A Subsonic Wind Tunnel Facility for Undergraduate Engineering Technology Education

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Abstract

Development of knowledge and expertise in the design and use of experimental techniques is critical in engineering technology curricula. Consequently, the effective use of experimental equipment and facilities is very important. In the School of Technology at Arizona State University, a closed circuit subsonic wind tunnel with a 4x5 foot test section capable of speeds between 30 and 200 ft/sec is maintained primarily for teaching wind tunnel testing techniques to Aeronautical Engineering Technology students, as well as students from other engineering technology disciplines. This paper describes the development of this facility and a course that is taught at the senior level in the Aeronautical Engineering Technology program in wind tunnel testing.

Although the wind tunnel is the most important experimental tool of the aerodynamicist, there are many other applications that allow the incorporation of the facility into the Mechanical and Manufacturing Engineering Technology curricula. For example, the wind tunnel has been used for many non-aerodynamic purposes such as studies in heat transfer, wind loads on structures, and automotive applications. Consequently, as will be described, students from all engineering technology programs at ASU utilize and benefit directly from the facility.

1. **Introduction**

In the Aeronautical Engineering Technology program at Arizona State University, students are required to complete an applied aerodynamics project in their senior year. The project involves the identification of an appropriate problem, followed by library research, basic analytical studies, and, finally, experimental investigations in the Technology Wind Tunnel at Arizona State University. There are two purposes for this project. The first is the obvious goal of familiarizing the students with the specialized instrumentation, data acquisition systems, and testing procedures that are used in the wind tunnel, which is the most important experimental tool in the field. In addition to this, however, an equally important goal of this project is to have the students apply the knowledge obtained in applied fluid mechanics courses to a practical problem so that they more fully understand the concepts taught in the earlier courses, as well as the limits and constraints of their knowledge.

The course was originally implemented a decade ago, and two approaches to the applied project have been attempted. At the present time the course has evolved into a project oriented course in which each student proposes a project of specific personal interest to investigate.

An obvious concern with the individual approach to projects is that the students no longer obtain the practical education that working as a team provides. In the last year this problem has serendipitously been addressed through efforts to improve on another difficulty that had been identified. Particularly, experience has shown that the goals of the course were often not fully realized because of the aeronautical students inability to manufacture appropriate and accurate wind tunnel models. Consequently, each aeronautical student is now paired with a senior manufacturing student. These students are extensively trained in modern aerospace manufacturing processes, and are capable of building highly accurate models on numerically controlled manufacturing equipment at ASU. The result is that, even though the students choose their individual projects, they still must work as a team to produce a high quality model.

2. **Facility Description**

The Technology Wind Tunnel (TWT) is a subsonic, closed circuit facility, which operates in the incompressible flow regime below Mach numbers of 0.3. At present, the velocity range in the test section may be varied between 25 fps to 200 fps. The test section is approximately rectangular (approximately because it diverges by 1/2 degree) with dimensions of 49.5 inches wide by 33.4 inches high at the test section entrance. Impetus for air motion is provided by a four-blade variable pitch propeller, powered by a 75 HP, 900 rpm synchronous electric motor. The facility is utilized by the faculty and students of Arizona State University for purposes of both undergraduate and graduate instruction as well as basic and applied research. The TWT was built using the resources of the Aeronautical Technology Department at Arizona State University, relying heavily on the (supervised) efforts of undergraduate students. The project was conceived in 1979 with the goal being the development of an exceptional quality aerodynamic test facility, as well as an instructional tool for both undergraduate and graduate students in Aeronautical Technology and related fields. Construction on the facility, earned out largely by students, was initiated in 1981, and the tunnel became operational in 1986.

Permanent instrumentation is installed to monitor the temperature in the test section, at the fan motor, and the test section mean velocity, which is measured through use of static pressure ports positioned in the entrance and exit of the contraction section. In addition, instrumentation and signal conditioning equipment is available to measure and record test section pressures, temperatures, velocities, model forces and fluid turbulence levels. These and other portable instrumentation equipment are linked to a PC-based data acquisition system.

Since its completion, the TWT has been utilized primarily as an instructional tool for undergraduate courses in wind tunnel testing. However, the TWT has also been used as a research facility in which several graduate students have carried out their research, as well as being utilized by industry for aerodynamic testing. As a research facility, the TWT has found a niche as an inexpensive and reliable facility, best suited for obtaining quick and reliable data appropriate for preliminary design purposes. Compared with other more extensive facilities, the TWT has the specific advantages of low cost, flexibility in testing, and fast turnaround.

