Connecting Industry Experience with Classroom Instruction

Richard Kunz[1]

Abstract – Building bridges between students' concept of engineering as a course of study and engineering as a career is an important aspect of the undergraduate curriculum. Courses in basic sciences, engineering sciences, design, laboratory methods, and professional practice each deal with one or more pieces of the puzzle, but the fusion of all the elements may not occur until a senior-year capstone experience, if at all.

This paper discusses specific instances in which artifacts from aerospace practice have been effectively introduced into traditional lectures in an attempt not only to illustrate key points, but also to provide a grounding frame of reference. "Hardware" refers to test specimens and small structural artifacts from actual aircraft to demonstrate specific concepts of load transfer or failure mechanisms; "firmware" includes excerpts from archival engineering reports showing that the techniques of structural analysis developed in class find real application in verification and documentation of flightworthiness; and "software" includes anecdotes addressing issues such as customer interaction, reporting and communication, and ethics.

Keywords: Mechanics, aerospace industry, structures, professional practice, ethics

INTRODUCTION

Students in traditional lecture-based engineering courses often have a difficult time making the connection between textbook problems and real-life engineering situations. Sometimes this connection is not made and cemented until subsequent laboratory-based courses are taken, or until a senior-year capstone project is experienced. This can be a significant obstacle for students who are visual learners, particularly in basic engineering courses, but it extends to more advanced courses as well. It is undoubtedly more pronounced in courses without a laboratory component.

The author taught basic and advanced engineering mechanics for seven years immediately after the completion of graduate studies, followed by twenty years as a practicing engineer in the aerospace industry. In 2006, I returned to the classroom to find that, while the academic landscape has changed significantly in the intervening years, the needs of the students have not. The fundamentals of statics, solid mechanics, and structural analysis remain engraved in stone, and students still have difficulty connecting these fundamentals to why airplanes fly, and what engineers do to make that happen.

Even in lecture courses, student understanding of the fundamental principles of mechanics has been shown to be enhanced by incorporating simple physical models [1, 2]. Computer-based lectures, incorporating animated example problems and multimedia [3, 4], are also effective in enabling students to visualize how basic concepts are manifested in the physical world. Integrating finite element analysis modules into mechanical design and analysis courses assists in the visualization of complex concepts such as stress concentrations and load transfer between structural components [5]. Each of these approaches helps students bridge the gap between the model of a physical process expressed mathematically and the process itself. Additional tools and considerations must be brought to bear, however, to extend the concept of engineering as a course of study to the concept of engineering as a career.

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The interplay among applying engineering principles and tools to the design, analysis, and testing of products to be used by the public, satisfying customer requirements, documenting results, and upholding the ethical standards of the profession need not be relegated to a single course in "Professional Practice." Such a course can be effectively supplemented and cemented by incorporating these concepts throughout the curriculum by drawing on the issues that practicing engineers are faced with on a regular basis.

This paper discusses specific instances in which "hardware," "firmware," and "software" from aerospace practice have been introduced into traditional lectures in an attempt both to illustrate key points and to provide a grounding frame of reference. "Hardware" refers to test specimens and small structural artifacts from actual aircraft, for example, to demonstrate specific concepts of load transfer or failure mechanisms; "firmware" includes excerpts from archival engineering reports showing that the techniques of structural analysis developed in class are used in part to verify and document flightworthiness; and "software" includes anecdotes addressing issues such as customer interaction, reporting and communication, and ethics.

HARDWARE

Many who have taught solid mechanics or machine design for any length of time have a collection of small structural artifacts that illustrate key concepts: a broken wheel stud that exhibits the classical 45º torsional failure surface for demonstrating stress transformation and failure criteria, for example. Such items provide a convenient and easily remembered visual confirmation that the equations derived in class have a real physical meaning. It is perhaps equally as important to discuss the context from which the artifact is derived: where the part came from, what is its function, and what are the possible consequences of its failure.

In statics and introductory solid mechanics, the calculation of area moments of inertia using the parallel axis theorem finds application in the flexure formula for beams. A simple related calculation can demonstrate that an I-beam or Wide Flange section is much more efficient in bending than a rectangular section. The students are often called upon to observe the frequency with which steel I-beams are used in building and bridge construction as a verification of the concept.

