NORTHERN ARIZONA UNIVERSITY

College of Engineering, Informatics, and Applied Sciences

Project 10
Pipe Loss Experiment Redesign

Keith Caton
Mark Frankenberg
Michael Garelick
Cole Nielsen

Project Sponsor: Dr. Constantine Ciocanel

Faculty Advisor: Dr. Constantine Ciocanel

Instructor: Sarah Oman

DISCLAIMER

EXECUTIVE SUMMARY

The 2018 capstone project is a complete redesign of a pipe flow experiment table that is used in the ME 495 lab at Northern Arizona University. The client for this project is Dr. Constantin Ciocanel. The system needs to be redesigned so that it yields more reasonable results so that the students can using it can take more knowledge from it and have a better understanding of the real-world concepts. The current table is also showing signs of age as certain components are wearing down and may not be as effective going forward. The design is implemented using the tenets of the design process that is defining the problem, developing solutions, implementing the solution, and finally iterating to improve the design. The authors were able to successfully implement a design that meets the requirements of the client and additional stakeholders. Utilizing systems such as MatLab and Ansys to perform complex analysis of the design, and then LabVIEW to collect the actual results of the system, the design requirements of the project are validated. These requirements are, in short, a Reynolds Number range of 10^4-10^6 with a pressure range is measurable with pressure transducers whose data can be collected using National Instruments LabVIEW. The authors faced many obstacles during the design and implementation process which were mostly overcome by the team to create a successful product for the Thermal-Fluids Lab. The product can produce a Reynolds Number range from 10^4-$2.5*10^5$, which is smaller than the desired range, but due to physical limitations is the highest possible values the design is able to produce. The additional requirements are all meet by the design. Overall, the authors learned valuable lessons about the importance of time management and communication. These aspects are of the upmost importance to industry and professional organizations, which the Capstone process at NAU provided a deep insight into.

Figure i - 1 Final Model of Design

ACKNOWLEDGEMENTS

The authors would like to express their deepest gratitude to the entire Mechanical Engineering Department of Northern Arizona University for their assistance with the design and technical analysis, but especially to the follow faculty for all their additional assistance:
Dr. Constantin Ciocanel – Design Client and Project Mentor
Dr. Tom Acker – Internal Pipe Flow Assistance
Professor David Willy – Internal Pipe Flow Assistance and First Semester Instructor
Dr. Sarah Oman – Manufacturing Assistance and Second Semester Instructor
.

TABLE OF CONTENTS

Contents

1 BACKGROUND

1.1 Introduction

Laboratory classes are crucial for helping students can get a physical meaning for topics that are taught in the more common lecture classes. They also give the instructors more opportunity to make meaningful teaching points for the subjects being introduced to the students. Experiments in a lab can quickly become outdated and not as much of an effective method for teaching students about complex topics. A team was put together in the capstone class to work together and find a solution to this problem. This project tasks the team with completely redesigning an experimental pipe flow table from the ME 495 lab portion of the class. The client, Dr. Constantin Ciocanel desires a new experimental setup that will function with clear, and meaningful results. The team must design and construct a new table that is easily accessible to students and instructors alike. The team has been able to bring the team's own designs and concepts to the decision-making progress that will shape the desired experimental setup, based on what the client requires, and what will be most beneficial to the students and instructors that will be utilizing it for years to come.

1.2 Project Description

The team must redesign and construct an experimental table for the ME 495 lab at Northern Arizona University (NAU). The stakeholders of the project will be; NAU, the school will benefit from students having a better understanding of the learning material, the client, Dr Ciocanel, and the students at NAU, they will have another form of instruction on the topic which could lead to better understanding of the subject matter. The client wants a new table that will replace the older model. The experiment was for demonstrating how a fluid can experience pressure loss in a pipe, and how it affects the flow. The students are to measure pressure differences through different lengths, and fittings of pipe. They are measured across long lengths of pipe, through elbow and T-joints, as well as diameter reductions and expansions. The pressures are then used to find the major and minor head loss of the flow. There are to be three different forms of flow rate measurement for users so that they can perform head loss and velocity calculation in the analysis. A pump was to push water through the system and should be able to be regulated to achieve for specific Reynolds numbers and flow rates for different calculations and analysis. This new table will be able to educate students in a more effective manner than before, yielding more meaningful data and clearer results that can show that there was something happening within the flow as it travels through the pipes. The team will also be responsible for writing up a new lab manual for users to follow and give a set of analysis questions to test the understanding if the experiment. The possibility of automated measurement by use of data acquisition devices and a lab software will be explored later.

1.3 Original System

The current system in the ME 495 lab has been in use for about 15 years. This has caused numerous problems with the setup as well as making it more difficult to operate and take a teaching point from. Some of the pressure taps leak when trying to take measurements from a manometer. The small sections of the pipe have too small of a diameter and are over constricting the flow and was yielding inaccurate results. The pump cannot be variably controlled to change the flow rate and Reynolds numbers. The Reynolds number that the system operates at, does not show enough pressure drop over the longer length of pipe, so the head loss was very small, and does not lead to a satisfactory teaching point. Some of the pressure taps are located too close to the fittings, and as a result, the flow was not really developed again when the reading was taken, this leads to poor results in the lab discussion. The current table uses a 0.75 HP centrifugal pump operating at 0.5 hp. Copper piping and common ball valves are used to direct the flow through the table. There are three forms of flow rate transducers involved in the system, two are invasive to the flow and are taken manually by those who are performing the experiment. The third way was a non-invasive, ultrasonic flow rate transducer than can be attached to a length of pipe and read the flow rate from outside of the flow. All the measurements done in the lab are done manually by the users, there was no automated data collection.

2 REQUIREMENTS

As with any engineering design, the requirements for the design are the most important aspect of the system. Without understanding the customer and engineering requirements, the project will ultimately fail, as such, the design team has spent considerable amount of time determining the requirements to the experimental pipe loss design.

2.1 Customer Requirements (CRs)

To ensure that the design that was created effective for the stakeholders and satisfies the overall goal of the client, A list of customer requirements was laid out for the team to base decisions from. If these requirements are followed, the design will be more effective and valuable to the stakeholders. The customer requirements given to us by the client are:

- **Reliability of Measurements:** this was the ability of the experiment to yield consistent and truthful results that reflect what was expected from the lab. This included the measurement devices as well as the structure itself to be a controlled system, such as pressure as being placed in sensible locations that will achieve accurate data.
- **Durability of Physical System:** The system will be required to withstand years of high flow rates and Reynolds numbers through the pipes, and measuring devices to last as well.
- **Variable control:** The flow need to be able to be altered in a simple way to achieve flow rates and thus, Reynolds number over a wide range.
- **Common types of fittings:** the system needs to have elbow, ‘T’, expansion, and contraction joints in different sections to show head loss across these types of fitting on a pipe system.
- **Three flow rate transducers:** For the students to measure the flow rate and perform head loss calculations, there needs to be three forms of flow rate measurement. Two are required to be invasive, and have one non-invasive measurement tool.
- **Labview integration:** This was a data acquisition system that will take data from the experiment and input into a software that can be used to analyze the results on the CPU unit. This was not a finalized requirement for the project, but was being considered to this point.

2.2 Engineering Requirements (ERs)

The customer requirements are not the only aspect of the design that are important, but an understanding of the engineering requirements was equally important as they dictate the feasibility and important aspects of the system. For the pipe loss experiment, the team identified the following engineering requirements.

- Voltage – 120 Volts RMS
- Operates within a set Reynolds Number Range – $10^4 – 10^6$
- Operates within a set Pressure Range - TBD
- Smallest Diameter Pipe Half Inch
- System has a Measurable Minimum Head Loss - TBD
- Cost - $3000 or less

Each engineering requirement was selected based on discussion with the client and analysis of similar systems. Cost was included as an engineering requirement because a set value and relation to each customer requirement can be determined. The customer and engineering requirements are cross analyzed using a House of Quality which is found in the next section.

2.3 House of Quality (HoQ)

A House of Quality was a tool used by engineers to relate the customer requirements to the engineering requirements and to determine a ranking for each engineering requirement. The complete house of quality is located in 11.3 Appendix D: Miscellaneous, Table D - 1 - House of Quality. For the Pip Losses Experiment, the team considered the following customer requirements and weights:

- Reliability of Measurements - 5
- Durability of the Physical System - 4
- Life Span of at least 10 Years - 2
- Variable Flow Rate Control - 5
- One Contraction Joint - 5
- One Expansion Joint - 5
- One Elbow Joint - 5
- One Tee Joint - 5
- Three Volumetric Flow Rate Sensors - 5
- Lab View Integration – 2

The weights where determined by discussing what the client wants most from the design, creating a set of weights and then presenting the weights to the client for his approval. The weights scored at a five are non-negotiable items that the design must meet as per the client. Any weight below a five are simply desires of the client for what he would like to have the design to accomplish. The engineering requirements determined by the team through research and discussion about the client requirements and finally approved by the client, with the target ranges and tolerances are in Table 1 - Engineering Requirements.

Table 1 - Engineering Requirements

Engineering Requirements	Target Range	Tolerances
Voltage	220 Volt RMS	± 0 volts
Current	20 Amps	Cannot Exceed 20 Amps
Operates within set Reynolds Number Range	$10^4 – 10^6$	± 100
Operates within set Pressure Range	5-280kPa	± 5 kPa
Smallest Diameter Pipe ½ in	½ inch	± 0
System has a Measurable Minimum Head Loss	5 kPa	± 2 kPa
LabView Integration	All pressure sensors utilize LabView	None
Cost	$3000	± $200

From the QFD, the team could determine the following ranking of engineering requirements:

1. The system has a measurable minimum head loss.

2. The system operates within a set pressure range.
3. The system stays within budget.
4. The system operates within a set Reynolds number range.
5. The smallest diameter pipe was half an inch.
6. The system operates of standard 120 Volts RMS power.

The rankings for the engineering requires show that the primary goal for the design, as given by the client, was also the primary engineering requirement for the design and has been approved by the client.

2.4 Testing Procedures (TPs)

To ensure that all engineering requirements are met for the design, the team will be completing a comprehensive testing procedure for each individual requirement. Several of the requirements are strict guidelines for the physical properties of the materials purchased and the pump selection, as such those tests will simply be a pass or fail, either it meets the requirement or does not. The remaining requirements will require the team to develop a testing procedure to ensure that the requirement was met.

2.4.1 Pass – Fail Tests

Pass or fail tests are a simple test to use to enforce hard rules or guidelines to a requirement within the project. There are several engineering requirements that facilitate a simple pass or fail test for the design, these requirements are: 1. Voltage of 120 RMS, 2. Smallest diameter pipe was half an inch, and 3. total cost was below \$3000 + \$200. To ensure that these requirements are met, the entire design will be broken down into individual components and compared against the three pass-or-fail tests. If the component fails, the component will be redesigned until it passes all tests, otherwise the component was designated as a successful component. For the cost test, the cost of each component will be tabulated and then the entire cost will be the summation of each components cost. If the total cost exceeds the \$3200 limit, then each component will be re-analyzed, starting from the highest cost component to the lowest cost, and possible redesigns will be determined evaluated in sequence until the cost demand has been met.

2.4.2 Flow Energy Tests

The remaining engineering requirements that are not simple enough for a pass-or-fail will be tested using the fluid flow energy balance equation. The energy balance equation was as follows: $\left(\frac{P_1}{\rho}-\frac{P_2}{\rho}\right)+\left(\alpha_1\frac{V_1^2}{2}-\alpha_2\frac{V_2^2}{2}\right)+(gz_1-gz_2)=h_t-h_p$, where P was the pressure, V was the velocity, Z was the height from a reference point, α was the kinematic energy coefficient ($\alpha \approx 1$ for turbulent flow and $\alpha = 2$ for laminar flow), h_t was the total head loss, and h_p was the head from turbo machinery. The energy balance equation for returns the energy of the fluid, as known as the head of the flow, in two common units, either $\frac{l^2}{t^2}$ (units of velocity squared, or energy per unit mass) or l (units of length), the team has used units of length for every other energy balance calculation and thus will be continued. With the energy balance equation, the pressure and velocity of the flow can be determined at any point within the flow, which, with the properties of the fluid at room temperate and the physical dimensions of the pipe network. The Reynolds Number, $Re=\frac{\overline{V}*D}{\nu}$, where $\overline{V}$ was average velocity of the flow, D was the diameter of the pipe, and ν was the kinematic viscosity of the flow, can be determined.

To use then energy balance equation for a fluid flow, the pressures, velocity, and the height was required. To determine these values, three processes will be used. First, for height, if all points of measurement are at the same height then the change in height was equal to zero, thus the Z terms are not needed. For the pressure, the pressure will be measured using a digital pressure transducer that will be connected to the pipe system at multiple points to be able to measure the pressure at that point. With the pressures at the two points and an approximation for the head loss, it was possible to determine the velocity of the flow. With the velocity of the flow, the average Reynolds number, and head loss can be determined.

Since, having an estimate of the head loss was needed to determine the velocity of the flow, it was often better to start with a velocity of the flow and get the head loss, pressures, and Reynolds that way. To do this, a flow rate was specified, which was a function of flow velocity, and cross-sectional area, more specifically $Q = \frac{V}{A}$ where Q was the flow rate, V was the velocity, and A was the cross-sectional area. A simplified derivation of the energy balance equation as a function of flow rate was provided in section **Error! Reference source not found.Error! Reference source not found.**. This equation will be used to determine the pressure and head loss across each section of the pipe network. With the head loss, pressures, and Reynolds number known, each property will be evaluated against the target range. If the total head loss, pressures, and Reynolds number within the system are within the bounds desired, then the design meets the customer requirements, if not, the design will be re-evaluated and changed until the requirements are met or the physical limits are determined.

2.5 Design Links (DLs)

To ensure that the engineering requirements, the test outlined in section 2.4 Testing Procedures (TPs), are carried out against the final implementation of the design. Each ER is broken down in the order that they appear in Table 1 - Engineering Requirements.

The Thermo-Fluids lab in the Engineering building at NAU is equipped with two different power supplies, first is standard 120 Volt and 20 Amps outlet that are utilized for most consumer grade power systems. This power system was the original requirement of the project, but after the team was informed that 220 Volts and 20 Amps is available with in the lab, the design was modified to utilize this power supply. The selected pump falls within this range exactly. The pump, Pentair H3-Plus 5Hp 60Hz pump, utilizes between 208-230 volts and 18.9-20.8 Amps, thus the pump falls in line with the available power within the lab. With this pump, both the 220 Volts and 20 Amp requirement is met.

The Reynolds Number (RN) requirement for the design is to be from $10^4 - 10^6$, this proved to be physically impossible as it is required a flow rate of approximately 250 – 300 gallons per minute depending on the pipe diameter, which would require around 3000ft of head provided by the pump. This would produce, not only a very expansive system, but also a dangerous system as the pressures would be sufficiently high enough to cause major bodily harm. As such, the design strived to reach the maximum possible Reynolds Number, which occurs at the maximum flow rate of approximately 40 gallons per minute. This translates to a maximum RN of approximately $2.5 * 10^5$. The client has accepted the achievable values for the RN based on the results produce from testing and theoretical analysis.

As for the pressure requirement, the falls within the target pressure range of 5 – 280 kilopascals (0 – 40.6 psi). By utilizing the pressure transducers placed around the system, the total pressure of the system can be analyzed. The location of highest pressure, with a pressure transducer available, is the pipe inlet to the upper system because as the fluid travels through the system, the fluid pressure will gradually decrease. The pressures measured at the first tap around maximized at the highest flow rate, this produce is a pressure of approximately 30 psi which is well within the desired pressure range of the system. A high-pressure range is important because it will provide a larger range of results for determining the pressure loss across different fittings.

The original system utilized a one-quarter inch diameter pipe that created a large amount of head loss across the system. This head loss forced the original pump to operate outside of safe operating parameters thus causing the pump to become over heated and needed to be shutdown. The new design is required to not utilize any pipe diameters smaller than half inch in diameters. The design's smallest diameter is exactly half inch in diameter, which meets the ER for the system.

To ensure that the system has head losses that are measurable by the pressure transducers, a smallest pressure loss is desired. The pressure measurements across the system reveal that the system meets this requirement for most fittings. For the contraction, expansion, elbows, and valve fittings the requirement is met as the head loss these fittings is orders of magnitude higher than the requirement. For flow across a tee, when not diverging, the head loss this fitting is very small, and for lower flow rates can dip below the requirement of the system. Fortunately, the pressure transducers utilized can detect this slight different, thus even though the requirement is not completely met, the need for pressure differences the system can detect is met. This requirement is then met for almost all the needed operating parameters.

To collect the data, National Instruments LabVIEW software and Data Acquisition (DAQ) system must be utilized. LabVIEW allows for DAQs that have connected sensors to collect voltage information and either collect or directly convert it other information, such as pressures. The pressures transducers utilize a change voltage across an outlet and ground connection to create a voltage difference as the pressure of the system changes. LabVIEW collects the voltage information from all pressure transducers simultaneously while writing the data to a tab delimited text file for further analysis. The LabVIEW Virtual Instrument developed is calibrated to convert the voltage output from the transducers directly to pressure values in pounds per square inch (psi) which can then be directly analyzed by the students preforming the experiment. With the pressure transducers utilizing LabVIEW, the LabVIEW requirement for the design is met.

The final ER, cost, is related to keeping the cost of the design as small as possible. The budget for the project is set at \$3000 with an additional \$200 provided if needed. The final cost of the entire design after construction and testing is \$2947.61 which is just below the budget for the design. It needs to be noted that this does not include the cost of the sensors and sensors mounts which adds an additional \$2295.63. This additional cost is part of the project budget but are provided by the Mechanical Engineering's Thermal-Fluid lab budget. With the cost of the sensors, the total cost of the design is determined to be \$5243.24, but the cost of the design without the sensors is the what relates to the engineering requirement, thus the design meets this ER.

Overall, the entire design meets most of the engineering requirements. The Reynolds Number and minimum head loss are the only two requirements not directly met but are within acceptable ranges from the client. As such, the design meets the requirements of the client and additional stake holders.

3 EXISTING DESIGNS

As with any engineering project, an understanding of what has already been developed was just as important as understanding what the design must do. For that, the team researched current designs to determine advantages and disadvantages with the current systems and to establish a base line. The results of that research can be found in this chapter.

3.1 Design Research

The team researched four other universities designs for similar experiments. The four universities researched are, University Warwick, Ohio Northern University, University of Vermont, and UC Santa Barbara. An evaluation and comparison of these universities experiment to Northern Arizona University's current experiment was in the follow sections.

3.1.1 University of Warwick's Head Loss Experiment

The University of Warwick preforms a similar experiment to what was being required for Northern Arizona University. Warwick's experiment only tests straight pipe head loss and not head loss caused by pipe fittings or joints [1]. The process for determining the head loss over the straight pipe section of the experiment was the same process that the current experiment the ME 495 students preform which uses pressure tap located at each end of the test section to record the difference in pressure across the test section [1]. The process of recording the differential pressure across the system was the same process that the design team was planning on using for the new experiment, thus the Warwick experiment still provides valuable insight into the process of collecting and recording the pressure difference.

