UNIVERSITY OF IDAHO FUTURETRUCK 2004

FINAL REPORT
OCTOBER 2004

KLK344
Report #N04-09

Prepared for

OFFICE OF UNIVERSITY RESEARCH AND EDUCATION
U.S. DEPARTMENT OF TRANSPORTATION

Prepared by

NATIONAL INSTITUTE FOR ADVANCED TRANSPORTATION TECHNOLOGY
UNIVERSITY OF IDAHO

Donald M. Blackketter, Ph.D., P.E.
Steven W. Beyerlein, Ph.D.
Frank Albrecht

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report outlines the re-engineering by the Advanced Vehicle Concept Team (AVCT) of a Sport Utility Vehicle to meet the goals of the 2004 FutureTruck Competition. FutureTruck challenged 15 schools to improve fuel economy and reduce emissions of a 2002 Ford Explorer while maintaining the performance, safety, utility, and convenience of the stock configuration. Included in this report is an overview of the competition requirements, summary of the vehicle design features and research results.

The objectives of this year's University of Idaho FutureTruck project were to

- Research and implement clean vehicle technologies that reduce the impact of transportation on the environment.
- Educate students and provide them with practical experience.
- Increase awareness and support of clean vehicle initiatives and progress.

The product of the work was a hybrid drive train that operates like any other vehicle. The vehicle's primary fuel was gasoline, an energy source that could be implemented with today's infrastructure. The hybrid components were lightweight, representing only 5 percent of the mass of the vehicle, and small enough to be easily integrated into other platforms. Key to the challenge, the vehicle had reduced emissions and improved fuel economy while maintaining safety, utility, convenience and performance similar to the stock vehicle.

DESCRIPTION OF PROBLEM

FutureTruck was a student competition sponsored primarily by the Department of Energy and Ford Motor Company. In response to international outcries concerning the potential of greenhouse gas emissions (GHG) to cause global warming, the goal of this competition was to encourage and promote the design and development of advanced clean vehicle technology. FutureTruck brought to light new technologies, as well as preparing a new fleet of automotive engineers in their application.

The focus of the FutureTruck Challenge was twofold: the reduction of emissions and the improvement of energy efficiency. An additional stipulation was that the original design intentions of the vehicle not be altered. The purpose of the metrics shown in Table 1 was to provide a vehicle that did not profligate harmful GHG emissions and that had a dramatically reduced need for non-renewable petroleum resources.

TABLE 1 FutureTruck Challenge Objectives

Fuel Economy	Minimum of 25 percent improvement over stock
GHG Emissions	Use technology to reduce total cycle GHG emissions
Exhaust Emissions	Comply with California ULEV emissions standards
Power	Vehicle must demonstrate 1/8 mile acceleration time of 11.5 seconds or less.
Consumer Acceptability	Vehicle must hold five adults and tow at least 2000 pounds, and air conditioning and all power accessories must function.

The emphasis for this year's team was to apply theories learned in the classroom to design and build a better vehicle while, at the same time, increasing the knowledge base for clean vehicle technologies. This project also brought together the lessons learned from the previous four years of FutureTruck, Clean Snowmobile and Formula SAE competitions.

APPROACH AND METHODOLOGY

TEAM BUILDING

AVCT began this project by building a multidisciplinary team because we believe that establishing a foundation of motivated people with diverse backgrounds encourages peer learning and improved information transfer through the learning community. While FutureTruck was often considered an engineering challenge, AVCT members relied on expertise from the business and environmental students on the team just as much. Using the three Es approach, outlined in Table 2, helped achieve the FutureTruck challenge goals as well as the team's individual goals.

Table 2: AVCT's Three Es Approach

Engineer	Exercise best practices in engineering
Education	Grow the learning community through peer techniques
Evaluation	Apply a system approach in studying vehicle performance and value

To manage a project as large as the FutureTruck, a multi-disciplinary teams were assembled Figure 1 illustrates the team structure and organization.

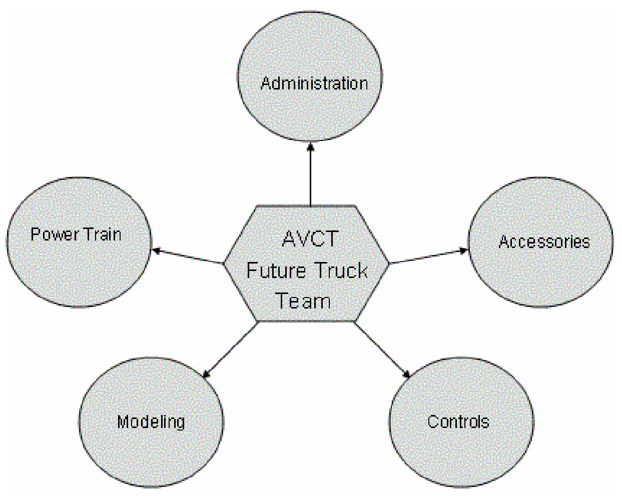


Figure 1: AVCT FutureTruck team layout and non-hierarchal structure.

The core of the team was composed of the team leaders in all major areas: Power Train, Controls, Accessories, Modeling and Administration. Instead of a hierarchical format, the team had a circular format that encouraged cooperation rather than domination. Supporting groups represented areas of learning beneficial on this type of multi-disciplinary project. Business, Environmental Science, Computer Science, Interior Design, Industrial Technology, Mechanical Engineering, Chemical Engineering and Electrical Engineering students all provided input for the project. Graduate students also proved to be valuable team assets.

The administration utilized mentoring techniques developed and taught in the Mechanical Engineering Department focusing on the professional development of the product, the team, and the individuals. Small teams met weekly to report on the previous week's goals and set the teams' goals for the next week. This technique helped the AVCT function efficiently. AVCT also used diversity to its advantage by having weekly skill sessions. Interdisciplinary groups would teach a particular skill about vehicle development based on their experience and background. Through the use of advanced teaming skills and utilization of a large, widely varied team, the AVCT managed to take on and successfully complete a very sizeable project. Throughout this experience AVCT learned to work and function as a business designing a product for a customer. In this case, the customer was the FutureTruck competition.

DESIGN CONCEPT

A mild electric hybrid configuration best satisfied our project objectives. The team decided to venture away from the standard of a parallel high-voltage hybrid. A low-voltage system was safer, cheaper, and easier to maintain. To overcome the low-voltage constraint and still produce output power high enough for a noticeable increase in efficiency, the system utilized an AC induction motor with an inherently low resistance. For reliability and power reasons, the energy storage mechanism was ultracapacitors. The fuel choice was Reformulated Gasoline (RFG). Figure 1 shows the diagram of the package that the team developed.

