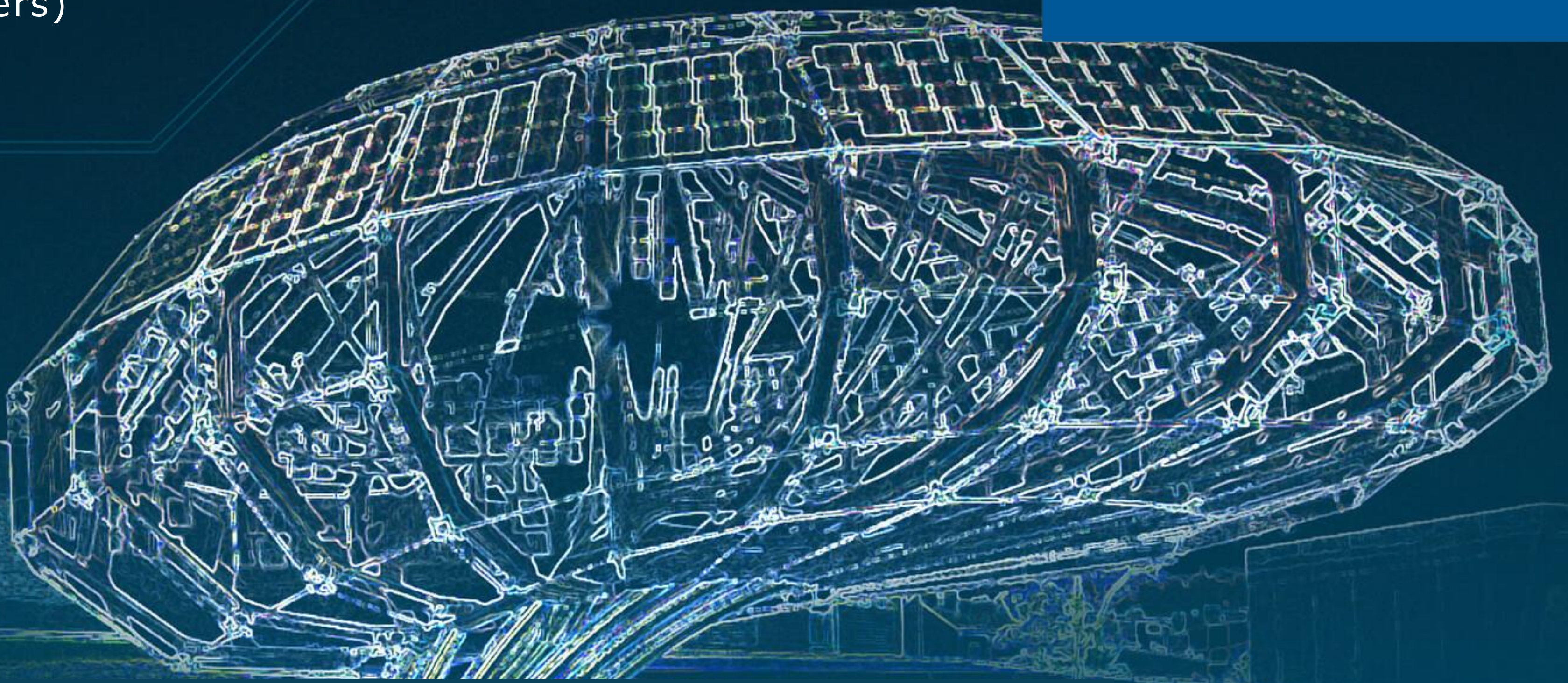
AVL List GmbH (Headquarters)

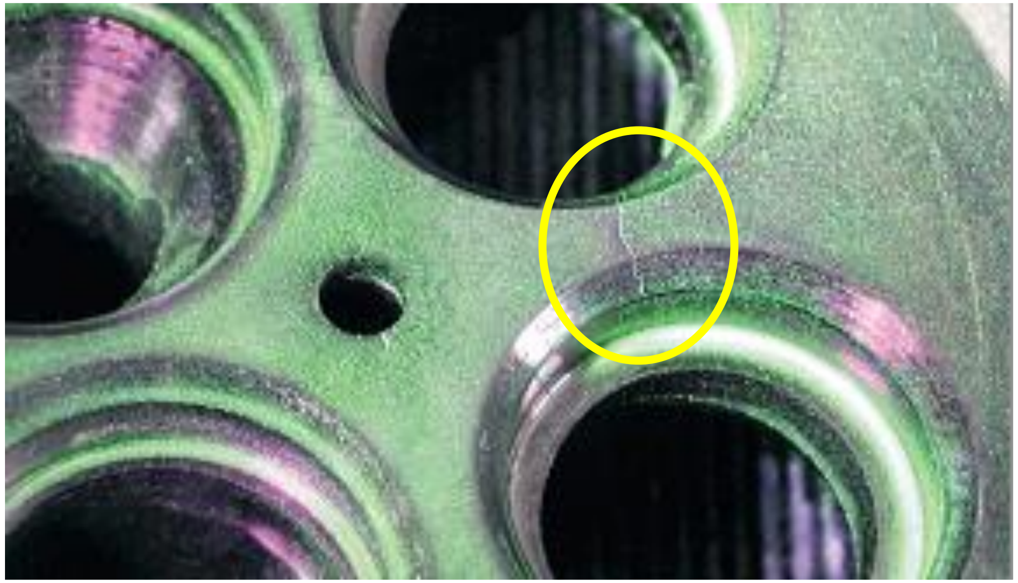


Predictive Engine Thermal Load

Simulation Meets Testing Conference, USA 2019

Public

THE CHALLENGE



Component design is driven by Performance, Durability, Reliability, Costs, …

… targeting compact, light weight design

… BUT potentially being exposed to high thermal loads.

Powertrain Hybridization is pushing even harder towards the limits.

Possible consequences include fatigue issues and component failures.

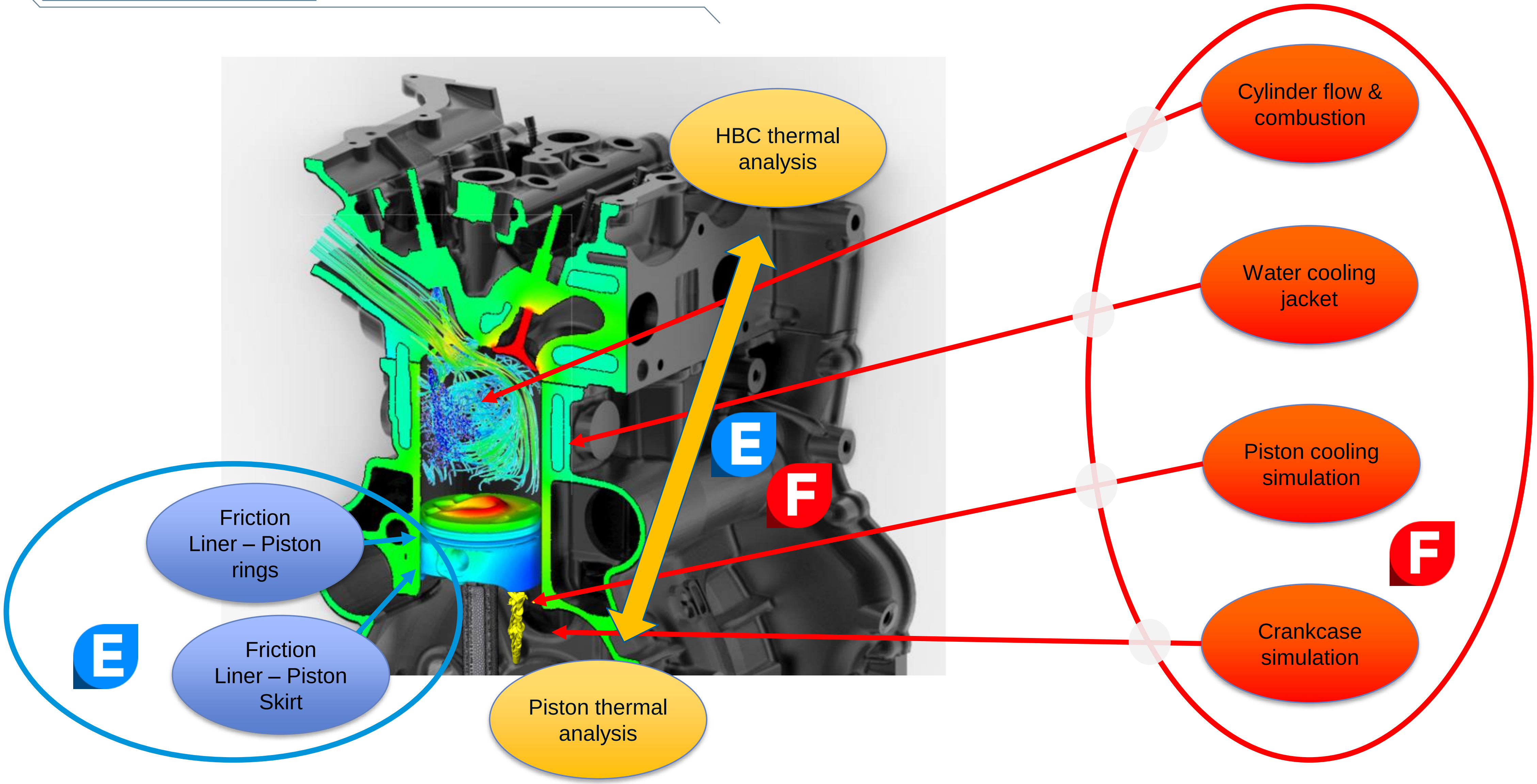
THE SOLUTION

PREDICTIVE SIMULATION of component THERMAL LOAD

to ensure functionality, efficiency and durability

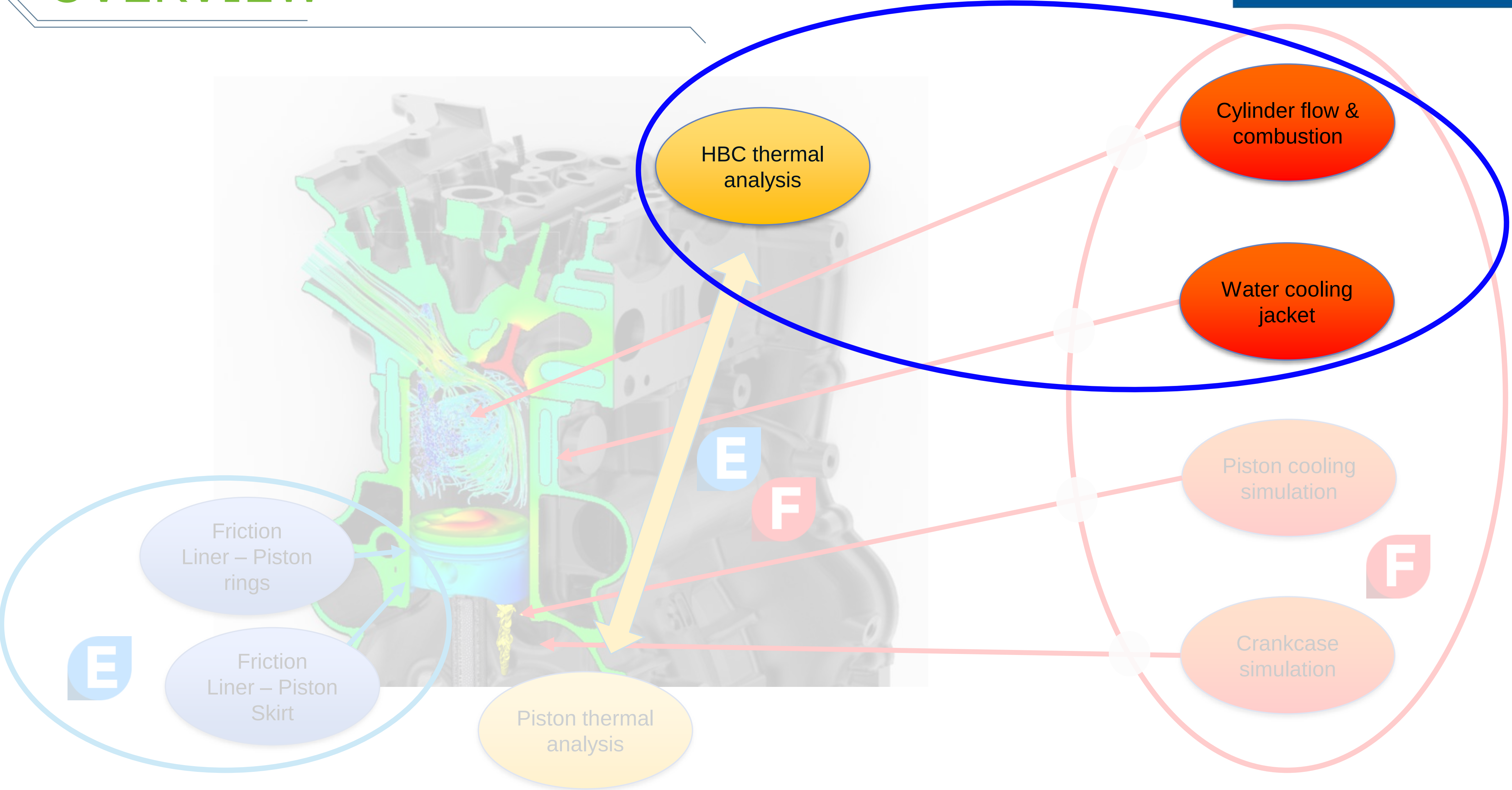
to avoid failure and warranty issues.

