AC 2007-1191: DESIGN, FABRICATION AND TESTING OF A LOW-SPEED WIND TUNNEL LABORATORY

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Abstract

Engineering Technology programs focus on delivering a hands-on engineering education. The students get introduced to the theoretical development of engineering concepts first, then they apply the concepts to solve practical problems and test the concepts in carefully designed experiments carried out in appropriate facilities. One of the key areas of instruction associated with a mechanical engineering technology program is thermofluids where thermodynamic and fluid dynamic concepts are addressed. The engineering areas that these concepts belong to are empirically based disciplines requiring a strong experimental component for the development of the concepts. Wind tunnels have always played a major role in the advancements made in these disciplines[1]. Thus a wind tunnel facility is an opportune tool for instruction in this key area of engineering. In the Mechanical and Manufacturing Engineering Technology (MMET) department at Arizona State University at the Polytechnic campus (ASU Polytechnic), a course entitled Applied Aerodynamics and Wind Tunnel Testing (AET420) is dedicated to addressing this area. The student is introduced to the basic concepts of how wind tunnels operate, the tunnel design process, and the associated measurement systems[2,3]. Then the student designs and carries out a set of experiments that reinforce these concepts.

A key requirement for this process to be successful is the availability of a wind tunnel facility that is capable of addressing the engineering tasks developed in the classroom. Making use of their applied engineering background, the MMET students designed, analyzed and built an instructional scale wind tunnel. The funding support for the tunnel fabrication was obtained from external sources with the provision that the tunnel would be used to address a specific problem faced by the industrial entity providing the funds. For example, the completed tunnel, with a maximum speed of 50 mph, was first used for testing an aerodynamic problem faced by the trash collection industry (material flying off the hoppers of collection trucks as they went from street to street) in an effort to provide solutions for improving the design of the vehicles. This, in turn, helped the students gain experience in solving problems of interest to industry.

The wind tunnel design and fabrication process required the coupling of key disciplines in engineering technology, including the aeronautical, mechanical and manufacturing engineering technologies which form the focus areas of MMET dept. The completed tunnel is now part of the MMET department's resources and plays a critical role in the curriculum.

Introduction

Engineering Technology programs focus on delivering a hands-on based engineering education. The students apply the theoretically developed engineering concepts to solve practical problems. In this process they have the opportunity to test the concepts in carefully designed experiments carried out in appropriate facilities. While the best option may be to train the students on the equipment and facilities they will be using when they join the industry workforce, establishing such facilities at the teaching institution is often prohibitively expensive and too narrow in focus. The best solution is to ensure that the experimental facilities are adequate enough to test and verify basic concepts so that the learning experience for the student leads to a good foundation on which to build a successful engineering career. There are many areas of engineering to which the student is introduced in the engineering technology curriculum, each of which requires unique experimental facilities to reinforce theoretical concepts. These facilities range from simple to very complex and are proportionately expensive to provide. For example, in aerodynamics there is typically a mismatch between the engineering problems introduced in the class room and the ability to study them in a hands-on type of setting because the educational facilities needed may be too expensive to build while research facilities are not available, or even appropriate, for undergraduate education. In the development of the facility described in this paper, that of a low speed wind tunnel, the approach has been to ensure that the laboratory is adequate to address representative engineering problems, and adaptable enough for the student to learn how to solve new problems by the suitable arrangement of models and instrumentation.

