GT-SUITE and TAITherm Coupling Methodology for Transient Cabin Simulation Using 3D CFD Data

European GT-SUITE Conference 2019

TME  Nick Buyens, Jeroen De Smet
AKKA  Gauthier Carteni (on-site consultant)

Powertrain 1 – Model Based Design
Contents

1. Project background
2. Methodology
3. Initial model results
4. Future development
Project Background

Cabin heating has a significant energy consumption impact for electrified vehicles

Electrified vehicles don’t have access to sufficient heat from traditional “free” waste heat sources (i.e. combustion engine) in winter

⇒ (HEV / PHEV) – turn on the engine to provide additional heat at cost of fuel consumption

⇒ (PHEV / BEV) – use additional heating devices at cost of electricity consumption

Project Background

A full vehicle model is required to virtually optimise cabin comfort and energy consumption

Development in wind tunnel requires
- Prototype vehicle preparation
- Extensive testing process (0.5h test + 4h soak)
- 40+ sensors for comfort assessment
  ⇒ Resource inefficient
**Project Background**

GT-SUITE methodology for 3D cabin heating with fast simulation time was evaluated

### Cabin modelling methods

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Calculation time</th>
<th>3D accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>high</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>

#### A.
- Simple 0D approach
- 0.1xRT
- 1 cell

#### B.
- Detailed 3D approach
- 400xRT
- 10M cells

#### C.
- Mapped 3D approach
- 1-2xRT
- 200K cells

### Cabin model image

- **Cabin model**
- Air temperature at any point in the cabin
- Solid temperature at any point in the cabin

- **Cabin inputs**
- Flow rate and temperature at the HVAC outlets

- **Cabin outputs**
- Air temperature at any point in the cabin
- Solid temperature at any point in the cabin

### Model targets
1. Simulate transient 3D cabin heat-up
2. Fast calculation time < 2xRT
A standard GT-Suite & TAITherm co-simulation process using 3D CFD data was developed.

Methodology – Principle

Provide geometry

CAD

Simplified Mesh

CFD Mesh

CFD run for each cabin condition

Material data

CFD maps

Solid temperatures

Air temperatures

Co-simulation
Methodology – CFD steady state

Thermal 3D CFD simulations are used to accurately capture cabin flow and heat flux

- **CFD inlet & ducts**
  - Constant high temperature
  - Imposed volume flow rate

- **CFD interfaces GT openings**
  - Interfaces used as inlet in GT

- **Cabin walls**
  - Constant low temperature

- **Cabin outlets**
  - Recirculation & ventilation

---

**Temperature (°C)**

**Low**  
**High**
Methodology – Principle

Co-simulation methodology developed with GT-Suite & TAITherm

CAD

Provide geometry

CFD

Material data

Calculated once for each case

CFD Mesh

Simplified Mesh

CFD maps

Air temperatures

Solid temperatures

Co-simulation

CFD

STAR-CCM+

TOYOTA MOTOR EUROPE (TME)

07-OCT-2019 - page 8

European GT-SUITE Conference 2019
Methodology – CFD maps

Extensive 3D CFD data are mapped on the coarsely discretised GT cabin

3D CFD maps contains 7 result files per case:

1. Inflow & Outflow Rate
2. Absolute Pressure Field
3. Velocity Field
4. Turbulent Viscosity Field
5. Boundary Heat Flux
6. Air & Solid temperatures
7. Extensive 3D CFD data are mapped on the coarsely discretised GT cabin

TOYOTA MOTOR EUROPE (TME)
07-OCT-2019 - page 9
European GT-SUITE Conference 2019
Methodology – Principle

CAD

Provide geometry

CFD

STAR-CCM+

Simplified Mesh

Material data

Calculated once for each case

CFD maps

Co-simulation

Solid temperatures

Air temperatures

TOYOTA MOTOR EUROPE (TME)
07-OCT-2019 - page 10
European GT-SUITE Conference 2019
Methodology – GT model discretisation

GT v2019 process is time-consuming ⇒ New process flow under development for GT v2020

1. Ducts removed
2. Vents closed

Closed Surface

1 hour

3. Vents shape
4. Vents location
5. Sensors position

Discretized

6 days

Total

7 days

1. Sensors position

Discretized

15 minutes

Total

1 hour

10 minutes

Export Mesh

30 minutes

GT model

CAD

Vents

Vents location

Sensors

Sensors position

Export

Mesh

CFD

STAR-CCM+
Methodology – GT flow processing

Transient cabin flow is only dependent on 4 HVAC parameters:
1. Inlet mode
2. Outlet mode
3. Air mix
4. Blower level

GT interpolates between mapped steady CFD points at every simulation time step

- 61 CFD maps (steady)
- GT look-up

<table>
<thead>
<tr>
<th>Flow rate level</th>
<th>HVAC mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Switch

Interpolate

Methodology – GT flow processing

Flow rate level

Velocity [km/h]

Time [s]

Flow rate level [\]
Methodology – Principle

CAD

Provide geometry

CFD Mesh

Simplified Mesh

Material data

Calculated once for each case

CFD maps

Co-simulation

Solid temperatures

Air temperatures

CAD

CFD STAR-CCM+

TOYOTA MOTOR EUROPE (TME)

European GT-SUITE Conference 2019
Methodology – TAITherm model set-up

TAITherm model is set up following standard procedures

1. Initial temperature
2. External temperature and velocity (transient)

1. Ducts removed
2. Vent openings kept

Simplified Mesh

Material properties

Reflectance
Transmitance
Specific Heat
Density
Thicknes
Conductivity
Transparency

CFD
STAR-CCM+

TOYOTA MOTOR EUROPE (TME)
07-OCT-2019 - page 14
European GT-SUITE Conference 2019
Methodology – Principle

CAD

Provide geometry

CFD Mesh

Simplified Mesh

Material data

Calculated once for each case

CFD maps

Co-simulation

Solid temperatures

Air temperatures

TOYOTA MOTOR EUROPE (TME)
07-OCT-2019 - page 15
European GT-SUITE Conference 2019
Methodology – Transient run

Final co-simulation can simulate cabin model on a transient cycle below 2x real time
Initial results – Air temperature

Model shows good prediction, but accuracy near cabin flow inlets to be improved

Simulation conditions
Ambient: Winter
HVAC setting: Cabin heating
Driving cycle: WLTC
Model inputs: CWT test data

※ CWT = Climatic Wind Tunnel
Initial results – Air temperature

Model shows good prediction, but absolute accuracy at end of cycle to be improved

High speed area to be investigated
Future development – next steps

Potential model improvement steps were identified and will be performed

1. Validation of GT-Suite mapped flow
   1. Set up transient CFD
   2. Set up co-simulation CFD-TAITherm
   3. Check accuracy of GT vs. CFD (airflow & temperature)

2. Investigate further model improvements e.g.
   1. Effect of external airflow (realistic aerodynamics)
   2. Further TAITherm model improvements (material properties, air gaps etc.)
Future development – next application

Application of the methodology to other mobility solutions requires additional development

Future Mobility as a Service (MaaS)

1. Fully electrified
2. Large interior volumes + window area

Commercial vs. private
⇒ initial heat-up has low priority

Ride sharing application
⇒ transient door opening

Development of transient door opening prediction is needed
Thank you