Session 2266

Integrating Design in Advanced Mechanics of Materials Through Industry Collaboration

Tom Mase
Associate Professor
GMI Engineering & Management Institute

Abstract

This paper presents an discussion of integrating design through industry collaboration in Advanced Mechanics of Materials, a junior-level course. It is hoped that this might act as another paradigm for integrating design into traditionally analytical courses. In teaching Advanced Mechanics of Materials this way, the students cover most of the topics taught in a prototypical class. However, one third of the class time and one third of the final grade is devoted to a design project. These projects are meant to help build the student's creative thinking and design skills. Students gain experience in solid modeling, enhancing their ability to work in multi-functional teams, and refining their presentation skills. This paper discusses the class structure, sample projects, and an evaluation of one such course.

I. Introduction

GMI Engineering & Management Institute (GMI) is an ABET-accredited private college offering degrees in electrical, industrial, and mechanical engineering, as well as management systems. Recently, degree programs in applied mathematics, applied physics, computer science, and environmental chemistry have been added. However, the major focus for the 2,500-3,000 undergraduate students is engineering; more specifically mechanical engineering which has an enrollment of around 1,100. Students in mechanical engineering specialize in automotive engineering design, plastics product design, manufacturing product design, medical equipment design, or machine design.

Students generally participate in a cooperative education experience where they alternate a term of classes with a term working in industry. All students complete a thesis as part of their undergraduate requirements (up to 4 credits out of 180 quarter-hours). In recent years, it has become difficult, if not impossible, to evaluate theses for design credits. Each thesis is greatly influenced by the corporate sponsor making a comprehensive design curriculum somewhat nebulous.

Because of this design credit ambiguity, it was decided to abandon design credits for the thesis and push these credits back in the curriculum so that the student sees a consistent thread of design. In addition to solving GMI's thesis problem, this solution is becoming a preferred way for delivering design in engineering[1]. Design throughout the curriculum is in addition to a traditional capstone design course.

There are two ways to administer design across the curriculum: with a separate program independent from a specific class or on a class by class basis. Viets[2] documents a program at the University of Rhode Island where freshman and sophomores begin a design project which they complete by their senior year. Examples of the mechanical engineering projects are the design of a light jet aircraft and the design of a vehicle for land, sea, and lunar surfaces. Clearly, these are open ended problems which are paper studies. Another approach is to have design as part of all engineering classes. Using this approach is consistent with McMasters and Ford's[3] statement that design and engineering are synonymous. Wilczynski and Douglas[4] have reported on design assignments in undergraduate fluids and thermodynamics courses.

In a Plenary address to the 1993 ASEE Centennial Conference, one of the points made by Black was that students need to get some "real-world industry-sponsored" projects in their education[5] . Industry sponsored design projects have been successfully used at Colorado School of Mines[6] , University of Sheffield[7] , and Brigham Young University[8]. In this spirit, the work reported on here strives to have industry sponsored design projects brought into the classroom.

This paper reports one such effort to incorporate industry-sponsored design into a class which has traditionally been primarily analytical. The overall class structure, including analytical and design portions, is first covered. Following that discussion are some anecdotal examples of design projects that have been undertaken.

II. Course structure

Advanced Mechanics of Materials was a long-standing technical-elective course with declining enrollment. Before its renaissance, it was a pure analysis class known as Super Solids-- a difficult class for students. Faculty involved in mechanical design and plastics product design specialties felt that the course was worth renovation because of the important topics covered. In the rejuvenated version of Super Solids, design was incorporated as an integral part of the course. This design content has helped to popularize the class among the students whose work experiences give them a healthy appetite for design. Upgrading the course has also helped the Mechanical Engineering Department in its goal to include design experiences in as many classes as possible.

To discuss this course as an design island that rose up from a sea of analysis is not entirely accurate. Curriculum development and cooperation played a substantial role in the course's evolution.

