# AC 2007-475: USING ASME PERFORMANCE TEST CODES IN THE UNDERGRADUATE MECHANICAL ENGINEERING CURRICULUM

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# Using ASME Performance Test Codes in the Undergraduate Mechanical Engineering Curriculum


## Abstract

The American Society of Mechanical Engineers Performance Test Codes (ASME-PTCs) are documents promulgated to standardize the testing of mechanical equipment. The primary emphasis of the PTCs is equipment used in power generation, however, PTCs are also available to guide testing of more widely used equipment. The Codes are written so that they can be incorporated into an equipment purchase contract for use in conducting an acceptance test, and they are meant to be applied to a field test as opposed to a laboratory or shop test. There are about 40 "equipment codes" and about 15 "supplements" covering fundamental measurement techniques and test (measurement) uncertainty.

The PTCs can provide a useful bridge between college courses in the energy stem and instrumentation/measurement and the "real world". Also, the introduction to the ASME Codes and Standards activity and the part that individual engineers play in developing voluntary standards is obvious link to the topics of professional ethics and volunteerism.

There are several ways that the PTCs might be used in undergraduate instruction:

- They might serve as textbooks or reference materials for lecture or laboratory courses
- Students may be asked to conduct a PTC-like test on a piece of equipment
- A PTC or a portion of it may be assigned for reading, after which students give written or oral reports.
- PTCs may serve as reference material in student (experiment) design courses.

This paper reports on experiences using the Performance Test Codes at three different universities and in three different ways. At a small liberal arts-based university students taking an elective course in turbomachinery were required to design and conduct a PTC-quality test on a pump, using the appropriate PTC as a guide. At a medium-sized technical university, students read and reported on PTCs as part of a senior thermal science laboratory course. At a large research university PTCs were used as reference material in a laboratory capstone design course. In addition to instructor's experiences, assessment data from student surveys are presented.


## 1. Introduction to Performance Test Codes

<u>A. What Are Performance Test Codes</u> The American Society of Mechanical Engineers (ASME) Performance Test Codes (PTCs) provide uniform rules and procedures for planning, preparation, and execution of performance tests and for reporting the results [1,2.] A performance test is an engineering evaluation, based on measurements and calculations, whose results indicate how well the functions of equipment are accomplished. PTCs began as "Power Test Codes" decades ago, so their main emphasis is on power plants and the equipment therein. The first engineering standard of any type issued by ASME was a "PTC": *Rules for Conducting Boiler Tests,* published in 1884. Today, there are about 40 PTCs covering specific equipment, entire systems,

and complete plants. In addition to these Codes, there are Supplements on Instruments and Apparatus covering measurements and techniques common to several Codes. A complete listing of PTCs currently available is given in Appendix A.

Codes are intended to be used as legal documents. Some Codes, such as the *ASME Boiler and Pressure Vessel Code*, are given the force of law by being adopted by state and local legislative authority. ASME PTCs are written in a format suitable to be cited in contracts as the standard methodology to determine if the equipment's guaranteed performance was attained. PTCs have the force of law only when incorporated into a contract.

In non-commercial applications, manufacturers and suppliers may be interested in the exact performance of their equipment, in order to better understand design margins and the impacts of manufacturing tolerances on performance. Therefore they may conduct Code tests outside of any performance guarantees.

<u>B. How Are Performance Test Codes Developed</u> PTCs are developed under the jurisdiction of the ASME Council on Codes & Standards, working through its Board on Standardization and Testing. Reporting to this Board is the Performance Test Codes Standards Committee. The Standards Committee appoints working Technical Committees who are responsible for drafting, updating, and maintaining individual Codes. The Technical Committee is a team of engineers with expertise in some or all fields covered by the specific PTC. It is extremely important to note that the members of all of these groups are volunteers, except for a small number of ASME full-time staff members who coordinate the activity. Volunteers' expenses are borne, in part, by their employers but they receive no financial support from ASME, nor do they have any financial interest in income derived from the sale of Code documents. While Technical Committee members formally represent only themselves, committee membership is balanced between the interests of: 1) equipment users/owners, 2) equipment manufacturers, 3) system designers/architects, 4) plant/process testing agencies, and 5)general interest personnel.

A preliminary draft of a new or revised Code is sent to knowledgeable persons in industry for review. This review and the incorporation of comments and recommendations strengthen the document. The completed draft is then approved by the Technical Committee and by the Performance Test Codes Standards Committee. The Code is sent to the American National Standards Institute (ANSI) for their approval and ASME publishes the document and sells it for barely more than the cost of the material, print and paper, and handling costs. Throughout the process, the focus is on building consensus, accordingly, ASME seeks input from all types of parties who may be interested in the Code and/or the equipment or process it covers.

