



## **Integrated Fluids and Electronics Labs to Measure Fluid Flow**

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## Abstract

Knowledge of theory is deepened by examining how the theory models the physical world. Exercises in the laboratory can enhance the understanding of the models by demonstrating both the accuracy and the shortcomings of the theoretical models. To help students achieve a better sense of connections between theory and the physical world, we have developed laboratory experiences to measure the flow of fluid using transducers and computer-based instrumentation. The goals of these experiments are to extend students' knowledge of fluid behavior as well as extend understanding of instrumentation systems. Several experiments were developed and implemented at a very low cost primarily using materials readily available at most hardware stores.

In the study of fluid flow behavior, the first lab examines water flow while a second lab looks at air as a fluid. In the first lab, students calibrate a flow meter by manually measuring the mass discharged during defined time intervals. Students use multiple flow rate measurements to ensure a linear response from the meter. The second lab uses air and the students are asked to determine how the calibration for the water flow rate compares to the air flow rate calibration. At this point students demonstrate that the linear velocity of the fluid that is the critical component. Manual verification of the air flow rate measurement is done using a Pitot tube attached to a water filled manometer. Use of the Pitot tube gives students additional experience with the Bernoulli Equation and this important device often used to measure airspeed.

The flow meter uses a magnetic turbine and a Hall Effect sensor to generate pulses for each rotation of the turbine. The pulses are read using the counter on the National Instruments MyDAQ and LabVIEW. The students are introduced to the NI MyDAQ in the electric circuit class and associated lab. Students are then instructed on how to build a LabVIEW™ program to read and convert the rotation rate to a linear velocity as well as a volumetric flow rate. This method of integrating theory from different engineering theory courses by engaging students in practical applications helps the students to further their knowledge and understanding in both targeted areas. We are working on new experiences to integrate additional topics.

## Introduction

To be an effective engineer and apply the fundamental principles of mechanics, materials, circuits, fluids, thermodynamics, etc. it is necessary to understand how these different distinct topics inter-relate. The skill of knowledge transfer is particularly difficult for students <sup>[1]</sup>. That is, the application of skills learned in one class to a in a different discipline. For example, students have difficulty translating skills learned in math classes to solving problems in physics classes <sup>[2]</sup>. As engineering educators, we are called to assist students' integration of material across the curriculum <sup>[3]</sup><sup>[4]</sup>. The ability to transfer knowledge to new situations requires students must work through Bloom's domains to develop these intellectual skills <sup>[5]</sup>. This laboratory experience is

designed to show “real world” applications to assist in moving students from the knowledge and comprehension to application and synthesis.

The authors determined that laboratory courses were ideal opportunities to include experiences to assist student development in bridging disciplines. Our goal was to design new experiments for the laboratory course associated with Fluid Mechanics incorporating material from other courses, in this case Circuits. Fluids and its laboratory are typically taken in either the junior or senior year. All students have taken Engineering Dynamics, Physics, and Chemistry. In addition, approximately half of the students have completed the Electric Circuits course. These laboratory experiments integrate use of National Instrument’s LabVIEW™ which is used extensively in Electric Circuits. Previously described experiences demonstrate the usefulness of LabVIEW™ in the context of Circuits<sup>[6]</sup>, Data Acquisition<sup>[7]</sup>, Signals<sup>[8]</sup>, and Fluid Dynamics<sup>[9][10][11][12]</sup> courses where the students use an interface designed by the instructor. In this set of experiments students create a LabVIEW™ program called a Virtual Instrument (VI).

The need to measure flow brings in a natural need for instrumentation, considered by Feisel and Rosa as the first objective for undergraduate engineering laboratories<sup>[13]</sup>. Rather than relying on pre-packaged instruments, students are expected to use their knowledge of physics, fluid dynamics, and circuits to acquire, manipulate, and calibrate the signal from a turbine style flow meter. Students then compare the value outputted by the sensor to an alternate method of measuring flow, in this case either by massing the water or the use of a pitot tube. To do this comparison, students need to convert the output signal from the sensor to conventional flow units, such as velocity or mass flow rate.

Focusing on relatively simple fluid theory, measurements of flow rate, affords the time examine fluid theory and work on programming and data acquisition skills simultaneously. Students are expected to extend their programming knowledge from the Circuits course in order to create and modify the VI to measure flow rates for different types of fluids. For the students who have not yet taken circuits, because these courses are offered every other year, this activity serves as a motivating exercise and these students were paired with students who had taken Electric Circuits.

