# A Proposed Vehicle for Delivering a Mechanical Engineering Systems Laboratory Experience

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## ABSTRACT

The practice of mechanical engineering requires the ability to investigate and analyze complex thermal and mechanical systems. An effective way for the students to develop their understanding of mechanical engineering systems is for them to get hands-on experience by working in small groups in a laboratory environment. This paper describes a plan to develop a unique capstone laboratory course that provides this experience. The course, *Engineering Systems Laboratory* will be based upon an integrated sequence of laboratory experiments on an automobile and its subsystems. The automobile is chosen as the system to study because it is compact, relatively inexpensive and in the direct realm of experience of most students. More importantly, its many complex subsystems provide opportunities for the students to apply the spectrum of their mechanical engineering knowledge, including the principles of mechanics, dynamics, thermodynamics, heat transfer, and controls.

## INTRODUCTION

An integral part of the undergraduate mechanical engineering curricula at the University of South Carolina is sequence of four mechanical engineering laboratory courses: *Measurements and Instrumentation, Engineering Materials, Fundamentals of Microprocessors, and Senior Laboratory*. *Senior Lab* is a two-credit hour course consisting of one hour of lecture and three hours of lab each week. Laboratories are offered to sections of about eight students. Currently, it is a good class, but not a great class. The existing experiments were selected primarily to support upper-level mechanical engineering courses, and include Psychrometric Study Of Conditioned Air, Air Conditioner COP As Function Of Condenser Temperature, Transient Heat Conduction, Heat Transfer To Circular Cylinder In Cross Flow, Hydraulic And Energy Grade Line, Internal Combustion Engine Performance, Parallel And Counterflow Heat Exchanger Performance, Wind Tunnel Experimentation NACA 4418 Airfoil Section, Vibration Of A Cantilever Beam, Fracture Mechanics Experiment, and the Hydraulic Trainer.

The major drawback of the existing laboratory experience is that the experiments themselves are not directly related to one another. Further, the existing lab equipment is suitable for students to gain insight into various engineering principles, but most items support one experiment only. The result is a large number of relatively expensive items which must be maintained, that occupy laboratory space, yet are used only once a semester. Because the students go from one unrelated experiment to another throughout the semester, they do not have the opportunity to develop the "system level" perspective necessary to analyze and understand complex thermal and mechanical systems. Further, with the current equipment, the experiments are "set-up" for the students and do not require any design of the experiment, or much in the way of instrumentation installation.

The USC Mechanical Engineering faculty decided that a more unified experience is appropriate for the senior laboratory course. It is believed that practicing mechanical engineers need a systems perspective, which can be fully developed only when systems lab experiences are also involved. To reflect this emphasis, the course will be renamed the *Engineering Systems Laboratory*. In it, students approach and analyze engineering problems from a systems viewpoint, design experiments, apply computer-based instrumentation to study system performance, document their results in writing, and make oral technical presentations.

## THE SYSTEM UNDER INVESTIGATION

It is not desirable or even possible to attempt to expose students to every type of system that they might work with throughout their professional career. In designing the systems lab, one must select a number of systems for the students to investigate in detail. The selected systems must provide opportunities for the students to apply the spectrum of their mechanical engineering knowledge, including the principles of mechanics, dynamics, thermodynamics, and heat transfer. The automobile is the ideal system for this laboratory for several reasons:

- It is compact, yet it incorporates such a variety of subsystems that it involves almost all of the fundamental principles of mechanical engineering;
- For all its complexity, it is a relatively inexpensive system for study; and
- It is in the realm of experience of all students, so they can easily relate to system performance criteria such as efficiency, handling and other factors affecting vehicle operation. These features make the automobile a powerful learning vehicle.

This laboratory course will be implemented at the University of South Carolina using the Legends car similar to the one shown in Figure 1. The National Collegiate Association for Racing (NCAR), an academic motorsport involving engineering colleges throughout the country, currently races these 5/8-scale replica vehicles. There are primarily two reasons to use the Legends car:

Figure 1. Legends car raced by USC NCAR Engineering Team

- There is tremendous enthusiasm among our students for the NCAR sport. Those surveyed are excited about applying their engineering knowledge and experimenting with a car similar to the one raced in competition. Such enthusiasm can be a tremendous asset to any required course, particularly a laboratory course; and
- The relationship between the *Engineering Systems Lab* course and the NCAR racing team is synergistic. Corporate sponsorship of the NCAR team provides funds that supplement the College's resources for updating the lab equipment, and the course provides an opportunity for all mechanical engineering students to benefit educationally from the NCAR program.

