Integrating Auto Racing in the Mechanical Engineering Curriculum

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I. Introduction

The Intercollegiate Auto Racing Association (ICAR) was formed in early 1998 for the purpose of organizing auto racing as a collegiate sport for engineering students. The race vehicles currently sanctioned for use by the Association are Legends™ cars. Legends cars are five-eighths scale models of stock cars from the thirties and forties powered by 1200 cc four-cylinder motorcycle engines, and are the basis of a popular spec-class racing series sanctioned by INEX, the international sanctioning body for Legends cars. The inaugural ICAR four-race championship series was held during the spring 1998 semester with seven southeastern universities participating, including the University of South Carolina, the University of Virginia, North Carolina A&T State University, North Carolina State University, The University of North Carolina at Charlotte, Duke University, and the University of Tennessee. Since then, three more semester-long series have been completed (fall ’98, spring ’99, and fall ’99). A typical semester series involves one event per month. Events usually consist of a practice session, a series of three practice heats, followed by qualifying and three points races involving three different engineering student drivers from each school. The race teams are comprised of from ten to twenty students who fulfill various roles such as drivers, mechanics, engine tuners, chassis tuners, statisticians, and team managers.

From the beginning, the intent has been for ICAR to be both an academic and a sporting activity, and all of the participating universities have begun to integrate motorsports into the engineering curriculum in a variety of ways. This paper describes the courses and laboratory exercises implemented thus far at three of the participating schools, viz. the University of Virginia, the University of South Carolina, and North Carolina A&T State University. It should be noted that these are nascent programs at these three institutions. Prior to 1998 and the inception of ICAR, none of the three schools offered motorsports courses or laboratories other than participation in the SAE sponsored vehicle design competitions including Mini Baja and Formula SAE.

II. The University of Virginia Motorsports Engineering Program

II.1. Overview

The University of Virginia started its motorsports engineering program in the spring of 1998. The primary goals of the program are to provide a forum to teach engineering fundamentals;

to provide a focus area for technical elective courses; to increase the range of technical topics for senior theses required of all undergraduate students; to develop a focused area for a recently developed co-op program in the engineering school; to provide a team focused competitive experience in ICAR that was being formed at the time.

To accomplish these goals, UVA has initiated two courses in motorsports engineering to augment its newly revised engineering curriculum and compliment an existing mechanical engineering technical elective, *Automotive Engineering*. Several students have held summer employment with professional race teams, including two NASCAR Winston Cup teams and a Pro Tour truck racing team. Two graduating students are employed by Ford Racing. Nearly a dozen senior thesis projects related to motorsports have been completed or are underway. Additionally, a student run race team has been formed to participate in ICAR events using Legends race cars and has attended more than a dozen race events with that league.

II.2. Motorsports Engineering Courses

UVA has developed two new motorsports engineering courses. One course, *An Introduction to Motorsports Engineering*, is a 1½ hour introductory survey course intended primarily for first and second year undergraduate engineering students. The material includes basic automobile acceleration performance, tire characteristics, basic aerodynamic concepts, basic suspension geometry, and suspension setup fundamentals for cornering performance. The technical level of the material is consistent with a first year course in engineering physics. Texts for the course include popular technical books on automobile racing [1] and course notes developed by the instructors especially for this course.

The course is intended for all engineering students, and although nearly half of the students are mechanical engineering majors or are planning to elect mechanical engineering as their major, students from all undergraduate engineering disciplines in the engineering school participate. Emphasis is placed on multidisciplinary aspects of engineering, design considerations, and decision making relating to engineering practice.

Some laboratory sessions have been included in the course. One involves the identification of automobile parts on several production and racing automobiles and students are required to note the different designs that exist to accomplish the same tasks. A second laboratory involves a team competition using radio controlled race cars with suspensions that are fully adjustable in wheel camber, caster, toe, and with spring and shock absorber adjustment. Teams of students compete against each other for best lap times with the cars operating on a tether. During practice sessions the teams determine the suspension setup they wish to use in competition. A load cell connected to the cars through the tether permit measurement of restraint forces through the tether to assist in determining an acceptable suspension setup.

