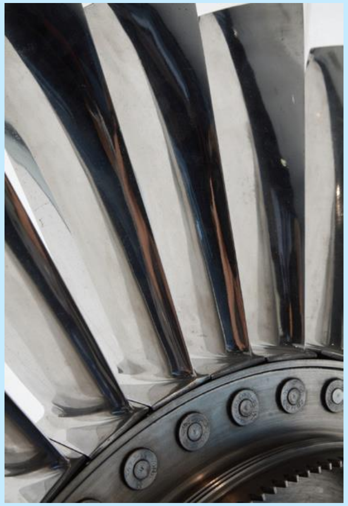
FS DYNAMICS

Your Simulation Expert

Jose Fonseca
Group Manager - Germany

FS Dynamics (Fluid Structural Dynamics)

- Consulting-firm concentrated on technical calculations with over +150 CAE engineers and +20 years of experience in several different industry segments.
- This narrow focus, together with the company's high competence and long-term customer relationships are success factors
- Today, FS Dynamics is the leading consulting-firm focused on calculation services within fluid dynamics (CFD) and structural dynamics (FEM) in the Nordic region.



CAE Services

All sites, 150+ FEA and CFD, Plasma and Molecular Dynamics consultants.

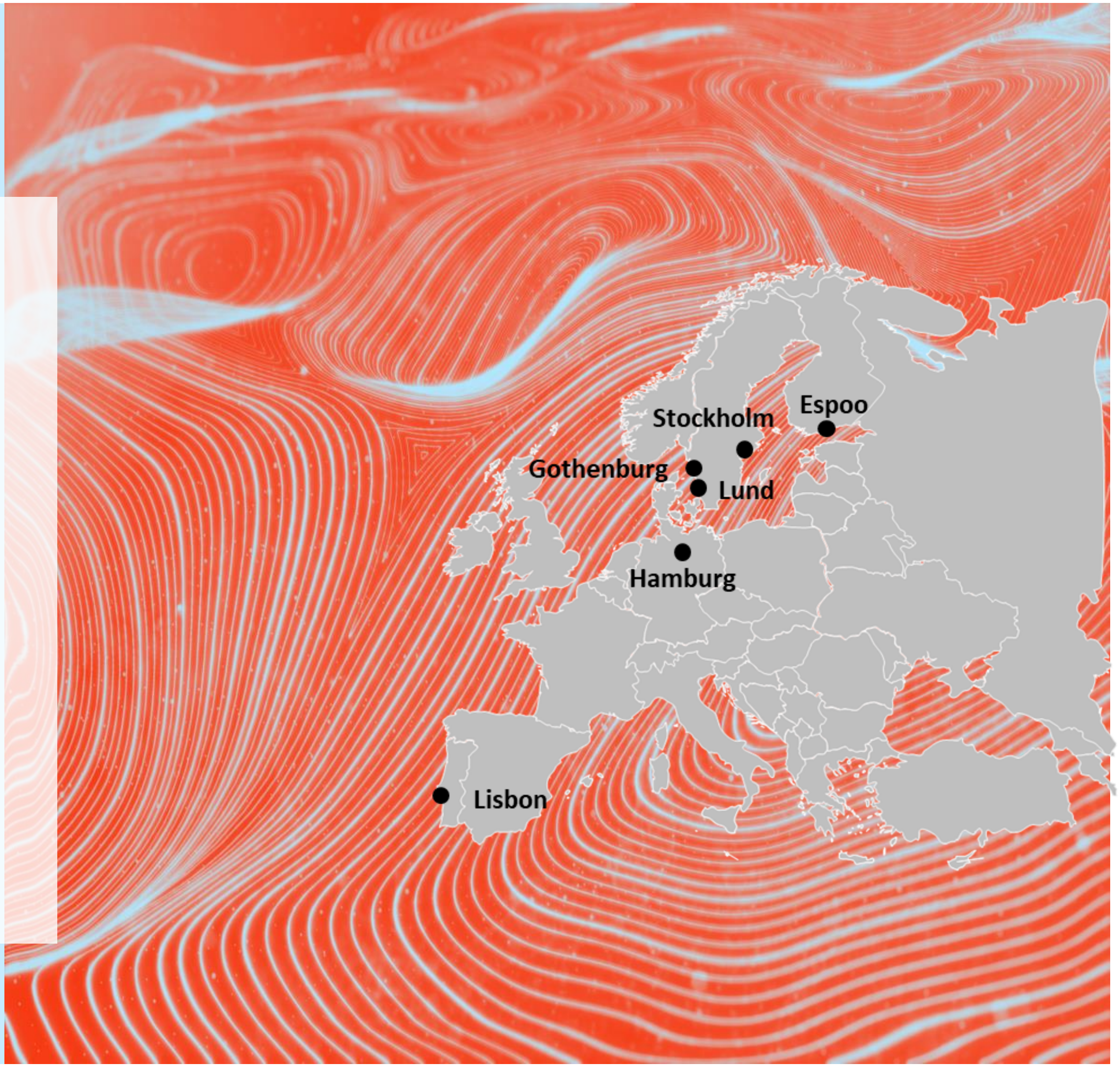
Top Talent recruitment
(~25% PhD, minimum MSc.)

500+ projects with 200+ customers every year

ISO9001: 2015
ISO14001:2015

~50% CFD / ~50% FEM split

Average of 8,5 years of experience per consultant

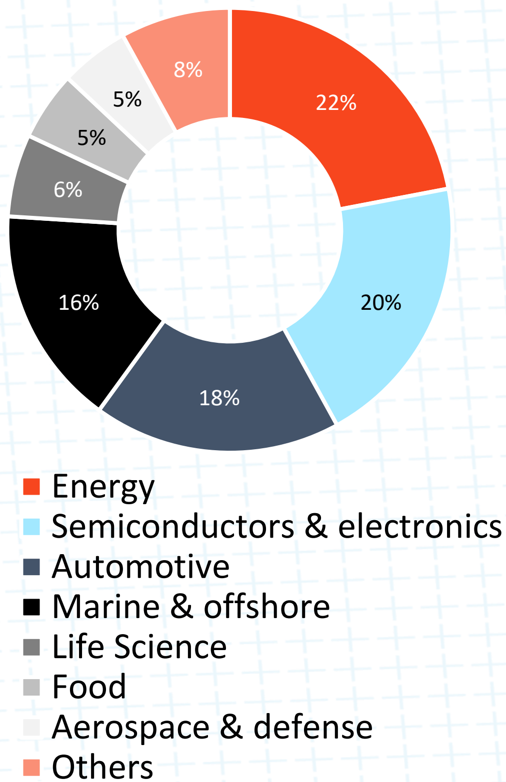


Great variation of industries

Work within all major markets and all size of companies

- Energy
- Food & Packaging
- Offshore
- Semiconductor
- Process Industry
- Nuclear Energy
- Automotive / Electrification
- Defense
- Medical / Life Science

Market



Diversity

- Mix of SMB and Enterprise customers
- Mix of markets
- Mix of consultant experience level
- Mix of Software

Suitable Ambition Level

- Consultation
- Hand calculation
- Simple Simulations
- Advance Simulations
- Method Development
- Research

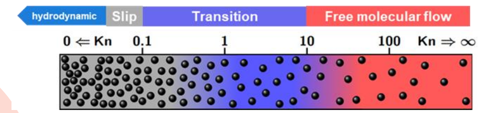
The tool is chosen based on the physics, application and customer preference.