<u>C. What is in an ASME PTC</u> Physically, a PTC is a soft cover, 8.5 by 11 inch document ranging from 10 to 300 pages in length. Each document has a standard format, beginning with an *Object and Scope* describing what equipment the test is intended to evaluate, the goals of a test, and the expected uncertainty of the results. This section is followed by *Definitions and Description of Terms* which also includes mathematical symbols and abbreviations. Next, *Guiding Principles* are covered in detail, including:

- necessary agreements before testing
- preliminary tests
- test preparations

- operating conditions
- equipment set-up for the test
- permissible deviations
- of observations and duration of test runs
- constancy of operations
- acceptability of test runs
- frequency

A section on *Instruments and Methods of Measurement* includes guidance on choice of instrumentation, including sensitivity, precision, number, alternatives, and duplication. Additional information is provided on the use and placement of instrumentation, limitations, sources of error, and precautions. Test methods are also described.

The next section outlines the *Computation of Results*. This section contains the formulas and directions for determining the equipment performance from the recorded data. It also contains the formulas and instructions for determining the uncertainty of the results. Each PTC contains a list of information to be included in a section on *Report of Results* and some provide the format of the report.

Many PTCs have appendices. Topics covered in the appendices might include sample calculations, detailed consideration of uncertainty, derivation of formulas, and, alternate test methods

## 2. Options for Using Performance Test Codes in the Undergraduate Curriculum

There are several reasons to consider using PTCs in the instruction of future mechanical engineers; most of them stem from the fact that these documents come from the "real world" of engineering and business practice. By studying and using PTCs, students can:

- Learn about the significance of Codes and Standards in engineering practice
- Become familiar with complex, real world equipment and systems (e.g., steam turbines and steam generators) – as opposed to the simple schematic representation in textbooks.
- Be aware of applications of the engineering sciences of thermodynamics, fluid mechanics, and heat transfer
- Appreciate the critical importance of instrumentation and measurement technology
- Develop a deeper understanding of measurement uncertainty and its practical implications
- Raise their awareness of professional societies in general and ASME in particular (i.e., learn that there is more to ASME than *Mechanical Engineering* magazine!)
- Have a tangible introduction to the importance of professional involvement and volunteerism

Since many of the PTCs are about thermodynamically important parameters (i.e. efficiency, flow rate, energy produced and consumed), they fit within the energy systems stem. Because they also cover performance measurement, they are most useful if associated with experimentation and laboratory exercises. A little thought suggests the following list of possible uses for PTCs:

- Use the Code documents as textbooks or required supplemental material.

- Use the Code documents for their primary purpose – as instructions for a (student-performed) performance test.
- Plan a supplemental exercise around one or more Code documents. Have students read the document and prepare a report.
- Use Code documents as guides and references for student-designed experimental projects.

Using the PTCs as textbooks or required supplemental material provides a few challenges. Most of the documents are too extensive and the (test) information is too complex. A few of the documents, however, can be easily adapted for as texts. Perhaps the most useful in this regard is PTC 19.1 *Test Uncertainty* which provides a through and accessible treatment of the subject. This document could be used in introductory courses in instrumentation and measurement. Similarly, the other "19 Series" documents provide ample instruction in measurement of essential parameters like Temperature (PTC 19.2), Pressure (19.3) and Fluid Flow (PTC 19.5 – recently updated).

Most of the equipment-specific codes are too narrow for use as general textbooks but can be useful as textbook or course supplements. PTC 10 *Compressors* has a very thorough treatment of the thermodynamics of compression processes as well as some useful models for Reynolds number effects in compressors. It has also been used as a helpful reference in an elective course in turbomachinery. PTC PM *Performance Monitoring* has been used in a course in power plant engineering. The upcoming documents on *Verification and Validation in Computational Solids Modeling* and *Verification and Validation in Computational Fluid Dynamics and Heat Transfer* represent a new direction for PTCs and may be useful in finite element and computational fluid dynamics courses.

The primary obstacle for using the PTCs in their "native" form *i.e.* as instructions for a student-conducted equipment performance test, is that most modern university laboratories do not contain equipment appropriate for such tests or such equipment as exists is not or cannot be instrumented extensively enough. A possible exception is fluid handling equipment – fans, compressors, and, especially, pumps. Experience with a student "engineered" pump test using PTC 8.2 *Centrifugal Pumps* will be described later in this paper.

