Enhancing MET Education: Innovation through Laboratory Equipment Development

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Introduction

Senior Design Capstone courses provide a hands-on learning environment where students gain valuable experience in project management, collaboration, problem-solving, and technical expertise. They learn to work as part of a team, making decisions about design, materials, and manufacturing processes. The students apply technical skills to practical scenarios, refining their engineering expertise in a real-world context, making connections with local communities or industries, and making them well-prepared and highly competitive in the workforce [1 - 7]. Design projects offer students a great opportunity to bridge the gap between classroom knowledge and real-world applications, enhancing their academic experience and preparing them for the workforce. From the faculty perspective, support ABET assessment [6, 8]

Furthermore, capstone projects offer the opportunity to drive advancements in the improvement, design, or refurbishment of laboratory equipment [1, 9-11]. The outcomes of these capstone projects can lead to tangible enhancements in laboratory equipment, improving functionality, accuracy, and overall effectiveness. Consequently, this contributes to the continuous improvement of educational resources within engineering programs, fostering a more robust and modern teaching environment, and providing engineering students with cutting-edge resources.

Through the integration of capstone projects centered on equipment improvements, and guided by faculty teaching respective courses, students engage in a comprehensive learning experience that goes beyond theoretical understanding. They are required to conduct in-depth research of the existing laboratory setup(s) identifying inefficiencies, technical limitations, and areas for improvement. Alternatively, their expertise can be used to design and create new lab setups along with corresponding lab guidance manuals. This hands-on approach allows students to apply their academic knowledge and cultivate critical thinking, problem-solving, teamwork, and leadership skills necessary to address complex, real-life problems. Furthermore, team collaboration on these projects mirrors a professional engineering environment, effectively preparing our students for their future workplace [11].

This paper aims only to showcase two senior capstone projects dedicated to developing hands-on laboratory demonstration units for fluid mechanics laboratories. It explores the challenges encountered by students in constructing functional prototypes and offers suggestions for future improvements. These two projects offer a cost-effective alternative to the expensive demonstration units available on the market.

Site and participants

Study Site: The site is the Engineering Technology Department (ET) in the College of Engineering (COE) at The University of Toledo. The ET Department offers five ABET-accredited Bachelor of Science (BS) in engineering technology programs, including Mechanical Engineering Technology. Historically, the student body is comprised of traditional students, transfer students, and non-traditional students, all bringing a variety of engineering skills and lifelong learning experiences to the ET Department.

Most core courses within the Mechanical Engineering Technology (MET) program are structured as 4 credit-hour (ch) courses, comprising a 3ch lecture and a 1-ch laboratory component. These one-credit hour laboratories incorporate diverse elements, including hands-on measurement, data acquisition, data analysis, interpretation, and technical reporting. They heavily rely not only on computer applications and software but, more significantly, on cutting-edge hands-on laboratory equipment. Unfortunately, challenges such as reduced funding and aging equipment may compromise the quality of the student lab experience. These laboratory components are pivotal for our engineering students, providing a profound understanding of discussed concepts and serving as a platform for experimentation, collaboration, and simulation of real-life applications. Exposure to laboratory experiences fosters skills such as measurement and data analysis, attention to detail and teamwork, etc., all crucial in a professional engineering setting. A study from the National Academy of Engineering further highlights the significance of "hands-on experiential knowledge of how things work..." [12]. Consequently, applying theoretical knowledge to practical scenarios, including through laboratory experiences, plays a pivotal role in preparing students for the dynamic challenges they will face in their workplaces.

The MET program currently houses two hands-on laboratories, with one specifically designed for material science and strengths of materials, and the other dedicated to thermodynamics and fluid mechanics. Both authors specialize in teaching within the thermal fluids focus area, and consequently, the proposed lab enhancements discussed herein primarily focus on the latter laboratory.

The course: GNEN 4050 Senior Technology Capstone. The ET Department offers the course to all students in its five programs. Traditionally, students are advised to take this course during their final semester. As per the course catalog description, the course offers students the chance to collaborate in a team setting to address design challenges and apply critical thinking skills. Throughout the term, students will reach design conclusions and present their work professionally at the Senior Design and Undergraduate Research Expo. The students expect to demonstrate substantial individual contributions to their team's project and to apply in their work design thinking strategies, focusing on effectiveness, material selection, ergonomics, safety, cost, environmental impact, ethics, and production efficiency.

