AC 2012-4486: A MOBILE LABORATORY AS A VENUE FOR EDUCATION AND OUTREACH EMPHASIZING SUSTAINABLE TRANSPORTATION

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A Mobile Laboratory as a Venue for Education and Outreach
Emphasizing Sustainable Transportation

Abstract

Educators at Michigan Tech have developed a versatile mobile laboratory that will travel the North American continent serving as a venue for a wide range of educational opportunities including support of curriculum based courses, targeted short courses, community education and outreach. The lab was built as part of a US Department of Energy funded program to develop an interdisciplinary curriculum in Hybrid Electric Vehicle Engineering that includes certificates at both the undergraduate and graduate levels.

The authors have found hands-on discovery based learning activities to be an effective means of enabling students to grasp and retain complex topics in engineering and science, and furthermore, that engineering students excel when they can relate an individual concept to the overall larger context of product development and societal advancement. With an emphasis on sustainable transportation systems, the mobile lab provides opportunities for hands-on discovery based learning throughout the development process from model based simulation and design to optimization of hardware and controls.

The mobile lab consists of several elements. The primary laboratory structure is a 16.2 m long van trailer that incorporates an expandable center section for a total of 65 m² of space. The expandable center section provides for instruction based learning and bench-top activities on four universal and configurable lab benches. The front and rear of the trailer contain test cells that can be operated from the lab benches in a number of modes including a steady state mode to study the operation of specific components and as a dynamic system with real-time Hardware-In-The-Loop functionality. The powertrain in the test cells is a match to the powertrain in a configurable Hybrid Electric Vehicle. The configurable Hybrid Electric Vehicle allows students to change many elements of the vehicle including hardware, embedded software and optimized parameter sets. Three production hybrid vehicles are provided to study the operation of production vehicles in real-world driving scenarios. In addition to driving on the road, these production vehicles, as well as the configurable hybrid vehicle can be tested on the mobile lab’s single role chassis dynamometer enabling the students to emulate specific drive cycles.

The experimental apparatus and activities on the mobile lab are scalable and configurable. This enables educators to tailor the learning experience to many demographics including K-12, college, and the community. Likewise the contact period with the participants can be as short as just a few minutes as in the case of some outreach events, a few days as in the case of some short courses, or a full semester in support of “for credit” curriculum based courses.

This paper provides technical details on the development and capabilities of the mobile lab and describes the pedagogy behind the educational activities that are conducted with the mobile lab. The outcomes of select activities are discussed as are ways in which participant assessments are guiding continued development.
Introduction

Educators at Michigan Tech have observed that hands-on, discovery based learning activities are an effective means of enabling students to grasp and retain complex topics in engineering and science. Furthermore, engineering students excel when they can see how an individual concept fits the overall larger context of product development and societal advancement. These observations are consistent with results of published research. Therefore, when a team of educators at Michigan Tech was awarded a US Department of Energy (DOE) grant along with industrial partnerships to develop a curriculum in Hybrid Electric Vehicle (HEV) engineering it was only natural to build upon Michigan Tech’s existing strengths, and infuse hands-on learning opportunities to the very core of the newly proposed HEV curriculum.

The new HEV curriculum was to have a significant electronic learning or e-learning component to accommodate a growing demographic of distance learning students. The majority of these students, primarily incumbent working, or displaced engineers are located in major metropolitan centers hundreds and even thousands of kilometers from Michigan Tech. This geographical separation presented a significant challenge for the program to overcome. Providing lectures, quizzes, exams, and homework to long distance students is a well established process at many, if not most, academic institutions including Michigan Tech where these processes have been in place for decades. However, what was not clear was how to provide these students with the same level and quality of hands-on, laboratory education as the traditional on-campus students.

To address this issue, a Mobile Laboratory has been designed and built which allows educators to bring the same hands-on experiences to distance students that the traditional on-campus students receive. Furthermore, it is an ideal venue for STEM related outreach to pre-college youth, especially those in the many geographically remote areas of the country that tend to be at a disadvantage in this field.

