2015 DOE Vehicle Technologies Office Annual Merit Review and Peer Evaluation Meeting

Integrated Boosting and Hybridization for Extreme Fuel Economy and Downsizing

Project ID: VSS162

Principal Investigator: Dr. Vasilios Tsourapas
Eaton Corporation
June 11, 2015

Powering Business Worldwide

Overview

Timeline

- Project Start Date: October 1, 2014
- Project End Date: Dec 30, 2017
- % Complete: 15%

Budget Period	Start Date	End Date
1	10/1/2014	12/30/2015
2	1/1/2016	12/30/2016
3	1/1/2017	12/30/2017

Budget

- Project Value: $3,499,640
  - DOE Share: $1,749,820
  - Cost Share: $1,749,820 (50%)
- Funding received in FY14: $12,256
- Funding for FY15: $449,408

Barriers & Technical Targets:

- Improve the efficiency of light-duty engines for passenger vehicles (cars and light trucks) and heavy-duty engines for commercial vehicles (heavy trucks) through and minimization of thermal and parasitic losses;
- Explore waste energy recovery with mechanical and advanced thermoelectric devices to improve overall engine efficiency and vehicle fuel economy.

Partners

- Prime: Eaton Corporation
- Subcontractor: AVL

EATON Powering Business Worldwide

AVL

Relevance

Program Objective

The objective of the program is to develop and demonstrate a highly efficient downsized engine for passenger vehicle that will combine roots Waste Heat Recovery (WHR) in the exhaust and an Electrically Assisted Variable Speed (EAVS) supercharger in the intake.

Technical Targets

Type	Metric
Fuel economy	>20% fuel economy improvement over a turbocharged and downsized engine
Cost	<$50/% of fuel economy improvement net impact
Performance	Achieve peak engine torque at <1100rpm
Performance	300ms time to peak torque
Efficiency	>80% of required energy from regeneration (brake and waste heat)

Milestones

Milestone	Status	Due
Vehicle and Engine Selected	Completed	2/20/2015
System Model Developed	On Track	6/30/2015
Modeling Report	On Track	9/30/2015
WHR functional test completed	On Track	12/20/2015
GO/NO GO: System Design Complete and WHR System Functional at Rated Temp.	On Track	12/20/2015
EAVS and WHR Installed	On Track	3/30/2016
Durability Test Complete	On Track	6/30/2016
Engine Hardware Integration Completed	On Track	9/30/2016
Engine preliminary calibration completed	On Track	12/20/2016
GO/NO GO: Engine Dynamometer Testing Achieves Efficiency Requirement	On Track	12/20/2016

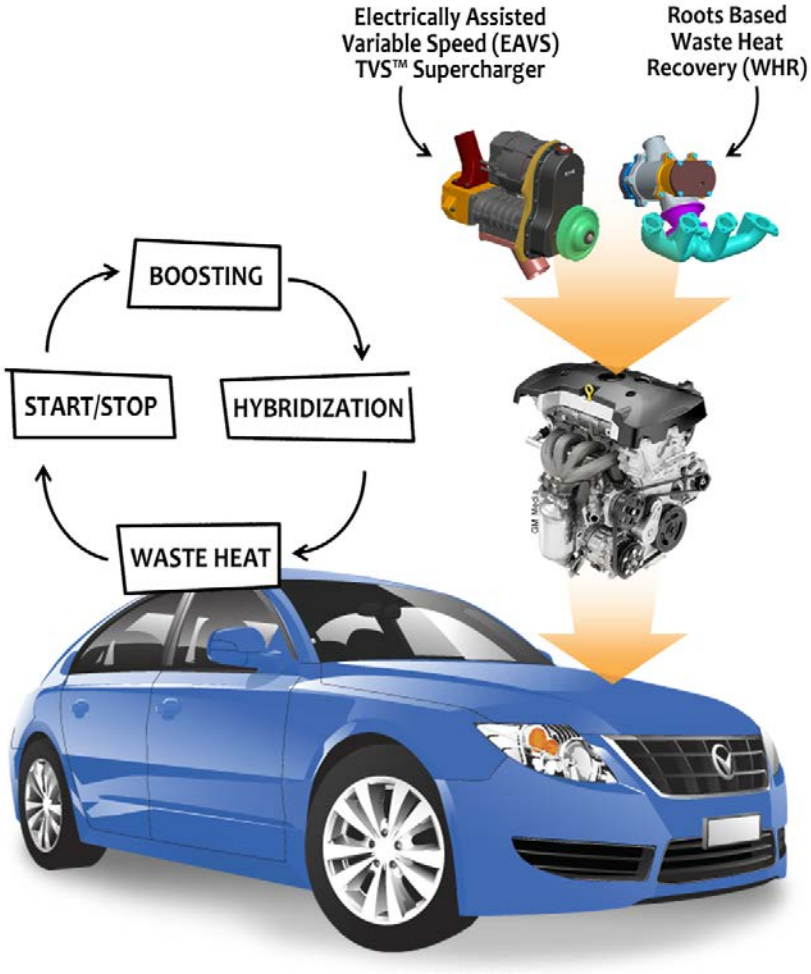
Proposed Technology Overview

Electrically Assisted Variable Speed (EAVS) Supercharger:

- TVS® Supercharger coupled to motor and engine via planetary
- Variable Ratio Boosting for instant response and reduced parasitics
- Engine start/stop (when supercharger locked)
- Brake regeneration and torque assist

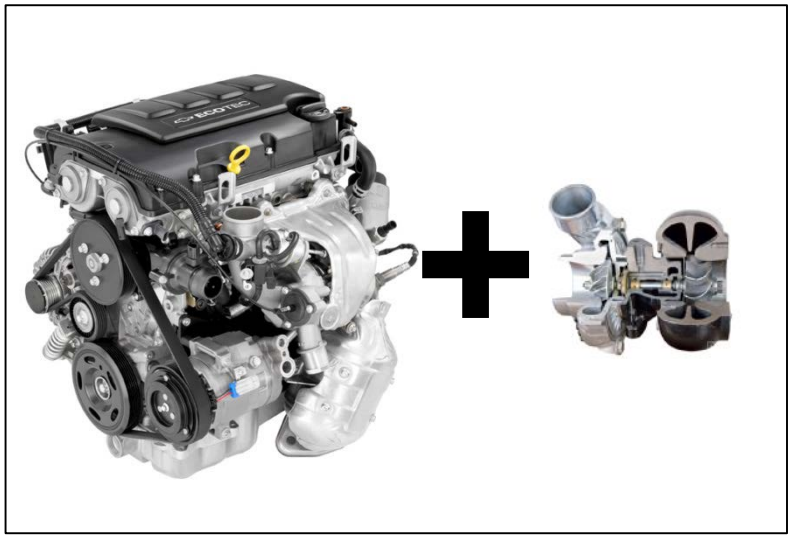
Roots Based Waste Heat Recovery (WHR):

- Positive displacement and volume driven device
- Recuperates exhaust energy through inlet to outlet pressure difference and pulse energy from exhaust valve opening event
- Broad efficiency island over large engine operating range
- Engine breathing improvement for knock mitigation and pumping loss reduction

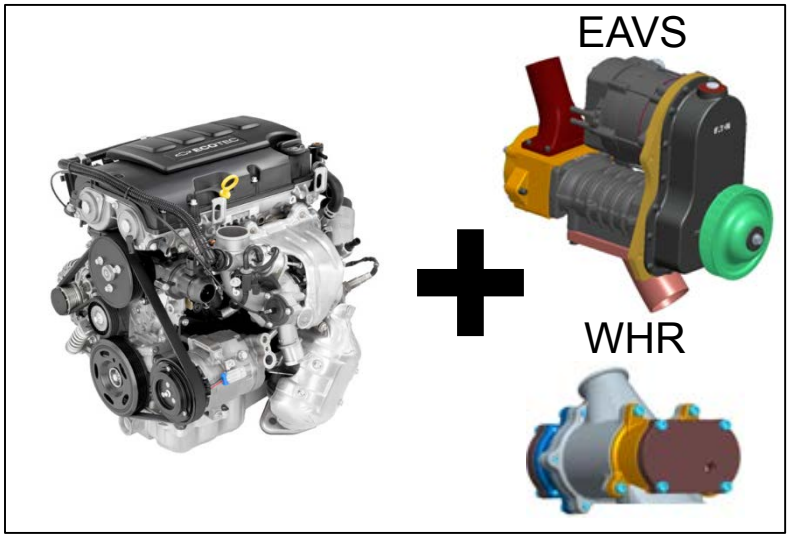


Approach / Strategy

Baseline Turbocharged Engine



EAVS/WHR Downsized Engine

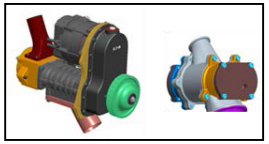


- Compare baseline turbocharged engine vs. downsized same engine with:
  - Electrically Assisted Variable Speed TVS Supercharger (EAVS)
  - Roots Based Direct Waste Heat Recovery (WHR)
- Integrate Boosting with Hybridization features to minimize system cost
- Maintain performance while improving on emissions and fuel economy