To perform the experiment, each student was required to review their text books and class notes about pipe flow and head loss and preform a series of calculations to review the governing equations for the practical part of the experiment [1]. The equations include the calculation for Reynolds Number, average velocity from volumetric and mass flow rate and from the Reynolds Number, straight pipe friction coefficient, mass flow rate, and cross-sectional area of the pipe [1]. After completing all preliminary calculations, the students perform the experiment over two different lengths, 17 millimeters and 15 millimeters, and roughness of the pipe, smooth for the 17 millimeters and rough for the 15 millimeters [1]. The students collect five sets of differential pressure readings for the two pipe segments and then determine the change in velocity, the Reynolds number and the friction coefficient [1]. Next, the change in pressure was plotted against the change in the velocity on a log plot and the friction coefficient was plotted against the Reynolds number on a log plot as well [1]. Finally, the students are required to write a report of their findings from the experiment and prove the head loss from the system was a function of the change in pressure and not from a change in velocity which cannot happen for an incompressible flow [1].

Warwick's experiment includes several items that Northern Arizona University's new experiment was also required to incorporate, mainly the head loss over a straight pipe and data analysis to prove the head loss in a function of the change in pressure. The new design for ME 495 will include, in addition to the straight pipe head loss, head loss over joints and fittings and was primarily focused on replicating the Moody chart and validating results.

3.1.2 Ohio Northern University's Experiment Proposal

Ohio Northern University preformed the same process that was currently being performed by the design team to develop an experiment to determine and validate the head loss of a pipe flow system [2]. A senior design project was created to develop a head loss experiment, the results of which was analyzed by the design team. The purposed experiment was very similar to the current and selected design for ME 495 in which the pump, reservoir and filter are located on the ender side of the experiment table and the test sections located on the top of the table [2]. The key difference was that Ohio Northern University's proposed design only determines the head loss of the flow traveling through a gate valve and not any form of an elbow, contraction, or expansion joints or fittings [2]. The tests of straight line pipe flow head loss and head loss over the gate value was like the process being considered by the design team.

Ohio's proposed design includes three pipe segments with pressure taps located at each end of the segment [2]. The first segment was a simple smooth three feet length of half an inch piping, the second was the same length and diameter as the first but the pipe interior has been roughened to increase head loss [2]. The final section was also three feet long and half an inch diameter but includes a gate valve located half way down the length of the pipe to determine the head loss over a simple fitting like a gate valve [2]. The simplicity of the design as well as initial designs considered using a gravity feed reservoir or using building supplied water but both of those approaches proved to be unfeasible for the requirements of the client [2]. Both designs considered are also possible for the new ME 495 but Ohio's analysis provides insight into the feasibility and potential problems with using similar designs such as the lack of consistency with supplied water and the size and height requirements of a gravity fed reservoir [2]. The experiment requires the students to validate their results using many different methods, each method for a different aspect of the system [2]. For example, to validate the flow rate sensor, the students are required to set the flow rate at a base rate and then record the time needed to fill a specified volume amount, this process was repeated for several different flow rates and the percent error was calculated to provide a correcting factor [2].

Ohio Northern University's proposed experiment was a prime example of how to empirically determine head loss over a series of different pipe flow segments. The proposal provided the team with abundant information and design ideas that are used to help narrow down the design and provide the best design for the client and Northern Arizona University.

3.1.3 University of Vermont's Head Loss Experiment

The University of Vermont has an experiment to determine the head loss of a fluid flow over different joint and fitting types [3]. The key difference between the Vermont's experiment and Northern Arizona University's experiment was that, Vermont's experiment uses air as the working fluid while the current and considered design uses water [3]. A simple system of a long straight pipe made up of multiple segments was used to perform the experiment, where the segment located half way down the pipe was replaced with different types of elbows to determine the head loss across the joint [3].

The students are given 20-30 minutes to record measurements including the stagnation, static, and dynamic pressures of different points of the pipe system [3]. The use of Pitot-Static tubes was used to generate a velocity profile of the flow for one of the segments, which was then used to determine an average velocity which was used for the rest of the experiment [3]. With the average velocity and static pressure measurement tools, the student fit the joint to be tested and record the pressure loss over the joint [3]. After recording the pressure loss, the head loss over the joint was determined and then the loss coefficient was then determined from the head loss [3]. Finally, the head loss and loss coefficient are validated using values from the class text book [3].

3.1.4 US Santa Barbara' Head Loss Experiment

At US Santa Barbara, mechanical engineer students undertake a several-week-long experiment to determine the head loss over a simple pipe flow system. The experiment requires the students to build a system to calibrate the sensors that are used, validate the calibration, build a simple pipe system that can vary pipe diameters and fittings, and record the pressure losses over the system. Using the pressure loss over different sections of the system, and information about the head loss coefficients, either in the form of a minor loss "K" value or a roughness to determine the friction coefficient from a Moody diagram. Finally, the students must replicate a section of the Moody Diagram and compare the loss coefficients vs length of pipe over the diameter to validate the results from the class text book.

The experiment requires the use of three different sensors, two flow rate sensors and one differential pressure sensor. The flow rate sensors used are an Omega paddlewheel flowmeter, which was an invasive sensor that has a cut in and cut out flow rate that outside of those boundaries will produce erratic and unreliable results. The students are tasked with determining these two boundaries and then collecting data points within the boundaries to determine a relationship. The functional relationship was left to the students to determine, but they are given hints that a 2nd order polynomial and higher as well as power function are good candidates to consider. Secondly, an Orifice plate flowmeter was used to measure the pressure drop across the orifice plate as a function of the flow are, which was then used to determine the discharge coefficient. The pressure sensor used was the Validyne differential pressure transducer and the student undergo a similar process to calibrating as the Omega paddlewheel flowmeter. The main difference was the relationship was expected to linear or 2nd order polynomial, and if the linear fit was a good fit, left to the students to determine what a good fit was, then they allowed to use the linear best fit for the remainder of the lab. After the sensors have been calibrated, the students build a test system and begin to determine head losses.

To test head loss over straight pipes, the students must prepare three six to eight feet long sections of pipes at three different diameters. Water was pumped through each section of straight pipe and the pressure difference over the section and the flow rate of the liquid was measured. Using the two measurements, the major head loss was determined for several Reynolds numbers and then plotted against a Moody diagram. A similar approach was handled for minor losses. A single diameter pipe was chosen and then multiple elbow and tee joints are attached to the system and the minor head loss for each fitting was determined using the flow rate and pressure difference across the fitting. Finally, the students create a complete pipe system using a Wheatstone bridge to measure the pressure, and head loss difference, between two pipe segments that are setup in the exact same way but will vary with height. The students then vary the height of one of the pipe segments and observe the change was head loss across the two segments. For each task within the experiment, the students collect data points that are used to validate the data.

Once all experiments are completed, the students produce a report that includes the pressure transducer best fit line, the paddlewheel flowmeter best fit line, and the relations between the flow rate and the pressure difference over the Orifice-plate flow meter. Additionally, the report includes the minor and major head losses as a replication of the Moody chart, then minor loss “K” value vs the length of pipe over the diameter of pipe, and the lost coefficient and the length of pipe over the diameter of the Wheat bridge technique. All results are compared against values from the text book to determine validity.

Overall the experiment does a good job of describing the head losses over a pipe system that utilizes all three terms to Bernoulli’s equation, pressure, velocity, and vertical position. The design(s) being considered by the capstone team includes the pressure and velocity terms of Bernoulli’s equation but does not include any differences in height, which was something the team should investigate. The major down fall to the experiment was that the students must build the experiment each time and then disassemble it which takes considerable amounts of time and was likely one of the reasons why the experiment was preformed over multiple weeks. Additionally, the NAU design was currently planning on using three flow rate sensors, one of which was non-invasive which the UC Santa Barbara experiment does not have, which increase experiment run time. The ability to determine head loss uses multiple processes to determine, which provides the students with the experience of multiple approaches to determine the same parameter. This ability to use different methods was greatly beneficial to the students and something the NAU design should consider. Overall, the UC Santa Barbara design was a good example that has several benefits but also several down falls which could be improved upon with the NAU design.

3.2 System Level

As the project was based around improving the design and functionality of one of the old ME 495 experiments, it was imperative to gather as much knowledge as possible. Investigating what other schools are doing in this case the team can gain a better understanding of what works and what doesn’t. Below are a few designs from schools and other companies that show some advantages and disadvantage of certain designs. Figure 1 shows a complicated maze of pipes and fittings that will yield various results. The increased amounts of pipes result in a greater range of values, but due to the budget, the team need to stay with as few of pipes as possible while reaching the same results. What can be taken from this design would be that it was unnecessary to have that many different pipes. The team can achieve the same results from lesser amounts of pipes if the team adjust the diameters and flow rate. This design was also meant to be displayed and used standing up. Due to the device being set on a table the team can achieve a more uniform flow rate than this design.

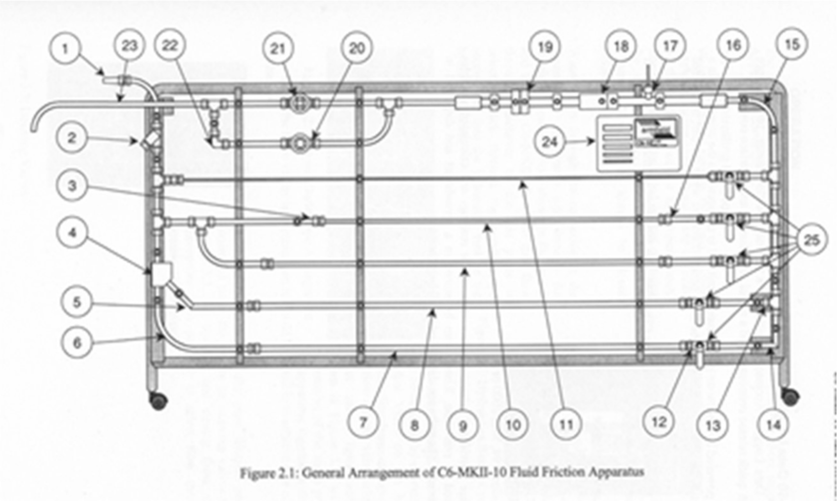


Figure 1 - Commercially Available Pipe Flow Experiment - Jfccivilengineer.com

A second design was evaluated to see what can be utilized within the own design or what the team should not include. Figure 1 - Commercially Available Pipe Flow Experiment - Jfccivilengineer.com sits upward on wheels, giving the flow an inconsistent measurement along the vertical pipe sections. What this device lacks are T-joints that the team require to have in the design. What the team can take away from this design would be that the team are on the right track with the design having the dimensions that the team do. This table was too big and does not fit within the allotted dimensions. Figure 3 can also be used as a basis for the so that the team know that to improve upon. There was already a very similar design as a separate experiment in the ME495 lab. The team must use this to better the own design so there will be no need for both experiments to be present. One way to do that would be to make it easier to use and for the results to be significantly better. Due to the simplicity of Figure 1 - Commercially Available Pipe Flow Experiment - Jfccivilengineer.com and Figure 2 - Commercially Available Pipe Flow Experiment - Lerneasy.info, the team cannot take much inspiration for them. However, it does show us that the team are on the right path to reach the goals.

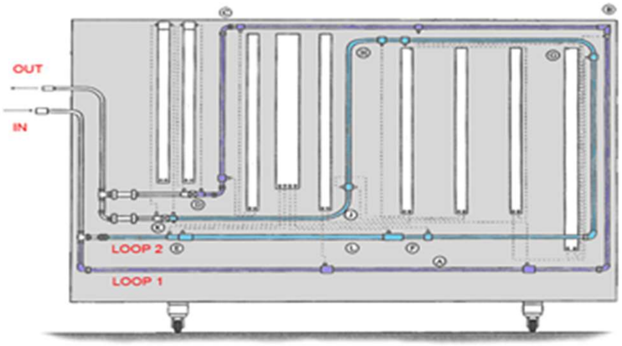


Figure 2 - Commercially Available Pipe Flow Experiment - Lerneasy.info

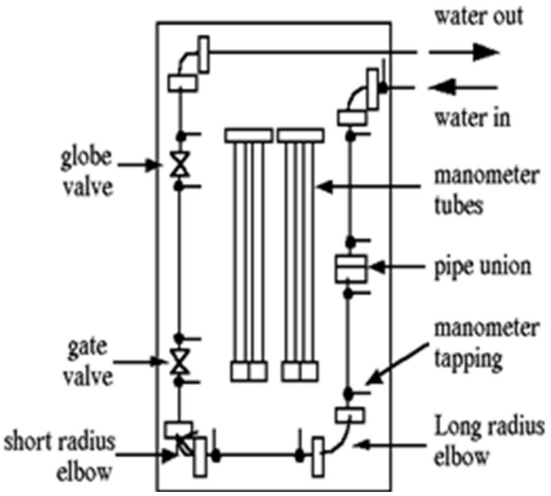


Figure 3 - Commercially Available Pipe Flow Experiment - Www2.latech.edu

Figure 3 - Commercially Available Pipe Flow Experiment - Www2.latech.edu shows a very similar design and functionality as to what the team should strive for. There are a multitude of elbow and T-joints, as well as an easy to read manometer. The design and application will improve on this by having more than just as single way to measure the flow rate. The team will have better sensors and sturdier materials for a long-lasted experiment. This design and how it functions will be a general basis for how the team design and build the finished project.

The end goal was to make a simple design that still gives us the results of a more complicated design. The team can utilize all these designs for us to achieve the goals.

Figure 4 - Commercially Available Pipe Flow Experiment

3.3 Functional Decomposition

The purpose of the experiment redesign project was to create a better-functioning pipe flow system for experiments. The overall function of the pipe flow experiment apparatus was to teach about pipe losses. This function can be generally described in a Black Box Model like in Figure 5 - Pipe Flow Black Box Model. The main material flows required for the function of the apparatus are the human interactions of the students and the instructor, and the water within the system that would occasionally be replaced between experiments. The main energy flows will be the electrical energy from an outlet to power the pump and the human energy to move the measurement components and data collection supplies. Energy will be dissipated due to losses and friction to export heat. The main signal flows will be the starting and stopping of the apparatus, the visuals of the measurements, and the indications that the apparatus was operating correctly through noise and water flow visuals.

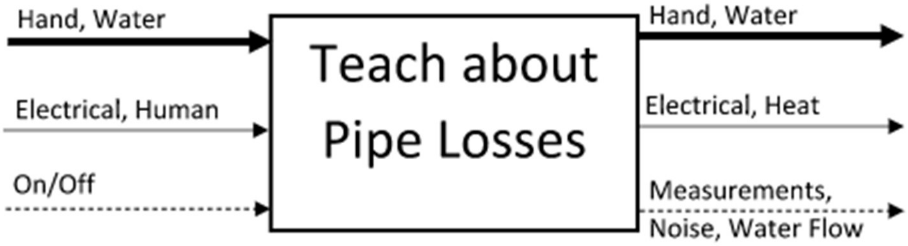


Figure 5 - Pipe Flow Black Box Model

To further analyze the flows required to make the apparatus function, a Functional Model was created and the result was shown in Figure 6 - Pipe Flow Functional Model. There are two main areas of functional flow in the experiment redesign: the physical pipe flow apparatus and the experimental procedures and lessons; both functional flows are required for the success of the apparatus. Just like in the Black Box Model, the human interaction, water, electrical energy, human energy, and starting the system are inputs and the human interaction, water, electrical energy, heat, measurements, noise, and water flow visuals are exported. There are other inputs that take place within the apparatus. They are sensors, data collection instruments, and report. Additional exports include the sensors, pressure measurements, flow rate measurements, and report. These extra inputs and outputs are part of the apparatus and they themselves flow throughout the Functional Model as well.

The Functional Model was essential for the understanding of the experiment redesign apparatus because it shows all the required components that make the experiment function correctly. The Functional Model shows the importance of certain components that flow through more junctions than others. For example, the data collection flow goes through the most junctions and interactions between other components so it was the most important component for the function of the experiment. This was understandable because the data collection can take the form of multiple measurements and was required for the report and the demonstration of the students' understanding. Another important component of the Functional Model was the flow of the water. The water was required to make the experiment yield results and it stays within the system to keep it running successfully. From the Functional Model, the experiment redesign could be analyzed into systems and subsystem levels for sorting design specifications.

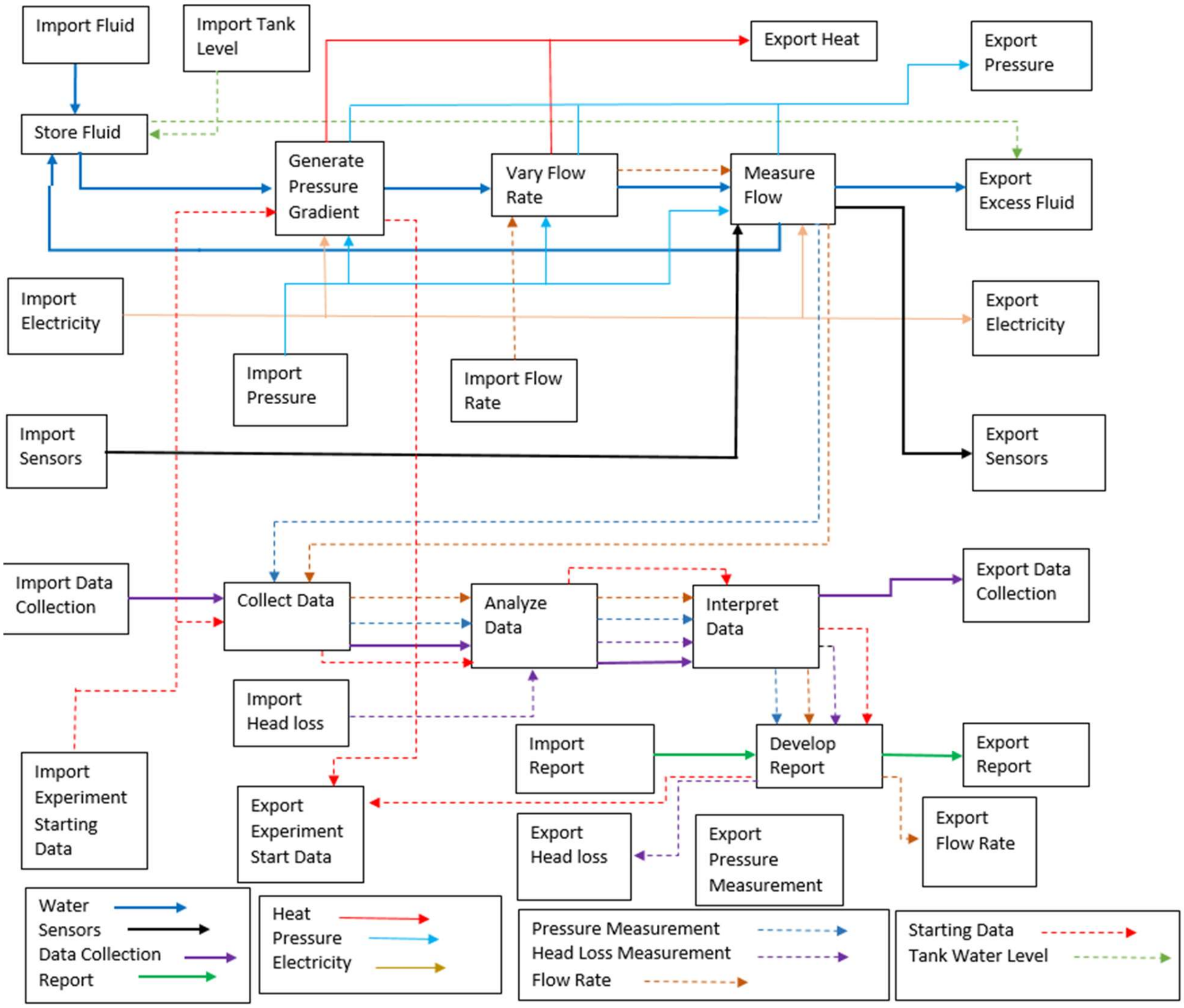


Figure 6 - Pipe Flow Functional Model

3.4 Subsystem Level

Some of the subsystems include the varying volumetric flow rate pump, and step up and step-down sections of the whole system. Because of the simplicity of the project there are not many separate subsystems that could be included. The most important subsystem would be the varying volumetric flow rate pump. This pump will be used to change the flow of water, giving us different flow rates for us to reach the right Reynold’s number and head loss values that the team are looking for.

