Special 2010 FED Edition

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FED ALPHA REVEALED!

Meeting Tomorrow's Operational Energy Challenges Today
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TARDEC

Meeting Tomorrow's Operational Energy Challenges Today

Alan R. Shaffer

Energy security is a national challenge. Since World War I, every conflict in which the U.S. Military has engaged has been shaped by the use and movement of fuel. Consequently, the Department of Defense (DoD) is committed to reducing the demand for energy in the form of both conventional fuels and electricity, and increasing the supply of assured or alternative energy sources to reduce the Nation's and military's long-term dependence on non-domestic energy sources.

In May 2006, the Office of the Secretary of Defense initiated an Energy Security Task Force to integrate disparate energy efforts across functional and organizational lines. The Task Force assessed fuel consumption of existing ground vehicle platforms and facilities, and then identified the largest energy consumers. The Task Force also examined the validity and performance of on-going programs and assessed the emerging needs for future programs to increase energy efficiency and develop novel technology-based alternatives. Using consumption rates as a key benchmark, the Task Force recommended 20 programmatic options to reduce energy consumption across DoD. One such project was funded in the President's Fiscal Year 2008 Budget Request — TARDEC's Fuel Efficient Ground Vehicle Demonstrator (FED).

Since fuel is the second-highest battlefield throughput commodity behind water, reductions in fuel consumption by our combat and tactical vehicle fleets will provide operational commanders greater freedom of action and mobility, and reduce the vulnerability of warfighter logistics elements in the theater of operations. At the tactical level, improved fuel economy will provide greater legs to our ground forces, further enhancing their combat effectiveness.

The concept of increasing the fuel efficiency of our military equipment, thereby reducing energy usage and distribution requirements, is not a new one. We know that shrinking the military services' dependence on fuel would reduce transportation requirements and decrease the number of Soldiers placed in harm's way. However, current operational contingencies in an era of persistent conflict have led to increased vehicle weight for added armor protection and greater communications payloads which, in turn, increase fuel consumption and drives down fuel efficiency across the fleet.

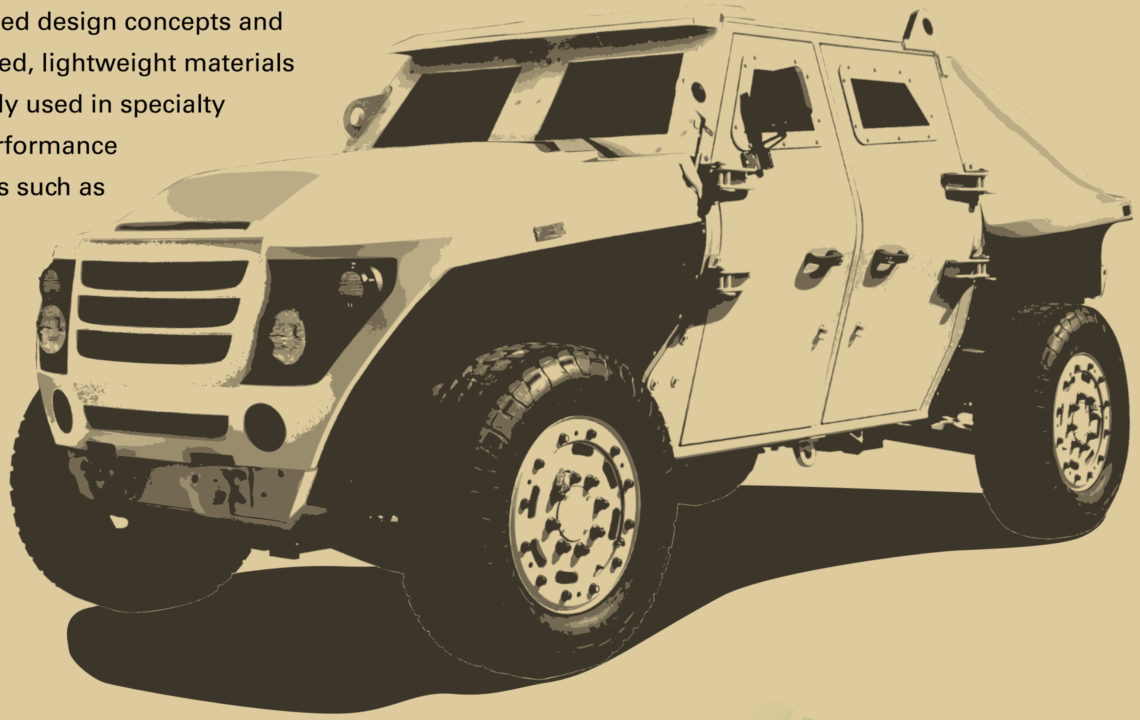
Make no mistake — keeping our warfighters safe is the department's top priority! Integrating systems engineered, energy-efficient capabilities into current and future combat and tactical vehicle fleets is a close second. Both priorities will, ultimately, provide our fighting force with unprecedented lethality and survivability, and accelerate the delivery of overmatch capabilities that will serve as significant deterrents against potential combatants.

TARDEC's FED program was conceived with the idea of demonstrating — using a systems engineering approach — what fuel efficiency is achievable in hardware operating in a realistic military environment and at what cost. To address this challenge, TARDEC formed two teams comprised of the brightest and best from government and industry. Expertise ranged from novel and non-traditional design, advanced automotive engineering and prototyping, to manufacturing expertise in military, specialty and performance vehicles (e.g., motor sports). The primary focus of these teams was to create a state-of-the-art fuel-efficient tactical vehicle from a 'clean sheet of paper' with the only design constraints being the requirement to achieve the maximum fuel efficiency possible without degrading the performance requirements or capabilities (i.e., reliability, survivability, mobility, operations and sustainment costs, etc.) of the M1114 uparmored High-Mobility Multipurpose Wheeled Vehicle (HMMWV). This approach should result in an apples-to-apples comparison.

What made this initiative truly different is that TARDEC used novel approaches to create an environment that promoted and fostered innovative ideas and continually challenged the status quo in design and manufacturing. By creating an environment that enabled engineers and designers to focus on innovation and the art of the possible, they leveraged the various science and technology investments made by DoD and industry — such as advanced vehicle propulsion, composite materials and structures, hybrid-electric power and energy, and modeling and simulation. Equally as important was the fact that these demonstrators would also draw from optimized design concepts and improved, lightweight materials currently used in specialty and performance vehicles such as NASCAR and Le Mans series race cars. In racing, if a component can't perform multiple tasks, it doesn't go on the car. This exposure to new approaches to design, manufacturing, system integration and maintenance will raise the bar for overall government fleet development. Industry also stands to gain from this effort with increased awareness of military vehicle requirements.

At the conclusion of this effort, the two FED demonstrators will not only show us what fuel efficiency is achievable, but will also inform new and existing programs (i.e., Joint Light Tactical Vehicle, HMMWV recap, etc.) and provide decision makers with additional insight regarding what is the art of the possible in achieving improved fuel economy.

Alan R. Shaffer
Principal Deputy, Office of the Secretary of Defense (Acquisition, Technology and Logistics) and Director, Defense Research and Engineering



FED

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U.S. ARMY RDECOM
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

TARDEC

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Innovative Systems-Engineered Designs Deliver Game-Changing Fuel-Efficient Tactical Vehicle Solutions

The Fuel Efficient Ground Vehicle Demonstrator (FED) Program was initiated by the Office of the Secretary of Defense to address energy conservation needs highlighted by the Defense Science Board's Energy Security Task Force. The overarching program goals are to improve military vehicle technology to reduce fuel consumption on the battlefield, and reduce U.S. ground and expeditionary forces' dependency on foreign oil for battlefield mobility.

Background

By forming a team of recognized government and industry subject-matter experts (SMEs), the FED Program Manager (PM) identified and engaged key industry SMEs with demonstrated expertise in novel and innovative design configuration, advanced automotive engineering and systems integration. Additionally, innovators with prototyping and manufacturing proficiency in military, specialty and high-performance vehicles (e.g., motor sports) were actively recruited. The Tank Automotive Research, Development and Engineering Center's (TARDEC's) crucial contributions were advanced computational and powertrain modeling expertise, and knowledge of future Army vehicle requirements, among others.

The TARDEC PM then surveyed government and industry experts to identify and harvest potential manufacturing and systems integration expertise in existing fuel-efficient commercial-off-the-shelf technologies, lightweight and composite materials, and fuel-efficient vehicles and systems components. His strategy was to quickly leverage government and industry modeling and simulation (M&S) capabilities to build an aerodynamic virtual vehicle that would enable engineers to predict performance outcomes and duty cycles, set objectives, refine design concepts and establish test criteria that would tap into the latest developments in fuel efficiency and power management.

Where Form Meets Function

Using well-documented M1114 Up-armored High Mobility Multipurpose Wheeled Vehicle test data and analyses collected from extensive pre-deployment ground testing and evaluation, and actual performance data compiled from the theater of operations, the government/industry team of engineers and designers set baseline performance standards against which the FED concept vehicle was evaluated. By using this collected data, the program management team was able to accurately model, and then assess, the demonstrator vehicle's potential mobility, performance, payload capacity and survivability capabilities against actual battlefield and environmental performance thresholds. The objective: demonstrate potential fuel efficiency achievement in hardware with an advanced, fuel-efficient, lightweight tactical vehicle demonstrator.

