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Abstract

In an upper level undergraduate elective course in vehicle dynamics, the author has developed some off-campus experimental-based assignments that involve the students (in pairs) designing the experiments and providing their own measuring tools and test vehicle to get results that they can compare with their calculated predictions. The students are free to design their own procedure or do some investigation and use an industry-standard approach. The students typically find that their experimental results vary considerably from their predictions. While this can be due to simple student implementation errors, it is typically a result of more complex issues. This leads to some deep learning (and a little frustration) for the students as they look into why their results, which they have clearly observed, should differ so much from those predicted by standard machine design and dynamics formulae they have previously used without question. Students must dig into and understand the assumptions behind the standard formulas and also the assumptions they made in designing and executing their experiments. (Texts and Internet articles are often misleading on this subject so students also get an appreciation for the nuances of interpreting what someone has written.) To balance the frustration factor associated with the "reality" of the assignment, there is a fun factor in testing using real vehicles (in various states of conforming to the original manufacturers' specifications) that pushes the students further in the assignment than they would go with a typical campus lab experiment. The paper describes two of the experiments providing some sample student approaches with examples of experiment-calculation discrepancies and their likely causes.

Introduction

In formal college on-campus courses in North America, it is traditional that the students attend some form of face-to-face interaction with the course instructor. There continues to be innovation by individual instructors as to the form of that face-to-face interaction. In addition colleges provide physical assets like lecture rooms, audio-visual aids, computer-based instructional support tools, physical labs and computer labs to help the instructor perform. With several subjects it is particularly advantageous to the student learning process for the student to engage in some physical experimentation. (This fits with the majority of student learning styles[1].) Traditionally experiments are done in a lab room using equipment provided by the college and using a procedure developed in detail by the instructor. The physical activity is designed to be completed within a certain lab time period, with the student often spending time after and away from the lab preparing a report on the lab according to provided guidelines.

Three other possibilities for the physical experiment experience are as follows:

- An open-ended experiment where students are given a situation to solve like "here is a piece of material – what is it?" Students can then use any equipment in the lab to design their own experiments to answer the question.
- An "at home"[*] experiment using commonly available materials[2] and a carefully outlined set of instructions.
- An "at home" experiment and an open-ended set of instructions.

There are advantages and drawbacks to each of the four approaches. While the first, the traditional approach, is still the norm, there are several situations where the other approaches are probably more effective. Certainly as colleges move more in the direction of on-line and blended learning experiences for their students, interest will grow in developing the "at home" lab experience. In this paper the author discusses some of his experiences with the last approach.

Why Do It At Home

The "at home" approach has two distinct features that can be an advantage for certain situations. The first feature is that there is no institutional restriction on the variety and size of objects to be tested. Thus if an experiment is to be done using an automobile, a potentially large number of "at home" automobiles are available for possible testing. While a college may have a single car available for on campus testing, it probably does not have a quantity and/or variety. The second feature is that the amount of time available for running an experiment/test is not restricted to the availability of a scheduled physical lab. Thus if the experiment requires taking readings every two hours for eight hours of the voltage of a loaded wet cell battery, that could be easily done "at home".

Why **Not** Do It At Home

A serious challenge to a successful "at home" experiment is that the instructor is not there to prevent potential disaster. This could be a safety issue or just ruined expensive objects. Thus the

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[*] For this paper "at home" does not mean literally in the home but rather means "not at the college". So tests done at a local manufacturing company or on the HVAC system in an apartment complex would be considered to be done "at home".

students need to be well coached before they do their tests so as to minimize the potential for disaster. Also it is recommended that 'at home" tests be restricted to ones that do not have the potential to cause personal or financial harm to the student or others. Students can work with expensive "at home" items, but their activity should be restricted to measuring things that would (or could) be happening anyway.

A second challenge for "at home" experiments is the student not actually doing what he thinks he is doing. This is more readily caught in the college lab where, for example, students may think they are measuring an object in centimeters but in fact they are using an inch scale. Having the student provide good documentation, especially including photos or videos of what they actually did, helps mitigate this problem.

Why Have Open-ended Experiments

Open-ended experiments have the potential to force students to think (possibly even deeply[3]) about their approach to satisfying the problem statement provided by the instructor and then think about interpreting their results (which invariably are to some varying degree not what they expected). Open-ended experiments are more like what would commonly occur in the workplace. A typical workplace example would be, "*a new product that worked fine in tests done (in Toronto) before product launch is now regularly failing in use, but only in the southwest United States. Something has to be done to find out what is going on and make some changes so the product does what is expected of it, no matter where it is used.*" Doing a typical "canned" campus lab experiment would not be particularly helpful preparation for this situation.

Why Not have Open-ended Experiments

Open-ended experiments can be a real problem for students who have difficulty assessing a situation and making a decision about it. Thus they will spend more time than appropriate for the credit value of the course just coming up with a test procedure. Other students are the opposite and will just charge forth with the first thing that comes to their mind in terms of a procedure and will then spend many hours haplessly executing something that has no chance of working. While this may be a good predictor of what they may be apt to do in real life (especially if they do not learn by the course experience), it is not effective in terms of learning the specific course material relating to the experiment. Thus it is important that the course instructor have certain toll gates in the setting up and execution of the experiments (whether done "on campus" or "at home") where the student provides a status report and the instructor provides constructive feedback to make sure the activity stays on track to support the intended learning outcomes.

