

Using the Capstone Senior Design Project to Retrofit or Design Laboratory Demonstration Units

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Abstract

As part of the rigorous curriculums for the Mechanical Engineering (MIME) and for the Mechanical Engineering Technology (MET) students, laboratory courses provide a critical component of the engineering education through hands-on observation, measurement, data acquisition, data analysis and interpretation, technical reporting, etc. The laboratory courses rely not just on computer applications and software, but most importantly on current, modern lab equipment. Reduced funding, combined with increased student population in engineering leading to more wear and tear of the existing equipment, can lead to less than optimal experience for the students in the lab. The College of Engineering at The University of Toledo has been continuously working on various means to avoid these pitfalls. This work describes some of the most significant experiences, including potential pitfalls, accumulated by the ET and MIME Departments through using the Capstone Senior Design Project course to retrofit or to design and build new equipment for the labs.

A first example was the retrofit of an Armfield FM10 Centrifugal Fan demonstration unit. This project was performed during the spring 2016 semester. The almost 20 year old laboratory equipment had not been operational for the past 10 years mostly due to a faulty membrane and air leakage. A group of four senior MET students took over this project, in which they assessed the equipment, redesigned and updated some of its components, calibrated and tested the equipment and developed an equipment manual. Currently the equipment is operational and has already been successfully used in the laboratory component of the Applied Fluid Mechanics course in summer semester 2016. In the MIME Department, a more complex project involving the design and building of a new small engine dynamometer was started by the group of four ME seniors and then continued the following term by an MS student.

These success stories determined the MET program to update two more Armfield laboratory units: the FM12 Centrifugal Compressor and the FM20 Centrifugal Pump Demonstration Units.

Keywords

Capstone, Mechanical Engineering, Mechanical Engineering Technology

Introduction

The Engineering Technology (ET) Department is the largest of the six academic departments in the College of Engineering at The University of Toledo. The Department offers ABET-accredited professional technical programs leading to the Bachelor of Science degree in four areas of study: Computer Science and Engineering Technology (CSET), Construction Engineering Technology (CET), Electrical Engineering Technology (EET), and Mechanical

Engineering Technology (MET). The Department also offers a Bachelor of Science degree in Information Technology (IT) in partnership with the College of Business and Innovation. Only seniors in their graduating semester are permitted to take the “Senior Technology Capstone” course, ENGT 4050. The three credit hour course is designed to provide each student with the opportunity to work in a team environment to solve design engineering problems and to utilize his/her critical thinking and knowledge in all engineering subjects. Each capstone team, usually made up of four or five students, work on a project proposed by either a faculty member, an industrial partner, or the team itself. Each team is guided by an experienced advisor, usually a faculty. The ET Department sponsors each team with \$200. During the semester, the students design and build a working prototype and make oral and professional presentations to their peers and to professionals at the Senior Design and Undergraduate Research Expo at term’s end. Each student is expected “to show evidence of significant individual contributions to team efforts, as well as due consideration of such design aspects as effectiveness, material selection, ergonomics, safety, cost, effect on the environment, ethics, ease of production, etc.” (from the ENGT 4050 course description)⁽¹⁾.

A similar course, entitled MIME 4200 “Senior Design Projects”, offered in engineering sciences by the Department of Mechanical, Industrial, and Manufacturing Engineering (MIME), provides engineering design experience for senior students organized in groups of 3 to 5 students.

Case Study No. 1 - Centrifugal Fan Lab

Background and Motivation

The project was done during the spring 2016 semester by a group of four mechanical engineering technology (MET) seniors (Team A-1). The project was proposed by the authors.

The Armfield FM10 Centrifugal Fan Demonstration Unit was originally acquired around 1997. At that time, the department was housed at a different University of Toledo campus, the Scott Park Campus. In 2007 the ET Department was relocated to the College of Engineering Main Campus. Throughout the years and probably during the move, the equipment was deteriorated and it has not been used for the past nine years. Since hands-on laboratory experience is always a necessity to complement the theory covered in classrooms and to provide a better-rounded curriculum, especially in the engineering fields, the authors salvaged the equipment and proposed to retrofit it by the means of a capstone project. Since May 2016, the FM10 Centrifugal Fan Lab has become part of the Applied Fluid Mechanics, MET 4100, course curriculum. A similar but new Centrifugal Fan Demonstration Unit is currently being sold by Armfield for more than \$15,000⁽²⁾.