The course objectives are in harmony with the five ABET criteria for Engineering Technology, specifically Criterion 3 Student Outcomes for baccalaureate degree programs, and Criterion 5 Curriculum Discipline Specific Content C, D, E, and Other Content, including encompassing areas such as professional and ethical responsibilities, diversity and inclusion awareness, quality, and continuous improvement [8]. Throughout the semester, the curriculum addresses various topics, including but not limited to: Value Engineering, Marketability, Value Added Design, Presentation Skills, Public Speaking, Budget Development, Ethics, Intellectual Property Overview, Resume Development, and Professional Appearance.

The distinguishing feature of the ET Department Capstone course, as opposed to those offered by the science departments, for example, lies in its inclusivity across all five programs: computer science for ET, construction ET, electrical ET, IT, and mechanical ET. This ensures that students from diverse technical backgrounds, possessing varied knowledge, skills, and experiences, are enrolled in the course simultaneously. Consequently, most teams are assembled with a mix of skills and knowledge, cultivating a dynamic collaborative setting. However, certain teams opt to comprise members exclusively from the same program, particularly if the research topic is narrowly focused on that specific program. For example, in spring 2023, a total of 103 students were organized into 18 design teams, while during the fall of the same year, 52 students were organized into 10 teams. Every team receives guidance from a faculty member within the department. The teaching faculty is urging all faculty advisors to provide a comprehensive end-of-semester assessment for their respective teams, including individual student evaluations when applicable. The faculty advisor can assess either individual student or the team on 7 criteria, assigning scores from 0 (no effort at all) to 5 (very good) on: quality of work; problem solving skills; teamwork; function effectively as a team leader; communication; and time management. The faculty advisor can evaluate either individual students or the entire team based on seven criteria. Scores ranging from 0 (no effort at all) to 5 (very good) can be assigned for the following aspects: quality of work, problem-solving skills, teamwork, effectiveness as a team leader, communication, and time management.

In support of the prototype development, each team is provided with $200 in support. If there are additional expenses beyond this amount, students are encouraged to seek sponsorship from local businesses or the department.

Project 1

Title / Team structure / Term: Tabletop Wind Tunnel / 6 MET students / Spring 2023

The Problem: The MET program did not have a wind tunnel or any other flow visualization demonstration units to be used as part of fluid mechanics hands-on laboratories, and due to limited funds, it was difficult to purchase a new demonstration unit. The planned experiment aims to visualize flow dynamics, alongside demonstrating the pressure variance between the upper and lower regions of the wind within the testing zone.

Objective: Create a small-scale prototype for a wind tunnel to be used for flow visualization and small data collection.

Application: MET 4100 - Applied Fluid Mechanics laboratory exercise.

Design and Analysis Process:

1. Research the Topic. The team performed an in-depth search of existing demonstration units on the market and of the literature review, and a review of the fluid mechanics knowledge. The starting idea was based on the Gonzalez Hernandez' et al. paper [13]
2. Design Considerations.
    a. Due to small scale demonstration unit, the dimensions of the test chamber were 6"x6" with a twelve-inch length. The team concluded that this size would be small enough to keep the overall size compact while big enough to accommodate future experiments.

b. To determine an appropriate contraction ratio, the ratio of the wind tunnel inlet area to the test chamber's area. This value is critical to the wind tunnel's efficiency because it affects the volume of air drawn into the tunnel. A low contraction ratio causes a less efficient system, while a too high of a ratio will cause significant additional length. Based on the literature review, the team decided to use a contraction ratio of 7. This means that for our 6"x 6" test chamber, with an area of $36in^2$, requires an inlet area of $252in^2$, with in turn requires a 16"x 16" cross section of the tunnel's inlet, see Fig.1.

