

AC 2010-145: EXTRACURRICULAR PROJECT ENHANCES STUDENT LEARNING: A CASE STUDY

Nicholas Harlow, Western Kentucky University

Nicholas Harlow is an undergraduate student in Mechanical Engineering and is currently in his senior year. He is also employed as a student worker for WKU's Thermal-Fluid Mechanics Laboratory.

Robert Choate, Western Kentucky University

Robert Choate is an Associate Professor of Mechanical Engineering at Western Kentucky University. He teaches thermo-fluid and professional component courses, including Sophomore Design, Thermo-Fluid Systems Lab and ME Senior Project Design course sequence. Prior to teaching at WKU, he was a principal engineer for CMAC Design Corporation, designing telecommunication, data communication and information technology equipment.

H. Joel Lenoir, Western Kentucky University

Joel Lenoir is the Layne Professor of Mechanical Engineering at WKU, and primarily teaches in the dynamic systems and instrumentation areas of the curriculum. His industrial experience includes positions at Michelin Research and Oak Ridge National Laboratory, as well as extensive professional practice in regional design and manufacturing firms.

Extracurricular Project Enhances Student Learning: A Case Study

Abstract

Recently at Western Kentucky University's mechanical engineering thermal-fluids laboratory, a student worker, the author of this paper, was given the opportunity to design, build, and test (DBT) a dust collector performance test bed. The development of this test bed was inspired by an article in Wood Magazine, which described a method for testing the performance of various portable dust collectors.

The test bed developed is being used for instructional purposes in one laboratory course in the Mechanical Engineering (ME) Program. Currently, the test bed is used in the program's Engineering Experimentation and Instrumentation course as a dust collector performance experiment. In this experiment students gain experience in method of measurement, selection of instrumentation, errors in and the proper use of pressure and air flow velocity measurements, and fan selection. Moreover, the test bed is capable of being used in a variety of other applications making it possible to be used in other laboratory courses in the future.

The test bed incorporates a common portable wood shop dust collector with a duct system consisting of round metal duct, plastic flexible hose, and various duct transitions. In the current experiment, air flow rates and static pressures are measured in the duct for several different duct configurations, or operating conditions. These operating conditions are then used to plot the dust collector's fan curve and compare it to the manufacturer's listed performance characteristics.

This paper focuses on the DBT process of the test bed and the development of the experiment. Moreover, an assessment of the project is provided through an analysis of the following project outcomes: 1) The student worker's learning experiences during the execution of this extracurricular project inclusive of both technical and project management aspects and 2) The impact of the implementation of this extracurricular project as a course experiment in the Experimentation and Instrumentation course as part of the ME Program's curriculum sequence.

Introduction

The Mechanical Engineering (ME) Program at Western Kentucky University focuses on creating professional learning experiences in order to "provide students with the opportunity to acquire tools and skills, as well as technical competency."^{1,2} These learning experiences are provided through various projects both in the classroom as well as in extracurricular environments. One way the ME Program creates these extracurricular environments is by employing undergraduate engineering students to work with faculty on various projects. This provides students the opportunity to gain practical engineering experience to supplement their undergraduate educations.

An opportunity for such a project arose when one of the mechanical engineering faculty found an article in Wood Magazine entitled, "Dust Collectors Under \$400"³. This article presented a

simple device that was used to characterize the air flow performance of several residential size portable dust collectors and the resulting fan curves measured by the device. Making the article even more relevant was the fact that one of the dust collectors tested in the article, a Jet® DC-1100A, is owned by the engineering department. This provided a good opportunity to design a lab experiment in which students could use a device similar to the one presented in the article to measure the air flow performance of the dust collector and gain an understanding of the fan selection process. It was desired that the experiment be incorporated into the ME Program's Engineering Experimentation and Instrumentation course to serve as a capstone lab experiment for the course that would incorporate various experimentation and instrumentation techniques developed throughout the semester. Moreover, this would create a link between this junior level lab and the thermal-fluids systems senior level lab which consists of similar type experiments.