Guiding the development of the lab exercise are the learning outcomes that students need to achieve. The outcomes of this laboratory experience are that the students will be able to:

- Perform several different fluid flow measurement methods
- Compare fluid flow measurements
  - Mass flow rate & Electric Meter
  - Pitot tube & Electric Meter
- Program and implement an electronic flow meter including
  - Programming of LabVIEW™
  - Calibration of the electronic meter
  - Conversion between multiple units to represent flow rate

The choice of the three learning outcomes above resulted in development of a sequence of lab experiences that would build upon one another and guide the students through the process of

learning about not only the properties of flow, but also the instrumentation itself. Thus, the experiments were designed to meet these outcomes by

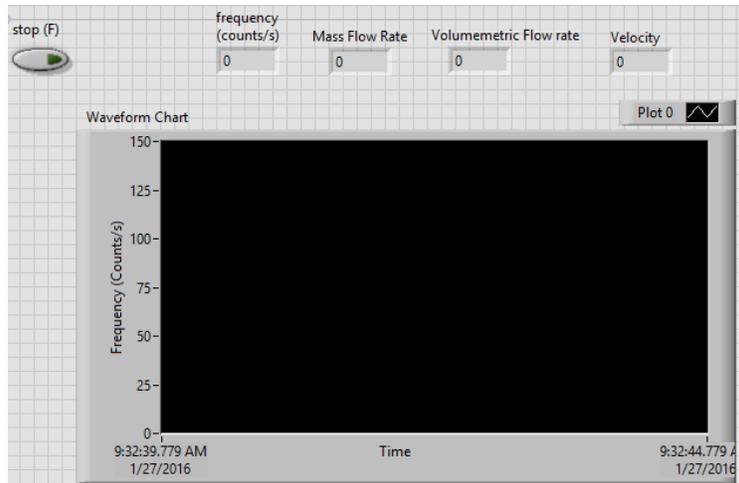
- Guiding student use of different flow measurement techniques
  - Mass flow rate
  - Pitot tube with water manometer
  - Electronic meter
- Asking students to compare of values obtained with each method
  - Water was measured using mass flow rate and electronic meter
  - Air was measured using a Pitot tube and electronic meter
- Students were guided through the process of setting up the electronic meter including
  - Basics of programming in LabVIEW™
  - Conversion of the raw signal from the meter to convention flow values.

### **Task 1: Setup Flow Sensor**

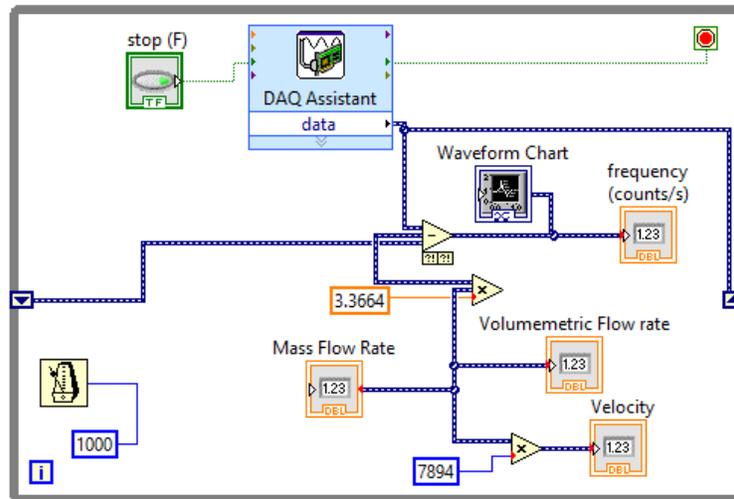
To start, students were instructed to set up the flow sensor. This involved not only making the appropriate electrical connections between the sensor and the National Instruments Data Acquisition Module (NI myDAQ) using a solderless bread board, but to build a VI within LabVIEW™. The created program was designed to use the signal from the flow sensor and translate that signal into a flow rate. This same program was then used in subsequent measurements of both water and air flow rates.

The flow sensor is a turbine style sensor, using the rate a small fan spins to demine the speed of the fluid passing through it. Details of this flow sensor and experimental set-up are provided in Appendix A. The magnetic blades within the meter spin past a Hall Effect sensor generating pulses as the turbine rotates. Understanding the sensor's workings, requires knowledge of ideas of kinematics and electromagnetism, introduced in physics classes.