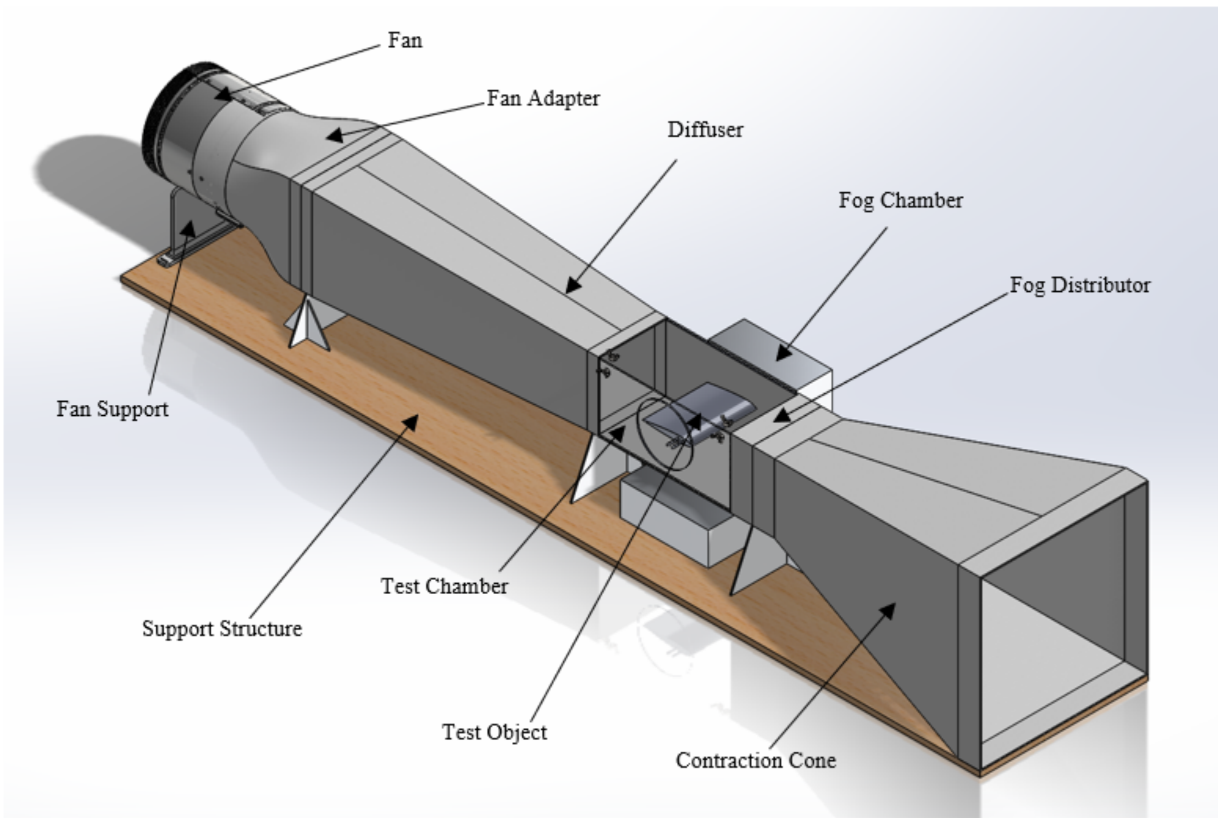
