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CAE/CFD仿真世界全面升级

专题技术巡展

北京站6月21日 上海站6月23日

Full Vehicle Applications Using ANSYS CFD

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ANSYS Inc.

Outline

- Front-End-Air-Flow (FEAF) Simulation for Vehicle
- Underhood Thermal Management (UTM)
- Full Vehicle Thermal Soaking
- Vehicle External Aerodynamics
- Common Model Approach

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Vehicle FEAF Simulation

What

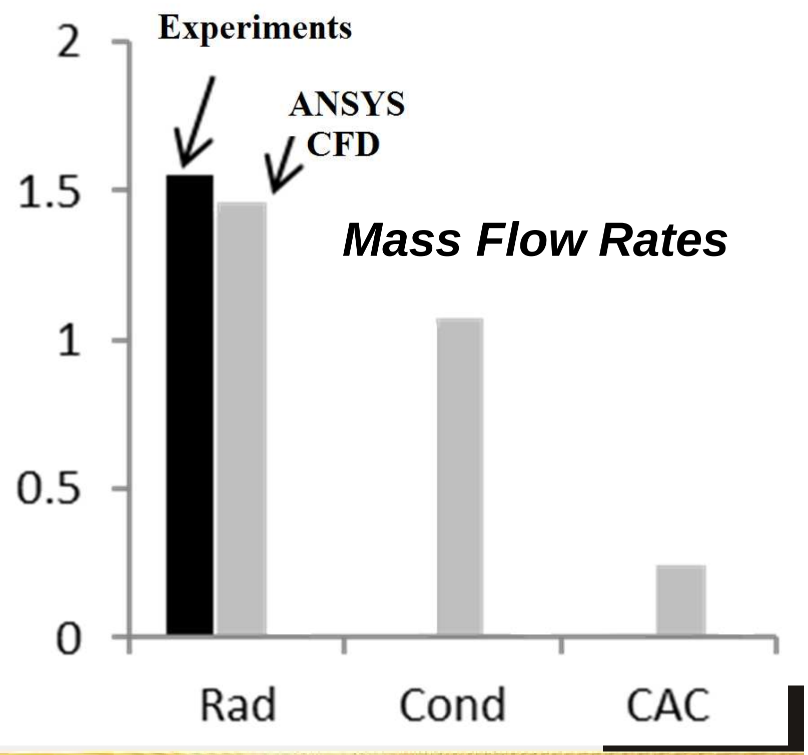
- The Front-End-Air-Flow (FEAF) analysis provides information of how flow goes through the cooling package of a vehicle.

Why

- Provides vital information to determine if the cooling package receives sufficient air flow to achieve the desired cooling capacity.
  - Helps choosing the proper cooling package.
  - Helps design the front fascia, especially the grille.
  - Indirectly affect the aerodynamics of the vehicle.
- Quick turnaround time in simulation compared with full vehicle UTM.

The main objective is to model full vehicle to predict flow through the cooling module.

Vehicle FEAF Simulation



Streamlines released from radiator outlet in reverse

Outline

- Front-End-Air-Flow (FEAF) Simulation for Vehicle
- **Underhood Thermal Management (UTM)**
- Full Vehicle Thermal Soaking
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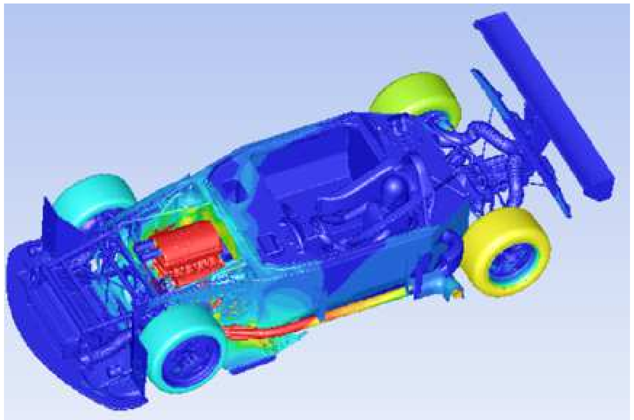
Underhood Thermal Management (UTM)

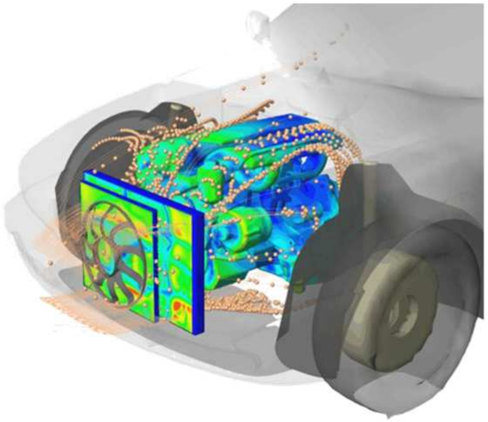
What

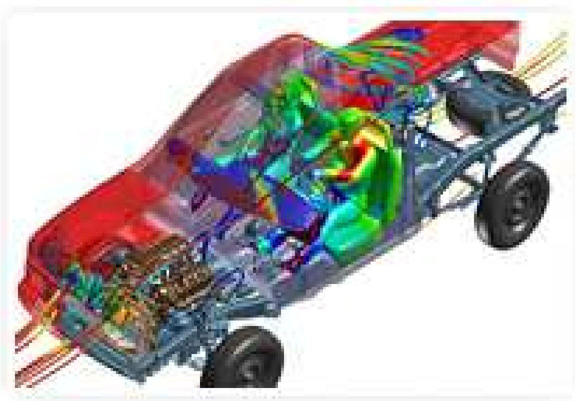
- Underhood/underbody flow and thermal analysis to predict the thermal footprint of the full vehicle under various driving conditions.

Why

- Many components in a vehicle can become so hot that they can potentially fail, or degrade nearby components, leading to safety, durability, and warranty issues.
- UTM becomes a more prominent task in the automotive industry with the introduction of new materials to vehicle designs and advent of new vehicle powertrains such as hybrid, electric and fuel cell.



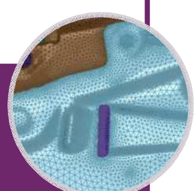




The main objective of UTM simulation is to predict the thermal footprint of key components throughout the vehicle with robustness and high fidelity.

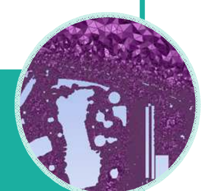
Underhood Thermal Management (UTM)- Challenges

- Complex Geometry: Many parts and high geometry details
- Dirty Geometry: Parts not sharing same source, coordinate, and unit system; overlaps, missing parts; intersections; corrupted geometry, etc.
- Localized poor quality mesh



Meshing challenges

- 10 ~ 200 million volume cells
- 10 ~ 400 cell zones, both fluid and solid type.
- Coupled physics of flow and heat transfer phenomena.
- Conjugated heat transfer.



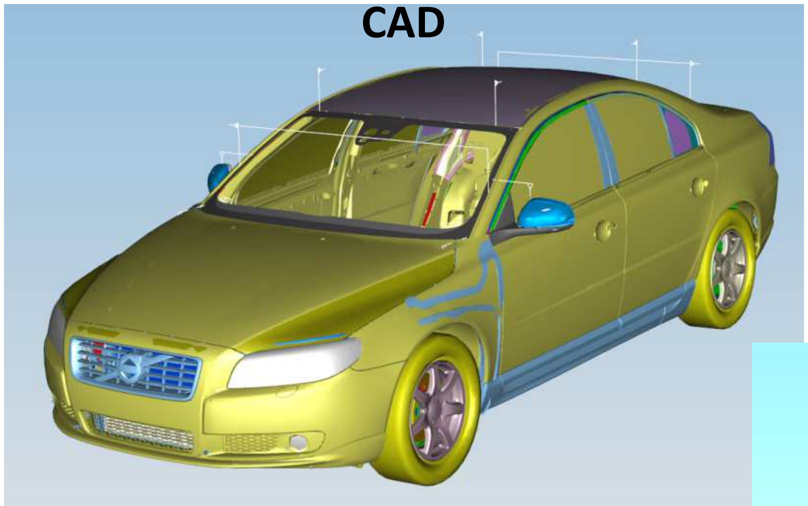
Large model size and complex physics

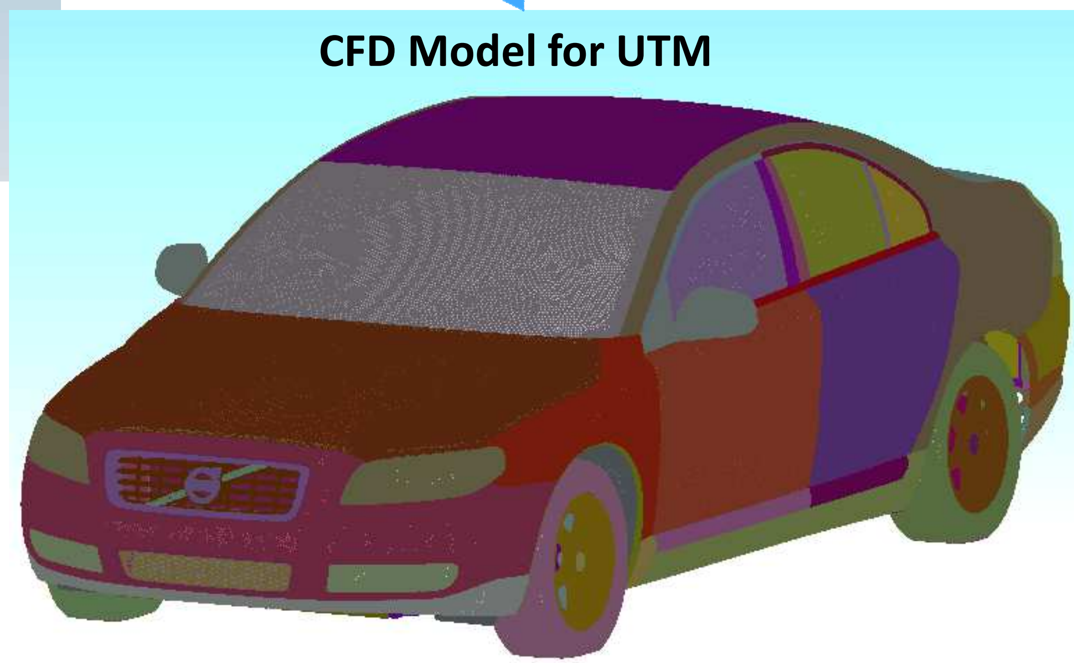
- unavailability of reliable data.

Experimental uncertainty

Underhood Thermal Management (UTM)

Volvo S80 model

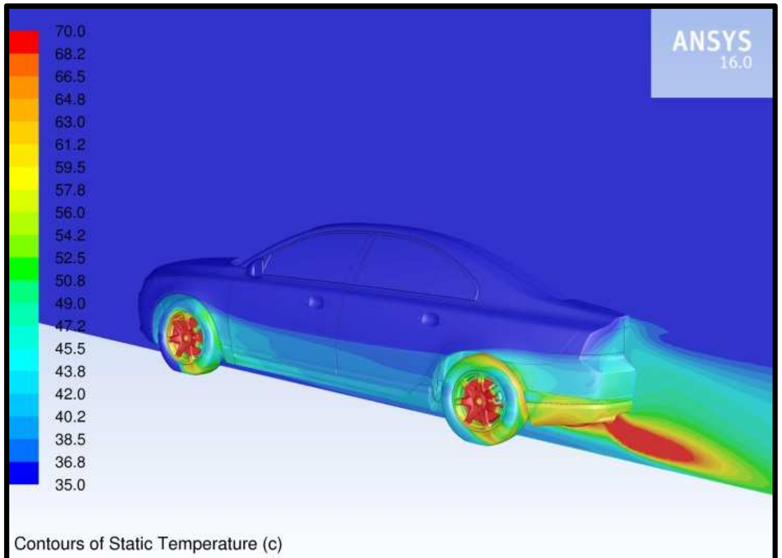


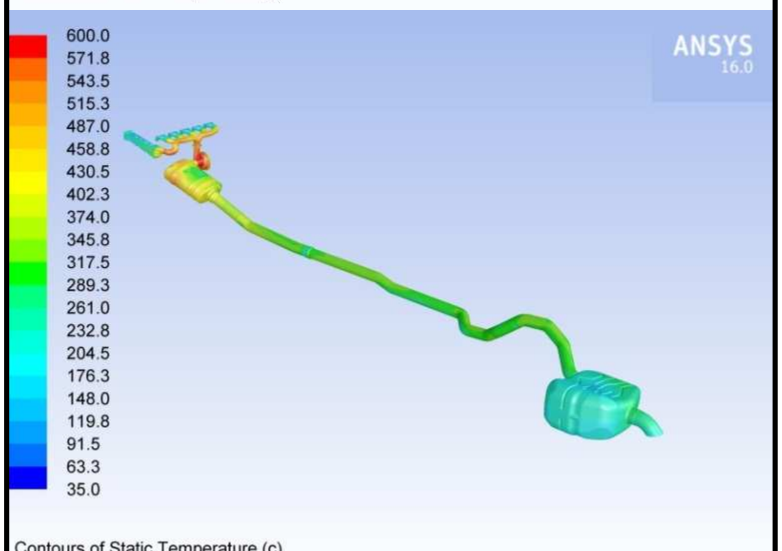


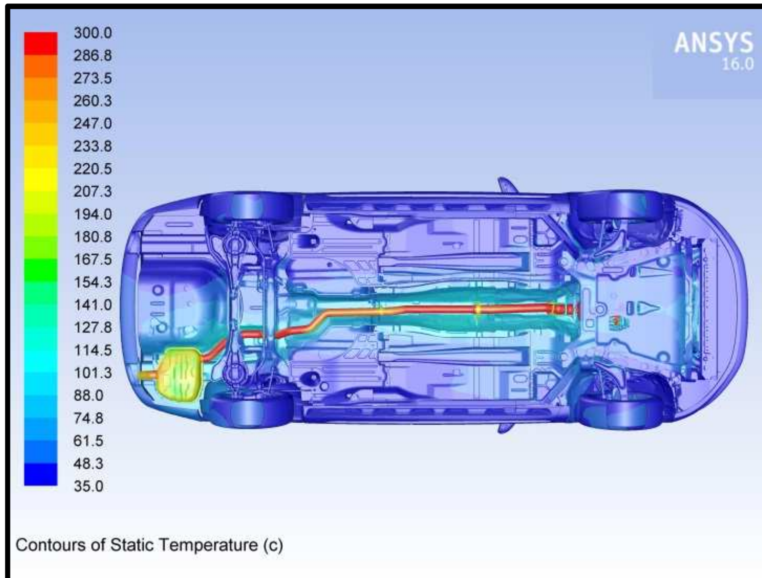
- **400+ solid zones.**
- **20+ fluid zones.**
- **Vehcle thermal footprint @ 110 kph and 2050 rpm engie speed.**
- **Porous media for Heat Exchanger and catalytic converters.**
- **Fan performance.**
- **Heat Exchangers thermal output.**

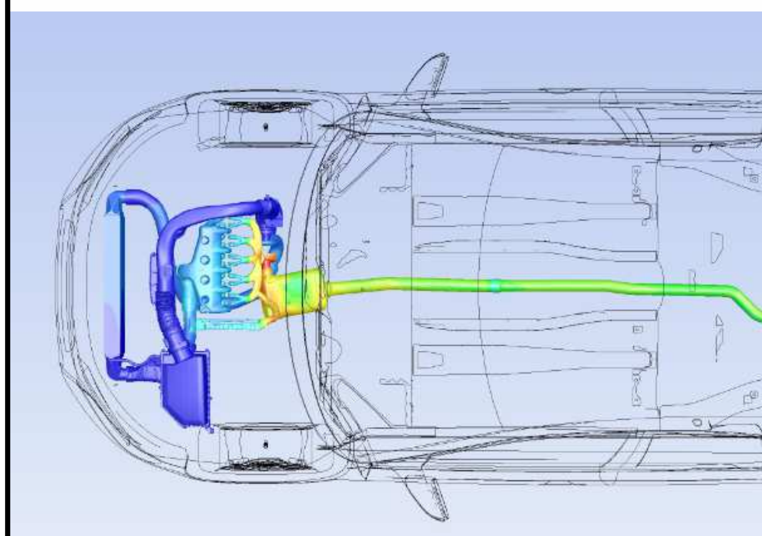
Underhood Thermal Management (UTM)

Volvo S80 model









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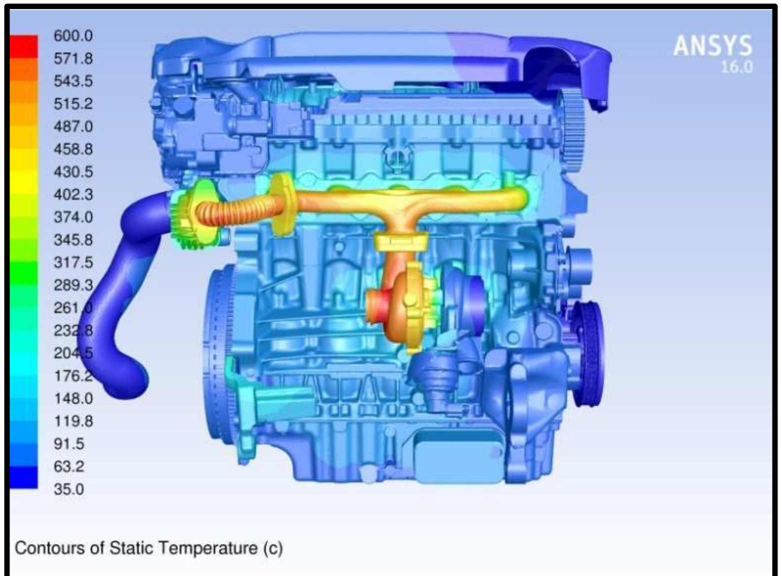
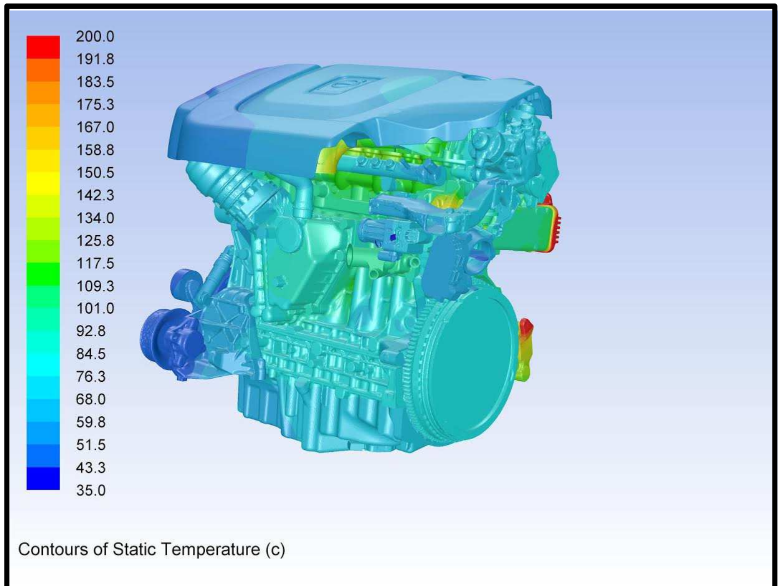
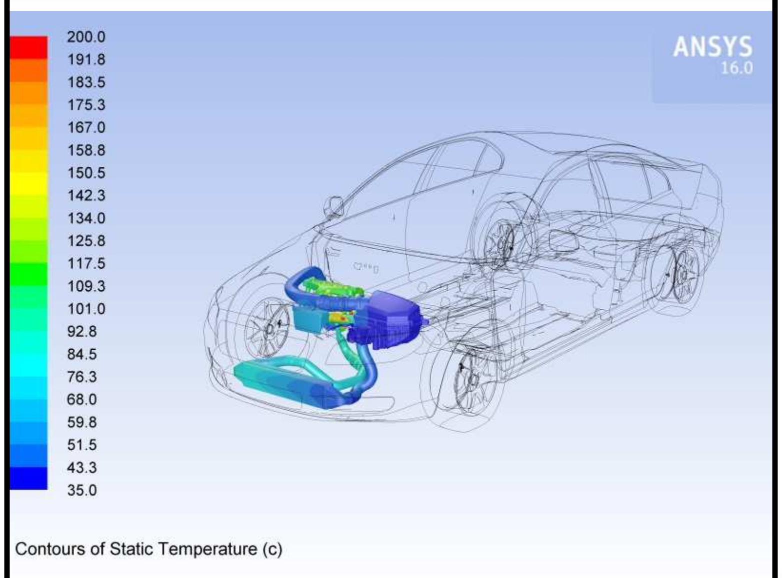
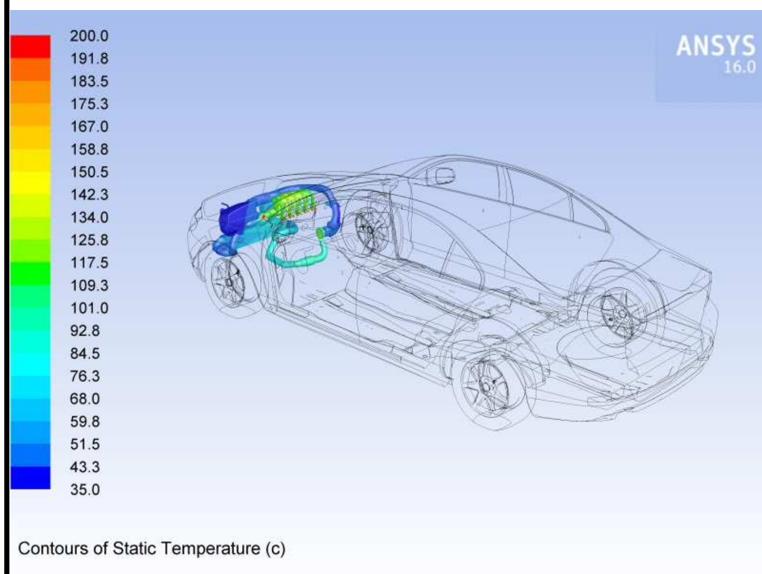
Underhood Thermal Management (UTM)