Students were introduced to the ideas of measuring dynamic signals with the NI myDAQ in the laboratory class associated with the Circuits course. Due to this prior knowledge, students are given limited instruction on the physical connection of the electronics. But, in the Circuits laboratory, students had not yet had the opportunity to construct a VI within LabVIEW™. This experience then facilitated not only a transfer of knowledge between classes, but an opportunity to extend their knowledge. To create the VI, students were given detailed instructions (Appendix B). The VI reads the data from the sensor and performs the mathematical operations to convert the rotation rate to a flow velocity. The created VI, shown in Figure 1, calculates both the linear velocity of the fluid, the mass flow rate, and the volumetric flow rate. The VI also displays the output from the sensor on a chart.



(a)



(b)

**Figure 1: VI in LabVIEW™ to measure flow rate from sensor. (a) User Interface (b) Program code.**

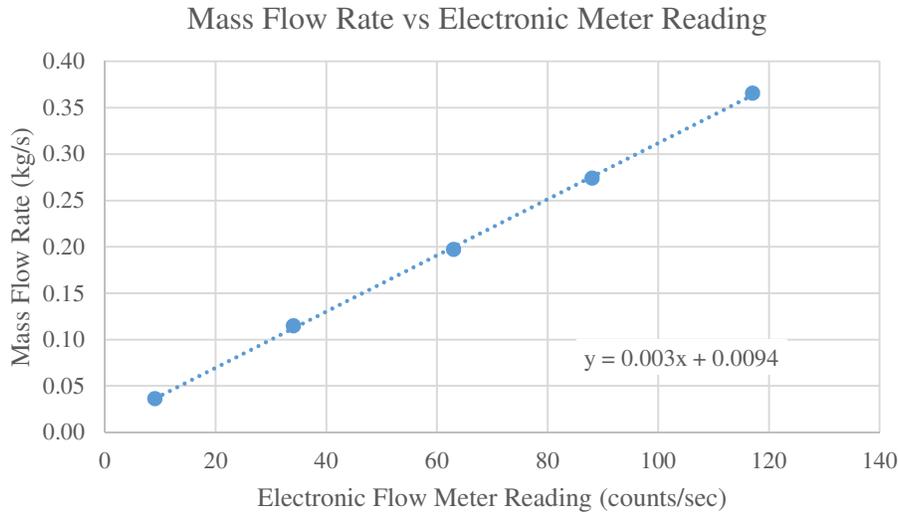
## Task 2: Water Flow Rate

In the study of fluid mechanics one of the fundamental equations,  $\dot{m} = \rho vA$ , relates the mass flow rate,  $\dot{m}$ , to the velocity of the fluid,  $v$ , by multiplying the velocity by the area,  $A$ , of the pipe, and the density of the fluid,  $\rho$ . Students investigate the application of this equation in the process of calibrating the flow meter using water. Although this equation is relatively simple, students often forget its utility. Use of this equation in the context of this experiment helps students better understand this equation and how to use it.

The experimental mass flow rate is determined using the mass (pail and scale) method, where a bucket of water is collected over a defined time interval and then placed on a scale. The density

of the water is determined by measuring the mass of a defined amount of water. The area of the pipe is found by measuring the inner diameter with a caliper.

Calibration is done by testing the response of the meter at different flow rates, as shown in Figure 2. In this system, the flow rate is controlled by changing the position of a ball valve mounted before the meter. Calibration showed that this meter's rotation rate increases linearly with increased flow rates within this range tested. Details of the experimental apparatus are provided in Appendix A and the lab manual is provided in Appendix B.



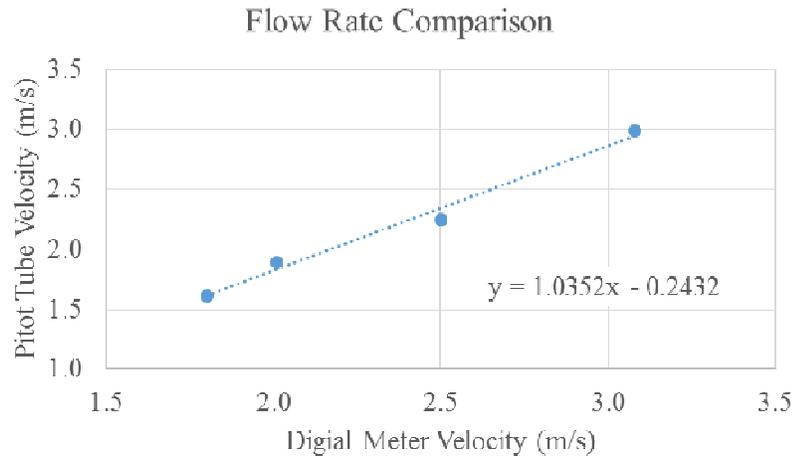
**Figure 2: Calibration Data for Electronic Flow Meter**

