**Paper 2004-1374**
**Session 3166**

# Mechanical Engineering Case Studies on the Web

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## Abstract

We describe the application of "case studies" and a case study web site developed for use in junior-level undergraduate courses in Mechanical Engineering. Case Studies developed by others in the past often focused on design problems while our case studies focus on data analysis. Case studies are small to mid-range out-of-class assignments based on the analysis of data obtained from senior-level design and laboratory courses, graduate theses, and reports from the literature such as NACA reports.. Through the application of the case studies, students learn design and data-analysis methods for real engineering systems using real experimental data in traditionally "lecture" courses. Furthermore, those case studies developed from the senior lab courses provide a bridge between the last two years of the undergraduate curriculum. The case studies motivate junior-level students by exposing them to experiences that will come in the senior year, and in graduate research.

## Introduction

Students in undergraduate lecture courses are often surprised to discover that empirical correlations do not predict real operating systems with high accuracy. A "case studies" web site has been developed to provide undergraduate Mechanical Engineering students the opportunity to analyze actual engineering systems with real experimental data within their lecture courses. These case studies are based on design calculations or are developed from experimental data obtained by ME seniors within their design and lab courses, honors theses, graduate student theses, Co-op experiences (with appropriate permissions), and data from the literature (e.g., NACA reports). Analysis of real data, often within a design framework, provides strong motivation for students to learn basic material in context with real-world applications. Furthermore, students become familiar with data analysis and the inherent uncertainties in experimental measurements before entering the laboratory courses

The case studies were developed in a format that allows them to be easily used as out-of-class assignments. Each case study includes a description of the objectives, the experimental facility, the experimental procedure, and the basic mechanical principles that underlie the analysis. Photos and video clips are often used to show the facility and illustrate the experiment. From the web site, students obtain a description of the case study analysis and can download the data in spreadsheets as well as engineering drawings of the models used in the experiment. The process of data analysis generally involves comparison of experimental results with predictions from mathematical models, and includes nondimensionalization, statistical analysis, spreadsheet and plotting techniques, and comparisons between experimental results and standard correlations. A statistics tutorial is also included on the web site to aid the students in the development of experimental data analysis methods specific to the assigned case study.

The case studies are placed on a web site for easy access by students and instructors. In addition, the web site serves as a resource library for instructors, and allows the students to easily download diagrams and experimental data to their own computer for analysis. The web site is available to the public at http://www.mne.psu.edu/undergrad/casestudy/, thereby increasing the visibility of the program to other universities, prospective students, and industry. Currently the web site is being expanded to include longer analyses as well as a data-bank from which faculty can draw to create other out-of-class assignments using real experimental data.

## Recent Efforts in Undergraduate Education

The past five years have seen many innovations in the undergraduate Mechanical Engineering program at Penn State.

1. The Learning Factory brings hands-on experiences to freshmen in the product dissection classes and to seniors in the capstone design courses. Students pursuing the Product Realization Minor are even more involved with the activities at the Learning Factory. The Society of Automotive Engineers also uses the facilities at the Learning Factory when building the Formula Car. The Learning Factory received the Boeing Educator Award in 1998 and has also participated in outreach to elementary and high school students including Take-Your-Daughter-to-Work Day.

2. The senior capstone design projects are almost entirely sponsored by industry. Each student design team works on a unique project proposed by industry. Visits to the company site and regular interaction with the company contact give the students a real-life design team experience before graduation. Students learn to plan a timeline and work under time and monetary constraints often encountered in the work force. A final presentation and written report teaches the students how to document their work in a professional way. A final "design poster fair" benefits both the students in the course as well as other students in the college.

3. The Texaco Lab has five test stands, an IC engine, refrigeration cycle, vibrations test, Rankine power cycle, and jet engine. This lab is visited by several junior Mechanical Engineering courses to demonstrate the different measurements and analysis methods required in one application. The Texaco Lab also includes computer simulations of laboratory experiments.

4. The IDEALS courses (Integrated Design, Engineering Analysis, and Life Skills) teach the theory of mechanical engineering analysis and then directly apply those skills to an engineering design problem. The IDEALS concept has been applied in ME 31, Thermodynamics II, and in a senior lab course where students must identify the course objectives and their design project.