Challenges and Solutions

At the beginning, the team was faced with the issue of not knowing which of the unit’s components were still operational and which had failed over the past several years. A considerable amount of time was spent in troubleshooting and deciding if the current equipment setup was best suited for manual readouts or for automatic data collection. One design idea for the rebuilding of the centrifugal fan was to incorporate new sensors, each with their independent

digital readout gages without the need of connecting them to a central data acquisition system. This design idea would make the equipment self-sufficient without the need of the original Armfield software. The digital readout equipment needed for this design included air speed sensors for the inlet and discharge tubes, a few differential pressure manometers, and a fan blade speed optical sensor. These devices would have been retrofitted to the existing equipment. Examples of potential sensors the students researched are illustrated in Figure 1.



Figure 1: Manometer, air speed, and velocity sensors

The second design option and the method that was implemented in the end was using the software provided by the original manufacturer. This software allowed the use of the original, standard sensors that came with the centrifugal fan setup. This design eliminated the need for retrofitting the equipment with newly purchased sensors, thus saving considerable school funding. However, this design solution required the original software that came with the equipment, which was not functional on current computers. This led to the second design challenge.

The second challenge was operating the 20 year old Armfield 16-bit software which does not run on the 64-bit versions of Windows installed on most university computers. In the end, the ET Department identified a computer running an older version of Windows and assigned it specifically to work with the Armfield demonstration units.

The third challenge was hardware related. The original demonstration unit had a manually operated adjustable aperture which enabled variable air flow rates. Over the years, the membrane cracked and could not be used anymore. Since orifice restrictions are needed to simulate different load values on the fan, the team investigated different solutions and, in the end, after analysis, the best one proved to be the use of pipe rubber caps cut to fixed increments of diameter size. These interchangeable rubber caps are designed to be easily attached to the discharge tube as shown in Figure 2. The smallest diameter is $\frac{1}{2}$ " , and increases by size increments of $\frac{1}{2}$ " to the largest of 2". By interchanging the rubber caps and using the automatic data-capturing software, the setup provides a functional equipment capable for student experimentation and study.



Figure 2: Orifice caps

The fourth challenge was software related. The demonstration unit was originally supplied with its own data acquisition software able to provide a selection of capabilities designed for a smooth operation and processing of the results. Unfortunately, the original installation disk was lost over time. The students were able to reach the Armfield Customer Support representative who provided the original software at no cost. The original software is now able to read all the original sensors (fan head pressure, orifice pressure, air temperature, fan speed, and motor power) and it is able to calculate the total pressure, flow rate, power output, and fan efficiency. Figure 3 shows a screenshot of the software. The collected data can be exported into an Excel file for future calculations required by the experimental report.