OVERVIEW



Slide animated 6x

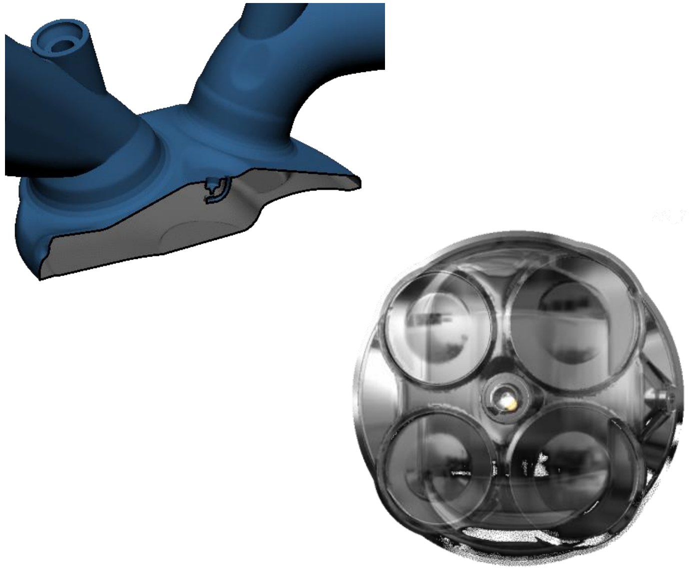
OVERVIEW

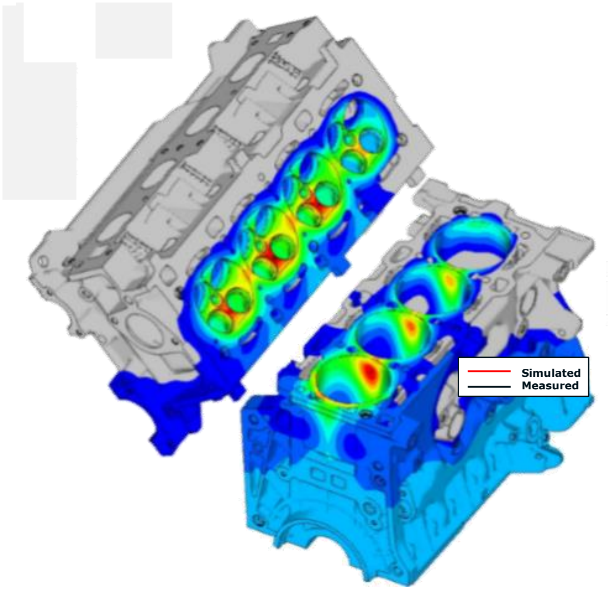


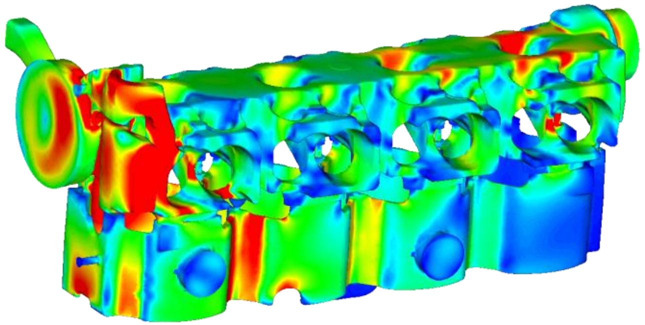
HBC thermal analysis
Cylinder flow & combustion
Water cooling jacket
Piston cooling simulation
Crankcase simulation
Friction Liner – Piston rings
Friction Liner – Piston Skirt
Piston thermal analysis
E
F
E
F

OVERVIEW

Combustion simulation ⟷ Structural thermal analysis ⟷ Coolant flow simulation







- well calibrated combustion simulation
- accurate heat transfer modelling
- high quality of spray, ignition combustion,… models

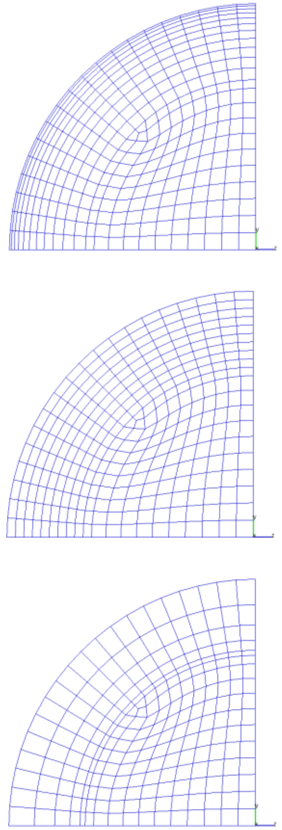
- correct boundary conditions
- temperature dependent material properties
- contact resistance

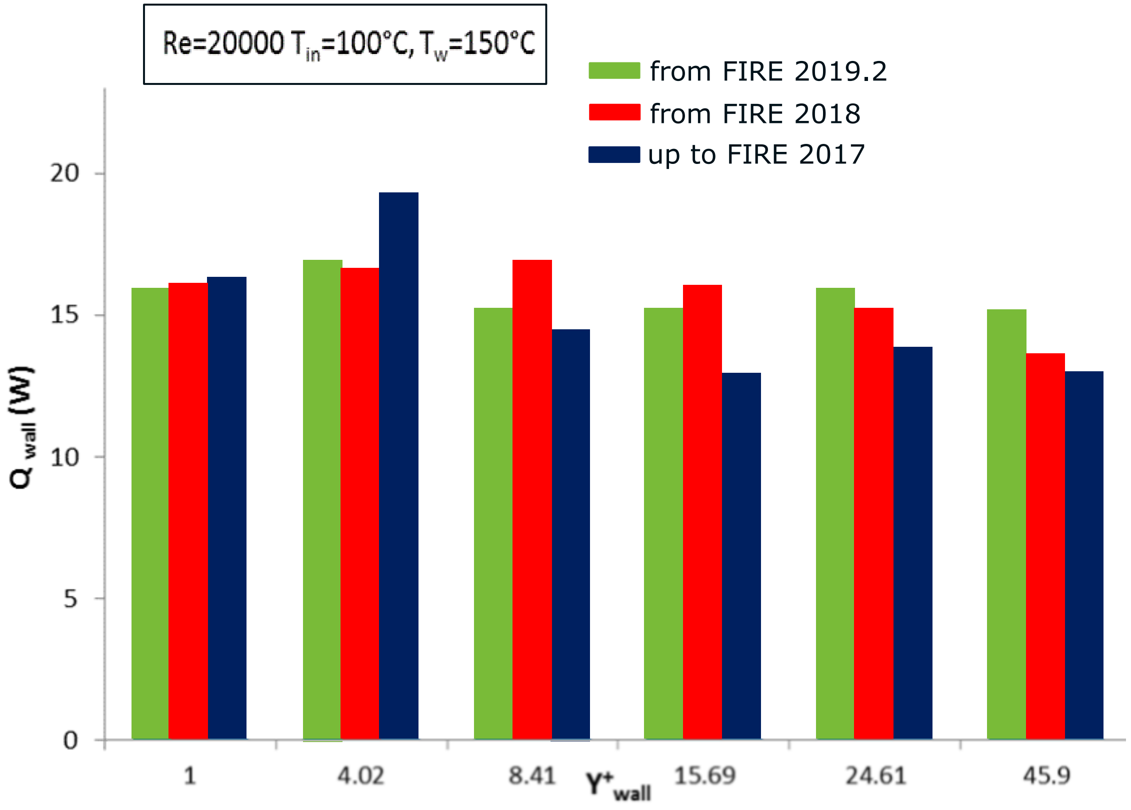
- accurate heat transfer modelling
- accounting for boiling effects

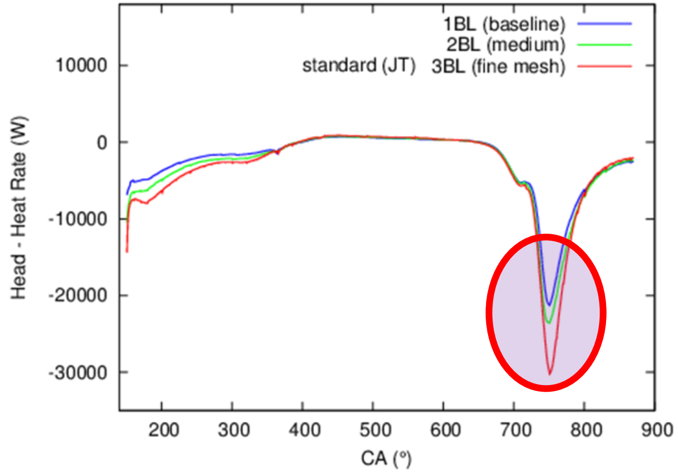
Slide animated 2x

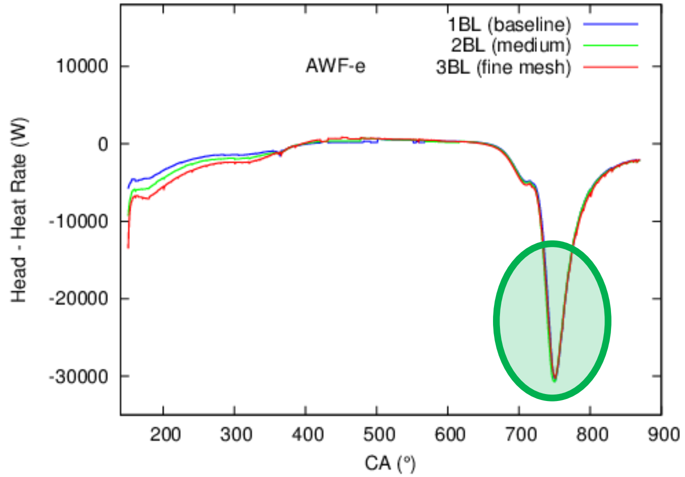
FIRE™ HEAT TRANSFER MODELLING
Performance

Evaluation Wall Heat Transfer Model, Water / Glycol 50:50, variable properties







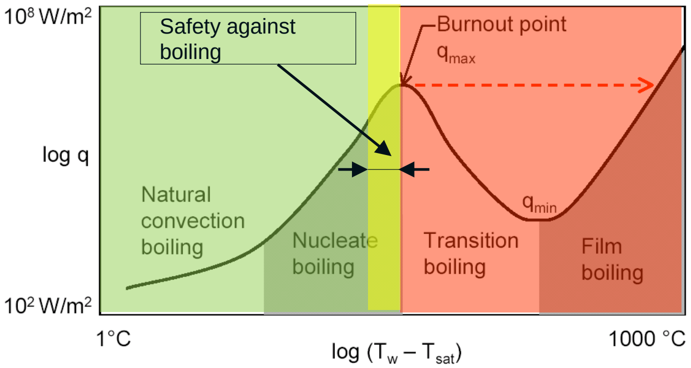


"Analytical wall-function strategy for the modelling of turbulent heat transfer in the automotive CFD applications" (SAE 2019)

"Towards mesh independent modeling of convective heat transfer in IC engines" IMEM 2019

Slide animated 2x

FIRE™ HEAT TRANSFER MODELLING
Boiling

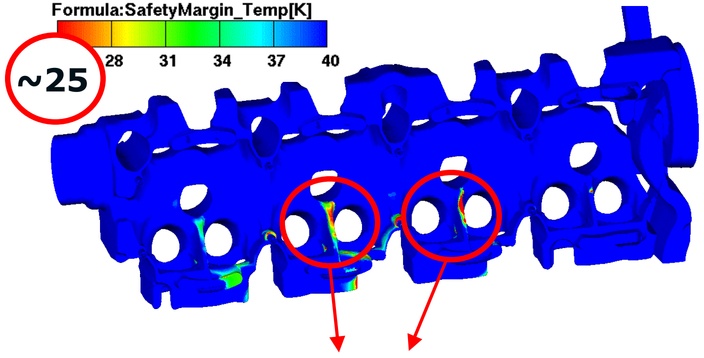


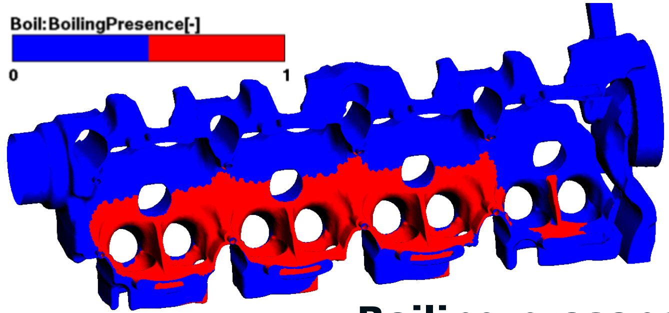
Convective heat flux

Nucleate boiling heat flux

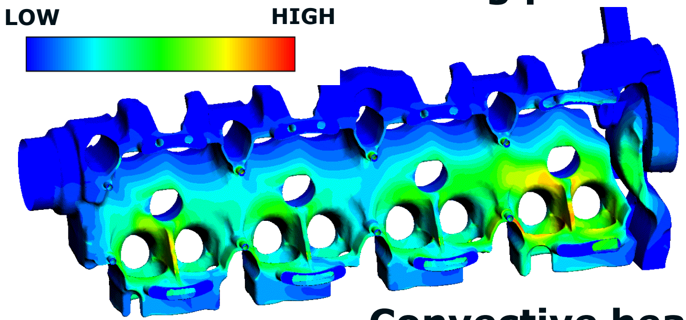
$$q_w = q_c + q_{nb}$$

Safety against transition boiling:

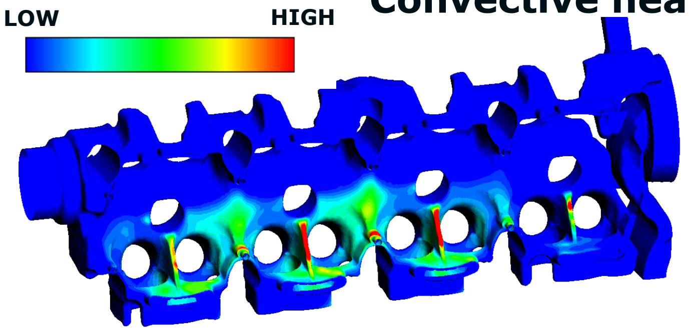




Boiling presence

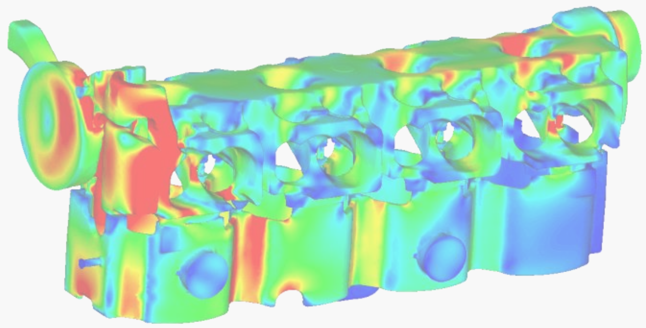


Convective heat flux



Nucleate boiling heat flux

Coolant flow simulation

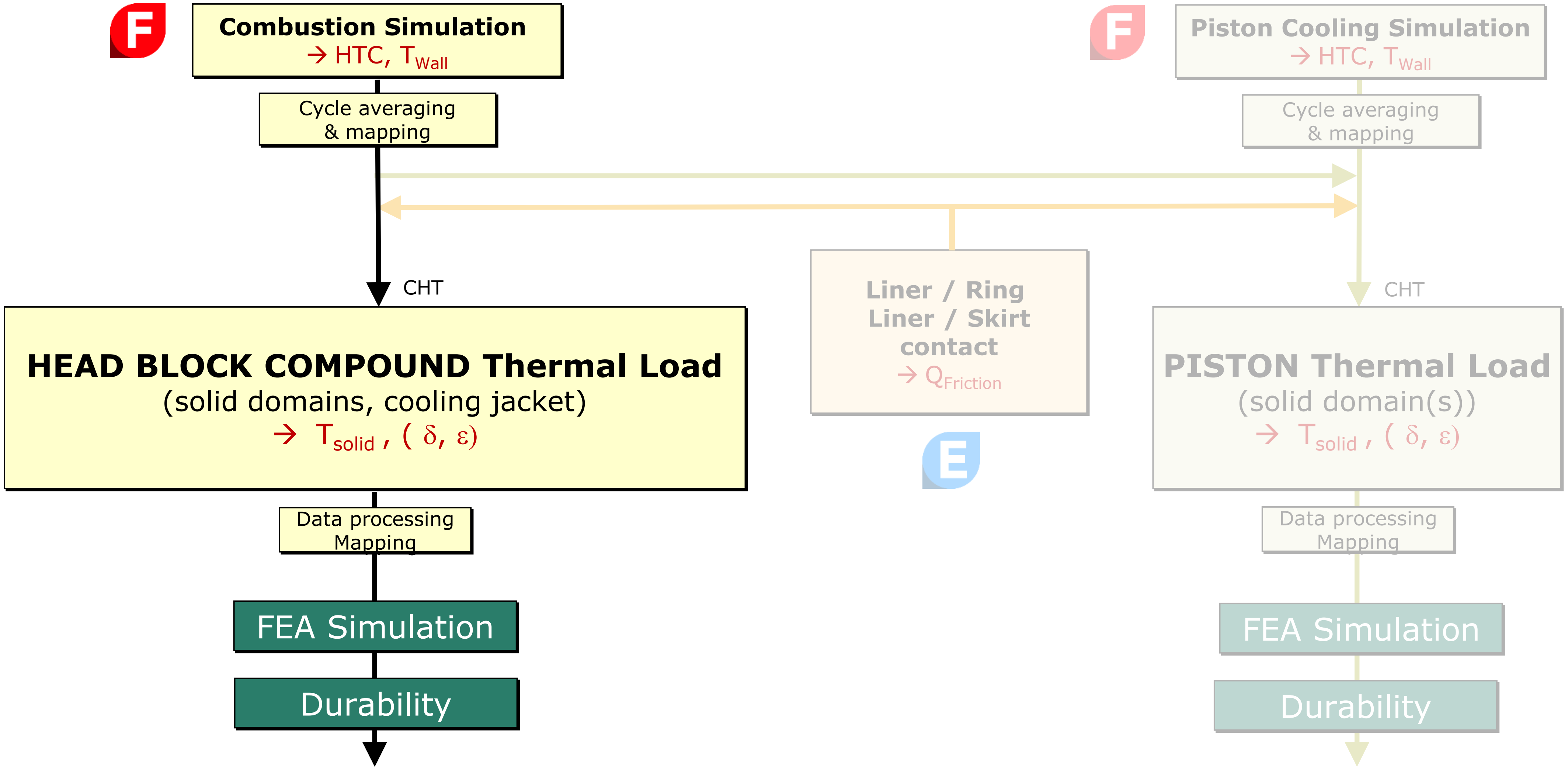


- Accurate heat transfer modelling
- Accounting for boiling effects

Slide animated 6x

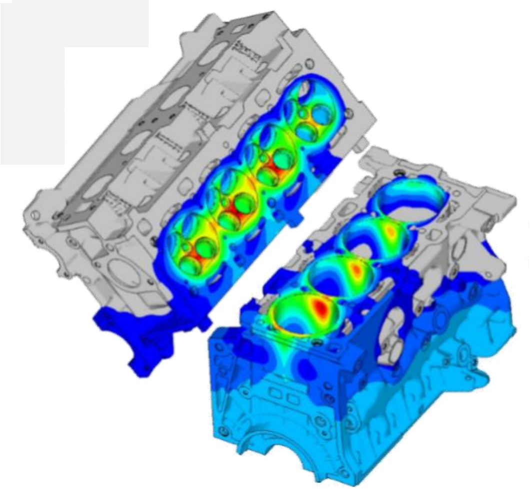
WORKFLOW

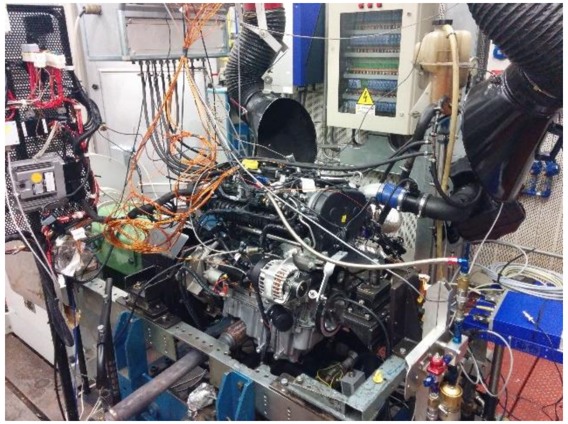
Head Block Compound → w/ Piston → w/ Piston / Liner contact

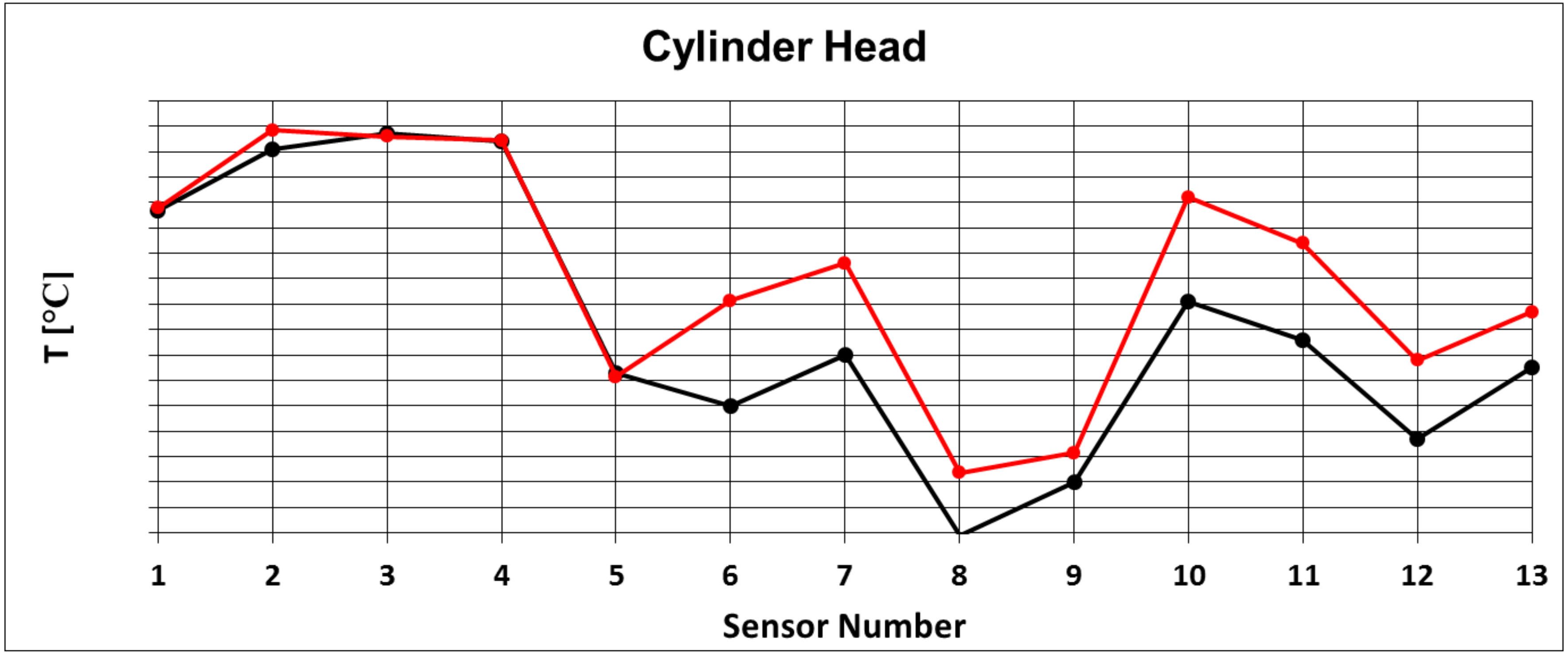


TYPICAL RESULTS

8 of 13 monitoring locations show differences below 10K.







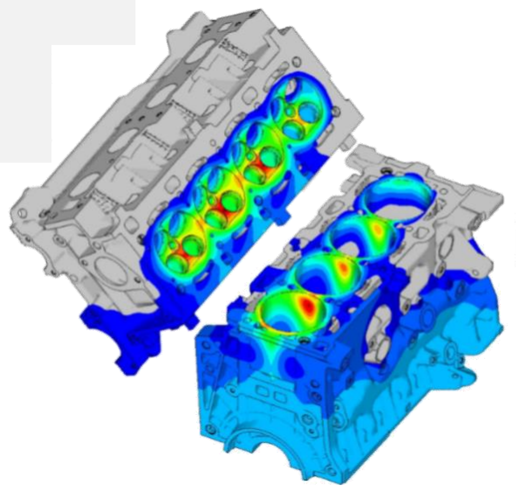
Exhaust bridges
Tolerance ≤ 10K

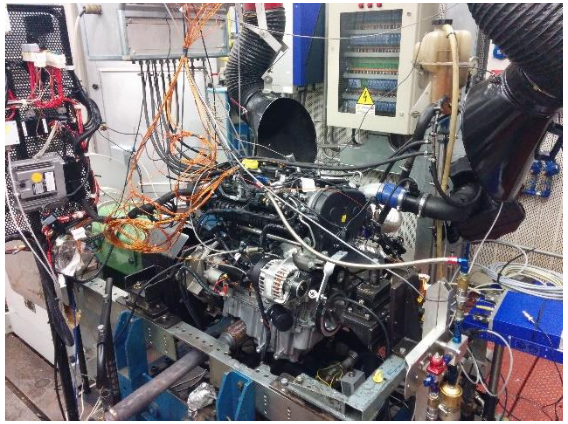
Exhaust ports

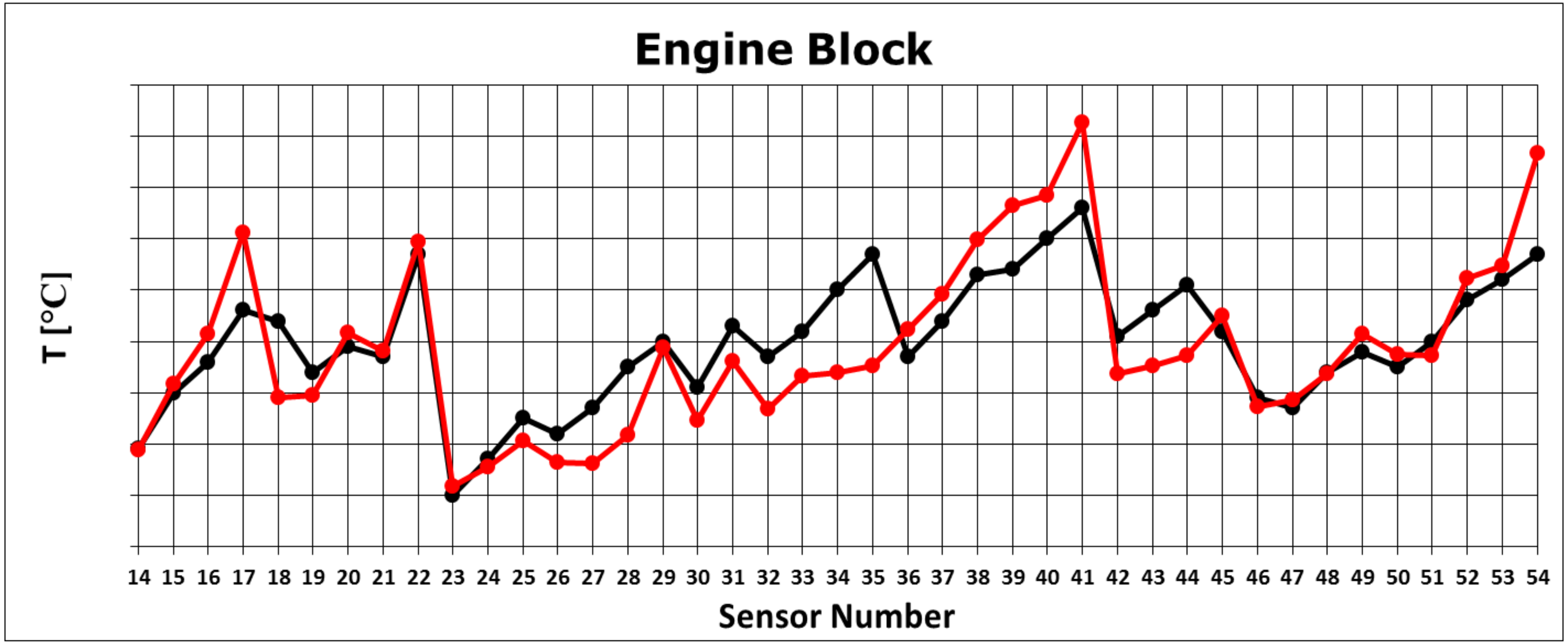
Intake ports

TYPICAL RESULTS

25 of 40 monitoring locations show differences below 10K.