3. **Course Description**

This course is concerned with experimental techniques in aerodynamics in general, with wind tunnel testing techniques emphasized. The pre-requisites for the course are a one semester course in fluid mechanics and aerodynamics, and a one semester course in instrumentation. Consequently, the students entering the course have an understanding of the basic Physics of fluid motion, as well as experience and expertise in the use of instrumentation, data acquisition systems and data analysis techniques. The course follows a lecture/lab format, in which the lecture is used to provide descriptive material concerning wind tunnel design, operation and construction, and to provide supplemental information on specialized instrumentation used in wind tunnel testing that goes beyond that covered in the pre-requisite instrumentation course. However, the emphasis of the course is on the laboratory portion, with 85% of the grade determined from the laboratory performance.

At the beginning of the course, the students perform a simple experiment in the wind tunnel to familiarized them with the facility operation, and the acquisition and analysis of experimental data. This experiment is the classical problem of a cylinder in crossflow at moderate Reynolds number, so that the drag crises is observed. The pressure distribution is measured at 15° intervals around the circumference of the cylinder, and the drag and drag coefficient are computed, and compared to published data. While this flow field is physically complicated, involving phenomena such as boundary layer transition and both laminar and turbulent separation, there is a large volume of experimental data that has been published on this problem. The result is that the students must interpret their results carefully, including the application of wind tunnel correction factors to their data, so that their results compare favorably to the published data (Rae& Pope, 1984), This experiment gives students an appreciation of the quality of raw aerodynamic data, and the careful interpretation that is necessary to ensure reliable results. The evaluation of student performance on this experiment is worth 15% of the grade.

The additional 70% of the grade is based on the students performance on the semester project, This project is a highly independent project in which the students identify a particular problem of interest to them in the field of aerodynamics, and study the problem in detail, both analytically and experimentally. The requirement is to research the problem, analyze the problem to the best of your ability, develop a test plan based on your research that will provide you with the appropriate data for your project, fabricate a model, carry out the testing, and compile the results in a formal report. The project is assigned on the first day of class, and each student submits a formal proposal for their project by the end of the second week of class. Upon acceptance of the proposal by the instructor, the students begin to research the problem in detail, including performing an analytical study of the problem to the best of their abilities, and a thorough literature search. This effort is to be completed by the end of the fifth week of school, at which time they have completed the preliminary experiment and are familiar with the wind tunnel operations and test procedures. At this time, the students submit a mid-term report which summarizes the results of the analytical study and the literature reviews, and presents a plan for manufacturing and instrumenting the wind tunnel model, a test plan for carrying out the necessary experiments, and a schedule for the project completion. The final report is due near the end of the semester, and consists of a standard formal laboratory report which describes their efforts. In addition to the written reports, each student is required give two oral presentations to the class concerning their project, one after the acceptance of their proposal, and the other after submission of their final report.

It is worthwhile at this point to mention a problem that has arisen in this course concerning these projects, and our attempt at a solution. In particular, the aeronautical students have shown considerable abilities in choosing, researching and analytically modeling their projects. However, in the experimental portion of the project the manufacture of appropriate models for testing in the wind tunnel is the point at which the quality of many of the students investigations begin to suffer. This occurs because of the aeronautical students inability to manufacture a model that accurately represents those hypothesized in their analytical studies. Consequently, they are often left with experimental results that are difficult to reconcile with their previous analytical predictions.

Traditionally, students have worked on projects such as this in a vacuum, being forced to rely only on their own education and experiences. However, this approach does little to prepare graduates for the industrial environment in which engineers and engineering technologists are required to work in teams, with each member contributing a particular expertise. In keeping with the philosophy of engineering technology programs at ASU, students are, as often as possible, exposed to and asked to solve realistic problems in an industrial-type environment. Therefore, it is logical to make use of the expertise of the manufacturing students by having them serve as a "manufacturing department" that aids the aeronautical students in the construction of high quality wind tunnel models. The benefits of cross-discipline cooperative education have been reported by several researchers (Barchilon and Kelley, 1995, Barnes and Fabiano, 1995). In this case we find that, in addition to experimental results which are meaningful and appropriate, aeronautical students gain an appreciation and understanding of modern manufacturing techniques through their interactions with the manufacturing students. The manufacturing students are exposed to wind tunnel testing and experimental work in general. In addition, they are faced with challenging problems in the manufacture of the wind tunnel models, which often involves the construction of unique and complex shapes. The results of these efforts have been very encouraging, and we plan to report on them in more detail at a later date.

