A PARALLEL HYBRID-ELECTRIC SPORT UTILITY VEHICLE— FUTURETRUCK 2003

FINAL REPORT
SEPTEMBER 2003

KLK325
NIATT Report N03-06

Prepared for

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

Prepared by

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EXECUTIVE SUMMARY

This final report details the development of the University of Idaho hybrid-electric, hybrid-hydraulic sport utility vehicle FutureTruck 2003 along with an overview of requirements, design features and results.

The objectives of the 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 University of Idaho Advanced Vehicle Concepts Team (AVCT) developed a unique hybrid vehicle while simultaneously hosting a series of public relations activities to highlight the vehicle's potential for decreasing toxic emissions and improving fuel economy. The team designed and then built a mild, parallel hybrid vehicle that improved fuel economy by using stored energy to help the internal combustion engine accelerate the vehicle from rest. By utilizing electrics and hydraulics, the team captured, stored and re-used energy that is wasted in a conventional vehicle. A passive cooling system further improved the vehicle's efficiency by reducing the amount of energy required to cool the engine and passenger compartment. Computer-controlled engine cooling and water injection decreased tailpipe emissions while the use of E85 fuel helped reduce greenhouse gas emissions. A telematics system enhanced vehicle control and analysis of vehicle performance. Test results showed a 41 percent improvement in fuel economy and reductions of all regulated emissions. The telematics system earned a second place at competition for best design.

DESCRIPTION OF PROBLEM

FutureTruck 2003 was a challenge to 15 top North American universities to reengineer a Ford Explorer Sport Utility Vehicle (SUV) for at least 25 percent higher fuel economy and reduced emissions without compromising performance, utility, safety, and affordability. The project required modeling to predict performance, written reports to document design details, and testing to verify concepts. Dynamic testing and static design events were scheduled for Ford's Michigan Proving Ground and emissions testing would take place at Ford's Allen Park Test Laboratory.

In addition to the objectives set forth by FutureTruck, AVCT goals required the vehicle make use of current technology, be highly functional in the regional mountainous environment, and be readily adaptable to high volume manufacturing.

The audience for education and outreach would have no boundaries. While primarily an engineering project, the team benefited from a diverse and multidisciplinary approach that included participation from students in subjects such as business, communications, and the environment. Although the UI campus is located in a rural area of the Pacific Northwest, the Internet would allow global connections for information exchange and increasing awareness about clean vehicle initiatives.

APPROACH AND METHODOLOGY

Our approach was to focus on engineering, education, and evaluation as related to the vehicle, team and community. We employed an engineering approach adhering to professional ethics and proven problem solving methods. We focused on education by forming diverse student teams that trained one another while applying classroom lessons to the practical aspects of vehicle design and development. In addition, the team educated the community through a series of public relations events and written reports. The team also spent time learning and applying principles of quality management. The team considered ISO 9001 guidelines in optimizing their business of producing an innovative concept vehicle for the future.

Vehicle Design and Development

The design and development process, detailed at http://www.its.uidaho.edu/PDM, provided a structured yet insightful approach to solving the problem of building an improved SUV. Primary areas for improvement included fuel economy and emissions and important related factors included performance, utility, safety and affordability. The overall design concept was a mild, hybrid vehicle with a downsized internal combustion engine, passive cooling, specialized controls, and a telematics system. The following sections describe how these features were designed and developed.

Vehicle Configuration

The team decided to venture away from the standard of a parallel high-voltage hybrid and focus on a mild hybrid configuration. Since the high voltage avenue has already been explored and already put into production in multiple vehicles, AVCT felt that it was more in the spirit of FutureTruck to pursue technology that is more emergent. This led to considering low-voltage electrics utilizing ultra-capacitors and hydraulic systems as two methods for storing energy. Rather than limit the design to a single technology, the team decided to integrate both on a single vehicle. This approach provided a unique testbed for validating computer model predictions about the efficiency and effectiveness of hybrid-electric and hybrid-hydraulics. With the use of custom controls, each technology could be tested individually on the same day and on the same vehicle or both technologies could be tested together.

Fuel Selection

For fuel, the team chose E85—85 percent ethanol and 15 percent gasoline—as the optimum fuel for our application. Argonne's fuel-cycle model GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) influenced our choice. This model accounts not only for the energy consumed in procuring and processing the fuel, but includes the renewability of the fuel source as a factor as well. E85, with a high oxygen content, burns more completely than gasoline, contains 80 percent fewer gum forming compounds, and reduces greenhouse gas emissions by nearly 30 percent.

Special modifications were required to utilize the chosen fuel of E85. Since ethanol is more corrosive then regular gasoline, certain materials (aluminum, brass, silicon) cannot be used. All of the fuel lines and fittings were replaced with stainless steel: the o-rings are Vinton, and sealants Teflon. These components ensured there would be no fuel leaks and contamination.

Ethanol has less energy per volume then gasoline (1 gallon of E-85 equals 72 gallons of gasoline). Since the engine does not have the option of being reprogrammed, the fuel injectors were replaced by injectors with 40 percent more capacity and are ethanol compatible. This higher capacity ensures that the same amount of energy in available to the internal combustion engine.

Engine Selection

The internal combustion engine (ICE) is the heart of the vehicle and careful consideration was taken in its selection. To avoid incompatibility issues with the Explorer and its on-board control system, the team considered engines solely from Ford and its subsidiaries. Since space is limited in the Explorer's engine compartment, only compact engines were evaluated. For an engine-to-engine comparison, the emissions, fuel economy, and size were normalized. The emissions were compared by the product of the power and the vehicles mass divided by the average mass of emissions generated. For a valid emissions comparison, data published by the Environmental Protection Agency was used. To normalize the fuel efficiency of the engines, the rated fuel economy was divided by the vehicle mass and engine power. The engine size was evaluated by dividing the engine power by the displacement. For a direct hybrid-to-hybrid comparison the Toyota Prius was included. Table 1 shows the normalized factors for the engines considered.

Table 1 Engines Considered and Overall Ranking

				Normalized to EXPLORER 4WD			
2001 Carline	Liter	kW		kpl/(kg-kW)	Avg kW-kg/emis	kW/L	Ranking
Escape 4WD	3.0	149	City	1.474	1.574	1	4.102
			Hwy	1.546	1.706		
Explorer 4WD	4.0	157	City	1.000	1.000	.7	2.746
			Hwy	1.000	1.000		
Lincoln LS	3.0	153	City	1.331	0.967	1	3.541
			Hwy	1.494	1.337		
Mazda MILLENIA	2.3	157	City	1.569	.581	1.3	3.686
			Hwy	1.729	.857		
Mazda MX-5 MIATA	1.8	116	City	3.346	.467	1.2	4.953
			Hwy	3.249	.445		
PRIUS	1.5	52	City	14.912	6.310	.7	19.603
			Hwy	10.209	6.443		

The Mazda MX-5 MIATA ranked highest, but on closer inspection, 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 3.0L engines from the Escape and the Lincoln LS were considered next. After reviewing cost and availability, the Lincoln LS was identified as the best engine choice.

