MODELING ENGINE FRICTION WITH TEMPERATURE DEPENDENCE FOR VEHICLE THERMAL MANAGEMENT

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Objective and Approach

- Simulation and Development
  - Part of Gasoline Thermal Management **Vehicle Demonstrator**

- Objective
  - Impact on fuel economy of several thermal management technologies and strategies

- Simulation - Test Results - Controls
  - Co-simulation
    - Controller in Simulink
    - Plant model in GT-Suite
Popular Mid-size (D-Segment) base vehicle.

- 2L displacement
- I4, turbocharged CR: 9.3:1
- 240 HP @ 5,500 RPM (premium gas)
- 231 HP @ 5,500 RPM (regular gas)
- 270 lb-ft @ 3000 RPM
- Head & Block: aluminum
Engine Cooling Layout

Advanced Thermal Components in Update Build

ADVANCED

Dual Mode Coolant Pump (DMCP)

Electric Coolant Control Valve (ECCV)

Exhaust Heat Recovery System (EHRS)

STANDARD

Engine Oil Heat Exchanger (EOHX)

Transmission Oil Heat Exchanger (TOHX)

Auxiliary Loop Control Valve(s)
Engine Cooling Layout
Baseline

Stat Closed

- Turbo
- Cabin Heater
- Head
- Block
- Water Pump
- Thermostat
- Radiator
- Expansion Tank
- Degas Hose
- Bypass
- Trans OC
Engine Cooling Layout
Baseline

Stat Open

Degas Hose
Expansion Tank

Turbo
Cabin Heater

Head
Block

Water Pump
Thermostat
Bypass

Trans OC

Radiator
Engine Cooling Layout Update Build

System Layout & Valve Definition

Turbo

Head

Block

DMCP Pump Inlet

Main CCV

Trans Oil Thermostat Valve

Trans Oil HX

Radiator

Degas Hose

Expansion Tank

ECCV

IN

HTR

Trans.

TOHX Valve

Gas Side Bypass Valve

Cabin Heater

EHRS Valve

EOHX Valve

Engine Oil HX

IN

HTR

IN

HTR

ALT

Degas Hose

HTR

IN

HTR

IN

IN

HTR

HTR

IN

HTR

HTR
Six operating modes

1. Cold start (zero engine flow, cab heater flow)
2. Engine oil warm up (flow through engine)
3. Transmission oil warm up (flow through TOHx)
4. Hot operation w/ stat closed (no flow through radiator)
5. Hot operation w/ stat open (flow through radiator)
6. Engine off – pump after-run
   - Hot soak operation (radiator on)
   - Cold soak operation (radiator off)
Simulation Model and Features

Integrated Model

- Mean Value Engine Model
- Vehicle Model
- Thermal System Model with coolant & oil circuits
- Thermal Controller
Simulation Model and Features
Vehicle/Transmission Model

- **Vehicle**
  - Throttle control set up to follow user defined drive cycle
  - Axle, vehicle body, tire rolling resistance, aerodynamic drag, road grade

- **Transmission**
  - Friction losses based on input speed and ATF temperature/pressure
  - Gear shift schedule correlated with vehicle data
Temperature dependent losses in the transmission.

This data comes from transmission bench tests at variable temperature.
Simulation Model and Features
Engine Model

- Engine mean value model Details

EHRS
Simulation Model and Features
Engine Model – Friction Model

- Engine Friction model Detail

Warm FMEP map
Inputs: RPM, imep

- T\text{\textsubscript{oil}}
- T\text{\textsubscript{blk}}
Simulation Model and Features

Engine Model – Friction Model

- Dyno testing used to determine the engine friction temperature effects

- Method was to collect IMEP during warm-up in neutral
  - IMEP above the ‘warm’ IMEP is attributed to friction
Simulation Model and Features
Engine Model – Friction Model

- Correction function determined by:
  - Subtract off trans spin loss
  - Normalize by the ‘warm’ IMEP

- The correction function and curve fit are shown to the right

- Different breakdowns of oil and spark base temperature were tested
Simulation Model and Features
Block-Head Model

- **Engine Block**
  - Engine block modeled with 3 masses (head, inner-block, outer-block)
  - Thermal loading of head and inner block as a function of engine operating conditions
  - Flow dependent heat transfer to coolant

... to Friction Model
Simulation Model and Features

Oil Thermal Model

- **Oil System**
  - Thermally loaded by block conduction, friction, and piston heat transfer
Simulation Model and Features
Integrated Model

- Cooling System
  - Full cooling system model
  - Simple under-hood flow model with radiator fan
  - heat exchanger performance maps based on SS test data
Simulation Results and Validation
FTP Validation – Baseline

- Engine Outlet Coolant T
- Engine Head Metal T
- Engine Oil Sump T
- Radiator Inlet Coolant T
Simulation Results and Validation
FTP Validation – Baseline, Adv Control

- Plots compare metal and oil temperatures for a baseline case and a ‘controlled’ case with zero flow strategy and oil heating.
Thermal Controller

- Simulation for control design and strategy optimization
- Manage thermal system to minimize fuel consumption
- Protect engine and vehicle components from thermal damage
Thermal Controller
Initial Dyno Test Results

[Graph showing various temperature and speed measurements over time, including Engine Inlet Coolant T, Engine Outlet Coolant T, Engine Oil T, Engine Outlet Coolant T - Set, Transmission Oil T, Pump Speed, Fan Speed, Thermostat Opening, and Thermal Mode.]

From SAE 14TMSS-0093
Conclusions

The overall system temperature effects were validated against vehicle dyno tests.

The simulation models we have developed enable the evaluation of effective thermal management approaches before and in parallel to test.

Similar % change in FE from different starting temperatures, simulation - dyno

<table>
<thead>
<tr>
<th>Start Temp</th>
<th>GT FE</th>
<th>Dyno FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Change from Room Temp to Hot</td>
<td>27 °C vs. 100 °C</td>
<td>+10.9%</td>
</tr>
<tr>
<td>% Change from Cold to Hot</td>
<td>-6.7 °C vs. 100 °C</td>
<td>+35.0%</td>
</tr>
</tbody>
</table>

Next Steps

FE results will be available next year.
Thank You For Your Attention

Questions?

Our Vision
- A Clean, Energy-Efficient World

Our Mission
- Deliver Innovative Powertrain Solutions that Improve Fuel Economy, Emissions & Performance

Fuel Economy  Emissions  Performance