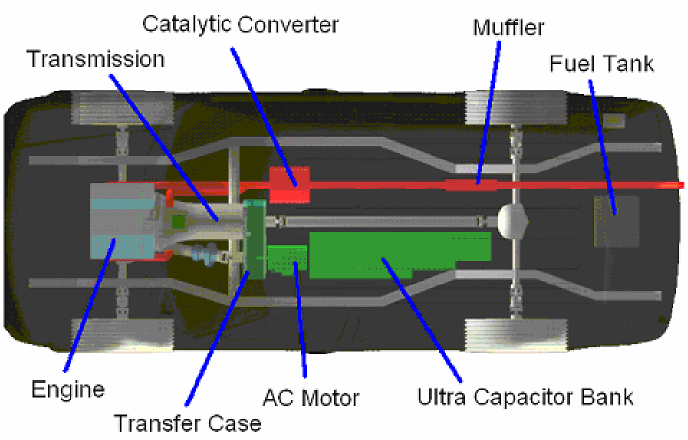


Figure 2: Packaging diagram.

DESIGN ELEMENTS

Engine

An Engine was selected, modified, and installed to provide the primary power source for the drive train. To avoid compatibility issues with the Explorer and vehicle computer modules, the team considered engines only from the Ford family of vehicles. For an engine-to-engine comparison, emissions, fuel economy, and size were normalized. The Mazda MX-5 MIATA ranked the highest, but the emissions were worse than the stock Explorer. The Mazda Millennia offered superior power to weight but interfacing the engine controller with the Explorer was a concern. The 3.0-liter engines from the Lincoln LS was identified as the best engine choice based upon EPA data.

Engine Modifications

The engine was a stock 3.0-liter Ford Engine from a Lincoln LS running on re-formulated gas (RFG) with water injection. Engine mounts were fabricated to adapt the new engine to the existing brackets on the frame. The mounts are made of 3/16 inch thick mild steel. A stress analysis was performed on the engine mounts using SolidWorks. The lowest factor of safety was found to be eight.

Powertrain

For the Lincoln engine and the hybrid system to work in the Explorer platform, several modifications needed to be made to the power train.

Transmission Modifications—Modifications were made to the Ford 5R55N transmission by removing the extension housing so that it could be mounted to a custom transfer case. The original mount point on the extension housing of the transmission was integrated into the custom transfer case. The Ford 55R5N transmission and the engine were connected to a stock Lincoln Power train Control Module (PCM). The stock transmission range selector switch needed was removed to provide room for the transfer case and its function was transferred to a microcontroller linked to the selector cable.

Transfer Case Modifications—The custom transfer case was created so that the 18hp alternating current (AC) induction machine could be coupled to the power train. The hybrid system required that the induction machine be hard linked to the rear axle due to two-wheel drive dynamometer testing at competition. This requirement led to the repackaging of the stock transfer case components so that the clutch assembly was on the front axle driveline rather than the rear as in the stock system (Fig.3)

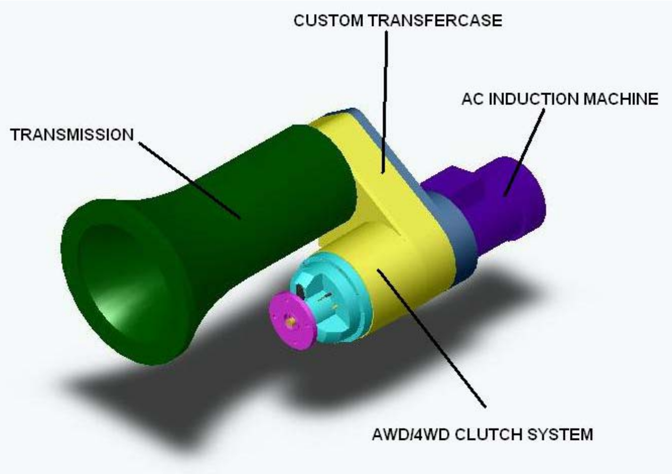


Figure 3: Assembly drawing of custom transfer case.

A custom transfer case housing, shafts and vehicle mounting cross members were constructed. Figure 4 shows new bearings and custom shafts created which allow for the unique loading conditions of this system. Aluminum cast housings from D8, Inc. provided strength, protection, and precision alignment. An inverted tooth Ramsey Chain provided the link between the front and rear drive shafts to handle load reversals at all vehicle speeds.

Figure 4: Housing, chain assembly and induction machine.

The custom transfer case used over 50 percent of the stock Borg Warner components, including the computer. The electromagnetic ball ramp clutch system, shown in Fig. 5, operated similar to the stock four-wheel drive/all-wheel drive system except for the low range mode. The low range was eliminated to help simplify the project but could be integrated for production. Off-the-shelf components represent 80 percent of the hardware. Custom hardware included the housing, shafts and spacers.

Figure 5: Four-wheel drive/all-wheel drive clutch assembly.

Electric Hybrid System

The secondary power source for the hybrid was electric, which provided power assist during acceleration and regenerative braking during deceleration. Figure 6 shows the relative locations and general wiring scheme for the induction motor, capacitor pack, emergency disconnect system (EDS) and the data acquisition system (DAS).

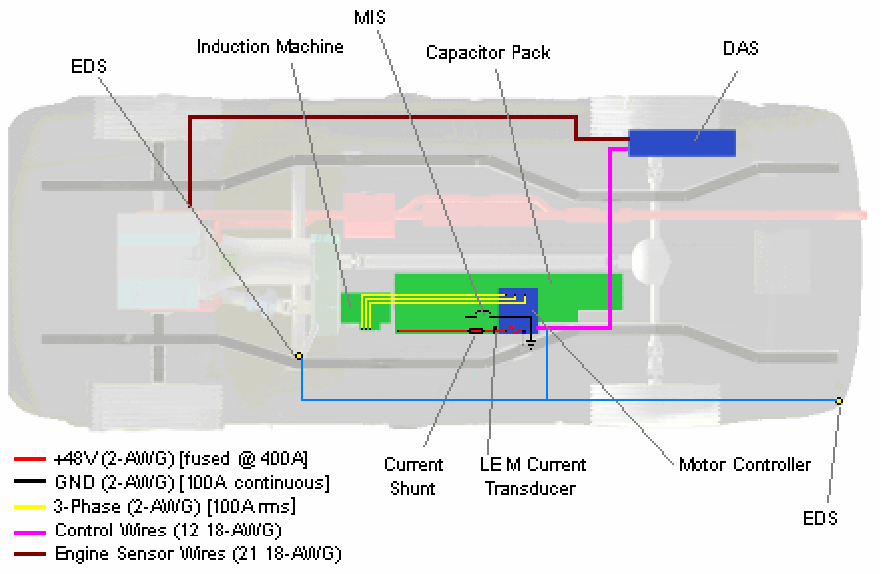


Figure 6: Low-voltage wiring schematic.

The induction machine functioned as a generator during braking and a motor during assist. During braking, the induction machine supplied three-phase AC current to the motor controller. The motor controller converted the AC current to direct current (DC) and stored the energy in the capacitor pack. During an assist, the induction machine acted as a motor. DC current was transferred from the capacitor bank to the motor controller. The motor controller converted the current to three-phase AC current and supplied it to the induction machine. Figure 7 illustrates the transfer of energy between the capacitor bank, the controller and the induction machine.

Figure 7: Motor controller and induction machine.

