Coupling TAITherm & OpenFOAM for Automotive Applications

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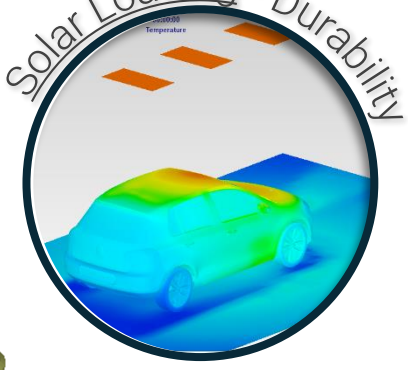
THERMO ANALYTICS

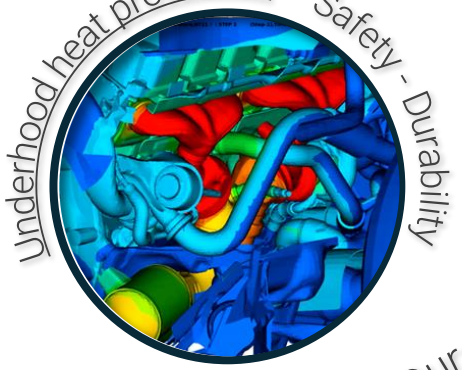
Overview

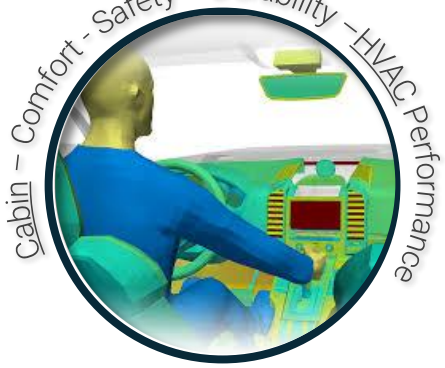
- Introduction
- Coupling Process
- Automotive Thermal Management Applications
- Advanced Process Customization
- Conclusions

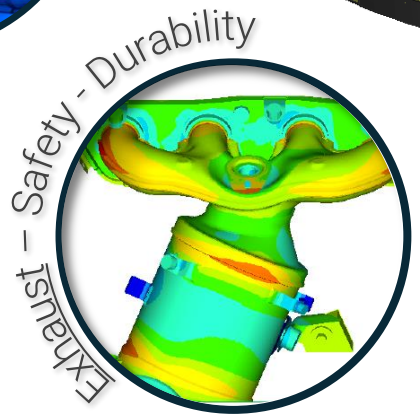
Introduction

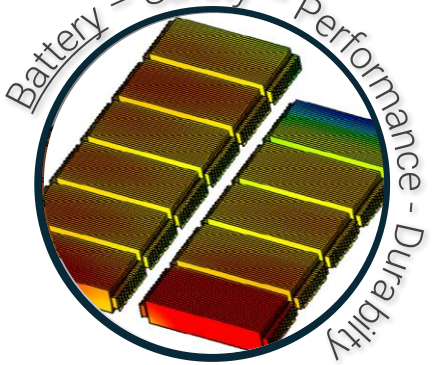
Core Automotive Applications

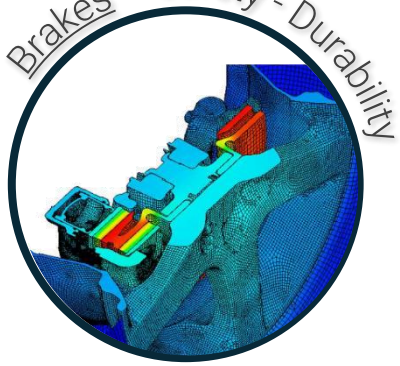






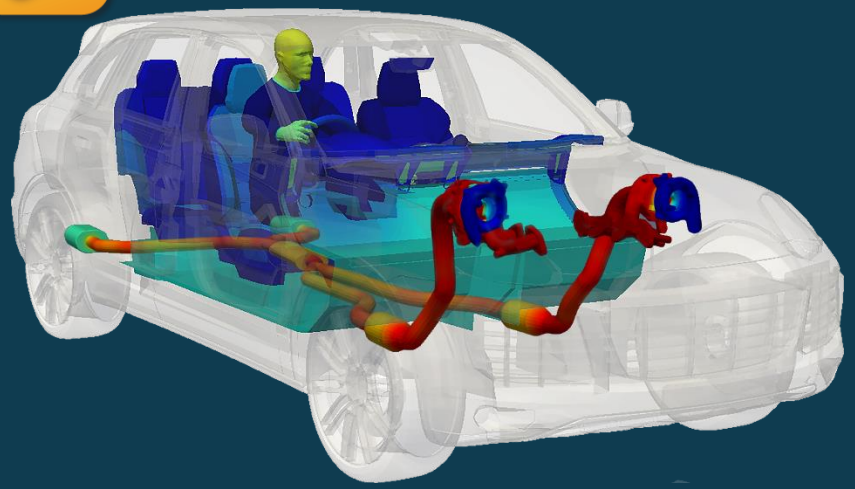






TAI Toolbox

TAITherm



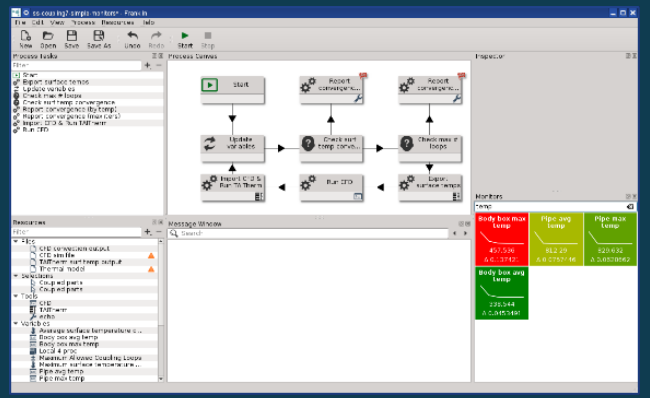
Complete 3D Thermal Modeling

Transient or Steady State

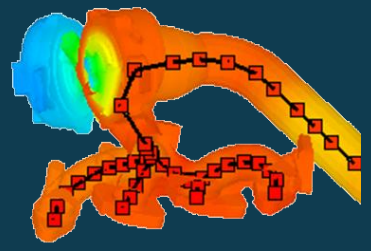
CFD/FEA/1D Coupling

Weather
Pre/post GUI & Report Generator
Parallelized
API

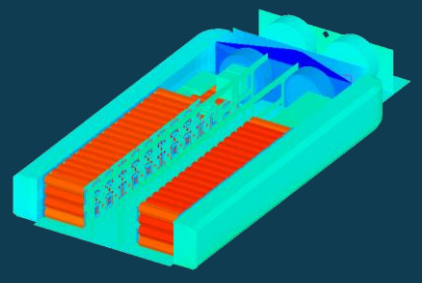
CoTherm



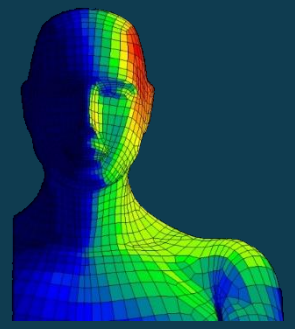
Exhaust



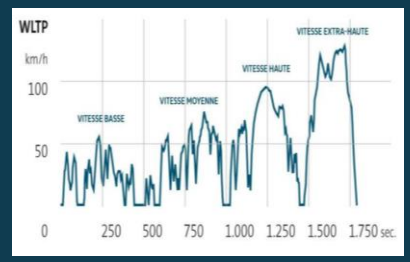
Battery



Human Comfort



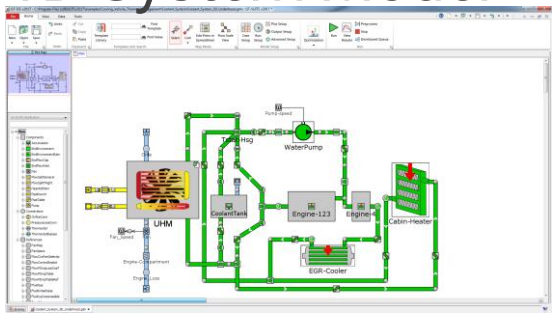
Drive Cycle Extension



Coupling Process

Multiphysics Simulations

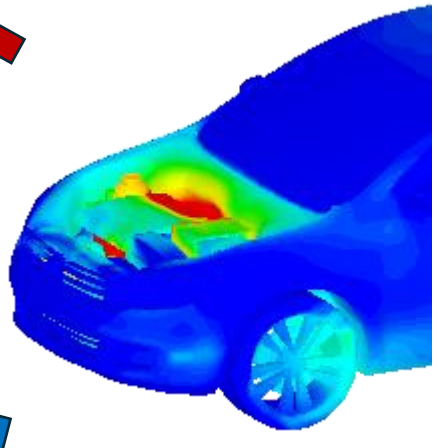
1D System Model



T components

Flow rates, HVAC Loads, etc....

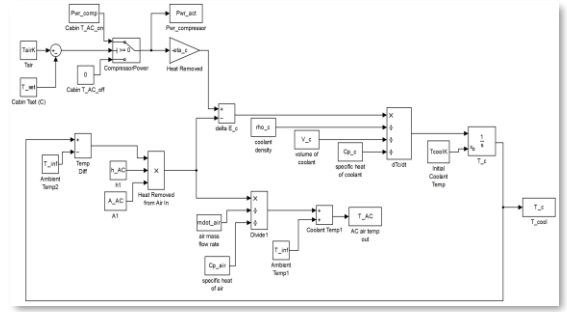
TAITherm Thermal Model



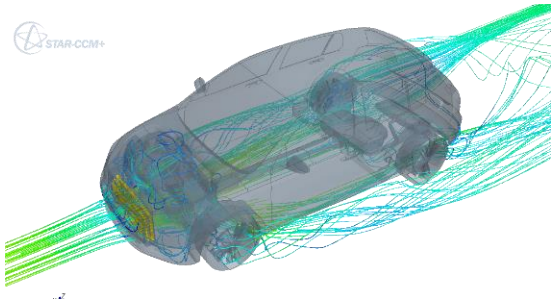
V components

T components

Electrical Network Model



External CFD Model



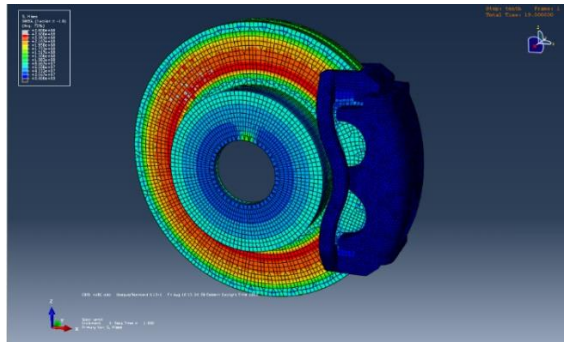
T surface

HTC &T Fluid

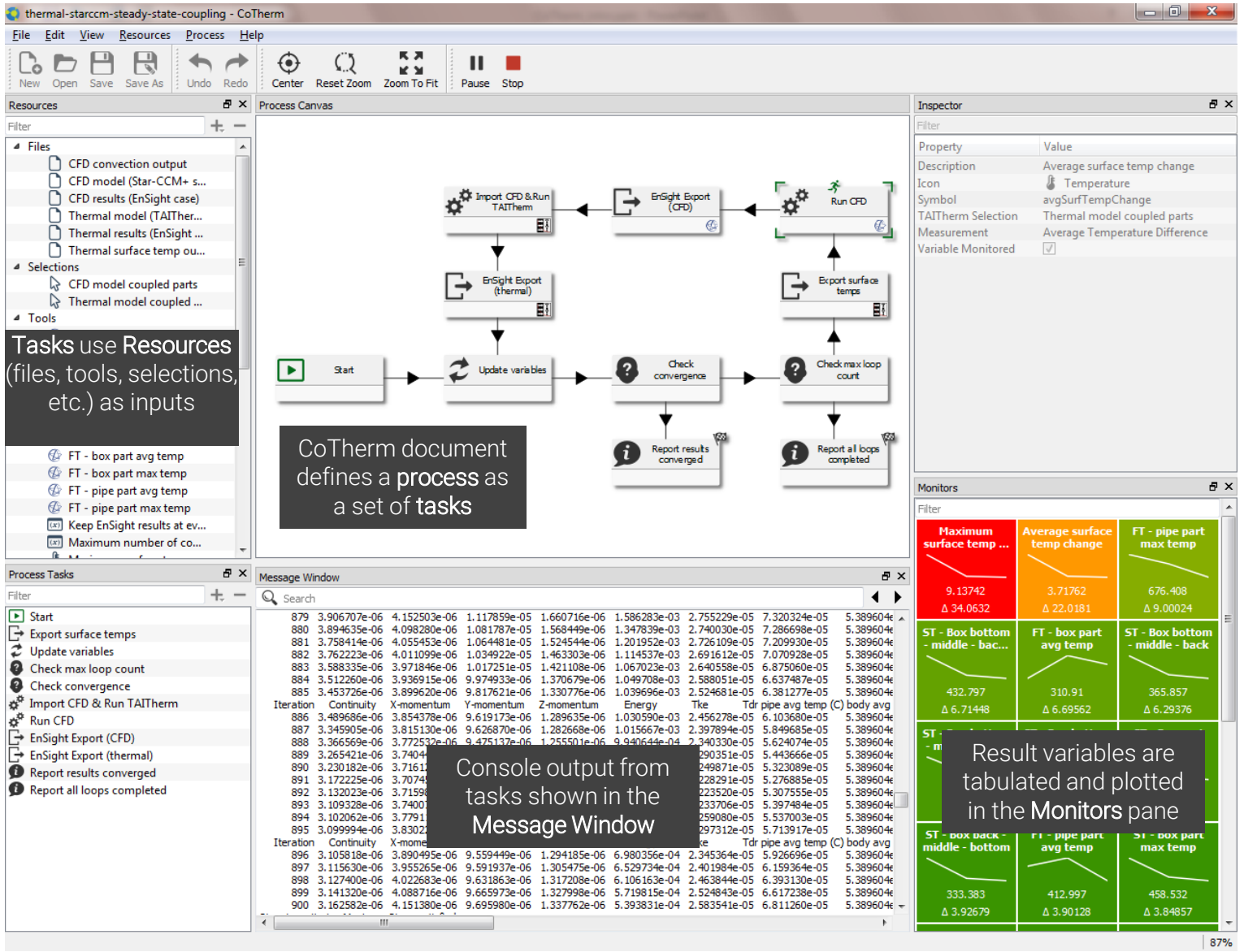
U elements

T elements

Structural Model

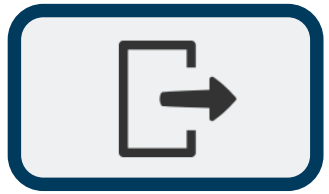


Coupling Tool

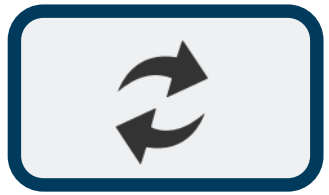


Run a command

Make a decision



Import/Export Data



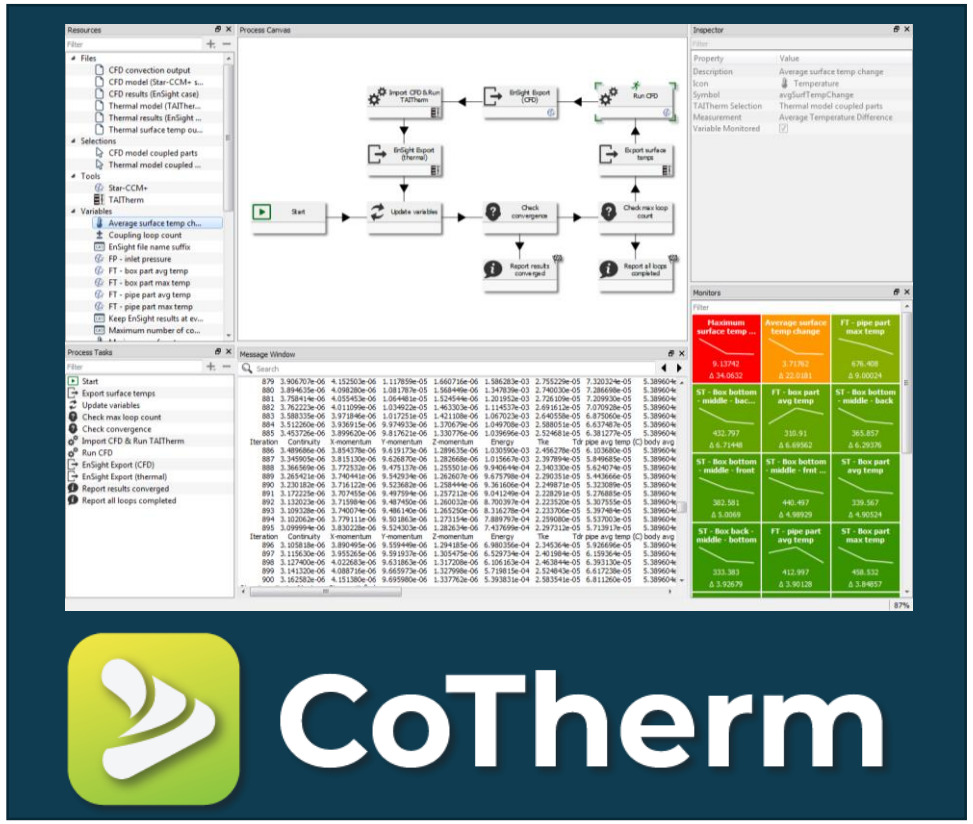
Update data

Message

And Much More

- Couple multiple tools
- Visual Scripting
- Real Time Monitoring

- Sub-Processes
- Parallel Tasks
- Python Journals
- External Macros
- CFD Model Scanning
- Built-in Optimizer



