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Cummins Light Truck Diesel Engine Progress Report

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ABSTRACT

The Automotive Market in the United States is moving in the direction of more Light Trucks and fewer Small Cars. The customers for these vehicles have not changed, only their purchase decisions. Cummins has studied the requirements of this emerging market. Design and development of an engine system that will meet these customer needs has started. The engine system is a difficult one, since the combined requirements of a very fuel-efficient commercial diesel, and the performance and sociability requirements of a gasoline engine are needed. Results of early testing are presented which show that the diesel is possibly a good solution.

INTRODUCTION

Cummins Engine Company and the Department of Energy have started the “Development of Technologies for a High Efficiency, Very Low Emissions, Diesel Engine for Light Trucks and Sports Utility Vehicles”, ref. 1.

The primary program goals are as follows:

1. EMISSIONS GOAL *

   For vehicle class of 5751-8500 GVW:

   NOx = 0.50 g/mile
   PM = 0.05 g/mile
   CO = 2.8 g/mile
   NMHC= 0.07 g/mile

   These goals were eventually modified by the publication of Federal Tier 2 emission standards early in 2000.

   * These goals are being revised to reflect the new EPA Tier II standards.

2. FUEL ECONOMY GOALl

   A 50 percent MPG improvement (combined city/highway) over the current (1997) gasoline powered light truck or sport utility vehicle in this class for which the diesel engine is being designed to replace.

3. COOPERATIVE DEVELOPMENT

   Regular design reviews of the engine program will be conducted with a vehicle manufacturer to insure that the concepts and design specifics are commercially feasible. DaimlerChrysler has agreed to provide Cummins with this design review input.

Cummins has started the development of an engine system with the intent to meet the above goals. The engine development project is in progress. Results are reported and should be considered only a Progress Report. Further development will improve the engine system allowing it to achieve all of the project goals.

MARKET BACKGROUND

The entire North American automotive market can be divided into two segments, light truck and car. Figure 1 shows the market penetration of these two segments since 1984 from auto industry sales data, ref. 2.

Two observations should be made from Figure 1. First, the trend from Car to Light Truck is gradual. There do not appear to be accelerations in the data. Second, the trend to Light Truck is not a recent phenomenon, and has been occurring for at least 15 years, and is expected to continue.

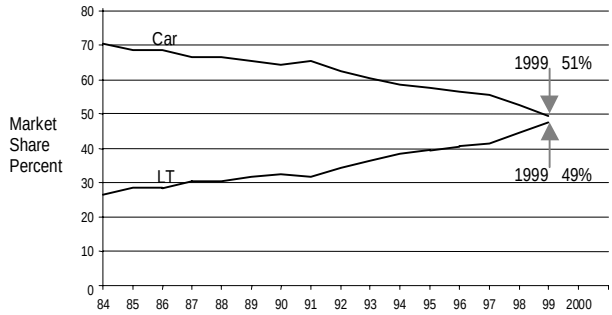

Figure 1. Car/Light Truck Market Share

Light Truck Market segments are shown in Figure 2. Pickup Trucks comprise about 39 percent of the sales in this market during 1999. Sports Utility Vehicles (SUV's) also comprise 39 percent, with vans of all types coming in third place at 22 percent.

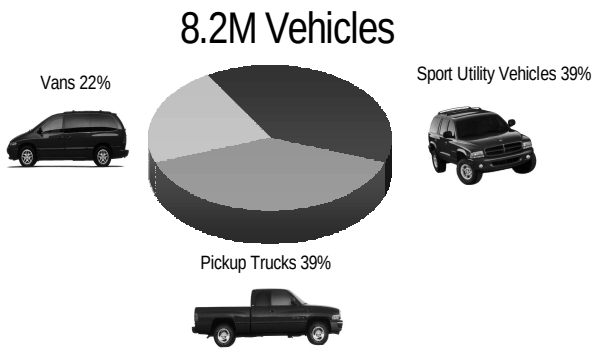

Figure 2. Light Truck Major Segments

Further analysis of the sales data for the past several years, ref. 3, shows that there are distinct buying trends.These are shown in Figure 3. The movement toward purchase of SUV's is the strongest and the most recent phenomena, as is shown by the relative width of the arrow in Figure 3. Most new SUV customers have replaced their car buying patterns with SUV purchases. The second trend, although not as strong, is the migration of car buyers to vans and pickup trucks. The third trend is a small migration of van and pickup customers to SUV's. And finally, there is also a small trend toward upgrade in the purchase of SUV's by some customers.