The step up and step-down sections of the system are important for us to get the values the team need. The step-up section acts as a link from a smaller diameter pipe to a larger one. The same goes for a step-down section, except in the reverse. These changes of diameters increase or decrease the flow rate allowing us to gain varying head loss across those sections. From various other experiments and the own calculations, the team can decide which the best diameter change was needed.

Each section of this design whether it be the pipes, joints, pumps, or steps are all being utilized to achieve the proper results that the client wishes. For the Pugh chart specifically, the systems analyzed were pipe material, pipe system orientation, pipe roughness change, addition of labels to the pipe system, pipe diameter change, and flow rate changes.

4 DESIGNS CONSIDERED

For the Pipe Losses Experiment the design space was well defined, so the designs considered were focused on materials, fitting types, joints types, and sensor systems with a final section for each member's individual overhead sketches of the table layout. For each area, the team conducted an analysis to gather all needed information to narrow down each item and create a final list for additional analysis. A breakdown of each section was detailed below in the order stated.

4.1 Materials

Pipes came in many different materials that are designed to meet different goals for different systems. The boundary for the materials are ones that are valid for fluid pipe flow. There are two major properties for materials that were considered. First was how corrosive the material was and reactive to fluids. To meet the life expectancy of the client, the materials need to be able to resist corrosion from the working fluid. Secondly, the roughness of the pipe was important as it directly affects the head loss over the system which was one of the major requirements for the design. The material selection was for the pipes that will facilitate transporting the fluid and the frame used to hold the system. The team considered seven pipe materials that are commonly used to transport fluids and are as follows:

1. Aluminum
2. Concrete
3. Copper
4. Clay
5. Glass
6. Plastic
7. Steel

A breakdown of each material was found in the following sections.

4.1.1 Aluminum

Aluminum piping has become an attractive alternative to copper because of the increase price of copper over the last ten years along with the ease of use and corrosive resistance provided [4]. The corrosion resistance was of desire to the team because of the request life span of the project which was a function of the corrosion of the pipes used. For fresh water, Aluminum has excellent corrosion resistance and usually only faces corrosion in the form of pitting on the wetted surface [4]. Water was the current fluid material that the design will use and thus the resistance to water corrosion was of great benefit.

Aluminum's corrosion resistance was a product of the how highly corrosive pure Aluminum was [4]. As Aluminum was exposed to a fluid, the outer surface of the material rapidly develops an oxidized layer that creates a protective layer for the remaining material [4]. The use of water in the system would ensure the creation of the protective oxidized layer and increase the life span of the Aluminum piping. With the creation of an oxidized surface, the corrosion of water was usually in the form of pitting on the surface [4]. The pitting created could be advantageous to the design as one of the major requirements was the requirement of a significant and measurable head loss over the system which the pitting could increase the overall head loss of the piping. The effect of the pitting to the head loss is still yet to be determined.

One of the main disadvantages of Aluminum is the inability to weld the material and thus the material is more difficult to work with. For piping, an Aluminum, Magnesium, and Manganese alloy has two characteristic that make it particularly attractive. First is the ability for the material to be welded, which would allow for stronger and tighter fittings within the design to prevent leaks and increase life span [4]. Second is the increase corrosion resistance that the alloy provides, which, again will increase the life span of the design and decrease the need for replacement pipes [4]. Aluminum alloys 535 and B535 are the main candidates for Aluminum, Magnesium, and Manganese alloys for the design [4] but initial research shows that the alloys are not cost efficient.

Aluminum drawn tubing has a roughness of approximately 0.0015 millimeters, which is on the lower end of the spectrum for pipe roughness [5]. The roughness is important for creating a signification amount of head loss over the system which is a requirement for the entire design. Finally, Aluminum's density is lower than other metals and thus will allow for a lighter system [6]. The requirement of weight is not important but being able to move the system is and thus Aluminum would increase the mobility.

Aside from pipe materials, the table and frame for pipe system also must be redesigned as well. Aluminum has many characteristics that are desired for building a frame the system. The main disadvantage was the requirement of special alloys to weld the material. Aluminum is also an effective heat diffusing material, high thermal conductivity value, but heat of the pipe system is not a major concern for the design [6]. As for the remaining functions, the pump could be made with aluminum, but the remaining functions are not affected by the material.

4.1.2 Clay

Clay piping is common for sewage and highly corrosive fluids because the use Vitrified Clay Pipe is natively inert [7]. Clay piping's native resistance to corrosion will allow for extended periods of fluid flow with no measurable degradation of the material. Additionally, clay is under the ceramic material category, and thus has the advantages and disadvantages of ceramics [6]. The resistance to heat is not important to the design but the stiffness would reduce changes to system from thermal sources or forces [6]. Unfortunately, ceramics have a major disadvantage in that ceramics do not show signs of failure but instead fail catastrophically and thus expresses a safety concern to the users [6]. Finally, clay piping as a large roughness range from 0.7 – 9.0 millimeters [8]. The possible large roughness for clay does make the material attractive for having a large amount of head loss over the system.

Clay has been used as a building material and could be used to build the frame and support system to for the design. The stiffness and strength of ceramics are attractive but, again, the short comings of ceramics and sudden failures make the material difficult to work with [6]. The remaining functions of the system are not affected using clay as a pipe material or building material.

4.1.3 Concrete

The use of concrete pipes is common practice all over the developed world and it has become a staple for construction and building. Concrete offers many advantages; the main advantage is the availability due to the simplicity of the production process. However, while concrete is a readily available material, it is not a practical material for small scale piping. Concrete piping is usually used in the transportation of large amounts of a fluid in civil style applications. The ANSI/AWWA C301 specification covers pipe diameters from 16 inches up to 60 inches, which is well outside of the range of pipe sizes for the project design space [9].

Concrete could be used to build the table and frame for the system. While a frame built with concrete would be very strong, it would also be very heavy and difficult to build. The remaining functions are not affected using concrete.

4.1.4 Copper

Copper is currently the most common material used for fluid pipes and what the current design uses. There are many reasons for the use of copper pipes but one of the main was copper's corrosion resistance [10]. Like Aluminum, Copper produces a protective film over the outer surface which allows for the high level of corrosion resistance [10]. Copper has many of the same qualities as Aluminum with a major difference being Copper pipes are soldered at the joints while Aluminum is threaded or welded (if weldable Aluminum). Additionally, the pipe roughness for drawn copper is the same for Aluminum at approximately

0.0015 millimeters [5].

Copper also has high thermal conductivity value, for transferring heat and will allow for the heat generated in the system to be dispersed easily [6]. Copper wiring is often used for electronics and was likely to be the medium use for the wires needed for the sensor system. While building the table and frame out of copper is possible, it is impractical and likely to be costly. The remaining functions are not affected using copper as the pipe material.

4.1.5 Glass

Glass piping was being considered for a potential flow visualization section of the system. While flow visualization was not a requirement from the client, the team is preforming some preliminary research to evaluate how difficult it would be to implement in the system. The use of glass tubing would make it possible to use flow visualization techniques, but glass does prove to be a challenge to work with. First, glass is of the ceramic material type and thus has the benefits of ceramics (heat resistance, high stiffness, etc.) but also the major down falls of ceramics (brittle, sudden catastrophic failure, etc.) [6]. Glass could still be a valuable material for flow visualization, but additional care would be needed for use.

Glass is considered highly corrosive resistant, such that many believe that glass would resist weather and corrosion for many of years [11]. The corrosion resistance of glass, as well as the ease of cleaning, does make glass a particularly attractive option for fluid flow, but do to the weaknesses of ceramic, only low speed flows are viable. Secondly, the roughness value for glass is like that of drawn tubing at approximately 0.0015 millimeters [12].

The frame and support structure for the design could also be constructed from glass, but the remaining functions for the are otherwise not affected using glass piping.

4.1.6 Plastic

There are many different types of plastics and many are used for fluid piping systems. Plastics are a polymer, or a repeating chain of a simple molecule, and are one of the most common materials available today [6]. Most plastics have a difficult time decomposing which was partly because plastics have a high corrosion resistance [13]. Again, the material corrosion resistance was important to increase the life span of the system but plastics provides other problems. Plastics, more commonly polymers are susceptible to material changes from even small heat sources [6]. Heat sources can make a ductile plastic into a brittle material that can begin to exhibit ceramic like properties, commonly losing the ability to express strain and warn of failures [6]. There are methods to deter the restructuring of plastics by reducing the heat transfer to the system.

Plastic pipe systems have similar roughness to values to that of drawn metal piping of around 0.0015 millimeters [12], or a very smooth surface which will reduce the head loss of flow through the system. Plastic does have an advantage over metal materials because it was easier to work with. Plastic pipes are often able to be cut with shears and fittings usually just use an epoxy so make a fluid tight seal. The frame and support structure could be made from plastic but the ductility of the material would likely make it difficult to create a stable, long lasting, structure. The sensors and sensor reading points are likely to use plastics are parts of the devices and will be used as parts of the wiring used throughout the system. The remaining functions of the systems are not affected using plastic.

4.1.7 Iron/Steel

Considered to be one of the most common building materials in the world, iron, and it counterpart steel, are used in almost every major construction project in the modern world. There are many reasons for how common steel is, the main one was the strength of the material [6]. Steel was considered one of the strongest materials in the world that was in abundant supply would be able to handle the forces applied by the pipe system. Additionally, steel was weldable, thus water tight fittings are possible with relative ease (relative to the other materials analyzed) [6]. There was one major drawn back to steel, and that was, steel is highly corrosion in the form of oxidation [6]. Oxygen and steel bound easily to form an iron oxide that causes the material to lose most of its strength and durability [6]. There are steel alloys that greatly improve the corrosion resistance, such as a steel and chromium alloy, also known as stainless steel, but those alloys often increase the cost of the steel and reduce the machinability [6]. Steel piping also does not have an increase in pipe roughness to other drawn metals unless the steel was casted or galvanized [5]. The galvanizing of steel would increase the corrosive resistance but at an increase to the cost and potential reduced machinability [6].

Steel could be used for the support structure of the system. The support structure does not facilitate the flow of the working fluid; thus, it was not subjected to the same corrosive environment. Additionally, the strength of the steel would help to ensure a stable and long-lasting design. The rest of the functions for the design are not affected using steel as a building or piping material.

4.2 Pipe Fittings

The project client was requiring the pipe system have a minimum number and type of joints but no bounds on the maximum number. For this, the team was required to determine the most efficient configuration for the overall pipe system. The minimum fittings required are as follows:

1. One T-Joint
2. One Elbow Joint
3. One Step-up (Expansion) Joint
4. One Step-down (Contraction) Joint

The client left each joint as generic version leaving the selection of a specific type to the design team to determine what works best for the system. For the fittings, the major determining factor was the head loss coefficient of the fitting, with the ability to incorporate the fitting into the overall layout a secondary factor. A breakdown of each fitting type was as follows with a breakdown of each general type of pipe fitting and its corresponding head loss coefficient located in Appendix A, table 1.

4.2.1 T-Joints

There are two types of T-Joints, branching and dividing line that differ in the way the flow was separated into multiple streams [5]. The difference in tee joints was just by the way it separates the flow, either is a "T" style or a "Y" style which varies the head loss coefficient for minor loss over the joint [5]. The major difference was that they the fittings change the layout of the system, which changes the overall design of the system and each type must be considered. Additionally, the material used will determine the connection type for the function, either press fit, or a threaded attachment both with a sealant. The use of the a threaded or press fit also changes the head loss coefficient for the joint [5].

4.2.2 Elbow Joints

Like tee joints, different elbow joints determine the head loss coefficient used for each fitting [5]. Elbow joints do not have the same geometry differences of tee joints because the elbow joints, usually, come in 90 or 45-degree direction changes to the flow with either a long bend or a short bend [5]. Since head loss one of the major components of the design, each different elbow's head loss coefficient will be a determining factor for which one was used but each type could be used to demonstrate the differences for each elbow.

4.2.3 Step-up and Step-down Joints

The last joints that are required for the design are expansion and contraction joints. As with all minor losses, the minor loss coefficient was the main factor for determining the optimal fitting to use for the system. Unlike the other fitting types, the minor loss coefficient was not a set value for the specific fitting but was a function of the smaller area vs the large area and how gradual the change in area was in the form of the angle of the gradient [5]. A smaller angle for the gradient results in a smaller minor loss coefficient, as well as a higher ratio to the areas (one being the highest value) results in a smaller minor loss coefficient [5]. The area ratio and the angle of change will both have to be analyzed to determine the most efficient combination of joints.

4.3 Sensor Types

As per the client's requirements, the system must be able to handle two sensor types, first, three different flow rate sensors, and secondly, a differential pressure sensor. The three different flow rate sensors are design to demonstrate three different techniques to measure flow rate through a pipe. Two of the flow rate sensors are to be invasive sensors that fit within the pipe system and record the flow rate by directly measuring the flow across the system. Invasive flow rate sensors act like pipe joints and fittings and create a minor head loss across the sensor, this head loss was usually far greater than that of simple pipe joints like the elbow [5]. The second type must be a noninvasive sensor that can be moved around the pipe system to determine the flow rate that specific section of the pipe. The client recommended the investigation of ultrasonic flow rate sensors like the current sensor used with the old design. Flow rate sensor research was still on going, but the cost of many sensors has become an issue which the client as provided a solution which will be elaborated upon within the budget section.

The pressure sensor to use was still under research but the current design uses a digital differential pressure sensor. The current sensor, while the client does know the rational for the sensors selection, was not sensitive enough for certain sections of the current system, which makes collecting data from the current system difficult. There are two approaches for determining an optimal sensor, first was to set a pressure range for the system and find sensors that operate within the set pressure range, or to choose a range of sensors that operate within a set pressure range and design the system to operate within that pressure range. The latter method was the method selected by the team and approved by the client, this method will give the team a base range for the design simulations.

4.4 Layouts Considered

While the materials and the fittings can be compared analytically, the layout of the system wa0073 a conceptual system that must be analyzed. To do this, each team member was tasked with producing a sketch of the overall layout of the system which includes the fittings, the joints, values and sensor locations. Each member's sketch was then presented to the rest of the team in a gallery method and each sketch was examined in detail by the entire team one by one to determine positives and negatives to each. All designs can be found in Appendix 11.1 .

4.4.1 Design 1

Design 1, located at Figure A - 1 - Concept 1is a simple straight path system that has all the needed joints and fittings in a straight line. This design is very simple, a straight path removes the requirement of values to divert the flow to different sections to test different components of the system. Additionally, if values are not used in the pipe system, mass balance calculations to determine the flow rate through each segment to determine the velocity in each section which is required to determine the head loss over the fittings. The design has the disadvantages of being a straight system, that is either very long, a purely straight system, or is very wide with many elbow joints to allow each section to facilitate each needed component. The loss of needing values also removes a potential learning opportunity of the head loss over different types of values.

4.4.2 Design 2

The second design is based on the current system that is used by the ME 495 lab, and because of this, it is an improvement to the current design instead of a complete redesign. The design, uses a long straight pipe to allow for straight pipe head loss determination, which then feeds into a section of pipe that has multiple tee-joints with values to redirect the flow to the individual sections of the system where the different joints and fittings head loss will be determined. The design has the advantages of being a compact design that could possible reuse the current frame and table top of the old design which was desired by Dr. Mazumdar to have a more compact design. Additionally, the values allowed for the need for mass balance evaluation of the flow over different segments unnecessary because the entire flow could be redirected to only a single segment, but if desired the flow could be directed to two segments and mass balance could be performed. The use of multiple valves, and two long sections of multiple tee-joints does increase the complexity system and has the potential to recreate the problems that the current design has, refer to the background section for information about the problems with the current design.

4.4.3 Designs 3 and 4

Designs three and four are both very similar so they have been grouped together. Both designs feature a system where the flow starts with a long straight section that then feeds into an elbow joint, which feeds into a tee-joint that separates the flow into to two segments which then converge into a single outlet from a second tee-joint. The designs differ in the layout of the two segments.

The third design features values and that allow the direction of the flow to be controlled, between a section with a pitot-static tube to determine flow rate followed by an expansion and contraction fitting over a small section of straight pipe. The second segment contains a series of different 90-degree elbow joints that allow for the head loss from different joint types to be analyzed. The third design is the most complex design of the four, requiring many values, elbow joints and tee joints, and will take up a large amount of space to ensure the flow has returned to a fully developed flow after each joint type.

The fourth design, also has two segments for the flow but with man differences. The first segment is another straight-line pipe to determine the loss of flow over a section with a different diameter or material. The second section includes two 90-degree elbow joints, one a long transition, the other a very sharp transition. In between the two joints is a 90-degree expansion and contraction joint. The two segments rejoin at a final tee-joint before returning to the fluid reservoir. The design is simpler than design two and three but not as simple as design one, and requires the use of mass balance to determine the flow rate through to two segments of the system. Additionally, the design removes some of the educational opportunities for the students which inhibits the primary goal of the design.

4.5 Component Designs Considered

For the individual component of the design, the team took part in the 6-3-5 method for three components. The components of the system that are analyzed are how to have a minimum measurable head loss, how to measure the flow rate of the working fluid, and how to vary the flow rate of the semester. The varying flow rate component of the system was considered twice because of the how important to the component is, the ability to vary the flow rate is fundamental to the design and trying to extract as many ideas as possible to determine the best possible solution.

5 DESIGN SELECTED – First Semester

As with all engineering problems, one of the early steps to generate as many designs a possible no matter what the circumstance or feasibility of the design. After designs have been generated, the team must be able to narrow down the designs to designs that meet the criteria and requirements of the client and what is engineeringly feasible. The process or narrowing down the designs is the process of design selection which has many different methods that all have their own advantages and disadvantages. The team decided to use two methods for selecting the best concepts, first a Pugh Chart which compares all designs to a set datum, and secondly a Decision Matrix, which compares all designs to each other with weighted categories. The Pugh chart was used to determine the best overall layout design created by the team and was compared against one of the designs from the research the team preformed, while the Decision Matrix was used to compare the individual components of the design. A special note for the joints and fitting design selection, since the primary goal of the design is to teach about head loss, the design will attempt to include all possible joint and fitting types as to demonstrate the differences in each type. With the desire to provide as many different opportunities to the students means that each joint and fitting are considered equal and will, instead, be determined as the layout of the system is finalized. It must be stressed that the selected design and components are preliminary and subject to major changes as the design process progresses.

