Flow Masters

MAE 4344 Senior Design Final Report

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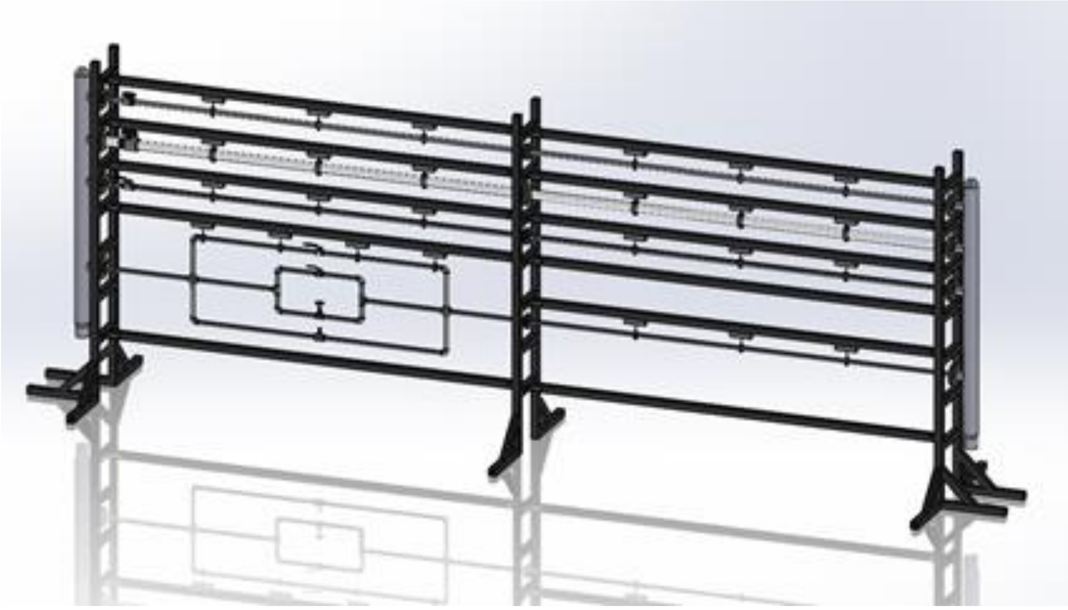

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1. Design Objectives and Constraints

The objectives for this project were to design a pipe stand that will be part of a flow laboratory and will demonstrate the principles of fluid flow, including: laminar and turbulent flow profiles, friction losses in different sizes and roughness of pipe, velocity profiles in pipes, loss coefficients for orifice and venturi meters, and friction losses for different types of valves.

Supporting the design is a full-scale prototype made of cheaper materials to keep a budget of $500. Its purpose is to validate the design, so that the full version of the design can be built in the *Endeavor* lab, and the proposed features can be added so that interactive lab modules can be done by students to support their fluids classes.

In addition to the prototype, a full structural support was built to hold both the prototype and full version of the pipe. It was designed to be able to hold the weight of the full model entirely filled with water.

The prototype was designed to demonstrate two lab modules. The first of these is to demonstrate the pressure loss associated with an orifice plate flow meter and the pressure recovery after the orifice. The second of these is a flow visualization module, where observers will see how water moves around objects and through pipe. This will be achieved with clear PVC pipe and microbeads that will flow through the pipe with the water.

A controls package that records flow rates and pressure drops across the pipes, using LabVIEW, was implemented in the prototype to show a proof of concept for the learning modules that were created for this project.

2. Team Organization and Project Management

With only a 3-person team and a lot of different aspects of the project to work on, we assigned general roles for each individual and assigned tasks week-by-week, helping each other out when needed.

Jake Armstrong, Team Lead: Encourage all team members to take an active role in the project, drive the project team for on-time deliverables, lead the design, planning and execution validation of activities. Also, the team lead was to be the point of contact with our supervisor, Mrs. Southard, and plan meetings with any other professors or faculty members as needed.

Jake Singleton, Instrumentation & Data Acquisition: Research, design, and implement proper instrumentation to demonstrate the necessary information needed to achieve the objectives of the project. Development of graphical user interfaces in LabView to record data obtained by the pipe stand.

Hunter Suntken, Design Engineer: Design the pipe flow learning environment that can demonstrate multiple learning modules. Design and analysis of a support structure that will support the weight of the pipes, fittings and instrumentation for the prototype, as well as, the actual installation.

The construction of the support structure and the prototype piping was a team effort. We all pitched in, in the welding of the supports, the connections of the unistrut and pipe hangers, and the gluing of the piping.

With the university being the primary customer of the pipe stand, we met with many different Oklahoma State professors who might use the pipe stand to get their input on what they wanted to achieve with the system.

The critical path is shown by the ‘x’ in the gantt chart:

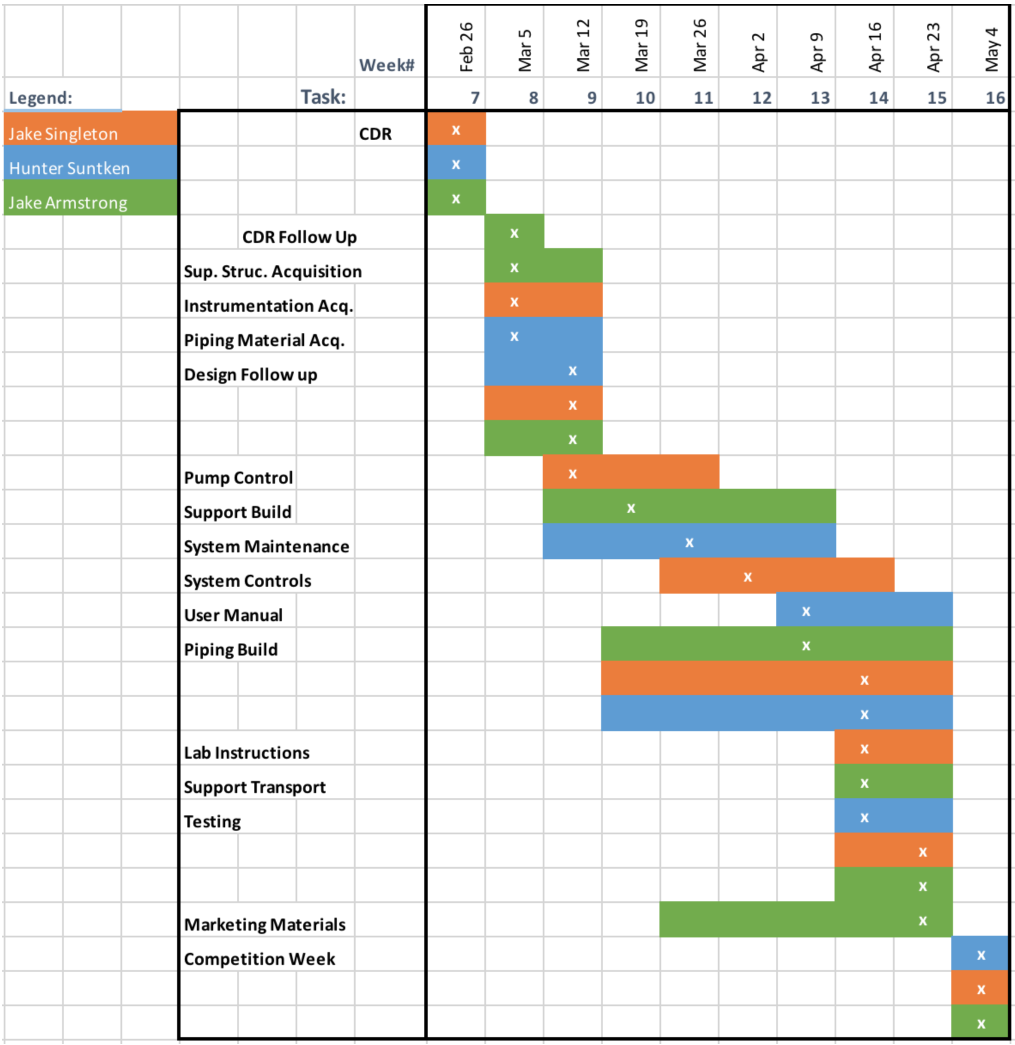


Figure 1: Flow Masters' Gantt Chart

3. Application of Relevant Standards

Several standards and codes will apply to this project. The bulk of these standards come from the International Plumbing Code. Other standards that will apply are the ASME standards and OSHA standards.

3.1. International Plumbing Code

The International Plumbing Code outlines specific guidelines for adding any plumbing to an existing structure such as maintaining structural safety and keeping safe plumbing practices.

3.1.1. IPC 301

This section of the International Plumbing Code states that all piping and structural support should be in accordance with all standards. It states that all waste water should be piped directly to the building's drainage system. It also states that all plumbing that uses water should be connected in some way to the building's water supply.

3.1.2. IPC 307

Section 307 of the International Plumbing Code outlines different precautions to be taken to maintain structural safety. Sections 307.1 and 307.2 are specifically important for the purposes of our project. 307.1 says that any structure in the building that must be changed will need to be done so that it is left in good condition and will still be in accordance with the International Building Code. 307.2 that any framing of the building cannot be cut excessively, so this will need to be kept in mind when installing the system to the *Endeavor* lab.

3.1.3. IPC 308

Section 308 of the International Plumbing Code gives guidelines for piping support. This will be specifically for this project because there will be 20' lengths of pipe that need to be supported. It states that pipe hangers must be used in a way that corrosion does not take place. It also gives a table that shows the maximum allowable distance between hangers for different pipe materials.

3.2. ASME Standards

The American Society of Mechanical Engineers outlines many topics including piping systems. The relevant sections are sections A and B.

3.2.1. ASME A13.1

This standard's purpose is to provide a system for the identification of hazardous materials in piping systems by creating a legend identifies the contents of the pipe system and by color coding the pipes to identify the hazards of the chemicals within the pipes. The legends need to be placed close to flanges or changes in direction and should show the name of the chemical and the direction of flow. It should be visible by anyone who is close to it, meaning, if the pipe is overhead the legend should be on the bottom of the pipe. A13.1 also has a table that defines a color scheme that would be able to show the fluid service.

3.3. ISO Standards

Our design must also take into account ISO standards, specifically one regarding connections for pressure transmitters.

3.3.1. ISO 2186

This standard is important to our design when taking into consideration differential pressure transducers. ISO 2186 states that impulse line sizes for pressure transmitters should be greater than 6 mm, preferably 10 mm but less than 25 mm. It also states that pressure taps should be in the centerline of the pipe so that no air measurements are taken from above or no sediment buildup is produced from below.

3.4. OSHA

We must also take into consideration OSHA standards so that we can safely construct and work on the pipe stand.

3.4.1. OSHA 1910

OSHA 1910 outlines several different standards to follow when constructing the pipe stand. We will have to weld, so we will need to follow safety precautions in Subpart H regarding compressed gases as well as Subpart L regarding fire protection. Subpart I tells us what personal protective equipment to use for our purposes. Finally, Subpart P gives safety information regarding hand and portable power tools.

4. Conceptual Design for *Endeavor* Lab

Two designs were created for this project. The first was the concept design of the full model that will eventually be put in the *Endeavor* Lab. The second was the design for the prototype that was built.

The pipe stand that will go into the *Endeavor* Lab is the basis for the prototype design. The ultimate goal of this project is to create a design that will be put into the lab and to create a proof of concept for that design by building a prototype that will demonstrate a couple of the lab modules that will be presented with the final version.

The original piping design in Figure 2 was designed with a modular approach. Each component shown has a purpose for specific learning modules. The flanged piping allows easy replacement and customization of the pipe stand. This is just one possible configuration for the pipe stand. The overall goal when designing the pipe stand was to be able to provide as many options and opportunities for expansion as possible to maximize the learning experience for a wide spectrum of students, whether they are freshmen undergraduates or students seeking their masters degree.