5mm below gasket

42mm below gasket

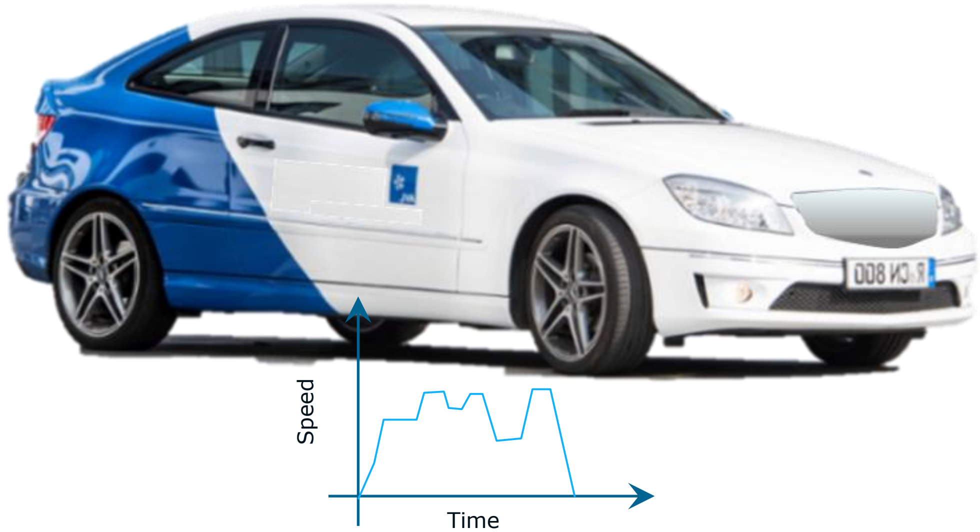
101mm below gasket

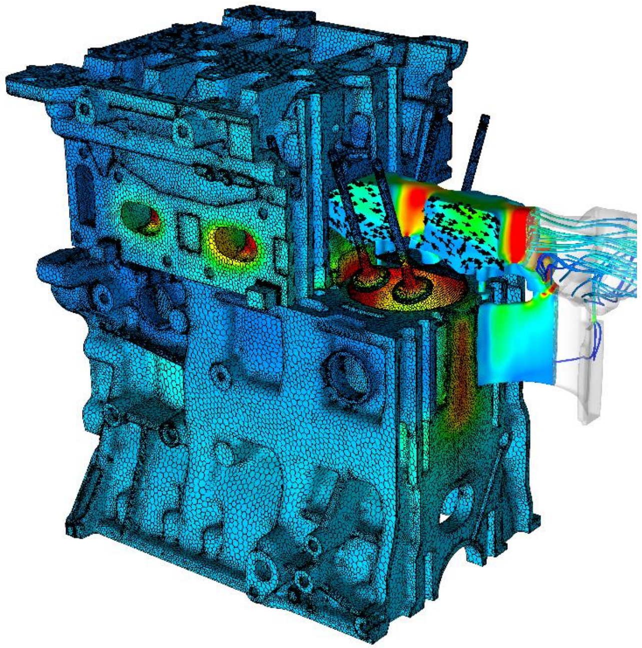
5mm below gasket

QUESTION

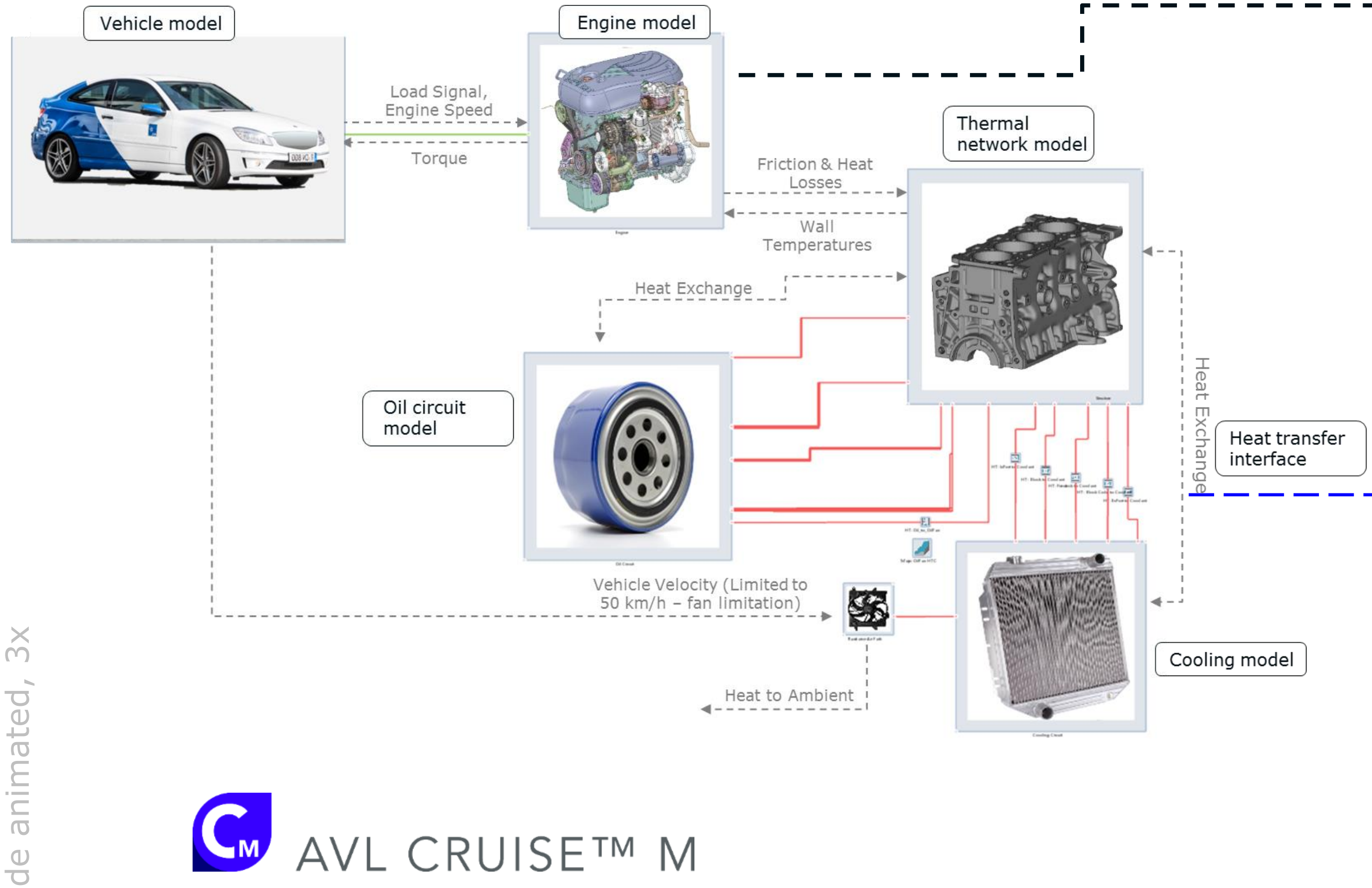
Engine / Vehicle is operated under transient conditions.

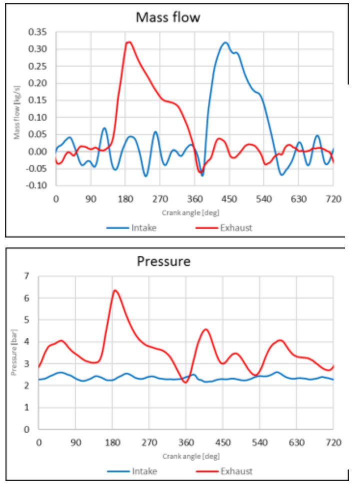
How does this affect the thermal load of the HBC?

