Lab Station for Dimensional Analysis Verification of Bernoulli

by

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ABSTRACT

Experimentation or laboratory testing satisfies over 30% of the curriculum requirements for OMI College of Applied Science's Mechanical Engineering Technology department. Until June 2003, the College of Applied Science (CAS) had no laboratory equipment to verify Bernoulli's equation with respect to water flowing from a hole in a container. In order to apply the concepts of Bernoulli and dimensional analysis introduced in the current fluid mechanics textbook, a new laboratory station was designed. To complete this new laboratory experiment, students will now perform dimensional analysis verification utilizing either the Raleigh MLT method or the Buckingham Pi method.

A survey of thirty-two students and two professors was compiled to develop the new laboratory station. Due to its one-of-a-kind design for the CAS MET department, marketing data was not part of the survey. The compilation of the survey data generated three major customer wants or needs. Incorporating classroom theory into the laboratory environment demanded a fully functional piece of laboratory equipment designed to extrapolate meaningful data.

Based on analysis of two prototype designs and the survey analysis, the final product design accounted for the needs of manufacturing and purchasing. The manufacturing function needed parts that were capable of being machined using ordinary household tools, a freestanding drill press, and a stationary table saw. Purchasing requested design incorporation of common stainless steel or zinc plated fasteners as-well-as standard construction materials. The water tank and out-flow trough utilized clear PVC pipe and were the only non-standard items.

The laboratory has functioned flawlessly during testing. When an orifice was opened water flowed freely in a tight jet. To determine the exact length of the water jet, the measuring slide performed effortlessly. When used in conjunction with the Zircon DM S50 sonic measuring device, the laboratory data was repeatable.

The results of this project were exciting. For $921.00, a new laboratory for dimensional analysis of Bernoulli has been delivered. The new laboratory data collection system returned repeatable data to a seven-sigma standard. Using the dimensional technique known as the Raleigh method, water jet lengths were predicted within 3% of actual laboratory data. In accordance with all survey results, this laboratory station forces the CAS students to decipher lecture material, visualize the functioning theory, and utilize dimensional analysis to predict the results of fluid flow.

ACKNOWLEDGEMENTS

I wish to thank my wife, Gina, for her support and encouragement during the last nine years. Without her love and faith, this would not have been possible. Additionally, I want to thank my family members and close friends Dave Wells and Ron Powell. Your support was greatly appreciated. To Dr. Muthar Al-Ubaidi your inspiration and dedication have made my CAS time enjoyable. Lastly, to Dean William Janna, thank you for the concept and personal interaction to complete this new laboratory station.

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1. INTRODUCTION

Over the course of a CAS Mechanical Engineering student's studies, the student must develop an understanding of theoretical models and apply that knowledge to laboratory work. To ensure that the concepts are developed, an engineering student spends approximately thirty-three percent of their time in a laboratory setting. In a student's junior year, they must complete a course in fluid mechanics. Up until June 2003, the Mechanical Engineering students at CAS had no laboratory procedure to review Bernoulli's equation.

Personal preferences, current CAS students, and professors shaped the new laboratory station. Upon review of the customer survey results and advisor input, this new one-of-a-kind laboratory station was designed and built solely for the students and MET faculty of CAS. Limiting the market for this product to CAS removed the need for a full-scale market analysis. Additional boundaries were placed on data accuracy, use of the Bernoulli equation, and utilization of classroom theory. The test data accuracy had to be repeatable within ±10% of test data nominal results. The new laboratory station had to be based on the Bernoulli equation, and it had to demonstrate classroom theory within the laboratory procedure.

Design constraints, limiting the laboratory station size and functionality, were imposed, but no design constraints were placed upon the laboratory station's shape. The designer had no requirement to either prove the stability of the station, or prove factors of safety for any of the components. With this said, the laboratory station had to function for its intended purpose, within the timeframe of the scheduled three-hour instructional period.

1.1 SURVEY AND QFD ANALYSIS GENERATION OF MEASURABLE DESIGN REQUIREMENTS

During the fall of 2002, the initial phase of research was completed. Surveys, personal interviews, and email transmissions generated numerous responses and suggestions. For the purpose of investigating currently available laboratory equipment, the Internet was utilized. To garner knowledge surrounding the use of the Bernoulli equation, numerous texts, including the current CAS Fluid Mechanics text, were consulted (refer to Appendix A, Annotated Bibliography).

1.1.1 Survey of the Customers

To implement a great product, the wants of the customer must be designed into the product. The main customer was defined as current and future CAS MET students. A secondary customer was the CAS MET faculty. The MET faculty member instructing the Fluid Mechanics class was Dr. Muthar Al-Ubaidi. Employers of CAS graduates and other teaching institutions were considered third tier customers.

Identifying the customers was important, but discovering their wants or needs was critical. The wants of the CAS student customers were congealed through the use of a seven question written survey (refer to Appendix B, figure 12, Customer Survey). The survey was written for the customer to express a need in terms of a numerical value. Each need was written and assigned a value of one through five. Declaring the importance of each need, the customer responded by circling one value. In order for the customer to articulate needs, space was allotted for a written response.

The second method used for surveying was the personal interview. In order to gain the perspective of the MET faculty and as professor of the Fluid Mechanics class, Dr. Al-Ubaidi was interviewed. Similar to the student survey, he was asked a series of questions and asked to expound on his needs as a professor and faculty member. The last person surveyed was Dean William Janna of the University of Memphis. His interview was conducted via email and was important for his input as the author of the current Fluid Mechanics textbook.

1.1.2 Customer Needs from Surveys

From the thirty-two distributed surveys, thirteen responses were compiled. The customer's three most important needs were elimination of laboratory confusion, easily obtained data, and a laboratory experiment capable of running in less than three hours. Two customers returned the same articulated need. This need was for a short summary of the equation and theory prior to operating the laboratory station. Finally, the customers agreed that the new laboratory station to demonstrate Bernoulli was a basic need.

The two personal interviews returned some interesting results. From both interviews, the basic need of incorporation of classroom theory into the new laboratory was important. Also, the articulated need of incorporating dimensional analysis was expressed. Dr. Al-Ubaidi's input included a latent need. For the final design of the water tank, he insisted upon incorporation of clear PVC pipe.

1.1.3 QFD Translation of Needs into Engineering Requirements

The planning and problem-solving tool used to translate customer requirements into engineering characteristics was the House of Quality. This graphical tool forced the designer to focus upon how the customer needs were addressed. How the designer addressed the needs was setup as ten measurable design targets (refer to Appendix C, figure 13, for the finalized House of Quality). Based on the results from the customer surveys, the ten requirements were weighted.

The requirements with the highest ranking led to the three most important targets. The top three design targets were repeatable data, incorporation of classroom theory, and dimensional analysis verification. A fourth and fifth targets were a detailed laboratory procedure and operation of the laboratory in less than three hours. Although not design targets for the physical laboratory structure, the fourth and fifth targets were addressed through the written laboratory procedure.

1.2 BERNOULLI'S CONTRIBUTION TO FLUID FLOW

Daniel Bernoulli was an 18th century physicist and astronomer. He was born February 8, 1700 in Groningen Netherlands. His life spanned eighty-two years until his death on March 17, 1782 in Basal Switzerland. His accomplishments were many:

- Defined the simple nodes and frequencies of oscillation of a system,
- Produced work on probability and political economy,

- Hydrodynamics: Work contained the correct analysis of water flowing from a hole in a container
- Taught physics at Basel for twenty-six years until 1776,
- Won ten grand prizes at the Paris Academy for astronomy and nautical topics.

Bernoulli's theories were as applicable in the 18^{th} century as they are today. Because of his enduring theories and concepts, the curriculum of the MET department of CAS included his work in their course requirements.

To design a piece of laboratory equipment incorporating Bernoulli's theory, the designer must understand Bernoulli's fluid flow equation (refer to Appendix D, figure 14, for Bernoulli equation and figure 15 for explanation of Bernoulli variables). When dealing with the fluid mechanics of incompressible fluids, Bernoulli's equation explains the system. According to Robert Mott, "Bernoulli's equation is used to determine values of pressure head, elevation head and velocity head change as a fluid moves through a system."[1] Referring to figure 1 of Appendix E[2] , the observer should note that as fluid moves from point one to point two, the value or magnitude of the term increases or decreases; however, "if no energy is lost or added to the head, the total head remains at a constant level."[3]

When working with Bernoulli's equation, the chosen reference point must be expressed in the same pressure terms. The various pressures must be resolved into either gauge or absolute pressures. Most situations in the laboratory or real world allow for the utilization of gauge pressure. In turn, the result is that the exposed area's pressure reading is represented as a net zero pressure.

In order to apply Bernoulli's equation to a system, several conditions must be met. According to Robert Mott, the limitations are as follows:

- "It is only valid for incompressible fluids since the specific weight of the fluid is assumed to be the same at the two sections of interest.
- There can be no mechanical devices between the two sections of interest that would add energy to or remove energy from the system, since the equation states that the total energy in the fluid is constant.
- There can be no heat transferred into or out of the fluid.
- There can be no energy lost due to friction."[4]

No system would likely meet all of these requirements. In the case of this new laboratory station design it met the first two requirements. By design there were no additions of mechanical devices, and the incompressible fluid was water. The last two conditions can only be theorized. In practical applications, losses stemming from friction and heat transfer are always introduced.

Referring to figure 16, Appendix E[5], one can see that the surface of the fluid is at height *h* from the centerline of the orifice or opening. Additionally, P_1 and P_2 are taken from their respective points at point 1 and point 2 and the same holds true for v_1 and v_2. Upon inspection of the system, parameters may be eliminated and others may be solved. In the case of a reservoir or large open container, several factors hold true:

- By using an atmospheric reference, $P_1 = 0$ psig, leading to $\frac{P_1}{\rho g} = 0$.

- Because the surface area of the reservoir or open container is large relative to the area of the orifice, and h will remain constant, v_1 can be considered to be 0. This event leads to $\frac{v_1^2}{2g} = 0$.
- In an ideal fluid condition, there is no head loss resulting in Bernoulli's equation reducing to $v_2 = \sqrt{2gh}$. This reduction is known as Torricelli's theorem.

After 200 years of validation, Bernoulli's concepts and theories are still applicable. The velocity of a fluid flowing from an open container while head pressure remains constant is $v_2 = \sqrt{2gh}$. This calculation coupled with the basic physics concept of a body in fall, produces the jet spray. Additional requirements for a new laboratory station design would include the use of an incompressible fluid, no moving mechanical parts, transfer no heat into or out of the system, and would incur no frictional losses.

1.3 INITIAL DESIGN CONCEPTS TO DETERMINE FUCTIONALITY

For product development, the initial project research was crucial. An initial design concept was needed. The concept had to encompass the customer needs and be developed within the defined project scope. Dean William Janna provided the initial design concept. With his input, student and faculty input, and research materials, the initial design was conceived.

1.3.1 Dean William Janna's Contribution to Design Concept

The textbook Introduction to Fluid Mechanics, chapter four, problem 4.69, described the design concept and utilization of dimensional analysis for a problem involving Bernoulli's equation. Those design considerations were incorporated into the new laboratory design and were listed as follows:

- Selection of the container (material and size)
- Determination of the container's cross-sectional area and overall height
- Determination of d1, d2, d3, L1, L2, and L3 (refer to figure 17 Appendix F)
- Sizing the orifices for acceptable fluid flow
- Selection of the appropriate liquid for testing

Based on all of the conceptual input, Dr. Muthar Al-Ubaidi agreed to sponsor this concept as a senior design project.