The experiment was developed through a design, build, and test (DBT) extracurricular project given to the ME Program's thermal-fluids sciences laboratory student worker. Developing this experiment as part of an extracurricular student project provided benefits to both the student worker and the ME Program. The student worker was given an opportunity to develop important project management and technical engineering skills culminating in the writing of this paper. The ME Program on the other hand, gained a rewarding lab experiment to enhance student learning in the laboratory sequence of courses. This paper presents the DBT project in a way that would allow other institutions to replicate or incorporate the developed lab experiment into existing curriculum. The paper also discusses the student worker's learning experiences throughout the project as an example of the value associated with incorporating such extracurricular projects into an undergraduate engineering program. Finally, an assessment of the implementation of the experiment into the program's Experimentation and Instrumentation course is provided.

Design Specifications

The overall purpose of the test bed was to allow students to be able to characterize the air flow performance of a common wood shop dust collector and its associated duct system. The general specifications as determined by the project's sponsoring faculty members are shown below:

- Characterize Air Flow Performance of Dust Collector System
- Connect to a Jet® DC-1100A, 1.5 HP Dust Collector
- Consist of Metal Duct and Flexible Plastic Hose
- Ability to Control Airflow
- Contain Duct Transitions (i.e. tees, wyes, elbows)
- Deliver an Experimental Procedure

The specific approach for controlling airflow was left up to the student worker. However, the test bed was to be capable of changing the system's impedance to produce a sufficient number of operating points in order to generate a fan performance curve for the dust collector. Duct transitions were desired so that the effects of the transitions with respect to air flow could be observed. The set design specifications gave the student worker the opportunity to gain experience in experimental planning, methods of measurement, and selection of instrumentation as set out in the ME Program's design of experiments components.^{1,4,5}

Design of the Test Bed

In order to meet the design specifications there were four major components that needed to be designed and/or selected: Ductwork, Dust Collector Connection, Duct Supports, and Instrumentation. The design and selection process for each of these major components are detailed in the sections that follow.

A. Ductwork

Due to a confined amount of space in the laboratory where the test bed would be set up, the layout of the ductwork was given primary consideration. The layout of the final design as shown in Figure 1 uses a tee to connect both metal duct and flex hose to the dust collector so that a wide variety of configurations can be implemented without having to change duct types during the experiment. Moreover, the blast gates give the test bed unique flexibility in being able to characterize dust collector performance for intakes using only metal duct, only flex hose, or a combination of the two.

Four inch round plastic flex hose was chosen for the test bed. A length of approximately 20 feet was appropriate for the available space as well as long enough to be bent into 45° and 90° bends without having to purchase metal and/or plastic transitions. To maintain consistency, 4" metal round duct was selected so that the flex hose could be easily connected over the metal duct. Metal duct was needed on the dust collector intake to provide a smooth airflow surface for measuring air velocity. An aluminum body blast gate and plastic blast gate were fitted to the metal duct and flex hose intakes, respectively as shown in Figure 1. More detailed information on these ductwork components is given in Table 1.

