ME 3300 Lab-05: Flow Sensor and Orifice Plate

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Contents

1 Learning objective

The objectives of this experiment are to provide the student with an opportunity to:

1. Calibrate a custom orifice plate using a rotameter as a reference standard.
2. Observe the dynamic response of piezoelectric pressure sensors during changes in flow rate.
3. Gain experience with non-linear regression (curve fitting).
4. Use the regressed calibration curve to create a flow measurement system.

2 Required Equipment

1. Air flow apparatus with Kings Rotameter and custom orifice plate with up- and down-stream pressure taps.
2. USB Data Acquisition Device (NI-MyDAQ)
3. One Honeywell differential pressure sensors with ± 30 psi range (P/N SSCDRRN030PDAA5) and two air hoses.
4. Breadboard (MyDigital protoboard)
5. Digital Multimeter (DMM)
6. DC Power Supply
7. Needle-nose pliers & wire strippers
8. Small flathead screwdriver
9. Power supply and wire kit

3 Introduction

Orifice plates and rotameters are two common types of flow sensors. Rotameters are displacement volume flow sensors; they measure flow by observing the displacement of a floating vessel in an upward flow stream. For this experiment, a purchased rotameter is provided as the flow measurement standard. More details are given in the References.

Orifice plates are obstruction flow sensors; they measure the difference between the upstream and downstream pressure caused by an obstruction in the flow stream. For orifice plates, the obstruction is a plate with a hole that is smaller than the existing flow pipe. The obstruction causes a pressure drop. For this experiment, a custom orifice plate with pressure taps has been provided. The internal geometry of the orifice plate is shown in Fig. 1.

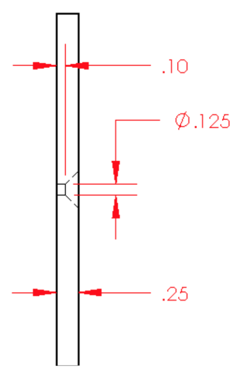

Figure 1: Orifice plate internal geometry. Flow is from left to right.

To create a custom orifice plate flowmeter, downstream and upstream pressure will be measured separately with the Honeywell pressure sensors. The differential pressure (pressure drop across the flowmeter) can then be correlated with the flow measured by the rotameter to create a calibrated flow measurement system. Flow through an obstruction meter, such as an orifice plate, can be calculated according to:

$$Q = \left(Y K_o A_o \sqrt{\frac{2}{\rho}} \right) \sqrt{\Delta P}, \tag{1}$$

where ΔP is the pressure drop, ρ is the density, A_o is the area of the throat, K_o is the flow coefficient, and Y is the adiabatic expansion factor (compressible fluids only).

In this experiment, the calibration equation will have the form:

$$Q = a_1\sqrt{\Delta P} + a_o \tag{2}$$

where a_1 will be the best estimate of the combined factor $YK_oA_o\sqrt{\Delta P}$ and should be close to zero. This regression can be performed by plotting the measured flow vs the square root of the measured pressure drop and then using the Matlab fitting function (polyfit).

4 Laboratory instruction

4.1 Part 1: Connecting the sensor and hardware

In this lab, you will be using two Honeywell SSCDRRN030PDAA5 pressure sensors (see Figure 2) with analog output. These differential pressure sensors have a ±30 psi range, require a 5V supply and are amplified and temperature compensated. For more information, see Honeywell pressure transducer SSCDRRN030PDAA5 webpage. A single apparatus will serve two stations; you will work with a group directly across from your station. Each station will have its own data acquisition but the flow apparatus, pressure sensors, and breadboard circuit will be shared and common. Please make sure to plan accordingly.