A second course initiated is *Automotive Vehicle Dynamics*, a three-hour technical elective course offered to advanced undergraduate students with prerequisites of statics and dynamics. This course focuses on advanced kinematic, static, and dynamic topics. The kinematics focuses on suspension geometry variations with wheel deflections and the effects on wheel camber, caster, and toe, and roll center movement. The dynamics includes acceleration, deceleration, and turning including the above kinematic effects to determine tire traction forces using advanced nonlinear tire force models as well as linear and nonlinear force models for shock absorbers based on shock dynamometer test data.

Students are required to write static and dynamic simulation programs using spread sheets or other programming platforms such as Mathcad™ or MATLAB™. These exercises allow them to investigate the static and dynamic effects of suspension setup on car balance, weight transfer, and longitudinal and lateral acceleration, and perform open-ended design problems on suspension geometry.

Laboratory sessions are being developed to permit students to measure the change in wheel camber, caster, and toe with vertical wheel deflection for an actual race car front suspension and to permit measurement of the spring force-deflection and shock absorber force-velocity relationships.

II.3. Student Senior Thesis Projects

As noted above, several senior thesis projects have been undertaken related to the motorsports engineering program. Several of these projects have been selected to help enhance the program. For example, one current project involves the design and construction of a test fixture for mounting a race car front suspension to permit measurement of wheel camber, caster, and toe changes with vertical wheel deflection. This fixture will form the basis for one of the laboratory experiments in the course *Automotive Vehicle Dynamics* discussed previously.

A second project has focused on the analysis of the torsional rigidity of UVA's Legends car chassis. The tubular frame chassis was modeled using finite elements and is shown in Figure 1. Applying simulated torsional loads to the frame, the torsional deflection of the chassis was calculated, and is shown in Figure 2.

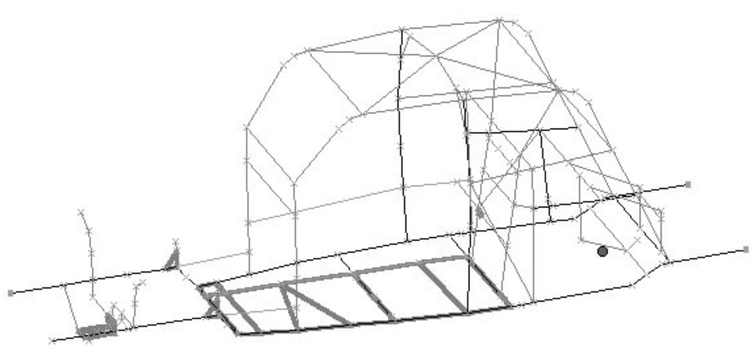

Figure 1. Finite element model of a Legends car chassis developed as part of a student undergraduate thesis project

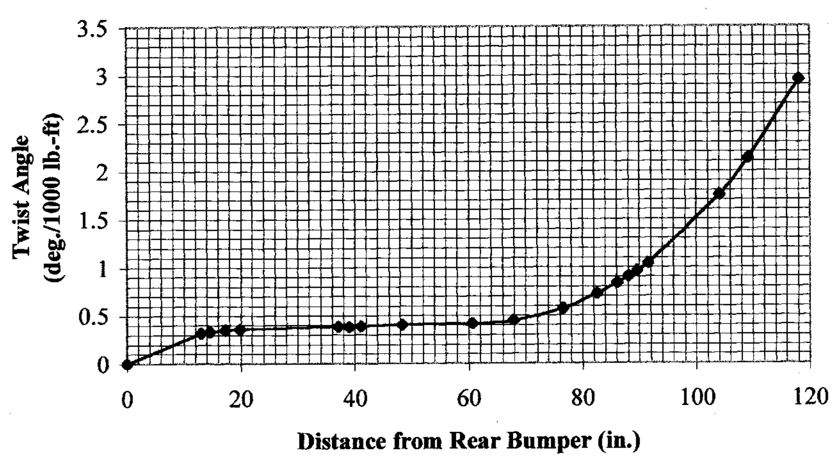

Figure 2. Torsional displacement for Legends car chassis predicted using finite element analysis

A third project involved the prediction of wheel camber, caster, and toe changes with vertical wheel deflection for UVA's Legends car using a kinematic analysis program, IMP©. A schematic of the 3-D independent suspension model is shown in Figure 3. Results of wheel camber and caster changes for a particular set of initial suspension settings are shown in Figures 4 and 5. These predictions will be verified using the test fixture discussed previously.