Having the students read and report on a PTC (or a few sections of a PTC) is simple to implement and allows for a wide range of flexibility. The topic of the course allows the instructor to pick the appropriate PTC(s) to be read and reported. For example, if the course is Fluid Mechanics, PTC 19.5, *Flow Measurement* would be an obvious choice. The exercise works particularly well in a laboratory course where the students can extend and strengthen topics and practices that may not be possible in a laboratory setting. The assigned report can be a lengthy well-crafted technical paper, a brief research note, an oral presentation, or a combination of these. The type of report assigned should be chosen to reflect the credit allotted for the exercise and the emphasis it deserves in the "big-picture" of the course. A specific example of the read-and-report exercise is described later in this paper.

Another potentially valuable use of PTCs is making them available as guides and/or reference materials for student-designed experiments. In typical capstone design courses, students are often given considerable latitude in developing objectives, approaches to the problem, and selecting appropriate analysis techniques. For experimental or laboratory-based design courses, students are additionally tasked with selecting transducers and instrumentation, and in designing a test format that can provide useful results. In many cases the weakest link for most students is simply lack of "practical experience" with the equipment under evaluation, or lack of familiarity with what constitutes "useful results."

PTCs can be especially useful in these regards, since they contain a wealth of real-world experience drawn from experts in a variety of areas relevant to experiment design. For example, PTC 19.5 *Flow Measurement* covers all the industrially-relevant techniques and hardware/transducers for measuring flow rates. It also includes detailed equations for data reduction, and lots of advice on applicability of various test methods for specific situations. This is exactly the type of practical information students will need in the design of experiments, much of which is missing in traditional laboratory textbooks.

A major obstacle to the widespread use of PTCs in the undergraduate curriculum is their cost. Paper copies of PTCs can be purchased directly from ASME or from several authorized resellers. Likewise, single-computer electronic copies can also be purchased. The two most important drivers for the price of these documents are 1) they are produced in small quantities for a relatively small-demand market (unlike textbooks which sell in the thousands of copies annually, each PTC sells at most a few hundred copies per year) and 2) when used as legal documents, even a steep price (a few hundred dollars) is insignificant in light of the larger legal and testing costs. For use of PTCs in education to become widespread, the cost will have to be lowered. (Note: Copies of PTCs used in the projects described in this paper were donated to the author's programs by ASME).

## 3. Experiences in Using Performance Test Codes in the Curriculum

<u>A. A Student-Performed Performance Test</u> This option was investigated at the University of Evansville. The students were enrolled in a senior-level elective, Principles of Turbomachinery. The emphasis in this course is primarily on industrial applications of turbomachinery such as pumps, fans, and compressors, as well as steam and gas turbines. About half of the course covers application and selection of machines and about half covers rudimentary design. The text is *Fluid Machinery: Performance, Analysis, and Design* by T. Wright[3]. In addition to the text, students are supplied with numerous handouts prepared by the professor and they receive loaned copies of PTC 8.2 *Centrifugal Pumps*, PTC 10 *Performance Test Code on Compressors and Exhausters*, and PTC 11 *Fans*.

One-fifth of the course grade is based on the course project, which is a performance test on a centrifugal pump. A pump test has been part of the course requirements for several years; in the Spring of 2005, the project requirement was changed to require that the pump be tested according to PTC 8.2[4]. Appendix B shows the project assignment sheet that is given to the students. Note that the course instructor plays the role of the Test Director; only he can approve deviations from the Code requirements. The students assume the role of the test engineers. Note also that the students are divided into very small groups (2 or 3 students each) to develop proposed test plans (all in accordance with the Code)*. The best test plan is selected and the students are then rearranged into larger teams (4 or 5 each) to perform the actual test and prepare reports.

There are several reasons for selecting a pump test and PTC 8.2 for this exercise. Perhaps the most obvious is that there is a pump available and it had been used in the course many times before! Another is that space constraints in the laboratory usually require that the pump testing set-up be disassembled after use in a given Spring semester so that it must be (can be) reassembled by the students for "their" pump test. Besides these, there are also reasons that derive from PTC 8.2 itself. Unlike many other PTCs, PTC 8.2 provides for two levels of testing; a "Type A" test and a "Type B" test. Type A testing is similar to most other PTC tests; it is intended to be run on large equipment (in this case, a boiler feed pump) in the as-installed condition and it requires extensive instrumentation to achieve a very low uncertainty. The Type B test, however, is well-suited for students in a university laboratory; it requires less instrumentation, can be performed on a smaller pump installed in a "custom built" (*i.e*., jury-rigged) test loop, and yields results of higher uncertainty. In performing a Type B test, students must study the Code, follow its rules, install and calibrate instruments, run the tests, do an uncertainty analysis, and write a test report – just like a "real" Code test – but at a scale that they can handle in a university laboratory.

