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Towards the Realization of a Digital Twin Model for Hot Shut Down Thermal Soak Simulation

InDesA GmbH
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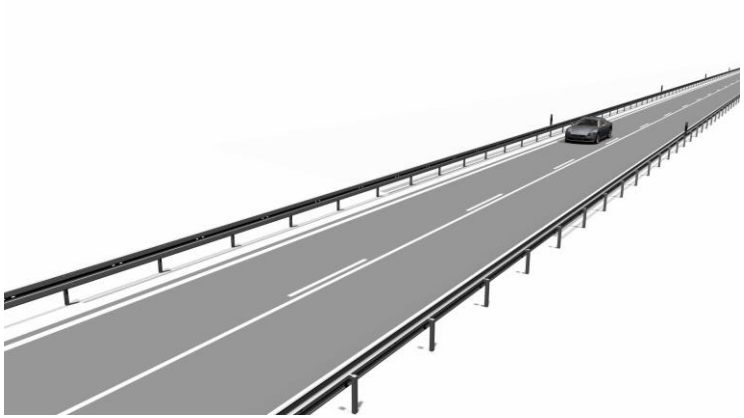
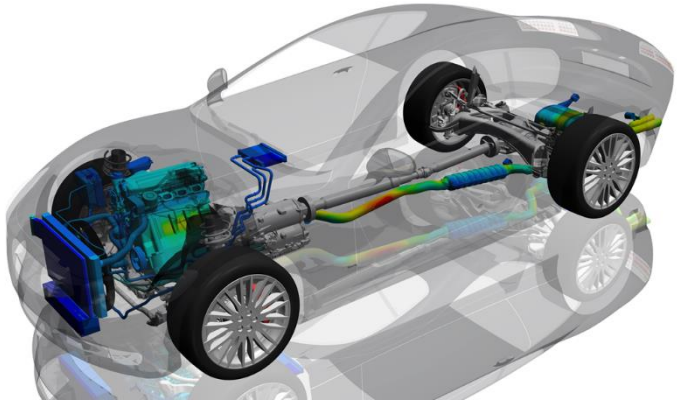
Digital Twin for Hot Shut Down Thermal Soak

PANDORA – InDesA's Virtual Concept Design Vehicle





PANDORA

InDesA's Virtual Thermal Management Vehicle

Designed to demonstrate thermal simulation techniques with options for different thermal management technologies.

- ICE Powertrain
- Electrified Powertrain (BEV)

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Digital Twin for Hot Shut Down Thermal Soak

Flow and Thermal Simulation - Streamlines

Deceleration from 200 kph to 0 kph in 10 seconds

Seamless simulation
(vs. stepwise, which is state of the art)

- cruising at high speed
- braking to vehicle stop
- Key-off
- Cooling fan on/off

Unlike wind tunnel testing **realistic inertia behavior of air is captured** when vehicle comes to stop.

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Digital Twin for Hot Shut Down Thermal Soak
Flow and Thermal Simulation – Temperatures

Ambient 30°C

blue haze 35°C

00:12 Vehicle Stop / cooling fan OFF
00:15 cooling fan ON
00:22 fast motion
01:17 tail wind 1 m/s
02:17 tail wind OFF / cooling fan OFF

Seamless simulation

- cruising at high speed
- braking to vehicle stop
- Key-off
- Cooling fan on/off
- Tail wind on/off

Adverse conditions with moderate tail wind and recirculation phenomena can be captured.

