A Senior Research Project Applied Across the Curriculum

Brian P. Self, Keith Bearden, Matthew Obenchain and Daniel Diaz

US Air Force Academy, Colorado

ABSTRACT

In most Engineering curricula, the courses are somewhat disjointed with very few projects or concepts tying classes together. In the Engineering Mechanics Department at the US Air Force Academy, we have the opportunity to create a common thread through at least a few of the cadets' senior level classes. At the same time, it is possible to involve the students in some research at the undergraduate level. Example projects that are used in courses involving experimental mechanics, finite element analysis, independent research, and competition teams will be presented, and benefits of this integrated approach discussed.

INTRODUCTION

When students enter most engineering programs, they are presented with many different tools to use in their chosen field. Engineering Mechanics curricula may include mechanics of materials, dynamics, materials sciences, fluid flow, and failure analysis. While these courses provide valuable skills to place in their engineering toolbox, they are often disjointed. The advent of capstone design projects had done much to help students synthesize what they must know as engineers, but often the scope of these projects is limited. Team sizes may be so large as to prohibit true synthesis, as the students tend to "divide and conquer" to complete the project.

Some programs have been able to make large gains in integrating their curricula, but most involve the first two years of studies.[1-5] While these efforts have made great strides in improving the students' introduction to the engineering field, they do not fully test the students' ability to apply their upper level course knowledge to solve engineering problems. Engineering projects that can be used in several different courses may prove useful in forcing the students to assimilate their engineering knowledge and will also serve to introduce them to research.

The US Air Force Academy is an undergraduate only institution; therefore faculty must recruit undergraduates to perform research if they need assistance. Currently, the time demands on most faculty are too great to allow significant research to be accomplished. Instructors usually teach three to four section of classes each semester, and typically must double prep. Unless they can obtain assistance from undergraduate students, it may be impossible to perform data collection and analysis. Faculty members are encouraged to mentor cadets in their research to introduce the future officers to the scientific method. Many cadets author abstracts each year at USAFA, and a current goal of the research community is to produce even more research publications in the coming years.

The cadets' time is in even more demand than that of the faculty. It is extremely difficult for most cadets to devote the amount of time necessary to create a research product worthy of

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publication. Students must graduate in four years and have an extremely challenging core curriculum to complete. Their military and athletic requirements also cut into the cadets' time, making it very difficult for them to devote efforts towards research. One of the solutions to this time crunch is to utilize the same project through several different courses.

DESCRIPTION OF PROJECT-ORIENTED COURSES

Most engineering curricula are finding the benefits of incorporating final projects into their courses. These projects may be solicited from industry, other departments, or internally. Such projects test to see if the students can apply the knowledge gained in their studies to an actual engineering problem. Often, the class members can choose something on their own, which should improve interest and motivation. Similarly, the projects are typically worked on by teams of cadets, which can help to lessen the time constraints placed on the individuals. Our department offers two accredited degrees, Engineering Mechanics (EM) and Mechanical Engineering (ME). A number of senior level courses in the department are project oriented.

EM 460 – Experimental Mechanics. During the fall semester of their senior year, all EM and ME majors are required to take a course in instrumentation. Experimental measurements and their application to the design process are stressed, including topics such as strain, vibration, temperature, and pressure. During the second half of the semester, students must submit a project proposal and test plan, then collect and analyze their data. Projects include analyzing accelerations during parachute openings, determining the stresses on a baseball bat, analyzing fatigue properties of alloy specimens, and examining the biomechanics of football kicking.

EM 431 – Finite Element Analysis. Students typically learn finite element analysis (FEA) during their senior year. Students are required to do an FEA of a self-selected structure during the semester. If this course is done during their spring semester, then it can be used to analyze experimental work done during the EM 460 course in the fall. If the course is taken in the same semester as the experiment, then the FEA can be used to help predict the experimental results. In the case that is discussed below, one of the cadets on the team took the FEA course in the fall and one in the Spring.

EM 499 – Independent Study. Students may take three hours of independent study credit that will count as an engineering elective. Topics are sponsored by a faculty member and must be approved by the Deputy for Curriculum. Topics include fatigue analysis of aircraft panels, biomechanics of football kicking, and the stress characteristics of friction stir welds. These projects can be applied as a continuation of one of the other course projects noted above.