1. Place pressure sensors on the breadboard. A sample circuit for the components on a breadboard is shown in Figure 2.
2. Supply each pressure sensor with a 5V supply and ground wire. Reference Figure 2 for the proper pin-outs. **Do not turn on the power supply until confirming your circuit with the TAs.**
3. Using the supplied air hose, connect each pressure tap on the experimental apparatus to Port 1 on each pressure sensor.
   - Port 1:"Pressure Port" (upstream)
   - Port 2: "Reference Port" (downstream)
4. Connect the output voltage from the sensor to your group's NI-MyDAQ as well as the daq for the group in front of you (for multi-group experiments).
5. Show the connections to the TAs prior to connecting the NI-MyDAQ to the computer.
6. Update the code **MATLAB_Data_Acquisition.m** to match the provided code on Canvas and with the following settings.
7. Collect the single-channel voltage output from ([0]).
   - Duration: 10 seconds
   - Sample rate: 100 samples per second
   - Keep the slope = 1, intercept =0, and $V_0 = 0.00$
   - enableCalibratedPressure = false;

Q: What type of pressure is measured by the pressure transducer? See figure 3 for the proper experimental setup.

4.2 Part 2: Record calibration data

In this lab, we will be using a King's Rotameter as a reference for flow rate. These rotameters measure air flow by correlation to vertical displacement of a float in the flow field (the rotameter must be vertical during measurements). Inspect the rotameter for flow units and proper reading technique. For additional information on the King's rotameter see website Rotameter. **During this part, you will work together with the station directly across from your station (e.g. stations 1 and 2 work together)**. Identify one person to vary the flow, one to read the rotameter, and one from each station to record the pressure sensor voltages from MATLAB and the flow data from the rotameter.

1. **NOTE: all pressurized flow comes from a single source in the room, so ensure only two orifice plates are run at the same time.**
2. **NOTE: Be considerate of other groups by not changing the flow rate during their data collection.**
3. Flow rate is controlled through a ball valve located between the air supply hose and the apparatus.
   - Practice opening the valve slightly to test your circuit and calibration MATLAB program.
4. Verify your circuit and setup with the TAs.