Volvo S80 model



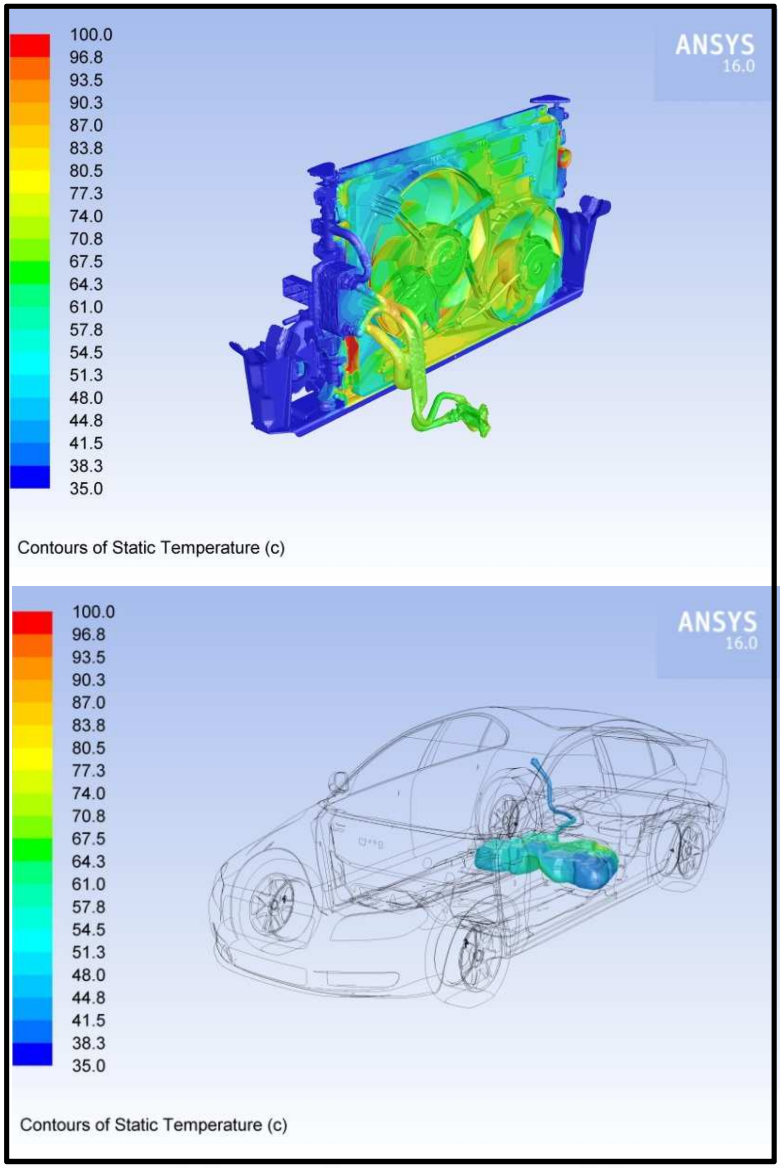


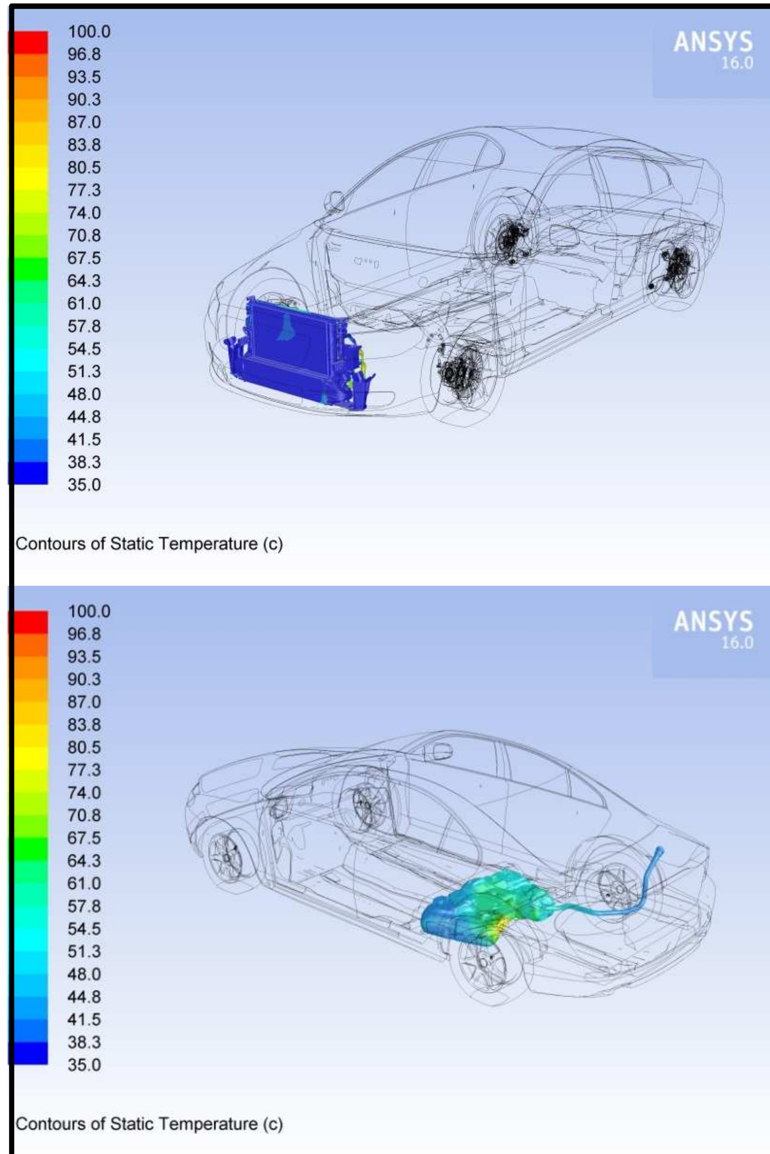




Underhood Thermal Management (UTM)

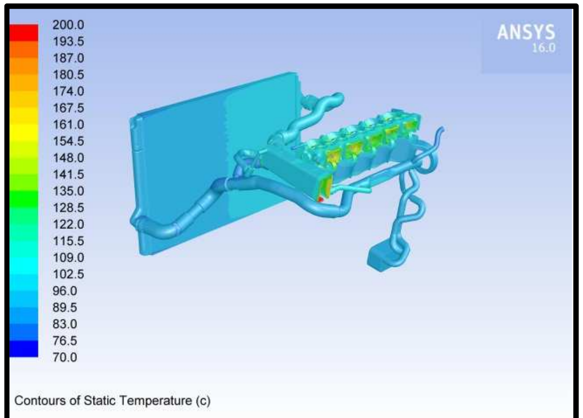
Volvo S80 model



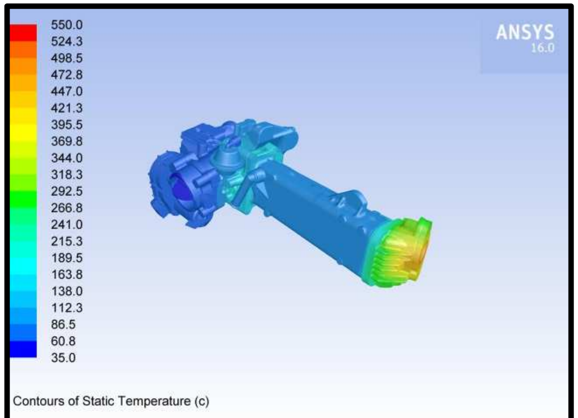


Underhood Thermal Management (UTM)

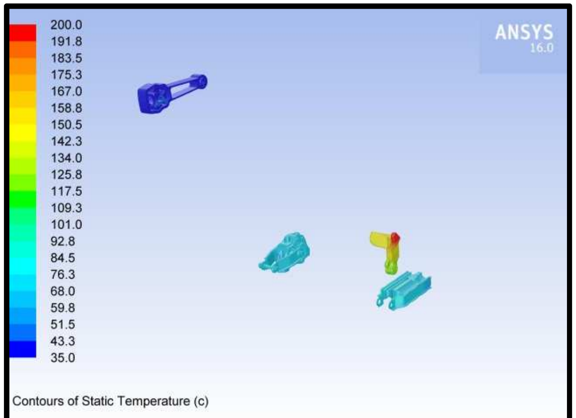
Volvo S80 model



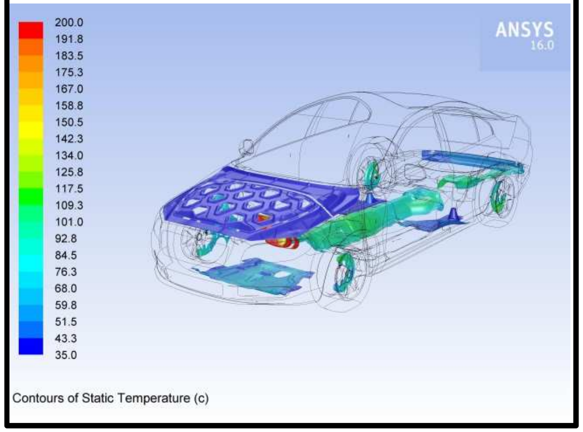
Coolant Stream



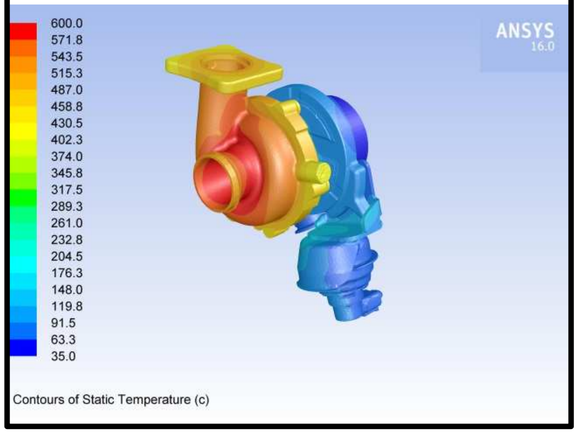
EGR



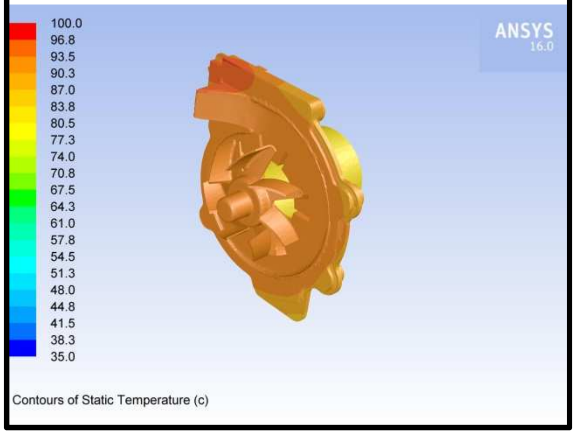
Mounts



Shields



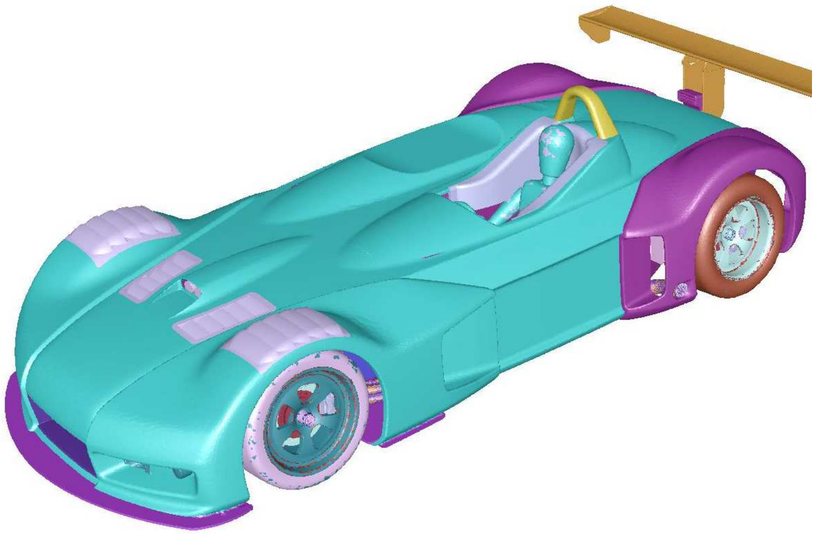
Turbo

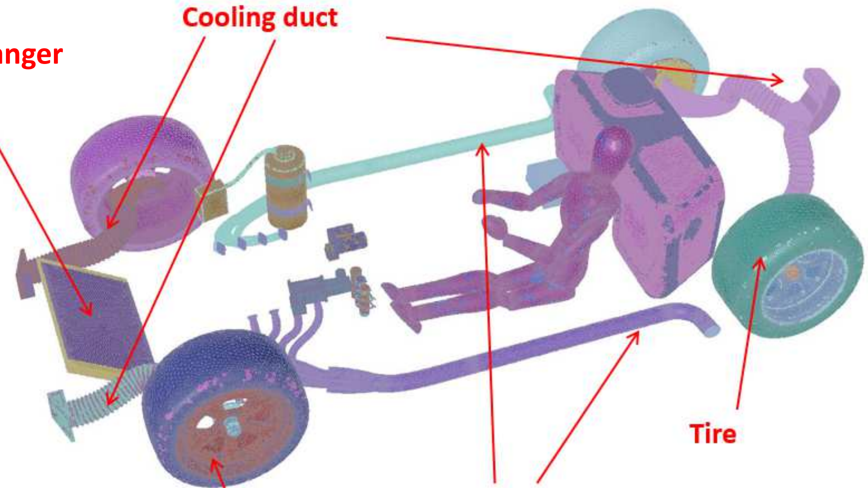


Water Pump

Underhood Thermal Management (UTM)

PTC World Car model

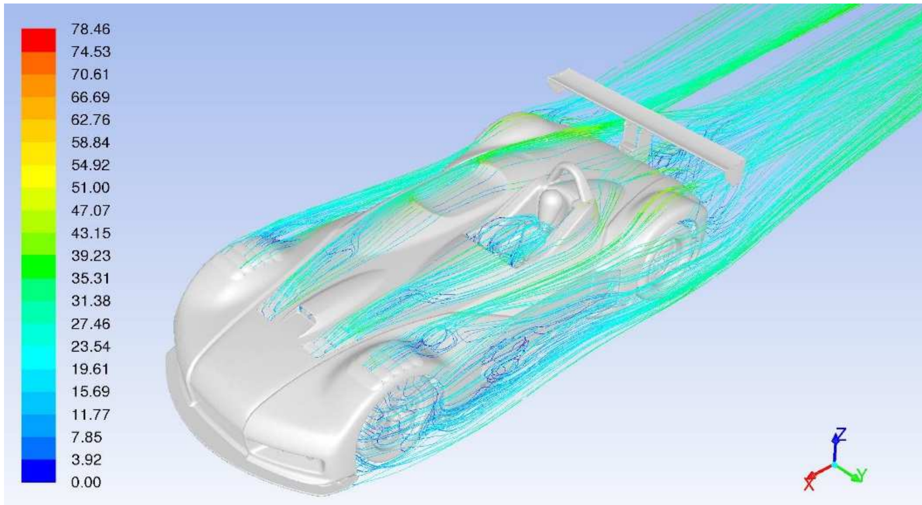




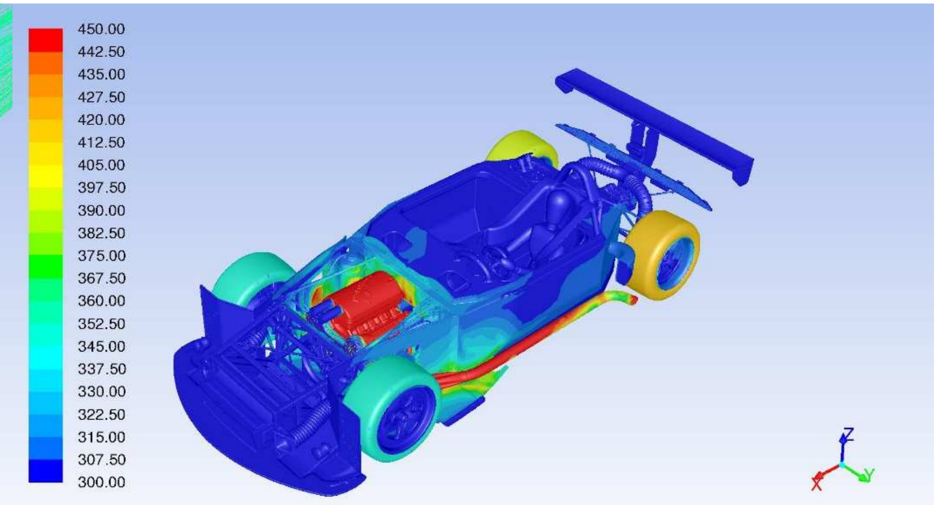
- **~48M cells.**
- **31 Solid zones and 4 Fluid zones.**
- **UTM analysis at vehicle speed 90mph.**
- **Exhaust gas is modeled as secondary flow and thermal source.**
- **Obtain accurate temperature prediction on more than 30 critical components with one simulation.**

Underhood Thermal Management (UTM)

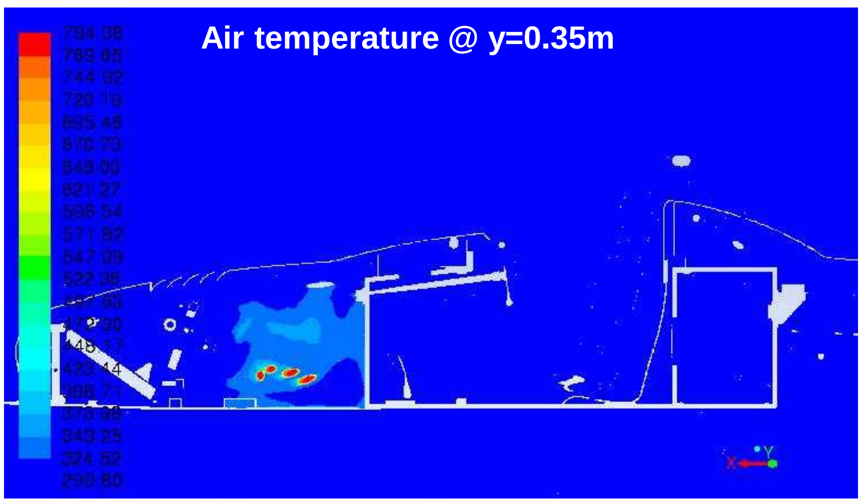
PTC World Car model



exhpipe
Pathlines Colored by Velocity Magnitude (m/s)

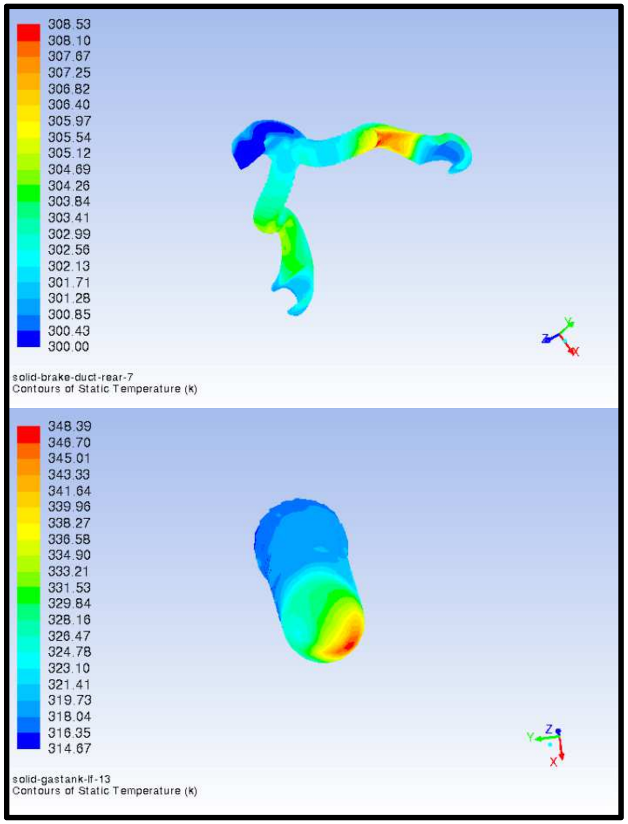


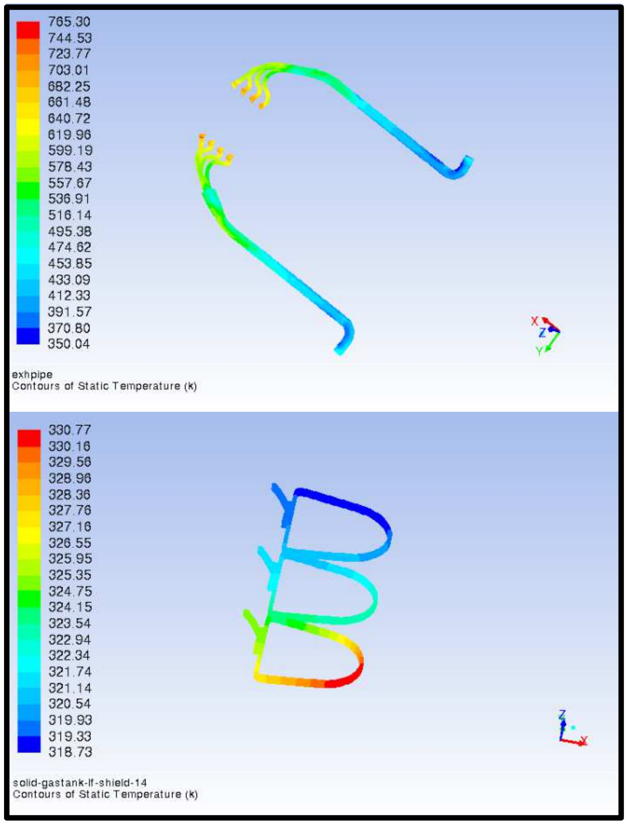
exhpipe
Contours of Wall Temperature (k)

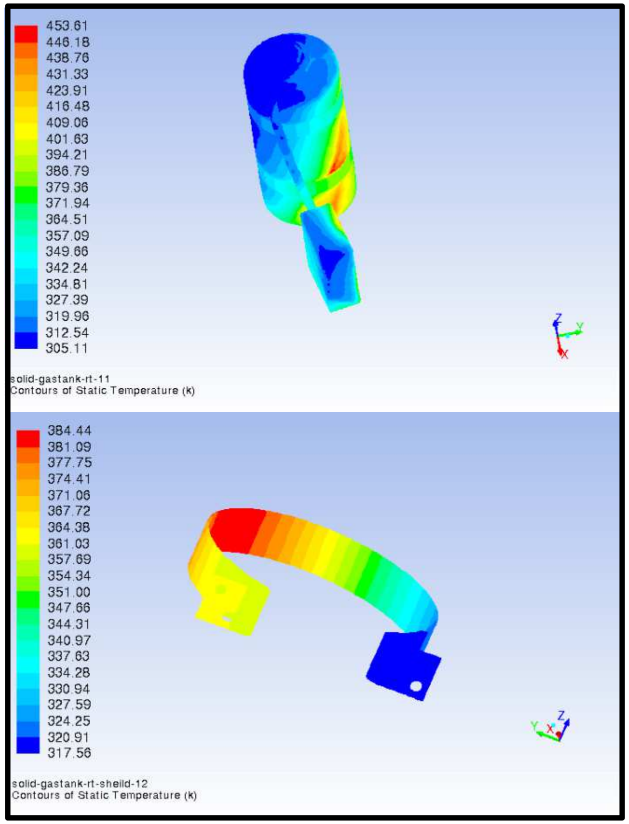


Underhood Thermal Management (UTM)

PTC World Car model







Outline

- Front-End-Air-Flow (FEAF) Simulation for Vehicle
- Underhood Thermal Management (UTM)
- **Full Vehicle Thermal Soaking**
- Vehicle External Aerodynamics
- Common Model Approach

Vehicle Thermal Soaking

What

- Thermal soaking or "Hot-Stop" refers to the build-up of temperature under the hood after high speed/load driving followed by immediate engine "key-off".
- As the fans stop operating and ram air is reduced to zero, some components near vicinity of the exhaust system will experience extreme temperatures.

Why

- The drastic change of convection mode compromises the capability of heat removal, resulting in possible increase of component temperature within a shot period of time in thermal soaking process. That increase of component temperature may cause degradation and failure which are not expected during normal working condition.

How

- Vehicle Thermal Management is traditionally based on two or three steady-state load cases : maximum velocity and trailer towing uphill
- In addition to steady-state load cases, unsteady thermal soak and idle is one of the most critical underhood operating conditions.

The main objective of the soaking simulation is to predict maximum temperatures experienced by sensitive components.

Vehicle Thermal Soaking - Challenges

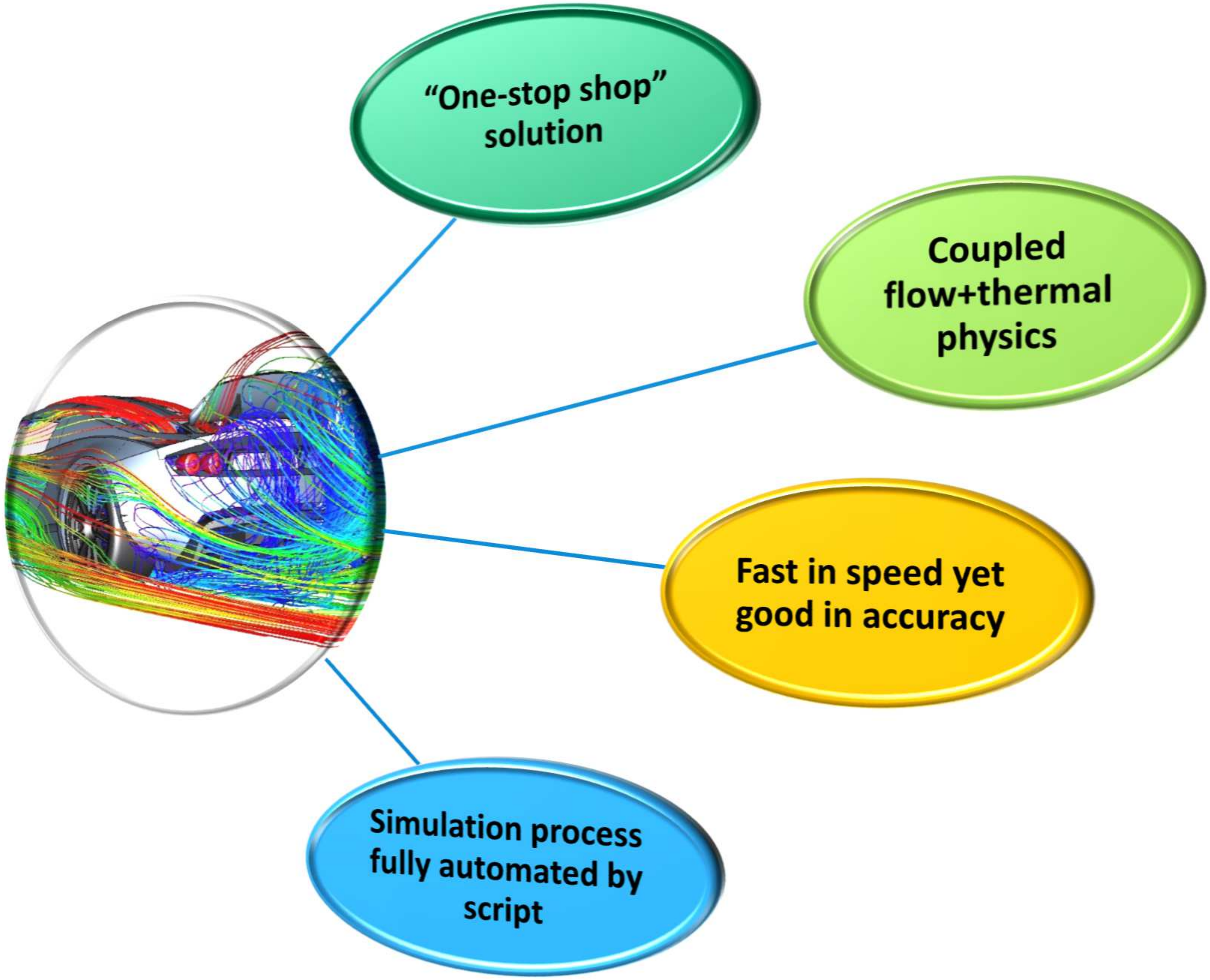
Large Problem: 10-100 million cells

Long Transient Simulation : Time durations of 100 to 1000 seconds

Large Thermal Constant Variation : Small time step needed.

