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Vehicle Structural Analysis for Automotive Systems: An Engineering Course for Fundamental Automobile Body Design

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David Schmueser joined the Clemson University International Center for Automotive Research (CU-CAR) in August 2013 as Adjunct Professor of Automotive Engineering. He received his BS and MS degrees in Engineering Mechanics, and a PhD degree in Mechanical Engineering, all from the University of Michigan-Ann Arbor. Prior to joining the CU-ICAR staff, Dr. Schmueser worked as a research engineer at Battelle Memorial Institute in Columbus, Ohio and as a senior staff engineer at General Motors Research Labs in Warren, Michigan. More recently, he was an Adjunct Professor in the Mechanical Engineering Department at Wayne State University in Detroit, Michigan and University Business Development Manager-US for Altair Inc. in Troy, Michigan. Dr. Schmueser has over 30 years experience in light-weight materials design, vehicle optimal structural design, and computer-aided-engineering instruction. He currently serves on the Board of Directors of the College-Industry Partnership Division of the American Society of Engineering Education.

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Introduction

The structure of the vehicle that you drove to work today protected your life. This simple "skeleton" of the car or truck is actually a highly complex multi-material, multi-degree of freedom structure that can fail in millions of different ways. As the automotive industry drives designs for light-weighting, the vehicle body is becoming even more of a complex structure that must operate robustly for 20 or more years.

For the development of this new course, a major US university teamed together with a major US automotive Original Equipment Manufacturer (OEM) to invent a new way to educate vehicle body design and manufacturing engineers. As the job of the body designer is to both model and validate through experiment, there has been a critical shortage of engineers that can not only do both, but also understand the interaction and feedback of the two activities, and how their integration provides for robust, long-lasting, and safe vehicle designs. Our objective was to team Professional Engineers from academia and industry to educate this new wave of Integration Engineers necessary to support more complex and data-driven vehicle design procedures.

Course Development Team

The team is composed of Engineers from a major US OEM, and faculty and students from the research center of a major US university. The research center is home to a school of complex systems design, development, and manufacturing. Here, over 200 students are pursuing graduate degrees centered on design and realization of complex products. Our students learn in an innovative research-and-educational program that focuses on the vehicle and its infrastructure from a systems-integration perspective.

The Research group of the OEM has a mission to take vehicle ideas "from the napkin, to the computer screen, to the customer focus group, to rolling off the assembly line." The focus here is hands-on engineering, so new employees must be not only competent in analytical and numerical modeling, but also capable in the testing lab. This requires a different kind of education model.

Team Members

- Senior Engineer (P.E.), Vehicle Structure Research and Reliability - Helped to define the structural analysis problem.
- Senior Engineer, Vehicle Structural Research and Reliability - Clarified OEM skills needs and current gaps.
- Manager, Vehicle Structural Research and Reliability - Provided prototype structural assemblies and testing jigs.
- Associate Professor (Ph.D., P.E.) - Expert in data collection systems.
- Postdoctoral Researcher (Ph.D.) - Expert in structural test programs.
- Adjunct Professor (Ph.D.) - Expert in structural modeling and optimization.
- Graduate Student - Developed structural model of automotive suspension.
- Undergraduate Student - Developed test system, designed and fabricated custom components.
- 32 Course Graduate Students - Gave feedback on the course content and delivery over 2 semesters.

Course Objectives

We wanted to establish a course that starts by teaching the fundamentals of structural modeling, but leads the students quickly and directly to the laboratory. At the graduate level this validation step is often excluded, so students end up with the skills to build complex models, but never to set up realistic experimental conditions and accurate data acquisition systems to test these models. Our goal was to provide the educational structure to teach the integration of the two disciplines, but to also take it a step further and have the exemplar application be a real structure being developed at a major Original Equipment Manufacturer (OEM). Teaming of Professional Engineers from both the industrial and university partners helped to define and execute a large-scale, multi-material structural analysis of a rear end suspension under development by the OEM.

