
AC 2011-761: ADVANCED ENERGY VEHICLE DESIGN-BUILD PROJECT FOR FIRST-YEAR ENGINEERING STUDENTS

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Advanced Energy Vehicle Design-Build Project for First-Year Engineering Students

Abstract

A design-build course with a focus on energy efficiency and management through student designed, built, and tested model-scale Advance Energy Vehicles (AEVs) was developed for first-year engineering Scholars students at The Ohio State University. The goal of the Engineering Scholars Program is to increase student awareness of green energy principles, innovation, and social responsibility through academic and co-curricular activities. The Fundamentals of Engineering for Scholars course sequence, comprised of 144 students, offered through First-year Engineering Program provides a multidisciplinary approach through lecture and laboratory experiences to the wide variety of engineering majors offered. The AEV design-build experience was developed specifically to facilitate innovation through energy management concepts within the multidisciplinary nature of design – complementing the acquisition of life-long learning skills offered through the First-year Engineering Program.

Each student is introduced to fundamental energy conservation and loss measurement techniques in designing energy efficient AEVs. Each team takes a hands-on approach in designing, building, and testing AEVs and AEV components with the use of desktop wind tunnels and desktop and classroom monorail track systems to measure, record, download, and analyze energy efficiency performances. The AEV design and build process offers student development in engineering intuition through the inductive/deductive processes, using experimentally gathered and analyzed data. The laboratory experiences provide opportunities for improvement of the students' self-learning ability, the ability to work in teams, and communication skills with both colleagues and peers.

Introduction

The Engineering Education Innovation Center has offered, through its Fundamentals of Engineering and Fundamental of Engineering for Honors course sequences, several hands-on laboratory experiences for first year engineering students that culminate in a quarter-long design-build project. These sequences retain the traditional material covered - engineering orientation, engineering graphics, and engineering problem solving with computer programming¹ while offering several design-build project topics. The current design-build projects include the fundamentals of potential and kinetic energy through model roller coasters, lab-on-a-chip with a nanotechnology component², and fully functional small autonomous ground-based robots.³⁻⁵ These course sequences are one of the most innovative and successful of its kind, and has received national recognition.⁶ Each year, approximately 1600 students complete this program.

A new sequence, Fundamentals of Engineering for Scholars, was developed in autumn of 2008, with the students in a living/learning community and adopting green engineering principals, innovation, and social responsibility as a class theme. The program and course sequence was well received by prospective students and doubled in size, to its current 144 student base, in

2009. Three new hands-on laboratory modules have been developed for this theme, two on solar energy and photovoltaic panels and one on hydrogen fuel cells.

A new model-scaled Advanced Energy Vehicle (AEV) design-build project was initiated and developed specifically to facilitate innovation through energy efficiency and management concepts within the multidisciplinary nature of design; while continuing to further facilitate the Engineering Scholars Program theme. Experiences gained from existing design-build projects and from the students' point of view,⁷ were used in the development of the AEV curriculum.

AEV development objectives for the design-build project included:

- Develop a framework and methodology that will enable first-year engineering students to successfully design, build and test model-scale advanced hybrid energy vehicles in a quarter-long laboratory setting;
- Develop representative model vehicle parts, assemblies, kits, and systems in support of objective 1;
- Develop design rules and constraints under which students can accomplish the project and course goals with supplied resources and within the allotted one-quarter time;
- Develop and adapt a specific (off-the-shelf) power source and energy storage technology that are appropriate in scale and energy capacity to make the model-scale vehicle's performance both functional and interesting to students;
- Develop functional requirements and performance criteria for the successful operation and testing of student-designed vehicles;
- Develop a relatively simple vehicle control system methodology that will allow students to program their vehicles to successfully navigate complex test tracks;
- Develop a methodology for defining and constructing challenging vehicle navigation tracks, courses, and obstacles (etc.) that will constitute a final test problem or competition;
- Understand and map the design space of operational parameters and performance constraints relative to how students would go about their designs;
- Develop methodologies to measure the energy efficiencies of such hybrid vehicles;
- Develop several advanced energy hybrid model-scale vehicles that can be used to introduce the course material and train teaching faculty and staff;
- Given the successful completion of the proposed project, develop a plan to incorporate the advanced energy vehicle design-and-build project into the first-year engineering curriculum.

The short- and expected long-term impact of the AEV design-build project for the first-year engineering students are to create awareness among incoming engineering students of the need for research and development of advanced energy technologies and system - set out as the Grand Challenges for the Engineers of the 21st Century by the National Academy of Engineering.⁸

This paper sets forth the project objectives, curriculum development, and short- and long-term impacts of the AEV design-build project.

