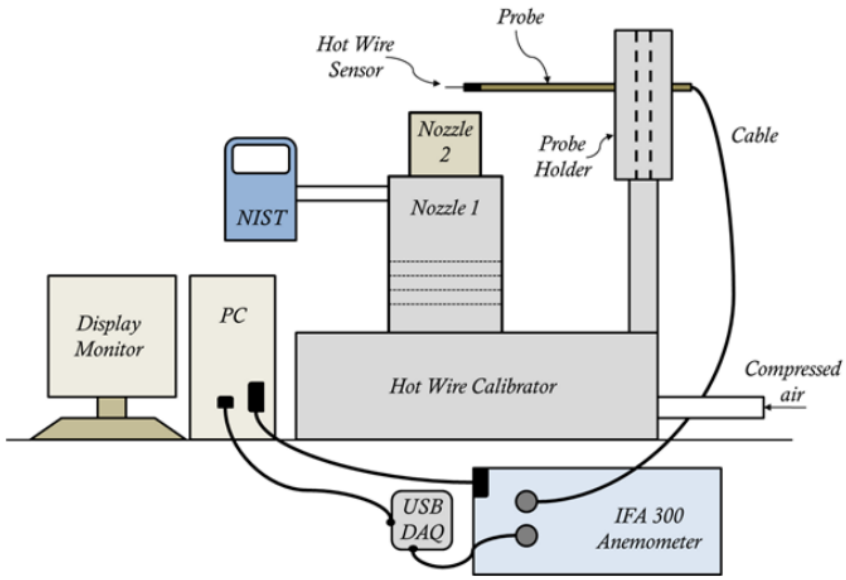

Fig. 2. Hot-wire calibration facility

Follow the instructions below to set up the IFA control unit and LabView program prior to starting calibration measurements. Most of this should be set-up prior to lab. Steps 4 and 5 are used to during data collection and shutdown procedures.

Instrumentation and Software set-up

1. Hardware setup
    a. Connect long BNC cable to “Channel 1 Probe” port on IFA 300 case and probe holder on traverse assembly
    b. Connect short BNC cable to “Selected Bridge” port on IFA 300 case and A/D converter board
    c. Connect 1/0 cable to “Port A” on IFA 300 case and DAQ computer
    d. Plug A/D converter board USB cable into DAQ computer
    e. Position traverse assembly as needed for measurement
    f. Check for sufficient probe clearance before inserting probe into probe holder
    g. Install probe 37-37 into probe holder
2. ThermalPro Software setup
    a. Turn on DAQ computer (login: DAQ, password: none)
    b. Turn on IFA 300
    c. Open ThermalPro software
    d. Select “Calibration” -> “Probe Data” Probe calibration window should appear
    e. Verify that settings are correct:
        i. A/D Channel: 1
        ii. IFA Channel: 1
        iii. Probe Type: S (single element)
        iv. Serial Number: S_FILM
        v. Cbl. Res: 0.35
        vi. Opr. Res. 9.38 (this value is provided by the probe manufacturer)

vii. Wire Film: F
viii. Gain: 4
ix. Temp. Chan. Off

f. Click save button to save probe data
g. Select “Acquisition” -> “Probe Table” (message will pop up stating that probe table is empty- click ok) -> “Add Probe” -> open “S_FILM.CL” in dialogue box
h. Verify correct settings (should match “Probe Data” settings from step e.)
i. Click “Save Line” (IFA 300 will make some clicking noises)
j. Do not exit out of current window. Leave open for duration of data collection

3. LabView Setup
    a. Open “HFA_DAQ_3D.Vi”
    b. Select “Show Block Diagram” -> right click on “DAQ Assistant” -> “properties”
        i. bottom of screen shows “samples to read” and “rate”
        ii. verify number of samples desired (default: 50k)
        iii. “rate” maximum is 48kHz (default: 10kHz)
    c. save DAQ Assistant settings by clicking “OK”
    d. Wait for LabView to rebuild VI
4. Data Collection
    a. Set “numeric” box to number of runs desired. This variable determines how many sets of 50k data readings are made in each .lvm file
    b. Click white run arrow to begin collecting data- VI will freeze briefly and display an hourglass during collection
    c. If data collection was successful, a data trace will be visible in the VI plot window
    d. Save data using dialogue box that automatically appears
    e. Check .lvm file to verify that data was collected- sometimes LabView will save a blank file
    f. Move on to next data point
5. Shutdown
    a. Exit out of LabView VI
    b. in ThermalPro, select “File” -> “exit”
    c. When ThermalPro has closed, turn off IFA 300
    d. Remove probe from probe holder and place in box
    e. Disconnect cables as needed, order is not important

Hot-film Calibration procedures

1. Open the IFA control program and the LabView program.
2. Normally, one would short the end of the BNC cable and read the resistance, however, since the equipment is not available, one will assume the 0.35 cable resistance.
3. The probe holder resistance can be found on the probe box. Typically it is around 0.05 Ohms. Add the cable and probe holder resistance together and type this value as the cumulative resistance in the “cable resistance” box in the IFA control screen.
4. Make sure that the regulator in the hot wire calibrator is open (no flow) or that the flow control valve is closed all the way.