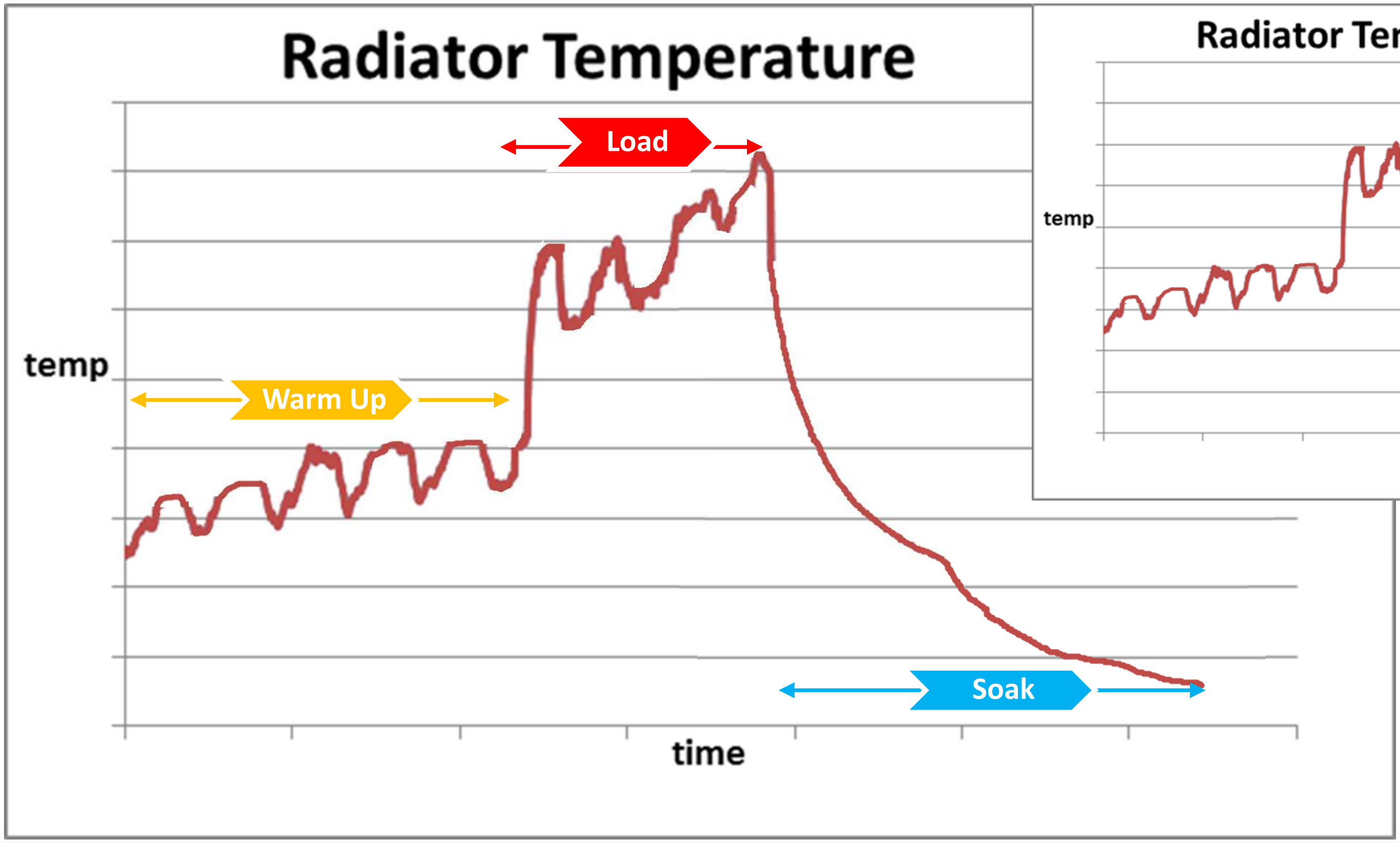
Coupled Physics : Temperature and velocity field coupling

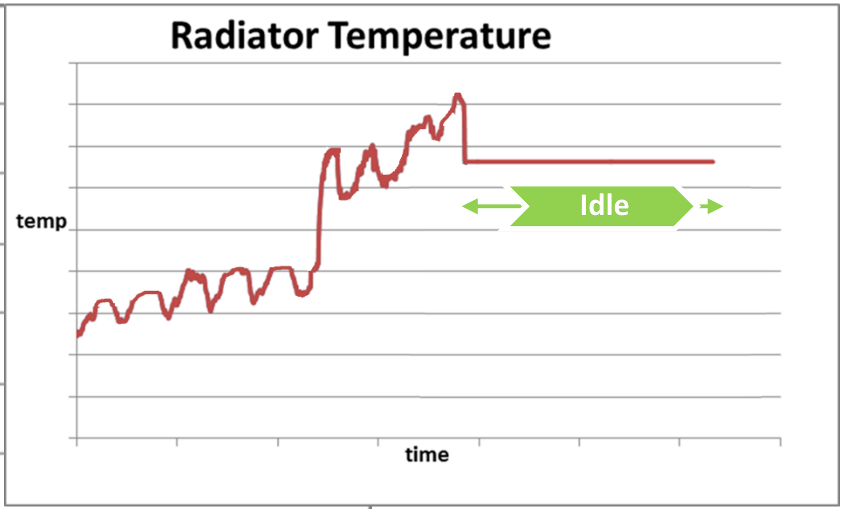
Vehicle Thermal Soaking : Why Use ANSYS Fluent for Transient Soaking?



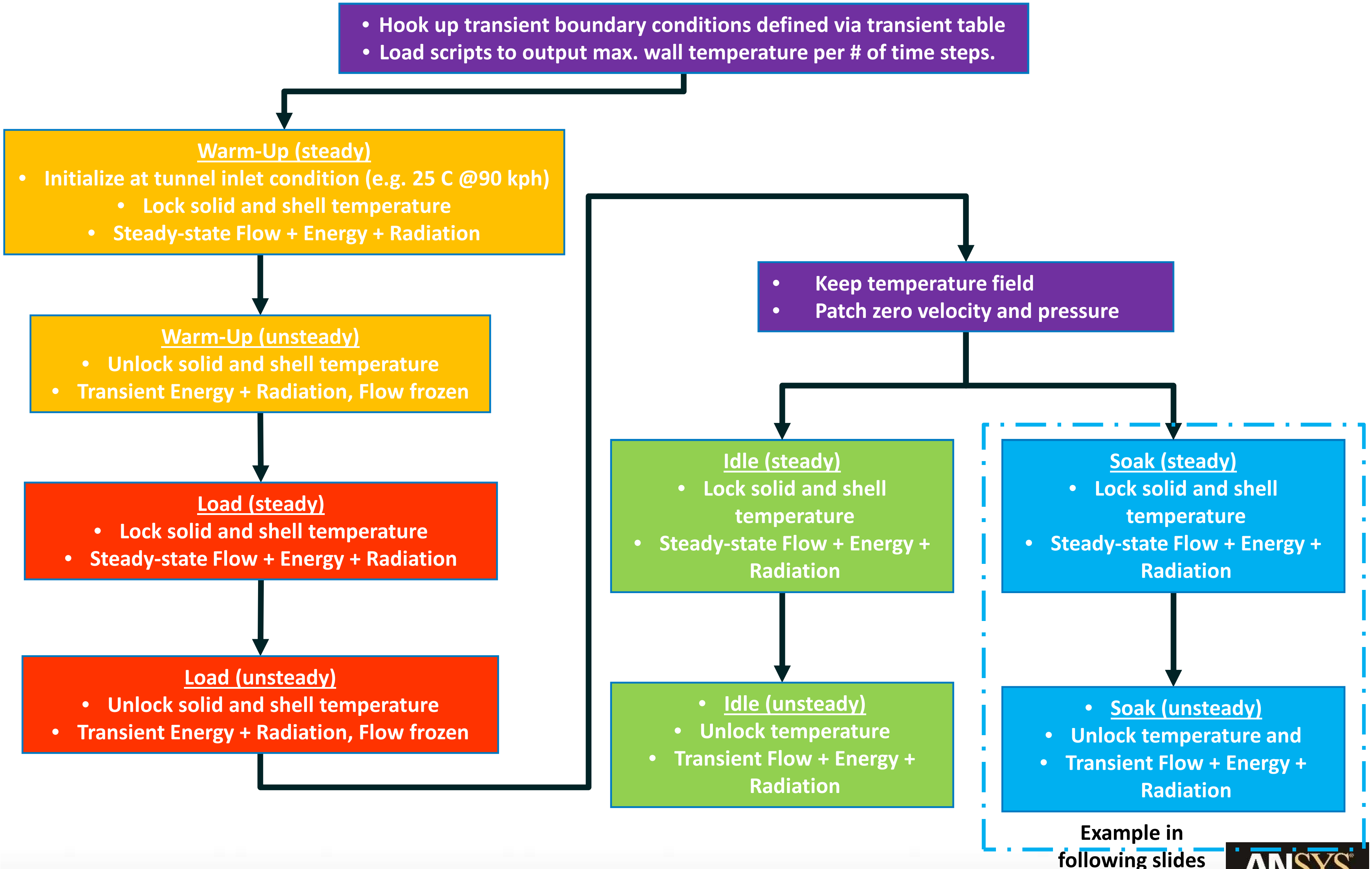
Vehicle Thermal Soaking

- **Transient BC profiles is applied to major heat sources as a results of the changing driving conditions, e.g.,**
    - o Radiator heat rejection.
    - o Heat flux/Heat Transfer Coefficient on certain boundary walls such as engine block.
- **Tabular input of the transient BC profiles.**





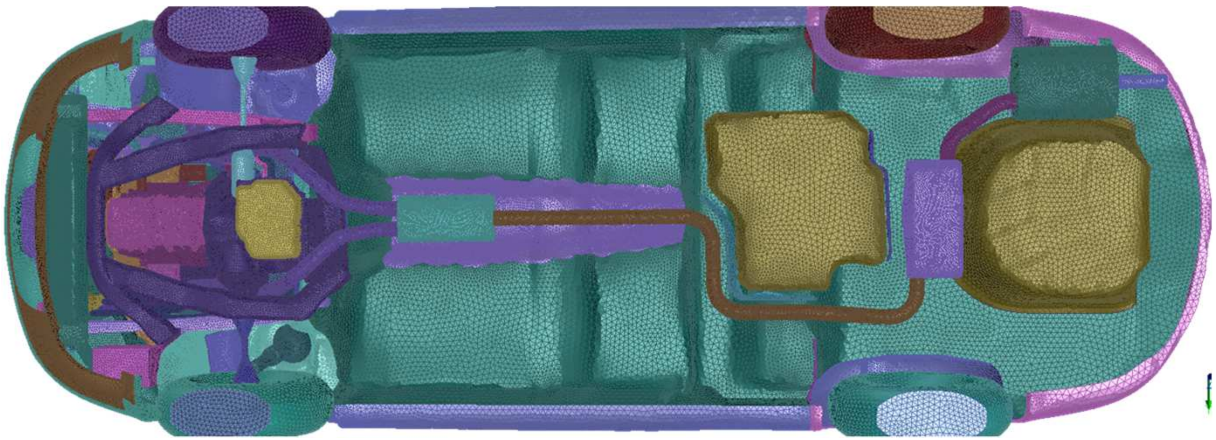
Vehicle Thermal Soaking: Process – automated via Fluent scripts



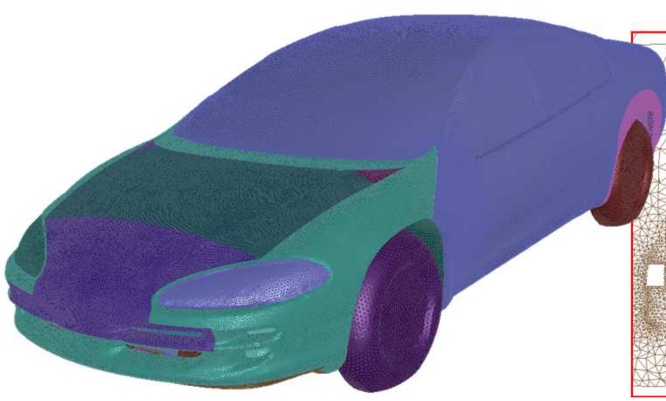
Vehicle Thermal Soaking – A Generic UTM Model

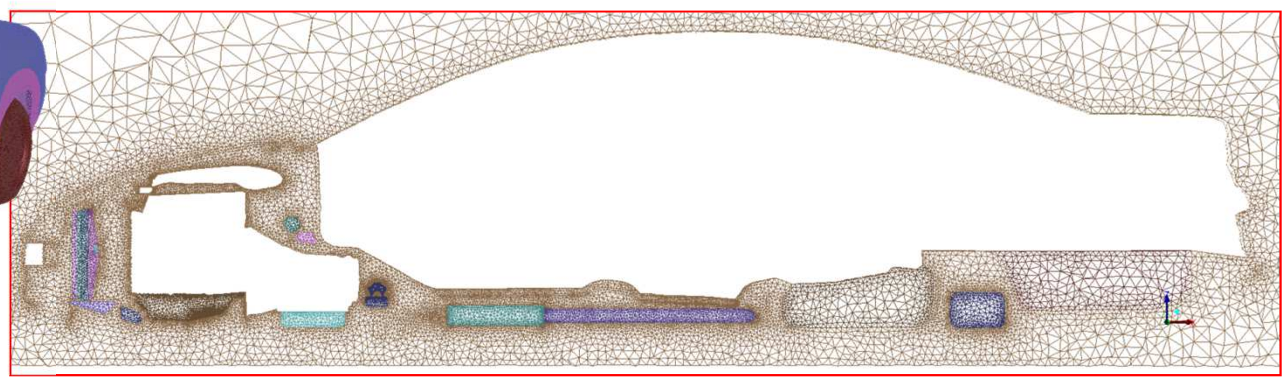
Model specifications.

- **12 million tet mesh**
  - **A dozen solids**
  - **Exhaust internal flow**
  - **Fuel tank**
  - **Tires**
  - **Baffles (heat shields)**
  - **Air induction system**



- **Road Condition:**
  - **Accelerate to 50 mph → Drive uphill for a long time → decelerate to 0 mph → Soak**

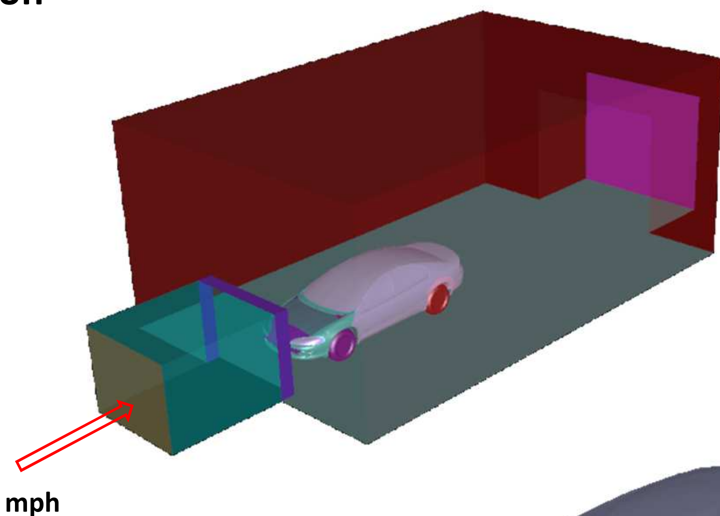


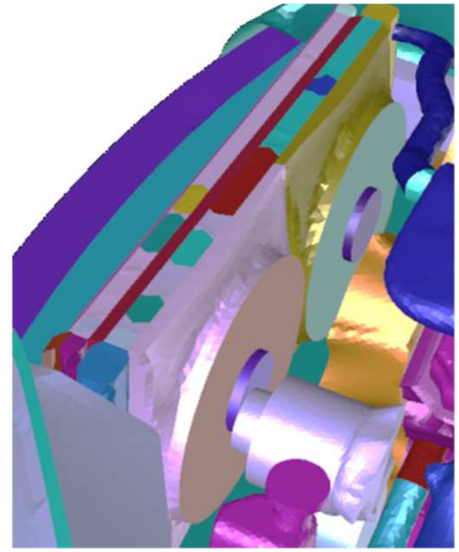


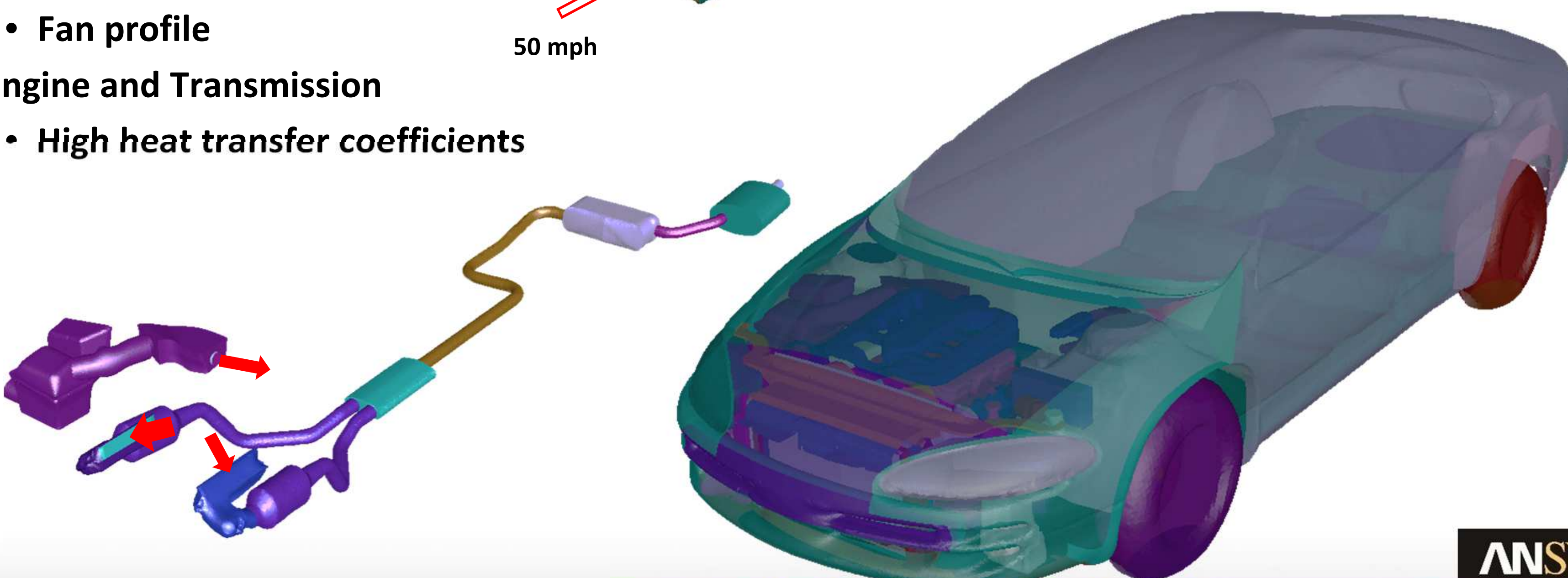
Vehicle Thermal Soaking – A Generic UTM Model

Steady State Load Condition

- Vehicle speed and ambient condition
  - 50 mph
  - 27 ^{o}C
- Exhaust gas inlets:
  - 0.02 kg/s and 860 ^{o}C
- Air Induction
  - 0.07 m/s (into the engine)
- Fan
  - Fan profile
- Engine and Transmission
  - *High heat transfer coefficients*

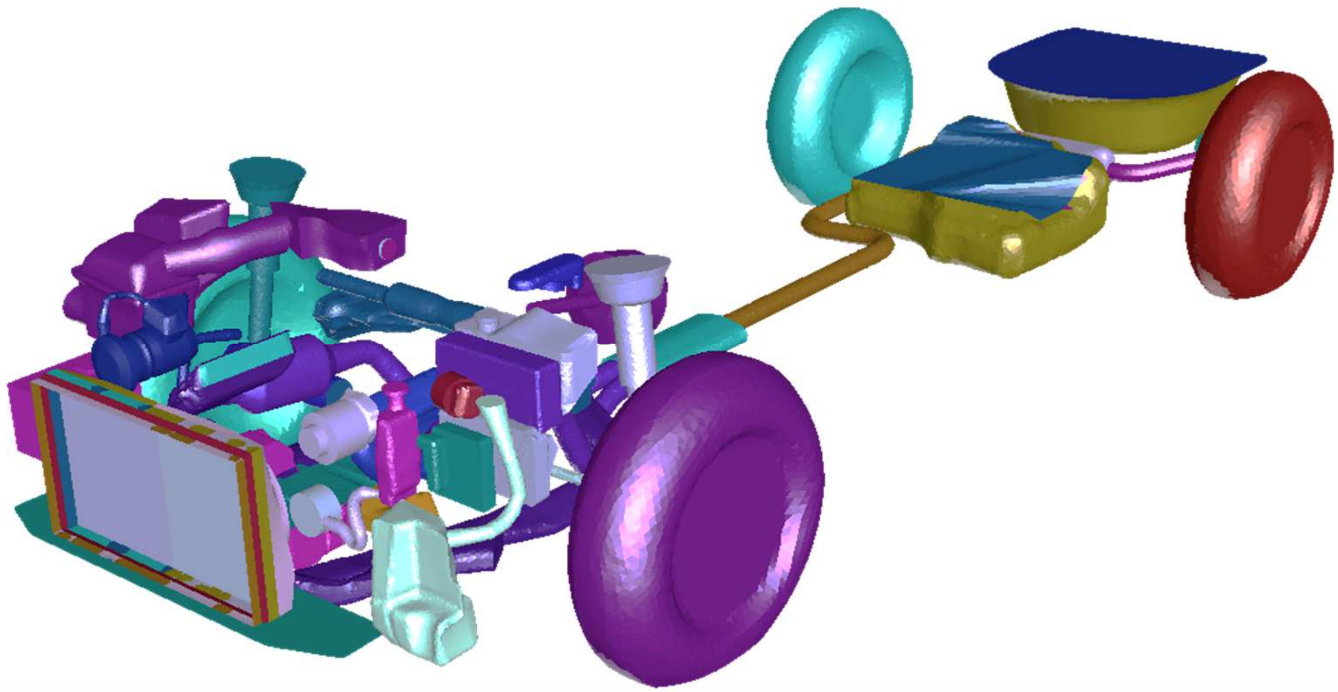






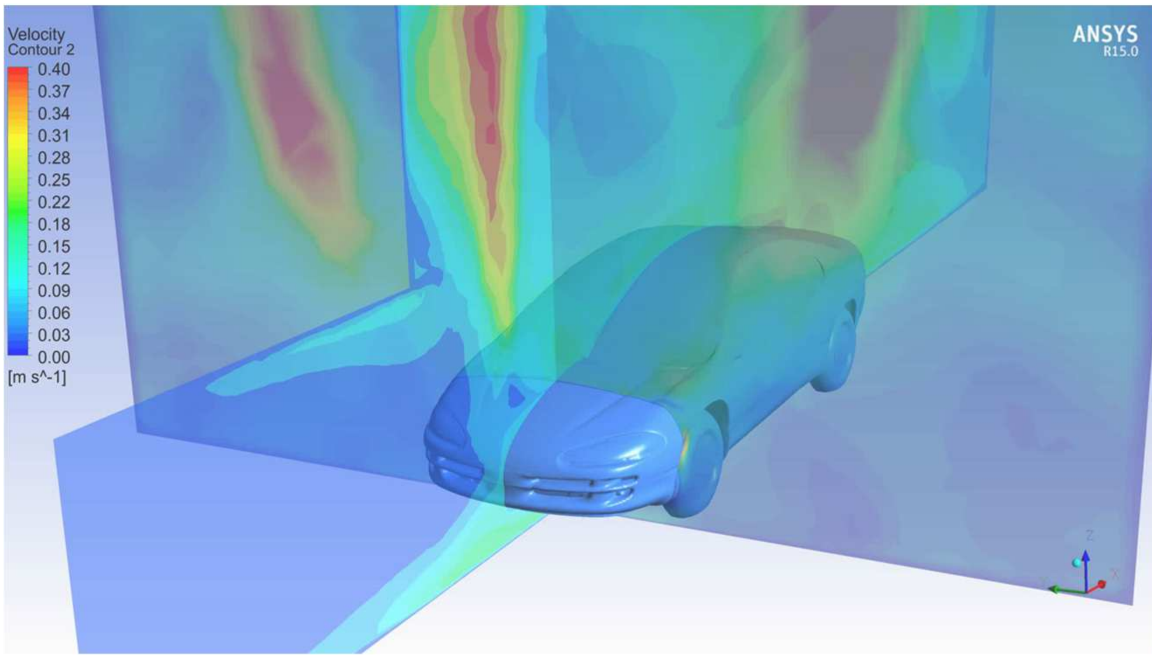
Vehicle Thermal Soaking – A Generic UTM Model