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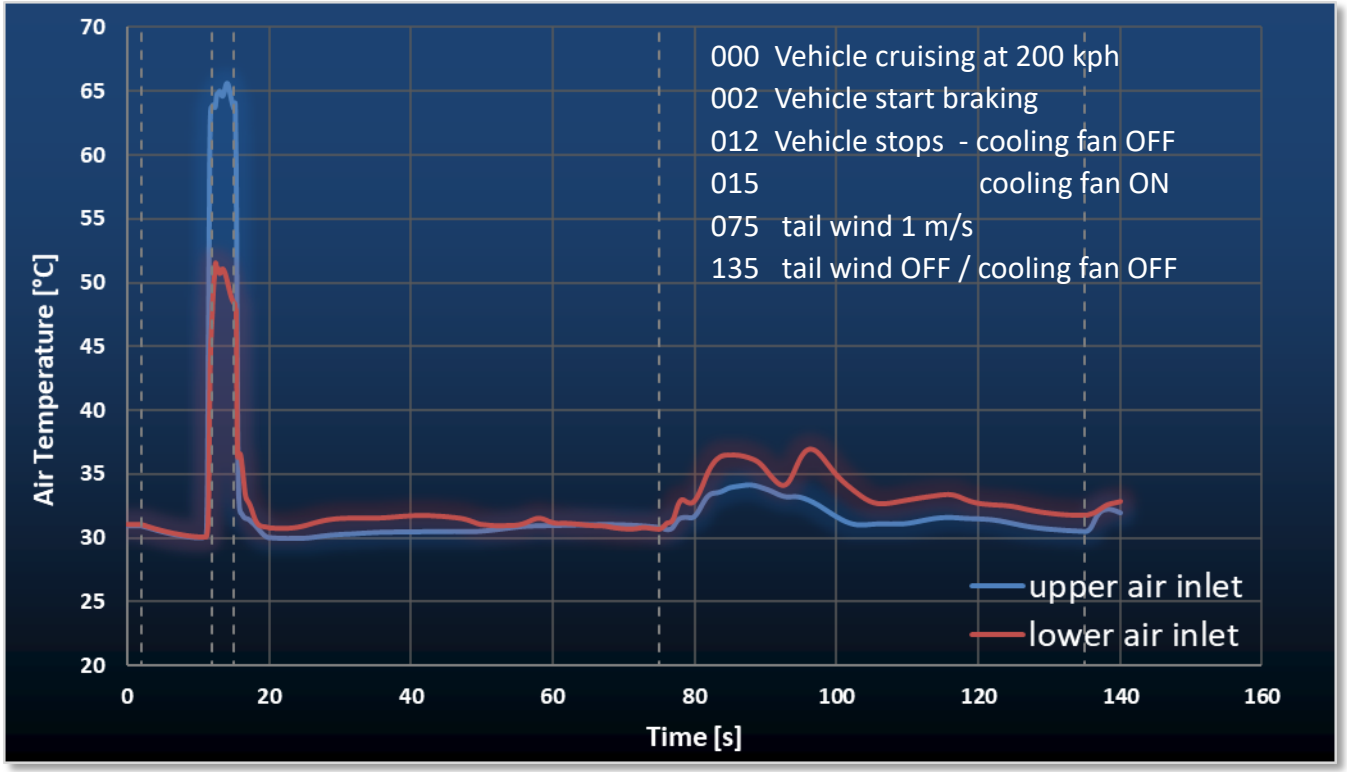
Digital Twin for Hot Shut Down Thermal Soak

Air Temperature in Lower/Upper Frontend Air Inlet



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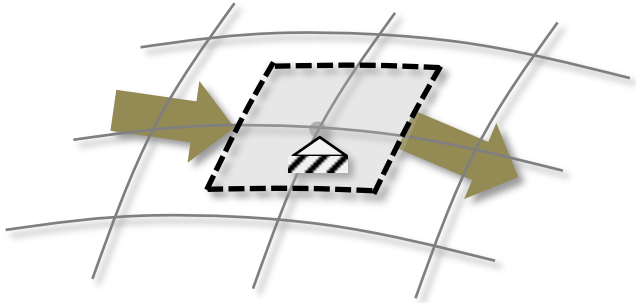
Digital Twin for Hot Shut Down Thermal Soak
Translatory Reference Field (TRF) Methodology