The selected over all layout is design 3. Design three featured every aspect of what is desired for the design, mainly the ability to educate and demonstrate head loss of a pipe flow system. The material selection is currently split between two different materials, first is plastic piping for the availability and cheaper cost, and second copper piping for the increased strength and reliability of the material.

5.1 Rationale for Design Selection

The team came to the selections using simple MatLab calculations, a Decision Matrix and a Pugh chart. The Decision Matrix and Pugh chart are in Appendix 8.1. The team started with material selection to determine which material would be the best choice for the final design and to provide additional information when selecting a design.

For the material selection, the team used a Decision Matrix to compare all the researched materials to each other to find the best material. The categories for the materials with their corresponding weights are:

- Cost – 3
- Corrosion Resistance – 5
- Roughness – 5
- Strength – 4
- Sizes Available – 5
- Ease of Fitting – 4
- Life Span – 3

The weights for each category where determined by the comparing the QFD to what the client and the team felt where the most important characteristics about the material. The corrosion resistance of the pipe, the roughness and the available sizes are the three most important criteria for the material for different reasons. The corrosion resistance is needed to ensure the experiment is safe and long lasting for the college of engineering. Second, the roughness is a weight of five because the roughness of the pipe is directly proportional to the head loss of the system, which is the primary goal of the design. Finally, the sizes available was originally scored very low, but upon researching pipe materials it became apparent that not all materials operate within the size restrictions for the system, because of this, the sizes available category was evaluated to a weight of five. From this analysis, the two highest materials are Copper and Plastics pipes. Copper came in with a score of 95, while Plastic pipes have a score of 97. Plastic pipes beat out

Copper piping only because of the cost of coper pipes being higher than the plastic. The strength and life span of the plastic piping is an area that the team will have to conduct additional analysis of because of the potential forces the fluid could apply to the system. To ensure that if plastic does not meet the standards needed for the system, copper will also be analyzed in parallel to the plastic pipes to allow for a simple transition should plastic not be up to the standards needed. Next the team analyzed each design using a Pugh Chart.

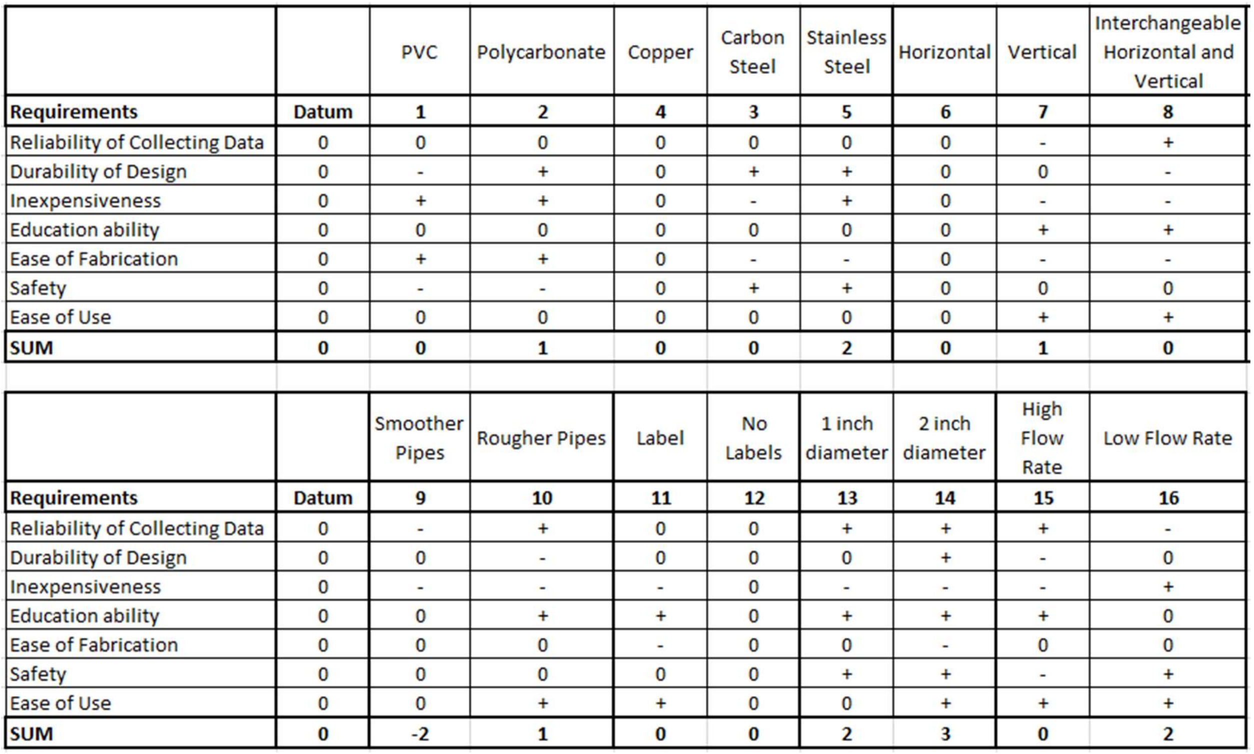
A Pugh Chart is used to determine the overall design used the following requirements to determine the best design.

1. Reliability of Measurements
2. Durability of Physical System
3. Three Forms of Flow Rate Measurements
4. Minimum Pipe of Diameter of 1/2 inch
5. All necessary fittings and joints types used
6. Ease of use
7. Ease of Assembly
8. Variable Flow Rate

Each concept was compared to Ohio Northern University's design as the benchmark, which was the closest system to the desired design the team could find. The Ohio design is a system for determining the head loss over three segments of straight pipe, one with a ball valve, with smooth and course pipes [2]. The desired goal for the Ohio experiment is to teach about head loss, which is the same primary goal for the new design for ME 495. As stated in the background section, the lack of joints and fittings other than a single valve be deviate from the client's requirements but the principle remains the same. The Pugh chart demonstrated three possible designs that are all within one point to each other, design 1, design 3, and design 4, with design 3 one point higher than design 1 and 4. The deciding factor between these three designed is the inclusion of a variable flow rate system within design 3, while designs 1 and 4 did not include this feature. Design 2, was the worst design because of the complexity of the assembly, the long series of tee-joints at the ends and need for several valves, the lack of a contraction or expansion joint, the lack of three forms of flow rate measurements and the use of plastic piping reduced the durability of the physical system. Design one and four were not chosen because of the lack of a variable flow rate or control system for variable flow rate, since this is one of the main requirements from the client, both designs were marked as inadequate. Design 2, being able to meet all the requirements of the client is thus the chosen preliminary design for the pipe system layout.

The Pugh chart show in Table 2 - Pipe Experiment Pugh Chart is separated into six main sections: pipe material, pipe system orientation, pipe roughness change, addition of labels to the pipe system, pipe diameter change, and flow rate changes. The datum set for the Pugh chart was based on the original design that needs to be improved. The original design has copper pipes, is oriented horizontally, has smooth pipes, does not have educational labels, has ¾ inch diameter pipes mainly, and has a variable flow rate but not by the pump. The first criteria analyzed in the Pugh chart was pipe material. Actual complete designs were not considered for the Pugh chart since there are many permutations that the pipes can be combined, however there are certain general characteristics of the apparatus that need to be considered individually to yield a cohesive result of the best attributes.

Table 2 - Pipe Experiment Pugh Charts



		PVC	Polycarbonate	Copper	Carbon Steel	Stainless Steel	Horizontal	Vertical	Interchangeable Horizontal and Vertical
Requirements	**Datum**	**1**	**2**	**4**	**3**	**5**	**6**	**7**	**8**
Reliability of Collecting Data	0	0	0	0	0	0	0	-	+
Durability of Design	0	-	+	0	+	+	0	0	-
Inexpensiveness	0	+	+	0	-	+	0	-	-
Education ability	0	0	0	0	0	0	0	+	+
Ease of Fabrication	0	+	+	0	-	-	0	-	-
Safety	0	-	-	0	+	+	0	0	0
Ease of Use	0	0	0	0	0	0	0	+	+
SUM	**0**	**0**	**1**	**0**	**0**	**2**	**0**	**1**	**0**

		Smoother Pipes	Rougher Pipes	Label	No Labels	1 inch diameter	2 inch diameter	High Flow Rate	Low Flow Rate
Requirements	**Datum**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Reliability of Collecting Data	0	-	+	0	0	+	+	+	-
Durability of Design	0	0	-	0	0	0	+	-	0
Inexpensiveness	0	-	-	-	0	-	-	-	+
Education ability	0	0	+	+	0	+	+	+	0
Ease of Fabrication	0	0	0	-	0	0	-	0	0
Safety	0	0	0	0	0	+	+	-	+
Ease of Use	0	0	+	+	0	0	+	+	+
SUM	**0**	**-2**	**1**	**0**	**0**	**2**	**3**	**0**	**2**

The five main materials chosen were PVC, Polycarbonate, Carbon Steel, Stainless Steel, and Copper. PVC and Polycarbonate had somewhat weaker yield strengths of 7,640 psi [14] and 13,000 [15] psi respectfully compared to the 10,152.6 psi for copper [16]. Carbon steel and stainless steel both had stronger yield strengths of 60,200 psi [17] and 31,200 psi [18] respectfully. The polycarbonate and stainless-steel pipes had positive results from the Pugh chart. Both materials were cheaper than the copper prices and had higher yield strengths. Stainless steel scored higher than polycarbonate because the modulus of elasticity for steel was 29,000,000 psi [17] whereas the modulus of elasticity for polycarbonate was 350,000 psi [19]. Stainless steel would be able to withstand more pressure than the polycarbonate and thus be safer to use. Carbon steel had the same modulus of elasticity of stainless steel and a higher yield strength, however carbon steel was less corrosion-resistant and more expensive than stainless steel. The two materials that will be considered in the decision matrix are polycarbonate and stainless steel.

The next criteria analyzed in the Pugh chart was pipe system orientation. The three orientations considered were Horizontal, Vertical, and Interchangeable Horizontal and Vertical. The original pipe design was horizontal and due to that, some locations on the display were hard to see and apparatus was difficult to transport. By considering a vertical design, the apparatus would be easier to see and present for education ability and be able to transport easy enough for one person to move it. Also, by having a vertical apparatus, the effects of gravity on the flow through the system could be studied for more applications to education. The possibility of an interchangeable horizontal and vertical apparatus was also considered for a flexible experiment that includes the ability of transportation and education ability as well as the sturdiness of being a horizontal table. The interchangeable system orientation would be a great way to combine both other possibilities, however the drawbacks include the fact that it would be more complex to manufacture, it would cost more to obtain the specialized mechanical parts for the orientation, and the apparatus would be subject to more wear and fatigue due to movable parts that may fail. The vertical and interchangeable orientation will both be considered in the decision matrix.

The next criteria analyzed in the Pugh chart was the roughness change. The inner roughness of the pipes could either be smoother, rougher, or be kept with the original roughness. By making the pipes smoother, purchasing the pipes would be costlier due to the added specifications and collecting data would be harder because the Reynolds number value would change less through the pipes. By making the pipes rougher, purchasing would still be costlier due to the added specifications and the pipes would be subject to more corrosive effects like water erosion to impact the pipe durability. If the pipes were kept with the standard roughness, the prices would stay the same for each material and the roughness would stay close to the estimated values for less error in experimental calculations. The standard and rougher pipe roughness will be considered in the decision matrix.

The next criteria considered was the addition of informative labels on the design. This possibility was considered due to their use in the HM 150.11 apparatus design from the Grunt Hamburg pipe systems. By having labels around the fittings, dimensions, and important comprehension aspects of the experiment, students would be able to have higher education ability when performing an experiment. The only drawback of adding labels was the complexity of manufacturing the labels and the cost to go along with the manufacturing. According to the Pugh chart, adding labels to the apparatus would provide a net neutral outcome compared to not adding labels, however the labeled design will be considered in the decision matrix along with the not labeled design.

The next criteria considered was the main pipe diameter change. The main pipe diameter was the diameter chosen from the manufacturer and the diameter that would be used in experimental calculations. The inner diameter will impact the Reynolds number range, the strain that the pump will endure to push water through the pipe, and the pressure that the pipe material will endure. The diameters considered in the redesigned apparatus were a 1 inch and a 2-inch diameter pipe. Both pipes would cost more than the original ¾ inch design, be safer to use because the endured pipe pressure and pump strains would be less, and have more reliable data collected from them. The 2-inch diameter pipe would be better than the 1-inch pipe because it would be more durable and easier to use since the pipes were thicker. Both diameters will be considered in the decision matrix.

The last criteria considered was having a high flow rate or a low flow rate as the main speed used for the experiment. Both flow rates would be able to yield the desired Reynolds number range of 10^4 to 10^6 depending on the diameters used in the apparatus. According to the Pugh chart results, the apparatus would function better with a low flow rate because it would be safer to operate the pump at lower flow speeds, and the pump used can have a lower max speed and thus cost less. The low flow rate for the experiment would be considered in the decision matrix.

5.2 Design Description

The final design is ultimately an iteration of the old design. The client rejected most of the designs presented by the team and then requested that the old design be updated to include all the desired fixes and changes. As such, the layout of the original design, the three different segments from a long inlet segment, with the two middle segments featuring the contraction and extraction requirements.

5.3 Prototyping

For the prototype requirement that team has agreed upon using the old design as a test bed for the future design. The client has agreed to replace the broken pump with the pump purchased by the team, this process will take place over the 2018 summer, as such the team will be meeting over the summer to perform the analysis and experiment.

The analysis will consist of multiple parts. First, the team will execute the old experiment in the entirety. During which, the team will record any areas of the experiment that have problems and difficulties, while also noting what the old design performs well. Secondly, the team will validate the mathematical models developed for the new design. The models will be adapted to model the old design and then results will be calculated using the models, then validated with the measured values from the old design. If the calculated values are within ten percent of the measured values then the model will be considered accurate, if within one percent, the model will be considered valid and can be used to future design iterations. If the model is outside of those bounds, the model will be reworked and retested until the model values are at least less that ten percent error. If unable to get the model within the ten percent, the error within the old design would have to be considered. Additional work to validate the model would then be required and will possibly require using one of the flow tables in the lab.

The second part of the analysis will include breaking down the old model and attaching new devices to the system. The primary desire for the analysis is to test the validity of using the quick disconnect taps for the differential pressure manometer. The connection of the quick disconnects is the most desired test, as the current pressure taps are prone to break free of the mounts. To determine the best method to fit, the team will attempt many different fitting types that will depend on the material of the quick disconnect and how to bound that to the copper pipe. Finally, the team will take these results to iterate the design to ensure that all the requirements are left and that the new design does not replicate the problems with the old design.

5.4 Design Model

The model for the design is developed using Solidworks 3D Modeling software. Solidworks provides a detailed tool to provide the needed information to accurately model the system. The design is broken into two sections, the upper pipe section and the lower structural and ancillary component, the pump and reservoir.

5.4.1 Upper Section

The upper pipe section is just the model of the pipe network and does not include the table top. This section was designated because it is where the students will be preforming most of the experiment and interacting with the design. The assembly is made up of several different parts that include,

- Straight Lengths of Pipes
- Elbows
- Tee Joints
- Contraction and Expansion Joints
- Pitot Static Tube Mount
- Ball Assembly
  - Internal Ball Valve
  - External Ball Valve Housing
  - Valve Grip

The complete assembly is located in **Error! Reference source not found.Error! Reference source not found. Error! Reference source not found.**. As stated above, the upper assembly is broken into three segments, with an entry segment and exit segment. The entry segment features a ball valve, a long straight length of piping, used to determine the head loss over a long length of pipe, and an elbow to redirect the flow into the tee joint that separates the flow into the different segments. The first segment features an expansion into a long straight length of pipe, designed to measure head loss over a larger diameter pipe, into a contraction, through a valve, to control the flow entering that segment, and then redirected using an elbow into the exit segment. The first segment is designed to test how an expansion will affect the head loss of the pipe system, mainly that diameter is raised to negative fifth power, so a small change is diameter causes a large change in head loss. The second segment is designed to further reinforce this idea that diameter is the most sensitive parameter for pipe head loss, as this segment features a contraction joint into a small diameter pipe, which then returns to the standard pipe size in an expansion joint before entering the exit segment. A valve located immediately after then expansion joint is designed to restrict the flow through the system when not needed. The final segment is designed to measure the head loss over two different common pipe flow devices. First, there will be a pitot static tube that will be inserted into the flow that will be used to determine the flow rate of the velocity, Pitot-Static tubes a very common and simple tool used to determine the velocity of the flow by comparing the stagnation pressure to the static pressure of the flow using $p_{stag} - p_{static} = \frac{1}{2}\rho V^2$ [5], where velocity can be solved for giving the following: $V = \sqrt{2\rho(p_{stag} - p_{static})}$. Using the solved for velocity, the flow can be determined using $Q = VA$, where V is the velocity, and A is the cross-sectional area. Additionally, the head loss across a ball valve will be determined. The ball valve is placed able to both restrict the flow through that segment and to get an accurate pressure measurement from the taps. Finally, the segment also includes an elbow to redirect the flow into the segment and then enters the exit segment.

Total size of the assembly is slightly larger than the total size desired for the table. The assembly is approximately five feet by ten feet, which is the maximum size for the table that is desired. Since the assembly needs to be slightly smaller than the table this size needs to be cut down. First impressions are to cut down the short length of pipe that connects the entrance segments to the three experimental segments, this would reduce the width of the system. Additionally, cutting down the lengths of each segment will reduce the length of the pipe system. Each of these comes with advantages and disadvantages. Frist, the disadvantages, the major disadvantage is the reduction of length to ensure that the flow as returned to a fully developed flow before the next pressure tap. The advantages are great, first the head loss over the entire system will decrease, this will improve the flow rate which is a requirement that the client is requesting. The current flow rates produce Reynolds numbers that are smaller than what the client is requesting and is requiring that the system be iterated to produce higher flow rates. Second, the cost of the entire design would be reduced. While the current cost of the design is within the desired budget, and reductions to the cost are valuable and pursued. The individual lengths of each pipe section are located in the drawings in Appendix C – CAD Model**Error! Reference source not found.**.

5.4.2 Lower Section

The lower section consists of just a few major components. First is the reservoir for the system, which will act as a holder to ensure that there is enough fluid to prime the system and act a filling and draining point. The next major component is the pump which will provide the flow rate and increase to pressure of the working fluid to push it through the system. Finally, the table and all connecting pipes are part of the lower section. The table and frame are purely structural and provide no other functions. There are connection pipes from the reservoir to the pump, then the to the entrance and exit segments of the upper section to complete the pipe network. A completed model is located in Appendix C – CAD Model**Error! Reference source not found.**.

6 PROPOSED DESIGN – First Semester

The plan for implementation of the design is simple, the team will be building the design to competition. Unlike other designs that require access to resources that are not available for university students, or have construction costs in the tens of thousands of dollars; the select can be constructed with the majority of the components supplied from a local hardware store. The only parts that being sourced from specialty suppliers are the pump, sensors, and reservoir, with the current design using an out sourced table but that can be replaced with a table fabricated by the students using the universities facilities. As such, the construction of the most complicated parts within the project are out sourced, and instead, the team only has to assemble all of the purchased parts into the final design. To provide insight into the construction process and increase the chances of a successful build, the team will be following the prototyping strategy as detailed in 5.3 Prototyping. Even with the benefit of having the previous design, special care and planning is needed to ensure a successful build, the process of which is detailed below.

