AC 2012-5030: EXPERIMENTAL STUDIES IN GROUND VEHICLE COAST-DOWN TESTING

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As a determined undergraduate student, Drew Dosson Brennan is currently pursuing a B.S. in mechanical engineering degree. He has always had a strong interest in engineering and energy. His research in coastdown testing has proved as a valuable experience to his education. Through testing, he was able to apply his engineering experience and conduct a test to observe first-hand how certain variables effect a vehicles energy loss. Other accomplishments include involvement in helping to develop a Hybrid Electric Vehicle Mobile Lab, serve as Chair for Alpha Society, and achieving the Deans' List every semester.

Experimental Studies in Ground Vehicle Coastdown Testing

Abstract

Hands-on engineering instruction is an important yet often underused component of the engineering curriculum. The lack of engineering laboratories can be attributed to a number of factors, one of which is the virtual nonexistence of pedagogically proven experimental activities. This paper introduces the potential of coastdown testing as an engineering experiment. It develops a thorough framework for a set of experiments and assignments within coastdown testing, with the overarching objective of instructing students about vehicle dynamics. Sample execution methods and results are included to ensure easy adaptability to the classroom setting. From the assessments conducted, it was clear that students both enjoyed themselves and developed an understanding of the subject matter. Therefore, due to the easy implementation and promising results of the class, it was determined that coastdown testing works well as a classroom engineering laboratory.

Introduction

The education of mechanical engineering students tends to favor theoretical concepts over practical applications. Students take multiple courses in topics such as dynamics, mechanics of solids and fluids, thermodynamics, and design theory. However, oftentimes the only exposure mechanical engineers receive to practical engineering comes in the form of a laboratory design course, in which they learn the operation of tools such as the mill and lathe. Few if any education programs exist that integrate theoretical and practical components of engineering. According to Arnold Kerr and Byron Pipes, students gain more when engaging in hands-on work[1]. Consequently, because of this inherent lack of hands-on experience, mechanical engineering students may not be as prepared as they could be when entering the workforce.

One topic in mechanical engineering which integrates vehicle dynamics with technical experimentation is coastdown testing. Coastdown testing is the process of accelerating a vehicle to a high speed on a flat, straight road and coasting in neutral down to a low speed. By recording the amount of time the vehicle takes to slow down, it is possible to obtain a model of the loss-inducing forces affecting the vehicle. Obtaining valid coastdown results requires several steps, including experimental planning, data collection, and data processing.

The inherent modular nature of coastdown testing allows for easy adaptation to a laboratory-based experiment as part of a course in a number of transportation related subjects including vehicular dynamics, automotive engineering, hybrid electric vehicles, etc. One rendition of a coastdown testing module is detailed within this paper.

The course that utilizes the coastdown experiment is Michigan Technological University course number MEEM/EE 4296, Introduction to Hybrid Electric Vehicles Laboratory. This course is one of seven new, and nine modified courses, and several existing courses that comprise a new curriculum in Hybrid Electric Vehicle Engineering. The courses can be taken individually as a technical elective as students obtain their undergraduate or graduate engineering degrees, or can be used to earn a fifteen credit certificate in Hybrid Electric Vehicle Engineering. The development of the new curriculum was funded through the US Department of Energy (DOE), under the American Recovery and Reinvestment Act.

MEEM/EE 4296, Introduction to Hybrid Electric Vehicles Laboratory is a hands-on, interdisciplinary course providing an introductory level experience in the overall theory, operation, and functionality of the subsystems comprising Hybrid Electric Vehicles (HEV's). The course consists of a traditional lecture period where the students are exposed to a particular technical topic and a hands-on experience where they conduct experiments pertaining to the technical topic. Following the experiments students complete an assignment involving additional data reduction, post-processing, analysis and interpretation of results, and reporting. The final report consists of written text and for some assignments the delivery of a presentation to a panel of experts. The hands-on experiences, and the associated data processing and analysis, reinforces the concepts that the students were exposed to in the lecture period, as well as the other courses in the curriculum. In this course, the HEV is examined from a thermodynamic point of view, treating the HEV as being comprised of a system of energy conversion processes. The functionality of each subsystem is investigated, including the major irreversibilities (losses) taking place within each subsystem. This is particularly useful in preparing students for the follow-up course MEEM/EE 5296, Advanced Hybrid Electric Vehicles Laboratory where students focus on system level integration and optimization issues. An overview of the schedule for Introduction to Hybrid Electric Vehicles Laboratory is shown in Table 1.