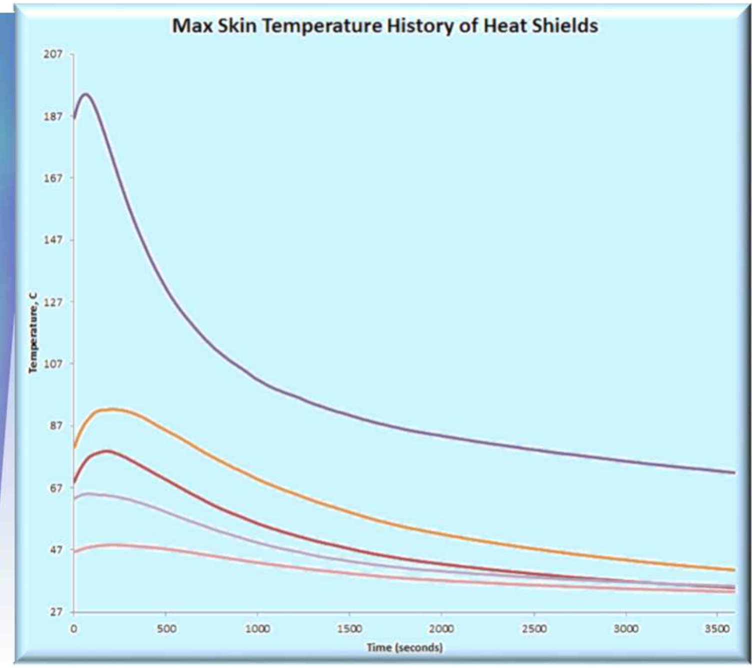
- **Thick solids**
  - **Assumed some material properties and emissivities**
- **Thin solids**
  - **Most are modeled using shell conduction**
- **Convection Augmentation Factor (CAF) applied on the inside exhaust walls to consider the enhanced thermal convection due to impulsive motion of exhaust flow.**

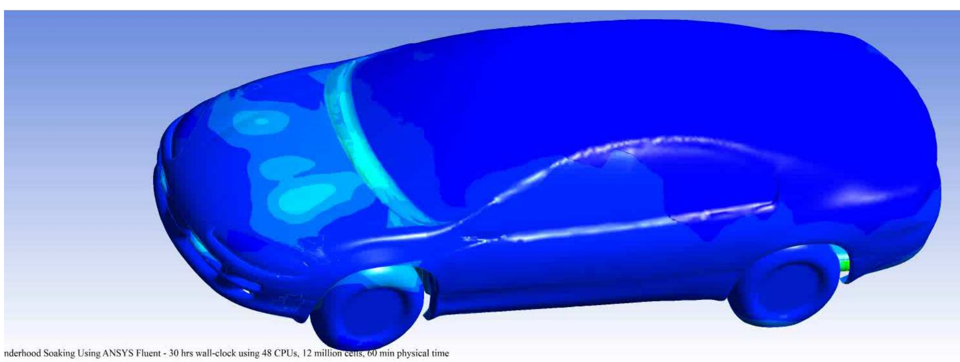


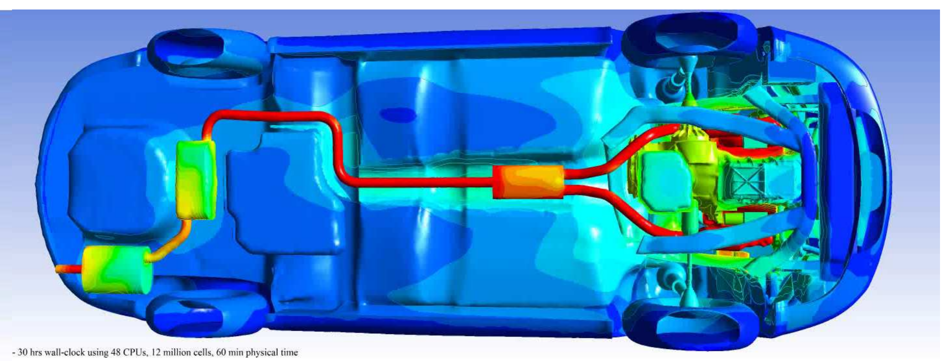
Vehicle Thermal Soaking – A Generic UTM Model

CPU Effort: 20 Hrs wall-clock with 144 CPUs for 60 minutes physical time









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- **Vehicle External Aerodynamics**
- Common Model Approach

Vehicle External Aerodynamics

What

- The aerodynamic characteristic of road vehicles, such as drag and lift.

Why

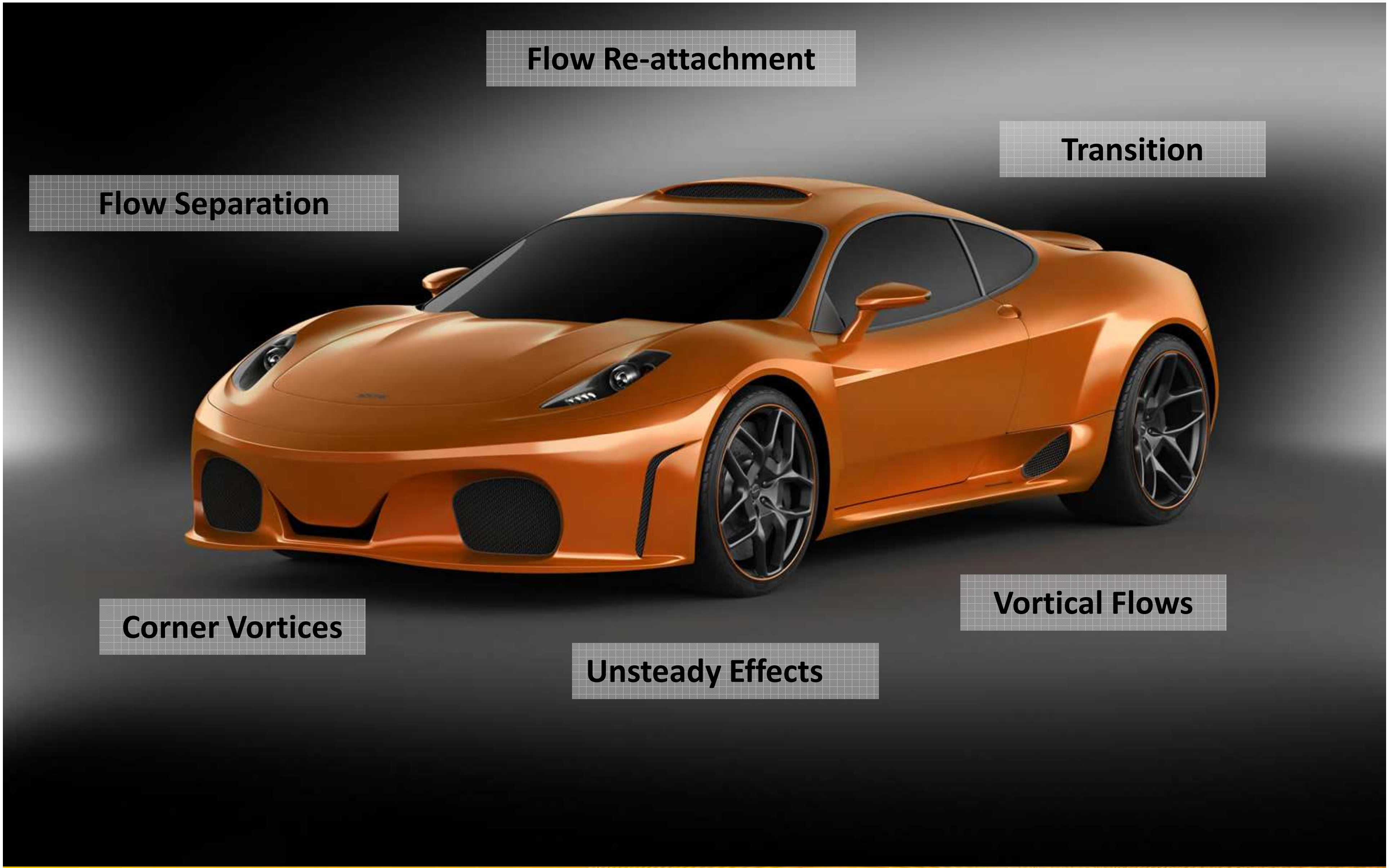
- Vehicle aerodynamic characteristic affects
  - Fuel economy
  - Performance and handling (acceleration, grip, stability, etc)
  - Wind noise
  - Esthetic

How

- Proper numerical models to capture the physics.
- Good-quality mesh to resolve the flow details.

- ✓ **Aerodynamic characteristic prediction for full-vehicle geometries**
- ✓ **Resolution of important flow features**
  - **Boundary layers**
  - **flow separation**
  - **Recirculation**
  - **Reattachment**
  - **noise sources**

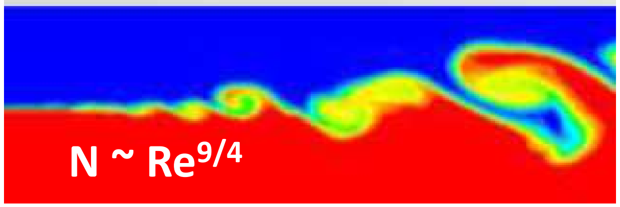
Vehicle External Aerodynamics



Vehicle External Aerodynamics - Turbulent Flow Simulation Methods

DNS

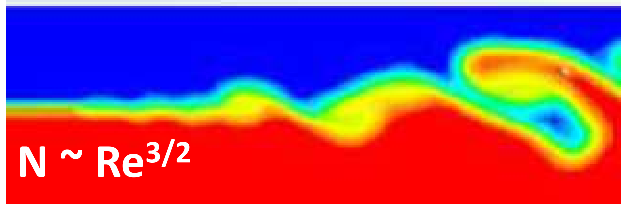
(Direct Numerical Simulation)



- Numerically solving the full unsteady Navier-Stokes equations
- No modeling is required
- A research tool only– far too much information for industrial applications

SRS

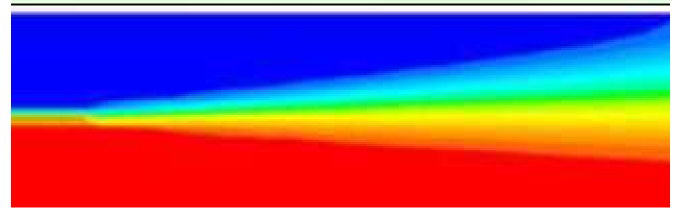
(Scale Resolving Simulations)



- Includes Large Eddy Simulation (LES)
- The motion of the largest eddies is directly resolved in the calculation, in at least a portion of the domain, but eddies smaller than the mesh are modeled
- Inherently unsteady method

RANS

(Reynolds Averaged Navier-Stokes Simulations)



- Solve Reynolds-averaged Navier-Stokes equations (time-average)
- Steady state solutions are possible
- All turbulence is modeled. Larger eddies are not resolved
- RANS turbulence models are the only modeling approach for steady state simulation of turbulent flows
- This is the most widely used approach for industrial flows

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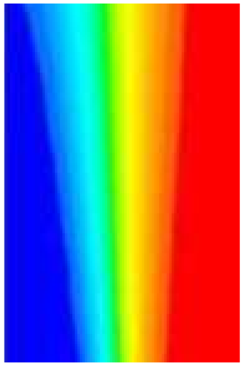
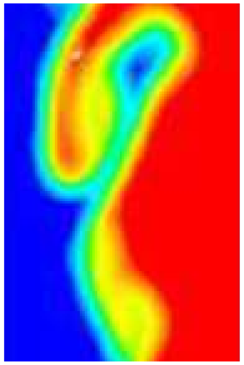
Vehicle External Aerodynamics - Comparison of RANS and SRS



RANS

Advantages: For many applications, steady state solutions are preferable, and for many applications a good RANS model with a good quality grid will provide all the required accuracy

Disadvantages: For some flows, challenges associated with RANS modeling can limit the level of accuracy that is possible to attain



SRS

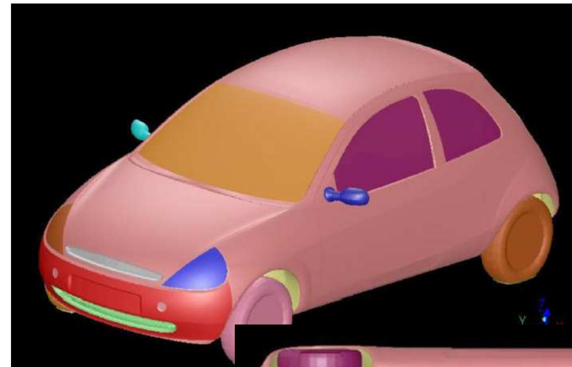
Advantages: Potential for improved accuracy when the resolution of the largest eddies is important or when unsteady data is needed

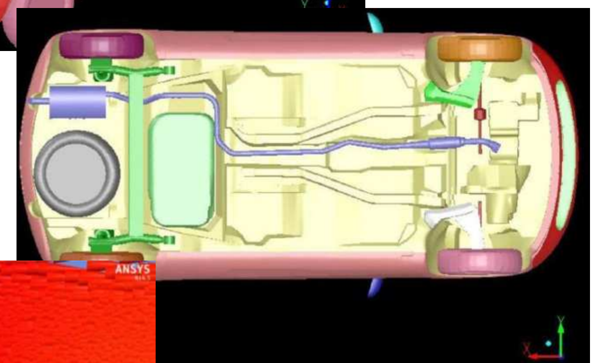
Disadvantages: computationally expensive; Higher grid resolution required; Unsteady simulation with small time steps generates long run times and large volumes of data

Vehicle External Aerodynamics - Turbulence Guidelines for External Aerodynamic CFD Analysis

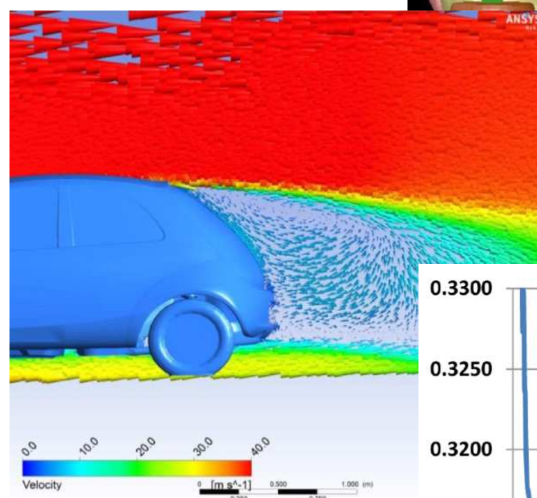
Aerodynamic Body, limited CPU resources	• Realizable k-e models with wall function (y^+>30)
Aerodynamic Body, adequate CPU resources	• k-w SST model or transition k-w models (y^+~1)
Bluff Body, limited CPU resources	• Realizable k-e models with wall function (y+>30)
(D)DES/(E)LES/SAS model in unsteady simulation	•Run unsteady for about 1~1.5*T* (*T=L/U* where *L* is the domain length and *U* is the vehicle speed) without collecting data or flow statistics. •Obtain statistics after that

Vehicle External Aerodynamics

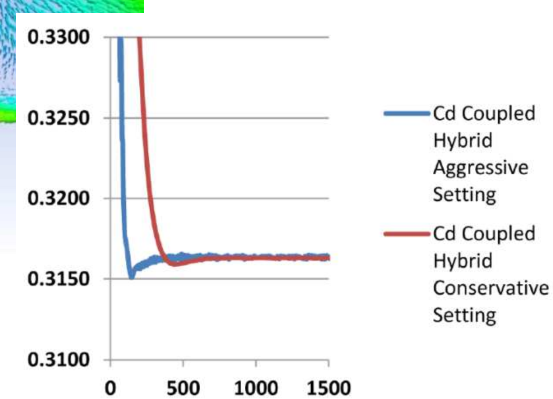




- Ford Ka
- 18M polyhedral cells
- $y^+ \sim 30 \ldots 300$
- RKE with non-equilibrium wall-function
- 8h on 24 CPUs



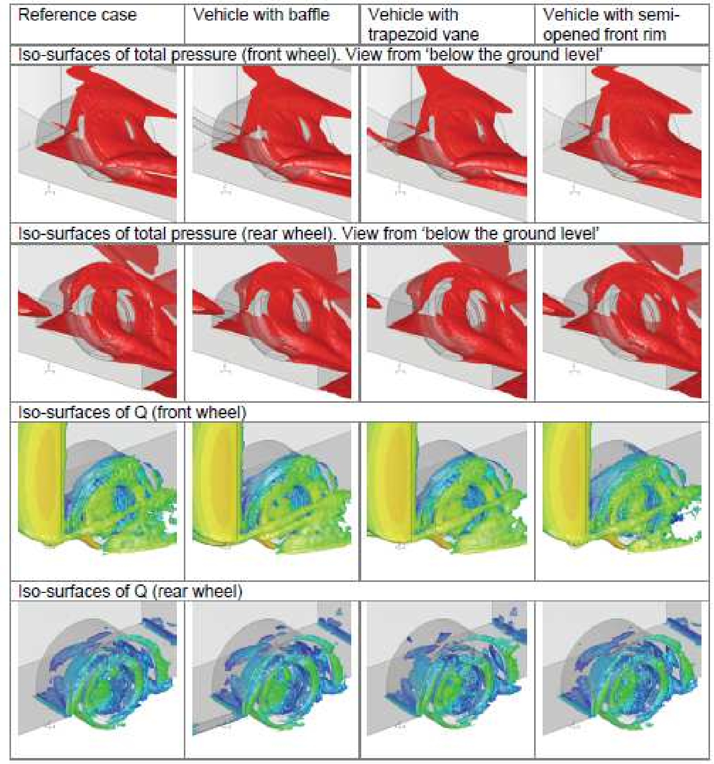
Cd (data)	Cd (CFD)	Δcd [%]
1	0.999	0.09

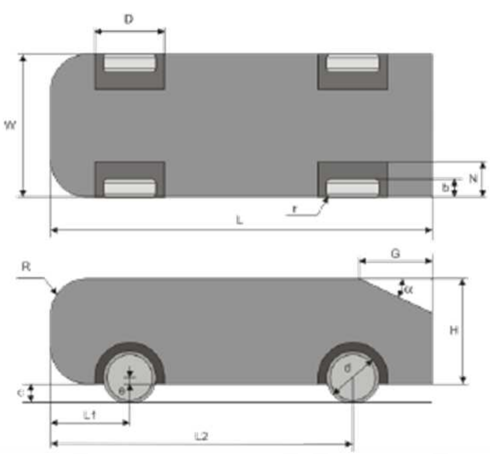


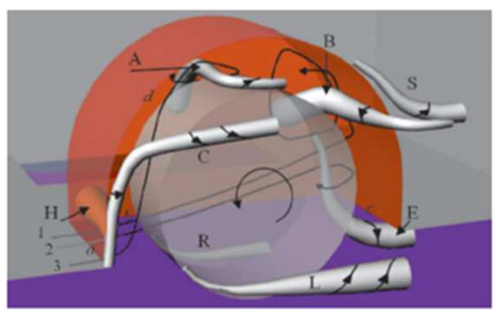
Aggressive settings: default PBCS
Conservative settings: Courant 50, explicit URFs 0.25

Vehicle External Aerodynamics - Wheel Aerodynamics

- **Ahmed Body with wheels**
- **3.3M cells**
- **Hybrid prism/tet mesh**
- **y^+ ~ 30**
- **RKE with non-equilibrium wall-function**







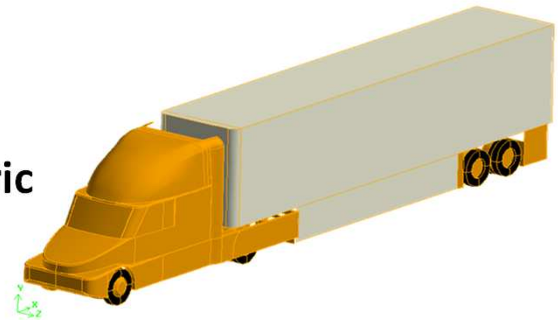
Investigation of Simple Possibilities for Reduction of Drag due to the Wheels of Road Vehicles - Attila Schwarczkopf, MSc

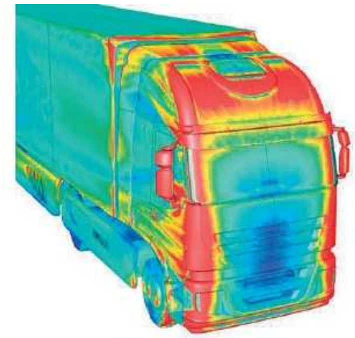
Abbott Risk Consulting Ltd., UK

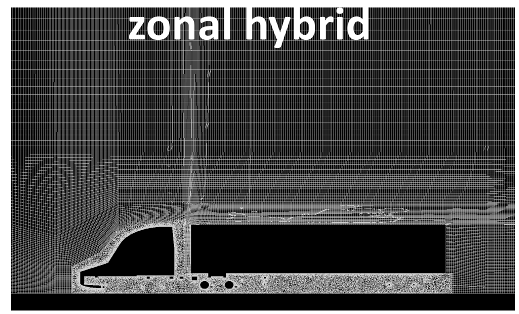
Case	Drag coefficient	Lift coefficient
CFD, Authors	0.281	0.288
Experiment [3]	0.289	0.280
Difference in %	2.7%	2.8%

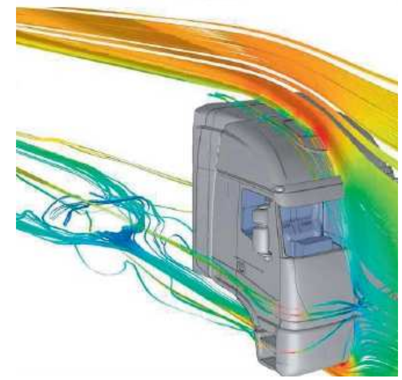
Vehicle External Aerodynamics – Truck Aerodynamics

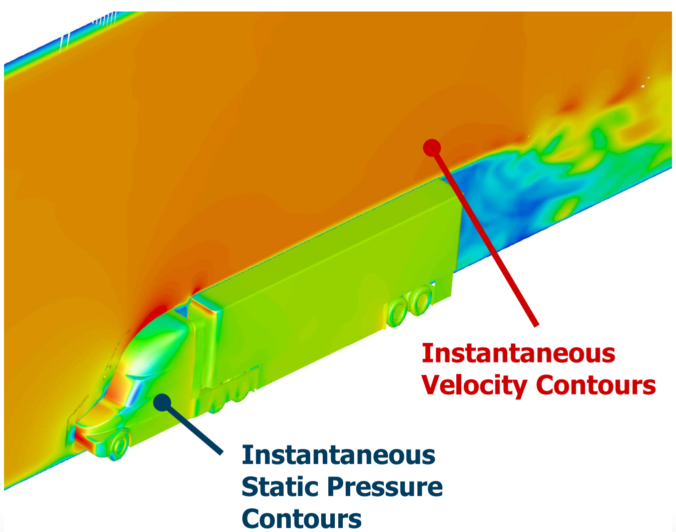
- **Simulation of Flow Field Around a Generic Tractor Trailer Truck**
- **Yaw angles 0° and 6°**
- **Steady-state vs. Transient**
- **(U)RANS vs. SRS**