STAR-CCM+®

ANSYS® FLUENT®

OpenFOAM

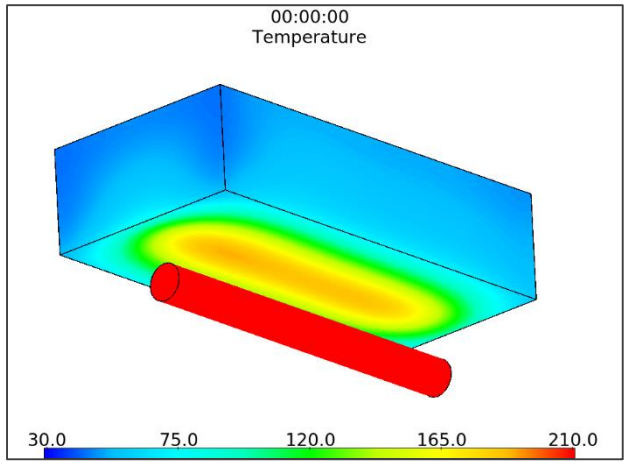
SIMULIA POWERFLOW

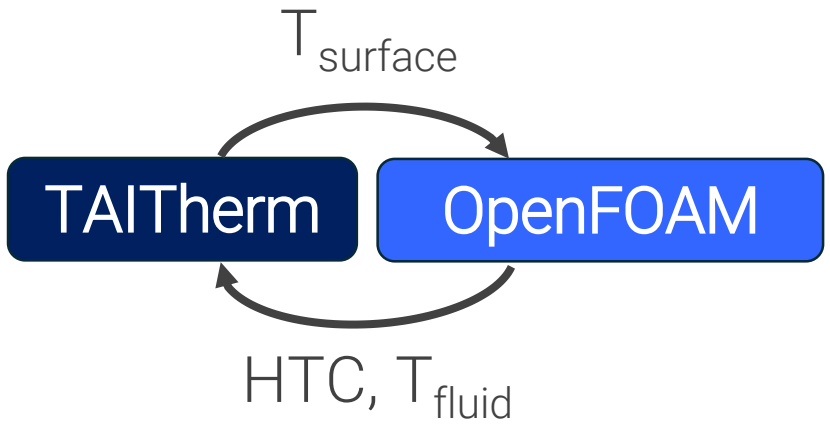
PreonLab

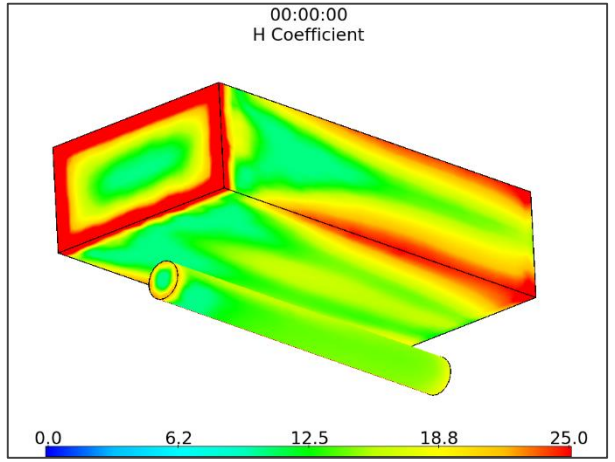
MATLAB

GT-SUITE

OpenFOAM Coupling Process Overview







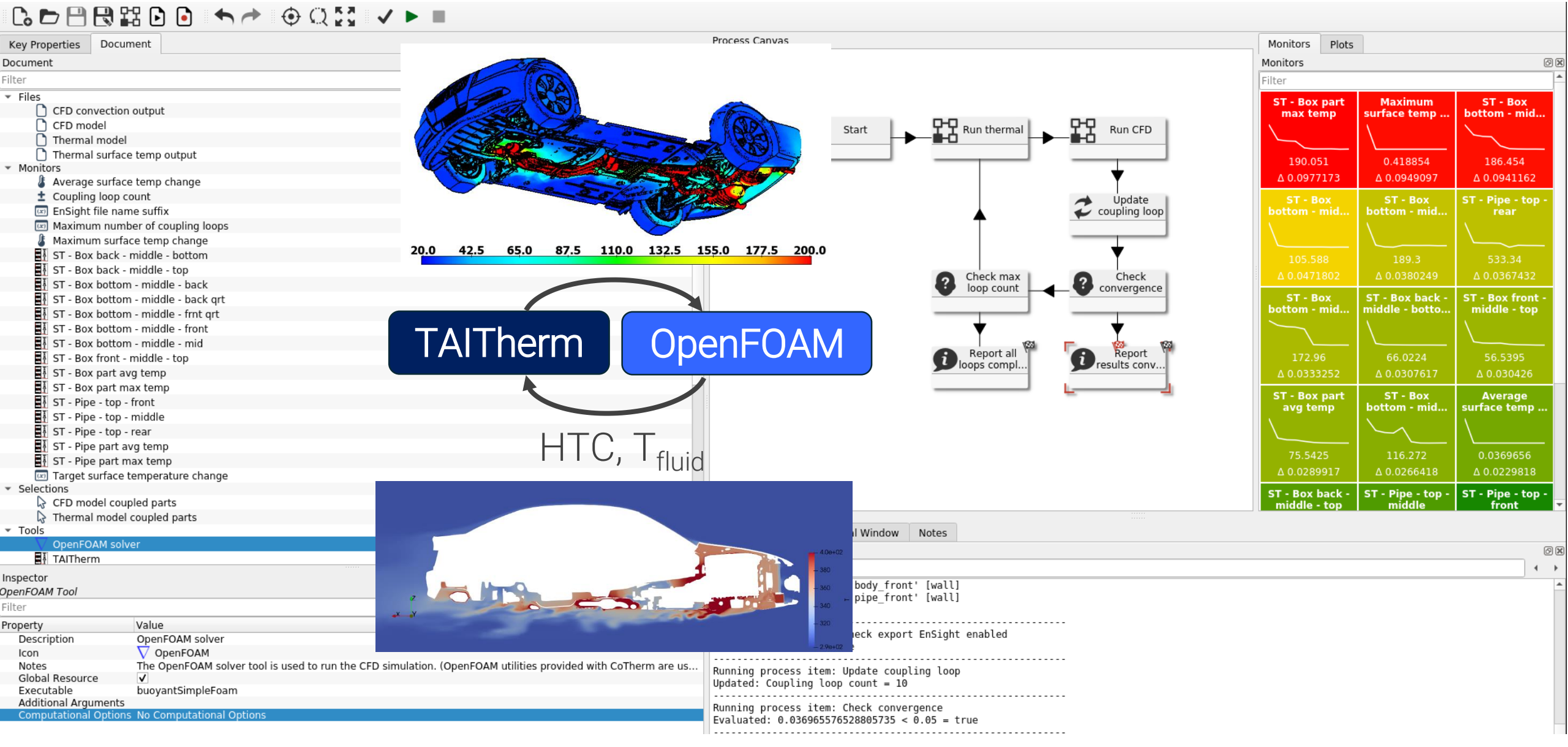
Readily Available Coupling Processes depending on Applications

- Steady to steady
- Steady to transient
- Transient to transient

Thermal Management Applications

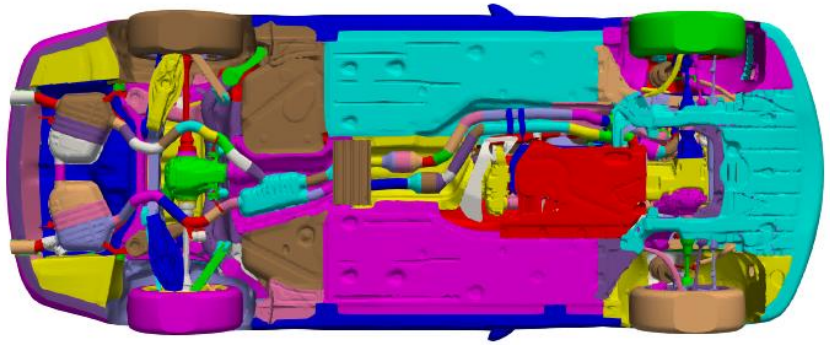
Underhood Thermal Protection

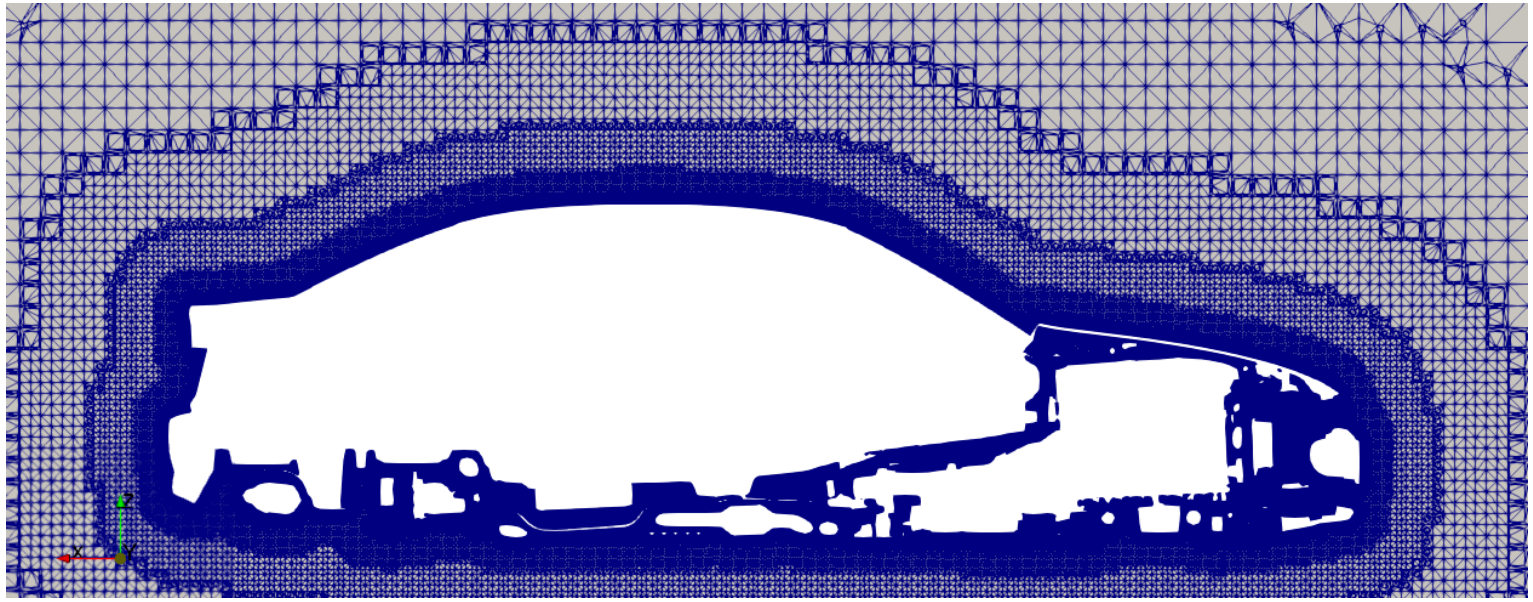
Coupling with OpenFOAM



Underhood Thermal Protection OpenFOAM Geometry

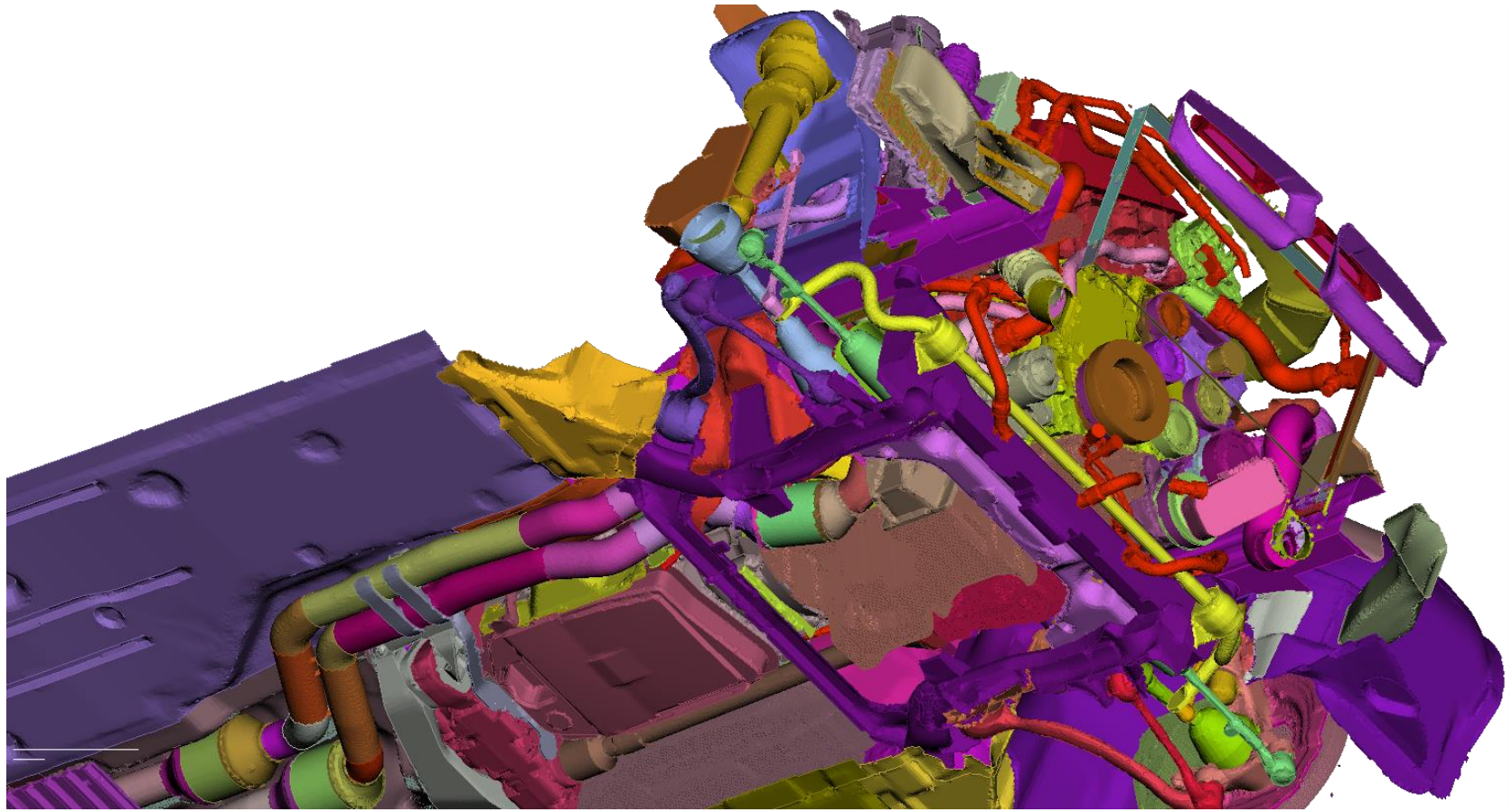
- Full underhood geometry is meshed in SnappyHexMesh
- 64GB machine
- 12 hours machine time
- Elements
  - 19M Volume
  - 6M Surface
- Underhood cell size:
  - 5mm





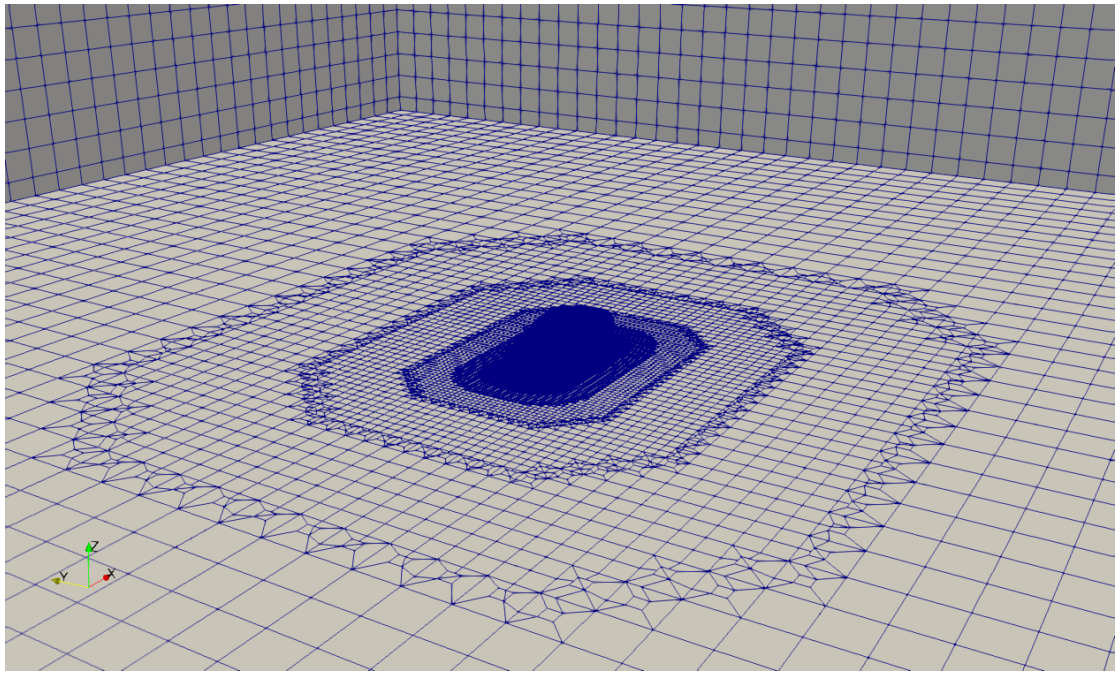
Underhood Thermal Protection
TAITherm Geometry

- The snappyHexMesh geometry can be used directly for simulation in TAITherm
- Elements
  - 3.5M Triangles



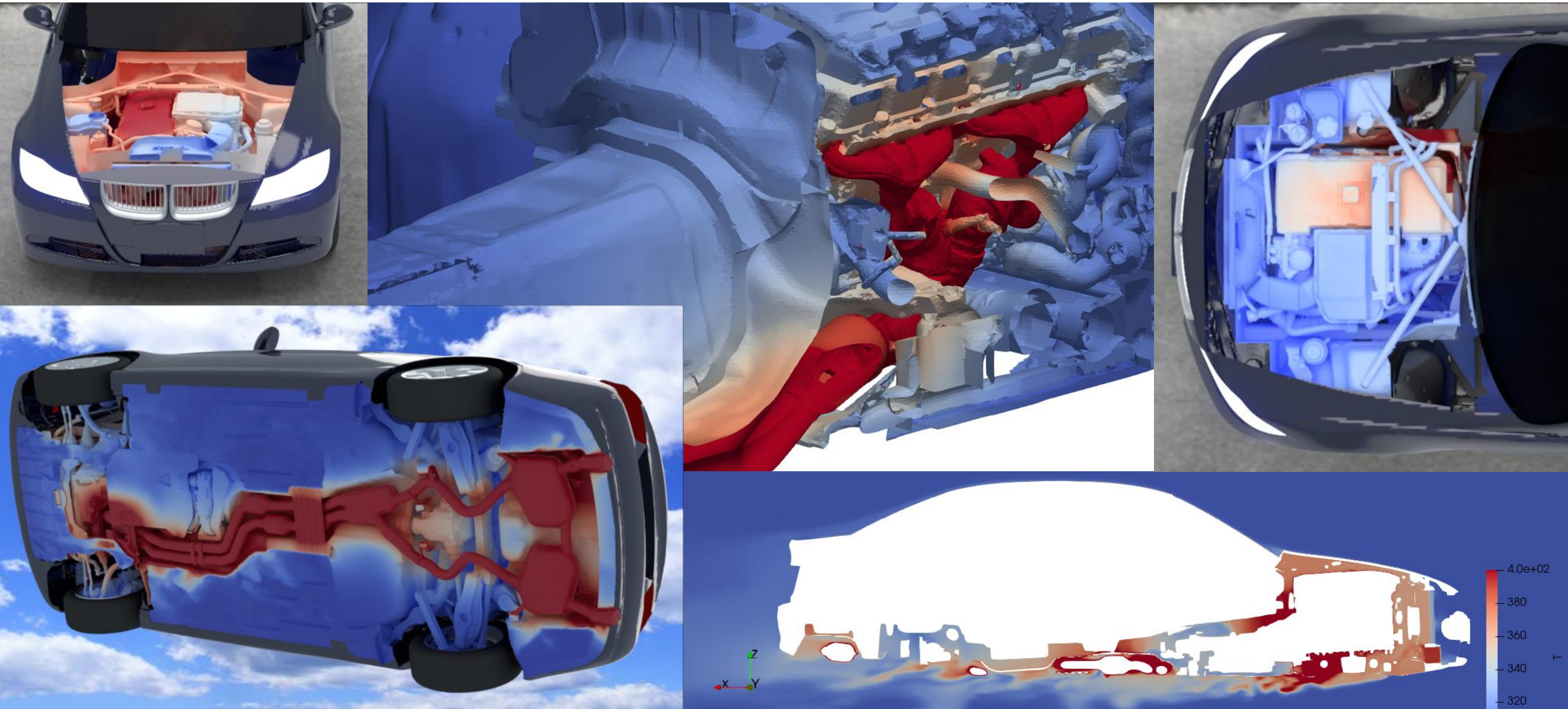
Underhood Thermal Protection
OpenFOAM Set-up

- Mountain uphill towing case
- 35 kph, 27°C
- MRF: Fan, Wheels
- PM with heat release:
  - Radiator, CAC, Condensor
- Steady State
- Turbulence Model RAS k-**ε**
- TAITherm Exhaust Model



