2011 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
POWER AND MOBILITY (P&M) MINI-SYMPOSIUM
AUGUST 9-11 DEARBORN, MICHIGAN

LIGHT TACTICAL WHEELED VEHICLES – A FUEL EFFICIENT SOULTION ENABLED BY BOOSTED DOWN SIZED ENGINES MANAGED WITH OPEN CONTROL SYSTEMS

Gustav Johnson
Engine Development
AVL Powertrain Engineering
Plymouth, MI

ABSTRACT

Modern medium and heavy duty Commercial Off The Shelf (COTS) diesel engines take advantage of state-of-the-art technologies to deliver excellent performance while meeting the most stringent emissions legislation. While some of these technologies offer significant advantages in terms of engine efficiency, performance and weight versus traditional military engines, others are driven purely by the need to meet emissions standards. In order to successfully adapt these COTS engines for military use and fuel (JP-8), the emissions-only systems must be removed and the engine recalibrated for maximum efficiency. The downsized, turbocharged engine would enable a simultaneous improvement in engine weight, performance and efficiency in one of the DoD's largest fleet of vehicles - High Mobility Multipurpose Wheeled Vehicle (HMMWV), when compared to the current configuration. This paper will illustrate how a modern diesel engine was quickly developed from COTS to military-ready configuration for potential use in programs like the High Mobility Multipurpose Wheeled Vehicle (HMMWV) recapitalization and repower programs. The conversion of a 2011 model year COTS engine is shown as a case study for defense application as funded by TARDEC.

INTRODUCTION

Modern medium and heavy duty Commercial Off The Shelf (COTS) diesel engines us technologies such as high pressure fuel injection, multiple injection events, exhaust gas recirculation (EGR), variable geometry turbochargers (VGT), and exhaust aftertreatment systems (EAS) to maintain performance while meeting the most stringent emissions legislation. While EGR and EAS serve only to reduce emissions without benefit to performance, the other systems can be tuned to drastically improve engine performance and are well suited to operation on military fuels such as JP-8. Specifically, VGT, high pressure fuel injection and multiple combustion events make it possible for the military to take advantage of the best modern engine design has to offer in terms of reduced weight, increased performance, reduced fuel consumption, and reduced heat rejection.

The OEM control systems used to control these advanced engine systems are complex, and the access to the OEM Engine Control Module (ECM) is not readily available. Deleting the undesired systems without adjusting the control system to compensate would result in suboptimal engine performance, and most OEM control systems have special diagnostic systems to prevent exactly such modifications. To overcome this constraint AVL has developed an open and flexible engine control system – the AVL Universal Diesel Engine Controller (UDEC). The AVL UDEC allows any COTS engine to be quickly converted to military application be replacing the OEM ECM while still using existing engine sensors and actuators. Settings and control strategies can be tailored to optimize efficiency and performance, and future changes are easily implemented since access to the ECM is available to the end user.

This paper will illustrate how a modern diesel engine was quickly developed from COTS to military-ready configuration for potential use in programs like the High Mobility Multipurpose Wheeled Vehicle (HMMWV) recapitalization and repower programs. The conversion of a 2011 model year 3.0L engine is shown as a case study for defense application as funded by TARDEC.

ENGINE MODIFICATIONS & CALIBRATION

The COTS engine was modified by deleting the EGR system, removing the EAS, and replacing the OEM ECM with the AVL UDEC system. The COTS engine is already a lightweight design with aluminum cylinder heads, and a compact package, but removing these components reduced the engine weight by a further thirty pounds to result in a final as-tested weight of 410 lbs. (dry). This modified engine was installed in a test cell at AVL's Plymouth testing facility and recalibrated to optimize performance, thermal efficiency and heat rejection on both standard diesel (DF2) fuel and JP8.

