EHRS modelling with GT-Suite
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Reduce CO2 by more than 50% in Europe, USA and China between 2005 and 2025

Strong short-term and long-term pressure on CO2 will create demand for fuel-saving technologies.
... While about **one third** of the fuel’s energy is **lost** as heat through **exhaust gas**

**... support the thermal system: Heat to Heat**
- Friction reduction engine & gearbox
- Cabin heating in cold weather
- Exhaust Heat Recovery Manifold (EHRM)
- Exhaust Heat Recovery System (EHRS)

**... generate on-board electricity: Heat to Power**
- Seebeck effect
  - Thermo-Electric Generation (TEG)
- Rankine cycle
  - Exhaust Heat Power Generation (EHPG)

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* Recovering Exhaust Heat to ...

* indicative values
Why EHRS improves fuel economy on an FHEV?

On **Hybrid vehicles**, typical strategies will trigger Combustion engine start on:

- **Wheel power demand**
- **Coolant temperature** typically 50 to 60°C
- **Battery State of Charge**
By improving engine warm-up on FHEVs, EHRS enables earlier and more frequently the pure Electric mode, thus improves significantly the **fuel economy**.

**EHRS** allows Coolant loop to reach **temperature threshold quicker**

⇒ **Combustion engine** running time is **decreased**
⇒ **Fuel mass** consumed is **lowered**
How to estimate EHRS Benefits on customer vehicles?

**Requirement**

- **Evaluate EHRS Design Performance**
  - Measured on Component bench
  - Predicted using CFD
- **Estimate Impact on vehicle**
  - Measured on roller bench on prototype

**Problem**

- Complex
- Expensive
- Not flexible

**Solution**

- Build 1D Model of EHRS component for EHRS Performance prediction
- Build 1D model of EHRS environment on vehicle for Impact prediction
Overview of System model

**Input**
- Driving conditions
- ICE Trigger strategy
- Ambient conditions
- Heating demand
- EHRS Configuration

**Output**
- Coolant Temperature
- Engine running duty cycle
- Fuel economy

Simplified thermal model to assess EHRS impact on vehicle thermal behavior and fuel economy
Generating Engine outputs by using 1D Engine model

1D Engine Model with Cylinder Twall Solver allows to use Vehicle Inputs to estimate:
- Combustion to Cooling heat transfer
- Engine Fuel efficiency
- Exhaust Enthalpy

1D Engine model can be used:
- Directly into the System Model as FRM Engine model
- To feed EngineState model with Heat, Fuel & Enthalpy Maps
Generating Engine outputs by using Customer data

- 1D Engine Model generates engine Outputs based on Vehicle data but
  - Requires time to be built
  - Not suitable for quick system evaluation (evaluation for customer)

⇒ Bench data Analysis: engine outputs based on 0D Engine model

- Drawbacks
  - Based on test data
  - Not predictive

- Advantages
  - Estimates EHRS Impact with customer data
  - Uses widely available data

- Principle

Calculation of Fuel to Heat efficiency & Calibration of Ambient Losses from bench transient profiles
Cooling system

Cooling Model Data
- Measured data
  Fluid & Components masses
  Pipes geometry
- Bench Data
  Radiator Heat power
- CAD estimated data
  Fluid mass distribution
  Heat transfer Area

Cooling Model
- Ambient Losses
  TWall Solver on each pipe + Engine Case HT Area

Cabin Model
- Cabin Volume
- Cabin ambient losses

Engine Model
- Combustion Heat Rejection
- Engine Speed – Pump flow

1D Cooling model is the key of Vehicle Model: translates EHRS design to understandable values

From EHRS Gas To Coolant heat transfer to
  ➞ Coolant temperature improved heating
  ➞ Fuel economy through earlier combustion engine shut-off
  ➞ Cabin Comfort with higher increase in cabin temperature profile
EHRS 1D model
Component Overview

- EHRS = liquid / gas heat exchanger
  - Counter-flow Shell / Tube heat exchanger
- Integrated bypass to avoid engine coolant overheating when coolant reach control temperature

**Heat Recovery mode**
- Bypass valve is closed
- Exhaust gases enters tubes and are cooled down by the engine coolant in the shell