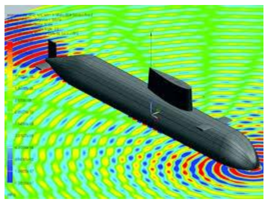
Branch-leading technical resources

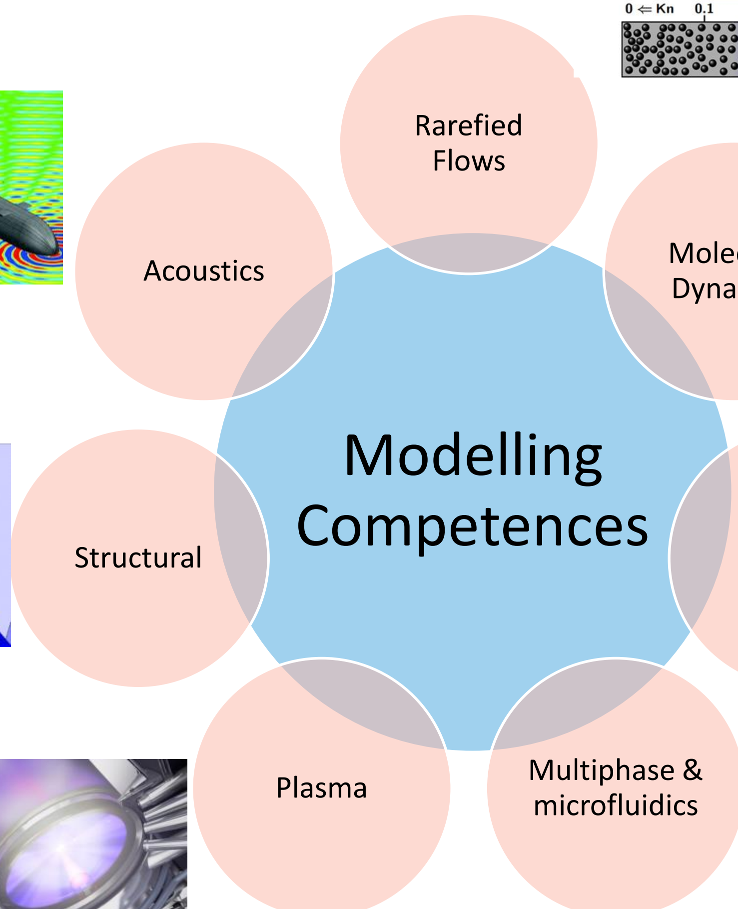
HPC

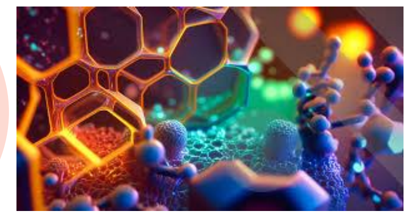
- Self-hosted server room in Gothenburg
- 2500 CPUs up to 4 TB RAM
- Available for CFD, FEM, Molecular Dynamics and Plasma computation.

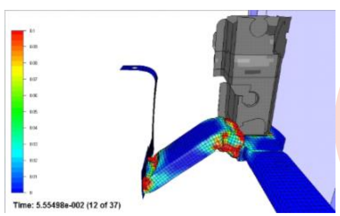
Additionally, to standard fluid flow, thermal, acoustics and electrical analyses, FS Dynamics has strong competences in: .

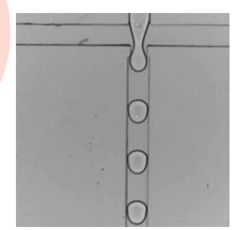












OpenFOAM *experience at FS Dynamics*

FS × DYNAMICS

1. Deploying OpenFOAM® anywhere the client needs it
    - Porting to Microsoft Windows - blueCFD-Core: http://bluecfd.com/Core
2. Developing GUIs and middleware for client's requirements in their use of OpenFOAM
3. Developing solvers to meet client's simulation needs
4. Developing meshing workflows beyond those available in OpenFOAM
    - Using ANSA from Beta CAE with Python
    - Modifying *snappyHexMesh* to include missing features
5. Setting up and running single phase, multiphase and multi-region simulations
6. Tackling existing modelling limitations in
7. Validating existing models in

OpenFOAM

FS Dynamics works with work packages

Technical Discussion

Under NDA, FS Dynamics & customer discuss in technical details the work package, focusing on the content, deadlines and budget.

Planning & cost estimation

FS Dynamics prepare a plan with time and cost estimation of each activity based on the scope of phase 1.

Customer Alignment

FS Dynamics align the planning and cost with the customer. Discussion regarding Statement of working and way of working can also be done here.

Quotation

FS Dynamics prepare and send quotation to the customer (Purchase Request)

Kick-off

Once the Purchase Order is received; FS Dynamics kick off the project with customer team following the agreements defined on Customer alignment phase (described on the quotation).

Portfolio

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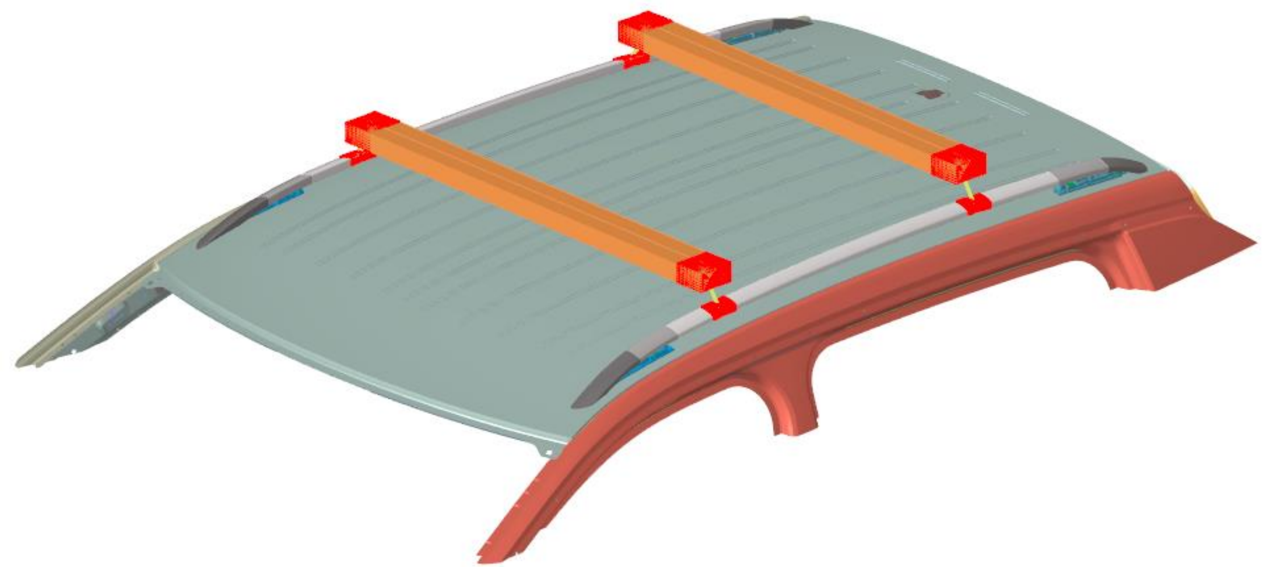
Transport
Energy
Electronics
Aviation
Space