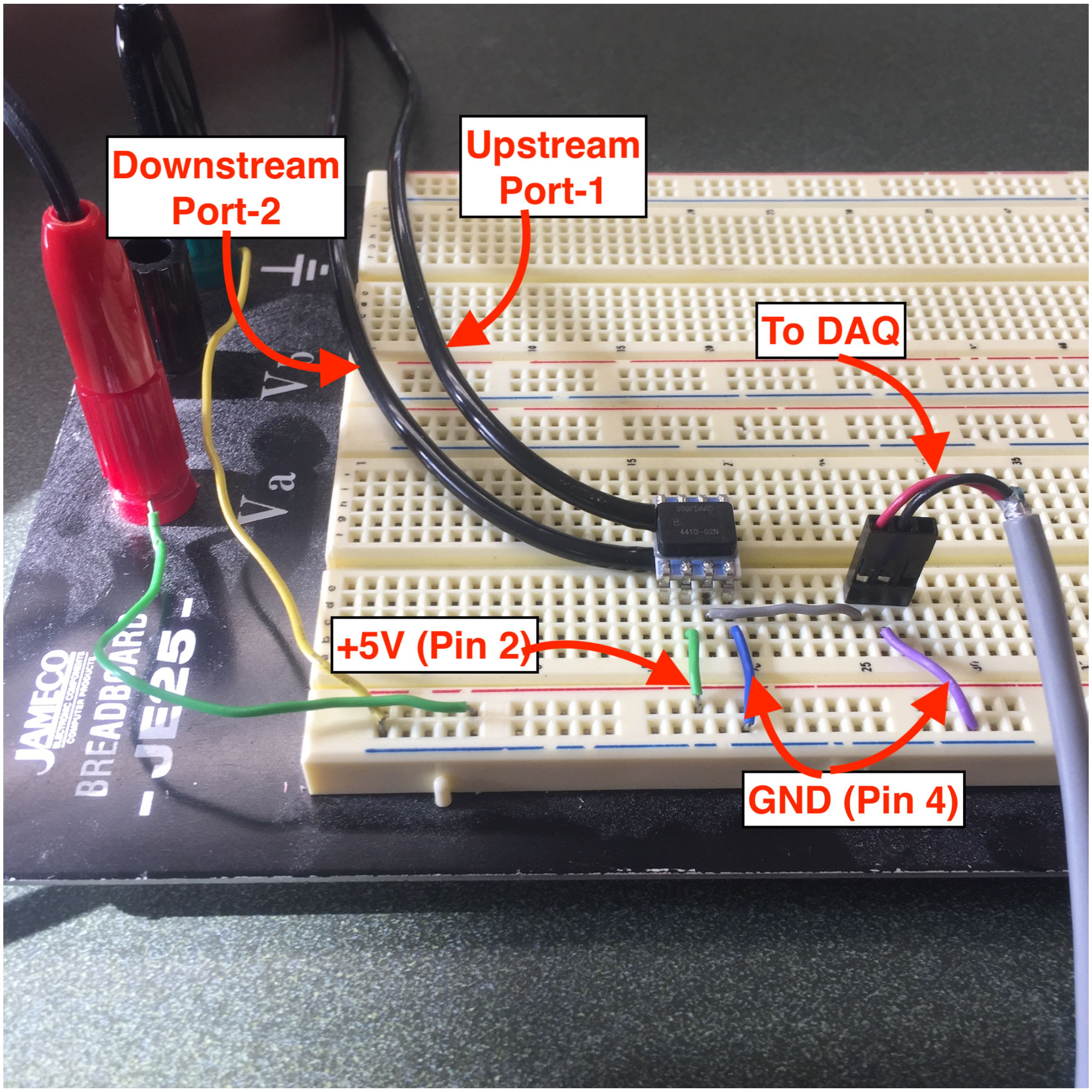

Figure 2: Sample connection for experiment 4.

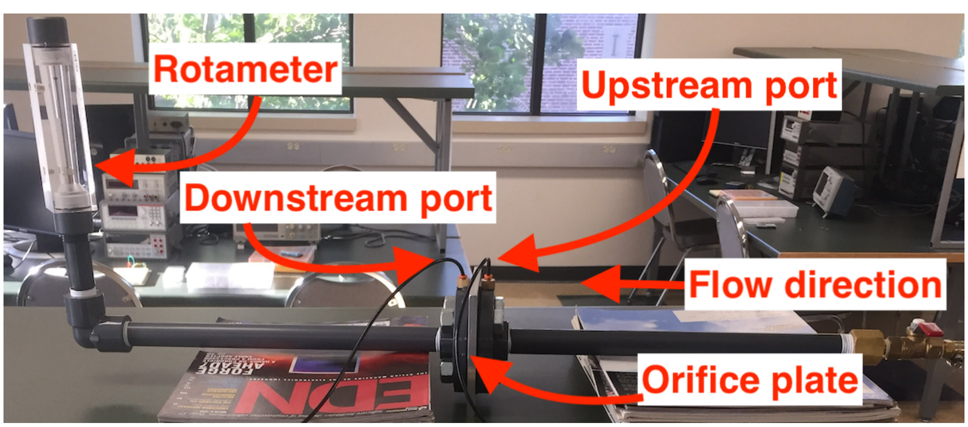

Figure 3: Experimental setup for orifice plate.

Table 1: Sample calibration data.

Flow rate (scfm)	Voltage (v)	Voltage - $V_{zero,flowrate}$ (v)
0	2.5534	0
1.0	2.5806	0.0272
1.6	2.6379	0.0845
2.0	2.6783	0.1249
2.6	2.7503	0.1969
3.0	2.8058	0.2524
3.6	2.9352	0.3818
4.0	3.0423	0.4889
4.6	3.2088	0.6554
5.0	3.3549	0.8015
5.6	3.5643	1.0109
6.0	3.6940	1.1408