A convenient illustration of this concept that enables students to have a hands-on verification is provided by honeycomb sandwich structure, in which thin aluminum face sheets are separated by a core consisting of aluminum foil in a honeycomb configuration, Figure 1. By themselves, neither the face sheets nor the core exhibit significant stiffness or strength, but when bonded together, an extremely stiff and lightweight structure results. A simple calculation shows that a core thickness of 1 in. reduces the bending stress by a factor of 75 and increases the flexural stiffness by a factor of 1875 compared to the two face sheets, all as a consequence of the parallel axis theorem.

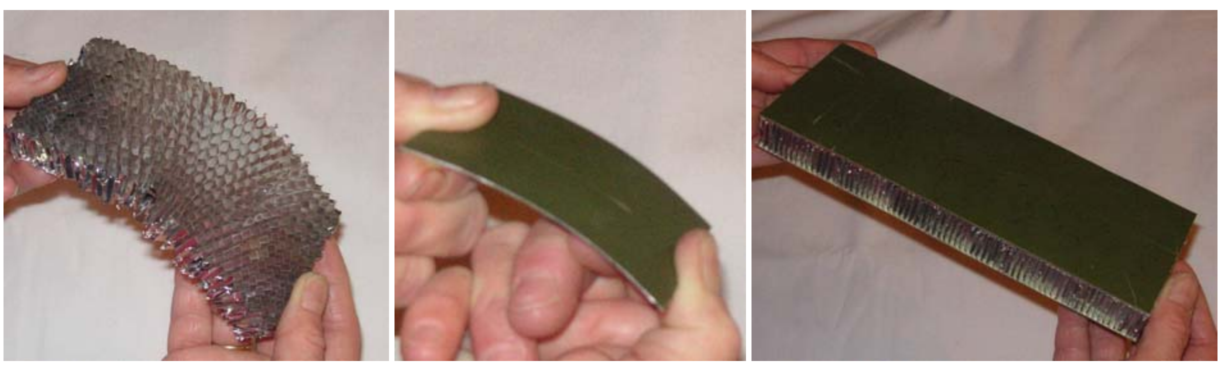

Figure 1. Demonstration of parallel axis theorem: aluminum honeycomb core; aluminum face sheet; sandwich structure

When presented in class, this example is supplemented by a brief discussion of the source of the sandwich samples: the torque deck in the aft fuselage of a C-5 military transport aircraft, as shown in Figure 2. A discussion of the basic structure of the aircraft itself, the location and function of this particular structural component, and the importance of structural efficiency in aerospace applications helps to establish the context for the students.

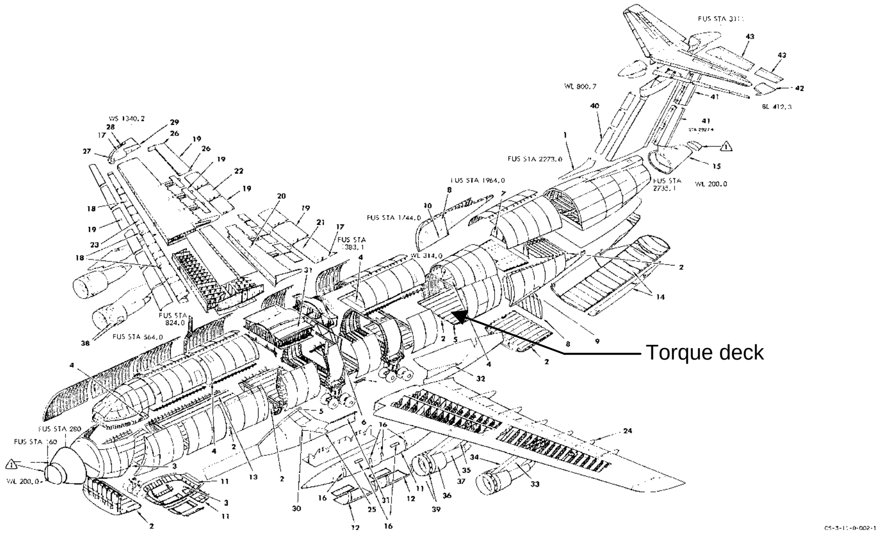

Figure 2. Exploded view of C-5 airframe with location of torque deck indicated

A second example of the introduction of hardware into the classroom is the test specimen shown in Figure 3. This is a specimen specifically developed for determining the tensile mechanical properties of solid rocket propellant, a rubbery material that exhibits nonlinear viscoelastic behavior. Because of its flexibility and geometry, this specimen is capable of illustrating a number of key concepts, including warping of non-circular sections in torsion, both bending and axial deformation kinematics, and stress and strain variation at the flared ends. Depending on the context, this can also be accompanied by discussion of considerations involved in test specimen design, and the significance of establishing the mechanical properties of solid propellant.