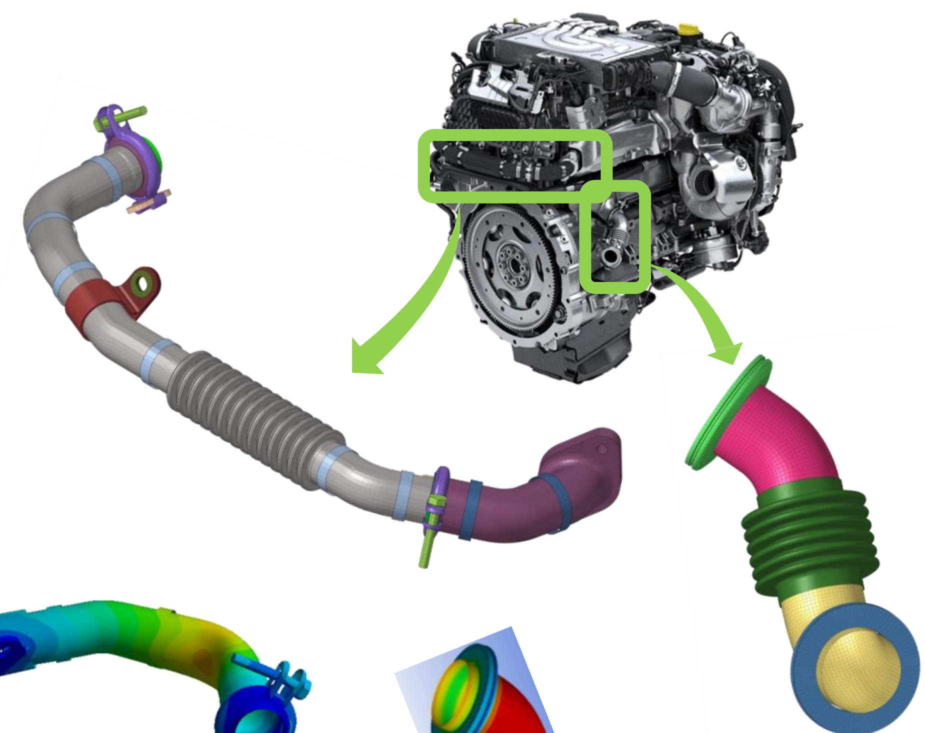
Roof rail systems - FEM

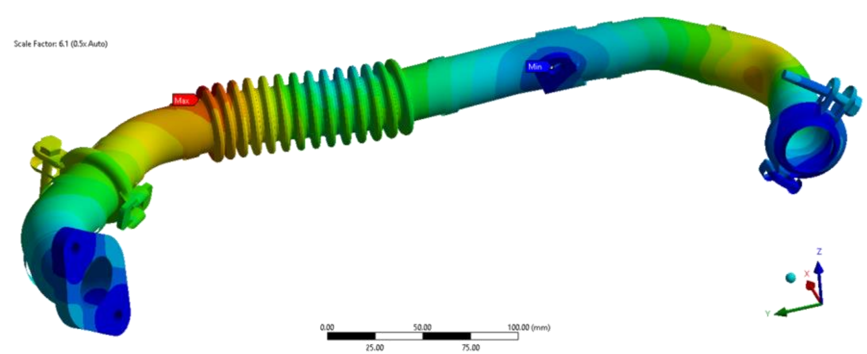
Objective
Validate different designs of the roof rail systems for the automotive industry simulating the standard tests scenarios.

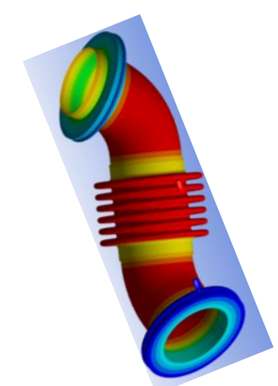


ICE tubes - FEM

Objective
Thermo-mechanical static and dynamics response of different manifolds installed on internal combustion engines.







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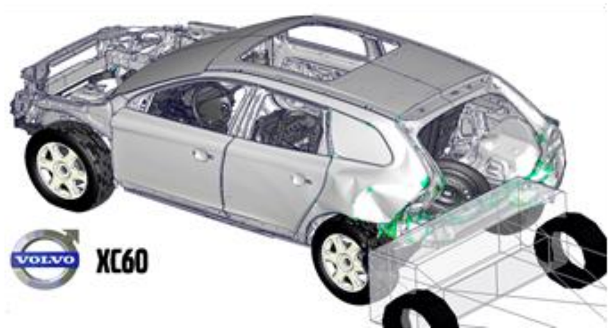
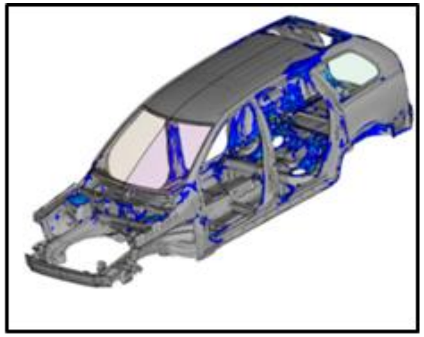
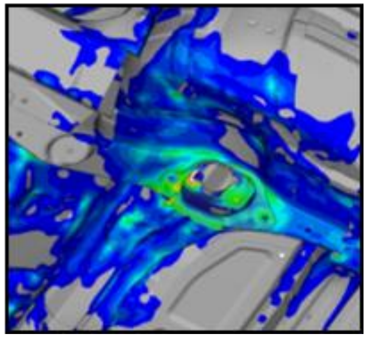
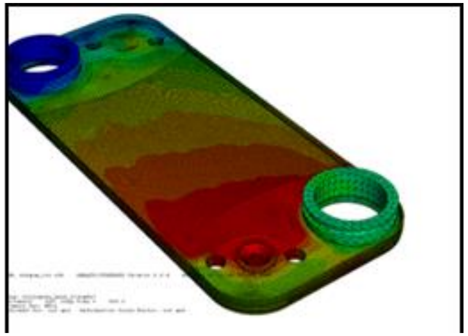
Crash test - FEM

Objective
Crash test simulation of vehicle with structural verification down to the single component level.