5. Procedure for calibration (make sure you collect at least ten points for calibration):
   (a) Open the valve to obtain a desired flow rate. Make sure to take care of parallax error and use the right readout location for float.
   (b) Wait for at least 10 seconds before collecting data. This will allow time for the flow and pressures to settle to their nominal value.
   (c) Collect the single-channel voltage output from ("AI0").
   (d) The first data point in your calibration should be for a zero flow rate condition (i.e., valve fully closed).
      - Duration: 20 seconds
      - Sample rate: 30 samples per second

      a. Run your program:
         - Save a data file using this naming convention: **SCFM_XX.csv** where
           – `XX` indicates rotatmeter flowrate.
         - Update the file name before each run to avoid overwriting data.

      b. Compute the Average Voltage:
         - Write a MATLAB script to calculate the mean voltage from each data file.
         - Record the result with at least two decimal places.
   (e) Take at least ten points evenly distributed across the flow range of the apparatus.
6. **NOTE: subtract the voltage for the zero flow rate case for all the other calibration data, while performing calibration**.
7. A sample dataset used for calibration is shown in table 1. Make sure to include a similar table in your logbook.
8. Refer to the next section to create a calibration plot with data (i.e, calibration data recorded in your log book). A sample calibration plot is shown in Figure 4.

4.3 Part 3: Create calibration of custom Orifice plate flow-meter

1. Create a figure with two subplots. See sample calibration plot in Figure 4. You will produce a similar plot for your calibration.
2. **LEFT PLOT:** Use markers to plot your measured flow rate vs. the square root($\sqrt{V}$) of the pressure drop.
   - Use the **polyfit** function in MATLAB, to create a linear fit line from the regression.
   - The determined slope and bias will correspond to those defined in equation 2.
   - Include axis labels (with units), a legend, etc.
   - Show the 95% confidence level for the curve fit.