The reference points utilized for the new laboratory station were at the open surface, at the top of the tank and the point at the exact opening of the orifice. Choosing these points as reference caused the P_1 and P_2 term to be zero and was based upon the water head remaining constant. By designing a system for zero head losses, Torricelli's theorem was applied. Utilizing Torricelli's theorem and basic physics (refer to Appendix G, figure 19 for these calculations) a water jet profile was constructed (refer to Appendix G, figure 20). The graphical results of these calculations clearly showed the bottom most jet spraying the furthest distance, and the subsequent higher jets spraying a shorter distance.

1.3.2 Search for Commercially Available Laboratory Equipment

Availability of currently available laboratory equipment led to a patent search of the United States Patent and Trade Office (USPTO). This source for designs was exhausted. Through the use of the Thomas Register, laboratory equipment manufacturer web site searches were conducted. These searches showed no available or compatible Bernoulli laboratory equipment. Due to equipment unavailability, the final design and construction of this particular piece of laboratory equipment rested solely on the designer.

1.3.2 Initial Results through Prototype Fabrication and Testing

In the winter of 2002, a design prototype was constructed of common four-inch PVC pipe. The top, middle and bottom orifices were spread equally over five feet. Additionally, two other orifices were added. These two were equally spaced between the top and middle and the middle and bottom orifices. The resultant spacing was fifteen inches on center and all orifices were sized at .225" in diameter. Utilization of this diameter orifice resulted in a 316 to 1 pipe diameter, to orifice diameter ratio.

Two areas of concern surfaced during testing of the prototype. The first was the inability of the system to sustain a constant pressure head. Additionally, there was no apparent easy method to align the system. In order to eliminate the pressure head concern, a second prototype was built. This included a redesign of the overflow outlet system. The second concern was addressed by the final design.

Due to no available commercial laboratory unit, a prototype unit was constructed. From testing, it was shown that a water jet spray, while maintaining a constant head pressure from a six-foot pressure head, resulted in an approximate jet distance of four and one-half feet. Additionally, for a three and one-half feet pressure head, the jet distance was tested. This resulted in a jet spray of over five feet. Additionally, prototype testing proved that a constant water head would be maintained.

1.4 DISTINGUISHING THE BEST DESIGN THROUGH A PUGH MATRIX

An initial design may or may not be the best engineering design. In order to build a new laboratory station that would meet the needs of the customers, the initial design concept, compiled survey results, and completed prototype testing results were incorporated into three alternative design concepts. One method of systematically eliminating designs to arrive at the “best” design is the Pugh method. The three design alternatives were compared to the prototype laboratory station and judged to be worse than, equal to, or better than the prototype. This evaluation delivered the best final design.

In an effort to design and construct the laboratory station that met the customer needs, three design alternatives surfaced. Design concept number one incorporated an electric motor and pump to circulate the water and a tape measure measuring system. Design number two incorporated a fluid leveling device and a tape measure measuring system. This eliminated the need for a circulation pump. The last alternative utilized a fluid overflow design and an upgraded jet spray-measuring device. This last alternative required a constant water supply.

With the categorization of three design alternatives, the Pugh matrix was built. The Pugh matrix used plus, minus, same sign designations. These designations were issued based upon whether the alternative was better than, worse than, or the same as the prototype equipment. Referring to Appendix H, at the bottom of the Pugh matrix, the reader is shown a series of plus, minus, and same sums. These sums showed the designer a higher plus sum and fewer same sums. Based upon the Pugh matrix's sum of three plus, one same and one minus scores, the design that stood out as the best was design number three (refer to figure 1, New Laboratory Station Concept).

To make the laboratory station as user-friendly as possible, three design alternatives were conceived. Design number three was chosen as the best design. The Pugh matrix categorized this design as best by its high score in the plus category and low score in the same and minus category. An added benefit to design number three was the lack of moving mechanical parts. This added benefit translated into a maintenance free system that will always be available for the students to operate.

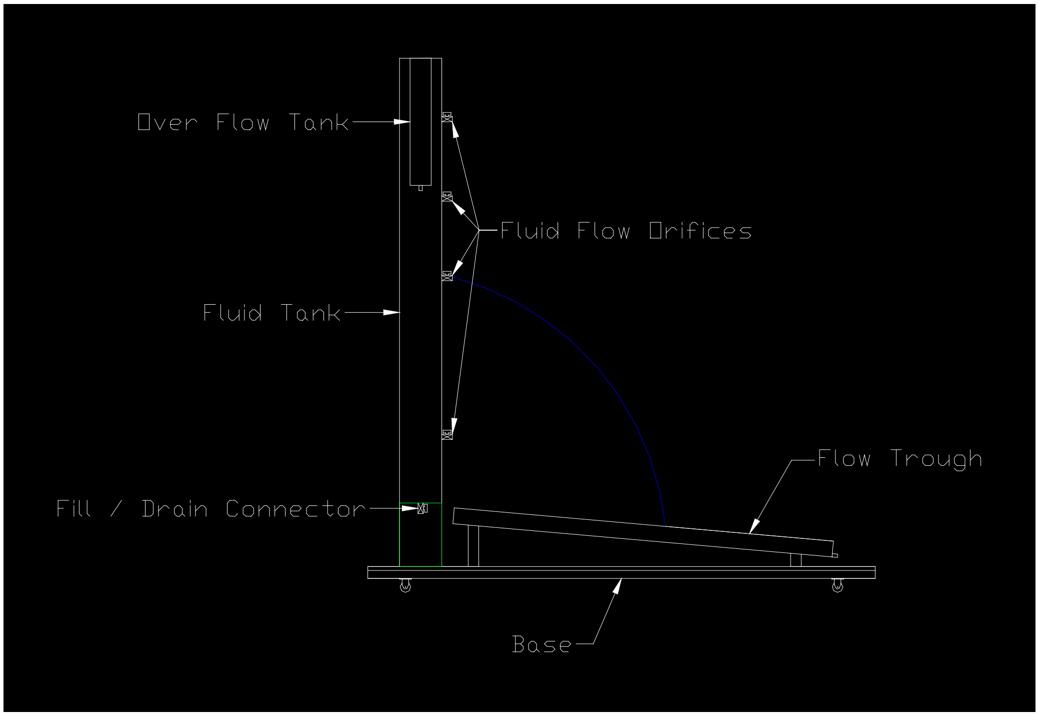

Figure 1 Design 3 New Laboratory Station Concept

1.5 COST OF NEW LABORATORY STATION

Even though cost was not a method of addressing any of the end user's concerns, the cost of the product was scrutinized. Dr. Muthar Al-Ubaidi reviewed and approved the entire budget. The original design concept required a budget of $1662.00 (refer to Appendix I for the original bill of materials). While in the process of manufacturing and assembling, the final product received numerous design changes. The overall affect of the design changes resulted in a final budget declaration of $921.00 (refer to Appendix J for the revised bill of materials). Price comparison shopping in Home Depot, Lowes, Big Lots, Harbor Freight and Grainger Supply for common fasteners, hardware, and plywood were the driving factors behind the budget reduction. Due to the requested use of eight-inch and four-inch clear PVC pipe, these products were the largest single budget expense.

1.6 PROJECT TIME SCHEDULE

To satisfy CAS's need to develop a new laboratory, this project was completed in nine-months. Launching in September of 2002 and ending in June 2003, the design and build process was driven by deliverable goals. The project had to be approved and funded by the end of winter quarter 2002-2003. Starting in winter quarter 2003, the product design was completed. By the start of spring quarter 2003, project materials were ordered and the manufacturing/building phase was initiated. At the May 16, 2003 CAS Tech Expo, the final product delivered. Twenty-six project tasks were organized in Microsoft Project Scheduler™. Due to the utilization of this software, tasks were easily managed and adjusted. For a snapshot of all completed tasks, the schedule of events is located in Appendix K, figure 24.

1.7 SCOPE OF REPORT

The following report sections will focus on the new laboratory station design, manufacturing and assembly, test results and conclusions and recommendations. Section two, new laboratory design, is broken out into eight sub-categories. These categories describe the sizing, selection, and design of the major components. Section three, manufacturing and assembly, details the manufacture and assembly of the water tank, outflow trough, and measuring mechanism. Section four, test results, details the test results of different orifices, statistical repeatability of test data, and the Raleigh method of dimensional analysis. Laboratory conclusions and recommendations are detailed in section five and quoted references are placed in section six. To expand upon the written content, the Appendices range from Appendix A to Appendix N and are the last sections of the report.

2. NEW LABORATORY STATION DESIGN

Six-months of research and project development went into the final product design. From the initial prototype, through its redesign and into this final design, this product was sized for a meaningful laboratory experience. Water was chosen as the testing fluid and was sprayed from five outlet orifices. Additionally, for unparalleled data repeatability, this design incorporated a sonic measuring device. For a complete list of all specified design materials, the BOM is listed in Appendix J, table 5.

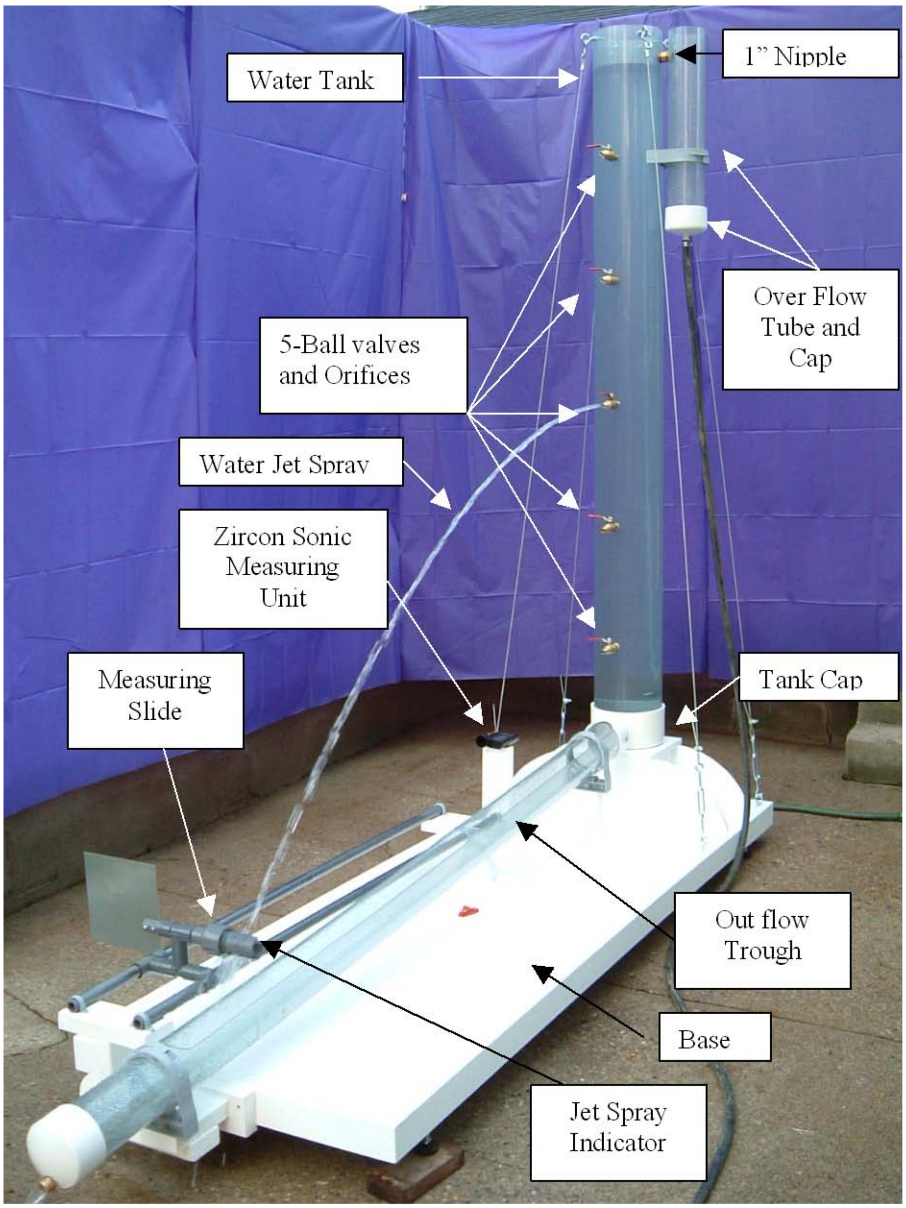

Figure 2 New Laboratory Station for Verification of Bernoulli

2.1 DESIGN FOR MANUFACTURING AND MATERIAL SELECTION

The new laboratory station needed to be bounded from a size standpoint. The critical dimensions were the height and length of the station. The classroom where the laboratory station was to reside had a maximum ceiling height of ten feet. The length of the station could have been up to twenty feet long and up to ten feet wide. The final dimensions of the laboratory were designed to stay within this ten-by-ten, by twenty-foot box and to utilize common materials wherever possible.