Additional projects center on the development of a data acquisition system employing real time data telemetry of various performance parameters including vehicle speed, suspension deflection, throttle position, and steer angle. This project also involves the development and implementation of signal filtering software.

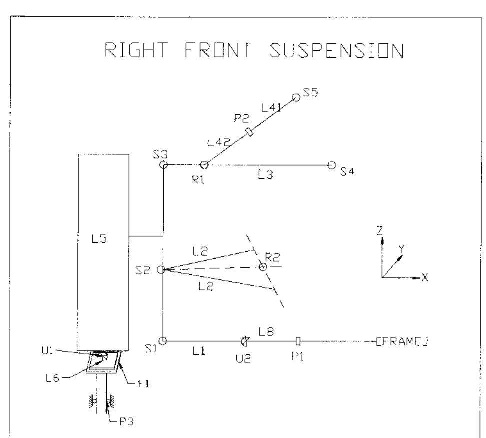

Figure 3. Independent suspension model used for a kinematic analysis of wheel camber, caster, and toe changes with wheel vertical deflection developed as part of a student undergraduate thesis project

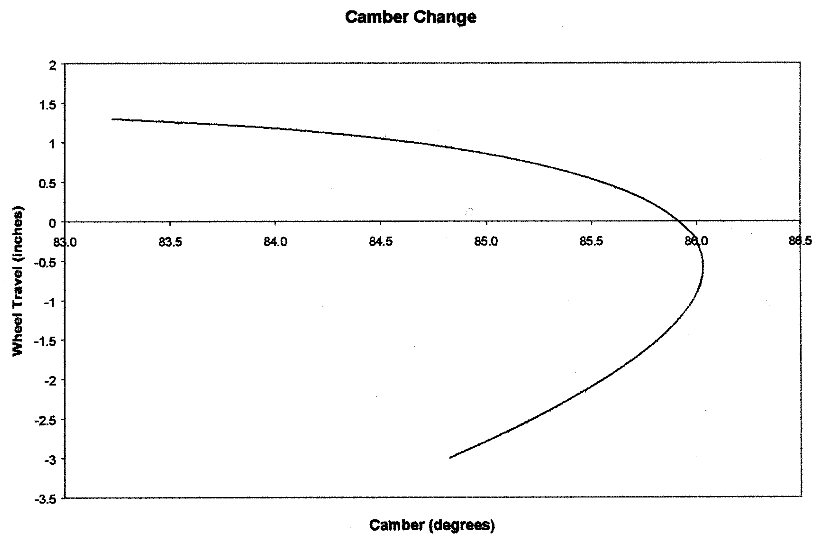

Figure 4. Wheel camber changes with vertical wheel deflection predicted using kinematic analysis

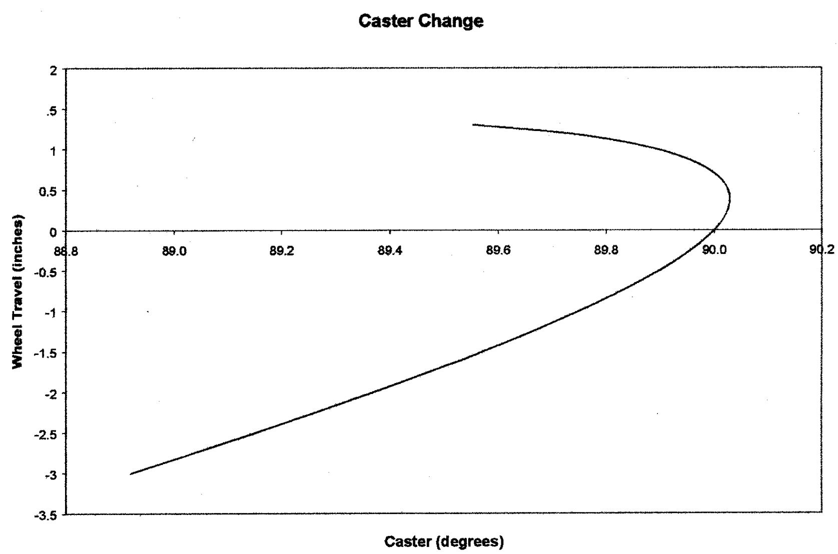

Figure 5. Wheel caster changes with vertical wheel deflection predicted using kinematic analysis