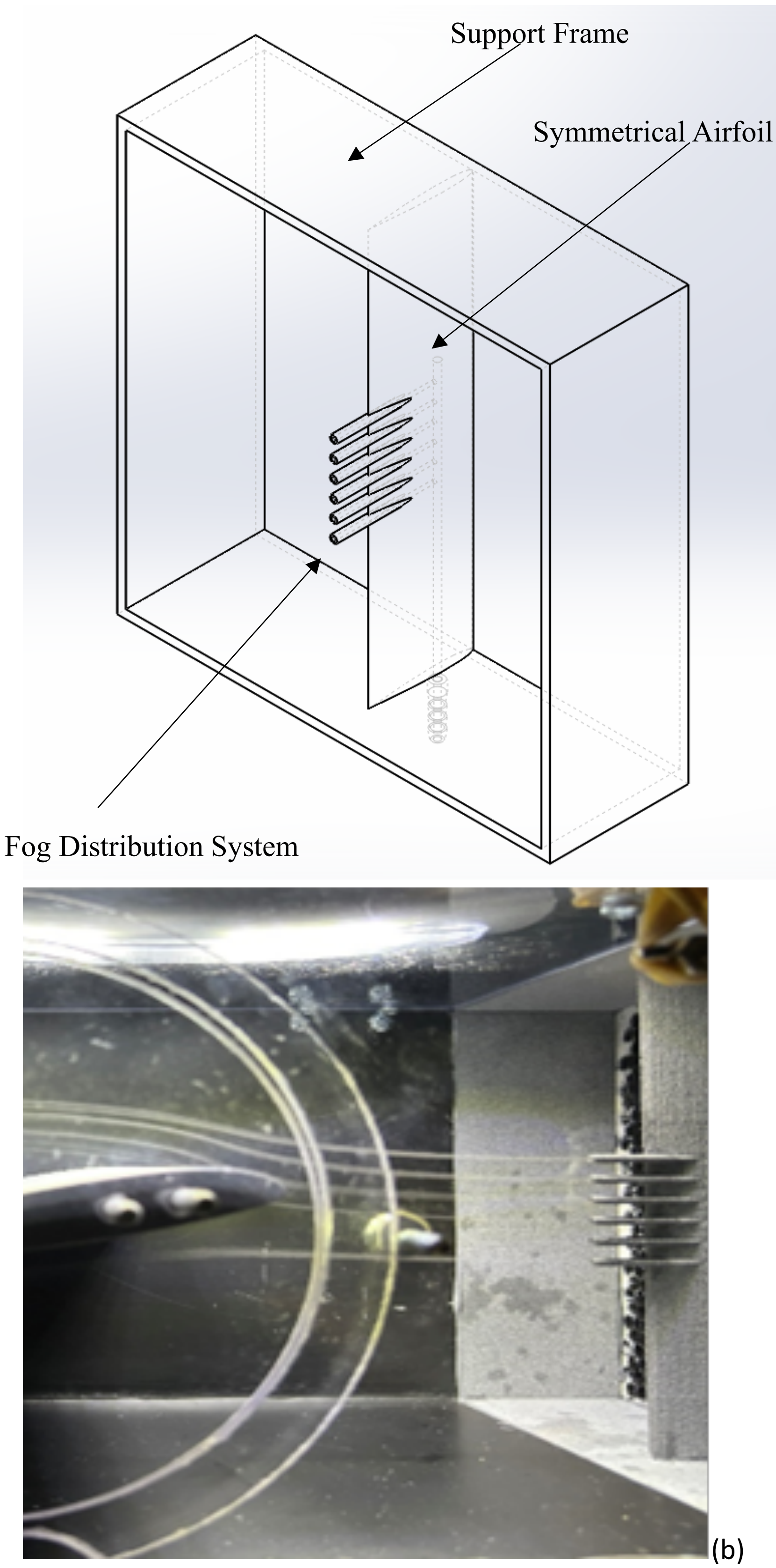