2.1.1 Water Tank Sizing, Material Selection, and Closure

The height of the water tank, seven feet four inches, was transferred from the prototype to the final design (refer to figure 2 on previous page). By limiting the search to clear PVC, one local company, Harrington Plastics, supplied clear PVC. To deliver a latent need of Dr. Muthar Al-Ubaidi, eight-inch diameter schedule 40 PVC was purchased. Using an eight-inch white schedule 40 cap, the tank was sealed on one end.

2.1.2 Base Sizing, Material Selection, and Stability

The prototype testing determined a jet length of five feet. Based on this data, the known height of the water tank and full utilization of commonly available medium density fiberboard (MDF), the base was sized at thirty-two inches wide, by eight feet long. In an effort to stabilize the base (refer to figure 2 on previous page), the height to width ratio was 7.34:1. In order to provide extra stability in the base, cross braces were specified on the underside of the base. Additionally, three and one half-inch side panels were designed to border the outer edge of the base.

2.1.3 Water Jet Outflow Trough Sizing and Material Selection

When the prototype was operated, water flowed into a bucket. For a fully functional laboratory this method of containment was unacceptable. An outflow trough (refer to figure 2) had to be designed. The material of choice was four-inch schedule 40 PVC. Again, Harrington Plastics supplied this material. From prototype testing, the length was determined. In an effort to "build-in" a reservoir at the end of the outflow trough, an eight-foot piece was incorporated. This allowed the trough to be positioned beneath the orifices while extending past the longest jet spray.

2.1.4 Water Tank Overflow Piping, Sizing, and Closure

By incorporating a one-inch overflow hole into an overflow catch tube (refer to figure 2), the design requirement to sustain a constant pressure head was solved. The overflow hole utilized a one-inch diameter by two and one-half inch long brass nipple. This nipple connected into a two-foot long, four-inch diameter clear PVC pipe. To allow the water to fill to the level of the nipple then flow into the overflow tube, the design intent of a constant head pressure was met. The overflow tank was sealed on the end by a standard issue white schedule 40 cap.

2.1.5 Selection of Orifice Shutoff Valves

Ease of controlling the water flow was a primary design concern. Straight nipples with caps, simple rubber stoppers, outdoor faucets and PVC shut-off valves were investigated. Utilization of half-inch, full-flow, brass ball valves was specified (refer to figure 3 below). The brass ball valves were easy to control, as well were maintenance free. Their full-flow design allowed for water orifices up to one-half inch in diameter.

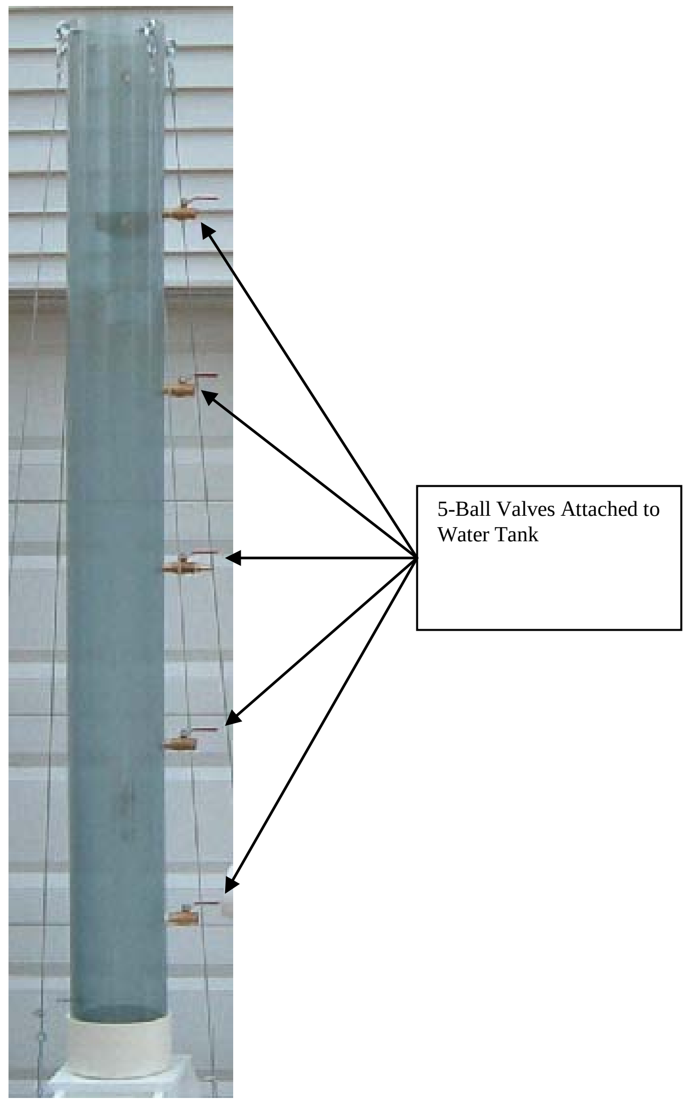

Figure 3 Five 1/2" Ball Valves

2.1.6 Orifice Sizing for Jet Consistency

Specifying standard plastic tubing as the orifice opening allowed for consistency of the jet spray pattern. Based on prototype testing, the initial orifice size was chosen to be .174” diameter (refer to figure 4 below). Utilization of plastic tubing controlled their diameter and delivered a low coefficient of friction. Due to its availability as an off-the-shelf item, this was a designer choice. In order to connect the tubing to the ball valves, plastic compression fittings were specified.

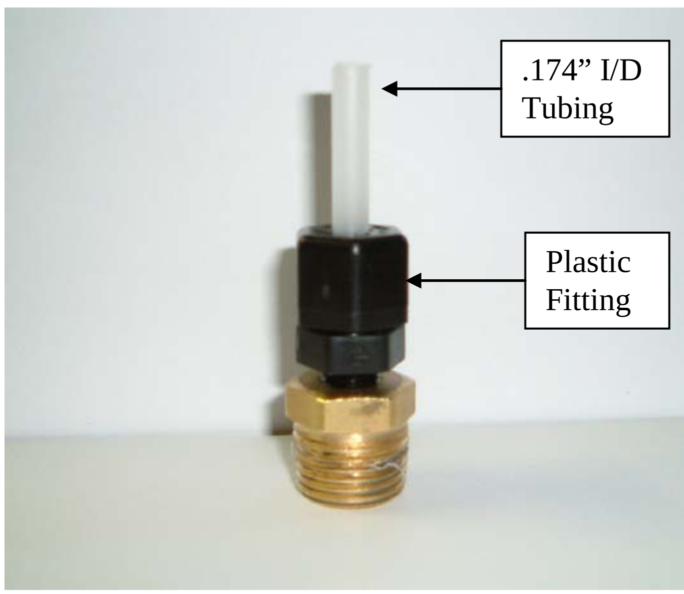

Figure 4 .174" Diameter Orifice

2.1.7 Water Jet Distance Measuring With the Zircon Sonic Measuring Device

One of the major problems of laboratory experiments has been data collection and data error. To eliminate this issue the designer focused on three alternatives. The possibility of utilizing a tape measure was dismissed as too error prone. The possibility of using a ball-screw type mechanism would add cost. The third choice was the developed design. Incorporated into the final design was a Zircon DM S50 sonic measuring device. The Zircon unit was purchased from Home Depot (refer to figure 5). For $29.95, the designer delivered 0.00 data accuracy. Additionally, due its one push button action (refer to figure 5) and digital display, the customer requirement for data accuracy was met.

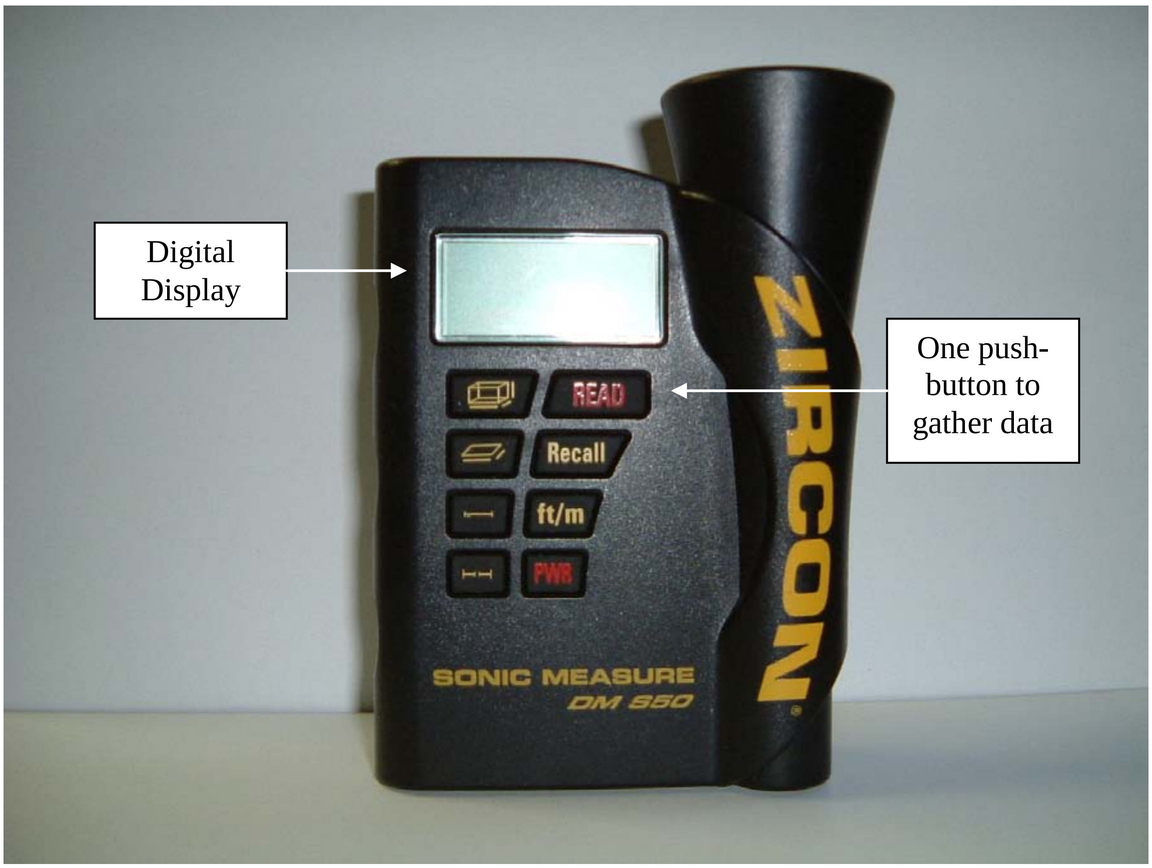

Figure 5 Zircon DM S50 Sonic Measuring Device

2.1.8 New Laboratory Water Tank Fill Design

Three requirements were met with this product's fill design. For ease of filling, draining, and the need to eliminate turbulence near the orifices, a three-quarter inch, brass, ball valve was specified. In the tank cap at the bottom of the tank, the valve was installed. For ease of installing a five-eighths inch garden hose, this valve was threaded for garden hose attachment.