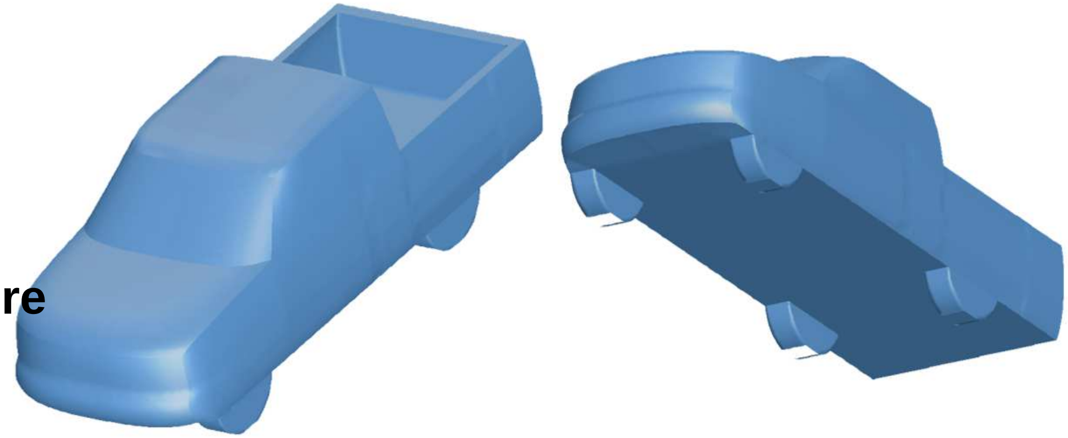


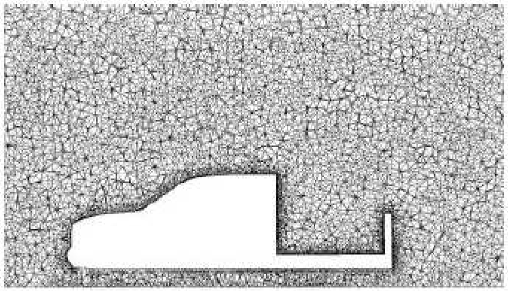
Yaw Angle	*Solver*	*Meshing Strategy*	*Turbulence Model*	*Deviation from Expt.*
0°	Steady State	Traditional Tet	Realizable k-ε	+13.3%
0°	Transient	Traditional Tet	RNG k-ε	+8.0%
0°	Steady State	Zonal Hybrid	Realizable k-ε	-1.6%
0°	Transient	Zonal Hybrid	RNG k-ε	0.0%
6°	Transient	Zonal Hybrid	RNG k-ε	+3.8%
0°	Transient	Zonal Hybrid	DES	+0.77%
6°	Transient	Zonal Hybrid	DES	-3.5%

Note: Traditional Tet Strategy = 5.5M cells, Zonal Hybrid Strategy = 8.3M cells

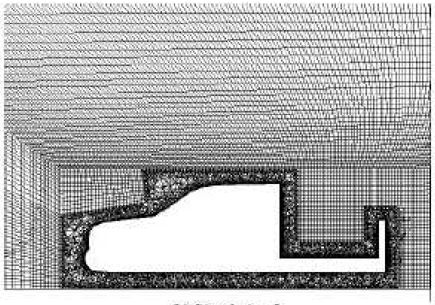
Vehicle External Aerodynamics - Pick-Up Aerodynamics

- **Transient Simulation of the Flow Field around a Generic Pick-Up Truck**
- **Simulation 1: LES**
- **Mesh was not fine enough for pure LES**
- **Simulation 2: k-e-RNG**

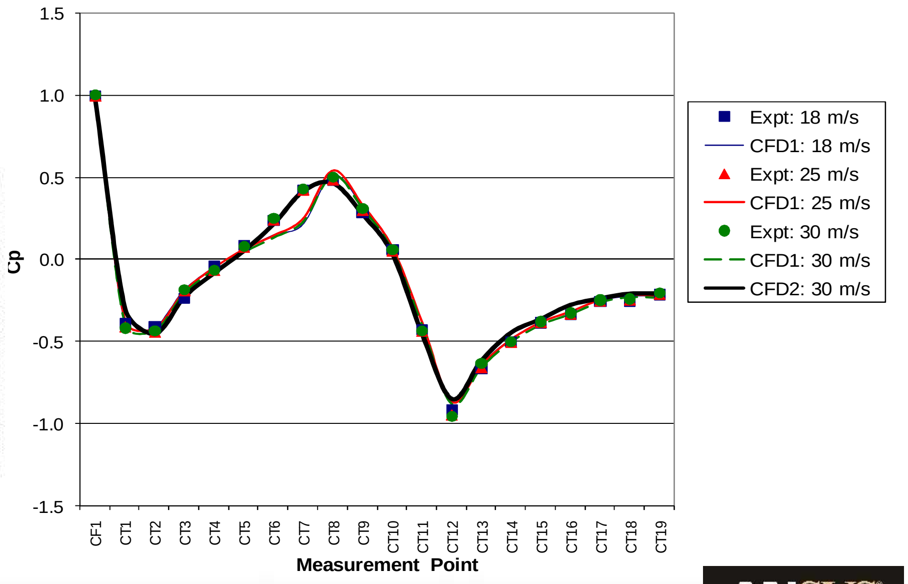




(a) Simulation 1



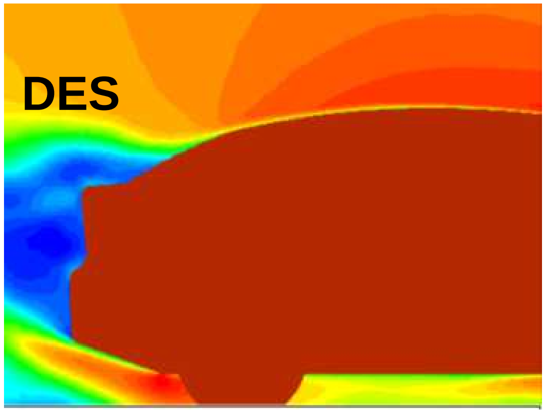
(b) Simulation 2

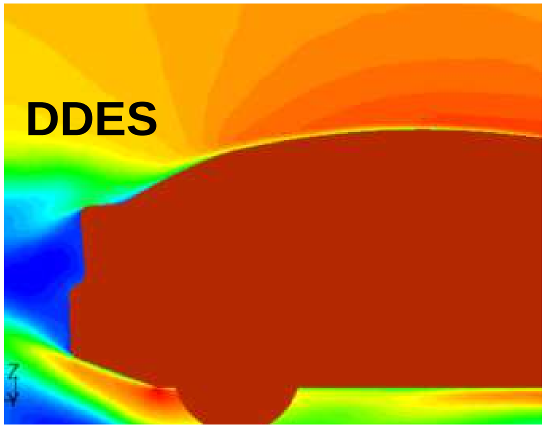


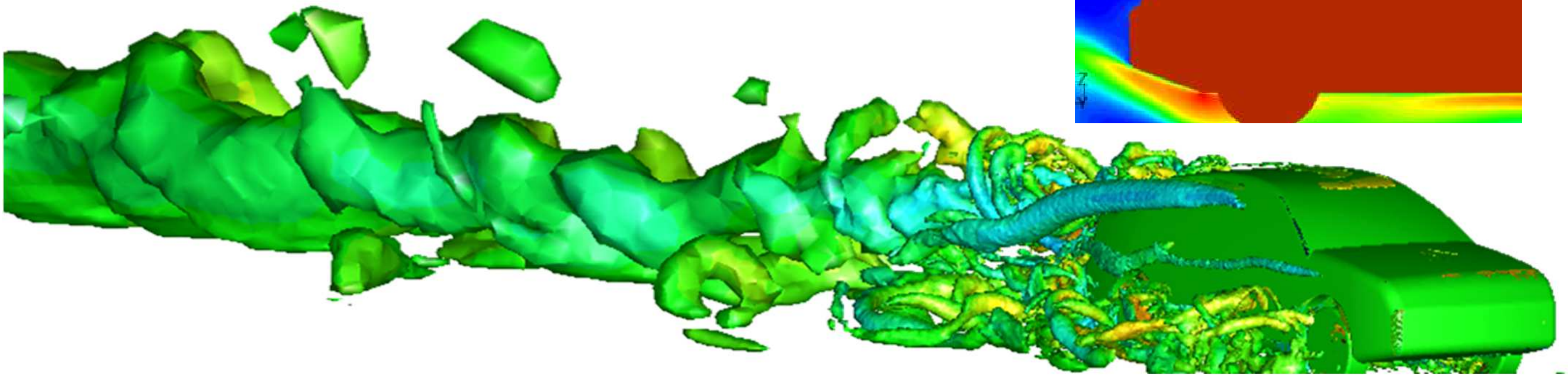
Vehicle External Aerodynamics - PSA Peugeot Citroën

- External aerodynamics with yaw angle 20°
- Velocity 40 m/s
- DDES Turbulence Model
  - DES can produce grid-induced separation

Model	Exp.	DDES	DES	LES
Drag (SCx)	1	1.014	1.071	0.986







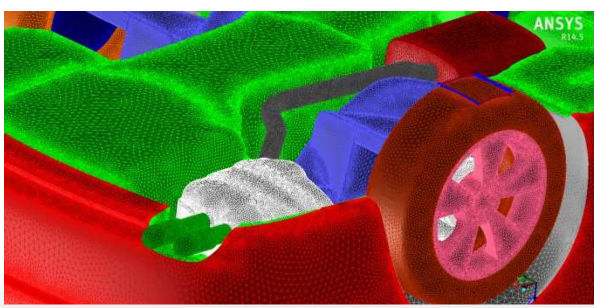
Courtesy PSA Peugeot Citroën

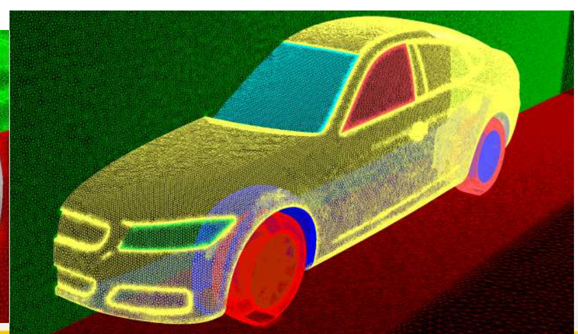
ANSYS

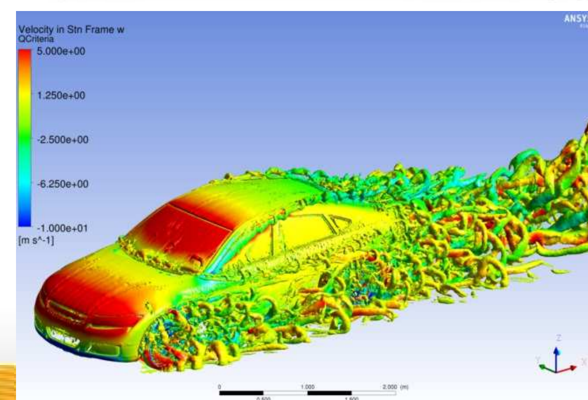
Vehicle External Aerodynamics - DrivAer

DrivAer Aerodynamics

- Mixture of BMW 3 series and Audi A4 series
- 113M cells, $y^+ \leq 1$
- 20 prism layers on car
- 15 prism layers on road
- Steady state case
- 15 hours (168 nodes)
- Transient SAS case
- ~ 15 days, 3s flow time

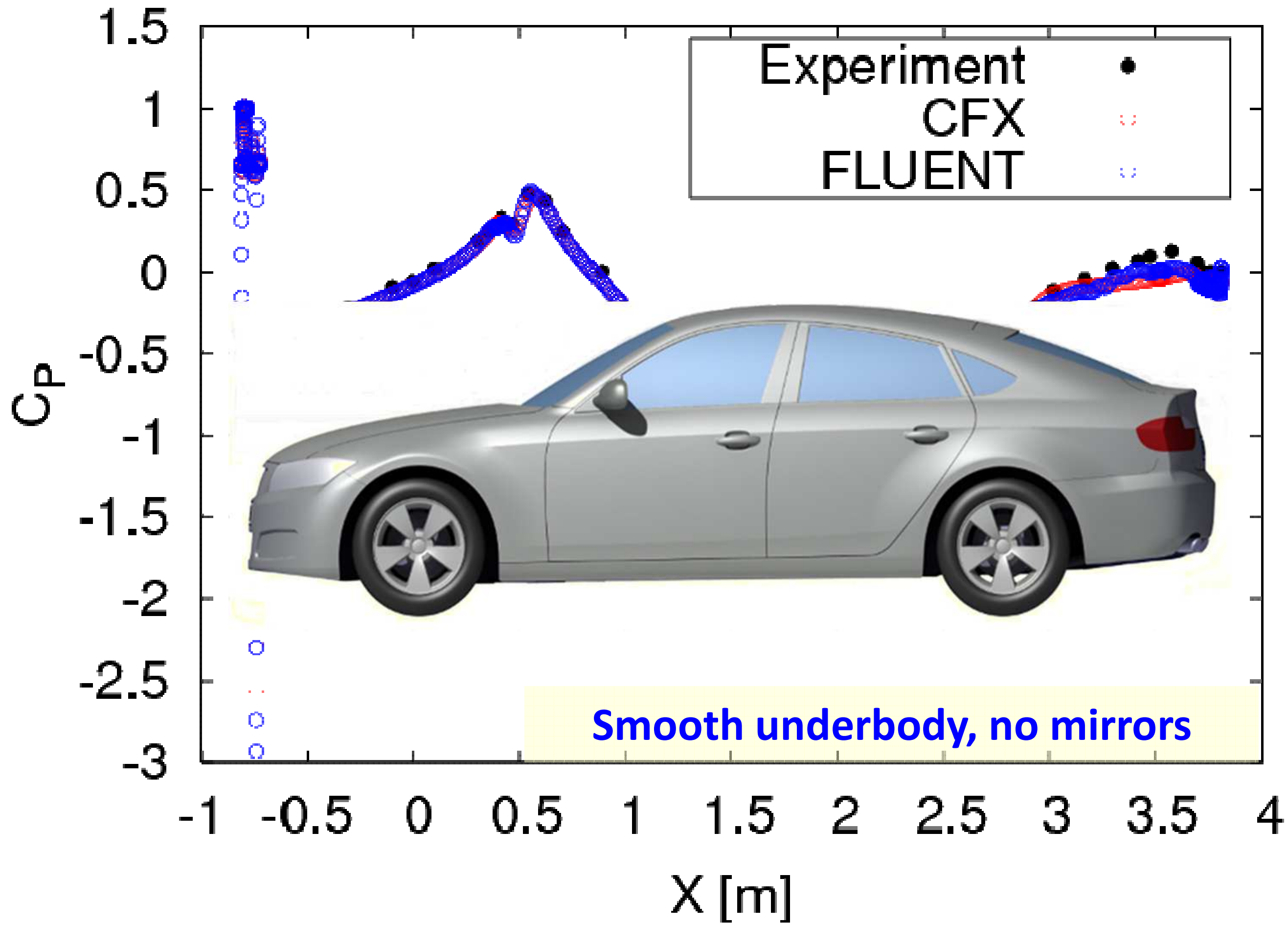






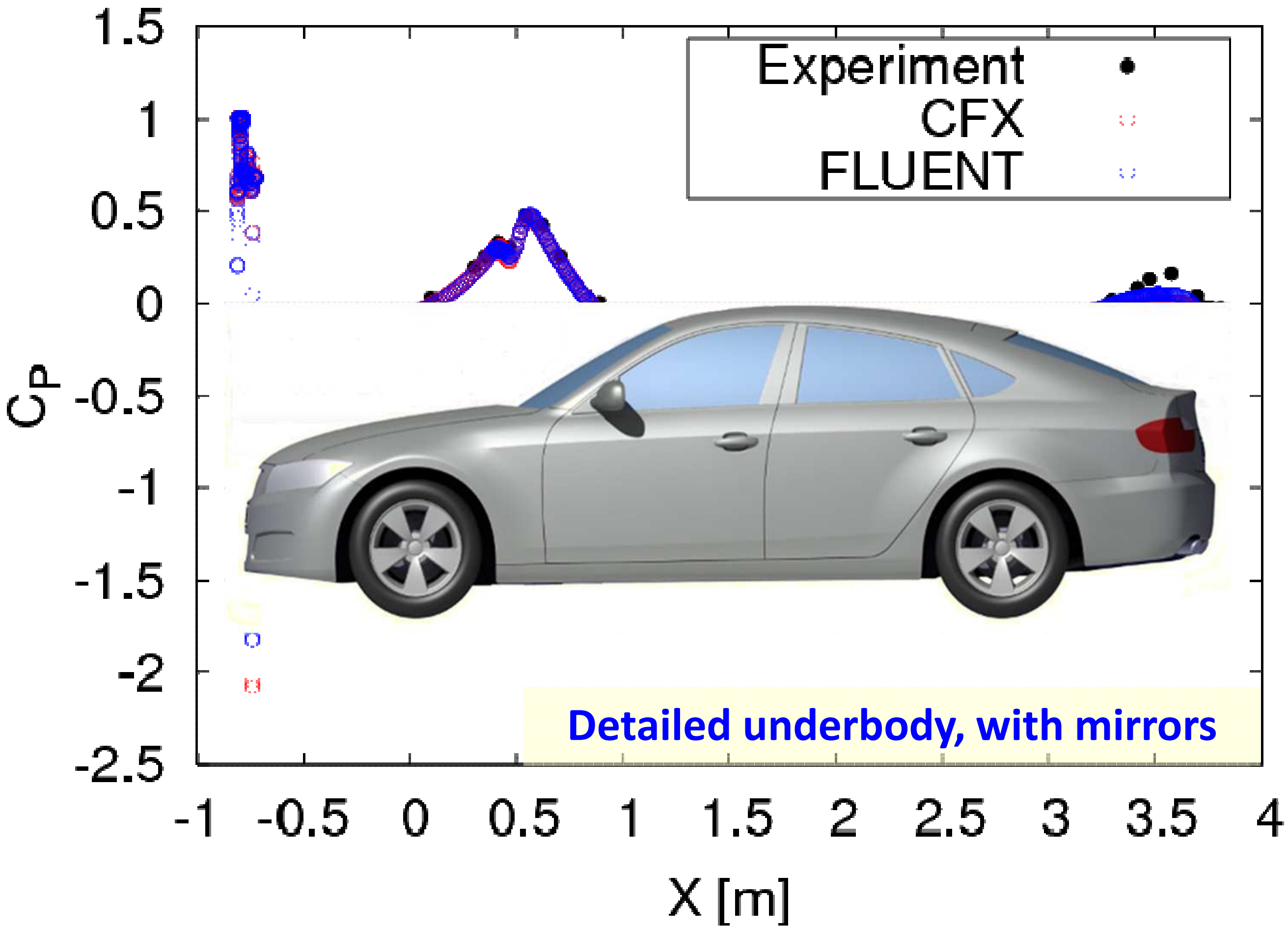
Vehicle External Aerodynamics - DrivAer

DrivAer Pressure Coefficient (1)

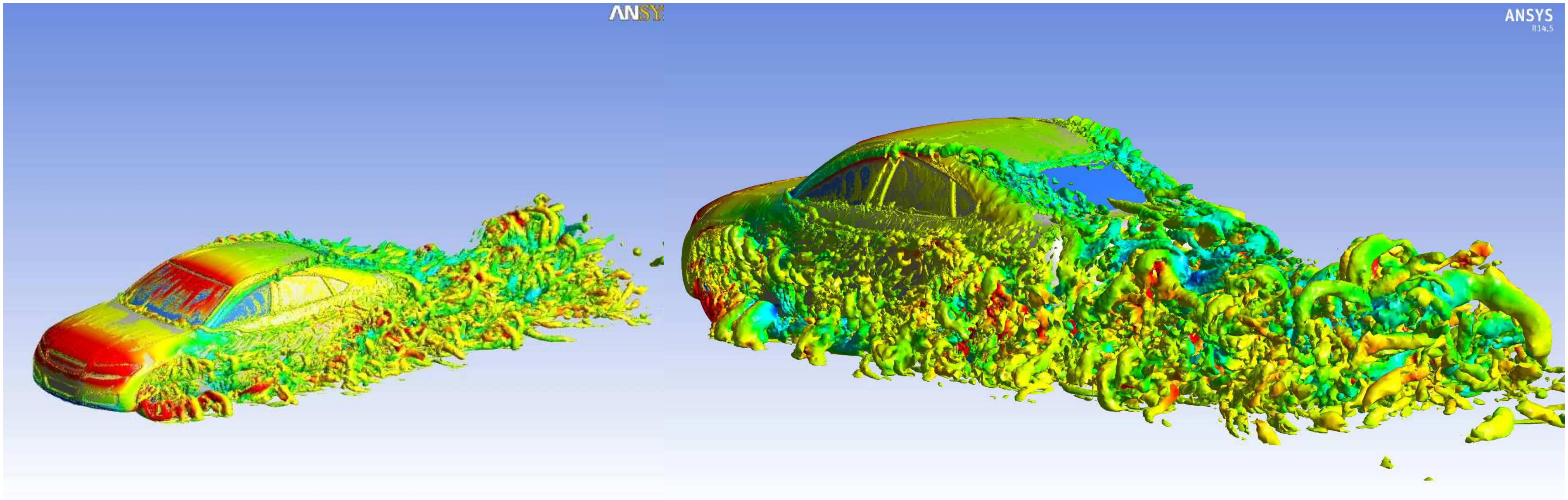


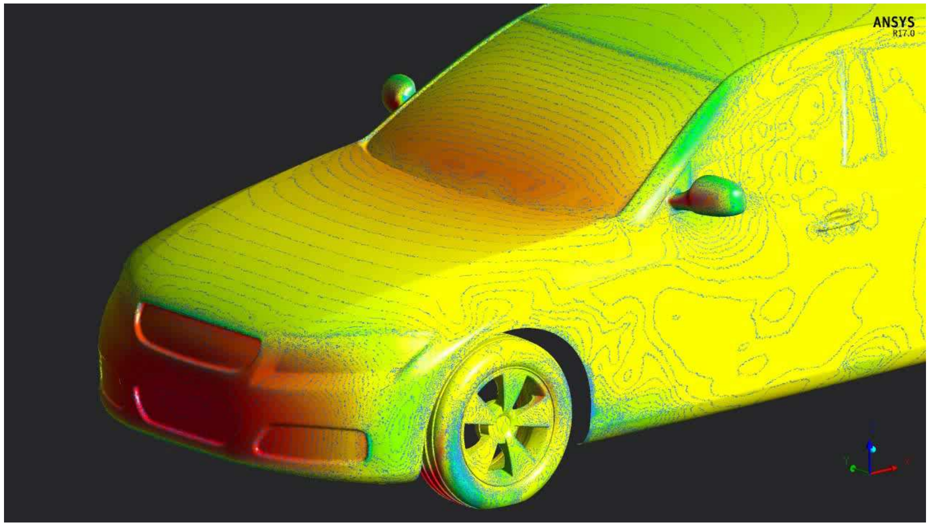
Vehicle External Aerodynamics - DrivAer

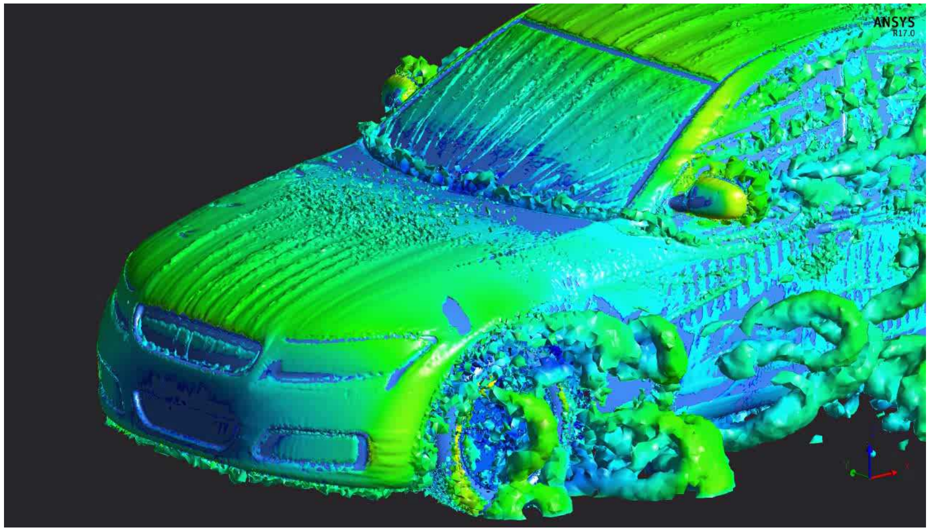
DrivAer Pressure Coefficient (2)



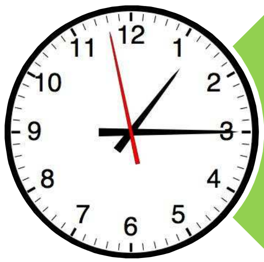
Vehicle External Aerodynamics - DrivAer



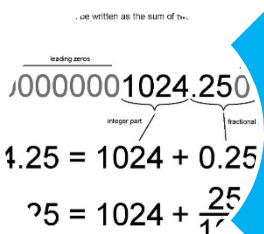




Vehicle External Aerodynamics - Summary



Steady-sate simulations for quick turnaround



Unsteady state simulation for ultimate accuracy

ANSYS Fluent Steady State and Transient simulation capability offers the customer a versatile portfolio to achieve balanced simulation result/cost based on their needs

Outline

- Front-End-Air-Flow (FEAF) Simulation for Vehicle
- Underhood Thermal Management (UTM)
- Full Vehicle Thermal Soaking
- Vehicle External Aerodynamics
- **Common Model Approach**

Vehicle Common Model Approach

What

- A common model is an approach to use a single unified model to incorporate multiple vehicle applications, including FEAF, UTM, external aero, etc.