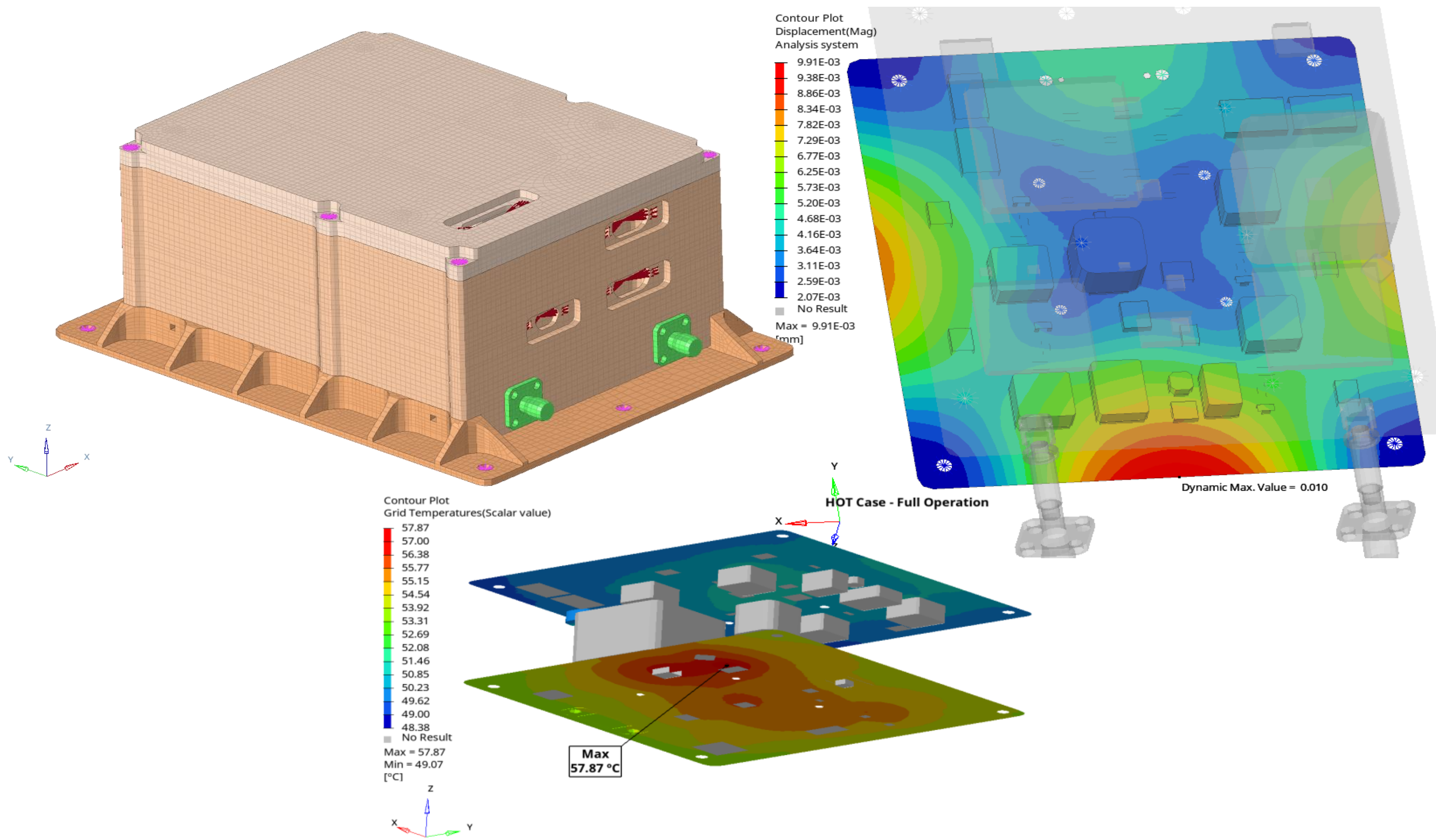






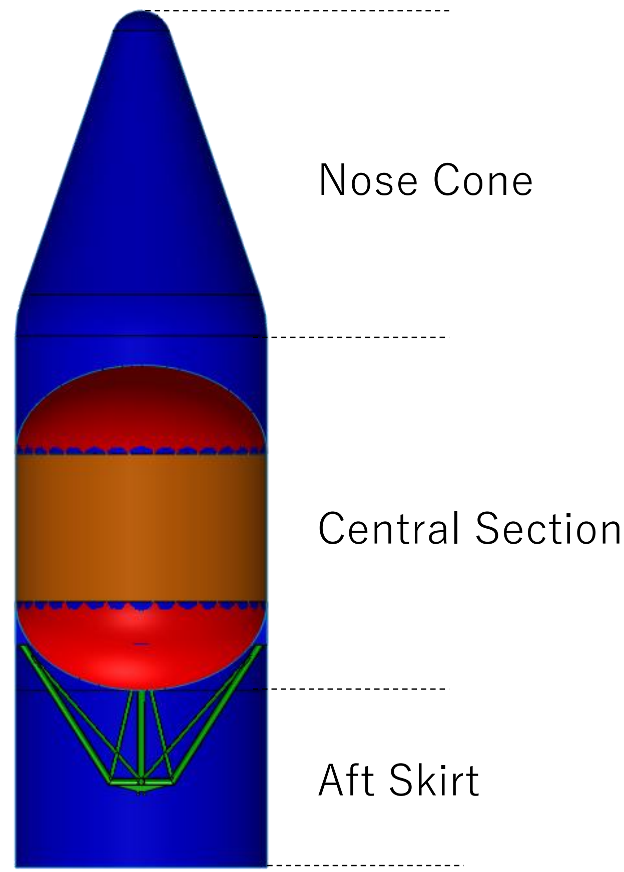
Payload and system hardware structural verification - FEM

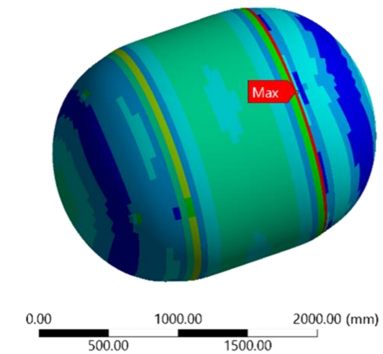
Objective
Thermal, static and dynamic response of electronics components for satellites according to ESA requirements.

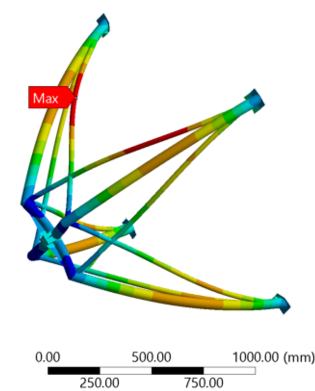


Rocket launcher - FEM

Objective
Predesign of a rocket with a tank built with composites materials.

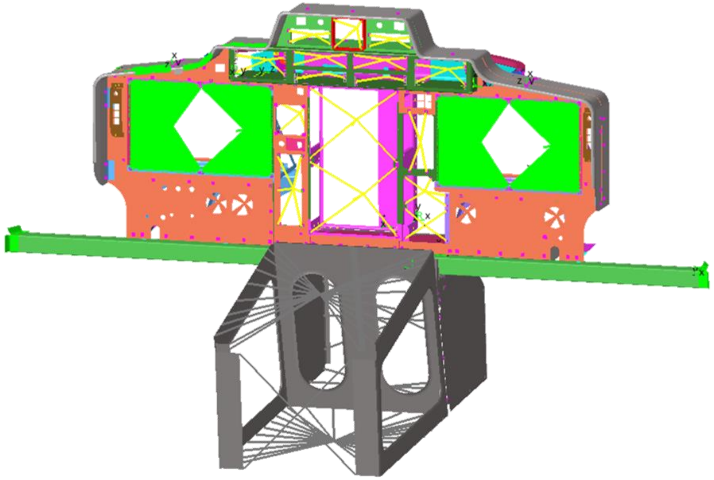






Cockpit avionics panel - FEM

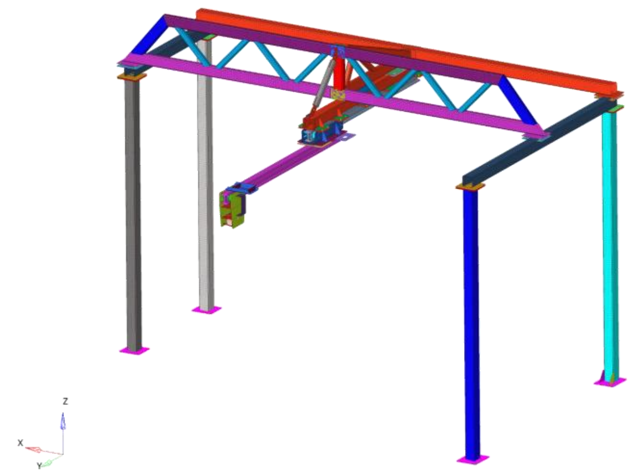
Objective
Static and dynamic response of the new upgrade kit for the C-130 cockpit.