6.1 Bill of Materials

As with any design, a detailed bill of materials in crucial for the construction of the design as often the designers are not directly purchasing the materials and parts for the design. Additionally, the designers must be able to defend any part or material choices and a detailed and itemized bill of materials will assist with cost analysis and comparison to different designs.

The entire bill of materials is located in 11.3 Appendix D: Miscellaneous, Table D - 2 - Bill of Materials and Table D - 3 Bill Of Materials Web Sites, which shows an itemized list of all the items that will be needed to construct the design. One thing that needs to be noted is that for the KEYENCE flow sensor is designed to work different types of clamps which are needed to be purchased separately. When purchasing the system itself, it comes with clamps of your desired size, so only additional clamp sizes need be purchased separately. There will be one system that requires multiple clamps in order to move the system to other sections of the design system. The total in the above portion of the BOM shows the cost that is covered by the Capstone budget. The lower total only includes the sensors. The client requested that the sensors be separate from the rest of the bill of materials due to their high cost. The only part that is missing from the BOM are the miscellaneous screws, bolts, nuts, and anything else that is needed when actually building the device. It is not needed in the BOM because it is currently unknown as to how many of each of these items that are needed. Fortunately, the design is well within the budget target $2500, as such the need for miscellaneous items are predicted to not exceed the budget cap.

6.2 CAD

Based on the chosen materials and design, a SolidWorks CAD model has been created of the final Experimental Pipe System. Figures showing the details of the final design are shown in Appendix C. By creating a simulated model of the design, the team was able to better understand the spatial relationships of the components. For example, the return tube length relied on the positions of the reservoir and the end of the pipe flow system. The return tube ideally would be a quarter-circle to minimize the flow losses due to the bend. The SolidWorks CAD model will be a guide for the construction of the prototype.

6.3 Construction Plan

For the second semester of the project, the team will be focusing on the actual construction and implementation of the ideas generated in the first semester. The full year Gantt chart is shown in Appendix D Figure 1. In order to construct the pipe flow experiment, the team will have begun prototyping the design on the old experiment table with the new pump. The process of attaching the pump to the old table will be carried out by Dr. Ciocanel and his team of classroom aids that will be present over the summer term. This will give a good picture of how the system works as well as proving the validity of the computer program used to predict experimental results. This process allows to iterate the design over the summer in order to have a good near finalized design that the team, along with the client, are happy with at the start of the next semester. The team can also use the old experiment table and piping components to experiment with mounting and manufacturing techniques. A majority of manufacturing and assembling will be done in the machine shop on south campus, as long as minor off-site construction being done at a team members homes. The construction process will begin with getting the final dimensions and building the table itself to accommodate all of the components so that there is adequate room and mounting for the pump and reservoir. From here, the team can have the piping ordered and all of the sensors that are needed to run the experiment. The pipes will need to be tapped at specific locations so that the team are able to attach the pressure valves. A mechanized drill will be used to place the holes along the pipe. The pipes will be press fit together and sealed with soldering to create a strong and reliable connection. The pipes will be mounted to the table with supports affirming the stability at key points of the system. The construction will surely create the need for modification as certain aspects of the design may not be as compatible as the team expected in the design process. These will be documented and hopefully kept to a minimum so that the team is able to efficiently complete the fabrication of the design and have a functioning experiment before the end of October. Testing would begin shortly after this to attempt to have acceptable results, and if not, then improvements made to iterate the design to attain the desired results of the experiment. A lab manual will then be written up to provide to the students, TA's, and course instructors with a step by step plan to perform the experiment as well as an analysis section to emphasize the goals of the experiment and that should be learned after performing.

7 IMPLEMENTATION – Second Semester

The construction process for the design includes two major sections. First, the upper section which includes the pipe system and table top that will students will be interacting with while preforming the experiment. Secondly, the lower section of the design which includes the pump, tank, and control components. There have been several changes to the design caused by manufacturing needs. These changes are mostly centered around the lower section to facilitate the connection between the pump, tank, and remaining system. The upper section has been able to follow the desired design closely with only minimal changes.

7.1 Manufacturing

The manufacturing started not with construction but the deconstruction of the original project. The deconstruction process included salvaging as much of the copper piping as possible while disposing of unusable parts of the old design. The removal of the old copper piping required cutting a single segment of pipe to free the experiment segment from the design. Once the upper segment is removed, the system is able to be broken down into useable pieces that has been incorporated into the new design. Next, with the upper segment removed, the old table top was removed which made the tank and pump system accessible. The majority of the lower segment is unsalvageable, as such is having been disposed of. A major challenge of disassembly is simply the connection points for most of the design corroded over the 15 years of use. This corrosion caused the bolts holding the system together to become very difficult to remove and, in many cases, impossible without considerable force. As such, a large majority of the lower segment remained partially connected to each other and is disposed of as a whole. Finally, the frame of the old design is removed of all old components. This frame is intended to be reused after cleaning of all corrosion.

With the old design disposed of, the construction of the new design can begin. The construction begins with the upper segment of the design being constructed first. This section is the simplest section since of the implementation of SharkBite connectors to allow the design to be assembled quickly. The use of SharkBite connectors is one of the major changes to the design, which is detailed in the next section. The assembly of the upper section is proving to be simpler than expected. The only major equipment that is needed is a saw to cut the piping to the correct length and a flow torch to "sweat" (solder) the expansion and contraction fittings as the diameter changes necessary are not available as SharkBite connectors.

Figure 7 - Half of the Upper Section

The location of the fittings and of the pressure tap along the upper section is one of the major areas of design and focus. To ensure a valid pressure measurement, the pressure tap should be placed in a location where the flow is fully developed. Unfortunately, turbulent flow is in many ways still an unknown science, as such the minimum distance for the pressure taps is usually determined empirically and has been shown to be in the range of 25 to 50 pipe diameters [5]. Since the design is using one-inch pipe, at a minimum two feet of pipe is recommended for pressure measurements, this unfortunately would result in a design that will be larger than the client can allow. To compromise, the location of reach pressure tap will be placed no closer than five inches to fitting within the system. This compromise is the best the location for each tapping while remaining within the size requirements provided by the client.

Finally, the total length of piping, including fittings, along the upper section is to be no more than nine and half feet, with a total width of four and half feet. This will leave at least a quarter foot along each edge of the table top. This provides approximately 43 square feet to build the entire upper segment. The only exception to the edge rule is the inlet and exit segments, which will have go beyond the minimal requirement to complete the piping circuit. Figure 7 - Half of the Upper Section, shows the initial pass of the upper section which is constructed using the materials that are available, and is shows of the upper section will look once finished.

The old table top is to be reused as it already has the mounting the points for the old frame. Since the old table top is smaller than required, a new table top will have mounted on top of the old. A ten foot by 5-foot piece of plywood will be laminated and then attached to the old table top to facilitate the mount of the upper section. The upper section is to be mounted to the table top using metal stand offs and a horse shoe style coupling which is placed around the pipes to secure them to the table top.

Figure 8 - Pentair 5Hp Pump

With the upper section proving to being easy to construct than anticipated, the lower section is proving to be more difficult. The chosen pump, Pentair's 5Hp Single Phase Pump, show in Figure 9 – Pentair 5 Hp Pump, takes up a considerable amount of the lower segment and with its outlet only able to be pointed up, a system of redirecting the flow around the pump will be needed. Additionally, the reservoir is raised up as the inlet for the pump is also located near the top of the pump. This will ensure that the pump is adequately filled with water just from the static water distribution from filling up the reservoir. Next, the lower section will feature PVC piping as that is what the pump is designed to interface with. The pump comes with two connecting brackets that provide the ability for PVC to be bonding to it directly. Fortunately, PVC is a readily available and cheap material that will constitute a minor change in the original design. Finally, additional mounting cross bars will be placed on the old frame to facilitate the mounting of the pump and reservoir.

Figure 9 - Final Model of Design

Finally, the upper section, with the table top, as shown in figure 9, is mount back onto the frame of the table. The lower and upper pipe sections are connected using additional piping and the chosen rotameter. With the upper section secured to the lower and the pipe system completed, the design is ready for preliminary testing and validation of engineering requirements.

The pressure sensors were implemented on the piping by drilling holes to the size of 25/64”, and then threading in a 1/8” FIP x 1/8” MIP brass coupling, and then soldering the brass fitting to the pipe. The sensors were then able to just be screwed in using Teflon tape to secure the watertight seal. This allowed us to read actual pressure measurements instead of doing the calculation based solely on the flow rate measurement from the rotameter.

The final aspect of the experiment to modify, was applying a new coat of paint to be more aesthetically pleasing. The original metal frame was painted black to match the pump, reservoir, and steel beams. The PVC pipes were also spot painted white to cover up the stains from the purple primer and other marks that occurred during construction. There will also be more final touches to the system, such as lacquering the wood to make it appear nicer and to sand away the stains and other marks from the copper piping on the top section.

7.2 Design Changes

The implementation process is broken into two segments, first the deconstruction of the old design, and second the construction of the new design. The two processes are detailed in the order in which each occurred below. Many changes have been made to the original design which have been either mandated by the client or from construction purposes.

7.2.1 Deconstruction of Old Design

As stated in section 7.1, the construction process began with the deconstruction of the old design. The old design has the same features of the new design, with an upper and lower section. The upper section is deconstructed first, as it is the most accessible section. The upper section of piping is only attached by a single fitting to the rotameter and then stand-offs to support the reset of the pipe system. The return segment is physically attached to the tank, instead was simply a pipe with a sleeve to guide the working fluid back into the tank. As such, the pipe system was cut at the fitting to the rotameter which frees the system. Once the pipe system is freed, the rest of the deconstruction can commence.

The table top of the old design and the upper pipe system are deconstructed in parallel. The pipe system was cut as close to each pressure tap and fitting as possible to attempt to preserve as much of the old material as possible to be able to reuse it in the new design. As the pipe system is cut into useable segments, the table top is removed from the old design to reveal the lower section. To remove the table top, the old rotameter has to be removed. The rotameter is attached to the old design using a pair of nuts and bolts, and the actually pipe connected to the rotameter. Since the upper connection of the rotameter is cut to allow the removal of the pipe system, this leaves only the bolts and lower connection. The bolts can be removed using a pair of wrenches which leaves only the lower pipe connection. Due to the age of the system, the threads for the lower segment have become corroded in place and removal of the pipe is extremely difficult. Fortunately, the rotameter is able to act as a large wrench and the pipes were able to break free and the rotameter is removed. It is at this point that the it is discovered that the old system is still filled with water. As such, the old system is drained as much as possible but large amount of water remained within the pump and pump inlet pipes. With the rotameter free, the table can be removed, this has two benefits. First, the lower section is made accessible, and second the old design is compact enough to fit through the doors of the lab so that is can be fully drained outside.

Due to the age of the system, several of the nuts and bolts holding the table top to the frame have corroded to the point that they cannot be removed using a wrench but instead had to be drilled out to free the table top. The remaining bolts can be removed a pair of wrenches, thus freeing the table top completed from the frame. With the table top removed, the old design is moved out of the lab to dispose of any remaining water and the old pump and tank assembly.

With the old design removed from the lab, the system is draining by tipping the old system on its side and letting the water flow out of the system. This process cleared out most of the remaining water within the system and made it possible to remove the tank and pump from the design. Unfortunately, the tank and pump are unable to be decoupled, thus they are disposed of as whole once the bolts holding the tank and pump assembly have been removed. With the rotameter, tank, pump, and majority of the lower section disposed of, the old system is deconstructed and the frame for the system is ready to be reused by the new design.

7.2.2 Construction of New Design

The construction process begins with the construction of a mock-up of the upper section of the design. Due to limitations of materials and delays in delivering of needed materials, the upper section is only able to be constructed as a mock-up at first to give the team a better understanding of the actual layout of the section. The recovered piping from the old design is able to relieve some of the delays from the delivery of the 1 in copper piping, but the old design is not able to provide all the piping needed. The change to using SharkBite connectors for the fittings instead of using traditional sweated on fittings has made the pipe segment construction process much quicker.

Since the SharkBite connectors are simple press-on fittings, that is no soldering or sweating is needed, the major time sink for construction has come from cutting the pipes to the correct length. As mentioned in section 7.1, a minimum distance of five inches between pressure table. This requirement, and the amount of pressure taps needed, require many cuts to be to the pipes before they can have connected together using the SharkBite connectors. To begin construction each available length of piping is cut the needed length and then laid out in the order that each is needed. Next, the pipe lengths are connected using the SharkBite fittings to allow quick and easy assembly. The only four fitting that are not using the SharkBite connectors are the contraction and expansion fittings as SharkBite does not provide the needed size changes for each fitting. These four connections are using traditional sweated on connectors to facilitate the connection required. With each segment connected, using either a SharkBite or sweated on fitting, the upper segment is constructed and ready for attachment to the rest of the design. While the upper segment is being constructed, the lower segment is being constructed as well.

The lower section features the pump and tank as well as all connections between the pump, tank, and upper segment. Due to the selected pump featuring connections designed for PVC piping, and the tank having threaded connectors for the inlet and outlet, PVC piping is being used for the lower segment. This is a major design change, as copper was originally planned for all pipes. Fortunately, this change represents a potentially significant cost savings and PVC is still one of the easier pipe materials to work with. As of October 16, 2018, the new design is awaiting the delivery of the one-inch copper piping, pressure taps, and PVC pipe to complete construction. Additionally, the placement of the tank is being adjusted to ensure that the static flow of water will be able to prime the system. As such, construction has stalled while the last remaining items are being delivered.

If the remaining pipe is not delivered within a reasonable time, the team will purchase the needed piping from local suppliers and a potentially increased cost and different wall thickness. Fortunately, this change in pipe should have very little, to no effect, on meeting the engineering requirements for the design. Finally, the pressure taps have been changed. Instead of using a tee fitting to get the pressure, the pipes will have a hole drilled into them and then the hole will be threaded so that the pressure taps can be connected directly to the pipe system. This change is mandated by the client to attempt to get as accurate of a measurement as possible. This change will reduce the reusability and reparability of the copper piping but the increase in measurement accuracy is of greater desire to the client. Not only have the pressure taps changed, but the sensor system has changed as well.

The pressure at each measurement point is no longer going to be measured manually, but instead the use of pressure transducers and a data acquisition will be used. National Instruments produces a suite of software known as LabView which allows for the collection of measurements to be performed in real time by a computer system. It is the combination of LabView and the pressure transducers that will now record the pressures of the system as a whole. The data will then be recorded to a file for further analysis. As such, a LabView Virtual Instrument is needed to facilitate the recording of the data. The team is currently working with the instructors and lab aids for the ME 495 lab to develop a suitable Vi to use for the data collection. This change in the system has resulted in a major inflation to the cost of the entire system, which is requiring extra detailed work to attempt to reduce the increases in cost as much as possible. The cost increase is still expected to be around three to four thousand dollars for the system. Which is more than the budget for the entire system as such all decisions are being taken with additional review to ensure that they are the best possible choice.

8 TESTING

With the design construction, testing of the Engineering Requirements can proceed. The team followed the procedure outlined in section 2.4 2.4 Testing Procedures (TPs) to validate the design against the ER's and other customer requirements.

8.1 Reynolds Number Range

The most important ER, one that the client stressed continuously throughout the design implementation, is the Reynolds number operating range of the system. Since the flow rate is variable, by a valve located at the entrance of the system, the low end of the desired Reynolds Number, 10^4 is easily achieved with a flow rate between 5 – 10 gallons per minute. The high end of the Reynolds number proved to be the difficult metric to meet. The clients request of a Reynolds number of 10^6 proved to be impossible as it required a flow rate of approximately 250 – 300 gallons per minute, which is not feasible, nor safe, for transport through one-inch diameter pipes. As such, the highest possible Reynolds number was then desired.

From simulations, a Reynolds number of approximately $2.5 * 10^5$ (in the half inch pipe section) is possible with the design, upon construction of the design and results collected from the rotameter the actual max Reynolds Number is determined to be $2.4 * 10^5$ within the half inch pipe section of the design. The one-inch and two-inch sections of pipe produce a Reynolds number of $1.2 * 10^5$ and $0.6 * 10^5$ respectively. While the design was unable to meet the client's requirements, the client understood the impossible nature of the physics and accepted the range that the design can produce.

8.2 Pressure and Head Loss

The design can produce a significant and measurable head loss which is the primary purpose of the project. The team tested four different fittings, an 90° elbow, a contraction, an expansion, and a ball valve and then compared that to the theoretical results. Each section had the flow rate measured using the rotameter and National Instruments LabVIEW software recording the pressures across each section. The results and comparison to theoretical are detailed in table 3.

Table 3 - Theoretical Verse Actual Head Loss Results of the Design

Fitting	Theoretical (Pa)	Actual (Pa)	Percent Error
Elbow	3177	3770	18.6%
Contraction	122567	103285	15.7%
Expansion	6609	573	91.3%
Ball Valve	3177	7586	138.0%

The actual design preforms well with the elbow and contraction, but the expansion and ball valve have significant errors from the theoretical. The errors for the elbow and the ball valve are likely the additional turbulence produced by the Shark Bite connectors which do produce higher amounts of turbulence compared to traditional fittings. Additionally, for the ball valve and the expansion, the likely cause of major error is that the flow is still highly turbulent at the location of the pressure sensor, thus producing errors in the readings. This is especially true for the expansion, as an expansion causes a very significant amount of turbulence, which in turn requires additional length for the sensor placement [5]. The results still confirm that the pressure sensors can measure the difference in pressure across the system which confirms the pressure measurement and head loss requirements.

8.3 Pass-Fail Requirements

The remaining ER's are all pass-fail requirements. As for the power requirement, the system utilizes a 220 Volt, 20 Amp pump that can be powered using the power available within the thermal fluid lab, as such the design passes the power reequipment. Additionally, all pressure sensors can integrate with National Instruments LabView for data collecting and analysis, so the LabView requirement is met. Finally, the smallest diameter pipe used within the entire design is a single length of one-half inch pipe, which meets the requirement for pipe diameters.

9 CONCLUSIONS

The success of the design hinged on the ability of the team to manage time, resources, and individual skills, which ended to be mostly successful. The can meet most of the Engineering Requirements from the client but not without compromise. Time management proved to be the greatest fault of the team, and the likely cause of small failures within the project. While time management proved difficult, the willing to work together and complete tasks contributed greatly to the successes of the design. While there is still much more that can be done for the design, the current implementation is the culmination of hundreds of hours of the work and many different iterations in an attempt to produce the best product within the 32-week time span of the project.

9.1 Contributors to Project Success

The greatest contributor to the successes within the project is simply every teammate's willingness and ability to take on difficult tasks and complete them within the desired time frames. At every instance of a problem or difficulty within the design, there is always a team member willing to take on the problem, develop and implement a solution utilizing his strengths. It is this utilization of strengths that proved to a be a great contributor to the project successes.