Table 1: Course Schedule

Academic Week	Lecture Topics	Experimental Topics
1	HEV Safety	Disabling the HV Electrical System, and prepairing for service
2	HEV Architecture	Component identification & Determination of Vehicle Architectures and Powerflows
3	Experimentation, Drive Cycles & Automotive Regulations	Development & Analysis of drive cycles, determination of fuel economy, and assessment of experimental variability
4-5	Chassis, Body, and Drivetrain	Coastdown Testing - The effects of tire pressure, mass, and aerodynamic parameters on rolling resistance and wind drag
6-7	Batteries	Determination of capacity, internal resistance, specific power / energy and efficiency under varying loads and charge
8-10	Engines	Determination of specific efficiencies, output, and mean effective pressures
11-12	Electric Machines	Determination of Torque Constant, effect of speed and load on efficiency in motor and generator modes
13-14	Why Hybridize a Vehicle	Measurement of energy recovered during regenerative braking and fuel saved during engine shutoff
Finals Week	NA	Student Presentations to Panel of Experts

The subject of this paper is the coastdown experiment used in weeks 4-5 to reinforce students' comprehension and understanding of some of the sources energy loss at the vehicle chassis level. Students conduct coastdown testing following the procedure established in SAE J1263 ("Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques")[2] while varying several common parameters including the mass of the vehicle, tire pressure, aerodynamic factors, and the road surface. Data analysis includes determination of rolling resistance and wind drag, enabling students to see how, and why, these factors affect vehicle fuel economy and performance. Figure 1 shows students conducting the coastdown testing in this course.

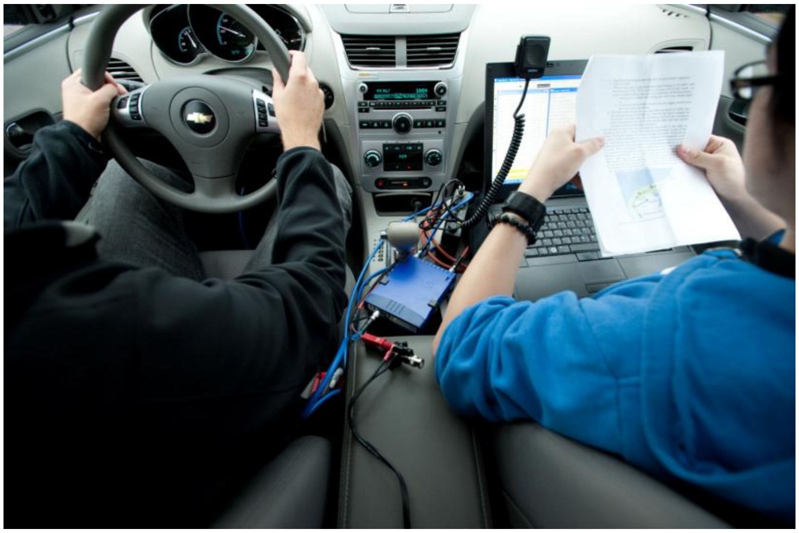

Figure 1: Students conducting a coastdown test.

Learning Objectives

The module on coastdown testing described in this paper will allow students to grow in several areas, enumerated below:

- Develop an understanding of basic vehicle dynamics; particularly losses associated with vehicle motion
- Become familiar with coastdown testing procedure and applications
- Gain experience with experiment design and methodology
- Learn about the rigorous nature of industry-approved procedures
- Become cognizant of real-world data variability and measurement error, and gain experience with methods of reducing variability and error
- Further preexisting knowledge in or develop new knowledge of coding in technical computing languages such as MATLAB
- Understand the importance of validation of code output against expected results, and gain experience performing such validation
- Gain experience in data analysis and interpretation
- Develop skills in technical writing

An Experiment-based Assignment on Coastdown Testing

The coastdown testing assignment detailed below is designed to take place in roughly four weeks. The first two weeks consist of lectures on vehicle dynamics and losses followed by a period of class time set aside to conduct coastdown testing and gather experimental data. In the remaining two weeks, students are expected to complete several data processing and analysis tasks. Students will write a report which summarizes their results.

Lectures and Background Information

As indicated previously, the assignment begins with lecture material that focuses on the sources of drag and rolling resistance. This includes tires, drivetrain components, body geometry and underbody aerodynamic effects. The students see where the losses originate and how to estimate their impact. Lecture material also covers the coastdown experimental procedures and the data reduction process required to determine drag and rolling resistance from the experimental data. Through this process students become familiar with the functional form of the expression describing the vehicle velocity as a function of time[3] as shown in Equation 1.

Equation 1

$$V(t) = \frac{V0}{Beta}\left(\tan\left((\tan^{-1}(Beta))\left(1-\frac{t}{t0}\right)\right)\right)$$

Fitting this functional form to a set of experimental velocity versus time data will return optimized Beta and t0 values, which are used to calculate the road load coefficients or drag coefficient (C_D) and rolling resistance (f_r).

Students will need to become familiar with the coastdown testing procedure by referring to the Society of Automotive Engineers (SAE) article J1263. Accurate data collection requires students to evaluate strict procedures outlined by SAE. Students should review the procedure and identify key elements such as:

- Testing Requirements
  - Weather Conditions
  - Vehicle Type/Qualifications
  - Testing Environment
  - Data Acquisition system
  - Required data parameters
- Coastdown Testing Procedure
  - Purpose
  - Method
  - Expected Results
- Mathematical Relationships
  - Determination of Road Load Coefficients
  - Calculation of Rolling Resistance and Drag Coefficient from Road Load Coefficients
  - Validation of Experimental Results

Experimental Setup

The procedural techniques practiced in this assignment can be used to assess the impact of any vehicle attribute on coastdown performance, and thus drag and rolling resistance. However, to fit within the time constraint of a college course the test variables are limited to those that can be easily and quickly varied during a lab sessions. Test variables that have been used in this course are shown in Table 2.