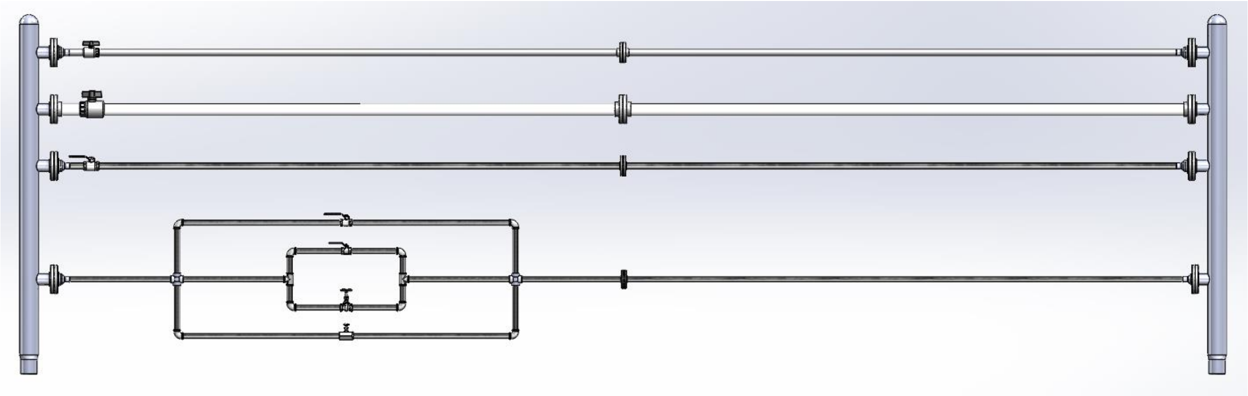


Figure 2: Endeavor Piping Design

4.1. Pipe Manifold

The inlet and outlet manifolds for the pipe stand, seen in Figure 3, are used to distribute flow of water to the different sections of piping along the stand. It has four 2" inlets of piping, to which sections of piping can be attached via flange connections. At the bottom, a 3" diameter inlet is used because the existing piping in the *Endeavor* Lab that will run to the pipe stand is 3" pipe. A 4" diameter of the header is used to calm the flow and reduce turbulence as the to water enters the manifold. These manifolds must be custom made, as none of these specifications exist.

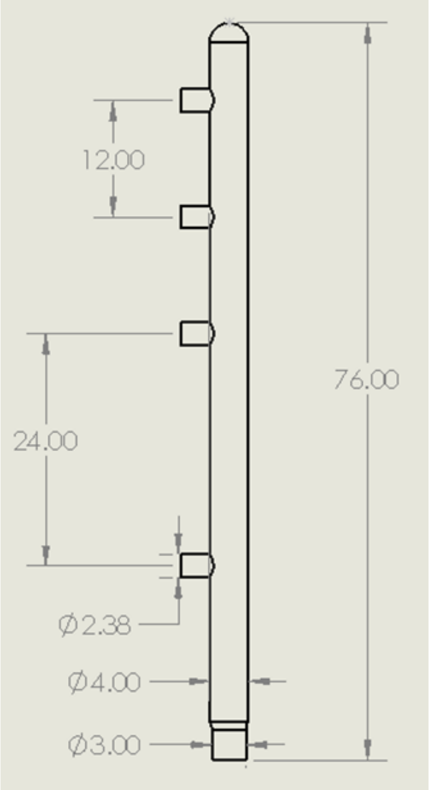


Figure 3: Pipe Manifold

4.2. 20’ Pipe Sections

The design for the pipe stand supports up to four 20 ft sections of pipe, of any material. These are connected with flanges at the manifold and in the middle of the section, to allow for easy removal and addition if different learning modules are being taught. This is shown in Figure 4. The piping on this stand should not exceed a 2” diameter because it is recommended that there should be at least 10 diameters of straight pipe in order to reach fully developed flow. For this design, the sections were made of PVC, the largest size being clear, to visualize flow with a dye injector.

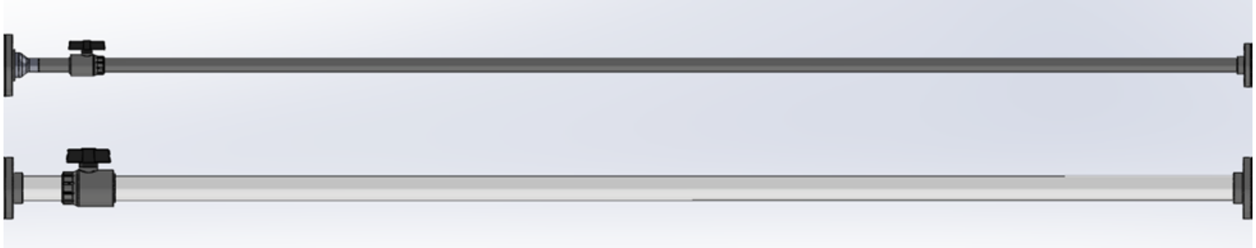


Figure 4: Piping Sections

4.3. Valve Tree

One of the major components for this design was a valve tree, shown in Figure 5. This, like any section of the pipe stand, is completely modular and can be removed if the space is needed for a different learning module. The idea for this section is that flow would come in to the section and divert to one of the valves in the section. Using a high accuracy differential pressure transducer, the pressure loss across the valves can be measured. This can also be used as a module for pressure loss across fittings, because of the various tees and elbows in the section.

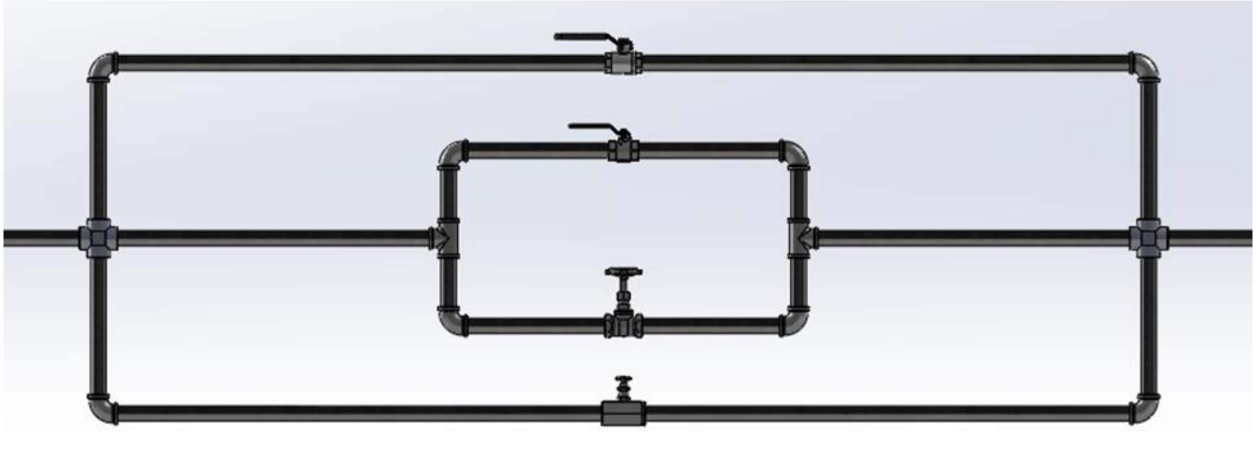


Figure 5: Valve Tree

5. Learning Modules

The final design for the pipe stand and the construction of the prototype was entirely dependent on the learning modules that were designed to be used in the *Endeavor* Lab. Several of these modules were created so that students taking fluids courses could come to the lab and participate in a hands on activity demonstrating fluids principles.

5.1. Laminar vs Turbulent Flow

For this learning module, students can visualize the difference between laminar and turbulent flow profiles and see how pressure drop varies with respect to these flow profiles.

A section of clear PVC will be used to demonstrate both laminar and turbulent flow. Using a control valve, the flow rate can be metered to laminar flow, which is about 1.34 GPM for 2" piping at the upper limit of laminar flow. So for this module, it would be beneficial to slow the flow to 1 GPM or below to get truly laminar flow. A syringe will be used to inject microbeads into the stream, and the profile for the flow can be seen. This process can be repeated at a higher flow rate of at least 2.33 GPM to visualize turbulent. The students should be able to see the difference is profiles which is seen in Figure 6.

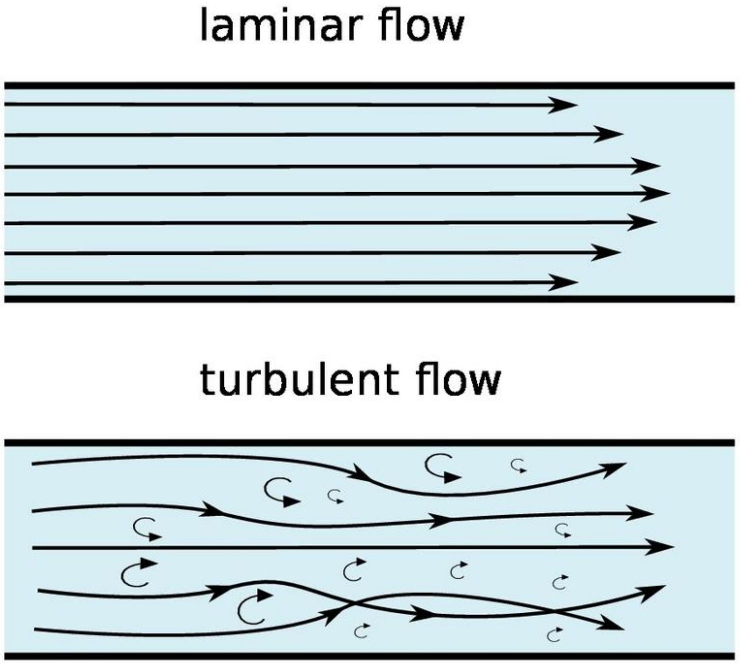


Figure 6: https://www.cfdsupport.com/OpenFOAM-Training-by-CFD-Support/sketch-laminar-flow-turbulent-flow.png

Along with the visualization of flow profiles, pressure measurements can be taken for both conditions. Expected pressure drops for laminar and turbulent flow are 0.00304 psi, and 1.092 psi respectively.

5.2. Flow Visualization

This module will focus on how flow is affected by obstacles in its path, and how turbulence can be induced into flow.

A 2” section of clear PVC can be used for this module. In this section, walls and obstacles can be placed into the pipe by sawing into the pipe, placing the object, and sealing it back with silicone. The microbead injector will add beads to the stream at the beginning of the section, and as the beads travel down the pipe they will encounter obstacles and mix up, showing turbulence. To best show this, laminar flow should be used for water entering the section, which again should be less than 1 GPM.

5.3. Friction Loss in Different Size Pipes

The objective of this module is to learn how the pipe diameter will affect the pressure drop within the length of pipe.

A 1” and 2” section of pipe will be used separately to find the pressure drop across the respective pipe. It is necessary to keep the flow rate constant so that the only variable is the diameter of pipe. A pressure reading will be taken at the inlet and outlet of the section. To manufacture a pressure drop of 5 psi in the 1” section, the flow rate should be 37.1 GPM.

Keeping the same flow rate but running the test on the 2” pipe, a pressure reading would again be taken at the inlet and outlet of the section. The expected pressure drop is 0.194 psi.

5.4. Friction Loss in Pipes of Different Roughness

The objective of this module is to measure the difference in pressure drop in straight sections of the same size pipe but of different material, and therefore, different roughness.

This experiment requires two sections of pipe of the same diameter but different roughness. Calculations for this experiment were made using 1” PVC and 2” type L copper. A flow rate of 25.7 GPM was used to create a pressure drop of 5 psi across the type L copper. Using this same flow rate, a pressure drop of 2.58 psi is expected across the PVC section. For this experiment, only one section will be tested at a time, so the other sections will be closed off with a ball valve.

5.5. Loss Coefficients for Valves

This module’s objective is to experimentally determine the loss coefficients associated with different types of valves on the “valve tree”. The types that were used in the calculations were a ball valve, globe valve, gate valve, and angle valve.

This module uses the “valve tree” that was designed in for the pipe stand. The calculations used a flow rate of 9.5 GPM (0.6 kg/s) through each valve. Each valve will be tested independently and differential pressure will be measured across each valve. From this, the loss coefficient can be calculated using Darcy-Weisbach. Table 1 shows the expected pressure drops for the given flow rate.

Table 1: Valve Drop Coefficients:

	Flow Rate (kg/s)	ΔP(psi)	Valve Coefficient
Ball Valve	0.6	0.013	0.05
Globe Valve	0.6	2.678	10
Gate Valve	0.6	0.051	0.15
Angle Valve	0.6	0.578	2

5.6. Orifice Plate Loss Coefficient and Recovery

This module's objective is to visualize how flow is affected by orifice plates and how flow rate can be calculated using orifice plates. The observers will understand how the pressure drops substantially at the orifice and then recovers over the length of pipe.

The calculations that were done for this module use a 1" section of schedule 40 PVC and a Dwyer TE-C-3 orifice plate which is inserted via flange connection. The orifice has a 0.72" bore, and the flow rate can be controlled to 35.6 GPM to see a pressure drop of 7.91 psi across the orifice. This pressure drop will be measured with a differential pressure transducer tapped into the orifice plate. Along the length of pipe, more pressure transducers can be tapped into the pipe to see how there is pressure loss leading up to the orifice, and then pressure gain after the orifice.