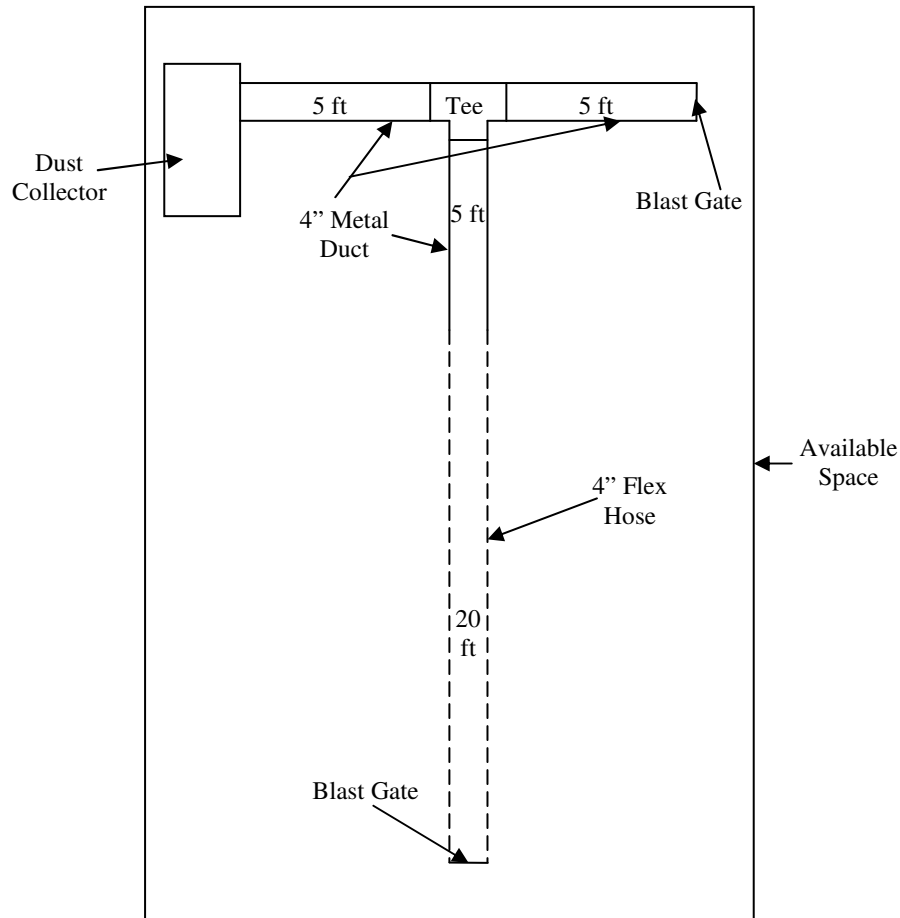


Figure 1: Layout of Ductwork

B. Dust Collector Connection

The Jet[®] DC-1100A dust collector that was used for the test bed has a 6" intake that is factory supplied with a plastic fitting for the use of 4" flex hose. However, 4" metal duct was desired to be connected to the dust collector intake in order to have consistency with the other ductwork in the system. Therefore, a connection from the 4" metal duct to the 6" dust collector intake had to be designed. Also, since the dust collector is occasionally used for other purposes within the engineering department the connection needed to leave the dust collector unmodified. The connection shown in Figure 2 was designed to meet these requirements. It consists of a 6" tabbed female collar sandwiched between two pieces of plywood. This plywood assembly can be slid over the dust collector intake in the same manner as the standard plastic flex hose fitting. A diffuser was used to connect the collar and the 4" round duct. This diffuser was also used in order to give as smooth a transition as possible from the duct to the dust collector and attempt to reduce fluctuations in static pressure measurements taken at the dust collector inlet.