Hybrid Configuration

FutureTruck 2003—named Summit—is a mild hybrid vehicle receiving electric power assist through the rear differential and hydraulic power assist through the front differential. The hydraulic system also receives power from the engine for extended four-wheel drive operation. The transfer case is eliminated and both hybrid systems are controlled by the same hybrid control system.

The hybrid systems are charge sustaining, stand-alone systems. Neither the electrical or hydraulic systems receive power from any source outside the vehicle. Their only method of power generation is regenerative braking. This method captures energy wasted during braking by using the electrical and hydraulic systems to decelerate the vehicle. This is much more advantageous than the standard mechanical brake. Mechanical brakes work well, but rely on friction to convert the kinetic energy of the vehicle to heat energy, which is then dissipated to the environment. Regeneration systems convert this kinetic energy into hydraulic or electric energy, which can be transferred back to kinetic energy. This reduces the demand on the ICE, and thus reduces fuel consumption.

Electrical System Component Selection

After deciding to pursue low voltage electrics, several issues needed to be addressed with the electrical portion of the hybrid system. Three of the major issues were power generation, storage, and power use. In other words, AVCT needed components that would enable us to collect power from regenerative braking, components to store that power, and components to utilize the stored power and convert it back into kinetic energy.

The charging system consists of three Zena Series 200 generators. These are configured in series, and combine to generate 7.2 kW. They have a 100 percent duty cycle as well as a 90 percent efficiency rating; both factors make the generators very practical for this application.

The storage system on a typical high-voltage hybrid vehicle consists of large banks of lead-acid batteries. These batteries are expensive, large, harmful to the environment, and have a life span shorter than that of the vehicle itself. It is for these reasons that AVCT decided it would be better engineering to pursue some other means of energy storage.

With this goal in mind, AVCT selected Maxwell PC2500 ultra-capacitors that have ten times the power of ordinary batteries and a longer life span.

Hydraulic System Component Selection

For component sizing, it was necessary to calculate the amount of energy available during vehicle deceleration. During a city driving cycle, it was estimated that most braking would occur from 35 mph. Although the control system would minimize the use of the friction brakes, it was estimated that 14 percent of available energy would consumed by the brakes.

$m := 2176.4$	Mass of Vehicle in kg
$V := 15.65$	Vehicle Speed at 35 mph in m/s
$KE := \frac{1}{2} \cdot m \cdot V^2$	Kinetic Energy Equation
$KE = 2.665 \cdot 10^5$	Kinetic Energy of Moving Vehicle in Joules
$E := KE \cdot 0.86 \cdot 0.93$	Energy losses due to braking friction (14%) and pump efficiency (93
$E = 2.132 \cdot 10^5$	Total Energy available for storage is 213.2 KJ

Figure 1. Vehicle energy.

The calculations in Fig. 1 show that there is roughly 213 KJ of energy available to the hydraulic system for storage. These calculations helped in the sizing of the accumulator tanks. Originally a 5000-psi accumulator tank was going to be used; however, the added cost and the difficulty of finding a clutch adequate to handling the increased torque limited the team to a 3000-psi accumulator tank. To achieve the desired amount of energy storage, two 3000-psi accumulator tanks with 2.6 gallons of gas volume were chosen. However, due to weight, cost, and space complications in using two high-pressure accumulators and one low-pressure tank, only one high-pressure tank and one low-pressure tank was used. Due to these limitations, the high-pressure accumulator tank did not store all the energy available.

To determine the energy storage capacity of the high-pressure accumulator tank, the nitrogen gas precharge pressure and minimum system pressure must be found. Prior research on hydraulic hybrids has shown that the high and low-pressure ratio should be between 2:1 and 3:1. The maximum pressure ratio recommended by the manufacturer of the accumulator tank is 4:1. With this in mind the precharge pressure was determined to be 1,186 psi (81.8 bar) and the maximum pressure is 3000 psi (206.9 bar). The recommended minimum system pressure is 1.1 times the precharge pressure due to variations in thermal loss through the bladder walls in the accumulator. Therefore the minimum system pressure is 1304 psi (90 bar). These pressures correlate to 1.67 gallons of fluid being moved into the tank.

Once the precharge pressure, minimum pressure, and maximum pressure are found, the total energy storage of the tank can be calculated. The energy equation is similar to the energy in a capacitor and is shown below.

$$\mathrm{E} = \frac{1}{2} C P^2 , \tag{1}$$

where: E = energy storage, C = accumulator capacitance and P = pressure.

The capacitance is dependent on the precharge pressure and is shown below. Due to the accumulator tanks using a compressed gas, all calculations use absolute pressures.

$$C = \frac{V_{air}}{P_1} , \tag{2}$$

where: V_{Air} = volume of nitrogen at precharge pressure and P_1 = nitrogen precharge pressure.

These calculations are repeated for the low-pressure accumulator tank. A minimum of 100 psi (6.9 bar) is necessary for the pump-motor inlet ports during system regeneration. Having this minimum pressure is what allows the design to not use the charge pump that is normally needed for the pump-motor. Note that the energy stored in the low-pressure accumulator takes energy away from the energy stored in the high-pressure accumulator. The system specifications for the hydraulic hybrid drive are summarized in Table 2.

Table 2 Hydraulic System Specifications

	High Pressure Accumulator	**Low Pressure Accumulator**
Precharge Pressure	1186 psi, bar	100 psi, bar
Maximum Pressure	3000 psi, bar	256 psi, bar
Minimum Pressure	1304 psi, bar	110 psi, bar
Energy Stored	151 kJ	25 kJ
Total Energy Storage		101 kJ
Maximum Pump-Motor Torque		171 ft-lb

Hybrid Operating Modes

Summit is capable of operation in four distinct modes: Full hybrid, internal combustion engine only, internal combusion with electric assist, and internal combusion with hydraulic assist. In order to minimize emissions and maximize economy, full hybrid is the most desirable of the modes. However for testing purposes, the vehicle was designed to be more flexible, allowing operation in any of the four modes.

Passive Cooling System

A passive cooling system reduced cooling loads on the engine and passenger compartment, accessory loads, and vehicle road load. Specially fabricated heat exchangers, replacing the radiator and air conditioning condenser, were mounted on the vehicle roof. The water pump and cooling fan were changed from mechanical to electrical versions for more precise control. An airfoil was specially fabricated for the front area of the roof to reduce aerodynamic drag, create a low-pressure region over the heat exchangers and for improved aesthetics. Assuming nominal temperatures for a typical summer day and a typical automobile, passive cooling is expected to increase heat transfer from the engine by 67 percent and decrease heat transfer to the passenger compartment by 22 percent.

Emissions Control System

Summit's emissions controls were developed to meet EPA's Tier 2 (SULEV) emissions standards. Baseline dynamometer testing showed that the stock Explorer meets California ULEV emissions standards in all categories except oxides of nitrogen (NOx). Changing the fuel from regular unleaded gasoline to E85 should further reduce the NOx level, bringing it to an acceptable level for California ULEV standards. These emissions levels will be further reduced by utilizing a computer controlled cooling system, vacuum packed catalytic converters with phase change salts, water injection at the intake manifold and a custom exhaust system (Fig. 2).