5.7. Minor Losses

This learning module will be used to demonstrate minor losses associated with fittings within pipe sections.

The section on the stand designated for the "valve tree" can be replaced with a section of ¾" type L copper pipe and fittings. One of this example would be having 22' of pipe with 6 elbows within that section. If the flow rate is to be controlled 8 GPM, the expected pressure drop across the 22' of pipe is expected to be 2.74 psi, while the measured pressure would be 3.07 psi. It can be seen that the valves would have an effect on the pressure drop, adding losses to the system.

5.8. Pressure Drop Across Heat Exchangers

This module would be useful for students taking a Thermal Systems class, so they can understand that heat exchangers can add losses to the system. Any section of the stand can be replaced with a section that has a heat exchanger added to it. Differential pressure can be read across the heat exchanger and it can be seen how it affects pressure losses.

6. Concept Design for Prototype

The design that was decided upon for the prototype of this project addresses the objectives given in the problem statement in that it will demonstrate two of the learning modules that the full model will have. The prototype has two sections, the first is a 20’ section of clear 2” PVC and the second is a 20’ section of 1” PVC, which is seen in Figure 7. The 2” pipe includes an injector that allows for the injection of microbeads into the flow, so that people who are using the prototype can see how flow changes along the length of the pipe. It can demonstrate laminar and turbulent flow and how flow changes as obstacles are introduced into the flow. The microbeads are matched with the density of water so that they will float with the stream and not rise to the top, like would happen with bubbles, and they would not cloud the water, which would happen with dye injection.

The 1” section of PVC demonstrates a module using an orifice plate, which will visualize the pressure drop across the plate and can calculate the flow rate using that pressure drop. The water flows through the orifice and sees a pressure drop because of the orifice, which is recorded with a differential pressure transducer. After the orifice, the pressure rises again, which could be seen with more pressure transducers or manometers along the length of the pipe.

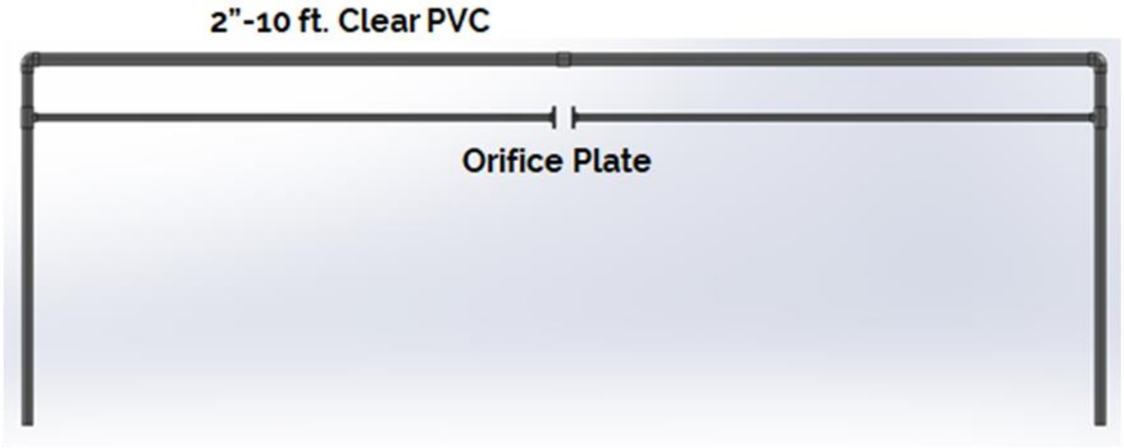


Figure 7: Prototype Design Sketch

7. Design Calculations

Fluid and mechanical calculations were done to select components of the prototype for the pipe stand. These calculations found the size of piping necessary, the size of pump required to circulate water through the system, and the gauge of steel to use in the support structure.

7.1. Fluid Systems

For the system, fully developed laminar and turbulent flow was desired. So, to find the entrance length the equations,

$$L_{laminar} = 0.06Re \tag{1}$$

$$L_{turbulent} = 4.4Re^{1/6} \tag{2}$$

were used to find the length required for fully developed flow. It was found that for 2" pipe, about 15' of straight pipe would be needed for fully developed flow. This is the reason that a design length of 20' was decided upon.

A flow rate of water of about 15 GPM of water was desired to create an accurately measurable pressure drop across the length of the 1" pipe. Using Darcy-Weisbach equation,

$$\Delta P_L = f\frac{L}{D}\frac{\rho V^2}{2} \tag{3}$$

a flow rate of 15 GPM, a length of 20 feet, and a diameter of 1 inch, the pressure drop across the span of the 1" section is 1.013 psi. The pressure drop across the orifice was calculated using,

$$\Delta P_o = \frac{1}{2}\rho(1-\beta^4)(\frac{Q}{C_d A_o})^2 \tag{4}$$

and came to be 2.044 psi, using the same values for flow rate, length, and diameter as before. A β of 0.69, a C_d of 0.6, and an orifice diameter of 0.72 were given by the manufacturer of the orifice plate. The pressure drop across the orifice is what is measured by the pressure transducer and 2 psi is well within the range of the transducer that was purchased. Once the desired pressure drops were found, a pump that would provide the flow rate necessary to create those pressure drops was sized and selected. The total losses along the length of pipes in the entire prototype and all of its fittings was found using,

$$\Delta P_L = (f\frac{L}{D} + \Sigma K)\frac{\rho V^2}{2} \tag{5}$$

and came to be 5.75 psi. A Grundfos 1/25 HP pump, capable of supplying 17.2 GPM was selected for use. Using the pump curve given by Grundfos and creating an equation for head loss versus flow rate, an operating point of this pump of about 9 GPM and a head loss of 3 psi was found which can be seen in Figure X. Because of this smaller flow rate, the pressure drop across the 20' span of 1" pipe reduces to 0.4145 psi, and the pressure drop across the orifice to 0.7357 psi. This is less than the desired pressure drops, because it results in a less accurate measurement, but a larger pump would not be capable of supplying laminar flow, which is desired for the flow visualization learning module.

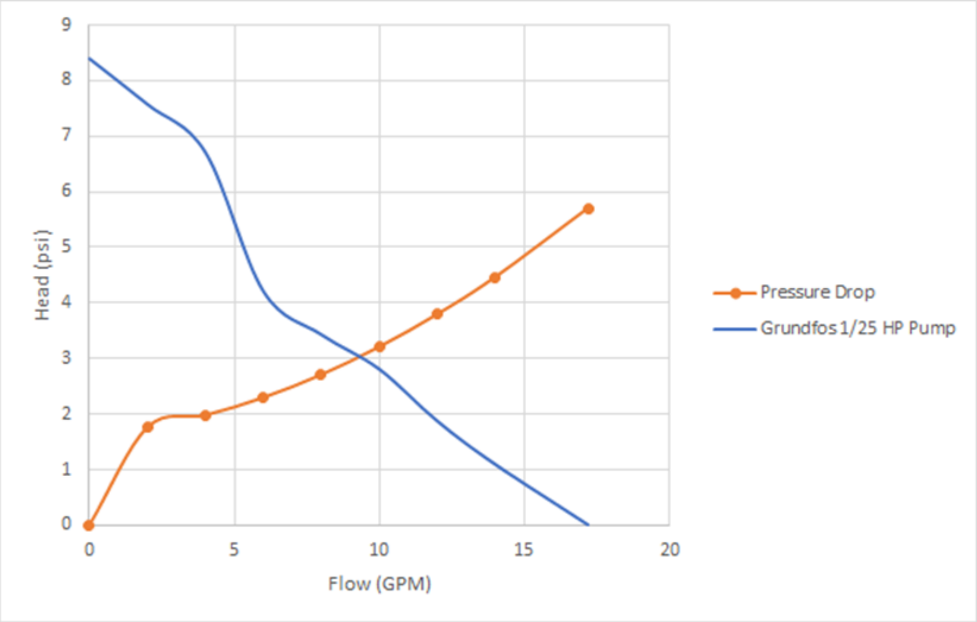


Figure 8: Pump Operating Point

7.2. Mechanical Systems

A support structure needed to be constructed to support the piping layout for the prototype, as well as, the full-scale design that will be placed in the new endeavor lab. With this in mind, we decided on creating a support structure that will able to support the most extreme weight of piping necessary. Another objective of the support structure is that it is not too tall, so that most people can reach the top pipe, but we still wanted to maximize the space for the piping. We assumed a maximum distributed load of 500 lbs. across the structure to size the square tubing. Simple moment and force equations,

$$\Sigma \boldsymbol{F} = \boldsymbol{0} \tag{6}$$

$$\Sigma M = 0 \tag{7}$$

were used around the bottom of the supports shown in figure X to determine the necessary reaction forces needed to keep the system properly supported.

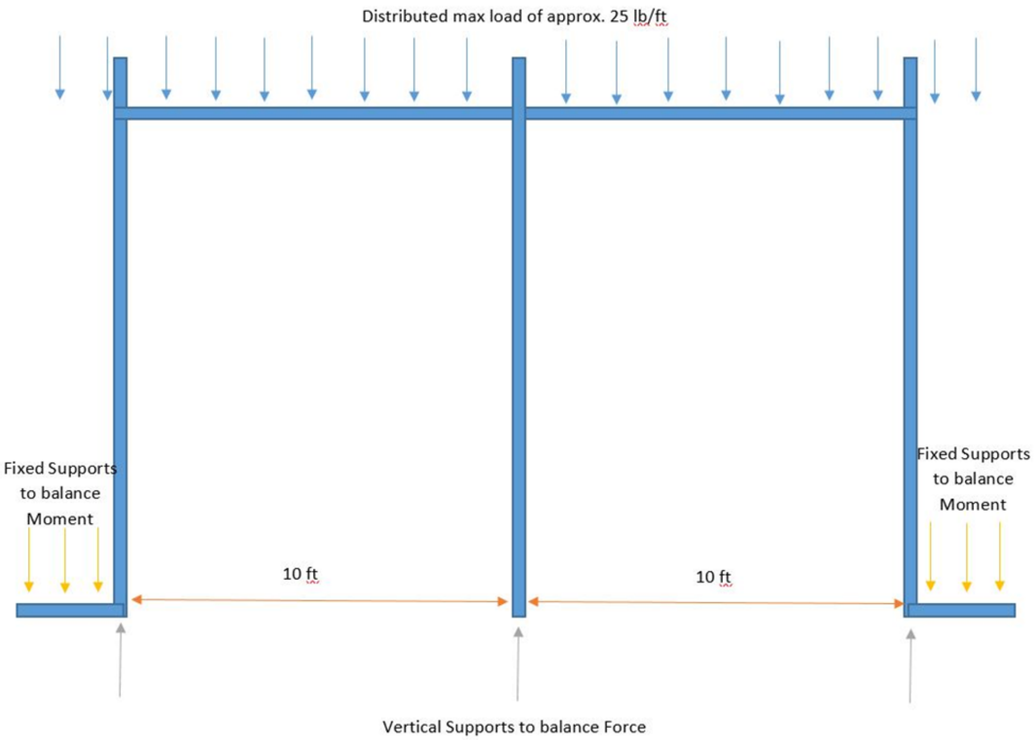


Figure 9: Free Body Diagram of Support Structure

An FEA analysis was done on the support to check the deflection of the support structure. The total deformation was only .049mm with negligible stresses.

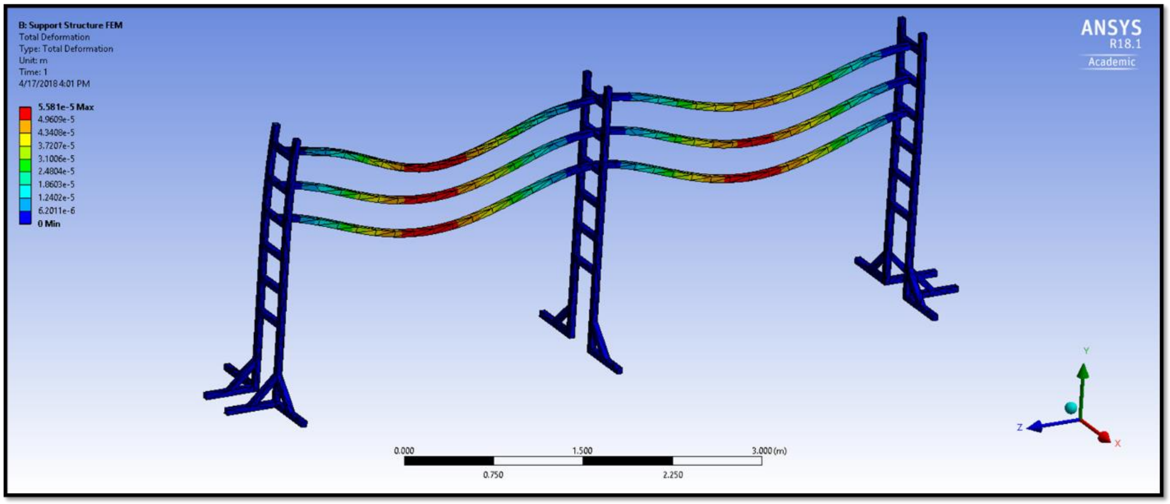


Figure 10: ANSYS Analysis on Support Structure

8. Component and Material Selection and Sizing

For the material selection of the piping, we chose to use pvc pipe for the prototype to minimize cost, but for the full-scale model, we chose different types of piping whether steel, pvc, or copper to provide a different roughness factor for the learning modules.