5. Senior laboratory courses in fluid mechanics, heat transfer, vibrations, and controls have been restructured to include statistical analysis of results. In the fluid mechanics laboratory, students use several facilities in prepared lab experiments and then design and execute a new experiment in one of those facilities.

6. The Society of Automotive Engineers (SAE) chapter at Penn State is growing rapidly with currently over 250 students. Each year SAE involves undergraduates of all years and graduate students in the design and building of the Formula Car and the Hybrid Electric Vehicle.

These developments have engaged our students and taught them the application of the theoretical analysis that is learned in the junior-level courses. Most of these experiences, however, do not actually occur within the basic courses that teach mathematical model development. It is difficult to include hands-on experiences in basic courses due to class size and time limitation. Juniors, in particular, would benefit greatly from the integration of real-world examples with these courses. Examples from industry can serve as a strong motivation in the lecture courses. Results from an experiment can be used to teach both theory and experimental error analysis. Students gain a better understanding and appreciation of mathematical model development by immediately applying it to real data, and learn that real data, like theory, is imprecise. .

## Case Study Web Site

When a visitor arrives at the front page of the current case study web site (Figure 1), a greeting appears that describes the web site. The greeting includes an invitation for others to use the case studies and to submit new case studies to the library. An editor tool has been developed so that a contributor can easily create the html files for a new case study.

The case studies are grouped by the topics covered in eight of the required Mechanical Engineering courses. These courses are:

**Thermal Sciences**
ME 30: Thermodynamics I
ME 31: Thermodynamics II
ME 33: Fluid Mechanics
ME 412: Heat Transfer

**Mechanical Systems**
ME 50: Machine Dynamics
ME 51: Mechanical Design
ME 54: Vibrations of Mechanical Systems
ME 440: Modeling of Dynamic Systems

As the Case Study Web Site is expanded and used at other Universities, we plan to remove the course names and only retain the titles of the areas.

Also included on the Case Study Web Site is a Statistics Tutorial. The statistics tutorial describes many common statistical calculations including: mean, median, mode, variance, standard deviation, Binomial Distribution, Poisson Distribution, Normal Distribution, Student's T Distribution, and Chi-Square Test. Each statistical calculation topic includes: the definition, examples, significance and meaning, EXCEL function name and usage. Many statistical calculation topics also have an applet which allows for an interactive demonstration. If a case study is assigned as homework in a course, the student can use the Statistics Tutorial to learn about the needed statistical calculations. This eliminates time required in lecture and gives students a reference that can be used at any time for review.