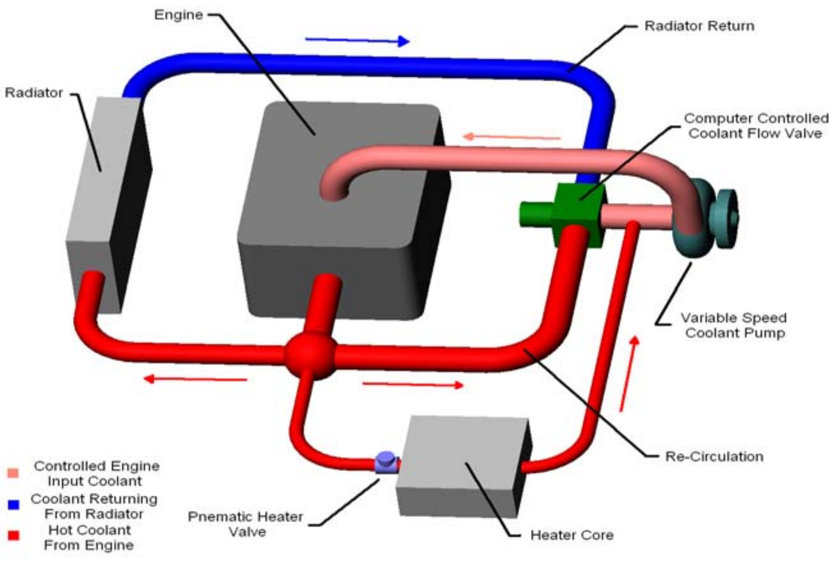


Figure 2: Emissions control system.

Computer Controlled Engine Cooling

This system is comprised of two major components, a variable speed coolant pump and a variable position thermostat. The variable speed pump propels the correct coolant flow rate through the system to reduce warm and cold spots. The pump is controlled according to the coolant engine output temperature. This ensures the pump is only working as hard as it needs to, improving pump life and reducing unnecessary electrical loads.

The variable position thermostat (Fig. 3) has two modes, cold start mode and normal mode. Cold start mode forces the thermostat closed, preventing coolant circulation, and allowing engine exhaust gas temperatures to reach operating temperatures faster. The control strategy switches from cold start mode to normal mode once a thermal sensor reaches operating temperature of approximately 400ºC.

Normal mode operates to provide even cooling of the engine and lessen the adverse effects of hot and cold pockets. This is accomplished by allocating the control system to use temperature readings to control the pump and thermostat. The temperature for controlling the pump is taken at the coolant exit; the temperature for controlling the thermostat is taken at the coolant inlet.

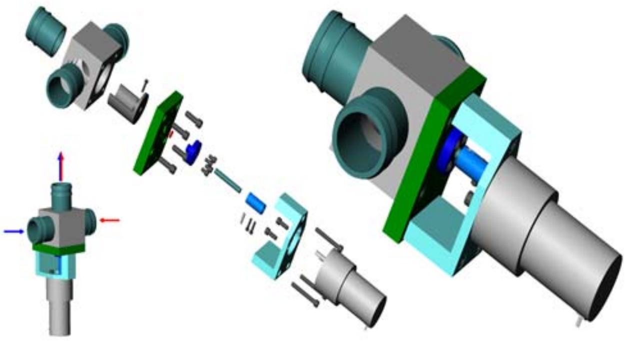


Figure 3: Variable position thermostat.

Vacuum Packed Catalytic Converters

Catalytic converters involving vacuum assist and chemical preheat as a result of sodium based PCM are used. This relationship allows thermal energy storage within the catalytic converters and further reduces time to operating temperature (light-off). The PCM maintains a catalyst temperature of 100ºC after 24 hours of cold soak by acting as a thermal heating blanket. A vacuum is also maintained during cold soak and cold start to reduce transient thermal effects inside the catalytic converters. The vacuum is released after light-off to ensure safe operation (Fig. 4).

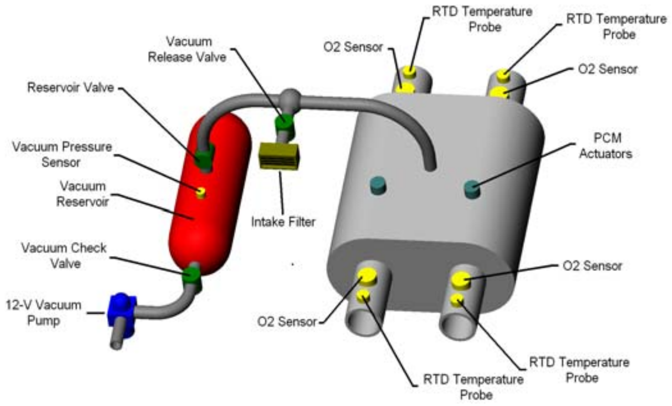


Figure 4: Catalytic design.

Water Injection

The water injection system, which injects a fine mist of water based on engine vacuum, consists of a water reservoir, control valve, spray orifice, and tubing.

Custom Exhaust

A ceramic coating was added to keep exhaust heat in. Exhaust manifold passages have also been extruded to decrease surface roughness and effectively reduced CO and HC emissions during cold start and normal vehicle operation.

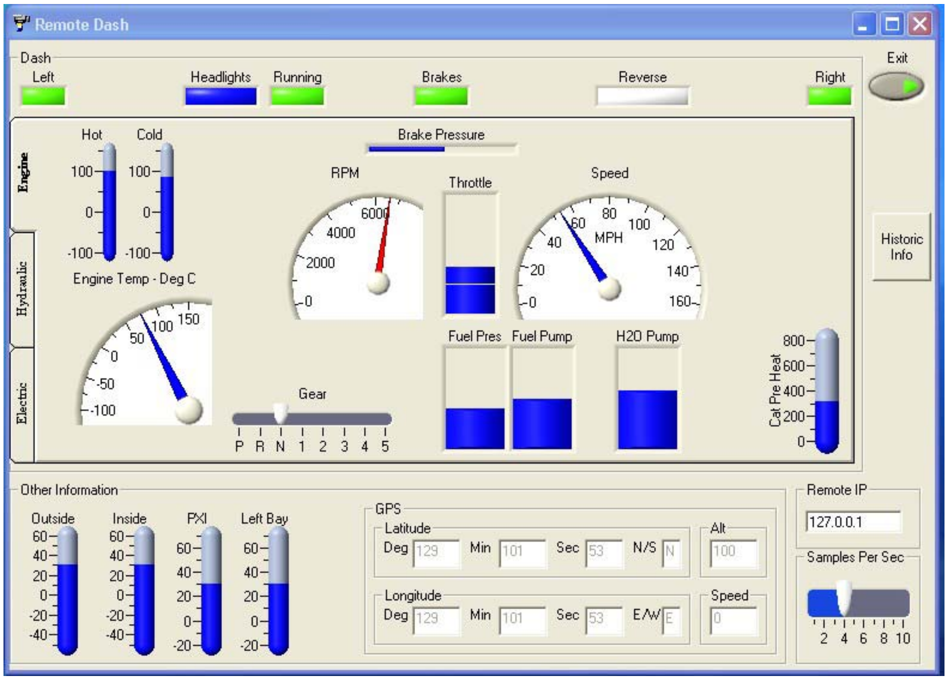
Telematics System

The telematics portion of the competition was designed to bring modern computer technology to the automotive industry. Two parts of this initiative were to provide aviation style black box data recording and to provide advanced diagnostic features for both the driver and the garage technician.