The design is able complete the purpose and goals of the team charter and those that were laid out by the client and instructors. By utilizing the ground rules laid out in the team charter and each team member is able to produce their highest quality work while also contributing greatly to the design, thus contributing greatly to the project success. The coping strategies of the team were all followed, even during the most tumultuous times of the project, and worked well to keep the project on track and meet deadlines. Not all aspects and coping strategies were needed, as ultimately, it is the simple understanding that all team members are busy and required their time and space to complete their tasks for the project. This understanding allowed for each member to engage in quality control of each other member with constructive criticism and feedback, this ability to openly discuss the all aspects of the project is of great benefit to the design.

9.1.1 Keith Caton

Keith's understanding of the theory of internal pipe fluid mechanics, electrical systems, and computer systems proved to be invaluable for the project. His simulation built in the first 16-weeks and then ability to tackle any electrical and computer problem (LabView mostly) provided the team with resources they needed to complete the project. Additionally, his time management and tracking of all assignments and general managerial duties helped to ensure that deadlines were met to the team's best ability. Without his abilities, the project would have proven to be significantly more difficult to implement.

9.1.2 Mark Frankenberg

Mark proved to be an invaluable asset when it came to the selection of pressure sensors and construction of the design. Him being one of two members with full shop training, Cole being the second, caused him to spend many hours in the machine shop crafting the purchased resources into the final product. This ability to manufacture the design contributed greatly to the success of the project, and his quick thinking of solutions provided the fixes needed for many small problems.

Additionally, his diligent work on selecting the sensors and working closely with the client to produce the best recording medium possible allowed the rest of the team to focus on other areas of the design. The task of selecting the sensors is no small feat, as such he deserves the upmost admiration and contributed greatly the success of the project.

9.1.3 Michael Garelick

Michael is an invaluable member of the team, both for positive attitude and willingness to contact manufactures and resellers. Whenever a part was needed, or more information from a manufacture is needed, he was quickly in contact with the desired target and getting the information needed. Additionally, his knowledge of mechanical engineering which assisted Keith his analysis and his desire to get shop training as to assist Cole and Mark, allowed him to take up any roles that is needed without hesitation. Finally, his constant positive attitude helped to keep the team and the project moving forward even when the worst has happened. Michael proved to a great asset, and a great contributor to the project success.

9.1.4 Cole Nielsen

Cole quickly became the go to person for all manufacturing and construction needs. His experience with wood working and tooling, and desire to be trained on manufacturing devices made him the primary builder of the project. Cole's time in the machine shop, and at suppliers to for turnaround of raw materials into the final product. Additionally, Cole does not hesitate to complete any task given and does so in a timely and effective manner. Cole's time management and construction abilities are pf great asset to the team and the project and contributed greatly to the design success.

9.2 Opportunities/areas for improvement

As with any design, there are always opportunities for improvement and this design is not different. Of all the designs opportunities, time management is the greatest. While planning is a constant factor, small changes and difficulties slowly delayed all aspects of the project. The team constantly found themselves needed a few extra days to meet the deadlines prescribed by the instructor and client. There is no one person to blame for this opportunity as each member of the design team faced difficulties meeting their individual deadlines. The project did provide an invaluable learning experience about the difficulties of taking an idea and implementing a completed project with a hard deadline of 32 weeks. The second major area of opportunity is communication.

While the team was in constant contact with each other, there were several cases where a delay or difficulty that could have been managed was not made aware to the other team members until it was too late to properly manage. This caused several of the last minute changes to the project to solve these difficulties, often using a quick fix that the team did not want to implement but was left with little other choice. The manufacturing process is the main sources of these difficulties as it required several people all working on the same aspects of the design but at different times. This staggering of machining and tooling, led to small defects that were often unnoticed or unmentioned until it had become a major issue. Even with these two major areas of opportunity, the design is still able to meet the major requirements of the client and instructor. For future projects and designs, each team member must learn to express their concerns early and often, so that small problems, such as concerns about not getting the work done time, can be rectified early. This will require the team to put their pride behind them and focus on the team as whole, and what would be best for the design, and not for them.

While the team and design faces plenty areas of opportunity, there are other aspects of the design and implementation process that were unexpected and out of the control of the authors. One major difficulty that came from delays in shipping and products simply getting loss. Early on in the implementation process, 30 feet of one inch copper piping is ordered to be used for the upper section. The shipping company consistently lost not only the first shipment, but also the second shipment of piping which introduced an additional three weeks of delay for construction of the upper segment. This delay could have been managed better, while the team used to time to determine the lengths of pipe needed, additional work could have been done to the lower section when proved to the most difficult section to implement. Instead, the team focused on the upper section and then struggled to construct the lower section. Better planning and again, better use of time, would have made the implementation process much simpler and produced a better implementation of the design. The change of the sensor system also proved to a difficulty that the team struggled to overcome, but the team learned the valuable lesson of the fact that a client may suddenly and without warning change the scope of the design and require the same time lines to be kept. These events happening in industry, and by experiencing them for this design, the team is able to better prepare themselves for the real world.

10 References

[1] University of Warwick, *ES2A7 Laboratory Exercises,* Warwick: University of Warwick.

[2] K. Lifer, R. Oberst and B. Wibberley, *Pipe Loss Experimental Apperatus,* 2011.

[3] J. M. Meyers, D. G. Fletcher and Y. Dubief, *ME 123: Mechanical Engineering Laboratory 2: Fluids,* University of Vermont.

[4] J. E. Hatch, Aluminum : Properties and Physical Metallurgy, ASM International, 1984.

[5] P. J. Pritchard and J. W. Mitchell, Fox and Mcdonald's Introduction to Fluid Mechanics, Wiley, 2015.

[6] W. D. Callister and D. G. Rethwisch, Materials Science and Engineering: An Introduction, 9th Edition, Danvers: Wiley, 2014.

[7] National Clay Pipe Institue, "Vitrified Clay Pipe Engineering Manual," National Clay Pipe Institute, 2015.

[8] Spray, "SF Pressure Drop Online-Calculator: Roughness of pipes," Spray, [Online]. Available: http://www.spray.com/calculators/Pressure_Drop_Calc/rauh.html. [Accessed 25 February 2018].

[9] AWWA, Concrete Pressure Pipe, American Water Works Association, 2008.

[10] A. Dodek, P. Fajnor, T. Liptakova, V. Zatkalikova, E. Anisimov and M. Vojsovicova, "Corrosion of Copper Pipes Joints in Simulated Operating Conditions," *Material Engineering,* vol. 18, no. 4, pp. 135-140, 2011.

[11] P. B. Adams, "Glass Corrosion A record of the past? A predictor of the Future?," *Journal or Non-Crystalline Solids,* vol. 67, pp. 193-205, 1984.

[12] J. Chaurette, "Pipe Roughness Values," February 2003. [Online]. Available: https://www.pumpfundamentals.com/download-free/pipe_rough_values.pdf. [Accessed 24 February 2018].

[13] K. Pangman, "Does Plastic Corrode?," Sciencing, 24 April 2017. [Online]. Available: https://sciencing.com/plastic-corrode-10042800.html. [Accessed 25 February 2018].

[14] Dielectriccorp, "PVC (Polyvinyl Choride) General Material Properties," Dielectric Corp, 2018. [Online]. Available: http://www.dielectriccorp.com/downloads/thermoplastics/pvc.pdf. [Accessed 3 March 2018].

[15] Gplastics, "Polycarbonate," G Plastics, 2018. [Online]. Available: http://www.gplastics.com/pdf/polycarbonate.pdf. [Accessed 3 March 2018].

[16] Engineering Toolbox, "Youngs Modulus of Elasticity for Metals and Alloys," Engineering Toolbox, 2018. [Online]. Available: https://www.engineeringtoolbox.com/young-modulus-d_773.html. [Accessed 3 March 2018].

[17] Brismet, "Price Sheet Number # 1211," Brismet, 2018. [Online]. Available: https://brismet.com/wp-content/uploads/2012/01/B-PRICESHEET1211PDF.pdf. [Accessed 3 March 2018].

[18] Lowes, "Cerror 1/2" x 2' Type L Copper Pipe," Lowes, 2018. [Online]. Available: https://www.lowes.com/pd/Cerror-1-2-x-2-Type-L-Copper-Pipe/3132303. [Accessed 3 March 2018].

[19] ASM Matweb, "ASM Material Data Sheet," ASM, 2018. [Online]. Available: http://asm.matweb.com/search/SpecificMAterial.asp?bassnum=mq304a. [Accessed 3 March 2018].

[20] Grainger, "GOULDS WATER TECHNOLOGY - 120/240VAC Open Dripproof Centrifugal Pump, 1-Phase, 1-1/4" NPT Inlet Size," Grainger, [Online]. Available: https://www.grainger.com/product/GOULDS-WATER-TECHNOLOGY-120-240VAC-Open-

Dripproof-4XW85. [Accessed 8 April 2018].

[21] Engineering ToolBox, "Piping Elbows - Thrust Block Forces," 2005. [Online]. Available: https://www.engineeringtoolbox.com/forces-pipe-bends-d_968.html. [Accessed April 8 2018].

[22] Davis Instruments, "Dwyer 475 000 FM Digital Manometer 1 WC," Davis Instruments, 2018. [Online]. Available: http://www.davis.com/Product/Dwyer_475_000_FM_Digital_Manometer_1_WC/YX-68062-66?referred_id=3388&gclid=EAIaIQobChMIgoGNo5ew2gIVD3R-Ch0_1QxYEAkYByABEgI7YvD_BwE. [Accessed 03 May 2018].

[23] Keyence, "KEYENCE Clamp-on Flow Sensor," KEYENCE, 2018. [Online]. Available: https://www.keyence.com/mykeyence/?ptn=001#enquteTop. [Accessed 26 Feb 2018].

11 APPENDICES

11.1 Appendix A: Designs Considered and Selected

Table A - 1 - Pugh Chart

Pugh Chart					
Customer Requirements	**Datum (Ohio Northern University Experiment)**	**Concept #1**	**Concept #2**	**Concept #3**	**Concept #4**
Durability of Physical System		0	-	0	0
Three forms of flow rate measurement		+	-	+	-
1/2" min diameter		+	0	+	+
One Elbow Joint		+	+	+	+
One Tee-Joint		+	+	+	+
One Contraction Joint		+	-	+	+
One Expansion Joint		+	-	+	+
Ease of use		0	0	0	+
Ease of Assembly		-	-	-	0
Variable flow Rate		0	+	+	0
Total		5	-2	6	5

Table A - 2 - Material Decision Matrix

Decision Matrix								
Materials	Cost	Corrosion Resistance	Roughness	Strength	Sizes available	Ease of Fitting	Life Span	Weighted Total
Weights	3	5	5	4	5	4	3	
Aluminum	4	3	1	3	4	3	4	88
Concrete	3	4	3	2	1	2	5	80
Copper	2	4	1	4	4	4	4	95
Clay	1	5	5	1	1	2	4	82
Glass	2	5	1	2	3	1	5	78
Plastic	5	4	1	2	4	5	3	97
Steel	3	1	3	5	3	3	4	88