Why

- Minimizing time spent on CAD assembly and CAD cleanup within the company
- No compromise/assumptions on boundary conditions at the interface of differenet attributes
- Respecting the coupled nature of the various subsystems as in the real world
- Using a common material database for all simulations

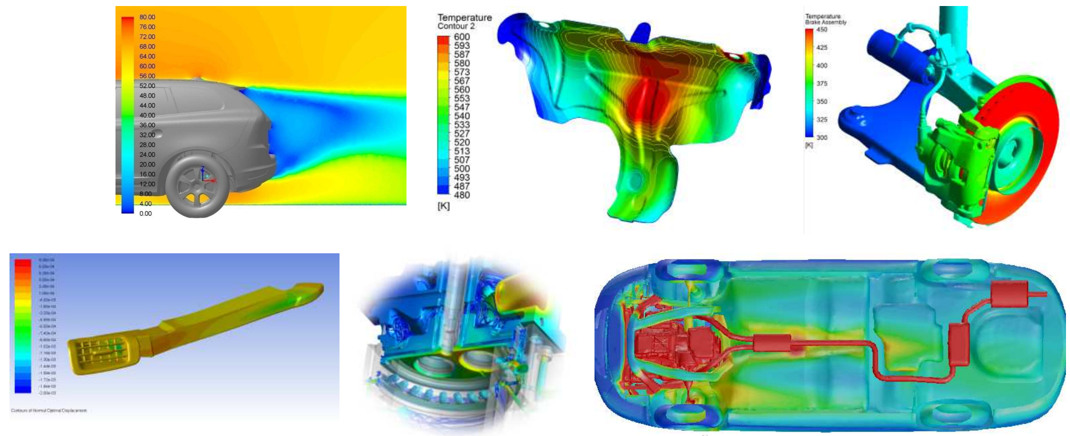
How

- Change of paradigm
- ANSA-Tgrid

Faster and more accurate results.

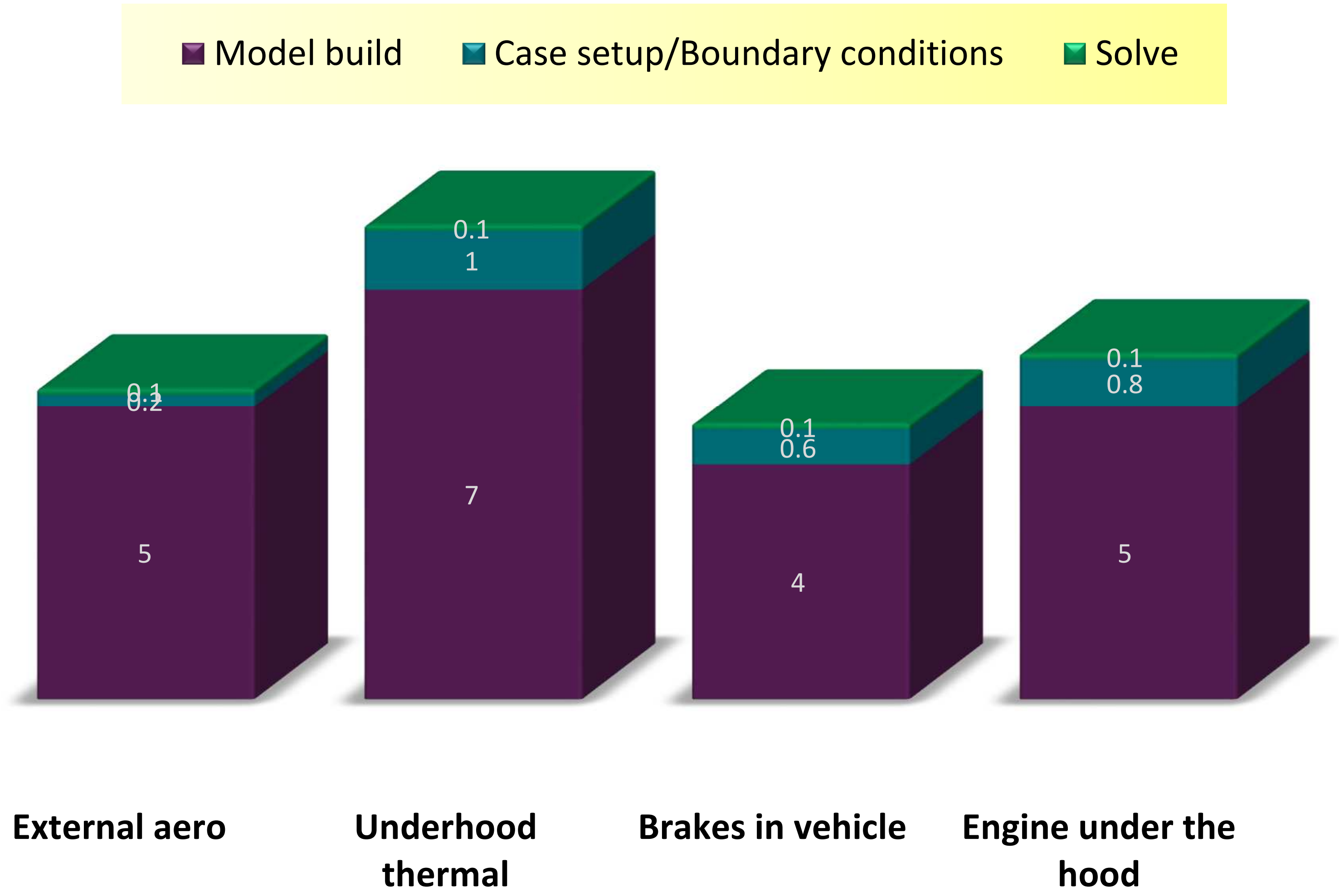
Motivation of Using a Common Model

- **Within the automotive OEMs, it is common to have separate teams for different areas of simulation focus**
  - Aerodynamics
  - Underhood Thermal Management
  - Aero Acoustics
  - Engine CHT
  - Brakes
  - Exhaust After-treatment
  - Climate Comfort
  - Contamination (Snow, Dust, Rain)
  - …

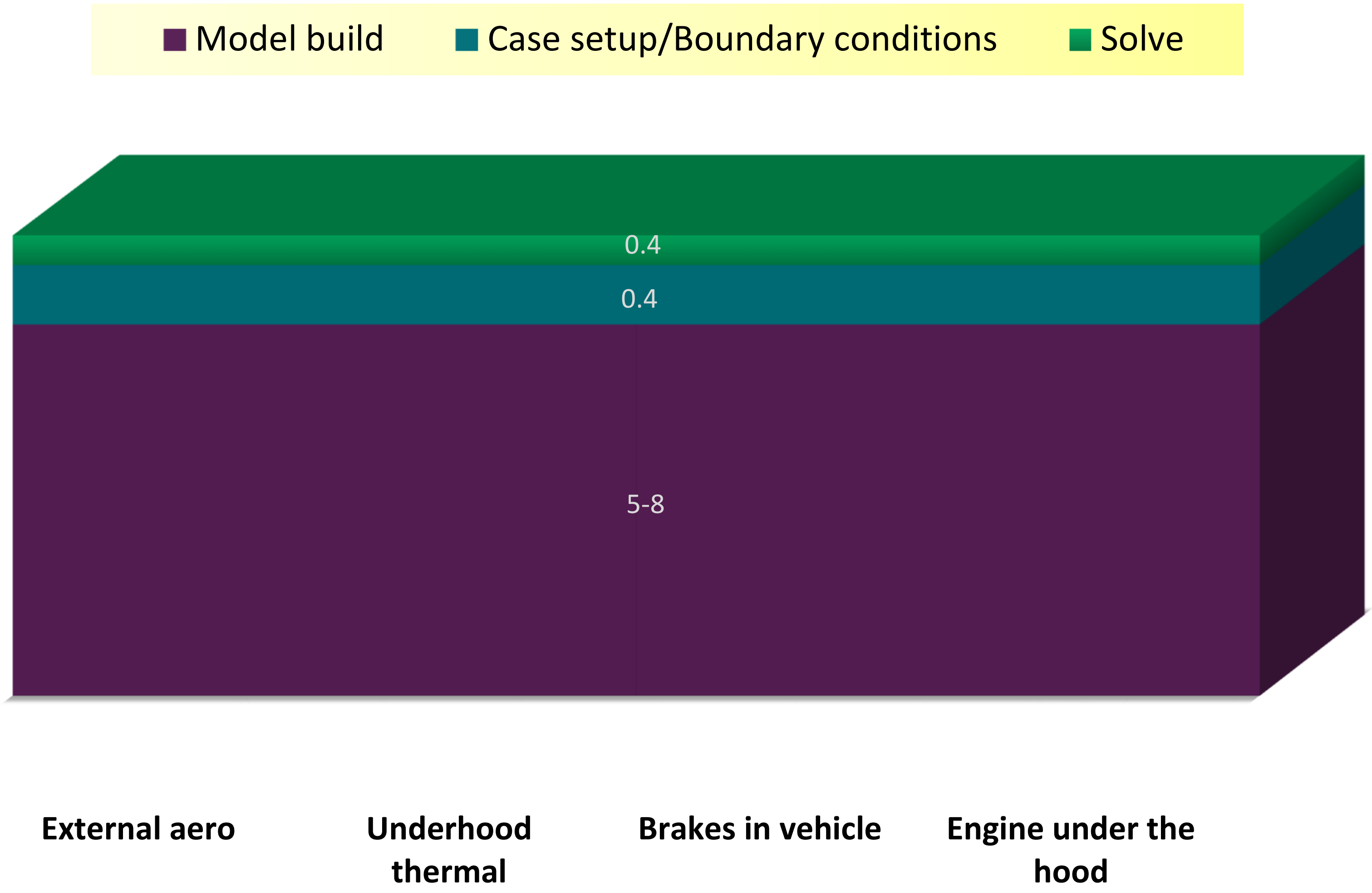


- **This allows each team to focus on individual areas.**
- **However, potential inefficiencies with this setup are**
  - Duplication of CAD work (Cleanup/assembly)
  - Duplication of Meshing
  - Inconsistency and excessive need of boundary conditions and material data
  - Potential compromise on accuracy due to interdependencies
  - Non-optimal simulation times

Model per Attribute



Common Multi-Objective Model



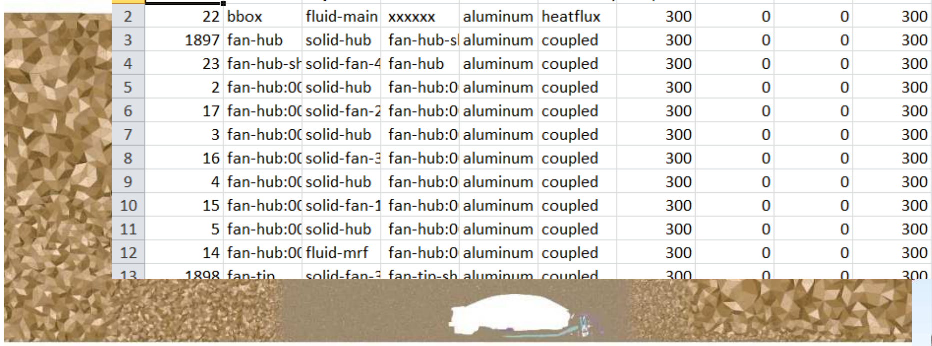
Ideal Workflow (Current Study)

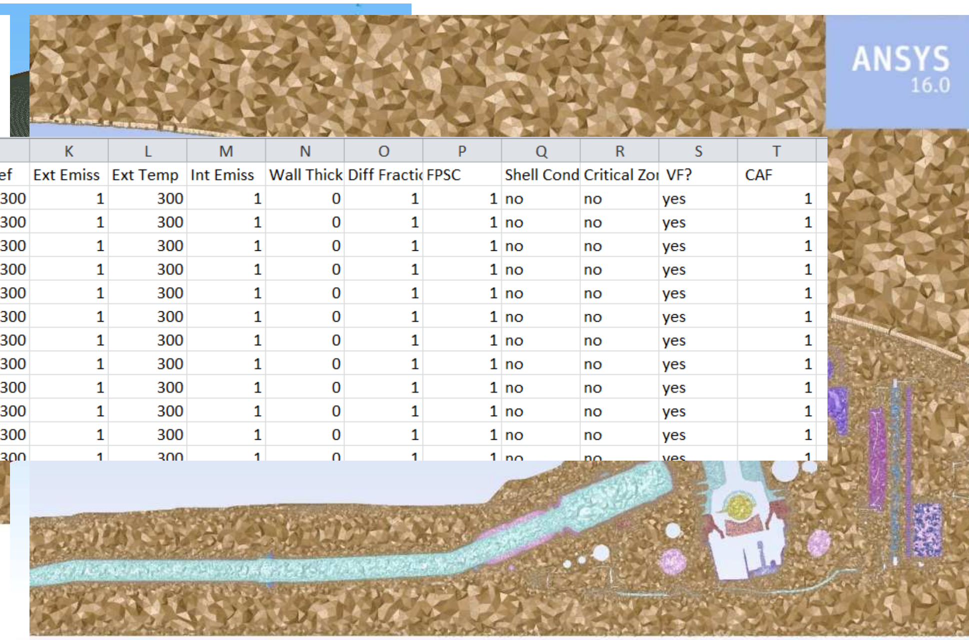
CAD
- CAD/Tesselated representation of the complete vehicle

Conformal HQ surface mesh
- Surface mesh suitable for all attributes

Volume Mesh
- Volume mesh suitable for all attributes

Case Setup
- Automated set up for all attributes





	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Zone ID	Wall Zone	Adj Cell Zo	Shadow Zc	Material	Wall BC Ty	Temperatu	HeatFlux	Convectio	HTC Ref	Ext Emiss	Ext Temp	Int Emiss	Wall Thick	Diff Fractio	FPSC	Shell Cond	Critical Zo	VF?	CAF
2	22	bbox	fluid-main	xxxxxx	aluminum	heatflux	300	0	0	300	1	300	1	0	1	1	no	no	yes	1
3	1897	fan-hub	solid-hub	fan-hub-sl	aluminum	coupled	300	0	0	300	1	300	1	0	1	1	no	no	yes	1
4	23	fan-hub-sh	solid-fan-4	fan-hub	aluminum	coupled	300	0	0	300	1	300	1	0	1	1	no	no	yes	1
5	2	fan-hub:0(	solid-hub	fan-hub:0	aluminum	coupled	300	0	0	300	1	300	1	0	1	1	no	no	yes	1
6	17	fan-hub:0(	solid-fan-2	fan-hub:0	aluminum	coupled	300	0	0	300	1	300	1	0	1	1	no	no	yes	1
7	3	fan-hub:0(	solid-hub	fan-hub:0	aluminum	coupled	300	0	0	300	1	300	1	0	1	1	no	no	yes	1
8	16	fan-hub:0(	solid-fan-3	fan-hub:0	aluminum	coupled	300	0	0	300	1	300	1	0	1	1	no	no	yes	1
9	4	fan-hub:0(	solid-hub	fan-hub:0	aluminum	coupled	300	0	0	300	1	300	1	0	1	1	no	no	yes	1
10	15	fan-hub:0(	solid-fan-1	fan-hub:0	aluminum	coupled	300	0	0	300	1	300	1	0	1	1	no	no	yes	1
11	5	fan-hub:0(	solid-hub	fan-hub:0	aluminum	coupled	300	0	0	300	1	300	1	0	1	1	no	no	yes	1
12	14	fan-hub:0(	fluid-mrf	fan-hub:0	aluminum	coupled	300	0	0	300	1	300	1	0	1	1	no	no	yes	1
13	1898	fan-tip	solid-fan-3	fan-tip-sh	aluminum	coupled	300	0	0	300	1	300	1	0	1	1	no	no	yes	1

Workflow Alternatives

CAD

- CAD/Tesselated representation of the complete vehicle

- Fine-tuned surface mesh for selected attributes

Conformal surface mesh

- Surface mesh suitable for all attributes

- Fine-tuned volume mesh per attribute
- Prism layers
- Refinement zones
- Solids
- Part Swapping

Volume Mesh

- Volume mesh suitable for all attributes

- Modified volume mesh per attribute
- Solids

Case Setup

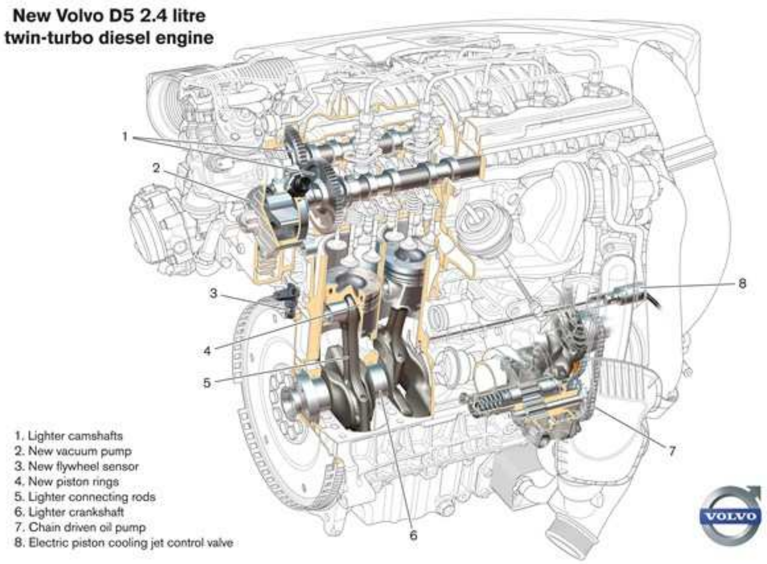
- Automated set up for all attributes

- Modifications per load case
- Morphing
- MDO
- 0D/1D couplings
- Multiphysics

ANSYS

Common Model Example : Volvo S80

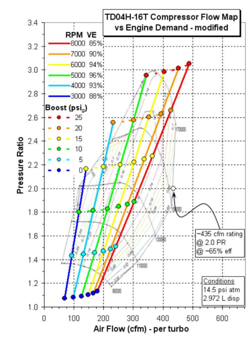
- **Volvo S80 D5 MY2012**
- **2.4-litre, 5-cylinder Twin-turbo Diesel Engine, 215 hp and 440 Nm**



Common Model

- **Attributes included**
  - Aerodynamics
  - Underhood Thermal Management
  - Engine CHT/Under the hood
  - Cooling system
  - Brake system
  - Air intake system
  - Exhaust system
- **~400 Solids**
- **~50 Shells (readily extensible to 1000's)**

- **Use case**
  - Vehicle moving at 110 kph
  - Engine rpm: 2050
  - Thermal sources:
    - Combustion heat in cylinders
    - Hot exhaust gas into exhaust system and environment
    - Frictional heat in brake rotor
  - Brakes engaged
  - Turbo and pump
  - CRFM (Fans and HXs)



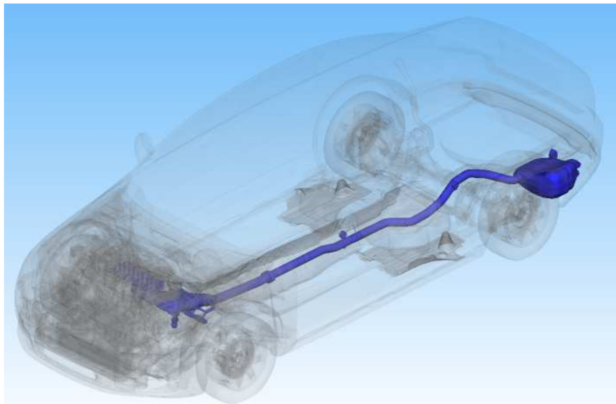
Turnaround

Sub System/Model	Model Build Time (days)
Body, grille	8
Powertrain: Entire engine solids Air intake Cooling circuit	 2.5 1 .1
UTM: Exhaust, turbo, EGR Mounts CRFM Shields	 2 .5 .25
Brakes	1.5
Misc. (CRFM, chassis, suspension, transmission, etc.)	.25
MRFs and Checks	1
Integration	4
Volume Mesh	.5
Detailed Case setup	2
Postprocess	2
Total	**26 (~5 weeks)**

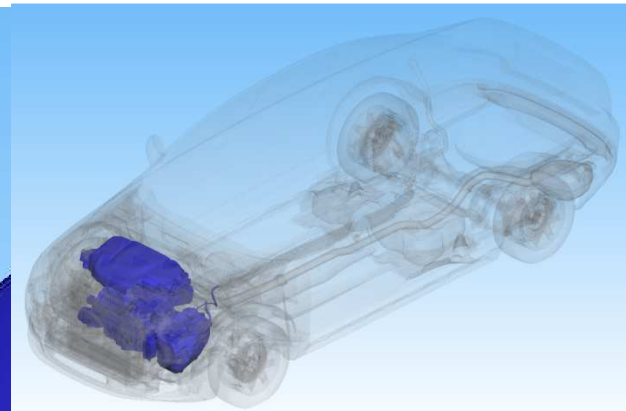
- **Full vehicle with all details**
- **One common model built**
- **CAD-to-Solution time reduced significantly with no compromise on accuracy**
- **Maximizing efficiency across multiple teams**
- **Foundation for common model MDO**