Figure 1. Initial Wind Tunnel Design

c. Maximum operating air speed was determined by the fan that the team could source for free, lowering the total project cost. The fan could generate 420 cfm of airflow through the tunnel, resulting in about 20 mph through the test chamber.
d. The diffuser and contraction cone were made of MaxMetal panels, joined using JB Weld Kwik-Weld, and sealed using high-strength silicone caulk. A rigid acrylic material was used for the test chamber, to allow visualization of the tests, and a combination of MaxMetal and plywood was used for the base of the chamber.
e. Four elements were required to be designed and 3D printed due to their complex geometry. These elements were designed in Dassault SolidWorks and include the fog trail generator, test object, fan adapter, and fan support. These models were then sent to be 3D printed at a local business, free of charge, using the powder bed fusion method (PBF). These 3D PBF printers melt layers of powder using a laser

and allow for extremely precise tolerances and more importantly, much higher strength parts. The PBF method also allows for finer finishing of parts. They can be easily sanded down to create extremely smooth surfaces while retaining their integrity.

f. Due to the powder used for the PBF printer, the two elements with small holes / tubing in them, airfoil, and fog distributor, had some issues with the holes being filled by the powder, so the team took some time after printing to manually clean up the holes with a highly specialized 3/64” diameter drill bit. Using this bit, unfortunately, added some unexpected extra time and an additional expense to the project.
g. Getting pressure data from the test object requires pressure taps. These taps are tiny holes drilled in a few locations of interest on the test object. This means the team could not simply purchase an airfoil but build it from scratch. The starting point was a standard NACA 23012 airfoil with two new distinct additions, pressure taps on both the top and bottom of the airfoil, so that a pressure difference can be observed and measured. created in the test. These taps needed to be as small as possible, so as not to disturb the airflow passing over and into them.
h. Pressure readings were possible using a LabQuest 2 system already in possession of the MET program, so no additional costs.
i. A 400W fogger was bought to produce high-density fog. However, the high temperature reached by the fog machine quickly melted the adhesive and the plastic tubing and would quickly condense inside the tubing and pool up. The solution was to fill a pre-chamber with the fog and force it through the tubing and into the test chamber. This increases our fog yield and slowly brings it towards room temperature, reducing the amount that is condensed on the walls of the tubing. The small amount of tubing that remained in between the fog chamber and the fog machine was replaced with automotive tubing, rated for high temperatures. High-strength silicone caulk was also used to fill any cracks in the structure.
j. Talking about fog distribution, multiple designs were required for the fog delivery system, see Fig.2. There were few resources available that described design and construction methods for a fog system such as ours, so this prototype was built from scratch and improved based on a trial-and-error strategy. The fog distributor was designed to be installed in line with the test chamber to supply fog streamlines form the shape of the fog lines. This part consists of a supporting frame consistent with the dimensions of the test chamber, a symmetrical airfoil to conceal the tubing inside, and the line generation tubes. Fog is forced through the tube on the inside of the vertical airfoil, and out of the horizontal tubes in the center. This final design proved to remain incredibly aerodynamic and produces consistent, fixed fog lines.



(a)

(b)

Figure 2. Fog Distribution System: (a) initial drawing; (b) final 3D printed element.

3. Final Prototype. This is a successful project finalized during one semester.

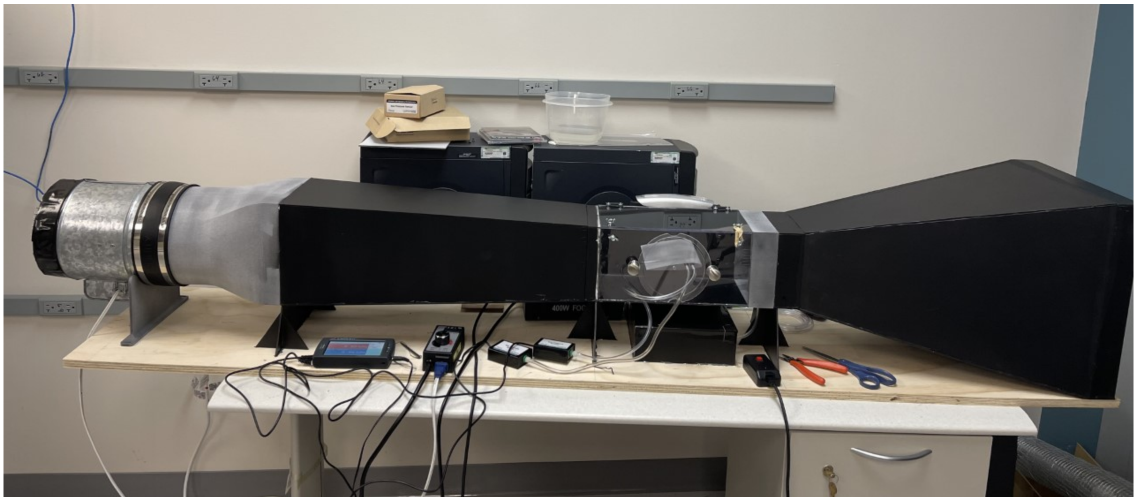


Figure 3. Tabletop Wind Tunnel Demonstration Unit.