Approach – Budget Period 1-3

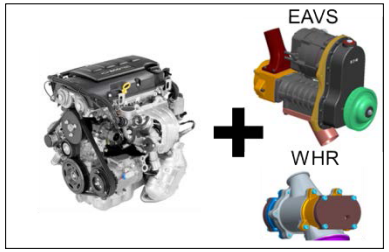
Period 1 – Component Development

Develop and test individual components. Develop component efficiency maps and durability



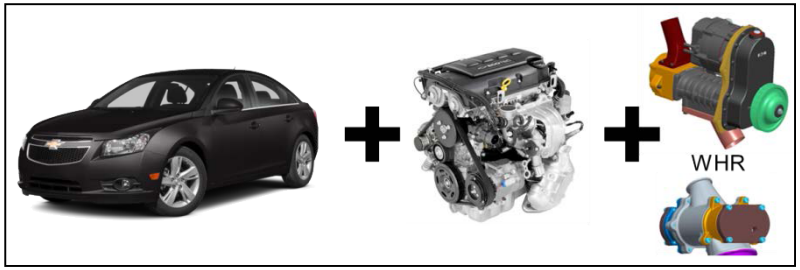
Period 2 – Engine Integration

Integrate components into downsized engine and calibrate controls and test performance/FE



Period 3 – Vehicle Integration

Integrate engine into vehicle and test performance and FE

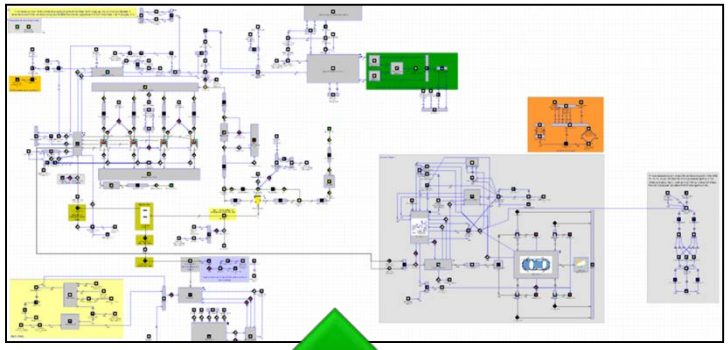


Technical Accomplishments and Progress

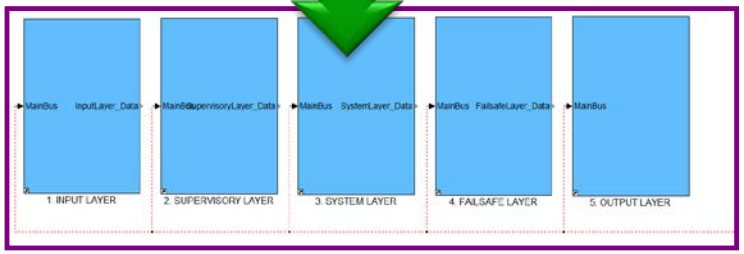
Analytical / Modeling Progress

- Co-simulation framework in progress
  - GT Power engine/vehicle
  - Simulink Controls for EAVS/WHR
- Simulation to be used for:
  - Component sizing optimization (EAVS, WHR, Engine Displacement etc.)
  - Controls Development for auto-code generation into ECU in Year 2 and 3
  - Performance and Fuel economy estimation

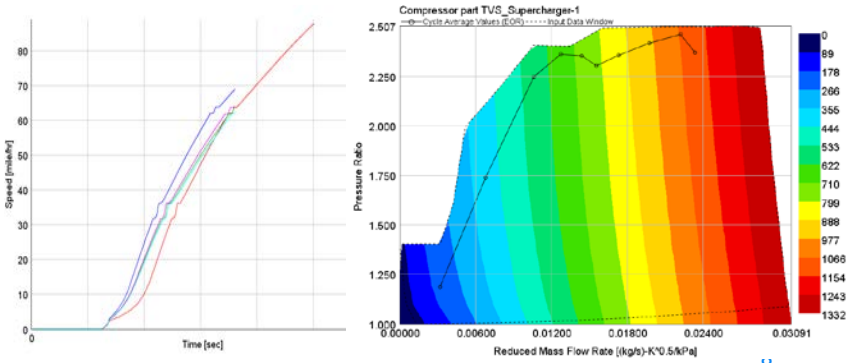
GT Power Vehicle Model (EAVS/WHR)