For the support structure, we thought of a few different options for materials including steel, aluminum, and titanium. Table 1 shows the important properties of each material. We decided to go with steel as the main material of our support structure due to its high modulus of elasticity which will be ideal for supporting the stresses that the pipes apply and Stillwater Steel has steel tubing for a fair price.

Table 2: Mechanical Properties of Various Materials

Material	Modulus of Elasticity (GPa)	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)
Steel	200	400	250
Titanium	120	900	730
Aluminum	69	110	95

The specific sizing of the steel tubing was not a huge factor, we just wanted something strong enough to support 500 lbs worth of pipe, while not being too big or bulky. After weighing the different pros and cons of the different size steel tubing in table 2, we decided to go with a nominal size of 2 x 2 x 14 Gauge (1/12 in) which we thought was a good compromise between anything bigger or smaller.

Table 3: Properties of Different Size Steel Tubing

Nominal Size	Mass (lb/ft)	Moment of Inertia (in^4)	Torsional Stiffness (in^4)
4 x 4 x 1/8	6.46	4.40	6.91
2 x 2 x 1/8	3.05	0.486	0.796
1-½ x 1-½ x 1/8	2.20	0.188	0.316

9. Instrumentation

For this project, a few instruments were selected for data collection. They include pressure transducers, a temperature sensor, and a flow meter. These sensors are responsible for finding the data that is required to do the learning modules.

The temperature sensor that was selected is a Dwyer 100 Ohm RTD. It was selected because it is accurate within a wide range of temperatures, -40 to 250°C. It has an accuracy of ±4°F. It has a ¼” NPT process connection, so to attach it to the pipe stand, a ¼” NPT tap was drilled into the pipe and the RTD was screwed into that.

An Omega FPT-3020 pitot tube flow meter was selected to measure the flow rate of the system. It has an accuracy of ±2% at a full range flow of 20.5 GPM. This means that the sensor is accurate at higher flow rates, but less accurate when the flow in the system is laminar. This was the case for most flow sensors on the market. Since the flows in the pipe stand will range from about 1 to 17 GPM, it is difficult to find a flow meter that will be accurate for both experiments intended to run on the prototype. The flow visualization experiment requires laminar flow to see how flow can transition from laminar to turbulent and the orifice plate experiment needs fully developed turbulent for the equations governing pressure drops to be valid. However, for the orifice plate experiment, there is other instrumentation whose accuracy is dependent on the accuracy of the flow meter, whereas there is no other instrumentation on the flow visualization experiment. Therefore, accuracy of a flow measurement is more important at the higher end of the flow range, so that the accuracy of the pressure transducers on the orifice plate will not be affected. So, it was decided that a flow sensor that was more accurate at higher flow rates should be purchased.

Two Dwyer 629-C differential pressure transducers were purchased for this project. One is to measure the pressure drop across the orifice plate for the learning module, and the other is to measure the pressure drop across the pitot tube to find the flow rate. These transducers operate on a range of 0-25 psid and have a full scale accuracy of 0.5%. Before purchasing these transducers, an uncertainty analysis was done for the pressure drop across the orifice (Equation 2) to make certain that the transducers would be able to get an accurate enough measurement. The sensors that will affect the uncertainty of the pressure drop calculation are the temperature sensor, the mass flow meter, and the diameter of the orifice. The temperature sensor has an absolute uncertainty of 0.4°C at a design temperature of 25°C, the mass flow meter has an absolute uncertainty of 0.0114 kg/s at a design flow rate of 1 kg/s, and the diameter has an uncertainty of 0.0128 cm at a design of 1.829 cm. Using the propagation of uncertainty shown in the equation below, the pressure drop across the orifice was found to be 0.7357±0.03592 psi. This is about a 5 % uncertainty, which was determined to be low enough to get an accurate measurement. The calculations for this were done in EES and the code of this can be found in EES Code of Appendix 1.

$$u_R = \pm[(\frac{x_1}{R}\frac{\delta R}{\delta x_1}u_1)^2 + (\frac{x_2}{R}\frac{\delta R}{\delta x_2}u_2)^2 + \ldots + (\frac{x_n}{R}\frac{\delta R}{\delta x_n}u_n)^2 \tag{8}$$

10. Final Prototype Design

The prototype design that was decided upon uses the conceptual design but completes it in a way that was feasible for the materials at hand and the budget given.

10.1. Support Structure

The support structure was designed and built in such a way that it can support a modular pipe stand and be very versatile in its use. It is able to hold most sizes of pipes that would be needed for a fluids demonstration. It is made of 14-gauge square steel tubing and was welded together to make three ladder-like sections that can support the weight of the stand. The three legs are attached with 10’ sections of Unistrut and are connected to the “rungs” via brackets. Model of the full support structure can be seen in Figure 11.

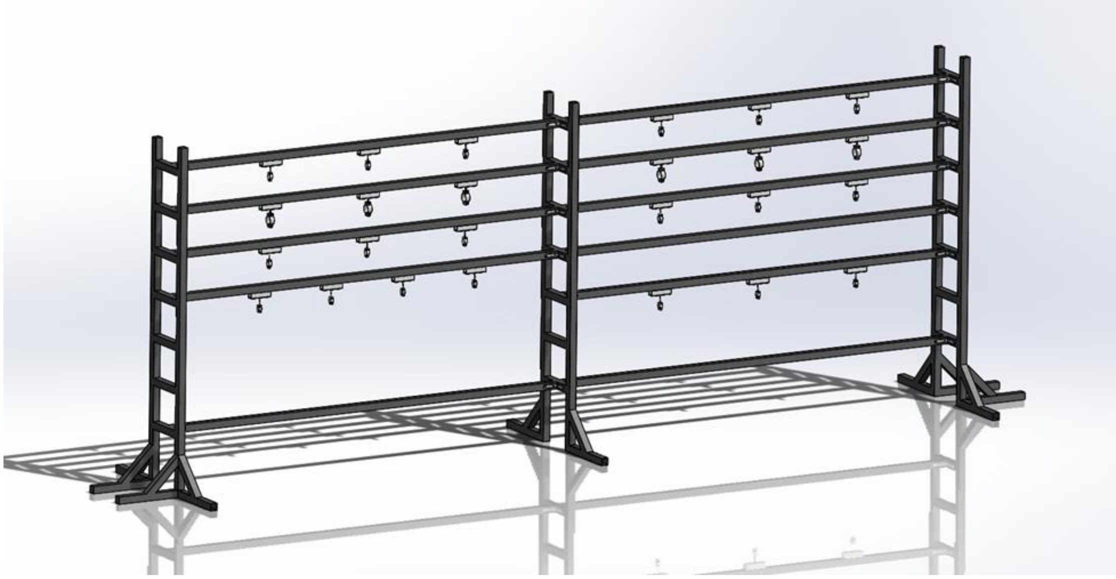


Figure 11: Support Structure

The support structure is stable in the lateral and axial directions. More stability will come from bolting the structure to the ground when it is eventually put in the *Endeavor* Lab.

One of the key features of this design is that it is modular in its design. The interface where the unistrut and the ladder rungs meet are bolted together with brackets, which makes for easy installation and removal. If one of the piping sections is too big, all that must be done is take out a section of the unistrut.

Another key feature is the ability to hang the pipes from any location along the length of the stand. Since the horizontal pieces are unistrut, hangers can be added with strut channel nuts anywhere on the section. An example of this can be seen in Figure X.

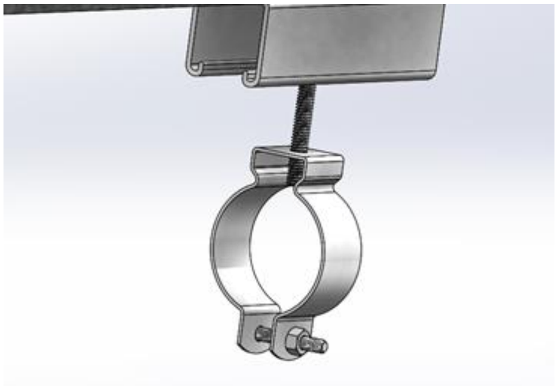


Figure 12: Hanger Design

10.2. Piping Design

The design of the prototype has two test sections. The top section is a 2” by 20’ long section of clear PVC. The lower is a 20’ long section of 1” PVC. These are attached to 2” headers on either side of the sections.

The original plan for the prototype was to have an overhead tank that would feed water into the system, like the *Endeavor* pipe stand will have, as can be seen in Figure 13. This was supposed to be a gravity fed, open loop system, but getting a water tank that high seemed like a challenge. More support structure would need to be constructed to hold the overhead tank and it would be a challenge to get enough flow rate for the learning modules.

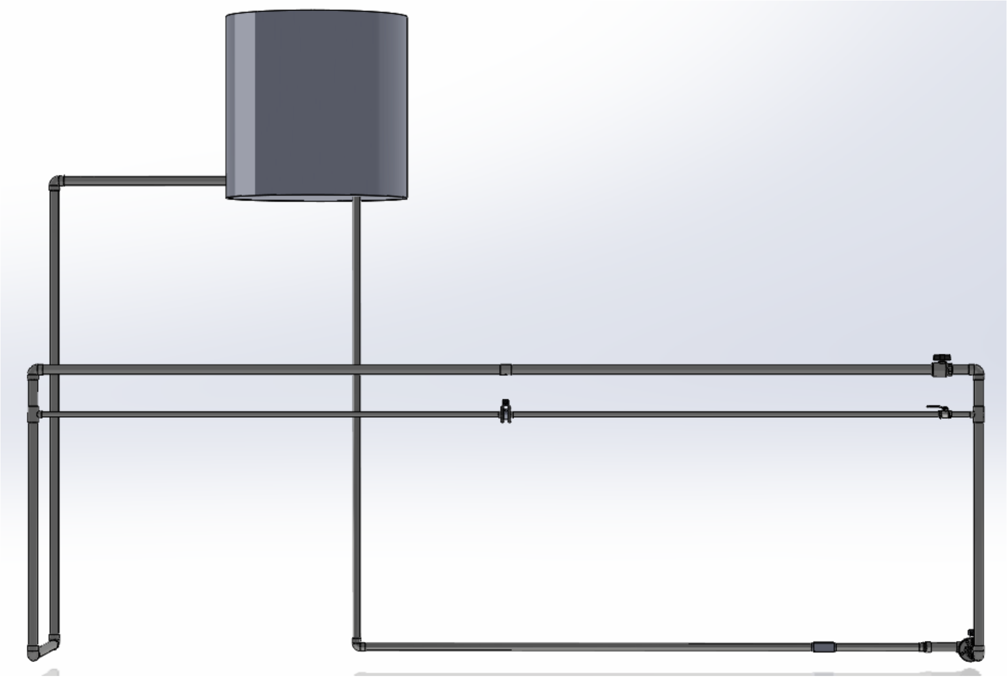


Figure 13: Original Prototype Design

The final design for the prototype had the water tank sitting on the ground in the middle of the pipe stand, as seen in Figure 14. This tank ended up being a 32 gallon trash can that the pipe was attached to with silicone. On the left of the water tank, the Grundfos 1/25 HP pump was placed to allow the pump to fill with water before circulating, so as to not allow cavitation. On either side of the water tank, ball valves were added to allow the tank to be isolated when necessary.