Power Assist Mode—Power assist mode was activated when the vehicle accelerated, the transmission was in the specified gear, and the throttle plate had a positive rate of change. Safety checks before energizing the motor included temperature of the induction machine and energy pack state of charge. The voltage applied to the induction machine from the motor controller varied between 0-10 volts and was a function of throttle position, maximum voltage that can be applied to the motor, and inverse of the engine speed. The control algorithm for power assist was

$$V_m\left(S_v\right) = \left[\left[1 - e^{-\left(\frac{P_{ta}-P_{te}}{5}\right)\cdot K_e}\right]\cdot\left[1 - e^{\left(S_v - S_{max}\right)\cdot K_s}\right] - R_f\right]\cdot 10.2 \quad ,$$

where

Vm = The motor controller signal voltage

Pta = The actual measured throttle position

Pte = The expected throttle position based on vehicle speed

Sv = The actual speed of the vehicle

Smax = The speed at which there will be no assist, drop out speed

Ke = The throttle position skew factor that affects the dynamics of the response

Ks = The speed skew factor that affects the dynamics of the response

Rf = A reduction factor that helps to conserve energy when needed

Figure 8 is a representation of how the induction machine's power output would decrease as vehicle speed increased. The dropout voltage was programmable. The top, middle and bottom lines show how the system behaved at 100 percent, 50 percent, and 20 percent throttle position respectively.

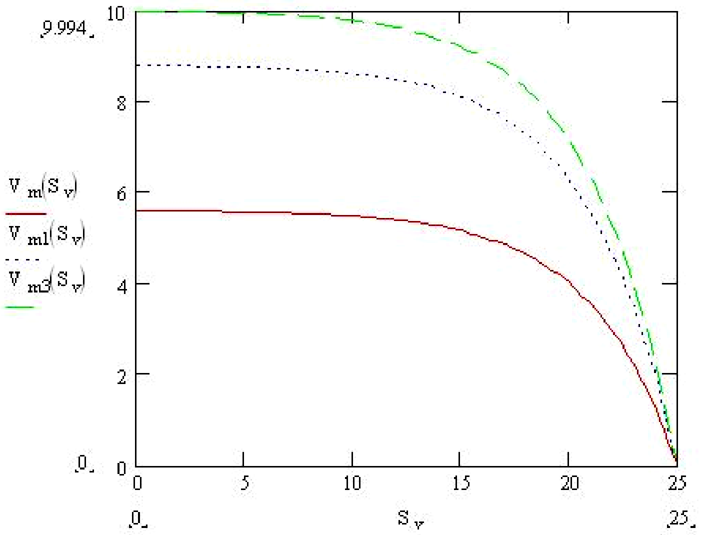


Figure 8: Controller signal voltage vs. vehicle speed.

Regenerative Braking Mode—During deceleration, the regenerative braking mode activated the induction machine as a generator to recharge the 48-volt ultracapacitor system. Control system inputs for regenerative braking included signals from the potentiometer on the brake pedal, vehicle speed sensor, and energy pack state of charge.

Energy Storage—The storage system consisted of 80 Maxwell ultracapacitors arranged in four parallel strings of 20 series-connected capacitors. Each ultracapacitor weighed 750 grams resulting in a total pack weight of 60kg. The pack stored up to 620kJ of energy with a maximum voltage of 48 volts. Each ultracapacitor has an effective series resistance (ESR) of 1mΩ giving the total pack a resistance of 5mΩ plus approximately 3mΩ in series connections. The voltage on each of the cells was monitored to prevent over voltage. The ultracapacitor data sheets indicated over voltage above 2.7V. Over voltage on a cell can reduce a cell's life length and increase its internal resistance.

In last year's (2003) FutureTruck design, a passive balancing scheme was used to prevent cell over voltage. A resistor was placed across the terminals of each capacitor. This resulted in balanced leakage currents, which would balance the cells over time. This passive system worked well at balancing the cells; however, it quickly bled the cells of their charge. The pack had to be recharged when it sat for long periods of time. This year, we placed 20 balancing circuits across groups of four parallel cells. The voltage of each group was compared via a comparator and current was discharged from the group with the highest voltage. Once the voltage of each group was equal, the circuit turned off. Figure 8 shows on of the balancing circuits.

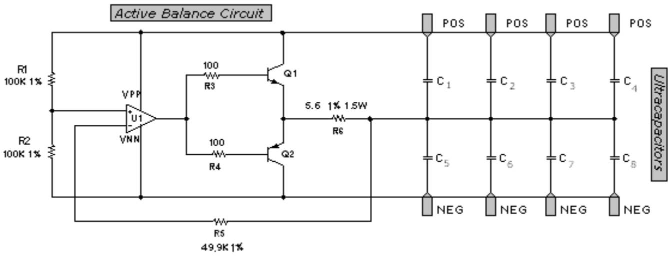


Figure 8: Active balancing circuit.

Test results of a balancing circuit are shown in Fig. 9. For this test, one group of four cells was charged to 2.05V and another group of four cells was charged to 1.75V. The balancing circuit required about 500 minutes to drive the cells to an equal voltage. The situation illustrated here is an extreme condition. Rather than a 300mV difference between groups, the circuits installed in the energy pack normally experienced around 50mV difference.

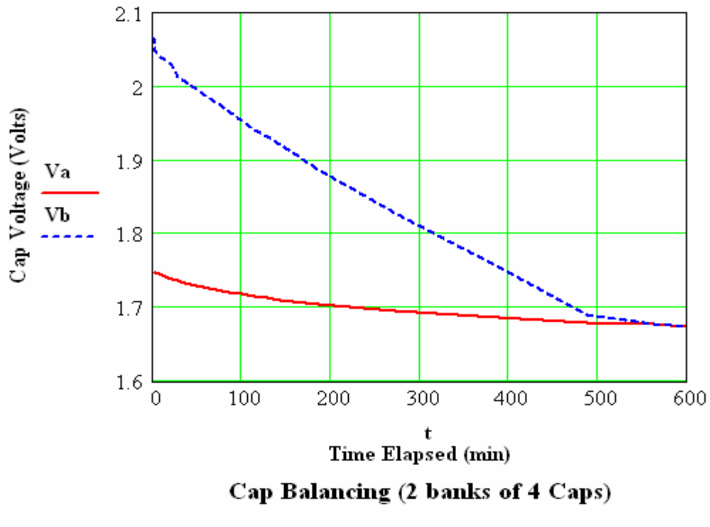


Figure 9: Balancing data.

The ultracapacitor enclosure shown in Fig. 10 was mounted under the vehicle. Designed to withstand 20G forces, the enclosure was constructed of diamond plate aluminum frame and was electrically isolated by a Lexan (polycarbonate) lined interior. Aluminum straps on the sides of the enclosure mount the box to cross members under the vehicle.

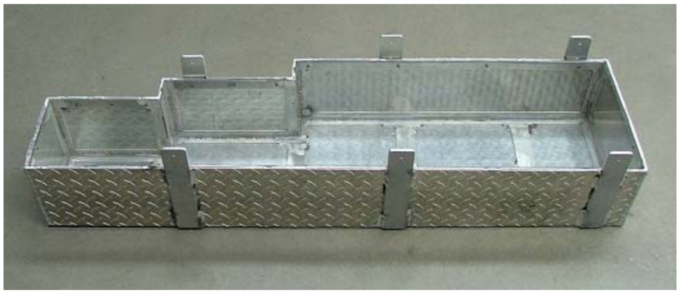


Figure 10: Ultracapacitor enclosure.