The PTC 8.2 Code test has been required for the past two years, Spring 2005 and Spring 2006. Each year, about 10 students enrolled in Principles of Turbomachinery so each year 4-5 test plans were proposed, one was selected, and two groups performed testing, so a total of 4 groups have performed a test. (It should be noted that, each year, the two teams shared some duties; *e.g*. one team would construct the test rig and the other would calibrate the instruments). Although varying in some details, on the whole the results have been excellent; both in the quality of the test, the data, uncertainty analysis, and report, and in the reception of the exercise by the students. They have learned the same things about pumps and pump testing that they would have learned in the old "instructor designed" activity, <u>plus</u> they learned about ASME, Codes, and standard processes for engineering investigations.

<u>B. Researching and Reporting on Performance Test Codes as a Laboratory Exercise</u> This option was investigated at Lawrence Technological University. The students were enrolled in a required senior-level Thermal Science Laboratory course. The students are placed in small teams to conduct and report on six experiments that strengthen and extend the material covered in Thermodynamics, Fluid Mechanics, and Heat Transfer courses. In addition to the team experiments, each student performs an individual research and reporting project. Because the students are already using pressure measurement, temperature measurement, and test uncertainty techniques throughout the course, each student is assigned to give an oral presentation on one section from PTC19.1 *Test Uncertainty*, PTC 19.2 *Pressure Measurement*, or PTC 19.3 *Temperature Measurement*. The sections in 19.1 and 19.2 are conveniently divided to each cover a specific instrument (*e.g*., manometer, optical pyrometer) or installation method (*e.g*., pressure taps, diaphragm seals), so an individual section lends itself well to a succinct presentation. Sections in 19.1 are also conveniently divided into presentable pieces. Besides using the PTC, the students are asked to supplement their research by using at least one other

* Invariably, students must also use PTC 19.5 *Flow Measurement* as the develop and execute their test plans

reference source such as manufacturers' specifications or catalog information. With multiple sources the student can report not only on the devices or techniques outlined in their PTC, but also on accuracy, precision, cost, and other specifics not covered in a PTC. The oral presentation is graded using the LTU Mechanical Engineering Department Oral Presentation Evaluation Criteria, with which the students are familiar by their senior year. Each student gives their formal presentation to the entire class including the instructor.

The benefits of the research and presentation project are threefold. First, every type of pressure and temperature measurement can not be performed in the laboratory course. The presentations allow all of the students to see a wide sample of devices and techniques. Second, the students gain the insight of real-world application of these devices. Third, the student gets one final opportunity (before graduation) to hone their presentation skills.

While as a concept, using PTCs in the classroom in this manner appears to be beneficial, it was unknown if the PTCs are a good learning tool. Therefore, an assessment has been completed to determine if the PTCs are worthwhile and practical documents for the students to increase their knowledge of measurement techniques and test uncertainty. PTCs 19.1, 19.2, and 19.3 were evaluated as a learning tool based on an indirect assessment (*i.e.*, a survey of student opinions). Students were surveyed after completing their research and presentation exercise. A copy of the survey instrument is reproduced in Appendix C. Prior to distributing the survey, the instructor did his best to stay opinion-neutral toward the students as to the effectiveness of the PTCs as a learning tool, even though the instructor serves on a PTC committee.

Much of the survey was quantified using a 5-point Likert scale, but written responses were also gathered. While many different exercises are possible using PTCs in the curriculum (as noted in Section 2), the survey is general enough that it is likely applicable to any use of PTCs in the curriculum. The results compiled in this paper are derived from 41 LTU student surveys spanning two years and multiple class sections.

Table 1 shows data on students' prior knowledge about PTCs. Fifty six percent of the students had never even heard of PTCs, while 44% had used them, knew what they were, or had at least heard of them.

| | Yes | No |
|---|---|---|
| Prior to this course, I had used Performance Test Codes. | 12.2 | 87.8 |
| Prior to this course, I knew what Performance Test Codes were. (Percentage is expressed from the remainder of those students that responded "No" to the previous statement.) | 19.5 | 80.5 |
| Prior to this course, I had heard of Performance Test Codes (but didn't know what they were). (Percentage is expressed from the remainder of those students that responded "No" to the previous statement.) | 43.9 | 56.1 |

**Table 1. Percentage of students that are familiar with Performance Test Codes.**

As shown in Table 2, after an in-class discussion of PTCs, the students gained a better understanding of PTCs. On a scale of 1 to 5, where 1 is "strongly disagree" and 5 is "strongly agree," the average student response was 4.17. The median was 4 with a standard deviation of 0.77. Also shown on Table 2, after reading a section of a PTC, approximately the same percentage of students increased their understanding of PTCs. The average response was 4.34, the median was 4, and the standard deviation was 0.66. Finally from Table 2, after presenting a section of a PTC to the instructor and their classmates, there is a slight decrease in understanding with an average response of 4.22. The median was 4 with a standard deviation of 0.79. The decrease can be attributed to the higher percentage of responses of "no opinion." This is likely because the level of detail in a PTC may be overwhelming to a student who has no industrial experience.