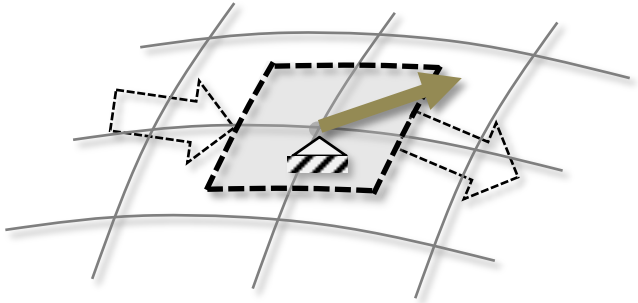
Inflow/circulation of a body:

- Classical approach ➔ observation in body fixed coordinate system. Air flows around body (cf. wind tunnel).
- Observer is in the moving coordinate system (from the point of view of an external observer)



$$\frac{\partial}{\partial t}u + \nabla H = 0$$

- Overset method ➔ the body moves into a resting fluid (e.g. falling ball)
- Observer is in the fixed coordinate system (from the point of view of an external observer)



$$\frac{\partial}{\partial t}u + \nabla H = \nabla F$$

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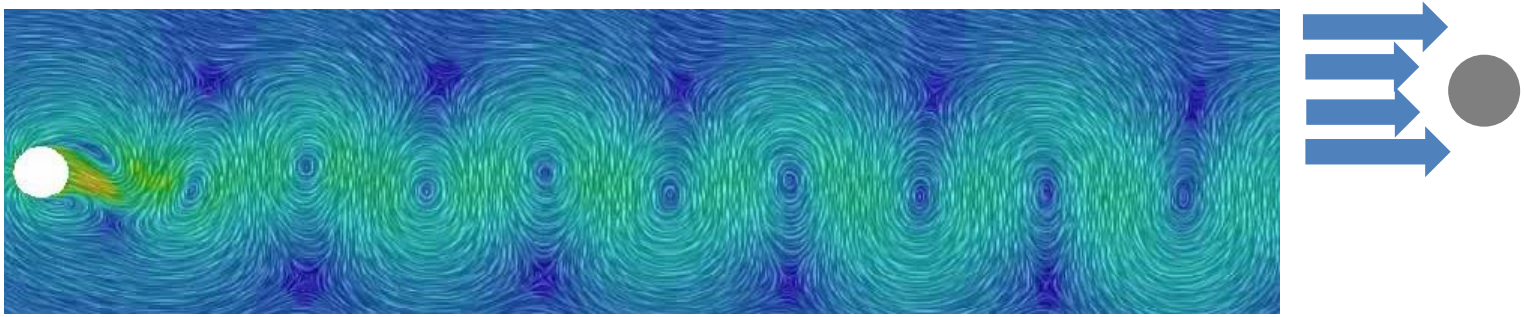

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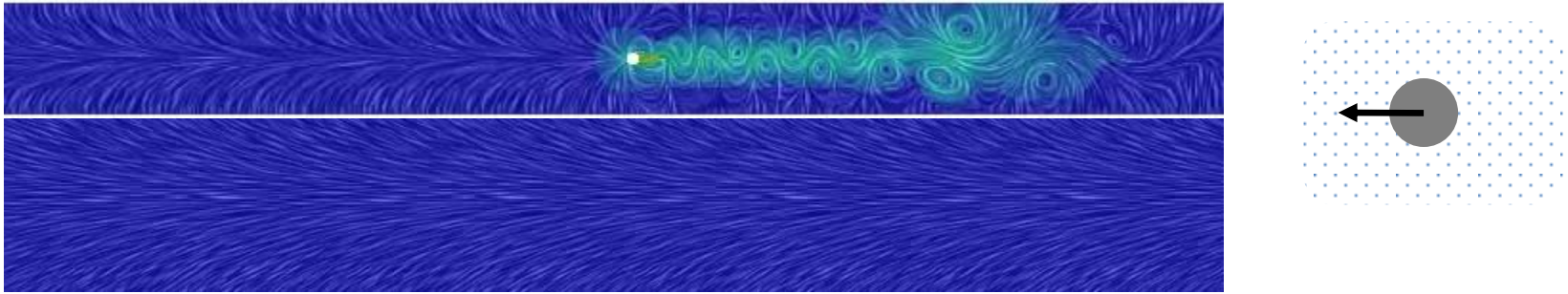

