Set-up and Validation of an Integrated Engine Thermal Model in GT-SUITE for Heat Rejection Prediction

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Agenda

1. Motivation
2. Sub-Systems Modelling
   2.1. Engine Performance Model
   2.2. Engine Thermal Model
   2.3. Hydraulic Models
   2.4. Predictive Friction Model
3. Integrated Model
4. Conclusions
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1. Motivation

Project Scope

- Heat rejection map required since early stages of development
- Current approach consists in *empirical* heat rejection maps

  - Requires considerable experimental data from prototype engines
  - Experimental map not available until fairly late in the development process
  - Heat rejection map often not consistent with what observed later on real vehicle

→ Improve the capabilities of engine heat rejection prediction via 1D simulation
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2. Sub-Systems Modelling

2.1. Engine Performance Model

- An existing GT-SUITE model of a 4-cylinder Diesel engine was thoroughly correlated on a steady-state mapping

  - The reference dataset included 176 points: from 800 to 4500 rpm, from 1 bar BMEP to Full-Load

  - Indicating data was provided along with cycle-average measurements
2. Sub-Systems Modelling

2.1. Engine Performance Model

- **Injection Rate Map** and **DIPulse** predictive combustion
  
  - Injection rates at various $P_{\text{rail}}$ and ET
  - Map characterizing injector performance
  - Populated from detailed injector model provided by JLR

  
  - DIPulse burn rate is **predicted** based on:
    - In-cylinder pressure and temperature
    - Mixture composition
    - Injection timings and profiles
  
  - 4 parameters optimized on 24 points via built-in ADO with Genetic Algorithm
2. Sub-Systems Modelling

2.1. Engine Performance Model

- **Correlation Results – Indicating (Full-Load)**
2. Sub-Systems Modelling

2.1. Engine Performance Model

• **Correlation Results – Engine Map**
2. Sub-Systems Modelling

2.2. Engine Thermal Model

• *TWallSoln* FE Wall Temperature Solver historically available in GT-SUITE, employing a “parametric” (i.e. simplified) representation of the engine structure.

• Now GT-SUITE consents the user to import the actual engine structure in the form of an FE mesh → The so-called “Custom Mesh” approach.
2. Sub-Systems Modelling

2.2. Engine Thermal Model

• 3D FE meshing of the engine structure in GEM3D
  – 3D FE models created on head, block, valves and piston (cylinder-by-cylinder)
  – Graphical “painting” of boundary heat transfer surfaces
2. Sub-Systems Modelling

2.2. Engine Thermal Model

- **Water jacket** coolant volume extracted from CAD using GT-SPACECLAIM
  - Discretized into 1D primitives in GEM3D
  - Water jacket model calibrated to match flow distribution from a CHT 3D-CFD analysis

- A detailed 1D **lube model** already available was used
2. Sub-Systems Modelling

2.2. Engine Thermal Model

- The “Custom Mesh” of the engine structure and the coolant/oil passages were integrated in a single 1D model, thermally connected to the performance model.

- Convection with ambient air
- Convection between metal and coolant/oil
- HTC from 3D-CFD
- Conduction between adjacent cylinder parts
- Friction heat @ piston-liner interface
- Metal-Side BCs
- Gas-side BCs
- Engine Model
2. Sub-Systems Modelling

2.3. Hydraulic Models

- The complete **coolant circuit** 1D model was built from CAD
- Heat exchangers, pump, thermostat, expansion tank, etc. were added
- An already calibrated **lube model** was used for the integration
In order to correlate the flow rate distribution among the different branches of the coolant system, pressure drops were tuned to match experimental measurements.
2. Sub-Systems Modelling

2.4. Predictive Friction Model

- GEM3D cranktrain converter tool used to build 1D model starting from 3D CAD
- Friction components added to the mechanical cranktrain model
2. Sub-Systems Modelling

2.4. Predictive Friction Model

- Friction model calibrated against experimental data in both strip-down and firing conditions

→ Model outputs used to provide boundary conditions to the thermal model
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3. Integrated Model

- All subsystems connect into a single integrated model
  - **Direct integration** between performance, thermal and hydraulic models
  - **Indirect integration** with predictive friction model
3. Integrated Model

- Validation of the integrated model results
- Tuning of **engine heat rejection** prediction (mostly on the performance model)

**Before tuning**

- 167 out of 176 points (95%) within the range ±3 kW

**After tuning**

- 60 out of 176 points (34%) within the range ±3 kW
- 167 out of 176 points (95%) within the range ±3 kW
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- 1D Simulation can support product development from the very beginning!
  - Predictive models can be inherited from previous programmes
  - They can be used from early stages to make informed decisions
  - As data become available, model can be updated/validated
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