ME 492z – Capstone Design for Intercollegiate Competition. Cadets from the department compete in four different intercollegiate competitions, including SAE Mini-Baja West, Formula SAE, SAE Aero Design West, and the ASME Human Powered Vehicle Challenge. The students must design, analyze, and use their final product to compete against other universities. More than any other capstone project, these team competitions require the cadets to utilize their skills from nearly all of their engineering courses. The team numbers are limited, however, and the

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time required from these members is very demanding. Often, they use problems from their competition teams for their EM 431 and EM 460 projects.

Other Possible Course Projects. Projects for several other courses might also allow cadets to pursue a research publication. ME 445 – Failure Analysis and Prevention could be used to analyze failure mechanisms, ME 490 – Automotive Systems Analysis for the Engineer could be combined with projects above. Many cadets also participate in our Cadet Summer Research Program, where they go to an outside agency for approximately six weeks between their junior and senior year. Some projects could easily be continued throughout their senior year.

Determining Stresses in a Juvenile Prosthetic Foot

During the Fall 2000 semester, cadets Matt Obenchain and Dan Diaz chose to perform an analysis of a Springlite juvenile prosthetic foot for their EM 460 project. Originally, we had planned to test the fatigue properties of a foot with an experimentally placed crack (a hole) after a composite patch was placed on the defect. The students decided that they should first determine what the static stresses on the foot were before performing the fatigue analysis. To do this, they used the strain gage information that they had learned in their EM 460 class to instrument the foot (see Figure 1 below).

Figure 1. Strain gage testing of the Springlite prosthetic foot.

The students are required to first perform a stress analysis using basic mechanics equations to determine if their experimental results are feasible. By doing this, a logical step-by-step experimental procedure can be established that helps teach the cadets how to perform research.

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The students were able to learn LabView and some of the difficulties in obtaining experimental data. They experienced problems with one of the strain gages, but were able to produce some experimental results. Sample data from their testing is shown in Figure 2. They were primarily interested in determining where the maximum stresses occurred in the foot; in order to examine their experimental data, one of the students also performed a finite element analysis of the structure.

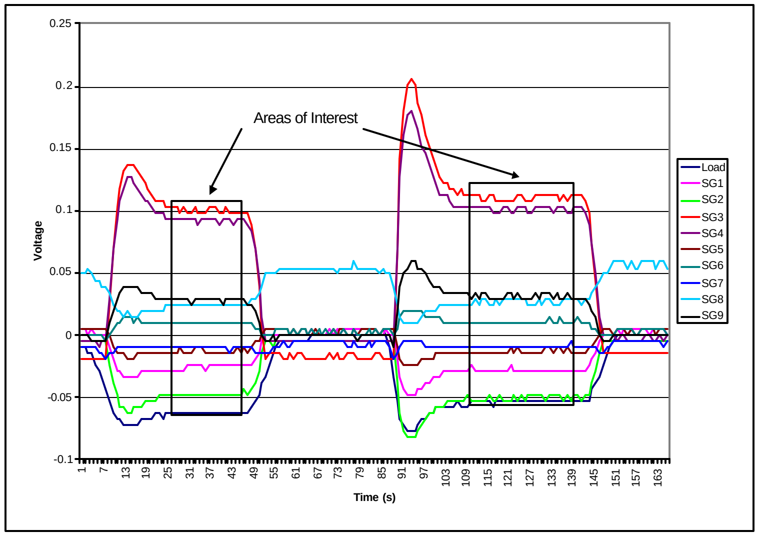

Figure 2. Strain gage measurements.

One of the students, Dan Diaz, took the FEM course during the Fall semester while the experimental testing was being performed. He was able to create a number of different models, including meshes with 600 and 900 elements. Some of the trends in the data matched reasonably well, although the actual stress measurements were off by an order of magnitude. The students were then required to determine why some of these discrepancies existed, as they would in any real life situation. Some of the reasons they discussed included not knowing the exact material properties of the specimen (information is proprietary), the geometry of the foot was tapered and the mesh may not have adequately represented the exact setup of the foot, and the probable inadequacy of the boundary conditions. A representative FEA result is shown in Figure 3.