Table 2: Test Variables Used in Coastdown Testing Experiment

Variable	Minimum Value	Maximum Value	Targeted Effect
Tire Pressure	40% less than OEM Recommended	40% greater than OEM Recommended	Rolling Resistance
Vehicle Mass	Driver and 1 passenger	Driver and 1 passenger +700 kg	Rolling Resistance*
Road Surface	Baseline Road	2 tires on shoulder rumble strip	Rolling Resistance
Aerodynamic Losses	Baseline Vehicle	All windows down and wipers ON	Drag
Aerodynamic Losses**	Modified Air Dam	Modified Air Dam	Drag

**Produces a secondary effect on drag due to a change in vehicle ride height.*

***Planned for implementation into course starting Fall 2012.*

Referring to Table 2, all changes are within the scope of what can be accomplished in a parking lot or similar mustering area if the test location is far from the vehicle shop. The discussion that follows provides additional details on the test variables shown in Table 2.

One method to alter tire pressure is to start with the highest pressure, then only reduce tire pressure for successive runs. Alternatively, small air tanks and portable air compressors are very manageable and can be transported to the mustering location in a support / logistics vehicle. For this course, the Michigan Tech Mobile Lab's Semi Tractor was used as a support vehicle, providing a high capacity compressed air through the tractor's air brake system. Having onsite air provides the advantage of 1) being able to compensate if too much air is removed from the tires, and 2) be able to randomize the order of tire pressure runs and / or conduct repeat runs, and 3) allow the tires to be inflated to the proper pressure before driving back to the vehicle storage location / shop. As will be discussed in the results section, tire pressure has a significant effect on vehicle coastdown, well within experimental variability, making it an ideal parameter for this educational activity.

It should be noted that changing tire pressure affects the tires effective rolling radius. This can introduce experimental error into the data if the vehicles own speed sensing system is used to log data, as was the case in this experiment. This effect is small compared to the overall affect of the tire pressure on rolling resistance, and other sources of test to test variability. An image of course participants altering tire pressure during the experiment is shown below.

Figure 2: Tire pressure adjustments being made at the mustering location between coastdown runs.

Vehicle mass can be quickly and easily altered with very little, if any initial cost required. For this experiment, mass was altered through a combination of vehicle passengers and steel ballast. The minimum mass was achieved with only a driver and one passenger to operate the data acquisition system present in the vehicle where as the maximum mass was achieved with three additional passengers and steel ballast. When using steel ballast they should be securely fastened to ensure passenger safety. It is also important to note a significant change in vehicle handling may occur from the weight addition. Strategically filling the vehicles fuel tank between runs is recommended to compensate for the small, but significant change in vehicle mass. Depending on the vehicle and fuel volume in the tank before filling, a minimum change in mass of 30 kg is possible.

It should be noted that changing vehicle mass certainly affects rolling resistance through increased tire deflection and wheel bearing friction. However, a secondary effect is the relationship between mass and vehicle ride height, and hence drag through underbody aerodynamic affects. Although this secondary affect complicates the test result, it does provide the instructor with an opportunity to demonstrate to students how test variables can be interrelated in ways they may not immediately think of.

Depending on the test location, a simple and effective way to investigate the effect of road surface on rolling resistance is to utilize the rumble strip along the shoulder that is present on some roads[4]. For this experiment, one additional test was run while maintaining two of the vehicle tires on the rumble strip during the coastdown. It is important to note that using a rumble strip to influence rolling resistance will introduce an additional variable; the imbalance in rolling resistance across the car tires necessitates countersteering to counteract vehicle yaw. While it would be more experimentally rigorous to perform tests across different paving surfaces, in reality such surfaces would be difficult to locate. For educational purposes, the rumble strip is an acceptable and convenient alternative. Through student observation driving on a rumble strip had a significant effect on the vehicle coastdown rate. However, due to a loss of communication between the data acquisition system and the vehicle's Controller Area Network (CAN) bus, data and results are not available at this time. The authors do feel however, that this is a worthwhile variable to include in future experiments.

Changing vehicle drag through aerodynamics can be more challenging than changing the rolling resistance. In this testing, an attempt was made to alter the vehicle aerodynamics by opening side door windows and activating the vehicles windshield wipers. The impact was not strong, and due to a low number of tests the trend is difficult to see above the test to test experimental variability, and therefore for brevity is omitted from this paper.

Plans are currently underway to develop a modified front airdam that can either be easily removed in the field or can be adjusted such that its clearance to the road surface is easily changed. It is expected that this will provide a more significant change in vehicle aerodynamics than what has been observed with the side door windows. Installation of additional panels on the vehicle may prove to be an easier method to increase frontal area; the feasibility of such techniques is currently being investigated. These aerodynamic variables will be preliminarily examined during the summer of 2012, and if successful will be implemented into the course in the fall of 2012.