Integrating Engineering Design and Innovation

The FED Program was designed to be innovative on a variety of levels, including how technology was selected, integrated and transitioned to the final vehicle configurations. Key upfront decisions — use a 'Monster Garage' process to select candidate fuel-efficient technologies for possible transition; and have TARDEC engineers work side-by-side with industry innovators and automotive engineering experts — have led us to potential technology solutions that will be profiled in this special *accelerate* Magazine edition.

This program has exposed our engineers and modelers to novel and innovative design approaches, advanced automotive and systems engineering practices, and industry methodologies that are incorporated into standard manufacturing processes. As anticipated, the by-product of this experience was having our engineers and designers approach the fuel-efficiency challenge differently than they had on past tactical vehicle platforms. Once test and evaluation is completed on both vehicle demonstrators in Fiscal Year 2011, I believe each vehicle's fuel efficiency performance data will speak for itself, providing the Army substantive engineering and M&S data for potential integration into future tactical vehicle systems.

Please take a few moments to review the articles and information we have compiled about the FED Program for you, and learn how this collaborative venture will potentially benefit our Army and U.S. Marine Corps partners with innovative, advanced technology solutions that will make the next generation of military tactical vehicles more maneuverable, sustainable, survivable *and* fuel efficient.

Thomas Mathes
Executive Director of Product Development

Fuel-Saving Design and Engineering Drive the Army's FED Program

Carl Johnson

Image above and below courtesy of AJ Mueller Photography/ Ricardo North America.

When engineers mount low-rolling-resistance tires on a Fuel Efficient Ground Vehicle Demonstrator (FED), the estimated miles-per-gallon improvement is approximately 7 percent. That may seem modest, but if the Army were to install low-rolling-resistance tires on its entire fleet of tactical vehicles, the resulting 7 percent jump in fuel economy could roughly translate to approximately $45 million in saved fuel costs per year based on recent cost estimates. "It would pay for itself in a year," remarked Thomas Mathes, Executive Director for Product Development at the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC).

The efficiency gains made by switching to an energy-saving tire represents just one lesson derived from the Office of the Secretary of Defense- (OSD-) funded FED program, which has prompted Army engineers to think in new and productive ways about fuel economy solutions that can be applied across the Army's ground vehicle fleet. It's also one piece in a mosaic of ingredients, including lightweight chassis and components, low-friction parts and other high-efficiency technology that, when combined using a systems engineering approach, is expected to increase fuel economy by at least 70 percent.

As the owner of the world's largest ground vehicle fleet, the U.S. Army has a significant stake in lowering its overall fuel consumption without sacrificing vehicle payload, protection or performance. To that end, OSD began programs to address fuel economy challenges. TARDEC's FED program involves collaboration with automotive partners and suppliers, including companies such as Goodyear, which supplied the custom-compounded, low-rolling-resistance, 22.5-inch tires. The program has applied a systems engineering approach to military vehicle technology design and development following two distinct and different intellectual approaches — one rooted in a traditional, highly analytic engineering process, and another engaged in a more unconventional brainstorming method to promote innovation and foster creativity. Either way, solutions tested and refined on the demonstrator vehicles could be transitioned and integrated into other Army ground vehicle systems.

"TARDEC is the Nation's leading ground vehicle systems integrator, so it is vitally important that we leverage technology, expertise and research existing outside our organization for the military."

FED Systems Engineers Explore New Approach

To succinctly evaluate vehicle technologies that save fuel and keep Soldiers safe, the FED Program tapped into the U.S. Army TACOM Life Cycle Management Command's (LCMC's) expertise, energy and enthusiasm, fully integrating the collaborative community's knowledge and capabilities. "TARDEC is the Department of Defense's (DoD's) leading ground vehicle systems integrator, so it is vitally important that we leverage the world's intellectual capital for automotive ground vehicles to ensure the department's current and future needs are met," explained Mathes. "TARDEC designed the FED Program to employ automotive proficiency and aptitude for the benefit of our Nation and its warfighters. At the same time, we are building crucial academic and industry partnerships that assist TARDEC in maintaining an elevated level of systems engineering success."

FED Program objectives include:

- Identifying and assessing new, fuel-efficient vehicle technologies.
- Maintaining tactical vehicle capability while increasing fuel efficiency.
- Investing in developing the next generation of government scientists and engineers.
- Demonstrating promising fuel-efficient technologies in hardware against the baseline performance of an M1114 High Mobility Multipurpose Wheeled Vehicle.

"TARDEC did a marvelous job doing incredible systems engineering and cost tradeoffs, coming out with two comparable vehicles that will get anywhere from 30 to maybe 50 to 70 percent energy reduction... The FED has been a tremendous success, bringing together various aspects of research, industry and systems engineering to deliver two prototype vehicles."

In 2009, the FED Program issued contracts to two technical engineering companies: Utah-based Select Engineering Services (SES) and Maryland-based World Technical Services Inc. (WTSI). Subsequently, SES brought Detroit's Ricardo plc onto the team to provide automotive and racing expertise. Employing a "dual-track" approach to vehicle development and fabrication was just one unique FED Program aspect.

Embedded Engineers Assist With Development

One team followed a more traditional development path. TARDEC engineers Allen Rubel, Richard Chase, Matt Collins and Alan Cichosz were embedded with the contractor-led team at Ricardo to perform different roles within the FED build team, including helping the contractor produce concepts, designs and data to support a set of military vehicle requirements. Rubel began working with the team early in the design process to learn about Ricardo's systems engineering processes, acquire TARDEC resources for the FED and share knowledge gained in theater to ensure the FED is a credible tactical military vehicle. Chase worked closely with Ricardo's electrical controls team in designing the FED vehicle's user interface. Collins supported the design of interior components and managed the receiving and cataloging of parts coming into the Ricardo garage. Cichosz used computer-aided design (CAD) tools to complete the final FED CAD package.

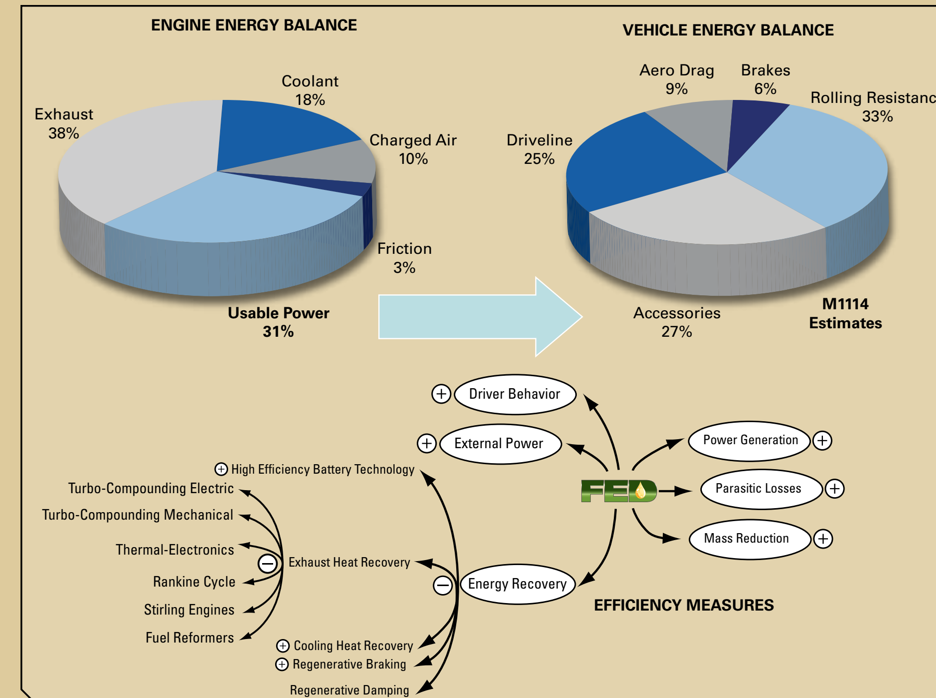
Together, the team employed a rigorous modeling and simulation (M&S) approach to understand potential energy savings and increase engine balance, which reduces vibration and other stresses, to potentially enhance performance and reliability, as illustrated in the figure. The engineers used CAD and computer programming software, along with wrenches, to help manage, design and build the vehicles. Initial assembly on the FED Alpha was completed in September 2010. The vehicle will then go through the contractor's commissioning process and be delivered to the government by year end. The embedded engineers will facilitate this transition and be prepared to provide support when the vehicle arrives at Aberdeen Proving Ground (APG), MD, in early 2011.

In addition to its Goodyear low-rolling-resistance tires, which minimize the energy wasted as heat between the tire and the road, the FED Alpha vehicle is expected to boost fuel economy from approximately 4 MPG to an average of 7.1 MPG on a typical urban patrol mission, using several designed components to achieve efficiencies:

- Optimized Cummins super/turbocharged 200-horsepower, 4.5-liter, inline 4-cylinder diesel engine.
- Alcoa Defense lightweight aluminum monocoque armored cab with underbody blast shield.
- Performance friction low-drag aluminum brake calipers.
- REM Chemical Isotropic Superfinishing gears — a finishing process often used in racing vehicles to reduce friction and vibration and improve shifting.
- Continental Teves accelerator force feedback pedal, which cues the driver to accelerate the vehicle for optimal efficiency.
- Carbon fiber body panels, which reduce weight and increase rigidity.