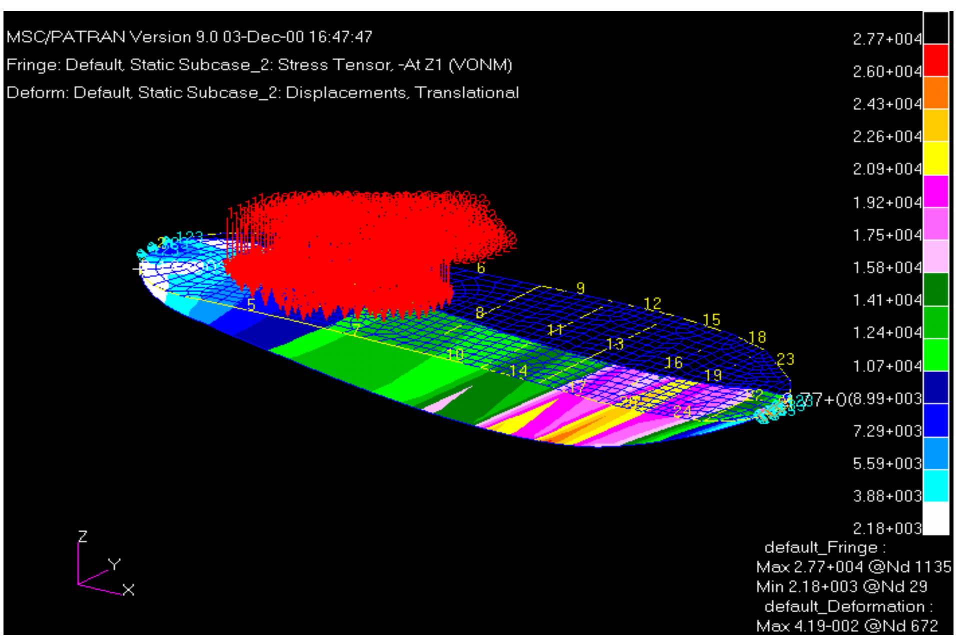

Figure 3. FEA of the Springlite foot.

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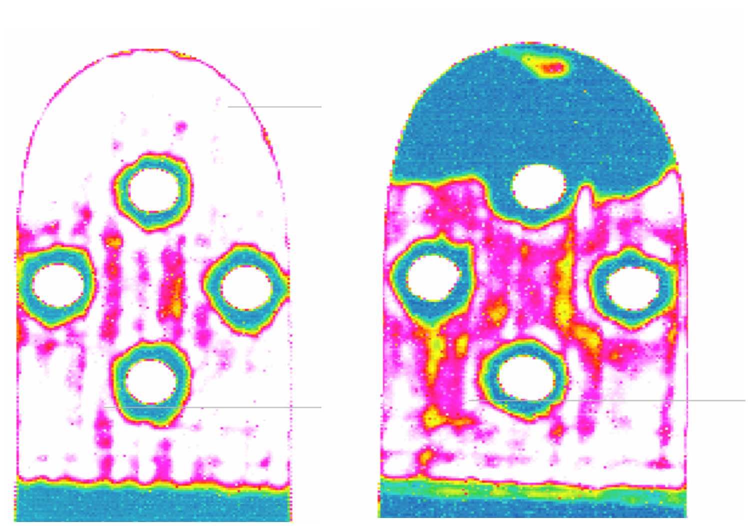
During the Spring semester, the cadets agreed to continue the analysis as part of an EM499 Independent Study course. At the same time, Cadet Obenchain took EM431 and created a slightly different FE model of the foot. Working as a team, the pair of students were able to continue the analysis of the prosthesis.

Experimental Work

During the EM460 testing, the cadets noticed an audible crack during one of their experiments. They were concerned that there might have been some damage done to the foot, and decided to determine if this was the case. After researching the problem and the lab assets, Cadet Diaz decided to perform an ultrasound test on the foot.



(a) (b)

Figure 4. Ultrasound results.