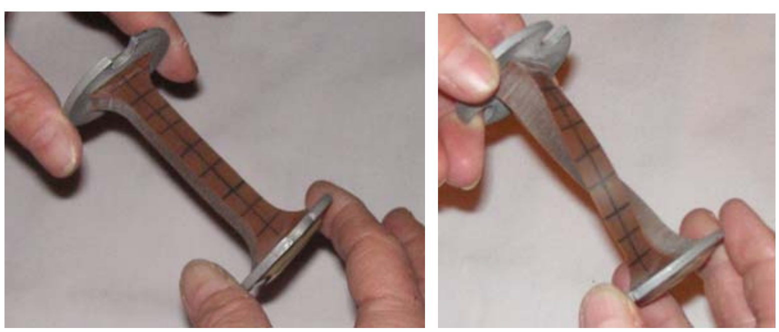

Figure 3. Solid propellant tensile test specimen

FIRMWARE

In this context, "firmware" refers to sharing pertinent portions of industry-generated engineering reports as the classroom situation merits. A significant portion of the engineer's time and effort in the aerospace industry is devoted to reporting: documenting designs, writing analysis reports, reporting test data. Clear, concise, and accurate written (as well as oral) communication is a powerful discriminator in an engineer's career. The ability to communicate effectively is a skill that can be developed; impressing the importance of attaining this skill is sometimes a greater challenge to us as engineering educators. We don't need to rely solely on the writing of lab reports or reports of design projects to emphasize this point. Incorporating excerpts of industry reports into the lecture classroom has been found to be effective in this regard.

An example is shown in Figure 4. This is an excerpt of the original stress analysis report for the C-5 transport aircraft, circa 1968. When presenting this example, additional contextual information is provided, such as the location on the aircraft of the component being analyzed. There are a number of valuable points that can be made on the basis of a simple example such as this:

- Students can clearly see the free body diagram of the beam, application of the equilibrium equations, the shear and bending moment diagrams, the calculation of the centroid and moment of inertia of the cross-section, and application of the formulas for normal stress due to axial load and flexure. These are all topics that are covered in a first course in solid mechanics, providing a powerful example of the application of these topics to verify flightworthiness.

- The documentation is complete and systematic, showing all steps taken to arrive at the solution. It is noted that this report is almost 40 years old, and C-5s are still flying. In order to make that happen, many structural modifications, repairs, and maintenance activities have been made through the years. Any major modification or material substitution requires knowledge of the critical loads applied to the affected components. These reports therefore continue to serve as primary reference documents. While the answer itself was important for the original user of the document, the path to the answer is more important now. Odds are the original authors are not available to answer questions or provide clarification. Show all work! Neatness counts!

- While engineering and reporting tools have changed significantly over the past 40 years, the fundamental principles and the need for accurate and concise documentation have not. C-5 stress reports total over 15,000 pages, either typed on manual typewriters or hand-written. Calculations were largely done using slide rules. Today's reports are word-processed and calculations are performed with liberal use of computers and electronic calculators, but concepts of equilibrium and bending stress are constant. While the communication media have changed, the purpose of reporting has not. Documentation of all assumptions and methods used is critical for unknown future customers. One cannot assume that the specific customer for whom the report is written is the only customer; rather, one must assume that every document produced will be archived indefinitely. This is a particularly important issue in the aerospace industry, where systems may remain in operation for decades, often far longer than their original design life.