The main goal of the University of Idaho's telematics project was to provide superior black box and remote diagnostics features for the team during the development cycle with the secondary goal of meeting competition requirements for telemetry data. To accomplish this goal, we relied on hardware from National Instruments, Cisco Systems and Planar Technologies, as well as custom-designed software. There were three main custom software packages, the telemetry server/simulator, the remote dashboard, and the glass cockpit.

The remote dashboard was especially useful for showing how the vehicle performed both real-time and after a driving event. The dashboard was designed to have an intuitive look and feel by emulating the behavior of a vehicle dashboard. This software was designed to allow the team, or garage mechanic, to view the full collection of recorded parameters from the truck for testing pieces. The three main abilities of the software were the viewing of live data, viewing of historical data, and the down sampling to a 1Hz sample rate for submission of information at competition (Figs.5-8).

With the need to display more information than a traditional dashboard, we were compelled to change the details of the display. Our design took advantage of the many parameters that the data server transmits with each signal. On many of the dial gauges, we displayed the unit parameter. This allowed us to make changes to the data stream on the server knowing that we did not have to change our client. The minimum and maximum parameters were used to configure the ranges for our indicators. The WarnHigh and WarnLow parameters were used to color the indicators on the display. We chose to standardize on having blue indicate a value that was inside those warning ranges and have red indicate a value that is outside that range, but still inside the range of valid values for that signal. Common lighting indicators found at the top of all dashboards were positioned at the top of our display. On the 2002 Ford Explorer, supplying voltage to both rear turn blinkers activates the brake lights. So, on our display, we activated the brake indicator by doing a logical command on both turn indicators.



Remote IP: 127.0.0.1

GPS

Latitude: Deg 129 Min 101 Sec 53 N/S N

Alt: 100

Longitude: Deg 129 Min 101 Sec 53 E/W E

Speed: 0

Figure 5: Remote dashboard: Engine information.

One of the features that we developed for our remote dashboard was the ability to view recent historical trends of critical information. Figure 8 shows a sample of these historical views in the development software. On all graphs, the X-axis is valued in samples since start. The system was configured to show approximately 60 seconds worth of historical information.

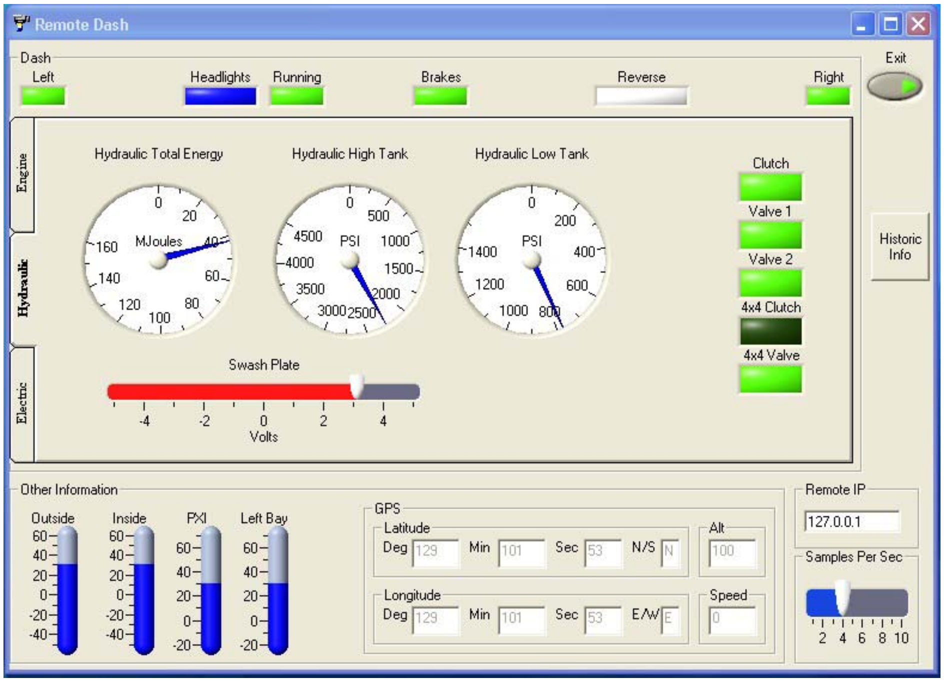


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Figure 6: Remote dashboard: Hydraulic information.

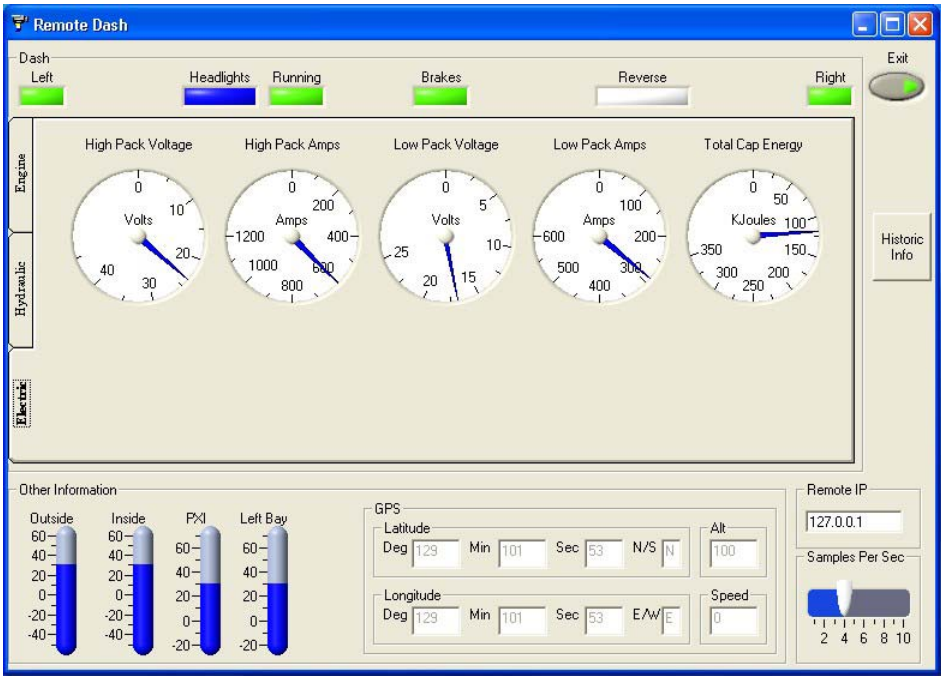

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Figure 7: Remote dashboard: Electrical information.