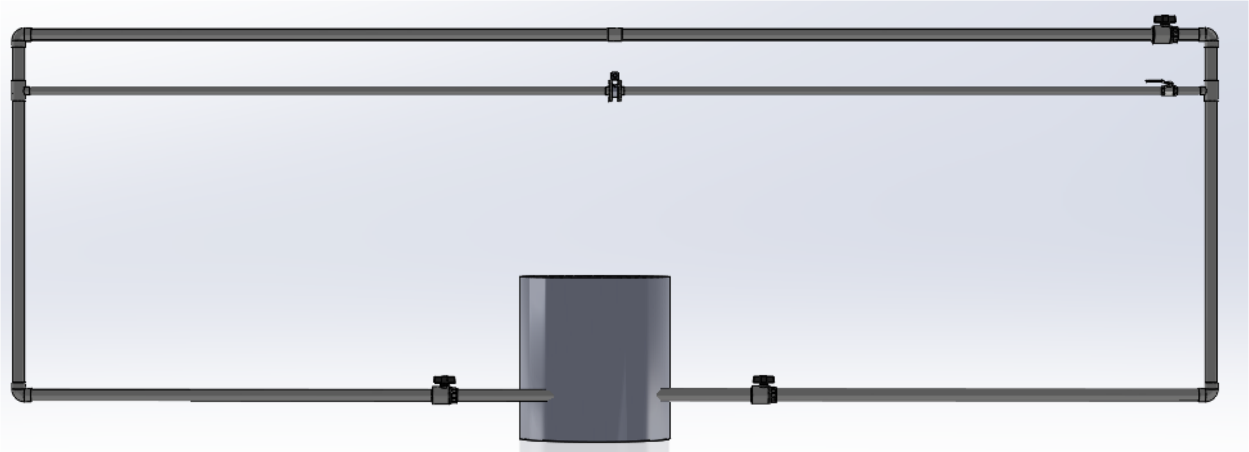


Figure 14: Final Prototype Design

The piping design allows for the demonstration of two learning modules. The first is the flow visualization module. It can show laminar and turbulent flow profiles within a 20’ section of 2” clear PVC. This was done by injecting fluorescent microbeads into the beginning of the section and watching them as the flow along the length. They are matched with the density of water, so they give an accurate visualization of the flow as the move with the water. They are able to show turbulence as the water is mixed up and when the flow is laminar, they move in a straight line like the flow profile. The second module the prototype is designed for is the orifice plate pressure drop. At the middle of the 1” PVC section is an orifice plate. On either side of that plate, a differential pressure transducer was to be tapped into the pipe to record the pressure difference. From this, the flow rate can also be calculated.

One important feature of the prototype was the microbead injector. To do this, it was planned to drill a hole in the pipe and add a piece of aluminum tubing, where a syringe could be placed to inject the beads.

At the end of the 2” clear PVC section, it was necessary to implement a way to filter out the microbeads from the system. To do this, a Y-strainer was placed into the section, as is seen in Figure 15. This strainer catches the beads as they enter and allows the water to continue flowing through. Then when the system is off, the strainer opens and allows the filter to be removed, thus saving the beads.

Figure 15: Y-Strainer https://www.mcmaster.com/#4425k46/=1co5ciy

11. Prototype Construction and Testing

There were three phases of the construction of this prototype: welding of the support structure, cutting and gluing the piping together, and installation of instrumentation and implementation of LabVIEW. The bulk of the time was spent on the support structure. Since it is the only part of the prototype that will actually make it to the *Endeavor* Lab, it was necessary to make sure that all of the welds were strong and that the structure would hold virtually anything that would be put on it.

Testing of the prototype consisted of leak checking the pipes and making sure all the instrumentation was working. This included testing the microbeads, to be certain that the flow visualization module would work as planned as well as checking whether the correct flow rates were being read on the instruments.

11.1. Prototype Construction

The first construction challenge that was encountered was the welding of the support structure. This took several days to complete because there were a significant number of welds that needed to be done. This was no small task, especially because nobody on the team had welding experience. Each member took a welding class to learn, but lack of experience still showed in the beginning welds of the support structure. Despite the lack of experience, as the welding process progressed, the welds go much better and ended up looking quite good.

The next challenge that was encountered was, the orifice plate that was ordered from Dwyer was not expected to arrive until several days after the project was due. This was a key component of the prototype because one of the two learning modules depended on it. Most other orifice plates that can be found were too expensive to be put in the prototype and without one, the construction was more or less at a standstill. This issue was resolved in a more unsophisticated manner. A piece of ¼” plastic was cut to the dimension that it would fit in the flange at the middle of the section, and a bore was drilled into it to roughly match the bore that the orifice from Dwyer would have. This was a less accurate way to do this, as orifice plates are very carefully manufactured to follow the pressure drop equation (Equation 4), but for the purposes of the prototype, it would work as a proof of concept.

Attaching the instrumentation was another challenge because during the design phase of the prototype, it was not discussed how the instrumentation would be attached to the pipe. Every piece of instrumentation came with ¼” NPT compression fittings, but there were no places on the pipe to connect those fittings. So, ¼” NPT taps were inserted directly into the pipe. This was difficult because the PVC stripped easily, and if it did too much, there would be no way to seal the hole again. So, much care went into tapping the holes.

Since the design called for a 32 gallon trash can as the water tank, a way to attach that trash can to the piping needed to be devised. It was important that the tank continued to feed water to the system, so it needed to be completely sealed. There were a couple options that were considered. The first was to find a fitting, such as a flange to connect to either side of the hole in the trash can, and insert pipe into that. This seemed unnecessarily expensive to do, so it was decided to cut the holes very close to the outer diameter of the pipe and add silicone to hold it and seal it.

11.2. Prototype Testing

After construction was complete, leak checking began. Each fitting was checked for leaks, which all held under the pressure that the pump was giving the system. However, what did give problems were the instrumentation taps. They were not sealed very well and leaked water as soon as the system started running. This problem was solved by simply adding silicone to each of the taps. This was an excellent way to keep them from leaking, as they held just fine after the silicone was added.

After the first day of test for leaks, the system seemed to be doing fine. However, when we came back to it the next day, when the tank was filled with water, it began leaking quite a bit. This caused us to have to drain the system and reseal it. We did not want this to become a recurring problem so, a lot of silicone was added to prevent more leaks.

After leak checking was finished, we focused on the learning modules that would be demonstrated. The first was the flow visualization module. We wanted to see how the strainer would work with the microbeads and how the microbeads would look in the water. We learned that injecting the beads into the water would be a difficult task because they like to stick to the walls of the syringe and did not inject well into the pipe. A surfactant was needed to make them slicker and to flow into the pipe better.

The second module was the orifice plate module. For this, the instrumentation needed to be tested. The instruments were a differential pressure transducer, a Pitot tube flow meter, on which another differential pressure transducer was attached, and a temperature sensor. The differential pressure transducers were supposed to read 0 volts when the system was off, but they were reading 0.008 volts, which corresponded to about a 0.02 psi differential. While this is not a huge amount, it is not insignificant, as it throws off the flow rate by quite a bit. There was a way to zero the sensors but doing that did not change anything. It was concluded that there was noise in the sensor because it was a voltage output sensor instead of a current output.

The Pitot tube flow meter caused quite a problem. No matter what speed the pump was running at, the pressure transducer was not reading a difference across the Pitot tube. It was not until later that it was discovered that the Pitot tube was installed incorrectly. It needs to be on the bottom of the pipe and have at least 20 diameters of straight pipe in front of it for fully developed flow to enter the tube and read a differential pressure. Pitot tubes are very sensitive to these specifications and do not perform properly if installed incorrectly. This was never corrected because of time constraints.

12. LabVIEW Interface

A LabVIEW interface was created for the prototype to help visualize fluid flow principles such as pressure drops and flow rates. This interface can be expanded to fit more learning modules that were not added to the prototype.

12.1. Front Panel

The Front Panel of the LabVIEW interface can be seen in Figure 16. From here, the students can see all the data that are being taken by the sensors in real time. On the left, temperature readings can be seen numerically and on a graphical indicator that looks like a thermometer. From the temperature readings, the density and viscosity were calculated and outputted to numerical indicators. Below, more numerical indicators show the voltage output, the pressure differential, and the flow rate of the Pitot tube flow meter. Here, the students can visualize how a pressure differential can relate to a flow rate.

The right side of the front panel shows the sensor data that is associated with the orifice plate learning module. To start recording data for this module, the LabVIEW program must be running, then the user presses the “Measure Orifice Plate” button. The pressure transducer will measure a voltage that transfers to pressure differential. These values are output to a numerical indicator and the pressure differential is shown on a gauge. Then, the student can see how the orifice plate can be used to measure flow rate. To do this, the enter an orifice plate diameter in inches and a flow rate can be output in the numerical indicator and the chart following.

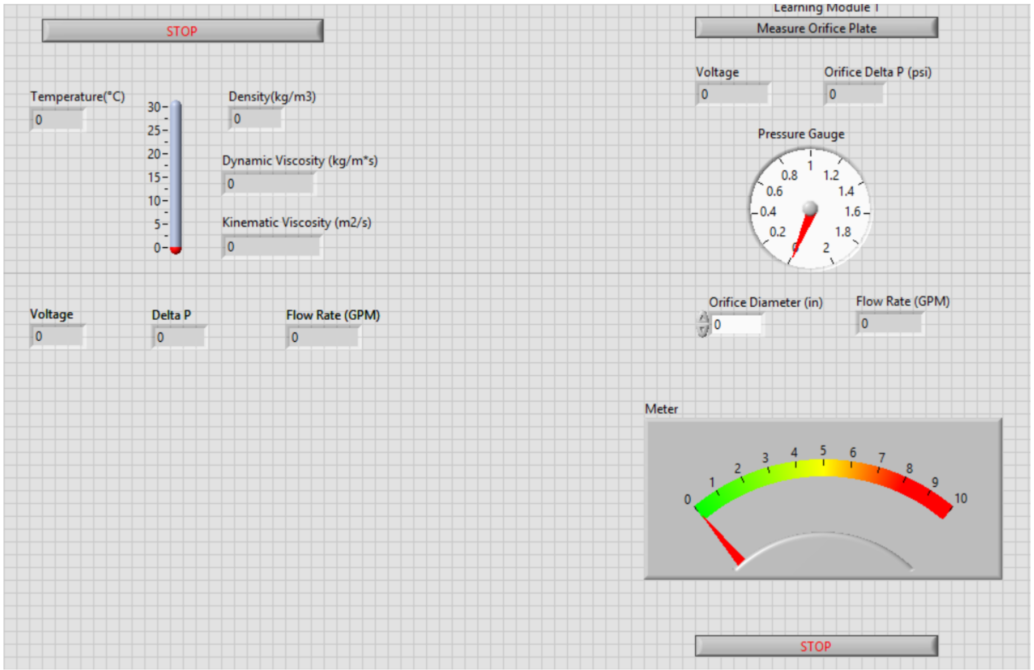


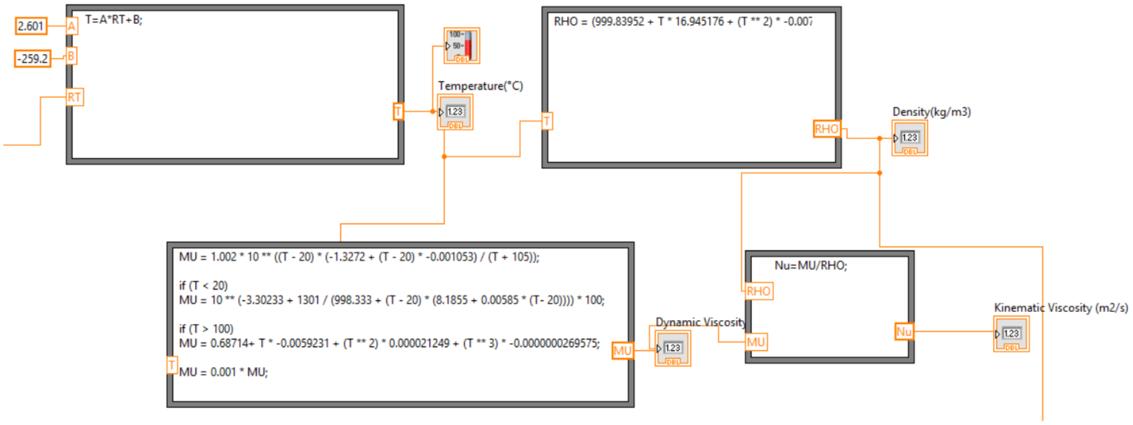
Figure 16: LabVIEW Front Panel

12.2. Block Diagram

The LabVIEW front panel that the user of the pipe stand will see is controlled by the block diagram that uses formula nodes to calculate the values that the sensors are measuring, based on the input voltage of the sensor.