III. Motorsports Engineering at North Carolina A&T State University

North Carolina A&T is the only Historically Black College or University (HBCU) currently participating in ICAR, and to the best of our knowledge, it is the only HBCU in the country with any type of motorsports program. Auto racing is the fastest growing sport in the country, and it is one of the few sports that relies heavily on engineering expertise for competitive success. African Americans have historically been underrepresented in auto racing as both participants and spectators, particularly in stock car racing which represents the fastest growing segment of the overall sport and also represents the major growth area for the field of motorsports engineering. Most successful teams at the upper levels of NASCAR competition have recognized the value of employing motorsports engineers. Also, the NASCAR organization recognizes the benefits to be gained by successfully addressing the issue of underrepresented minorities in the sport and has launched several initiatives aimed at increasing the participation of African Americans as team owners and drivers. Increases in the number of African American fans and spectators should automatically follow if and when there are drivers and owners with whom to identify. Minority team owners quite naturally seek minority talent to support their teams, including drivers, mechanics, and engineers. Thus, the time is right for NC A&T to play a role in addressing the developing need for engineering graduates with some background in motorsports engineering. Being located in an area that is home to many Winston Cup and Bush Grand National teams is an added incentive.

The ICAR program provides an excellent training opportunity for the application of motorsports engineering principles because it allows students to apply classroom theory in a very real race environment on a regular basis. A&T's participation in ICAR has sparked the interest and provided the incentive to develop courses and facilities to support a motorsports engineering program.

Currently, the course offerings related to motorsports include two lecture-style courses plus a special section of the senior mechanical engineering capstone design course. The two lecture courses are *Principles of Race Car Engineering* and *Internal Combustion Engines,* both of which are upper-level three-credit-hour technical electives. The race car engineering course was newly developed to support the motorsports program, while the IC engines course has been a long-standing course-offering, but has been newly revised to place increased emphasis on high performance engines for racing applications to reinforce the motorsports theme.

Principles of Race Car Engineering was offered for the first time in spring 1999. The course covers topics related to race car design, including tires, aerodynamics, chassis types and design, suspension and steering systems, handling, transient stability and control, engines, fuels, and lubricants. Two paperback books[2,3] covering the bulk of these topics are required textbooks, and a race vehicle dynamics text[4] is used as a reference for the stability and control topics. Students use the ODE45 solver in MATLAB to perform handling response simulations for the simplified two-degree of freedom automobile model in reference 4. Figure 6 is an example of the predicted yaw velocity of the vehicle model for a step steering input of 10 degrees at 80 mph. Students can manipulate vehicle parameters and observe the effects on handling response characteristics.

Students are assigned exercises in such topics as spring analysis and testing, and suspension design and analysis using the SusProg3D© program. The Legends car is used as a demonstration platform for handling effects of suspension adjustments, commonly referred to as the "setup". This includes such factors as caster, camber, and toe settings, tire pressure and stagger, spring rates, ride heights, weight distribution, and rear axle offset and pinion angle. A Pi Research Inc. vehicle data acquisition system has recently been acquired which will allow quantification of suspension tuning measures in future offerings of this course.

A&T is fortunate to be located within easy driving distance of several major race shops, which affords the opportunity for field trips to view state-of-the-art race operations and for team engineers to visit the classroom and present guest lectures on specialized topics. During spring