~400 Solid zones
~50 Shell zones
~265 M conformal cells

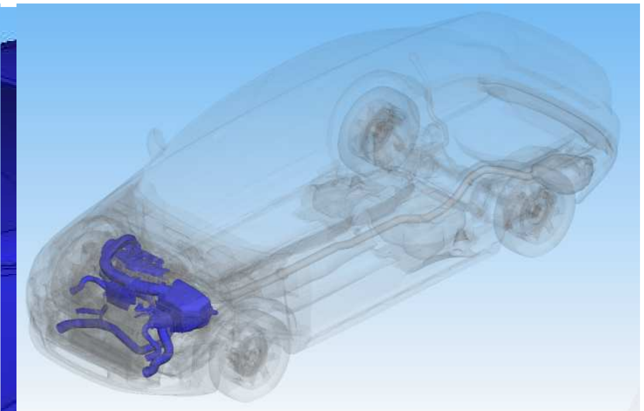
Sub Systems



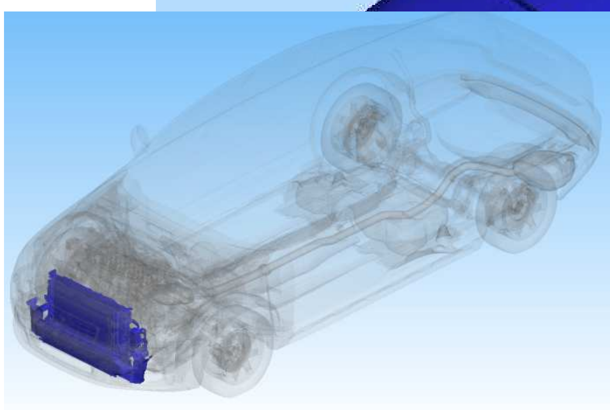
Exhaust System



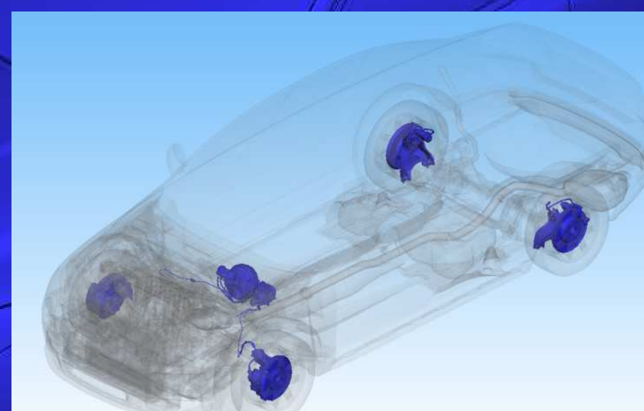
Engine



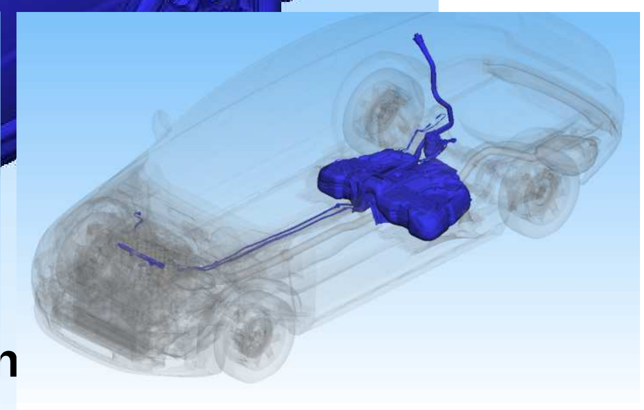
Air Intake System



Cooling System



Brake System



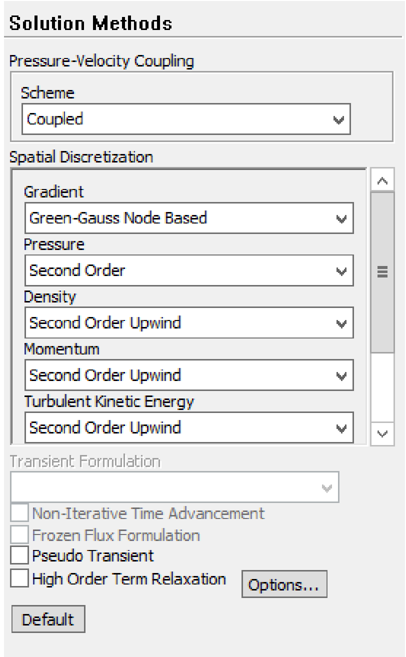
Fuel System

Simulation Details

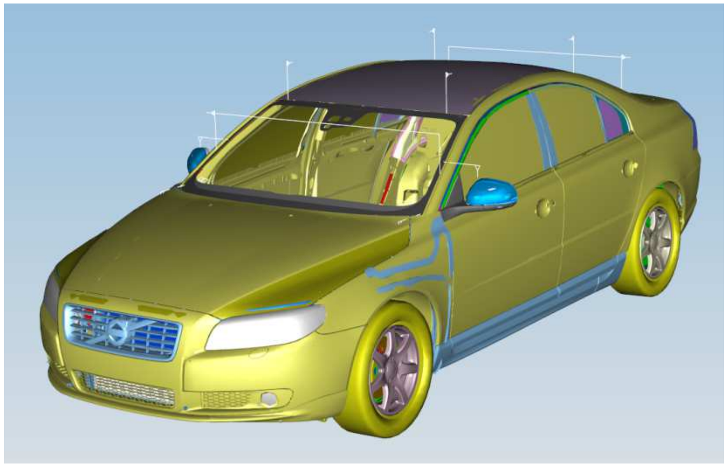
- **One single simulation**
- **Realizable k-ε Turbulence Model with Enhanced Wall Function**
- **Second Order Upwind discretization, Coupled Solver, GGNB**
- **Surface to Surface (S2S) Radiadion Model**
- **Secondary streams**
  - **Exhaust**
  - **Air intake system**
  - **Cooling**

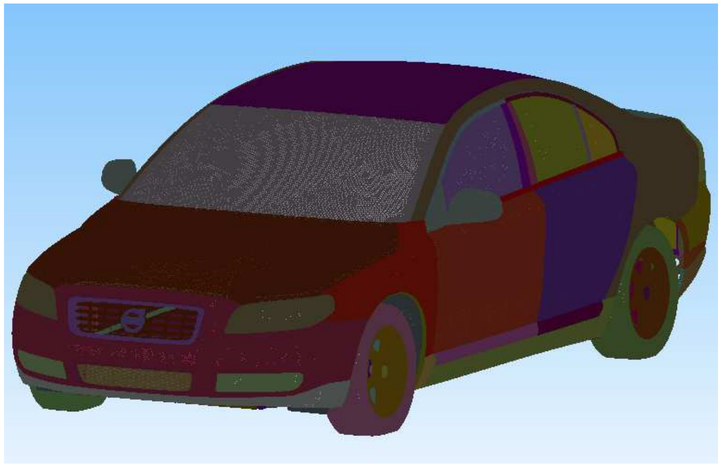
Mix at EGR (Exhaust, Air intake system)

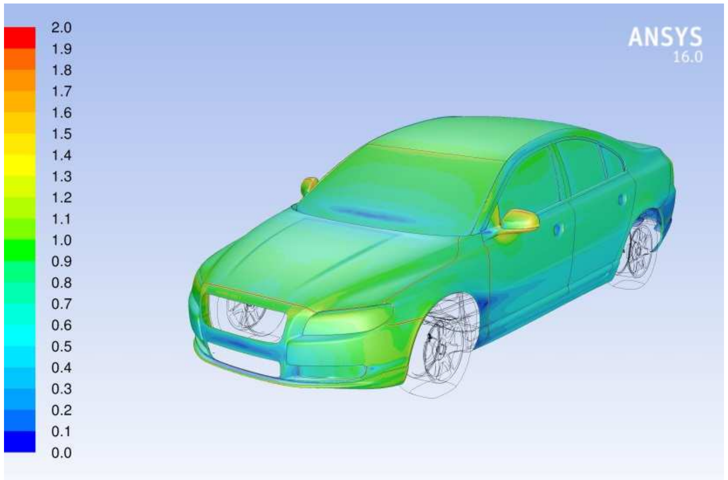
- **Ideal gas**
- **Turbocharger modeled using MRF, 140k rpm**
- **110 kph, 35°C inlet**
- **Fans, RPM from supplied data**
- **Water pump modeled with MRF, 2050 rpm**
- **3000 iterations**



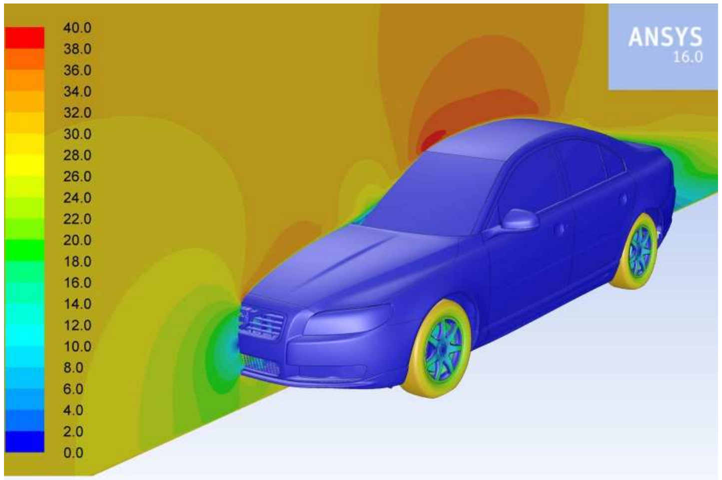
CAD, Mesh, Results – Aerodynamics







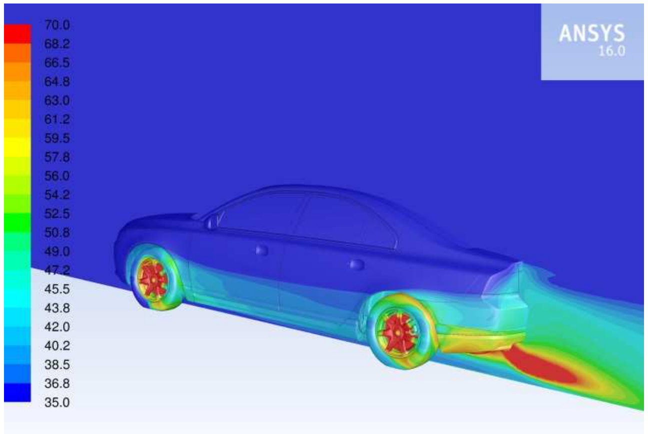
Contours of Wall Yplus



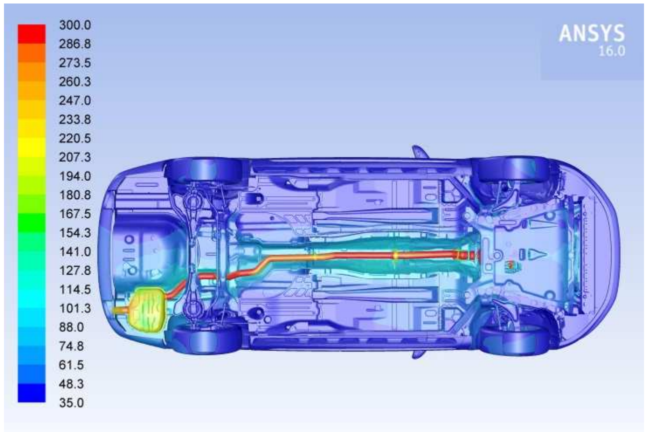
Contours of Velocity Magnitude (m/s)

- **Detailed capture of all styled surfaces with no deviation from the exterior geometry**
- **12 prism layers on styling surfaces with first height 0.02mm**
- **Rotating rims (MRF)**
- **Moving ground**
- **Refinement regions at wake and flow separation regions**
- **Cd = 0.27**

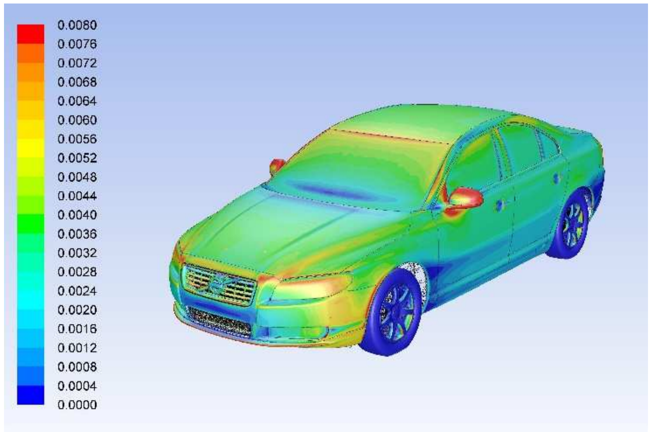
CAD, Mesh, Results – Exterior



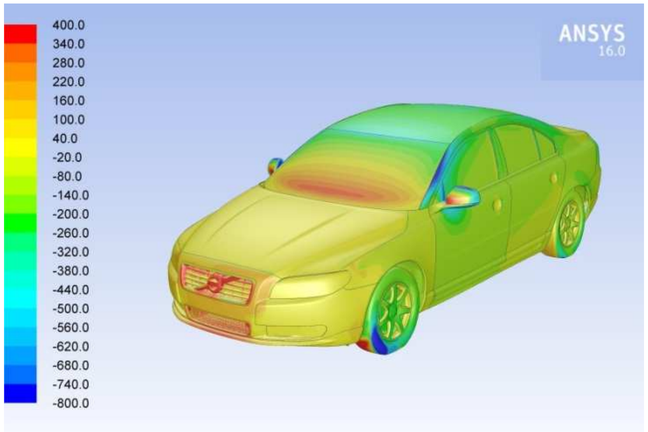
Contours of Static Temperature (c)



Contours of Static Temperature (c)

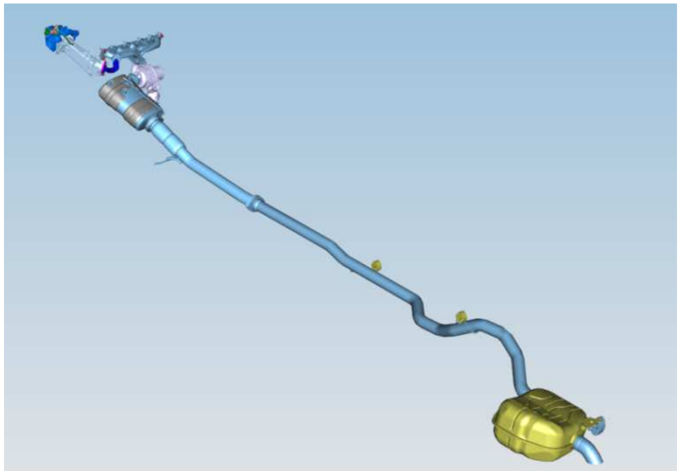


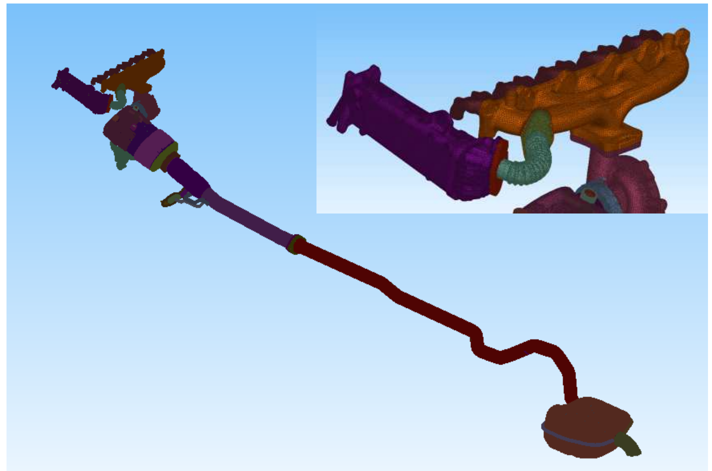
Contours of Skin Friction Coefficient

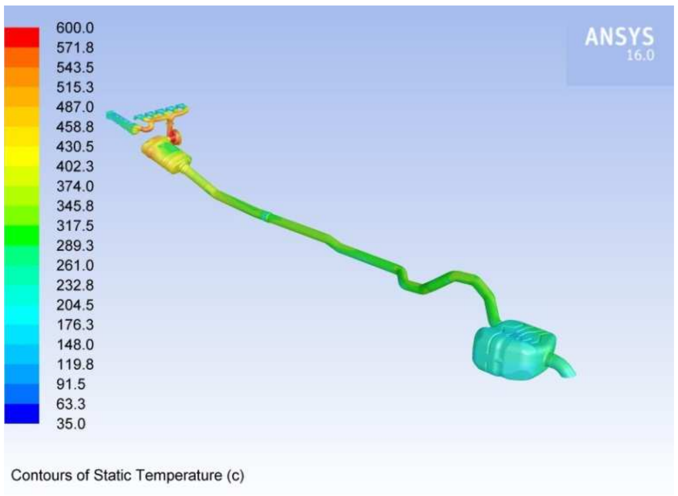


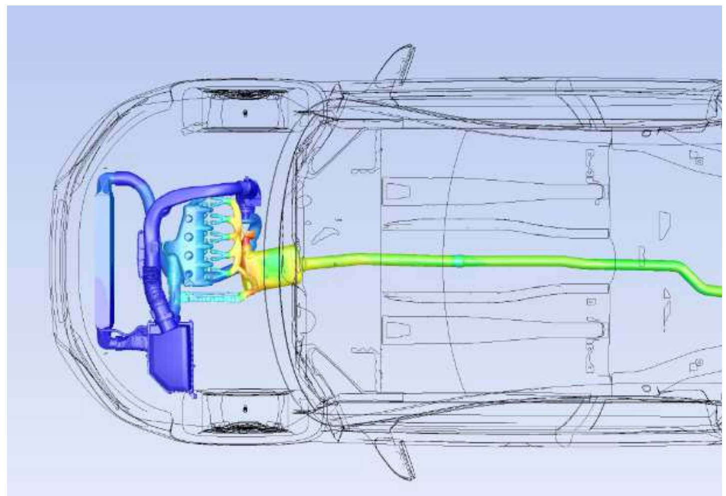
Contours of Static Pressure (pascal)

CAD, Mesh, Results – Exhaust



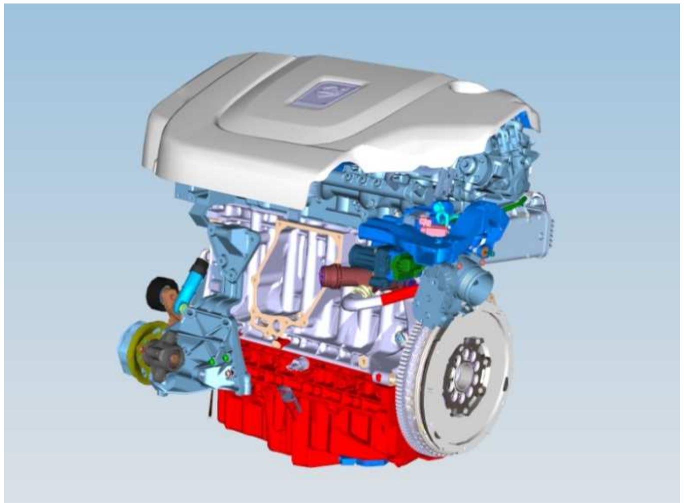


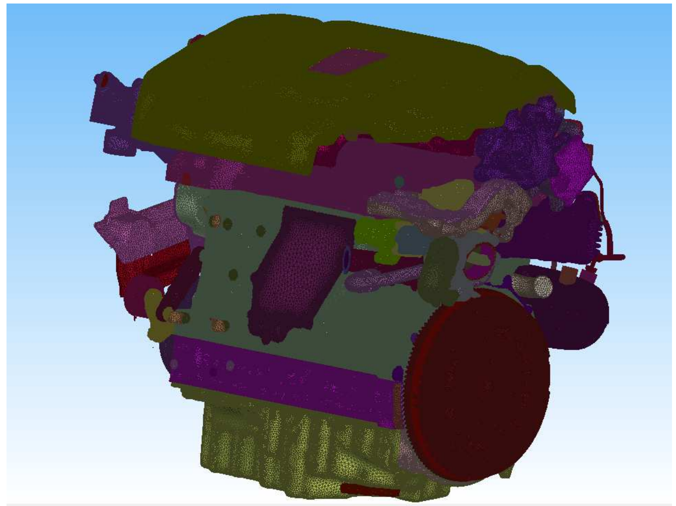


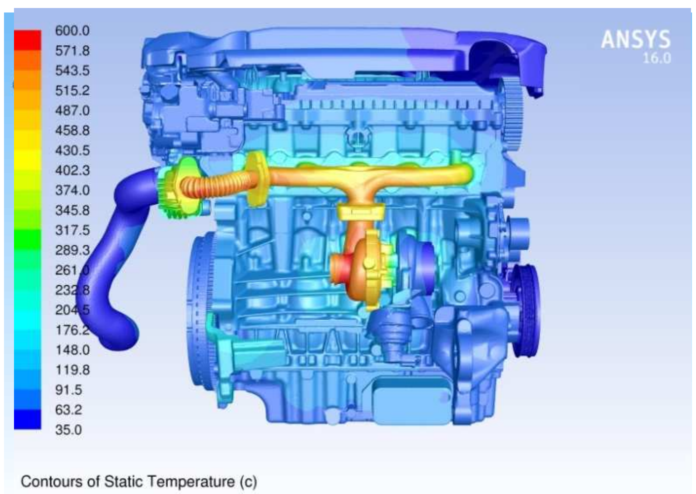


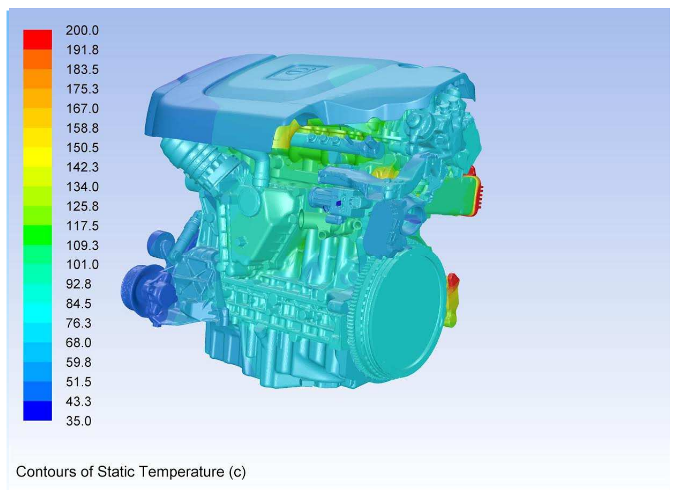
- **Complete exhaust system from ports through tailpipe including manifold, turbo and EGR**
- **Gas flow mixes with AIS stream at EGR**
- **Includes hangers, brackets, bars as solids**

CAD, Mesh, Results – Engine



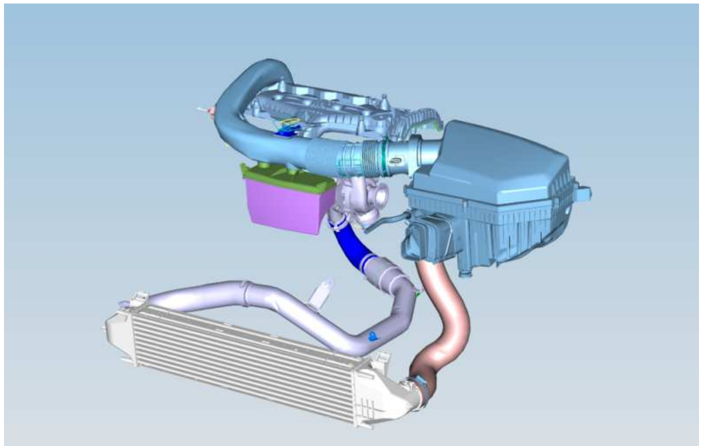


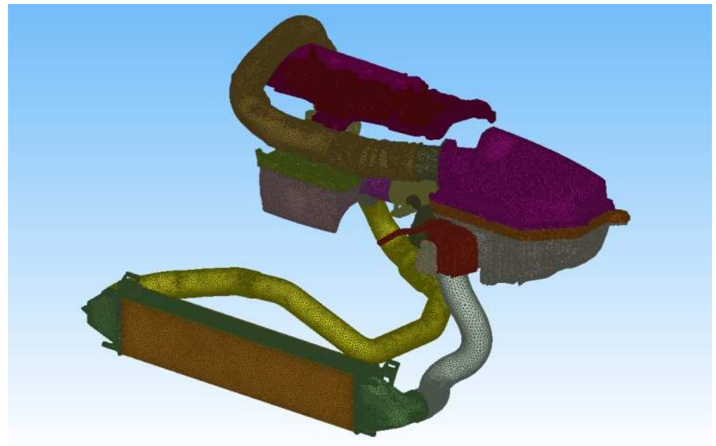


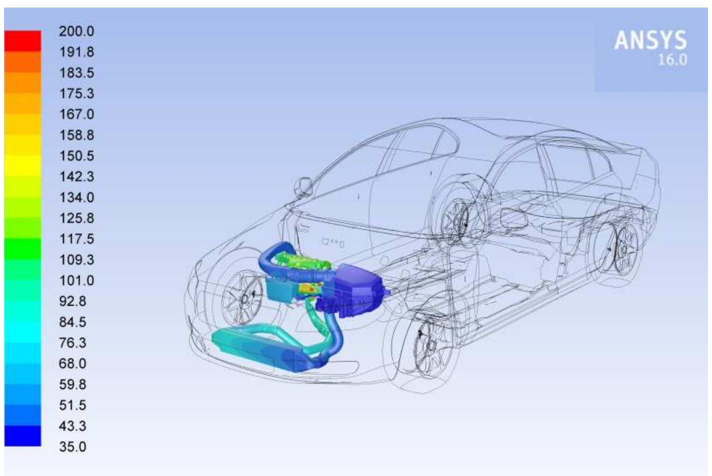


- **Internal components included: head, block, crank and case, camshaft, valves, pistons, pins, rods, pulleys, gear sets, oil sump, fuel pump, oil separator, mounts**
- **Manifold heat shield is laminated steel/ceramic**

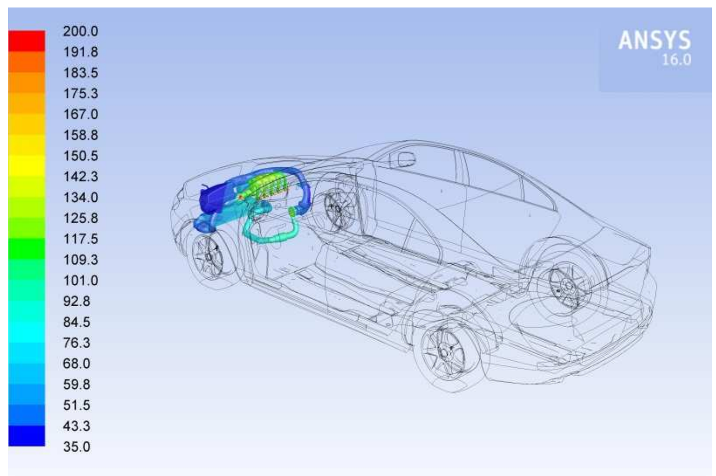
CAD, Mesh, Results – Air Intake System







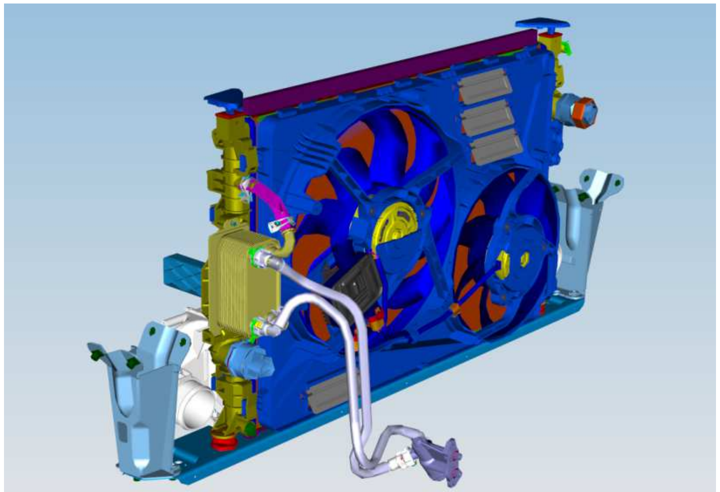
Contours of Static Temperature (c)