3. MANUFACTURING AND ASSEMBLY OF THE NEW LABORATORY STATION

The designer manufactured all non-purchased product components. This was accomplished using a table saw, drill press, band saw and other common homeowner tools. The three most difficult items to manufacture were the water tank, outflow trough, and the measuring slide. As manufacturing progressed, the components were assembled using standard hardware.

3.1 MANUFACTURE AND ASSEMBLY OF WATER TANK

Manufacturing of the water tank was accomplished in two weeks. To ensure accurate data, the positioning and spacing was completed using a jig. While the pipe was positioned from hole to hole on the drill press, the manufacturing jig clamped the eight-inch PVC. Over the five-foot orifice span, the holes were marked off at fifteen-inch increments and centered at each point. To ensure that the half-inch pipe taped holes were square to the tube, each hole was drilled and hand tapped before moving to the next hole.

To position the overflow outlet and its mounting bracket, the water tank was rotated ninety degrees and re-clamped. At one-foot above the top orifice opening, the overflow hole was marked for a drill and tap operation. To accept a one-inch NPT tap, this hole was drilled and hand tapped. While clamped in this position, the overflow tank-mounting hole was drilled and tapped. To accommodate the c-clip clamp, a one half-inch NPT was inserted. A one half-inch NPT brass fitting was center drilled and tapped for a three-eighths by sixteen stainless steel bolt. This fitting held the c-clip in place.

Utilizing a standard eight-inch white schedule 40 PVC cap, closure of the bottom of the water tank was completed. Into the center of the cap a one-inch by eleven and one half NPT hole was tapped. This hole accepted a one-inch by three-quarter inch reducing bushing. The three-quarter inch standard boiler valve was inserted into this hole.

Assembly of the tank components required one week. One-inch long brass nipples inserted the half-inch brass ball valves onto the tank. To ensure that all ball valves were installed to the exact same height, the ball valves were line checked. Fitted to the tank with a one-inch diameter by two and one half-inch long brass nipple was the overflow tank. For the purpose of the overflow drain, the cap on the bottom of the overflow tank accepted a three-eighths inch plastic barbed fitting.

Sitting on an eight and one half-inch high riser, the water tank was positioned. The riser established the height of the tube to the measuring mechanism. To hold the tank square to the base, four guide wires were installed. The wires were attached to the top of the water tank with four five-sixteenths stainless steel eyebolts. The guide wires were cut from four Clopay garage door support cables and attached to the base with nine and one half-inch long zinc plated turnbuckles. The turnbuckles allowed for one-person water tank alignment.

Alignment of the water tank to the base was important. A novel approach was utilized. A $2.99 plumb bob was used. It was positioned at the top of the water tank and draped to the bottom. With another eyebolt, alignment at the bottom was accomplished. As the turnbuckles were tightened/loosened, the plumb bob simply centered itself into the lower eyebolt.

3.2 MANUFACTURE AND ASSEMBLY OF OUTFLOW TROUGH

Completion of the water tank was important but two other major components were left. The outflow trough was designed from four inch diameter clear PVC. It utilized two white schedule 40 PVC ends. The bottom end was drilled and tapped to accept a half-inch NPT. This connected to a standard five-eighths garden hose and then to a drain. To accept the water jet spray, the top of the outflow trough was cut lengthwise. A saber saw accomplished this task. Manufactured wood posts mounted the outflow trough to the base. Allowing for a consistent flow to the drain, the mountings provided six inches of drop over eight feet. To fasten the outflow trough to the mounts, c-clips were utilized.

3.3 MANUFACTURE AND ASSEMBLY OF THE MEASURING MECHANISM

Functioning side-by-side to the outflow trough was the measuring slide (refer to figure 6 next page). The slide rails were fabricated from three quarter inch schedule 80 PVC. Four PVC tees formed the slide bar and a one and one half-inch nipple made the spray collector.

On the opposite side of the spray collector was the sonic measuring plate. This plate reflected the sonic beam back to the measurer (refer to figure 7 on next page). In this way, the center of the spray jet was measured. On wooden mounts to the base of laboratory station at twelve inches below the bottom tank orifice, the measuring unit was mounted. The jet spray was always measured at this twelve-inch drop.

Overall the manufacturing and assembly of this laboratory was very challenging. Skills needed to complete this portion of the project were not part of the project scope.

Although this was not measured, these mechanical skills were crucial to the manufacturing and assembly of the water tank, outflow trough, and measuring system. Additionally the use of bargain shopping skills reduced the final cost from $1500.00 to $921.00.

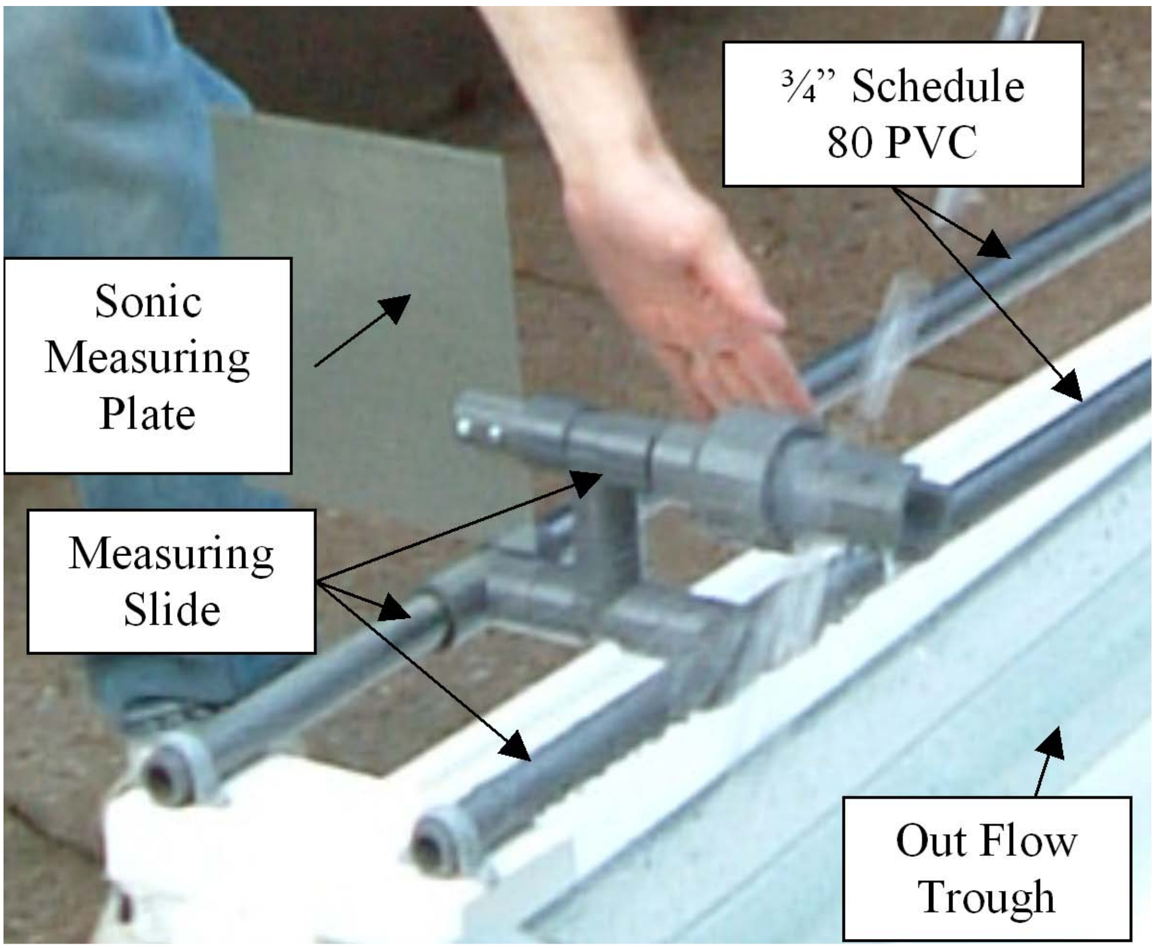

Figure 6 Measuring Slide and Components

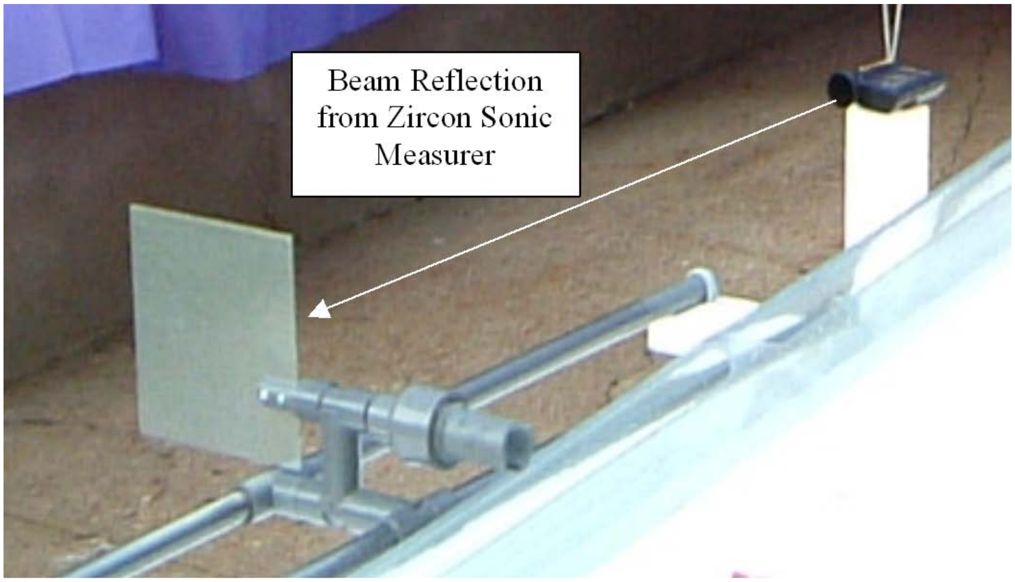

Figure 7 Sonic Measurer and Reflecting Plate

4. TEST RESULTS FROM THE NEW LABORATORY STATION

The design and manufacturing of this project resulted in a fully functional Bernoulli laboratory station. The laboratory station was capable of measuring orifice flows from 5 different outlets and 5 different static head pressures. Over the course of testing this apparatus, ten tests of each orifice outlet were conducted. In order to examine the repeatability of the data, statistical analysis was performed using a computer software package.

4.1 TEST RESULTS OF DIFFERENT ORIFICES

Testing of the water jet sprays for 3 different orifices was conducted. The water spray pattern varied between the three. The .174" diameter orifice's spray pattern was fairly "tight". In this case, tight meant the spray pattern was concentrated as opposed to a fan pattern. Additionally, as shown below in figure 8, a .090" diameter nozzle was tested. The water jet spray length emitted from this orifice was shorter than that of the .174" orifice. Also, at the end of the spray, the .090" orifice produced a fan pattern. For the purpose of accurate measurements, this orifice was judged "unacceptable". A final orifice size of .375" was tested. This orifice sprayed further than the other two. Additionally, the spray pattern was tight or concentrated. The .174" orifices were removed from the laboratory and the .375" orifices were installed. Listed below in table 1, were the results from the orifice testing.

