

## **Detroit Diesel Engine Technology for Light Duty Truck Applications – DELTA Engine Update**

**Charlie Freese, Nabil Hakim and Stan Miller**

The early generation of the DELTA engine has been thoroughly tested and characterized in the virtual lab, during engine dynamometer testing, and on light duty trucks for personal transportation.

This paper provides an up-to-date account of program findings. Further, the next generation engine design and future program plans will be briefly presented.

**DEER**

**The Detroit Diesel DELTA Engine  
for Light Trucks**

**2000 Update**

**22AUG00,  
San Diego, CA**

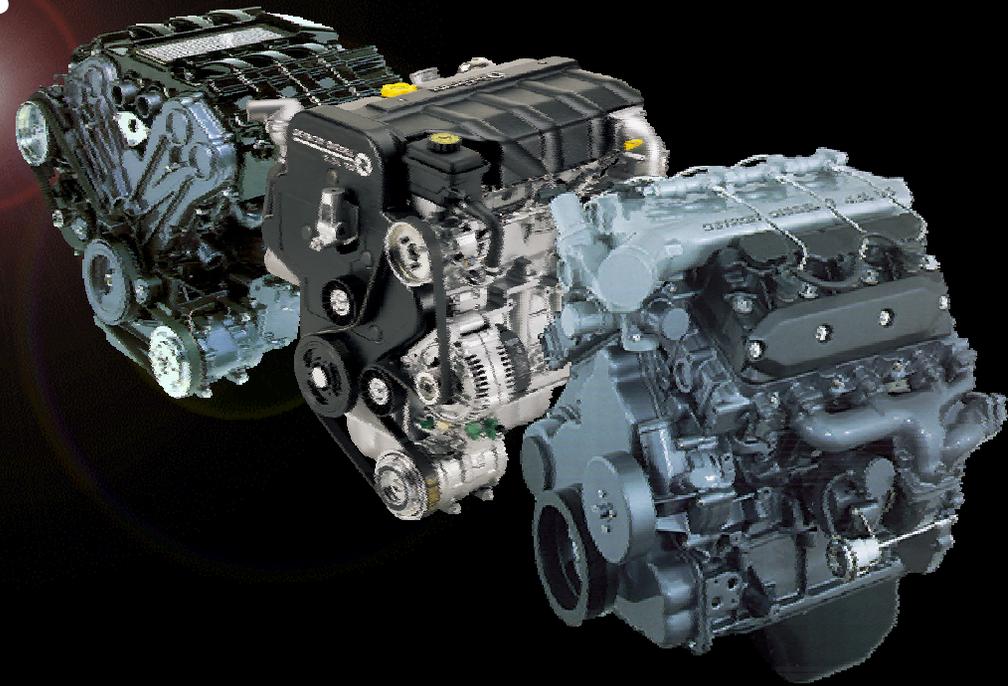
*Presented by:* **Charles Freese**

**Detroit Diesel Corporation**



# Outline

- North American Market Requirements
- 4.0L V6 DELTA Design Strategy
- Demonstration Vehicle Results



# North American Market

- **Low Cost, High Volume Gasoline Competition**
- **Relatively Low, but Recently Increasing Fuel Prices**
- **Diesel Acceptance Concentrated Only in Medium Duty**
- **Larger Vehicles with High Displacement Engines**
- **Vehicles Optimized for Gasoline**
- **Utility Functions**
- **Extended Durability**



# CAFE

- **CAFE Requirement**
  - Car: 27.5 MPG
  - Light Trucks: 20.7 MPG
- **Actual Light Truck: 12 to 20.7 MPG**
- **CAFE Standards Likely to Increase**
- **Automaker Vehicle Mix is Changing**



# Vehicles are Getting Larger . . .

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***Grand Cherokee***



***Durango***



. . . and Larger

*Explorer*

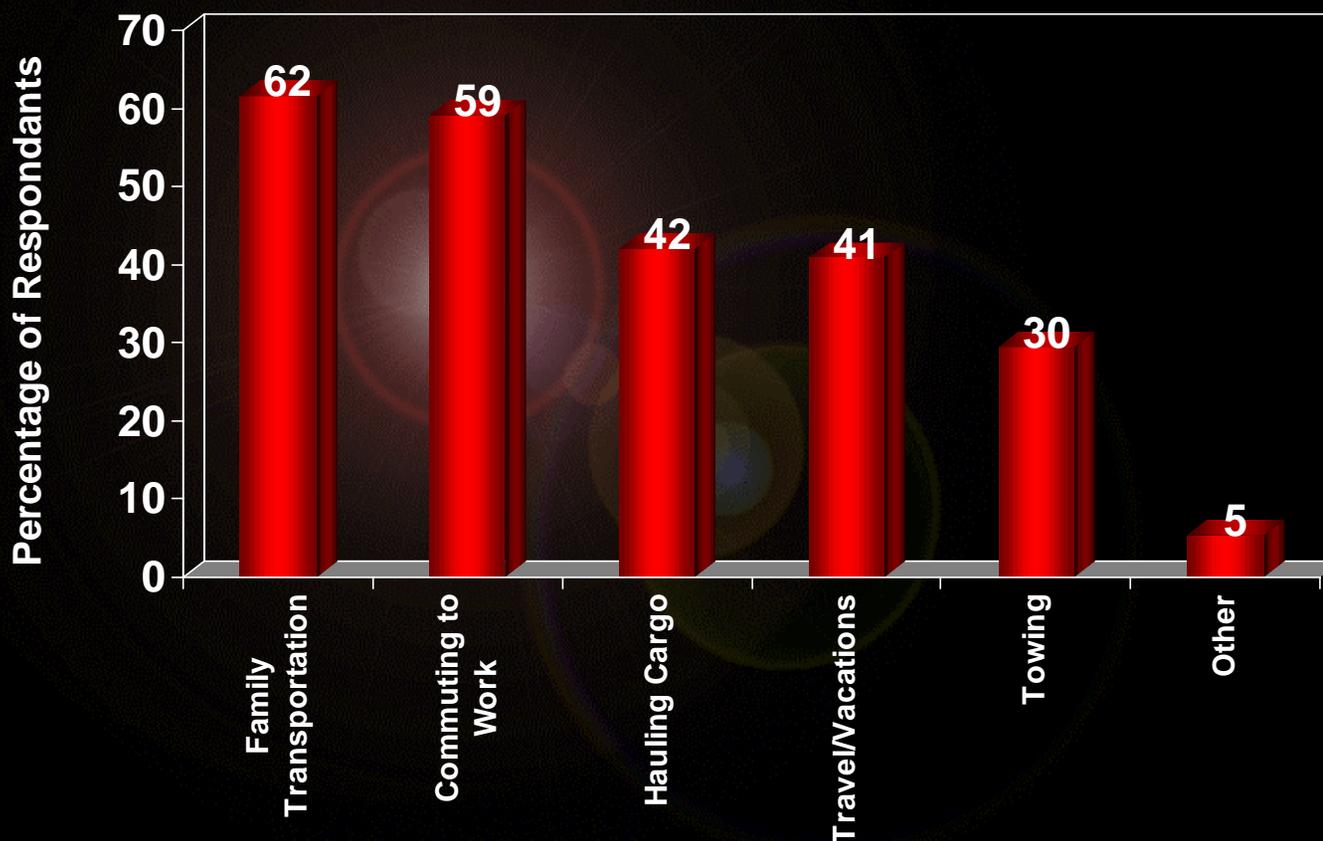
*Expedition*

*Excursion*



# North American Diesel Market Primary Uses for SUV & Light Trucks

- What are the primary uses, for which you purchase an SUV or Light Truck?



Data from PTM Research, Compiled at 1999 Detroit International Auto Show



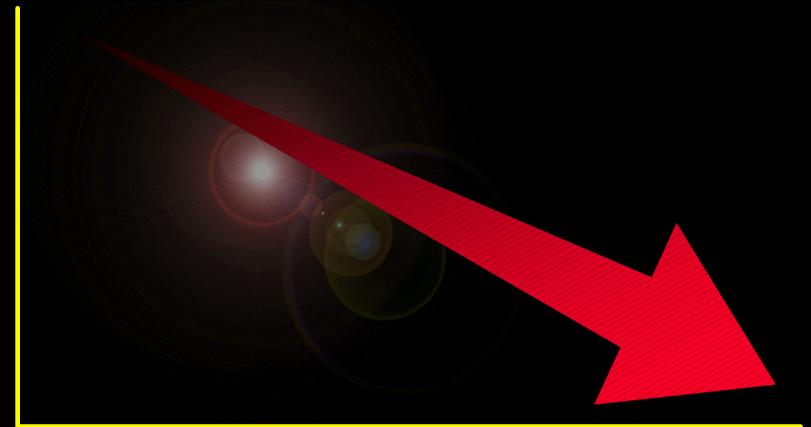
# “Green Movement”

- **Greenhouse Gas Emissions**

## U.S. Reaction

White House hails treaty; Congressional Republicans balk

CO<sub>2</sub> Emissions (g/mile)



Fuel Economy (MPG)

## Automotive News

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### Kyoto puts heat on makers