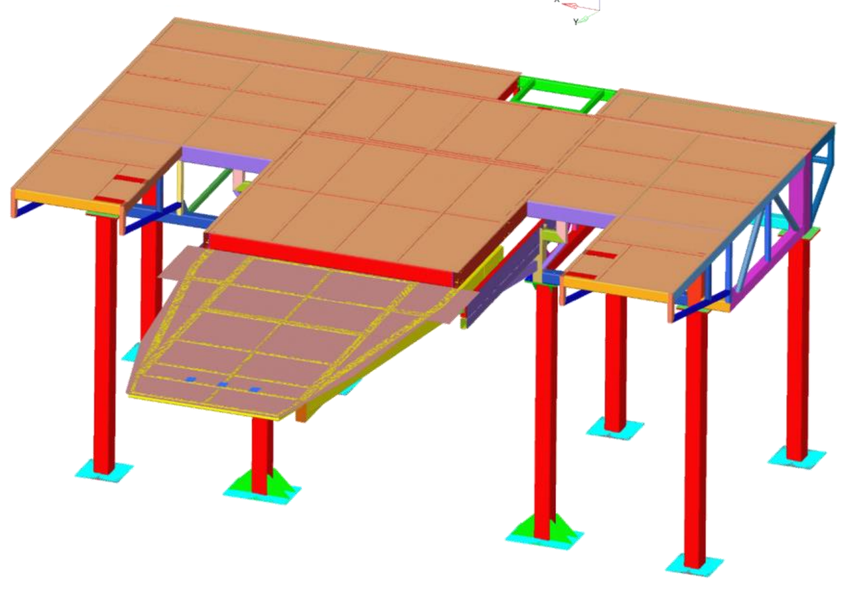


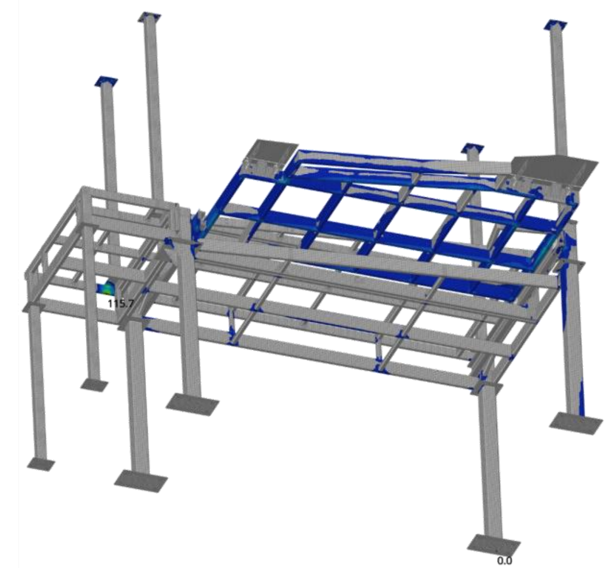
Maintenance platforms - FEM

Objective
Structural integrity and displacements evaluation of platforms for maintenance of civil aircraft.

FEA methodology driven by the Eurocode norms for metal structures.



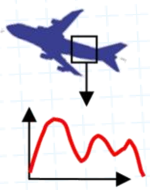


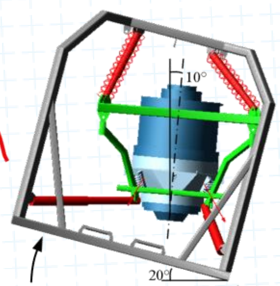


Acceptance Testing of transportation system - Drop test Acceptance testing

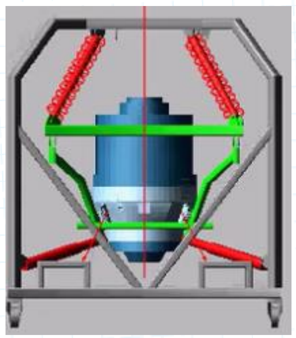
Early development phase tools: MBS Adams simulations

Air plane take off

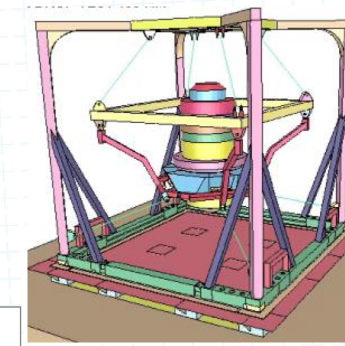




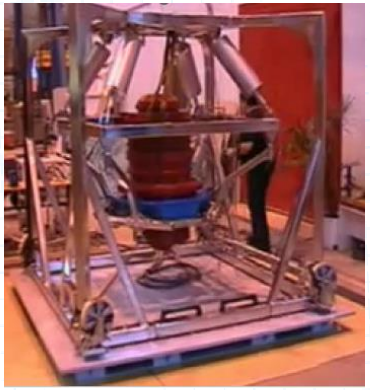
Drop test assessment

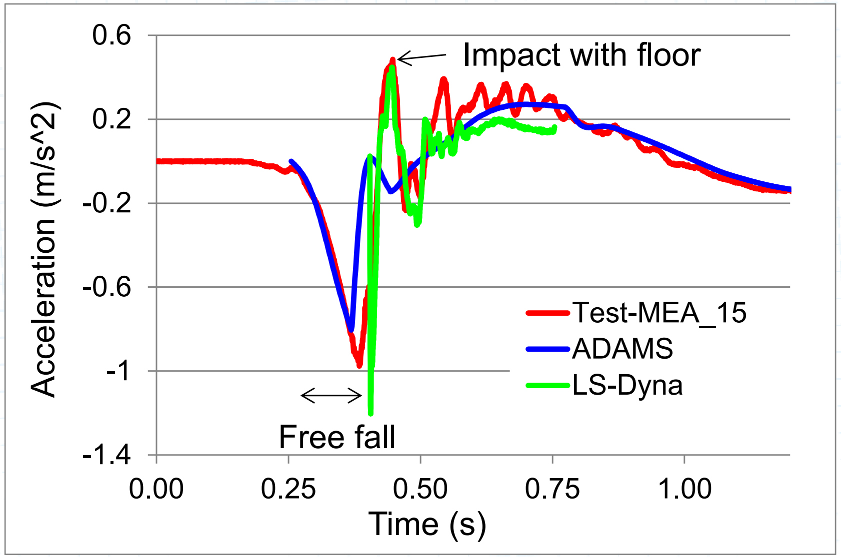


Detailed development phase tools:
FEA LS-Dyna simulations drop test



Physical experimental test





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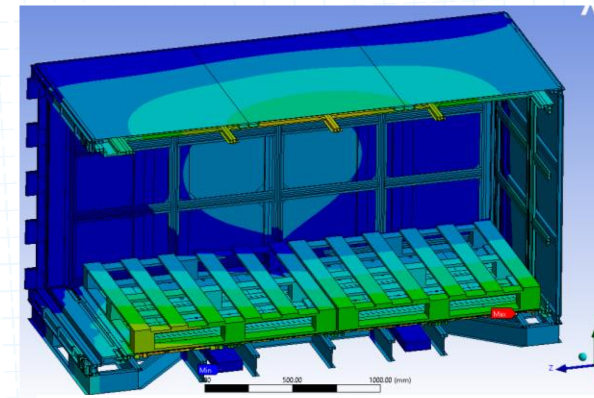
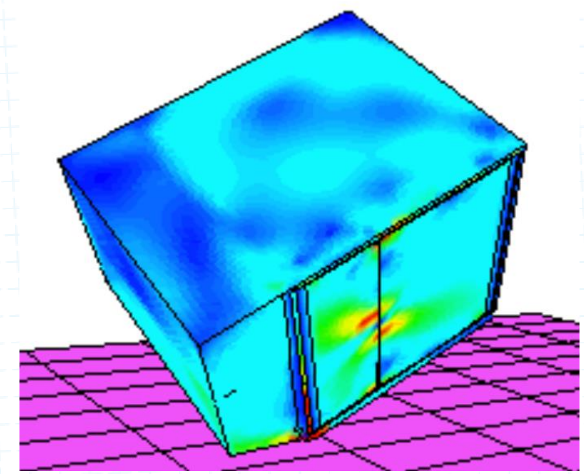
Container Shipment – Development and certification