The plastics product design specialty originally had Super Solids and Introduction to Finite Elements as technical electives. While finite elements was thought to be an important skill for someone in the plastics design area, consensus was that analyzing force systems and their resulting stress components along with failure theories was more important than the finite element formulation. In addition to this, a three course sequence utilizing the computer-aided engineering program I-DEAS was desired. With this in mind, Super Solids was made a required course for plastics product design students with the understanding that one engineering design credit would be allocated for the course. Also, the students were to get their first exposure to solid modeling and finite element application using I-DEAS. Subsequent plastics product design courses in Properties of Polymers and a capstone Plastic Product Design course continue the use of I-DEAS for solid modeling, finite element stress analysis, and mold flow analysis.

The current class is three-credit hours (based on a quarter system) which are divided up into two credits engineering analysis and one credit engineering design. As with most three credit courses, this one meets for three hours per week. At GMI, the term is eleven-weeks long with one week added for final exams. In order to apportion the class properly for the design credits, one hour per week is devoted exclusively to design projects. The remaining two hours are conducted in a traditional lecture format with exams being taken from this part of the course.

In the near future, a format that has two lecture periods per week (on separate days) along with a two-hour laboratory period will be implemented. This is to remedy the need for one-on-one help in getting the students working with solid modeling, finite elements, and a design project. If enrollment numbers require, a lecture section of 32 to 36 students can be accommodated by having two laboratory sections for the design syllabus. Enrollments over 24 students make this course a substantial time sink for the professor if a teaching assistant is not available. Building a design experience into Advanced Mechanics of Materials is a time consuming but rewarding task.

Course Goals

To embark on this course, the instructor needs to provide the students with a clear statement of objectives. The course objectives in Advanced Mechanics of Materials at GMI is as follows:

- Complete mastery of elementary mechanics of materials
- Advanced mechanics of materials topics (listed below)
- Beginning familiarization with the following:
    - solid modeling using I-DEAS
    - finite element modeling using I-DEAS
    - finite element formulation
- A design experience

III. TRADITIONAL ANALYSIS PORTION

The traditional analysis portion of the course is conducted on a lecture basis in which topics are developed and examples worked in class. With the design portion of the class taking up one third of the time, it is best to have lectures and examples for the analysis part well developed. That is, in Super Solids a set of PowerPoint® notes are passed out so the students don't have to write everything down in their notes. These notes are purposely incomplete so that most of the lecture the students are filling in the gaps. This approach allows for covering the material without making the students feel overwhelmed in the lecture. However, teaching evaluations indicate that a few students are indeed overwhelmed, but most students recognize and appreciate the course preparation. It also gives the students a nice complete set of notes.

Analysis Course Topics

In the analysis part of the course, the traditional advanced mechanics of materials topics are covered. The following is a list of topics that is currently covered in the 11 week class:

- Review stress, Mohr's circle
- 3-D stress analysis
- Strain-displacement equations
- Yield and failure theories
- Unsymmetric bending
- Shear center
- Thick-walled cylinders
- Elementary elasticity
- Torsion of non-circular cross sections
- Torsion of multi-cell sections
- Flat plates
- Castigliano's theorem-determinate
- Castigliano's theorem-indeterminate
- Rayleigh-Ritz method
- Elementary finite element method

Integrating design into this course comes at the expense of topic coverage. However, design as part of the course should be considered one hierarchical level above a topic. Therefore, the sacrifice of a few topics (viscoelastic behavior, shells, more finite element coverage) is overlooked. No matter how hard the students are worked, it is impossible to teach every advanced mechanics of materials topic in a quarter course. Teaching students how to practice advanced mechanics of materials using less topics is desired.

Student Assessment

Student evaluation for the analysis portion is done through a mid-term and a final exam. In addition to these exams, homework from the text is handed in throughout the term. Homework and exams account for sixty-five percent of the final grade.

Textbook

The current course is somewhat of a mezzanine course between core Mechanics of Materials and senior capstone courses. Because of this early junior-level offering, an appropriate textbook is difficult to find. Several options have been attempted including using a general-purpose mechanical design text, a mechanics of materials textbook, and an advanced mechanics of materials book.