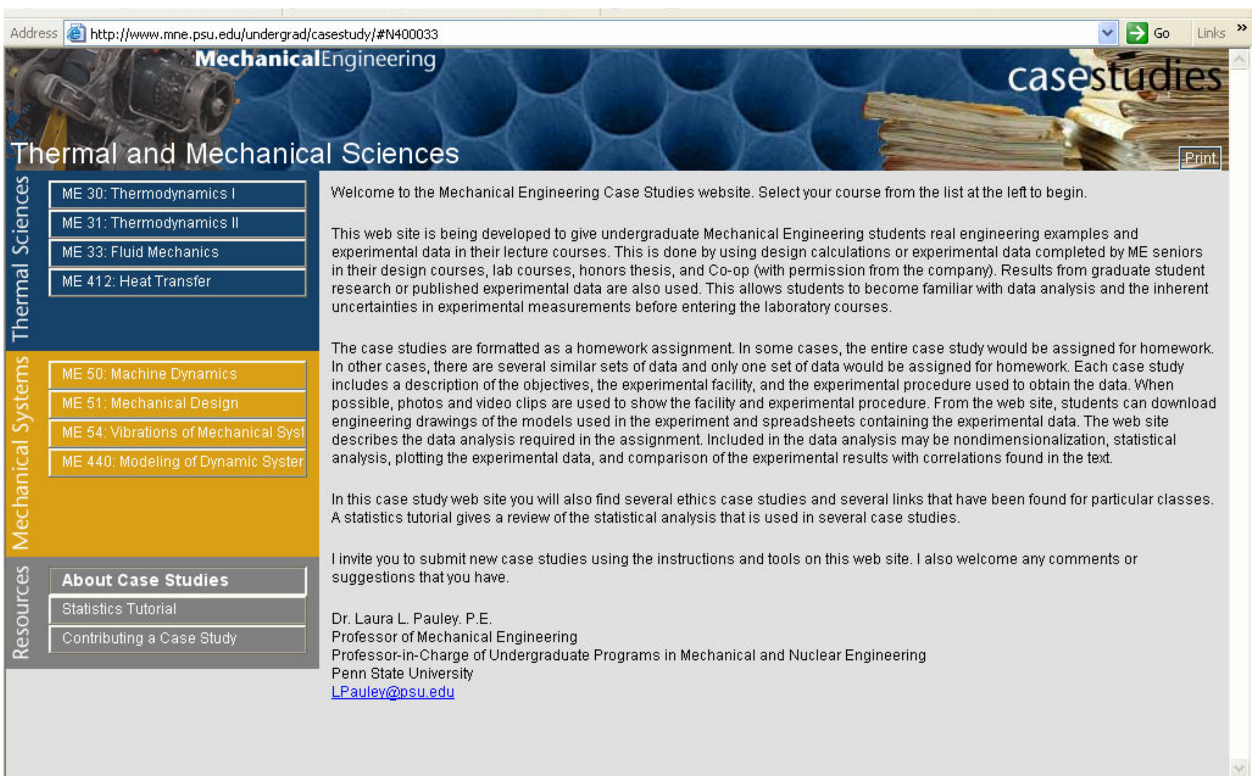


**Figure 1.** Front page of Case Study Web Site.

Each course title can be selected to send the user to a list of case studies related to that course. These cases have been developed from laboratory course projects, senior design courses, IDEALS designs, the Society of Automotive Engineers design calculations for the Formula Car and the Hybrid Electric Vehicle, graduate theses, and from data in the literature such as NACA reports. Although the primary objective of our web site is to archive data analysis case studies, some ESL design case studies[1] have also been added for convenient access. Through the web site, students in the junior-level courses can see real-world applications of theory and also obtain a preview of

what to expect in the senior-level courses as well as in graduate research. The web site also serves as a student-to-student link between juniors, seniors, and graduate students, as well as a theory-to-application link for the course material.
As an example, when Fluid Mechanics is selected the user currently finds the following list of case studies:

**ME 33, Fluid Mechanics Case Studies**

1. Drag Measurements for Ten Geometric Bodies
2. Drag Measurements on Round and Wing Tubes
3. Hydraulic Jump through a Sluice Gate
4. Optimal Drafting Position for Marathon Runner
5. Experiments on a Series of Symmetrical Joukowski Sections

Upon selecting a case study, a complete description of the experiment or design problem is given along with the experimental data. Experimental data is provided in an EXCEL spreadsheet that can be downloaded for analysis. For example, the introduction page for a fluid mechanics case study is shown in Figure 2. The experimental data in this case study were obtained from a final project in our senior-level fluid mechanics laboratory course. We consider this reference to be an important motivation for students. The source of the experimental data is stated just below the case study title. When a student observes that an experiment was conducted by senior ME students, this gives the student a foretaste of future courses in the program, potentially an important motivational tool. When experimental data for the case study is derived from graduate research, the case study becomes a recruiting tool and demonstrates to the undergraduates the type of research being conducted in graduate studies.

The case study in Figure 2 contains drag measurements for a range of air speeds over two different tube geometries. Photographs are included showing the wind tunnel and tube models. Each photo can be enlarged to full screen. In some case studies (such as this one), short movie clips show the experiment in progress. In the categories marked in blue, each case study describes the objectives of the experiment, experimental set up and procedure so that students can gain an understanding of experimental methods. The categories marked in yellow are components of the homework assignment to be submitted by the student. The assignment includes data analysis, plotting of results, and discussion and conclusions. In the case study shown in Figure 2, students are asked to apply dimensional analysis to the experimental data and to plot results in dimensional and nondimensional form. Comparison is made to theoretical and experimental data found in their textbooks, and experimental error is assessed. Some race car designs use tubes with wing cross-section instead of rounded tubes to reduce vehicle drag. The final step of this case study is to evaluate the reduction in drag obtained when the wing tube is used with the Penn State SAE formula car.