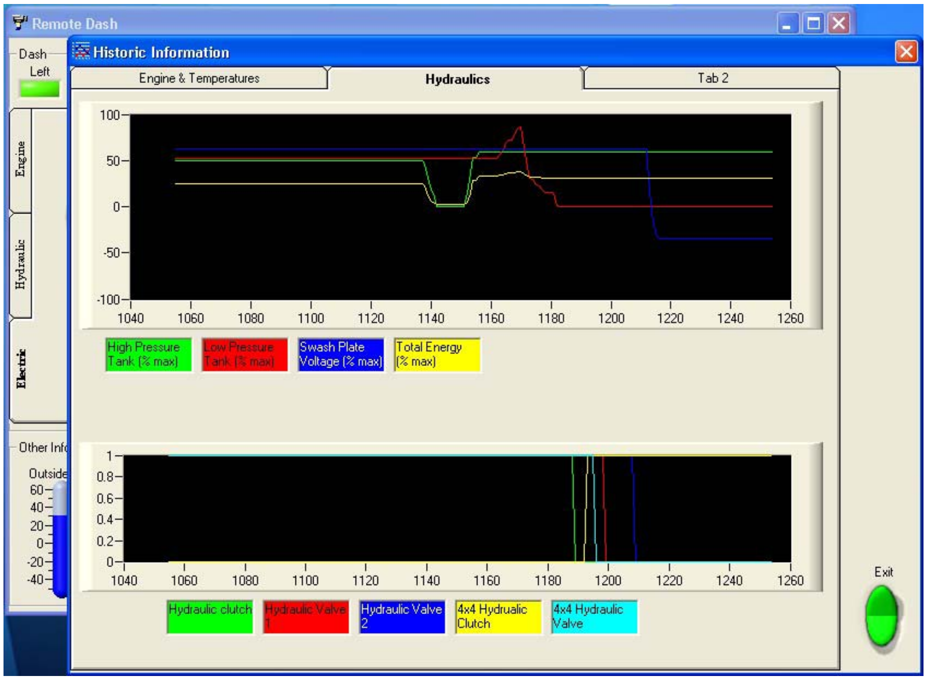

Figure 8: Remote dashboard: Recent hydraulic information

Vehicle Modeling

The AVCT primarily used ADVISOR to predict fuel economy and emissions. ADVISOR is a hybrid electric vehicle (HEV) simulation model written in a widely used software environment called MATLAB/Simulink. The team used ADVISOR to predict the fuel economy of various modifications made to the stock vehicle.

First, a model was created that roughly predicted the fuel economy of the stock vehicle compared to EPA testing. Next, individual modifications were then made in iterations to the stock vehicle, each one adding on to the previous modification. Since the FutureTruck is a mild hybrid, it is very difficult to model the electrical and hydraulic systems together in ADVISOR. Therefore, energy that is released into the vehicle with the hybrid drive systems was individually calculated, and a fuel savings estimate was made (Table 3). Fuel economy of the 2003 Summit versus the 2002 competition FutureTruck is shown in Table 4.

Table 3 Estimated Increase in Fuel Economy for Modifications

	City	Highway
3.0L Engine	2 percent	2 percent
Engine Mod	20 percent	14 percent
Aero Mod	22 percent	18 percent
Electric Hybrid	25 percent	17 percent
Hydraulic Hybrid	44 percent	17 percent

Table 4 Summit Fuel Economy Versus Stock

	City	Hwy
2002 Explorer	15.0 mpg	20.0 mpg
2003 Summit	22.76 mpg	22.6 mpg

Using ADVISOR, simulations in each cycle were run in the following six configurations:

1. Stock 4.0L: Based on EPA testing of the stock 4 Liter 2002 Explorer, an ADVISOR model was created using a modified version of the SUV platform.

2. 3.0L and Lincoln LS transmission: Once the stock vehicle was accurately represented, the engine and transmission were modified to simulate a 3.0 liter engine and a 2000 Lincoln automatic transmission

3. 3.0L engine modification: The 3.0 Liter vehicle was further modified to show the improvements in efficiency from the engine improvements. The efficiency improvements were based on observed improvement from the previous year's testing of the 4.0 liter 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, belly pan and

front air dam. The passive cooling coefficient of drag changes were determined by wind tunnel testing conducted at the University of Idaho.

5. Electric hybrid addition: Since ADVISOR is limited in its ability to model a mild hybrid and a dual hybrid, energy calculations were performed by hand to determine the fuel economy improvements from the electric hybrid system. The energy that will be supplied by the motor during acceleration was compared to the city UDDS cycle.

6. Hydraulic hybrid addition: The method used to model the addition of the hydraulic system in Advisor was quite similar to the method used for the electric hybrid system. The energy used in acceleration was calculated by hand and simply added as an additional amount of energy in the Advisor model.

Student Team

To accomplish the large task of modifying a Ford Explorer, AVCT used a heavyweight team structure. In the heavyweight team, a designated project manager has firm control over all functional areas. In the FutureTruck project, eight functional areas were identified: Power Train, Operations, Public Relations, Ener-Vations, Controls and Telemetrics, Fuel Systems and Emissions, Testing and Experimentation, and Modeling and Simulation. The team structure is shown in Fig. 9. Each functional area had a team leader, which was the point through which all information for the area passed. This reduced communication gaps and ensured that one person in each area would know what needed to be done. The heavyweight team structure puts the responsibility for the work in the hands of the project manager.

Personnel from functional areas are placed on the team under the guidance of the project manager and team leader. This environment gives the team member a great deal of ownership in the team and the project since little bureaucracy occurs between any member and the project manager. Through this feeling of ownership, the team members are well motivated.

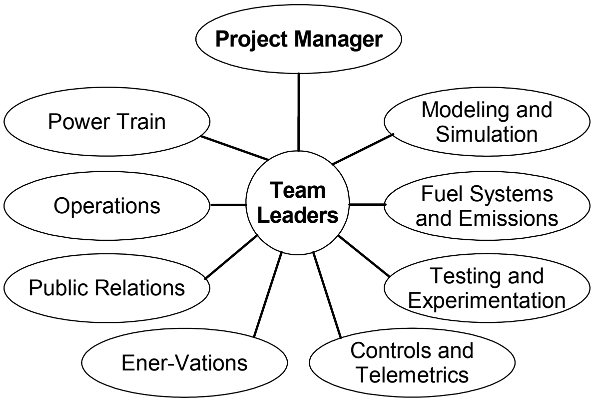

Figure 9. AVCT team structure.

The AVCT team incorporates participants from numerous University departments. Members are from nearly all engineering departments in addition to the departments of business, communications, marketing, computer science, and industrial technology. This diversity in the team population provides a general knowledge base from which truly innovative ideas develop. Cross-functional work of this caliber is paramount in order to accomplish such a large-scale project.

Business Case

Included in the engineering of this vehicle was a business approach to design and implementation. A member of the AVCT was in charge of gathering all price data from the design vehicle and comparing it to the stock Explorer. A complete cost analysis was done to determine what the cost of manufacturing would be. This analysis included life cycle costs, option costs and money saved by better fuel economy.

For instance, one particular option calculated had the electric assist as well as the telemetry and entertainment packages. This package was estimated at about $18,500 in production costs, roughly $7,500 more than a stock Explorer

This data was used in determining what cost savings could be incorporated as well as developing a business case for marketing the final version of the vehicle.