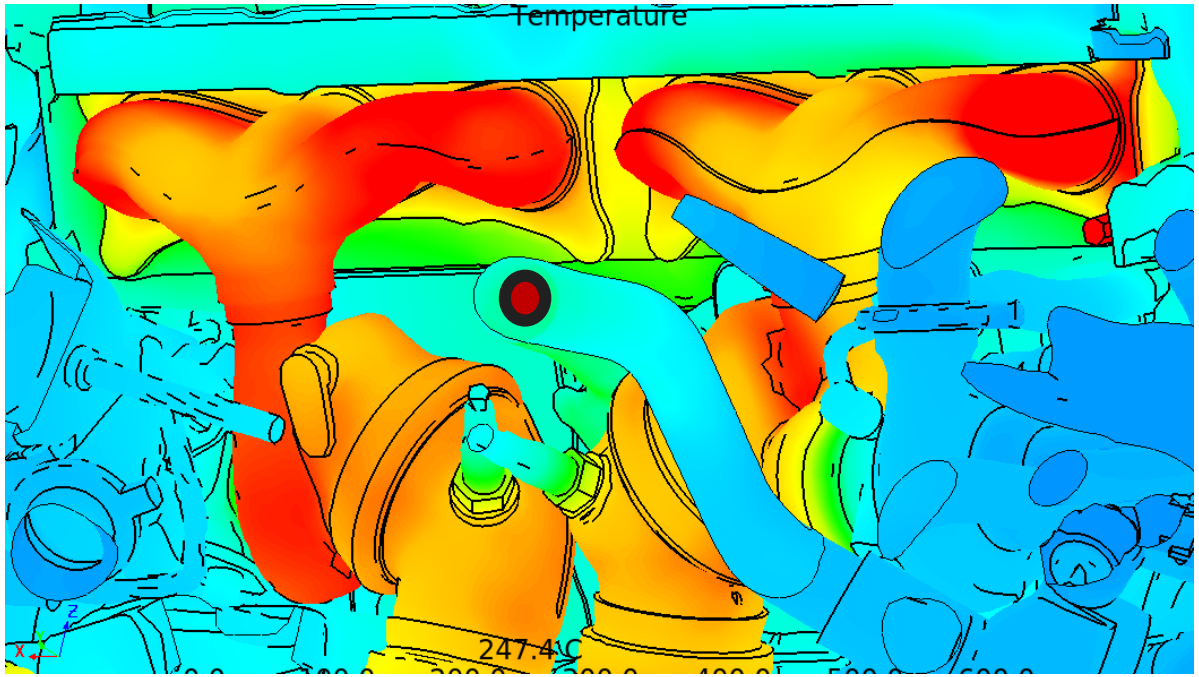
- Runtime (coupled simulation):
  5000 iterations in 24h on 20 procs (480 CPU-h)

Underhood Thermal Protection Results

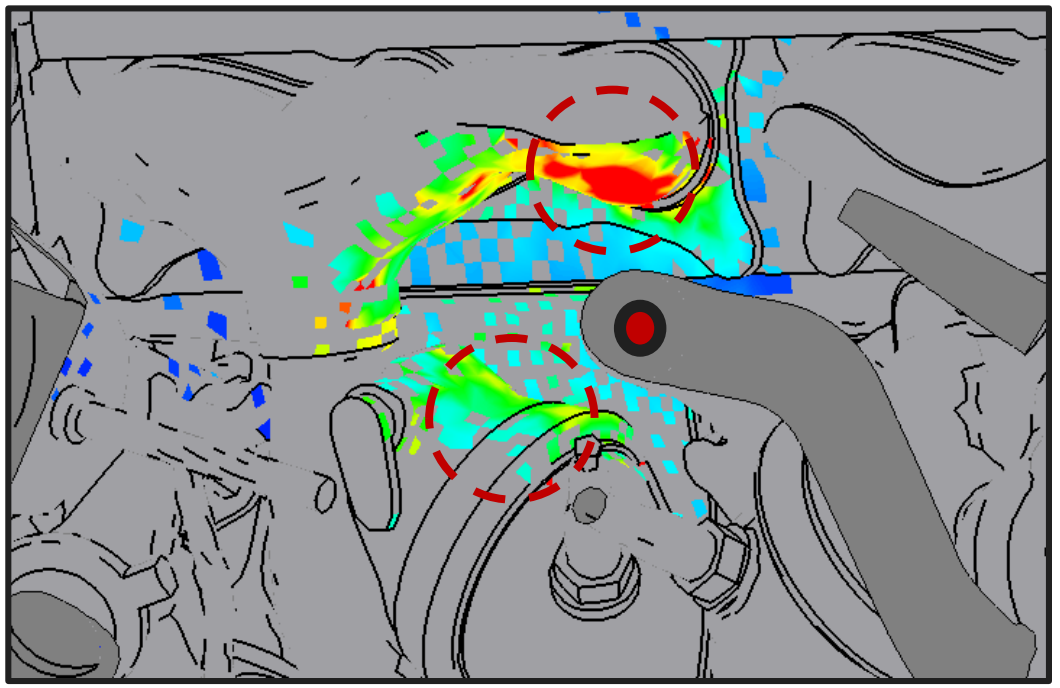


Underhood Thermal Protection Results

Temperature



Incoming radiation

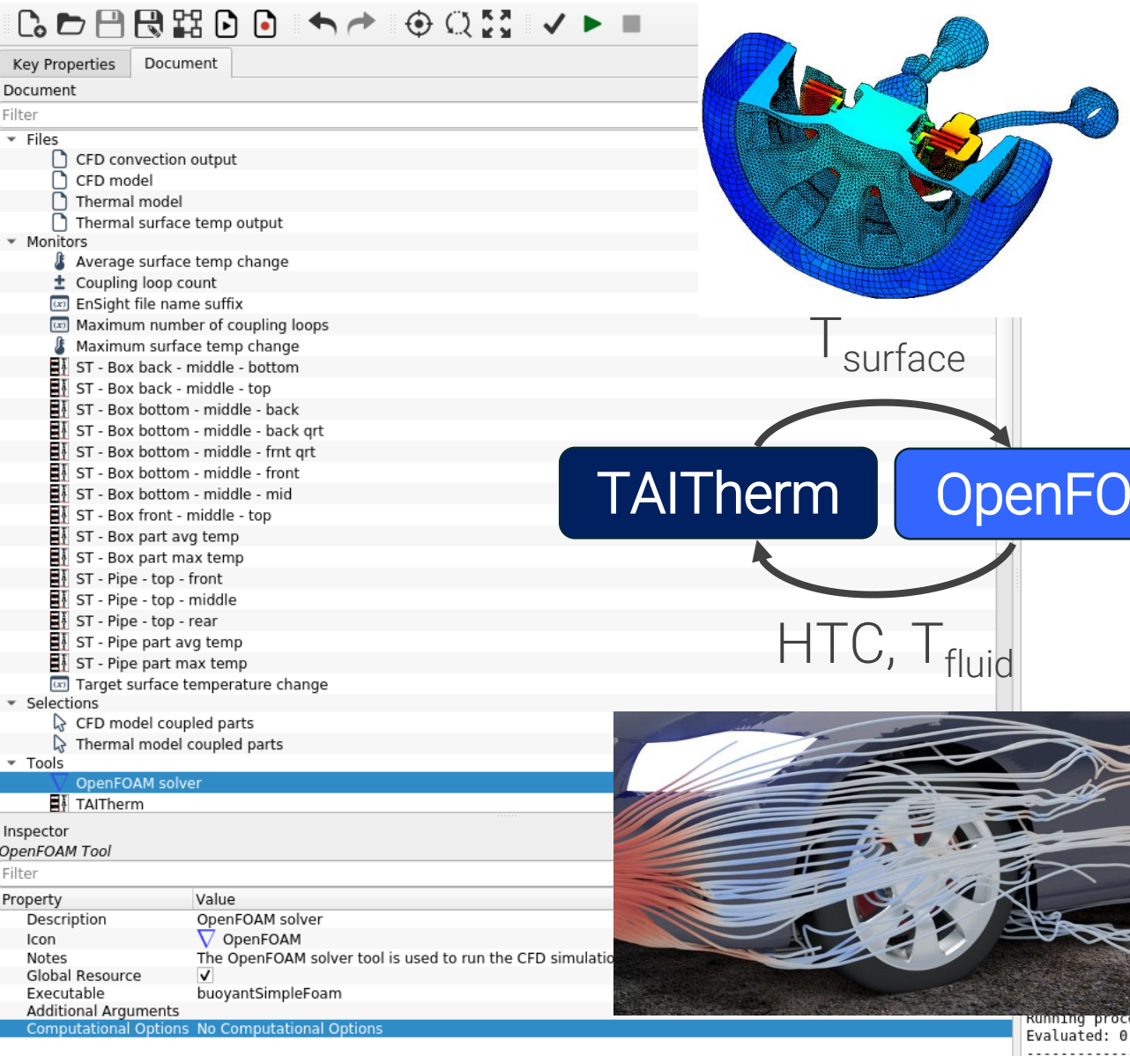


Heat Rate Flux (W/m²)

	Incident	Outgoing	Net
Q Conduction	2.01996	2099.65	-2097.63
Q Convection	0	8224.65	-8224.65
Q Radiation	16056.7	5734.38	10322.3

Brake Cooling

Coupling with OpenFOAM

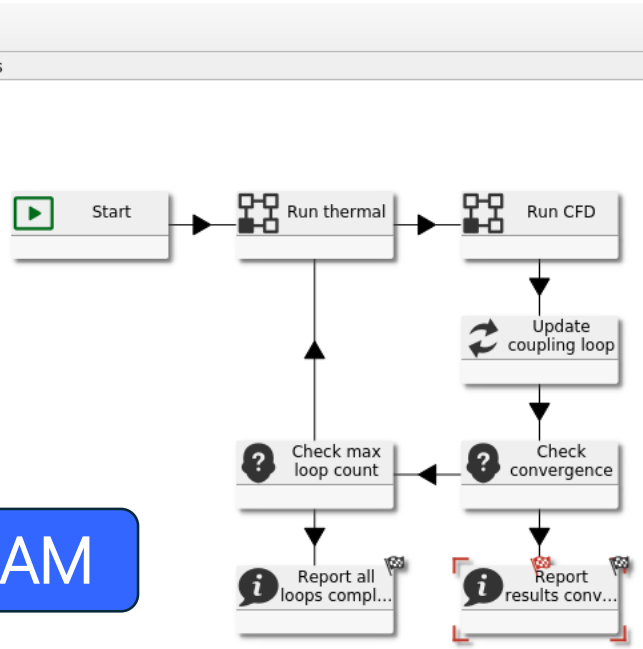


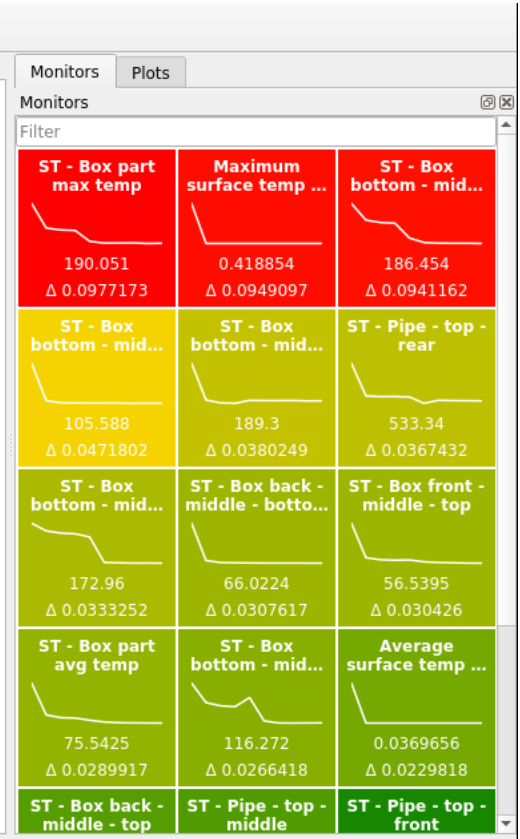
$T_{surface}$

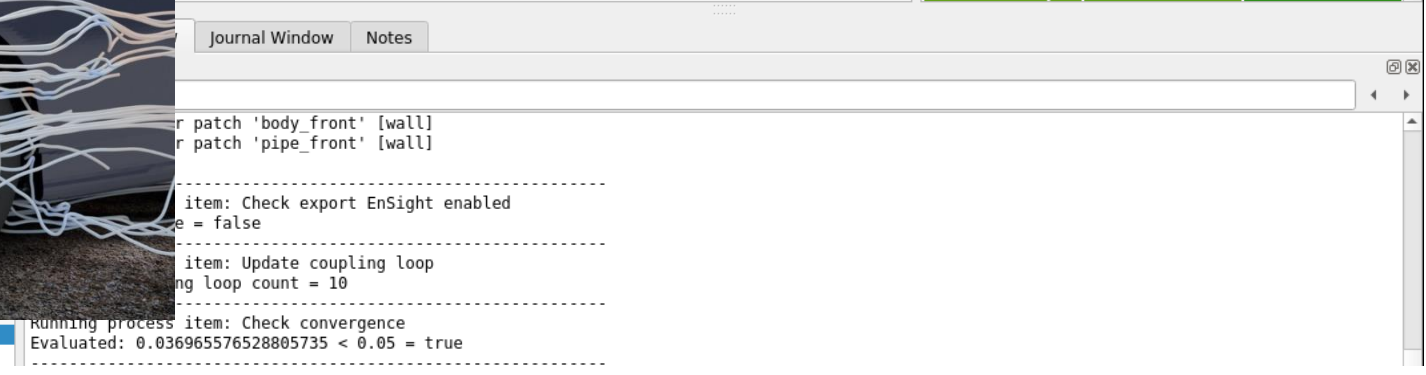
TAITherm

OpenFOAM

HTC, T_{fluid}

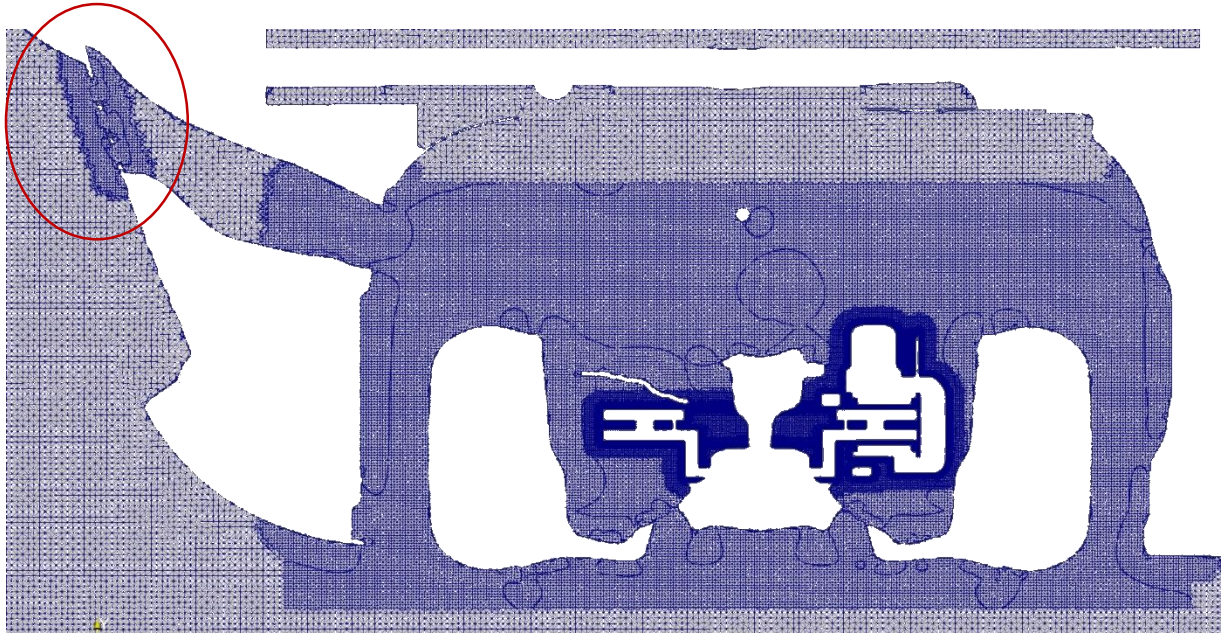


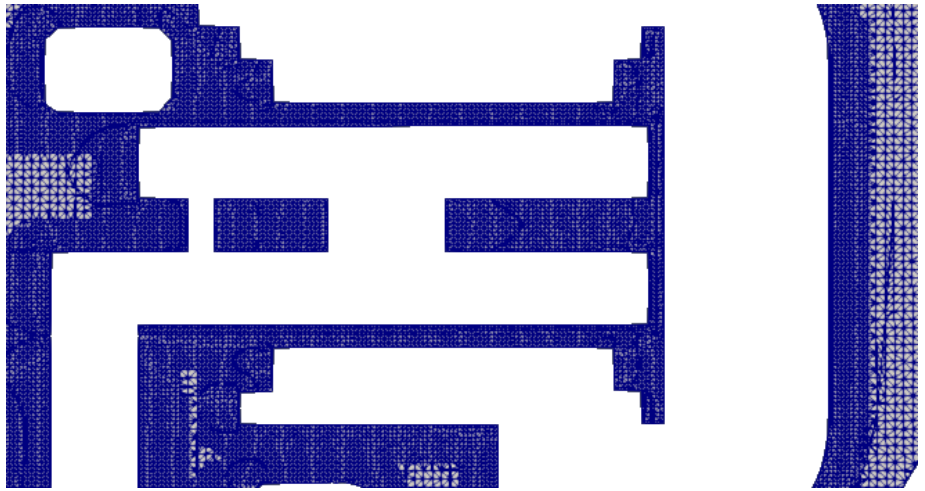




Brake Cooling
OpenFOAM Geometry

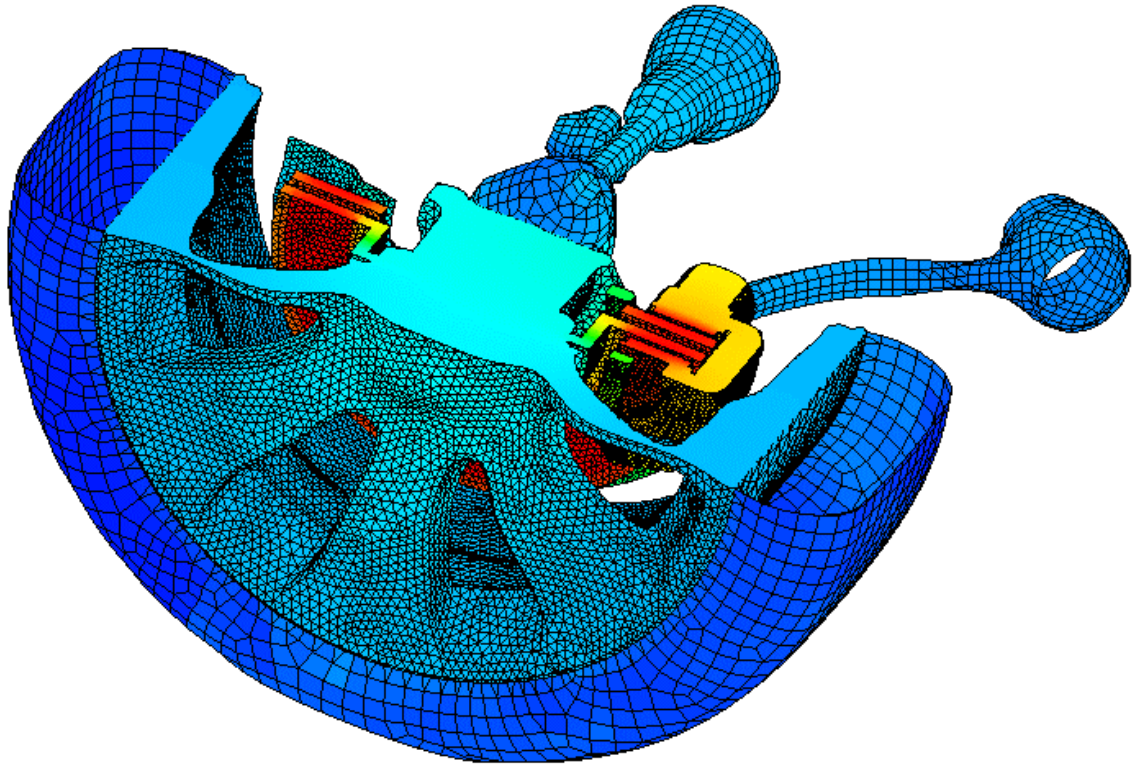
- Symmetry plane
- Meshed in SnappyHexMesh
- 64GB machine
- 8 hours machine time
- Elements
  - 29M Volume
  - 4M Surface
- Brake disc cellsize:
  - 1mm