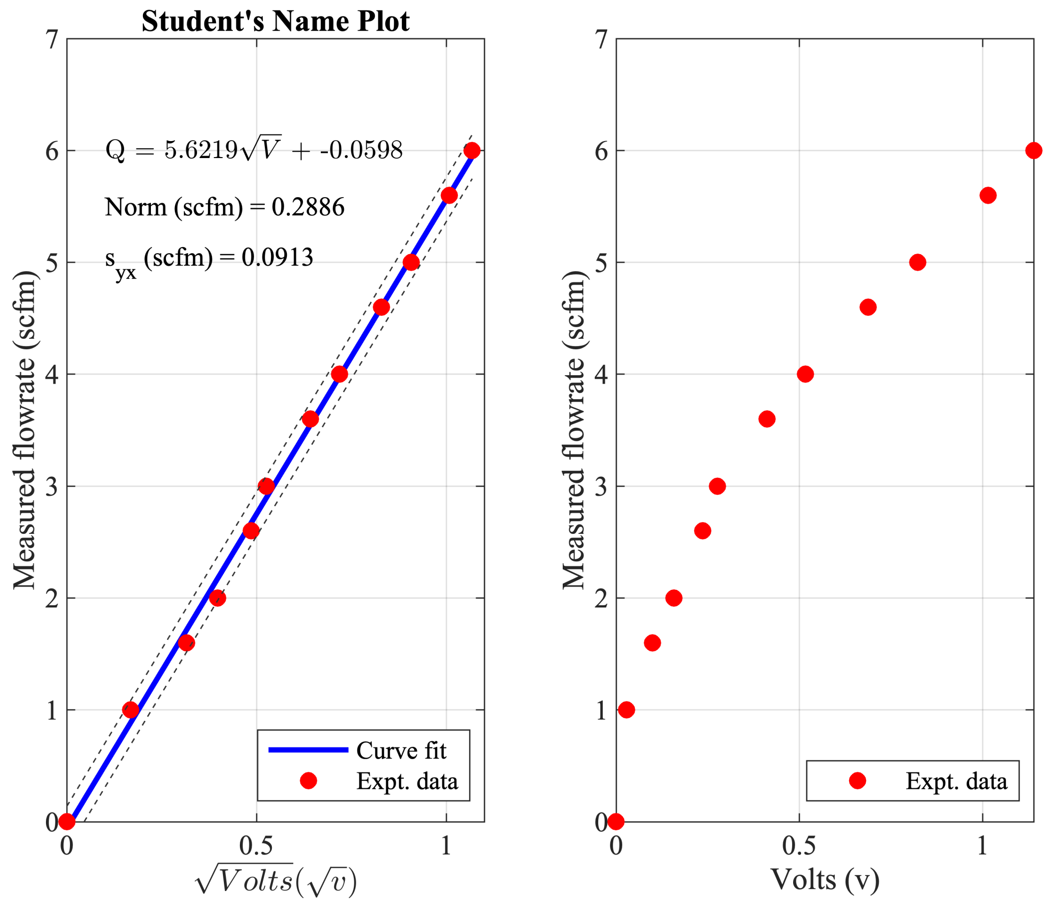

Figure 4: Sample calibration plot with all the relevant details.

3. **RIGHT PLOT:** Use markers to plot your measured flow rate vs. the pressure drop (NOT THE SQUARE ROOT OF PRESSURE DROP).
4. Write down your calibration slope value and intercept value in the log book. These values will be used for the following parts of your experiment.

5 Part 4: Custom Orifice plate flowmeter verification.

Verification should be performed for five distinct flow rates.

1. Update the code **MATLAB_Data_Acquisition.m** to match the provided code on Canvas and with the following settings.
2. Collect the single-channel voltage output from ("AI0").
   - Duration: 20 seconds
   - Sample rate: 200 samples per second
   - Change the slope, intercept, and V_0 to your values
   - enableCalibratedPressure = true;
   - Comment line for double header and uncomment line for triple header

   a. Run your program:
      - Open the values to get a desired flow rate and wait for 10 seconds for the rotameter reading to stablize.
      - Save a data file using this naming convention: **Verification_SCFM_XX.csv** where
        - `XX` indicates rotatmeter flowrate.

- Update the file name before each run to avoid overwriting data.

b. Compute the Average Voltage:

   - Write a MATLAB script to calculate the mean voltage and SCFM from each data file.
   - Record the result with at least two decimal places.

3. Compare your average calibrated flowrate indicated in from DAQ system to flowrate indicated by the Rotameter.
4. Make sure to check your recorded data file. The file should be stored in three columns: the first column is time data, the second column is voltage data, and the third column is flow rate data.
5. Record the rotameter reading and average flow rate reading from the DAQ system in your logbook.
6. Repeat this at five distinct flow rates, recording both flowrates (from the DAQ and from the Rotameter).

Q: How accurate is your calibration? Is it an accurate flow measurement? Is it repeatable?

5.1 Part 5: Record flowrate vs time for a step input of the ball valve

1. Collect the single-channel voltage output from ("AI0").
   - Duration: 7 seconds
   - Sample rate: 1000 samples per second
   - Change the slope, intercept, and V_0 to your values
   - enableCalibratedPressure = true;
   - Comment line for double header and uncomment line for triple header

   a. Run your program:

      - Open the values to get a desired flow rate and wait for 10 seconds for the rotameter reading to stablize.
      - Save a data file using this naming convention: **Step_Input_of_ballvalve.csv** where
      - Update the file name before each run to avoid overwriting data.

   b. Compute the Average Voltage:

      - Write a MATLAB script to calculate the mean voltage and SCFM from each data file.
      - Record the result with at least two decimal places.

2. With the inlet valve closed, start recording in Matlab DAQ program.
3. Open the valve half way at approximately 2 seconds. Repeat as needed for timing.
4. Make sure to save this time series data for plotting.
5. Create a plot with two y-axis scales using **plotyy**: the left y-axis should be in volts for the pressure drop voltage and the right y-axis should be in the calibrated flow units (SCFM). Plot both pressure drop and calibrated flow rate vs time for the 5 second step response, reference 5.