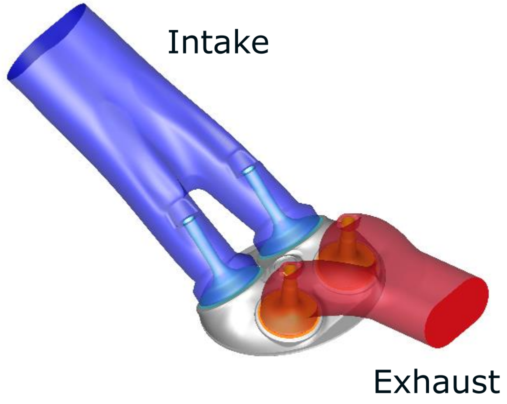




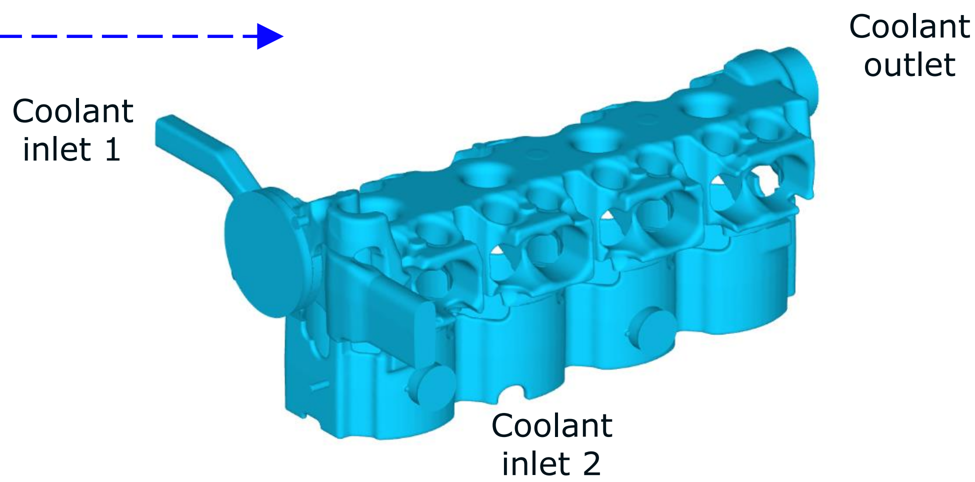
MODELLING APPROACH
1D System Simulation







AVL FIRE™

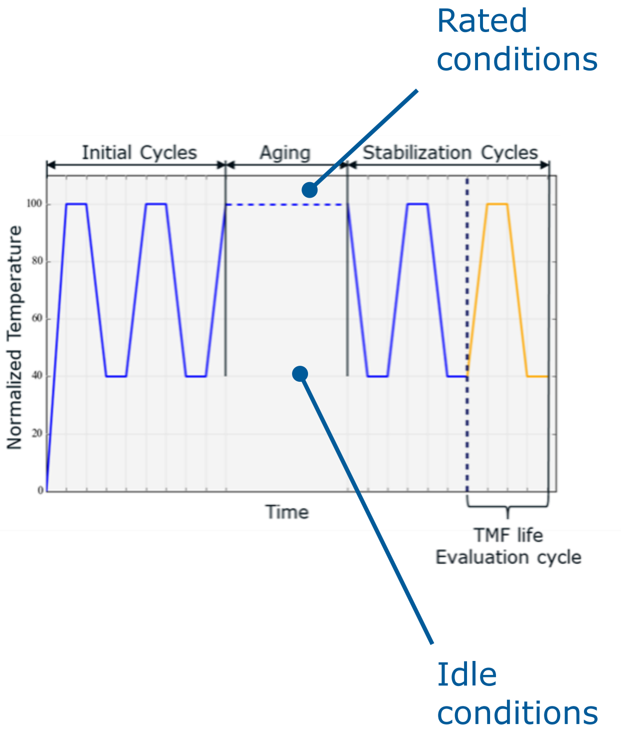


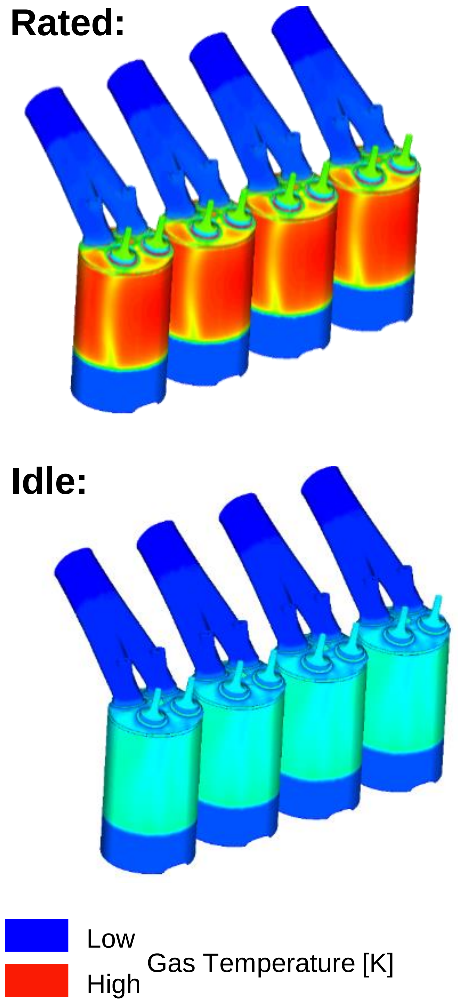
Slide animated, 3x

MODELLING APPROACH
3D Combustion

Slide animated, 2x

Combustion Simulation
→ HTC, T_{Wall}

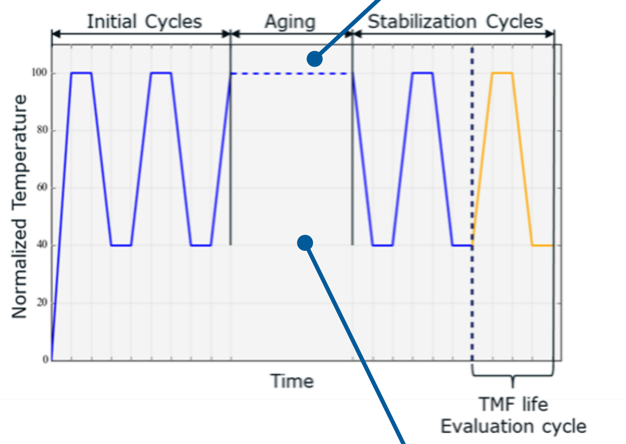




→ near wall gas temperature for each LP

MODELLING APPROACH
3D Thermal Load

Rated conditions



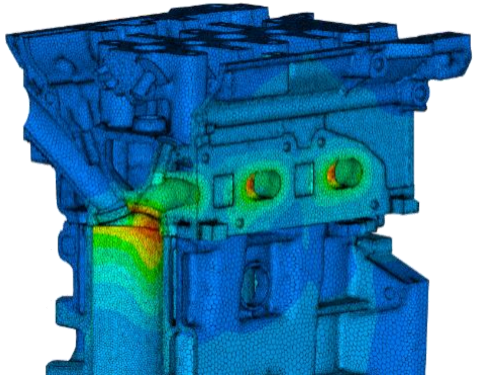
Idle conditions

Combustion Simulation
→ HTC, T_{Wall}

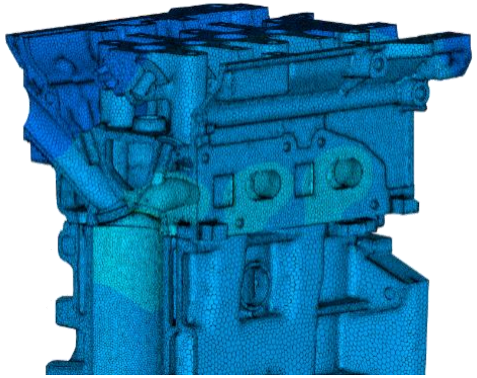
Cycle averaging
& mapping

HEAD BLOCK COMPOUND
Thermal Load
(solid domains, cooling jacket)
→ T_{Solid} , (δ, ε)

Rated:



Idle:



→ Solid temperature for each LP

Low
High
Structure Temperature [K]

Slide animated, 2x

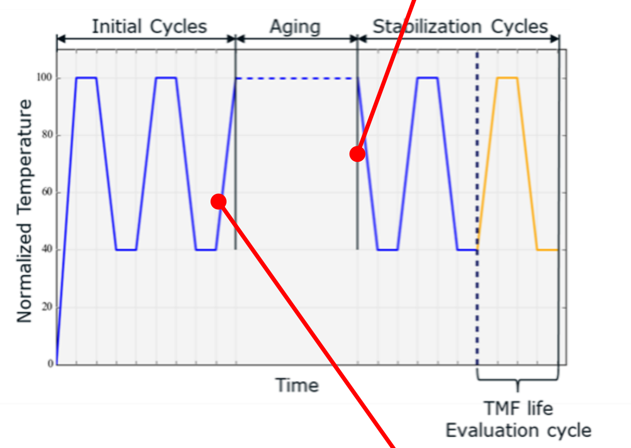
MODELLING APPROACH

Transient BC for gas side

To imitate the **transient** operating cycle, …

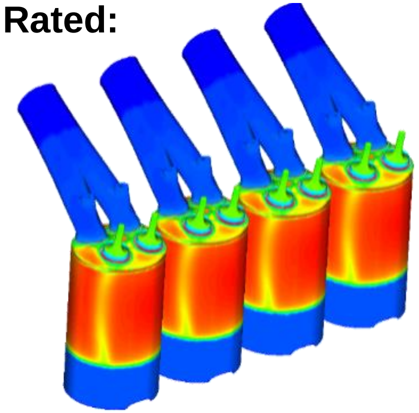
- gas side (combustion chamber) thermal boundary conditions for each point in time are obtained by interpolating between rated and idle conditions

Conditions?

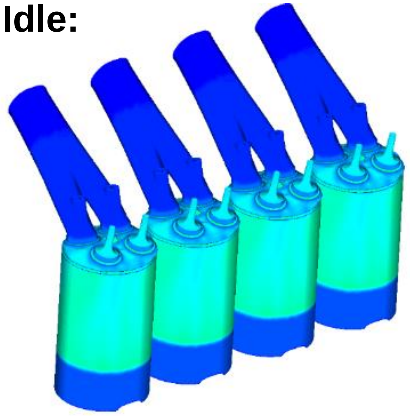


Conditions ?

Rated:



Idle:



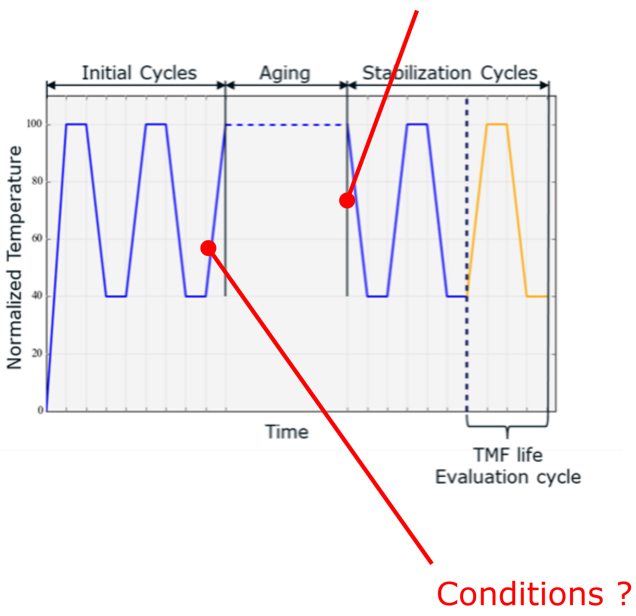
Low
High
Gas Temperature [K]

$T_{Gas} = T_{Idle} + (T_{Rated} - T_{Idle}) * \text{Load [\%]}$

$HTC_{Gas} = HTC_{Idle} + (HTC_{Rated} - HTC_{Idle}) * \text{Load [\%]}$

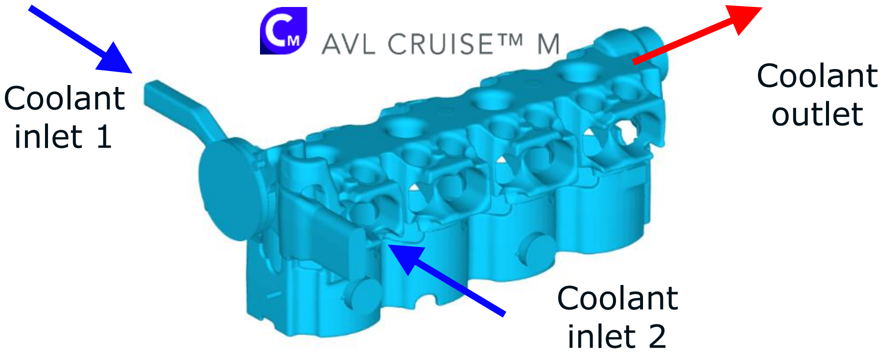
T, HTC = cycle averaged, space resolved

MODELLING APPROACH
Transient BC for coolant side



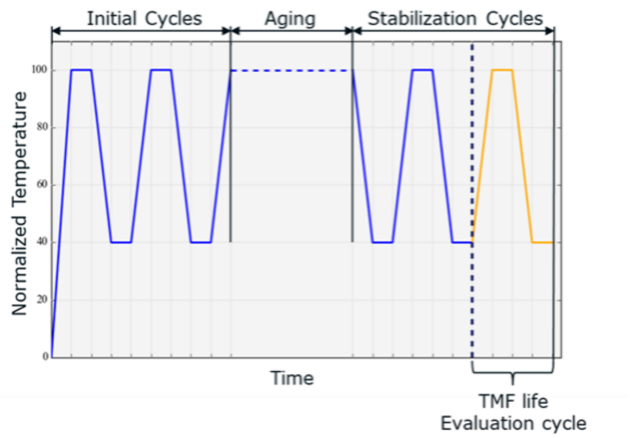
To imitate the **transient** operating cycle, …

- gas side (combustion chamber) thermal boundary conditions for each point in time are obtained by interpolating between rated and idle conditions
- water side (CWJ) thermal boundary conditions for each point in time are calculated simultaneously to the HBC structure temperature, based on inlet / outlet conditions obtained from the 1D System simulation



Slide animated, 1x

MODELLING APPROACH
Compute rune mode



To imitate the **transient** operating cycle, …

- gas side (combustion chamber) thermal boundary conditions for each point in time are obtained by interpolating between rated and idle conditions
- water side (CWJ) thermal boundary conditions for each point in time are calculated simultaneously to the HBC structure temperature, based on inlet / outlet conditions obtained from the 1D System simulation
- computing the transient HPC Thermal load is done in a **single transient simulation**, $\Delta t = 0.1 \ldots 1s$

Compute effort: ~24h on 40 … 50Cores

(for the DEMO Cases, 500s)

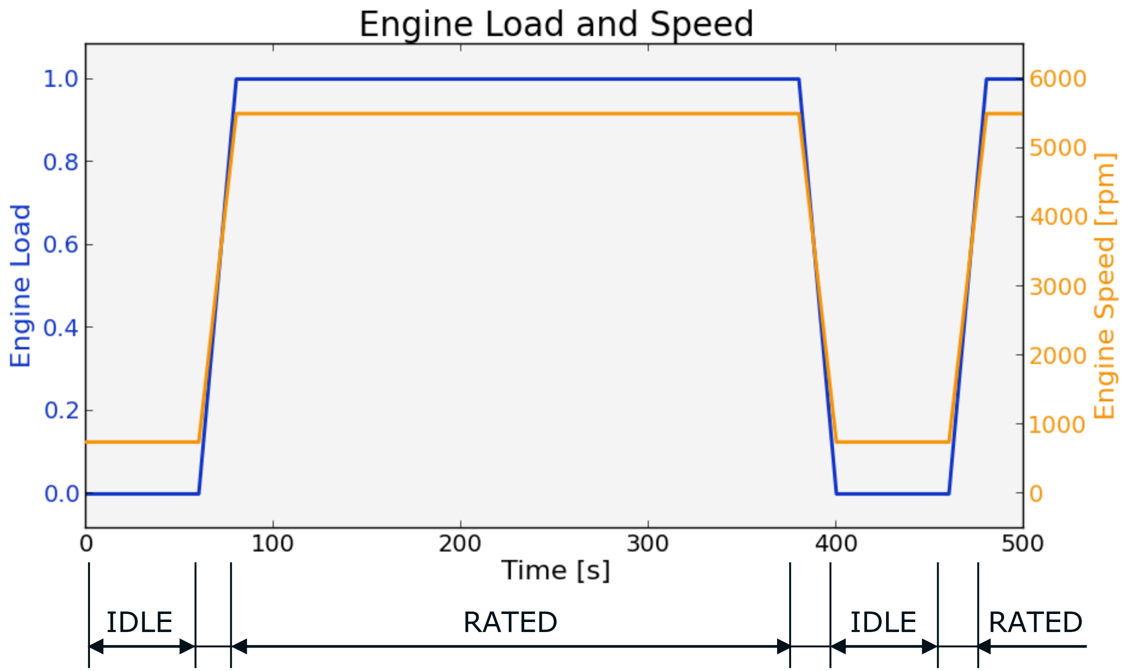
Slide animated, 2x

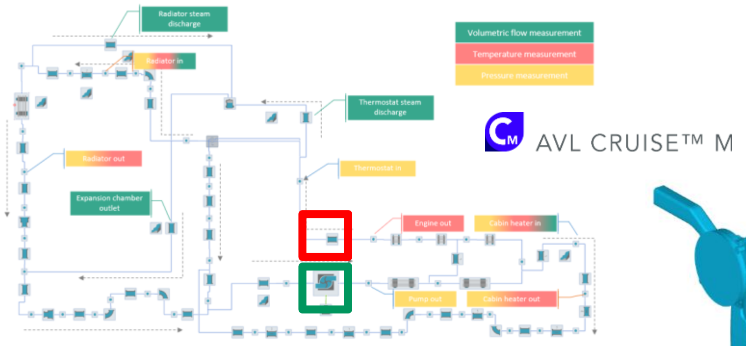
DEMO CASES

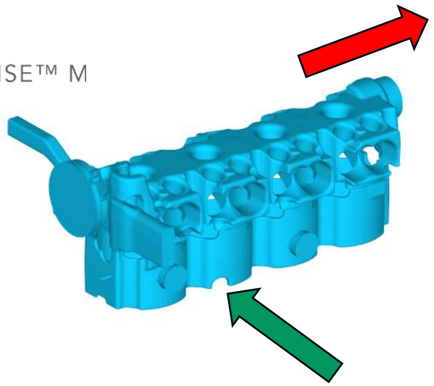
- CASE 1: TMF Cycle
- CASE 2: UPHILL Drive

