A Mechanical Engineering Design Laboratory - Integrating Numerical and Experimental Analysis.

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As we enter the twentieth century, engineers must have the tools which will permit them to fulfill multiple engineering tasks in the workplace. This is especially true in this era of downsizing and the competitive global industrial climate. Employers would rather hire one employee who can perform many tasks, rather than several employees which are capable of limited skills. In the area of mechanical engineering design, where the product development cycle is very complex, there are numerous phases which must be completed before a product is shipped; such as initial design and layout, prototyping, testing, analysis, final design, manufacturing, and quality assurance, to name a few steps. In each of these steps, the engineer is involved with the product and it's development. In many cases, several mechanical engineers with varying expertise are called upon, at different points in the process, to carryout the specific tasks. To examine one step in the design process; as cost becomes the driving issue in the area of design, experimental analysis is giving way to numerical analysis. Thus, the mechanical engineer must have knowledge of both experimental procedures and numerical analysis methods. It is at this point where the well rounded engineer comes is beneficial to the company.

Creating a mechanical engineer who is capable of satisfying many roles is left to the mechanical engineering curriculum. We, as educators, must provide a mechanical engineering curriculum which is diverse and yet integrates the key knowledge bases in the traditional ME concentrations. It is important to have courses which integrate this basic knowledge into a design project where the engineer must use numerical work and experimental methods. In the Mechanical Engineering program at Wilkes University, students of senior standing must take a capstone design laboratory course which integrates the stems of the program into a semester long design project incorporating a laboratory and numerical component. The ability to set-up and apply both experimental and numerical analysis to a design problem, and interpret the results, is very important to the mechanical engineering student. The results of this projects are presented both in written and oral form to fellow students, faculty, and industry. The combination of analysis techniques in the different areas of mechanical engineering give the students a complete introduction to various analysis techniques which are demanded in industry.

Introduction

The goal of any engineering educator must be to produce marketable students which have the ability to undertake a variety of engineering tasks. That is to say that we, as engineering educators, must supply the students with the necessary skills which will allow them to tackle difficult industry problems[1-4]. In general, engineering students graduate with the necessary theoretical skills, however, when it comes down to experimental skills, or application of theory in an experimental environment, many of the students are not as well equipped. To solve this problem, the Mechanical Engineering Department at Wilkes University has developed a capstone Mechanical Design Laboratory course. The course, as it's name implies, is laboratory based (experimental), taken during the student's senior year. The course is set up to solve two problems in the mechanical engineering curriculum. The first is that the students are introduced to experimental methods in the design area of the mechanical curriculum. The second is that as a capstone laboratory course, the students utilize experimental methods to solve a industrial design problems, which are collaborative with local industry. This course has one additional benefit, the instruction and application of numerical analysis. As part of the course, the students are taught applications in numerical analysis, finite-element-analysis (FE), outside of the theory course which they take. This application of FE allows for three modes of analysis, theoretical, experimental, and numerical, and the students must utilize each analysis tool in the solution of their design project. This paper outlines this particular course and the benefits which are derived by the students.

Laboratory Set-up

The senior level design laboratory is structured to satisfy two basic requirements; the introduction of the students to laboratory techniques used in mechanical engineering design, and as a capstone design course. It should be noted that it is a goal of the course to base the design component around an experimental procedure. In addition to the use of experimental analysis to solve a particular design problem, the students are instructed in areas of computer-aided engineering, such as finite-element-analysis, solid modeling, and computational fluid mechanics, to name a few. Thus, this course ties together various aspects of mechanical engineering design which are taught during the four year program, and it also incorporates new concepts in numerical analysis which prepares the students for industry. The students work in teams of three in order to complete the basic prescribed laboratories and the design project.

Experimental Procedures

In order for the students to utilize any equipment in the experimental solution of the given design project, the students must be competent using a variety of equipment. During junior year, the students are taught basic experimental methods in the areas of fluid mechanics, manufacturing, heat transfer, and controls. However, it is left to this course to teach the basic usage of experimental methods and procedures in the area of mechanical design. To learn the workings of each piece of equipment, including the necessary data reduction and presentation, the students are expected to complete a series of basic laboratory experiments. The following is a list of basic experiments which are performed by each group..

- Tensile Testing
- Fatigue
- Material Hardness
- Stress Determination - Strain Gage
- Gear Analysis

One of the main goals of the experimental portion of the course, in addition to familiarizing the students to the various equipment used in this area, is the interpretation of the results which are obtained and determination of existing sources of error. Sources of error exist in all aspects of experimental analysis, and it is very important that they be identified and quantified, if possible. If the experimenter blindly accepts the results as accurate, severe consequences may result.