The lid for the enclosure was made of Lexan polycarbonate. A circuit breaker was installed, and spacers were used to hold the capacitors in place. We also installed a quick disconnect so that the pack could be easily disconnected and removed from the vehicle. The quick disconnect also allows for alternative operation with batteries. The completed capacitor enclosure is shown in Fig. 11.

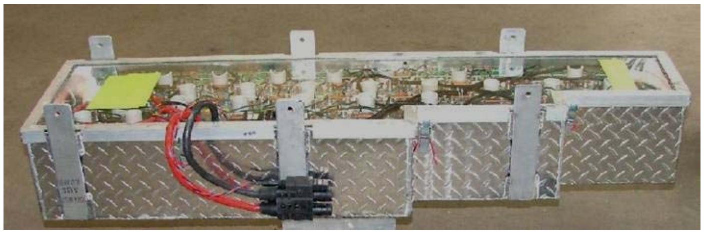
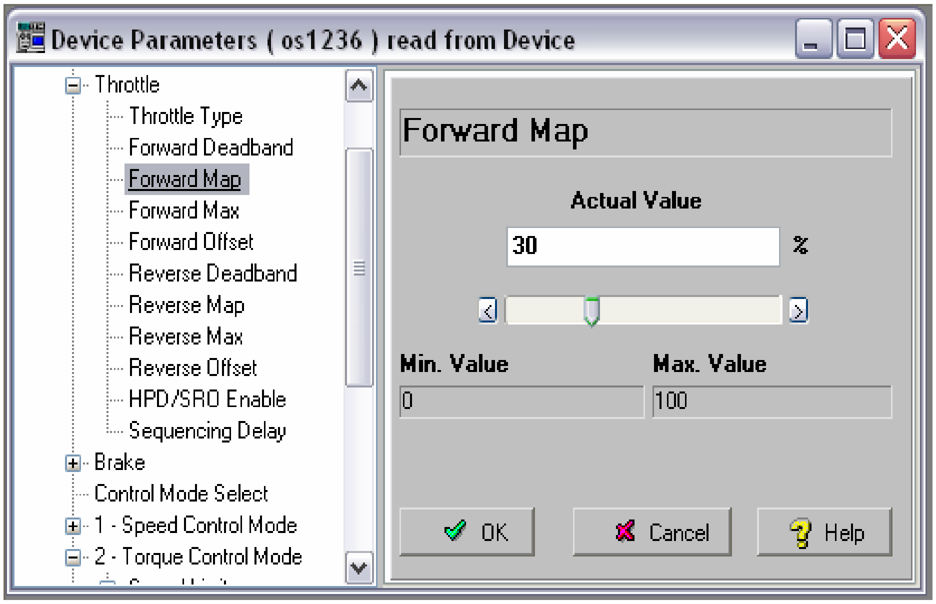


Figure 11: Completed Capacitor Enclosure

Motor Controller—A Curtis 1238 AC motor controller was used to convert the DC voltage supplied by the energy storage system to the three-phase output voltage required by the induction machine. The controller had a built-in torque control algorithm using parameters such as maximum speed, maximum current, normal operating voltage and system response. The parameters were stored in the controller’s memory and were modified using the Curtis 1314 Programming Station. This software allowed the user to modify parameters in real time as well as view current operating conditions in real-time. Figure 12 is a screenshot illustrating how a specific parameter, forward map, could be easily modified.



Device Parameters (os1236) read from Device

Forward Map

Actual Value
30 %

Min. Value 0
Max. Value 100

Figure 12: Modifying Parameters

In addition to the customizable control algorithm, the controller allowed the user to write Vehicle Control Language (VCL) code. VCL, a programming language similar to C++, was developed by Curtis Instruments. By using VCL, the user could customize the motor controller for nearly any application.

AC Induction Machine—The induction machine was connected in parallel with the gasoline engine. Although the induction machine was rated at 50V and 100A, we actually used the machine for short periods of time at nearly 300A. The induction machine had a peak output torque of 81lbf-ft and a maximum horsepower of 18hp. The induction machine was capable of operating in both regeneration and assist modes. Compared to a DC motor, the induction machine was smaller, weighed less, and had higher electrical efficiency. Table 3 displays the induction machine and controller efficiencies at various operating conditions.

Table 3: Motor and Controller Efficiencies

Motor Speed	Motor Current	Motor Efficiency	Controller Efficiency	System Efficiency
[RPM]	[A rms]	[%]	[%]	[%]
2000	80	89.00%	94.40%	84.00%
2000	150	85.00%	95.30%	81.00%
2000	250	80.00%		
3000	80	89.00%	94.40%	84.00%
3000	150	86.00%	95.30%	82.00%
3000	250	82.00%		
4700	80	87.00%	95.40%	83.00%

Data Acquisition and Control—The Compact FieldPoint System (Fig. 13) consisted of a central processing unit, analog input, analog output, and relay modules.

Figure 13: Compact FieldPoint

Compact FieldPoint used a graphical based programming software package called LabVIEW. The code was stored in the CPU module and it interfaced with the other modules in the Compact FieldPoint system. A sample section of LabVIEW code is shown in Figure 14.