'Monster Garage' Brings Together Top Experts

On a separate track, the second team applied a 'Monster Garage-' like process to build FED Bravo. This TARDEC-led government-industry team of subject-matter experts (SMEs) sifted through the most innovative and compelling fuel-efficient technologies available in industry. The 'Monster Garage' process



This graphic illustrates the FED Program's evolutionary systems engineering approach to improving engine balance to reduce vibration and other stressors that may hinder vehicle performance, fuel consumption and reliability. (Image courtesy of Ricardo plc.)

brought together the brightest and best government, industry and academia representatives from around the country to focus on the U.S. military's ground vehicle fuel consumption and logistics burden to build FED Bravo. These experts examined vehicle tradeoffs using a top-down, systems-level approach with fuel efficiency and performance as primary requirements. During the second phase, the government-led team worked hand-in-hand to design the FED, leveraging 'Monster Garage' results and continuing the collaborative effort through partnerships with various technology industries. In addition, engineers worked directly with students from the College for Creative Studies (CCS), Detroit, MI, through a sponsored project to explore new ideas with tomorrow's innovators.

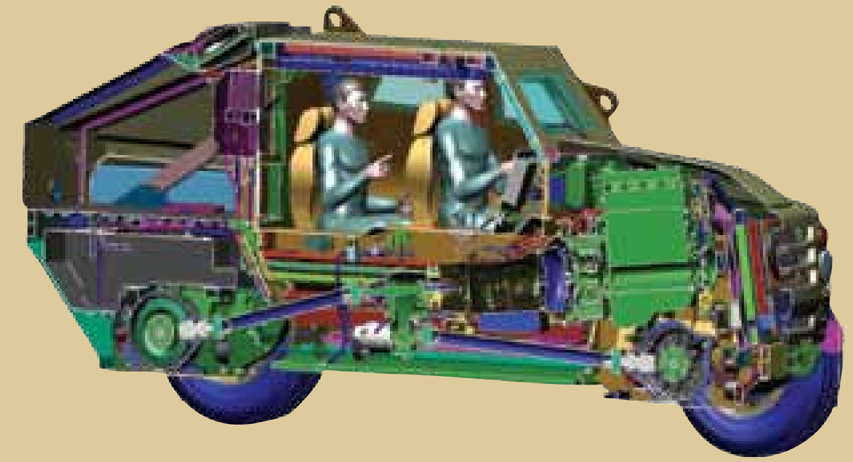
During the second phase, several companies' technologies were reviewed for each system within the vehicle. The team worked with multiple suppliers to pursue solutions that met FED requirements and specifications that would provide fuel-efficiency benefits. The collaboration between TARDEC and WTSI also included prime power engine and controller development, computational fluid dynamics analysis, propulsion system M&S, and dynamic and structural analysis performed by several TARDEC engineers. "One unique aspect of this government-led collaborative effort is that WTSI will be providing complete source code for the hybrid system controller," remarked WTSI Engineer Brandon Card. "This is understood to be a first and will be the foundation for continuing the development of TARDEC engineers' knowledge and understanding of propulsion system optimization for fuel efficiency."

TARDEC FED Team Leader Carl Johnson (right) explains the significance of the FED concept vehicle to TACOM LCMC Commanding General MG Kurt J. Stein (center) while TARDEC National Automotive Center Director Paul F. Skalny looks on during the Society of Automotive Engineers 2010 World Congress in April. Creating and improving the design for the FED concept vehicle has been a collaborative effort across the TACOM LCMC, industry and academia. (U.S. Army TARDEC photo by Elizabeth Carnegie.)

A final design review was conducted in September, with fabrication scheduled to begin in late 2010, and vehicle assembly slated for early 2011. Following a summer of final calibration and tuning, the government-led collaborative FED will begin shake-out testing and then launch into full test mode during the following months.

M&S Capabilities Support Demonstrators

Both approaches incorporate cutting-edge M&S capabilities, allowing teams to predict vehicle performance and optimize clean-sheet, systems-level engineering and design solutions. The FED Program also provided teams with critical support, including Lean Six Sigma tools, structured innovation training and theory of problem-solving historical benchmarking resources.



By leveraging automotive systems engineering, the FED Program was able to accelerate the traditional design process from concept to build in just 15 months. (Image courtesy of Ricardo plc.)

To deliver the best end-product possible, the FED Program established a rigorous validation process to ensure that the proposed vehicle designs and technologies met the needs of stakeholders and customers. This process was used to evaluate the six vehicle architectures that were considered by the teams.

Propulsion systems studied included dual internal combustion engine technology, series hybrid and parallel hybrid architectures, and conventional, lightweight modern diesel engines with integrated starter generators. Transmission technologies — such as 32-speed binary logic transmissions and suspension concepts that use adjustable height suspensions — were also contemplated for the concept designs. Other technologies, such as low-friction coatings, advanced synthetic lubricants, Lithium-ion batteries, advanced body materials, ceramic brake rotors, aluminum wiring, regenerative braking, central tire inflation systems, driver feedback, V-shaped hulls, isotropic finishes and remotely operated weapon stations, were investigated to lower fuel consumption.

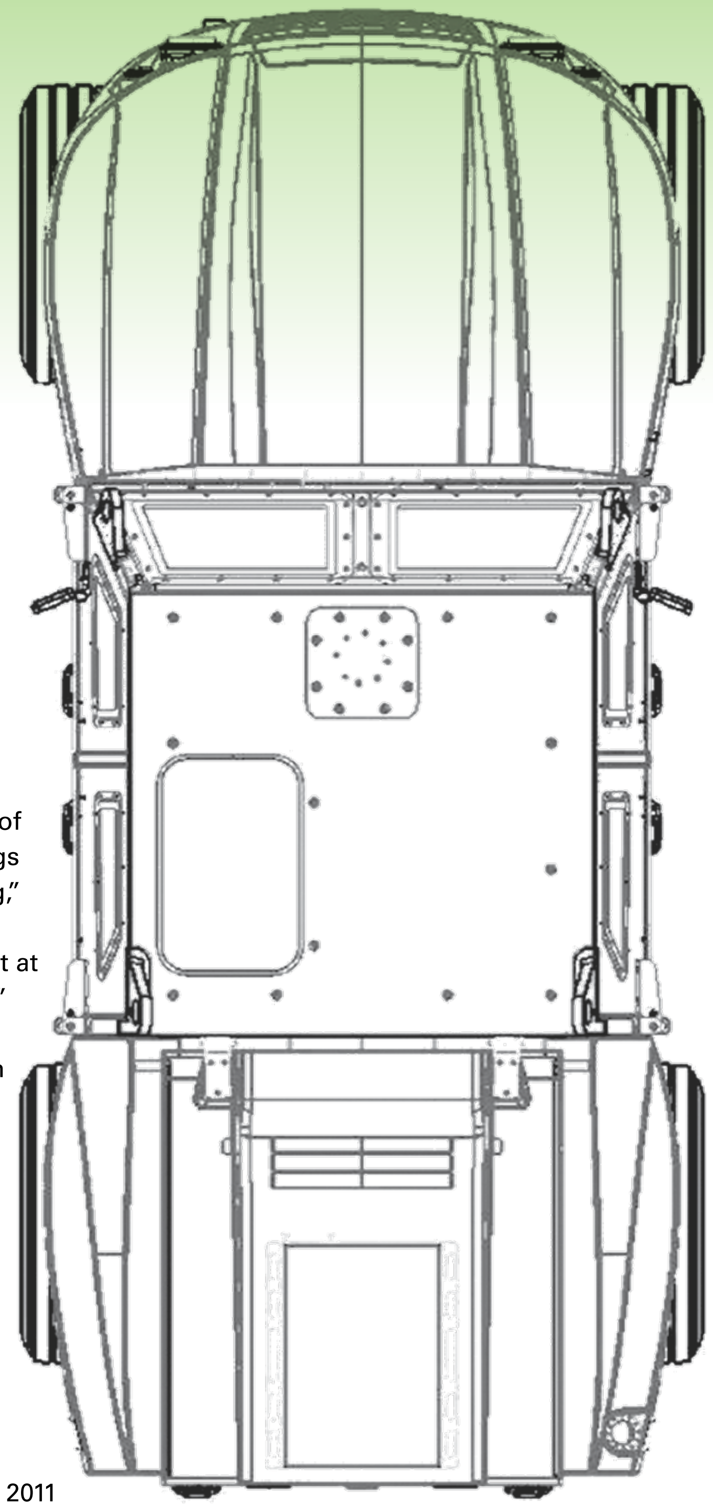
The FED Program's unique approach to addressing fuel economy has been lauded by those throughout government for its innovative and collaborative nature. "TARDEC did a marvelous job doing incredible systems engineering and cost tradeoffs, coming out with two comparable vehicles that will get anywhere from 30 to maybe 50 to 70 percent energy reduction," remarked Alan R. Shaffer, Principal Deputy, OSD (Acquisition, Technology and Logistics)/Director, Defense Research and Engineering. "That's what this is all about — how do we think about delivering capabilities without hurting survivability or taking capability away from our Soldiers? The FED has been a tremendous success, bringing together various aspects of research, industry and systems engineering to deliver two prototype vehicles."