Design Component

One goal of the course is the introduction of the mechanical engineering students to experimental procedures in the area of mechanical design, however, it is a greater goal of the course for the students to be able to utilize this basic experimental knowledge in the solution of a semester long design project. Typically, the design projects which are completed center around one particular area of mechanical engineering, such as fluid mechanics, thermal analysis, structural design, controls, or machine design, for example. The particular projects are either assigned to the design teams or the teams can propose a project to the instructor. At this point, the instructor of the course becomes a consultant to the group; thus the group can ask questions of the consultant whenever the need arises. It is also the role of the instructor to present new material to the group whenever this need arises. As the design teams progress along the path to solution of the design problem, there are several core analysis tasks which must be incorporated into the project. It should be noted that the teams must incorporate many forms of analysis and redesign into the project. The first analysis task is experimental; in most cases, the design projects have an experimental component. The groups have the responsibility of determining which experimental method is applicable, either in the area of design using knowledge obtained from the experiments performed, or in the area of thermal or fluids; and the design of fixtures to utilize the testing apparatus. As part of the design process, the design teams are required to present their projects in both oral and written form. In the project presentations, the teams make extensive use of CAD, solid modeling, as well as any other graphical techniques which might be applicable. The oral presentations are solely centered around the use of PowerPoint computer presentation software.

Numerical Analysis

In industry, there is a shift away from expensive experimental testing of the initial design iterations, only instituting experimental testing during the latter design phase. There is a higher emphasis placed upon the use of numerical analysis; such as finite-element-analysis, solid modeling, computational fluid mechanics, and numerical dynamic analysis, to name a few. In any numerical analysis, the adage *garbage in, garbage out* applies. This especially true when teaching numerical analysis at the undergraduate level. In general, the students spend much time preparing a numerical model and only a fraction of that time analyzing the solution. In this laboratory course, most of the design projects are based, not only around an experimental method, but are also modeled numerically. Thus allowing the students to see if the results correspond to theory or to experimental procedure. If one method shows a high percent error, the analysis is redone. This process allows the students to make the assumptions and simplifications to both the experimental procedure and the numerical analysis, and after comparison of the results, they will be able to determine if the results are within an acceptable range. In addition, there are many different ways to model a problem, 2-D, 3-D, symmetrically, among others. The students are able to utilize the method which they feel is appropriate for the problem. Before the senior students take this laboratory class, they are required to take a Mechanical Design course in which they are introduced to finite-element concepts. In addition, approximately half of the mechanical engineering students take finite-element-analysis as an optional technical elective. The instructional portion of the design laboratory allows the instructor to work with the student teams, thus offering additional instruction in the area of numerical analysis, of all types. In certain projects, based upon fluid mechanics, the students create models for testing in the wind tunnel; which are also analyzed using the CFD. Since this is not taught in class, as with many other software tools, the instructor can teach this subject to the design team. In the years which I have been an instructor in this laboratory course, the use of numerical analysis has been an integral part of the course. The students learn to utilize a very important tool in a manner which they must design the model, loadings, and analyze the results which are produced.

Projects Undertaken

The cornerstone of this course is the completion of a semester-long design project in any stem, or a combination of stems, in the mechanical engineering curriculum. Each year that the course is taught the projects are altered. The following is a sample of the student design problems undertaken over the past three years.

Design and construction of a athletic shoe testing apparatus - The project proposal called for the team to design a system which will provide a constant impact to an athletic shoe. This project incorporated many aspects of kinematics, stress analysis, dynamics, and vibrations, as well as accelerometer data acquisition. In this project, the students made extensive use of FEA in the identification of stresses from impact and dynamic loading.

Design and construction of a mini-baja frame - As part of Wilkes University's involvement in this national competition, the team proposed a design solution for the mini-baja frame system and used experimental analysis to analyze critical welds. Using the experimental analysis and numerical analysis, the team selected all materials, lengths, and cross-sectional properties based upon costs and strength. Figure 1 shows the final design which was developed. FEA was used to model the structure and examine the natural frequencies.

Design of a rear spoiler for an automobile - The students arrived at an optimal design of a rear spoiler of a given length. The team designed the shape of the spoiler based upon the drag and lift measurement through testing in the wind tunnel on various shapes. The group then used FEA to look at stiffness, in order to minimize the deflection under high speed driving conditions.