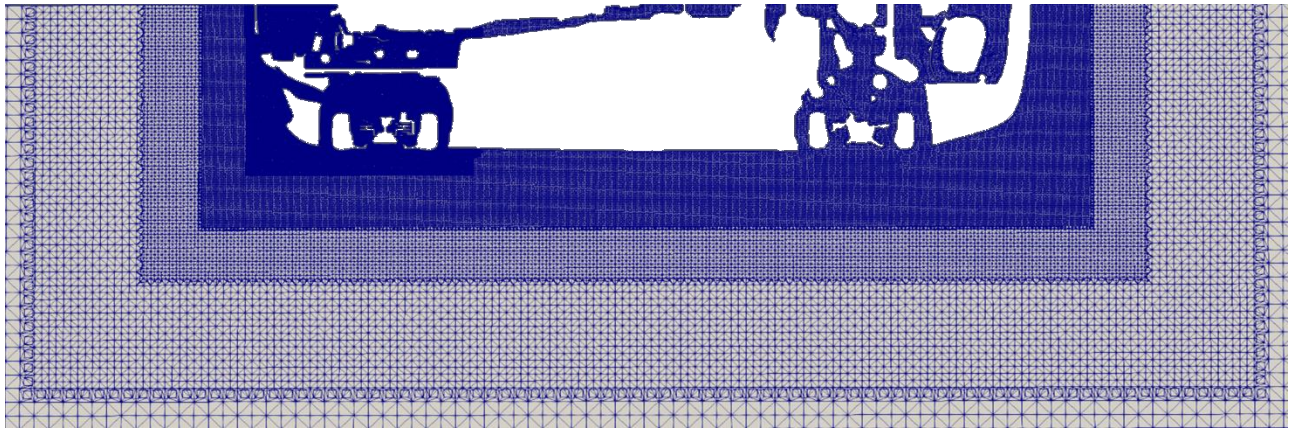
Brake Cooling
TAITherm Geometry

- The Brake System is meshed with volume elements
- This represents the conduction accurately
- Elements
  - 0.7M Volume
  - 0.1M Surface



Brake Cooling
OpenFOAM Set-up

- Brake duct
- 100 kph, 20°C
- MRF: Brake, Wheels
- Steady State
- Turbulence Model RAS k-**ε**



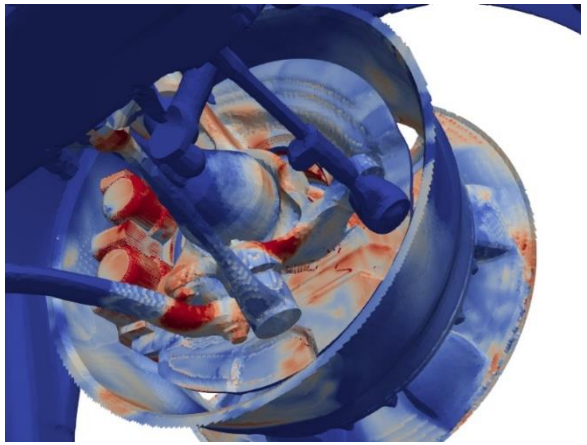
- Runtime (coupled simulation):
  - 4000 iterations in 22h on 20 procs (440 CPU-h)

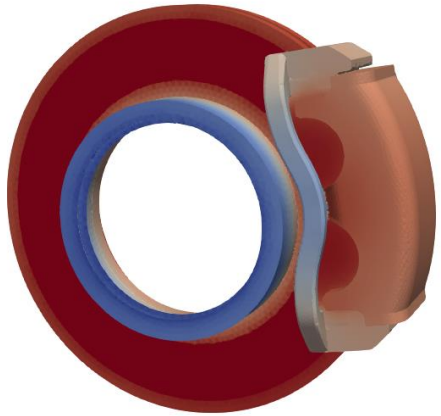
Brake Cooling Results

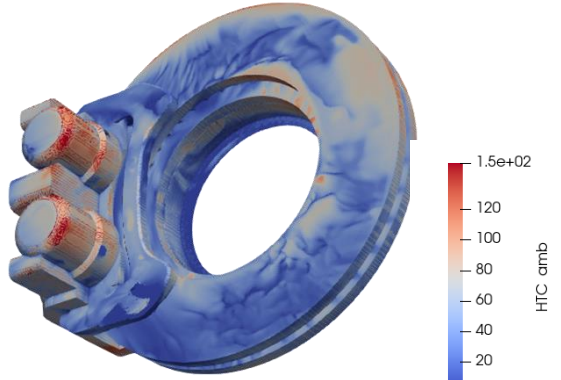
The duct is providing cooling air to the brake system

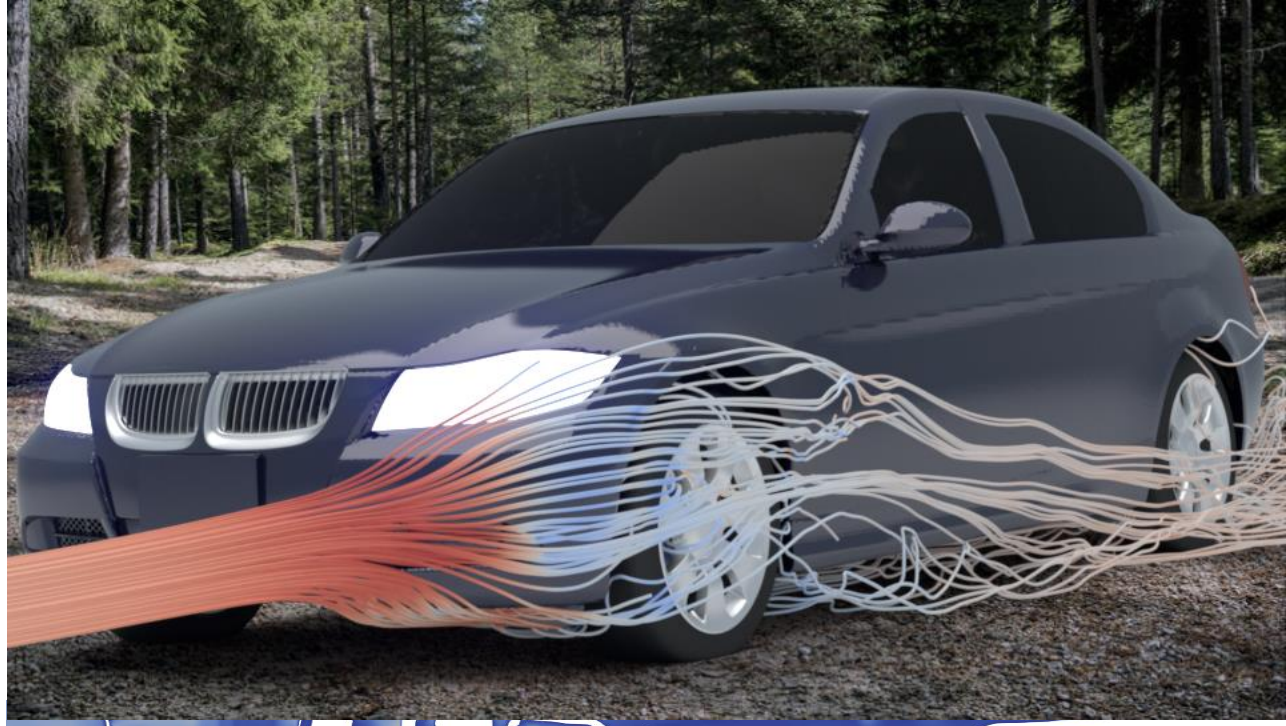
Surface T

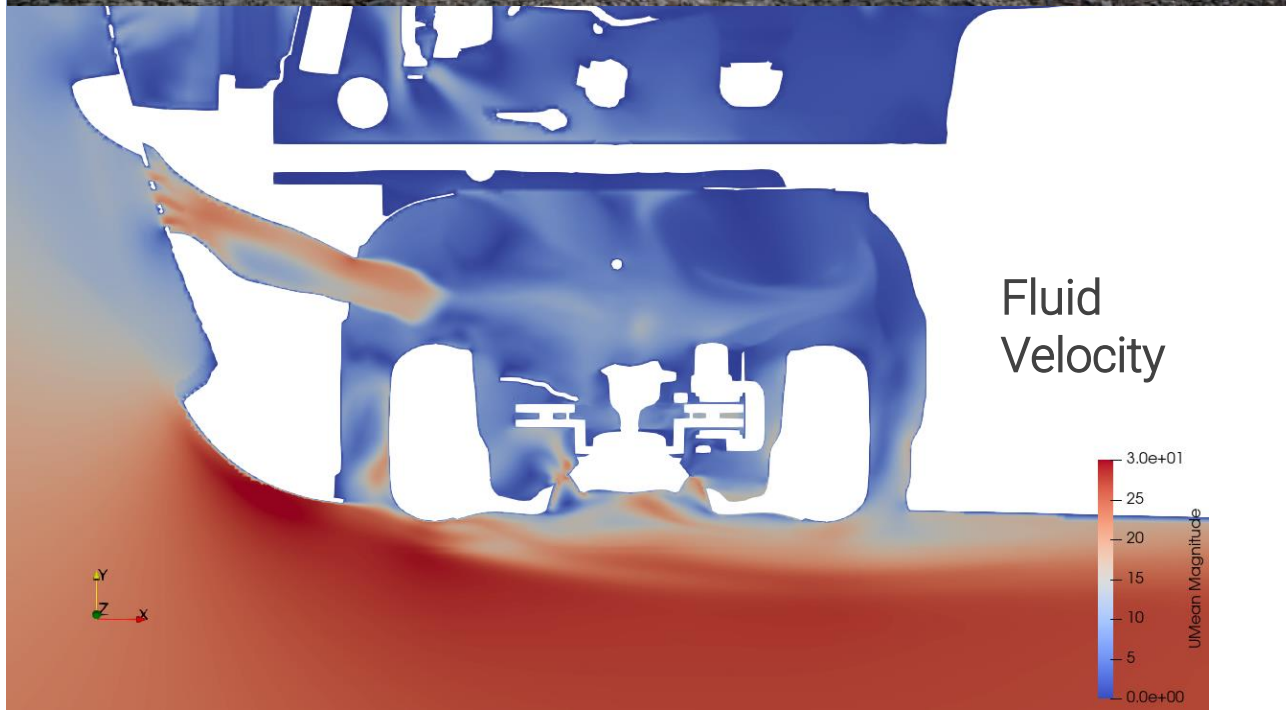
Surface HTC



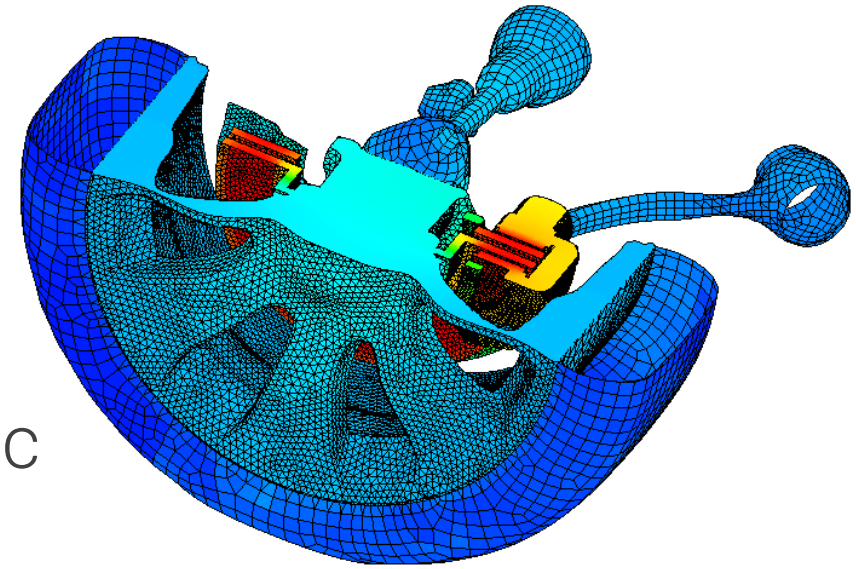






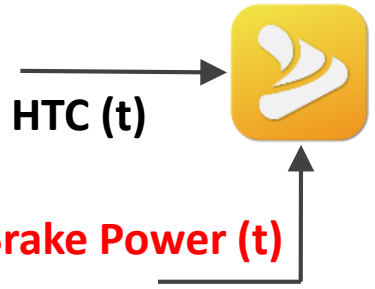


Brake Cooling
Braking Cycle Example

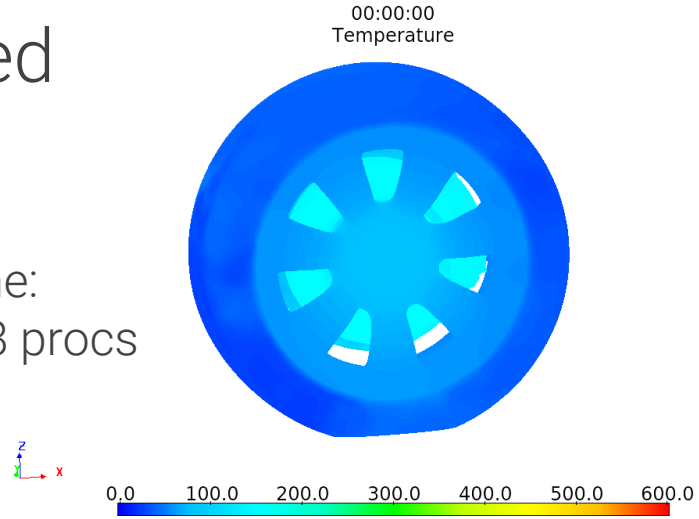


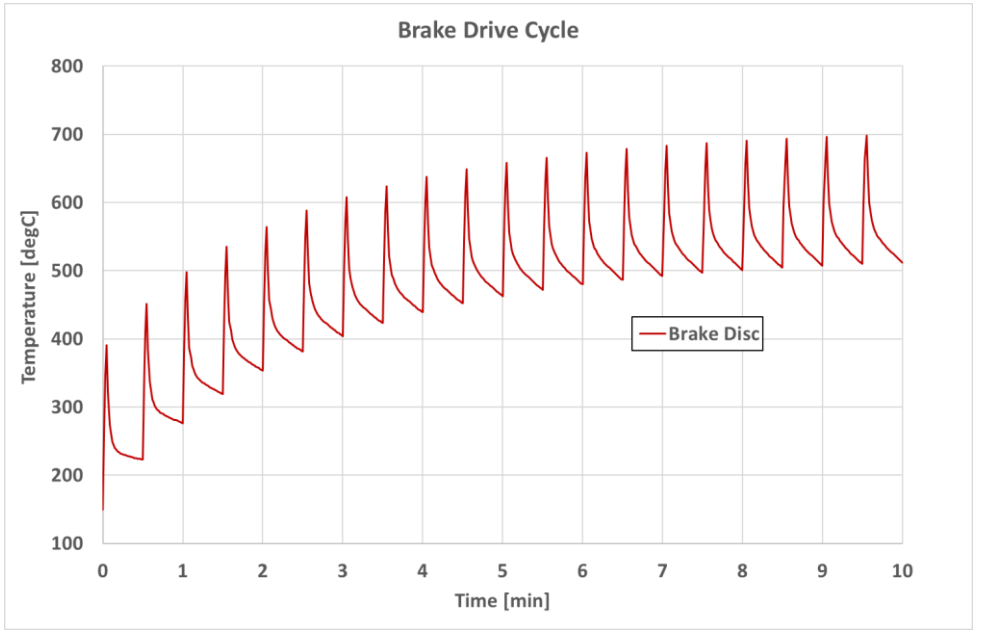
- TAITherm Stand-alone
- Brake from 100km/h to 0km/h in 5 sec
- Accelerate from 0km/h to 100km/h in 25 sec
- Repeat 20 times
- HTC‘s from CFD linearly interpolated with vehicle speed

Brake disc duty cycle (t)



