Eaton TVS Supercharger for Downsizing

Presentation to Engine Expo
Stuttgart June 16th, 2009
Our Environment

- Global warming & pollution health risks
- Volatile fuel costs on a upward trend
- Increasing vehicle population
- Urban and arterial route congestion
- Average speeds
  - London 18 to 23 Km/hr
  - Urban UK 33 to 40 Km/hr
- Power & Torque still command a premium in the market ?????
- DRIVING PLEASURE IS A TRANSIENT EXPERIENCE
Supercharger Heritage

• What is the traditional image of the Supercharger?
Eaton Supercharger History

- 1988: The first Eaton production application was used on the Ford Thunderbird Super Coupe.

- 1990: GM teamed with Eaton to supercharge the Buick Park Avenue Ultra.

- Eaton has since designed and developed superchargers for 59 production vehicle applications and has manufactured over 4 million units.
## Eaton Supercharger Applications (OEM)

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<tr>
<th>Engine Size</th>
<th>Car Model</th>
<th>Supercharger Type</th>
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Latest Eaton TVS® Supercharger Application

VW Hybrid Power

- VW group recently announced an all new supercharged hybrid gasoline electric drive system.
  - 3.0L Direct Injection V6 with R1320 TVS supercharger
  - 8 speed dual clutch transmission
  - 288 volt battery pack
- Initial application in VW Touareg
  - 328 gasoline HP
  - 51 electric HP
  - 0-60MPH in 6.8 seconds
- TVS supercharger technology chosen for improved efficiency, fuel economy, ease of packaging, and excellent stop / start emissions
  - 26.1 MPG combined fuel economy
  - CO2 emissions < 210 g/km
  - 2014 Euro-6 emissions compliant
Supercharger technology enhancements... An Ongoing Story

Eaton continues to improve the Roots-type design.

- **Gen I**
  - Patented Rotor Profile and Outlet port

- **Gen II**
  - New patented Inlet and Outlet port

- **Gen III**
  - Patented rotor coating electrostatic epoxy powder

- **Gen IV**
  - Patented Island Bearing Plate Outlet Port

- **Gen V**
  - Patented Abradable Powder Coating

- **TVS**
  - Patented high-twist rotors

- **Next Gen**
  - New levels of boost and efficiency
Automotive News
PACE Award Winner 2008

Eaton TVS® Supercharger recognized for Innovation in the New Product Category
Eaton TVS® Supercharger Engineered for Fuel Economy.

The Eaton Twin Vortices Series (TVS®) supercharger delivers an attractive value proposition to competitive technologies:

- **The ability to Downsize & Downspeed for fuel economy (CO2 reduction) without compromising performance particularly response.**
- **25% reduction in packaging size & weight**
- **Patented design featuring:**
  - 2.5 pressure ratio capability
  - 75%+ thermal efficiency
  - Improved NVH characteristics
TVS® Supercharger – Rotor Design

V1 = Inlet Air Speed
V2 = Speed of rotor separation
V3 = Speed of rotor mesh
Rotor Mesh Comparison

TVS Rotors: 4 lobes, 160° twist
5th Gen Rotors: 3 lobes, 60° twist

Inlet Side
Inlet Port Design

- Improved airflow handling characteristics
  - Larger inlet port – lower air velocity
    - Driven by higher face to face twist

TVS
Large inlet shape.
Increased fill time for 160 degree twist rotors.

5th Generation
Standard inlet shape.
Typical inlet timing for 60 degree twist rotors.
Fundamental Cycles of Eaton Roots Type Supercharger

1) Expansion

2) Dwell

3) Seal

4) Backflow

5) Exhaust

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<th>5th Gen</th>
<th>Event</th>
<th>Degrees Rotation</th>
<th>TVS</th>
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<td>Inlet (Expansion)</td>
<td>280</td>
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<tr>
<td>50</td>
<td>Dwell</td>
<td>20</td>
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<tr>
<td>40</td>
<td>Seal</td>
<td>10</td>
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<tr>
<td>40</td>
<td>Backflow (Compression)</td>
<td>80</td>
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<tr>
<td>200</td>
<td>Outlet (Exhaust)</td>
<td>220</td>
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Inlet (Expansion) 200

Outlet (Exhaust)
Eaton M112 5th Generation Map (1.86L)
Isentropic Efficiency Map (Thermal)

Pressure ratio and speed is limited by outlet temperature.
R1900 TVS Map (1.90L)
Isentropic Efficiency Map (Thermal)

Pressure ratio is limited by temperature.
SC speed is limited by bearings.
Next Generation TVS® Supercharger

Next Gen Goal:  

>3.0 PR  
Current limit at  
2.5 PR
TVS® Supercharger Family Table

Supercharger Size (cc) vs. Supercharger Maximum Mass Flow (kg/hr)

- **< 1.0 L**
  - 38-75 kW

- **1.0-1.5 L**
  - 65-115 kW

- **1.5-2.5 L**
  - 100-160 kW

- **2.0-3.5 L**
  - 130-250 kW

- **3.0-4.5 L**
  - 200-375 kW

- **4.0-8.0 L**
  - 350-500 kW

- **> 7.0 L**
  - 450-800 kW

**IN DEVELOPMENT**
- R200
- R250
- R340
- R410
- R570
- R720

**PRODUCTION READY**
- R900
- R1040
- R1320
- R1650
- R1900
- R2300

**PLANNED DEVELOPMENT**
- R3100
- R3400
- R4000
Supercharger Input Power Requirements
At cruising conditions, the supercharger’s input power is less than 0.5 kW.
Response & Downsspeeding
TVS® Supercharger Drives Fuel Economy