# North America Diesel Sociability Challenge

- **Historical Perceptions**

**“Sluggish Performance”**

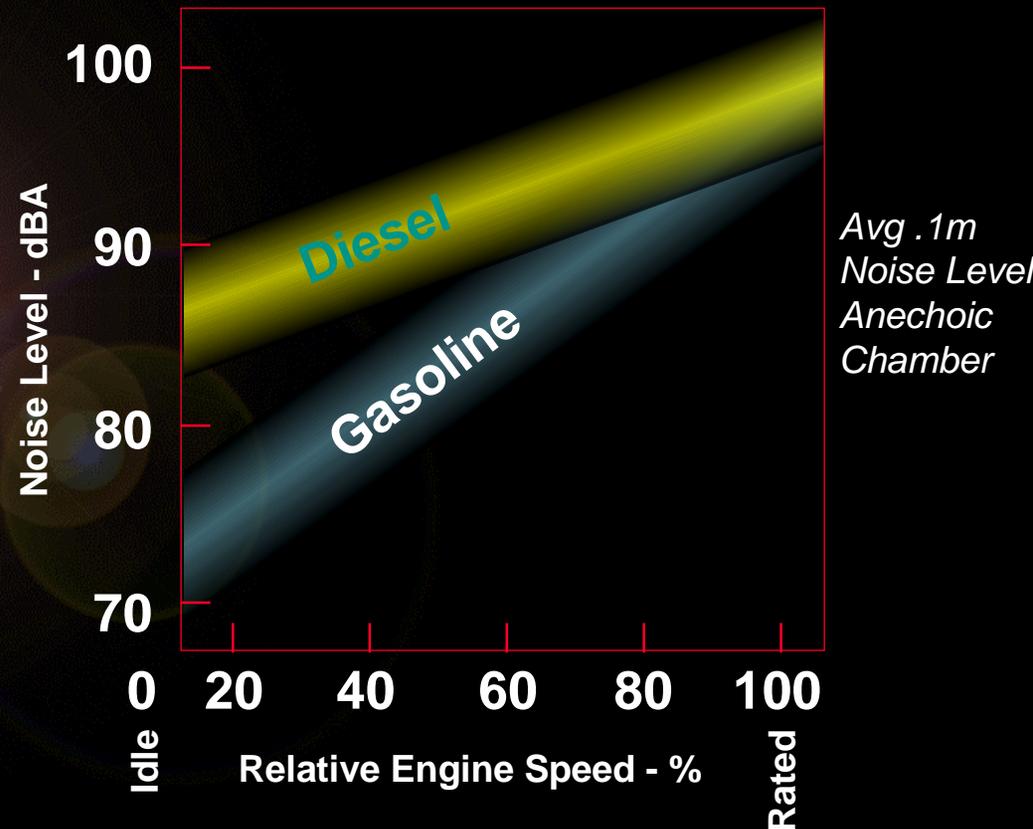
**“Noisy”**

**“Difficult to Shift”**

**“Offensive Smell”**

**“Smoke”**

**“Dirty”**

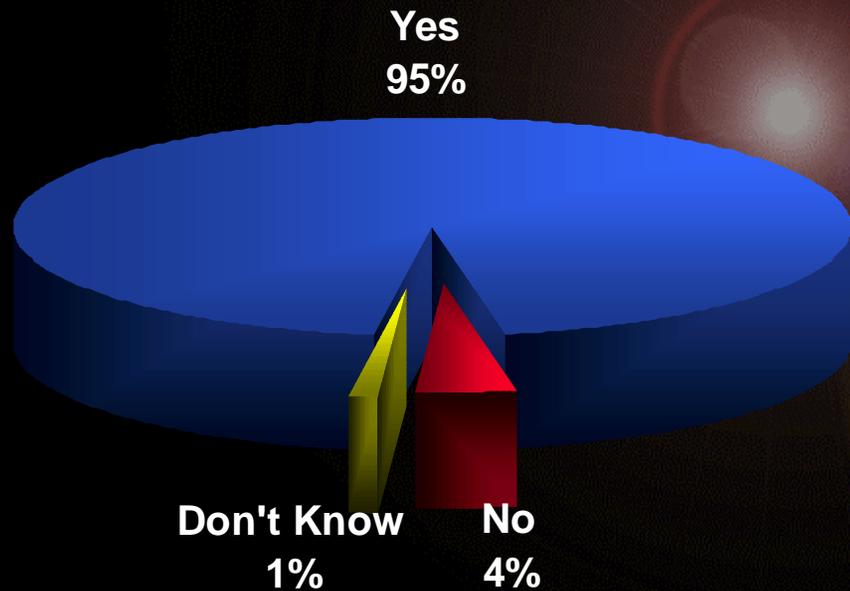


- **Modern Diesel Technology is Changing Public Preconceptions**

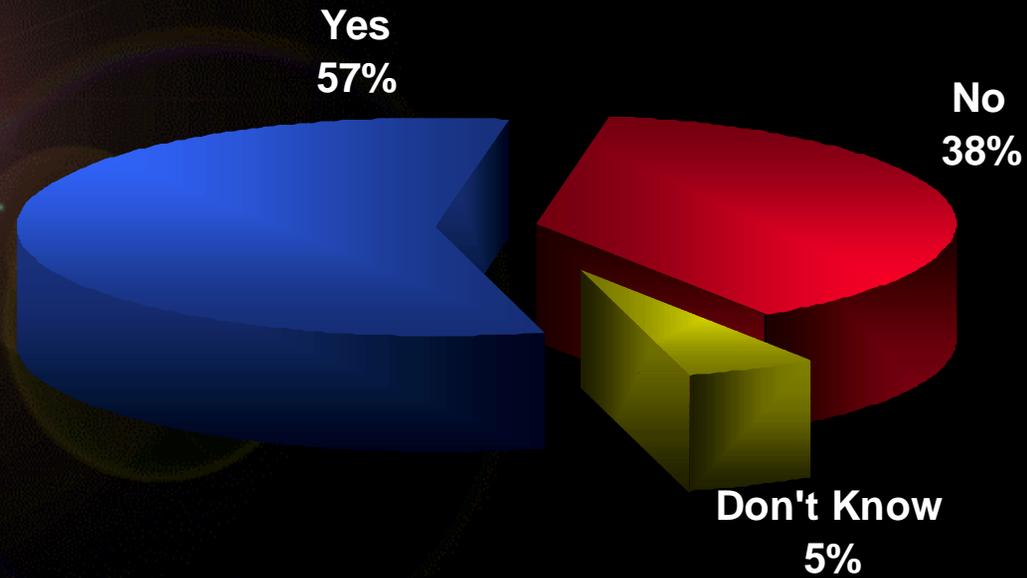


# North American Diesel Market

Would you Purchase Another Diesel Truck?



Would you Consider Buying a Diesel SUV?

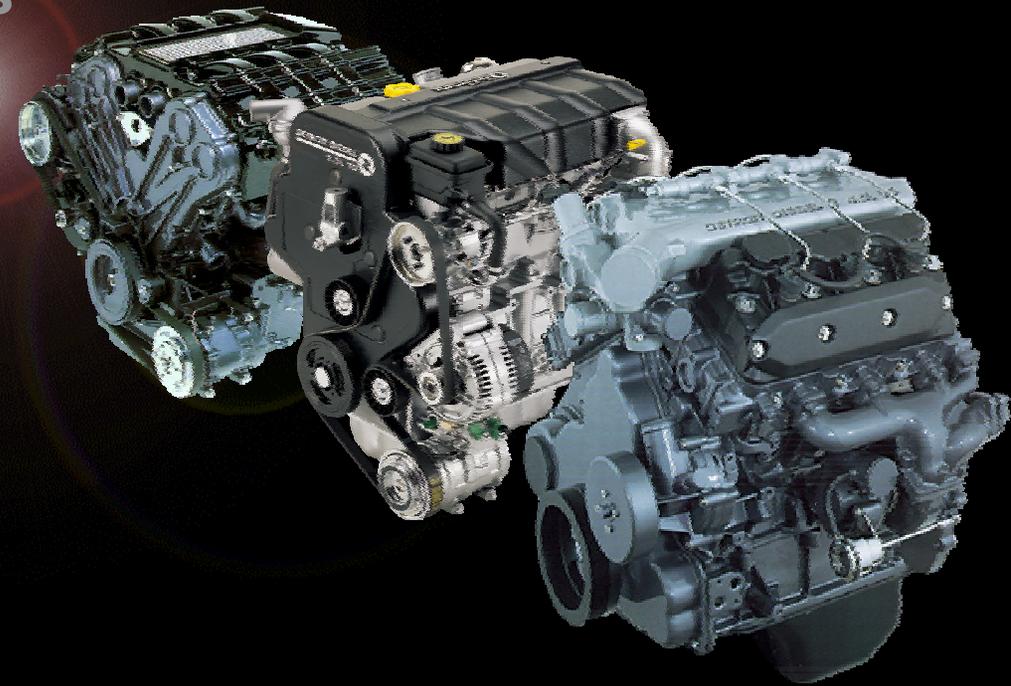


Data Based Upon Survey by Power Systems Research

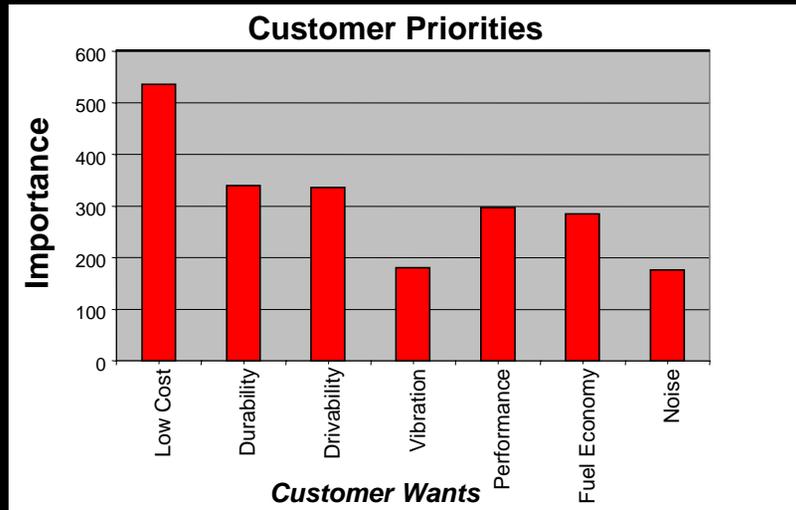


# Outline

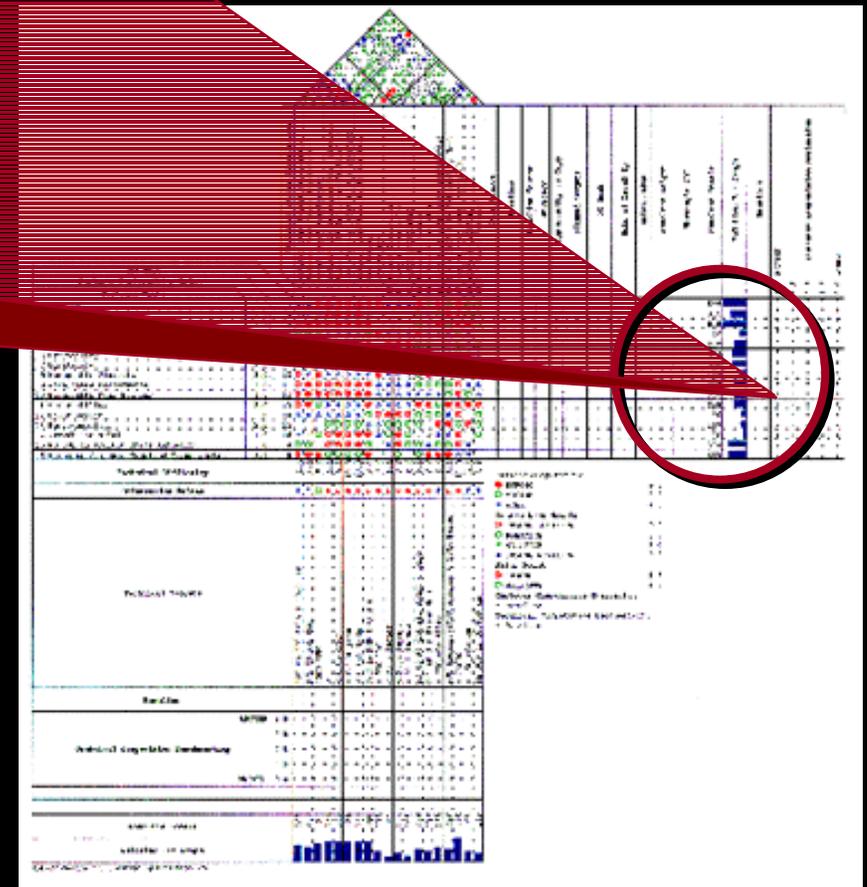
- North American Market Requirements
- **4.0L V6 DELTA Design Strategy**
- Demonstration Vehicle Results