Using a mechanical design text by Shigley and Mischke[9] to cover mechanics topics has the disadvantages of the lack of coverage of topics such as shear center and unsymmetric bending of transversely loaded beams. Some topics are treated in a manner which requires the instructor to add material for more complete analysis. For instance, Shigley and Mischke do not cover radial stresses for curved beams. Students will quickly point out the advantage of this option as saving money by using a book for more than one class.

Advanced mechanics of materials texts such as Boresi, Schmidt, and Sidebottom[10] and Cook and Young[11] are good advanced mechanics of materials texts, but they can overwhelm the students. These texts are better suited for a graduate class in mechanics of materials. Books by Ugural and Fenster[12] and Budynas[13] are more appropriate for an undergraduate student.

Having taught this class from all of the aforementioned textbooks, the following recommendations can be made. In considering all of the advanced mechanics of materials books, they all seem to have too much material when one or two design credits is a course objective. Having these texts in the library on reserve while using a mechanical design textbook is recommended. This solution requires the instructor to have some good class notes and handouts for some topics, but the basic material to be covered is in these mechanical design texts. Also, the students get a design perspective in these texts.

IV. Design portion

The design aspect of Super Solids is weighted as one third of the class. This being the case, one of the three lecture periods per week is devoted to design. Also, thirty-five percent of the final grade is determined from the design syllabus. The latter being a separate syllabus from the analysis part of the class, that helps accomplish the design goals.

Dixon[14] pointed out that when more intelligent CAD and solid modeling systems become available they will have an impact on engineering design education. These systems are now available and should play an important role in design education. Thus, one of the design goals of this class is to introduce the student to I-DEAS. This is done with an advanced CAD/CAE portion of the design segment.

Much of the work done in industry is done with project-oriented teams including traditional employees, contract workers, and consultants[15]. As pointed out by Deutch[16], many engineers are not accustomed to sitting on problem solving teams that change from year-to-year or project-to-project. Because of this, another goal of the design experience is to get the students to work together in multifunctional teams. In this class, students formed their own teams (Method 5 from Bickell, *et.al.*[17])

A final goal is to have the students work on a problem that involves as much synthesis, ethics and safety issues, creative thinking, and cost issues as possible.

Advanced CAD/CAE Familiarization

During the first half of the term, the design hour is spent working with UNIX workstations and doing three exercises which are fashioned to expose students to I-DEAS. A first assignment, which must be completed by all students, gives them the basic workstation computer skills of logging in, editing and deleting files, and changing passwords. Over half of the students have no experience using UNIX based computers. However, because of the cooperative nature of GMI, a few of the students have spent a whole work term using one of these workstations.

A second computer assignment has students working in groups of two to draw a simple three dimensional object using solid modeling techniques. The outcome of this exercise is not to make the students experts at solid modeling (we have another course for that), but to give them an awareness of the capabilities of an advanced CAD program.

Finally, the students working in groups of two generate a finite element model of a simple part such as a cantilevered beam or a transversely-loaded plate. As part of this exercise, they do a hand calculation to check their results. Different groups are assigned different meshing parameters so, collectively, they can see how element size can affect results. Again, having everyone do their part is a team building exercise.

The Design Experience

Once the students have some computer basics and are starting to work well together, the design experience fills up the remainder of the term's design hours. In Super Solids, the design experience has taken on many forms depending on what project(s) have been cultivated from industry.

There are two basic ways the class can operate for the projects: i) several unrelated projects can be undertaken by the student groups or ii) one project can be undertaken with different student teams. Each way has its individual merits. When many projects are undertaken, the students can pick a topic of their choice. The professor should have several possible choices, since students don't always have a project in mind. Often, and preferably, students bring a project in from their work term. This benefits the class, the student, GMI, and the company. The big advantage to student's work-term projects is that the students are involved in a real-world problem. Alternatively, a sizable project with multidisciplinary student teams forces the students to work in a more realistic environment.

To demonstrate projects from both multiple and single project terms, several projects will be described. The first two are examples from terms when 4-5 projects were undertaken using groups of 3-5 students. Next, two projects are described in which the whole class worked on a single project.