	Orifice Diameter		
	.090"	.174"	.375"
Observed Spray Pattern	Fanned out at end	Fairly Concentrated, Some Fanning	Tight and Concentrated

Table 1 Orifice Jet Spray Pattern

Figure 8 .090" Diameter Orifice

In table 2, below, the average jet length was listed. The full set of results from laboratory testing was positioned in Appendix L. In addition to the tabular results, a graphical depiction was completed. Figure 9, located on the next page, depicts the water jet curve derived from these results. This graph showed the increase in jet length from 1.28 meters up to 1.86 meters followed by a steady decrease back to 1.29 meters.

	Head Height (Meter)				
	0.3048	0.6858	1.0668	1.4478	1.8288
Average Jet Distance	1.28	1.69	1.86	1.68	1.29

Table 2 Average Jet Distance verses Head Height

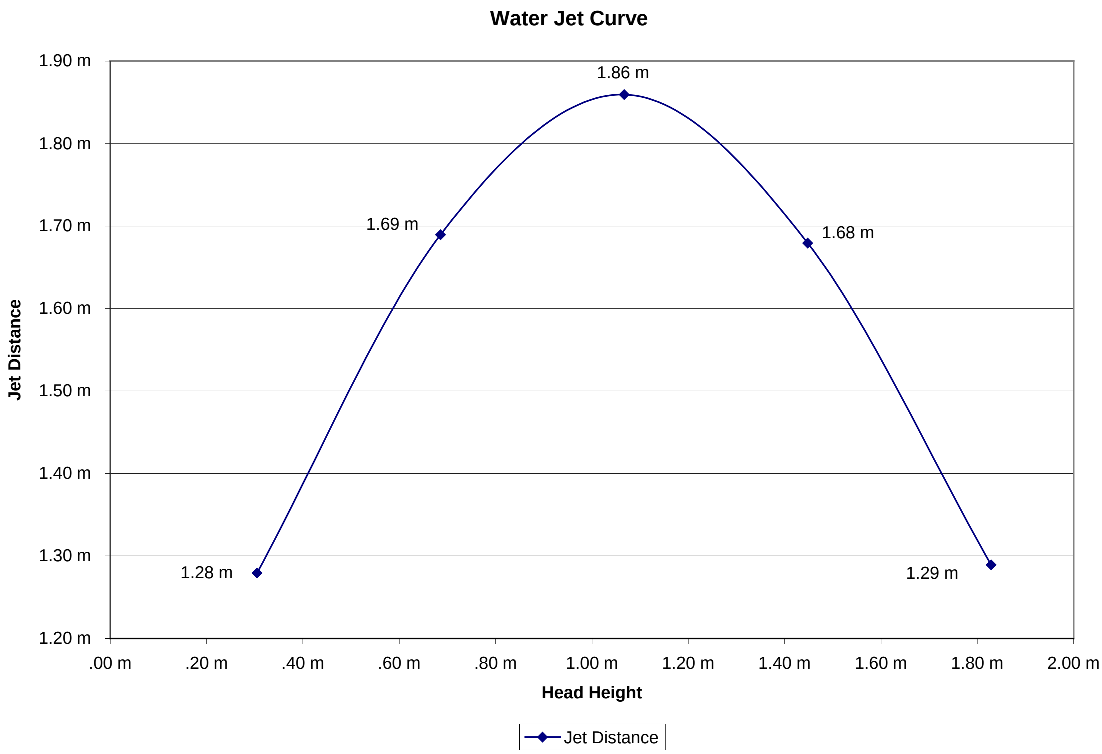

Figure 9 Distance of Water Spray

The jet lengths corresponding to head heights of .305 and 1.829 meters were within 10% of each other. Additionally, the jet lengths corresponding to head heights of .686 and 1.448 meters were within 10% of each other. The jet with the longest length corresponded to a head height of 1.067 meters.

4.2 STATISTICAL REPEATABILITY OF TEST DATA

From the test data of 50 individual tests referenced in Appendix L, statistical analysis was performed. For data comparison, Mini tab™ software was utilized. The results arre presented in graphical form on the next page. Figure 10 shows that based upon ±10% limits, the laboratory station generated seven-sigma repeatable results. In other words, if this laboratory station were operated one million times, the data would repeat every time.

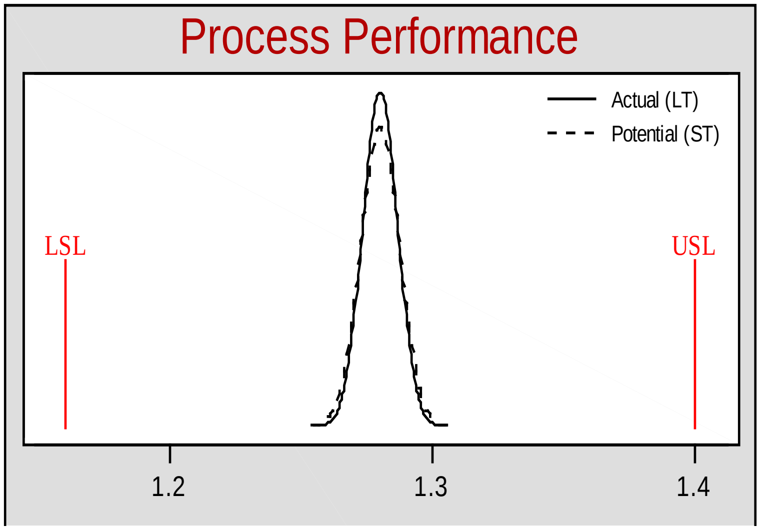

Figure 10 Minitab Results for Data Repeatability

4.3 RALEIGH METHOD OF DIMENSIONAL ANALYSIS

With repeatable data to predict the additional orifice's jet length, dimensional analysis was used. The method of choice for this project was the Raleigh method. A full description of this method was listed in chapter four of the current fluid's textbook. The full set of calculations for this laboratory analysis is positioned in Appendix M figure 26. Generated from the top, middle, and bottom orifices and listed on the next page in figure 11 is the final equation. This equation was used to predict the jet distance from the final two orifices. In reality, this equation would accurately predict the jet distance from any orifice positioned between the top and bottom orifice.

$$L = \left[\frac{3.5162E^{13} \left(h_1 h_2\right)^{.5169} \left(\frac{h_1 \mu}{V \rho}\right)^{2.0088}}{h_1} \right]$$

Figure 11 Final Equation for Prediction of Jet Length

After the generation of the equation for predicting jet distance, values of height for the final two orifices were inserted and checked. The results from these two calculations were excellent. The actual jet spray distance to the calculated distance were within 3% of the actual test results. Shown below in table 3 are the actual test values compared to the calculated values.

Head Height (m)	Actual Jet Distance (m)	Calculated Jet Distance (m)	% Difference
0.6858	1.69	1.732	2%
1.4478	1.68	1.737	3%

Table 3 Percentage Difference Between Calculated and Actual Jet Distance

Utilizing two CAS students and one high school student, two weeks of testing were compiled. The top and bottom orifice and the second and fourth orifice showed an almost perfect match of jet distances. The middle orifice displayed the longest jet distance. After 50 repeatability tests, the laboratory displayed a seven-sigma process. Having this accurate data allowed the numerical analysis to accurately predict the jet length of the second and fourth orifice. The percentage difference between the actual jet lengths and the calculated lengths was three percent.

5. CONCLUSIONS AND RECOMENDATIONS

Based upon nine-months of project management numerous conclusions were made. The conclusions came from the project scope, laboratory functionality, data repeatability, formulation of dimensional analysis and orifice size.

When this project was started, a co-effort was used to contain the scope of the project. What the project should demonstrate was based on input from the project designer, students, Dr. Muthar Al-Ubaidi and Dean William Janna. With this input for the final product's function, the designer was allowed total design freedom. This freedom allowed the final product to be delivered under budget.

When the product was delivered, it was fully functional. The functionality was displayed from a low maintenance design and the station encompassed the original goals. The laboratory station was easily setup and leveled by two people. This was accomplished in less than fifteen minutes. After the system was filled with water, the orifices were opened, water flowed and jet distance was easily measured.

When the jet distances were measured and statistically examined, the result was a seven-sigma process. Because of the data accuracy, no student should ever record erroneous data. In order to ensure that this happens, a Zircon DM S50 fully digital sonic measuring device was used. With an accuracy of 0.00 and a digital readout, this measuring system was practical, easy to use, and inexpensive. Additionally, using this accurate data for dimensional analysis yielded excellent data correlation. The derived formula and seven-sigma data resulted in jet length predictions within 3% of actual lengths.

Referring to figure 9 from the result section, this jet distance curve was not expected. From Bernoulli's equation, the bottom jet distance was calculated at almost eight feet. The velocity in the bottom orifice was the largest and did not explain the shape of the curve. From all available information, the one-foot drop hampered the development of the flow pattern. At some drop point the bottom jet would shoot further than those above it. By examining the data this should occur when the head height is equal to the drop height of the bottom jet.

The length of the jet spray was directly correlated to the size of the orifice opening. Prototype testing proved that the smaller orifice resulted in a shorter jet distance. As the orifice opening decreased in size, the frictional effect of the surface finish on the orifice wall caused the water jet to "fan". This fanning occurred at the end of the jet spray. This caused the .090" orifice data to be useless. Because of this fanning, additional testing was required. Further testing proved the application of a .375" diameter orifice.

There are always methods to change the scope of a product. In the case of the new laboratory station, the dimensional analysis could be redone to include an orifice diameter and a frictional loss variable. This change may help the calculated verses actual data correlation results. The laboratory station could be redesigned for a vertical water jet. In affect, this change would change the scope of this new laboratory station. Also, the experimental procedure could be changed to include changing the orifices to different sizes. In effect, this change would produce a new laboratory experiment.

This laboratory was an excellent example of how classroom theory could be brought into a laboratory setting. By directly referring to chapter four of the current textbook, this laboratory examined and applied Bernoulli's theory. Dimensional analysis was utilized to correlate actual data to a theoretical model. Overall, everyone who operated (refer to Appendix N, New Laboratory Operating Procedures) or saw this new laboratory station in action gave it a two thumbs up.

6. REFERENCES

APPENDIX A Annotated Bibliography

Al-Ubaidi, Muthar, Department Head, MET. OMI College of Applied Science, Interview, October 2002.

I Met with Professor Al-Ubaidi to discuss the possibility of completing a MET laboratory that would ensure the graduation requirements of OCAS. This meeting led to two possible laboratory experiments.

Arthur, Allen, Assistant Dean, OMI College of Applied Science, Interview/e-mail correspondence, October 2002.
I corresponded with Dean Arthur to determine the feasibility of continuing with a project for the MET department. This gave an initial "go-ahead" to continue the Bernoulli experiment.

Cheremisinoff, Nicholas P., *Practical Fluid Mechanics for Engineers and Scientists*, Technomic Publishing Co, Pennsylvania, 1990.
I used this reference to investigate applications of Bernoulli's equation.

Fogiel, Dr. M., *The Fluid Mechanics and Dynamics Problem Solver*, Research and Education Association, New York, 1983.
Used this reference to further investigate Bernoulli's equation. Gave well-defined problems and solutions.

Henke, Russel W., *Introduction to Fluid Mechanics*, Addison-Wesley Publishing Co., Massachusetts, 1966.
I used this reference for summary of variables and reference to Bernoulli's equation.

Park Plastic Prouducts, Liquid Storage and Transportation Solutions, October 2002.
http//www.parkplasticproducts.com
This web site was utilized to gain sizing and pricing for plastic tanks. Site had an excellent selection of all types of plastic tanks.