# Light Truck / SUV Requirements Drove DDC's Design



- Identify Unique North American SUV/LT Requirements
  - Performed Quality Function Deployment (QFD) Analysis
  - Identified Constraints
  - Identified Customer Wants



# North American Diesel Engine Objective Summary

- Develop **LOW COST** Diesel Engine Alternative
- Provide Better **DURABILITY & FUEL ECONOMY** than Gasoline
- Satisfy Unique Light Truck / SUV **DUTY CYCLE**
- Establish Unprecedented Diesel **SOUND QUALITY** Standards
- Minimize **VIBRATION** Effects on System
- **EMISSIONS COMPLIANCE**
- Clean Sheet Solution Required



# A New Class of Diesel Engine

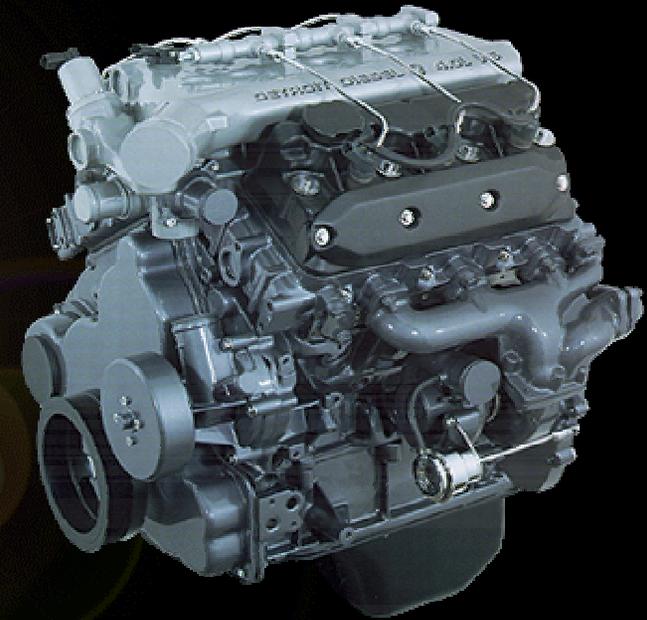
- **4.0L V6 DELTA Program**
  - Development Effort Based in Detroit, MI
  - Light Truck / SUV Diesel
  - Designed Specifically for North American Market
  - Program Started 27SEP97
  - Targeted Running Vehicle by 3<sup>rd</sup> Quarter 1998
  - 228 Day Development Period  
Clean Sheet to Running Prototype



# 4.0L V6 DELTA

## Basic Engine Data

- Configuration 60° V6
- Displacement 4028 cc
- Bore & Stroke 92mm x 101mm
- Engine Type Diesel
- Combustion System Direct Injection
- Compression Ratio 18.5:1
- Specific Power 39.9 kW/Liter
- Air Induction Turbocharged Intercooled
- Block Cast Iron
- Cylinder Head Reversible Cast Iron Slab
- Emission Devices Electronically Controlled Cooled EGR, Catalyst
- Injection System Common Rail
- Valve Train OHV, 4 Valves / Cylinder, Hydraulic Lifters



## Dimensions

- Length 533 mm
- Width 635 mm
- Height 787 mm
- Weight (dry) 290 kg

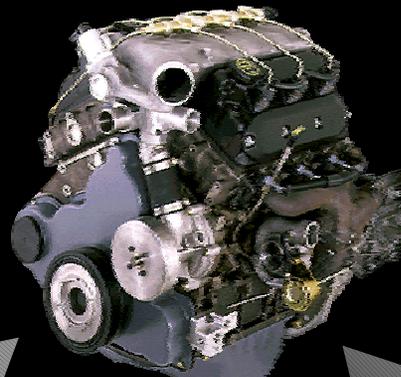


# Utilized DDC's Core Competencies



## European Light Duty

HSDI = High Speed Direct Injection  
 Popular in European Passenger Cars  
 Technology Centers in Europe & U.S.  
 World's Largest Independent Automotive  
 Diesel Engine Maker



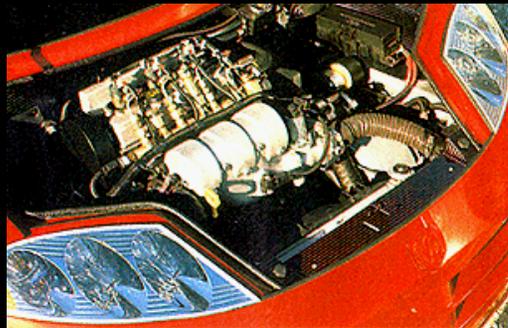
## 4.0L V6 DELTA

A New Class of Diesel Engine  
 Low Cost  
 High Performance  
 High Durability



## Series 60 Heavy-Duty

Best-In-Class  
 World Fuel Economy Leader  
 Over a Million Mile Engine  
 3 to 30% Penetration in 10 Years



## Research & Development

Advanced Diesel Engine Technologies  
 Lightweight Materials  
 Advanced Analysis Technologies  
 Vehicle Pilot Center