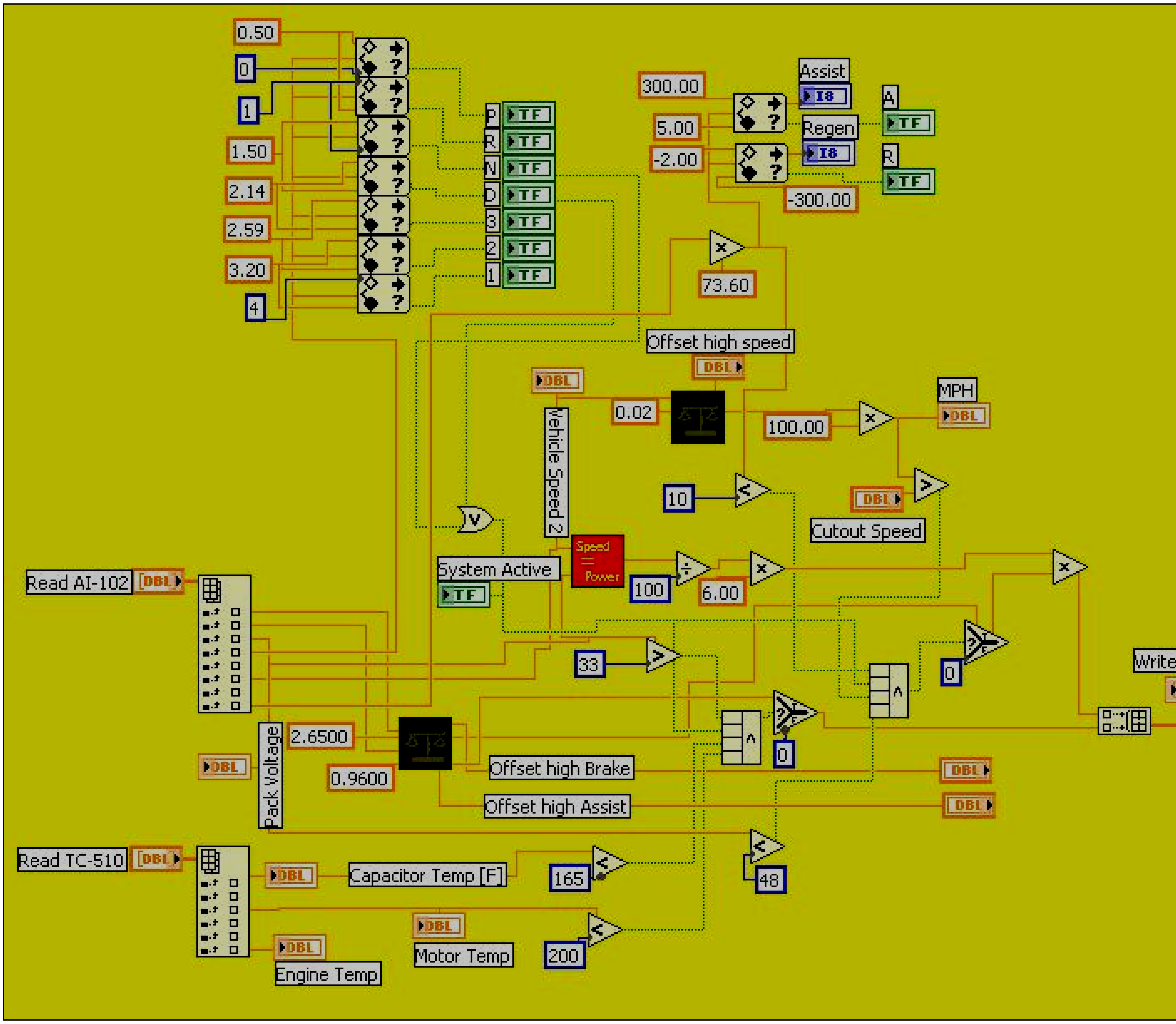


Figure 14: Sample LabVIEW code.

A graphical user interface (GUI) allowed the user to interface with the hybrid system in real time. In addition to the hybrid system, the six-inch liquid crystal display (LCD) was also connected to onboard diagnostics, Internet, and a video entertainment system with DVD player. Figure 15 shows the integration of the LCD in the vehicle dash and Fig. 16 shows a sample GUI display.

Figure 15: Vehicle Display

Figure 16: LabVIEW GUI

Safety and Convenience—Safety and convenience items were built into our system for user protection and ease of installation. As part of an emergency disconnect system to disable the vehicle in case of an accident or malfunction, two kill switches were installed—one on the exterior of the vehicle and one on the dash panel to the left of the steering wheel. A circuit breaker was installed to provide a safety disconnect from the capacitors. Also, a quick disconnect facilitated removal of the capacitor box from the vehicle and allowed for alternative operation with batteries. All bus bars and capacitor terminals inside of the energy storage box were coated with liquid electrical tape to electrically isolate the ultracapacitor pack and to prevent shorting of nodes if a conductor was dropped inside the box. The quick disconnect is shown during installation of the box in Fig. 17.

Figure 17: Capacitor pack installation.

Fuel System

The stock Lincoln fuel system and an eight-gallon polyurethane race tank were adapted to fit into the Explorer. This returnless type of fuel system was controlled by a rear electronics module (REM) from the Lincoln. Major components of the system are shown in Fig. 18.

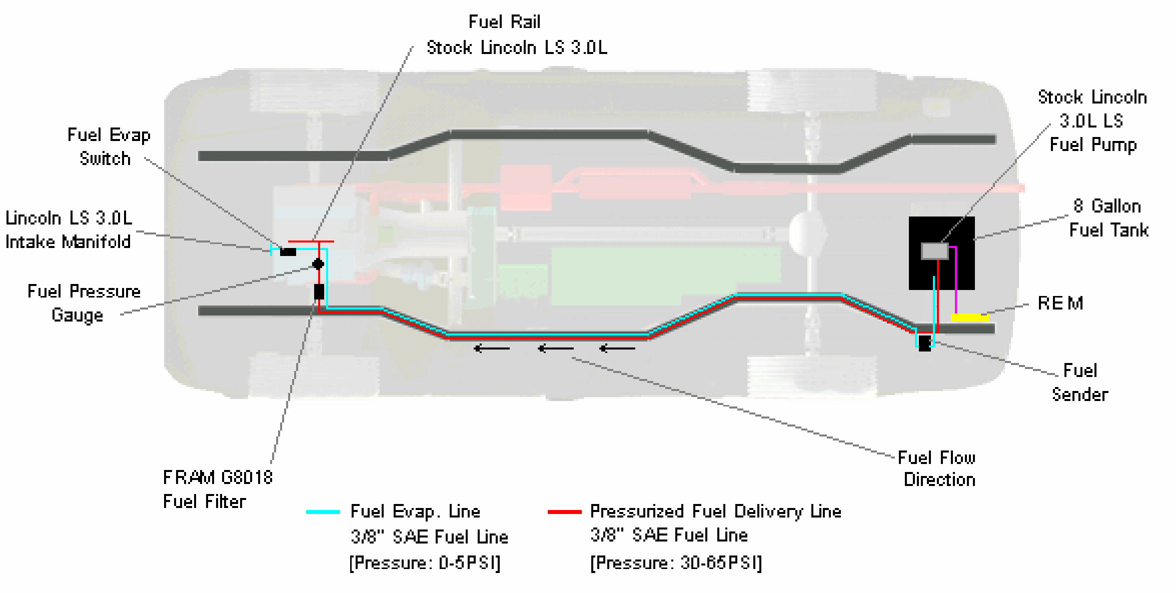


Figure 18: Fuel system schematic.

Emissions Control Strategies

Along with the hybrid powertrain, several innovations were implemented to help reduce the emissions and engine load.

Micro-Controlled Engine Cooling System—To control the engine temperature and reduce regulated emissions, a micro-controller based system used two electric pumps to direct the flow of engine coolant and two electric fans to help cool the radiator. One pump forced coolant through the engine while the other pump forced coolant through the radiator. The micro-controller used several temperature sensor inputs (input and output coolant temperatures and exhaust gas temperature) to control the speed of each pump and operation of the radiator fans. The objective was to improve engine efficiency and reduce catalytic converter light-off time by precisely controlling engine temperature.

Passive Cooling—To reduce cooling loads, accessory loads and vehicle road load, major heat sources were removed from the front of the engine. The engine's radiator was mounted on the vehicle roof where it could also function as a heated roof rack. The thermal siphon principle would be used to move the coolant and reduce pumping loss. To reduce aerodynamic drag, the vehicle radiator grill was replaced with a solid aluminum panel and a spoiler smoothed airflow over the roof.

Chemically Preheated Catalytic Converter—To reduce cold start emissions, the catalytic converter was redesigned to reduce the rate of heat loss during times when the vehicle was parked and not running. Vacuum insulated, chemically preheated catalytic converters used sodium based phase change material (PCM), which were similar to consumer chemical hand warming pads. This PCM acted as a thermal battery, storing thermal energy within the catalytic converter. When the engine was turned off, a vacuum was placed around the PCM to help insulate it. This system maintained the catalyst temperature at 100º C after 24 hours of cold soak. Figures 19 and 20 show the system components of the vacuum insulated catalytic converter and a cutaway view of the catalytic converter.