### Task 3: Air Flow Rate

The third task is to use the electronic flow meter to measure the flow rate of air and compare this value to the reading from a pitot tube attached to a manually read water/air manometer. The equation  $\dot{m} = \rho vA$  can be used with any fluid, including air, by changing the value of density. In this case a constant density for air, under standard conditions, is used because the low pressure air travels at relatively slowly.

When measuring air flow rate using a manometer with the pitot tube, a simplification of the Bernoulli equation,  $v = \sqrt{2(P_S - P_F)/\rho}$ , relates the velocity of the fluid flow to the pressure difference across the two points on the pitot tube. Here  $P_S - P_F$  is the difference between the stagnant pressure,  $P_S$ , and the pressure of the flowing stream,  $P_F$ , read off of the manometer. As shown in Figure 3, students found that the velocities determined using both the electric flow meter and the Pitot tube correlated in the range of flow rates tested.

| Digital Meter (m/s) | Pitot Tube (m/s) |
|---------------------|------------------|
| 1.80                | 1.62             |
| 2.01                | 1.89             |
| 2.50                | 2.25             |
| 3.08                | 2.99             |



**Figure 3: Correlation of air speed determined by the electronic flow meter and Pitot tube.**

### Evaluation

This laboratory experience was successful in helping students transfer and integrate knowledge between disciplines, primarily in the areas of Fluids and Circuits. The memo reports submitted by students in conjunction with these experiments displayed that the students met the outcomes of this experience, where students will be able to:

- Perform several different fluid flow measurement methods
- Compare of fluid flow measurements
  - Mass flow rate & Electric Meter
  - Pitot tube & Electric Meter
- Program and implement an electronic flow meter including
  - Programming of LabVIEW™
  - Calibration of the electronic meter
  - Conversion between multiple units to represent flow rate

In the memo reports, students showed that they were able to utilize the fundamental equations for measuring flow, specifically  $\dot{m} = \rho vA$  and the Bernoulli equation. Focused experience in use of these equations, had the benefit of helping students better utilize these equations on homework and exams in the Fluids lecture.

Students found that the velocity measured by the flow meter was accurate when using either water or air. Many found this surprising because the “fluids are so different”. The use of the two different fluids reinforced the ideas that the theories of Fluid Mechanics hold despite changes in the working fluid properties.

The largest struggle with this lab was students’ retention of LabVIEW™ programming. This problem was both recognized and alleviated by doing two experiments, separated in time by a few weeks. At the start of the second experiment, air flow rate measurement, students initially

did not recall how to program in LabVIEW™. This difficulty was quickly overcome and all groups successfully implemented both the water and air measurement programs. In addition, for a class in the subsequent semester, students used LabVIEW™ in to measure water levels in a tank. Students' recollection of how to use LabVIEW™ was much improved, despite not having used it in several months. Successful implementation of a new VIs by all groups shows that students were not only able to remember the material from the previous class, but to transfer their knowledge of the instrumentation system to a new applications. This observation is consistent with current educational theory of Spaced Learning, showing that repetition of content at different times aids in retention of the material <sup>[14]</sup>. In addition, as students are searching for permanent positions, they have expressed gratitude at being exposed to LabVIEW™ several employers asking for experience in this area.

## Conclusion

While it is not generally recommended to mix water and electricity, the need for instrumentation to determine the flow rate was an ideal intersection of the fields of Electric Circuits and Fluid Mechanics. These experiments were successful in building off previous experiences, both in lecture and laboratory classes, in the engineering curriculum as well as be a reference point to future experiences. In this sequence, students meet ABET's outcome (b) "an ability to conduct experiments, as well as to analyze and interpret data" <sup>[15]</sup>.