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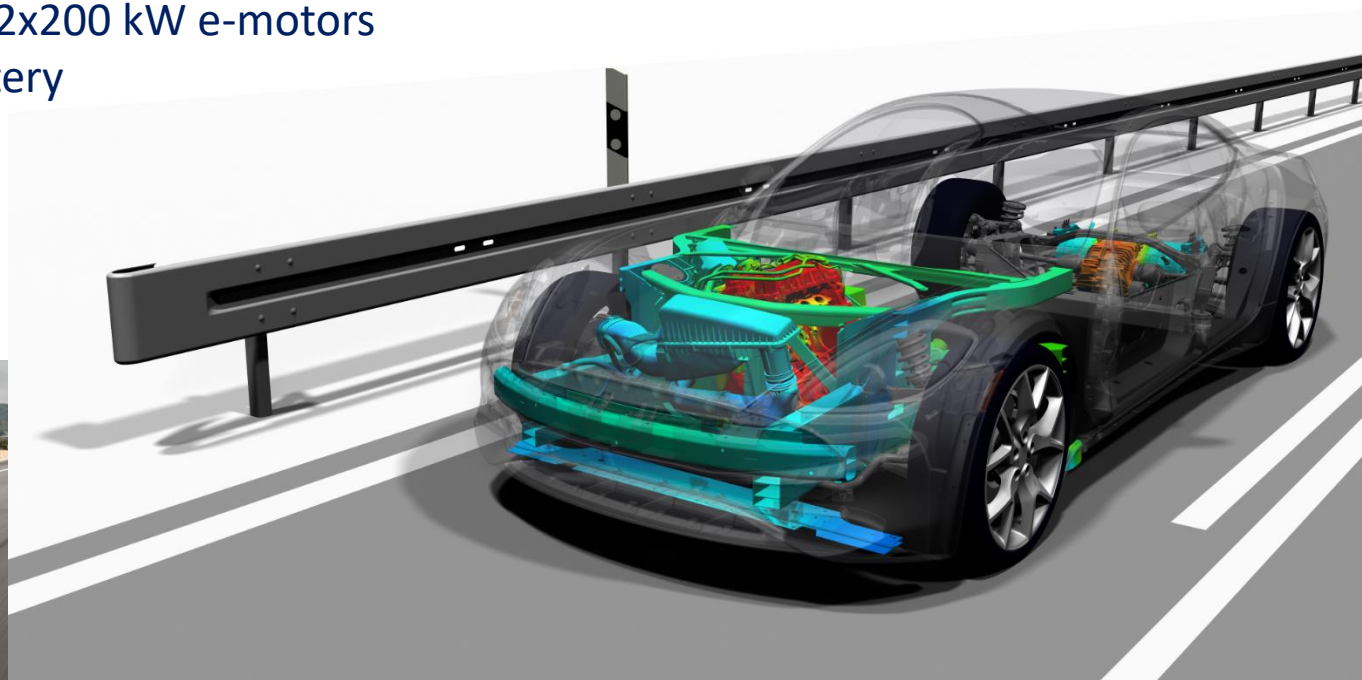
Digital Twin for Hot Shut Down Thermal Soak
Testing with Aero and Thermal Digital Twin

Aero and Thermal Digital Twin
2020 Karma Revero GT
with BMW 3-Cyl 1.5 l turbo engine as range extender
Propulsion: 2x200 kW e-motors
28 kWh Battery