12.2.1. Temperature Reading

The temperature that was collected was measured with a 100 Ohm RTD. The MyDAQ that was used connects to the temperature probe, which measures the resistance caused by the temperature change and sends that resistance back to the DAQ. The logic that follows this can be seen in Figure 17.



```
T=A*RT+B;
```

```
RHO = (999.83952 + T * 16.945176 + (T ** 2) * -0.007
```

```
MU = 1.002 * 10 ** ((T - 20) * (-1.3272 + (T - 20) * -0.001053) / (T + 105));

if (T < 20)
MU = 10 ** (-3.30233 + 1301 / (998.333 + (T - 20) * (8.1855 + 0.00585 * (T- 20)))) * 100;

if (T > 100)
MU = 0.68714+ T * -0.0059231 + (T ** 2) * 0.000021249 + (T ** 3) * -0.0000000269575;

MU = 0.001 * MU;
```

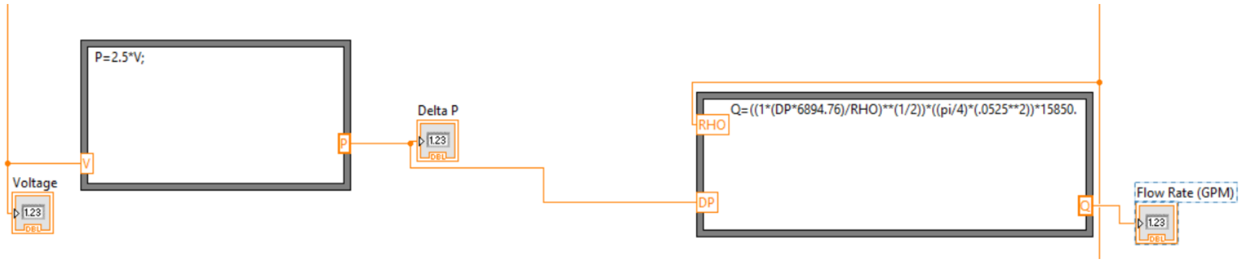
```
Nu=MU/RHO;
```

Figure 17: Temperature Logic

The resistance is input to a formula node, which converts the resistance to a temperature. The reason for finding the temperature is to find water properties, i.e., density and viscosity. The temperature is input into a formula node that calculates density and one that calculates viscosity. The equation that calculates density is the Kell equation (Jones & Harris). The equation that calculates the dynamic viscosity comes from the CRC Handbook. These two values are put into another formula node that calculates kinematic viscosity.

12.2.2. Pitot Tube Reading

The next sensor that was read in LabVIEW was the pitot tube. It was simply a differential pressure transducer that uses an equation to calculate the flow rate as seen in Figure 18.



```
P=2.5*V;
```

```
Q=((1*(DP*6894.76)/RHO)**(1/2))*((pi/4)*(.0525**2))*15850.
```

Figure 18: Pitot Tube Logic

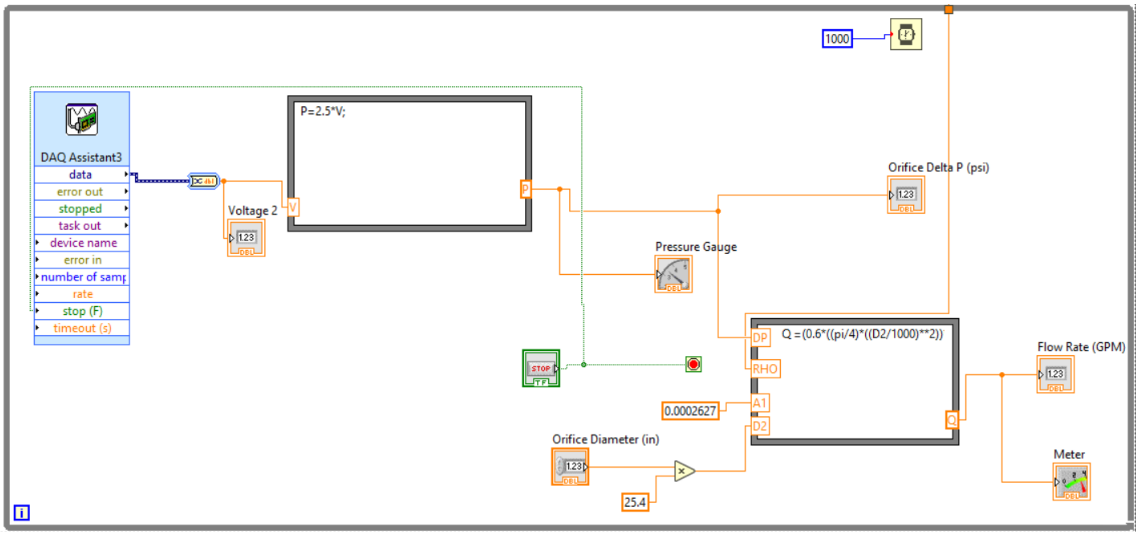
The pressure transducer operated on a 0-10V output for a 0-25 psid reading. The DAQ would see a voltage from the transducer and scaling that voltage by a factor of 2.5 gives the pressure drop. This pressure difference is sent to another formula node which calculates the velocity using,

$$v = \left[\frac{2*\Delta P}{\rho}\right]^{1/2}. \tag{9}$$

Multiplying that by the area of the cross section of pipe gives the flow rate, which is then output to a numerical indicator.

12.2.3. Orifice Plate Reading

The logic that controls the reading for the orifice plate pressure drop and flow rate is similar to the logic behind the pitot tube.



```
P=2.5*V;
```

```
Q =(0.6*((pi/4)*((D2/1000)**2))
```

Figure 19: Orifice Plate Logic

The DAQ sees a voltage from the pressure transducer and then converts that to a differential pressure. Then that differential is put into a formula node that uses Equation 4 to calculate the flow rate that is seen across the orifice plate. These values are output to numerical and graphical indicators.

13. Budget

The budget for this project was broken into three subsections: support structure, piping, and instrumentation. Since the support structure will be used in the *Endeavor* Lab, it seemed necessary to have a separate budget for it. The instrumentation budget was a separate budget from the pipe stand, so it will be counted separately as well.

13.1. Support Structure Budget

The support structure consisted of the steel tubing that made up the frame and all the hangers that the pipes would be supported by. It also consisted of any nuts and bolts that held the Unistrut together.

Table 4: Support Structure Budget

Supplier	Description	Quantity	Price
Stillwater Steel	24 ft, 2x2, 14 gauge Steel Tubing	1	$216.00
Lowes	Unistrut	4	$18.97
McMaster Carr	Cross Strut Channel Connector	2	$5.91
McMaster Carr	1" Pipe Hangers	1	$4.55
McMaster Carr	2" Pipe Hangers	1	$10.44
McMaster Carr	1/4-20 Strut Nuts	2	$6.94
McMaster Carr	1/4-20 Threaded Rod	1	$14.91

McMaster Carr	1/4-20 Nuts	1	$2.77
McMaster Carr	T Strut Channel Connector	4	$5.34
McMaster Carr	3/8-16 Lock nut	1	$8.97
McMaster Carr	3/8-16 Bolt	1	$9.03
McMaster Carr	3/8 washer	1	$8.00
McMaster Carr	1" Pipe Hangers	1	$6.18
McMaster Carr	2" Pipe Hangers	1	$11.68
McMaster Carr	5/16"-18 Threaded Rod	1	$10.30
McMaster Carr	5/16"-18 Strut Nuts	2	$7.79
Lowes	5/16" hex nuts	22	$0.21
Lowes	3/8" x 3" bolt	1	$23.75
Total		$ 469.72	

The support structure was almost enough to break the allowed budget for the entire project, but, it was given the go ahead because it is a final product. This piece will be used in the final version of the flow laboratory, so it was necessary to make it as sturdy as possible, while spanning the entire length required.

13.2. Piping Budget

The piping budget consists of the PVC pipes, all the fittings, the flanges, the tank, the circulator pump, and all miscellaneous items that did not directly affect instrumentation and support structure. The budget for piping can be seen in Table 5.

Table 5: Piping Budget

Supplier	Description	Quantity	Price
Lowes	1-1/2" PVC pipe - 10ft	1	$6.74
Lowes	1" PVC - 10ft	2	$4.39
Lowes	2" PVC - 10ft	3	$9.03
McMaster Carr	PVC Y Strainer	1	$196.16
Cospheric	Florescent Microbeads	1	$148.50
Lowes	2" PVC Elbow	6	$1.04
McMaster Carr	2"-1" Reducing Tee	2	$2.41
Lowes	2" PVC Coupling	1	$1.05
McMaster Carr	2" PVC Flange	2	$10.52
McMaster Carr	1" PVC Flange	2	$7.51
Lowes	1" PVC Ball Valve	1	$5.55

Lowes	2" PVC Ball Valve	2	$14.85
Lowes	2"-1-1/2" PVC Reducer	1	$1.34
Lowes	PVC Glue and Primer	1	$8.98
Grainger	2" x 8 ft. Clear PVC Pipe	3	$128.70
McMaster Carr	Stainless Steel Dispensing Needle	1	$10.30
McMaster Carr	10 ft. Aluminum Tubing	1	$14.12
McMaster Carr	10 mL Plastic Syringe	1	$7.50
Supply House	Circulator Pump	1	$87.95
McMaster Carr	1" Flange Gasket	1	$1.44
McMaster Carr	2" Flange Gasket	1	$2.47
Supply House	1-1/2" GF 15/26 Iron Pump Flange Pair	1	$7.95
Cospheric	Tween Biocompatible Surfactants	1	$15.00
McMaster Carr	Adapter with Hex Body, 1-1/2 Socket Female x NPT Male	2	$0.90
McMaster Carr	1" Flange Gasket	1	$1.44
Lowes	Caulk Gun	1	$2.88
Lowes	5/8 x 3 in bolts	4	$1.13
Lowes	5/8" hex nuts	4	$0.36
Lowes	Silicon Sealant	1	$6.18
Lowes	2" PVC ball valve	1	$14.85
Lowes	1-1/2" PVC ball valve	1	$11.44
Lowes	3 Wire GFCI adapter	1	$12.97
Lowes	10 ft 14 gauge wire	1	$13.98
Lowes	3/8" x 3" bolt	1	$23.75
Lowes	32 gallon trash can	1	$14.98
Total		$ 1,124.07	

The original budget for piping was supposed to be limited to $500, but that was quickly surpassed. This is because the flow visualization that was desired by the customer was very expensive and they were willing to pay for it. The Y-strainer and the microbeads themselves account for 30% of the total budget and the clear PVC was much more expensive than regular PVC. Without this, the budget would have been closer to the desired $500.

13.3. Instrumentation Budget

Included in the instrumentation budget is everything that was used to collect data, including sensors and fittings to connect them to the pipes. The budget for instrumentation is shown in Table X.

Table 6: Instrumentation Budget

Supplier	Description	Quantity	Price
Dwyer	Differential Pressure Transducer	2	$285.00
Grainger	100 ohm RTD	1	$18.65
Swagelok	1/4" NPT to Tube Connector	8	$7.55
McMaster Carr	1/4" -3ft Seamless Steel Tubing	1	$18.79
Automation Direct	3 Wire Extension	1	$50.50
Omega	Pitot Tube Flow Sensor	1	$244.00
McMaster Carr	Yor-Lok Compression Fitting	2	$8.27
Total		$	978.88

The budget for instrumentation is about where it was expected to be, considering the cost of the pressure transducers.

14. Marketing Plan

Marketing of this pipe stand will be relatively easy, as it will be part of a fluids laboratory. If it does a good enough job of demonstrating fluids principles, professors will want to use it. However, it will need to have a good aesthetic appeal. Powder coating the frame and painting the pipes will make people want to use it more. LED lights were added to the prototype, to light up the clear section, to make the visualization look even better. This should be done on the final project as well.

The pipe stand will be placed in front of a glass wall and will be the centerpiece of the entrance to the *Endeavor* Lab. A large piece of equipment will naturally attract people to use it, especially if it looks aesthetically pleasing.

A marketing video was done by the team. It does a demonstration of the learning modules that can be done on the pipe stand. If this video is played outside the flow laboratory, it will likely attract more people to us it. Along with this, a poster demonstrating the design, construction, and all the key features of the pipe stand was made. Placing this poster in the hallway in front of the pipe stand will pique peoples interest in the pipe stand and get more use out of it.

15. Commissioning Plan

To make this pipe stand completely operational, the first step that needs to be done is take the support structure to the *Endeavor* Lab and bolt it in place. The structure is sturdy on its own but bolting it to the floor would make it much sturdier and safer to use.

Next, the manifold for the pipe stand needs to be manufactured. The design for this was outlined in Section 4.1. Once those are manufactured, they can be installed and attached to the existing piping that is in the lab.

After this, the first learning modules that are going to be demonstrated need to be decided. Once this is done, the test sections should be put together and installed on the pipe stand. They should have flanges at the beginning and end of a 10’ section so they can be installed easily.