Course Progression Phases

The course development was initiated with the OEM providing jigs and production assemblies for destructive testing, as well as the full assembly model with geometry, material properties and interfaces defined (Figure 1). The university provided software, instruction, and actuation/data collection systems for testing.

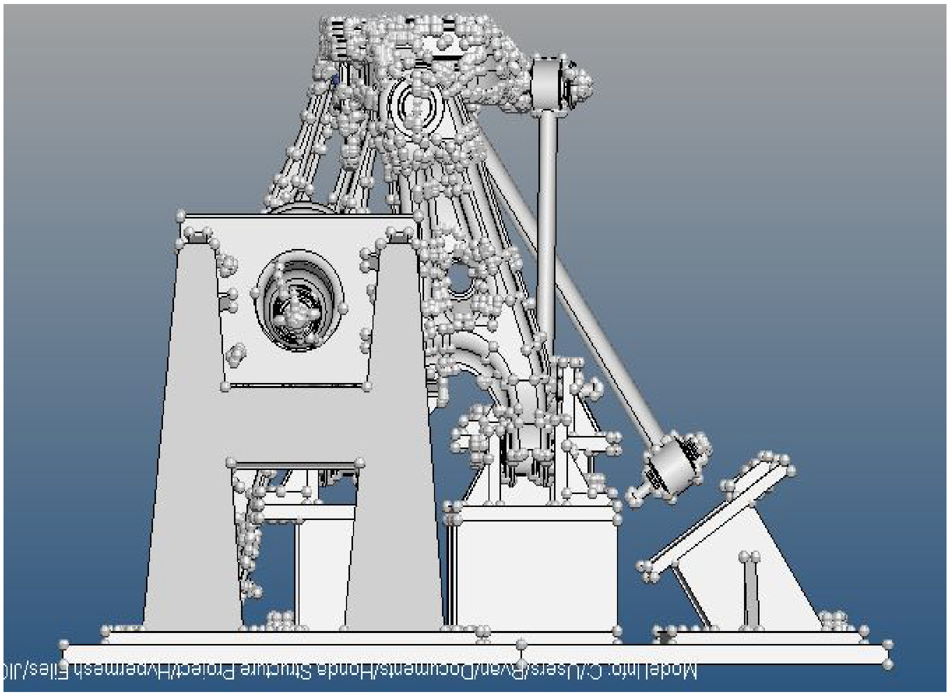


Figure 1. OEM full assembly model of chassis

The students completed the multibody solid model initially provided by the OEM (which was made purposefully deficient to illustrate the effect of poor modeling) and incorrectly predicted the failed component(s). The next instructional phase was in experimental setup, nondestructive measurement techniques, data acquisition systems, and analysis of experimental data. This led to students running destructive experiments on real OEM assemblies in the lab, and discovering that their predictions did not match reality. We took advantage of the teaching opportunity to illustrate the effect of problem setup in meshing the solid models; students corrected and optimized their model and were able to correctly predict the failed component. This exactly mirrors what happens in the OEM's own labs.

The final step was to have OEM engineers lecture on the importance and relevance of the integration of analysis and experimental techniques. The students' reflection on collective learning wrapped up the course, and helped to prepare them for competence and relevance in their own automotive engineering careers.

Course Project Preparation

In order to accomplish the previously described course objectives, two of the faculty members worked in collaboration with a professional engineer and two additional participants from the OEM research lab. A test setup mimicking the OEM laboratory was constructed (Figure 2), and all components were checked for safety as a practice run was performed in attendance of the professional engineer. With the support of the professional engineer, the results of the practice run were analyzed. It was found out that the results were as expected; therefore the system was set up for actual experimentation.

