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Design of Automotive Cooling Systems with GT-COOL and COOL3D

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Design of Automotive Cooling Systems with GT-Cool

Presentation Overview

- Design Objectives of Automotive Cooling Systems
- Vehicle Derivatives in the Product Design Process
- Overall Simulation Approach
  - Drive Performance Module
  - Engine Heat Flux Module
  - Underhood Module (Cool 3D)
- Simulation Results
- Conclusion
Main Functionality of Vehicle Cooling:

- cool hot spots in engine structure
  Impact on thermal stress, fatigue, endurance limit

- keep engine structure at reasonable operating temperatures
  minimize friction, impact on distortion of engine structure

- keep coolant and engine oil below max. allowable temperatures
  boiling of coolant, deterioration of oil, impact on service intervals

- absorb the heat discharged from the engine,
  transport and release the heat to the ambience.
Objectives of Automotive Cooling

Secondary Cooling Functions:

- cool charge air, exhaust gas for EGR
- cool transmission oil (ATF), electronics, auxiliary devices,

Engine Warm Up:

- warm up the engine as fast as possible.
- distribute heated water to components which would take the most benefit of additional heat during warm up to reduce frictional losses.

Engine cooling has developed towards sophisticated vehicle thermal management systems.
Design of Automotive Cooling Systems with GT-Cool
Heat Flux Management for a BMW 6-Cyl. Engine

Heat Release through:
- Condenser
- Radiator
- Engine
- Exhaust system
- Transmission
- Differential

Underhood flow @ 250 km/h

Coolant Circuit
- 105 kW
- 190 kW
- Exhaust Enthalpy Flux at engine outlet ports

Engine Oil Circuit
- 72 kW
- ~400 kW

Transmission Oil Circuit
- 5 kW

Shaft Power
- 190 kW @ 6600 rpm
- ~190 kW
The design process must handle a great number of derivatives:

**Design Derivatives for a vehicle platform:**
3-series, sedan, coupe, 1-series, Z3, SUV, ...

**Engine Derivatives:**
4-/6-cylinder, different displacement, turbo charged

**Transmission Derivatives:**
manual, automatic, dual clutch, hybrid

**Market Derivatives:**
moderate / hot / extreme climate

... results technically in 200 derivatives or more

... must be limited to a reasonable number of
cost and performance optimized modular cooling systems

**Design and Analysis must be backed up by a powerful integrated simulation toolset.**
Design of Automotive Cooling Systems with GT-Cool
Organization of Cooling System Modules

Drive Performance Module

- Operating Point of Engine
- Operating Point of Vehicle
- Controler
- Underhood Flow

Engine Heat Flux
- Engine Oil Circuit
- Transmission Oil Circuit
- Coolant Circuit

Q\_coolant
Q\_oil
Q\_ATF

Q\_Heat Ex 1
Q\_Heat Ex 2

45°C
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Data Definition and Drive Performance

*Data Sheets*
for
Baseline Vehicle Configuration
and Derivatives

- Vehicle and Powertrain
- Stationary Operating Points
- Relevant Driving Cycles

GT-Drive Modell

evaluates operation point of engine
controls GT-Cool model / calculation
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Organization of Cooling System Modules

Drive Performance Module

- Operating Point of Engine
- Controller
- Coolant Circuit
- Engine Oil Circuit
- Transmission Oil Circuit

Underhood Flow
- Operating Point of Vehicle
- Heat Ex 1
- Heat Ex 2
- Engine Heat Flux
- Coolant
- Engine Oil
- Transmission Oil

45°C

Engine Heat Flux

Q coolant

Q oil

Q ATF

Q Heat Ex 1

Q Heat Ex 2
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Engine Heat-Flux Measurements
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Engine Heat-Flux Measurements

Conditioning of temperature levels:

- Engine Oil
- Coolant

Heat Release Maps

<<< Engine Oil – Coolant >>>

for at least four different temperature levels
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Engine Heat-Flux Map Generation

Multi Dimensional Table Lookup

Start of Simulation (cold)
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Engine Heat-Flux Map Generation

Multi Dimensional Table Lookup

End of Simulation (converged)

T_Coolant

T_Oil

25/25°C

95/105°C

115/105°C

108/125°C

105°C

130°C

95/130°C

115/130°C

25/25°C 95/105°C 115/105°C
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Organization of Cooling System Modules

Operating Point of Engine

Operating Point of Vehicle

Engine Heat Flux

Controller

Coolant Circuit

Transmission Oil Circuit

Engine Oil Circuit

Drive Performance Module

Underhood Flow

45°C
Full CFD Analysis:

- predicts volume flow rate through heat exchangers and heat transfer
- accounts for inhomogenous flow phenomena
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Cool 3D Approach with BMW Configuration
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Simplified CFD Underhood Simulation with Cool 3D

- Air Inlet (total pressure)
- Air Intake Mask
- Charge Air Cooler
- Condenser
- Radiator (high)
- Radiator (low)
- Engine compartment
- Shroud
- Fan hub
- Fan
- Air Outlet (static pressure)
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CFD Results for Cool 3d Underhood Configuration

velocity vector overlay
from full CFD calculation
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CFD Results for Cool 3D Underhood Configuration

detailed fan and shroud geometry:

engine at idle; cooling fan rotating; vehicle speed 0 kph
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Boundary conditions for Cool 3D

Air Intake Design

Pressure in underfloor flow

Cooling Module Design

Fan Momentum Source
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Comparison of Full CFD vs. Cool 3D Simulation

**Full CFD Underhood Simulation**
- accounts for detailed geometry
- accounts for inhomogenous flow phenomena
- needs only CAD Geometry and Heat Exchanger maps
- processing time: ~ 3 months
- aspired accuracy for the prediction of volume flow rates: ± 3%

**Cool 3D Underhood Simulation**
- accounts for overall geometry
- directly coupled to GT fluid circuits
- accounts for inhomogenous flow phenomena
- needs pressure b.c. and fan performance data from CFD analysis and Heat Exchanger maps
- processing time: ~ 3 days
- aspired accuracy: ± 10%
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Fully Coupled System Simulation with GT-Suite

Drive Performance Module

Operating Point of Engine

Operating Point of Vehicle

Engine Heat Flux

GT Drive

Controller

Coolant Circuit

GT Cool

Cool 3D

Engine Oil Circuit

Transmission Oil Circuit

Underhood Flow

\( Q_{\text{coolant}} \)

\( Q_{\text{oil}} \)

\( Q_{\text{ATF}} \)

45°C

Engine Heat Flux

Operating Point of Engine

GT Drive

Controller

Coolant Circuit

GT Cool

Cool 3D

Transmission Oil Circuit

Underhood Flow

\( Q_{\text{Heat Ex 1}} \)

\( Q_{\text{Heat Ex 2}} \)

45°C
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Prediction of Coolant Temperature for Highly Dynamic Driving Cycles

Recorded Test Data:
- Vehicle Speed
- Engine Rotational Speed
- Torque
- Gear
- Ambient Temperature
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Conclusion

- Engine cooling has developed towards sophisticated vehicle thermal management systems.
- Large number of vehicle/drivetrain combinations created need for a modular, cost and performance effective cooling system design.

➤ Design and Analysis must be backed up by a powerful integrated simulation toolset.

GT Suite has been successfully used with the following features:

- coupling of all fluid circuits (GT Cool)
- integrated drive performance module (GT Drive)
- direct coupling with the new underhood module (Cool 3D)
- integration of multidimensional engine heat release maps
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