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## Appendix A: Apparatuses

### Water Flow Rate Apparatus

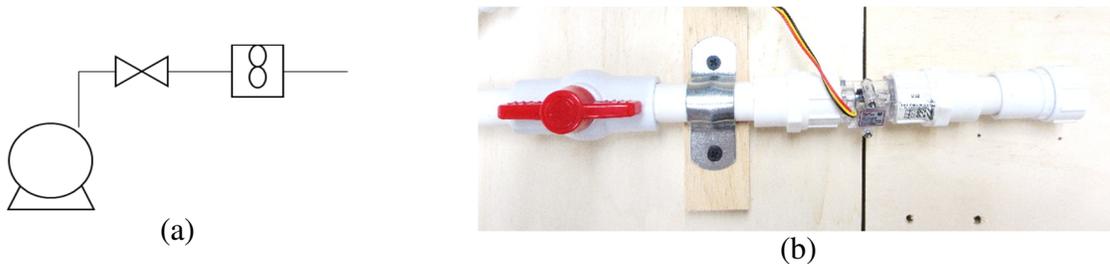
This apparatus used to measure the water flow rate is constructed from PVC piping, in most cases using  $\frac{1}{2}$  inch diameter. This size is selected to connect to the flow sensor, a Sea Water Flow Sensor (Model Number: YF-S201C), shown in Figure 4, obtained from eBay.com. Water is supplied to the system by a  $\frac{1}{4}$  horsepower submerged utility pump (Barracuda Pumps, Model Number: 91250) connected to a vertically mounted  $1\frac{1}{4}$  inch PVC pipe until above the fluid level in the reservoir tank. Above the reservoir tank, a hose (conventional green garden hose) is connected to the  $\frac{1}{2}$  PVC pipe to attach to section containing the flow sensor. Use of a hose offers flexibility in moving the reservoir. After running through the flow meter, the water is sent back into the reservoir tank again through a hose. The hose is easily pulled out of the tank to redirect the flow to a bucket in order to measure the mass flow rate of the water.



**Figure 4: Fluid Flow Meter**

The section of piping containing the flow sensor, shown in

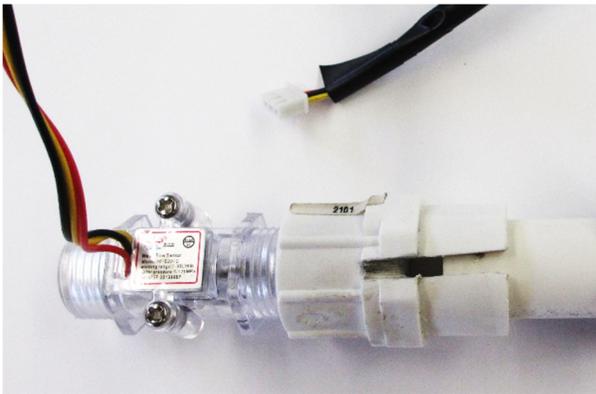
Figure 5, is mounted on a piece of plywood. This board was then clamped to the table top, but could also be mounted vertically. A ball valve is placed before the flow sensor to manipulate the flow rate, while the pump runs at a constant speed. The PVC is glued into the fittings while connections to the meter use a threaded fitting using a female-female FIPS/slip fitting. At either end are fittings to connect to the garden hose.



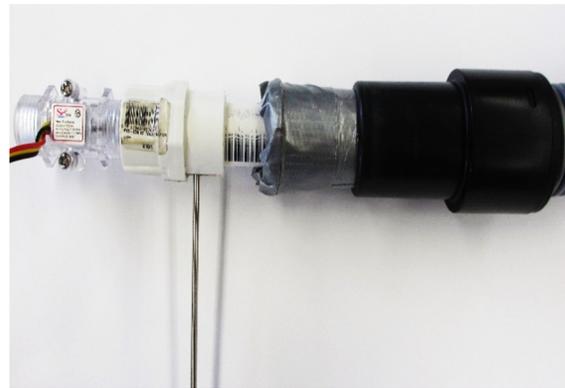
**Figure 5: Water Flow Apparatus. (a) Diagram (b) Photograph**

## Air Flow Rate Apparatus

The apparatus to hold the flow sensor in the air flow is also constructed from  $\frac{1}{2}$  inch PVC. To make room for the Pitot tube within the flow stream close to the flow sensor, a female-female FIPS/slip fitting, has a slot cut in the side, as shown in Figure 6(a). A Pasco Variable Output Air Supply, commonly used with air tracks in physics experiments, is used to supply the air for this experiment. The flow rate is adjusted using the dial on the Pasco unit on a scale of 0 – 5, where the maximum flow rate corresponds to approximately 3 m/s in this configuration. A film canister wrapped in duct tape was used to make the connection between the air supply hose and the  $\frac{1}{2}$  inch pipe, shown in Figure 6(b). To make this specialized fitting, the bottom of the film canister was removed and a hole was cut into the lid to accommodate the  $\frac{1}{2}$  inch pipe. The duct tape was used to secure the lid in place as well as to achieve a tight fit into the air supply hose fitting. The apparatus was held in place using a ring stand. None of the connections were glued so that it would be easy to disassemble.