Content and Development

The Michigan Tech Mobile Lab consists of several elements including an interactive classroom and testcell facility, several vehicles, a chassis dynamometer, an interactive micro-grid, and logistics and support vehicles. Figure 1 and Figure 2 show the primary lab, along with the HEV’s in the operational state and transport state respectively. Each major laboratory element is discussed in detail in the following sections. With the exception of the primary lab facility and associated infrastructure, all laboratory apparatus has been developed by graduate and undergraduate students, thus making the lab development itself a hands-on learning endeavor.
Figure 1: Michigan Tech Mobile Lab's interactive classroom and testcell facility and Hybrid Electric Vehicles.

Figure 2: Michigan Tech Mobile Lab in transportation mode.
**Interactive Classroom and Testcell Facility**

The structure that houses the interactive classroom and testcell facility is a modified dry van semi trailer with an expandable side. The trailer was manufactured by Kentucky Trailer, and immediately modified to include the expandable side, HVAC, insulation, and aesthetic treatments on the floors, walls, and ceiling by Kentucky Trailer Technologies, a division of Kentucky Trailer. The basic specifications of the facility are shown in Table 1 and the overall floor plan of this part of the facility is shown in Figure 3.

Because of the expandable wall, the classroom space is approximately 48.5 m$^2$. The expanding wall contains two 1.5 m flat panel plasma screens for display of lecture slides or other media from the lab’s desktop PC’s or any laptop. The expanding wall also has a 2.4 m white board to facilitate traditional lecture methods and open discussions. A small podium on wheels can be positioned in a convenient location for the speaker.

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<th>Table 1: Basic Specifications - Interactive Classroom and Testcell Facility</th>
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* Excluding Tractor

** Including Tractor
The four lab benches are also on wheels, allowing them to be placed in a multitude of locations and arrangements within the room, to facilitate a wide range of learning situations. The benches are constructed with modular materials to enable future modifications, and feature a T-slot top surface and a flat dry-erase surface as shown in Figure 4. In addition to serving as desks during classroom instruction, they can be used to support benchtop scale experiments as shown in Figure 5. Mounted on the stationary wall are four power panels to support each of the four benches. The power panels supply 5V, 12V, and 48V DC power, 110V single phase, 208 V 3-phase power, and compressed air, all of which can be used to support various benchtop activities. Furthermore, the lab benches serve as control consoles for the two dynamometer testcells. The two forward benches control Testcell #1, and likewise the two rearward benches control Testcell #2. Between the two benches for a given Testcell, control is grated via a software switch.

The entire facility is insulated and has dual electric heating, cooling, and ventilation systems. This allows the lab to be utilized year round in any climate.

Figure 3: Layout of interactive classroom and testcell facility.
Figure 4: The universal lab benches are on wheels and employ T-Slots and removable dry erase hard surfaces.

Figure 5: The universal lab benches support a wide variety of STEM related hands-on activities. Here a student builds a battery and learns the fundamental principals governing battery operation and performance.
**Testcells**

As previously indicated, the lab contains two testcells (refer again to Figure 3). Both cells are currently configured to facilitate testing of an HEV powertrain. The powertrain, which includes the engine, propulsion motor, battery pack, control system, and drivetrain (upstream of the drive axle, which is not included) is a duplicate of the powertrain in the lab’s Configurable Hybrid Electric Vehicle (CHEV) (which will be discussed in a subsequent section). The testcells use a 100 kW Baldor 480V 3-phase permanent magnet electric machine as the dynamometer. The four-quadrant ABB drive enables the dyno to operate in either an absorbing or motoring condition with either clockwise or counterclockwise rotation. This enables both steady state testing as well as dynamic tests to emulate a recorded vehicle drive cycle. Currently dynamometer absorbed power is dissipated through a liquid cooled load bank, although plans are underway to integrate this system into the labs micro-grid (discussed in a subsequent section) to further demonstrate energy storage and usage.

All data acquisition is handled with National Instruments PXI hardware and Wineman Technologies INERTIA software. The same National Instruments / Wineman system also controls the overall testcell facility, such as dynamometer speed and torque commands, test cell ventilation, fuel pumps, and initiates appropriate remedial action sequencing if key measured and calculated parameters are out of limit, including signals from the three CO and HC sensors.

The testcell fuel tanks are located in the bellybox area under the trailer floor. Currently two fuel tanks supply both test cells. The dual tanks allow for learning activities and demonstrations comparing alternative fuels such as E85 vs. gasoline or Biodiesel vs. petroleum diesel. The design and construction of the testcells has been carried out by graduate and undergraduate students funded through the DOE curriculum development grant.