Simulink Vehicle controls



Analysis: Vehicle Performance and FE

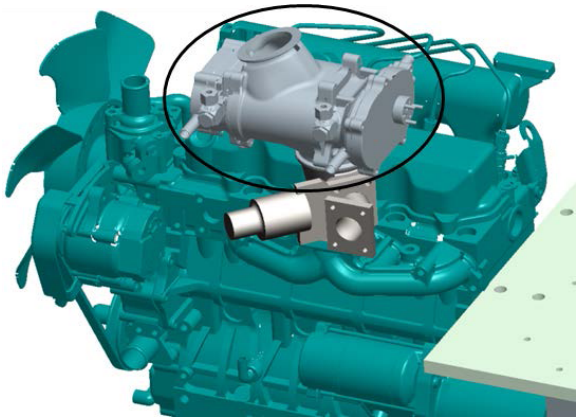


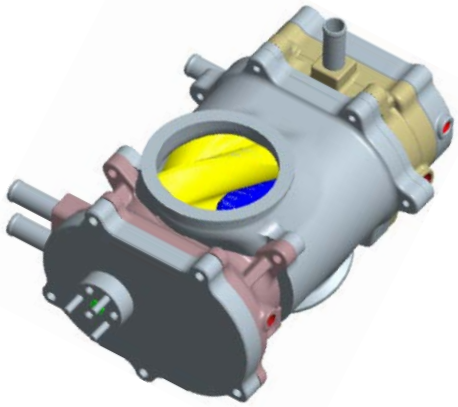
Powering Business Worldwide

Technical Accomplishments and Progress

WHR System Design / Definition Progress

- Material selection to maximize efficiency and be able to handle operating conditions
- Development and incorporation of heat dissipation mechanism
- Optimized outlet port geometry to maximize generated expander output shaft torque
- Casting structural integrity optimization for application operating condition
- Finalize bearing layout and design direction with vendor inputs
- Development of high temperature air cavity coating that will abrade to maximize efficiency
- Integration of a generator coupled to the expander





Responses to Last Year Reviewers' Comments

- This project started October 1, 2014.

Collaborations / Team

- Prime Contractor / Program management
- Requirement definition and System Design
- Component Development and Testing
- System assembly
- End-user demonstration Commercialization

- Controls Definition
- Engine/Vehicle calibration and integration
- Engine Dyno Testing for emissions and fuel economy

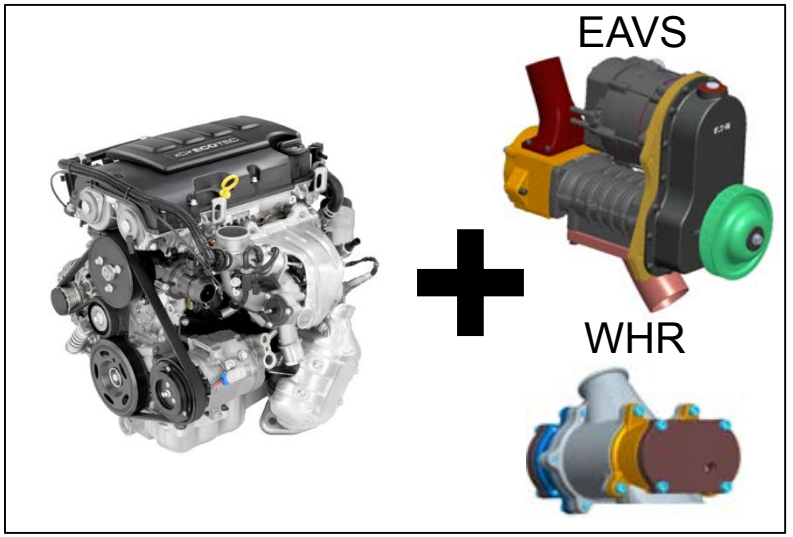
Suppliers:

Remaining Challenges and Future Work

FY	Challenges	Future Work
2015	WHR High Temperature Operation and Efficiency	Design/procure WHR system and test operation in firing engine to map efficiency and understand durability
	System Control for efficiency and drivability	Develop model based framework for system sizing optimization and controls development
2016	Emissions and Fuel Economy Optimization	Integrate components in target engine and develop/ calibrate control strategies on dynamometer
	Vehicle Integration	Further component durability testing and prepare mechanical/ electrical layout of demonstration vehicle

Summary

- Objective of the project is to demonstrate fuel economy potential via integrated boosting and hybridization including:
  - Electrically Assisted Variable Speed TVS Supercharger
  - Roots based Waste Heat Recovery
- System can recover both braking energy as well as exhaust heat/pulsations
- Downsizing is enabled by instant and variable boost control with coordinated exhaust recovery



Type	Metric
Fuel economy	>20% fuel economy improvement over a turbocharged and downsized engine
Cost	<$50/% of fuel economy improvement net impact
Performance	Achieve peak engine torque at <1100rpm
Performance	300ms time to peak torque
Efficiency	>80% of required energy from regeneration (brake and waste heat)


Powering Business Worldwide