(a)



(b)

**Figure 6: Air Flow Apparatus (a) Bottom view (b) Side view**

## Appendix B : Laboratory Manuals

### Lab 6: Electric Meter

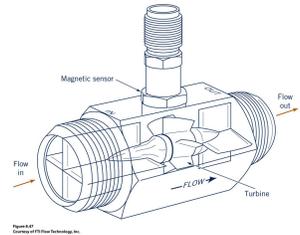
**Introduction:** Our objective for this lab is use LabVIEW™ to set-up and calibrate an electric, turbine style, flow meter. The flow rate will be verified manually using the “pail and scale” method.

**Outcomes:** After completing this exercise you should have a better understanding of the

- use of LabVIEW™ to collect and manipulate data.
- electronic meter calibration.
- relationship between fluid speed and mass flow rate
- 

**Background and Theory:** There are several types of electronically monitored flow meters. One of the most popular is the turbine style meter, as shown in Figure 1. A small, freely rotating propeller or turbine within the meter rotates as the fluid passes through.

The fluid enters a small turbine which has a magnet on it. Electronics on the sensor measure the changing magnetic field as the turbine rotates and provides a pulse back to the measurement system.



**Figure 1: Turbine Meter**

By counting these pulses we can determine the velocity of the fluid passing through the turbine. These pulses might indicate one complete rotation or a fraction of a rotation. The higher the rotation rate in a specific period of time, the higher the flow rate.

Thus, from this meter, you can determine the velocity of the fluid as it moves through the meter. Once the velocity of the fluid is known, this can be converted to mass flow rate using  $\dot{m} = \rho v A$ , where  $\dot{m}$  is the mass flow rate,  $\rho$  is the fluid density,  $v$  is the velocity of the fluid, and  $A$  is the area of the pipe.

Your MyDAQ has a built-in hardware counter that can be connected to a digital input. The counter can be set to count rising edges of the pulses from the flow sensor. The count from the sensor can be converted to flow in any desired units.

**Equipment (at workstation):**

- 2 gallon bucket
- 5 gallon bucket
- 5 ml volumetric flask
- Turbine meter apparatus
- Reservoir with pump
- Balance
- Signal Generator
- Wires

**Equipment (shared):**

- Mop
- 0.1, 0.2, 0.5, 1 & 5 kg masses
- Electronic Balance (in Chemistry)
- Caliper

**Equipment (Fluids):**

- Water

**Note : Safety glasses will be required at all times while in the lab.**

## Procedure: LabVIEW™ Setup

1. Install LabVIEW™ from the disk that came with your MyDAQ. Hopefully, you did this before coming to lab today since it takes close to 30 minutes to install.
2. While the install is running or you are just getting ready, go to the National Instruments website (<http://www.ni.com/academic/students/learn-labview/>) You will want to watch the following videos:
  - a. LabVIEW™ environment Video.
  - b. While Loop Video.
  - c. Recommended: Programming Tools
  - d. Optional: For Loops
  - e. Optional: Case Structures
3. Build your first VI. Open “NI LabVIEW” and then “Create Project” and then a “new VI”. This will open up the “Block Diagram” and “Front Panel” windows. Write a VI (Virtual Instrument) that reads in a number using a control of your choice and then converts the number to speed (such as m/s) as well as mass flow rate (such as kg/s). Determine the density of the water in the reservoir using the 5 ml volumetric flask provided. The program should handle an input range of 0 to 5 cfs. Make sure the interface is clean and easy to read. Use whatever types of controls and indicators you like. But, keep in mind, the user should be able to know the values entered and displayed to a reasonable number of digits. Set the scales for your controls and indicators to something reasonable for the 0 to 5 cfs input. Add loop timing to have the program update ten times per second.
4. Demonstrate this program to your instructor.
5. Watch a video to learn how to read an input from a data acquisition system. - <http://www.ni.com/academic/students/learn-daq/measurement/> . Your computer will probably not bring up a window that asks you what to do with the device. But, it will likely install a driver when the MyDAQ is connected. Make sure it finishes the driver installation successfully. Write a VI that reads the value of the counter from the MyDAQ. Select “edge detection”. Use the DAQAssistant to set up and read the values from the counter. Use the default settings: Active Edge: Rising; Initial Count: 0; Count Direction: Up; Input Terminal PFI0 (labeled DIO 0 on the MyDAQ); Acquisition Mode: 1 Sample (On Demand). When you have everything set, click OK and finish your VI. LabVIEW should ask you if you want to put in a Loop. The answer is Yes, you do.