Figure 2. University laboratory replication of OEM structural test setup

A university graduate student developed the simulation of the vehicle rear suspension to allow the software to correctly identify the failing part. Then by applying structural optimization methods to the failing part, it was possible to drive the modeled failure to a different area; this would serve as the beginning model for the course (and one not immediately representative of reality). Course students could then compare the experimental findings to the simulation outputs, and use the experiment to optimize the model. In our contrived problem, students are forced to rethink the model, and how experiment can feed back and integrate to modeling efforts. This profoundly reinforces the importance of virtual and real systems integration as a skill for the new knowledge manufacturing age.

Current Course Status and Expansion

We have now offered this course twice to a total of 32 graduate students. The courses have been co-instructed by two faculty, one Adjunct Professor (with a 35-year professional career) in the finite element-based simulation content of the course, and the second instructor in the experimental and data analysis portion of the class (Figure 3). The OEM P.E. also gave lectures in the importance and the use of testing and simulations, and their applications in their workplace.

Figure 3. University faculty instructs on suspension mounting and loads

The course was expanded for its second offering to include full-vehicle body-in-white (BIW) design and simulation from a systems engineering perspective[1]. Using this approach, BIW structural requirements are established using benchmarking test procedures for bending, torsion, and vibration BIW performance[2]. These requirements are then flowed down to the design of BIW structural members through the application of first-order solid mechanics models and computational finite-element analysis[3]. Students are required to complete benchmarking tests for bending (Figure 4) and vibration performance.

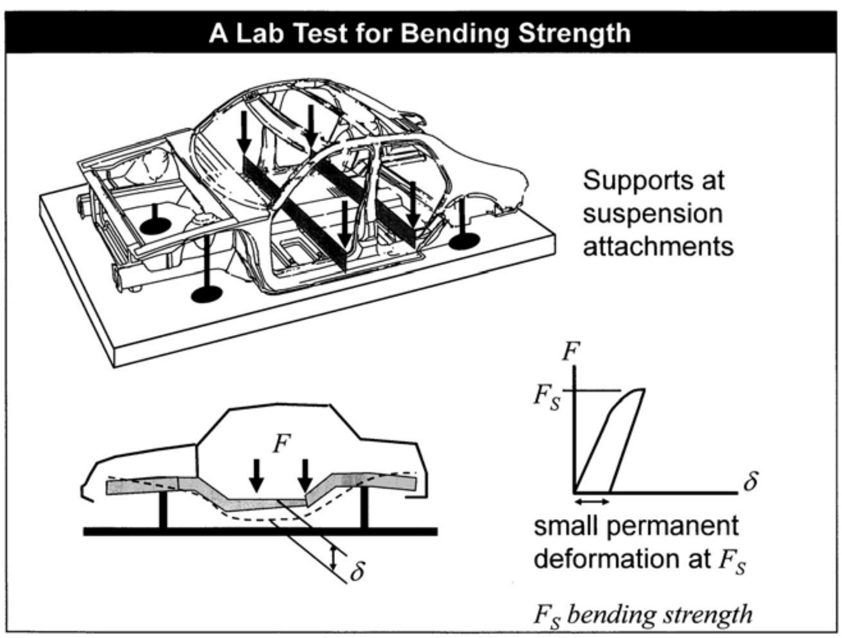
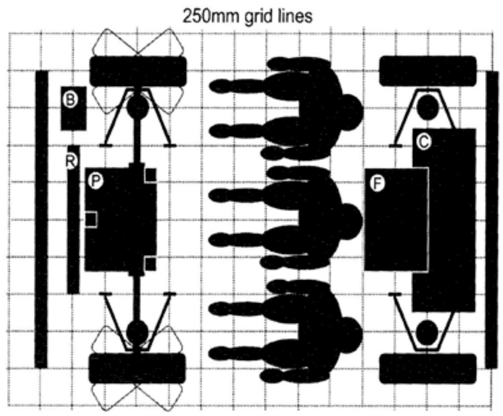
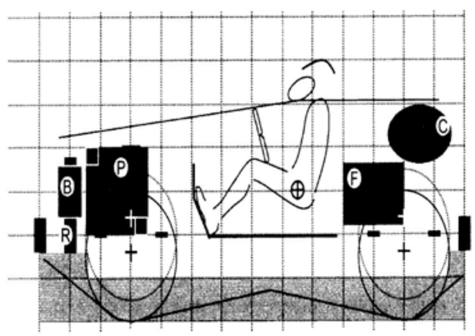