## THE STRUCTURE OF THE REVISED COURSE

The new *Engineering Systems Lab* course will consist of four inter-related subsystem experiments plus a final analysis laboratory, all performed on one system, the racecar. This approach, using the same system through a sequence of complex experiments and analyses, will help the students develop the systems' perspective needed to practice mechanical engineering. The approach will also include a three-week cycle for each of the four experiments:

- Designing of the experiment in the first week;
- Instrumenting and running the experiment in the second week; and
- Presenting written and oral reports on the results in the third week.

The experimental design process involves designing the instrumentation system from the components available as well as applying fractional factorial DOE methods to determine the operating conditions for investigation. The course will culminate with the students performing an integrated analysis of the semester's results and recommending changes in the experiment design, the vehicle design, or both. This final exercise, directed towards improving overall system performance and safety, will help integrate these empirical experiences into the students' on-going design-related education.

Every semester, experiments will be performed in each of four major areas: the engine, driving stability, drag and mechanical losses, and controls. Examples of the experiments that will be performed are shown in Table 1. It should be noted that because the instrumentation specified is of general purpose, the experiments can be modified from semester-to-semester to keep them from getting "stale."

Within each of the three-week experiments, there will be a number of individual experimental measurements and set-ups possible, but not all will be used in a given semester by each lab team. Some specific tests may be done by different lab teams (different sections) or by different team members. In these cases, the test results must be combined by the students (and instructors) to present a coherent experiment to address the problem statement.

The use of remote wireless telemetry equipment allows the entire lab section to control and monitor the experiments while the car is driven. Secondly, a telemetry capability provides the opportunity to transmit the information to the lab when the experiment is performed at a site remote from the University, such as a regional racetrack.

## IMPACT ON ENGINEERING EDUCATION

The revised *Engineering Systems Laboratory* course will do more than support upper-level mechanical engineering classes. The students will learn to approach and analyze engineering problems from a systems viewpoint, design experiments, apply computer-based instrumentation to study system performance, document their results in writing, and make technical presentations. By using a Legends car as the test system, the course will channel the enthusiasm among our students for the NCAR motor sport into a useful and productive educational experience.

## ACKNOWLEDGEMENT

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**Table 1. Examples Of The Experiments That Will Be Performed In The Revised Course.**

| **Thermodynamics of the Power System** | |
|---|---|
| **Problem Statement:** What are the material and energy inputs and outputs for the engine? | |
| **Approach:** The fluid flow rates and properties are measured. Convection/conduction heat transfer from the engine block is determined via temperature measurements and external airflow rates and coefficients. Mechanical power measured from shaft torque and RPM measurements. Conservation of mass and energy equations used to determine "balance." | |
| **Measurements/tests needed:**<br>• Flow rates for combustion air, fuel, exhaust, and atmospheric air over engine.<br>• Exhaust emissions.<br>• Temperatures of fluids and engine.<br>• Combustion temperature and pressure.<br>• Shaft torque and RPM. | **Equipment required:**<br>• External/Internal Air Flow Pressure Array.<br>• Portable Exhaust Gas Analyzer.<br>• Liquid Micro Flow Sensors.<br>• Thermocouples, RTDs, Strain Gages.<br>• Telemetry System for Rotating Shafts.<br>• Rotation Speed Encoders and Amps.<br>• Data acquisition/transmission system. |

| **Dynamic Stability of the Vehicle System** | |
|---|---|
| **Problem Statement**: What are the stability characteristics and limits for the car? | |
| **Approach:** The center of gravity is determined through weight measurements and tilting. Accelerometers are used to measure "breakaway" conditions. Comparison is made to predicted spinout and/or roll-over conditions. Adjustments made to wheel set-up, suspension/tire stiffness and weight distribution to change stability characteristics. | |
| **Measurement/tests needed:**<br>• Wheel weight distribution.<br>• Roll-over tilt angle (sideways and/or end-over-end).<br>• Rear-end spin-out breakaway.<br>• Tire friction coefficients. | **Equipment required:**<br>• 4-Wheel Weight Balance.<br>• Tilt Table.<br>• 3-Axis Accelerometer System.<br>• Load Washers.<br>• Data acquisition/transmission system. |

| **Fluid Flow Drag and Mechanical Loss Analysis** | |
|---|---|
| **Problem Statement:** What are the aerodynamic losses and the mechanical losses? | |
| **Approach:** The aerodynamic losses are determined using surface pressure measurements. Mechanical power determined using torque and RPM measurements at drive shaft and at rear wheel axle. Delivered power measured using wheel-based (chassis) dynamometer. Differential tire friction determined from tire temperature profile. | |
| **Measurements/tests needed**:<br>• Shaft and axle torque and RPM.<br>• Wheel-based power.<br>• "Engine-off" pull force.<br>• External flow pressure distribution.<br>• Tire temperatures (across the tread). | **Equipment required:**<br>• Telemetry System for Rotating Shafts with Strain Gages.<br>• Rotation Speed Encoders and Amps.<br>• Chassis Dynamometer.<br>• Air Flow Pressure Array.<br>• Infrared Pyrometer Sensor Kit.<br>• Data acquisition system. |