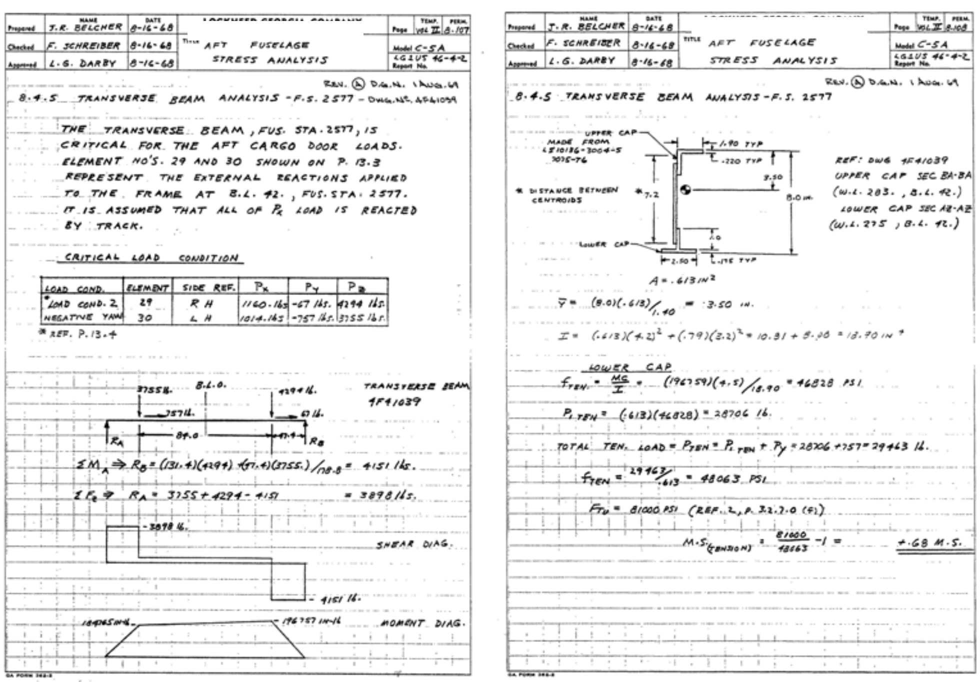

Figure 4. Excerpt from C-5 stress analysis report

SOFTWARE

The term "software" is used here to convey the use of story-telling, as it were, to convey some of the flavor of what it means to be a practicing engineer. Students often don't do "real" engineering until their senior year capstone design project. Even then, try though we might, the experience does not duplicate the life of an engineer in industry (nor, perhaps, should it). Many curricula include topics such as ethics and professional practices early on, but unless there is reinforcement throughout the undergraduate years, the concepts taught may be largely forgotten before graduation. This reinforcement can be provided, in part, by selectively including pertinent anecdotes from industry experience. These may take many forms, including example problems couched in terms of an assignment given to an engineer by his supervisor; issues of ethics, small or large, that can be worked into the topic at hand; or a sense of the variety of activities that an engineer may be called upon to simultaneously juggle (and therefore must possess the associated skills), including design, analysis, testing, reporting, customer interaction, and marketing.

Engineering ethics in particular is a topic that is generally broached as part of a one-term course early in the curriculum, but may never be explicitly introduced nor reinforced again. Recent graduates entering industry are often not fully prepared for the situations that they encounter that may test their understanding of their responsibilities as engineers. As one who spent 15 years at a company that is closely associated with the 1986 Challenger accident, I may be particularly sensitive to the extent to which engineers are equipped to deal with ethical dilemmas. Certainly not all questions of ethics are as far-reaching as Challenger, but graduates should be prepared to deal early on with the "little things" that, in aggregate, may unwittingly establish a pattern that can lead to bigger issues:

- An engineer and a marketing representative are working a booth at a trade show, and the engineer overhears the marketer making unsubstantiated claims to a potential customer about the capabilities of a product under development.
- An engineer is encouraged by his supervisor to charge time to one project while working on another because one is under budget and the other is over.
- An engineer completes the structural analysis prior to a design review, and one component has a margin of safety of -0.1. When the results of the analysis are presented by her superior to the customer and to upper management, the margin has been changed to +0.1.

Most who have spent any time at all working in industry have had similar experiences. I believe that the impact of stories such as these is far greater when selectively presented as a personal experience in context in a course not primarily dealing with professional practice, if for no other reason than that the students may not be expecting it. After all, in practice, issues of ethics often arise when one is least expecting it.

Just as importantly, personal anecdotes can be used to convey some sense of the excitement that engineering practice has to offer. How does it feel to watch the first test flight of an aircraft when you have been involved in its development? Your new and innovative design has just completed its first proof test, and your analysis successfully predicted the test outcome. You have spent months designing the instrumentation for a rocket motor static test to verify new analysis predictions, enduring unending red tape in the process, and the test comes off successfully. Certainly engineering is not all bright lights and glamour, but it does have its rewards, and especially in some of the more challenging courses, the promise of these rewards can be a welcome change of pace to both instructor and student.