The Wind Tunnel Teaching Facility at ASU Polytechnic

Mechanical and Aeronautical engineering technology programs deal with problems that are associated with the interactions between fluids and other aspects of engineering. For example, the performance analysis of an aircraft will need the dynamics of interaction between the fluid flow and the geometry of the airplane. Reliable operation of a computer depends partly on the efficiency with which heat is removed from the circuit board by the fluid flow introduced by the cooling fan(s). Efficient power plant operation depends heavily on the interaction between fluid flow (working fluid) and the heat and work interactions associated with the fluid. There are a number of other engineering applications where fluid flow plays a significant role and so the student training in these discipline areas should have access to a good fluid flow experimental facility. The most common fluid flow facility suitable for this purpose is a wind tunnel. Problems in aerodynamics, heat transfer, environmental issues such as pollution dispersion, and a wide range of other topics can be studied in a reasonably appointed wind tunnel facility. Any institution that delivers programs in mechanical, aeronautical and civil engineering technology must strive to establish such a facility and introduce its utility into the learning process via courses designed especially for it or experiments in other courses that utilize it. This paper is related to the hands-on learning aspect of the program delivered in the Mechanical & Manufacturing Engineering Technology (MMET) Department at ASU Polytechnic. Specifically, the paper describes the design and fabrication of a low speed wind tunnel by the students of the department and outlines the role played by the tunnel in delivering engineering technology education.

The MMET department offers two ABET accredited degrees at the baccalaureate level: Manufacturing Engineering Technology and Mechanical Engineering Technology. The four concentration areas within the Mechanical Engineering Technology curriculum are aeronautical, automation, automotive and mechanical. For the aeronautical concentration, the curriculum includes a course in Wind Tunnel Design and Testing. The course outcomes include the following:

1. A basic understanding of how a wind tunnel operates.

2. Familiarity with wind tunnel measurement systems such as pitot-static probes, pressure transducers, manometers, thermocouples etc.

3. The ability to set up basic experiments and measure relevant data in both analog and digital formats.

4. The ability to calibrate the wind tunnel including pressure and velocity mapping in the test section.

5. Experience in the design, fabrication and testing of infinite wing geometries.

6. Ability to carry out flow visualization demonstrations and a working knowledge of the basic flow features that are observed.

7. Working knowledge of loads (lift and drag) acting on aerodynamic bodies and the means to measure them.

8. The ability to produce a detailed technical report and presentation encompassing all aspects of wind tunnel operation that the student dealt with during the course of the semester.

9. Exposure to group learning experience including time management, communication skills, ability to work as part of a team and the opportunity to be innovative in carrying out specific tasks.

In terms of ABET Criterion 3 Program Outcomes and Objectives a through k, this course is especially relevant to criterion 3b, an ability to design and conduct experiments, as well as to analyze and interpret data. In addition, the course supports criteria 3e, the ability to identify, formulate and solve engineering problems, 3g, the ability to communicate effectively, and 3k, the ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

In addition to the wind tunnel course, this laboratory is also utilized to some extent in five other courses in the curriculum, including AET 210, Measurement & Testing, AET 300, Aircraft Design, AET 432, Applied Heat Transfer, MET 434, Applied Fluid Mechanics and MET 460/461, Capstone Project. This facility has become an essential element of the MMET department curricula not only for students within the aeronautical concentration, but within other mechanical concentrations and the Manufacturing Engineering Technology program. In addition, students from all MMET department programs are involved in applied projects of interest to the engineering industry.

Facility Development

A perfectly funded engineering or engineering technology program that focuses on teaching is hard to find in the present university environment. Invariably, laboratory/experiment facilities are inadequately funded in most of the programs where teaching is emphasized over funded research. In most of the departments that fit this description, the instructor of a specific course is expected to build up the experimental facility (for teaching) by a combination of resources from a variety of different sources. For example, the typically small amount of funding available from the department is augmented by funds from external sources in the form of donations or earmarked for a short term project of interest to build up a certain part of a facility. Interspersed among these resources is the biggest resource of all: the time and effort put forth by the students themselves in building the facility or experimental setup. For the wind tunnel facility required for a successful conduct of the program (meet the requirements set forth in the curriculum), the MMET department at ASU Polytechnic took a similar approach.

The wind tunnel at ASU Polytechnic was initially constructed with funds available from the MMET Department and private donations, with significant improvements achieved with the help of funding from a waste collection facility located in Phoenix, AZ. The waste management company had a problem with material loss (debris flying off the vehicle) from the hopper (container) of the dump truck as it moved along city streets collecting trash and recycling materials[4]. Since the existing facility was inadequate for this project, the funding was used to develop a facility that was capable of addressing the problem at hand. Most of the associated design, fabrication and assembly tasks were carried out by students from all the curricula within the MMET Department, with supervision from the department faculty and laboratory staff. (The exception was a few parts such as the motor & fan that were ordered off the shelf.) Upon completion of these improvements, a scale model of the truck was built, and students and faculty used the facility to experimentally investigate the problem under a variety of environmental conditions, and reported the results. The outcome of this partnership was a facility with improved capabilities, both for educational and applied research applications.