**Chassis Dynamometer**

A team of Undergraduate Capstone Senior Design students have designed and built a portable vehicle chassis dynamometer. A Land & Sea 300 kW single role eddy current dynamometer has been mounted on an 8 m long flatbed trailer. A highly mechanized ramp and platform system was created to position the vehicle atop the roll. A National Instruments Compact DAQ system is under development for data acquisition and control. The dynamometer is towed with the Mobile Lab’s logistics and support vehicle, which can also supply compressed air and electrical power to operate the dyno, if it is used far from the primary classroom and testcell facility.

The dynamometer allows students to experience a wide range of concepts in the automotive and transportation fields, which has far reaching implications in the larger STEM area. Tests can be conducted on any of the Mobile Lab’s test vehicles including the CHEV. The 300 kW capacity allows the testing of most production vehicles. An image of the Chassis Dynamometer is shown in Figure 6.
Test Vehicles
The Mobile Lab consists of three road-legal vehicles which are used for hands-on learning activities by the students in the HEV Engineering curriculum, and can also be used for a wide range of outreach and community education opportunities. The vehicles, a Chevy Volt Extended Range Electric Vehicle (EREV), a Chevy Malibu Belted Alternator Starter (BAS), and a Saturn Vue Mult-Mode HEV represent a majority of the technology currently available in Hybrid and electric automobiles today. Data acquisition is done with ETAS hardware running INCA software. The data acquisition system interfaces with the vehicles CAN bus through the OBD-II connector. Plans are underway to utilize a National Instruments CAN module running in a Compact DAQ chassis as an alternative to the ETAS system. All three vehicles can be seen in Figure 1, and Figure 2 while Figure 7 shows a student preparing to collect data during a coastdown experiment.
Configurable Hybrid Electric Vehicle

As discussed, the road-legal vehicles are an invaluable teaching tool. They allow the students to make real-world measurements, and see the end result when a vehicle manufacturer produces a product. This includes being able to see how the various subsystems operate together. However, one limitation is that it is impractical for students to be able to make changes to the vehicle, either hardware or software, and assess the impact of those changes, unfortunately limiting the overall pedagogy being targeted with the mobile lab.

To address this shortcoming, a unique HEV was designed and built by an interdisciplinary team of undergraduate Senior Capstone Design Students at Michigan Tech. The objective was to create an educational tool, that employed an open architecture throughout, thus permitting a high degree of configurability in all aspects of the vehicle. Figure 8 shows an image of the CHEV.

Figure 8: The Mobile Lab's Configurable Hybrid Electric Vehicle (CHEV) allows students to change virtually all aspects of the vehicle, and assess those changes on vehicle performance.

The CHEV is a rear wheel drive platform with a longitudinal powerflow. An IC engine and electric motor operate in parallel on a common shaft. The engine is currently an 18.6 kW fuel injected Kohler 2 cylinder, 4 stroke, spark ignited engine, and the propulsion motor is currently a 9.7 kW 48V DC motor. Both power sources are mounted on a universal mounting mechanism, allowing alternative configurations. The gearing between the engine and mainshaft and motor and mainshaft is also easily configurable, as is the gearing in the Halibrand rear axle. The battery pack is currently comprised of four, 12V lead acid modules, although, like the motor and engine, was designed to be easily reconfigured. Mass can be added or removed to the vehicle in
9 kg increments up to 100 kg through ballast plates. Aerodynamics can be changed with an adjustable airfoil. Rolling resistance can be changed by either altering tire pressure, or changing tires, as the vehicle utilizes typical automotive tires and wheels.

The CHEV utilizes a MotoTron 112 pin controller as the supervisory controller, which communicates via a CAN bus to the motor controller. Currently engine control is performed through the production Kohler controller, with plans in place to integrate the engine controls into the MotorTron controller. The MotoTron controller supports rapid prototyping, allowing students to quickly evaluate the impact of changes they make on both the algorithms and the calibrations.

Additional configuration options are being continually added. Forthcoming configurations that are being developed include an AC motor, a Compression Ignition engine, and a Lithium-Ion battery pack.