Now set up the proper timing. Inside the while loop, add the “Wait Until Next ms Multiple” block. Create a constant set to 1000 as the input to the block. This delay means that the instrument is counting pulses for one second before displaying the result. If you input a 60 Hz square wave from the function generator, your VI should display 60 counts per second. The flow sensor also gives a square wave as an output. The frequency of the square wave depends upon the flow through the sensor. In the later part of this lab, you will calibrate your VI to show the mass flow rate in appropriate unites.
6. Watch the video on using a shift register. You will need to use one of these to find the number of pulses from the flow sensor since the last reading <http://www.ni.com/academic/students/learn-labview/execution-structures/> Modify your VI from part 5 to display the difference in counts between loop iterations. You should connect the output of the DAQ assistant to the right hand side of the shift register and to the top input of a

“subtract” icon. Connect the left hand side of the shift register to the bottom input of the subtract icon. The output should then be displayed on the front panel.

7. Run the VI with the function generator as input. Since you set the loop timing interval to be 1000 ms, the number displayed should be the frequency from the function generator.
8. Now that you have your basic VI written, connect the MyDAQ to the flow sensor. Red is connected to 5 Volts, black to DGND, and yellow to the digital input on the MyDAQ used to drive the counter.

### Procedure: Wet Equipment Setup

1. Make sure the water reservoir is filled with enough water to cover the pump.
2. Check the hose connections between the pump and the piping network. Make sure the return hose is placed inside the reservoir.
3. Make sure the one or two valves are in the open position. The handles should be parallel to the direction of flow.
4. Make sure that the power strip is off and plug in the pump. **If the pump turns on, switch the power strip off immediately.**
5. Obtain the weight of the 2 gallon bucket. Since the bucket will have some residual water in it between samples, you might want to do the same here. Put some water in the bucket and dump it out to see what the actual tear weight should be.

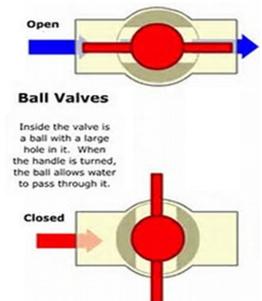


Figure 2: Ball Valves

### Experiment:

1. While holding the hose in the reservoir, turn on the pump using the switch on the power strip. **If there is any water leaking out of the system turn off the pump immediately and contact your instructor.**
2. Once the system is function properly, turn the valve before the sensor so that it is just barely open, about 10° from vertical.
3. Manually measure the flow rate by placing the 2 gallon white bucket on the board on top of the water reservoir. Use the hose to drain the water into the bucket while timing. Aim to time for 30 seconds, unless the flow is such that it will overflow the bucket. In this case, time for 15 seconds or use the 5 gallon bucket. *Note, if the 5 gallon bucket is used, do not place this on the scale. Instead pour some of the water into the 2 gallon bucket until all of the water has been weighed.*
4. Demonstrate your measurement to your instructor.
5. If you are certain that everything is working electrically and as a program, it is time to devise a method of calibrating your flow measurement system. Design an experiment and set up to take several (at least 5) measurements at different flow rates and then analyze your data to determine a function that converts pulses per second to a volumetric flow rate in units of your choosing. Discuss your experiment design with your instructor. If approved, run your tests. **You should measure the flow rate manually (“pail and scale”) and electronically at least twice for each flow rate.** If the measurements are different, then a third measurement is required.
6. Modify your VI to perform the calibration and display the mass flow rate. Run a few tests to see how well your VI works.
7. **When complete, unplug the pump.**

## Memo Report

In this case you are the engineering team responsible testing flow meters and providing the necessary programming to an end user. You are expected to pass along a LabVIEW program that can be used in conjunction with the flow meter to provide the end user with a flow rate (fluid velocity and mass or volumetric) in the units of your choice. Your report should include a graph of the fluid velocity vs the output value from the sensor. Note in your memo how you determined the “calibration factor”. In addition, note if this value is constant or flow dependent and describe the range of flow rates (and corresponding fluid velocities and Re values) tested. As an Appendix, include a table of results (weight measurements and corresponding counts each with corresponding time interval).