The Tank Depot, October 2002.
http//www.tank-depot.com
This web site was utilized to gain sizing and pricing for plastic tanks. Site had an excellent selection of all types of plastic tanks.

Janna, William S., *Introduction to Fluid Mechanics*, PWS Publishing Co., Boston, 1993.
Used this reference to help determine scope of this project. Reference gave an excellent example of the type of project that is trying to be constructed. Dr. Janna also sent a picture of a similar lab apparatus that was constructed at the University of Memphis (see figure 4 Appendix B).

Langer. *Fluid Mechanics and Dynamics Problem Solver,* Research and Education Association, New York, 1983.
I used this reference for investigating applications of Bernoulli's equation.

Mott, Robert L., *Applied Fluid Mechanics*. 5th ed., Prentice Hall, New Jersey, 2000.
I used this reference for summary of variables and reference to Bernoulli's equation. Also, this book had visual data that could be incorporated into this report.

Sabersky, Rolf H., *A First Course in Fluid Mechanics*. 4th ed., Prentice Hall, New Jersey, 1999.
I used this reference for summary of variables and reference to Bernoulli's equation.

Thomas Register, October 2002.
http://www.thomasregister.com/
This web site was utilized to research Laboratory equipment companies. This site offered hundreds of links and was easily used.

United States Patent and Trademark Office, October 2002.
http://www.USPTO.gov
I used this web site to search for patented or trademarked equipment for the Bernoulli laboratory station. This site is the official government site for all registered trademarks and patents.

APPENDIX B Customer Survey

For the purpose evaluating student requirements for a new lab procedure for verifying Bernoulli's equation and utilization of dimensional analysis, the following survey is being issued. This survey will be helpful in the design, operation and efficient use of lab time.

Please evaluate the following statements and circle the response that most accurately agrees with your level of agreement.

1 = Strongly Agree 2 = Disagree 3 = Neutral 4 = Agree 5 = Strongly Agree

1) In general, do lab experiments help the student with the class work (i.e. Homework)?

1 2 3 4 5

2) Should the lab experiment help the student understand classroom theory?

1 2 3 4 5

3) Have you ever been confused about the purpose behind the labs you have completed?

1 2 3 4 5

4) The lab experiment must be capable of being completed in one class period.

1 2 3 4 5

5) Is the accuracy of the collected data important (i.e. +-10%)?

1 2 3 4 5

6) Is it important for the student to apply dimensional analysis to real applications?

1 2 3 4 5

7) For a greater understanding of dependant or independent experimental variables, is it important for the student to have the ability to alter experimental settings?

1 2 3 4 5

Are there any suggestions for improving the labs process before this experiment is designed?

Figure 12 Customer Survey

APPENDIX C House of Quality

Customer Requirements (What) \ Design Requirements (How)		Detailed Laboratory Procedure	Coordinate Classroom Lecture Material To Laboratory	Demonstrate Formulae Used in Class	Design Lab Run in Alloted Class Time	Easy to Read Scale	Repeatable Data	Adjustable Orifices	Dimensional Analysis Instructions	Minimal Setup	Low Maintenance	Customer Rating: Importance (1-5)	Customer Rating: New Laboratory	Customer Rating: Sales Point	Customer Rating: Modified Importance
Performance	Eliminate Laboratory Confusion	9	9	3			9		3			5	5	1	25.00
	Demonstration of Classroom Theory		9	9								3	5	1	15.00
	Improve Classroom Knowledge	1	9	9				3				3	3	1	9.00
	Run Lab in alloted class time	9				3	3	3		9	3	4	5	1	20.00
Data Acquisition	Easily Obtained	3	3	1	3	9	9		3			5	5	1	25.00
	Useful Information	3	3				9		9			5	4	1	20.00
	Variable Experimental Settings							9		3		2	3	1	6.00
	Perform Dimensional Analysis	3							9			1	4	1	4.00
Technical Importance		561	576	316	75	285	690	87	366	180	60				
Order of Importance		3	2	5	9	6	1	8	4	7	10				

Figure 13 House of Quality

APPENDIX D Bernoulli Equation

$$\frac{p_1}{\rho g} + \frac{V^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{V_2^{\ 2}}{2g} + z_2$$