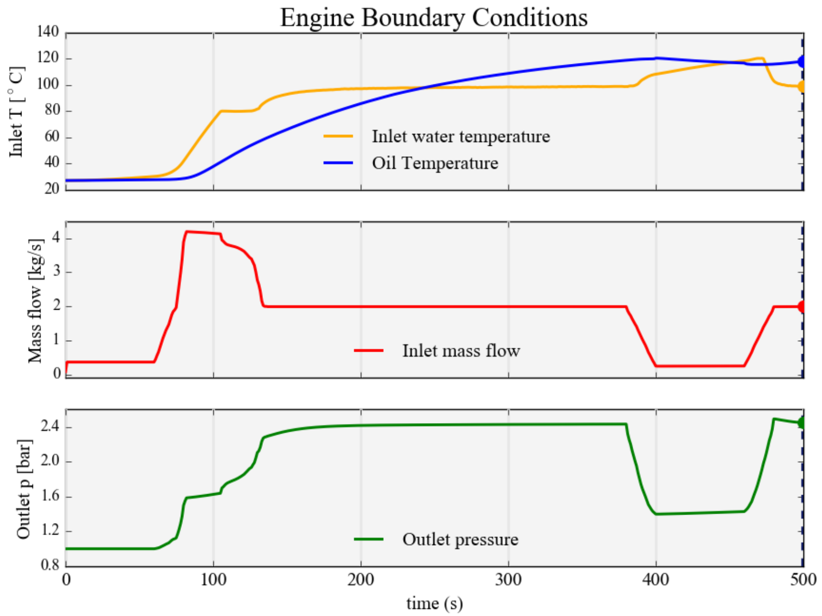
DEMO CASE 1
TMF Cycle

TMF Cycle

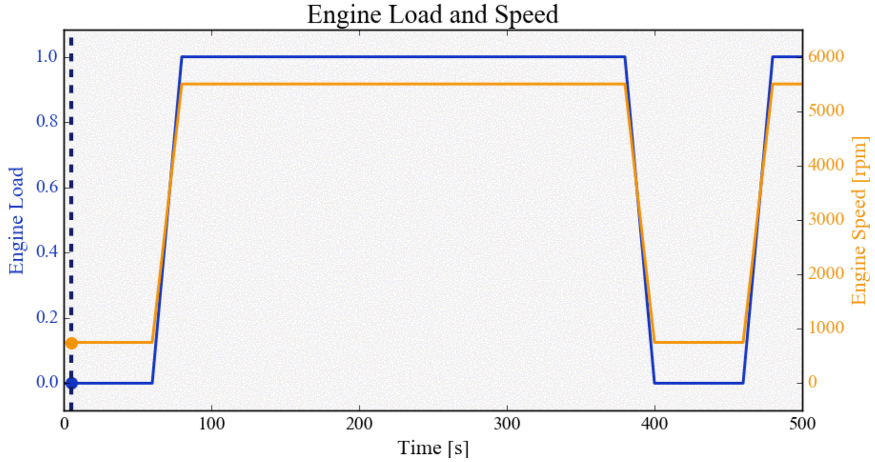


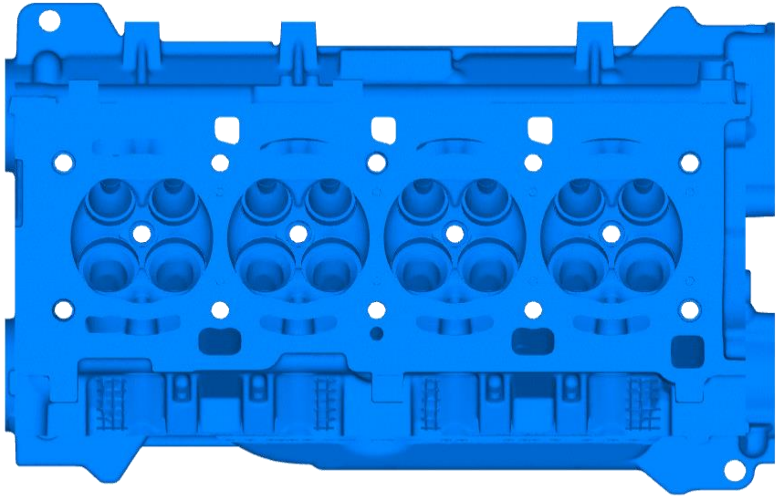






RESULTS
Transient Engine Operation, TMF Cycle

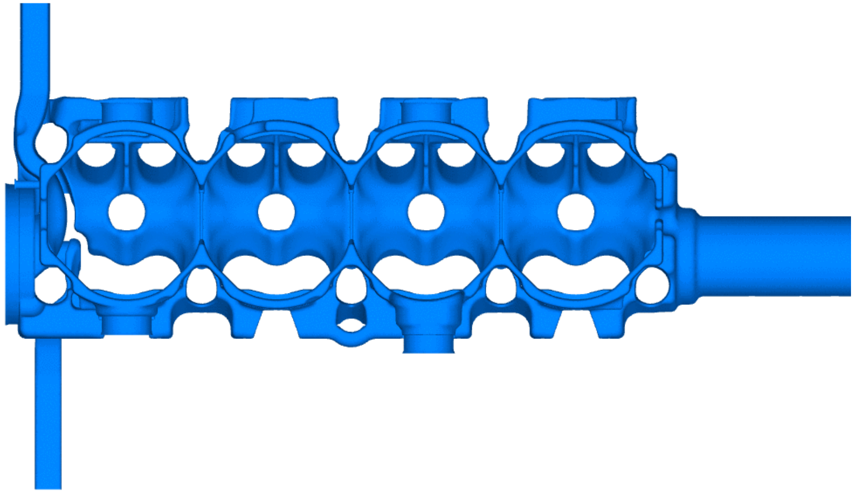




Low
High
Structure Temperature [K]

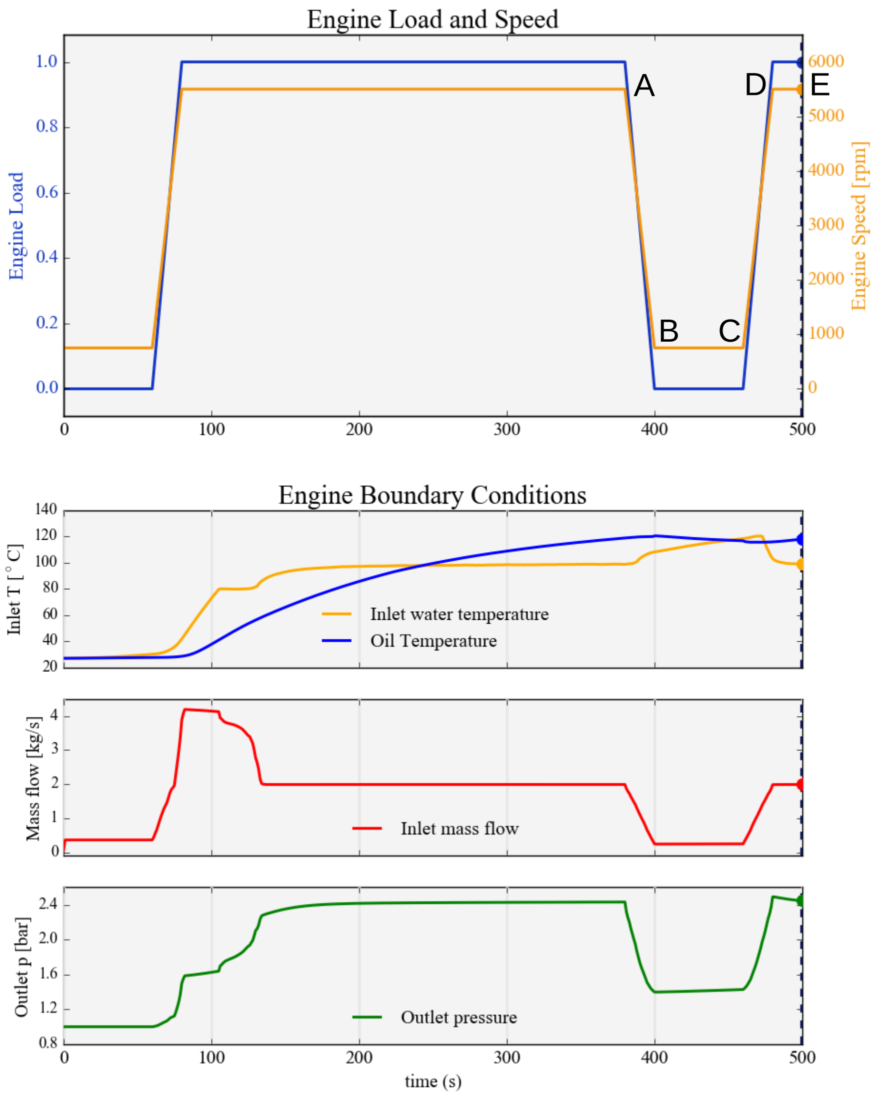
Results:

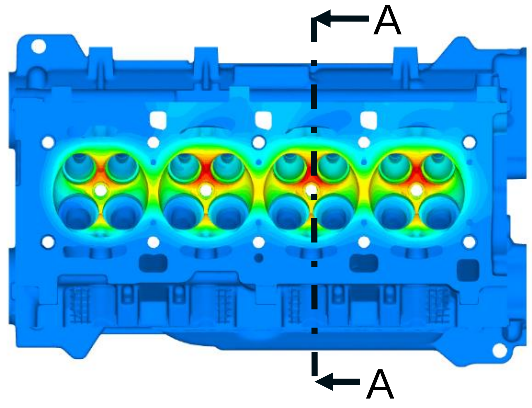
- Cylinder Head temperature
- Boiling response

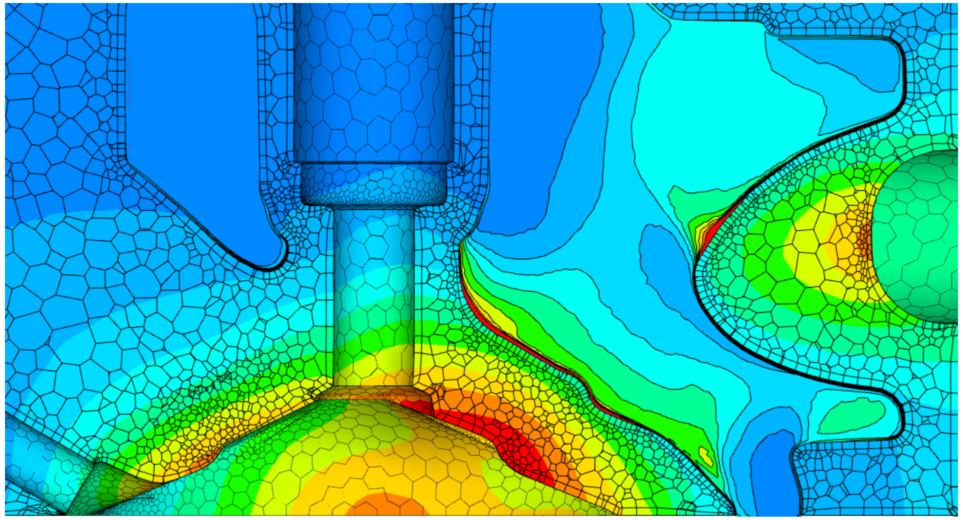


0
1
Boiling Presence [-]

RESULTS
Transient Engine Operation, TMF Cycle





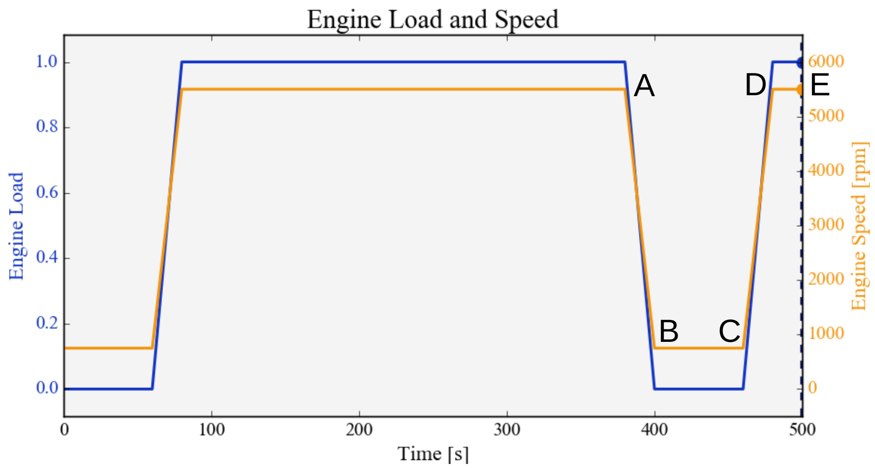


Low
High
Fluid Temperature [K]