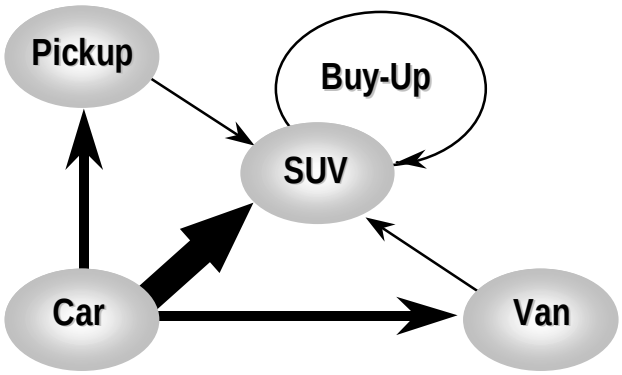

Figure 3. Migration to SUV's

ENGINE DESIGN PROPOSAL

Design of a new engine that would carefully consider the above customer needs and trends was undertaken. An outline of this design is shown in Figure 4.

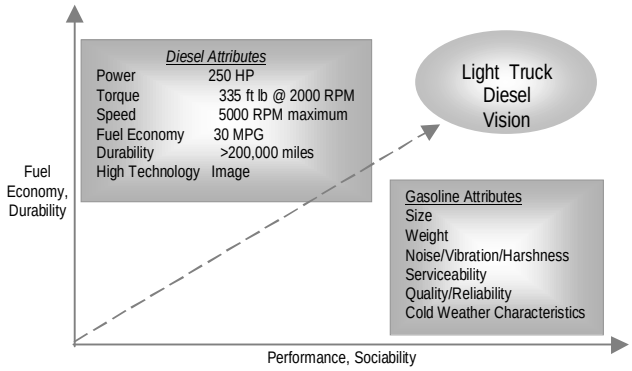

Figure 4. Light Truck Diesel Proposal

The engine design proposal combines the traditional best features of gasoline and diesel engines. The sociability strength of gasoline engines is combined with the fuel economy and durability of diesel. The Light Truck engine proposal is shown in Table 1.

Table 1. Light Truck Diesel Features

Attribute	Proposal	Comment
Power	250 hp, 185 kW	Equivalent to small V-8 gasoline
Torque	335 ft-lb at 2000 rpm, 455 Nm	Held to this low level to allow usage of commonly available drivetrain components
Speed	5000 rpm (max.)	Flexible application and driver usage.
Fuel Economy	30 MPG	General highway usage.
Durability	200,000 miles (typical), 325,000 km	Generally greater than other vehicle components
Image	"High Tech"	Reinforce notion of new technology
Size	L=652;W=685;H=730 mm	Fit space also used by small V-8 gasoline engines
Weight	550-600 lb, 250-275 kg	Similar to small V-8 gasoline.
Noise/Vibration/Harshness	71 dB at idle, hood open	Similar to small V-8 gasoline
Serviceability	Equal to gasoline	Diesel fuel filter an exception
Quality/Reliability	Equal to gasoline	Includes diesel injection system
Cold Weather Characteristics	Equal to gasoline	Includes starting and warm-up

The Light Truck Diesel Engine CAD model is shown in Figure 5.