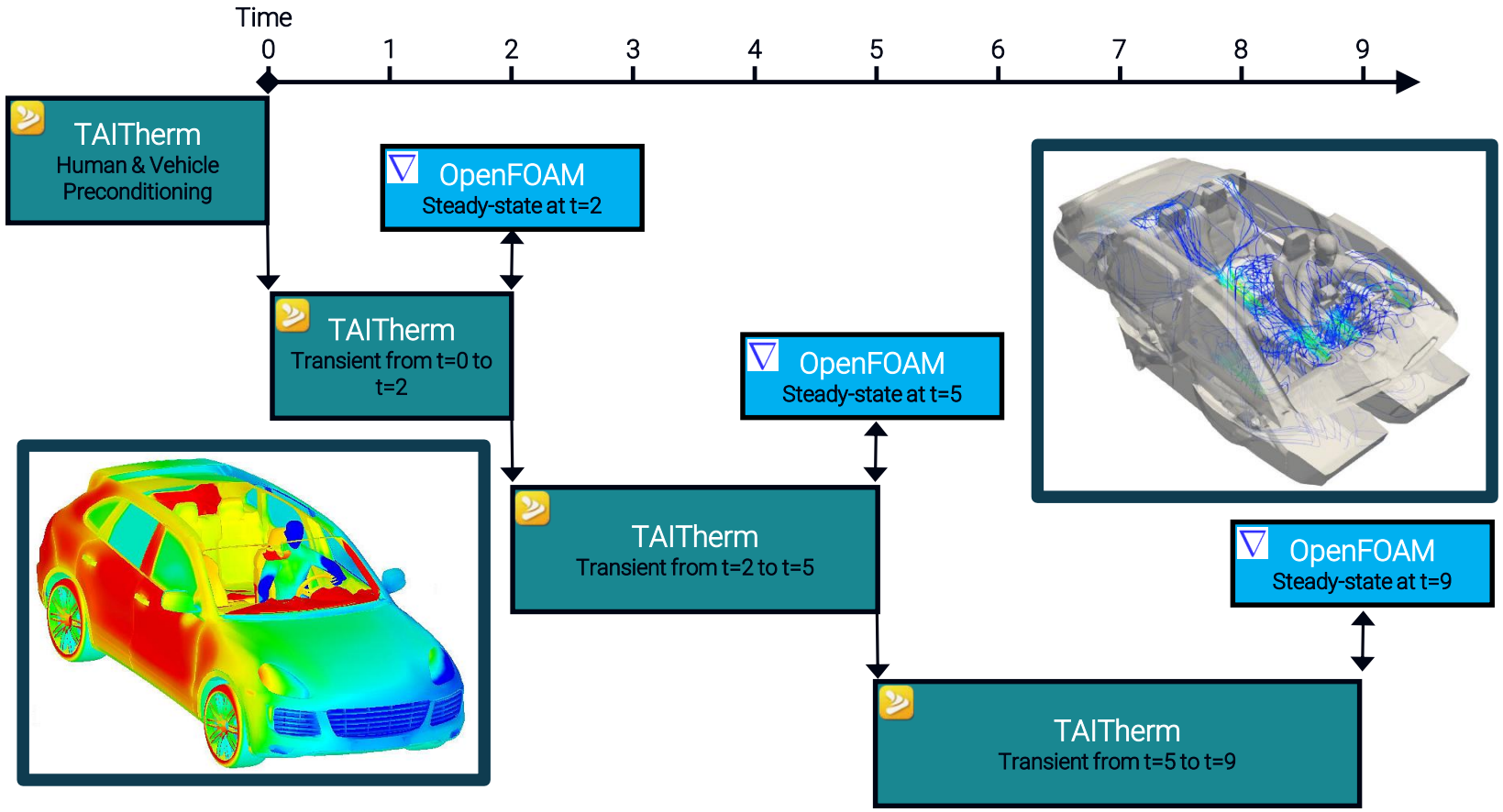
Runtime:
8h on 8 procs





Cabin Cooling

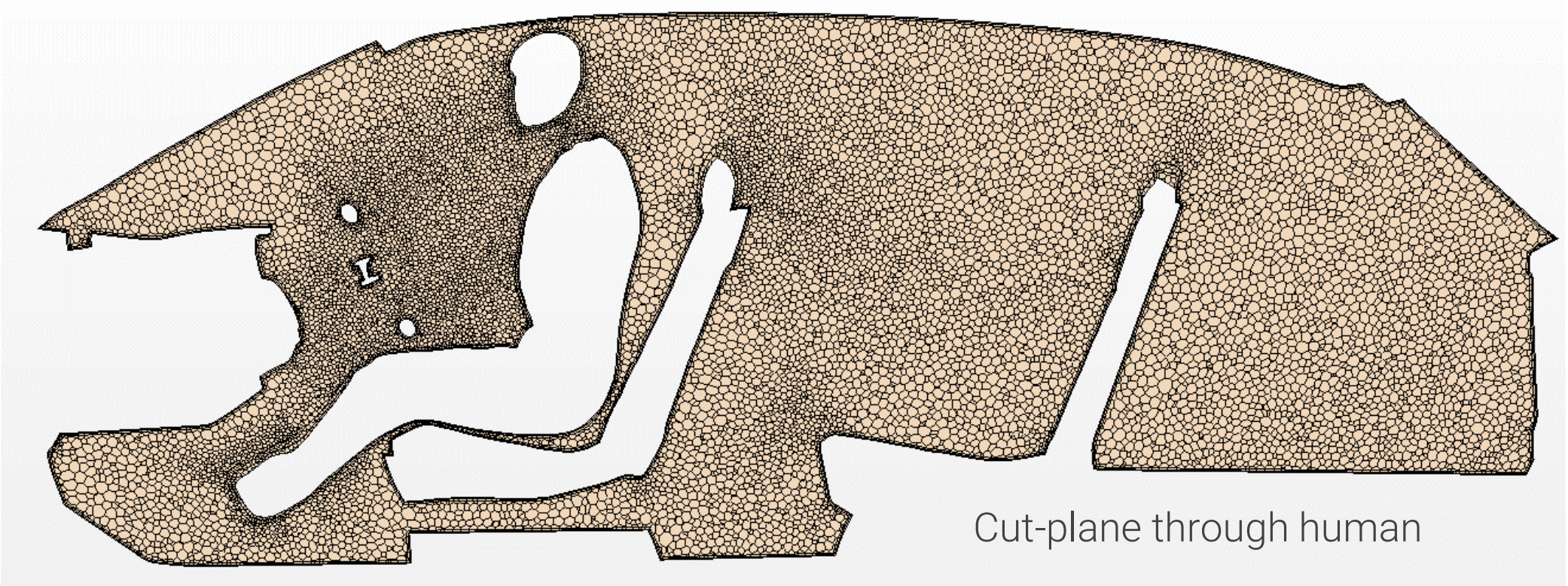
Pseudo-Transient Coupling with OpenFOAM



AC-Cooldown Coupling Points	
Index	**Time**
1	5 s
2	1 min
3	4 min
4	9 min
5	15 min
6	30 min

Cabin Cooling
OpenFOAM Geometry

- Polyhedral mesh
  - Base size: 20 mm
  - Min size: 5 mm
- Boundary layer thickness: 6 mm
- 1,944,323 cells



Cut-plane through human

Cabin Cooling
Set-up AC Cooldown, base case scenario

- Vehicle preconditioning – Hot Soak
  - Natural weather: Phoenix, Arizona (8/16)
- Human preconditioning - Office
  - 2 hours transient in office setting (25 ºC)
- 30 minute AC cooldown (10:30-11:00 AM)
  - Constant vehicle speed = 50 mph
  - Vehicle heading: 0º North
  - Max AC cooldown
    - Air inlet temperature = 7 ºC
    - Total mass flow = .25 kg/s
      - 4 dash vents
      - 2 rear console vents

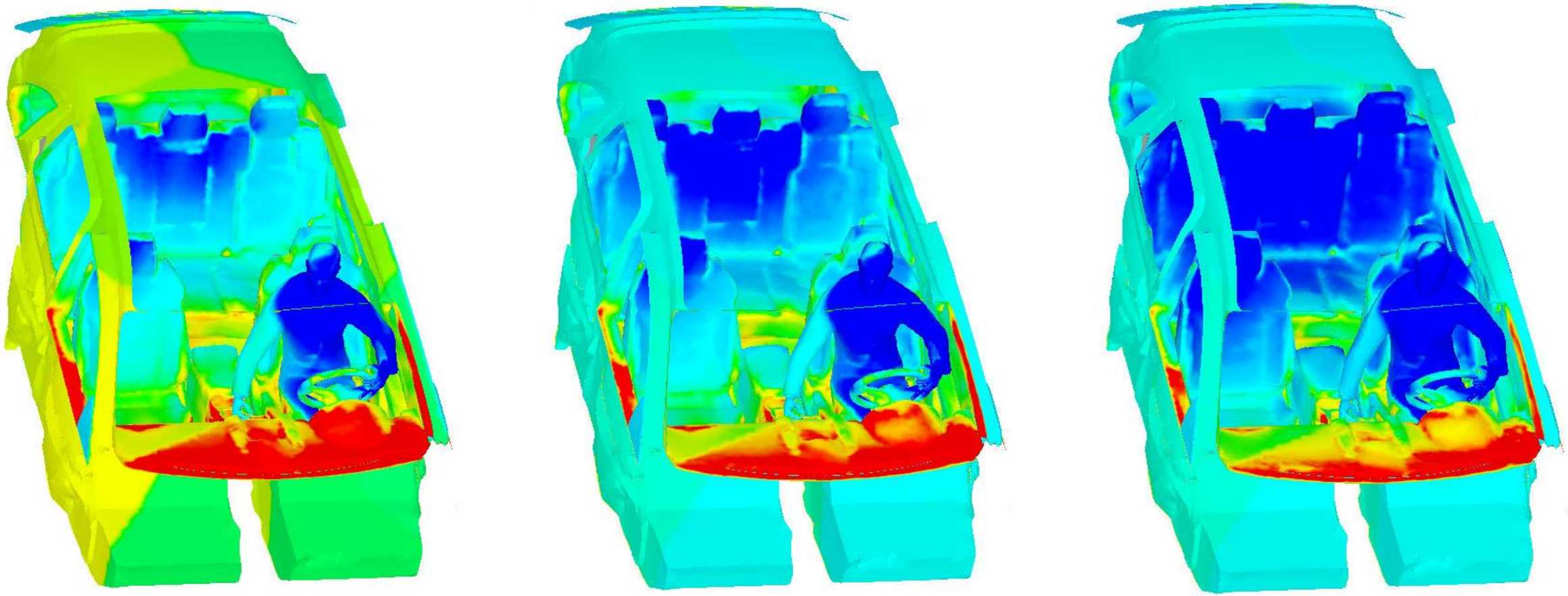
Geometry TAITherm

Cabin Cooling
Near wall air temperatures

10:31 AM – 1 minute

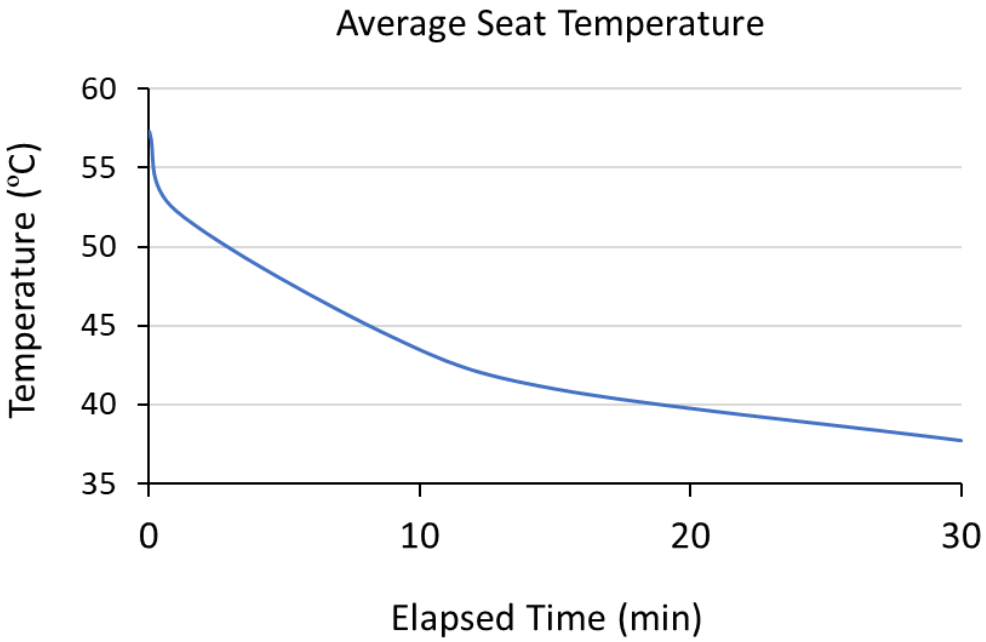
10:45 AM – 15 minutes

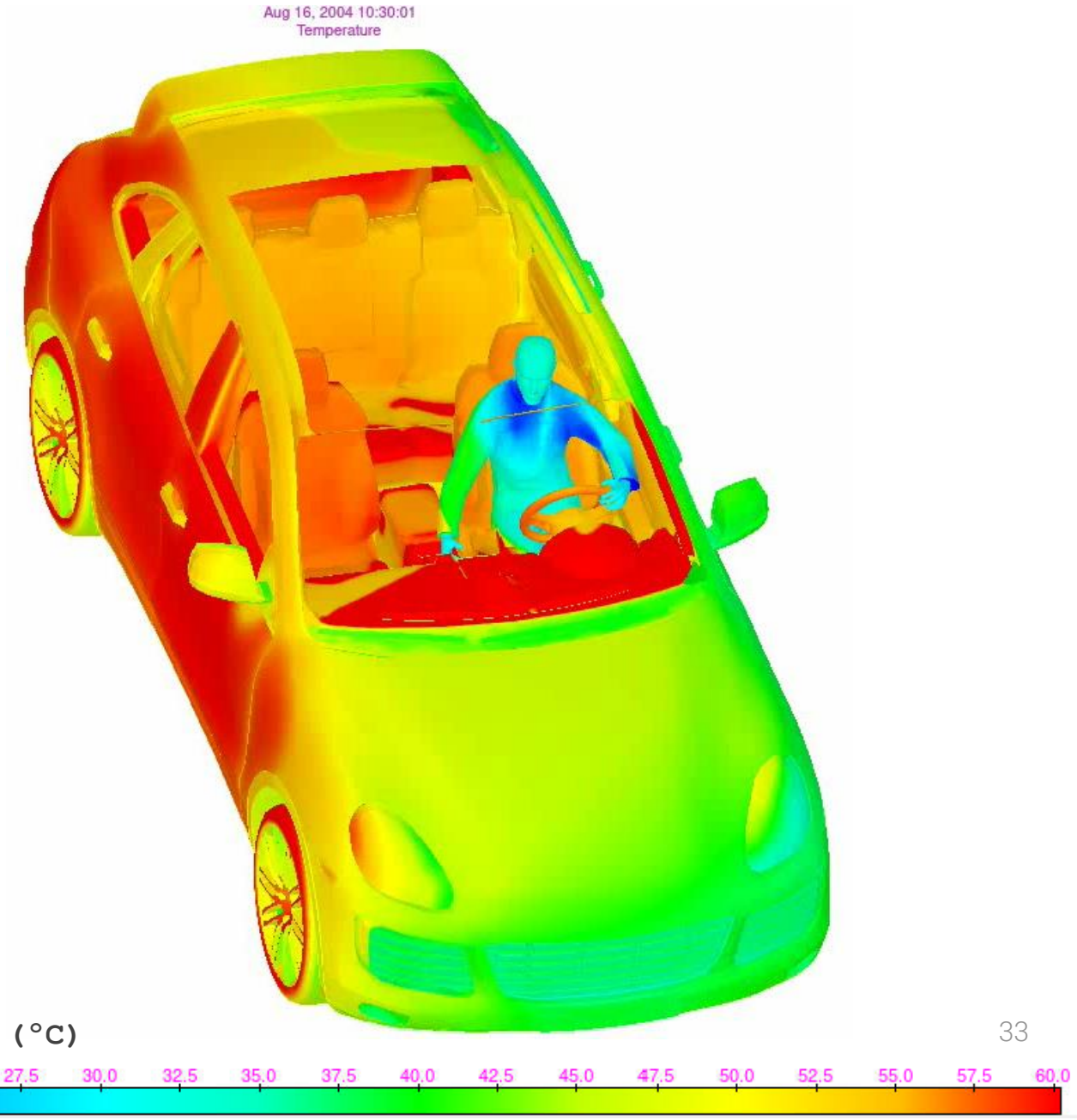
11:00 AM – 30 minutes



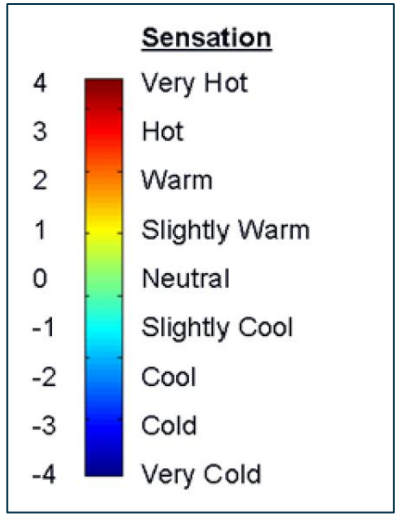
Temperature (°C)

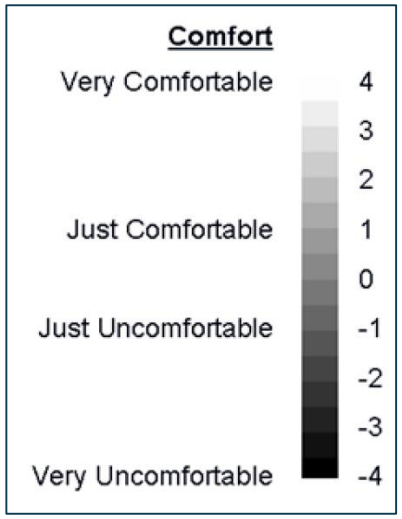
Cabin Cooling Surface Temperature

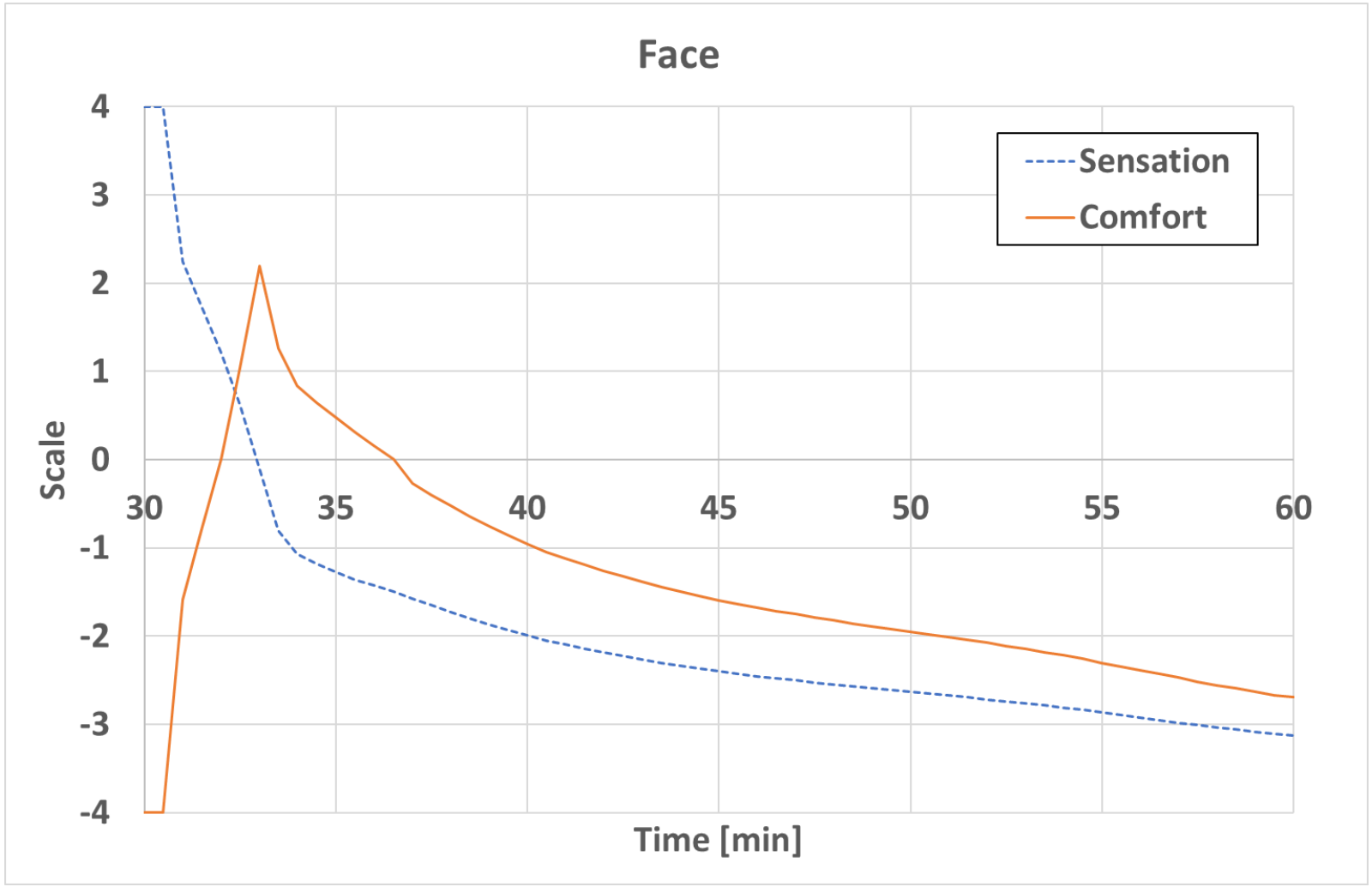




Cabin Cooling
Human Sensation & Comfort



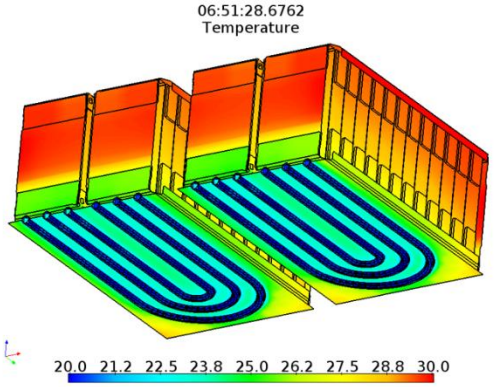


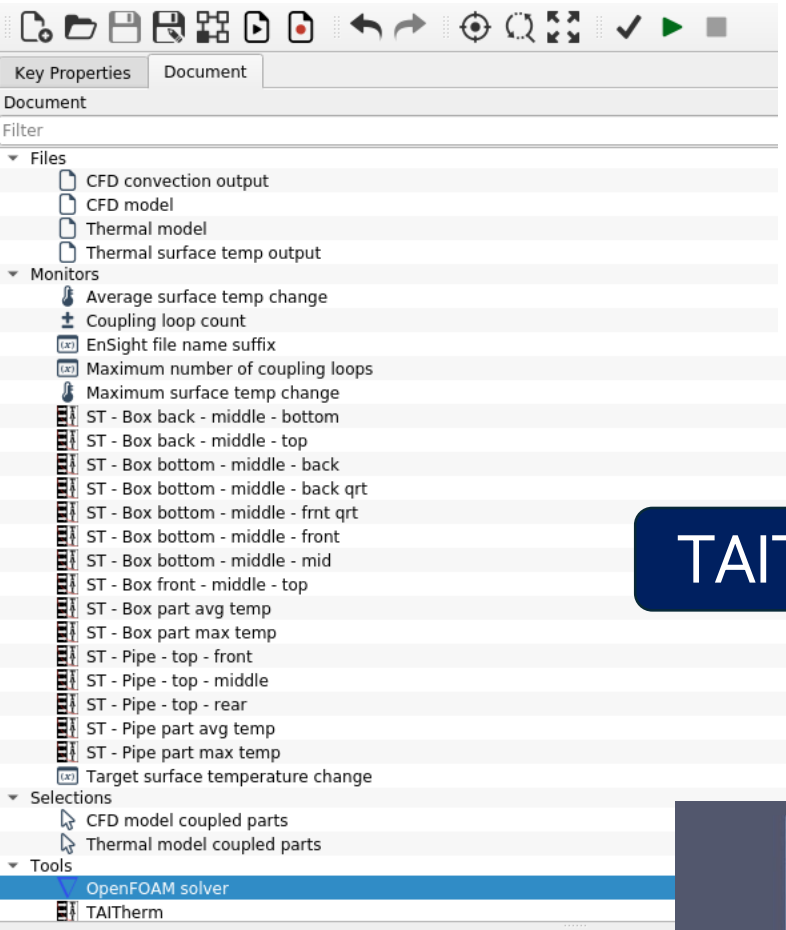


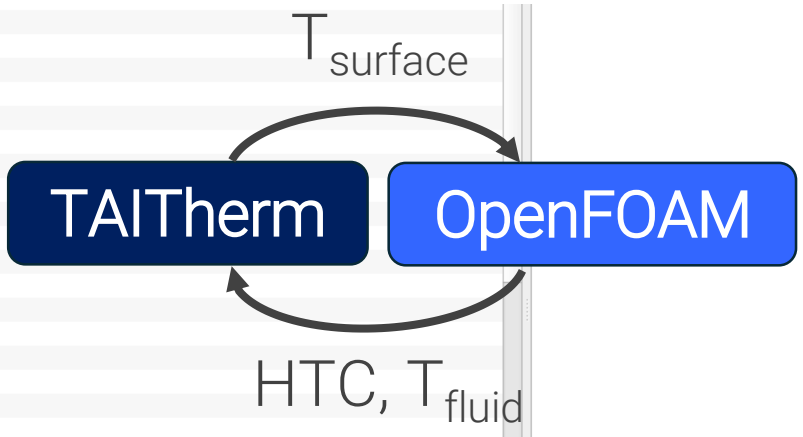
Berkeley Comfort & Sensation Scales [1]-[5]