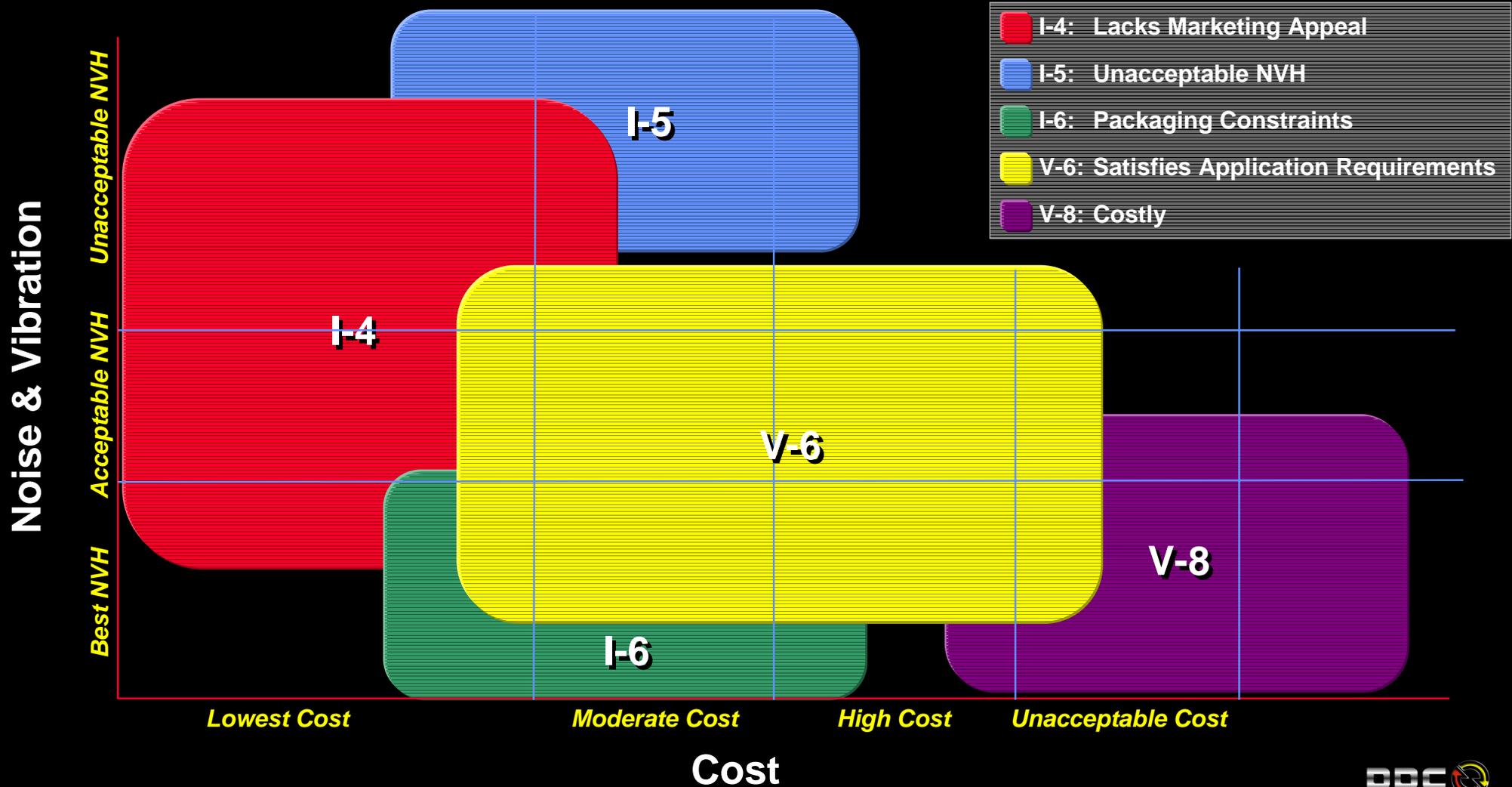


## Supplier Teamates

Supplier Expertise



# Noise & Vibration Refinement Engine Architecture



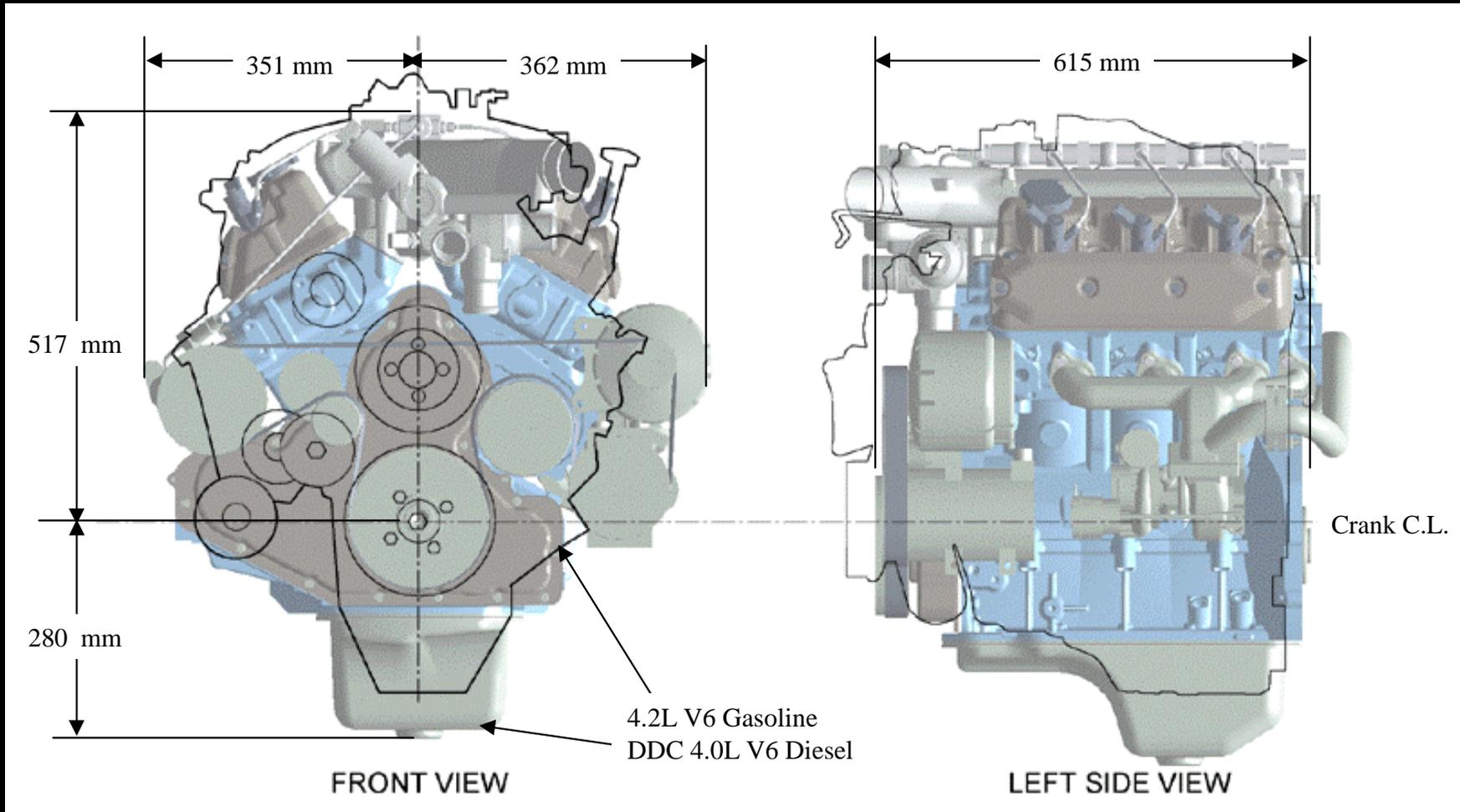
# 60° vs. 90° V6

Evaluation Criteria	60° V6	90° V6
Length	21.0"	24.4"
Width	25.0"	27.8"
Height	31.0"	27.3"
Turbocharger Packaging	<i>Side or Front</i>	<i>Side, Front, In-Vee</i>
Intake Manifold Options	<i>Single</i>	<i>2 Divided</i>
Fuel System	<i>Single Common Rail</i>	<i>Two Rails &amp; Junction Block</i>
First Order Balance Shafts for Full Balance	<i>None</i>	<i>1</i>
Second Order Balance Shafts for Full Balance	<i>1</i>	<i>2</i>



# Packaging

## Engine Envelope Comparison (DDC 4.0L V6 to 4.2L V6 Gasoline)

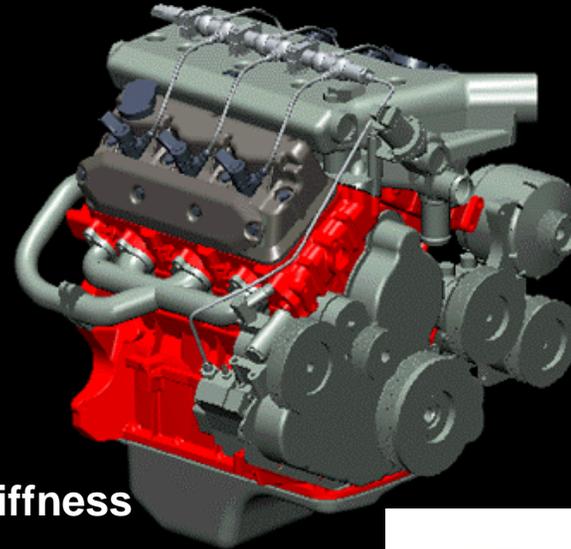


# Cast Iron Block, Bedplate, & Heads

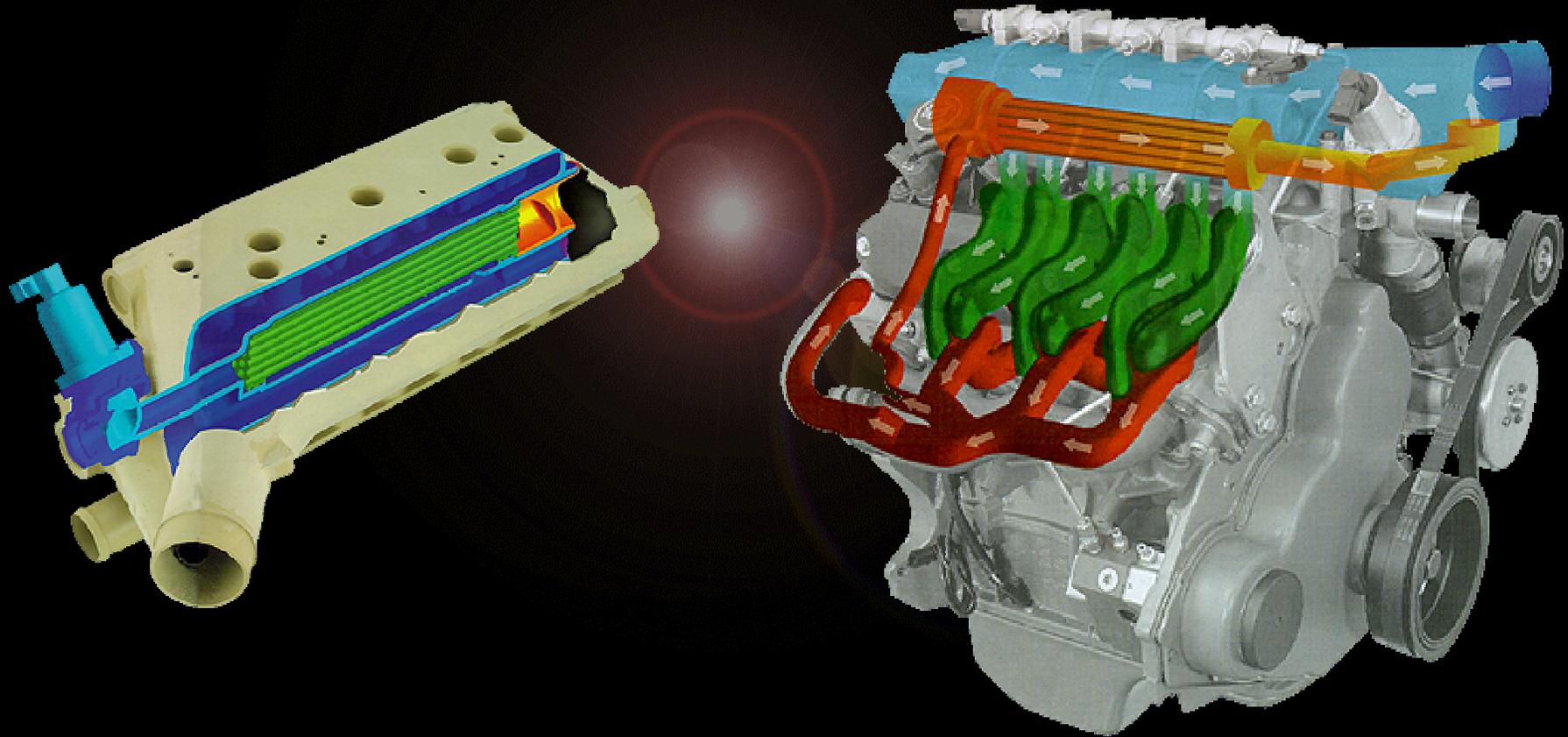
- **Cast Iron Construction**

- **Lowest Cost**
- **Exceptional Durability**
  - » **Minimizes Fatigue & Creep**
  - » **Robust Threaded Passages (Permits 1.2 x Thread Diameter)**
- **High Strength, Stiff Structure**
  - » **Cored Passages Increase Structural Stiffness**
  - » **Minimizes Bore Distortion**
- **Optimal NVH**
- **Maximum Valve Area in Head**
- **Improved Warm Start Emissions**
- **Improved Cab Heating**