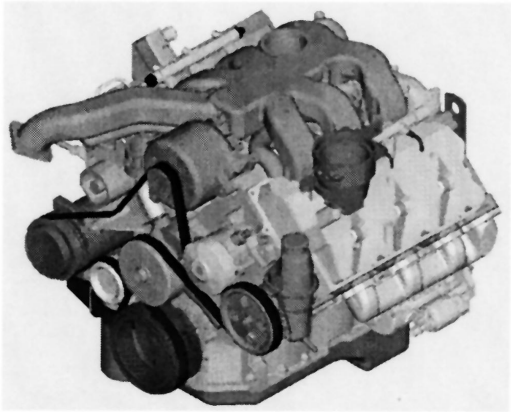

Figure 5. Light Truck Diesel Engine

An overall description (architecture) of the major subsystems of the engine is described in Table 2 below.

Table 2. Light Truck Diesel Subsystem Description

Subsystem	Description
Configuration	90 ° V-6
Displacement	4.2 L
Bore and Stroke	94 X 100 mm
Valvetrain and drive	Single overhead cam, chain-driven
Valve system	Four valves per cylinder with hydraulic lash adjustment
Fuel system	High Pressure Common Rail (HPCR)
Control system	Full electronic
Emissions Control	Modulated-Cooled EGR plus deNOx catalyst
Aspiration	Wastegated Turbocharged
Intercooling	Vehicle mounted air-to-air
Block	Cast iron, thin-walled
Head	High temperature alloy aluminum
NVH control	Deep skirted block, with bedplate
Accessories	Common automotive V-8 gasoline
Accessory drive	Single serpentine belt, self-adjusted

EMISSIONS RESULTS

Emissions development of the Light Truck Diesel Engine started with a benchmarking activity. A 4.2 L engine, sold in Europe for 1997 automotive use, was procured. The engine was brought to the US and tested on the light duty EPA FTP cycle. The results are show in Figure 6.

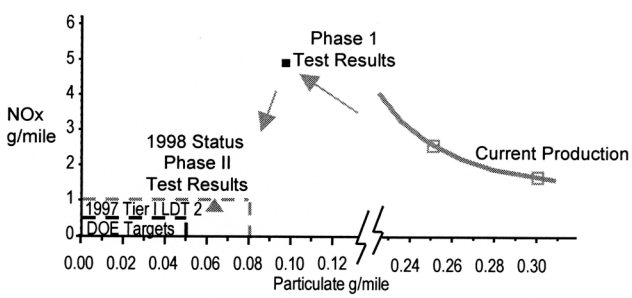

Figure 6. Emissions Progress Summary

The results show that the engine as produced will have emissions results of NOx=1.8 g/hp-hr and PM= 0.30 g/hp-hr at a test weight of 4900 lb. This was far from the Tier 1 LDT 2 standards that it would need to meet from 1997-2003.

Development of the engine emissions control system then started. The first step was to simply remove the EGR system. The results were as expected, with NOx=2.6 g/hp-hr and PM=0.25 g/hp-hr.

The emissions control equipment was removed from the engine and the Cummins fuel and air handling systems were installed. The first result are described in Figure 6 as the Phase 1 Results, and show NOx=5.0 g/hp-hr and PM=0.10 g/hp-hr. There was an expected rise in NOx since the EGR system was removed. The reduction in PM was dramatic, with a 3:1 reduction from the original configuration.

The next step was to add a new EGR system. The results were very encouraging with Tier 1 requirements achieved: NOx=0.9 g/hp-hr, and PM= 0.06 g/hp-hr.

Development continued with the refinement of the combustion system and the control system. (A simple deNOx catalyst was used in all cases. The exact effectiveness was not measured but was generally estimated to be less than 10 percent.) The results are shown in Figure 7.

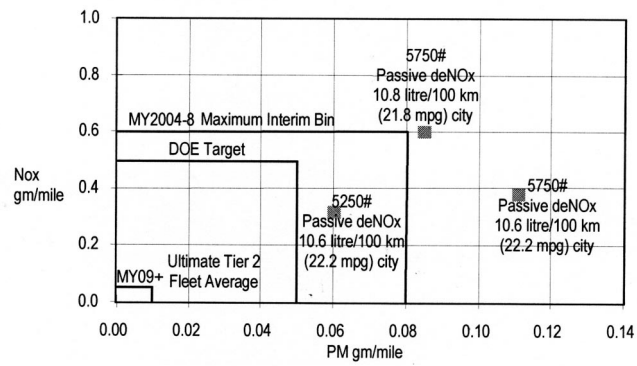

Figure 7. Demonstrated Emissions

The first series of result are shown at test weights of 5750 lb. Two data points are presented: first NOx=0.6 g/hp-hr and PM=0.09 g/hp-hr; and second NOx=0.4 g/hp-hr and PM=0.11 g/hp-hr. Control system calibration was changed to get the different results.