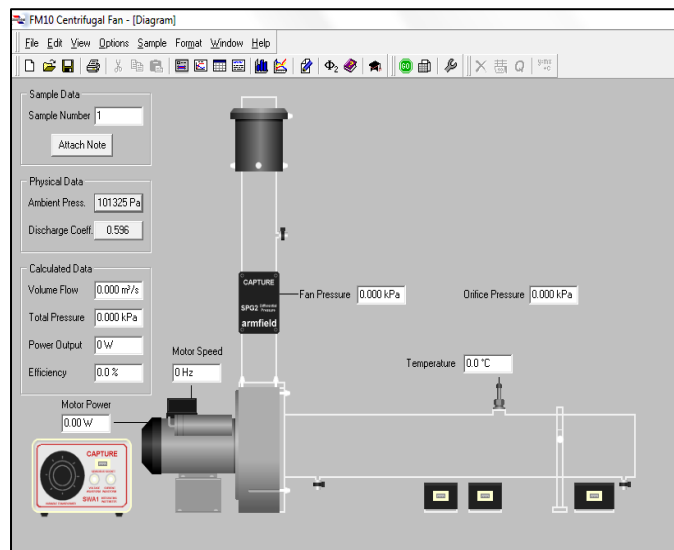


Figure 3: Software screenshot

The fifth challenge was writing a Laboratory Manual for this newly operational laboratory equipment, such as a procedure for collecting and calculating the necessary data to simulate the fan's performance curves at constant speed. In addition, using different fan-speed runs, the students running the experiment in the Fluids Laboratory will be asked to check the centrifugal fan affinity laws. The senior design team, under the authors' guidelines, developed and wrote this new laboratory manual, entitled "Centrifugal Fan Characteristics" detailing the centrifugal fan theory, including the affinity laws, the experimental setup, data acquisition system, test preparation steps, and experimental procedure steps.

Finally, another challenge was to keep the overall project's cost under \$200. The original idea of buying a new data acquisition interface console IFD7 and new sensors was proven costly, around \$3600. By using an existent, older interface, still functional, and eliminating the need of new sensors for pressure, temperature, and speed, the budget was reduced to \$185. Of this, the orifice caps and required drill bits were under \$50 and the remaining cost went to acquiring a digital manometer, an instrument to be used not only for calibration purposes on this equipment, but as an instructional tool for other laboratory experiments as well.

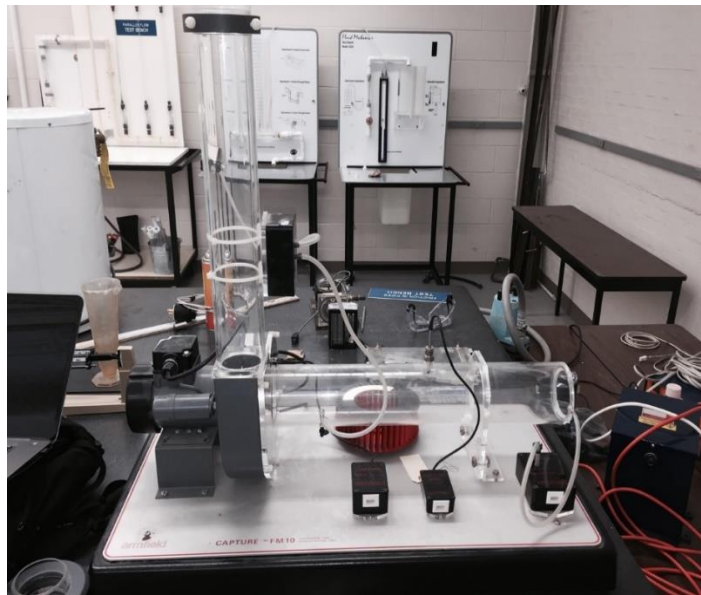


Figure 4: Final centrifugal fan setup

Case Study No. 2 - Centrifugal Compressor Lab

Background and Motivation

The project is work in progress during the Fall 2016 semester by an interdisciplinary team (Team A-2), consisting of four mechanical engineering technology (MET) seniors and one construction

engineering technology (CET) senior, all enrolled in the “Senior Design Capstone” ENGT 4050 course.

The FM12 Centrifugal Compressor Demonstration Unit is another piece of equipment acquired by the ET Department around the same time as the Centrifugal Fan, and also not working due to the same reasons mentioned previously. The unit is a seven-stage compressor and the authors are planning to incorporate it in the Thermodynamics and Fluid Mechanics laboratories.

Challenges and Solutions

The capstone team has devised a plan to upgrade the nearly 20 years old FM12 Centrifugal Compressor by researching the current demo unit sold by the same manufacturer Armfield under the name FM42⁽³⁾. The challenges were numerous but the team developed a design and at the time of writing this article, they are close to finalizing the project.

The unit has a missing “sleeve” which fits in the outlet duct. When the output is throttled, by rotating the grey PVC collar, the exhaust orifice diameter is changed, thus controlling the flow rate through the outlet duct. The rotating PVC collar, minus the aperture, is shown in Figure 5. Its concept and design are similar to the manually open aperture described under case Study No.1.