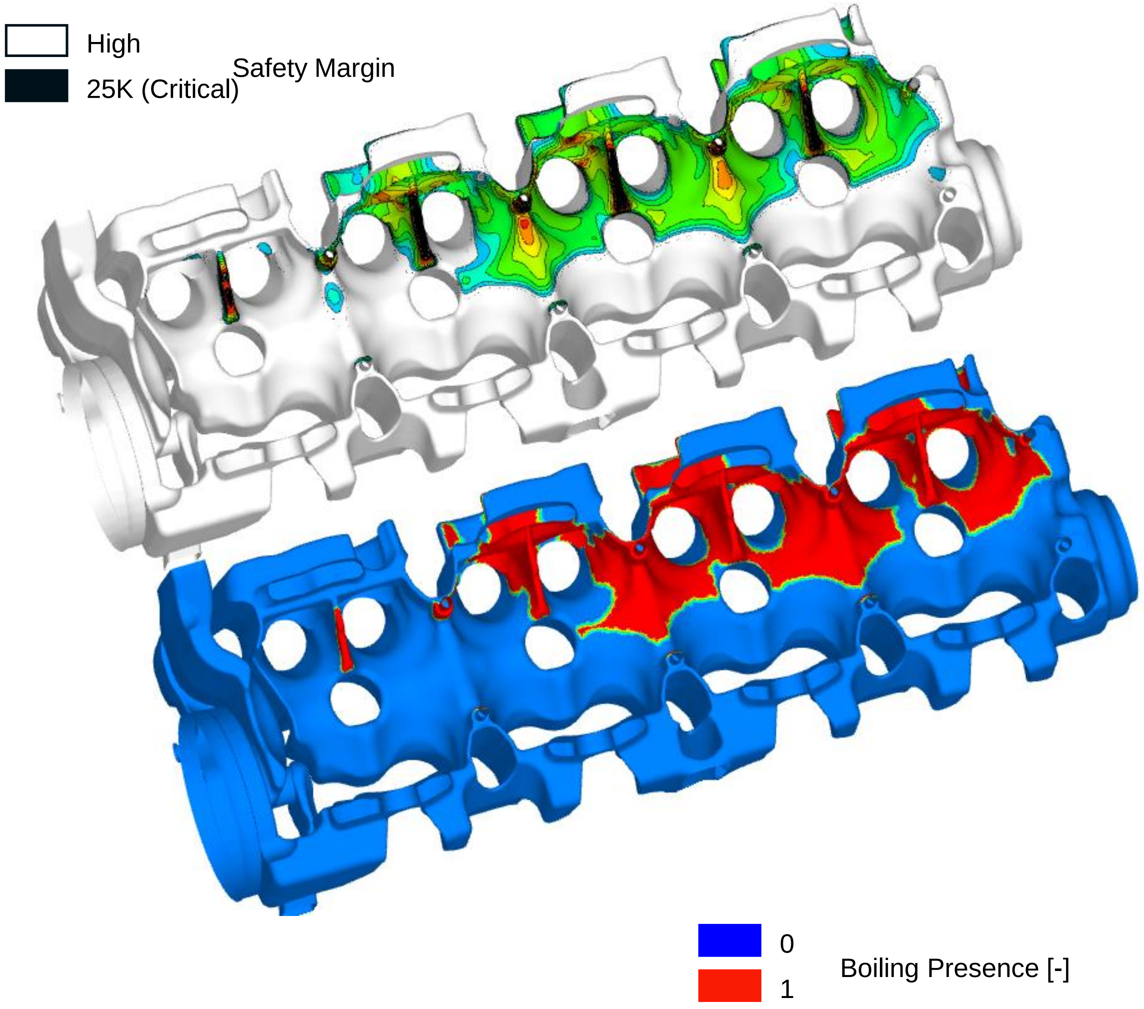
Low
High
Structure Temperature [K]

Slide animated, 4x

RESULTS
Transient Engine Operation, TMF Cycle



Critical conditions: Point “C”

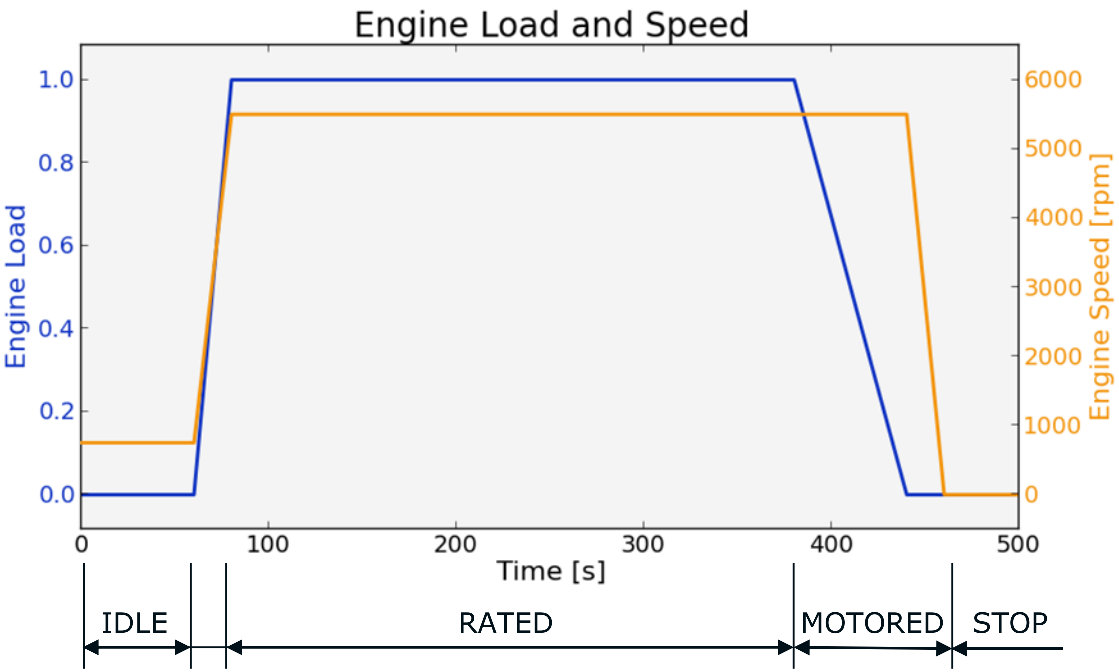


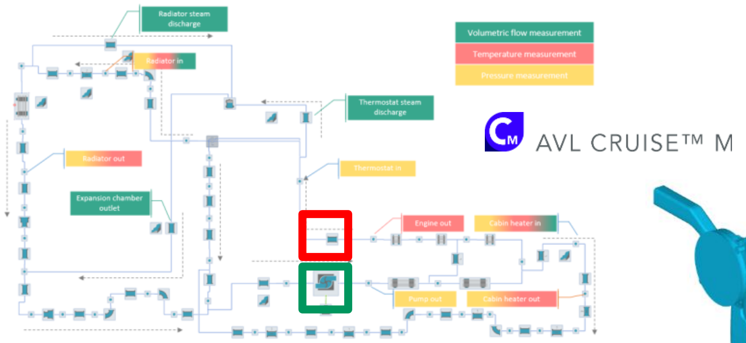
Slide animated, 5x

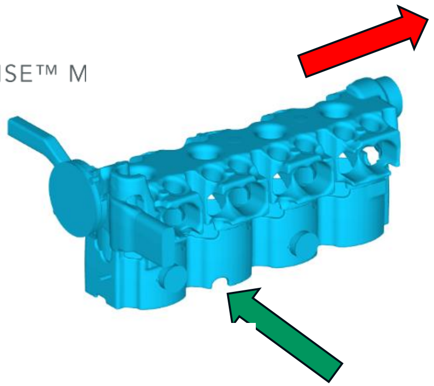
DEMO CASE 2

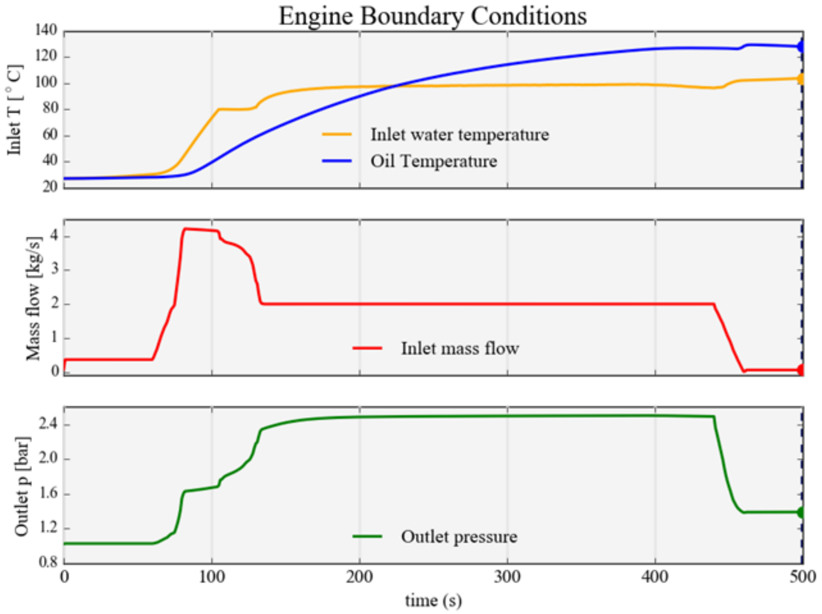
Transient Engine Operation, UPHILL Drive

UPHILL Drive

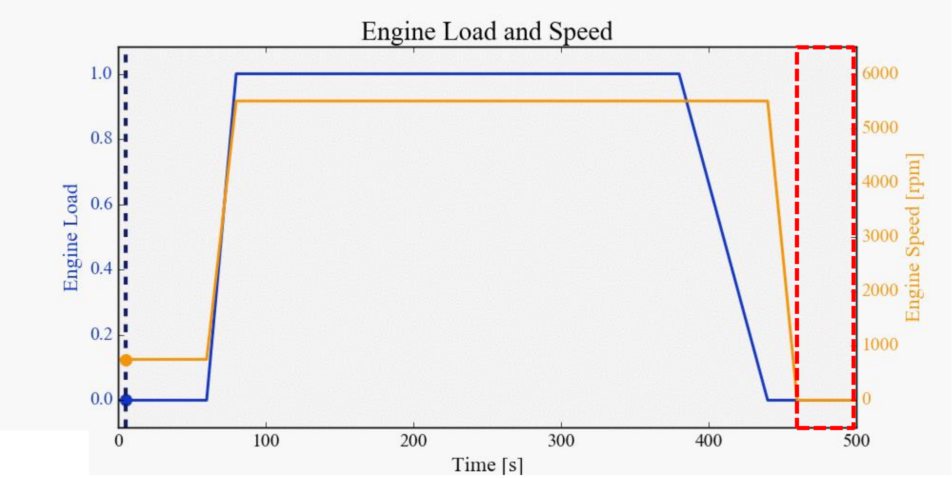


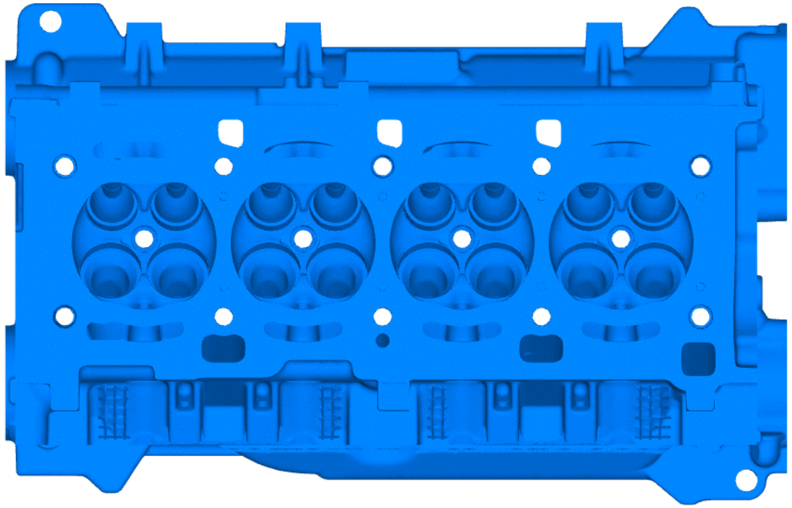






RESULTS
Transient Engine Operation, UPHILL Cycle

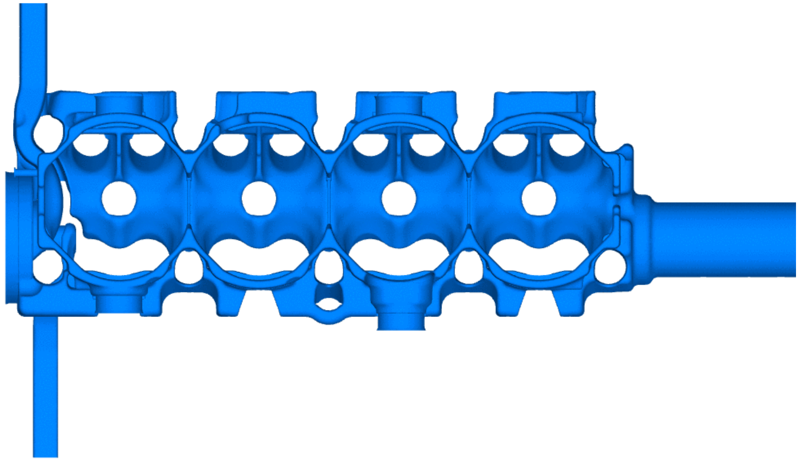




Low
High
Structure Temperature [K]