The second test was run at a test weight of 5250 lb. This case more closely approximates typical medium weight SUV's. The results were very encouraging with NOx=0.4 g/hp-hr and PM=0.06 g/hp-hr. For comparison the Maximum Interim Bin for MY 2004-2008 is shown in Figure 7. The data clearly shows that the emissions are within the requirements through MY 2008.

For reference, the ultimate Tier 2 fleet average requirement of NOx=0.07 g/hp-hr and PM=0.01 g/hp-hr is also shown.

FUEL ECONOMY RESULTS

Fuel economy was measured during the emissions testing described above. Results as measured are shown in Figure 8 for a series of test weights. The range used was 4500 lb approximating a small pickup truck, to 5250 lb approximating a medium SUV, to 5750 lb approximating a full-size pickup truck.

Highway fuel economy ranged from 34 mpg for the small pickup to 32 mpg for the full-size pickup. City fuel economy varied from 25 mpg to 22 mpg for the same vehicles.

The measured results are then corrected to reflect in-use consumer fuel economy, and industry procedures for vehicle labeling are used. The resulting combined mpg improvement Vs gasoline for the SUV test weight is 59 percent.

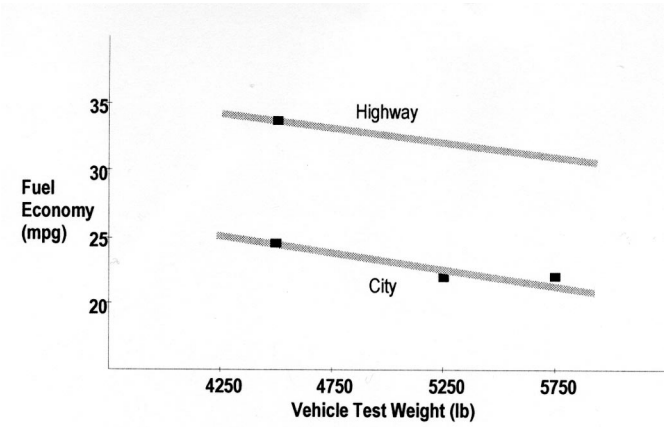

Figure 8. Fuel Economy

ENGINE PERFORMANCE

Performance curves for the Light Truck Diesel V-6 are shown in Figure 9. The data shows that the engine at its current state of development is capable of achieving its torque goals and is able to achieve power goals at speeds up to 3500 rpm. Further development is planned to achieve power from 3500-4500 rpm.

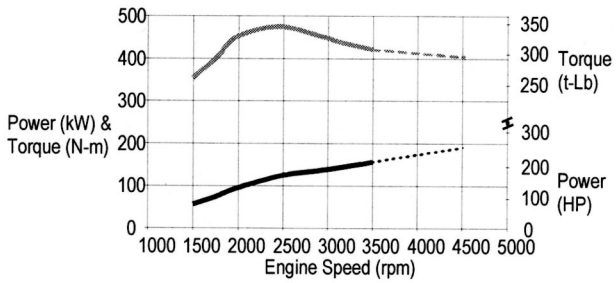

Figure 9. V6 Performance

NOISE TEST RESULTS

Noise results, comparing the Light Truck Diesel with a current production gasoline V-8 engine are shown in Figure 10. Testing was conducted on an engineering prototype MY 1998 Durango. This vehicle with a 5.9 L V-8 gasoline engine was used as the base case. The vehicle did not have production trim noise equipment; however it was considered adequate to compare the differences between diesel and gasoline engines. Three test conditions are reported: interior noise at idle, 60 mph cruise, and exterior at 3 ft with the hood open.