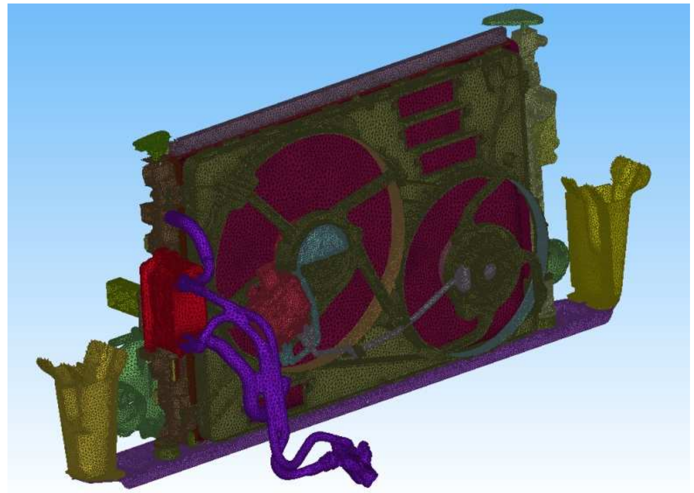


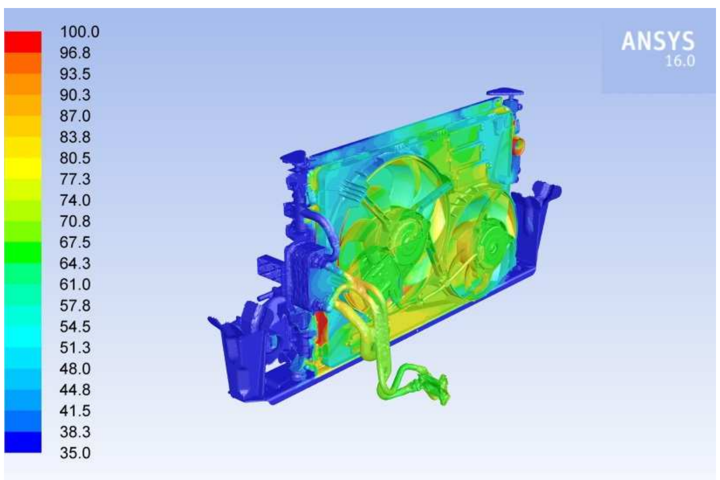
Contours of Static Temperature (c)

- **From ambient to ports including turbo, CAC, EGR manifold**
- **Mix with Exhaust stream at EGR**

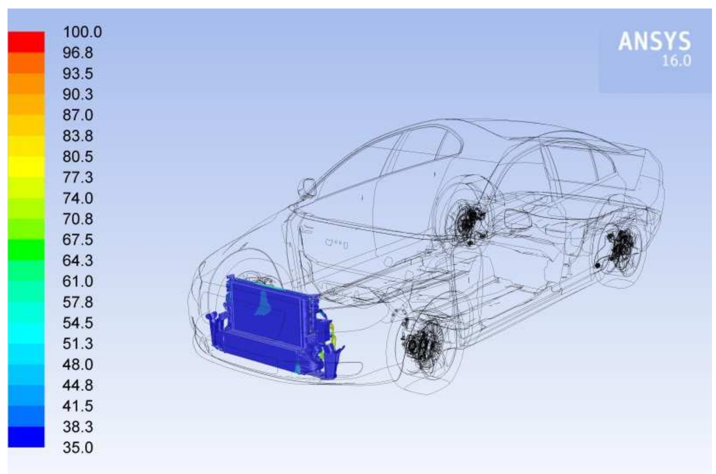
CAD, Mesh, Results – CRFM







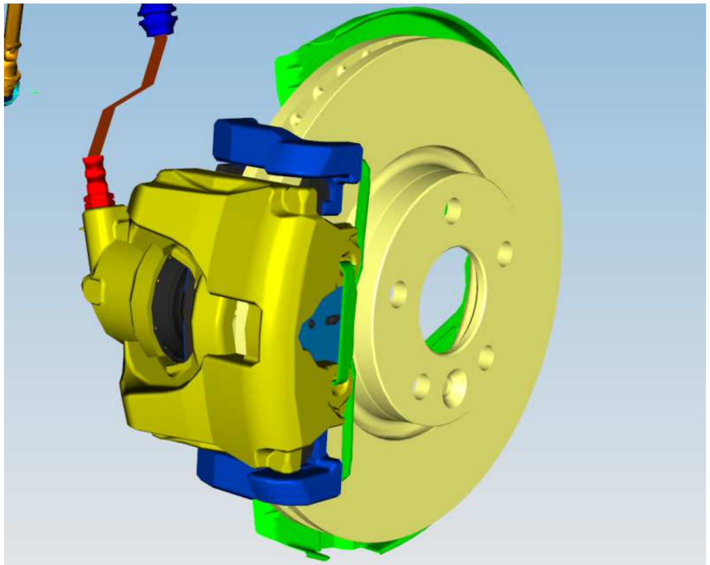
Contours of Static Temperature (c)

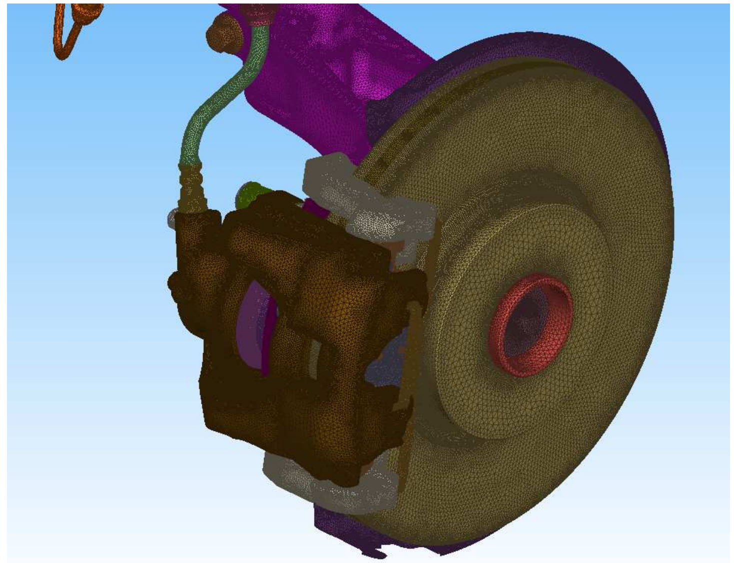


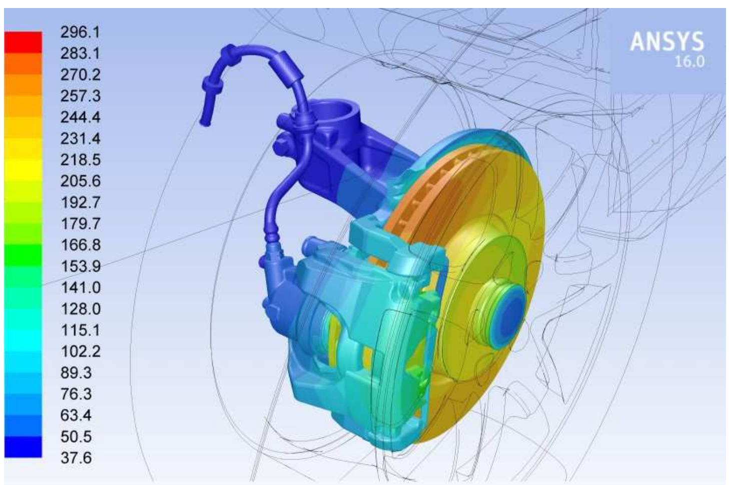
Contours of Static Temperature (c)

- **Dual-Fan setup**
- **Fans modeled with MRF**

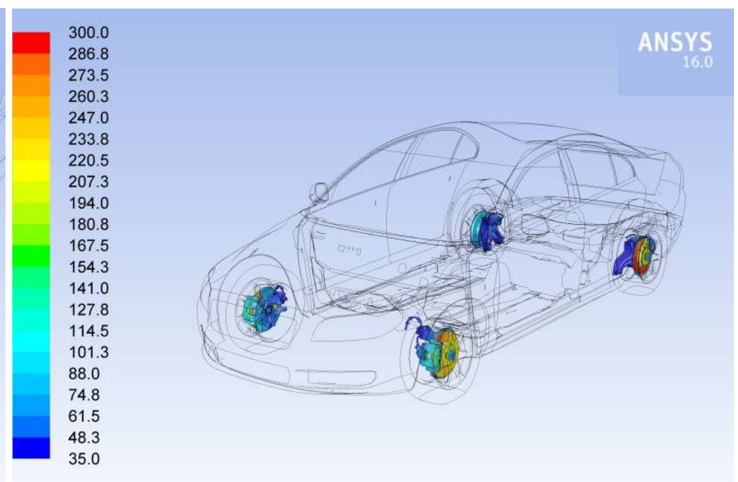
CAD, Mesh, Results – Brakes







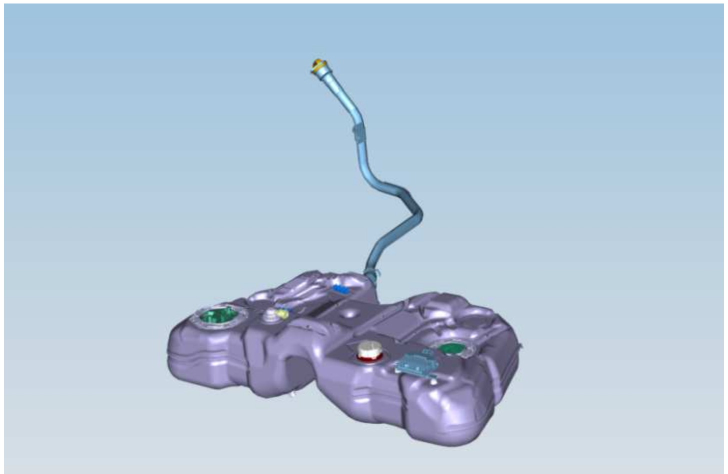
Contours of Static Temperature (c)

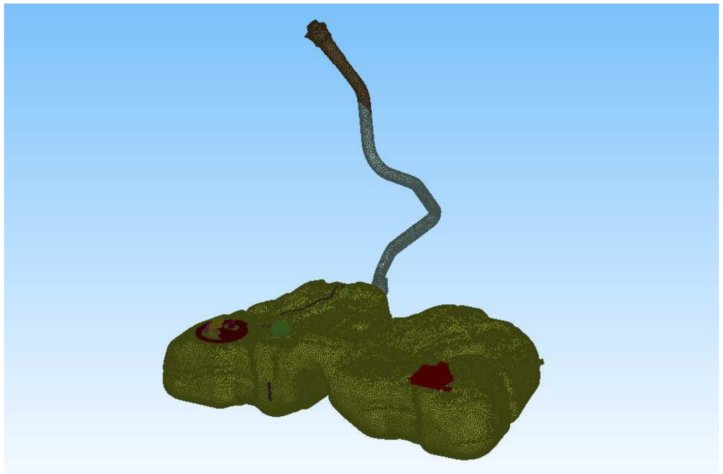


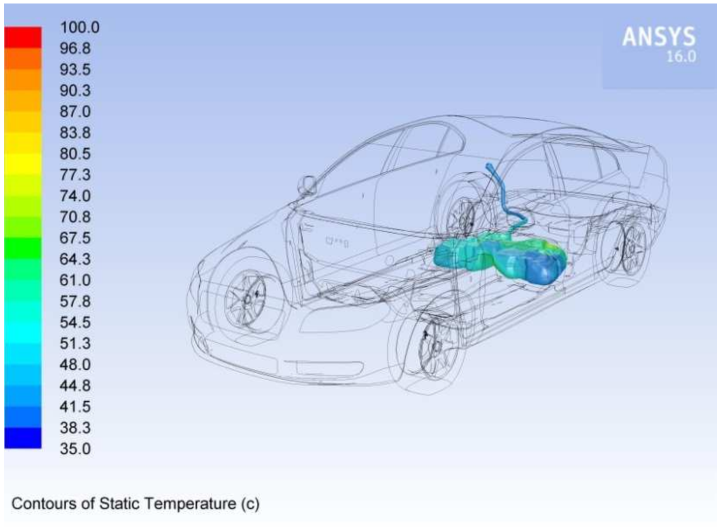
Contours of Static Temperature (c)

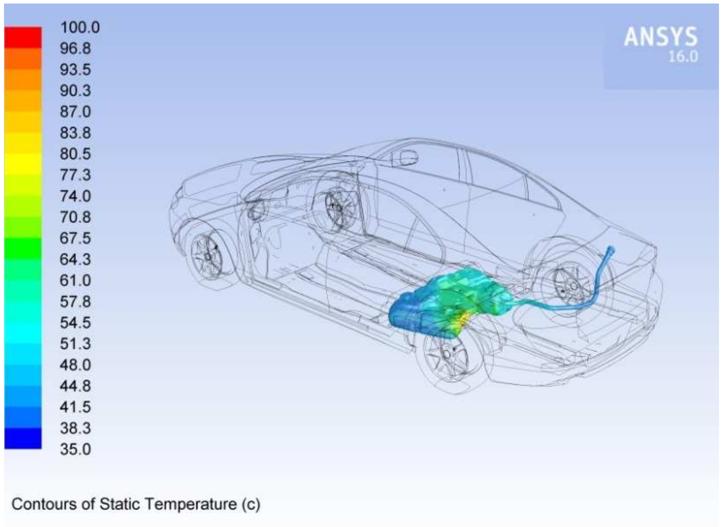
- **~200 solid zones**
- **All components accounted for**
- **MRF zones for the cooling slots (2x40)**
- **Frictional heat applied in the brake rotor**

CAD, Mesh, Results – Fuel Tank



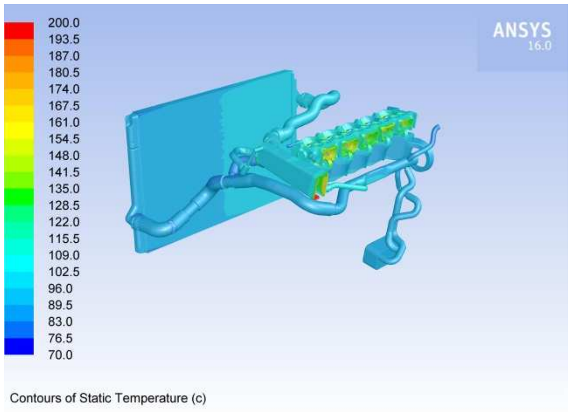




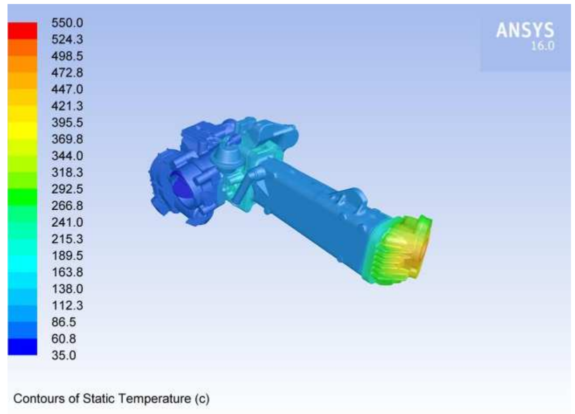


- **Fluid-like material in the fuel tank**
- **Simplified internal components**
- **Accounts for accumulation of heat within the fuel tank**

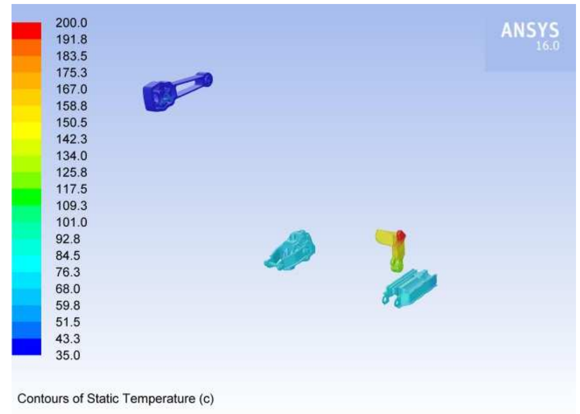
Results – Misc



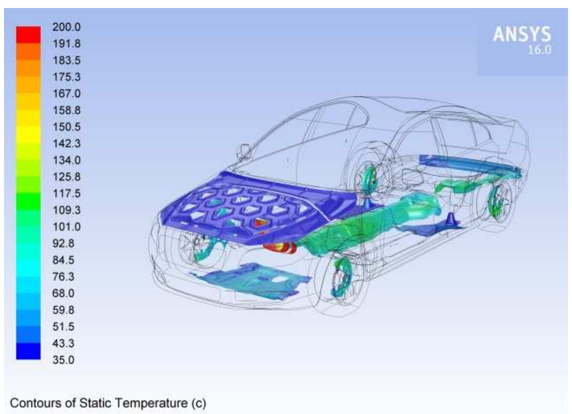
Coolant Stream



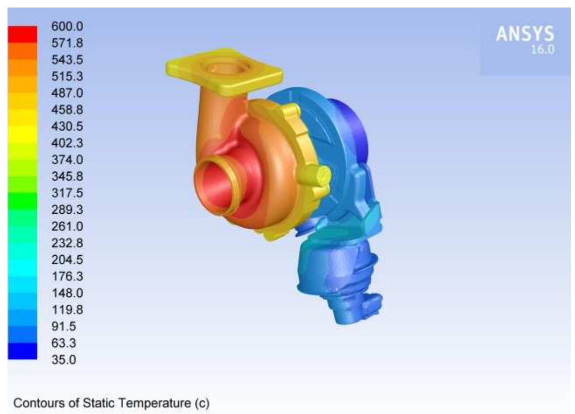
EGR



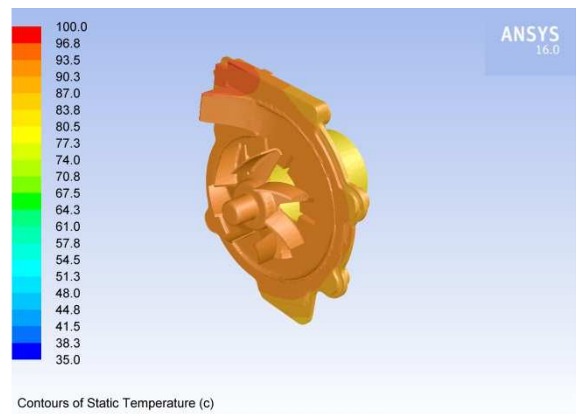
Mounts



Shields



Turbo



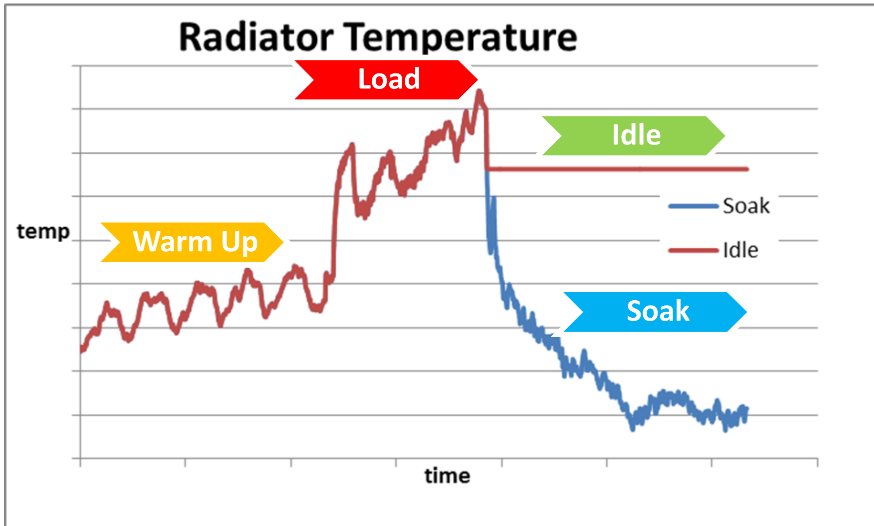
Water Pump

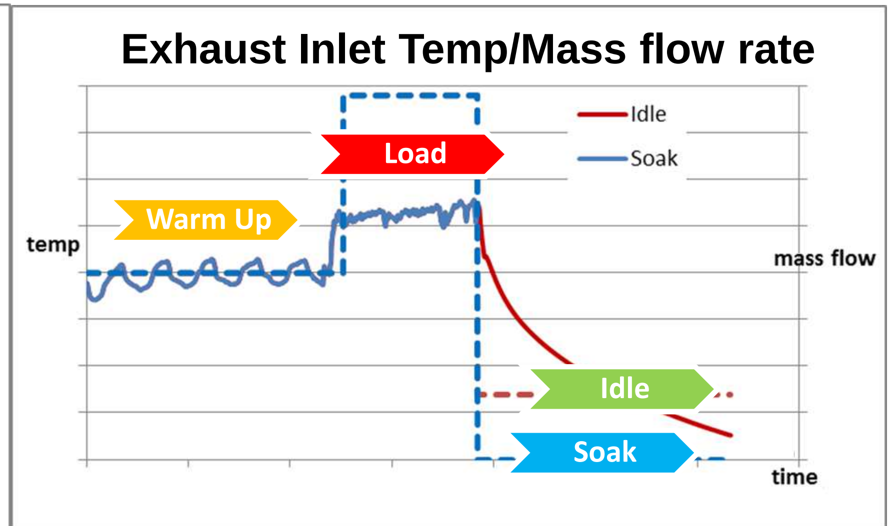
Acknowledgement

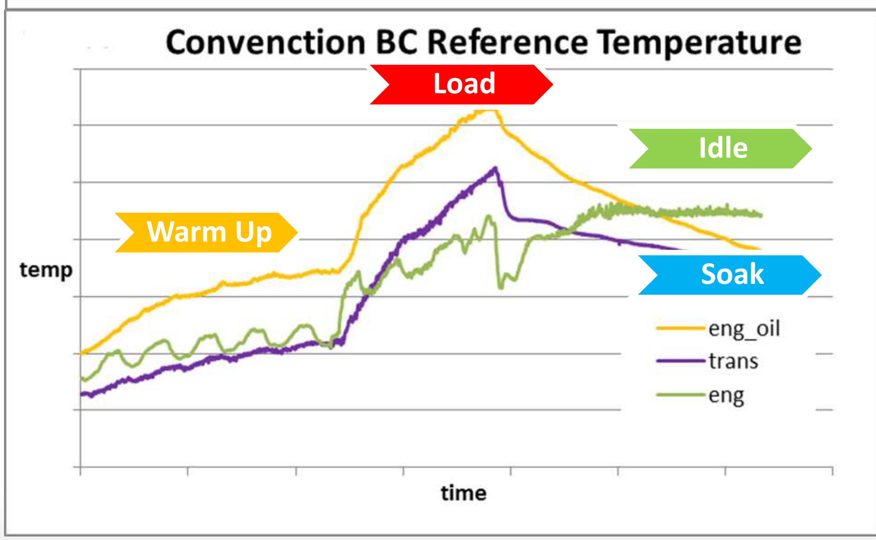
- Torbjörn Virdung
- Hamid Ghazialam
- Place holder for external
- Peyman Davoudabadi
- Xingshi Wang
- Evangelos Koutsavdis

Vehicle Thermal Soaking

- **Transient BC profiles is applied to major heat sources as a results of the changing driving conditions.**
- **Tabular input of the transient BC profiles.**







gm_utm 8 3165 1					
time	gas_temp	rad_temp	cond_temp	oil_pan	put
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1	912	374.15	355	350	360
2	912	374.15	355	350	360
3	912	374.15	355	350	360
4	912	374.15	355	350	360
5	912	374.15	355	350	360
6	912	374.15	355	350	360
7	912	374.15	355	350	360
8	912	374.15	355	350	360
9	912	374.15	355	350	360
10	912	374.15	355	350	360

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