**Table 1. Examples Of The Experiments That Will Be Performed In The Revised Course. (Continued)**

<table>
<tr><th colspan="2">Kinematics and Dynamics of the Steering Linkages</th></tr>
<tr><td colspan="2"><b>Problem Statement:</b> What are the operating limits and safety factors for the steering system?</td></tr>
<tr><td colspan="2"><b>Approach:</b> The steering system will be examined as an example of a complex linkage. Force, displacement and acceleration of the components will be investigated as functions of input parameters. Input parameters will be controlled by driving the vehicle over a series of bumps of predetermined height and profile while turning a corner at different curvatures and speeds. The results will be compared to those obtained by a solution of the system equations.</td></tr>
<tr><td><b>Measurements/tests needed:</b><br>• Forces on linkages.<br>• Position of linkages.<br>• Acceleration of linkages.<br>• Vehicle speed and location.</td><td><b>Equipment required:</b><br>• Load Washers, Load Bolts.<br>• 3-Axis Accelerometer and Strain Gages.<br>• DC-DC Conditioned LVDTs.<br>• Global Positioning System.<br>• Data acquisition/transmission system.</td></tr>
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<tr><th colspan="2">Suspension Dynamics and Tire Performance</th></tr>
<tr><td colspan="2"><b>Problem Statement:</b> How does a steady state turn affect the suspension and tires?</td></tr>
<tr><td colspan="2"><b>Approach:</b> A circular or oval track will be used to study steady state cornering, quantified by lateral acceleration. Both lateral and front to back shifts in suspension can be monitored as affected by lateral acceleration. Using wheel encoders, the difference in distance traveled by each wheel position can be compared to theoretical, and if this changes with cornering effort. The effects of cornering on tire temperature will be monitored with different turn radii and vehicle speeds.</td></tr>
<tr><td><b>Measurements/tests needed:</b><br>• Lateral acceleration.<br>• Suspension position, vehicle roll and pitch.<br>• Tire temperature.<br>• Vehicle speed and location.</td><td><b>Equipment required:</b><br>• Rotation Speed Encoders.<br>• 3-Axis Accelerometer.<br>• Infrared Pyrometer Sensor Kit.<br>• DC-DC Conditioned LVDTs.<br>• Global Positioning System.</td></tr>
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<tr><th>System Improvement Analyses</th></tr>
<tr><td><b>Problem Statement:</b> What improvements to the car can be made?</td></tr>
<tr><td><b>General Approach:</b> The student will examine the data taken from the four experiments with an eye towards improving car and/or driver performance and safety. Data from all teams will be made available to all teams since different tests can and will be run under differing conditions. Analysis Areas: mechanical and power efficiencies/improvements, mechanism design, driver controls and safety issues.</td></tr>
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## BIOGRAPHICAL INFORMATION

JED LYONS is an Associate Professor of Mechanical Engineering at USC.  He teaches engineering materials, manufacturing processes and mechanical design.  Recent research areas include high temperature crack growth in superalloys and viscoelastic behavior of thermoplastics. Educational projects include developing mechanical engineering laboratories and leading the NSF Gateway Coalition's Materials Program Area team.

JEFFREY MOREHOUSE is an Associate Professor of Mechanical Engineering at USC.  His long-term research interests involve energy-related systems, including solar, automotive, HVAC and general power producing devices. Teaching is focused on the thermal sciences and their applications, plus the capstone design course.  He is the faculty advisor to the student chapters of SAE, Pi Tau Sigma, ASHRAE, and the collegiate auto racing team.

DAVID ROCHELEAU is an Assistant Professor of Mechanical Engineering at USC.  His primary research interest is in the area of applied mechanisms and robotics.  Teaching responsibilities include courses in Computer-Aided Design, Computer-Aided Manufacturing, Kinematics and Dynamics of Machinery, and Introduction to Engineering.

EDWARD YOUNG is a Visiting Professor of Mechanical Engineering at USC. He teaches courses in the thermal-fluid area and is responsible for the senior mechanical engineering laboratory course. He has over thirty years of engineering experience including management of research and development organizations.

KENNETH MILLER is a Ph.D. candidate in Mechanical Engineering at USC.  His advisor is Dr. Y.H. Chao where he is studying the impact strength of welded joints.