4. Case Studies.

Since inception of the individual student projects, approximately half of the students have chosen to investigate traditional aerodynamic projects with applications directly concerned with aircraft and other aerospace vehicles. On the other hand, many students have chosen problems which involve applications of aerodynamics to other disciplines, such as automotive applications, aerodynamic forces on structures and others. Consequently, in this section we will qualitatively describe one project of each type that were performed by students in the fall of 1995. The first is a test of the effects of turbulator strips on the performance of a natural laminar flow airfoil. The second project concerns the aerodynamics of golf balls.

4.1 The effect of turbulator tape on a natural laminar flow airfoil

It is well known that at low speeds and high angles of attack, an airfoil can undergo an aerodynamic “stall”, in which the flow separates from the upper surface of the wing, with a catastrophic loss of lift (Anderson, 1991). The phenomena of aerodynamic stall, and flow separation in general, is physically complicated. Essentially, by increasing the level of turbulence in the boundary layer, in can be expected that the high momentum free stream fluid will serve to energize the boundary layer through turbulent momentum exchange, and delay the separation. However, accurate analytical treatment of the problem from first principles must involve solution of the complete (elliptic) Navier-Stokes equations, which pushes the state of the art in CFD. Consequently, empirical techniques based on experiment are of paramount importance. In this experiment, the student investigates the effects of adding a strip of rough material to the wings upper surface so that the boundary layer is “tripped”, and becomes turbulent near the leading edge of the airfoil, rather than further back on it’s surface (Schlichting, 1979).

In this investigation, the student constructed an airfoil and tested it both with and without the turbulator tapes. The basic measurements of lift and drag were recorded, and the flow patterns were visualized through attachments of tufts along the chord of the airfoil. The results did not show a significant performance enhancement to the airfoil. The student attributed this to wind tunnel wall effects, and to the free-stream turbulence level in the test section. An investigation of the free stream turbulence level indicated that it was too high to support the natural laminar flow behavior, so that the boundary layer was pre-maturely turbulent even without the presence of the turbulator strip. The student concluded the by investigating the level of free-stream turbulence that would be necessary to reliably determine the performance of the turbulator strip.

4.2 Aerodynamic drag of a golf ball.

In this project the student, a passionate golfer, undertook an investigation of the aerodynamics of a golf ball. It was observed that the design ofa golf ball is tightly constrained by the rules of golf, so that improvements in the aerodynamics of a golf ball will be incremental at best, and can be achieved only through detailed investigations of the effects of relatively small changes in the design.

In order to match Reynolds number to that achieved by (competent) golfers, the student was forced to construct a model out of a relatively large sphere, in this case a bowling ball. The results of the investigation clearly demonstrated the decrease in drag that occurs because of the dimpled surface. However, attempts by the student to investigated the lift, drag and, particularly, the starboard side force experienced by a spinning golf ball failed because the student was unable to construct a mechanism that allowed him to spin the ball in the test section.

Consequently, even though a primary objective of the investigation failed, this project was a valuable learning experience for the student, First, the basic aerodynamics of the dimpled golf ball design was studied and confirmed. Second, the interdisciplinary nature of wind tunnel testing was clarified to all of the students in no uncertain terms: it is not sufficient to study simply the aerodynamics of a problem. To conduct a successful investigation, all aspects of the engineering technology education can be important. In this case, the student underestimated the difficulty of the machine design necessary to spin an object in the wind tunnel at a controlled speed.

5. Conclusions

The Technology Wind Tunnel at ASU has proven to be an effective educational tool for undergraduate students in engineering technology curriculums. The specific advantages of low cost, flexibility in testing, and fast turnaround in the facility allow for a realistic and practical course in wind tunnel testing. The policy of allowing the students to choose their topic of research in the class has resulted in several creative projects, with applications both directly in the aerospace field and in aerodynamic applications in other fields. Even though many of these projects fall short of the students initial goals, they have proven to be a valuable learning experience, both directly in the aerodynamic testing field and in conceiving and carrying out a sizable project.

6. References

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