For some subjects there are just so many possible plausible wrong tracks that can be taken, it is best for the instructor to create a tightly outlined experiment. Otherwise the students get wrapped up more in "real-life" experience instead of learning the details of the subject at hand. For example, if the point of the experiment is that the students more fully comprehend that conservation of energy applies to various kinds of collision situations, then the results of the experiment had better support that conclusion.

Experience with a Vehicle Dynamics Class

The author instructs a senior elective engineering technology course in land vehicle dynamics. The course includes material relating to bicycles, motorcycles, cars, trucks and trailers. About 60% of the time is spent with cars with the rest spread over the other vehicle types. While the department does own a donated (by Toyota) pickup truck "front end" which is used for some experiments in the course, the department does not own any cars that could be used for testing. On the other hand, all the students taking the course either own or have ready access to a car that they are relatively willing to test in various ways. Thus for certain experiments it makes sense for the students to use their own car. For safety's sake, having the students work in pairs is important. Also the students really enjoy the opportunity to do something using their own vehicle.

The first "at home" experiment is based on a standard skidpad test done by American car testing magazines (like *Road and Track*). In a standard skidpad test, the test car is driven in a 200 foot diameter circle as fast as possible. Speed is increased relatively slowly so the car behavior is essentially steady state. From the maximum speed the lateral force measured in g's can be computed and that becomes a published number for that vehicle. For the test for the class there is an additional requirement beyond that for the standard skidpad test. Using their own devised method, the students must record the steering angle of the car steering wheel at five mph increments of the vehicle speed. Using ratios published for the vehicle as well as physical testing the students must relate the steering wheel angle to the steering angle of the front wheels. The objective is to produce a plot of front wheel steering angle versus steady state lateral acceleration for a constant radius turn (like in Figure 1). If the students are unable to find a flat piece of unobstructed 100-foot radius pavement they are allowed to use a smaller radius and note it in their write-up. The lateral acceleration, a_y is given by the formula

$$a_y = V^2 / (R \cdot g)$$

where V is the speed of the car (in feet per second), R is the radius of the turn (ideally 100 feet), and g is the acceleration due to gravity (= 32.174 ft/sec^2). Figure 1 shows a typical plot for a car with a tire to road surface static coefficient of friction of 0.9. Also shown in the Figure are the (extreme case) student obtained results for a 1998 Mustang and a 2001 Ford F250 (pickup truck).

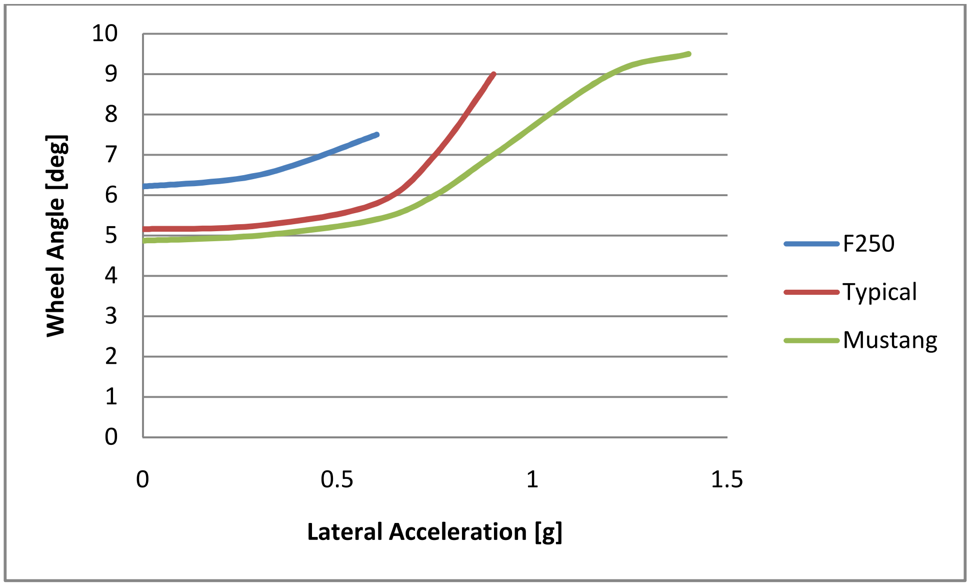

Figure 1 Steady State Cornering Results for a Constant Radius Turn

The second "at home" experiment is fully experimentally determining the front suspension spring rate for a vehicle and comparing the value to a calculated value based on using design formulas (presented in undergraduate machine design textbooks) with the dimensions taken from the car being tested. If the car has a front stabilizer bar (which acts as an additional spring under certain loading conditions), then it must be factored into the calculations and testing. Also the students are required to experimentally determine the effective tire stiffness as distinct from the suspension system stiffness.

An important piece of data for the second experiment is the weight of the front of the car, usually referred to as the front axle weight. It is the weight that a scale placed under the two front tires would show. While some students actually went to a truck scale and weighed their vehicle, most used numbers published by the manufacturer or by Road and Track (or similar) magazine.