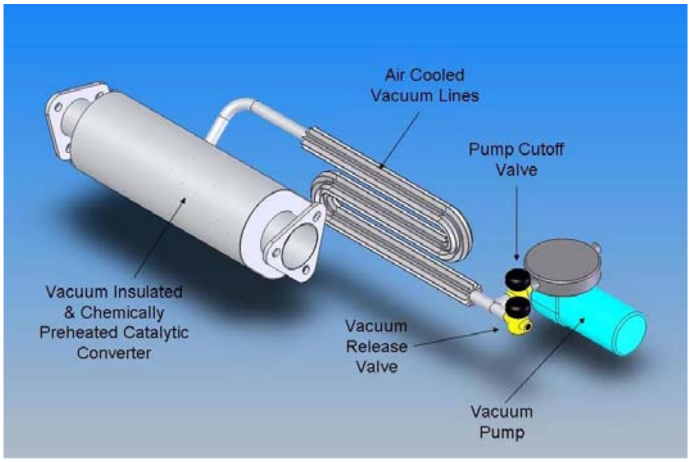


Figure 19: System components for catalytic converter with chemical preheat.

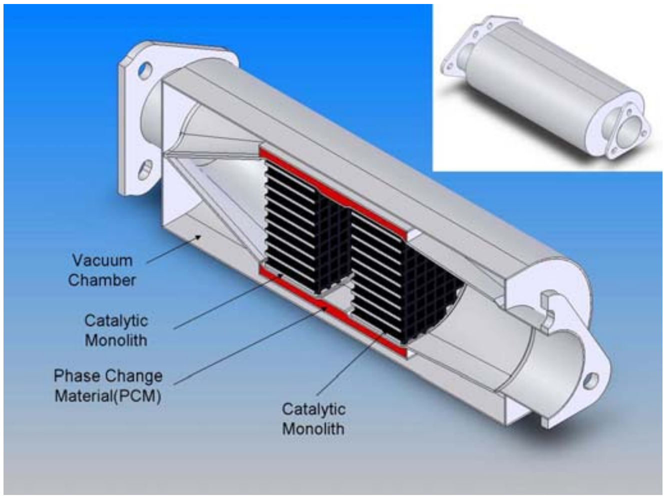


Figure 20: Catalytic converter cutaway showing the monolith, PCM, and vacuum chamber.

Structural Modifications

Modifications were made to the frame and body to improve performance and handle installation of the components.

Exterior Modifications—The front grill was sealed for aerodynamic purposes. The radiator system was located on the top of the vehicle and centered between two sections of a custom roof rack made of Nerf style aluminum tubes.

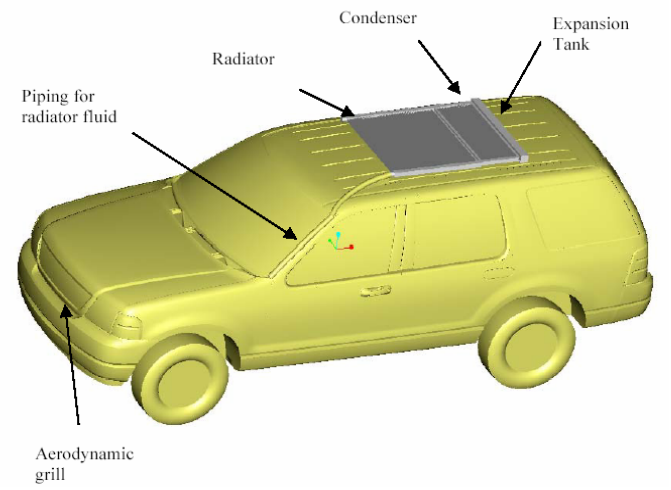


Figure 21: Exterior modifications.

Four steel cross members were added to support the transfer case, transmission, and ultracapacitor bank. Figure 22 shows stresses from a 20G loading on the transmission member. Finite element analysis (FEA) work was processed in SolidWorks with COSMOS and ALGOR.

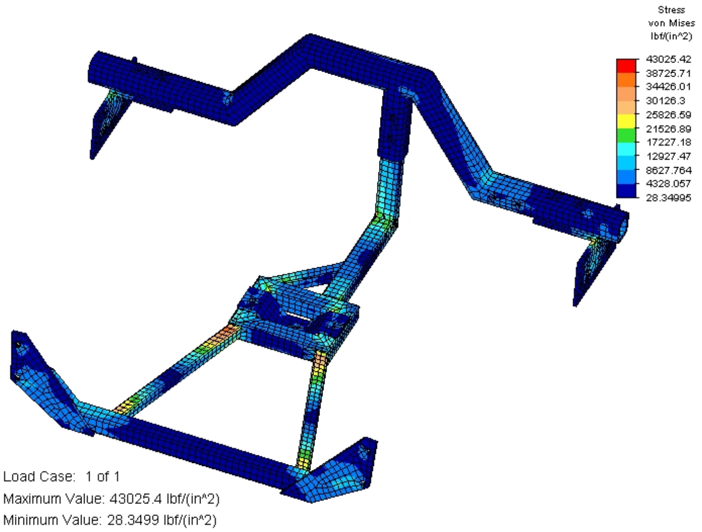


Figure 22: FEA results for transmissioin cross member.

FINDINGS; CONCLUSIONS; RECOMMENDATIONS

Computer modeling provided performance estimates while testing and judged events evaluated the final product.

MODELING

As shown in Table 4, we used several different algorithms to optimize the systems and subsystems. Programs such as Pro-E, Solid Works, PSAT, Simulink and P-Spice were used to aid in determining the best configuration for aerodynamic improvements, engine modifications, and electrical hybrid design to improve fuel efficiency and emissions.

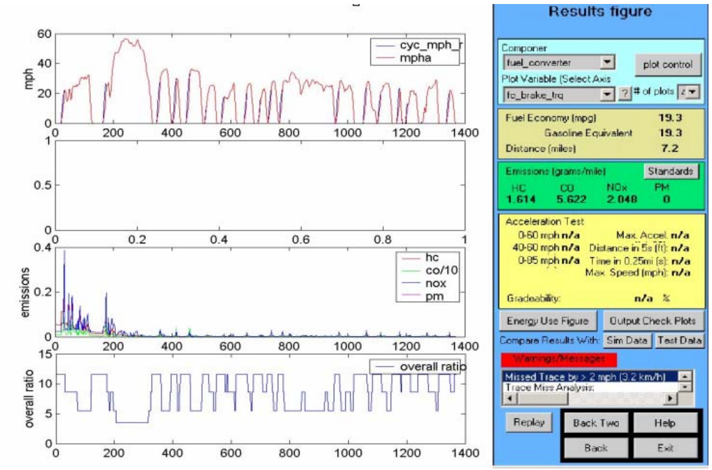
Table 4: Computer Modeling Tools Utilized to Optimize Design

Modeling Tool	**Application**
PSAT, ADVISOR, MathWorks with Simulink	Full vehicle modeling, controls, evaluation and testing
GREET	Greenhouse gas impact
P-Spice	Electrical system characteristics and efficiency
Pro-Engineer	Thermo and aero modeling
SolidWorks	Virtual mockup, tolerance checks, mass balancing
CSMOS, ALGOR	FEA thermal and structural

ADVISOR, a hybrid electric vehicle (HEV) simulation model written in a MATLAB/ Simulink environment, predicted the fuel economy of various modifications made to the stock vehicle. First, team members created a simulation of the stock vehicle. Then the simulation was modified in iterations as shown below to account for each major modification to the vehicle.