Figure 5: Rotating PVC collar

Based on their predecessors’ solution, Team A-2 designed and built several rubber caps to replace the removable grey PVC collar at the end of the outlet duct, with the caps drilled to certain design diameters in order to throttle the output with discrete amounts. The total cost for six caps was only around \$20, compared to buying a new FM12 Valve Sleeve from the manufacturer at a cost of \$350.

A major challenge is that the unit shows signs of physical damage, particularly with the white resin compressor housing. This is an unfortunate situation, since there is evidence of air leakage between the seven rings, which in turn leads to the lack of required buildup in pressure. The leak test fluid applied to the compressor housing confirmed the leakage. In order to fix this issue, the

students sealed the housing using a repair kit, thus avoiding any damage that could incur in dismantling the housing and re-sealing each stage.



Figure 6: Main housing showing air leakage

Another major issue is calibrating the sensors. Since the manufacturer has discontinued the product many years ago, and the original manual was lost, no information was found about sensor calibration. However, with the help from the Armfield Customer Support service, the students were able to find an old inspection procedure detailing the acceptable range of values for each of the sensors. Currently the team is working to certify that the current sensors are properly calibrated.

Case Study No. 3 - Centrifugal Pump – Fluids Lab Experiment

Background and Motivation

The project is also being performed during the fall 2016 semester by a group of four mechanical engineering technology (MET) seniors (Team A-7).

The FM20 Centrifugal Pump Demonstration Unit is the third piece of equipment acquired by the ET Department around the same time as the previous two and, like them, it is has not been in working condition for many years. The authors plan to have it operational, with a live data acquisition system, and a new laboratory manual, as part of the Fluid Mechanics courses starting with the spring 2017 semester.

Challenges and Solutions

The salvaged equipment was in a distressed shape, as seen in Figure 7. Upon initial assessment, it was found that there was a water leak at the pump inlet, a water leak at the gate valve, and all of the hardware needed to be cleaned. In order to resolve these issues, the team was able to disassemble the system, including the electrical motor, clean all parts, rebuild the motor, change the seals, and consequently one set of leaks was fixed. The solution did not incur any cost to the project; an independent electrical motor rebuild would have amounted to a cost of \$64, while replacing it with a new motor would have been \$199. To fix the leak at the gate valve, the team purchased a new generic clear gate valve for \$25.



Figure 7: Centrifugal pump equipment as found

After rebuilding and running the demonstration unit for longer periods of time, it was found that the motor was overheating. A viable solution was developed by adding a cooling fan to the motor's end. The students created a new fan using SolidWorks software and a 3D printer. This solution did not add any new cost to the project because the 3D printer is operated by the department using general laboratory fees. After installation, the overheating issue was solved.

As with the previously discussed case studies, the sensors needed to be calibrated. After multiple measurements and readings and hand calculations it was found that the differential pressure readings were not accurate and the frequency sensor on the motor was giving inconsistent values. Through literature research, the team was able to find the proper techniques for calibrating the sensors.

In order to improve this equipment, Team A-7 decided to also purchase a digital in-line flow meter, used for flow rate calibration and which will also allow the students in the lab to compare their calculated flows with independently measured values. Furthermore, the team is investigating the possibility of adding an additional parallel branch of different pipe diameter for future measurements involving flow in branches.

The original software installation disk was available, and the associated software was installed on the same computer able to run 16-bit software as shown in Figure 8. The software is able to read and record the motor power and speed, water temperature, pump pressure, and orifice pressure, and automatically calculate the volume flow rate, total head, power output, and pump efficiency.

For all three case studies presented, the most difficult task was perceived by the student teams to be sensor calibration and data validation. The difficulty was due not just to the theoretical aspects of this task, for which the faculty advisors provided guidance, but also to the fact that this issue had to be dealt with when the equipment was close to being assembled and ready to run, which happened towards the end of the semester, close to the due date for the project. Consequently, in future iterations of this senior design lab improvement concept, the project timeline will have to account for this issue and allocate additional time to this task from the start.