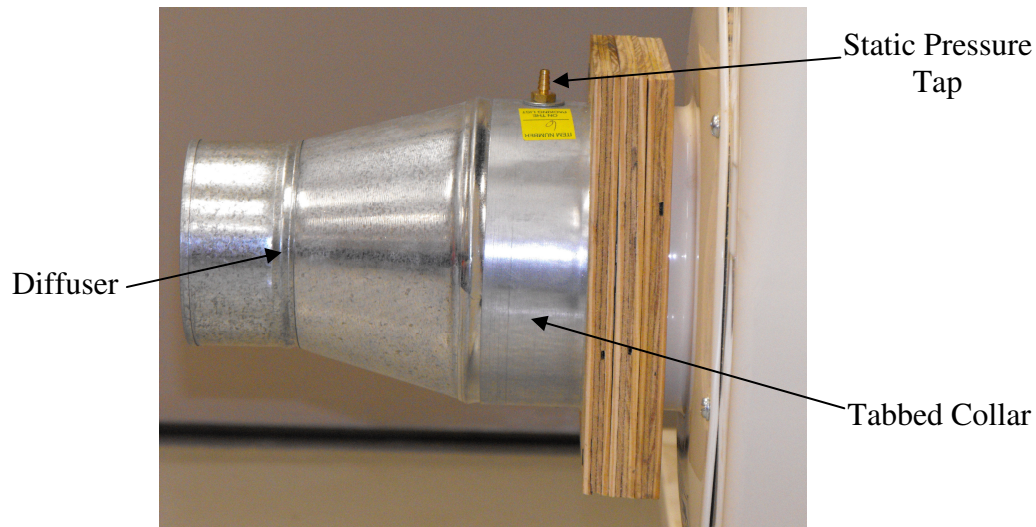


Figure 2: Dust Collector Connection Shown Connected to Dust Collector

C. Duct Supports

The Jet® DC-1100A dust collector that was required for the test bed is a floor stand model on a rolling platform that resulted in the duct being one foot above the floor and in need of supports. Due to the short timetable for the project and the specialized purpose needed for the supports, it was decided to design a support rather than spend time trying to purchase supports. The design of the supports was based on quick and easy construction while providing sufficient stability for the ductwork. A metal duct support is shown in Figure 3. Diagonal struts were incorporated to allow for good longitudinal stability for the duct. The struts are offset from the center of the support allowing for easy access to the connecting screws. The flex hose was decided to be supported by three 5 foot troughs that would give enough support for the entire length of flex hose to be level while still allowing the flex hose to be formed into elbows. The troughs (can be seen in Figure 4) were made by splitting a 6" PVC sewer drain pipe which could be supported by the same type of support used for the metal duct.



Figure 3: Metal Duct Support

D. Instrumentation

The student worker and the sponsoring faculty members worked closely together to devise a method for measuring the necessary parameters to create a fan performance curve for the dust collector. Due to time and budget considerations, it was decided to measure the necessary parameters using instrumentation already available in the thermal-fluids sciences lab. A TSI VelociCalc® Plus (Model 8386A) hot film anemometer was selected to measure air velocity. This is accomplished by traversing the duct cross section through a series of holes drilled 10"

apart in the metal duct connected to the dust collector. Static pressure across the dust collector impeller was measured using the VelociCalc® Plus' differential pressure gauge via a pressure tap in the collar of the dust collector connection (see Figure 2). The dust collector exhaust was allowed to dump straight to room atmosphere so that a second pressure tap would be unnecessary and would allow for the dust collector to remain unmodified. The use of liquid manometers to measure static and velocity pressures from a Pitot tube were also considered. However, it was decided that the VelociCalc® Plus' pressure measurement range was better suited for handling the pressure ranges created by the large air flow rates of the dust collector.

E. Bill of Materials

The bill of materials for all of the major components of the test bed is shown below in Table 1. Small items such as fasteners and duct tape are not listed since the cost of these items are minimal compared to the costs of the major components. Instrumentation is not shown in Table 1 because the specific digital meter used for this project has been discontinued and because prices on instrumentation can vary significantly based on which method of measurement is selected. Construction and assembly of the test bed cost approximately 25 labor hours.

Table 1: Bill of Materials

Part	Supplier	Quantity	Unit Price	Cost
Jet® DC-1100A Dust Collector	Sears	1	\$ 429.99	\$ 429.99
4" Galv. Steel Round Duct (5' Long)	McMaster-Carr®	3	\$ 10.55	\$ 31.65
4" Metal Duct Blast Gate	McMaster-Carr®	1	\$ 8.92	\$ 8.92
4" Flex Hose Blast Gate	McMaster-Carr®	1	\$ 5.21	\$ 5.21
4" to 6" Round Duct Diffuser	McMaster-Carr®	1	\$ 9.17	\$ 9.17
4" x 4" x 4" Duct Tee	McMaster-Carr®	1	\$ 11.38	\$ 11.38
6" Tabbed Female Duct Collar	McMaster-Carr®	1	\$ 2.62	\$ 2.62
6" PVC Pipe (10' Long)	Lowe's®	1	\$ 11.75	\$ 11.75
2" x 8" Pine Wood (8' Long) (for duct supports)	Lowe's®	3	\$ 5.25	\$ 15.75
2" x 4" Pine Wood (8' Long) (for duct supports)	Lowe's®	1	\$ 2.08	\$ 2.08
Total Cost				\$ 528.27

Assembly

Assembly of the test bed is made quick and simple by using aluminum duct tape to secure the duct connections. Aluminum duct tape was chosen in order to provide a smooth inside duct wall by avoiding burring of the inside duct wall that typical sheet metal screws would cause. The final assembled test bed is shown in Figure 4.