TARDEC will begin testing the two demonstrator vehicles at APG in mid-2011. Thus far, M&S evaluations are forecasting improvements in fuel economy by approximately 70 percent without sacrificing payload, protection or performance.

Carl Johnson is the FED Vehicle Program Team Leader. He has a B.S. degree in electrical engineering from Michigan Technological University.

Modeling the FED — New Concepts, New Techniques

Chris Williams



While designing the new Fuel Efficient Ground Vehicle Demonstrator (FED), U.S. Army engineers weren't just building a vehicle that would apply innovative solutions for increasing fuel economy. They were also forging new systems design techniques.

For instance, cooling plays an important part in system design and fuel efficiency for military vehicles. Shape also affects fuel efficiency. Consequently, the Army's traditionally boxy vehicle designs would need a major makeover for the FED platforms to achieve true fuel efficiencies. To better understand cooling and aerodynamic concerns, engineers turned to the U.S. Army Tank Automotive Research, Development and Engineering Center's (TARDEC's) Computational Fluid Dynamics team within the Concepts, Analysis Systems Simulation and Integration (CASSI) group.

"They basically do all the aerodynamics work in terms of airflow and how to position things. They did some things that helped us, particularly with under-the-hood cooling," FED Team Leader Carl Johnson remarked. "They really brought out a new capability that didn't previously exist at TARDEC and which none of our contractors had, either."

TARDEC's CASSI group was fully involved in the design of the two FED demonstrators. To do this required not just an understanding of vehicle space, weight, power and cooling (SWAP-C) concerns, but also new research into fuel efficiency and aerodynamics. "We don't normally design vehicles for fuel efficiency; we design vehicles for protection or payload," Johnson explained. "What might be very efficient from a space claim and packaging standpoint may not be very efficient from a fuel standpoint."

The first FED demonstrator, FED Alpha, to emerge from this ambitious collaboration will go into testing in early 2011 at the Aberdeen Proving Ground (APG), MD. The vehicle itself, a variation on the conventional military motif, will see action only on test tracks and in labs. As a demonstrator, it will help engineers validate systems and components, modeling and simulation (M&S) tools and techniques, and identify new technologies that can then be transitioned into the current and future fleet of ground vehicles.

Meeting Mission-Effectiveness Vehicle and Relevancy Challenges

TARDEC's Advanced Concepts team was involved with the FED Program from the start. Engineers used advanced computational modeling to design the FED platforms, creating a demonstrator vehicle that uses the latest developments in fuel efficiency and power management. However, designing a fuel-efficient *and* mission-effective vehicle posed some major engineering challenges.

While proven solutions exist to improve fuel efficiency, not all are suitable to meet the power needs of the Army's fleet of heavy, electronics-intensive ground vehicles. "You could use the University of Michigan's solar car to get 3,000 miles per gallon, but then it's not mission-effective [for Soldiers]," Johnson stated. "We identified several vehicle requirements, such as it should be able to cross the terrain at APG and be able to generate onboard power. Our biggest concern was how to make the vehicle relevant."

As TARDEC associates designed the FED, they worked from existing vehicle platform baselines to understand where to place seats, engines, equipment and other necessary items without over-burdening SWAP-C requirements. In designing the vehicle, TARDEC engineers used the High Mobility Multipurpose Wheeled Vehicle (HMMWV) as their baseline, but also maintained an awareness of future Army vehicle requirements to make the platforms relevant.

"The requirements that we came up with were derived from the HMMWV, but we also looked at future programs like the Joint Light Tactical Vehicle [JLTV] and said, 'What growth happened between HMMWV and JLTV?' To keep the vehicles relevant, we designed the vehicle with a V-shaped hull because of today's threat," Johnson explained. "The other thing we knew we needed was an integrated starter-generator [ISG], because onboard power is very important. To paraphrase MG [James R.] Chambers, the Army has no intention of applying appetite suppressant to its power needs. So we made the conscious decision to keep the FED relevant to current and future vehicle needs, which makes a direct comparison to a HMMWV a little tricky because we have requirements beyond that."

"We don't normally design vehicles for fuel efficiency; we design vehicles for protection or payload. What might be very efficient from a space claim and packaging standpoint, may not be very efficient from a fuel standpoint."

Filling Fuel-Efficiency Gaps

A challenge faced in creating the FED's computational models concerned the vehicle technology used to achieve high fuel efficiency. At the program's outset, few models existed to rank vehicle fuel efficiency standards or what available models would provide the greatest fuel economy improvement. For decades, military vehicles were designed for range, and fuel economy was rarely a consideration. The Advanced Concepts team leveraged the CASSI analytical team's expertise to obtain a better understanding of fuel-efficient designs, concepts and powertrain technologies.

Drafting the Most Promising Concepts

The CASSI Powertrain M&S team supported the FED Program through the use of propulsion system models to guide the program through each phase. Powertrain team members participated in the preliminary working group sessions, which spawned a series of powertrain architecture concepts that might meet FED Program needs. The Powertrain M&S team then took those concepts and fleshed them out to include individual propulsion system components and performance characteristics before putting into action an M&S-based analysis plan to down-select the most promising concepts. The analysis plan included deriving peacetime and wartime drive cycles to predict total fuel consumption.

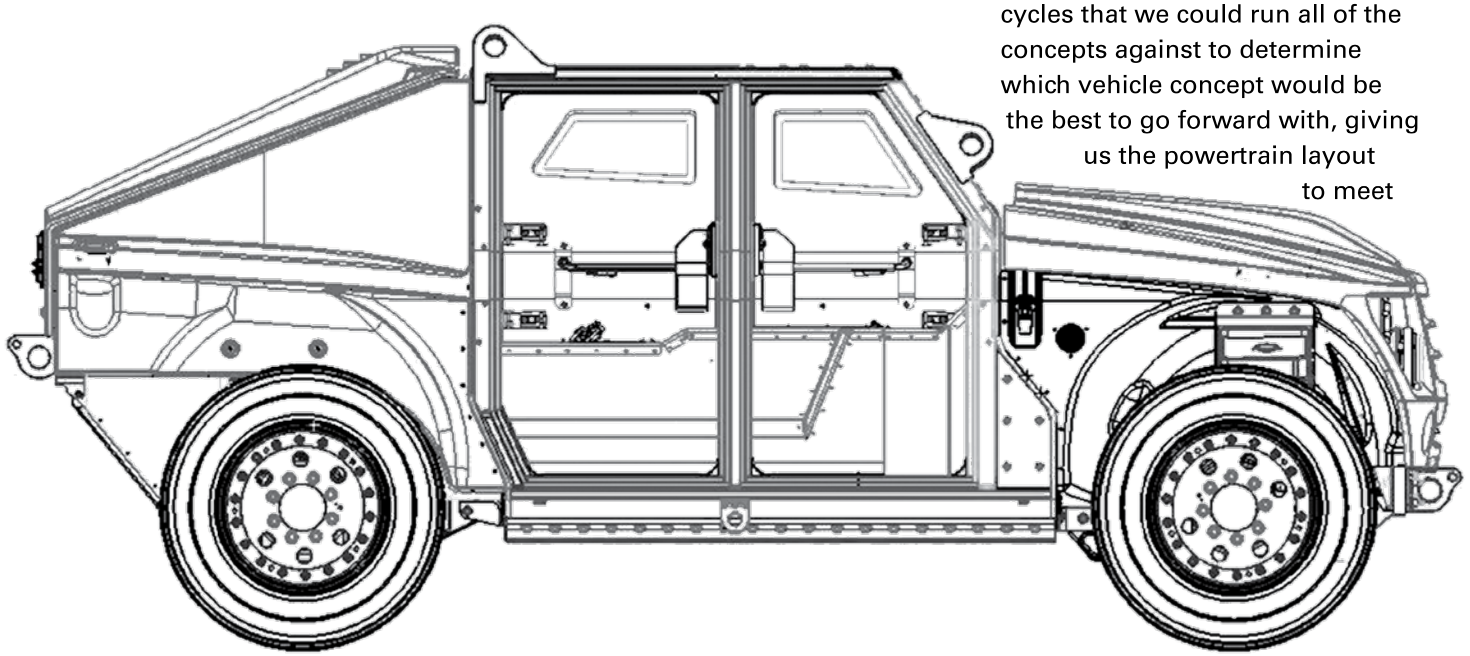
The powertrain team also developed preliminary concept models and established consistency throughout the concept evaluation in such areas as gross vehicle weight, electrical (hotel) loads, fan power and auxiliary power requirements, to establish a level playing field for evaluating all concepts.