Experimental Procedures

The experimental data shown in this paper was collected while developing the assignment and course materials on coastdown testing. Using the procedure outlined in SAE J1263 the data was collected at the local airport. Even though ultimately in the course the students would need to conduct testing on public roads (due to the cost associated with renting the airport) the test was pursued at the airport to reduce experimental variation, enabling a stronger focus on ensuring the scientific principals could be worked out. The airport offered a straight runway 2.0 kilometers long with slight grade variation as deemed acceptable by SAE. The other advantage to the airport is its close proximity to a weather station which is maintained and operated by the University, thus significantly increasing the convenience in collecting high accuracy environmental data during the test. Accurate weather data is vital at the time of testing to ensure the data falls within SAE regulations. The weather station has a refresh rate of every 1 minute and keeps a record of this 1 minute resolution data for the past 24 hours. An aerial view of the runway used and weather station location is shown in Figure 3.

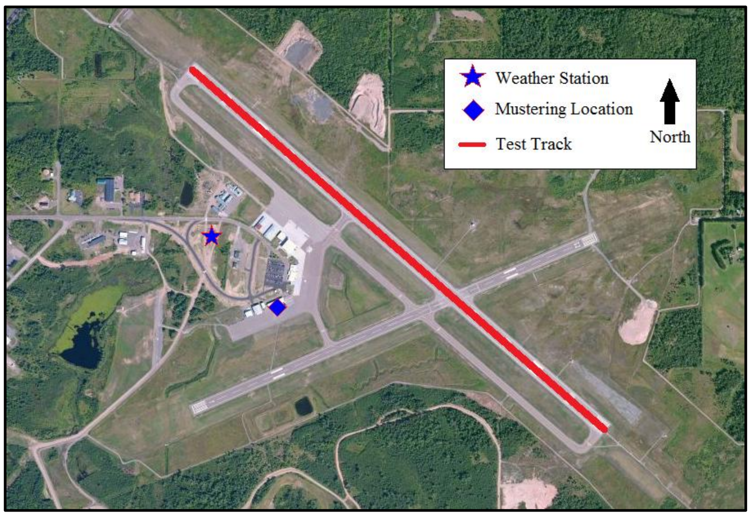

Figure 3: Aerial view of Houghton County Airport testing location.

For testing during the course, students utilized a Brunton ADC Pro hand-held weather meter. Utilization of the Brunton ADC Pro, as shown in Figure 4, provided students with wind speed, air temperature, humidity, and barometric pressure.

Figure 4: In-Situ measurement of environmental conditions. Measurements obtained included wind speed, air temperature, humidity, and barometric pressure.

In addition to recording accurate environmental data, it is also vital to have an accurate method of recording the vehicles velocity during the coastdown experiment. For testing at the airport and in class an ETAS system in collaboration with INCA recording software was used. The ETAS module plugs into the vehicles OBD-II port allowing it to pull data from the vehicles Controller Area Network (CAN) bus. Communication to the host laptop is through an Ethernet cable. In addition to being able to control the sample rate, this also provides the student the option to record additional variables such as engine speed, operating temperature, etc. A more accurate method of recording vehicle velocity would be through external sensors, however, this increases cost and complexity. For an educational project such as this, the authors did not feel this additional cost and complexity was warranted.

For the assignment development phase, two test variables were swept on two different vehicles. The effect of tire pressure variation on rolling resistance was swept on a 2009 Chevy Malibu Hybrid incorporating the belt alternator starter or BAS system. A 2009 Saturn Vue 2-Mode Hybrid was used to study the effects of weight addition on the vehicle drag coefficient. The test matrix is shown in Table 3.

Table 3: Experimental test matrix used during the assignment development activities.

	Tire Pressure (KPa)	Weight Addition (kg)
Malibu	241.3 - Spec	Spec
	137.9	Spec
	193.1	Spec
	344.7	Spec
	241.3 - Spec	Spec
Vue	Spec	0 - Spec
	Spec	136
	Spec	272
	Spec	408
	Spec	0 - Spec

For each variable tested, two control runs were performed to ensure consistency throughout testing. One control is performed at the start of testing and a second after all variables have been tested. The control results are used to gauge the repeatability of the test data.

A specific procedure for coastdown testing can be found in SAE J1263. However, to ensure accurate results for future students conducting the coastdown test a recommended procedure is outlined below incorporating procedural recommendations and practices used during testing at the airport:

1. Prepare vehicle for testing at muster location
    a. Confirm vehicle adherence to SAE J1263 specifications and manufacturers' specifications.