As can be seen in Figure 4, there was significant damage done to the rear portion of the foot. This made them suspect that their results from their final two experimental tests might have been flawed, and they decided to reanalyze these results. As a direct result of questioning an experimental outcome, the cadets were exposed to a non-destructive analysis technique that they would not have learned otherwise. We feel that this experience was valuable in helping them develop their problem solving skills and will aid them in their future graduate education.

The students also decided that the strain gages did not fully meet their research goal of determining where the maximum stresses occurred in the foot. Realizing this, they decided to utilize another technique that they learned in their EM 460 class: photoelasticity. With the help of another instructor, they were able to prepare a photoelastic coating for the bottom of the foot. They were then able to learn yet another experimental technique which would not have normally been included in their undergraduate education. The experimental setup and stress distribution for the photoelastic testing are shown in Figure 5.

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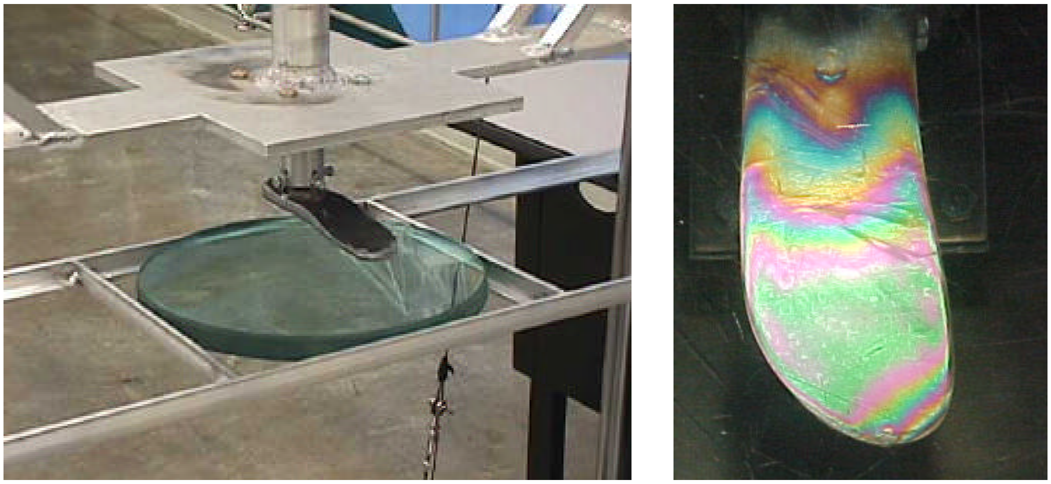

Figure 5. Experimental setup and representative fringe patterns for photoelastic testing.

By applying several different experimental and analytical approaches to the same basic problem, cadets were able to gain a great deal of insight into their future careers as engineers. Instructors were there to provide guidance, but the majority of the work was performed by the students. Many of the same objectives of a capstone design project were also met by using this approach in senior level courses: (a) assimilating knowledge gained in different courses for tackling a given problem, (b) developing problem-solving skills by identifying the problem, developing a test plan, creating a model, and making conclusions from the data, and (c) attacking a project from start to finish.

Student Perspectives
One cadet expressed his experience with the prosthetic foot project:

"In my opinion, the greatest benefit of researching the Springlite prosthetic foot was that it provided hands-on experience with a real world problem. During the course of two classes, I was able to use the foot as a basis for applying the skills taught in the classroom. As part of the senior level experimental mechanics course (EM 460), I used strain gages to investigate the stress distribution in the foot as a result of typical loading conditions. I was able to further analyze the foot during the second semester while taking the introductory course in finite element analysis (EM 431). Having gained an understanding of the mechanics of the foot during the previous term, it was very beneficial to use it as the subject of an in-depth finite element model. I was able to experiment with different modeling options while having a basis to validate my results. Finally, I was able to extend my research into an independent study project. This project involved using photoelastic material to visually examine the effects of various loading conditions on the foot. In EM 460 the use of photoelastic material was the subject of a lecture and a short lab, but it was the practical use of this medium to study the prosthetic foot that most clearly illustrated its usefulness."