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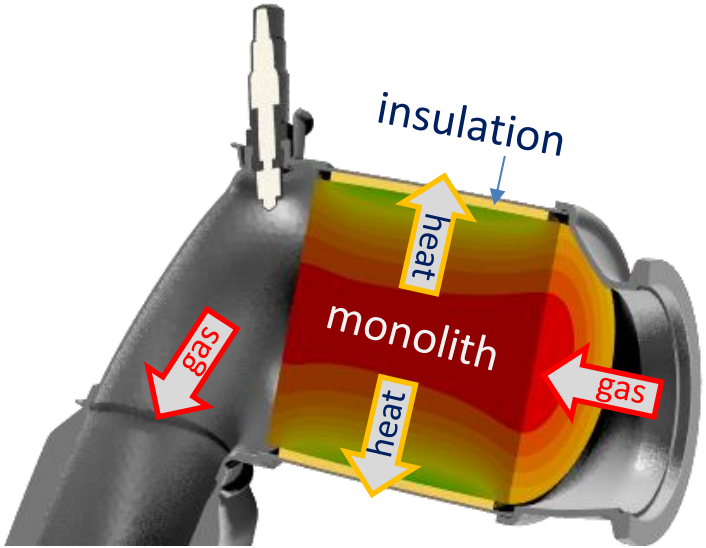
Digital Twin for Hot Shut Down Thermal Soak
Model Approach for the Monolith of Catalyst

Transient Thermal Model for Monolith:

Similar to the dual stream approach two identical meshes are overlaid, one for the monolith structure and one for the exhaust gas.

- The monolith structure allows for heat conduction in radial and axial direction and is connected to the surrounding insulation layer.
- The monolith gas flow passage is modelled as porous media, connected to the flow region up and downwards of the monolith.
- Exhaust gas and structural regions exchange heat through programmed user functions.



Hot soak of monolith

- Exhaust gas flow “off”
- Heat gradually removed from monolith structure

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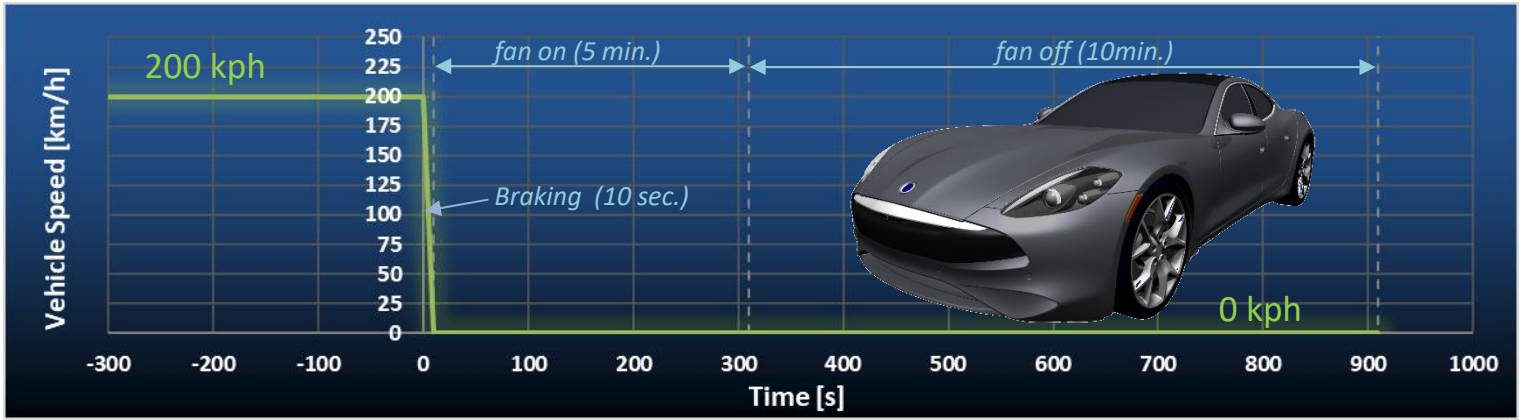
Digital Twin for Hot Shut Down Thermal Soak