Figure 4. Test procedure for bending BIW performance

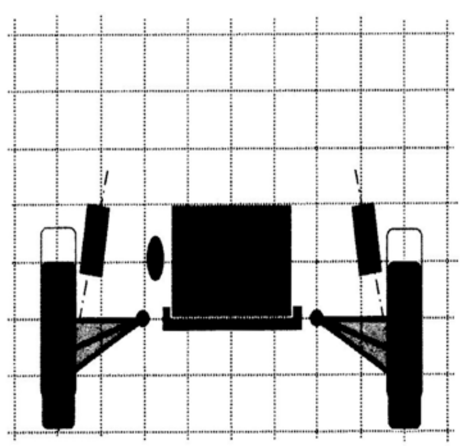
They then complete a team term project, applying the course design and structural analysis techniques to generate a BIW structural design for a provided vehicle lay-out drawing (Figure 5). The OEM has continued to work with us by providing the BIW for benchmark testing.



Top View



Side View



Front View

Figure 5. Vehicle lay-out drawing for student group term project

Course Outcomes: Collaboration of Faculty, Students, and Licensed Professional Engineers

Feedback from Clemson faculty, students assigned to set-up the experiments, and licensed OEM professional engineers participating in the course was obtained from formal interviews at the conclusion of the course. The interviews were conducted by the adjunct professor responsible for teaching the course and the associate professor responsible for the course origination.

Course feedback from the coordinators and instructors indicated that close, positive collaboration was experienced throughout the course planning and teaching phases. Persistent efforts by the OEM professional engineer to visit the experimental lab frequently to work with students assigned to setup the experimental hardware enhanced course collaboration and allowed for accurate experiments to be completed. The same engineer presented two guest lectures to the class, further enhancing student-sponsor interaction. From these collaborations, the OEM engineer developed relationships with the university department for further research possibilities. He also observed students for future recruiting activities. Furthermore, the OEM has established regular summer internship positions at their North America engineering facility as a direct result of the course development and execution.

Course Outcomes: Student Knowledge and Skills

The course impact on student knowledge and skills was assessed from the formal student course evaluations completed at the end of the term, and from specific common questions posed to each course project team at the conclusion of the team oral project presentations.

Feedback from the students related to each of the two primary course subject areas: the laboratory experiment and the computer modeling for revising the suspension component structural design. Comments from the students indicated that they gained essential knowledge on how to set up an experiment, including the importance of choosing sensors, actuators, and the data acquisition system, as well as how to identify possible failure scenarios for experimental hardware components. They also learned how to interpret and evaluate the results of an experiment.

Student feedback from the computational modeling techniques and application indicated that the students fully comprehended the finite element modeling procedures presented to them and were totally capable of setting up the necessary features of a structural optimization problem – the formulation applied to redesign the tested chassis component. They specifically stated that the simulation skills and knowledge related to structural optimization would serve them well in any future job that would require them to design light-weight vehicle structures and components.

Summary and Conclusion

The students who completed this vehicle structural integration course gained valuable experience regarding how to select components for an experiment, how to set up an experiment, how to evaluate experimental results, and how to improve a design via computational simulation. In their future engineering positions they will be either designing or evaluating experimental results on a regular basis. The skills gained from this course will make them more valuable in such a design environment. In addition to these technical skills, the students also acquired project management skills as they had to work together in teams to complete their term project and interact with faculty, professional engineers, and technicians.

Through this course development and partnership with industry, a graduate-level course has been established to educate a new breed of integration engineer capable of understanding efficient application of computational modeling and its limits, and having practical knowledge on how to set up a vehicle component-level experiment to validate simulation-driven design. This approach can serve as a future educational model where industry is fully in partnership during course development and execution.

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