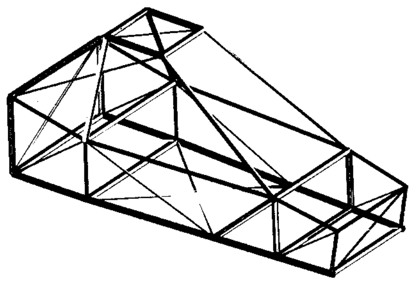

Figure 1 - Mini-Baja optimal frame design

Design of an electrical cabinet for military application - As part of a military purchase requirement, the local military depot was called upon to design an equipment rack for electronic equipment which is mounted in a jeep and thus subject to a vibrational loading. The group modeled the structure, including forces, and studied the cross-sectional and material properties, and where stiffeners should be placed to alter natural frequencies.

Heat sink design and analysis - The design teams first experimented with various shapes of heat sinks and the thermal modeling to determine the correlation between experimental and numerical analysis. The group then determined the optimal configuration of the sink fins to accomplish various heat removal tasks. Figure 3 shows the solid model and the FE model which was used in the analysis.

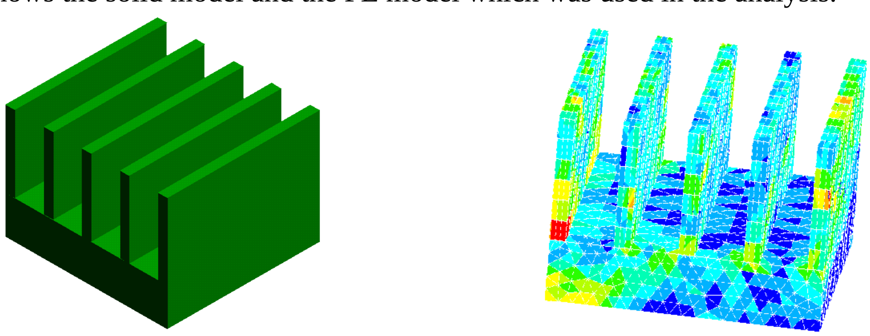

Figure 2 - Solid model of tested heat sink and FEA thermal model of heat sink

Drag reduction analysis - The design team looked at various methods in which the drag attributed to automobile rear-view mirrors may be reduced. This analysis was accomplished in two parts, again, numerical and experimental. At first, the group looked at the drag reduction which a golf ball has over a solid sphere of the same radius. This analysis was also modeled in 2-D using a CFD program, such that the swirl patterns could be seen. This same dimple pattern was applied to a series of mirrors, and studied in the wind tunnel to quantify the effects.

Conclusion

The preceding text describes all facets of a senior year mechanical engineering design laboratory at Wilkes University. The course is designed as capstone lab course, in which the students are required to complete a team design project. The lab has two components, one experimental, and the other design. Since this course represents the only laboratory exposure in the area of mechanical engineering design, the experimental portion teaches the students to utilize the various experimental procedures in the design area. The other component is the group design project. This project is designed to incorporate many aspects including experimental and numerical analysis, as well as theoretical. As a result of this lab, the students are taught to both develop experimental testing procedures and fixtures needed to analyze the given area. In addition, the students are taught the numerical skills which are needed to analyze the given problem. It is the combination of these two important analysis tools from which the students benefit. As industry turns more to the numerical analysis of the various components and systems, student education must keep pace. Through this course, the students are taught valuable skills which they will need when they enter the work force.

References

1. Lambert, J.M., "Team Projects in Computer Science and Engineering", Proceedings of the ASEE Mid-Atlantic Conference, Wilkes-Barre, PA, 11/96, Pgs. 104-107.

2. Uhran, J.J., "A Model for the Engineering Laboratory of the Future", Proceedings of the Fourth World Conference on Engineering Education, Saint Paul, MN, 10/95, Pgs. 112-116.

3. Ratcliffe, M., Parker, G., and King,C., "Meeting the Needs of the Employer: An Innovative Course in Software Engineering", Proceedings of the Fourth World Conference on Engineering Education, Saint Paul, MN, 10/95, Pgs. 39-42.

4. Condoor, S.S., Suh, S., and Burger,C.P., " Creating an Innovative Design Program at Texas A&M University", Proceedings of the Fourth World Conference on Engineering Education, Saint Paul, MN, 10/95, Pgs. 137-139.

Dr. Mirman received his Ph.D. Degree from the University of Illinois at Chicago in 1991. Since then, he has served on the engineering faculty at Wilkes University. He has been heavily involved in the introduction and advancement of the new mechanical engineering program in the area of design. He has also served as the director of the CAD laboratory and oversaw it’s renovation. Dr. Mirman is a member of ASME, ASEE, and Sigma-Xi.