Examples: Multiple Projects

Elevator Bracket

One of the individual projects that was brought in from a student's work term was the analysis of an elevator bracket used in the manufacturing of riding lawn mowers. Students in this group had several of the brackets sent to them from which they could get dimensional and geometric measurements. They examined the bracket for a critical stress area and measured the strain at relevant locations using strain gauges. This group had four students which split into two teams; one experimental and one numerical. Results from both teams indicted that the bracket was over designed. However, this project also made them think about the cost savings that might come from redesigning this part. The number of parts utilized by the company was not great, so they wouldn't gain a savings from material cost. Keeping an over-designed bracket allows for future product changes without switching brackets and avoids the cost of shutting the line down if an under-designed bracket were to break. Furthermore, hourly workers do not lift the brackets often, so repetitive motion injuries are not an issue.

Radiator Pressure Test

As another small project (not requiring the whole class) example, a student brought in a Honda radiator design from an automotive supplier with whom he worked. This project was a good one because it gave the students many of the features of a real-world problem. In the work term prior to the class offering, a prototype radiator design failed a pressure test, fracturing on the opposite side of one of the mounting brackets. An IGES file was sent to the student for modeling purposes. This file was imported into I-DEAS, and a model was made. One of the important lessens learned in this project was that the whole part need not be modeled; the best solution is to focus on the area of interest. With the part modeled, finite element stress analysis iterations showed that the mounting brackets on only one side were causing the problem. A further lesson was the need for feature suppression (an I-DEAS term for getting the fillets out) when going from a solid to finite element model. Finally, the exercise of visualizing the loads that were applied versus seeing arrows in a textbook was useful.

The advantages of having the class involved in different projects are that students' work term projects can be accommodated. This can create a nice industry tie for the school. Another advantage is that students get hands-on experience on the whole project.

Disadvantages of these smaller-scale problems are that multidisciplinary teams are not needed. Among the team of 3-4 students, different tasks are assigned, but intergroup communication is not critical. Another disadvantage is that several diverse projects can spread the department's resources thin causing difficulties. Many teams using I-DEAS for both solid and finite element modeling can create disk space problems. This is because the students are relatively inexperienced in meshing and usually rely on automatic mesh options. Temporary files during the finite element solve have grown to be as large as 200 Mb, flagging a students disk allocation and aborting the analysis. Other disadvantages of this approach are that students can wait too long for their company to ship the part, or they tackle a problem that is too much work to complete in the given time frame.

Examples: Single Project

PGA Tour Robot Arm

As an example of a larger, full-class project, the redesign of a robot arm for hitting golf balls was undertaken. For this project, the broad goals where those of reducing the mass of the arm so that greater velocities could be achieved while, at the same time, increasing the repeatability of the resulting ball flight. Since most of the robot already existed, certain constraints were in place with regards to the robot's geometry. Students were supplied with a set of blue prints from which to work.

In this term, the students were divided into five teams: a benchmark team for the existing arm, a benchmark team for the existing impacting head, a drive shaft team, a metallic redesign team, and a composite redesign team. Students were encouraged to work together in sharing information that different groups might need. One of the best lessons of this term was trying to determine the appropriate load from a golf ball being impacted at 140 mph. This indeterminate aspect of the problem caused the students think about how they were going to come up with a reasonable load.

Engine Decking Bar

The best type of full-class project is one that works closely with local industry. As an example of this, one term an engine decking bar was used as a platform for the design phase of the course. Clear-cut design goals were provided by Ford and the various contractors and vendors: i) reduce the weight by 40 percent, ii) reduce the cost by 40 percent, and iii) reduce the development time by 40 percent. In addition, the students also got a chance to observe a real-world project being solved by a team of engineers from different companies. These included Ford employees from three different cites and groups, contract companies including Sandalwood Enterprises, Inc., Ingersoll-Rand, Creative Techniques, Inc., and Watson Engineering, as well as the LNP Engineering Plastics, Inc. a supplier. This project showed students how a multifunctional team attacks a problem.

To get the students started on the project, the manager from Ford in charge of the project came in to give the students a talk on the definition of the problem. He also supplied the class with blue prints and sample parts. A video of the existing steel bars being used in the plant was supplied for the students to view.