**Micro-Grid**

The smartgrid, renewable energy sources as well as a plug in vehicle charging infrastructure are critical topics for electric power education. The mobile lab is a standalone electric power grid and thus enables a unique opportunity for participants to study electrical energy interactions of various electrical sources and loads on a micro-grid. The labs electrical system is fully instrumented with current and voltage sensors on all electrical circuits. To further enhance the educational experience, a 600 W photovoltaic solar array and a 300 W wind turbine are being added as part of a Capstone Senior Design Project. A graphical interface allows students to see, in realtime, the flow of power among various sources and loads. Sources include the 80 kW diesel fueled generator, the test cell dynamometers (when in absorbing mode, and once connected to the micro-grid), and the solar or wind generation systems. Loads include the HVAC system, test cell support systems, computers, lights, dynamometers (when in motoring mode), an electric vehicle supply equipment (EVSE) charging station for plug-in HEV’s and EV’s including the lab’s Chevy Volt and CHEV. A controllable 5 kW loadbank has been installed to provide participants with additional degrees of freedom in creating perturbations and injected harmonics into the microgrid. A National Instruments PXI system (separate from the systems used to control the testcells) is used to monitor the sensors, and control the loadbank.

Through this system, the micro-grid will allow lab participants to view the flow of energy, and understand how real-time control decisions are made. The microgrid component of the mobile lab will be used as an educational tool to highlight the balance of energy generation and needs in domestic and public buildings, and how the increasingly electrified transportation and renewable energy sectors interact with these buildings\(^5\). Figure 9 provides a schematic representation of the Micro-Grid.
Utilization

The Michigan Tech Mobile Lab is utilized in three primary ways; instruction of curriculum based courses, instruction of short courses, and outreach based instruction to the community and pre-college youth. The process flow through the hands-on based courses in the HEV Engineering curriculum is shown in Figure 10.

Figure 10: Educational process flow through the HEV Engineering Curriculum courses that utilize the Mobile Lab.

Through several courses in the curriculum, students create a model of an HEV, and utilize the hardware in the lab to understand the fundamental operating principals behind the primary HEV
subsystems including engines, electric machines and power electronics, batteries, and chassis drivetrain components. Utilizing the lab equipment provides them with unmatched opportunities to experience important lessons in experimentation, including test to test variability and statistical significance of results, as well as the difficulty associated with designing and conducting a test to provide them with the data they need. While the students are learning the fundamentals behind the subsystems they are studying, they are also obtaining data to describe the performance of those subsystems, which in turn increases the accuracy of the model they are developing for the CHEV. Examples include the establishment of fuel consumption maps for the engine, determination of the torque constant and efficiency of the propulsion motor, and characterization of battery capacity under different loads.

The final project presents the students with a host of configuration options for the CHEV, and requires them to use a combination of their validated simulation and experimental data to optimize the performance of the vehicle. Performance is rated in a number of categories including fuel consumption on a mock city and highway drive cycle, acceleration, top speed, and various driveability and consumer acceptance metrics.

In addition to support of curriculum based courses, the Mobile Lab provides an ideal venue for short courses, such as those sought by many industrial professionals. In this mode, the lab can be transported to either a large metropolitan area, or with enough demand, could be setup at a corporation or other interested party. The short courses can be accelerated versions of the curriculum based courses, or could be custom developed courses based on specific needs of a particular demographic.

Finally, the Mobile Lab is a unique tool that can be used to excite, and attract pre-college youth to the STEM fields, or promote community education. Because of the configurable nature of the entire lab, activities and demonstrations can be developed to appeal to any demographic, in a wide array of STEM areas.

Outreach activities are continually being developed and modified. Several outreach activities are in use currently. For example, a stationary Human – Electric hybrid bicycle is used to demonstrate the basic operating and energy conversion principals governing HEV’s. An interactive tutorial teaches participants basic battery chemistry while they build and test both commercial batteries and batteries they construct themselves from common supplies. The CHEV is used for various simple vehicle level demonstrations such as the impact of mass and gearing on acceleration. Participants are guided through a simple simulation, then make the change to the CHEV, and test the effect of the change. Activities also exist in the area of controls, electric machines, and engines. Figure 11 shows several of these outreach activities.
Although primarily focused on sustainable transportation, the Mobile Lab’s inherent configurability makes it well qualified for a wide range of STEM related educational activities. For example, a new hands-on course which will rely entirely on the Mobile Lab, yet is not related to HEV’s, will be offered starting in the Spring of 2013.

