GT Cabin Modelling

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Mercedes-Benz
The best or nothing.
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Motivation

Build a cabin model which caters the need of

- Full vehicle simulation for efficient thermal management, and
- Controls development

With objective of

- Cabin air average temperature prediction
- Solids temperatures prediction
- Real time running model
Model Details

- Single flowsplit represents the entire cabin volume
- Solids in CFD are represented as individual lumped mass
- Solids to air-volume interaction via convection connections
- Solids to solids interaction via surface radiation connections
Cabin Heat Transfer Modelling: Outlook

Conduction

• Multiple wall elements
• Discretization along thickness

Convection

• HTCs map for each surface
• Data import from CFD

Radiation

• Modelling of thermal and solar radiation
• View factor import from CFD
Conduction Modelling

1. Identification of right template

2. Discretization of solid across thickness

Surface temperature GT vs CFD

- CFD
- DISCRETIZED
- NON-DISCRETIZED
Convection Modelling

- **Outside**
  - HTC Correlation based on vehicle velocity

- **Inside**
  - HTC based on cabin total mass flow rate and recirculation percentage

*Fig: Verification of HTCs map prediction (90 perc blower level and 0% recir)*
Physics Modelling: Solar Radiation

Opaque Surfaces

Heat Flux = Solar Intensity * \textbf{Geometry factor} * (1 − Reflectivity)

Transparent Surfaces

\dot{Q}_{\text{upper,flux}} = \text{Solar Intensity} * \textbf{Geometry factor} * (1 − \text{Reflectivity} − \text{Transmissivity})

\dot{Q}_{\text{trapped,flux}} = \text{Solar Intensity} * \textbf{Geometry factor} * \text{Transmissivity} * (1 − \text{Transmissivity})

Note:

- Geometry factor imported from 3D CFD
- Heat flux modelled in GT using math equation template
Physics Modelling: Thermal Radiation

Option 1
- Modelled using the radiation connections available in GT
- View factor from CFD
- No. of radiation connections for n surfaces:
  \[ \frac{n(n-1)}{2} \]
- Modelling effort \(\approx 7\) days

Option 2
- Solving simultaneous equations for heat flux
- View factor from CFD
- Use of python scripting in GT
  \[ a_{11}q_1^* + a_{12}q_2^* + \ldots + a_{1N}q_N^* = C_1 \]
  \[ a_{21}q_1^* + a_{22}q_2^* + \ldots + a_{2N}q_N^* = C_2 \]
  \[ \vdots \]
  \[ a_{N1}q_1^* + a_{N2}q_2^* + \ldots + a_{NN}q_N^* = C_N \]
- Modelling effort \(\approx 1\) day
Results Cool down- Cabin Average Temperature

Fig: Boundary Conditions

Fig: Average cabin temperature (GT vs CFD)
Results Cool Down: Surface Temperatures

INSIDE-SURFACE-TEMP-DOOR-LEFT

INSIDE-SURFACE-TEMP-ROOF

INSIDE-SURFACE-TEMP-REAR-WINDOW

INSIDE-SURFACE-TEMP-PILLARS-LEFT
Results - Cool Down, low flow rate

**Fig: Average cabin temperature (GT vs CFD)**

- **Cabin-Average-Temperature**
  - CFD
  - GT

**Fig: Boundary Conditions**
Results - Heat up, low flow rate

**Fig: Boundary Conditions**

**Fig: Average cabin temperature (GT vs CFD)**
Results - Heat up, high flow rate

Fig: Average cabin temperature (GT vs CFD)

Fig: Boundary Conditions
Reasons of Deviation

- Energy difference of the exit air leaving the cabin

\[ \dot{Q}_{solids-air} \]

\[ T_{out,local} \]

3D model, CFD

- Less discretization of solids

- Load case specific heat transfer coefficient needed
Conclusions

1. Different modes of heat transfer for cabin was modelled in GT (with Star ccm+ as the basis)
2. Model can predict the cabin volume average temperature and solid surfaces temperature
3. Model is fast running: ~22 times faster than real time
4. Deviation in average cabin air temperature between CFD and GT is ~3°C
5. Model has dependency on CFD data
   1. Heat Transfer coefficients
   2. View factors – Solar and thermal
6. Model needs load case(heat up/cool down) specific calibration
Thank you