Getting the spring rate for the suspension requires removing the contribution of the tires, typically by jacking the car up and placing a rigid object between the bottom of the suspension and the hard ground surface (essentially replacing the flexible tire with the rigid object). The deflection of the car fender is measured (with devices ranging from yard sticks to laser gages), while known weights (typically the students themselves) are placed on the fender above the wheel. Negating the effect of the stabilizer bar is done (most simply) by working with both front fenders simultaneously with identical weights. It is important to note (something the students typically forget) that this overall experimental procedure determines the effective suspension stiffness (including the effects of the suspension linkage geometry) not the actual spring rate of the front springs.

Finding the tire stiffness is most easily accomplished by doing the experiment again without blocking out the tire. Then by using the standard formula for springs in series, the tire stiffness can be calculated. The tire stiffness could be measured by removing the tire from the car (while the car is jacked up for the suspension only tests) and directly applying vertical loads to the tire and measuring the vertical deflection of the tire rim. While this method is more direct, it has the problem of not measuring the stiffness in the load range of the tire. It is suspected that tire stiffness is not linear over a wide range of loads, so it is important to measure the stiffness in the range of normal tire loading.

Based on vehicle technical literature[4,5], the front suspension spring stiffness (measured in lbf per foot) for vehicles should be in the range of 0.5 to 5 times the weight (in the units of lbf) on the front axle of the vehicle. The typical passenger car would be near 0.5, a high performance sports car near 3, and race cars and commercial trucks would be near 5. (For the metric world, a typical passenger car with a front axle mass of 760 kg would have a front suspension stiffness of 13 N/mm.) Except for a few students who had problems with their units and thus had erroneous results, the suspension stiffnesses determined by the students were about what one would expect for the type of vehicle tested. For passenger cars the range for the stiffness (as a multiple of the front axle weight) was from 0.6 for a Dodge Neon to 2 for a Chevrolet Camaro. However the students universally had trouble relating spring stiffness, as determined from using measurements of the actual suspension spring and standard machine design book formula calculations[6], to the spring stiffness obtained from the suspension spring rate tests adjusted to account for the suspension geometry. To date every student has done something wrong in making that comparison so that there were no valid comparisons. However the explanations for the discrepancies between the two results have been quite interesting! (The author has resolved to give the students more ongoing advice --i.e. make the problem a little less open-ended -- in this area for the upcoming Spring 2008 class.)

The tire stiffness results have presented a challenge. Students have measured stiffness varying from half of the suspension stiffness (for a 235/75-15) to twelve times the suspension stiffness (for a 275/40-17). The text for the course[4], published in 1992, says that the tire stiffness should be about 12,000 lbf/ft. Another, slightly newer, reference[5] provides the tire vertical stiffness range of 120 to 250 N/mm that converts to 8220 to 17,130 lbf/ft, which is numerically about five to eleven times a typical 1600 pound front axle weight. Cars with tires on the low end of the stiffness range would also be expected to have a suspension stiffness on the low end of the range, so it would not be expected that the tire and suspension stiffnesses would be of comparable values as several students found. Since the mid 1990s car manufacturers have generally moved in the direction of using lower profile tires, which are stiffer than higher profile tires. Thus higher, not lower, tire stiffness measurements were expected. After the Spring 2008 tire and suspension stiffness measurements are taken, this issue will be more thoroughly investigated. Every indication is that the past student measured stiffnesses were correct for the conditions under which they were measured, so the question of why the range of measured tire vertical stiffness values went so low needs to be understood.

Conclusions

Not surprisingly the author has had both some good and some challenging results in using open-ended at home assignments. As issues are raised specific to those assignments, it becomes possible, after subsequent analysis, to give the students some guidance that lessens the potential for the students to easily come to erroneous conclusions in their experiments. However this takes away from the open-endedness of the project. This leads the author to the conclusion that in the at home situation where continuous instructor monitoring of the process does not occur, the kind of experiment that is given has to be very carefully chosen and thought out. In particular the students need to be warned and reminded about certain procedures and facts that if not considered will lead to an unsatisfactory result. In other words the experiment becomes only partially open-ended where some critical (but not total) guidance is provided. Thus a reasonable conclusion is that for an at home experiment, the experiment description and up-front guidance has to be greater than what would be used for a similar open-ended on-campus experiment.

The students really enjoyed the at home open-ended experiments, many saying in their course evaluation that it was the best part of the course. Since this was the part of the course the students remembered well (some of them having some unique college high-point experiences), it is even more important that they get results that support the learning objectives for the course. This does put more pressure on the instructor to "get it right" than with a typical on-campus lab experiment.

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Biography

DR. GEORGE H. SUTHERLAND is a professor in the Manufacturing & Mechanical Engineering Technology and Packaging Science Department at Rochester Institute of Technology. Dr. Sutherland is interested in the dynamics of high speed machinery and vehicle dynamics. He was formally an associate professor in ME at Ohio State University, a manager at General Electric, a VP at CAMP Inc and President of Washington Manufacturing Services.