5. Insert the probe into the probe holder. Position the probe such that it is best aligned with the jet center as possible. Measure the cold wire probe resistance. Type the measured value in the "probe resistance" box. <u>Ensure the wire is perpendicular to the flow</u>.
6. Distance above jet plane should be <2 mm. Be very careful to not break the wire or film.
7. Input the desired "Over-heat ratio" or resistance value to the hot film probe- begin with the recommended operating resistance of the probe (see box holding probes). Choose the appropriate filters for the frequency of data to be acquired.
8. Turn the bridge on.
9. Record the voltage at zero velocity. If the voltage reads a value other than zero, play with the offset to get the reading as close to zero as possible.
10. Slowly open the flow control valve in the calibrator and let the air into the calibration setup. Increase the flow to its maximum capacity. If the voltage reading is low compared with the range of the DAQ board, change the gain and the offset values.
11. Turn the flow off and record the zero flow voltage once more. Perform the calibration for at least 10 points if increasing and decreasing flow rates. At each flow condition, record the pressure transducer reading and the hot wire voltage (at >10 kHz) for at least 5 seconds.
12. Perform calibration for two other over heat ratios: one that is 0.15 lower then recommended, and 0.3 lower than recommended. Recall that the overheat ratio is defined as the ratio of the resistance of the wire when it is hot to that at ambient temperature. The resistance of the wire has the following general dependence on temperature, $R(T) = R_o + (R_{100}-R_o)*(T-0)/100$. You can identify the resistances by looking at the box from the manufacturer.

Calibration data analysis

1. Determine the film (sensor) temperatures corresponding to the three overheat ratios.
2. Plot calibration curves for the three overheat ratios.
3. Determine the velocity sensitivity, S_u, for the three overheat ratios. Is the trend in velocity sensitivity with overheat for any fixed voltage in agreement with what you would expect from the hot-wire voltage-velocity equation (see class notes)? Discuss the implications of the trends.
4. Determine the calibration uncertainty in the mean velocity U as well as in S_u.

Jet flow experiment

You will measure the velocity and turbulence conditions of **coflow** exiting from the MILD flame burner, as seen in Figure 3. This burner is unique because it is used to generate a MILD flame, which is a form of combustion which can generate less pollution. The volumetric flow rate is monitored via a LabVIEW DAQ with a pre-calibration orifice dedicated for this laboratory facility. Since the main objective of this lab is to use the calibrated hot-wire system, it is assumed the calibration of the flow rate is ~2% of reading. The desired flow rate (and likewise Reynolds number) will be set using an upstream pressure regulator. It should be noted that your calibration that was conducted in the previous section should cover the entire range of Reynolds number(s) that you wish to run the experiment. For this experiment the HWA will be traversed in the x-direction. The datum that will be used in the x-direction will be the coflow tube inner diameter and while the datum for the y-direction will be the fuel jet. This means that before the experiment is started, the height of the probe needs to be adjusted (preferable by the TA) to be < 2 mm from the jet plane. For this experiment you will run two different Reynolds numbers of the co-flow. At each Reynolds number (you will be provided flow rates at the time of conducting the laboratory) you will traverse the coflow tube in the x-direction at datum height (< 2 mm from jet) and at ~ 30 mm above the burner.

Fig. 3. MILD combustion burner (E. Walters, 2016).

1. Rotate the film probe from the calibrator exit to just above the center of the burner exit. <u>Insure the probe is perpendicular to the flow</u>. The probe should be as close to the burner exit as possible, without touching or damaging the probe (<2 mm).
2. Note the outer dimeter of the tube jet and inner diameter of the coflow tube.
3. Ensure the pressure regulator at the build is turned on between 60 to 80 PSI
4. Adjust the upstream pressure regulator (near LabVIEW station) to increase the flow rate to desired value
5. Ensure that the LabVIEW program operates and the flow rate readings are recording correctly.
6. Turn off the flow to zero using the upstream pressure regulator.
7. Energize the hot-film at the standard overheat ratio. Record a zero flow reading of the wire (5s, 10kHz).

8. Turn the air flow on to the first Reynolds number conditions. Record the voltage of the signal.
9. Move the probe using the traverse table in the X-direction, in 5 mm increments. Traverse across the burner. Record the voltage at each location.
10. Increase the height of the probe by 30 mm, using the marking tape. Repeat in measurements in the X-direction.
11. Repeat steps 7-10 with the next Reynolds number.
12. Turn on the bridge excitation. Now energize the hot film at the higher or lower overheat ratio calibrated and record data as indicated.
13. Repeat steps 7-10 with one of the other two overheat ratios (you only need to pick one condition), with the first Reynolds number. Repeat steps 7-10. Collect additional data with the second Reynolds number as time permits.
14. Turn off the bridge excitation. Turn off the air flow to the nozzle.
15. Make sure all team members have access to the data collected.

Jet flow data analysis:

1. Plot the mean velocity vs radical distance for the two overheat ratios. Discuss the trends and any sensitivities.
2. Plot the turbulence intensity (if any) vs. radial distance for the two overheat ratios. Discuss physics associated with trends in the velocity distribution as the probe is traversed radially and axially.
3. Plot the FFT of the fluctuating velocity. Are there any dominant frequencies in the flow? Do they change as a function of axial position or overheat ratio. Discuss trends.

Report:

Present a brief introduction, describe the methodology used, design stage uncertainty, and any assumptions for the measurements. Respond to the questions posed in the handout and include the required plots. Conclude by describing what you learned from this laboratory. **Ensure that the final report is professional.** It is anticipated that no more than two pages of text is required to complete the report. Include in the Appendix documentation about how the design stage uncertainty was determined, your uncertainty trees, and anything that is needed to support your discussion.