Project Objectives

It was determined, based on well established and successful design-build projects within Fundamentals of Engineering and Fundamentals of Engineering for Honors sequences, that the Fundamentals of Engineering for Scholars AEV design-build project would retain the same curriculum objectives and technical references^{9,10}. The three main objectives for the student AEV design-build project include;

1. *Project Management and Teamwork* - which includes, but is not limited to; time management and task scheduling, team communications and meetings, fair division of labor and team member responsibilities.
2. *Design Process* - which consists of: identifying the project requirements and constraints, gathering background information, brainstorming, identification of management of materials, preliminary analysis and initial design, and the build/test/modify/document cycle.
3. *Project Documentation* - which includes three parts:
 - i. Project notebook - complete documentation of the project, and which was reviewed on a weekly basis
 - ii. Final oral presentation - overview of design experience
 - iii. Final written report - complete summary of all aspects of the design

How each objective was addressed in the development of the AEV design-build project will be discussed, following the initial project concepts, the steps taken to arrive at the current AEV design-build project, and details of the AEV components.

Project Development

Initial AEV design-build project concepts to meet the development and project objectives included ground-based vehicles that used advanced energy concepts such as solar and fuel cell power and super or ultra-capacitors. The AEVs would be fully autonomous and navigate through a predefined course satisfying operation objectives and constraints. However, when considering major hurdles when designing and developing an autonomous ground-based robot, it was soon determined that the automatic feed-back control system and programming strategies were significant. This was addressed in the Fundamentals of Engineering for Honors sequence by having two quarters prior to the design-build project, in which a significant portion of the time is dedicated to computer programming. However, for the Fundamentals of Engineering for Scholars the traditional two quarter sequence was set; and therefore was not capable of providing the time necessary within the sequence for the rigorous computer programming curriculum component.

From this initial assessment, it was determined that it was impractical to expect the first-year engineering Scholars students to develop the programming skills necessary for ground-based

autonomous control. Instead the required programming of AEVs were to be focused on power control in order manage energy use, while meeting operation objectives that did not require autonomous directional feed-back control.

Further consideration of developing a ground-based vehicle that followed a pre-defined course was soon determined to be undesirable due to the time-intensive and logistics of building, storing, and maintaining the track. An alternative method was sought of maintaining emphasis on designing, building, testing, and modifying efficient AEVs with autonomous propulsion control for energy management while satisfying inner program operational constraints and logistics.

Options were continued to be weighed and a final concept was selected that met all development objectives and operational constraints; and one in which provided a platform for continual development potential with the capability for adapting to technology growth with advanced energy concepts.

The Advanced Energy Vehicle

AEVs are small (< 500grams), autonomous, electric motor-powered, propeller-driven vehicles that are suspended from and maneuver along a closed circuit monorail track systems hung from the laboratory ceilings. An example AEV can be seen below.

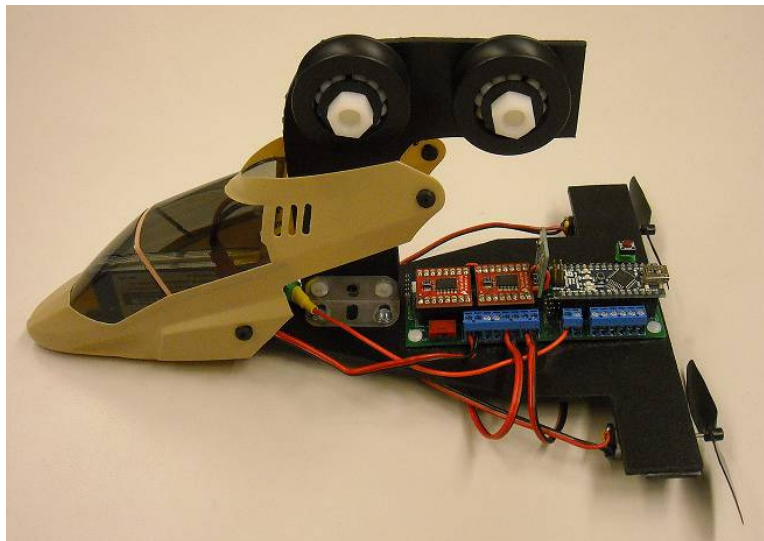


Figure 1: Example AEV

Student teams receive an AEV Kit at the beginning of the design-build project with each of the AEV components selected based on the “off-the-shelf” development objective.

The AEV structure and monorail support arm are composed of two millimeter thick PVC sheet that require basic techniques for working with and modifying. The propulsion system to teach fundamental measurement techniques included electric motor and propeller combinations; and the energy storage system is a two-cell lithium polymer battery. Other energy storage devices

were considered, such as 100 and 250 microfarad ultra-capacitors. However, when comparing the energy density to weight ratio with the current advancements in battery technology, specifically lithium polymer batteries, did not promote the use of efficient systems.