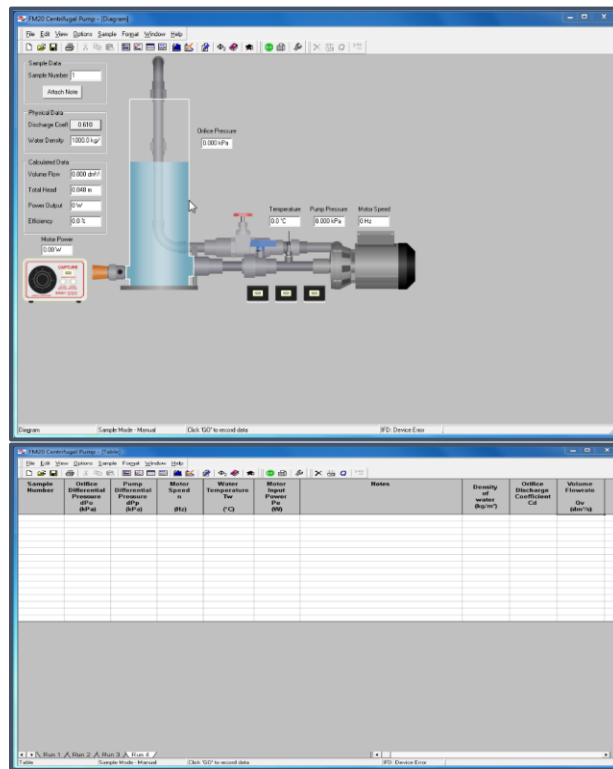


Figure 8: FM20 Armfield software

Case Study No. 4 – Small Engine Dynamometer – Internal Combustion Laboratory

Background and Motivation

In this project, the MIME senior design team was assigned to design an engine dynamometer and test bench for a Honda GX35 engine to be used in the Energy Lab and Internal Combustion Engines Lab of the MIME Department. Dynamometers load the engine by absorbing energy, while allowing measurements of the engine speed, torque, and power.

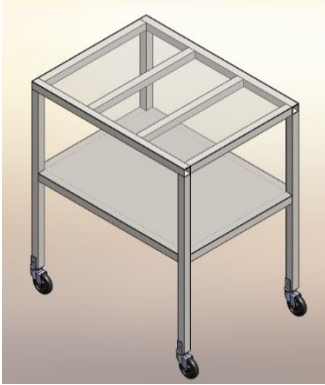
Challenges and Solutions

The most important tasks were to finish installation of a fuel injection kit (previously started as an undergraduate special topics project), choose an energy absorption method, and design a test bench with sensors for ease of acquiring the data. Additional design constraints were that the dynamometer be mobile, user friendly, safely displayed, rigid enough to prevent unneeded vibrations, and provide variable loading. This was a fairly complex design, and some of the most significant phases were: design of a test stand (see Figure 9a), an alternator mounting system allowing the measurement of the torque (see Figures 9b and 9c), a belt tensioner system (see Figure 9d), an electrical system to control and dissipate the engine load (see Figures 9e and 9f), and a torque measurement system using computer data acquisition in LabView.

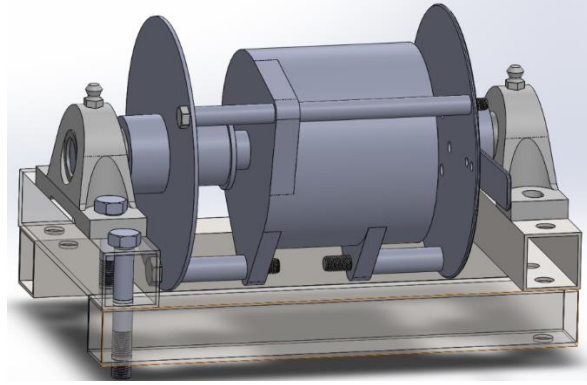
The five-student team was able to finish the main tasks of this project on time, including building a working prototype. However, due to the limited time and the complexity of the project, including a significant electrical engineering component, which the team decided upon during the design stage, they were not able to optimize the final design and bring it to a stage where it can be used in the lab as a finished product. Specifically, the electrical component of the design, while functional, was only developed at a basic level. The conclusion of the authors was that, for multidisciplinary projects, including on the team students from other relevant majors in engineering (electrical engineering in this specific project), can be beneficial. This work was further continued by an MS student candidate as part of his MS project. The total cost for this project was close to \$2100, while a new, equivalent equipment, can be purchased for about \$30-40,000.