Next, the powertrain team populated the model templates with real-world performance data for all components, trying to minimize assumptions whenever possible. Models were developed for a conventional powertrain with an ISG, series hybrid powertrain, parallel hybrid powertrain, road-coupled parallel hybrid powertrain and a conventional powertrain with ISG and Continuously Variable Transmission (CVT). Multiple simulations were run for each architecture to determine the most favorable control strategies for fuel economy, while maintaining automotive performance required for acceleration and speed on a grade. The various simulation results indicated that the road-coupled parallel hybrid system provided the best opportunity for fuel savings based on the drive cycles used for the analysis. The team determined that additional fuel savings might be realized by optimizing the projected control strategies. During the program's final phase, as the actual hardware for the propulsion system is selected, TARDEC will update its models to reflect the as-built FED vehicle and validate the model with actual performance data. This will allow additional analysis to be performed over a wide variety of Army drive cycles that cannot be reproduced on the proving ground and further determine control strategies for fuel economy maximization.

"What we're going to show is the best fuel efficiency you can expect in a vehicle of this weight class while still being military-relevant. I think it helped validate some of our internal M&S group's skills and showed what our teams are capable of. The work that we're going to do at Aberdeen will further validate those models."

Johnson remarked that the powertrain team's contribution was invaluable to the program's overall success. "They looked at several powertrain concepts, including generic, series-type and parallel hybrids to determine which one was best and most fuel efficient."

"They did some of these generic tests for us and created FED drive cycles that we could run all of the concepts against to determine which vehicle concept would be the best to go forward with, giving us the powertrain layout to meet Advanced Concepts' space claim layout," Johnson commented. "Powertrain modeling is very strong here at TARDEC, and I think it helped to validate that."



"What we're going to show is the best fuel efficiency you can expect in a vehicle of this weight class while still being military-relevant," Johnson declared. "I think it helped validate some of our internal M&S group's skills and showed what our teams are capable of. The work that we're going to do at Aberdeen will further validate those models," Johnson concluded. APG testing will help validate the FED Program's strides in designing a fuel-efficient, mission-capable platform that will further validate CASSI and TARDEC's modeling expertise.

Editor's Note: TARDEC Engineer Mike Pozolo contributed to this story.

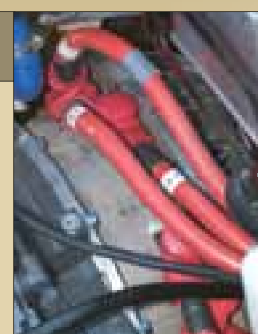
Fuel-Saving Design and Systems Engineering Lead to Innovative Solutions

DRIVELINE

The FED Alpha vehicle is powered by a modern CUMMINS 4.5L ISB engine optimized for fuel efficiency and designed to burn JP-8 fuel. The transmission is a 6-speed automatic from Aisin. A number of the driveline components, including the transmission, transfer case and differentials, were treated with a superfinishing process from REM Chemical. The superfinishing decreases the friction between gears and increases the fuel efficiency of the entire driveline. Ricardo also removed the wheel-end reduction units that are typically found on trucks. The absence of gear sets eliminates friction and losses in the entire system.

INTEGRATED STARTER-GENERATOR (ISG)

Between the engine and transmission Ricardo included a Kollmorgen 24-volt ISG. This motor will start the vehicle and then produce up to 30kW of power for vehicle and military equipment loads. Because of high electrical power output requirements, most of the engine accessory drives have been removed from the engine belt and replaced with electric pumps and motors. Electric pumps and motors can be run only when needed, reducing parasitic losses, and can be more easily packaged away from the front of the engine.



LIGHTING

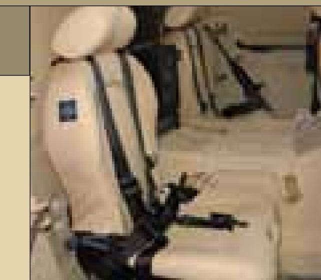
The lighting systems for both the FED Alpha vehicle as well as the FED Bravo feature LED headlamps, side markers, backup lighting and blackout lights. The FED vehicles use Truck-Lite systems, which are already DoD-approved components on several combat platforms. LED headlamp systems typically feature longer life, increased durability and minimal power consumption (about 4kW) when compared to conventional truck lighting systems.

TIRES

Rolling resistance is the term for the amount of drag force caused as the tire treads press against the road while driving. Reducing drag leads to better fuel efficiency. The Goodyear Custom Compound Low Rolling Resistance Tires on the FED Alpha vehicle feature a tread design, depth and compound to reduce this energy loss and boost miles-per-gallon numbers. These new 22.5-inch military tires could account for 7.8 percent fuel economy gains over conventional military tires.

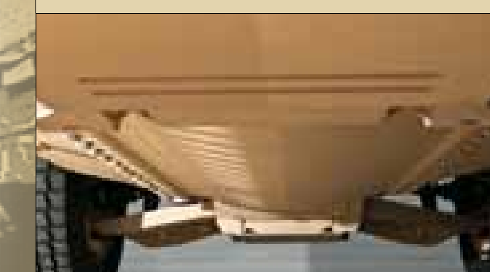
SEATS

The FED Alpha vehicle uses GSS Cobra Blast Attenuating Seats, which are designed with blast mitigation for military tactical vehicles. Systems have weight sensors to adjust the level of energy absorption to the Soldier in the seat.



LIGHTWEIGHT STRUCTURE

The Lightweight Aluminum Monocoque Armored Cab and underbody blast shield on the FED Alpha vehicle is designed to be "lighter, faster and stronger," according to its supplier, Alcoa Defense. The Alcoa alloy increases strength, durability and ballistic performance while also reducing weight.

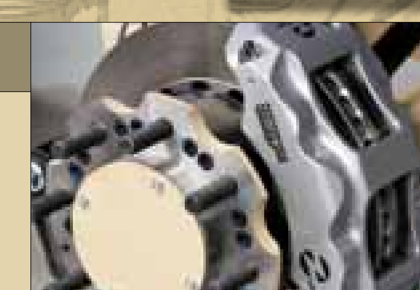


ACCELERATOR

A Force Feedback Pedal sends cues when the driver pushes the accelerator too hard or too often. In the FED vehicles, the Continental Teves Accelerator Force Feedback Pedal will help the driver find the pedal position ensuring the highest possible fuel economy. This device is important because even the most advanced fuel economy systems can be undermined by a driver with a lead foot.

BRAKES

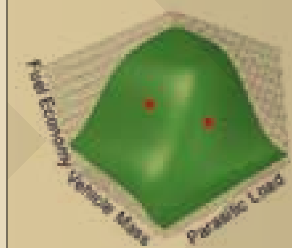
The brake calipers on the FED Alpha vehicle use Performance Friction Brakes Zero-Drag technology, which eliminates brake drag for fuel savings, increases pedal response and improves component life. These brake systems have been proven in motor racing and are built with lightweight materials that maintain stiffness and durability.



FED
FUEL EFFICIENT GROUND VEHICLE DEMONSTRATOR

FED Alpha Vehicle Timeline —
Embedded Engineers/Select Engineering Services (SES)/Ricardo

SEPTEMBER 2008
Contract for the project was awarded to Select Engineering Services Inc. Subsequently, SES subcontracted with Ricardo plc to provide automotive and racing expertise. SES/Ricardo planned a traditional approach, working with embedded engineers from the U.S. Army Tank, Automotive Research, Development and Engineering Center (TARDEC) to produce a non-hybrid vehicle that would improve energy efficiency through systems engineering design and technology integration.



JANUARY 2009
Analysis of more than 60,000 computer simulations was completed. TARDEC engineers are embedded with contractor.

APRIL 2009
Concept/market survey completed.

JUNE 2009
During an Executive Review, the concept was reviewed and approval given to move into the project's design phase.

NOVEMBER 2009
A preliminary design review was conducted.

JANUARY 2010
During an Executive Review, approval was given to move into the project build stage.

APRIL 2010
The FED Alpha vehicle build began.

OCTOBER 2010
The vehicle build phase was completed, and the FED Alpha vehicle rolled out under its own power.

APRIL 2011
Testing of FED Alpha vehicle will begin testing at Aberdeen Proving Ground, MD.

FED Bravo Vehicle Timeline —
'Monster Garage'/World Technical Services Inc. (WTSI)

Timotae Vang
CCS student

Jake Bosnak
CCS student

AUGUST 2008
Contract for the project was awarded to WTSI. A 'Monster Garage' approach was taken by the TARDEC-led government-industry team of subject-matter experts who would sift through the most innovative and compelling fuel-efficient technologies available to determine which should be incorporated into the hybrid-electric vehicle.

SEPTEMBER 30, 2008
A FED Industry Day was held at Automation Alley in Troy, MI. The overarching goal for the program was to improve military vehicle technology to reduce fuel consumption on the battlefield and reduce dependence on foreign oil. A series of FED working group sessions were planned.

James Scott
CCS student

OCTOBER 2008
FED Working Group No. 1. More than 100 candidate technologies were put in priority order for overall utility in balancing fuel-efficiency improvements with other metrics such as cost, technological maturity, technical performance and interaction complexity.

DECEMBER 2008
FED Working Group No. 2. Six system level concepts for the optimal combination of technologies were developed. The concepts formed the basis for the project's modeling and simulation (M&S) phase.