The case studies currently represented on the web site are shorter analyses easily assigned in place of traditional homework. Two case studies are currently being implemented on the web site that require the student to analyze at a more in-depth level with correspondingly greater time requirements. These case studies are more of the "mini-project" variety and are intended to teach the student the analysis of more complex engineering systems. Two additional in-depth case studies are under development using data from the Applied Research Laboratory at Penn State in which the students are given multiple samples of experimental data (> 1000) from which means, standard deviations, and other statistical quantities are to be calculated. In this way, the student learns not only the scatter inherent in experimental data, but also how to improve experimental results through ensemble averaging of independent data sets.

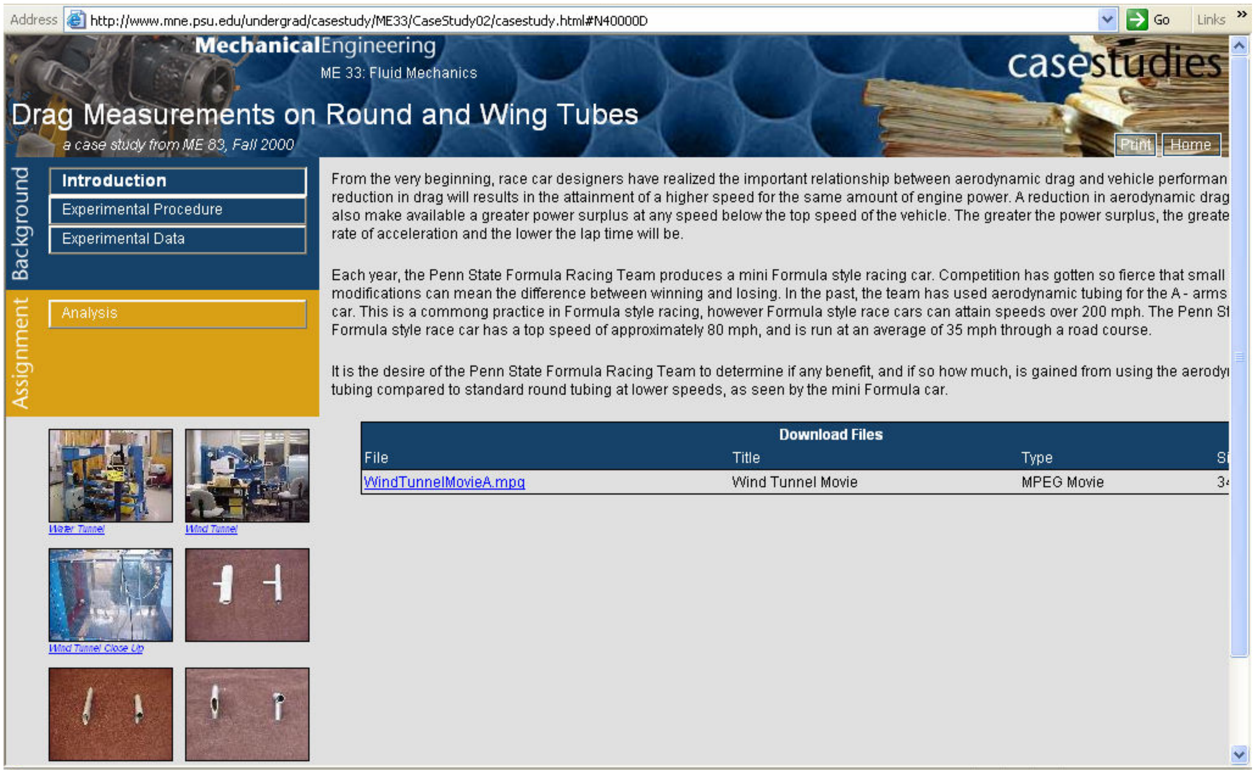


**Figure 2.** Introduction page for "Drag Measurements on Round and Wing Tubes" case study used in the fluid mechanics course.