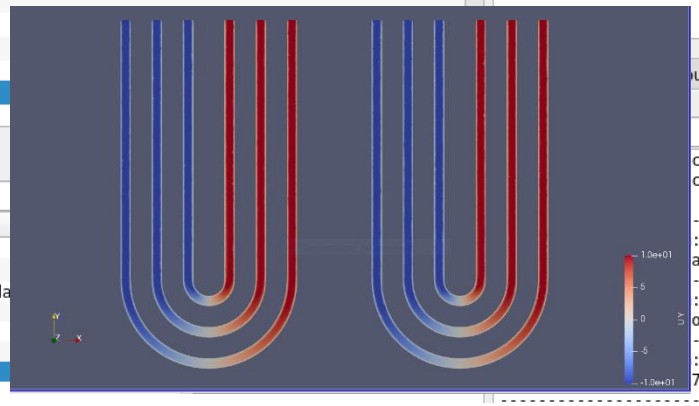
Battery Cooling

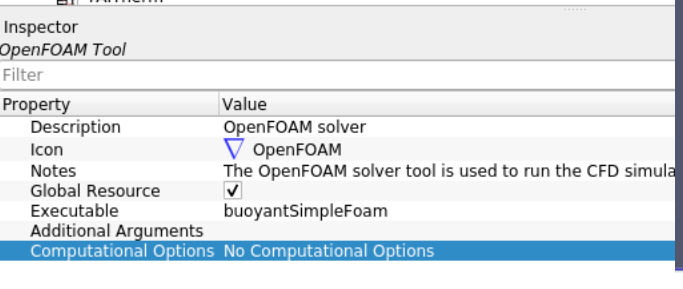
Coupling with OpenFOAM

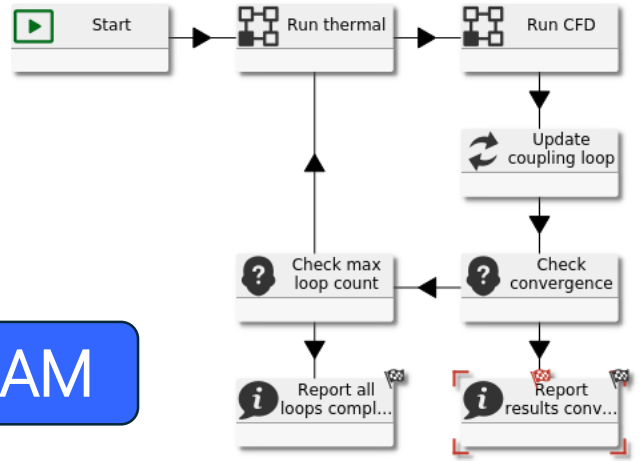


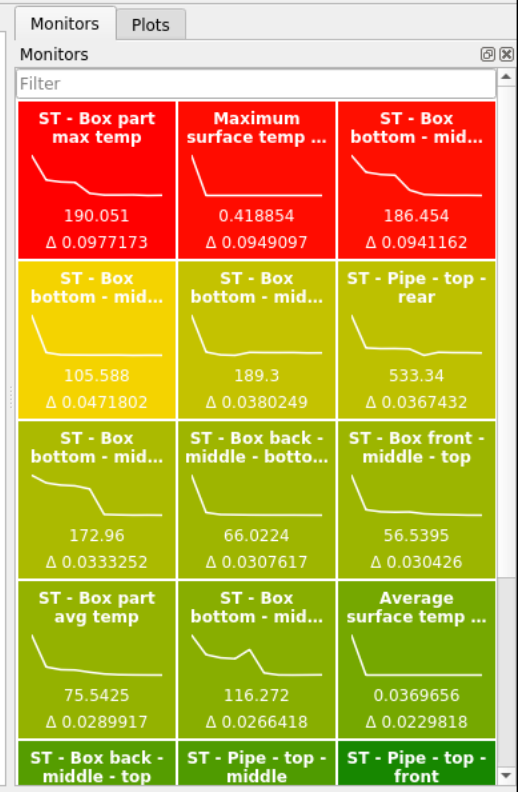


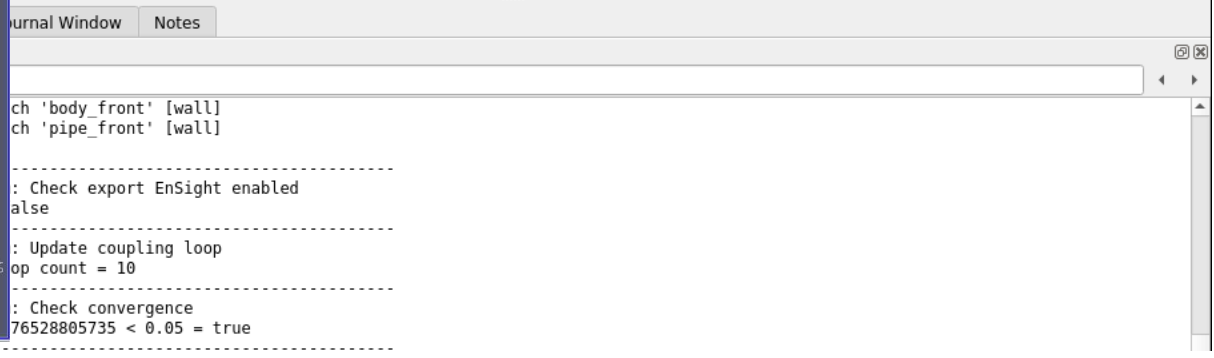






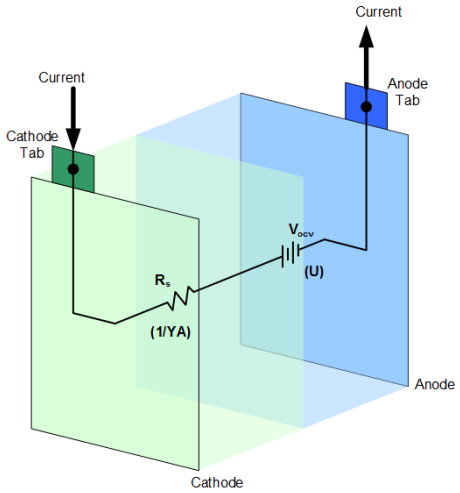




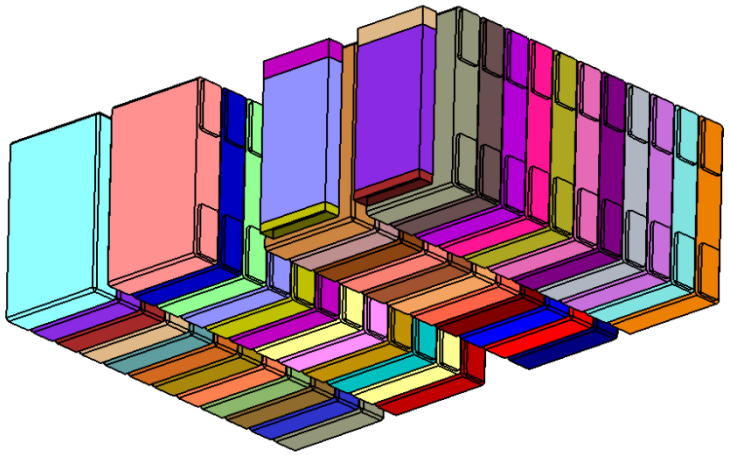


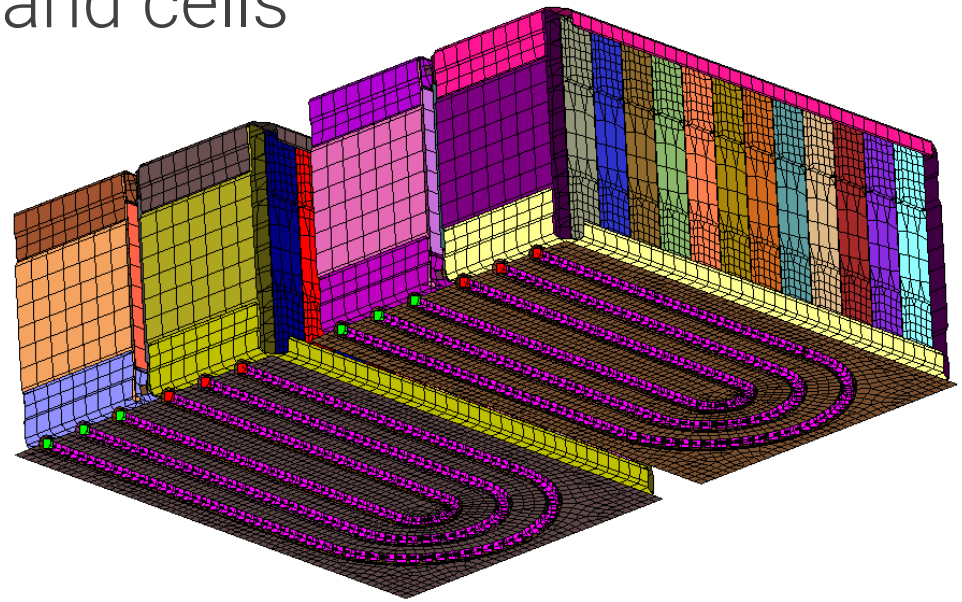
Battery Cooling Set-up

Battery Electrical Model
NTG Equivalent Circuit Model:



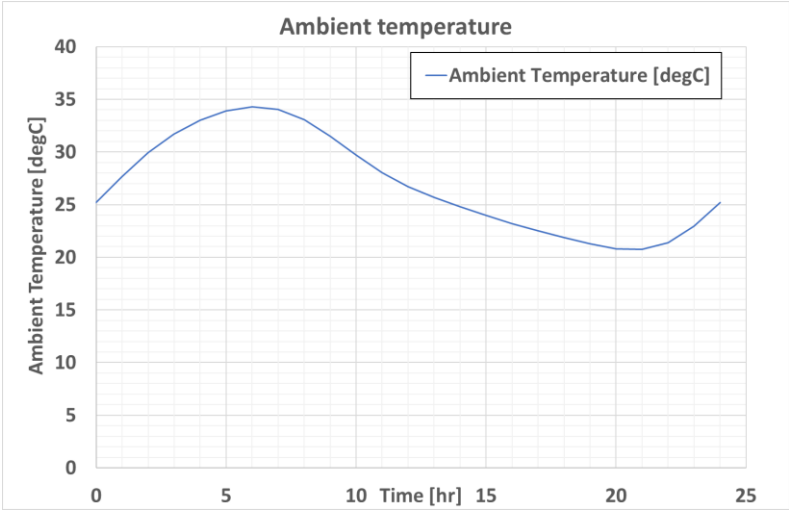
- Geometry and materials
  - 4P12S prismatic cells
  - Cell capacity 25.036 Amp-hrs
  - Cooling plate with U-Shape liquid cooling channels
  - TIM material between cooling plate and cells
  - Plastic cover and steel casing

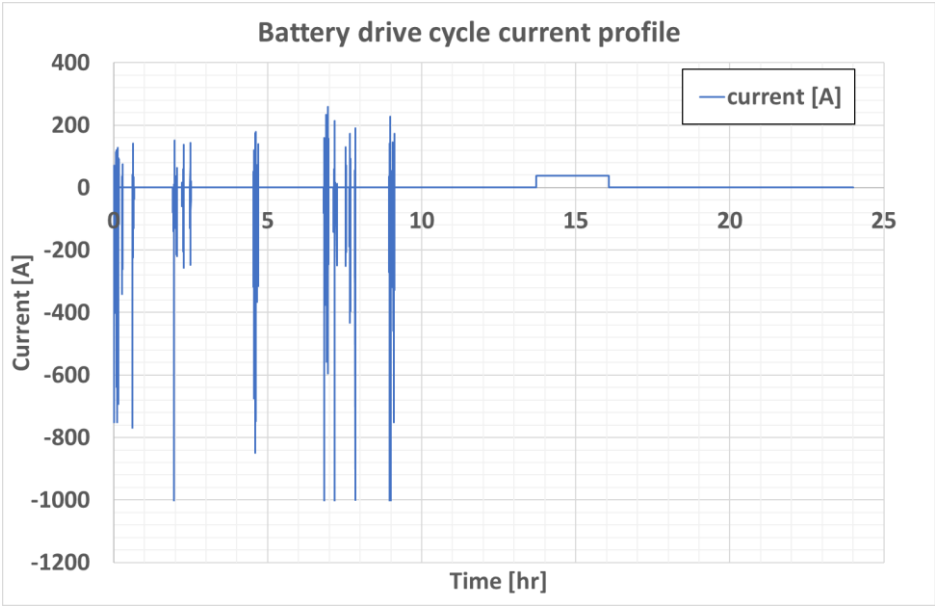


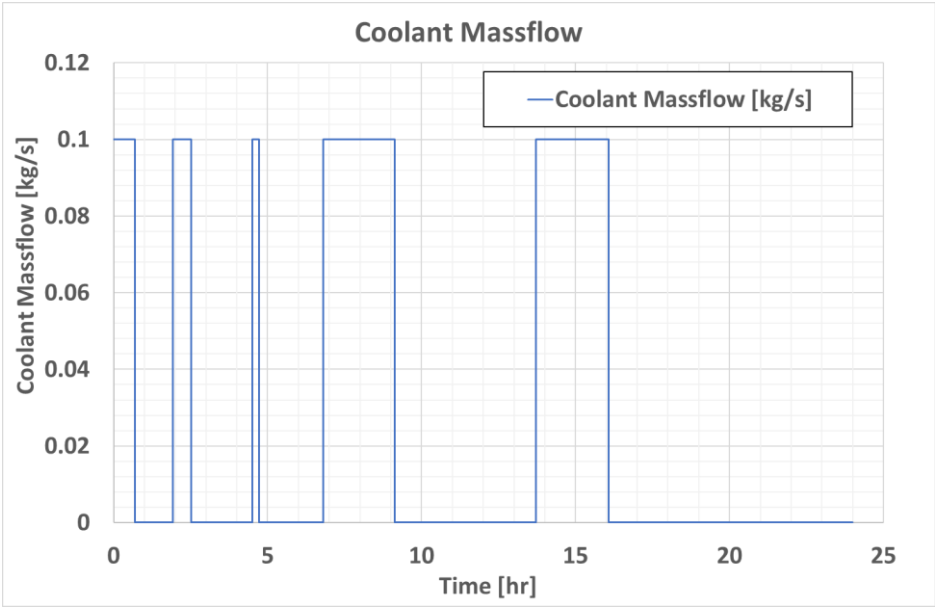


Battery Cooling Boundary Conditions

- Drive cycle
  - 24h, starting at 8AM
  - Driving during the day, charging at night
  - Coolant inlet 20°C
  - 0.1 kg/s Coolant massflow
    - Running only when driving or charging
  - 24h Ambient temperature curve