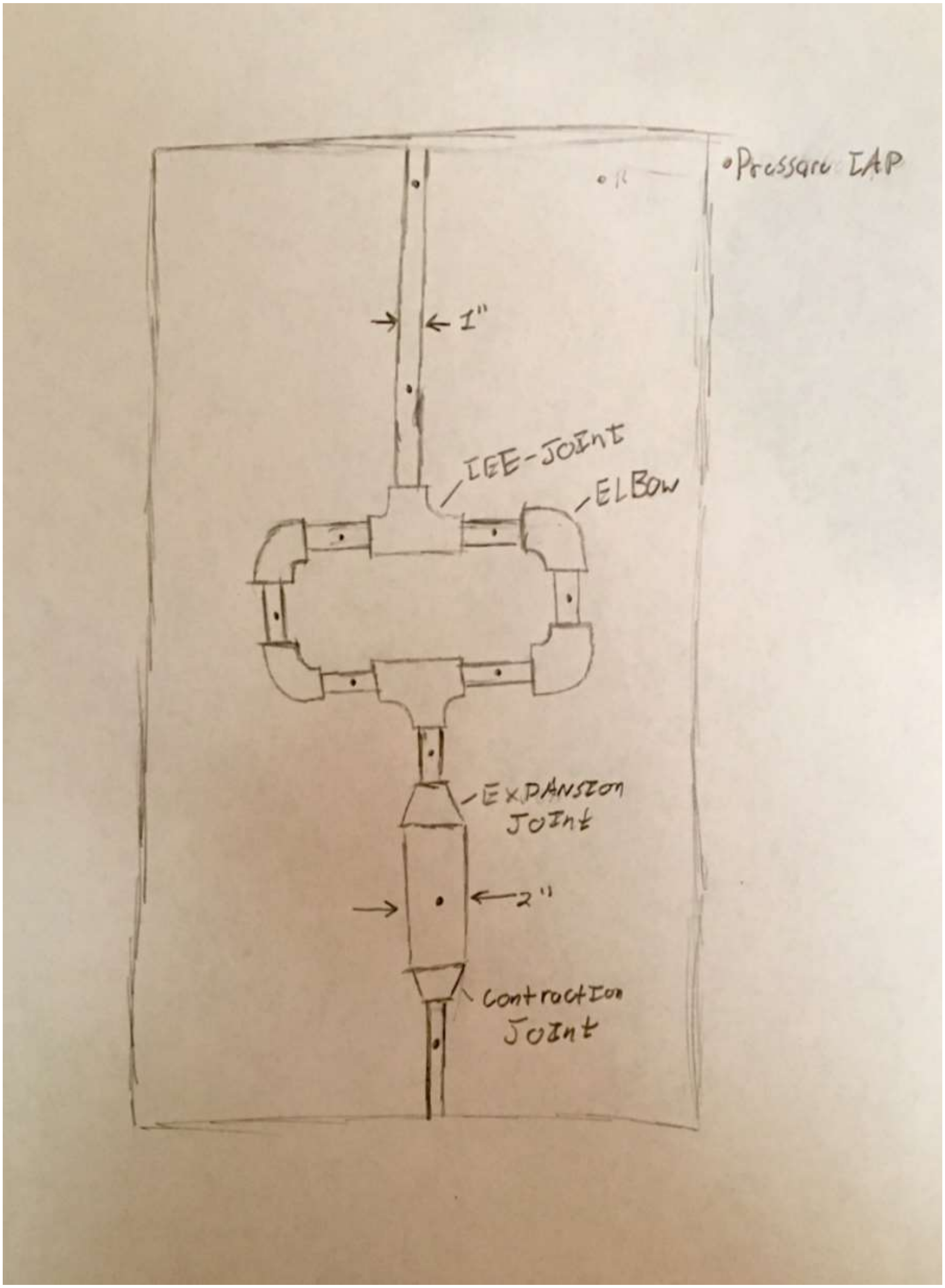


Figure A - 1 - Concept 1

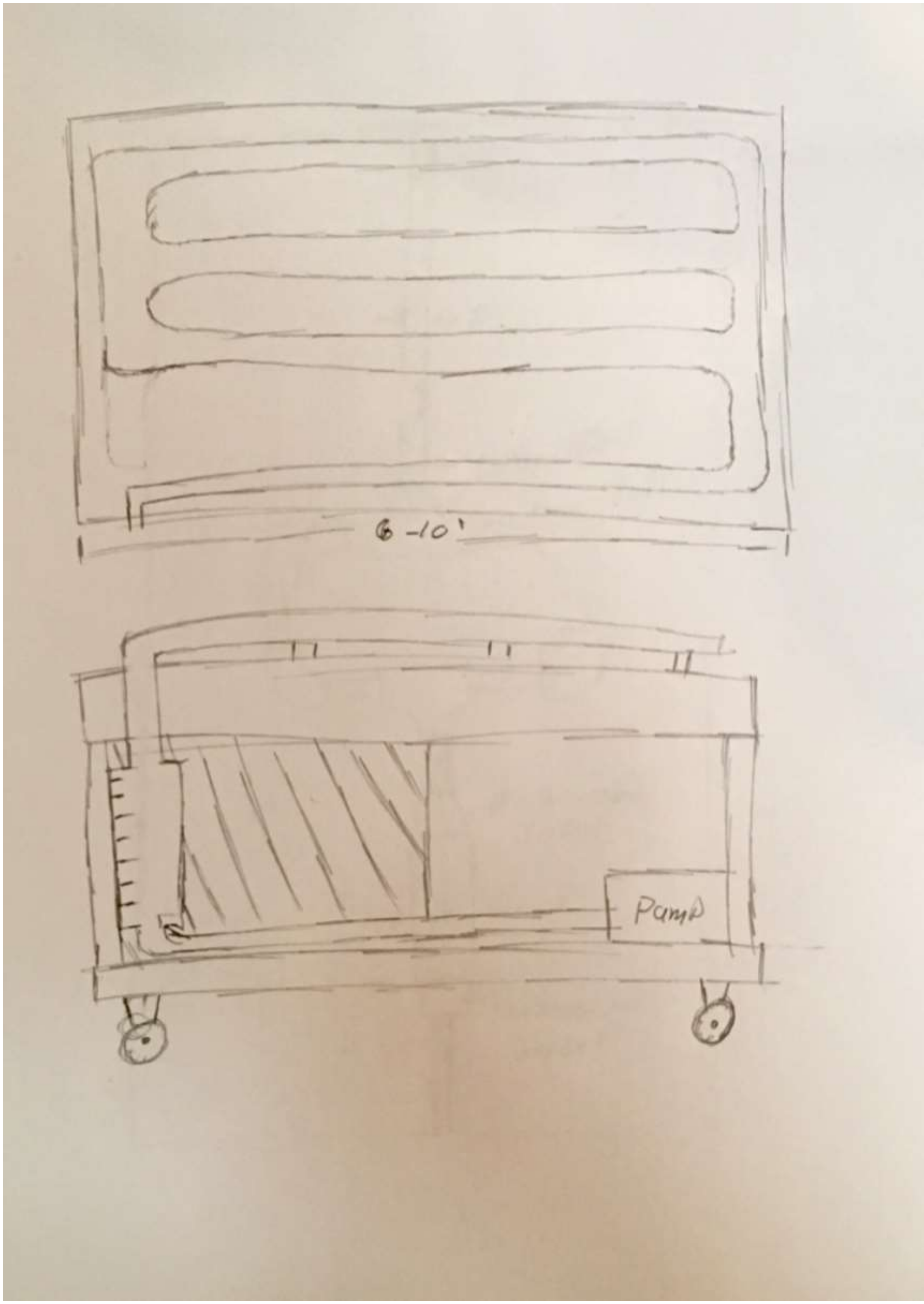


Figure A - 2 - Concept 2

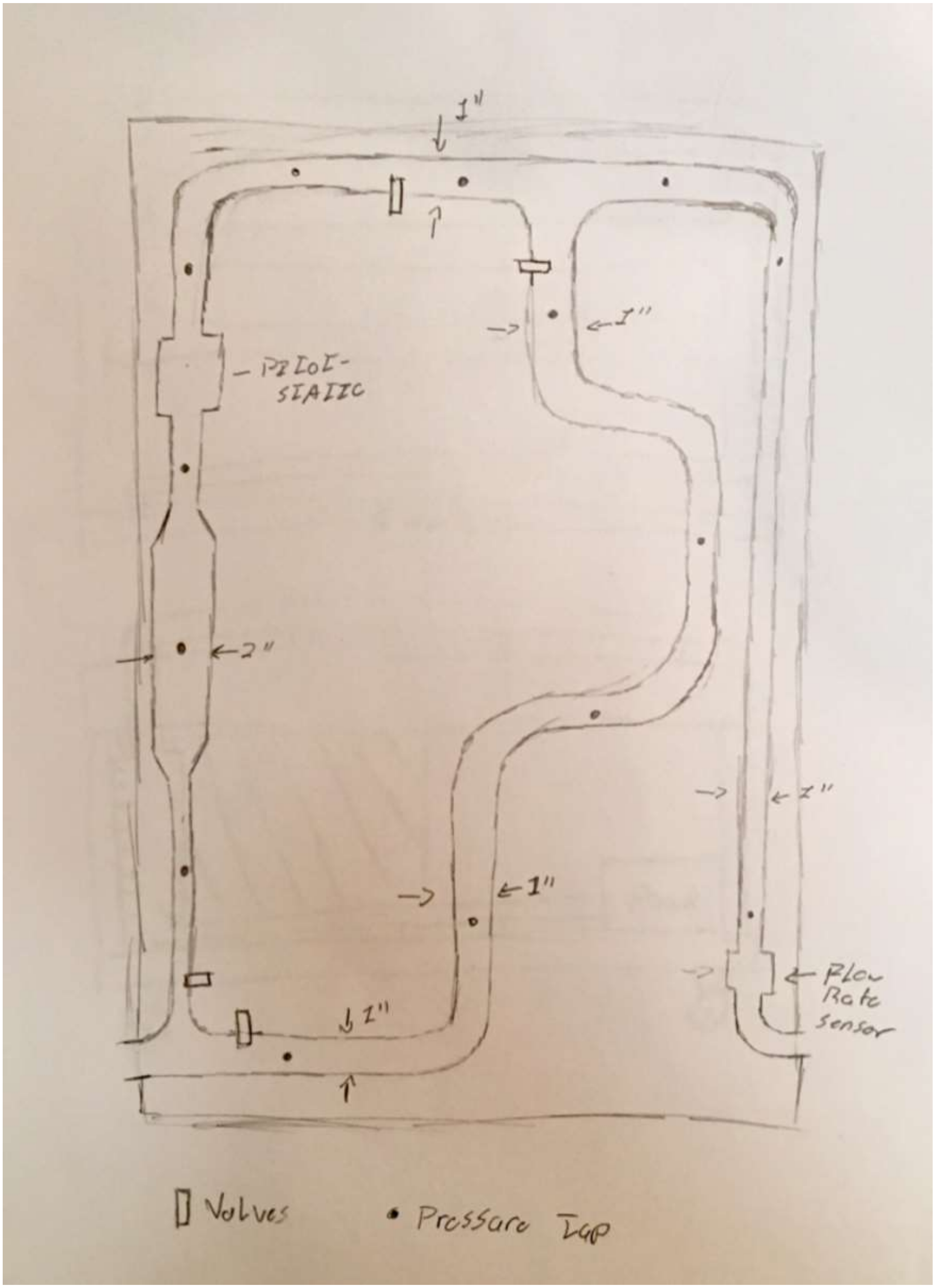


Figure A - 3 - Concept 3

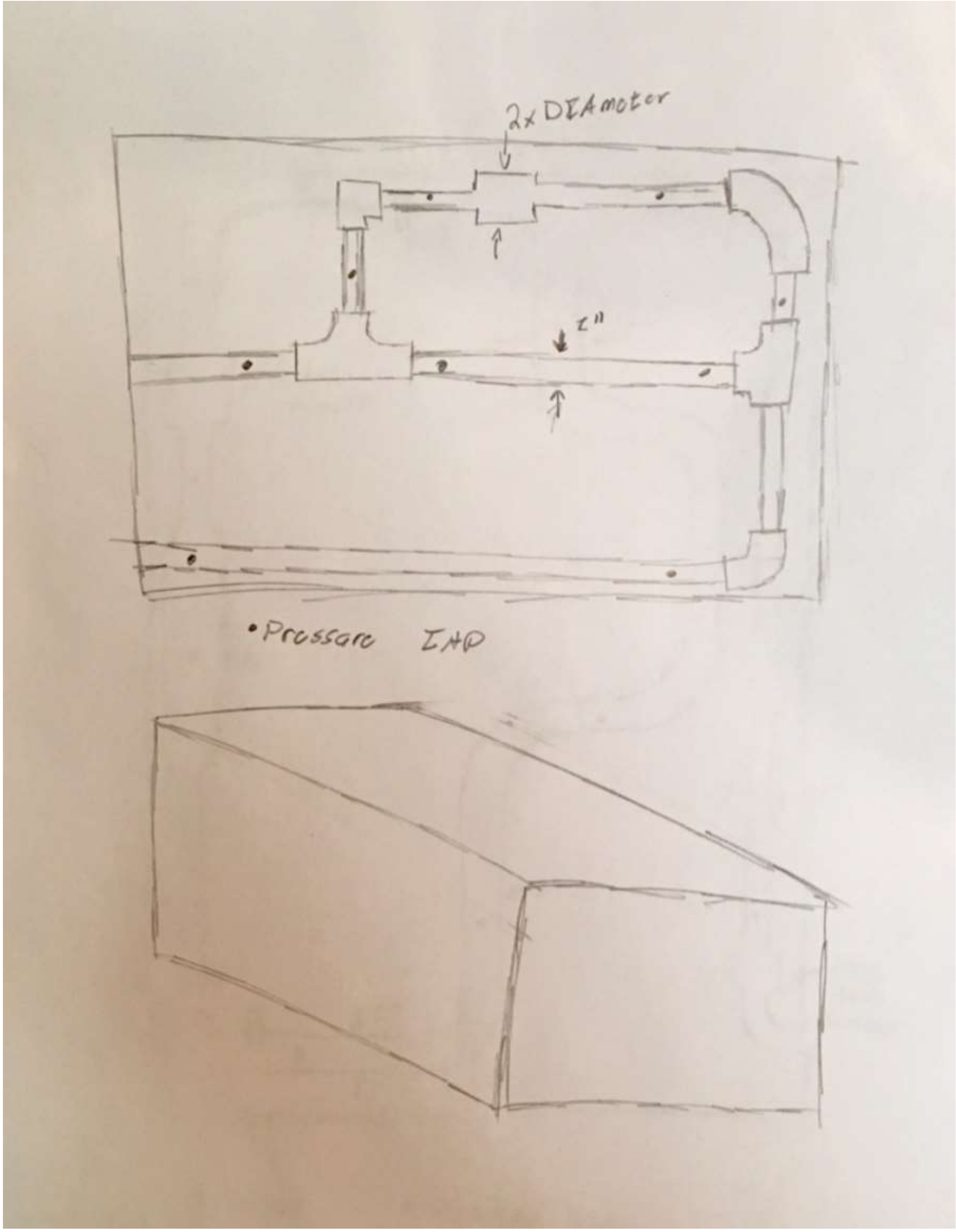


Figure A - 4 - Concept 4

`Qs(1,1), Qs(2,1), Qs(3,1))`

11.2 Appendix C – CAD Model

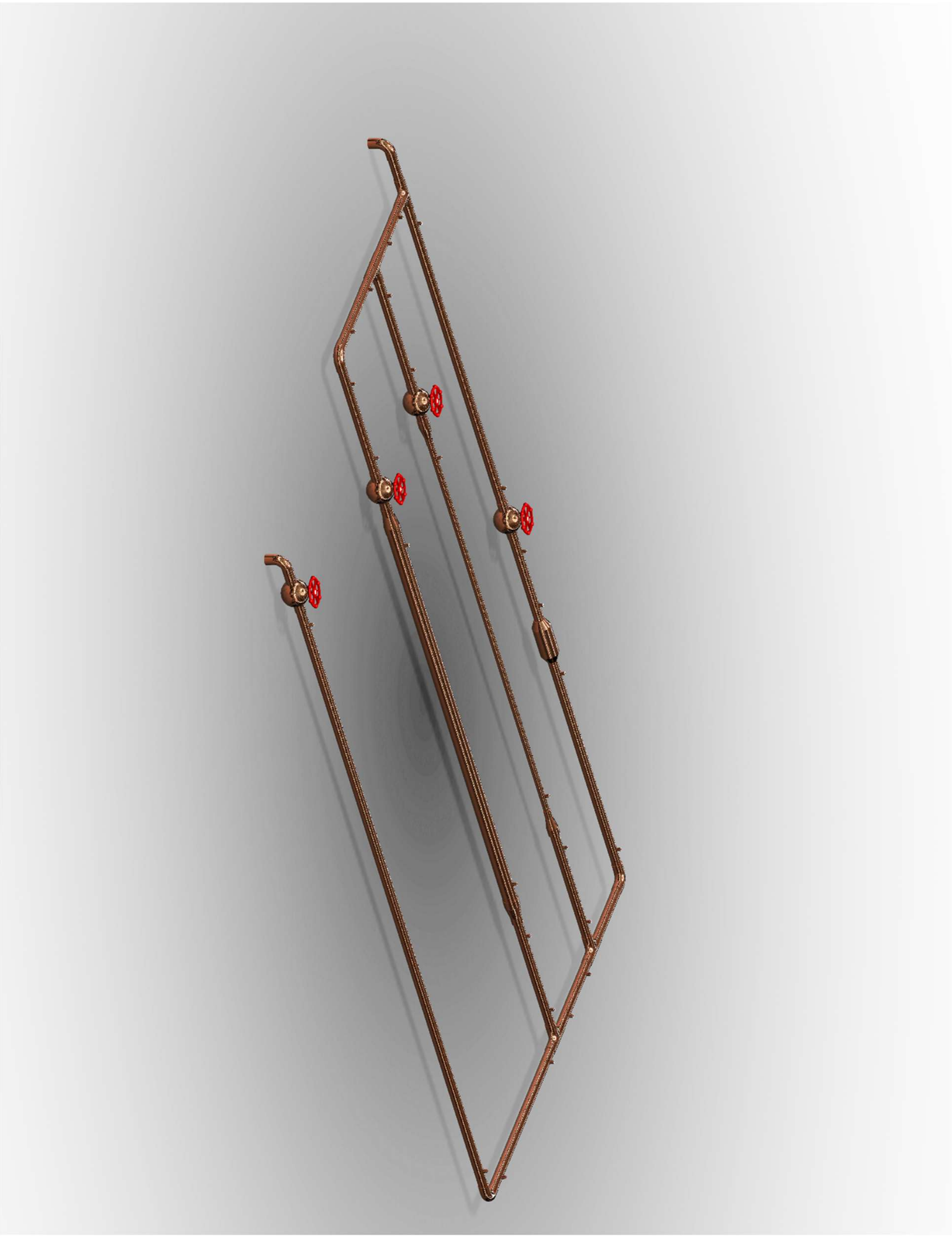


Figure C - 1 Upper Section Assembly

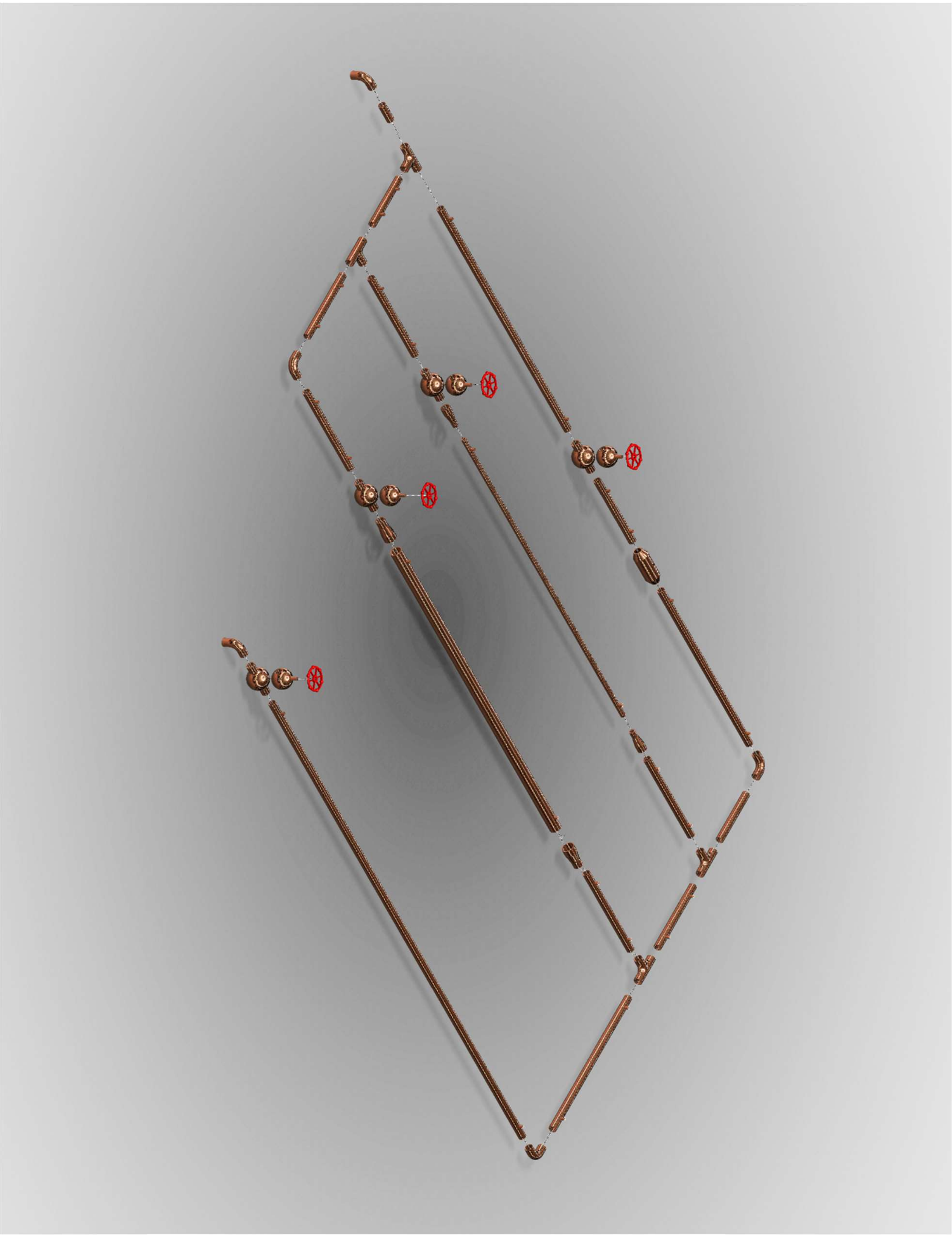
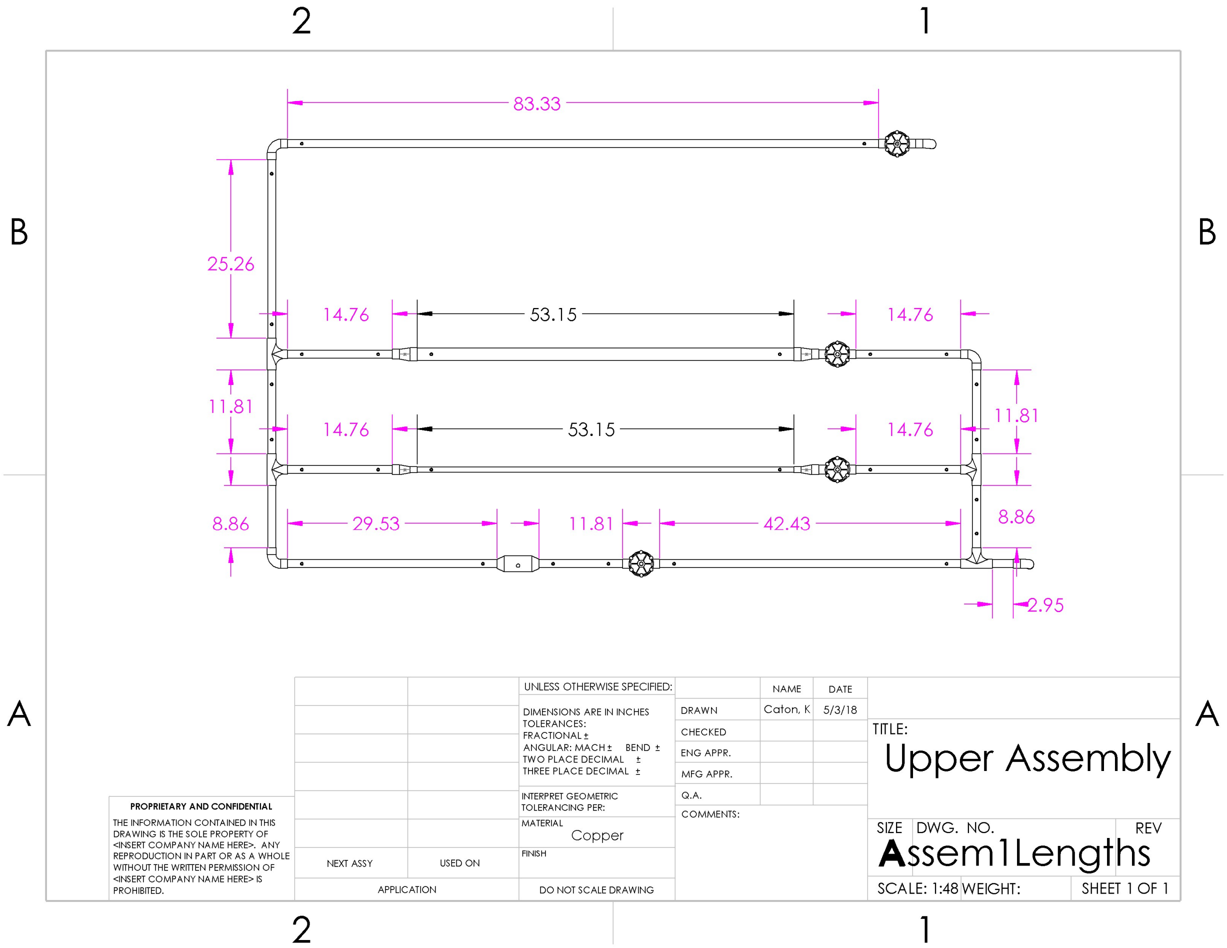


Figure C - 2 - Upper Exploded View



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Copper

FINISH

	NAME	DATE
DRAWN	Caton, K	5/3/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: Upper Assembly