Test Profile for KARMA Revero GT Digital Twin



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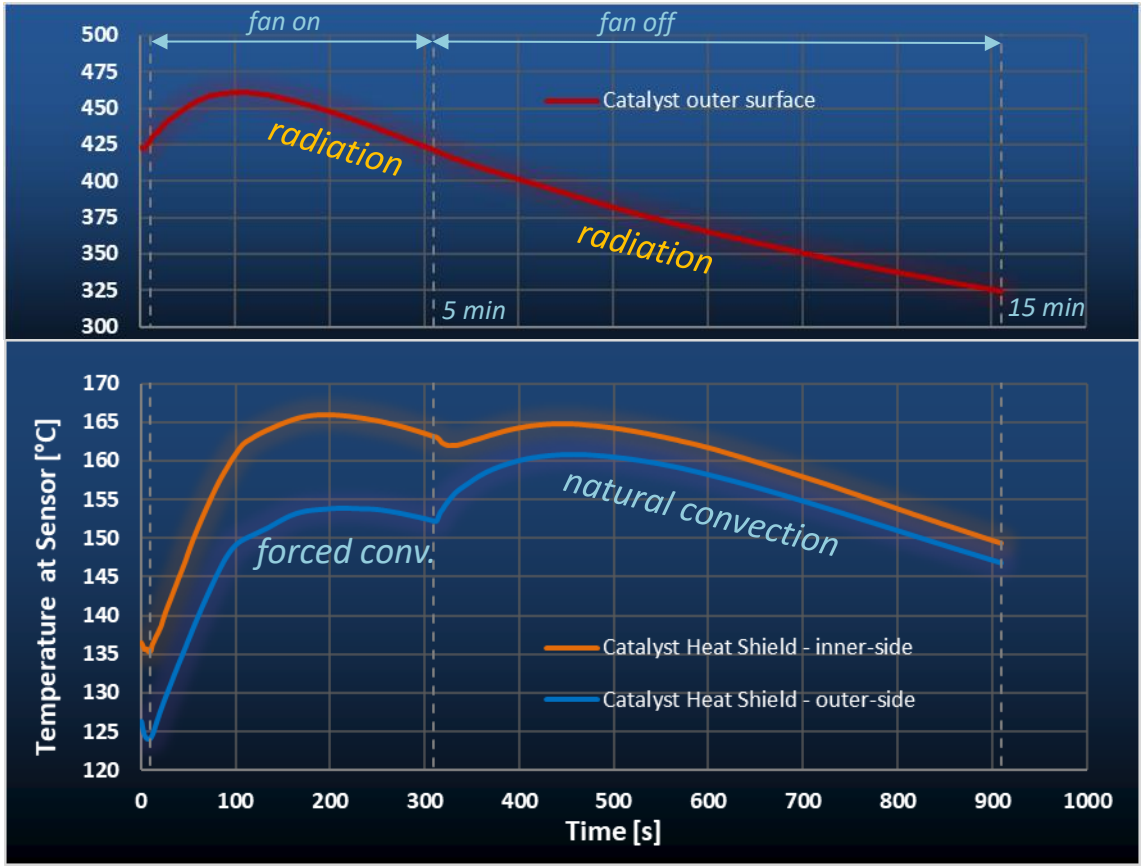
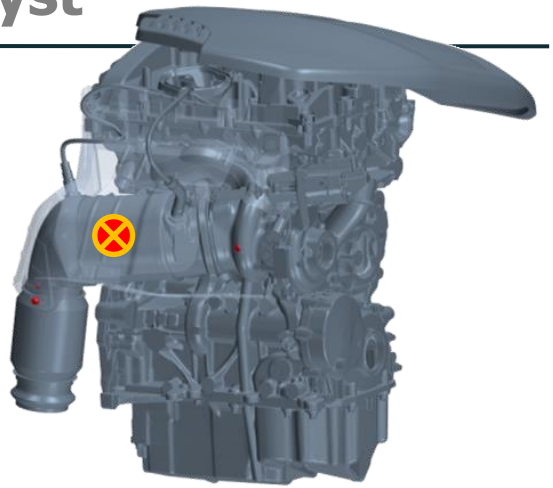
Digital Twin for Hot Shut Down Thermal Soak

Heat Shield Optimization for Catalyst





Design goals for Heat Shield:

- Shielding parts in vicinity of catalyst from radiation.
- Allowing for cooling of catalyst surface (radiation & convection).
- Efficient cooling of outer side of heat shield through cooling fan.