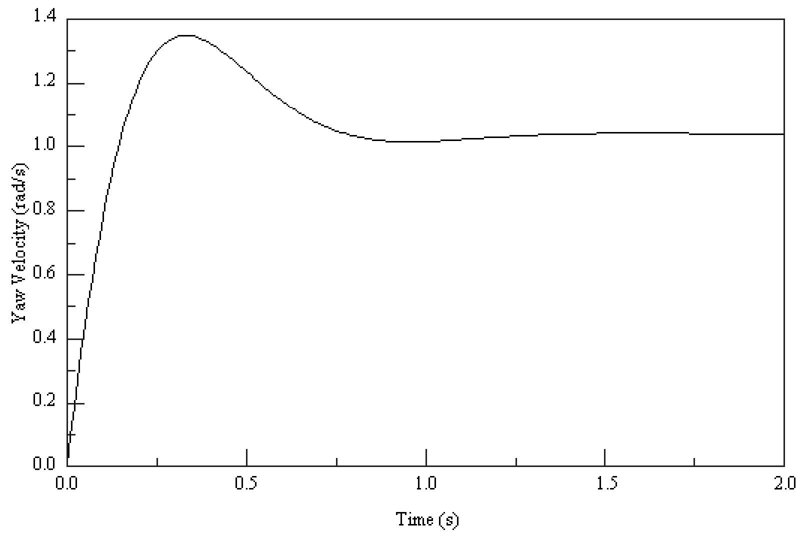

Figure 6. Yaw velocity vs. time for 10 deg. steering input at 80 mph

'99, guest lecturers from well-known teams spoke on topics including the life of a race engineer, Winston Cup engine development and testing, and the aerodynamics and wind tunnel testing of Winston Cup cars.

The IC engines course covers the usual introductory topics for an engine course and then introduces the students to the Engine Analyzer Pro™ software package for engine performance analysis and parametric studies of high performance engines. The section of the capstone design course devoted to the Mini Baja and Formula SAE competitions also makes use of the engine analysis software, as well as the IronCAD™ solid modeling package for design, ANSYS™ for FEM stress analysis of structures and components, and the SusProg3D program for suspension design.

Students in our program have served internships with NASCAR Winston Cup and Bush Grand National teams. One former student is now working as a race engineer for a major Winston Cup team and another is driving for an African American owned team that fields cars in a variety of stock car and open-wheel classes. Plans for the immediate future call for the development of an automotive engineering laboratory equipped with modern analysis tools, fabricating equipment, and test equipment, funded through a recent grant from the Ford Foundation for that purpose. This facility will support the ICAR racing activities, the design and construction of vehicles for the Mini Baja and Formula SAE competitions, and the motorsports related courses.

IV. The University of South Carolina Motorsports Activities

IV.1. Overview

The University of South Carolina (USC) has no formal motorsports discipline or program. However, USC began its involvement in collegiate motorsports by hosting the first Mini-Baja competition in 1976. For the next 17 years, motorsports activities were limited to small semi-supervised student teams building Mini-Baja vehicles every third year or so. In 1993, an ABET-inspired two-semester 'capstone' senior design course was initiated, wherein either vehicle competition or industrial-based design projects could be chosen by the students. During the last 6 years, about one-third of the seniors have chosen vehicle competition projects for their senior design project. While only 50% of the design teams actually finish their project 'in time' and/or 'well enough' to go to the actual competition, in these last 6 years USC teams have competed in three East Mini Bajas, two Midwest Mini Bajas, two Formula SAE's, two East Aeros, three Supermileages, and six ASME Solar Splashes. In addition, a solar car and a hybrid car (natural gas/electric) have been built but not competed. As an aside, the student vehicle design teams are required to raise funds for financing their projects, for both construction and attending the competition.

The intercollegiate racing activity (ICAR race team) is an extracurricular sport for the students at USC. The team generally has 20-25 members, two-thirds being juniors and seniors, with 40 hours of work as a crew member (doing setups, repairs, etc.) being required before a member can begin training to be a driver. The team is student led and organized, with a coach and a faculty advisor providing guidance and interface with the school. As with the competition design teams, the race team is responsible for raising funds for its operation.

The primary reasons for the introduction of these motorsports activities have been to stimulate the 'hands on' approach to engineering education and to motivate the students. With the student interest shown in these activities, further automotive-related topics, experiences and courses have been revived and/or introduced into the curriculum, as described below.

IV.2. The ICAR Team and 'Spin-Offs'

The ICAR team's purpose is to race – and for students to continue in this activity, it must be fun for them since they are not required to participate. However, in addition to the fun part, the race team has taken on responsibilities which provide several 'spin-off' benefits to the university, college, and ME department, including publicity, recruiting, and education. The publicity generated not only includes races and the media reports arising from them, but also involves city and county parades, fairs, and festivals to which they are invited. Recruiting activities by the team range from visiting high schools with the car and trailer to giving rides to visiting student prospects and parents. The team's educational aspect is associated with supplying the 'hands on' automotive background for many students that have never been exposed to automotive systems and mechanisms. Often this knowledge of automotive mechanisms is assumed in engineering classes – instructors assume the students know how a piston/cylinder works, how brakes operate, etc. (in thermo, fluids, dynamics, kinematics, etc.). Also, the race team 'educates' many of the students in general vehicle design before they get into the capstone vehicle design projects, thus supplying a valuable knowledge base for the project which was not always there previously.