| | strongly disagree | disagree | no opinion | agree | strongly agree |
|---|---|---|---|---|---|
| After an in-class discussion, I had a better understanding of the Performance Test Codes. | 2.4 | 0 | 7.3 | **58.5** | 31.7 |
| After reading a section of the Performance Test Codes, I had a better understanding of the Performance Test Codes. | 0 | 0 | 9.8 | **46.3** | **43.9** |
| After presenting a section of the Performance Test Codes, I had a better understanding of the Performance Test Codes. | 0 | 2.4 | 14.6 | **41.5** | **41.5** |

**Table 2. Percentage of students agreeing with the statements concerning their understanding of the Performance Test Codes.**

After the students were exposed to PTCs, they were asked if they might use them in industry (even if the student is not in the Power Generation Industry and may have no need of a Performance Test). As shown in Table 3, in general the students will consider using PTCs. The average student response was 3.83, the median was 4, and the standard deviation is 0.77. The results from Table 3 indicate that they believe that they are learning practical material that can be applied after they are employed. The students were asked, "Why would you (or why wouldn't you) use PTCs once employed?" The responses were very positive: "Provides a better understanding of operation and limitations of equipment." "[PTCs can] establish reliability of measurements." "I currently work in braking system research and development. Using appropriate equipment during experiments is critical." "Extremely useful tool to analyze the necessary (yet cheapest) method of measuring some value." "They give a common set of criteria for everyone to follow." "Good information; general and easy to read." "[They are useful] for [the] purpose of accuracy in testing." "Gives you a basic idea of what errors could occur while using a certain product." One student made an interesting comment, but appears a bit misguided by the reliability of internet sources: "[PTCs contain] a lot of thorough information. However, the internet is making the PTC less-needed." A couple of students noted, "They have good info", or "They are a useful tool." One student had no opinion because, "I have no interest in this area." One student already uses PTC 19.1 *Test Uncertainty* at his work. Another student uses PTCs at work in the Process Piping Industry.

| | strongly disagree | disagree | no opinion | agree | strongly agree |
|---|---|---|---|---|---|
| Even if I am not employed in the Power Industry, I would consider using the Performance Test Codes. | 0 | 4.9 | 24.4 | **53.7** | 17.1 |

**Table 3. Percentage of students that may find the Performance Test Codes useful as in industry.**

As shown in Table 4, the students believe that the PTCs are a useful learning tool. The average student response was 4.02, the median was 4 , and the standard deviation was 0.57. Again, this is a strong indication that the students view the PTCs as useful and practical to their future employment. The students were asked, "Why (or why not) are the PTCs a useful learning tool?" All but one of the written responses were positive. Five students noted that the PTCs contain "good information." Three students noted that the PTCs contain "lots of information," while another student stated, "It is informative and very detailed in many areas." Other student responses are: "They familiarize the student with real-world technical applications of topics covered in course material." "They deal with real-world, useful application and not theoretical fluff." "[They] inform you on how things should be done. For example, certain calibrations." "[They] teach real application that backs-up theoretical concepts." "[They are a good learning tool] to better understand mechanical equipment [and] how to use them correctly." "[They contain] more information than a text book and even [more than a] device's manual. Very well organized information." "You have a better understanding of what is used/needed in any application." "[They are a good learning tool] because you can learn more specific information about what is/isn't important to control." "If you need information on certain tools, it explains clearly what they are." "[One can] learn a lot about instrumentation, calibration, and implementation." "[They could] help for a project at work." "I learned a lot that I didn't know." "Exposes students [to instrumentation] so they will know what they are when in the field." "They gave a more in-depth look into problems faced in applications." "They thoroughly teach the uses and applications of various measuring devices." "They will help you decide which [type] of…gauge or measurement device [to use]." "They are very specific if you need to learn about the applications of an instrument." "[They give a]…better understanding of [specifics of a measurement instrument]." One student noted that they contain information pertinent to many engineering industries. There was only one negative comment from a student who stated, "[They are] kind of hard to understand."

| | strongly disagree | disagree | no opinion | agree | strongly agree |
|---|---|---|---|---|---|
| The Performance Test Codes serve as a useful learning tool. | 0 | 2.4 | 7.3 | **75.6** | 14.6 |