Once the learning modules are set up, the LabVIEW interface for all of the modules that were not a part of the prototype should be set up and all of the instrumentation should be installed. Then power must be run to the instrumentation and testing of the pipe stand can begin.

16. Recommendations and Future Work

From the design and construction of the prototype, a lot was learned about fluid flow and how a laboratory demonstrating fluids should be. The key point that we learned is that mobility is a must. For the final pipe stand, if the pipes are not flanged at the ends and in the middle, it will be incredibly difficult to move the stand if ever required. When the prototype was built, it was basically two sections that came together in the middle with flanges, which we thought would be easy enough to handle. However, it was a huge pain to take apart and put together. If it would have been put together with unions just before the headers, then it would have come apart much easier. Breaking it into small parts will make it easier to handle and will prevent a lot of frustration.

Another recommendation for the *Endeavor* pipe stand is to find a way to seal off the injection port for the microbeads. During prototype testing, if the syringe was not hooked into the injection port, they system would depressurize and spray water all over the place. Leaving the syringe left the injection port in quite a precarious position and left it susceptible to being hit by something and bending the injection tubing. So, it is necessary to find a way to seal the injection port when the syringe is taken out, to prevent a slip hazard.

For instrumentation, a higher accuracy pressure transducer may want to be purchased. The Dwyer 629-C, is decently accurate, but if the flow rate is low, the readings will be off. Also, the 629-C had trouble zeroing. As discussed in Section 11.2, it would read 0.008 Volts, when it should be zero. This was close enough to zero for the purposes of the prototype but for the *Endeavor* Lab, something more accurate will certainly be desired. This offset could have been produced by noise in the system. If this is the case, then a 4-20 mA output transducer should be used instead of a voltage output. Milliamp output devices are less susceptible to noise and are generally more accurate. For this, the Setra Model 239 high accuracy differential pressure transducer is suggested. It can have a 4-20 mA output and has an accuracy of 0.073%. Setra pressure transducers are also supposed to come with a calibration certificate, meaning they are completely calibrated when they arrive and no extra should be done. The Dwyer instruments did not come with this guarantee.

It is also recommended that a proportional solenoid control valve be purchased. This will allow for more accurate control of flow than the simple ball valve that was attached to the prototype. It can also be controlled by LabVIEW. This would let the users specify what kind of flow rate they want to see, and the valve would open or close an amount accordingly.

17. Cost Analysis and Maintenance Plan

A detailed bill of materials for the prototype system can be found in section 13.2. Besides the initial cost support structure and piping, there isn't much of an operating cost since the overhead tank is providing the flow. The only electrical energy that is required is the power of the pump that is pumping water into the overhead tank to make sure the water level stays at an adequate height, and power for all of the instrumentation. Another possible cost is the development of a new modular component for the system, which is the customer's decision.

A 5-year maintenance plan for the pipe stand is pretty simple and inexpensive. When dealing with water pipes, the most common maintenance issues that occur are leaks and corrosion. It is recommended that once every year, all of the pipes and connections be thoroughly inspected for possible leaks and corrosion occurring inside the pipes. This could be done by a fellow engineering professor of the university, or if necessary, a local plumber could be hired to inspect the pipes.

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Appendix 1

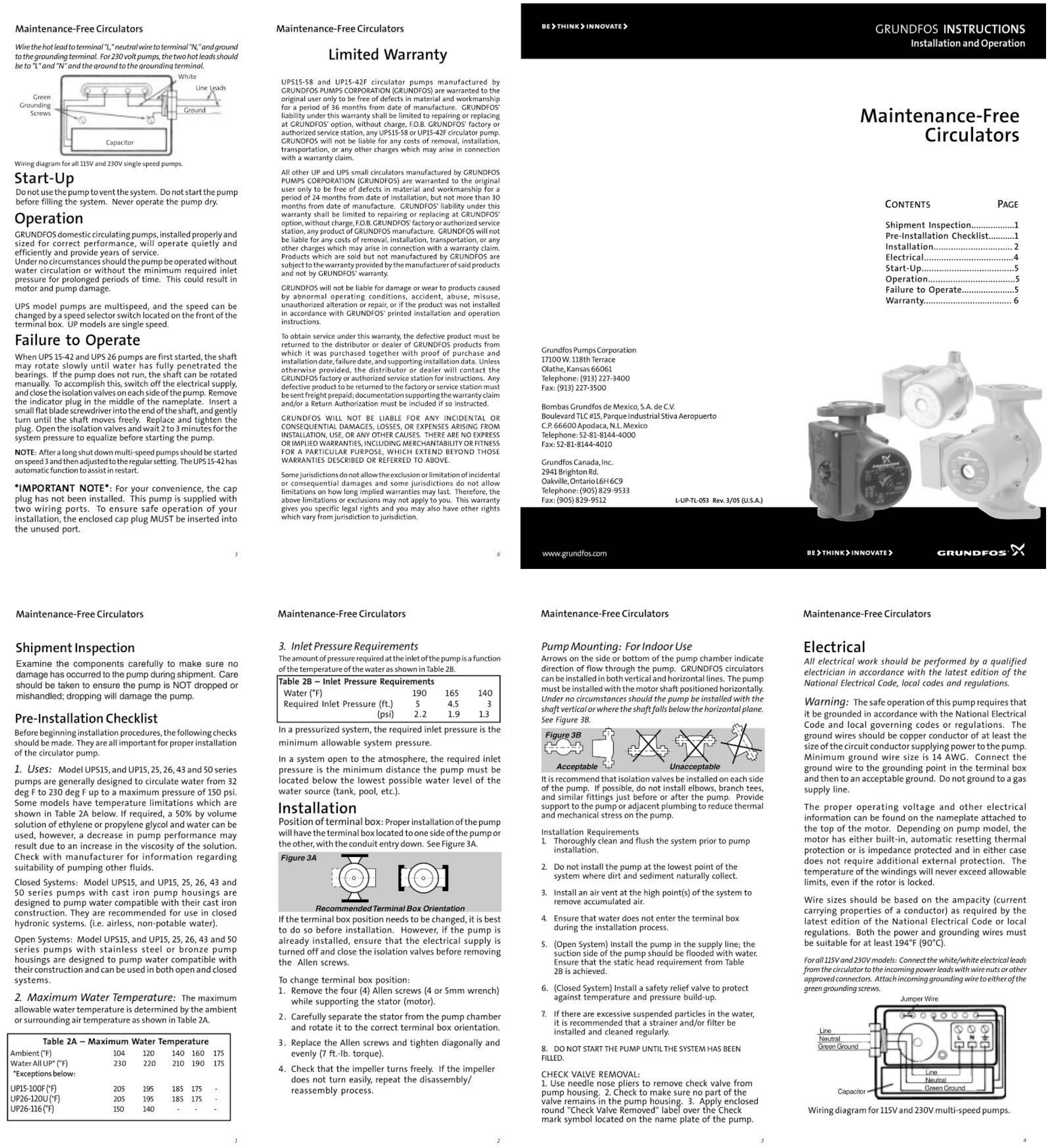
1. EES Code

```
{Calculation of Pressure Drop Across Orifice}
Fluid$='Water'
D=0.026665 [m]
T_avg=25 [°C]
L=20*convert(ft,m)
rho=density(Fluid$,T=T_avg, P=101.3 [kPa])
mu=viscosity(Fluid$,T=T_avg, P=101.3 [kPa])
m_dot=.57 [kg/s]
Q=m_dot/rho
C_d=0.6
beta=0.69
A_1=(pi/4)*D^2 [m^2]
V_1=Q/A_1
D_orifice=0.018288 [m]
A_2=(pi/4)*D_orifice^2 [m^2]
V_2=Q/A_2
Re=V_1*D/(mu/rho)
f_1=0.3164/(Re^(0.25))

{DELTAP_orifice=(0.5*rho*V_2^2 -0.5*rho*V_1^2 )*convert(Pa,psi)}
DELTAP_orifice=(0.5*rho*(1-(beta^4))*((Q/(C_d*A_2))^2))*convert(Pa,psi)
DELTAP_length=f_1*(L/D)*rho*V_1^2/(2)*convert(Pa,psi)

Q_exp=C_d*A_2*sqrt(2*DELTAP_orifice/rho)
m_dot_exp=rho*Q_exp
```

2. Maintenance Manual

2.1. Prototype Maintenance

The prototype built was a mere temporary setup and requires little preventative maintenance. Visual inspection of piping and leak checking is all that is required of the piping. The supports should be regularly checked for rusting and any unwanted corrosion. The pump should follow all specifications listed in the below manual.



Wire the hot lead to terminal "L," neutral wire to terminal "N," and ground to the grounding terminal. For 230 volt pumps, the two hot leads should be to "L" and "N" and the ground to the grounding terminal.

Wiring diagram for all 115V and 230V single speed pumps.

Start-Up

Do not use the pump to vent the system. Do not start the pump before filling the system. Never operate the pump dry.

Operation

GRUNDFOS domestic circulating pumps, installed properly and sized for correct performance, will operate quietly and efficiently and provide years of service.
Under no circumstances should the pump be operated without water circulation or without the minimum required inlet pressure for prolonged periods of time. This could result in motor and pump damage.

UPS model pumps are multispeed, and the speed can be changed by a speed selector switch located on the front of the terminal box. UP models are single speed.

Failure to Operate

When UPS 15-42 and UPS 26 pumps are first started, the shaft may rotate slowly until water has fully penetrated the bearings. If the pump does not run, the shaft can be rotated manually. To accomplish this, switch off the electrical supply, and close the isolation valves on each side of the pump. Remove the indicator plug in the middle of the nameplate. Insert a small flat blade screwdriver into the end of the shaft, and gently turn until the shaft moves freely. Replace and tighten the plug. Open the isolation valves and wait 2 to 3 minutes for the system pressure to equalize before starting the pump.

NOTE: After a long shut down multi-speed pumps should be started on speed 3 and then adjusted to the regular setting. The UPS 15-42 has automatic function to assist in restart.

IMPORTANT NOTE: For your convenience, the cap plug has not been installed. This pump is supplied with two wiring ports. To ensure safe operation of your installation, the enclosed cap plug MUST be inserted into the unused port.

Limited Warranty

UPS15-58 and UP15-42F circulator pumps manufactured by GRUNDFOS PUMPS CORPORATION (GRUNDFOS) are warranted to the original user only to be free of defects in material and workmanship for a period of 36 months from date of manufacture. GRUNDFOS' liability under this warranty shall be limited to repairing or replacing at GRUNDFOS' option, without charge, F.O.B. GRUNDFOS' factory or authorized service station, any UPS15-58 or UP15-42F circulator pump. GRUNDFOS will not be liable for any costs of removal, installation, transportation, or any other charges which may arise in connection with a warranty claim.

All other UP and UPS small circulators manufactured by GRUNDFOS PUMPS CORPORATION (GRUNDFOS) are warranted to the original user only to be free of defects in material and workmanship for a period of 24 months from date of installation, but not more than 30 months from date of manufacture. GRUNDFOS' liability under this warranty shall be limited to repairing or replacing at GRUNDFOS' option, without charge, F.O.B. GRUNDFOS' factory or authorized service station, any product of GRUNDFOS manufacture. GRUNDFOS will not be liable for any costs of removal, installation, transportation, or any other charges which may arise in connection with a warranty claim. Products which are sold but not manufactured by GRUNDFOS are subject to the warranty provided by the manufacturer of said products and not by GRUNDFOS' warranty.

GRUNDFOS will not be liable for damage or wear to products caused by abnormal operating conditions, accident, abuse, misuse, unauthorized alteration or repair, or if the product was not installed in accordance with GRUNDFOS' printed installation and operation instructions.

To obtain service under this warranty, the defective product must be returned to the distributor or dealer of GRUNDFOS products from which it was purchased together with proof of purchase and installation date, failure date, and supporting installation data. Unless otherwise provided, the distributor or dealer will contact the GRUNDFOS factory or authorized service station for instructions. Any defective product to be returned to the factory or service station must be sent freight prepaid; documentation supporting the warranty claim and/or a Return Authorization must be included if so instructed.

GRUNDFOS WILL NOT BE LIABLE FOR ANY INCIDENTAL OR CONSEQUENTIAL DAMAGES, LOSSES, OR EXPENSES ARISING FROM INSTALLATION, USE, OR ANY OTHER CAUSES. THERE ARE NO EXPRESS OR IMPLIED WARRANTIES, INCLUDING MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, WHICH EXTEND BEYOND THOSE WARRANTIES DESCRIBED OR REFERRED TO ABOVE.