Assessment

No assessment has been given specifically addressing the Mobile Lab, or the outreach events that have been held in conjunction with it. However, assessments have been given to the students who have taken the laboratory based courses through the HEV Engineering curriculum. The results of these assessments has been generally very positive. The questions that could be interpreted to have particular significance relative to the Mobile Lab are “The Classroom and equipment (if applicable) were adequate to support effective learning” and “I am more interested in the subject now than I was before I took this class”. For the class offered during the Fall of 2010, these questions resulted in a 4.1 out of 5.0 and a 4.4 out of 5.0 respectively. Written comments have generally been very positive, with many students specifically commenting that they enjoy being able to conduct hands-on experiments and actually drive the types of vehicles that they are learning about. A formal assessment is being developed that will specifically evaluate the Mobile Lab and its content. The assessment will include several pre and
post technical questions to assess a participant's level of learning in a particular topical area, as well as general questions that evaluate the level of excitement and enthusiasm felt for individual activities or the lab as a whole.

Lessons Learned

The Mobile Lab is a unique facility and brings with it many considerations and challenges. Although there were technical challenges that came up during the design and build phase, none of these technical issues were outside the scope of what one might expect when performing any engineering design project, and in all cases provided the students working on the project with valuable engineering experience. These technical issues included packaging of many components into small spaces, while being mindful of transportation laws governing maximum allowable axle weights, sizing of components such as dyno’s, the generator, HVAC systems, heat exchangers, pumps, wires, and plumbing components.

The more interesting challenges are the logistical issues. Most academic institutions are not well versed in the heavy duty transport industry, yet many of the same laws and regulations that govern this industry apply to the mobile lab. This includes being sure the final product does not violate axle weight restrictions, which change as a function of the time of year, the particular road, and local and state regulations. All Department of Transportation (DOT) permits must be sought on a regular basis, and this is further complicated by the fact that most certified inspectors are not accustomed to dealing with a vehicle of this nature.

When planning routes and venues, one must be mindful of maximum clearance to bridges, overpasses, electrical cables, signage and other obstacles. Minimum ground clearance to curbs, ramps, and other terrain features can be problematic due to the very low nature of the belly boxes under the floor, and the maximum allowable axle loading permitted over all roads and secondary surfaces that will be driven upon must be accounted for. One must also consider the total space available for maneuvering at a particular venue both before, during, and after an event. These issues must be considered even more closely than in the trucking industry, because unlike a cargo truck which delivers cargo along established trucking routes between established loading docks, many venues which might be considerations for the Mobile Lab (such as college campuses) have not been designed with such considerations in mind. The fuel for the generator must be considered, ensuring there is either an ample supply to sustain operation throughout the entire event, or there is a plan in place for refueling during an event.

Finding qualified drivers at an academic institution can be challenging. Setting up and operating the lab requires extensive training, including following a rigorous leveling and setup procedure, driving the commercial vehicle, and operating the multitude of high tech instrumentation and other scientific systems. Training students to perform these tasks is possible, but the attrition rate with students can be high, making it a potentially inefficient method. Professional employees are another possibility, but this solution drives up operating costs substantially. To maintain a professional appearance, the vehicles must be washed upon arrival at a venue, and finding a facility to clean a vehicle of this size can be a challenge. Adding to these complications is the need for a second commercial vehicle to support the primary facility with the transport of vehicles and the chassis dynamometer.
Conclusions

A curriculum in HEV Engineering, which includes certificates at the graduate and undergraduate level has been developed at Michigan Tech. Maintaining a high level of hands-on education and catering to the needs of long distance students were driving factors in much of the curriculum development. Together these factors led to the development of a unique Mobile Laboratory. The mobile lab is themed around Sustainable Transportation and specifically Hybrid Vehicle engineering, but due to its highly configurable nature, can be used for a variety of STEM related activities. The Mobile Lab is well suited to three educational modes; support of curriculum courses, delivery of short courses, and outreach to pre-college youth and the community. Collectively, the Mobile Lab will be a valuable tool allowing Michigan Tech to deliver exciting and engaging hands-on educational experiences to a diverse, and geographically far reaching demographic for years to come.

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References