1. Stock 4.0L—Based on EPA testing of the stock four-liter 2002 Explorer
2. 3.0 liter and LS Transmission—Once the stock vehicle was accurately represented, engine and transmission parameters were modified to simulate a three-liter engine and a 2000 Lincoln automatic transmission

3. 3.0L Engine Modification—The 3.0L vehicle was further modified to show the improvements in efficiency from engine improvements. The efficiency improvements were based on test data from a similarly modified 4.0L engine.
4. Aerodynamic Modification—Changes made to the aerodynamics consisted of the increase in coefficient of drag due to the passive cooling system on the roof of the vehicle, and the decrease in coefficient of drag from the grill cover, and spoiler. Passive cooling coefficient of drag changes were determined by wind tunnel testing conducted at the University of Idaho.
5. Electric Hybrid Addition—The final model was the mild electric configuration. This model incorporated the AC induction machine and ultra capacitors. Figure 23 shows results from the Urban Dynamic Dynamometer Schedule (UDDS).



Componer: fuel_converter

Plot Variable (Select Axis: fc_brake_trq

# of plots: 4

Fuel Economy (mpg) 19.3

Gasoline Equivalent 19.3

Distance (miles) 7.2

Emissions (grams/mile)

HC	CO	NOx	PM
1.614	5.622	2.048	0

Acceleration Test

0-60 mph n/a

40-60 mph n/a

0-85 mph n/a

Max. Accel. n/a

Distance in 5s (ft): n/a

Time in 0.25mi (s): n/a

Max. Speed (mph): n/a

Gradeability: n/a %

Compare Results With:

Missed Trace by > 2 mph (3.2 km/h)

Trace Miss Analysis:

Figure 23: Screen shot of results from UDDS city cycle simulation in ADVISOR.

Modeling was verified through city and highway road testing, Wind Tunnel Testing, and Engine Dynamometer Testing. Figure 24 shows a scale model of the Explorer undergoing testing in the wind tunnel.

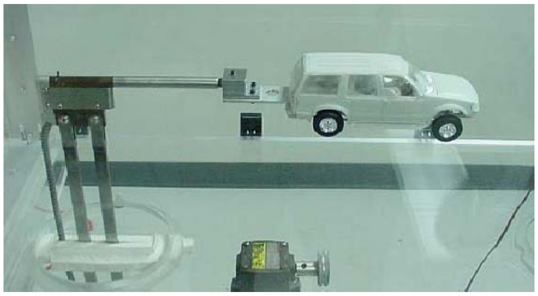


Figure 24: Wind tunnel testing of scaled vehicle model.

Figure 25 shows predicted efficiency improvements for each of the major vehicle modifications.

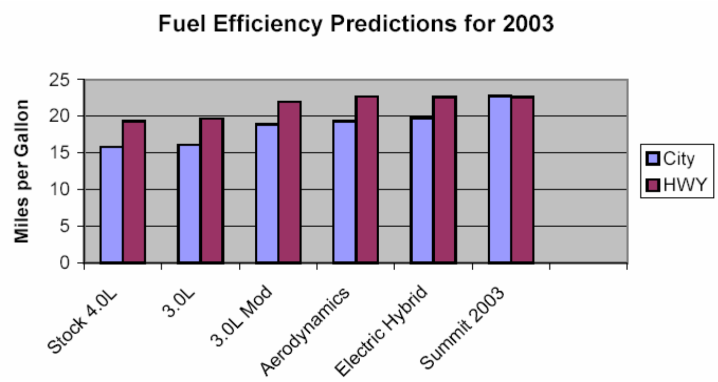


Figure 25: Fuel efficiency predictions.

EFFICIENCY AND EMISSIONS

Coast-down testing determined the increase in road load due to the passive cooling system. Using a stock Explorer and our modified Explorer, the team conducted two coast-down tests. One test was from 65 mph to 25 mph and the other from 70 mph to 50 mph. The team conducted several runs during each test, recorded the time required to decelerate, and averaged the results. Using F=MA or F=M (deceleration), the team calculated the vehicle's road load force. Using linear interpolation, the team determined that at 52mph, the modified vehicle consumed 3KW over the stock vehicle. This was due almost exclusively to a radiator mounting configuration that projected the radiator vertically 2 feet on the top of the vehicle. Subsequent analysis of the engine coolant data showed that the radiator flat could be laid flat, which reduced the drag to a value that was only 6 percent over the stock vehicle.

Dynamometer testing of the engine showed the effects of water injection and thermostat operation on hydrocarbon emissions. Figure 26 shows hydrocarbon emissions versus time for three test configurations. The diamond line shows the stock configuration; the star line shows the effect of operating without the engine thermostat; and the circle dot line relates is with water injection. The water injection hydrocarbon emissions were the lowest through the entire cycle. The square dot line is an average of water injection data and no thermostat which shows that for up to 600 seconds (400˚F EGT), the hydrocarbon emissions were lower by approximately 44 percent. Once this exhaust gas temperature was reached, the control strategy switched out of cold start mode, and returned to normal operation.

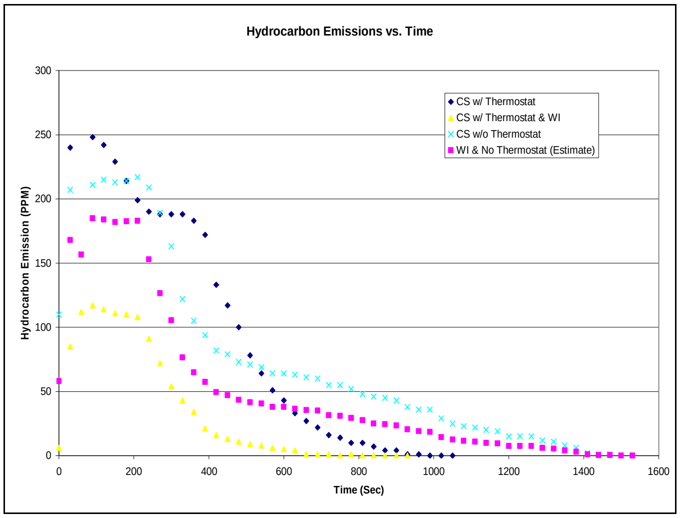


Figure 26: Hydrocarbon emission testing.

Figure 27 shows the impact on carbon monoxide (CO) emissions. During the first 250 seconds of cold start, CO emissions of the modified system were higher then stock, but after 250 seconds the modified system’s emissions stabilized quicker.