- **Interchangeable Heads**



# Cost Reduction Through System Optimization

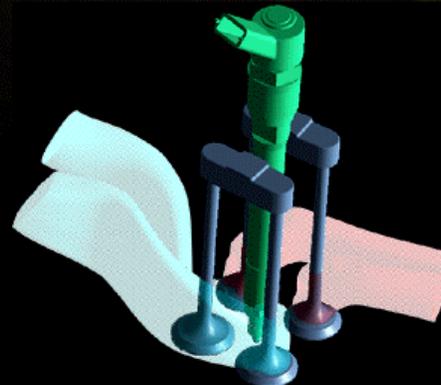


*Patented Pending Design*



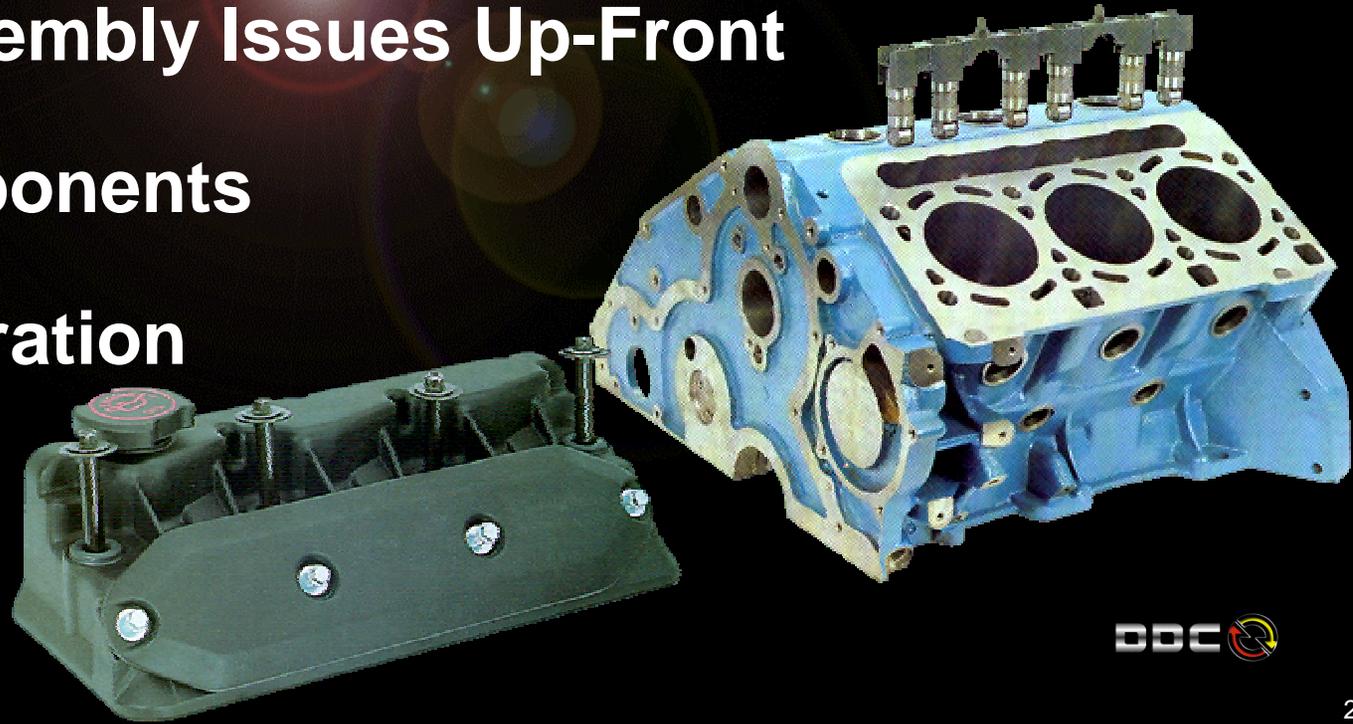
# Low Cost Approach

- Satisfy Customer Requirements
- Maximize Customer Value
- Minimize Engine Cost
  - 4000 rpm Rated Speed
  - Overhead Valve Configuration (OHV)
  - 4 Valves per Cylinder
  - V6 Market Entry
  - Compact Geartrain



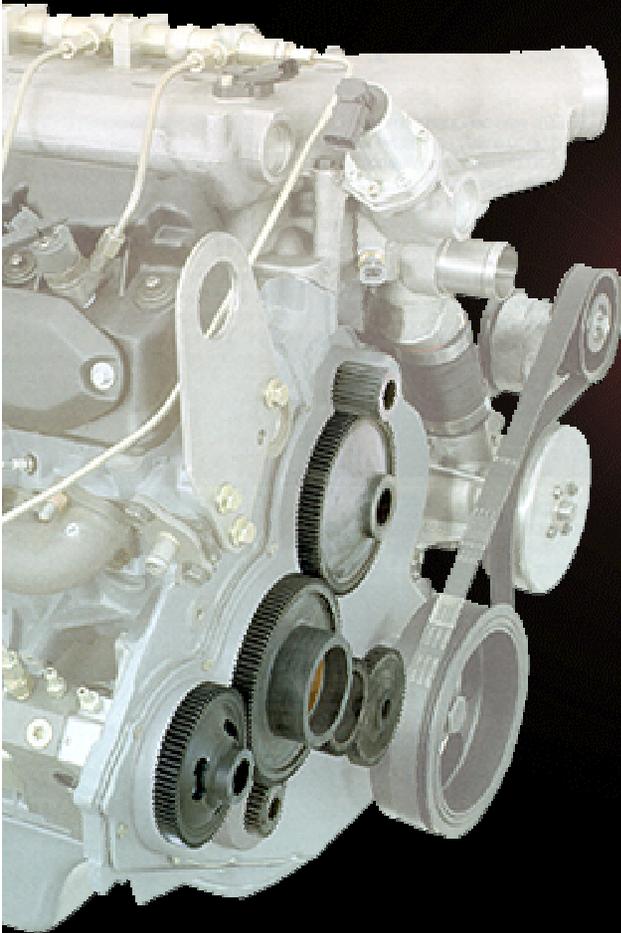
# Cost Reduction Through Assembly Considerations

- **Designed for Assembly (DFA)**
- **Manufacturing Engineers on Design Team**
- **Considered Assembly Issues Up-Front**
- **Minimized Components**
- **Feature Incorporation**



# Life Cycle Cost Reduction

## 250,000 Mile Durability



- North American Truck Requirements
- Cast Iron Block & Heads
- Hydraulic Lash Adjustment
- Gear Driven
  - Camshaft
  - High Pressure Fuel Pump
  - Oil Pump
  - Vacuum Pump
  - Optional Balance Shaft
- Low Service Costs



# Common Rail Fuel System

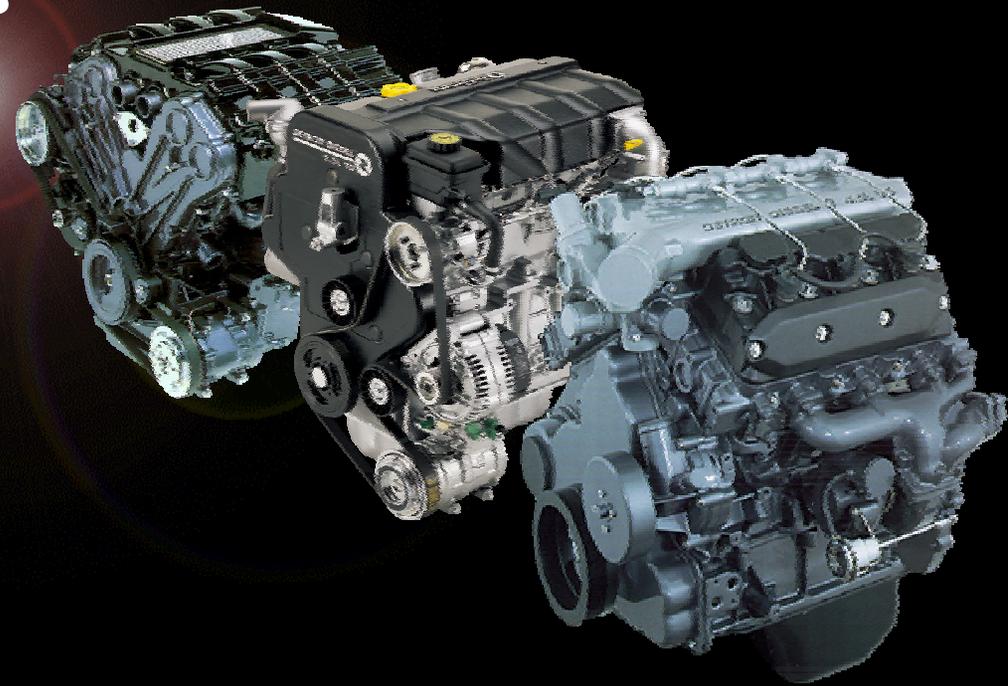
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- **High Pressure System**
  - 1350 bar Maximum Pressure (Current)
  - 1600 - 1800 bar in Future
- **Variable Displacement Pump**
  - Reduced Parasitic Losses
  - Minimize Fuel Heating
  - Integrated Fuel Transfer Pump
- **Multiple Pilot & Post Injection**
  - Combustion Noise Reduction
  - Sound Quality Improvement
  - Rate Shaping
  - Developing Repeatable Multiple Pilot Approach
  - Aftertreatment Flexibility



# Outline

- North American Market Requirements
- 4.0L V6 DELTA Design Strategy
- **Demonstration Vehicle Results**