Some jurisdictions do not allow the exclusion or limitation of incidental or consequential damages and some jurisdictions do not allow limitations on how long implied warranties may last. Therefore, the above limitations or exclusions may not apply to you. This warranty gives you specific legal rights and you may also have other rights which vary from jurisdiction to jurisdiction.

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GRUNDFOS **INSTRUCTIONS**
Installation and Operation

Maintenance-Free Circulators

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Shipment Inspection

Examine the components carefully to make sure no damage has occurred to the pump during shipment. Care should be taken to ensure the pump is NOT dropped or mishandled; dropping will damage the pump.

Pre-Installation Checklist

Before beginning installation procedures, the following checks should be made. They are all important for proper installation of the circulator pump.

1. Uses: Model UPS15, and UP15, 25, 26, 43 and 50 series pumps are generally designed to circulate water from 32 deg F to 230 deg F up to a maximum pressure of 150 psi. Some models have temperature limitations which are shown in Table 2A below. If required, a 50% by volume solution of ethylene or propylene glycol and water can be used, however, a decrease in pump performance may result due to an increase in the viscosity of the solution. Check with manufacturer for information regarding suitability of pumping other fluids.

Closed Systems: Model UPS15, and UP15, 25, 26, 43 and 50 series pumps with cast iron pump housings are designed to pump water compatible with their cast iron construction. They are recommended for use in closed hydronic systems. (i.e. airless, non-potable water).

Open Systems: Model UPS15, and UP15, 25, 26, 43 and 50 series pumps with stainless steel or bronze pump housings are designed to pump water compatible with their construction and can be used in both open and closed systems.

2. Maximum Water Temperature: The maximum allowable water temperature is determined by the ambient or surrounding air temperature as shown in Table 2A.

Table 2A – Maximum Water Temperature

Ambient (°F)	104	120	140	160	175
Water All UP* (°F)	230	220	210	190	175
*Exceptions below:					
UP15-100F (°F)	205	195	185	175	-
UP26-120U (°F)	205	195	185	175	-
UP26-116 (°F)	150	140	-	-	-

3. Inlet Pressure Requirements

The amount of pressure required at the inlet of the pump is a function of the temperature of the water as shown in Table 2B.

Table 2B – Inlet Pressure Requirements

Water (°F)	190	165	140
Required Inlet Pressure (ft.)	5	4.5	3
(psi)	2.2	1.9	1.3

In a pressurized system, the required inlet pressure is the minimum allowable system pressure.

In a system open to the atmosphere, the required inlet pressure is the minimum distance the pump must be located below the lowest possible water level of the water source (tank, pool, etc.).

Installation

Position of terminal box: Proper installation of the pump will have the terminal box located to one side of the pump or the other, with the conduit entry down. See Figure 3A.

Figure 3A

Recommended Terminal Box Orientation

If the terminal box position needs to be changed, it is best to do so before installation. However, if the pump is already installed, ensure that the electrical supply is turned off and close the isolation valves before removing the Allen screws.

To change terminal box position:
1. Remove the four (4) Allen screws (4 or 5mm wrench) while supporting the stator (motor).
2. Carefully separate the stator from the pump chamber and rotate it to the correct terminal box orientation.
3. Replace the Allen screws and tighten diagonally and evenly (7 ft.-lb. torque).
4. Check that the impeller turns freely. If the impeller does not turn easily, repeat the disassembly/reassembly process.

Pump Mounting: For Indoor Use

Arrows on the side or bottom of the pump chamber indicate direction of flow through the pump. GRUNDFOS circulators can be installed in both vertical and horizontal lines. The pump must be installed with the motor shaft positioned horizontally. *Under no circumstances should the pump be installed with the shaft vertical or where the shaft falls below the horizontal plane. See Figure 3B.*

Figure 3B

It is recommend that isolation valves be installed on each side of the pump. If possible, do not install elbows, branch tees, and similar fittings just before or after the pump. Provide support to the pump or adjacent plumbing to reduce thermal and mechanical stress on the pump.

Installation Requirements
1. Thoroughly clean and flush the system prior to pump installation.
2. Do not install the pump at the lowest point of the system where dirt and sediment naturally collect.
3. Install an air vent at the high point(s) of the system to remove accumulated air.
4. Ensure that water does not enter the terminal box during the installation process.
5. (Open System) Install the pump in the supply line; the suction side of the pump should be flooded with water. Ensure that the static head requirement from Table 2B is achieved.
6. (Closed System) Install a safety relief valve to protect against temperature and pressure build-up.
7. If there are excessive suspended particles in the water, it is recommended that a strainer and/or filter be installed and cleaned regularly.
8. DO NOT START THE PUMP UNTIL THE SYSTEM HAS BEEN FILLED.

CHECK VALVE REMOVAL:
1. Use needle nose pliers to remove check valve from pump housing. 2. Check to make sure no part of the valve remains in the pump housing. 3. Apply enclosed round "Check Valve Removed" label over the Check mark symbol located on the name plate of the pump.

Electrical

All electrical work should be performed by a qualified electrician in accordance with the latest edition of the National Electrical Code, local codes and regulations.

Warning: The safe operation of this pump requires that it be grounded in accordance with the National Electrical Code and local governing codes or regulations. The ground wires should be copper conductor of at least the size of the circuit conductor supplying power to the pump. Minimum ground wire size is 14 AWG. Connect the ground wire to the grounding point in the terminal box and then to an acceptable ground. Do not ground to a gas supply line.

The proper operating voltage and other electrical information can be found on the nameplate attached to the top of the motor. Depending on pump model, the motor has either built-in, automatic resetting thermal protection or is impedance protected and in either case does not require additional external protection. The temperature of the windings will never exceed allowable limits, even if the rotor is locked.

Wire sizes should be based on the ampacity (current carrying properties of a conductor) as required by the latest edition of the National Electrical Code or local regulations. Both the power and grounding wires must be suitable for at least 194°F (90°C).

For all 115V and 230V models: Connect the white/white electrical leads from the circulator to the incoming power leads with wire nuts or other approved connectors. Attach incoming grounding wire to either of the green grounding screws.

Wiring diagram for 115V and 230V multi-speed pumps.

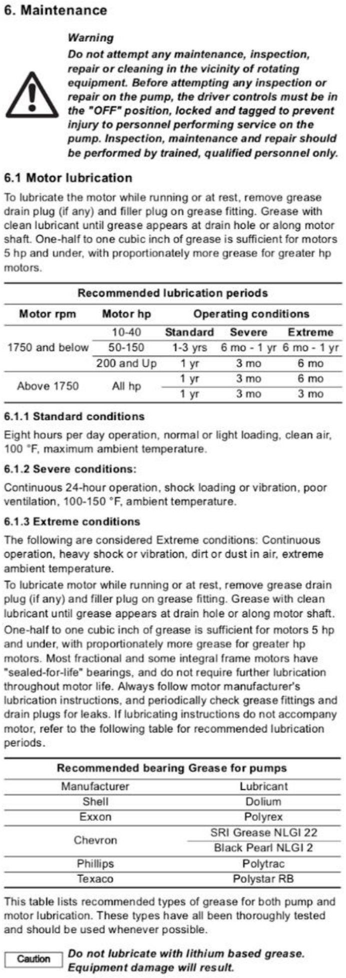
2.2. Final Design Maintenance

The final design will be a permanent piece of equipment used within the CEAT Endeavor Lab, and as such, will require much more stringent preventative maintenance. This section will outline all the required categories and what maintenance should be performed.

2.2.1. Pump

The full-scale system will utilize a much larger, Grundfos pump. This pump will be used to refill from the sump pit into the 500-gallon head tank. The particular model used is the Grundfos

Paco Series VL Line Centrifugal Pump. Assuming the pump is properly installed to manufacturer's specifications, the maintenance for the pump is as follows.



6. Maintenance

Warning
Do not attempt any maintenance, inspection, repair or cleaning in the vicinity of rotating equipment. Before attempting any inspection or repair on the pump, the driver controls must be in the "OFF" position, locked and tagged to prevent injury to personnel performing service on the pump. Inspection, maintenance and repair should be performed by trained, qualified personnel only.

6.1 Motor lubrication

To lubricate the motor while running or at rest, remove grease drain plug (if any) and filler plug on grease fitting. Grease with clean lubricant until grease appears at drain hole or along motor shaft. One-half to one cubic inch of grease is sufficient for motors 5 hp and under, with proportionately more grease for greater hp motors.

Recommended lubrication periods

Motor rpm	Motor hp	Operating conditions		
	10-40	Standard	Severe	Extreme
1750 and below	50-150	1-3 yrs	6 mo - 1 yr	6 mo - 1 yr
	200 and Up	1 yr	3 mo	6 mo
Above 1750	All hp	1 yr	3 mo	6 mo
		1 yr	3 mo	3 mo

6.1.1 Standard conditions

Eight hours per day operation, normal or light loading, clean air, 100 °F, maximum ambient temperature.

6.1.2 Severe conditions:

Continuous 24-hour operation, shock loading or vibration, poor ventilation, 100-150 °F, ambient temperature.

6.1.3 Extreme conditions

The following are considered Extreme conditions: Continuous operation, heavy shock or vibration, dirt or dust in air, extreme ambient temperature.

To lubricate motor while running or at rest, remove grease drain plug (if any) and filler plug on grease fitting. Grease with clean lubricant until grease appears at drain hole or along motor shaft.

One-half to one cubic inch of grease is sufficient for motors 5 hp and under, with proportionately more grease for greater hp motors. Most fractional and some integral frame motors have "sealed-for-life" bearings, and do not require further lubrication throughout motor life. Always follow motor manufacturer's lubrication instructions, and periodically check grease fittings and drain plugs for leaks. If lubricating instructions do not accompany motor, refer to the following table for recommended lubrication periods.

Recommended bearing Grease for pumps

Manufacturer	Lubricant
Shell	Dolium
Exxon	Polyrex
Chevron	SRI Grease NLGI 22
	Black Pearl NLGI 2
Phillips	Polytrac
Texaco	Polystar RB

This table lists recommended types of grease for both pump and motor lubrication. These types have all been thoroughly tested and should be used whenever possible.

Caution ***Do not lubricate with lithium based grease. Equipment damage will result.***

2.2.2. Piping

Every time the pipe stand is used, it should be inspected for leaks. If one is found, the maintenance personnel for the *Endeavor* Lab should be notified immediately to fix the leak. The solution for a leaking pipe will depend on where the leak occurs. If the leak is at a flange connection, fixing it can be as simple as tightening the bolts on the flange. If the leak occurs at a fitting interface, the solution depends on what kind of pipe it is. If it is steel or copper pipe, adding to the braze or weld will fix it. If it is PVC, then adding glue to the joint will seal it well.

In the steel pipe sections, the pipes need to be checked for corrosion frequently. Once a year, the pipes should be taken off the stand and checked for corrosion. If the section of pipe is not currently being used in an experiment, it should be drained fully so that stagnant water does not stay in the pipe, which will cause corrosion quicker.

3. Laboratory Instructions

This section will outline the instructions for setting up the pipe stand and using it to perform experiments.

3.1. Transport

To transport the system, first, be sure that the system is drained completely of water. Then, take the pipe sections apart at the flange connections. There should be flanges at the beginning, middle, and end of each section. These will come apart by loosening the bolts. Then, by loosening the hangers, the pipe sections should come off of the stand and will be ready for transport.

To transport the support structure, the structure will break down into three pieces. To do this, unbolt the Unistrut at each ladder section and take the stand apart.

3.2. Setup of System

To setup the system at the *Endeavor* Lab, the support structure must be put into place first. The three pieces of the structure must be moved in individually and attached with Unistrut, to make it stable. Then the structure should be bolted to the ground to add more stability.

Then the piping should be installed. The 10’ sections of pipe can be hung on the hangers that are attached to the Unistrut. The manifolds can be attached to the flanges of these pipe sections and clamps can be added to the support structure to support the manifolds. The manifolds can be connected to the existing piping in the *Endeavor* Lab.

3.3. Use of Software

The software that is used for this project is LabVIEW. To use the interface that was developed for the learning modules, first open the project. When it is open, click the run program button on the top. The software should start recording the temperature of the water that is in the system and the flow rate within the system. For the current revision of the software, there is one learning module that can be recorded with LabVIEW. To run this module, simple click the button that says, “Measure Orifice Plate”. Then, the pressure drop and flow rate for this learning module should be recorded in the following indicators.

3.4. Shutdown of System

To shut down the system, the valve allowing flow to the system should be turned off and the water should be drained to the sump. Then the piping can be taken apart at the flanges. The support structure can be taken apart the interfaces of the Unistrut and stand.