   b. Alter test variable (Refer to section labeled "Experimental Setup," for details and methods on how to alter test variables).
   c. Perform warm up procedure by driving vehicle for 30 minutes at an average speed of 80 km/hr.
2. Record initial environmental data
   a. Record the following variables: Ambient Temperature, Atmospheric Pressure, Wind Velocity (parallel and crosswind direction), and the max observed wind speed.
   b. If any of the above variables are out of bounds of SAE constraints, then the test should not be pursued.
3. Execute coastdown test
   a. With the data acquisition system in standby mode and occupants ready to record, accelerate vehicle to 105 km/hr on a straight, level, smooth road.
   b. Once speed is obtained, release accelerator, shift vehicle into neutral, and initiate data acquisition system to record vehicle velocity at a specified sample rate. System must be initiated before coasting to 100 km/hr to ensure appropriate range of data is recorded for post processing.
   c. Keep vehicle straight on path in neutral while performing coastdown. If a dangerous situation shall arise such as a foreign object in roadway abort test immediately and re-run test when appropriate.
   d. Once the vehicle velocity has decreased below 40 km/hr, stop data acquisition system, return vehicle to gear, bring vehicle to a stop in a safe location, and save data file.
4. Repeat
   a. Repeat step 3, pairing coastdown runs in opposite directions. A total of ten runs should be executed making a complete set per each variable value tested.
5. Record final environmental data
   a. After performing one set (10 runs), record the final weather conditions.
   b. Confirm the final weather conditions are within SAE limits. If any conditions are outside of the limits, repeat a paired test run by repeating step 3 until a total of 10 valid runs are recorded. For the max wind speed constraint; it is recommended that an individual tabulates wind data throughout the test if possible rather than recording only an initial and final value to ensure the peak wind speed is within SAE limits.
6. Repeat procedure from step 1 until all variables have been swept and recorded. It is very important to keep an organized record of the data during testing for post processing.

Experimental Results

A plot of vehicle velocity vs. time during a costdown event is shown in Figure 5 . This plot is typical of the data students will acquire from this test, and will subsequently use for further data analysis.

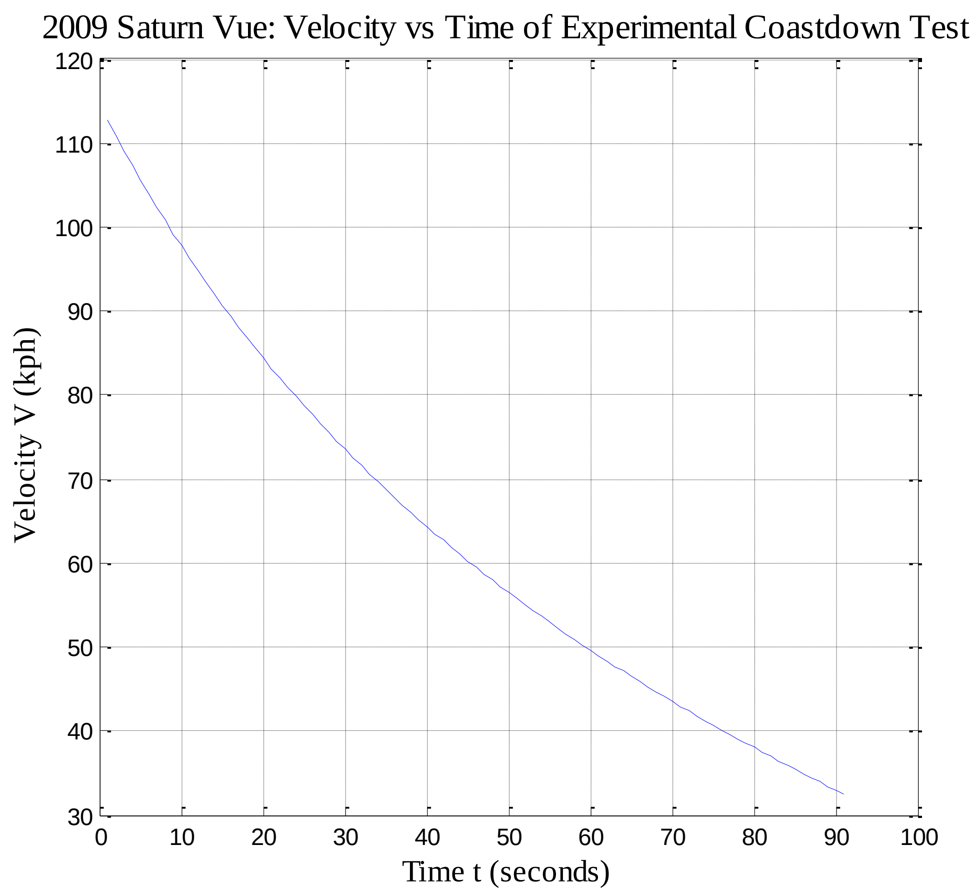

Figure 5: Velocity vs. time during a coastdown for a 2009 Saturn Vue 2-Mode Hybrid Vehicle.

Figure 6 shows the coefficient of rolling resistance against tire pressure. These results are from the testing that was conducted on the airport runway as the assignment was developed prior to the course. As shown, rolling resistance decreased as tire pressure increased. The trend is very clear, the repeat point at 246 kPa falls on the data trendline, and the results were as expected. One may notice that the rolling resistance is, on average, slightly higher than would be predicted from common reference material[5] for pneumatic tires on a concrete surface. The most probably explanation for this is that although the track surface was constructed of concrete, it did have small grooves milled in the surface, which would directionally have the effect of increasing the rolling resistance.