The business case also took into account the intended market and customer expectations. During the design phase of the project, AVCT conducted an online survey of consumer needs and wants (data from this survey is available at www.idahofuturetruck.org.). The team utilized this data to develop some of the design criteria used; such as onboard diagnostics, entertainment system, vehicle utilities and efficiency.

Outreach

Education about clean vehicle technologies was as important to this project as the engineering and evaluation already discussed. Besides educating themselves during the design and development process, the student team also spent time in transferring the lessons learned to outside persons and groups. As a partnership between industry, government, and academia, the FutureTruck competition is structured to encourage the sharing of ideas and information.

Industry was a key player during this project. The primary industrial contact for the student team was the Ford Motor Company mentor. The mentor answered the team's technical questions, obtained proprietary resources, monitored student progress, conducted safety inspections, periodically visited the university campus, and reviewed reports. In addition to Ford, other sponsors such as National Instruments, Cisco Systems, Delphi, The MathWorks, PPG, the Aluminum Association, and Parker Ford of Moscow, Idaho, provided equipment, supplies, software, and technical data. The accelerated level of learning that resulted from using leading edge technology would not have been possible without this support.

The Department of Energy, the government sponsor, teamed up with Argonne National Laboratory as the organizer of the FutureTruck competition. Both of these agencies sought to use FutureTruck as a means to facilitate the nation's transition to cleaner and more efficient vehicles. They organized workshops, disseminated information from complementary projects, developed rules, provided test facilities, arranged public relations events, established avenues for oral presentations and written technical reports, organized the competition, and published results.

While some FutureTruck teams were close to metropolitan areas where they could take advantage of a wide media selection, the AVCT concentrated on small community events such as Vandal Friday, basketball games, the 2003 Engineering Expo, tours in conjunction with Parents' Weekend, a tour of solar homes, and Women in Engineering Day. The team displayed the vehicle to an eighth grade class, two high school classes, at four university events, at an Earth Day show, and at the workplace of two of our local sponsors. The AVCT members described and demonstrated the clean vehicle technologies onboard the vehicle.

Figure 10. Elementary students look inside the FutureTruck.

Findings

This section summarizes the results from testing and competition. Testing, which was performed before and after modifications, consisted of road testing for fuel economy and engine dynamometer testing for emissions. Testing at competition was a comprehensive evaluation of the vehicle's design, safety, performance, and consumer features.

Test Results

Testing included over 2000 miles of city and highway driving and two months of engine dynamometer testing. The engine dynamometer testing determined the effectiveness of emission reduction strategies while on-road testing over a simulated city driving cycle provided fuel economy.

Tailpipe Emissions

The following figures show the effects of thermostat operation and water injection on the quantities of regulated tailpipe emissions produced from the Summit's internal combustion engine.

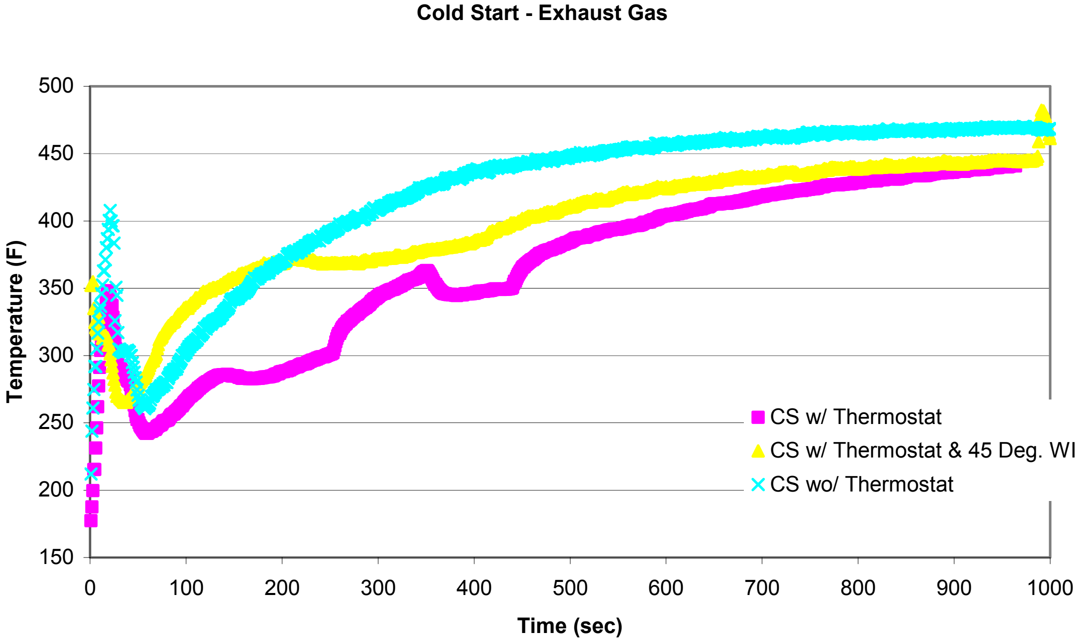

Figure 11: Baseline engine testing.

Figure 11 shows exhaust gas temperature (EGT) versus time. The lower line is of the stock Lincoln LS system, where the next line up is stock system with water injection and top line is stock system with the thermostat removed. This data shows that with the modifications, it is possible to get higher exhaust gas temperatures during cold start, which translates to quicker light off times of the catalytic converter, which will reduce overall emissions significantly. The LS fuel system goes into closed loop control of the fuel system when the temperature of the catalytic converters reaches 300˚ F. In Fig. 11, this can be seen as steep slope change on the stock configuration line at 300˚ F and 270 seconds. With this, it is shown that with the modified cooling system, it is possible to reach this point in only 70 seconds, which is three times quicker then the stock system.