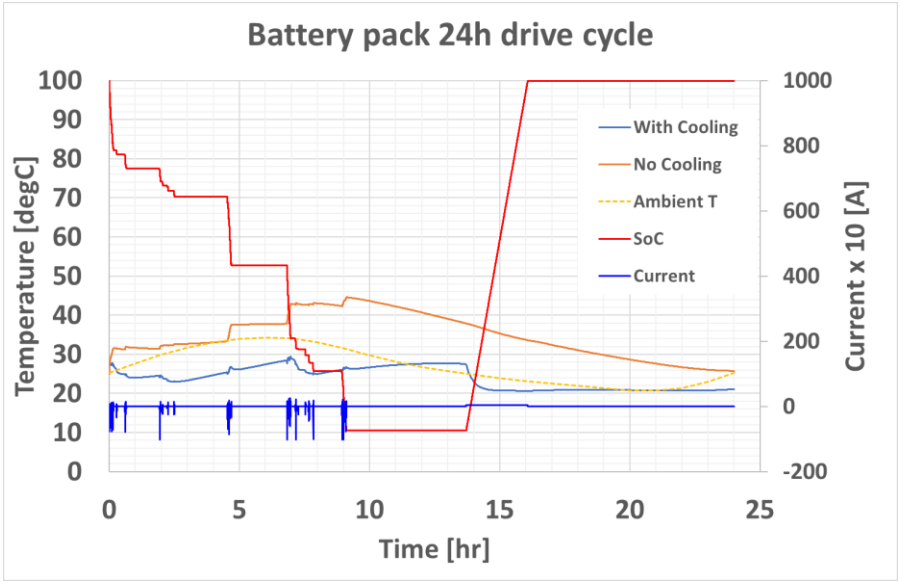


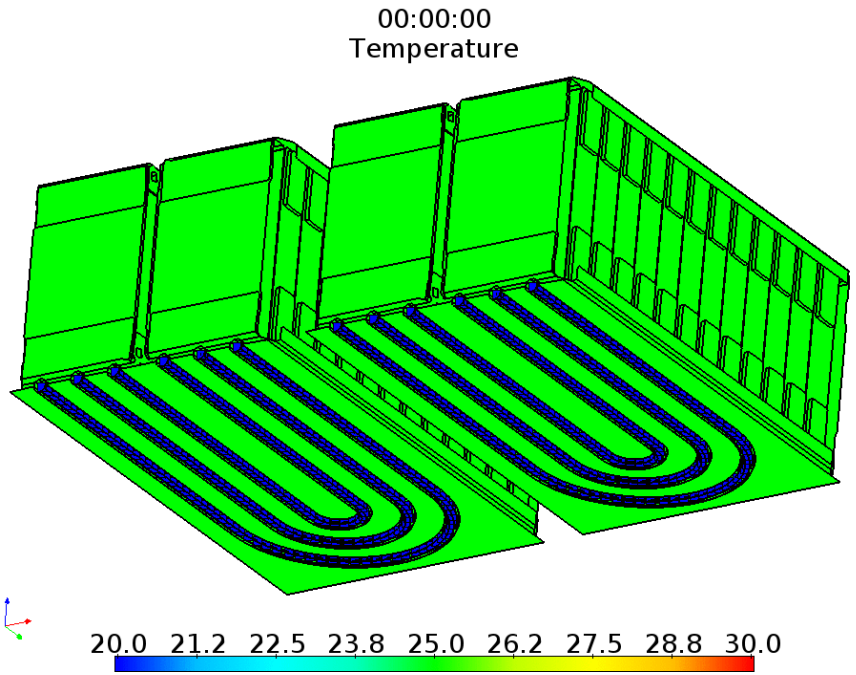


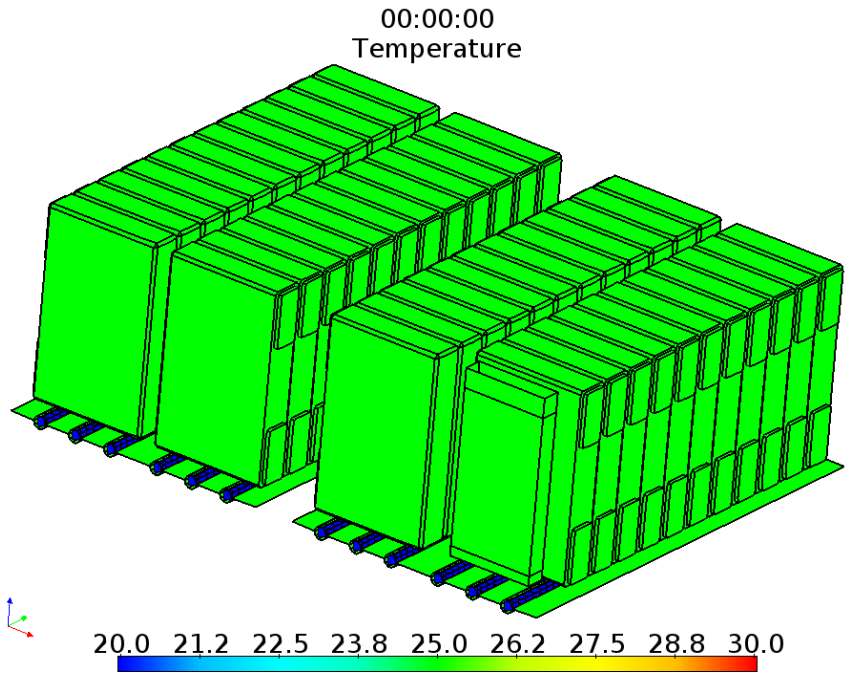


Battery Cooling Results Drive Cycle

- Liquid Cooled case
  - 24hr time animation
  - Cooling applied during driving and charging



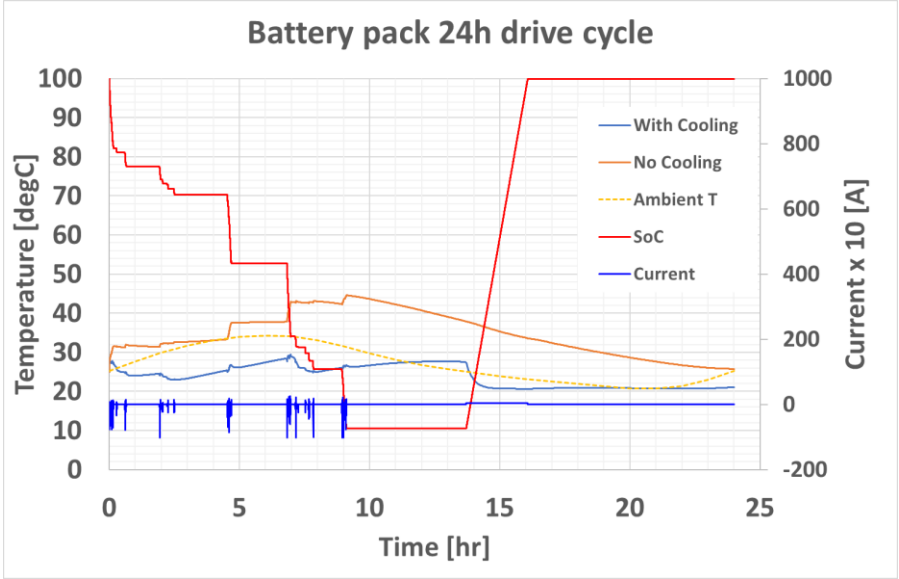


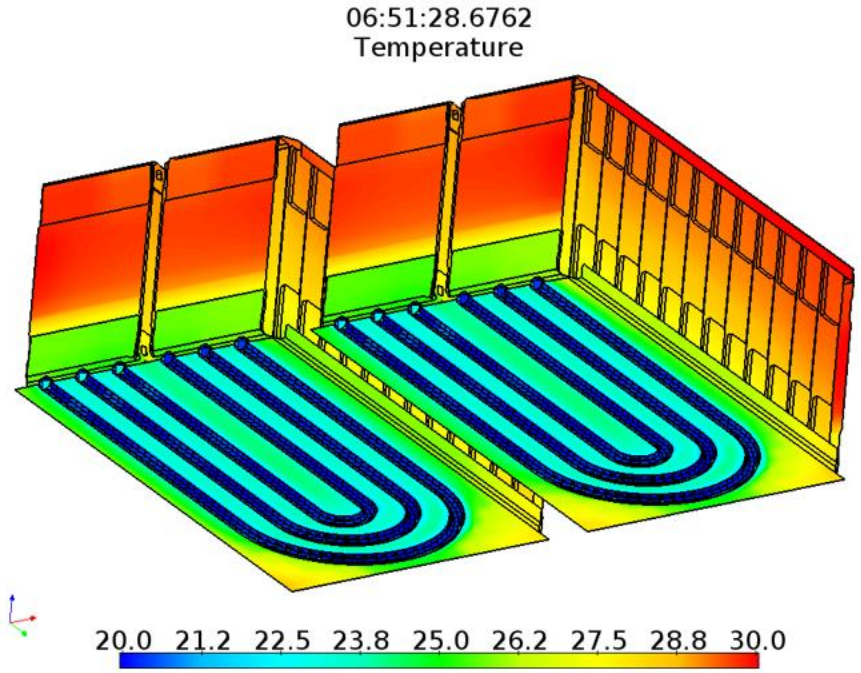


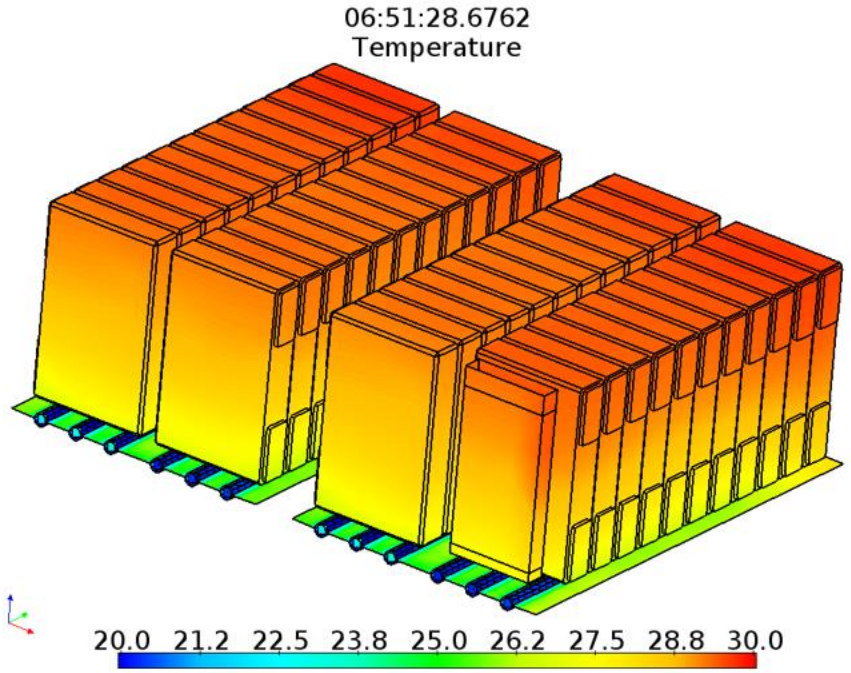
Runtime:
2h on 8 procs

Battery Cooling Results Drive Cycle

- Liquid Cooled case
  - Results after 7hr
  - Strong temperature gradients in pack
  - Should be uniform temperature





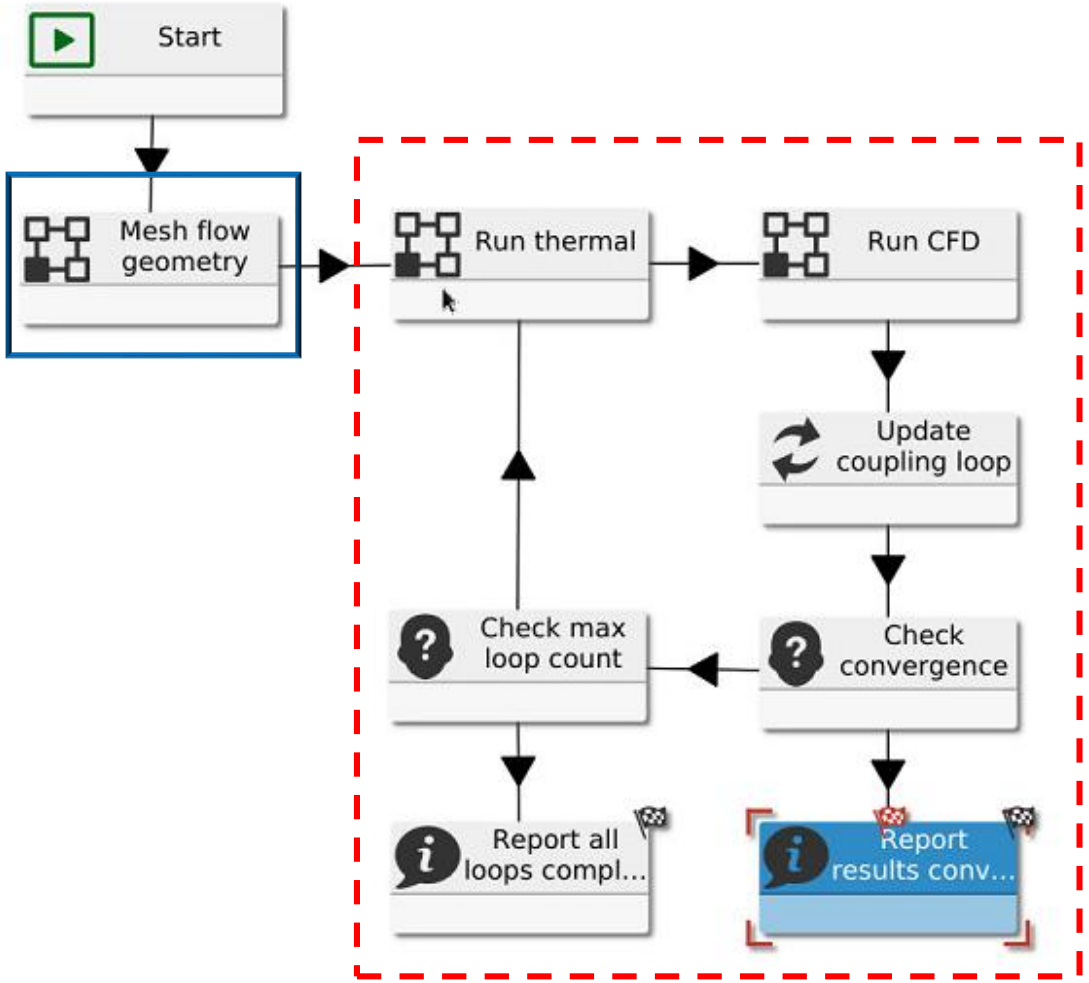


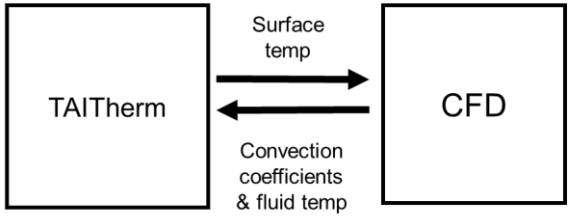
Advanced Process Customization

Advanced Process Customization

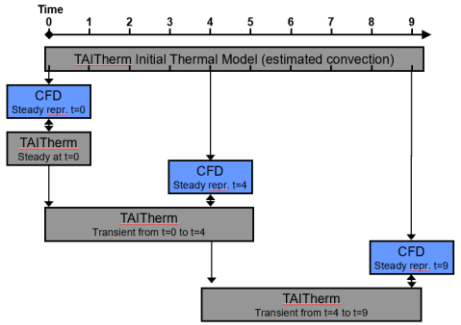
- CoTherm allows advanced process customization
- The following shows an example for:
  - Mesh generation using snappyHexMesh and automated OpenFOAM base setup from thermal model
  - Customization/Control of Mesh Refinement based on assembly naming in TAITherm model
- Method could be extended to other OpenFOAM parameters

TAI-OpenFOAM Template

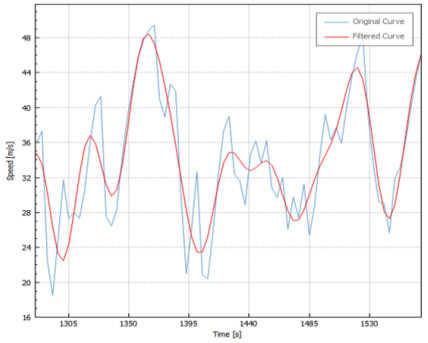




Two-way steady-state

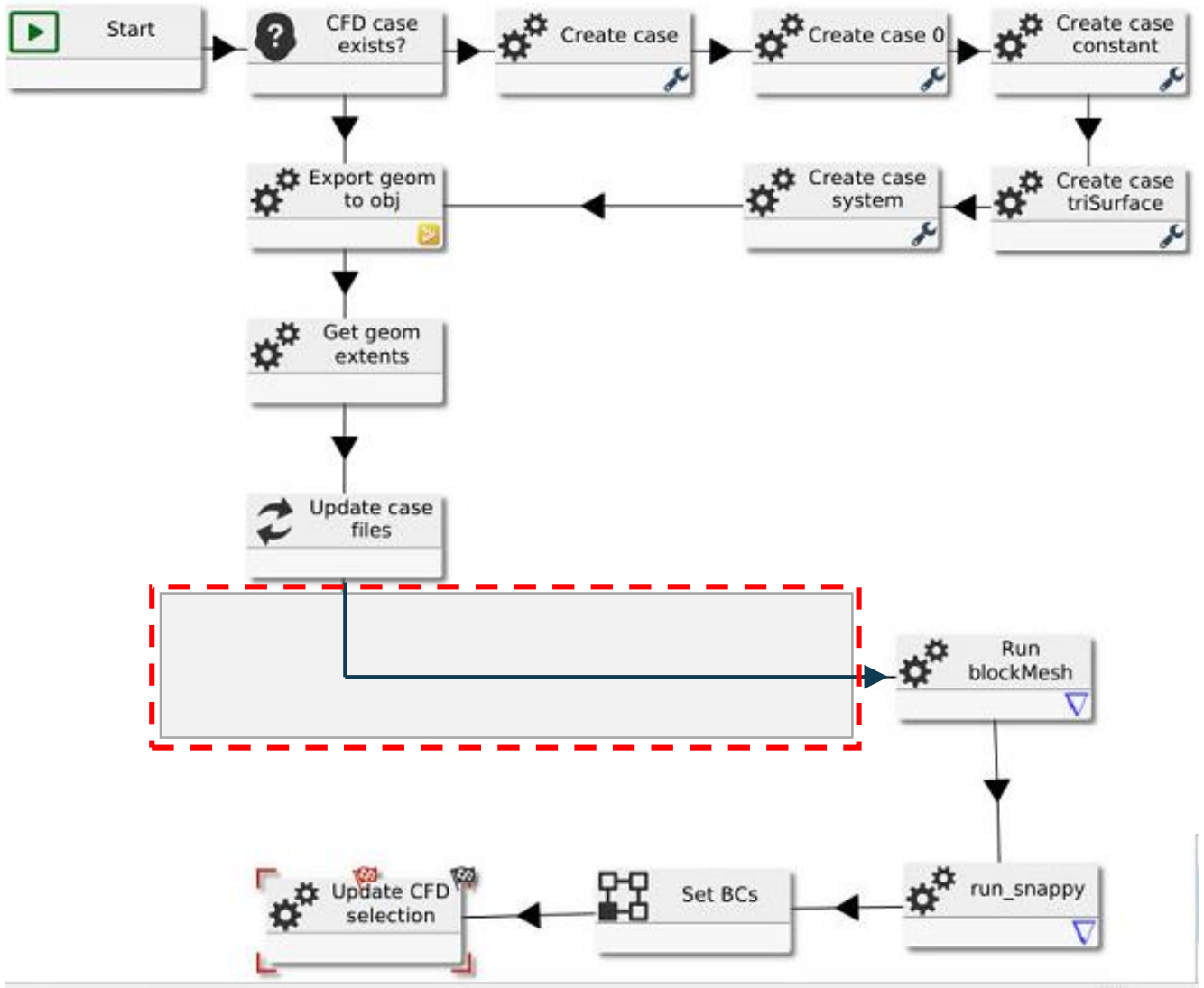


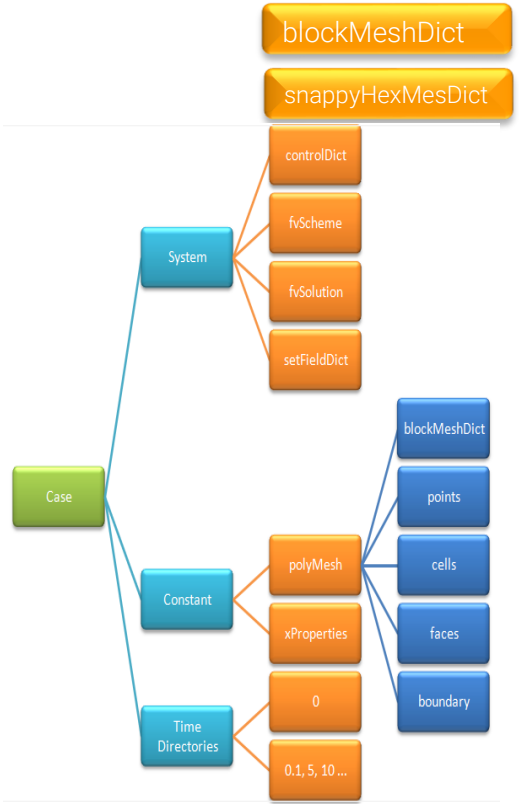
Two-way pseudo-transient

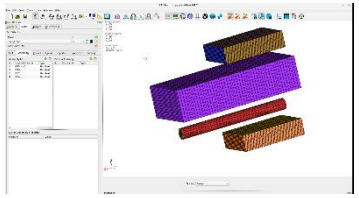


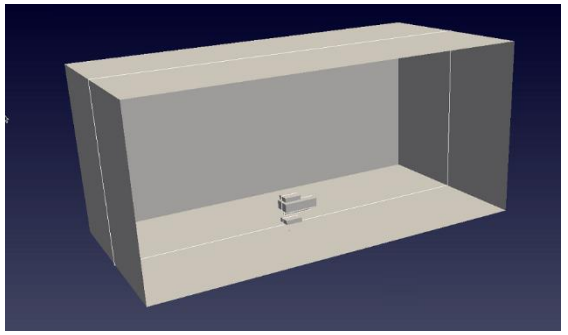
Transient coupling / Drive-cycle

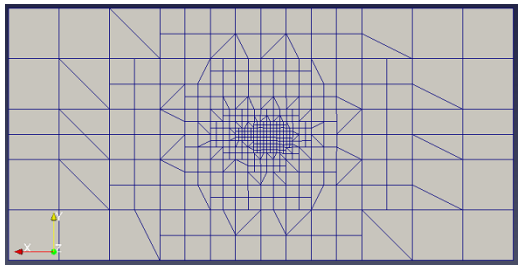
Automatic Mesh Generation From Thermal Model