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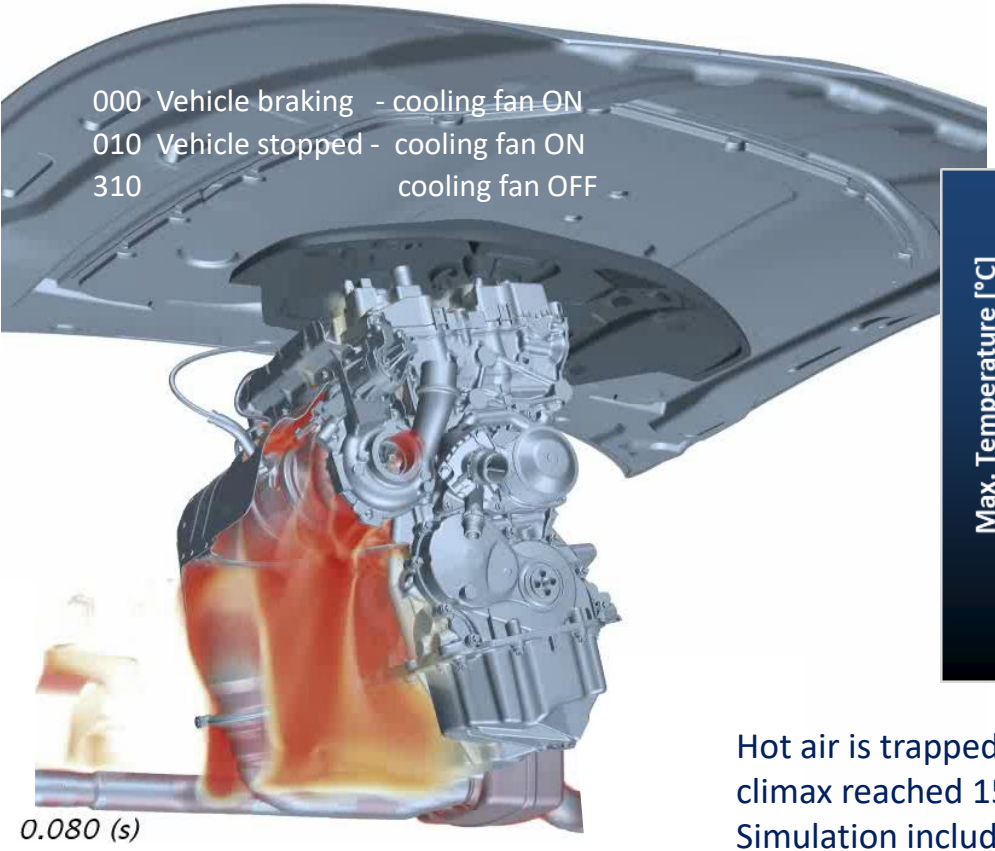
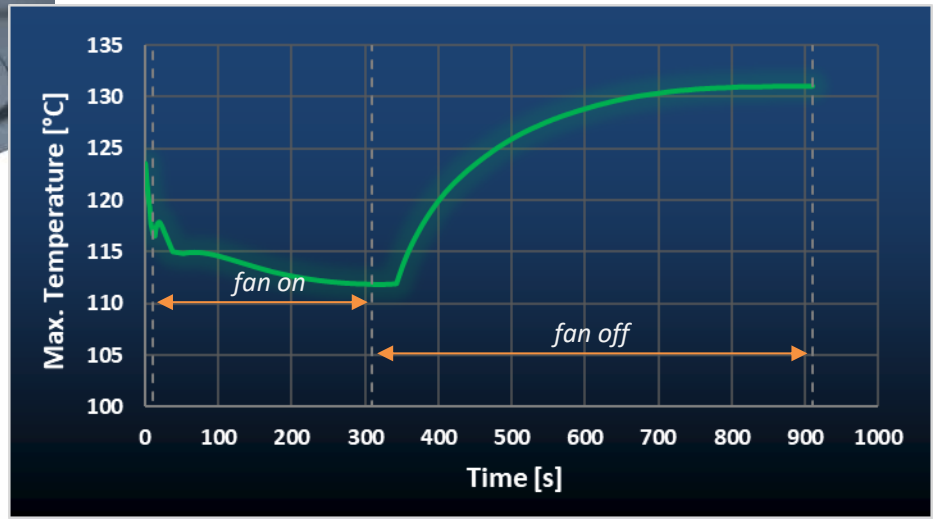
Digital Twin for Hot Shut Down Thermal Soak