**Table 4. Percentage of students that found the Performance Test Codes class exercise as a useful learning tool.**

As shown on Table 5, the level of material contained in the PTCs is rated by senior-level students as just barely advanced with an average score of 2.87, where 1 is “too advanced,” 3 is “just right,” and 5 is “too easy.” The median was 3 and the standard deviation was 0.75.

| | too advanced | advanced | just right | easy | too easy |
|---|---|---|---|---|---|
| The level of material covered in my chosen section of the Performance Test Code was: | 4.9 | 20.7 | **57.3** | 17.1 | 0 |

**Table 5. Percentage of students rating the level of material covered in a selected section of a Performance Test Code.**

Finally the students found the PTC reporting exercise slightly increased their interest in the thermal-fluid sciences (see Table 6). On a scale of 1 to 5, where 1 is “strongly disagree” and 5 is “strongly agree,” the average student response was 3.07. The median was 3 and the standard deviation was 0.88. By their senior year, students have already decided where their interests and/or strengths lie. A single laboratory exercise is unlikely to change their perception. Therefore it is pleasantly surprising that 29.2% of the students “agreed” or “strongly agreed” that the exercise increased their interest in Thermal-Fluid Sciences.

| | strongly disagree | disagree | no opinion | agree | strongly agree |
|---|---|---|---|---|---|
| The Performance Test Codes increased my interest in the thermal-fluid sciences. | 7.3 | 9.8 | **53.7** | 26.8 | 2.4 |

**Table 6. Percentage of students agreeing with the statement concerning their interest in the thermal-fluid science field due to the Performance Test Codes.**

At the end of the survey, the students were asked for any additional comments or observations. One student gave high praise for the PTC format stating, “Very easy to read and understand.” In contrast, another student stated, “The material was not too advanced but [is] presented in an overly complicated and poorly explained manner.” This comment was directed at PTC 19.1, Section 6. One student who thought the PTC was “very specific” for <u>applications</u> of an instrument (a thermometer in this case) stated that the Code “could be a little more specific” in instrument <u>description</u>. Another student thought that “Some of the test code info is very old and outdated.” Perhaps the best praise came from a student who derived his/her own equation stating, “Good assignment. Not too difficult + nice relaxed presentation atmosphere + presenting technical content = good times.”

Overall, the use of PTCs in the classroom and the associated assignment performed quite well as a learning tool, according to the students. They reported that their knowledge of diagnostic devices and testing increased. They found the material very practical and will consider using the Codes in their future employment. More than a quarter of the students believe that the assignment raised their interest in the Thermal Sciences. Finally, the level of the material was appropriately challenging for upper-level engineering students.

C. Using Performance Test Codes As Resources in Student-Designed Experiments This approach was investigated in a capstone laboratory design course at Mississippi State University, a research university with a large and comprehensive undergraduate program. MSU's senior laboratory courses are a three-semester sequence covering basic measurement transducers, data acquisition with Labview programming, statistics and experimental uncertainty analysis, capped with an experiment design project involving the modification and verified improvement of an existing experimental apparatus or system. In their final semester student teams are allowed to select their own experiment topic, then they are required to formulate their own objectives and approach to completing the experiment design – consistent with typical university "time and funding/resources" limitations. Successful completion of the project is measured in terms of creativity, documented results with uncertainty analysis, and oral and written presentation of findings.

PTCs covering the measurement of flow, temperature, pressure, and frequency (time) were printed, bound, and made available as "references" in a common student lounge area[†]. One lab lecture was also devoted to introduction of the PTCs, along with examples of typical transducers and analysis information covered in the documentation. Students were of course encouraged to use these materials as part of their research in designing their experiments.

Out of eight student teams, only two groups actually used one or more PTCs for significant input to their design. One project involved the selection of flow and temperature sensors for instrumenting a coolant flow loop as part of an engine heat exchanger design. Another project team consulted the PTCs to evaluate the failure of existing pressure transducers. The students in this group discovered that, based on PTC recommendations, differential transducers were the only way to obtain reasonably low uncertainty in their final results for discharge coefficients. However, most student groups were able to find equivalent design guidance using internet searches or direct phone conversations with equipment vendors. A significant limitation of our "printed and bound" copies of the PTCs is that most of our students are very enthusiastic about using web-based electronic formats for information they use in "reporting". Using "cut-and-paste" techniques for both figures and equations from electronic media allows them easier access to referenced "report quality" information. Hence they prefer to utilize these other resources for design information as well.

This limitation of "access" to the PTCs is a significant barrier to full utilization of the PTC information. Several students had requested that PDF-format PTCs be posted on our own ME webpage, however copyright limitations prevented such access. It is believed that this limitation

[†] Duplication of the copyrighted PTC documents was done with the permission of the ASME, who gave their full support to the investigations reported in this paper.

was a significant factor in students choosing other sources for design information. During our final project presentations, many groups agreed that easy electronic access to the PTCs would enhance their value as a "reference" considerably.