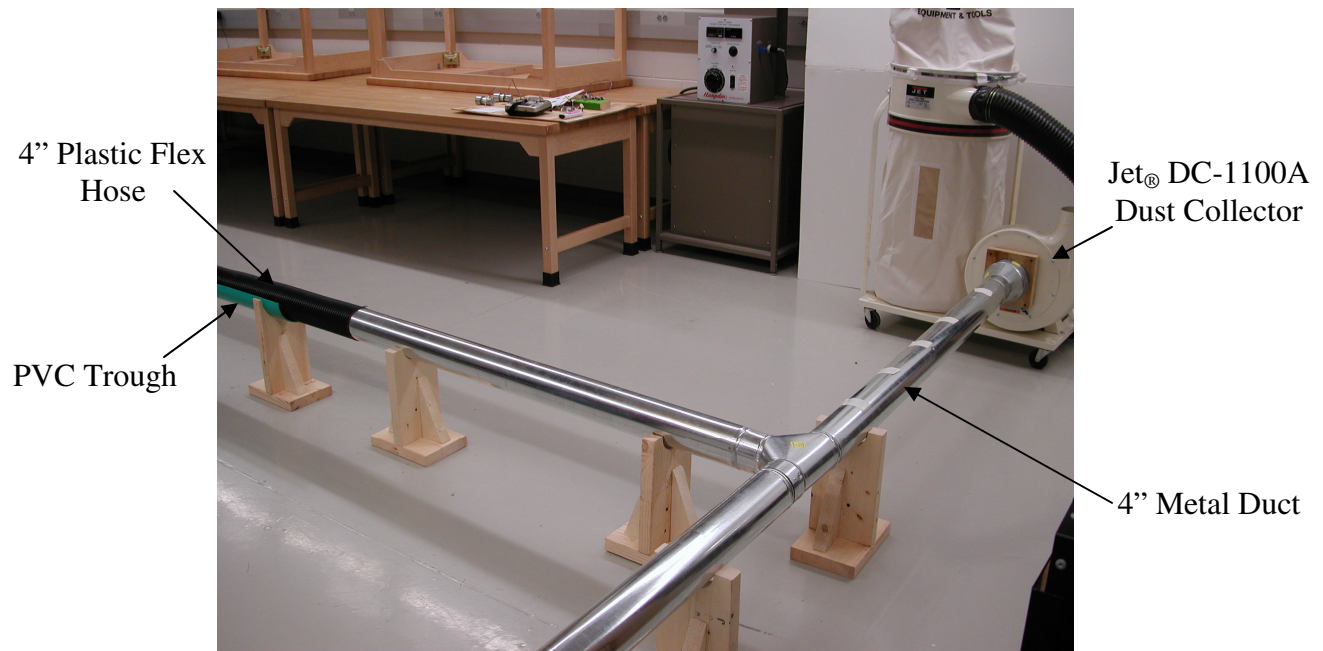


Figure 4: Assembled Test Bed

Testing

The initial desired purpose for the test bed as dictated by the design specifications was to be able to characterize the performance of the dust collector by measuring its fan curve. The way the test bed accomplishes this is by changing the system impedance via the blast gates and flow configurations (bending of the flex hose into 45° and 90° elbows) and measuring the corresponding operating points for each impedance. The operating point is defined by the static pressure change across the dust collector impeller and the air flow rate. These procedures and definitions were developed to be consistent with the general measuring and reporting methods for fan performance outlined in the ANSI/AMCA 210-99 standard.⁶ However, the intent of the test bed is for student experimenters to gain insight into the relationship between the dust collector differential pressure versus flow rate rather than an explicit aerodynamic characterization for an air handler via this standard. The ability of the test bed to measure the dust collector's fan curve was tested by using the blast gate on the metal duct to create 7 different impedances thus resulting in 7 different operating points ranging from the minimum to the maximum air flow capabilities of the test bed. Figure 5 shows the dust collector performance curve measured by the test bed during this test.