## Faculty Participation

The growth of the Case Study Web Site is due to the strong interest by ME faculty and their mentoring of students who develop the case studies. Faculty who teach the senior laboratory courses are solicited for appropriate experimental data from their class. All faculty members are invited to submit graduate student data or to advise an undergraduate during the summer to develop a case study.

Success of the web site comes when the case studies are used in courses. Each semester, an email announcement reminds faculty and instructors about the Case Study Web Site and encourages them to use a case study as an assignment for their course.

## Student Participation and Technical Support

The ME Case Study Web Site was initiated in 2001 with financial support from the Penn State Teaching and Learning Consortium. With this support we hired both undergraduate and graduate students to work with faculty over the summer to develop case studies. Case studies were developed from existing data from a laboratory or published research. Other case studies were developed from new experiments conceived and conducted specifically for the case study. One example of an experiment developed specifically for a case study is the Torsional Pendulum Experiment shown in Figure 3. Developing and running an experiment expressly for the case study web site resulted in a more comprehensive set of photographs of the experimental components and several short movie clips showing the experiment. This level of photo documentation was often not possible in an experiment that was run months or years earlier by a different student for a laboratory course. In the future, we hope to develop more experiments solely for the case study web site.

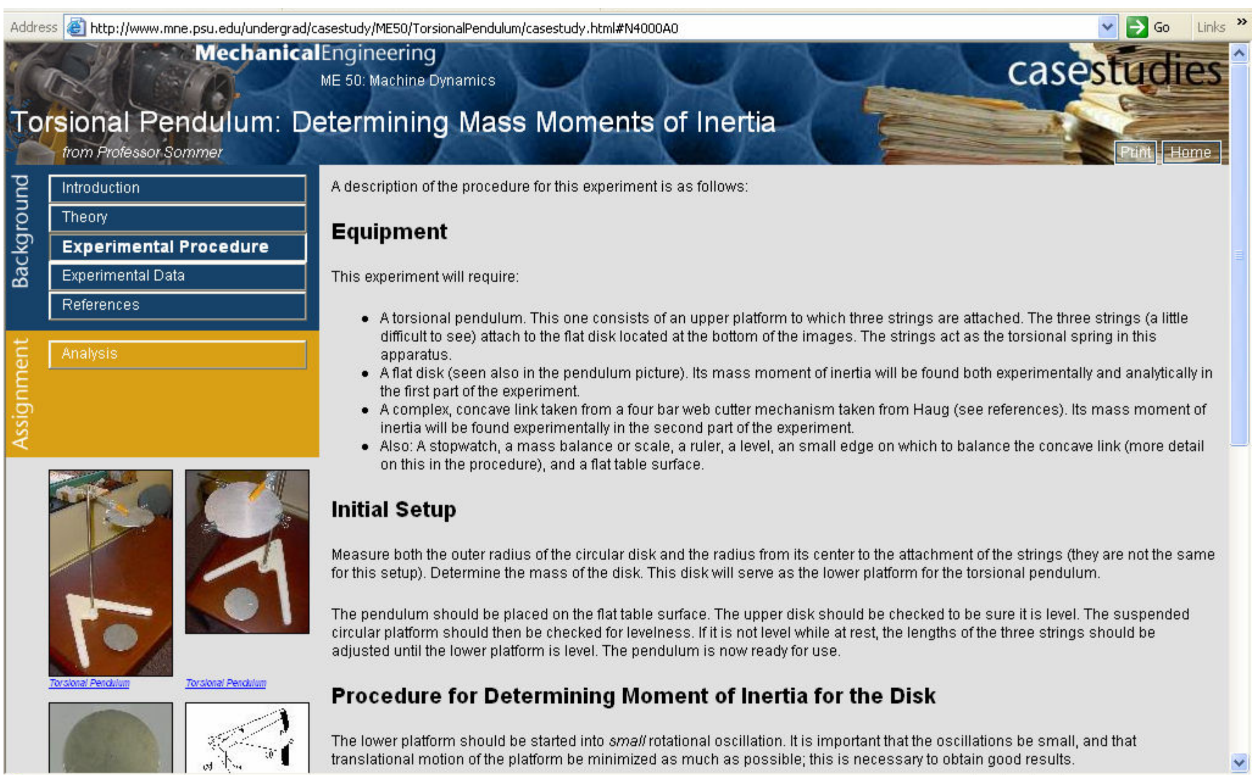


**Figure 3.** Experimental Procedure page for the "Torsional Pendulum" case study used in the machine dynamics course.

The financial support from the Teaching and Learning Consortium has allowed us to hire expert assistance in developing the web site. A graduate student with much experience in developing web sites was hired to work on the development of the statistics tutorials and another graduate student has developed several in-depth case studies from more complex data sets. We have also hired a web site designer to develop the web site and editing tools.

## Student Outcomes

Student surveys were carried out after the application of case studies in two courses.

In the Fall semester 2003 two in-depth case studies were assigned in ME 33, Fluid Flow. The first was entitled "Pressure Losses Across Evaporators," and the second "The Separating Turbulent Boundary Layer." In the head loss analysis, students were asked to first apply the classical correlations for round piles to estimate friction factors and pressure drop in a real evaporator that was the subject of a M.S. thesis. These estimates were compared with measured pressure drops. The students were then asked to calculate friction factors from the data and compare with the classical correlations. Among other things, the case study taught the students that the transition between laminar and turbulent pipe flow is not so clear in real engineering systems with highly noncircular pipes. In the second case study, using data from a classical NACA report the students were asked to analyze, in detail, differences in velocity, pressure, and