Conclusion

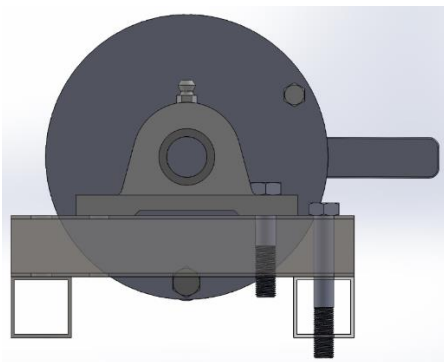
The experience of using the Senior Technology Capstone course to update the teaching laboratories was very positive and this concept will continue to be used in the future. In each of the first three cases presented, the student teams were able to take an existing (but non-working) equipment setup, refurbish, and update it, resulting in a functional laboratory equipment which will be used the Fluids Laboratory for years to come. In the fourth case presented, the students developed a new design. In each case, the teams had to run through the design steps of analyzing the problem at hand, propose multiple solutions, select the best solutions according to an array of criteria, including cost and time constraints, build and test a working device, and prepare reports and presentations of their work. They worked closely with faculty advisors who guided them through the process. In addition to the positive experience the senior students had in this course, the two departments had the benefit of improving their teaching labs in a cost-effective way. The cost associated with each refurbished equipment was under \$200, compared with the acquisition of new similar demonstration units, each costing more than \$15,000.



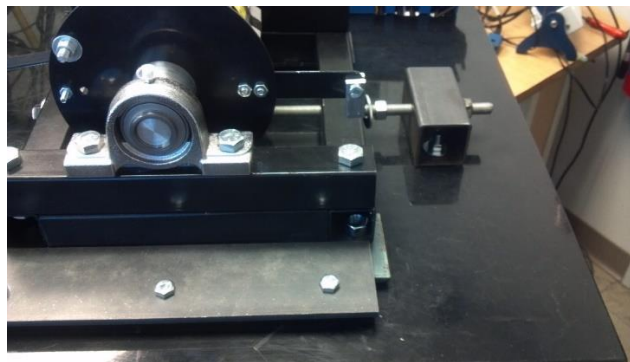
a) Test stand



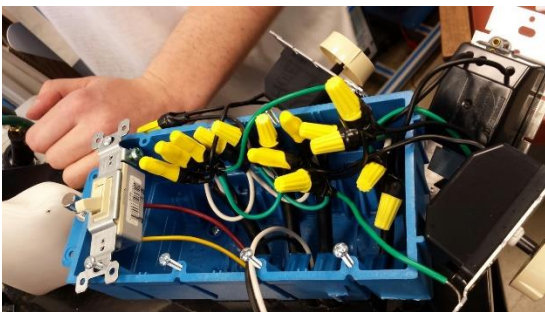
b) Alternator mounting system



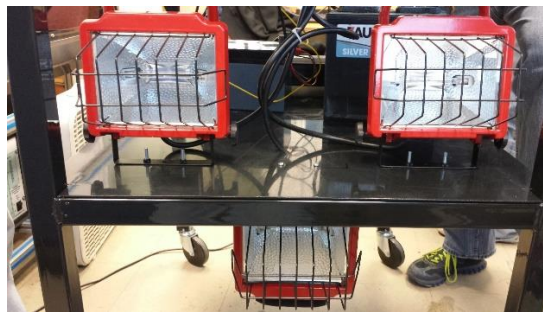
c) Alternator mounting system with load arm for torque measurement



d) Belt tensioner system



e) Electrical connections for the electrical power dissipation



f) Electrical power dissipation system

Figure 9: Dynamometer Design Components

References

- 1) <http://www.et.utoledo.edu/>
- 2) <http://discoverarmfield.com/en/products/view/fm40/centrifugal-fan-demonstration-unit>
- 3) <http://discoverarmfield.com/en/products/view/fm42/centrifugal-compressor-demonstration-unit>
- 4) <http://discoverarmfield.com/en/products/view/fm50/centrifugal-pump-demonstration-unit>

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