## 4. **Conclusions**

American Society of Mechanical Engineers Performance Test Codes can be incorporated into the Mechanical Engineering curriculum in a variety of ways. Their direct use as textbooks in either classroom or laboratory courses is problematic; however they can be used to supplement laboratory-based projects. One program was successful in assigning a class project wherein students actually designed and performed a Code-level test on a pump. A similar exercise could be conducted with a fan.

The most promising applications for PTCs focus on the Supplements on Instruments and Apparatus, especially those for Temperature, Pressure, Flow, and Test Uncertainty. These documents can be made available for reference when students design their own experiments and measurement systems, or the focus can be on the documents themselves, via a "read and report" exercise. Students have responded favorably to such an exercise at one university.

In addition to what the Codes can teach about performance testing and measurement technology, they provide a valuable introduction to the use of Codes and Standards in engineering practice, the importance of voluntary standards development, the premier position that ASME occupies in this endeavor, and the contributions of "ordinary" practicing engineers to the Codes and Standards process.

A major obstacle to the widespread use of Performance Test Codes, indeed all Codes and Standards, in the Mechanical Engineering curriculum is the high cost of the documents themselves. The authors have no doubt, however, that a widespread interest in using the documents in education could result in a more favorable price for the documents or a more accessible electronic distribution for faculty and students. Closely allied to this is the student's preference for web-based or electronic format. Although many codes are in fact available in PDF format, these versions of the documents were not available for this project.

Acknowledgement The authors would like to thank the Codes and Standards Department of the American Society of Mechanical Engineers, Mr. William Berger, Mr. Steve Weinman, and Mr. Jack Karian for their assistance in this project.

References:

1. Korellis, S.J. and Gerhart, P.M.; "Performance Evaluation and Testing"; American Power Conference, Illinois Institute of Technology, Chicago, IL, April 1999.
2. ANSI / ASME PTC 1, "General Instructions," American Society of Mechanical Engineers, New York, 1999.
3. Wright, Terry; *Fluid Machinery: Performance, Analysis, and Design*; CRC Press, 1999
4. ASME PTC 8.2, *Centrifugal Pumps* American Society of Mechanical Engineers, New York, 1991

## Appendix A

## List of Performance Test Codes Currently Available from ASME

PTC- PM, Performance Monitoring
PTC 1, General Instructions
PYC 2, Definitions and Values
PTC 4, Fired Steam Generators
PTC 4.3, Air Heaters
PTC 4.4, Gas Turbine Heat Recovery Steam Generators
PTC 6, Steam Turbines
PTC 6.2, Steam Turbines in Combined Cycles
PTC 8.2, Centrifugal Pumps
PTC 10, Compressors and Exhausters
PTC 11, Fans
PTC 12.1, Feedwater Heaters
PTC 12.2, Steam Surface Condensers
PTC 12.3, Deaerators
PTC 12.4, Moisture Separator Reheaters
PTC 12.5, Single Phase Hear exchanges.
PTC 17, Reciprocating Internal Combustion Engines
PTC 18, Hydraulic Power Movers
PTC 19.1, Test Uncertainty
PTC 19.2, Pressure Measurement
PTC 19.3, Temperature Measurement
PTC 19.5, Flow Measurement
PTC 19.6, Electric Power Measurement
PTC 19.7, Measurement of Shaft Power
PTC 19.10, Fuel and Exhaust Gas Analysis
PTC 19.11, Steam and Water Purity in the Power Cycle
PTC 19.22, Digital Data Acquisition Systems
PTC 19.23, Guidance Manual for Model Testing
PTC 19.25, Transient Measurement Uncertainty
PTC 21, Particulate Matter Collection Equipment
PTC 22, Gas Turbines
PTC 23, Atmospheric Water Cooling Equipment
PTC 25, Pressure Relief Devices
PTC 29, Speed Governing Systems for Hydraulic Turbine Generator Units
PTC 30, Air Cooled Heat Exchangers
PTC 30.1, Air Cooled Steam Condensers
PTC 31, High Purity Water Treatment Systems
PTC 34, Waste Combustors with Energy Recovery
PTC 36 Measurement of Industrial Sound
PTC 39, Steam Traps
PTC 40, Flue-Gas Desulfurization
PTC 42, Wind Turbines

PTC 46, Overall Plant Performance
PTC 47, Integrated Gasification Combined Cycle Power Plant
PTC 50, Fuel Cell Power Systems
PTC 51, Combustion Turbines Inlet Air Conditioning Equipment (Cooling/Heating)*
PTC 55, Aircraft Engines*
PTC 60, Verification and Validation in Computational Solid Mechanics*
PTC 61, Verification and Validation in Computational Fluid Dynamics and Heat Transfer*

* Codes currently under development

**Appendix B**

**Assignment for the Pump Performance Test**

**ME 463 : Principles of Turbomachinery**

**Course Project**

**Object** The object of the course project is to determine the performance of the ITT Bell & Gossett Model 1510 Centrifugal Pump that is currently installed in the pump test loop in the UE Fluid and Thermal Science Lab, Room KC 285.