structure associated with accelerating, constant velocity and decelerating flow external to a boundary layer. Universally the students reported that their understanding of boundary layers was much higher as a result of this case study than from the text-book material. The students were required to write their work in classical manuscript format with proper discussion in good English. Each case study replaced two "traditional" problem sets, and together the case studies represented 20% of the student's grade.

Recently, in the Spring 2004 semester, the students were sent a questionnaire to assess student learning from the perspective of the student. 36% of the class of 52 students responded to the survey. The questionnaire began with the following three questions: "To what extent did the case studies improve your (understanding of fluid mechanics)/(understanding of data analysis)/(understanding of engineering applications) as compared to "traditional" homework assignments?" The choices were "more, same, less." To an "understanding of fluid mechanics and data analysis," 82-84% of the class responded "more" with the rest responding the "same." 59% responded "more" and 41% "same" to "engineering applications." Interestingly, 65% responded "yes" to the question "Was the extra time involved in carrying out the case studies worth it in terms of the extra learning that you obtained?" with 34% "neutral;" and 12% "no." Most interestingly, however, the question "Would you recommend that I assign similar case studies in my future classes?" lead to a unanimous "YES." Although the statistics for this one course are insufficient to draw hard conclusions, it appears that the additional knowledge represented by these in-depth case studies was well appreciated by the students.

In Spring 2004, the Diesel Engine Case Study was assigned as homework in ME 30, Thermodynamics I. This case study required the students to integrate P-V in a cycle to determine the work output. Variation in experimental text runs was also demonstrated by the differences in the six data sets. A survey was distributed to the class after they received their graded homework.

Student response showed that they found the case study interesting and that it helped them better understand P-V work. The students also responded that the case study showed them the difference between a theoretical process and an actual process. There was a positive student response when asked if a case study should be assigned in future sections of the course.

## Conclusions

The ME Case Study Web Site developed at Penn State has successfully incorporated experimental data analysis into junior level lecture courses. Positive feedback has been received from students and faculty. We will continue to expand this web site and invite others to use these case studies and submit new case studies.


## Acknowledgements

The development of the Case Study Web Site has been supported by the Penn State Teaching and Learning Consortium. The web site design and the interactive editor were created by Ken Kubiak.


## Bibliography


[1] The Engineering Case Library (ECL) by the Design in Engineering Education Division (DEED) of ASEE, Rose-Hulman Institute of Technology, and Carleton University. Contact: Richard A. Layton, P.E., Ph.D., Rose-Hulman Institute of Technology.


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