# Demonstration Vehicle



# Vehicle Development

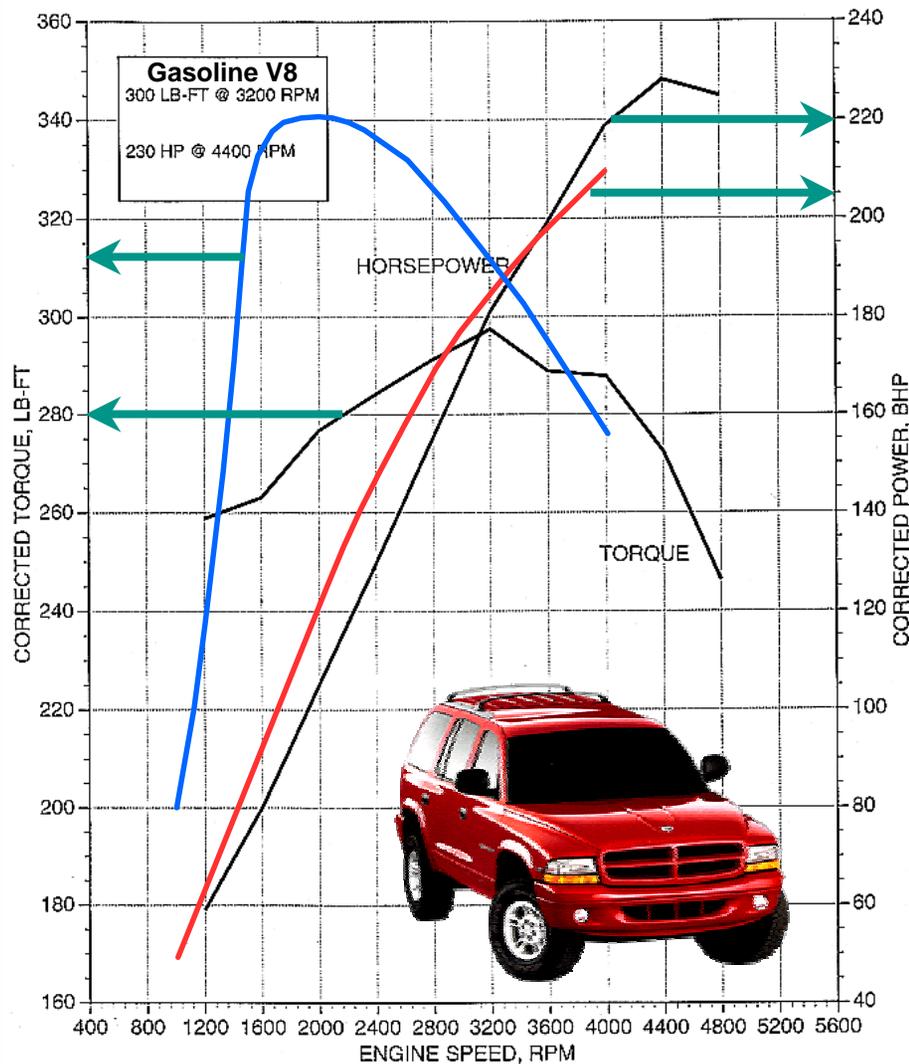
## Fuel Economy & Performance

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- **Highway Fuel Economy: Over 30 mpg**
- **City Fuel Economy: 22 mpg**
- **70% Improvement Over Actual Test Route**
  - **Vehicle Loaded to 6,450 lb GVW**
  - **(21.8 mpg vs. 12.7 mpg)**
- **0 to 60 mph in 10.7 Seconds**



## Dodge Durango



# Engine Performance

- Comparison to Existing V8 Gasoline Engine

DDC Automotive Power  
**BHP** —————  
**Torque** —————

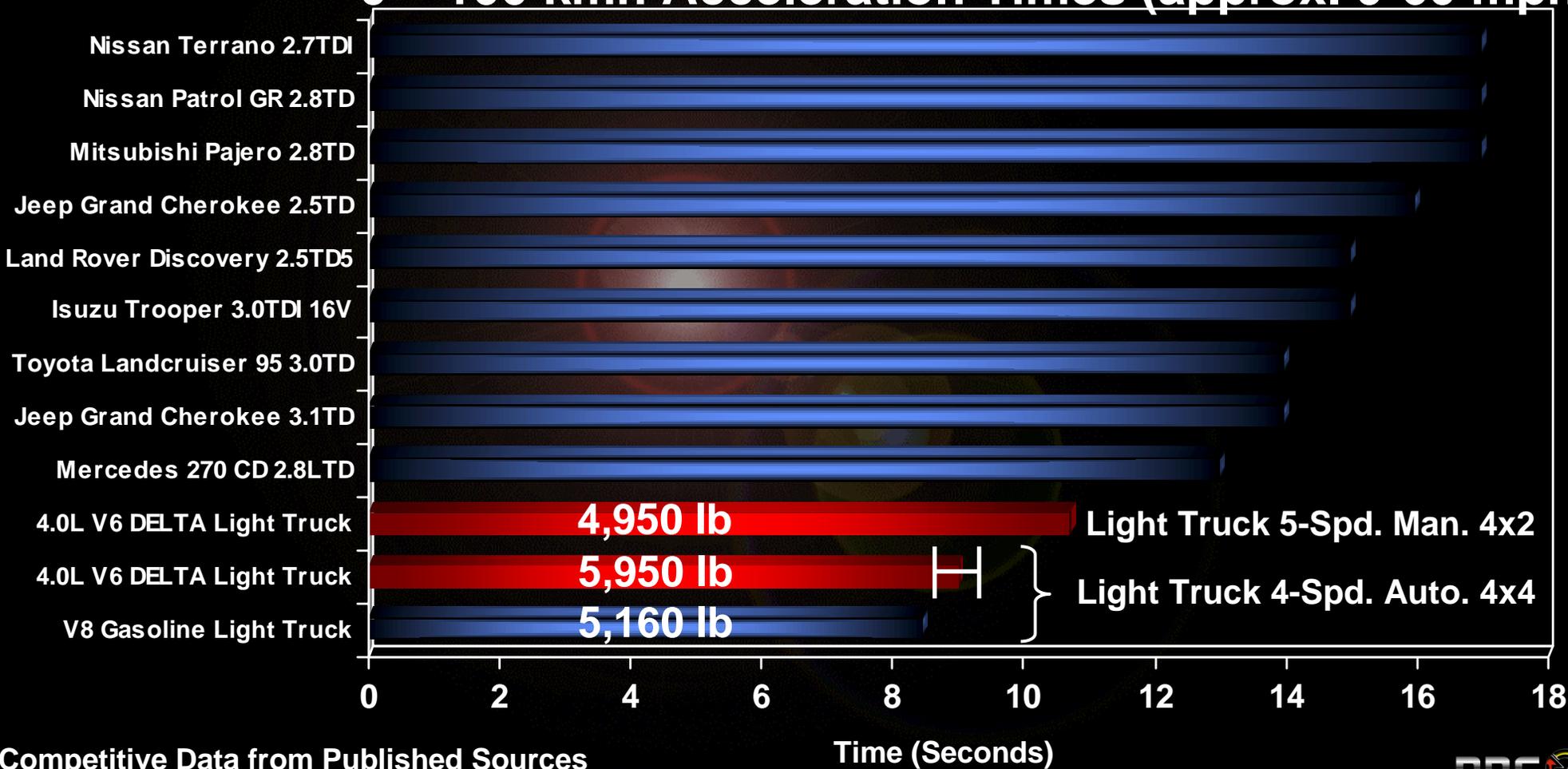
- 4.0L V-6
- 210 bhp @ 4000 rpm to 235 bhp
- 340 ft-lbf @ 2000 rpm to 375 ft lb
- Torque may be Electronically Optimized for Transmission Limitations & Shifting



# Vehicle Acceleration Benchmark

## 4.0L V6 DELTA in Light Trucks

0 – 100 kmh Acceleration Times (approx. 0-60 mph)



Competitive Data from Published Sources

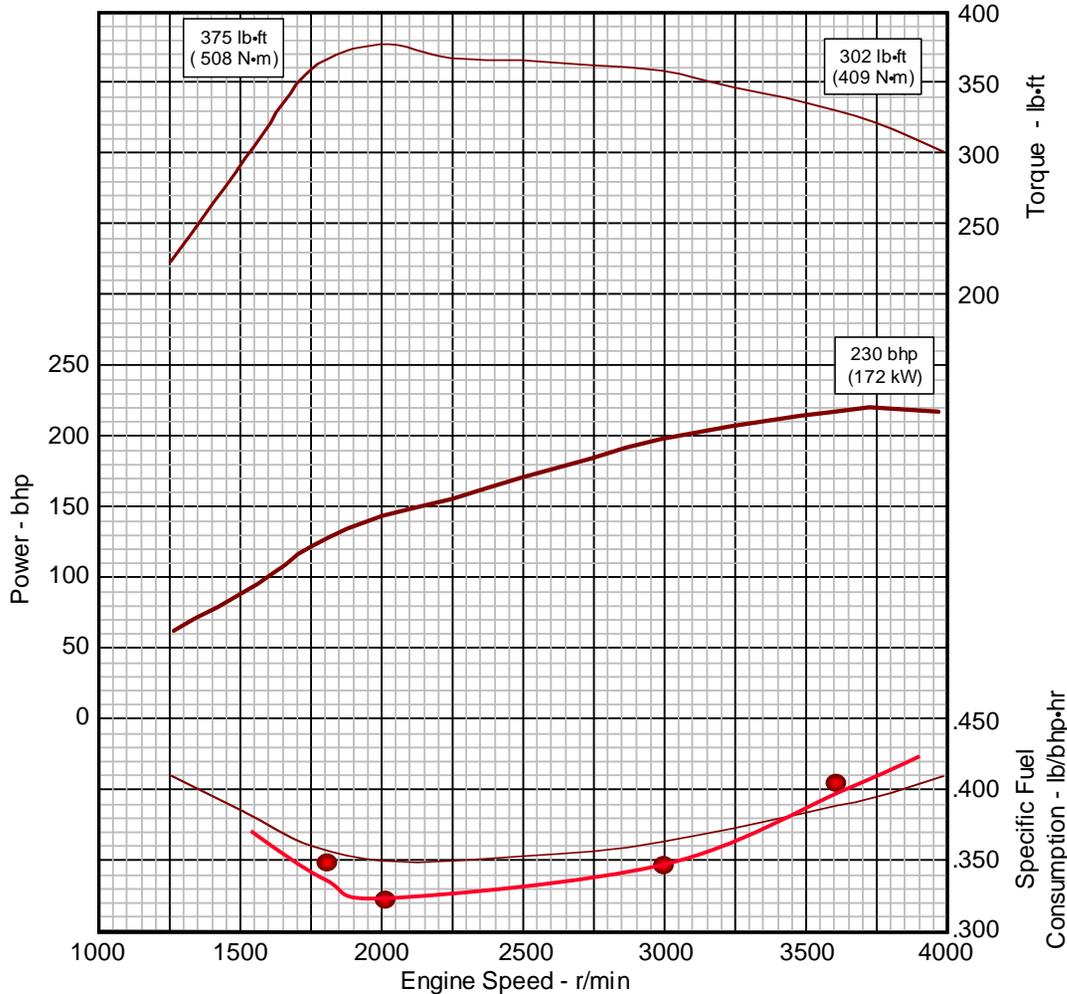
Time (Seconds)