JUNE 2009
During an Executive Review, the concept was reviewed and approval given to move into the project design phase.

SEPTEMBER 2010
During an Executive Review, approval was given to move into the project build stage.

Stephen Dick
CCS student

JANUARY 2010 to APRIL 2010
College for Creative Studies FED design class works with TARDEC and WTSI staff to design exteriors for 'Monster Garage' FED Bravo demonstrator.

AUGUST 2011
Expected vehicle build FED Bravo phase completed.

CCS Students Learn to Balance Aerodynamic Design and Functionality

Chris Williams

CCS student Dan Nikonchik created a concept rendering as part of TARDEC's FED Program, which engaged a team of transportation design students at CCS to help develop the interior and exterior features of vehicles under development. (Image courtesy of CCS.)

> ***"Some of the ideas the students came up with were different than what we would normally see because they're not bound by engineering thinking, where it's function before anything else."***
>
> — Brandon Card
> *WTSI Engineer*

Most Army vehicles are engineered to perform a variety of specific functions based on operational and mission requirements. Historically, tasks that impact the vehicle's shape, style and form traditionally have been signature management or ergonomic concerns. However, associates at the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) knew they had to take a novel approach to designing the Fuel Efficient Ground Vehicle Demonstrator (FED) with an exterior shape that would minimize drag, improve aerodynamics and enhance fuel efficiency.

TARDEC and industry partner World Technical Services Inc. (WTSI) worked closely with transportation design students from the College for Creative Studies (CCS) in Detroit, MI, to design exteriors for TARDEC's 'Monster Garage' FED Bravo demonstrator.

"We always wanted to make a change, appearance-wise, in our approach to the demonstrator," explained TARDEC Engineer Mohammed Mazhar. "Most military vehicles tend to be boxy, but aerodynamics is a major concern for this particular vehicle. As CCS has a lot of experience in automotive engineering, we thought we should take advantage of what they had to offer."

TARDEC FED Team Leader Carl Johnson commented that the organization's partnership with CCS was a prime example of the Army using innovative and collaborative approaches to advance technology. "We're looking for new and different ways to drive innovation to the Army. Besides style, industrial design can also help with packaging, which plays a key role with fuel efficiency and aerodynamics. I think industrial designers are able to look at things a bit differently than engineers do," Johnson stated. "The results were better than we could have anticipated, and I'm very impressed by the outcome. The students really stepped up and did some phenomenal work."

The 'Monster Garage' team initially approached CCS Professor Mark West about a possible collaboration in late 2009. The partnership with CCS provided an opportunity for students to participate in a project with real-world applications and challenges. "This project was unique because the students had to build something to be executed in full scale, which is very different than the work we normally do," West remarked. "The value is that they get to work in a real-world scenario on a full-size vehicle. A real person is going to have to sit in and

TARDEC Director Dr. Grace Bochenek (left) observes CCS student Jake Bosnak as he works on a CAD 3-D rendering of his FED vehicle design during her visit to the school on April 1, 2010. TARDEC Associate Rachel Agusti (rear) looks on. (U.S. Army TARDEC photo by Elizabeth Carnegie.)

drive this vehicle and be able to use all of the interior components."

To give students the freedom to design a unique and aerodynamic vehicle, engineers provided only a few key parameters and requirements at the outset. "Some of the ideas the students came up with were different than what we would normally see because they're not bound by engineering thinking, where it's function before anything else," remarked WTSI Engineer Brandon Card. "We gave the students a great deal of freedom at the beginning, and as the course went on, we began supplying more requirements so they had to go back and look at refining and changing their concepts."

The project challenged students to consider functionality and work alongside engineers with very specific needs. "We went from doing whatever we wanted to fitting their criteria and making our design into their package. My design changed a lot because I'm limited in how flexible I can get with the curves, seating of the passengers and various views and angles," remarked CCS student Fardos Abbas. "It was also a challenge to work with engineers, who think differently than we do. It's more of a real-world situation — we're actually getting a taste of it before we do it for any other company, which is exciting."

"I learned from the students, who have a different design approach than we do at the Army, and they received knowledge of Army vehicles."

— Mohammed Mazhar
TARDEC Engineer

The students began with 2-dimensional (2-D) renderings, which were then developed into 3-D computer-assisted designs (CADs). Every few weeks, the 'Monster Garage' team would bring in new requirements, such as specific tires, engine sizes and transmission locations, for the vehicle. The students then revised their designs to incorporate these changes without sacrificing their initial concepts' originality.

"I like projects that are much more practical and give us a more realistic approach," stated student Jake Bosnak. "We have to think about what the engineers go through for a vehicle that will actually go into production. The engineers have been great, and it has been a challenge to make sure they're happy with what we're doing and that they understand what we're drawing, because a lot of engineers don't have much design familiarity. We have to be really descriptive and specific."

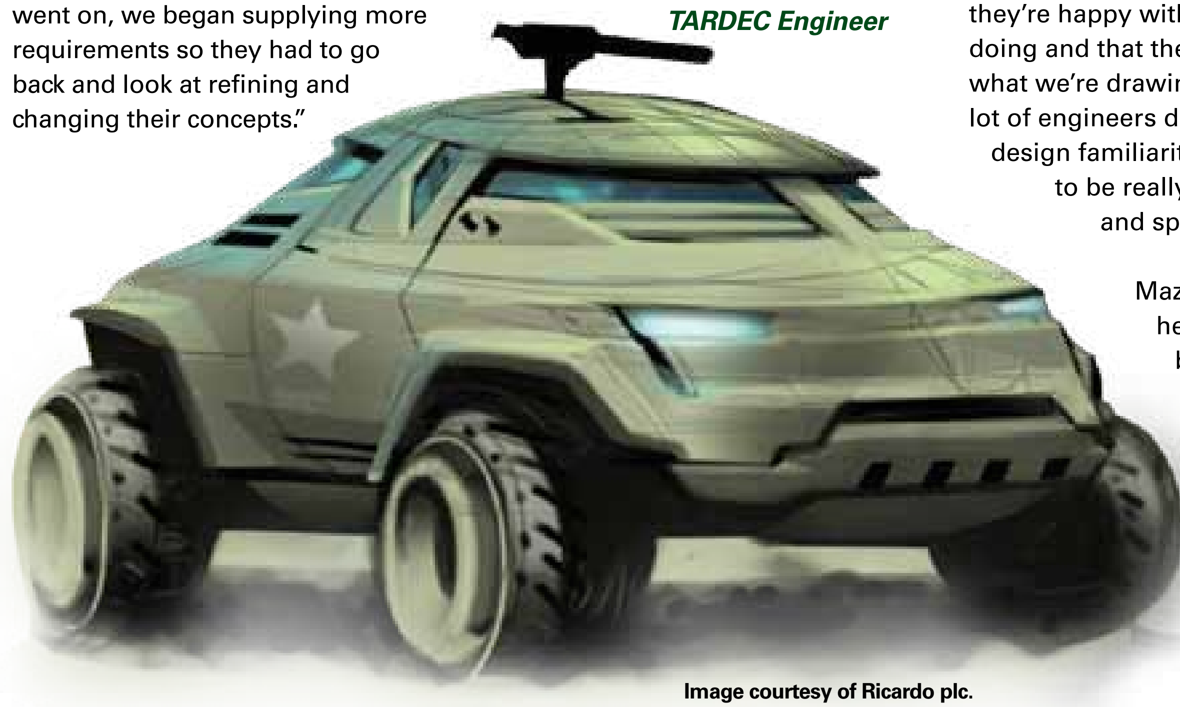


Image courtesy of Ricardo plc.

Mazhar remarked that he was impressed by the students' commitment and responsiveness and that the project was beneficial to both the students and TARDEC. "If you look from the first sketch to what they have now, they have refined their concepts," he explained. "I learned from the students, who have a different design approach than we do at the Army, and they received knowledge of Army vehicles."

CCS student Joel Zastrow's design was chosen as the program's first-place finalist. Zastrow was brought onboard with WTSI over the summer to refine the concept and assist with interior and exterior designs. "I'm honored," Zastrow remarked. "I always enjoyed military vehicles as a kid, and it's an honor to be able to do this for my country."

FED vehicle design by CCS student Zack Stephanchick. (Image courtesy of CCS.)

FED vehicle design by CCS student Joel Zastrow. (Image courtesy of CCS.)

CCS transportation design student Joel Zastrow (left) reviews his 2-D FED concept drawing with TARDEC Engineer Mohammed Mazhar. (U.S. Army TARDEC photo by Carrie Deming.)

College for Creative Studies

Systems Engineering Approach Crucial for FED Vehicles

Mike Seaton and Jim Gardini

Critical to achieving the Fuel-Efficient Ground Vehicle Demonstrator (FED) Program's stated goals is employing a systems engineering (SE) approach to solve technical challenges. The FED Program executed two SE approaches to create fuel-efficient concepts.