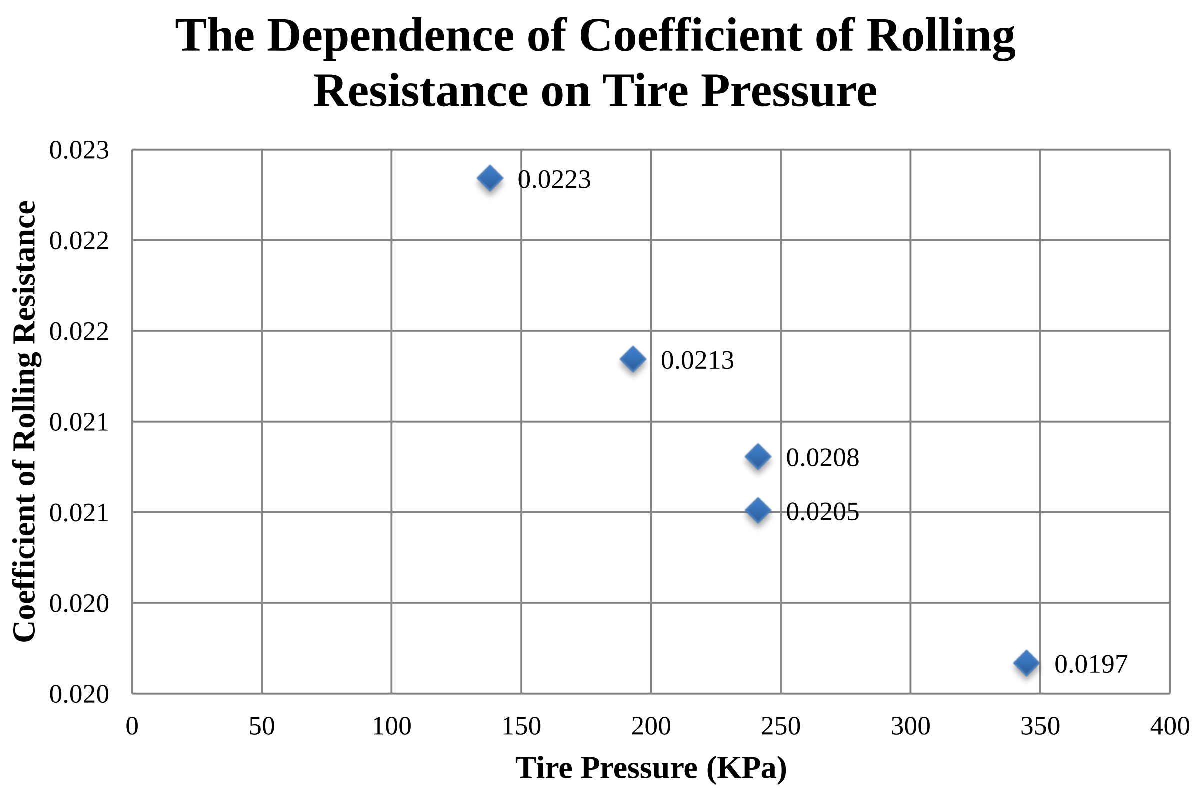

Figure 6: Results of data collected during the development of the assignment with a 2009 Chevy Malibu BAS Hybrid. A clear trend is shown between tire pressure and the Coefficient of rolling resistance.

Student Assignment

In the Michigan Tech course Introduction to Hybrid Electric Vehicles Laboratory, students work in groups to complete this assignment which includes generation of a data processing code and a technical report. Details on these assignments are discussed below.

The SAE procedure on coastdown testing includes an appendix with FORTRAN code that processes experimental velocity data and produces a mathematical vehicle force model. Students will be expected to reproduce this code in a modern programming language such as MATLAB. The process of code transcription consists of several steps. Students will have to determine the functionality and process of the preexisting code, and decide what changes have to be applied in order to fit the constraints of the assignment.

There are several key functions which the script must execute; the suggested implementation is shown in the flowchart of Figure 7. In summary, the script reads in velocity over time data for several runs. It pairs those runs together, fitting a pair of curves for each pair of runs while noting the root mean square error. Using the function constants returned by the curve fit algorithm, the script calculates f0 and f2 values. It then proceeds to narrow down the list of valid f0 and f2 values, throwing out data that does not meet the acceptability criteria outlined in SAE J1263. Student-written code should be able to produce the same output as the SAE published code[4] when given the same input data. Table 4 shows the results of the code validation that was conducted during the assignment development phase.

Table 4: Code Validation results.

Value\Run	1	2	3	4	5	6	7	8	9	10
SAE f0	29.4	21.5	28.9	21.4	27.9	21.3	25.5	23.6	25.5	24.8
Adapted f0	29.36	21.46	28.93	21.38	27.88	21.31	25.53	23.63	25.51	24.80
SAE f2	.0254	.0224	.0242	.0225	.0246	.0222	.0252	.0224	.0244	.0224
Adpt. f2	.0254	.0224	.0242	.0225	.0246	.0222	.0252	.0224	.0244	.0224
SAE RMS	.1529	.1209	.1135	.1193	.1017	.1028	.1001	.0741	.1038	.0910
Adpt. RMS	.1529	.1209	.1135	.1193	.1017	.1028	.1001	.0741	.1038	.0910

In this course the students' technical report consists of an abstract, introduction, experimental methods, results, analysis, and conclusion. The analysis section of this report should be particularly detailed; students are expected to discuss aspects of the experiment that did not go according to plan. If any unexpected results are encountered, students are expected to offer explanations. One such issue that is likely to arise is high RMS error due to the high test to test repeatability that is unavoidable when attempting to run a test of this nature in a relatively short class period.