# Improvements

- Higher Ratings
  - 230 hp @ 4000 RPM
  - 375 ft\*lb @ 2000 RPM
- Improved Fuel Economy

**Model:** DDC 4.0L V6 DELTA  
**Rating:** 230 bhp @ 4000 r/min  
 375 lb-ft @ 2000 r/min



Power output conditions:		Conversion Factors:	
Intake manifold temp:	104°F (40°C)	Power: kW = bhp x 0.746	
Fuel inlet temperature:	104°F (40°C)	Fuel: kg/kW-hr = lb/bhp-hr x 0.608	
Air inlet restriction:	14 In. H <sub>2</sub> O (3.5 kPa)	Torque: N-m = lb-ft x 1.356	
Intercooler restriction:	20 In. H <sub>2</sub> O (5.0 kPa)		
Exhaust back pressure:	7.4 In. Hg (25 kPa)		
No Accessories			
Fuel Lower heating value:	18400 Btu/lb		

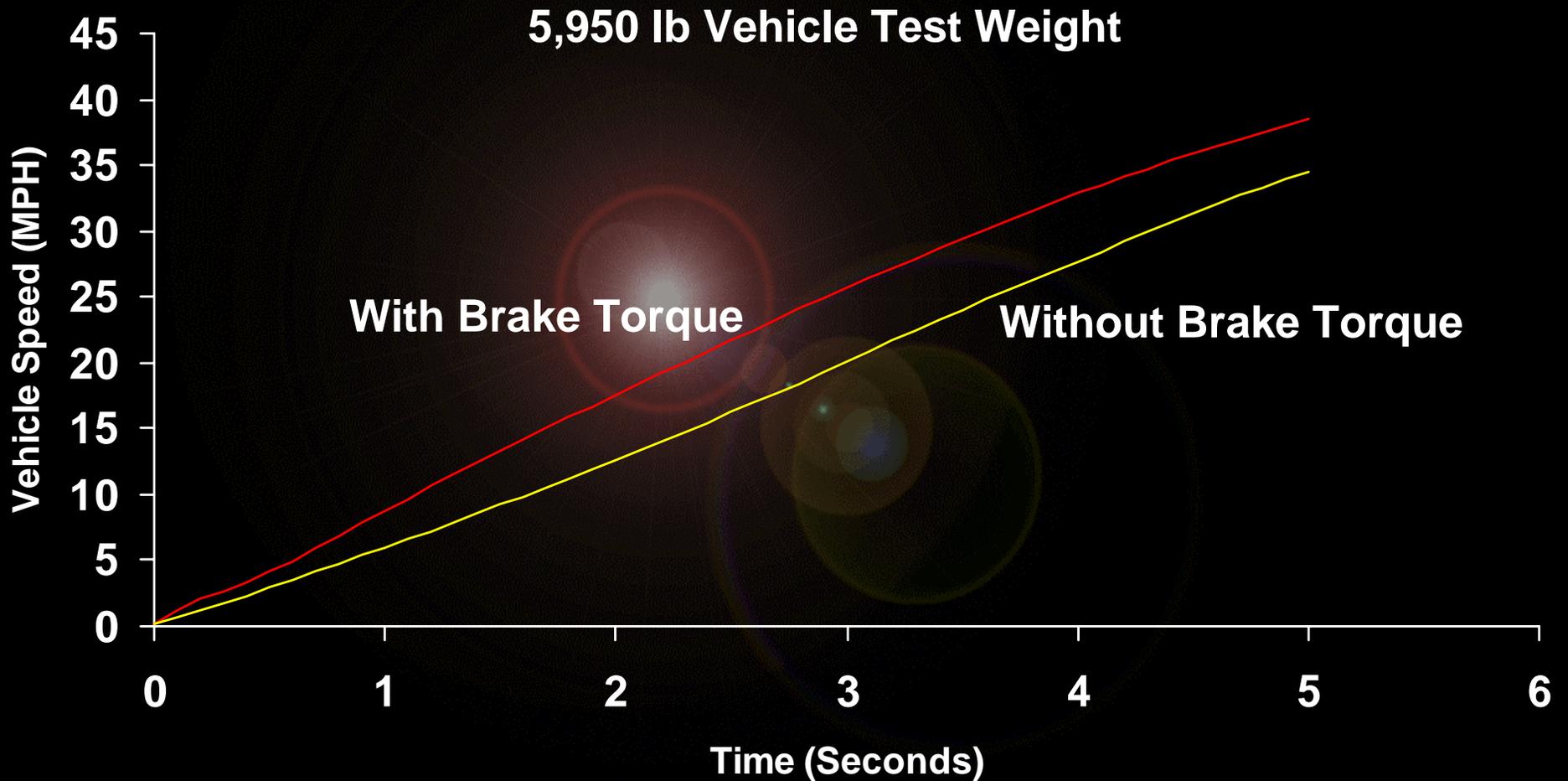
**Preliminary Performance Curve**

**Curve No.** E4-S067-31-07  
**Rev. / Date:** New / 11-18-99  
**Sheet No.** 1 of 2

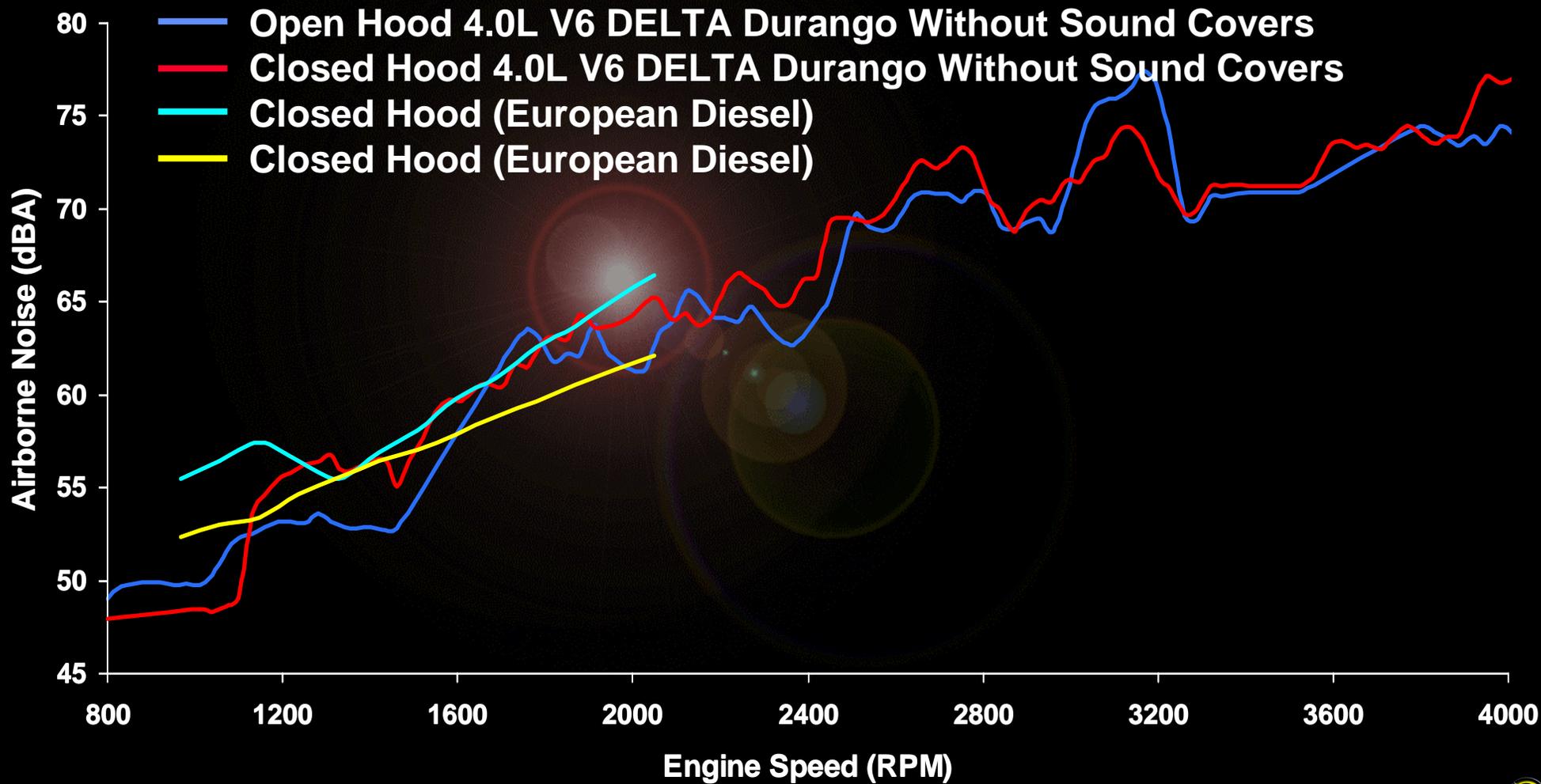