IV.3. Engineering Systems Laboratory (Senior Lab)

USC received an initial equipment grant under NSF's Instrumentation for Laboratory Improvement Program to restructure the senior laboratory capstone course. The new course, *Engineering Systems Laboratory*, is based upon an integrated sequence of laboratory experiments on an automobile and its subsystems. 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 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.

The automobile chosen for the lab was the ICAR Legends race car because:

- There is tremendous enthusiasm among our students for the ICAR 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 ICAR racing team is synergistic. Corporate sponsorship of the ICAR 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 ICAR program.

This new laboratory course, offered for the first time in fall '99, is based on studying the Legends car as an interrelated dynamic system. The car has been extensively instrumented and several experiments have been, or are being, developed. The use of remote wireless telemetry equipment allows the entire lab section to control and monitor the experiments while the car is driven.

The experimental design process involves designing the instrumentation system from the components available as well as applying fractional factorial design of experiment (DOE) methods to determine the operating conditions for investigation. The course culminates 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.

A second NSF grant was received associated with this laboratory development. The project's objective is to develop the student's ability to confidently design and conduct an experiment, by using a series of activities designed to bring the student through the various learning experiences needed to establish a level of competence in the design of experiments. A constructivist or “learning by example” approach is followed to develop the students’ competencies in designing experiments; specifically, a series of “learning modules” are being developed, used and evaluated. Upon successful completion of the learning modules, the students are presented with an “open-ended” problem that requires that they design an experiment that involves the entire system.

The learning modules draw upon what the student has learned in related course work and introduces the student to a particular set of problems that arise in designing experiments. They require that the student use external sources such as the library or Internet to collect information pertinent to solution of the problems posed. Each module consists of an example experiment where the student is required to install existing instrumentation and a data collection system and then to perform measurements on a sub-system. In each module the student learns through example what factors are important in sensor selection, how to integrate the sensor into a data collection system, how to calibrate the sensor-data collection system and finally how to reduce the data obtained. The student then operates the system in a prescribed manner in order to exercise the measurement-data collection system, and thus obtains data on the particular sub-system. As the student progresses from module to module, he/she should, in addition to learning the principles in designing an experiment, develop an understanding of the various sub-systems, how required parameters are measured and how these measurements are used to evaluate sub-system performance. The approach for implementing these modules includes a two-week cycle of: (a) designing part of the experiment and then performing it during the first week; and (b) presenting written and oral reports on the results in the second week. The experimental design process taught in these first labs will involve selecting sensors to use from those installed or easily attached to the racecar, as well as applying statistical DOE methods to determine the operating conditions for investigation.

The modules are the individual steps in the step-by-step learning process. The *Engineering Systems Laboratory*’s design includes four modules: Telemetry and Data Acquisition, Engine Performance, Vehicle Performance, and Vehicle Dynamics. Each learning module consists of three elements: Module Description, Material to Student, and Lectures. The content of the Module Description element involves the purpose and overview of the experiment. The Material to Student element includes specific information that needs to be provided to the student for that experiment. The Lectures section includes the material to be covered in the lecture, outlines and source material for the instructor.

IV.4. Other Motorsports-Inspired Course Changes

The student interest in motorsports initially has impacted several courses through the use of automotive examples, with many course instructors using automotive examples since they know students are interested. Recently, the interest in motorsports has caused the “Combustion” course to be offered twice after several years of no interest, and a special topics course on “IC Engines” was offered this last summer. While these latter two courses are primarily for seniors, a course is under development that will be for all students (no prerequisites). The course is called *Automotive Systems Fundamentals* and will be a 1-1/2 credit course. It will have an

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equivalent follow-on course for 1-1/2 credits. The course will have an hour lecture and a two-hour hands-on session weekly. The hands-on session will involve the Legends car and demonstration of the actual mechanical structure and operation associated with the system from the lecture topic.

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