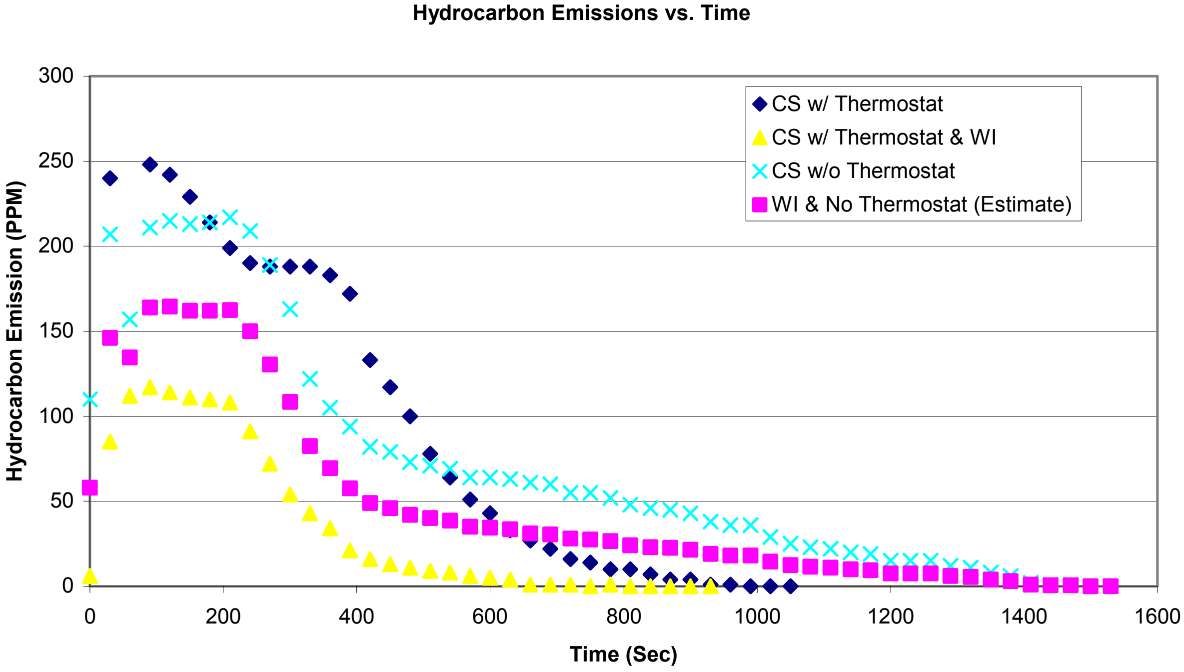

Figure 12. Hydrocarbon emission testing.

Figure 12 shows hydrocarbon emission versus time for three testing cycles. The diamond line shows the stock configuration, the star line is with out thermostat and circle dot line is with water injection. The water injection hydrocarbon emissions are the lowest through the entire cycle. The square dot line is an average of water injection data and no thermostat data, this shows that up to 600 seconds (400˚F EGT) the hydrocarbon emissions are lower by approximately 44 percent. Once this exhaust gas temperature is reached, the control strategy will change out of cold start mode, and return to normal operation keeping emissions what they would be with stock system with the benefits of the new cold start mode.

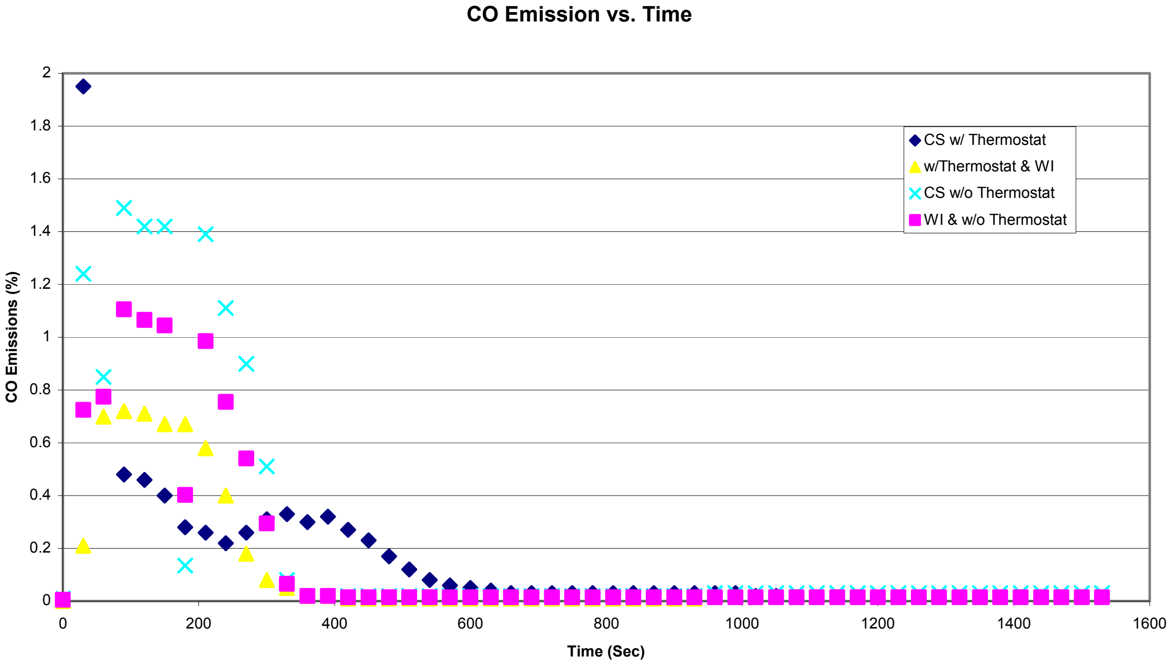

Figure 13: CO emissions testing.

Figure 13 shows that during first 250 seconds of cold start, CO emissions of modified system are higher then stock configuration, but after 250 seconds the modified system's emissions bottom out much faster. The overall difference with the modified system and the stock system is approximately 1 percent.

Figure 14 shows that with the modified system, carbon dioxide CO_2 emissions are lower then the stock system. The total reduction in CO_2 emissions is approximately 16 percent with water injection and no thermostat.

Figure 15 shows that with the modified system, NOx emissions are lower then stock. The modified system reduces overall NOx emissions by approximately 72 percent over a cold start period.

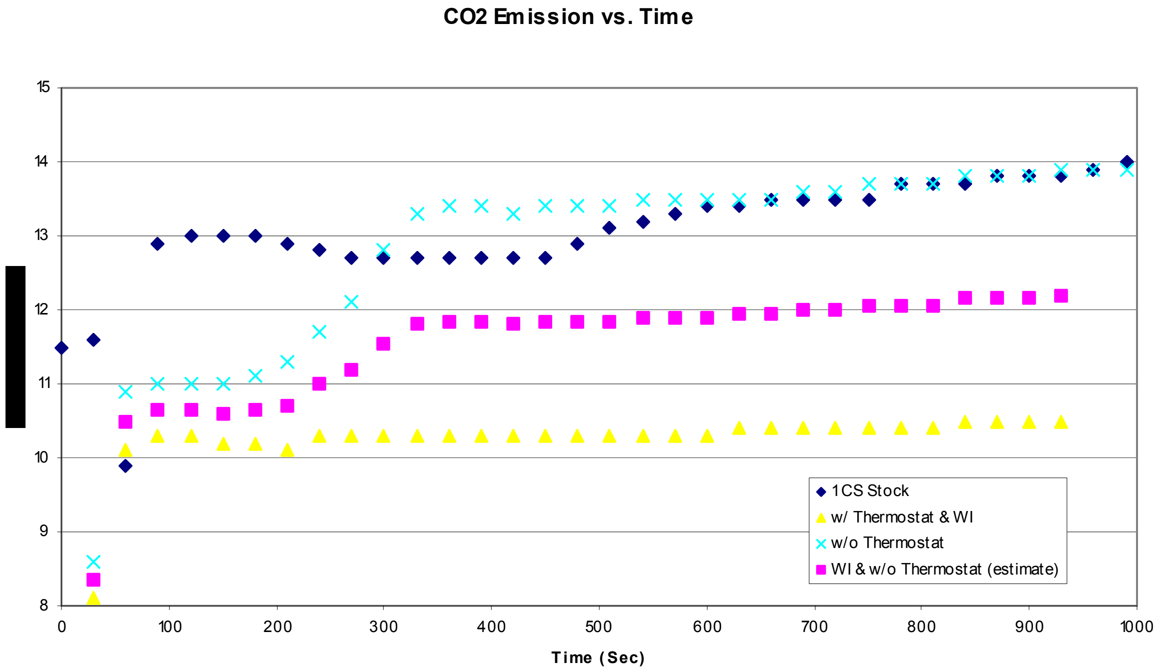

Figure 14: CO_2 emissions testing.