An in-house, custom-made automatic controller and performance recorder system featuring off-the-shelf Arduino Nano microcontroller¹¹ and speed controllers were developed and provided to each team. The AEV automatic control and data recording system can be seen below.

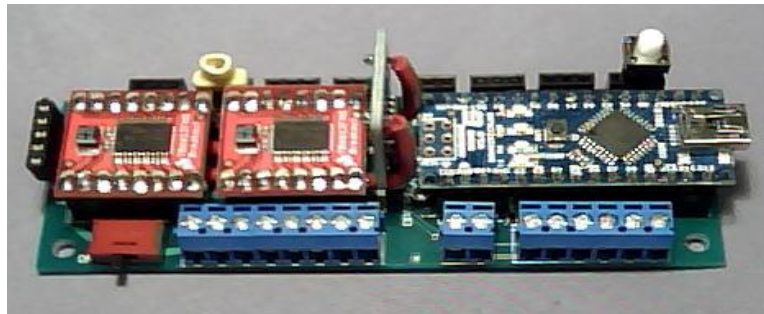


Figure 2: AEV Automatic Control and Data Recording System

The goal of the AEV controller was the creation of a fairly small, lightweight, device that could control up to three electric motors, with each motor having a maximum constant current draw of up to two amps using a high energy density lithium polymer battery. The device also had to be capable of recording the current draw, battery voltage, and wheel counts for a minimum of 240 times over a 120 second run, and be easily programmed. The collected data would be used to monitor current and battery voltage during a defined vehicle run in order to determine overall energy consumption and provide the necessary information for developing energy management modeling of the AEV.

Two computer program mainframes are provided to the engineering teams, one to autonomously control the AEV power (AEV Controller Software) and the other to download post-run current and voltage data that is recorded (AEV Data Recorder Software). The students input predefined function calls within the AEV Controller software program; and lay out desired performance characteristics to meet the operational objectives. The AEV Controller command allows for control over the vehicle's acceleration/deceleration, constant velocity, and thrust reverse if desired. The thrust reverse power settings are also set based on desired settings. This allows for complete control of developing AEV power-time curves and overall energy use when performing AEV operations on the closed-circuit track.

Aerodynamic body components are not required for AEVs. However, aerodynamic body components are highly encouraged to increase team's artistic creativity and visual appeal to the vehicle.

The AEVs, once designed and built, must fit within the team's storage box, approximately six inches wide, twelve inches long and five inches deep. The monorail support arm does not have to be mounted on the vehicle for storage; and is not required for meeting the size constraint.

Project Management and Teamwork & Project Documentation

Along with the AEV kit, the students are provided with and required to read an AEV design-build project description document that lists the AEV components and, in detail, the project objectives and deliverables.

Teams are formed, managed, and monitored using Team-Maker software¹² to ensure that the students receive timely feedback on their team formation and performance. Project management throughout the design process is regularly evaluated by requiring an updated AEV Project Schedule and Notebook. Each team tracks and manages the design-build project through notebook records that ultimately contain: a cover page, table of contents, project description document, team working agreement, project schedule, initial AEV concepts, brainstorming notes and supplemental research material, weekly performance test summaries, laboratory team reports, and final design and documentation.

As part of, the project notebook, each team is required to prepare a PowerPoint presentation and Final Report. Each team is provided with approximately 12 minutes to present to the other [Scholars Program] teams on the overview of the design process, final AEV design, and operation. The final report is a formal written document that is required to include, at minimum, a cover page, table of contents, list of figures and tables, executive summary; and the following sections: introduction, requirements, constraints, and information needs, initial concept design and analysis, final design, performance analysis, and conclusion.

AEV Design Process and Cycle

The AEVs are designed and built based on a series of labs and performance tests that utilize desktop wind tunnels and cover topics such as electric motor and air-breathing propulsion performance and evaluation, system efficiency, automatic control programming, and energy management.

Effort was made to differentiate between the design process and experiences that would place emphasis on the design cycle, specifically allocating necessary time allowed and constructive guidance to address the divergent nature¹³ of the AEV design-build project. For instance, other design-build projects within the Fundamentals of Engineering and Fundamentals of Engineering for Honors tend to be more convergent in nature, in that due to the project and curriculum layout, the time allowed for significant design variations. This, by observation, results in a significant amount student teams building one concept and focusing the remainder of the design process on detailed design in order to meet the operational objectives. With regards to designing energy efficient systems and with AEV as the tool, the magnitude of different design variables provides the opportunity to place emphasis on AEV design trade studies. Therefore, this was taken advantage of and dedicated time and performance test requirements were set to address this opportunity.