# Launch Characteristics

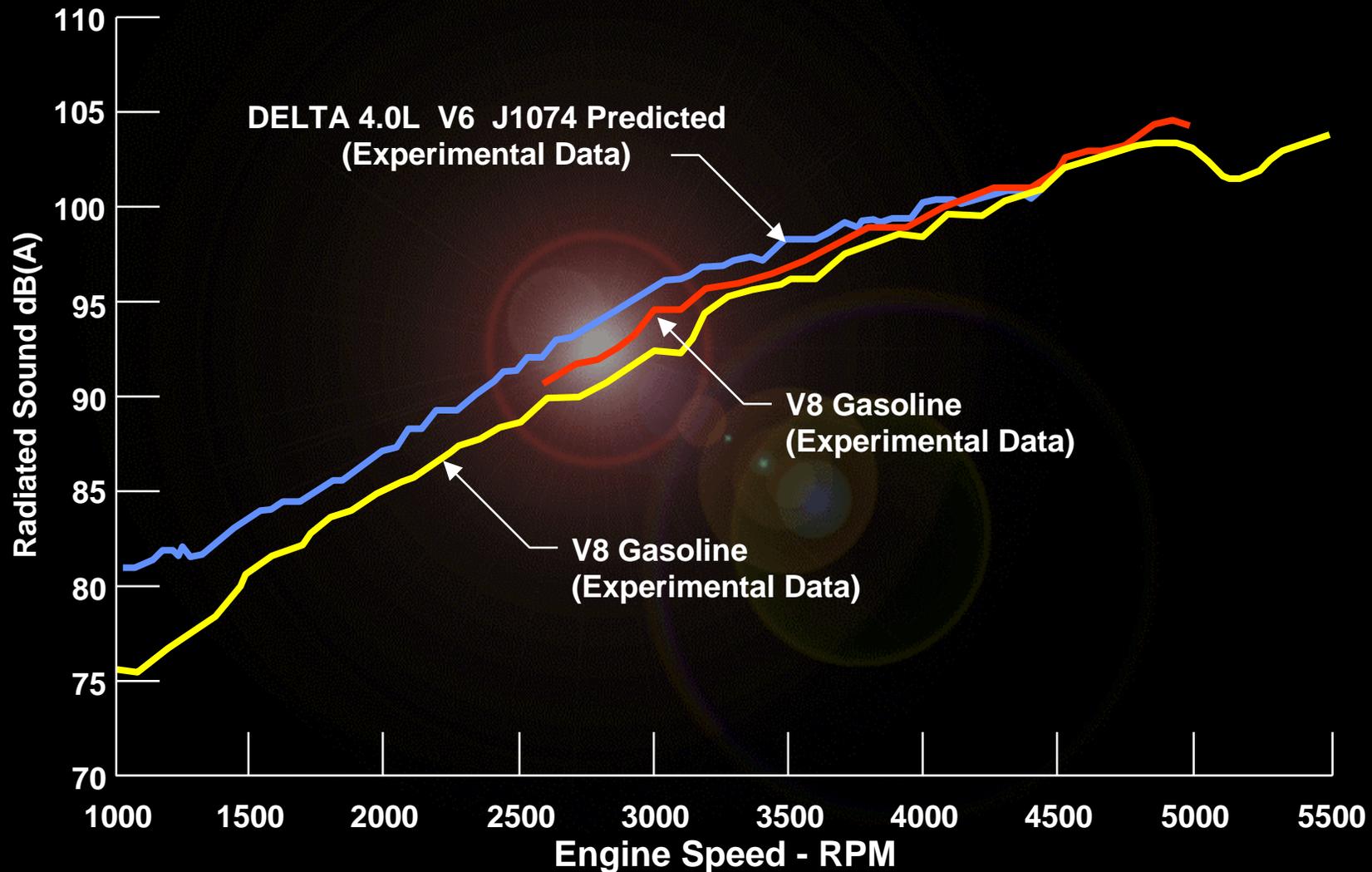
## 4.0L V6 DELTA w/ 4-Speed Automatic Transmission



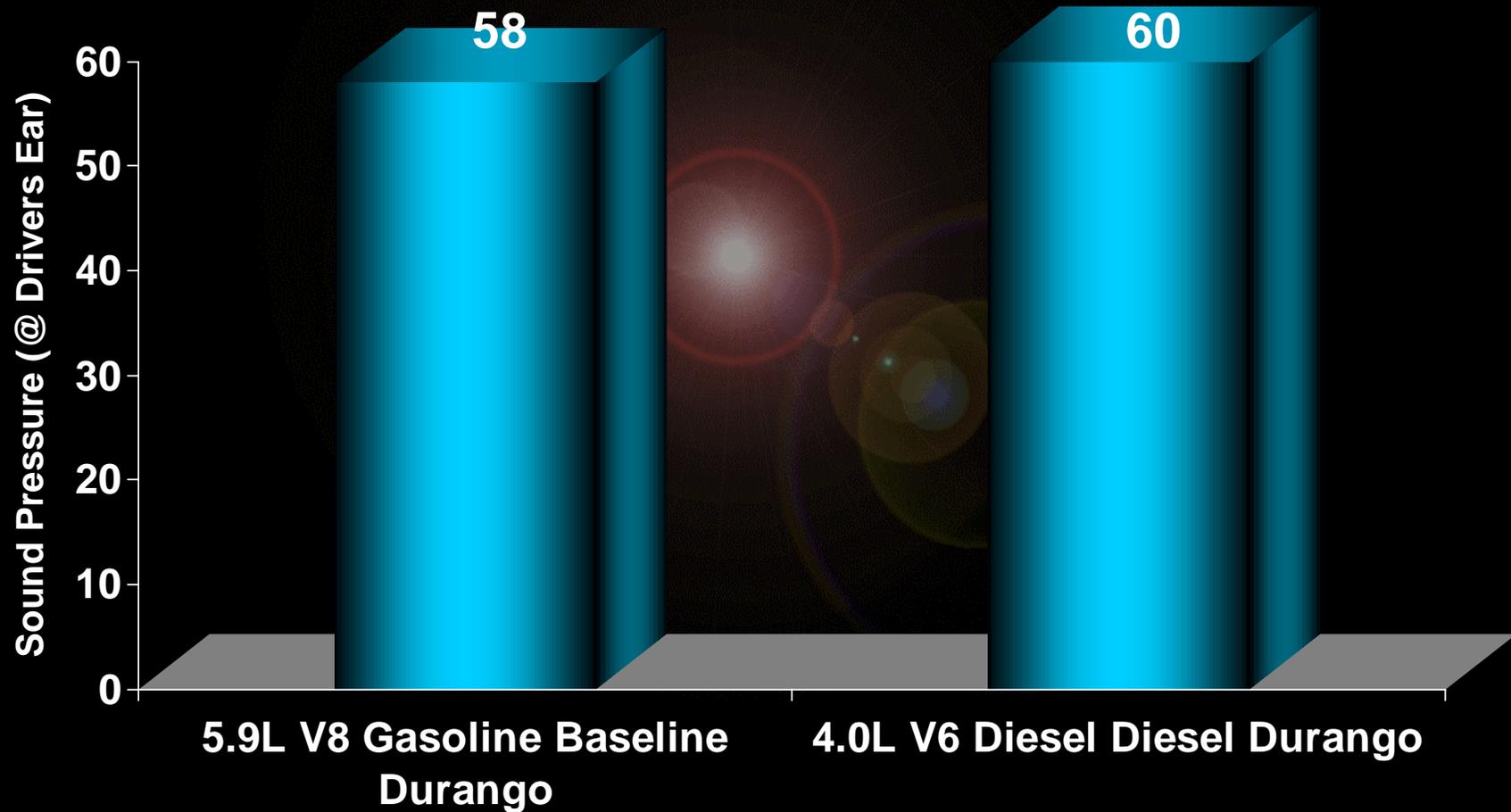
# 4.0L V6 DELTA Interior Vehicle Noise Measured @ Drivers Ear



# J1074 Engine Noise (Measured Acoustic Data)



# 4.0L V6 DELTA Vehicle Interior Idle Noise





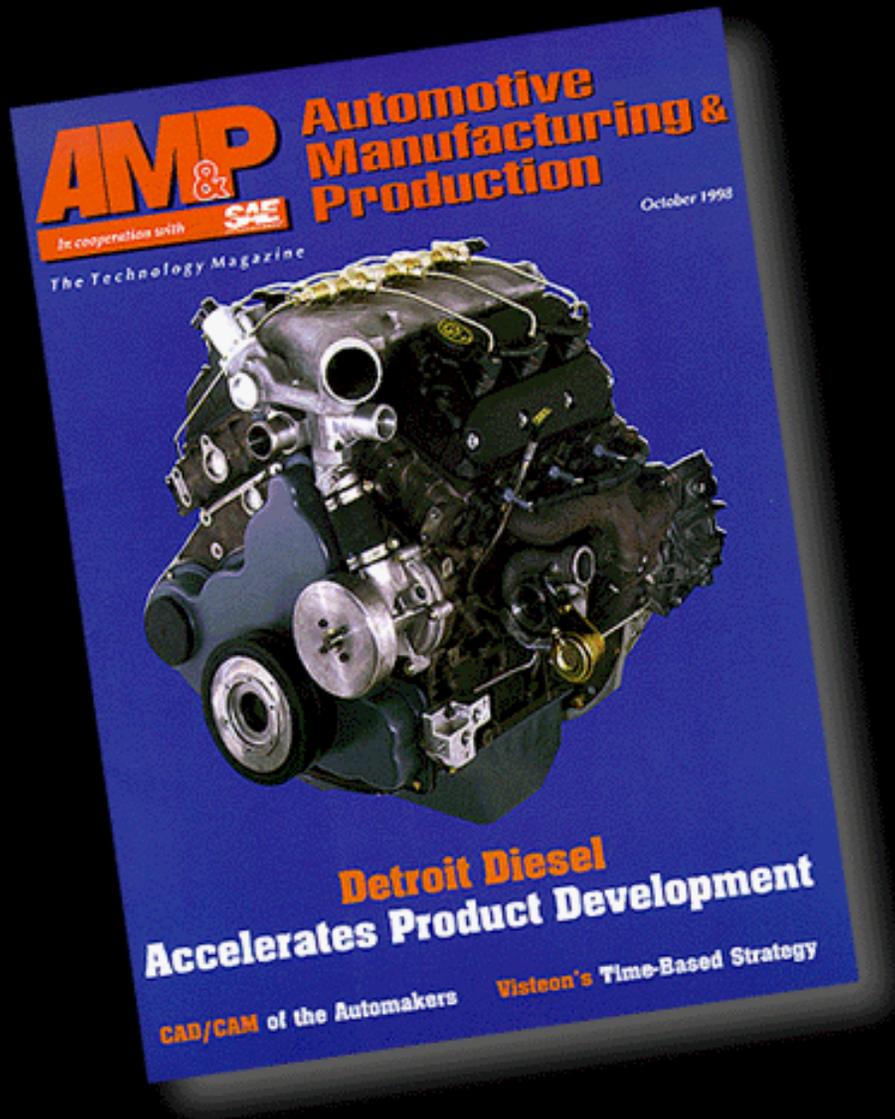
# Emissions Sociability

## PM Aftertreatment on 4.0L V6 DELTA

- **Clean: Virtually Soot-Free Exhaust**



# Validation



## Press Quotes:

***“I have driven a lot of diesels, but this is amazing!”***

***“It’s truly quiet.”***

***“Compared to my Grand Cherokee with a 5.2L Chrysler gasoline engine, there is no degradation of performance . . .”***