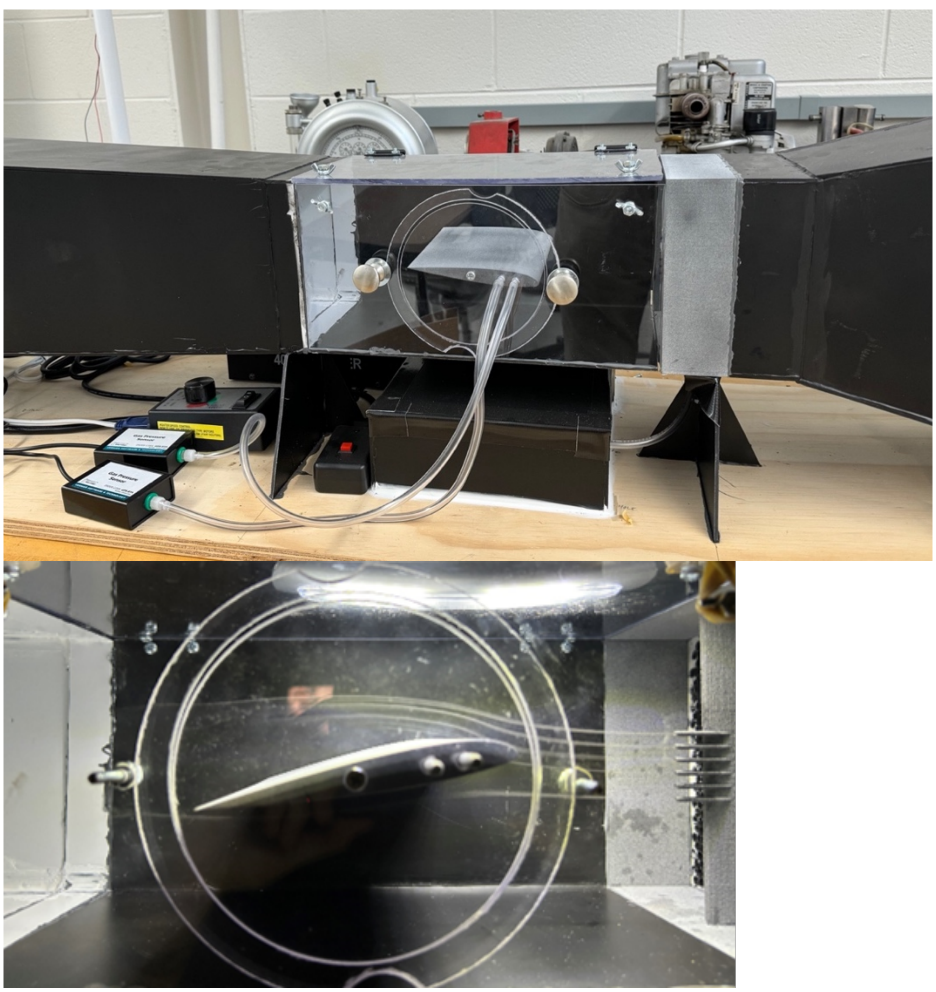


Figure 4. Test Chamber

Proposed Improvements. Create a larger demonstration unit that would include more fog trail tubes, giving a better visual effect. A larger unit will require a larger fan, and a larger expected wind speed and a larger pressure difference on the airfoil or on any other testing object. A larger model could have made additional test models such as a car model. Furter investigate the fog distribution system and install a streamlined fog system that would be easier to adjust and control the smoke trails in the test chamber.

Costs: Final: $186.36. Estimated value, without labor: $1367.71. Note that the difference between estimated and final was covered by various donations either in kind or monetary.

Project 2

Title / Team structure / Term: Enhancing the Fluid Lab Learning Tool for Students/ 6 MET students / Fall 2023

The Problem: The current fluid mechanics test bench is an archaic, small, demonstration unit that requires changing the test section for each laboratory exercise. This unit was used for Darcy's Equation, Orifice Plate, Friction Through Elbows, laboratories. as seen from Fig. 5. Unfortunately, this unit has multiple issues over the years, from yearly leaking and difficulty reading pressure data.