When students run their scripts in order to determine C_D and f_r, they may encounter high values of RMS error, well outside the boundary of 0.25 required by SAE J1263. The SAE procedure throws out both pairs of the coastdown run if a run in either direction has excessive error. Students may choose to forgo this strict data processing criterion, as it often eliminates all of the experimental data collected. This is best accomplished by raising the tolerance of RMS error. For purely experimental purposes of coastdown testing, there is much more leeway for RMS error than in industry-related coastdown testing. The authors feel it is acceptable to relax this criterion as it only has a minimal negative impact on the overall pedagogy of the assignment.

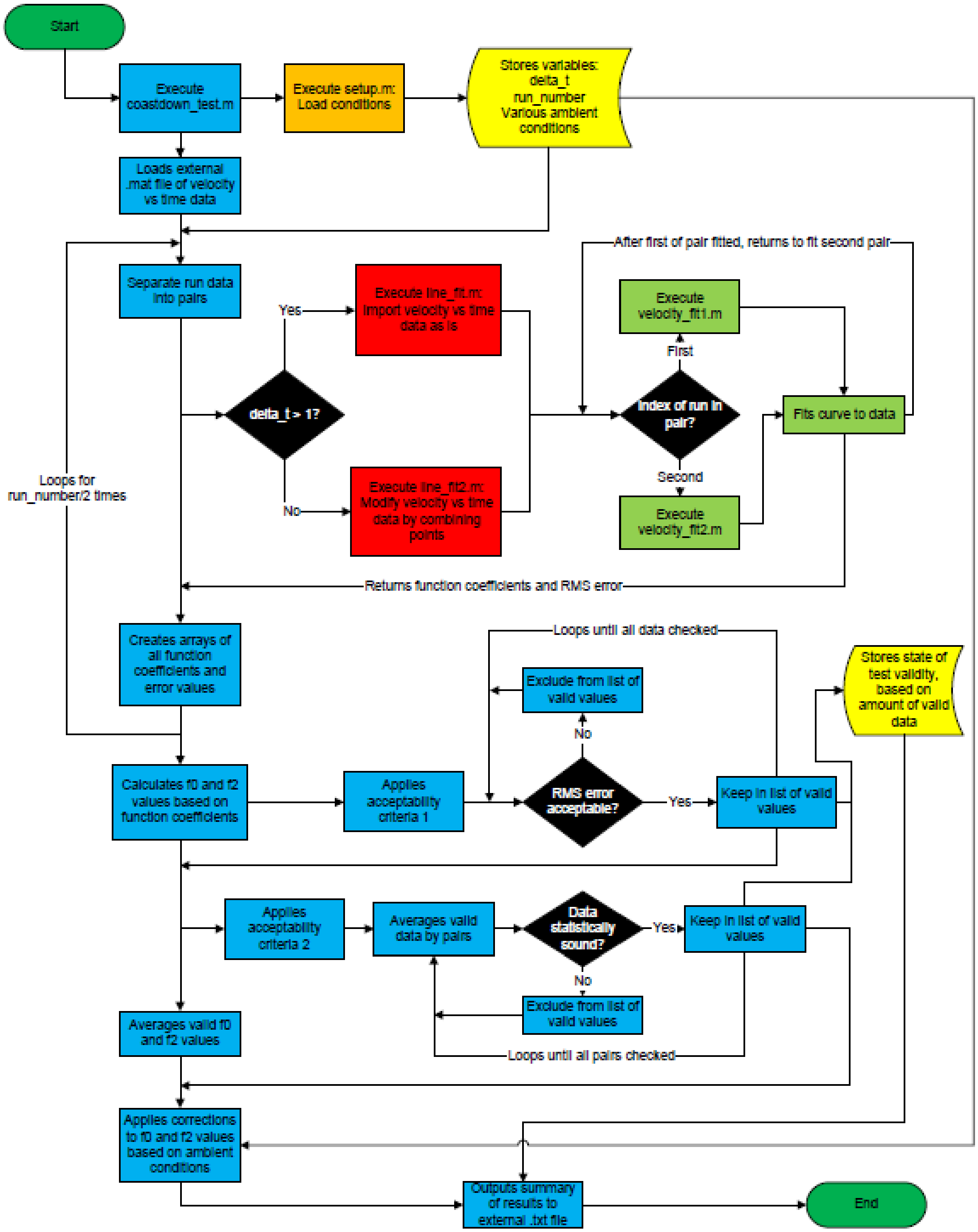

Figure 7: Data Processing Code Flowchart

Assessment of Student Learning

After the initial administration of this nascent course, it was difficult to collect quantitative assessment data. For future renditions, it will be possible to narrow the focus of assessment and thus collect more numerical data. Nevertheless, certain qualitative metrics of student learning reveal the effectiveness of coastdown testing as a teaching tool.