Figure 14 Bernoulli Equation

p_1 = pressure at point 1

p_2 = pressure at point 2

ρ = density of the fluid

g = acceleration due to gravity

V_1 = velocity of the fluid at point 1

V_2 = velocity of the fluid at point 2

z_1 = elevation head of the fluid at point 1

z_2 = elevation head of the fluid at point 2

$\frac{V_1^2}{2g}$ = Velocity head

$\frac{p_1}{\rho g}$ = Pressure head

Figure 15 Bernoulli Equation Variables

APPENDIX E Fluid Flow in Pipes

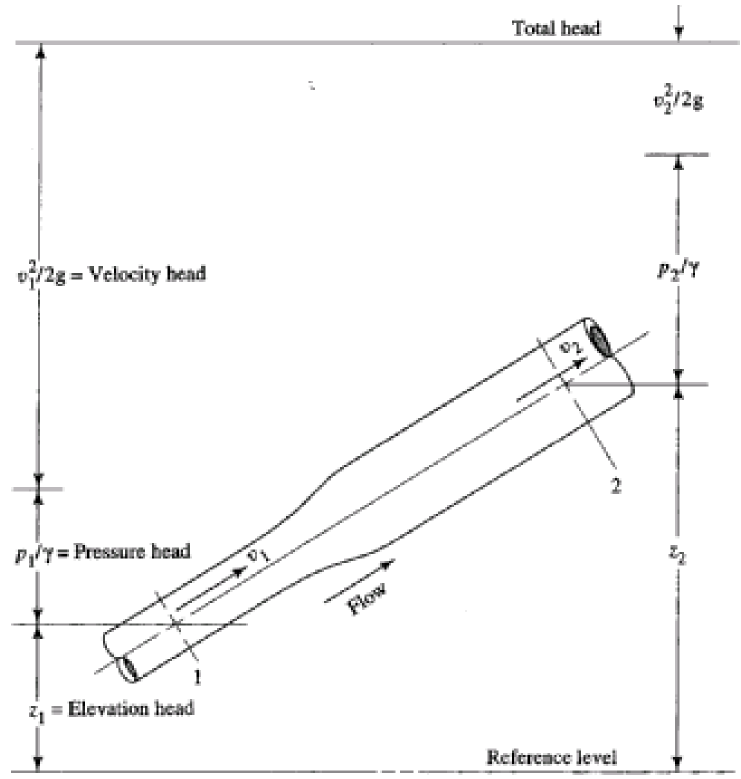

Figure 16 Bernoulli Fluid Flow in Pipes

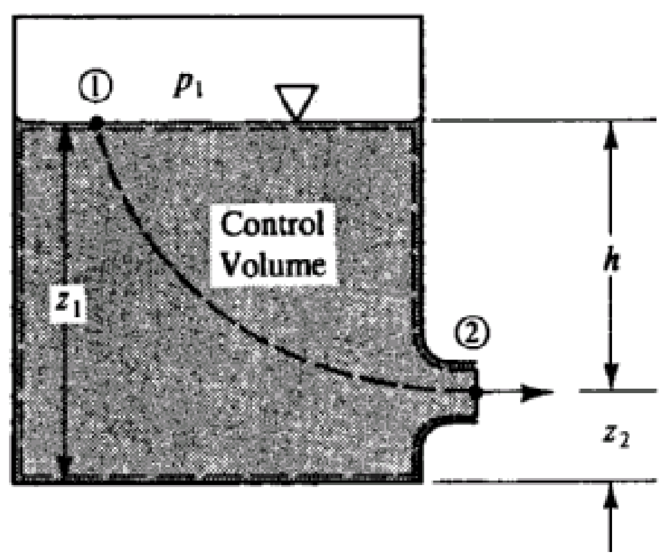

Figure 17 Bernoulli Variable Locations

APPENDIX F Original Design Concept Variable Location

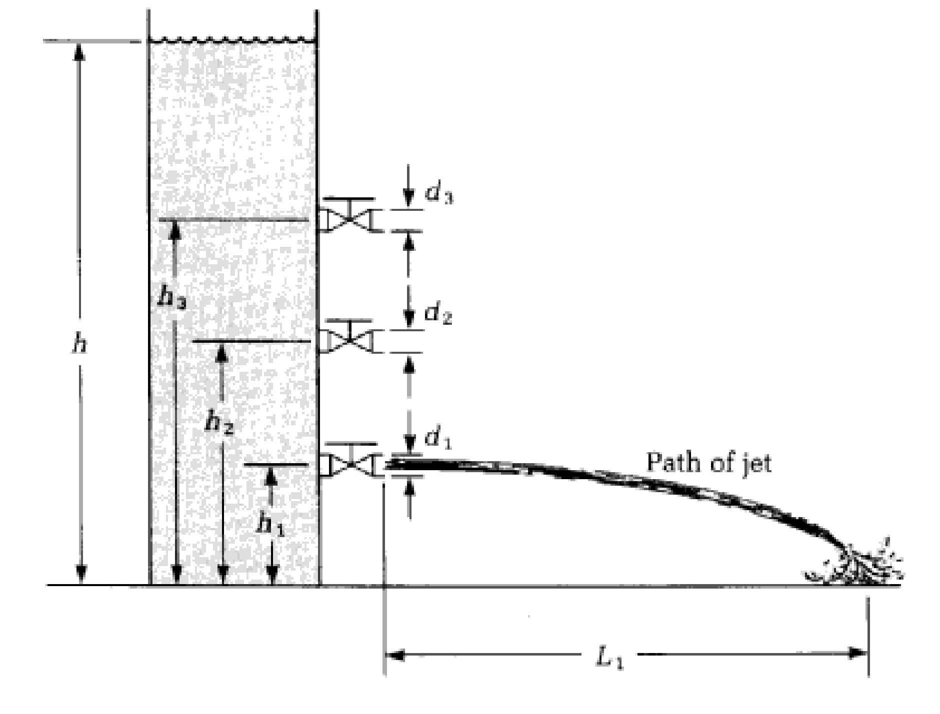

Figure 18 Original Design Concept Variable Location

APPENDIX G Bernoulli/Torricelli Calculations

$$V = \sqrt{2gh}$$

$$V = \sqrt{2 * 32.2 \frac{ft}{s^2} * 6\, ft}$$

$$V = 19.657 \frac{ft}{s}$$

$$t = \sqrt{\frac{2h}{g}}$$

$$t = \sqrt{\frac{2 * 1\, ft}{32.2 \frac{ft}{s^2}}}$$

$$t = .249 s$$

$$dis\tan ce = Vt$$

$$d = 19.567 \frac{ft}{s} * .249 s$$

$$d = 4.899\, ft$$

Figure 19 Torricelli Calculations

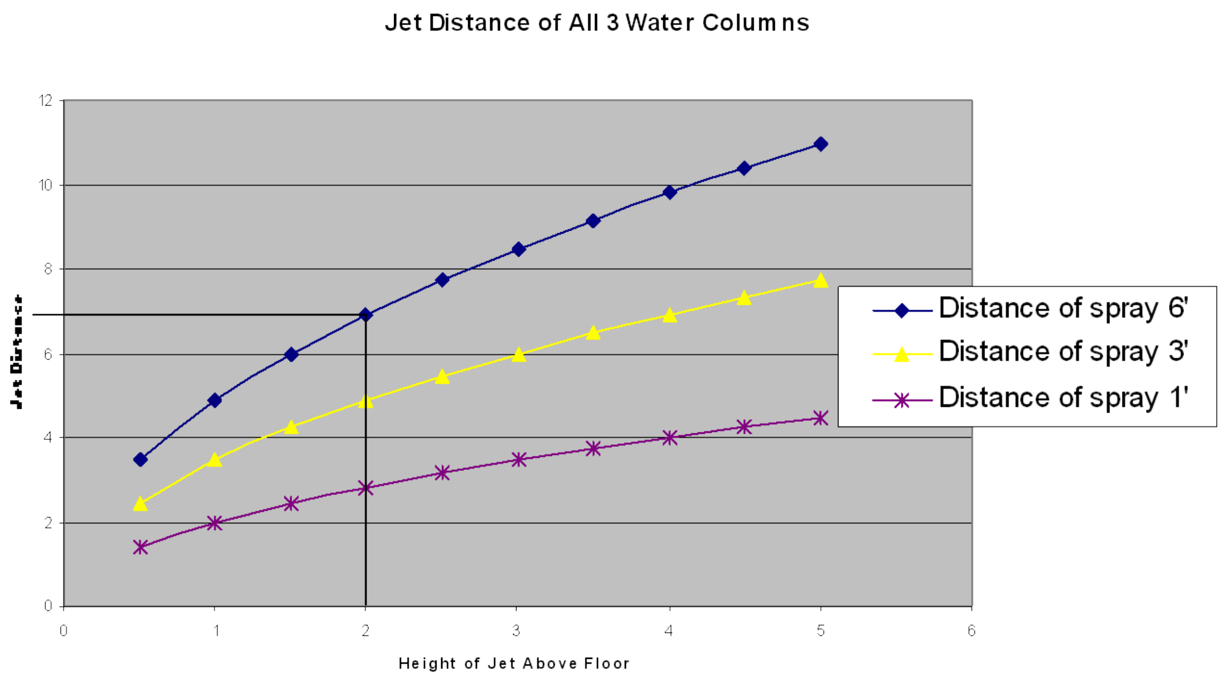

Figure 20 Water Jet Distance Profile

APPENDIX H Pugh Matrix

Survey Criterion	Alternative Design #1	Alternative Design #2	Alternative Design #3
Eliminate laboratory Confusion	**-**	**-**	**-**
Data easily obtained	**S**	**S**	**+**
Laboratory experiment easily run in allotted Class time	**+**	**+**	**+**
Laboratory data provides useful information	**S**	**S**	**S**
Laboratory demonstrates classroom Theory	**+**	**+**	**+**
€+	**2**	**2**	**3**
€-	**1**	**1**	**1**
€ S	**2**	**2**	**1**

Figure 21 Pugh Matrix

APPENDIX I Original BOM

Part Description	Supplier	Part #	Quanity	Price	Total Cost
Clear Rigid 8" PVC	Harrington Plastics	400CL-080H	12 ft	$50.00 per foot	$ 600.00
Cap 8" PVC	Harrington Plastics	447-080	1	$51.20	$51.20
Clear Rigid 4" PVC	Harrington Plastics	400CL-040H	12 ft	$ 25.11	$ 301.32
Cap 4" PVC	Harrington Plastics	447-040	1	$8.48	$8.48
PVC 4"	Home Depot		8 ft	Donated	Donated
Cap PVC 4"	Home Depot		1	Donated	Donated
1/2" Brass short Nipple	Home Depot	48643071551	5	$1.63	$8.15
1/2" valve	Home Depot	434646	5	$5.97	$29.85
Polyflex 50 tubing	Harrington Plastics	875-4281	1	$21.00	$21.00
Pipe Connector	Harrington Plastics	P4MC2	5	$2.05	$10.25
Clic Pipe Hanger	Harrington Plastics	113CLIC	3	$11.00	$33.00
Clic Stud	Harrington Plastics	LT-103CLIC	3	$0.26	$0.78
3/4"*4'*8' MDO Board	Home Depot		1	$50.00	$50.00
12' Bench Tape	Grainger Supply	5MG46	1	$9.30	$9.30
Superstrut Channel, Non-slotted	Grainger Supply	4A975	10	$27.68	$276.80
Superstrut90 deg. Fitting	Grainger Supply	4A979	16	$1.24	$19.84
Superstrut 90 degree, 7-hole	Grainger Supply	4A981	4	$4.35	$17.40
Superstrut Nut	Grainger Supply	4A986	1	$18.79	$18.79
Superstrut Hex Head Screws	Grainger Supply	4A987	1	$10.52	$10.52
S&W Leveling Pads	Grainger Supply	5VM99	4	$5.11	$20.44
Casters	Grainger Supply	1G302	2	$6.85	$13.70
Casters	Grainger Supply	2G311	2	$13.24	$26.48
Garden Hose, 50'	Home Depot		1	$25.00	$25.00
Labeling/Misc			1	$50.00	$50.00
Paint				Donated	Donated
Six Copies of Report	Kinkos		6	$10.00	$60.00
				Grand Total	$ 1,662.30

Table 4 Original BOM

APPENDIX J Final BOM

Part Description	Supplier	Part #	Quanity	Cost
Clear Rigid 8" PVC	Harrington Plastics	400CL-080H	10 ft	$ 384.80
Cap 8" PVC	Harrington Plastics	447-080	1	$ 22.55
Clear Rigid 4" PVC	Harrington Plastics	400CL-040H	10 ft	$ 150.60
Cap 4" PVC	Harrington Plastics	447-040	1	$ 3.75
Polyflex 50 tubing	Harrington Plastics	875-4281	1	$ 9.00
Pipe Connector	Harrington Plastics	P4MC2	5	$ 4.55
Clic Pipe Hanger	Harrington Plastics	113CLIC	3	$ 33.00
Clic Stud	Harrington Plastics	LT-103CLIC	3	$ 0.78
Freight				$ 100.00
			Total	**$ 709.03**

Cap PVC 4"	Home Depot		2	
5/16" SS Eyebolts	Home Depot		8	3.76
Wire Rope & Fastners	Home Depot		1	21.52
Misc nuts & Washers	Home Depot		1	25.5
3/4" PVC "T"	Ferguson Supply	P80STF	4	5.84
20' 3/4" schd 80	Ferguson Supply	P80SCF	1	9.15
3/4" coupling	Ferguson Supply	P80SCF	1	1.65
1-1/2"*3/4" Bushing	Ferguson Supply	P80SBJF	1	2.65
1" Brass Nipple	Ferguson Supply	BRNGL	1	3.28
Sonic measure	Home Depot	42186584295	1	29.97
3/4" vavle	Home Depot	32888074949	1	7.98
3/4" Brass short nipple	Home Depot	486430782849	1	1.53
1/2" Brass short Nipple	Home Depot	48643071551	5	6.8
1/2" valve	Home Depot	434646	5	29.9
3/4"*4'*8' MDO Board	Home Depot		1	18.99
S&W Leveling Pads	Grainger Supply	5VM99	4	15.92
Casters	Harbour Freight	1G302	4	27.96
Garden Hose, 50'	Home Depot		1	
Labeling/Misc			1	
Paint	Donated			
Six Copies of Report	Kinkos		6	
			Total	**$ 212.40**
			Grand Total	$ 921.43

Table 5 Final BOM

APPEDNIX K Project Schedule

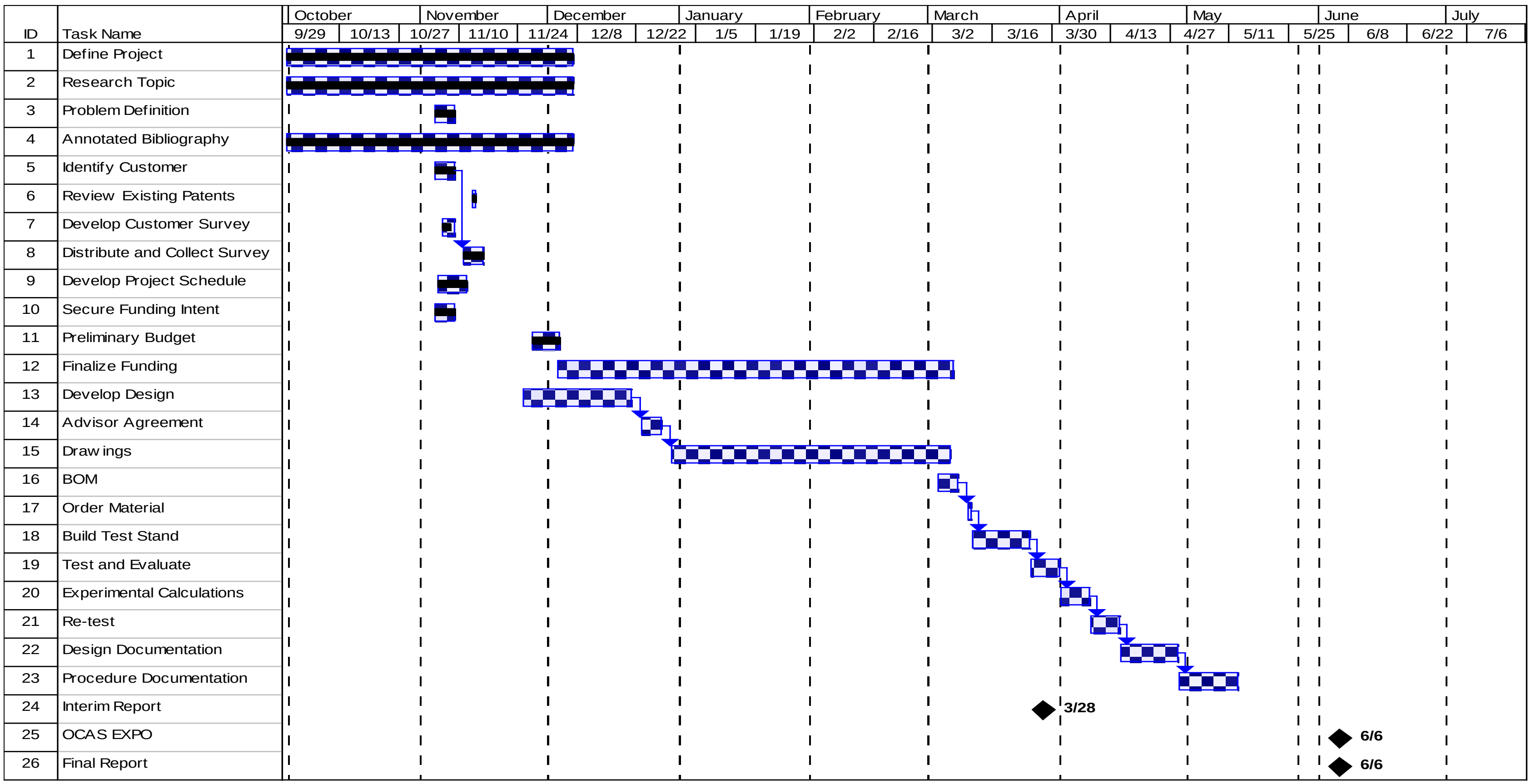

Figure 22 Project Schedule

APPENDIX L Jet Distance Test Data from New Laboratory

	Head Height (Meter)				
Test #	0.3048	0.6858	1.0668	1.4478	1.8288
1	1.28	1.7	1.86	1.68	1.28
2	1.28	1.69	1.86	1.69	1.28
3	1.29	1.69	1.86	1.68	1.29
4	1.28	1.68	1.86	1.69	1.29
5	1.27	1.69	1.86	1.67	1.29
6	1.28	1.69	1.86	1.68	1.29
7	1.28	1.69	1.86	1.68	1.3
8	1.29	1.69	1.86	1.68	1.29
9	1.27	1.69	1.86	1.67	1.29
10	1.28	1.69	1.86	1.68	1.3