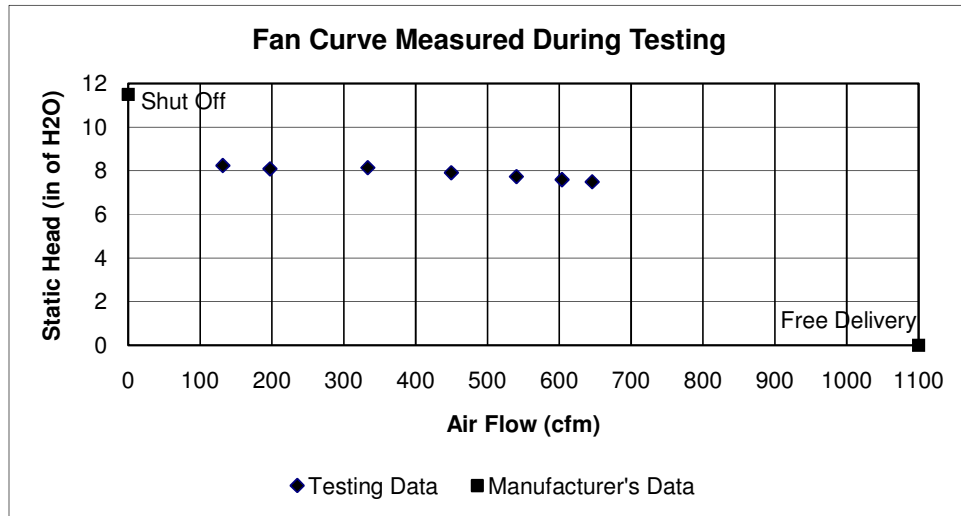


Figure 5: Dust Collector Performance Curve

As Figure 5 shows, the dust collector's performance is quite flat ranging only from 8.24 inches of water to 7.49 inches of water. Figure 5 also shows the manufacturer's listed shutoff (0 cfm, 11.5 inches of water) and free delivery (1100 cfm, 0 inches of water) operating points. Therefore, it is evident that a portion of the dust collector's fan curve and not the entire curve is portrayed in the fan curve measured by the test bed. In order for measured fan curves to portray a larger portion of the dust collector's curve, it would be desirable for the test bed to be capable of more closely approach the dust collector's free delivery and shutoff operating points. It should also be mentioned that the free delivery air flow of 1100 cfm is impossible for a test bed of this type to obtain since the ducted inlet results in pressure losses in the system. However, it should be possible to have a test bed to approach somewhere between 800 and 900 cfm to give a better representation of the overall fan curve. This could be facilitated by using shorter lengths of ductwork and more precise flow controls that create less impedance than blast gates.

It should be noted that the intention of this test was not to prove the manufacturer's listed performance characteristics (this could not accurately be done with this type of test bed nor could it be done without knowing the manufacturer's entire fan curve). However, assuming that the manufacturer's listed performance characteristics (shut off and free delivery operating points) are correct, the results of this test show that the test bed portrays an acceptable trend in the fan curve that falls within the manufacturer's listed performance boundaries. Moreover, the manufacturer's listed free delivery value of 1100 cfm was estimated by removing the duct on the dust collector inlet and measuring air flow velocities on the dust collector's inlet and outlet, using a hot film anemometer, that ranged between 1000 and 1100 cfm.

These results show that the test bed is very much able to create a sufficient number of operating points to measure a fair portion of the dust collector's fan performance. Therefore, testing verified that the test bed can serve as a valuable laboratory experiment. Moreover, the fact that the test bed cannot portray all of the dust collector's fan curve, is actually quite valuable in a laboratory experiment since it allows students to see how common duct configurations and components are related to system impedance and operating flow rates.

Current Experiment

The final responsibility for the student worker in this project was to develop an experimental procedure that would allow for the designed test bed to be used in the ME Program's junior level Engineering Experimentation and Instrumentation course. The experiment developed requires students to measure the operating points for several different system impedances. The students are required to create at least 3 to 4 impedances for three base configurations: 1) Metal Duct Only, 2) Flex Hose Only, and 3) Metal Duct and Flex Hose Combined. The exact impedance for each of these base configurations is left up to the students in order to give them freedom to explore any interesting configurations. For example, one possible impedance using the combined base configuration would be to set the metal blast gate at 50% open, the flex hose blast gate at 100% open, and have two 90° elbows in the flex hose. This allows students to see how various duct configurations affect the system's performance.

The students are also given freedom in how they measure the flow rates in the system. The test bed contains five different openings in the duct near the dust collector where flow velocity can be measured using a hot film anemometer. This allows students the opportunity to explore how the measurements vary along the length of the duct. The static pressure across the dust collector is measured using a digital manometer which gives the students an opportunity to measure pressure using an instrument that they have not used in the course until that point (previous experiments use liquid manometers).