For this term the students split into teams to address certain aspects of this project. At this point in the project, a fiberglass filled nylon design was being evaluated. This design had to pass a group of tests which were proposed by the industry engineers. In one of these tests, one of the chains holding the engine and transmission was dropped and the decking bar broke. The students were asked to make recommendations to help make this design work. A group was charged with evaluating the material properties of the nylon decking bar. Even though a materials data sheet was provided by the supplier, material properties from one of the actual decking bars was desired. Another group studied stress concentrations at the points where the bar rested on the cradle. A steel insert was integrally molded into place and was where failure initiated in the engine drop test. Two students groups worked closely together in the redesign and analysis of the decking bar. A real-world constraint was placed on them because their redesign had to use the existing tool with modifications. Their redesign was conveyed to the other group who was doing the benchmark and redesign finite element analysis. The final student group used photoelasticity to examine stress in the baseline decking bar. This was possible because Ford made a half-scale model using stereo lithography for demonstration purposes.

Evaluation of Design Projects

As was previously mentioned, the design portion of the class counted for one third of the grade. This third of the final grade is divided between problem statement (5 percent), oral presentation (10 percent), and written report (15 percent). The I-DEAS exercises are counted for 5 percent. The problem statement is a good way for the students to think ahead and to try to size their project into a reasonable amount of work. For terms in which several projects are undertaken, this is an important step. Students bringing a project in from their cooperative work term often forget the level of support they get while working in industry. Also, they overlook the fact that they are taking five or six other classes.

During the last week of class, each student group gives a 15-20 minute presentation on their project. Everyone in the group participates in the presentations, which are generally done with an overhead projector. While having everyone take part in the presentation makes for a somewhat choppy delivery, participation by all students is important. Student presentations are judged by the professor and fellow students on communication of work done, professional presentation, and effective use of visual aids.

Finally, each student team writes a report on their work. These reports are expected to be professionally done with all members contributing. An interesting observation is that there are usually clear-cut, obvious demarcations showing that the report writing has been delegated among the team members.

V. STUDENT QUESTIONAIRE

During one of the terms in which a single project was used, a survey of the students was taken when they filled out the class presentation forms. This section had fourteen students who worked on the engine decking bar. The results of the survey are shown in Table 1 and indicate that the students view the design portion of the class favorably.

Table 1. Summary of student survey on Super Solids

	Agree	Neutral	Disagree
1. This project helped me understand the course material better.*	4	9	2
2. Project helped me understand "real world" engineering problems.	14	0	0
3. Our team's effort was exemplar.	14	0	0
4. My effort was above average as compared to other team members.	2	11	1
5. The overall experience in the project was positive.	14	0	0

- One student marked two boxes on this statement.

VI. Conclusions

There is still room for improvement in design-integrated Super Solids. Some of the concerns spring from both student and professor issues. First, a non-uniform design experience is unavoidable. For instance, students working on the material characterization had a different experience than those who used their information to model the engine decking bar. Second, a lot of time outside the classroom is spent which is a concern for the students and instructor. Again, an example comes from the decking bar project. The professor has a tremendous demand on his/her time when students are working on projects in the photoelasticity, computer, and materials laboratories. At GMI, these laboratories are on different floors and at different ends of the building. Use of these diverse facilities also takes cooperation from faculty colleagues for the use of laboratories.

There is no convenient simple way to find industry projects for the class. Personal contacts and research are the best sources.

Finally, and maybe most importantly, comes the concern for institute liability in collaborative projects like these. For an example of the level of liability, engine decking bars carry engines from floor to floor in an assembly plant. A failure of one of these bars when it is near the ceiling of a floor creates a life-threatening situation. Currently, this issue hasn't been adequately addressed in Super Solids with one small exception. The students are required to write a disclaimer in their reports which are read by the industry project manager.

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Tom Mase is an Associate Professor at GMI Engineering & Management Institute. In 1980 he received a BS in Mechanical Engineering from Michigan State University. Subsequently, he received a MS and PhD from the University of California, Berkeley in 1982 and 1987, respectively.