The parameters optimized were fuel injection timing, boost pressure, and fuel injection pressure. Fuel injection timing was advanced significantly compared to the COTS configuration to reduce fuel consumption and improve engine thermal efficiency. Boost pressure was tuned to provide sufficient airflow for engine operation, while optimizing turbocharger efficiency. The result is boost pressure that is no higher than necessary for all engine operating conditions – resulting in improved engine thermal efficiency and reduced heat rejection from the charge air cooler. Similarly, fuel injection pressure was significantly reduced from the COTS configuration to reduce parasitic losses in the high pressure fuel pump and maximize engine combustion efficiency. The common rail fuel system was also optimized to minimize the quantity and temperature of the return fuel flow to reduce heat rejection. The result was a fully featured engine calibration capable of full transient performance, and an abbreviated NATO durability cycle was conducted to demonstrate the robustness of the final calibration.

Table 1: Optimized Performance of Modified 3.0L Engine

Max Brake Thermal Eff.	42.0%
Max Indicated Thermal Eff.	51.3%
Peak Torque @ Speed	443 ft-lbs @ 1,800 rpm
Rated Power @ Speed	230 hp @ 3,600 rpm

IMPROVED PERFORMANCE

The final performance achieved on the modified 3.0L engine reproduced the COTS configuration in terms of torque and horsepower, and demonstrated a significant improvement in thermal efficiency and reduction in heat rejection. Figure 1 below shows the torque curve for the final calibration running on JP-8 (performance on DF2 is identical, but requires a slightly different calibration to compensate for different fuel properties).

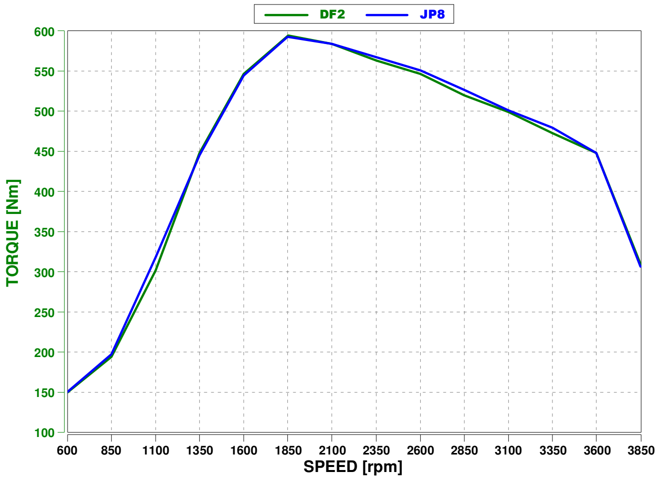

Figure 1: Modified 3.0L Torque Curve.

While the gross output of the modified engine exceeds the performance of the current HMMWV, the difference in performance is even more pronounced when the difference in engine weight is taken into account. Figure 2 shows the final performance of the modified 3.0L engine versus the 6.5L engine in the current HMMWV, and Figure 3 shows the same corrected for engine dry weight. These improvements are a direct result of using the AVL UDEC system to take advantage of state of the art engine technology. With the recent increase in HMMWV vehicle weights to provide increased armor and protection, a new engine with reduced weight and increased power would help to recover lost mobility.