Thermal Exposure of Engine Design Cover



Maximum Temperature at Engine Design Cover



Hot air is trapped underneath the cover with temperature climax reached 15 minutes after key-off.
Simulation includes convection, buoyancy, and radiation.

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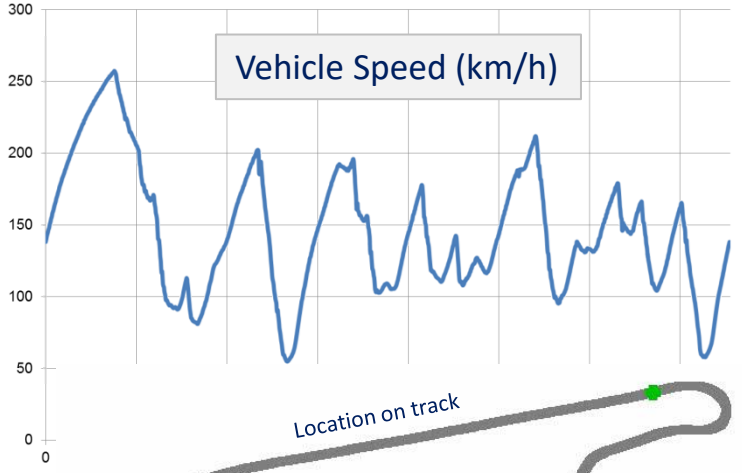
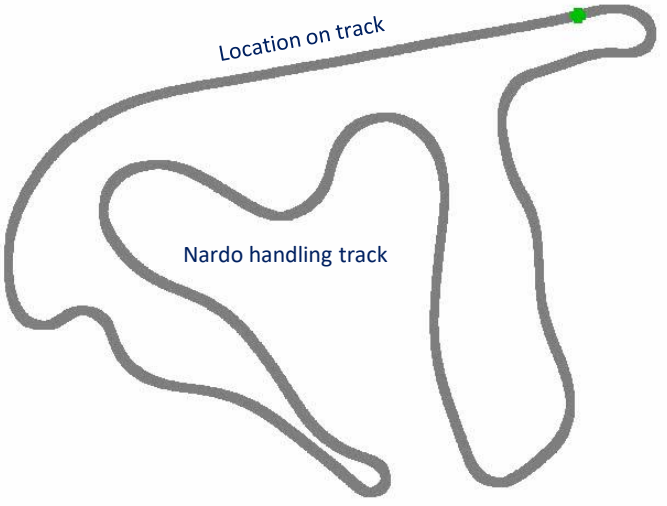
Digital Twin for Hot Shut Down Thermal Soak
Using the Methodology for Race Track Simulation

Vehicle flow: fixed coordinate system





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Digital Twin for Hot Shut Down Thermal Soak
Summary and Conclusion

Translatory Reference Field (TRF) Methodology introduced for hot key-off thermal soak simulation.

TRF Methodology Development

- extended to realistic catalyst hot soak behavior.
- developed and tested for InDesA's virtual Thermal Management Vehicle PANDORA.
- tested and verified for Revero Digital Twin from Karma Automotive.
- applied to highly dynamic race track simulation for the Mercedes- AMG GT.

TRF Methodology Capabilities

- captures real world transient flow and thermal behavior,
- allows for seamless simulation procedures and is,
- applicable to complete virtual thermal management Digital Twin vehicles.

Towards the Realization of a Digital Twin Model for Hot Shut Down Thermal Soak Simulation

Thank you for Your Attention!

Special thanks to Karma Automotive and Mercedes AMG for letting us present examples of our project work.