**Scope** The following are to be determined

- Performance Curves of Head vs. Flow, Power vs. Flow, and Efficiency vs. Flow, all at 1600 RPM
- Identification of the Specific Speed of this particular pump
- Comparison of measured performance with that expected for a pump of this type
- Test and computational uncertainties associated with the above items

Testing will be carried out in accordance with the specifications for a "Type B" test according to ASME PTC 8.2 – 1990 *Centrifugal Pumps*. In the event that the provisions of PTC 8.2 cannot be met, exceptions must be approved by the owner's representative, Dr. P. M. Gerhart. Reporting will be consistent with PTC 8.2 and the *University of Evansville Mechanical Engineering Program Standards*.

**Resources** The resources of the University of Evansville Department of Mechanical and Civil Engineering Laboratories may be applied to this investigation. Assistance may be obtained from Mr. O. D. Putler and Mr. Mark Randall. A budget not to exceed $200 has been allocated to this project. All class members will be provided with a copy of PTC 8.2 as a loaned item (This document must be returned with the project report). Several photographs of the pump impeller will be forwarded by e-mail.

**General Approach and Schedule** The following will constitute the general approach

1. Students will divide into five 2-person teams. Each team will investigate the requirements of PTC 8.2, examine the test facility, and prepare a written test plan. These plans will be due on February 17, 2006
2. The best test plan will be selected for further development
3. Two new teams will be formed and test preparations will be made. Test preparations will be completed by March 1
4. Testing will be completed by March 17
5. Reports will be submitted on March 24 and practice presentations delivered

**Appendix C**

# Lawrence Technological University
# Thermal Science Laboratory
# Performance Test Code Survey

The following survey is used purely for assessment. It will remain confidential and will not contribute to your grade. Be honest in your responses. The goal of this survey is to assess the usefulness of the Performance Test Codes.

I took Thermodynamics in: Fall Spring Summer of (year) _________ Grade: ____

I took Fluid Mechanics in: Fall Spring Summer of (year) _________ Grade: ____

I took Heat Transfer in: Fall Spring Summer of (year) _________ Grade: ____

I read and presented PTC _______ Section __________________________

Prior to Thermal Science Lab, I had used the Performance Test Codes:
Yes _______ (skip next two statements) No ________ (answer next statement)

> Prior to Thermal Science Lab, I knew what Performance Test Codes were:
> Yes _______ (skip next statement) No ________ (answer next statement)
>
> > Prior to Thermal Science Lab, I had heard of Performance Test Codes (but didn't know what they were):
> > Yes _______ No ________

After an in-class discussion, I had a better understanding of the Performance Test Codes.

| Strongly disagree | disagree | no opinion | agree | strongly agree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

After reading a section of the Performance Test Codes, I had a better understanding of the Performance Test Codes.

| Strongly disagree | disagree | no opinion | agree | strongly agree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

After presenting a section of the Performance Test Codes, I had a better understanding of the Performance Test Codes.

| Strongly disagree | disagree | no opinion | agree | strongly agree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

Even if I am not employed in the Power Industry, I would consider using the Performance Test Codes.

| Strongly disagree | disagree | no opinion | agree | strongly agree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

Why or why not? ______________________________________________________________

_____________________________________________________________________________

The Performance Test Codes serve as a useful learning tool.

| | | | | |
|---|---|---|---|---|
| Strongly disagree | disagree | no opinion | agree | strongly agree |
| 1 | 2 | 3 | 4 | 5 |

Why or why not? _______________________________________________________

_______________________________________________________________________

_______________________________________________________________________

The level of material covered in my section of the PTC was:

| | | | | |
|---|---|---|---|---|
| Too advanced | | just right | | Too easy |
| 1 | 2 | 3 | 4 | 5 |

The PTC increased my interest in the thermal-fluid sciences.

| | | | | |
|---|---|---|---|---|
| Strongly disagree | disagree | no opinion | agree | strongly agree |
| 1 | 2 | 3 | 4 | 5 |

Additional comments/observations: __________________________________________

_______________________________________________________________________

_______________________________________________________________________