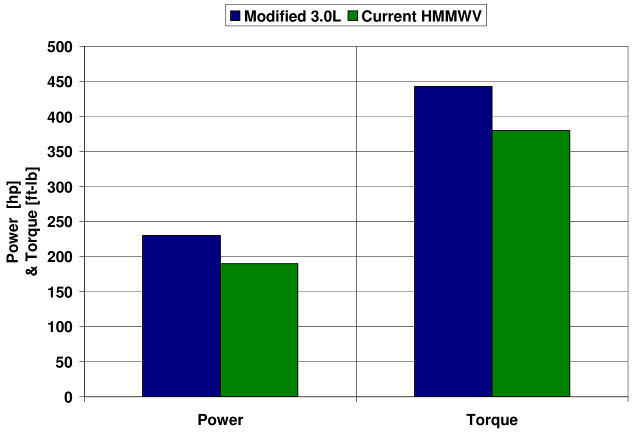

Figure 2: Gross Power and Torque Comparison vs. Current HMMWV Configuration

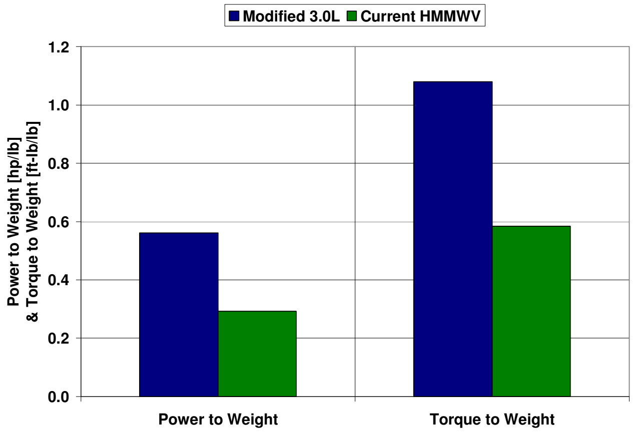

Figure 3: Power and Torque to Weight Comparison vs. Current HMMWV Configuration

FUEL CONSUMPTION

By optimizing the performance of the engine's entire operating range by use of injection timing, boost pressure, and fuel injection pressure, significant improvements in thermal efficiency are achieved when compared to a typical COTS configuration. Many of the calibration decisions made to meet emissions regulations result in a reduction overall engine efficiency. Figure 4 below shows a contour plot of brake thermal efficiency over the entire operating range of the modified 3.0L engine. The peak brake thermal efficiency achieved was 42% near peak torque, but thermal efficiency was maintained above 35% for all engine speeds above 150 Nm torque. Typical COTS engines comparable to the 3.0L have maximum thermal efficiencies of 39% and only maintain thermal efficiency greater than 35% for a small set of engine speeds near peak torque.

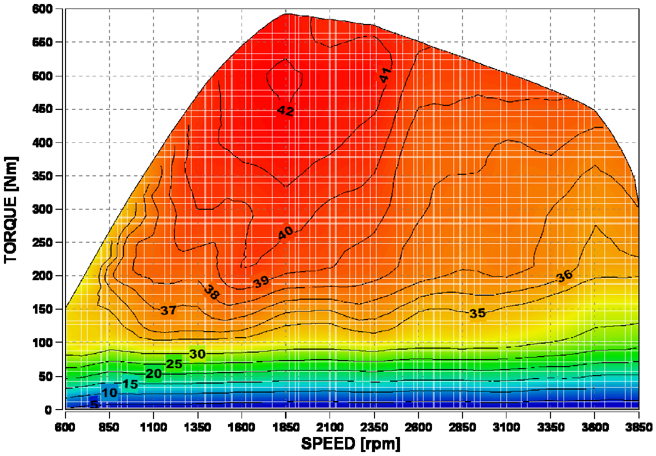

Figure 4: Modified 3.0L Brake Thermal Efficiency [%]

This improvement in brake thermal efficiency directly translates into reduced fuel consumption. Figure 5 below shows a contour plot of brake specific fuel consumption (BSFC) over the entire operating range of the modified 3.0L engine. The minimum BSFC achieved is 202 g/kW-hr, and BSFC is below 230 g/kW-hr for the vast majority of the operating range. By comparison, a COTS engine of similar configuration would have a minimum BSFC of 210 g/kW-hr and would only stay below 230 g/kW-hr in a small region near peak torque.