## Lab 10: Airspeed

**Introduction:** Our objective for this lab is to use three different techniques to measure air flow, also called anemometers. One technique uses a hand-held meter that measures the air flow using a fan shaped sensor. Another technique uses a pitot tube attached to a water filled manometer. The pitot tube is often used in aircraft to measure the plane’s air-speed. The last technique is to use the same digital meter used in previous labs to measure the flow rate of water.

**Outcomes:** After completing this exercise you should have a better understanding of the

- use of various anemometers including electric meters and a pitot tube.
- differences between air flow rate and water flow rate measurements.

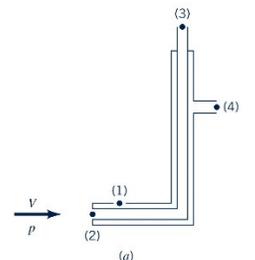
**Theory:** Pitot tubes are one way to measure fluid velocity. This tube is constructed to compare the pressure difference between a point where the fluid is moving (1) to a stagnation point (2), as shown in Figures 1 and 2. These two concentric tubes, points (3) and (4) in figure 2, are then attached to either individual pressure gauges, such as piezometers, or a differential gauge, such as a manometer.

The Bernoulli equation can be used to convert the pressure difference can to the velocity of the moving fluid using 
$$v = \sqrt{2(P_3 - P_4)/\rho} \quad (\text{eq 1})$$

In order to get an accurate reading it is important that the port at the end of the tube be pointed directly into the air flow so that the air actually stops moving in that direction to measure the stagnation pressure. Additionally, it is important that the air flow move directly across the tube to the pressure taps on the side to have symmetrical. Therefore, if the yaw exceeds 20° an error in excess of 1% will be created.



**Figure 1 :** Image of a pitot tube showing the ports along the side (1) measuring the pressure of the moving fluid and the port at the end (2) measuring the stagnation pressure.



**Figure 2 :** Cut out of a pitot tube.

**Equipment (at workstation):**

- Air compressor
- 2 ring stands
- Pitot tube
- Manometer

**Equipment (Fluids):**

- Handheld digital meter
- 1 – Breadboard
- ½” digital meter
- Air

**Note : Safety glasses will be required at all times while in the lab.**

*Note, the procedures for each anemometers are written separately. It might be best to record the air speed using all three techniques before changing the fan output.*

**Procedure: Pitot tube**

1. Attach the two pressure ports on the end of the pitot tube to the manometer. Use the clamp on the ring stand with a 3-fingered clamp to hold the pitot tube horizontally. **Be careful to not tighten it too much to avoid damage to the pitot tube.**
2. Use the other clamp to hold the end of the error hose with the ½” PVC pipe in the end. Adjust the hose and pitot tube so that the pitot tube is pointed axially into the pipe and as close to the center as possible.
3. Turn on the fan and measure the pressure difference at four different outputs.
4. Convert these height values to pressure and velocity.

**Procedure: Handheld meter**

1. Without disconnecting or moving the pitot tube, turn on the handheld meter by selecting the appropriate display units. *Note: It will likely be easiest to use m/s.* Hold the fan part of the meter as close to the tube output as possible, with the display facing the tube and record the value. *Note that the fan is larger than the ½” tube. Try to have the air passing through the fan blades rather than the axis.*
2. Turn on the fan and measure the air speed at close to the same four different outputs as possible.

**Procedure: Digital meter**

1. Open the LabVIEW™ VI that you created for Lab 6. Adjust the calculations to account for the density of air under standard conditions
2. Connect the digital meter to the breadboard and the breadboard to the NI myDAQ.
3. Hold the digital meter on the end of the ½” pipe at the end of the air hose and measure the air velocity.

**Memo Report**

In this case you are the engineering team responsible for recommending a method to measure air flow. You have been requested to provide a report detailing the pros and cons of each measurement technique.

In particular in this memo you should also include:

1. Table showing results using each of the three methods of measuring flow (include you manometer measurements of height and pressure).
2. Recommendation on the best method to measure air speed.