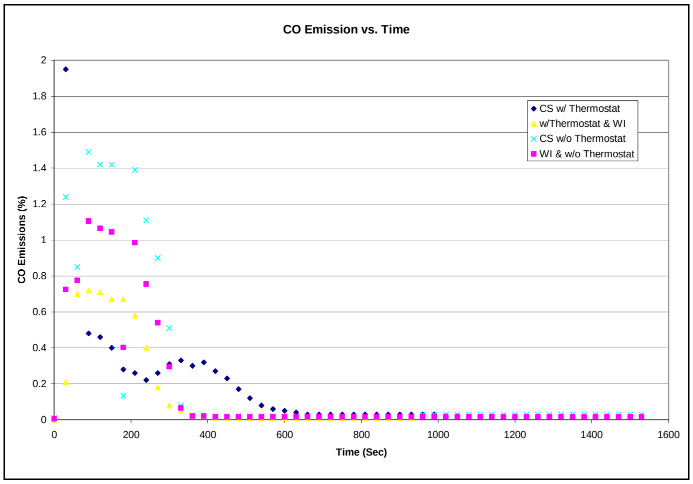


Figure 27: CO emissions testing

Figure 28 shows that with the modified system, carbon dioxide emissions are lower then the stock system. The total reduction in CO2 emissions were approximately 16 percent with water injection and no thermostat.

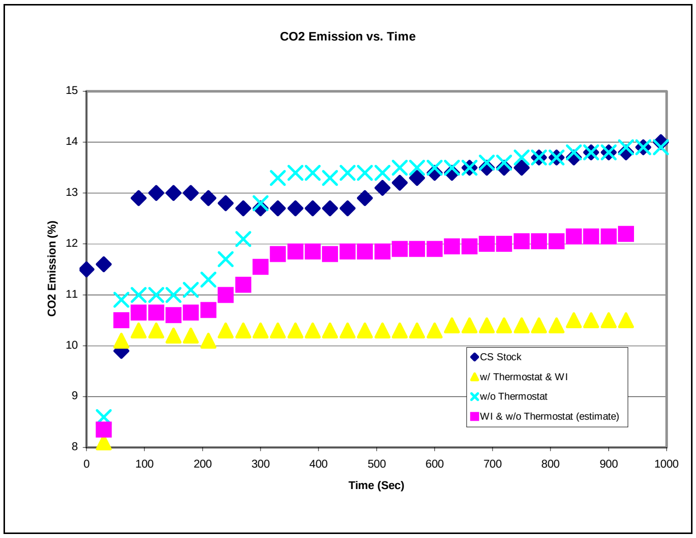


Figure 28: CO_2 emissions testing.

Figure 29 shows that with the modified system, nitrogen oxides (NOx) emissions were lower then stock. The modified system reduced overall NOx emissions by approximately 72 percent over a cold start period.

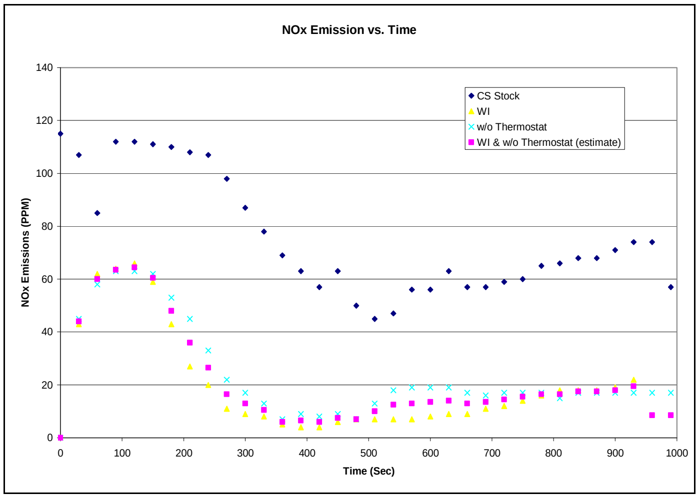


Figure 29: NOx emissions testing.

COMPETITION RESULTS

Overall, the UI team placed 6th out of 15 university teams. Point categories included pre-competition reports and inspections, dynamic readiness, handling, trailer tow, off-road, on-road fuel economy, greenhouse gas impact, emissions, written technical report, vehicle design inspection, oral presentation, and consumer acceptability.

The off-road event was an excellent test for our custom transfer case. We were one of 12 teams to successfully complete navigate the muddy hills and three-foot-deep pits lined with logs and rocks.

The trailer-towing event also tested our drivetrain. We were oneof 11 teams to successfully pull a 2000-pound trailer within a specified time period over a 15-mile-long “hill route” that varied from 7 percent to 17 percent grade.

CONSUMER ACCEPTANCE

The operation of our FutureTruck was similar to stock vehicle and the feedback from test drives validated the quality feel of the vehicle. The AC induction machine and hard-linked post transmission smoothed out torque spikes associated with typical vehicle shifting. The cross member modifications reduced chassis deflections and the hybrid packaging improved the vehicle's weight distribution.

The intended market for the re-engineered SUV was both present and future Ford Explorer buyers. Notable features included a fuel type with an established infrastructure, stock four-wheel drive/all-wheel drive capabilities, seating for seven, and a telematics system with advanced capabilities.

The experience in creating the hardware turned a group of students and faculty into a high performance team that overcame obstacles to demonstrate the quality engineering and education of the University of Idaho.

ACKNOWLEDGMENTS

The University of Idaho AVCT would like to thank the following for helping to make Summit a possibility:

ANL, Ford Motor Company, Wholesale Hydraulics, National Instruments, Arvin Meritor, National Instruments, Visteon, BP, NSF, Delphi, Parker Ford, University of Idaho Facilities Management, Maxwell, PTC, D8, LA Aluminum, Ramsey Chain, Access I/O, BlueRidge Numerics, MathWorks Corporation, Extrude Hone Corporation, McQuillen Racing Engines, NIATT, Ed & Mary Schweitzer, Bill Weidenaar, Russ Porter, Steve Beyerlein, Edwin Odom, Dean Thompson, the #13, all of those who donated time and money, friends and family who were sympathetic to all the time required for building, the AVCT members who were not attending for class credit rather just there to help, and to Frank Albrecht for his advising and leadership.

REFERENCES

Albrecht, Frank. *Supervisor Safety Handbook for AVCT Vehicle Shop 2003*. University of Idaho. 2003

FutureTruck 2004 Rules and Regulations. 2004. www.futuretruck.org/sproot/Studens/FutureTruck%20Rules/FT04%20Rules%20v020304.pdf

*2000 LS Ford Workshop Manua*l. 1999. Ford Motor Company

*2002 Explorer Mountaineer Workshop Manua*l. 2001. Ford Motor Company

Material Safety Data Sheets Cornell, www.msds.pdc.cornell.edu/msdssrch.asp, Oct. 24, 2003.

Clark, K. B., and S. C. Wheelwright, “Organizing and Leading ‘Heavyweight’ Development teams” in *Strategic Management of Technology and Innovation*. 3rd Ed. Eds. Ra. A. Burgelman, M. A. Maidique, and S. C. Wheelwright, S.C. Boston: McGraw-Hill, 2001. pp. 810-822.

National Institute for Advanced Transportation Technology. January 15, 2004. NIATT Main Page. December 2003. <http://www.webs1.uidaho.edu/niatt>