Table 6 Jet Distance Test Data from New Laboratory Station

APPENDIX M Dimensional Analysis Calculations

$L(h_1, h_2, V, \mu, \rho)$

Where h_1 is the head height

h_2 is the drop height from the orifice to the measuring plane

V is the fluid velocity at the orifice opening

μ is the viscosity

ρ is the fluid density

$$L = C_1 h_1^{a1} h_2^{a2} V^{a3} \mu^{a4} \rho^{a5}$$

$$L = C_1 L_1^{a1} L_2^{a2} (\frac{L}{T})^{a3} (\frac{M}{LT})^{a4} (\frac{M}{L^3})^{a5}$$

$$M : 0 = a_4 + a_5$$

$$L : 1 = a_1 + a_2 + a_3 - a_4 - 3a_5$$

$$T : 0 = -a_3 - a_4$$

So we can say that $a_5 = -a_4$ and $a_3 = -a_4$

By sustitution :

$$1 = a_1 + a_2 - a_4 - a_4 + 3a_4$$

$$1 = a_1 + a_2 + a_4$$

or $a_1 = a_2 + a_4 - 1$

$$L = C_1 h_1^{a_2 + a_4 - 1} h_2^{a_2} V^{-a_4} \mu^{a_4} \rho^{-a_4}$$

$$L = C_1 \frac{h_1^{a_2} h_1^{a4}}{h_1} h_2^{a_2} \frac{1}{V^{a_4}} \mu^{a_4} \frac{1}{\rho^{a_4}}$$

Group like terms

$$L = C_1 \frac{1}{h_1} h_1^{a_2} h_2^{a_2} \frac{h_1^{a_4} \mu^{a_4}}{V^{a_4} \rho^{a_4}}$$

or

$$L * h_1 = C_1 (h_1 h_2)^{a_2} (\frac{h_1 \mu}{V \rho})^{a_4}$$

Figure 23 Dimensional Analysis Calculations

APPENDIX N Operation Procedures for New Laboratory Station

Purpose

To provide the CAS students a laboratory experiment to test Bernoulli's equation.

$$\frac{p_1}{\rho g} + \frac{V^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{V_2{}^2}{2g} + z_2$$

p_1 = pressure at point 1

p_2 = pressure at point 2

ρ = density of the fluid

g = acceleration due to gravity

V_1 = velocity of the fluid at point 1

V_2 = velocity of the fluid at point 2

z_1 = elevation head of the fluid at point 1

z_2 = elevation head of the fluid at point 2

$\frac{V_1^2}{2g}$ = Velocity head

$\frac{p_1}{\rho g}$ = Pressure head

Objectives

Utilizing the Bernoulli equation, determine the correlation of theoretical water jet distance to actual laboratory results

Utilizing the current textbook dimensional analysis methods, derive an equation that predicts the water jet's distance.

Theory

When dealing with the fluid mechanics of incompressible fluids, Bernoulli's equation explains the system. According to Robert Mott, "Bernoulli's equation is used to determine values of pressure head, elevation head and velocity head change as a fluid moves through a system." The observer should note that as fluid moves from point one to point two, the value or magnitude of the term increases or decreases; however, "if no energy is lost or added to the head, the total head remains at a constant level."

When working with Bernoulli's equation, the chosen reference point must be expressed in the same pressure terms. The various pressures must be resolved into either gauge or absolute pressures. Most situations in the laboratory or real world allow for the utilization of gauge pressure. In turn, the result is the exposed area's pressure reading is represented as a net zero pressure.

In order to apply Bernoulli's equation to a system, several conditions must be met. According to Robert Mott, the limitations are as follows:

- "It is only valid for incompressible fluids since the specific weight of the fluid is assumed to be the same at the two sections of interest.
- There can be no mechanical devices between the two sections of interest that would add energy to or remove energy from the system, since the equation states that the total energy in the fluid is constant.
- There can be no heat transferred into or out of the fluid.
- There can be no energy lost due to friction."

No system would likely meet all of these requirements. In the case of this new laboratory station design it met the first two requirements. By design there were no additions of mechanical devices, and the incompressible fluid was water. The last two conditions can only be theorized. In practical applications, losses stemming from friction and heat transfer are always introduced.

Referring to figure 1 below, one can see that the surface of the fluid is at height *h* from the centerline of the orifice or opening. Additionally, P_1 and P_2 are taken from their respective points at point 1 and point 2 and the same holds true for v_1 and v_2. Upon inspection of the system, parameters may be eliminated and others may be solved. In the case of a reservoir or large open container, several factors hold true:

- By using an atmospheric reference, P_1 = 0 psig, leading to $\frac{P_1}{\rho g} = 0$.
- Because the surface area of the reservoir or open container is large relative to the area of the orifice, and h will remain constant, v_1 can be considered to be 0. This event leads to $\frac{v_1^2}{2g} = 0$.
- In an ideal fluid condition, there is no head loss resulting in Bernoulli's equation reducing to $v_2 = \sqrt{2gh}$. This reduction is known as Torricelli's theorem.

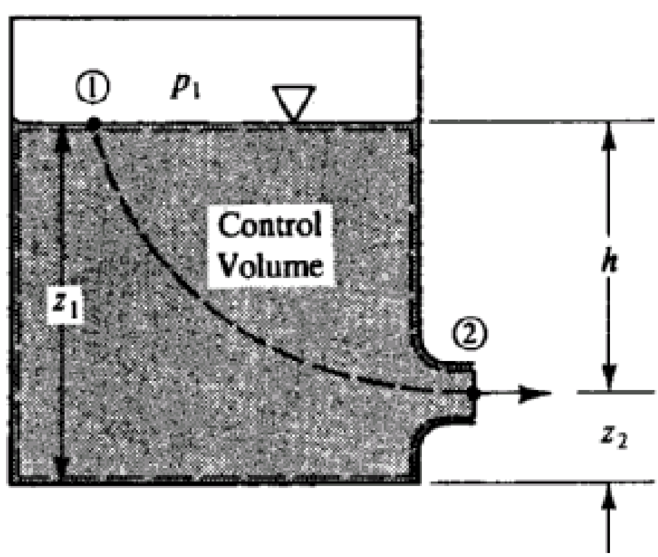

figure 1

After 200 years of validation, Bernoulli's concepts and theories are still applicable. The velocity of a fluid flowing from an open container while head pressure remains constant is $v_2 = \sqrt{2gh}$. This calculation coupled with the basic physics concept of a body in fall produces the jet spray.

Procedure
1) Connect the water tank fill hose to the water supply located on the wall.
2) Make sure the water hose is attached to the fill valve located on the bottom of the water tank.
3) Turn on the water supply valve then turn on the fill valve in the bottom of the water tank.
4) After filling the water tank to its overflow level, open the bottom water outlet.
5) Slide the measuring apparatus to the spot where the water jet flows through the opening.
6) Turn off the water to refill the system.
7) Once the system has reached equilibrium turn on the same valve.
8) Readjust the measuring apparatus so the water flows into the middle of the opening and turn off the water.
9) Once the system has reached equilibrium turn on the same valve and check for alignment.
10) Turn off water and turn on Zircon measuring device (refer to figure 2). If meter is not set for length in meters, depress the "ft/m" button to change. Also, depress the "line" button located to the left of the "ft/m" button. Depress the "read" button and record the jet distance.
11) Repeat steps 1 through 7 and record all fivejet distances.
12) Turn off Zircon measuring device.
13) Turn off tank fill valve.
14) Before completing the next step, MAKE SURE the water supply valve on the wall is OFF!
15) Disconnect the water supply hose from the wall connection and place it in the floor drain.
16) Turn on the water fill valve located on the bottom of the water tank. This will drain the tank.

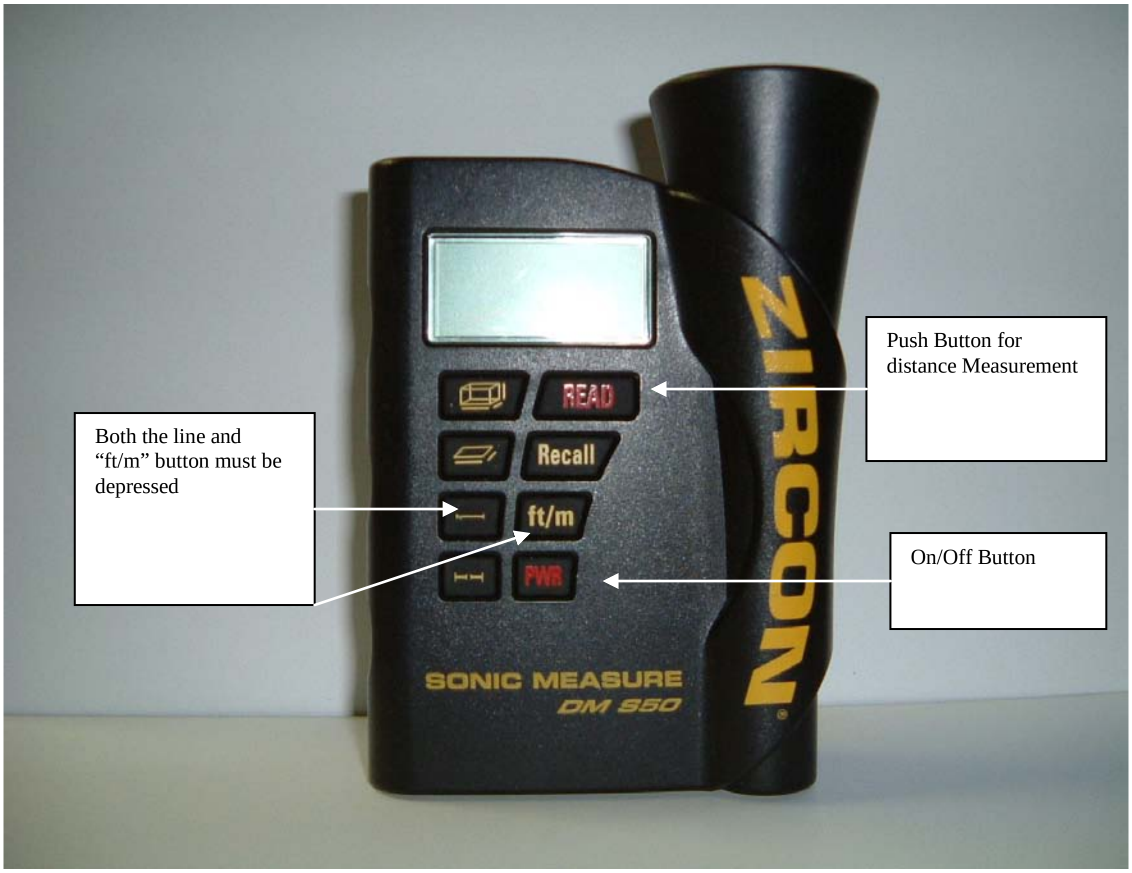
Push Button for
distance Measurement
Both the line and
"ft/m" button must be
depressed
On/Off Button
READ
Recall
ft/m
PWR
ZIRCON
SONIC MEASURE
DM S50

figure 2

6. REFERENCES

[1] Mott, Robert L. *Applied Fluid Mechanics*, 5th ed., Prentice Hall, New Jersey, 2000, p160.

[2] Mott, Robert L. *Applied Fluid Mechanics*, 5th ed., Prentice Hall, New Jersey, 2000, p160.

[3] Mott, Robert L. *Applied Fluid Mechanics*, 5th ed., Prentice Hall, New Jersey, 2000, p160.

[4] Mott, Robert L. *Applied Fluid Mechanics*, 5th ed., Prentice Hall, New Jersey, 2000, p161.

[5] Janna, William S. *Introduction to Fluid Mechanics*, 3rd ed., PWS Publishing Co., Boston, 1993, p206.