Perhaps the most direct assessment of student learning and comprehension is through student success in answering targeted questions pertaining to the assignment. In this particular case, the assignment required students to give a Powerpoint based presentation, with the objective being to convince the audience (made up of their peers and the course instructor) that the parameters they tested either are, or are not important factors affecting vehicle fuel economy. In the spirit of such a presentation, the students were given a high degree of creative freedom in making their points, and thus were not required to rigorously answer targeted questions. However, based on the students' responses to the required and implied questions, an assessment of student learning can be made.

All groups of students were successful in reducing their raw experimental data to produce plots of the coefficient of drag and coefficient of rolling resistance vs. the test variables, and as instructed to do so, noted that their values matched well with published data for similar vehicles. This suggests success in not only applying the mathematical techniques covered in lecture, but also in being able to develop a functional data processing code. Furthermore, through their presentations, students were largely able to explain their observed trends in C_D and f_r including how and why vehicle mass, tire pressure, and window position affected these parameters.

Students also performed well when asked to address the topic of experimental variability and what it meant to their interpretation of the experimental results. All groups of students were able to address the more obvious conclusions, such as indicating if they had more time they would make additional repetitive runs to increase statistical certainty, and various environmental factors leading to variability such as the occasional light breeze, and a short period of very light rain. However, a large number of students also made note of some advanced details including the subtle change in vehicle mass as fuel is consumed during a test, the change in tire rolling radius with tire pressure, and the change in vehicle ride height with mass. This demonstrates a high level of understanding, and perhaps more importantly, an appreciation for the degree of commitment required to generate high quality test data, and the limitations imposed by real-world experimental data.

Additionally, a second, more intangible assessment of student learning can be drawn from the course assessments with the students are requested to complete. Although the results for the end of course assessments are not yet available at the time of this writing, a mid-term course evaluation was conducted near the end of this assignment. It is certainly difficult if not impossible to gauge the students' learning of the specific objectives of this assignment, however, the students comments during this assessment do indicate that generally speaking, they are responding well to the concept of a hands-on course, and specifically using the full functionality of automobiles in the course. A subset of the students comments that support this conclusion are included below:

- *"This course and teaching gives me a lot of practical knowledge about modern cars. It also gives me "hands on" experience on various tests that are conducted on cars."*
- *"I like the concept of the course! I mean, its cars that we are learning about."*
- *"I like the lab session because I can gain more hands-on experience."*

It should also be noted that two out of the fifteen students in the course felt that the level of work required was excessive, as indicated by the following two comments:

- *"The pace of learning is great but the amount of work that some lab reports require is a little too much."*
- *"The lab write ups take a long time to write and the data takes a long time to process. Instead of formal write up on the labs with a lot of data just have students make a few graphs."*

Collectively, these assessment indicators would suggest this experiment is successful in providing students with an understanding of energy losses at the body and chassis level, while simultaneously building upon their appreciation and ability to deal with experimental variation and difficulties associated with real-world testing and data collection.

Conclusions

The following conclusions can be drawn from this paper:

- Previous research, as well as observations by the teaching team, suggests that students respond well to a hands-on learning environment, as it aids in their learning and comprehension process.
- A course entitled Introduction to Hybrid Electric Vehicles Laboratory has been developed as part of Michigan Tech's curriculum in Hybrid Electric Vehicle engineering that provides students with the opportunity to make experimental measurements, and apply those measurements to various concepts they are learning relative to hybrid vehicles at both the systems and subsystems level.
- A specific module for the Introduction to Hybrid Electric Vehicles Laboratory course has been developed which requires students to conduct vehicle coast down testing following established industry procedures.
- The coastdown educational module requires students to apply basic equations of motion, to reduce the vehicle velocity vs. time data to produce values for road load coefficients, drag coefficient, and coefficient of rolling resistance.
- Through the coastdown educational module students sweep common variables, which can include tire pressure, vehicle mass, aerodynamic characteristics, and road surface, and analyze the impact those parameters have on coastdown characteristics, and thus drag and rolling resistance. This process aids in their understanding of vehicle level loss parameters and their impact on fuel consumption.
- The coastdown module can be easily applied at any educational institution as it does not require extensive equipment or facilities. Test vehicles can be production automobiles, with simple CAN based instrumentation, and can be operated on low traffic public roads.

References

1. Kerr, Arnold and Byron Pipes. "Why We Need Hands-On Engineering Education," Technology Review, MIT, October 1987
2. “Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques”, J1263. Society of Automotive Engineers, 1996.
3. White, RA, and HH Korst. The determination of vehicle drag contributions from coast-down tests. New York, NY: Society of Automotive Engineers, 1972.
4. Technical Advisory: Shoulder and Edge Line Rumble Strips. T 5040.39, Revision 1. Federal Highway Administration: November 7, 2011.
5. Bosch, Robert. “Automotive Handbook”, 4th Ed. GmbH. 1996. Pg. 330-331.