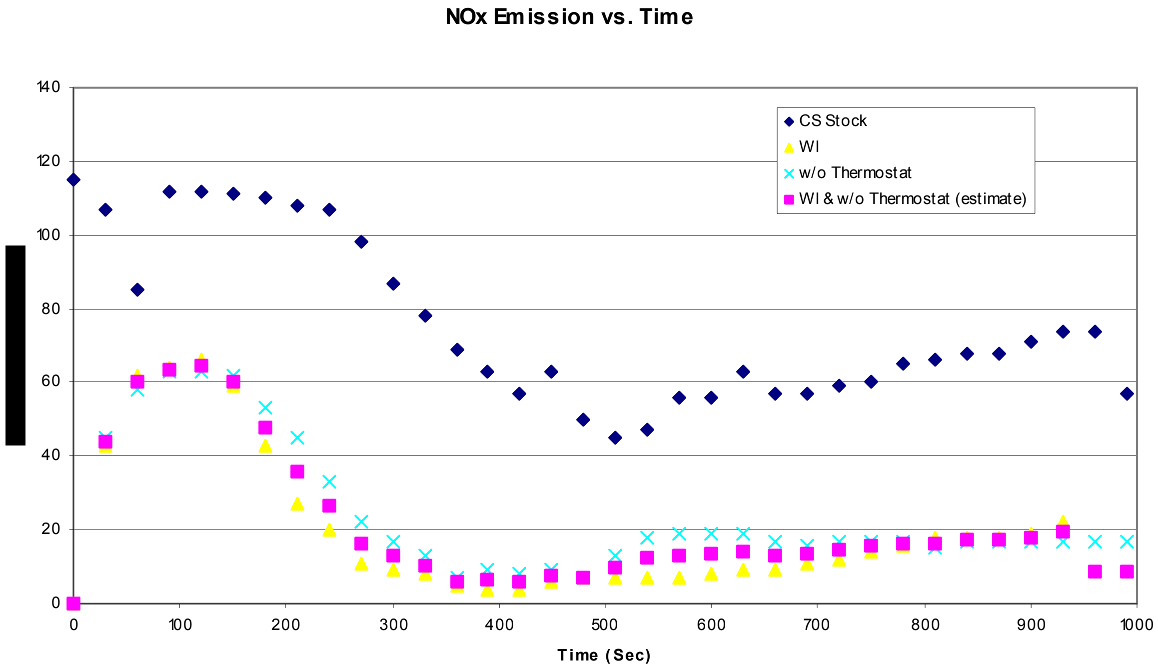

Figure 15: NOx emissions testing.

Fuel Economy

Fuel economy testing was conducted over a three-mile city loop around the University of Idaho campus. The loop consisted of changes in elevation, flat portions, and stop-and-go driving to accurately simulate real-world driving. Since air consumption is a direct correlation to fuel consumed, the vehicle stock mass-flow rate sensor was used to measure air consumption.

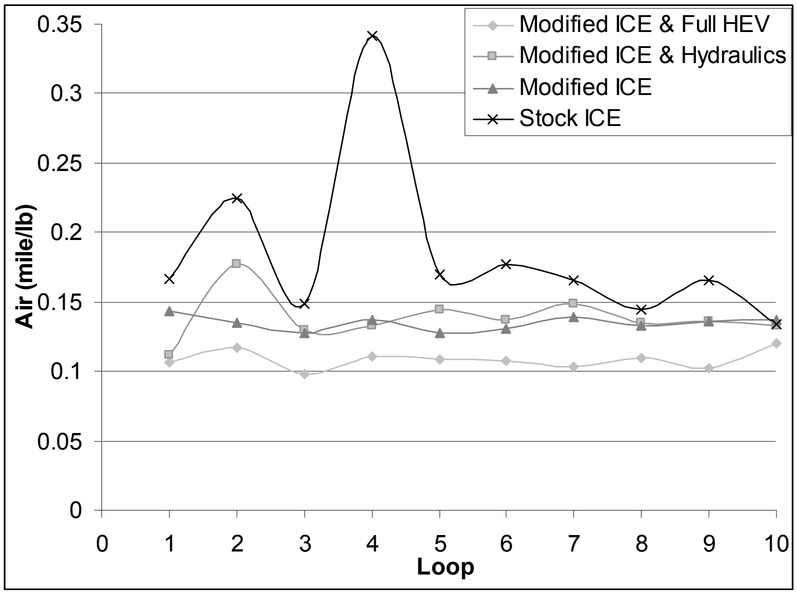

Figure 16: Fuel economy testing.

This data (Fig. 16) shows full HEV mode improved fuel economy 41 percent compared to the stock vehicle and 19 percent over the modified ICE

Competition Results

At the June 2003 FutureTruck competition at Ford's Michigan Proving Ground, the Summit placed 11th out of 15 vehicles. Successes included a telematics award and fully functional electric and hydraulic systems during all competition events. During the 105-mile fuel economy and acceleration events, the systems performed without incident. However, lack of refinement in the hydraulics system and problems with the vehicle's internal combustion engine were setbacks.

The primary problem with the hydraulics centered on the design concept of providing regenerative braking, power assist, and extended four wheel drive with the same system. With a myriad of hoses and valves, the system was complex with many opportunities for failure. During competition, the energy captured during regenerative braking and stored in the high pressure accumulator tank would drain back to other parts of the system before the energy could be utilized for power assist. In addition, the engine–driven pump would periodically operate to readjust pressures as specified by the control system. These inefficiencies had a negative effect on fuel economy.

Problems with the internal combustion engine included failure of the accelerator cable, dirt in the fuel system, and failure of the engine management system to operate in closed loop mode. The breakdowns resulted in a loss of points, and having to operate in a back-up, open loop mode increased the tailpipe emissions.

The telematics system received a second place award for best design. Cisco Systems, a headline sponsor, presented this award.

CONCLUSION

The University of Idaho Advanced Vehicles Concepts Team successfully modified a 2002 Ford Explorer SUV into a unique, mild-hybrid vehicle to improve fuel economy and reduce emissions. With both electrics and hydraulics providing regenerative braking and power assist on a city-driving loop, fuel economy increased by 41 percent compared to the stock vehicle. By utilizing computerized cooling control, water injection, and vacuum packed catalytic converters during engine cold start, hydrocarbons decreased by 44 percent compared to the stock engine.

The telematics system, which included specialized controls and displays for hybrid operation and vehicle entertainment, earned a second place award at competition for the best design.

The backbone of this project was the multi-disciplinary team, which represented a large cross-section of the UI student population. By implementing a professional, business approach for this project, the team safely modified and tested a modern SUV while gaining valuable knowledge and experience. By conducting a series of public relations events and partnering with industry and government, the student team successfully transferred their enthusiasm and knowledge about clean vehicle technologies to a broad spectrum of people.

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