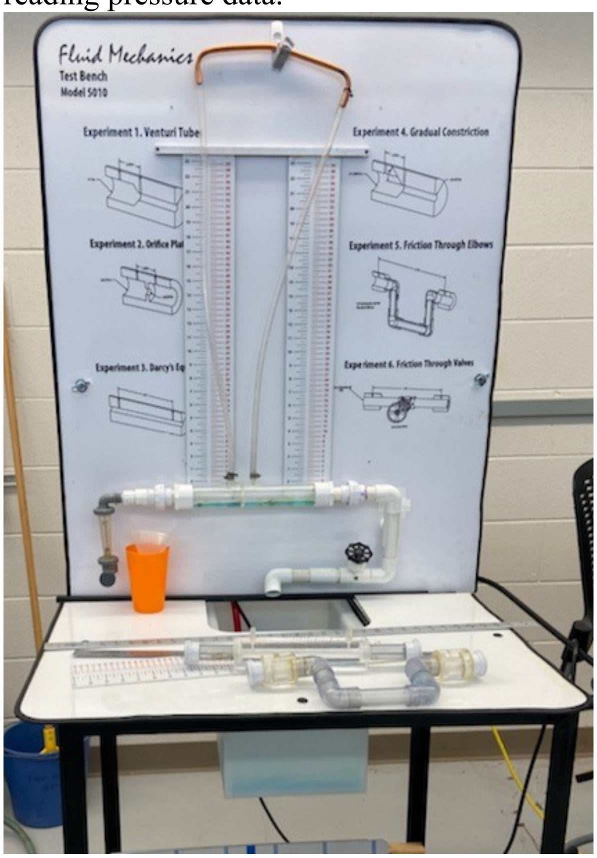


Figure 5. Existent Fluid Mechanics Test Bench

Objective: Create a new and improved fluid mechanics laboratory demonstration unit to replace the existing one.

Application: MET 4100 - Applied Fluid Mechanics laboratory exercise.

Design and Analysis Process:

1. Research the Topic. The team performed an internet search of fluid mechanics demonstration units observing various designed and measurement capabilities and reviewing the fundamental fluid mechanics knowledge of the fluid flow through pipelines.
2. Design Considerations.
    a. The goal was to create a test bench that can be used to demonstrate the losses through various pipelines and fittings. The initial design consisted of nine fluid lines: three of same diameter but different materials, three of different diameters but the same material, and three lines with different fittings. The costs associated with this first design exceeded $1,000, way above the team's allowance of $200.
    b. A decision was taken to reduce the number of lines from 9 to 5. In support of this decision was also the unit's weight, accessibility, and mobility.

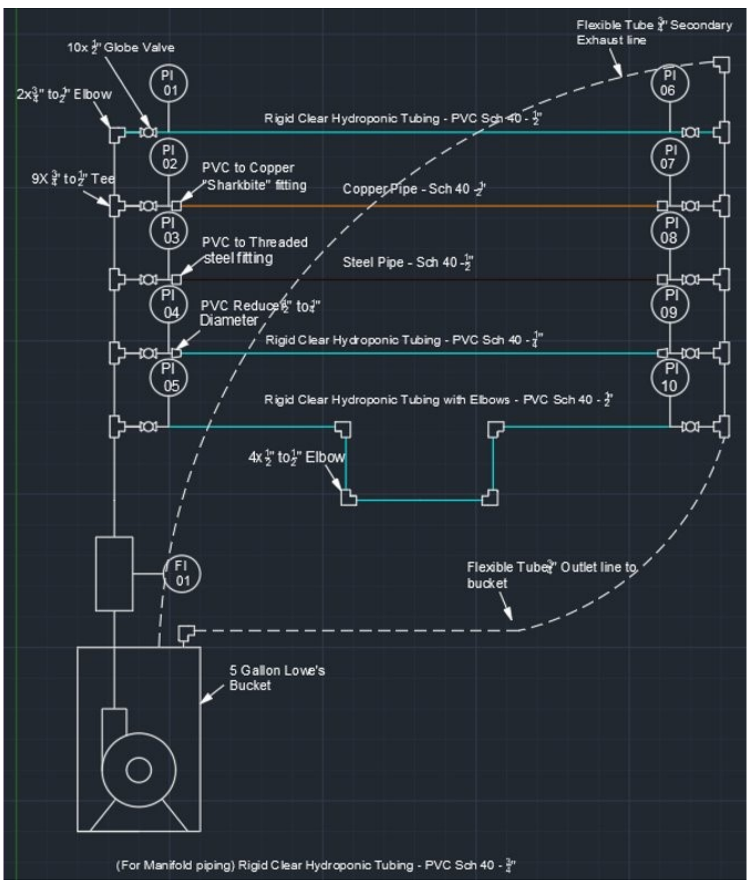


Figure 6. Final Draft

    c. Special attention was given to identifying the perfect pressure gauges and flowmeters for this job, as well as the associated expenses. The team utilized a pump available in the MET laboratory, which was generously donated for this test bench. Based on the pump's specifications, the team chose a manometer with a measurement range encompassing both the maximum and minimum pressures anticipated during pump operation. A comparable approach was taken in the selection of the flowmeter.

d. Working on such a project also requires considerable plumbing. Fortunately, one MET student had previous experience in this area, and he took initiative showing leadership and mentoring his team.