Facility Description

The wind tunnel is an open circuit, suction facility where the fan and motor assembly is located at the exit plane of the tunnel inducing the flow to enter the inlet smoothly and pass through the test section with reduced large scale turbulence. The tunnel test section is 18-inch square with the test section length at 36 inches. The test section is made entirely of plexiglass. The tunnel sections are primarily aluminum except the transitioning section that houses the fan and motor assembly, which is stainless steel, and the two transition forward sections which are fiberglass. The cross section of the tunnel changes from a square (from inlet to the test section) to a circle (downstream of the test section) through the transition section. The overall configuration of the tunnel is shown in figure 1 below:

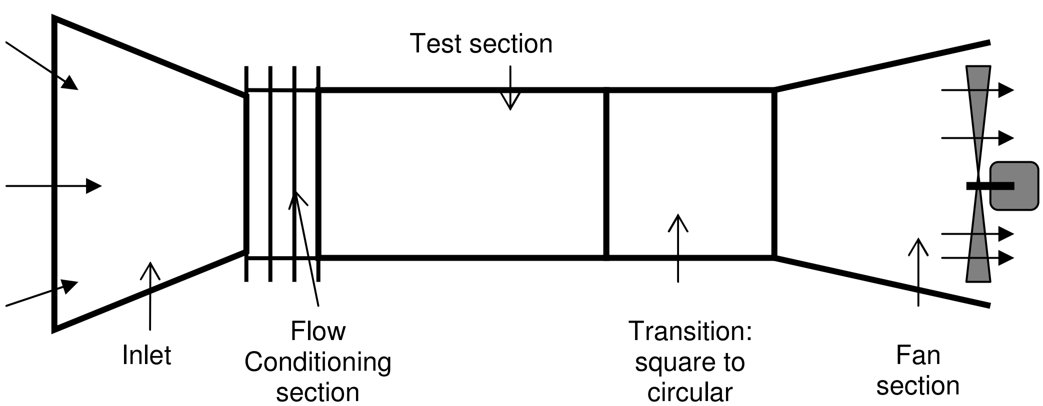

Figure 1 – Wind Tunnel Schematic.

As mentioned in the previous section, the wind tunnel was fabricated by students in the MMET department. The design and fabrication process was flexible enough to accommodate changes during the assembly of the tunnel sections. Figure 2 illustrates the tunnel fabrication and Figure 3 shows the completely assembled tunnel.

Figure 2 – Wind Tunnel under Construction

The support structure, constructed from donated aluminum extrusions, is shown on figure 3 as well. It must be noted that during the fabrication and assembly process, the students exhibited substantial resourcefulness in redesigning parts and structures, scavenging out-of-commission equipment for parts, modifying and/or fabricating parts where needed and testing the structural integrity of the framework.

The tunnel is powered by a 3 HP single phase AC motor which drives a 36 inch diameter four bladed fan. The maximum speed attainable in the test section of the wind tunnel in its present configuration is 52 mph. This maximum speed will increase with the redesign of the inlet section, a project which is underway at present. Instrumentation includes two multi-tube manometer banks built by students which are capable of measuring 20 different pressures simultaneously, a digital pressure transducer system, data acquisition using PC driven HP data loggers, temperature measurements using thermocouples, and velocity measurements with pitot tubes. In addition, flow visualization is provided by a smoke system using a fogger and/or dry ice. Occasionally, black light is used to enhance the visualization process.