- Container sizes has a tare weight of 50 to 2000 kg, the full weight including payload is 75 - 9000 kg.
- Comprehensive FEA is defined with global assessment as well as local assessment of:
    - Rivets and bolts. Typically found in aluminium frames as the primary means of connecting parts.
    - Contacts
    - Hinges and Joints
    - Composite material functionality. Monopan sandwich sheets included with equivalent material properties established with Ansys Material designer.
- Representative load cases defined to fulfil standard certification together with internal customer criteria.
    - Fork lift load cases
    - Drop test (corner, edge and flat)
    - Transportation vibration





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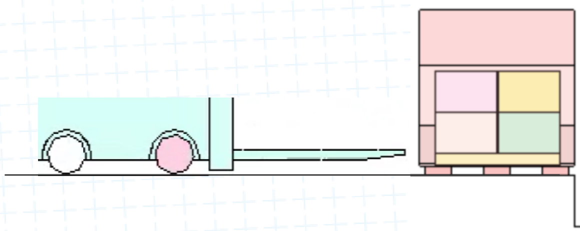
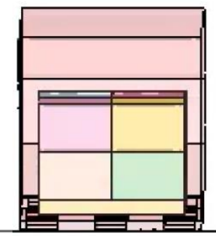
Container handling - Structural assessment of fork truck abuse

For truck running into container with packages standing on an edge

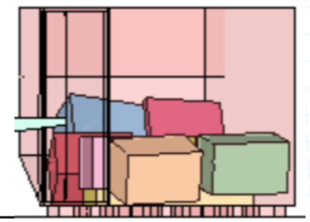


Results from two scenario:

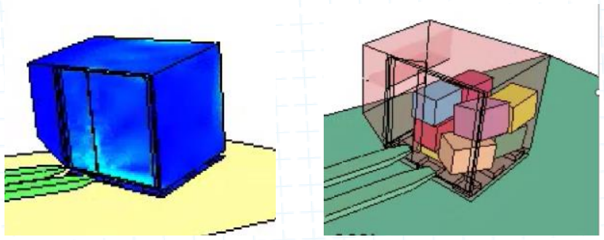
Constrained packages



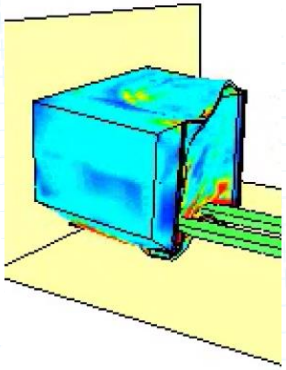
Unconstrained packages

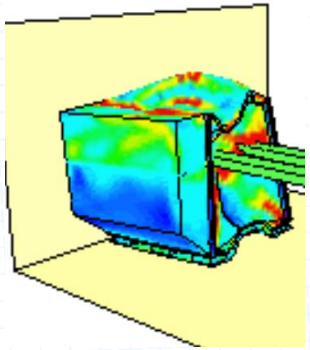


For truck running into container with unconstrained packages



For truck running into and crushing the container. Fork blades at different elevations



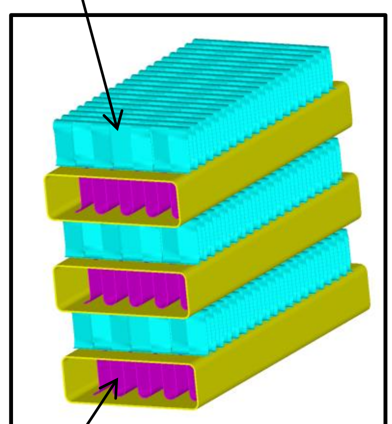


Transport
Energy
Electronics
Wastewater
H.V.A.C.
Biomedical
Process
Machinery

Fin Design for compact HE

Objective →
Optimize fins in Cold and Hot streams of a compact gas-gas intercooler so that cost can be reduced (reduced metal use) and improve efficiency.

Cold stream fins may change, but:
- thermal efficiency should be increased at the same or smaller pressure drop;
- constraints on geometrical settings.

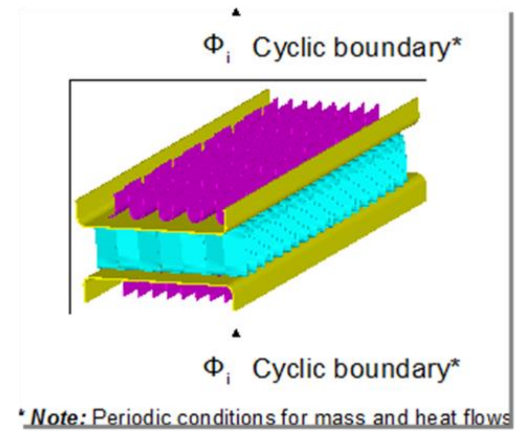


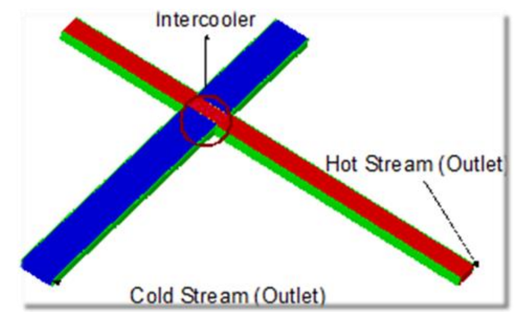
Intercooler bulk example

Hot stream fins may change but they are less important than the cold stream fins.

Complex geometries – Reduced computational molecule with around 4M grid nodes of structured, purpose built, mesh, for quality.

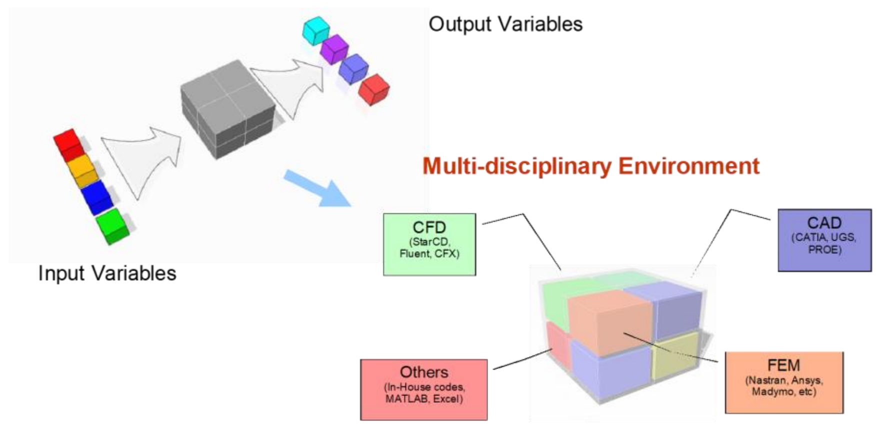
Improve computational efficiency





Fin Design with Automatic Optimization

Objective → Devise economical optimization procedure



Based on initial fin configuration, parametric runs were performed coupling an optimization tool, **modeFRONTIER**, with **STAR-CD**

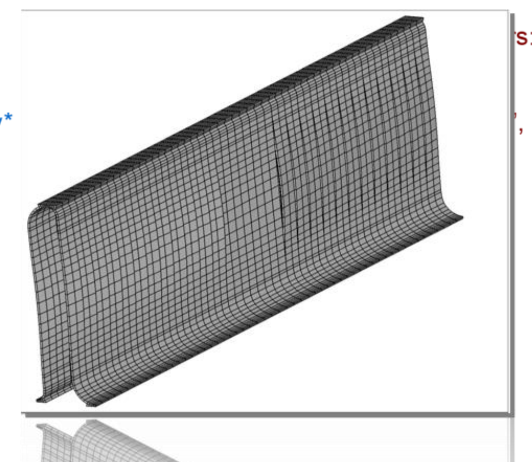
Optimization Objectives:

Maximize Thermal Efficiency*

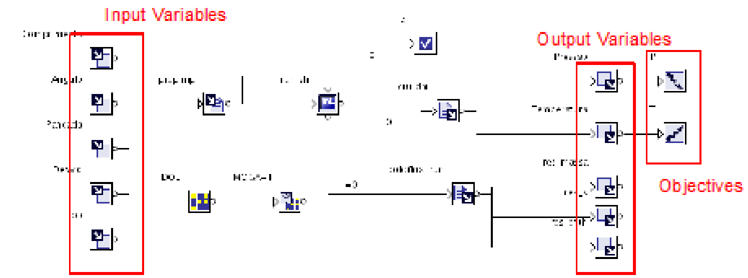
Minimize Pressure Drop

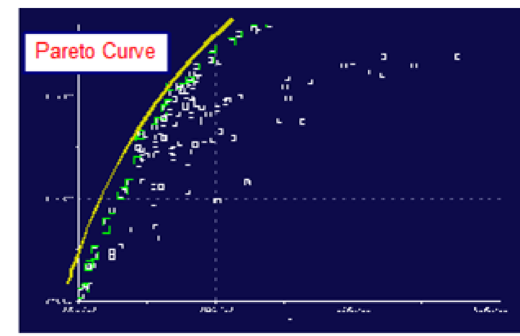
** defined as:*

$\eta = (T_{out}-T_{in})/(T_w-T_{in})$



Optimization Workflow





Points marked green are **Pareto points**, i.e., they are all **optimal designs**.

Pressure drop versus Outlet temperature

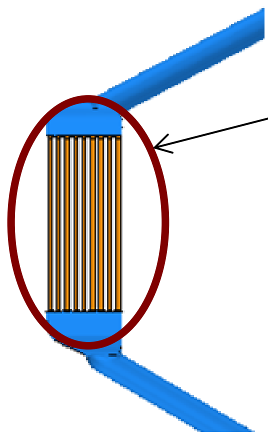
Over 150 runs performed

⬇

Potential for significant gains at a reduced computational cost

Full Intercooler Simulation – How-To

Objective →
Allow simplified but accurate full-intercooler simulations



Cold and hot stream bulk simulated as a porous medium due to high computational cost

Coefficients determined via direct simulation.

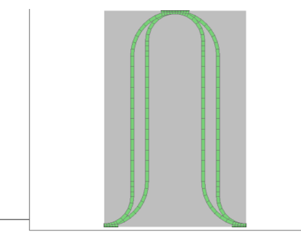
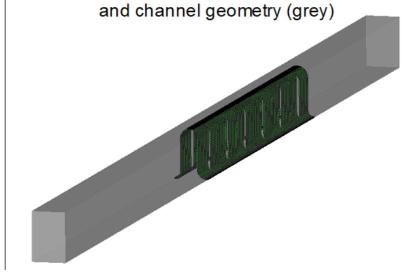
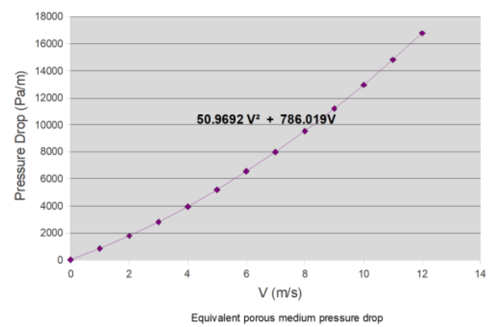


Figure 1 – Offset Fin (green) and channel geometry (grey)



$$\frac{DP}{Dx}[Pa/m] = \frac{\mu}{xK1}V + \frac{\rho}{xK2}V^2 \quad with \quad V\,[m/s]$$

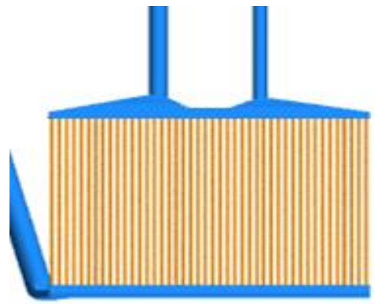


Simulations possible for any intercooler fins.

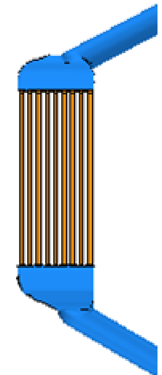
	Intercooler	"Mosaico"	"Downface"	"Fullface"	"Alumec"	"AirWater"
Hot Stream	Type	Offset	Offset	Offset	-	Louvered
	Height (mm)	7.2	7.2	7.2	-	7.5
	Half-Step (mm)	1.4	1.7	1.7	-	1.5
	# Steps	28	16	N.A.	-	N.A.
	Thickness (mm)	0.115	0.115	0.115	-	0.08
	xk1	1.31E-007	1.12E-007	1.12E-007	-	2.73E-008
	xk2	7.27E-002	9.00E-002	9.00E-002	-	1.12E-002
Cold Stream	Type	Louvered	Offset	Offset	Louvered	-
	Height	7.5	7.2	7.2	N.A.	-
	Half-Step	1.6	1.6	1.4	N.A.	-
	# Steps	94	148	N.A.	N.A.	-
	Thickness	0.08	0.115	0.115	N.A.	-
	xk1	3.71E-008	1.05E-007	1.31E-007	N.A.	-
	xk2	1.71E-002	8.29E-002	7.27E-002	N.A.	-

Intercooler Simulation

Objective →
Allow simplified but accurate full-intercooler simulations

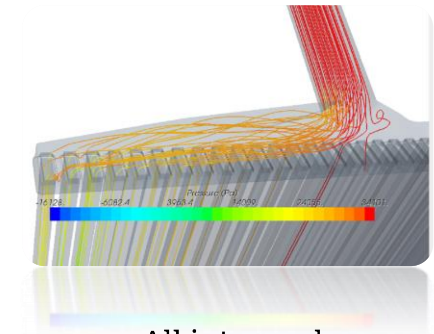


“Fullface”

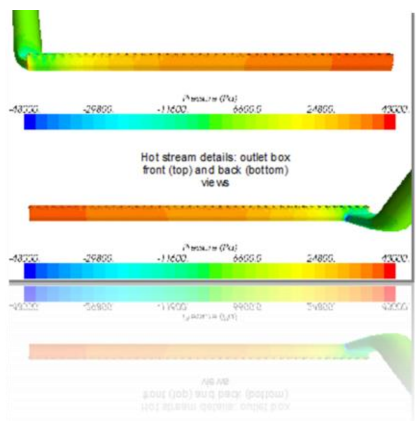


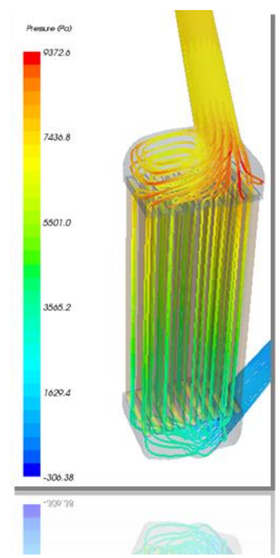
“Mosaic”

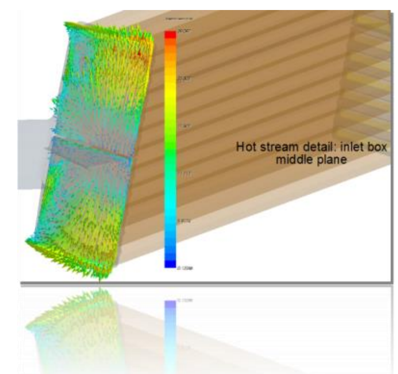
“Downface”



All intercooler simulations showed good agreement with available experimental data.