3. Final Prototype. This is a successful project. The final product is a 4' by 5.5' test bench holding five lines, each line ending with two pressures gauges and two valves, as seen from Fig. 7. The length of each line is measured between the pressure gauges, and details about this configuration are as follows:

    Line 1 (at top): ½" PVC Sch. 40 (49" length)
    Line 2: ½" (ID) Copper (52 3/8" length)
    Line 3: ½" (ID) Steel (53" length)
    Line 4: ¼" (ID) Vinyl Tube (53 ½" length)
    Line 5 (at bottom): ½" PVC Sch. 40 (68" length) with four standard 90^{o} elbows

    The suction and discharge lines are ¾" PVC Sch. 40

    This test bench can be used during several fluid mechanics laboratories, all covering laboratory exercise done using the old test bench, plus new ones, like the pipeline material's influence on the friction losses. Furthermore, the valves attached to either side of each line will enable further investigations transforming the unit from a series pipeline to a parallel flow.

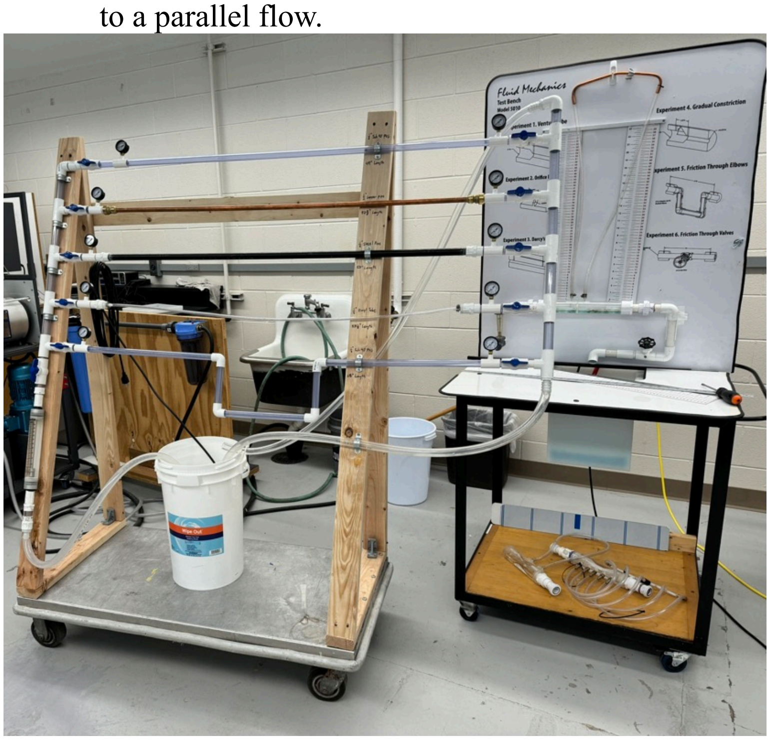


Figure 7. Fluid Laboratory Demonstration Unit

Proposed Improvements. Replace the existent flowmeter with a digital flowmeter for a more precise flow reading. In addition, investigate solutions to eliminating or treating the sitting water in the system so no mold builds up in the pipelines.

Costs: $504. The difference between the final cost and the $200 allowance was covered by various donations either in kind or monetary.

Conclusions

Both projects will be integrated into the curriculum for the Applied Fluid Mechanics course commencing in the fall semester of 2024. A subsequent paper will analyze the influence of these internally developed laboratory tools on the Mechanical Engineering Technology (MET) curriculum, along with the evaluations linked to each upcoming laboratory experiment.

In conclusion, the development and integration of in-house laboratory demonstration units have proven to be essential in enhancing our engineering technology students' content knowledge, fostering curiosity, creativity, promoting effective teamwork and collaboration while creating value for the program. These initiatives not only empower students with practical, hands-on experiences but also significantly contribute to the overall value of the department and the academic program they apply. The Senior Design Expo, held at the conclusion of each semester and open to the public, serves as a platform for engineering students to proudly display their innovative projects and the overall engineering skills they developed over the years. By proposing new topics for capstone projects that focuses on developing new educational tools, nationwide institutions not only enrich the learning experiences of their students but also prepare them for the real-world challenges expecting them in the field of engineering.

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