Once students measure a sufficient number of operating points they are required to generate a fan curve for the dust collector. They are then asked to investigate why the dust collector did not reach the manufacturer's listed maximum flow rate. This allows students to see firsthand how it is important to select a fan that meets the desired flow rate at the system's impedance and not just at the fan's maximum flow rate.

Future Experiments

One of the most intriguing aspects of the designed test bed is its ability to provide a variety of laboratory experiments. A more simplistic experiment that could be developed would be to use just the metal duct to perform an air flow measurement experiment. In this experiment, the duct openings could be used to do a radial velocity traverse along each of the five evenly spaced openings. This would allow students to explore the velocity profile in a duct with a circular cross section.

Another experiment that could be developed using the test bed would be to incorporate fan speed (rotations per minute) and motor power into the air flow performance experiment. This would be done by measuring the current draw and voltage of the dust collector's motor for each operating point. The relationship between the power and fan speed or air flow rate could then be explored. This experiment would be particularly interesting since some dust collector hobbyist publications suggest that operating a dust collector at free delivery and no load (no duct on inlet) can result in motor damage due to current overload.⁷

Other experiments that could be developed include exploring how various dust collector bags and bag connections affect performance. Also, an experiment that would involve transporting debris common to dust collectors and exploring how the quality of transport relates to air flow could be developed.

Assessment of the Extracurricular Project

An important aspect of this project was the fact that the ME Program was able to enhance one of its laboratory courses while giving an undergraduate student valuable learning experiences by managing and executing the project as an extracurricular activity. These learning experiences, present throughout the project, consisted of both project management and technical aspects and are detailed in the following sections.

A. Project Management Aspects

Many of the rewarding aspects of this project were the direct result of the project's schedule and fixed date of delivery. The student worker was given 6 weeks to design, build, and test the test bed so that it could be used as the last experiment in the Engineering Experimentation and Instrumentation course. The fact that this project was needed for a class lab experience, on a date that could not possibly change, resulted in only two possible outcomes for the project: success (operational test bed) or failure (non-operational test bed). This provided a unique experience since most student projects are evaluated on degrees of success and failure (i.e. grade of A, B, C, D, or F) instead of on overall success or failure. This succeed/fail nature of the project created a strong desire to accomplish the task at hand resulting in the necessary adoption of project management techniques such as detailed scheduling and organization and utilizing multiple resources to accomplish several tasks at once.

For example, once the design of the ductwork and supports were completed there was only three weeks remaining to get the test bed built and ready for use. This resulted in having to effectively manage the construction process. The most time consuming aspect of construction was building the 12 duct supports which required the help of the university's Engineering Prototype Facility (EPF). The student worker in charge of the project in coordination with the EPF's staff engineer developed a plan that would allow the EPF to prepare the duct supports for assembly and aid the student worker in assembling the supports. With the EPF taking responsibility for the time consuming process of cutting the pieces for the supports, the student worker was given enough time to focus on building the dust collector connection, ensuring the correct ordered parts arrived on schedule, developing the experimental procedure, and obtaining and implementing instrumentation.

B. Technical Aspects

Along with the mentioned project management experiences, the project also provided valuable technical experiences. Since the student worker had not yet taken Fluid Mechanics at the time the project was started, the most notable technical challenge was the recurring need to quickly learn about unfamiliar topics (i.e. fan characterization and air flow measurement techniques) in order to understand how to design, build, and test an effective test bed. Also present during the

design and build stages was the need for the student to learn about various measurement techniques and instruments in order to select and design for the proper instruments needed for this particular project. For example, the student learned the importance of looking to industry standards⁶ as a source to gain understanding in common testing and measurement procedures. The standard proved to be a valuable resource in gaining a general understanding of testing methodology and terminology that guided the development of the experimental procedure used for this particular application. Once the test bed was built the technical challenges shifted to testing the test bed and developing the experiments. This gave the student the opportunity to learn about experimentation and verification techniques as well as experience in designing an experiment to accomplish a certain task.