One approach, FED Alpha, was devised by industry partner Ricardo plc and the U.S. Army Tank-Automotive Research Development and Engineering Center (TARDEC). This contractor-led team focused on a data-driven approach to include requirements analysis, detailed modeling and simulation (M&S) of the design space and concept refinement, and used several SE methods and tools. In addition, TARDEC engineers were embedded with the contractor's engineering team and were exposed to many of these tools and have brought new systems engineering skills and knowledge back to TARDEC for use on current and future programs.

A second approach, FED Bravo, was devised by TARDEC to partner with commercial automotive design contractor World Technical Services Inc. (WTSI Inc). This government-led team focused on leveraging local engineering expertise to bring together a plan demonstrating reduced fuel consumption for military light tactical vehicles.

An M978 Heavy Expanded Mobility Tactical Truck stands ready for a night convoy to deliver fuel to a forward-operating base in Iraq. The FED Program could lead to fuel-efficiency improvements that reduce the amount of fuel on the battlefield and the number of Soldier convoys to deliver fuel. (U.S. Army photo by SGT Holley Baker.)

Program requirements called for both teams to design and fabricate full-scale, fully operational demonstrator vehicles. These vehicles are each one-of-a-kind technology demonstrators and, as such, are not intended to go into production.

The SE approach used by the FED teams can be viewed as a search within the available design space for an optimal "solution path" resulting in the "goal state." As alternative solutions are created, some rationale for evaluating and selecting a partial solution path is required.

According to the *Defense Acquisition Guidebook*, the SE Process Model consists of three design processes, five realization processes and eight technical management processes. The FED Program is designed to evaluate methodologies within the design space for improving fuel economy on all Army ground tactical vehicles and to improve the core capabilities and competencies of TARDEC associates. Accordingly, the SE emphasis was primarily placed on the technical management processes. We will briefly discuss several SE program management methodologies used to date.

Technical Planning Stage

Although the FED Program is not required to have a Systems Engineering Plan (SEP), the FED team realized the benefits inherent in creating and using a SEP. The FED Program's SEP is based on the TARDEC Army Technology Objective Development (ATO-D) SEP instructions, which were specifically tailored to be relevant to FED Program needs. The SEP documents the FED Program's SE approach and serves as a technical foundation for the program. The plan covers five main areas: program requirements, technical staffing and organizational planning, technology maturation, technical review planning and integration with overall program management.

Requirements Management Stage

Initially, baseline High Mobility Multipurpose Wheeled Vehicle (HMMWV) requirements were reviewed to determine which capabilities characterize an HMMWV. FED Program engineers then extracted a set of HMMWV performance requirements that were subsequently translated into a statement of work (SOW) for each contracted program partner. The SOW for each contractor was captured in IBM's Dynamic Object Orientated Requirements System (DOORS). DOORS allowed the FED Program to directly trace SOW requirements to testing, and testing to test results. Each requirement was linked to the test matrix to ensure all salient requirements were being verified through testing. Tracing test data back to the requirements will provide

(Photo courtesy of Ricardo plc.)

Battery B, 2nd Battalion, 12th Field Artillery Regiment Fire Direction Officer 1LT Matthew Basilico kneels beside his vehicle while scanning the area below a bridge in the battalion's operational area. Bridges have multiple requirements, such as weight and carrying strength. These competing needs help demonstrate the variety of pressures a system can feel from various directions. SE brings value to projects by finding ways to balance needs and requirements with one another. (U.S. Army photo by PFC Kimberly Hackbarth.)

validation that FED vehicles have met programmatic requirements.

The FED Program did not have a rigid set of requirements in the traditional sense. The purpose was to allow a degree of design freedom. This resulted in two design concepts with slightly different performance objectives. A significant lesson learned was the impact certain requirements have on a vehicle's fuel economy. For example, the ability to tow a vehicle of equal size and weight requires a larger engine that directly impacts fuel efficiency. In the future, this understanding may very well drive requirement definition by fully realizing the

"We wanted a rigorous SE and data-driven approach to select technology and develop architectures."

impact on cost, space, weight and power needed to meet a particular requirement or set of requirements.

Risk Management Stage

All FED Integrated Product Team (IPT) meetings directly addressed risk. Potential performance, schedule and cost risk have been continually reviewed during the IPT meetings with a focus on potential programmatic impacts. FED Program's risk management strategy was to employ commercial-off-the-shelf parts as much as possible. Initially, FED Program design risks were managed by the contractor team and briefed to the FED team at IPT meetings. TARDEC also embedded systems engineers working directly with the contractors which reported back to TARDEC on a regular basis.

Technical Reviews

The FED Program conducted event-driven technical reviews. These reviews were held when the progress of the product under development merited review and encompassed subsystem and critical technology elements. Each technical review had a set agenda based on pre-review analyses and assessment and included: specifications, drawings, manuals, schedules, design and test data, trade studies, risk analysis, effectiveness analyses, mock-ups, breadboards, in-process and finished hardware, test methods, technical plans (test, support, manufacturing and training) and trend (metrics) data as appropriate.

The FED Program benefited from the experience of an Executive Steering Group (ESG), which provided executive direction to the FED core planning team. The ESG had the authority to change the overall FED direction (within budget and schedule constraints) and served as the governing body that approved the concept configuration that moved the project forward into the design

"Government, DoD and NASA are the leaders in SE... DoD and NASA are involved with complex and large systems, and less complex products will follow the same practices."

phase. The FED Program held ESG reviews with the contractor-led team on Jan. 20 and the government-led team on Sept. 15, respectively, during which the FED team was given permission to move into detailed design and fabrication for each respective demonstrator.

Requirements Development

Requirements development translates user and stakeholder needs into engineering requirements. As with any program requirement, prioritization is necessary. During requirement development, it is necessary to realize the inherent "cost" of every requirement. A top-down approach was taken for

FED Program engineers used the M1114 HMMWV Frag 5 as the baseline vehicle for benchmarking threshold requirements for the FED vehicle. Systems engineers are integrating available technology to maximize fuel economy. (U.S. Army photo by SGT Benjamin R. Reynolds.)

the FED vehicle. User/stakeholder needs were translated into system requirements, which were then decomposed in subsystem and component specifications.

Using the M1114 HMMWV Frag 5 as its primary source of performance objectives, the HMMWV became the benchmark from which threshold requirements were derived. The overriding expectation for the FED vehicles is that they will perform no worse than the legacy fleet and will employ modern technology to maximize fuel economy.

The FED Program's requirements were derived from the following HMMWV requirements: payload, ride and handling, mobility gradeability and transportability. Additional requirements added for the FED Program included: electrical power generation, underbody blast protection and Human Factors Engineering (HFE) analysis to make the FED vehicles relevant to current and new vehicle programs. The FED Program Manager (PM) allowed contractors to trade some requirements to explore alternative solutions.

Configuration and Data Management

The approach TARDEC used for configuration and data management was to allow the contractors to use their own internal systems with oversight by TARDEC engineers. As the program transitions through the build and test phases, the TARDEC SE Group has created a file structure using the TARDEC Advanced Collaborative Environment Windchill gateway.

A U.S. Army fuel truck convoy lines up at the "fuel pits" at Sahl Sinjar Airfield, Ninawa Province, Iraq. The FED Program is just one of the Army's initiatives to increase ground vehicle fuel efficiency which, ultimately, will help decrease the number of Soldiers involved in fuel convoys, thus saving warfighter lives and reducing Army operating costs. (U.S. Marine Corp photo by CPL Kelly R. Chase.)

This will primarily provide a repository and archive for all the program deliverables such as M&S results, vehicle Bills of Material (BOMs), test plans and Design of Experiments, test results, conclusions and recommendations.

U.S. Army SFC William Pegler, battalion fuel handler for 3rd Battalion, 20th Special Forces Group at Camp Montrond, Afghanistan, fills an MRAP vehicle for an upcoming convoy. Work done by the U.S. Army on the FED vehicle demonstrators will help decrease the number of fuel convoys in the field and help keep Soldiers out of harm's way. (U.S. Army photo by SGT Katryn McCalment)

Verification and Validation Stage

The latter half of the standard systems V-model is entirely devoted to verification and validation of product configuration. Verification confirms that the system element meets the design-to or build-to specifications and answers the question: "Did you build it right?" Validation, as such, tests the system elements against their "build-to" specifications.

The FED verification planning included M&S such as Computational Fluid Dynamics and Finite Element Analysis. Through the use of M&S, the FED team was able to develop vehicle architectures, and from them, BOMs that fit within the design envelope.

The FED verification planning also included a Department of Energy methodology that will allow FED engineers, with their contractor counterparts, to develop test plans that will correlate the impact of individual subsystems based on the assumptions used in the M&S phase and best design practices.

A FED Program objective is to validate the M&S models developed at the beginning of the program with the test results obtained on the vehicle demonstrators at Aberdeen Proving Ground, MD. according to program test plans being developed.

The Ricardo FED Alpha vehicle, shown here, under construction, was completed in September 2010 and will begin field testing at Aberdeen Proving Ground, MD, in Spring 2011. TARDEC engineers embedded with Ricardo assisted with designing and developing the demonstrator, utilizing an SE approach in bringing the vehicle from concept to reality. (Photo provided by Ricardo plc.)