Results:

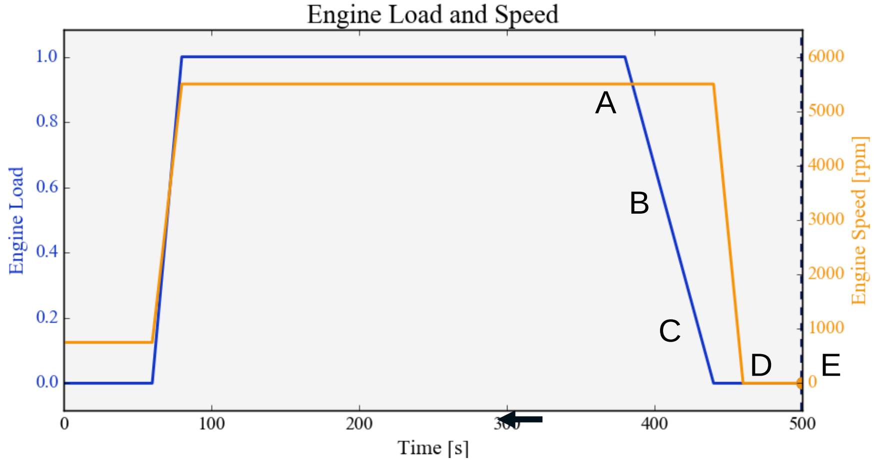
- Cylinder Head temperature
- Boiling response
- *Engine stop, no coolant flow*

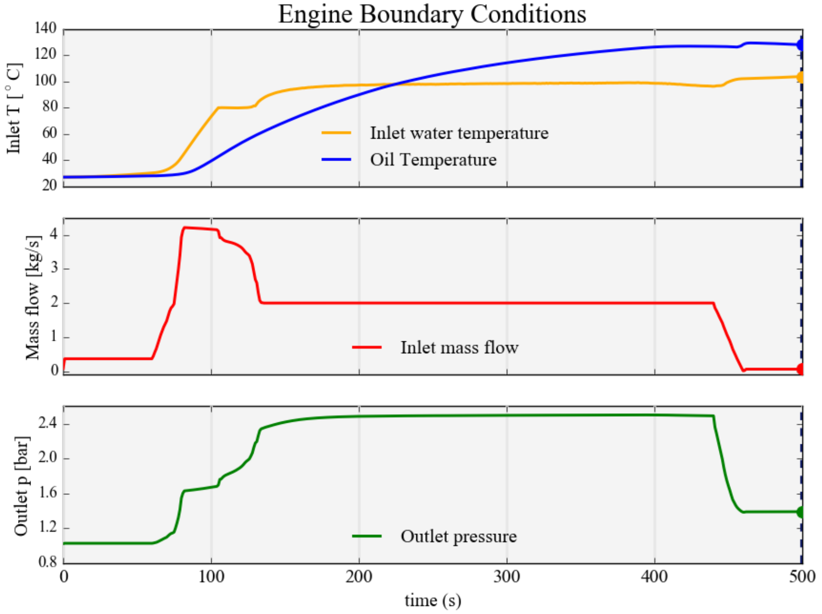


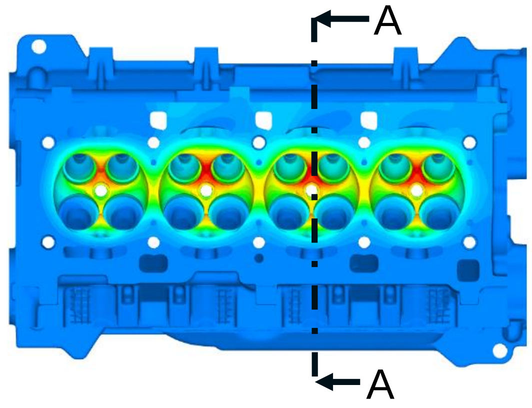
0
1
Boiling Presence [-]

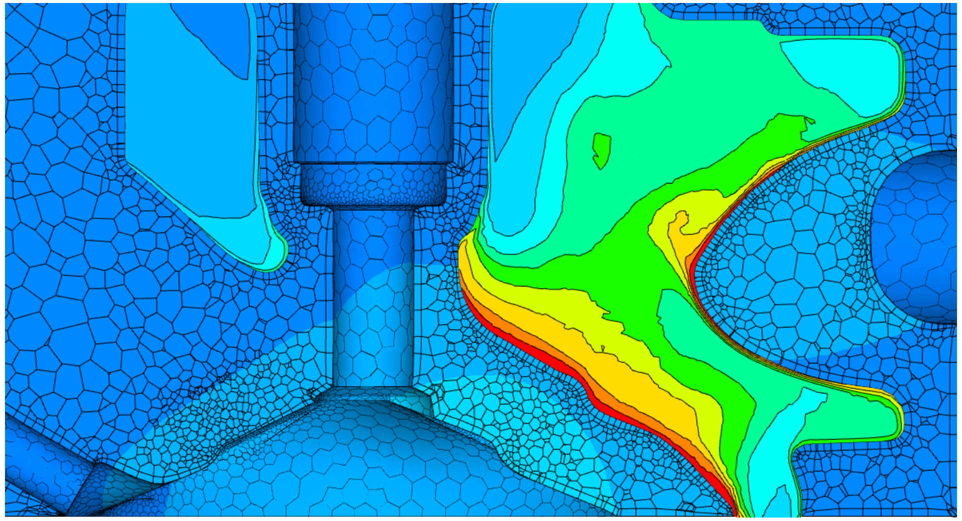
Slide animated, 1x

RESULTS
Transient Engine Operation, UPHILL Cycle









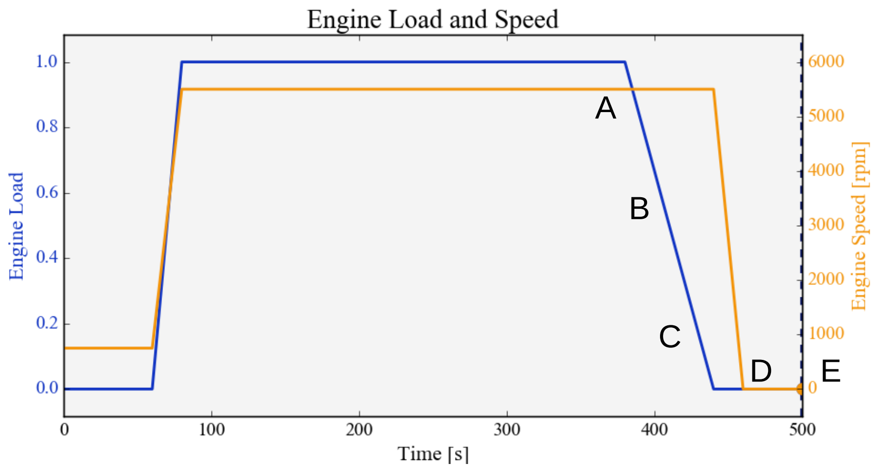
Low
High
Fluid Temperature [K]

Low
High
Structure Temperature [K]

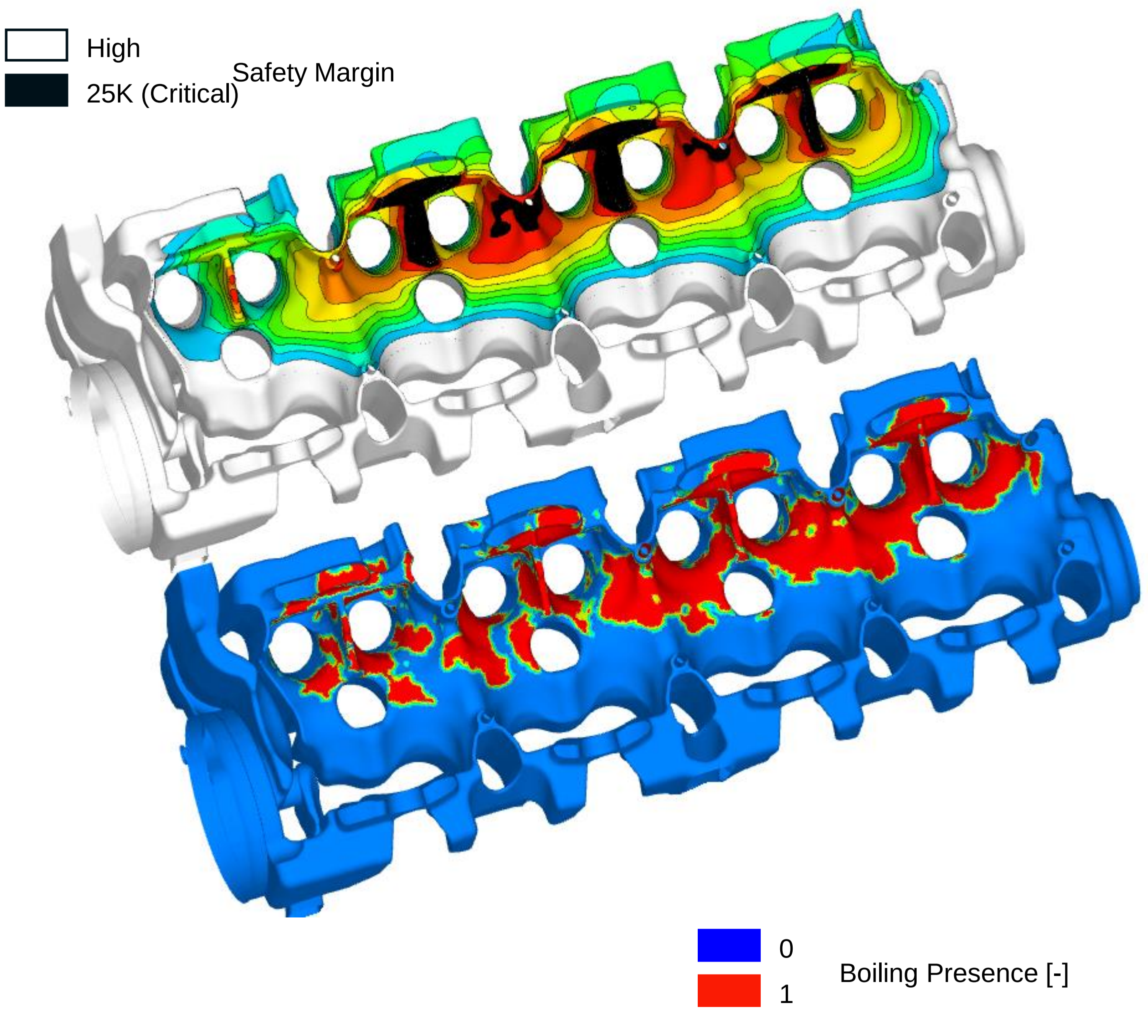
Slide animated, 4x

RESULTS

Transient Engine Operation, UPHILL Cycle

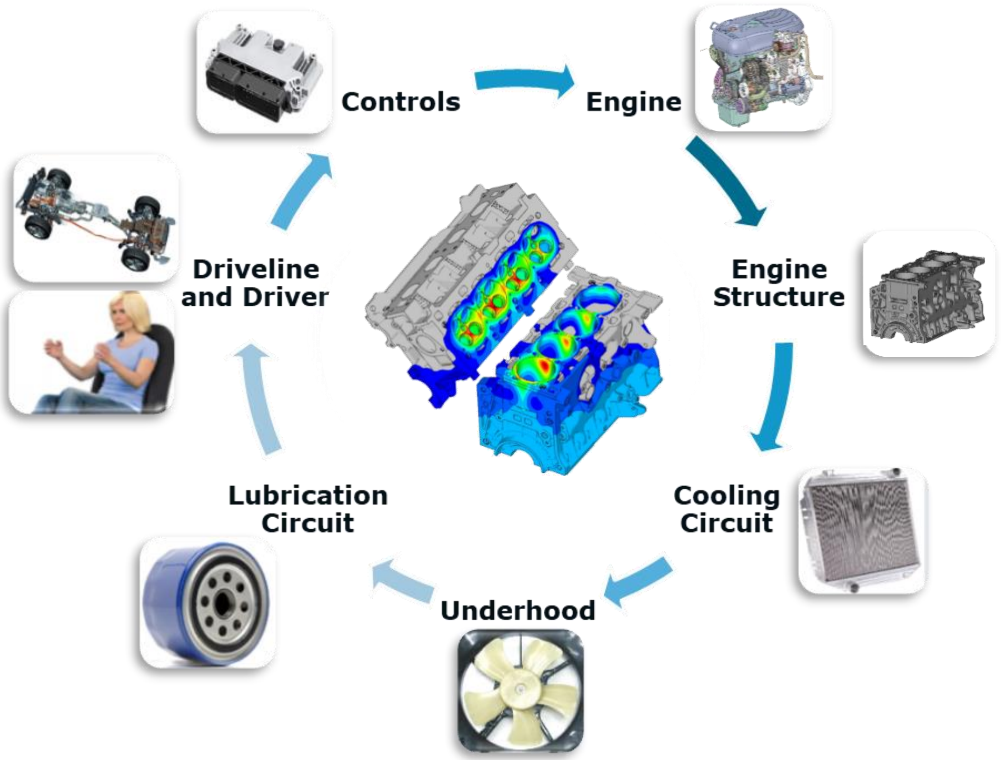


Critical conditions: Point “E”



Slide animated, 5x

SUMMARY



1. Introduction to relevant simulation capabilities
2. Introduction to simulation methodology
3. Solution for steady thermal load extended and applied to transient cycles
4. boiling areas can be detected (time, location)
5. critical points detected. UPHILL Drive with sudden engine stop leads to strong boiling → nucleate → transition boiling

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