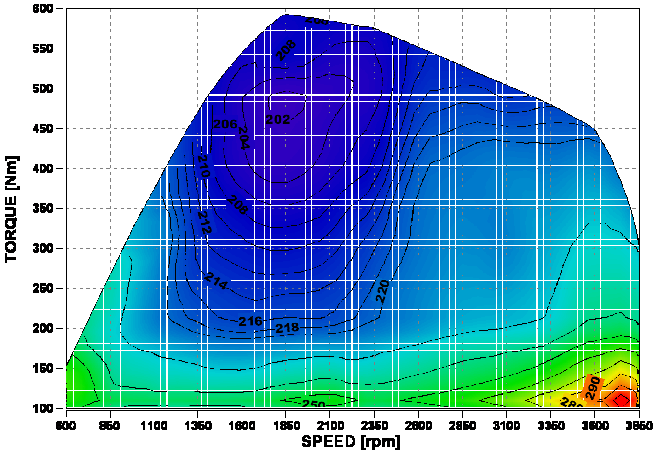

Figure 5: Modified 3.0L BSFC [g/kW-hr]

HEAT REJECTION

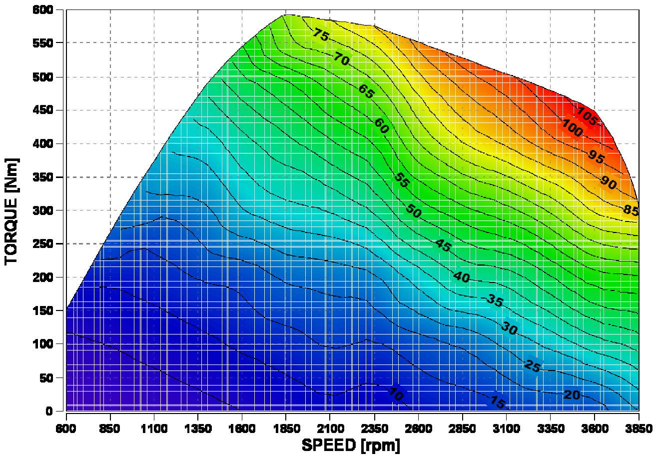

Figure 6: Modified 3.0L Total Heat Rejection to Coolant [kW]

Given the increasing amount of appliqué armor used on the HMMWV, rejecting heat from the engine has become more difficult. By deleting EGR and EAS from the COTS engine, the total heat rejected by the engine can be reduced by as much as 20% from the COTS configuration. Figure 6 shows the total heat rejected to coolant (both engine and charge air cooler) for the final calibration settings. The specific heat rejection is 0.63 at rated power – which is very low for an engine of this bore and stroke size.

CONCLUSION

Through the use of an open and flexible control system like the AVL UDEC, the military can take advantage of modern COTS engine technology such as VGT turbochargers, common rail fuel systems, and advanced engine materials to realize improvements in performance, while reducing fuel consumption, minimizing engine weight, and reducing heat rejection. These modern, compact engines can recover mobility lost by the increasing need for armor and other system upgrades to the HMMWV. The current AVL UDEC is capable of running on both DF2 and JP8 with minor calibration changes. Although the case study shown is an excellent candidate for application in the HMMWV, any COTS engine could be developed for use in other applications as well. Also, future development will enable the engine to automatically adapt to different fuels without any operator input to maintain consistent performance regardless of the fuel or fuel mixture being burned by the engine. With AVL UDEC, the military now has access to every COTS engine in the market to deliver more compact, powerful and flexible engines for use in light tactical vehicles for any mission.

REFERENCES

[1] AM General, "M1165A1 HMMWV Specification", AM General, South Bend, IN, 2011.

[2] G. Johnson, "JP-8 Compatible Development and Calibration of a Ford 4.4L V8 Engine", AVL Powertrain Engineering, Plymouth, MI, 2010.

[3] G. Johnson, "JP-8 Compatible Development and Calibration of a Jaguar Land Rover 3.0L V6 Engine", AVL Powertrain Engineering, Plymouth, MI, 2011.

[4] B. Baldwin, "JP-8 Compatible Development and Calibration of a Ford 6.7L V8 Engine", AVL Powertrain Engineering, Plymouth, MI, 2010.