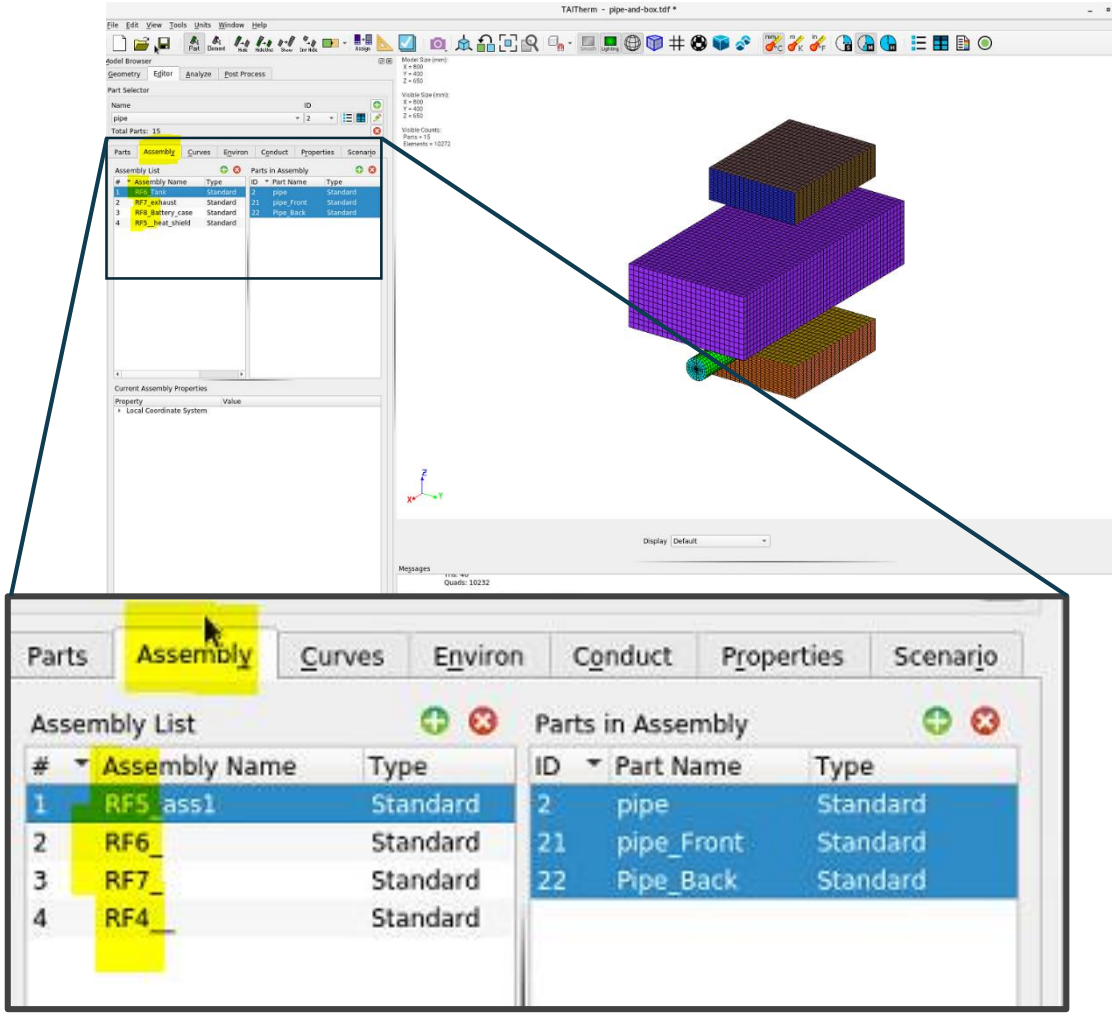


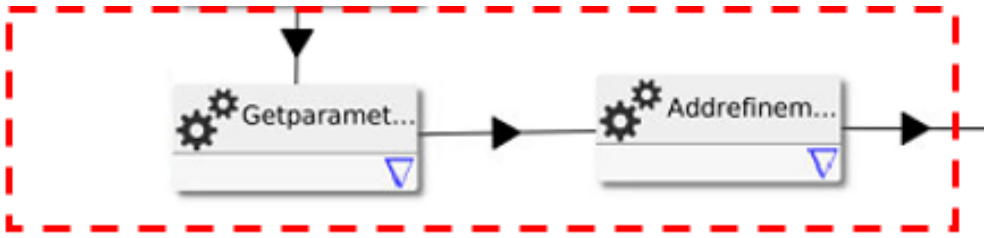












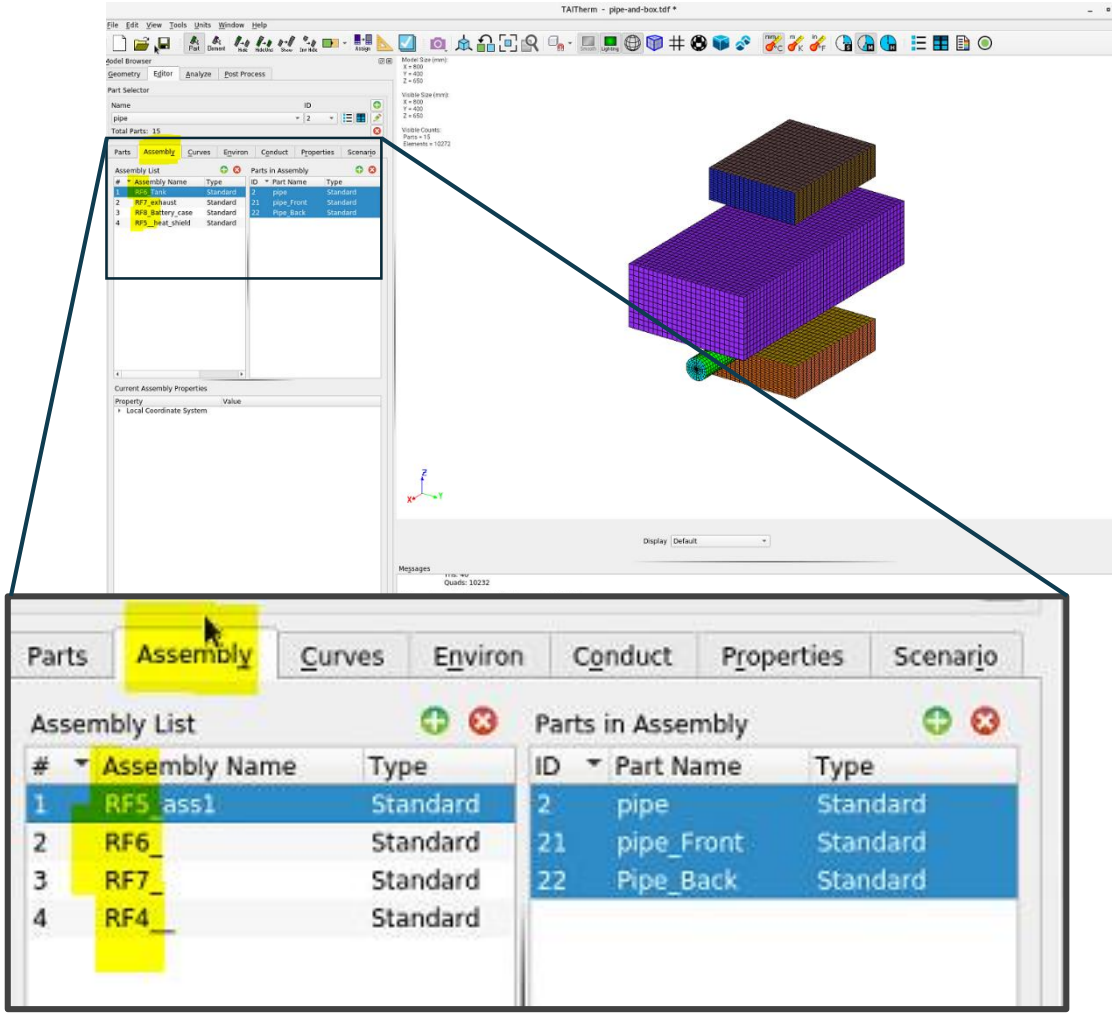
Edit File Contents

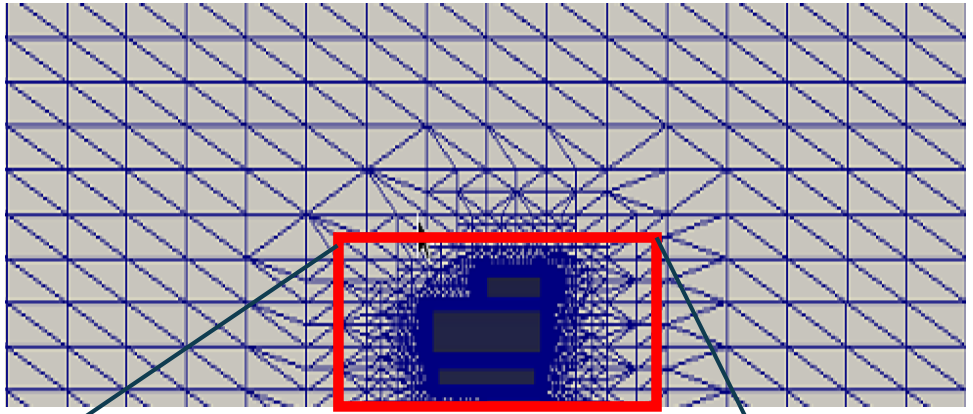
```
    {
        //{
        //    file "geom.eMesh";
        //    level 4;
        //    //levels ((0.0 3) (1.0 2));
        //}
    );


    // Surface based refinement
    // ~~~~~~~~~~~~~~~~~~~~~~~~

    // Specifies two levels for every surface. The first is the minimum level,
    // every cell intersecting a surface gets refined up to the minimum level.
    // The second level is the maximum level. Cells that 'see' multiple
    // intersections where the intersections make an
    // angle > resolveFeatureAngle get refined up to the maximum level.

    refinementSurfaces
    {
        $thermalGeomObjBasename
        {
            // Surface-wise min and max refinement level
            //level ($modelMinRefine $modelMaxRefine); //KKR
            level (4 5);
            // Optional region-wise level specification
            // ========== TAI_ADD_nSurfaceLayers_For_PIDs_START   ==========
            /*regions
            {
                secondSolid
                {
                    level (3 3);
                }
            }
                    */
        // ==========  TAI_ADD_nSurfaceLayers_For_PIDs_END    ==================
            // Optional specification of patch type (default is wall). No
            //patchInfo
            //{
```

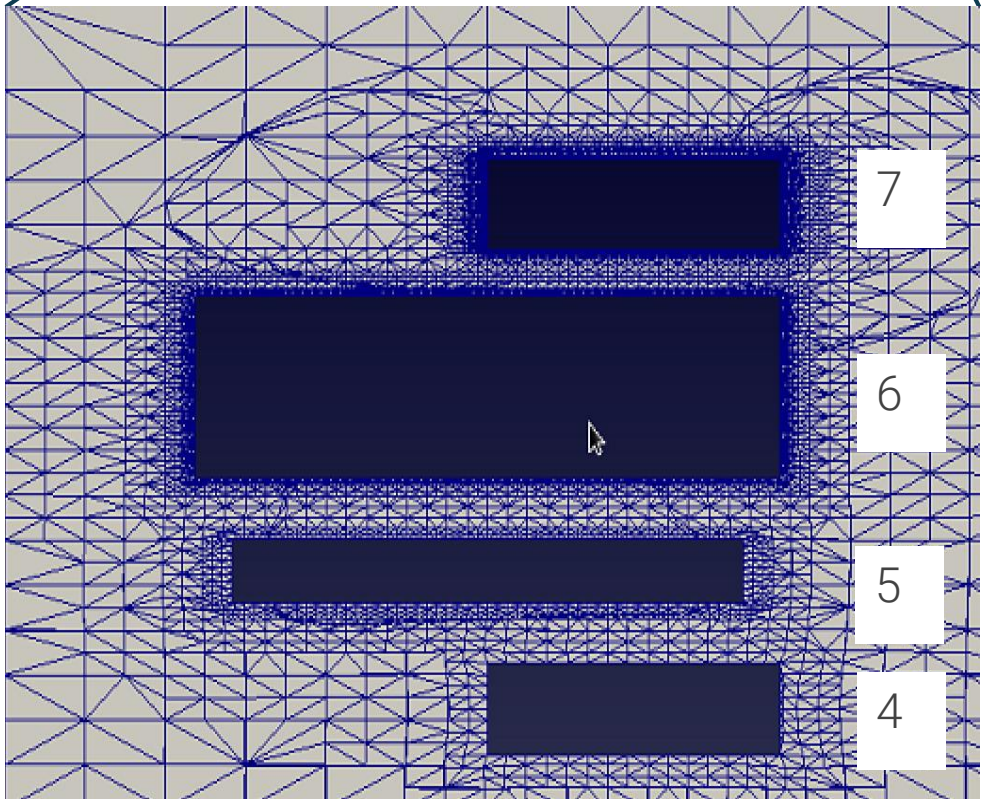
```
//level (13 14); //KKR

level (4 5);

// Optional region-wise level specification

// ========== TAI_ADD_nSurfaceLayers_For_PIDs_START   =

regions
{
    body
    {
        level ( 6 6); patchInfo { type wall; }
    }
    pipe
    {
        level ( 5 5); patchInfo { type wall; }
    }
    Box3_Bottom
    {
        level ( 4 4); patchInfo { type wall; }
    }
    Box3_Front
    {
        level ( 4 4); patchInfo { type wall; }
    }
    Box3_Back
    {
        level ( 4 4); patchInfo { type wall; }
```

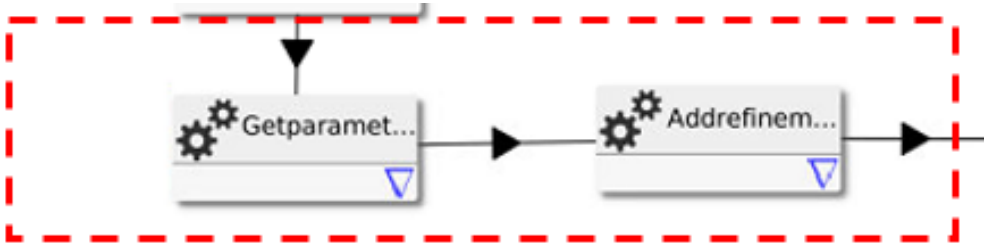
snappyHexMeshDict

Define snappyHexMesh refinement levels from TAITherm assembly names


TAITherm - pipe-and-box.tdf *
Parts
Assembly
Curves
Environ
Conduct
Properties
Scenario
Assembly List
Parts in Assembly
Assembly Name Type
1 RF5_ass1 Standard
2 RF6_ Standard
3 RF7_ Standard
4 RF4_ Standard
ID Part Name Type
2 pipe Standard
21 pipe_Front Standard
22 Pipe_Back Standard



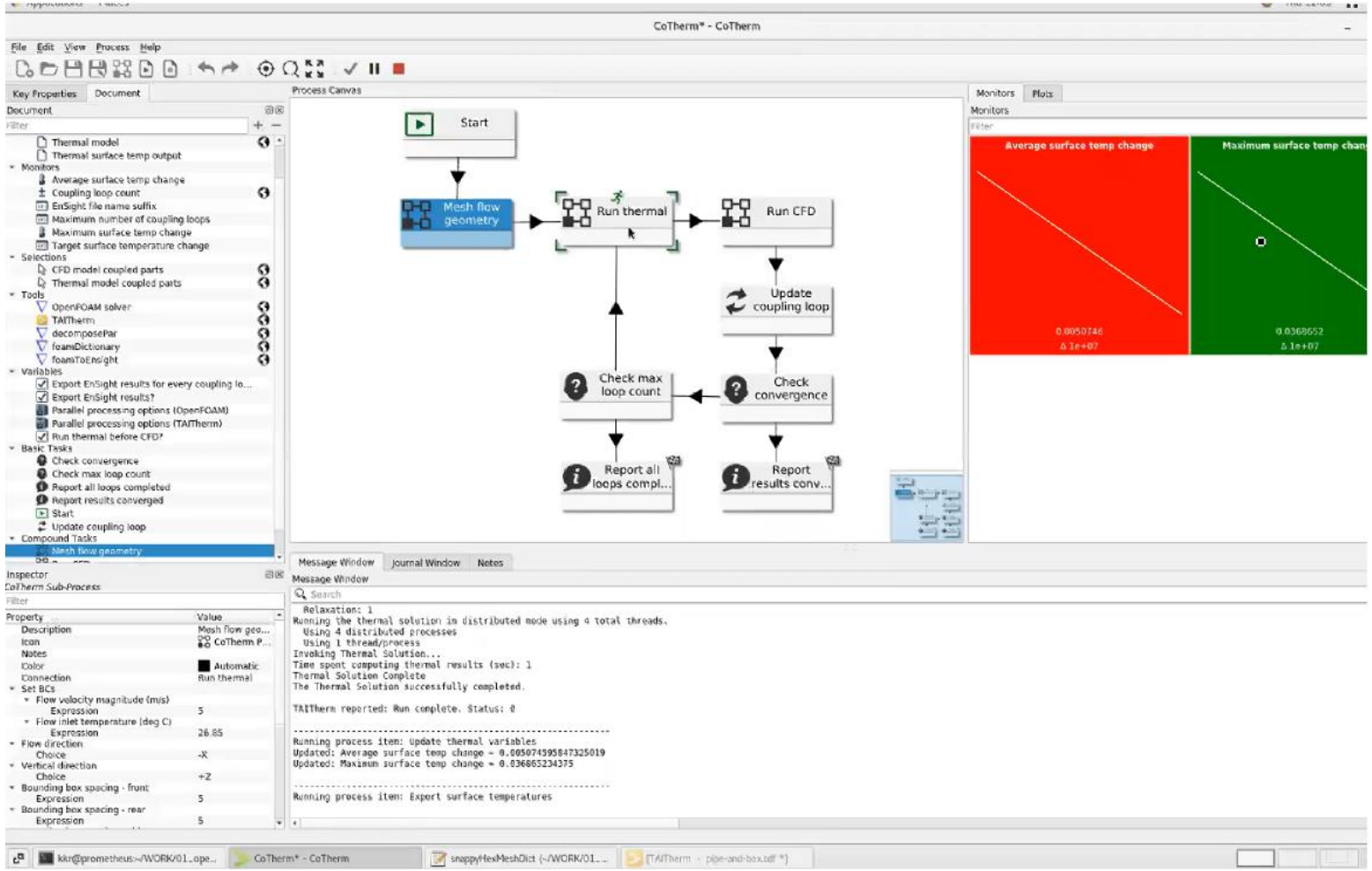

7
6
5
4


Getparamet...
Addrefinem...

Advanced Process Customization

This method could be extended to other OpenFOAM parameters like Boundary layer refinement, volume mesh controls etc.

Advanced Process Customization



Further Customization and Automation capabilities:

- Add New Physics
- Add Controls
- Couple with other tools
- Include Optimization

This method could be extended to other OpenFOAM parameters like Boundary layer refinement, volume mesh controls etc.

Conclusions

Conclusions

- ThermoAnalytics provides a robust and easy to use coupling process between TAITherm and OpenFOAM.
- Templates for common automotive applications are readily available within CoTherm.
- Customization capabilities allow for further automation of setup and solution.

Questions?

US Locations

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