In all honesty, I find the "software" aspect the most difficult of the three to effectively implement. Course syllabi are often so ambitious in terms of the amount of material to be covered that time is at a premium for even brief discussions related to professional practices. The challenge then is to integrate these discussions within the context of the material without unduly taking time away from the academic subject at hand.

STUDENT REACTION AND CONCLUSIONS

No systematic survey of student reactions to any of the techniques and examples described above has yet been attempted. As a result, no quantitative claims are made as to the effectiveness of these techniques. Nor is this to be considered in any respect a new method of teaching; but rather a means for facilitating students in making an immediate connection between textbook derivations and examples and real-life engineering applications. From a qualitative perspective, all of the examples cited have been successful in generating student interest, sparking class discussion, and precipitating conversations outside of class. The students seem to come away from these discussions with a deeper appreciation of the role and responsibilities of the engineer in the aerospace industry. By integrating these discussions within existing basic mechanics and upper-level structures courses, the close coupling among theory, application, and engineering practice is readily appreciated.

Certainly the discussion and examples cited herein are not exhaustive. Many other examples could be used, and other related techniques can be developed. The approach need not be limited to mechanics and structures courses. Educators' experiences in other industries can serve to demonstrate both the commonality among industries and differences across industries; but I believe it is important to draw examples primarily from actual experiences, rather than from second-hand accounts. Having been back in the academic environment for only three semesters, I am continuing to seek additional avenues for getting the message across to students without detracting from the primary course objectives. I am convinced that this general approach adds an important dimension to the students' educational experience that was largely missing during my first tour of duty in academia.

One of the challenges inherent in any discussion of adding meaningful content to a course is the choice of what to sacrifice from the existing course coverage. Particularly in basic mechanics courses, instructors have a difficult job in adequately covering all the required material in the allotted time. The use of demonstration articles ("hardware") and examples from engineering reports ("firmware") directly applicable to the topic *du jour* can certainly be worked into the existing material without sacrifice. In fact, a pertinent piece of hardware illustrating a key point, such as the sandwich structure cited herein as an example, can effectively and immediately provide a physical verification of a mathematically-derived principle, eliminating literally minutes of arm-waving.

On the other hand, incorporating discussions of ethics and the importance of clear and effective report-writing without displacing course content can present more significant challenges. If such topics are introduced at the beginning of a class period, the ensuing discussion can easily consume the whole hour. Timing such material to be introduced during the last ten minutes of class has been found to be effective in getting the point across and sparking out-of-class discussions among the students and with the instructor. Perhaps an added benefit of this approach is the element of surprise; in practice, ethical issues often crop up when they are a least expected. Does it make sense, then, to restrict students' exposure to engineering ethics in a regimented block of time in an introductory course?

Preparing students for lifelong careers as engineers is one of many important functions of engineering curricula, providing significant value both to the students and to their employers. There are numerous approaches to building a bridge between engineering as a course of study and engineering as a career. Senior design projects, summer internships, co-op work experiences, and courses in professional practice all serve essential functions in this regard. Drawing upon industry experience, and finding ways to integrate this experience into the classroom in meaningful ways, can serve a valuable purpose in helping to complete the bridge.

References

[1] Henkel, Melissa and Scott Schiff, "Supplemental Teaching Modes for Engineering Mechanics: Statics," *Proceedings, 2000 ASEE Southeast Section Conference,* ASEE, 2000.

[2] Steif, Paul S. and Anna Dollar, "Reinventing the Teaching of Statics," *International Journal of Engineering Education,* Vol. 21, No. 4, pp. 723-729, 2005.

[3] Holzer, Siegfried M. and Raul H. Andruet, "Learning Basic Mechanics with Multimedia," *Proceedings, 1999 ASEE Southeast Section Conference,* ASEE, 1999.

[4] Kraige, L. Glenn, "Unified Lecture Software for Statics and Dynamics," *Proceedings, 2005 ASEE Southeast Section Conference,* ASEE, 2005.

[5] Jenkins, Hodge and Jack Mahaney, "Improving Mechanical Design Education using Solid Modeling and Finite Element Analysis Modules," *Proceedings, 2005 ASEE Southeast Section Conference,* ASEE, 2005.

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