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"The ability to use the foot as the subject of study in more than one course was very beneficial. By using various techniques to study the foot, I was able to understand the advantages that each one provides to the engineer, and I was able to see how different modeling and experimental tools can be used together to validate and understand results. Using a common project for the various courses helped to tie them together. The use of a real world problem such as the prosthetic foot also provided an added level of motivation to the work I did throughout the year. Not only was I completing course requirements and applying course material, but I was also helping to investigate a real problem that needed to be solved. It was valuable to get this type of experience while still an undergraduate student." -- Cadet Matt Obenchain

Using a Single Research Project Across the Curriculum

While using this approach during the senior year cannot be used for all students, it appears to be an excellent model for those students who may pursue a graduate degree. Using a single project in several different courses not only helps tie things together for the student, but it can also provide invaluable manpower for the US Air Force Academy instructor. The teaching load is so great on our instructors that this may be one of the few ways to get meaningful research produced in a timely fashion. While the primary goal at the Academy is to mentor cadets in engineering and research, academic promotion is of course tied to research output.

The following is a suggested framework for involving cadets in research:

1. Identify candidate researchers to participate in the Cadet Summer Research Program (CSRP)

Cadets with strong research interests and ability should be identified before their senior year. If possible, they can then be placed in a Cadet Summer Research Program that utilizes the project to be used during their senior year. A collaboration can be established between a government or other laboratory during the summer, then that research continued throughout the following year.

2. Begin or continue experimental work during EM460

Most engineering projects should contain some type of experimental data collection and analysis. Cadets can work in teams to further analyze their research project; however, if research was not begun during CSRP the work can begin during the Fall semester of their senior year.

3. Perform Finite Element Analysis for the Project

Students may take the FEA course during the Fall or Spring, usually during their senior year. In the prosthetic foot project, both of the cadets took EM431 but in successive semesters. This is an ideal way to examine and improve upon the FE model throughout the year.

4. *Perform an Independent Study EM499*

The final step to the sequence should be an independent study, where the student(s) can finalize their experiments and analysis of the project.

By following this framework, students preparing for graduate school can be exposed to a continuous engineering project. While this approach may not be appropriate for all students, advanced cadets can gain valuable experience in applying their knowledge to solve a real world problem. An additional advantage is the potential for an undergraduate publication, which is also beneficial to faculty members who devote most of their time to teaching.

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Biographies

BRIAN P. SELF
Brian Self is an Assistant Professor of Mechanical Engineering at the U.S. Air Force Academy. He received his B.S. and M.S. in Engineering Mechanics from Virginia Tech and his Ph.D. in Bioengineering at the University of Utah. He has four years of experience with the Air Force Research Laboratory and is in his third year of teaching in the Department of Engineering Mechanics at the US Air Force Academy. Areas of research include impact injury mechanisms, sports biomechanics, and aerospace physiology.

KEITH L. BEARDEN
Keith Bearden graduated from USAFA in 1988 with a degree in Engineering Mechanics and Math. His first USAF assignment was to Hanscom AFB, MA working in a systems program office. From there he was selected to attend the AFIT in residence program for a Masters Degree in 1991. He graduated from AFIT in 1992 with a MS in Aeronautical Engineering and was assigned to the Flight Dynamics Lab at Wright-Patterson AFB, OH. The next assignment was to USAFA as an instructor in 1994. In 1998 he was selected for the AFIT civilian institution program for a PhD. He completed his PhD from the Colorado State University in 2000 and returned to USAFA as the director of the Applied Mechanics Lab.

MATTHEW OBENCHAIN
Matt Obenchain was the top graduate at the US Air Force Academy in May of 2001. He earned a degree in Engineering Mechanics, and was awarded a Draper Fellowship to attend the Massachusetts Institute of Technology. After obtaining his Master's Degree, Matt plans to come back to the Air Force Academy to teach in the Engineering Mechanics Department.

DANIEL DIAZ
Dan Diaz obtained a bachelor's degree in Mechanical Engineering from the US Air Force Academy in May of 2001. He is currently serving as a Second Lieutenant at the University of Washington in St Louis as a recruitment officer for the US Air Force.

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