SIZE A DWG. NO. Assem1Lengths REV

SCALE: 1:48 WEIGHT: SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

Figure C - 3 - Upper Segment Pipe Lengths

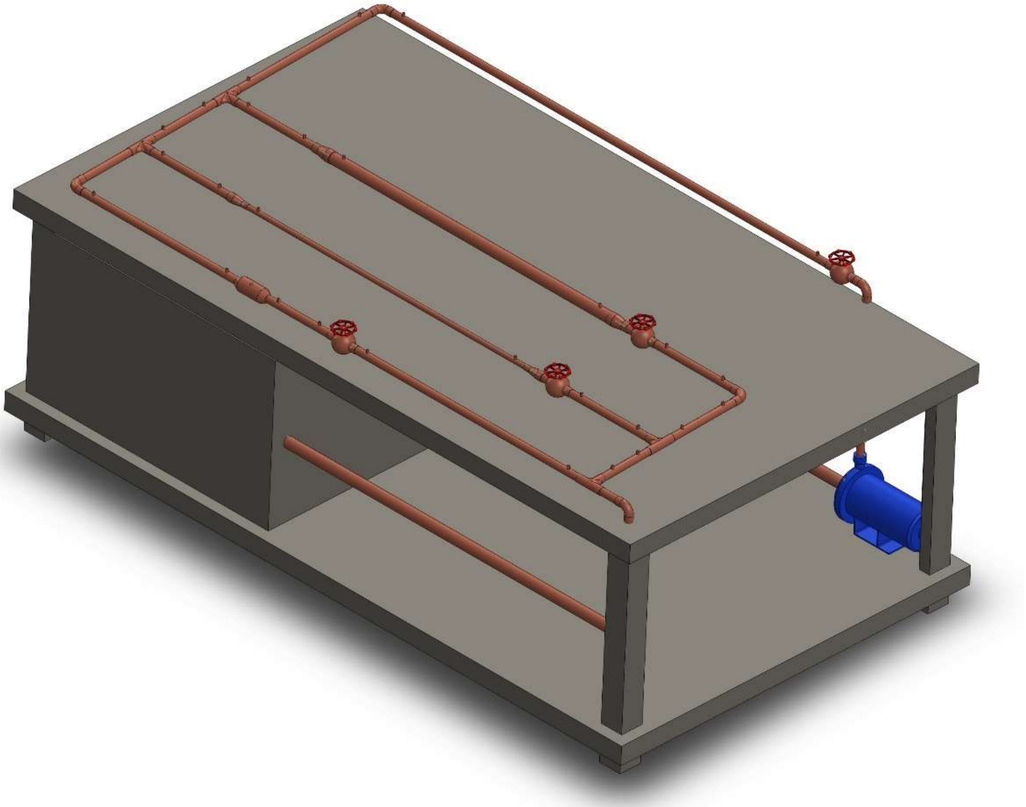


Figure C - 4 Complete Assembly

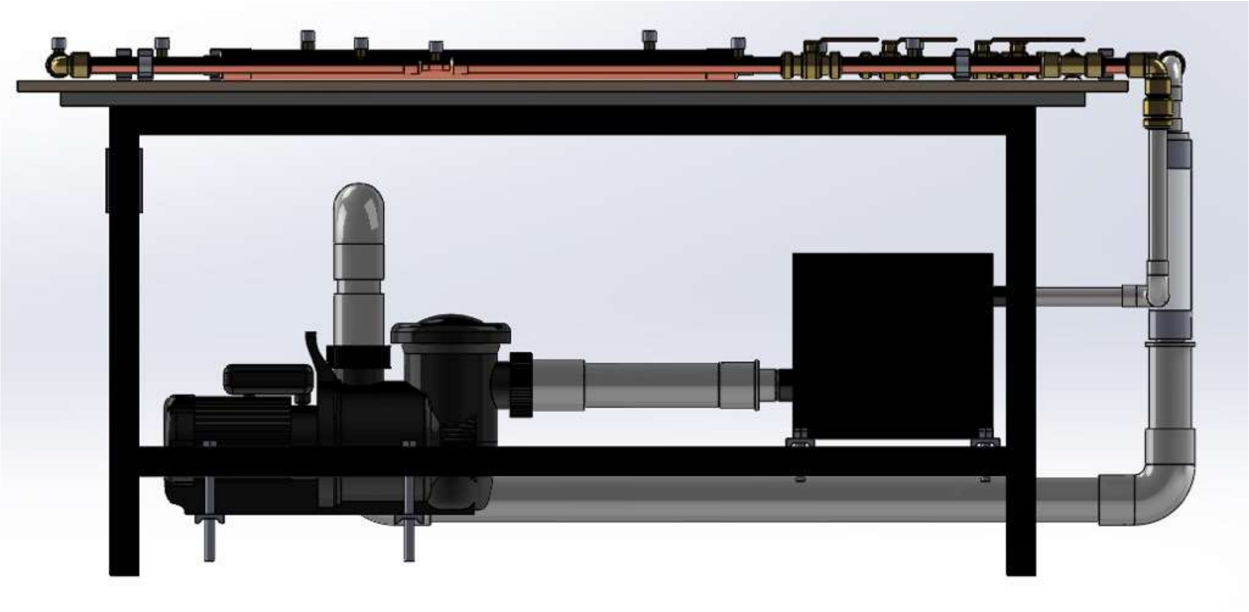


Figure C - 5 Final Model Lower Section

Figure C - 6 Final Model Upper Section

11.3 Appendix D: Miscellaneous

Table D - 1 - House of Quality

System QFD	**Project:**	**Experimental Pipe Flow Losses**
	Date:	2/1/18
		Input areas are in yellow

Voltage (V)						
Operates within Reynolds Range (10^4 - 3*10^5)						
Operates Within Set Pressure Range		9				
Smallest Diameter pipe is 1/2 in		6	6			
System has a measureable minimun head loss		9	9	9		
Cost	6	1	3	9	3	

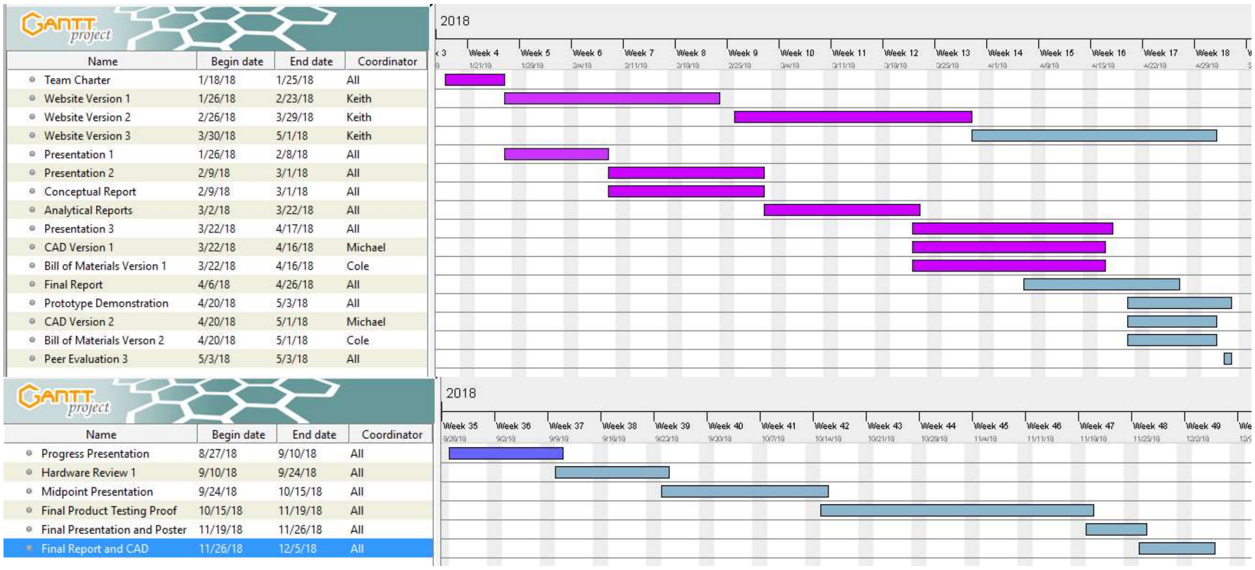
		Technical Requirements					
Customer Needs	**Customer Weights**	Voltage (V)	Operates within Reynolds Range (10^4 - 3*10^5)	Operates Within Set Pressure Range	Smallest Diameter pipe is 1/2 in	System has a measureable minimun head loss	Cost
Reliability of Measurements	5	1	6	3	1		9
Durability of Physical System	4	1	6	6	1		6
Last 10 years	2	1	3	3	1		9
Variable Flow Rate Control	5	6	9	9		6	6
One Contraction Joint	5		3	6	6	9	1
One Expansion Joint	5		3	6	1	9	1
One Elbow Joint	5		3	6	1	9	1
One T Joint	5		3	6	1	9	1
Three Volumetric Flow Rate Sensors	5		1	1	3	3	6
Lab View Intergration	2				1	9	6
Technical Requirement Units		Voltage (V)	Re	Kilopascal (kPa)	Inch (in)	Kilopascal (kPa)	Dollar ($)
Technical Requirement Targets		120	10^4	5 - 50	1/2	10	3000
Absolute Technical Importance		41	170	215	73	243	179
Relative Technical Importance		4.45	18.5	23.34	7.93	26.4	19.4

Table D - 2 - Bill of Materials

Capstone Bill Of Materials						
Item	Quantity	Price per unit ($)	Price ($)	Item #	Manufactu	Source
1 in x 10 ft Copper Pipe	4	35.93	143.72	100354226	Cerro	Homedepot
1/2 in x 10 ft Copper Pipe	1	9.76	9.76	100354198	Cerro	Homedepot
1 in Copper Elbow Joint 90 deg	6	4.98	29.88	100346976	Unknown	Homedepot
1 x 1/2 in Copper Reducer	2	4.51	9.02	100348139	Unknown	Homedepot
1 in Copper Tee Joint	4	11.58	46.32	100343973	Unknown	Homedepot
Centrifugal Pump	1	775	775	4XY85	Goulds Wa	Grainger
Regency 30 in x 72 in work table	1	155.99	155.99	600T3072G	Regency	Webstauran
NIBCO Ball Valve 1 in copper	4	14.49	57.96	S-FP-600A	NIBCO	Supply.com
10 Gal Hydraulic Reservoir	1	370.50	370.50	24W703	Grainger C	Grainger
Total			1598.15			
Dr. Ciocanel's Budget						
Item	Quantity	Price per unit ($)	Price ($)	Item #	Manufactu	Source
Keyence Flow Sensor System	1	790	790	FD-Q series	Keyence	Keyence
Keyence Flow Sensor clamps	3	60	180	FD-Q20C (1/2 in	Keyence	Keyence
				FD-Q50C (1 1/2-2 in)		
Dwyer Digital Manometer	1	217.08	217.08	YX-68062-66	Dwyer	Davis Instrur
Portable static pressure tip	1	12.79	12.79	G2603474	Dwyer	Zoro
Total			1199.87			

Table D - 3 Bill Of Materials Web Sites

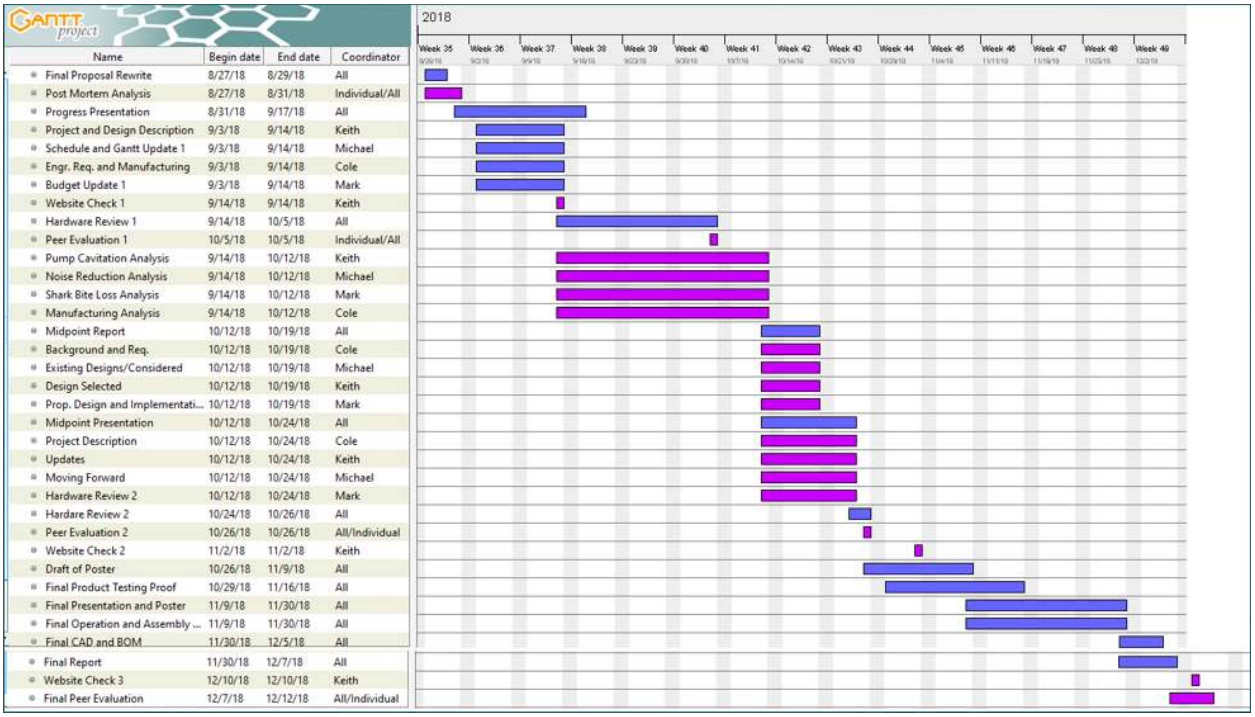
Item	Website
1 in x 10 ft Copper Pipe	https://www.homedepot.com/p/Cerro-1-in-x-10-ft-Copper-Type-L-Hard-Temper-Straight-Pipe-1-L-10/100354226
1/2 in x 10 ft Copper Pipe	https://www.homedepot.com/p/Cerro-1-2-in-x-10-ft-Copper-Type-M-Hard-Temper-Straight-Pipe-1-2-M-10/100354198?MERCH=REC-_-SearchPLPHorizontal1_rr-_-NA-_-100354198-_-N
1 in Copper Elbow Joint 90 deg	https://www.homedepot.com/p/1-in-Copper-Pressure-90-Degree-Cup-x-Cup-Elbow-C607HD1/100346976
1 x 1/2 in Copper Reducer	https://www.homedepot.com/p/1-in-x-1-2-in-Copper-Pressure-FTG-x-C-Fitting-Reducer-C6002HD112/100348139
1 in Copper Tee Joint	https://www.homedepot.com/p/1-in-Copper-Pressure-Tee-C611/100343973
Centrifugal Pump	https://www.grainger.com/product/GOULDS-WATER-TECHNOLOGY-120-240VAC-Open-Dripproof-4XW85
Regency 30 in x 72 in work table	https://www.webstaurantstore.com/regency-30-x-72-18-gauge-304-stainless-steel-commercial-work-table-with-galvanized-legs-and-undershelf/600T3072G.html
NIBCO Ball Valve 1 in copper	https://www.supply.com/shop?nid=489177&d=13116-13060&wmh_cid=242274502&wmh_aid=15352618702&wmh_kid=117838584982&gclid=EAIaIQobChMItcbCpZXo2gIVDNRkCh0K9gS-EAQYAiABEgLj7fD_BwE
10 Gal Hydraulic Reservoir	https://www.grainger.com/product/GRAINGER-APPROVED-10-Gal-22-1-4-x-14-x-12-1-24W703
Total	
Dr. Ciocanel's Budget	
Item	Website
Keyence Flow Sensor System	Call: 1-888-KEYENCE
Keyence Flow Sensor clamps	Call: 1-888-KEYENCE
Dwyer Digital Manometer	http://www.davis.com/Product/Dwyer_475_000_FM_Digital_Manometer_1_WC/YX-68062-66?referred_id=3388&gclid=EAIaIQobChMIgoGNo5ew2gIVD3R-Ch0_1QxYEAkYByABEgI7YvD_BwE
Portable static pressure tip	https://www.zoro.com/dwyer-instruments-static-pressure-tip-a-303/i/G2603474/feature-product?gclid=EAIaIQobChMI8IH1iqDm2gIVl_hkCh0IpwLOEAkYCyABEgIVVvD_BwE



Name	Begin date	End date	Coordinator
Team Charter	1/18/18	1/25/18	All
Website Version 1	1/26/18	2/23/18	Keith
Website Version 2	2/26/18	3/29/18	Keith
Website Version 3	3/30/18	5/1/18	Keith
Presentation 1	1/26/18	2/8/18	All
Presentation 2	2/9/18	3/1/18	All
Conceptual Report	2/9/18	3/1/18	All
Analytical Reports	3/2/18	3/22/18	All
Presentation 3	3/22/18	4/17/18	All
CAD Version 1	3/22/18	4/16/18	Michael
Bill of Materials Version 1	3/22/18	4/16/18	Cole
Final Report	4/6/18	4/26/18	All
Prototype Demonstration	4/20/18	5/3/18	All
CAD Version 2	4/20/18	5/1/18	Michael
Bill of Materials Verson 2	4/20/18	5/1/18	Cole
Peer Evaluation 3	5/3/18	5/3/18	All

Name	Begin date	End date	Coordinator
Progress Presentation	8/27/18	9/10/18	All
Hardware Review 1	9/10/18	9/24/18	All
Midpoint Presentation	9/24/18	10/15/18	All
Final Product Testing Proof	10/15/18	11/19/18	All
Final Presentation and Poster	11/19/18	11/26/18	All
Final Report and CAD	11/26/18	12/5/18	All

Figure D - 1 – First Semester Gantt Chart



Name	Begin date	End date	Coordinator
Final Proposal Rewrite	8/27/18	8/29/18	All
Post Mortem Analysis	8/27/18	8/31/18	Individual/All
Progress Presentation	8/31/18	9/17/18	All
Project and Design Description	9/3/18	9/14/18	Keith
Schedule and Gantt Update 1	9/3/18	9/14/18	Michael
Engr. Req. and Manufacturing	9/3/18	9/14/18	Cole
Budget Update 1	9/3/18	9/14/18	Mark
Website Check 1	9/14/18	9/14/18	Keith
Hardware Review 1	9/14/18	10/5/18	All
Peer Evaluation 1	10/5/18	10/5/18	Individual/All
Pump Cavitation Analysis	9/14/18	10/12/18	Keith
Noise Reduction Analysis	9/14/18	10/12/18	Michael
Shark Bite Loss Analysis	9/14/18	10/12/18	Mark
Manufacturing Analysis	9/14/18	10/12/18	Cole
Midpoint Report	10/12/18	10/19/18	All
Background and Req.	10/12/18	10/19/18	Cole
Existing Designs/Considered	10/12/18	10/19/18	Michael
Design Selected	10/12/18	10/19/18	Keith
Prop. Design and Implementati...	10/12/18	10/19/18	Mark
Midpoint Presentation	10/12/18	10/24/18	All
Project Description	10/12/18	10/24/18	Cole
Updates	10/12/18	10/24/18	Keith
Moving Forward	10/12/18	10/24/18	Michael
Hardware Review 2	10/12/18	10/24/18	Mark
Hardare Review 2	10/24/18	10/26/18	All
Peer Evaluation 2	10/26/18	10/26/18	All/Individual
Website Check 2	11/2/18	11/2/18	Keith
Draft of Poster	10/26/18	11/9/18	All
Final Product Testing Proof	10/29/18	11/16/18	All
Final Presentation and Poster	11/9/18	11/30/18	All
Final Operation and Assembly ...	11/9/18	11/30/18	All
Final CAD and BOM	11/30/18	12/5/18	All
Final Report	11/30/18	12/7/18	All
Website Check 3	12/10/18	12/10/18	Keith
Final Peer Evaluation	12/7/18	12/12/18	All/Individual

Figure D - 1 Second Semester Gantt Chart