Results to Date

With the first FED Program vehicle ready to roll out, engineers will continue to verify improvements, validate M&S models and monitor overall vehicle performance and efficiencies. M&S models are indicating potential fuel economies that could reach 70 percent, versus the original HMMWV benchmark. Additional features and technologies were also identified as potential improvements for the vehicle, but were outside the current program cost and timing constraints.

Several outputs from the FED Program will potentially influence the design of current and future military ground vehicle programs. The program will, ultimately, demonstrate a wide range of fuel-efficient technologies derived through fabricating, testing, M&S and SE and systems integration. FED Program lessons learned will be used to inform requirements developers as to how particular requirements affect vehicle system fuel efficiency. Program lessons can also inform original equipment manufacturer engineers about best practices for designing vehicles more fuel efficiently, especially military vehicles. TARDEC will apply the knowledge gained through these models directly to new M&S and vehicle development efforts. Promising technologies identified as part of FED can be further developed and matured for integration into existing vehicle platforms, and for future vehicle programs.

Michael Seaton is a TARDEC System Engineering Group (SEG) member. He provides SE support to the FED Program and program executive office customers. He holds a B.S. in mechanical engineering from Lawrence Tech and is currently pursuing an M.S. in mechanical engineering at Lawrence Tech.

Jim Gardini is a Senior Systems Engineer for SAIC and is currently assigned to the TARDEC SEG. Gardini received his degree in metallurgical engineering from New York University-Polytechnic Institute in 1972. No stranger to the military, Gardini served as a Development Engineer at Textron Lycoming and later as the Program Manager for turbine powerplants used in the Army Chinook helicopter and Abrams tank. He also served as Principal Engineer at the NASA Lewis Research Center for the study of thermal mechanical fatigue. A commercial aviation business veteran, he served in senior management positions in quality and manufacturing engineering, including implementing quality systems that were certified by Boeing, Bell and Ford at Roush Industries. He is a Designated Engineering Representative for the Federal Aviation Administration with the authority to approve major design changes, repairs and alterations on both piston and turbine aviation powerplants.

Hybrid FED Bravo Vehicle Uses 'Monster Garage' Approach to Fuel Efficiencies

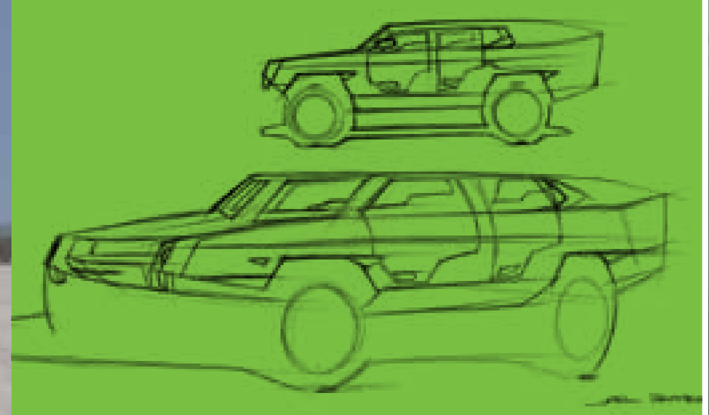
Veering slightly but deliberately from the conventional engineering path can yield innovative results. Designers adopted a 'Monster Garage' approach for Fuel Efficient Ground Vehicle Demonstrator (FED) Bravo to take advantage of the former television show's brainstorming dynamic.

The 'Monster Garage' television series, which aired from 2002 to 2006 on the Discovery Channel, gathered a team of experts from different disciplines and turned them loose to convert an average vehicle into something extraordinary. In the FED team's case, they simply wanted to borrow the creative process from the show's format, which included assembling the talent for the development team, encouraging the open flow of ideas, and departing from traditional engineering methods. The 'Monster Garage' gang might turn a New York City hot dog cart into a dragster, but the FED team focused on designing an Army ground vehicle that would achieve much higher fuel efficiencies.

This demonstrator vehicle is nearing the end of development and the beginning of its production phase. This will be the second FED vehicle created for this project, which will potentially transfer technological and structural design features to existing vehicles and Future Force vehicles.

Here are a few FED Bravo key points:

- This program has been orchestrated by TARDEC working with private World Technical Services Inc. (WTSI).
- Program leaders gathered government, private industry and academic resources from around the country to address the issues of fuel economy and logistics impact.
- The first project phase used a 'Monster Garage' approach to gather ideas and input. The second phase leveraged those results by assigning TARDEC and WTSI engineers to design the vehicle.
- The team reviewed technological contributions from several companies for each system on the vehicle.
- The final design review was held in September. Fabrication was scheduled for late 2010.
- Vehicle assembly is scheduled to take place in early 2011.
- Engineers will conduct final calibration and tuning of components and systems next summer.
- Shake-out testing, followed by full test mode, will happen during the second half of 2011.
- Once the technology on the FED Bravo passes evaluation, it can be exported to other military platforms to improve fuel efficiency and performance.



Editor's Note: The artist renderings on pages 28 and 29 are the FED Bravo vehicle by CCS student Joel Zastrow.

COLLABORATION LEADS TO WELL-ENGINEERED SOLUTIONS

ELECTRICAL ARCHITECTURE

TruckLite provided the electrical architecture for the WTSI FED Bravo vehicle. The hybrid-electric system will include a DC-DC converter that will deliver about 4 kilowatts (kW) of power to the low-voltage electrical system. By integrating light-emitting diode, or LED, lighting, WTSI can reduce the current draw on the vehicle's low-voltage battery, and power can be conserved in the vehicles overall electrical system.

DASHBOARD

Medallion Instrumentation Systems designed a dashboard that follows commercial truck design rather than a typical military instrumentation panel. Medallion's custom gauge cluster has form and function — attractive while still displaying mission critical information.

BRAKES

The WTSI FED Bravo vehicle is using a MICO Full Power Hydraulic Brake System with ABS. The MICO system was designed to handle up to eight channels of HABS control and can support J1939 protocol. Additionally, the system is able to be combined with the steering system to supply the hydraulic demands of the steering rack to eliminate a second pump, providing a more efficient solution at the vehicle level.

SEATS

Blast mitigation seats were designed by Jankel Tactical Systems LLC. They feature automatic weight adjustment and a function that resets the seat location should it go airborne, in a manner that increases passenger survivability.

2011 FED

FUEL EFFICIENT GROUND VEHICLE DEMONSTRATOR ALPHA

FUEL ECONOMY ESTIMATES

Estimates reflect simulated TARDEC Duty Cycle Experiments using JP-8 fuel.

Fuel Economy Information

URBAN ASSAULT MISSION MPG	7.1
CONVOY ESCORT MPG	12.6
CROSS COUNTRY MPG	4.8
TACTICAL IDLE MPG (GALLONS/HOUR)	0.51

COMBINED FUEL ECONOMY

4 — 8 (This Vehicle)

All Light Duty Trucks

Length: 16 feet, 11.0 inches
Width: 7 feet, 6.10 inches
Height: 6 feet, 10.2 inches (Adjustable)
Transportable By: C130, CH47, CH53, MV22

Curb Weight: 11,650 pounds
Payload: 2,900 pounds
Gross Vehicle Weight: 14,550 pounds
GVWR: 15,400 pounds

U.S. ARMY
TANK AUTOMOTIVE
RESEARCH, DEVELOPMENT
& ENGINEERING CENTER

SES/RICARDO FUEL EFFICIENT GROUND VEHICLE DEMONSTRATOR 4WD

Exterior Color: Desert Sand/Black Trim
Interior Color: Desert Sand/Black Trim
Interior: 4 x 95th percentile crew members + equipment
Engine: Optimized Cummins Super/Turbocharged 200 HP 4.5L Inline 4-Cylinder Diesel
Transmission: AISIN High-Efficiency Six-Speed Automatic

STANDARD EQUIPMENT

FUNCTIONAL/SAFETY FEATURES

- Kollmorgen 30kW 24V Integrated Starter-Generator
- ALCOA Defense Lightweight Aluminum Monocoque Armored Cab w/ Underbody Blast Shield
- Friction-Stir Welded Chassis
- Hutchinson Lightweight Composite Runflats
- Performance Friction Low-Drag Aluminum Brake Calipers
- AxleTech Integrated Spring and Damper Suspension
- KONI Frequency Selective Damping Shocks
- REM Chemical Isotropic Superfinishing

INTERIOR FEATURES

- Global Seating Systems Cobra Blast Attenuating Seats
- Touch-Panel Computer w/Fuel Economy Display
- Continental Teves Accelerator Force Feedback Pedal
- Bergstrom HVAC w/Allen Vanguard Cooling Vests
- TRW Column Drive w/Tilt
- Door-Mounted Gun Locks
- Commercial Vehicle Group Thermal Insulation

EXTERIOR FEATURES

- Goodyear Custom Compounded Low-Rolling Resistance Tires 335/65R22.5
- Truck-Lite LED Headlamps/Markers/Blackout Lights
- Carbon Fiber Body Panels
- Central Tire Inflation System
- Intergral Bustle-back
- Ring Mount for Remote Weapons Station
- Roof Escape Hatch
- Refractive Paint on Roof & Doors
- Integrated Solar Panels
- Aluminum Short-Long Arm Suspension System

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