• Engine downspeeding is required for improvements in vehicle fuel economy
  • Downsampling decreases frictional losses
    • Following a constant power curve in a BMEP vs. engine speed BSFC map
      • BSFC decreases as engine speed decreases
  • Current turbocharged vehicles are challenged to support engine downsampling with downsizing due to transient response
  • Supercharger instant response drives downsizing and downsampling
  • Enables the customer-required vehicle dynamics
GM Ecotec Comparison

- **Supercharged Configuration (Eaton Prototype)**
  - 2.0L I4 with TVS® Supercharger
  - R900 Supercharger (0.9L/rev)
  - 270hp (201 kW) Estimated
  - 203-210 kPa Boost Pressure

- **Turbocharged Configuration (Production Vehicle)**
  - 2.0L I4 with Borg-Warner K04 turbocharger
  - 260hp (194 kW)
  - 224 kPa Boost Pressure

**Baseline Configuration**

- 2.8L V6 Naturally Aspirated
- 208 hp (155 kW)
Response: Supercharger vs. Turbocharger

Supercharger achieves 90% boost in 0.5 seconds.

Turbocharger achieves same boost in 5 seconds.

Engine = GM 2.0L I-4.

Transient Response = 3rd gear passing maneuver starting at 30 KPH, 1100 RPM.
2.8L V6 Naturally Aspirated BSFC Map

- Reserve power in 0.5 seconds = 29 kW.
- Transient performance baseline
- Road load at 100 km/hr is estimated at 18 kW.
- BSFC = 305 g/kW-hr @ 2000 RPM

Steady-State Torque Curve
Downsizing – 2.0L Turbocharged

Road load at 100 km/hr is estimated at 18 kW.

BSFC = 258 g/kW-hr @ 2000 RPM

Fuel Economy Savings = 15.4%

Transient Torque Curve

Reserve power in 0.5 seconds is only 15 kW.

Unacceptable drivability
Downsizing – 2.0L Turbocharged

Road load at 100 km/hr is estimated at 18 kW.

BSFC = 275 g/kW-hr @ 2500 RPM

Final Turbocharger Fuel Economy
Savings = 9.8%

To maintain the original reserve power of 29 kW in 0.5 seconds, the engine must be upspeeded.
Downsizing – 2.0L Supercharged

Road load at 100 km/hr is estimated at 18 kW.

BSFC = 270 g/kW-hr @ 2000 RPM
Fuel Economy Savings = 11.5%

Reserve power in 0.5 seconds = 34 kW.

Improved drivability
Downspeeding – 2.0L Supercharged

Road load at 100 km/hr is estimated at 18 kW.
BSFC = 265 g/kW-hr @ 1800 RPM
Final Supercharged Vehicle Fuel Economy Savings = 14.1%

To maintain the original reserve power of 29 kW in 0.5 seconds, the engine can be Downspeeded.
# Fuel Economy Comparison

## Combined L/100km
- **BMW 535xi**: 11.8 L/100km
- **Lincoln MKS**: 12.7 L/100km
- **Mercedes E350**: 12.3 L/100km
- **Cadillac CTS-4**: 12.9 L/100km
- **Audi A6**: 11.7 L/100km

## Power (kW)
- **BMW 535xi**: 224 @ 5800
- **Lincoln MKS**: 204 @ 6250
- **Mercedes E350**: 250 @ 5700
- **Cadillac CTS-4**: 475 @ 3500
- **Audi A6**: 3.5L Twin Turbo

## Torque (Nm)
- **BMW 535xi**: 407 @ 1400
- **Lincoln MKS**: 366 @ 4250
- **Mercedes E350**: 475 @ 3500
- **Cadillac CTS-4**: 350 @ 2400
- **Audi A6**: 3.5L Twin Turbo

## Engine
- **BMW 535xi**: 3.0L Twin Turbo
- **Lincoln MKS**: 3.7L
- **Mercedes E350**: 3.5L
- **Cadillac CTS-4**: 3.6L
- **Audi A6**: 3.0L Supercharged

## Transmission
- **BMW 535xi**: Auto - 6
- **Lincoln MKS**: Auto - 6
- **Mercedes E350**: Auto - 6
- **Cadillac CTS-4**: Auto - 5
- **Audi A6**: Auto - 6

## Drive
- **BMW 535xi**: AWD
- **Lincoln MKS**: AWD
- **Mercedes E350**: AWD
- **Cadillac CTS-4**: AWD
- **Audi A6**: AWD

### 4.3% Fuel Economy Savings

Versus Competitive Turbocharged vehicle!
TVS® Supercharger Summary

- Instantaneous boost response and torque availability enables engine downsizing while maintaining downspeeding for maximum fuel economy.

- High efficiency supercharger design drives high specific engine outputs and improves packaging.

- Boost available at all speeds and temperatures.

- Internal lubrication system not impacted by engine stop start

TVS® Supercharger engineered for excellent drivability and best-in-class fuel economy!