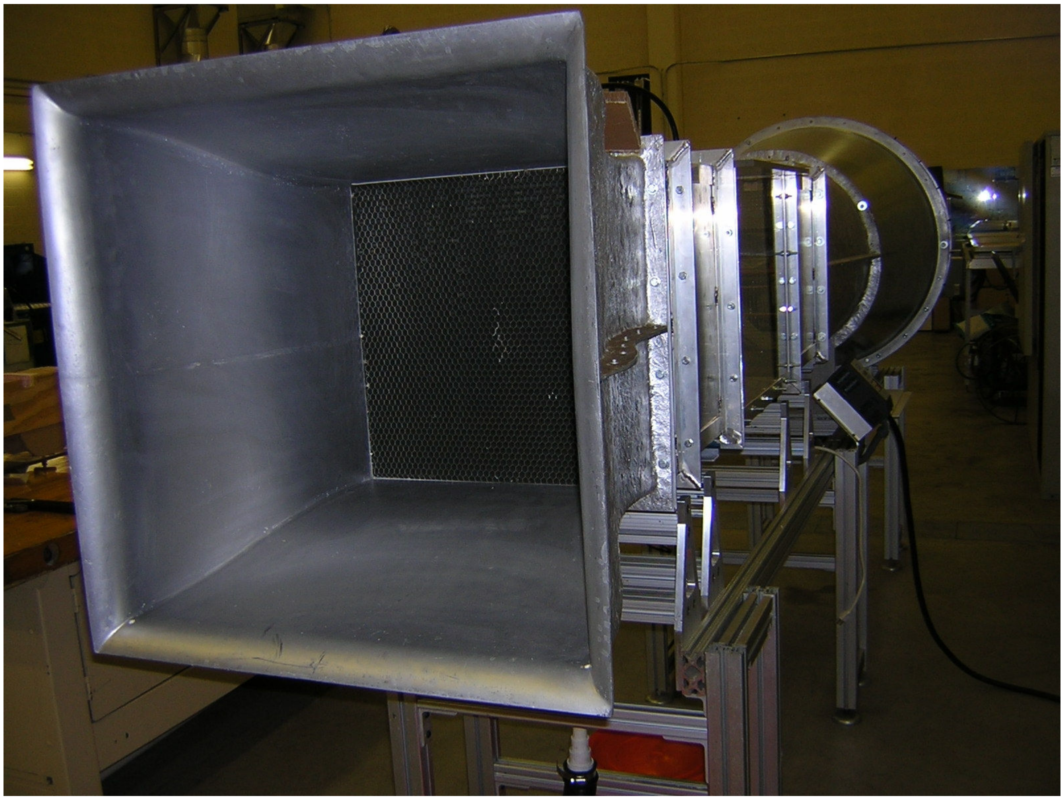

Figure 3 – Completed Wind Tunnel

Future plans include installation of a more powerful motor and more efficient fan, in addition to the redesigned inlet mentioned above, which will increase the maximum speed to about 85 mph. Additional improvements which will occur as funding becomes available include enhanced instrumentation and data acquisition equipment, and enhanced flow visualization capability.

Example Projects

While the wind tunnel has been built with teaching as its primary function, applied research projects that can be integrated into both the undergraduate and graduate curriculum is a major area of focus for this facility. Particularly, additional partnerships for which funding can used for both enhancing the tunnel and instrumentation as well as carrying out the investigations are being pursued. Target areas are automotive design, aircraft system design, electronic packaging, convective cooling management, city planning and pollution control and environmental impact. In this section, a few of the projects that have been completed in the facility are described.

As mentioned previously, funding for the facility was obtained from a waste management company interested in reducing the amount of debris escaping from their garbage trucks. The model that was constructed for studying this problem is shown in shown below in figure 4:

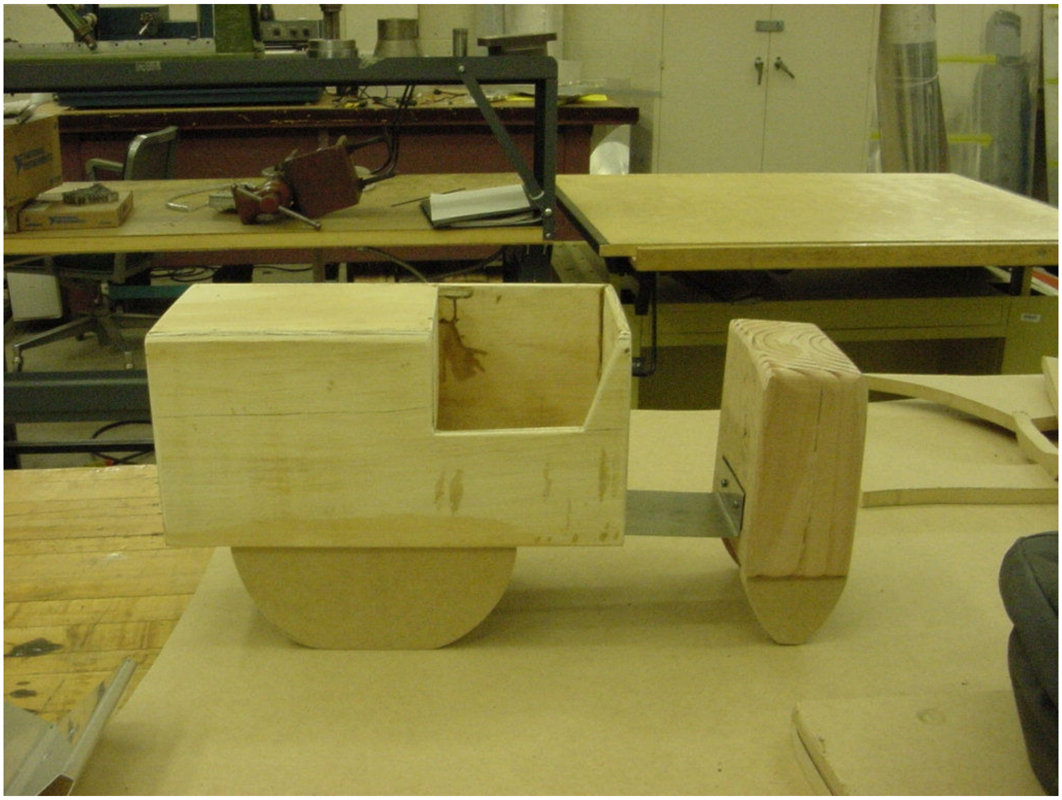

Figure 4 – Wind Tunnel Model of Waste Removal Truck

Results of this investigation demonstrated that the swirling flow inside the open hopper had the tendency to push the loose material upwards which when combined with the forward motion of the truck caused the debris to leave the confines of the hopper. Modified geometric configurations were tested to alter the flow field and reduce the strength of the circulatory flow. The results were partially successful, but the circulatory flow was not completely eliminated. Therefore, a second phase has been proposed in which a survey of the pressure field inside the containment volume will be measured in an effort to compare it with computational fluid mechanics predictions, and the model is being modified to accommodate this follow on study.

Another project completed in this facility was the development of a thermal and fluid boundary layer experiment for use in fluids and heat transfer courses. Specifically, the experiment consists of a heated and instrumented flat plate placed in longitudinal flow. Measuring the temperatures on either side of the plate and the heat transfer rate across it, one can evaluate the convection heat transfer coefficient of the flow. This experiment is designed to support the applied thermodynamics courses offered in the department.

A third, and very important experiment that the students enrolled in the class carry out addresses the design, fabrication and testing of a two-dimensional wing of known airfoil cross section[5]. The fabricated wing is instrumented for surface pressure survey and the measured pressure distribution along with the speed and density information is used to calculate the lift and drag acting on the wing. This exercise is central to force evaluations on fast moving vehicles such as aircraft, automobiles and boats. A typical experimental setup is shown in Figure 5 below. The flow pattern around the wing can be seen. Also the surface pressure tubes can be seen in the foreground.

Figure 5. Two-dimensional wing: flow field evaluation

Conclusions

This tunnel and its support facilities like the instrumentation systems reflect positively on the hands-on type of education the students receive in the MMET Department at ASU Polytechnic. In addition to playing a vital and central role in delivering a meaningful engineering technology program, the tunnel is also an asset for conducting graduate thesis work as well as funded applied projects that are of immediate utility to the industry in general.

References

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