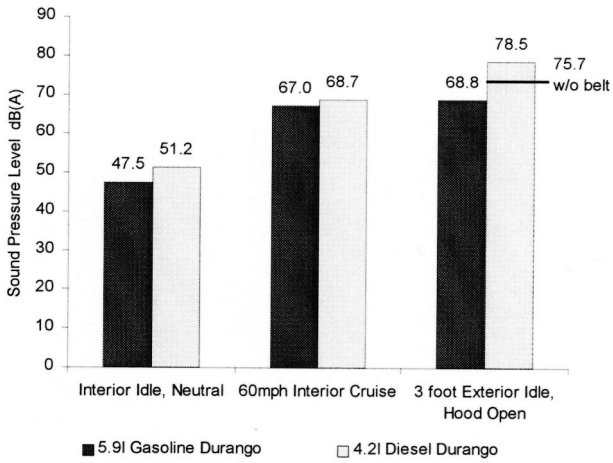

Figure 10. Noise Test Results

The diesel engine was 3.7 dB(A) noisier at idle. At highway cruise conditions the diesel was only 1.7 dB(A) noisier. With the hood open at 3 ft, the diesel was 9.7 dB(A) noisier; this value reducing to 6.9 dB(A) with removal of problem belts.

PERFORMANCE TEST RESULTS

Performance test results, comparing the Light Truck Diesel with a current production gasoline V-8 engine are shown in Figure 11. Testing was conducted on the engineering prototype Durango vehicle discussed above. Again, the V-8 gasoline powered vehicle was used as the base case. Both vehicles used an automatic transmission.

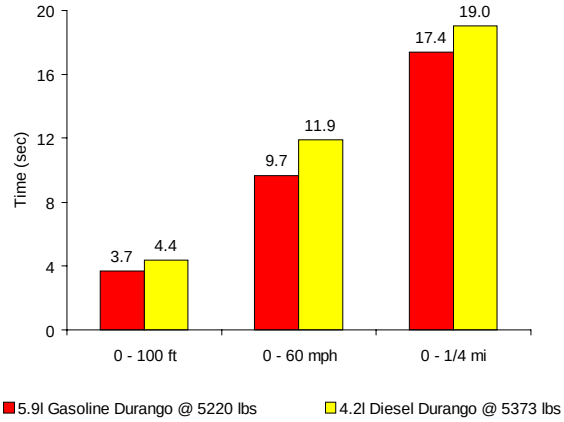

Figure 11. Acceleration Test Results

Three acceleration tests were used to assess the performance of the Light Truck Diesel Engine. In the 0-100 ft elapsed time test, the Light Truck diesel completed the distance in 4.4 sec Vs 3.7 sec for the gasoline engine. The elapsed time to achieve 60 mph was 11.9 sec for the diesel Vs 9.7 sec for the gasoline engine. The elapsed time for the ¼ mile distance was 1.6 sec slower for the diesel at 19.0 sec.

SUMMARY AND CONCLUSIONS

The early development results for a new Light Truck Diesel engine show much promise and achievement.

An engine has been designed that will fit into SUV vehicles which today are powered by V-6 and V-8 gasoline engines. The new diesel engine has the same size envelope, comparable weight, and comparable power density. The basics have been achieved.

Fuel economy advantage over the gasoline engine is clear. Depending on driving conditions, 60 percent improvement over gasoline should be regularly reported by customers.

There is also great promise and achievement in the areas of performance and sociability. While the diesel currently lags in performance, it is believed that continued development will overcome the difference. A similar situation exists in the case of noise. Again the diesel is noisier, but by only small amounts. These differences can also be overcome by final development work on the product.

Emissions remains the area were the greatest amount of development work remains, long term. The ability to meet the interim Tier 2 Standards has been demonstrated. This will allow production and sale through 2008. This also provides lead-time for the continued refinement of the engine emissions control package.

There is a path to market for the Light Truck Diesel.

REFERENCES

1. DOE Contract No. DE-FC05-97OR22533
2. “Automotive News “ 1/17/2000, Page 31
3. 3Internal Cummins Analysis