The AEV design process and design cycle, with the labs and performance tests (PT) marked is shown below.

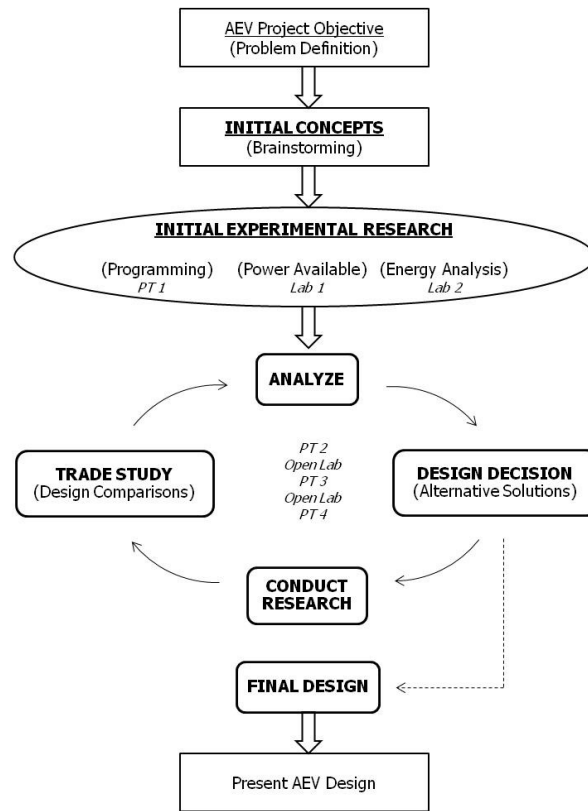


Figure 3: AEV Design Process

The AEV design process starts with each team brainstorming and developing two initial concepts and discusses, in paragraph form, the reasoning for the AEV layout, potential obstacles, and four unanswered questions that will need to be addressed during the design-and-build process. A hand sketch with three orthographic views with overall size dimensioned and components clearly labeled are required.

The following three weeks the student teams perform initial experimental research through a single performance test and two hands-on laboratory experiences. The first performance test covers automatic control programming concepts, while the labs focus on developing power available and system efficiency curves, along with power-time energy analysis spreadsheets of a team built AEV. The performance test requires a team written summary report addressing automatic control programming, while the two labs are combined for formal lab write-up. The experimental research provides a foundation for the design teams to enter in the design cycle, with three more performance tests required to be completed.

The second performance test, first within the design cycle, requires the design teams to analyze the data gathered from the combined labs, make a design decision for an alternative AEV component or layout configuration, conduct further research, from the skills gathered previously,

and develop trade studies to compare the results from the design changes. The second design cycle performance test requires the teams to focus on accomplishing the operational objective while continuing to explore design alternatives in order to determine a desirable efficient AEV and energy management tasks.

The current operational objectives are focused on the The Ohio State Universities Campus Area Bus Service (CABS) and provide an energy efficient alternative public transportation system for the year 2020 (CABS 2020). The operation requires three stops, for a predetermined amount of time to be made throughout the closed circuit monorail track.

The final performance test, performance test four, requires the team to arrive at a final AEV design and demonstrate the vehicle performing the operational objective. For each performance test, summary write-ups addressing certain questions and listing lessons learned are required.

Immediately following the design-build project and completion of the design process, the students are tested with an individual competition. Typically, this includes slight modifications made to the classroom track and/or operational objectives and announced two-weeks prior. Each team has to prepare for and demonstrate the given task to the instructional team. Following the individual competition, a final public competition/exhibition, open to student family members and the general public, brings all Scholars students together to compete with their AEVs. The student teams prepare and display their AEVs, project notebooks, and poster boards, summarizing their overview of the design process and final AEV design and performance.

Conclusion

A design-build course with a focus on energy efficiency and management through student designed, built, and tested model-scale AEVs was developed for first-year engineering students in the Engineering Scholars Program. The goal of the Engineering Scholars Program is to increase student awareness of green energy principles, innovation, and social responsibility through academic and co-curricular activities. The AEV design-build project was developed using lessons learned and project objectives from national recognized design-build projects within the Fundamentals of Engineering and Fundamentals of Engineering for Honors course sequences. The AEV project takes advantage of the diverse nature of its design process and places emphasis on design trade studies and comparisons in developing energy efficient systems and energy management skills to meet operational tasks.

The short- and expected long-term impact of the AEV design-build project for the first-year engineering students are to create awareness among incoming engineering students of the need for research and development of advanced energy technologies and system. The AEV design-build experience was developed specifically to facilitate innovation through energy management concepts within the multidisciplinary nature of design – complementing the acquisition of life-long learning skills offered through the First-year Engineering Program.

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