Assessment of Implementing the Experiment

This experiment was incorporated into the Engineering Experimentation and Instrumentation course. This course follows two earlier laboratory courses, one in material science and another in mechanics of materials and systems. The course provides formal coverage in instrument selection and implementation, uncertainty and error analysis, and statistical treatment of data. The course leads into two senior level laboratory courses, covering thermal-fluid systems and dynamic modeling and is typically taken at the same time as the ME Program's Fluid Mechanics course.

The dust collector experiment was found to contribute positively to student learning in three aspects and raised an important concern in the students. First, the experiment was an opportunity to use actual industrial instrumentation in a larger scale system, correlating to lectures in the fluids course. The decision to use existing instrumentation meant that special classroom measurement systems were not used. Industrial grade flow measurement equipment already present in the department is checked out for the lab. These systems are capable of extending the student experience beyond the Experimentation and Instrumentation course as they tackle larger projects in the senior laboratory or perhaps a senior project. If a laboratory setup had been purchased, this flexibility would not likely be possible.

Secondly, the dust collector experiment does not have a “cookbook” outcome where students simply fill out a data sheet. The dust collector is very sensitive to the ductwork attached, the condition of the dust bag, etc. As students had seen in earlier course experiments, they needed to carefully document the setup to generate reproducible results. For instance, the blast gates are relatively non-linear in their operation when used to throttle flow. This experiment provides an excellent opportunity for the students to attempt to estimate the error in their data, illustrating the need to report their results in a manner others can use to make decisions about the system.

Third, using an actual shop dust collector was exciting for the students. It is loud, with lots of air moving through the system. Students had a sense of doing real engineering work, since many are hobbyists who have seen similar machines. Others are familiar with industrial collection and HVAC systems at their internships. This system strikes a chord with students since it is a real machine with a part number, not a contrived bench experiment set up to prove a point.

However, this last benefit left the students somewhat unsure about the relationship between the flows measured and the ability of the system to do its task of transporting chips and dust from a machine. As mentioned earlier, an opportunity for future work is in the area of using the dust collector in a real conveying system with a chip producing machine such as a planer or jointer. Keeping with the theme of this DBT project, all these elements are already present in the department.

Conclusions

In conclusion, this DBT project was a valuable experience for both the ME Program and the student worker in charge of the project. The ME Program gained a test bed at little monetary cost that provides an appropriate student learning experience for laboratory courses. Moreover, the adaptability of the test bed makes it possible to use in a variety of laboratory experiments based on the specific needs and desired outcomes of the specific course.

On the part of the student worker, this extracurricular activity has provided learning experiences that no one course can provide. As a result, the student worker has been able to add value to his undergraduate education by applying and refining a variety of engineering skills. Moreover, the rewards personally witnessed by the student have inspired him to continue to seek out ways to add value to future engineering education and career endeavors.

Using this experiment in the junior level Engineering Experimentation and Instrumentation course brought value to the students due to the practical value of the setup and the use of industrial measurement tools. The experiment reinforces material in both the Experimentation and Instrumentation and the Fluid Mechanics courses. Students can use this experiment to improve their report writing skills due to the unique setup requirements of the device.

Acknowledgements

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Bibliography

1. Choate, R., Schmaltz, K., Byrne, C., and Lenoir, J., "Senior ME Capstone Laboratory Course," Proc. 2005 ASEE Annual Conference, Portland, OR.
2. Schmaltz, K.S., Byrne, C., Choate, R. and Lenoir, J., "Integrated Professional Component Plan from Freshmen Experience to Senior Project," Proc. 2004 ASEE Annual Conference, Salt Lake City, UT.
3. Hunter, B., Hall, J., March 2008, "Dust Collectors Under \$400", *WOOD Magazine*, 182, 66-71.
4. Holman, J.P., 2001, *Experimental Methods for Engineers*, McGraw-Hill, Boston.
5. Wheeler, A.J. and Ganji, A.R., 1996, *Introduction to Engineering Experimentation*, Prentice Hall, Englewood Cliffs, NJ.
6. ANSI/AMCA Standard 210-99, 1999, *Laboratory Method of Testing Fans for Aerodynamic Performance Rating*, AMCA and ASHRAE.
7. Nagyszalanczy, S., 2002, *Woodshop Dust Control*, Taunton Press, Newtown, CT.