**Bypass mode**
- Bypass valve is opened
- Exhaust gases do not enter exchanger
**EHRS 1D model**

**Component Overview**

- **TECT build up complete exchanger specifications**
  - Type of tubes
    - Corrugated
    - Internal fins
  - Number of tubes

- Bypass actuator type
  - Wax actuator (opens when wax melts)
  - Vacuum actuator (use vacuum network of engine)
  - Electric actuator (use electrical command)

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For this study, we will use Finned tubes + vacuum actuator
The more accurate the assumptions, the easiest the calibration process
## EHRS 1D model

**Way to model heat exchanger within GT**

<table>
<thead>
<tr>
<th>Master/Slave</th>
<th>Detailed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built-in template</td>
<td>Primitive flow &amp; thermal components</td>
</tr>
<tr>
<td>+ Easy to build with experimental data</td>
<td>+ Complete thermal balance</td>
</tr>
<tr>
<td>+ Scaling capability</td>
<td>+ Better bypass modelling (can include leak)</td>
</tr>
<tr>
<td></td>
<td>+ Could be used for acoustic modeling</td>
</tr>
<tr>
<td>- Heat transfer maps include all losses</td>
<td>- Require more time to build</td>
</tr>
<tr>
<td>- Out of range behavior ?</td>
<td>- Require CAD data</td>
</tr>
<tr>
<td>- No internal finned tube template</td>
<td></td>
</tr>
</tbody>
</table>

**Detailed model is well adapted for our application**
**EHRS 1D model**

**Detailed model**

- Detail model discretize heat exchanger using primitive template
  - Flow pipes: gas and coolant path
  - Thermal masses: wall / fins
  - Thermal connections: convection / conduction / radiation
  - FlowSplits: cones / fluid distribution

- A custom PipeFin template was created to avoid a (very) long model building task

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**Simplified 1D thermal layout**

- Tubes {Gas + fins}
- Internal wall
- Coolant
- External wall
- Ambient air

**Example of discretized exchanger**

**1x gas + fin element**

**Custom PipeFin template**
Thanks to user compounds, model map looks quite simple.
EHRS 1D model
Calibration workflow

3D to 1D geometry simplification
- Heat transfer area
- Hydraulic diameter

CFD Calibration
- Gas and coolant HTM calibration
- Gas and coolant pressure drop calibration

Synthetic gas bench
- Valve leakages calibration: gas pressure drop matching

Engine bench: Driving cycle
- Transient / global validation
Experimental vs simulation
NEDC: Temperature

Detailed model better predict gas temperature, especially in bypass mode.

High mass flow = low $\Delta T$
better consider heat rate
Experimental vs simulation

NEDC: Heat rate

- Detailed model better predicts coolant and gas heat rate
- Detailed model can predict some «parasitic losses» (heat transfer into coolant when bypassed)
- Detailed model is more reliable in “out of range” mode

<table>
<thead>
<tr>
<th></th>
<th>Gas heat rate (W)</th>
<th>Coolant heat rate (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>1000</td>
<td>515</td>
</tr>
<tr>
<td>Detailed</td>
<td>938</td>
<td>593</td>
</tr>
<tr>
<td>Hx Master/Slave</td>
<td>657</td>
<td>647</td>
</tr>
</tbody>
</table>
System Model outputs & Results

- **Cabin Heating is improved with noticeable reduced time to reach target temperature**
  - Electric Load of Auxiliary heaters could be decreased: SOC savings

- **Fuel Consumption is decreased by up to 8% on cold conditions**
  - In line with OEM claims & experimental test results
Conclusion

- A method has been developed to build a Transient 1D EHRS model under GT suite

- It can be used for various purpose
  - Using customer input, predict how much heat can be extracted
  - It can be embedded in a vehicle model to perform system model
  - Comparison can be made with other exchanger model to compare performances

- This model can generate maps to feed an HxSlave model to perform scaling studies

- Simulation plateform is valuable to
  - Simulate any powertrain and thermal management strategies
  - Simulate any exhaust configuration and EHRS architectures
  - Estimate benefits of our component on customer systems
THANK YOU FOR YOUR ATTENTION!!

Technical perfection, automotive passion