Q: Is there a significant transient response? Is there overshoot? Do you think the flowrate calibration is valid during the transient response? Is the pressure drop during the transient response within the calibration range?

Refer to the sample result figure 5. Make sure to generate a similar plot using your data.

6 Part 6: Return Lab Space to Prior Condition

1. Remove all breadboard wires and place them back in the wire kit in an organized fashion.
2. Remove the pendulum wires from the breadboard and set them aside.
3. Confirm your data files are saved to OneDrive.

   a. Check that files are available online using your phone or personal laptop to confirm.

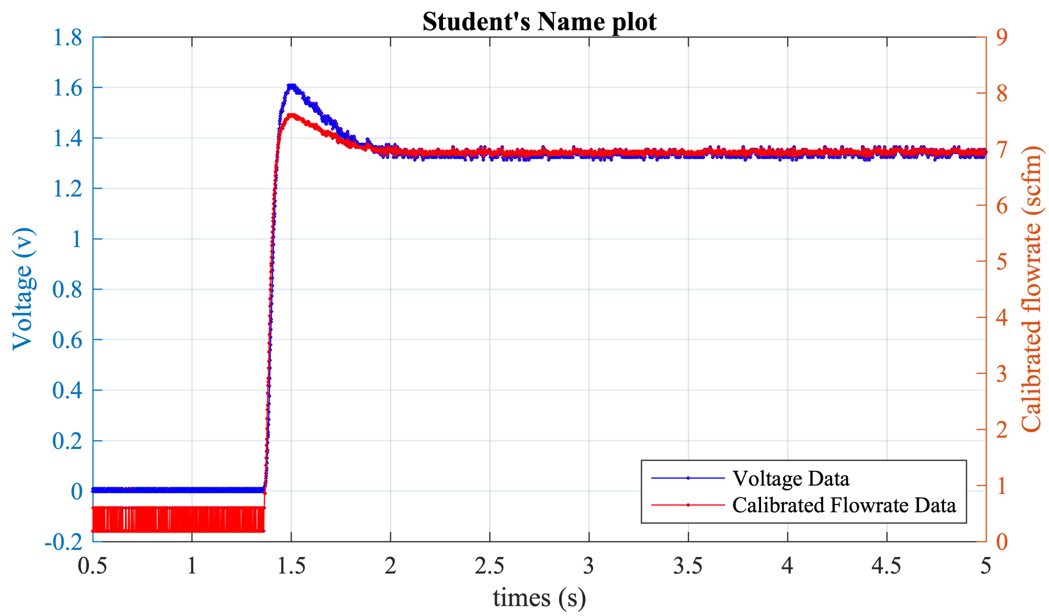

Figure 5: Sample transient response plot

b. Make sure that all team members have access to experiment files, including data and scripts.

4. Log off the computer.

7 Post-Laboratory Assignment

For this experiment, submit the following items on Canvas for your post-laboratory assessment.

1. **Custom orifice plate calibration plots**
   - Use of subplot to create the figure.
   - The calibration plot should include:
     – Using "scatter" plot function, raw data points should be with `MarkerSize = 90`.
   - The plot should be 5" tall and 6.5" wide.
   - Properly annotate your plot: axis labels, title, legend, etc.
   - Include legend of all different sampling types.
     – Use title: "FirstName LastName's Calibration Plots".
   - Set axis grid lines on, box off, and figure background color to white.
2. **Step input response plot**
   - The calibration plot should include:
     – Using "scatter" plot function, raw data points should be with `MarkerSize = 10`.
   - The plot should be 3.5" tall and 6.5" wide.
   - Properly annotate your plot: axis labels, title, legend, etc.
   - Include legend of all different sampling types.
     – Use title: "FirstName LastName's Step Input Response Plot".
   - Set axis grid lines on, box off, and figure background color to white.
3. **Answer All Questions in the Post-Lab Canvas Assignment**
   - Compare your plots to the example plots shown in figure 4 and 5 to confirm that you have completed the assignment correctly. Note that your values will differ, but your formatting and annotation should match.