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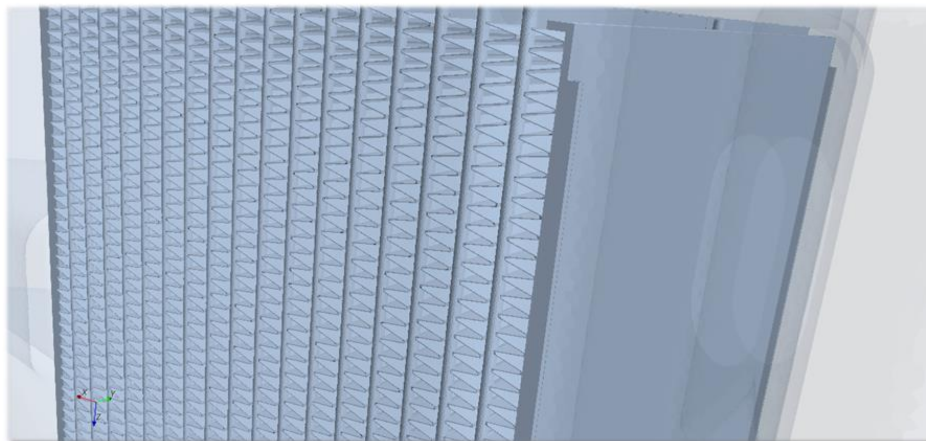
Introduced new simulation methodology in costumer’s R&D department.

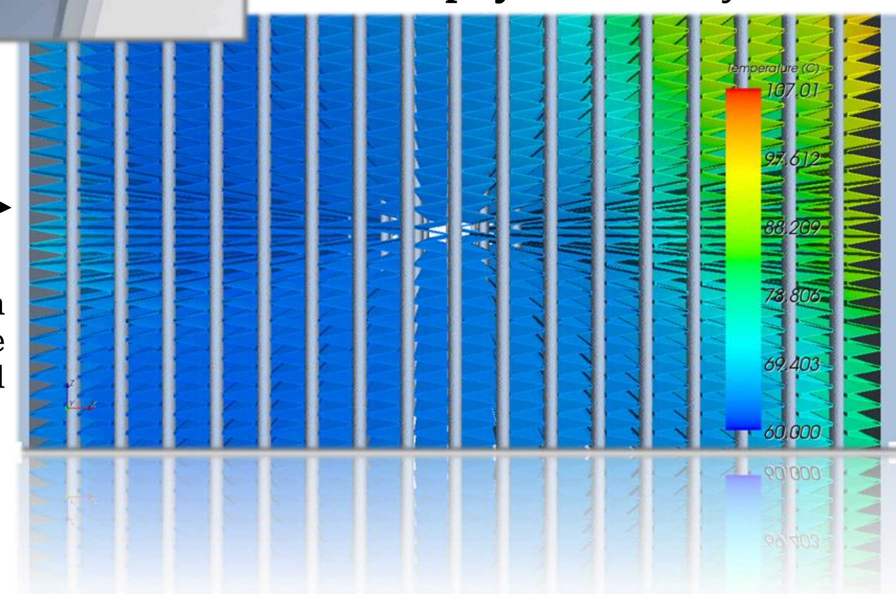
Full Intercooler Simulation – PROGRESS

Objective →
Reduce simplifying assumptions



With time, increased computational power has allowed for the introduction of **fin geometries** in full intercooler simulations.

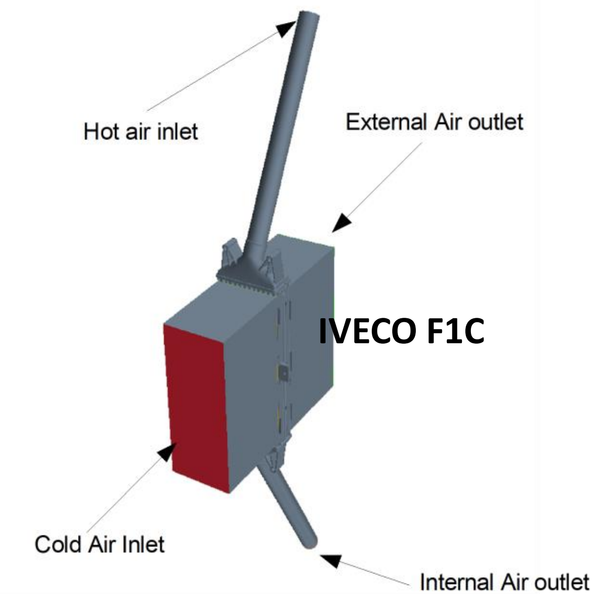
Increased **geometrical** and **physical** fidelity



Fin temperature detail

Thermal Load Induced Solid Stresses

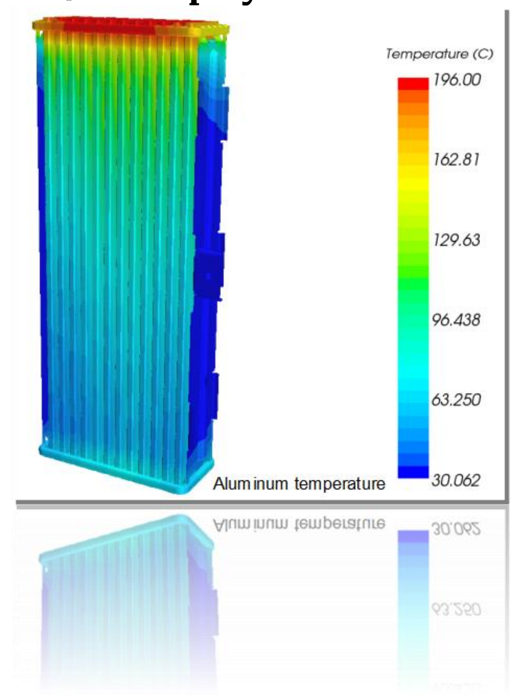
Objective → Accurate temperature distribution in solid material to enable the computation of solid stresses and the identification of high-stress regions

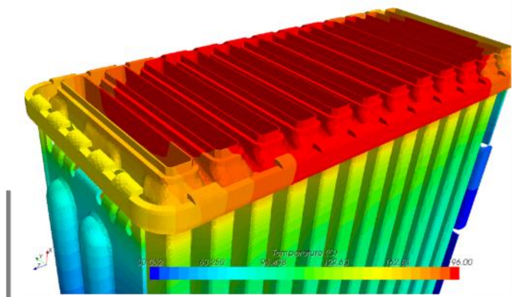


Full geometry

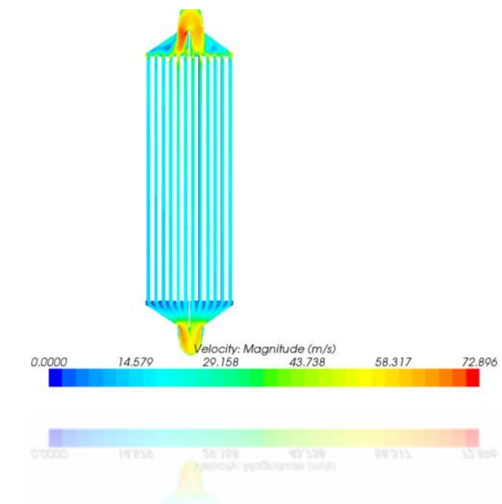
NB: Just temperature is shown. Solid stresses computed in SI units, *i.e.*, *Pa*.

Complex geometry.
7000000 polyhedral cells



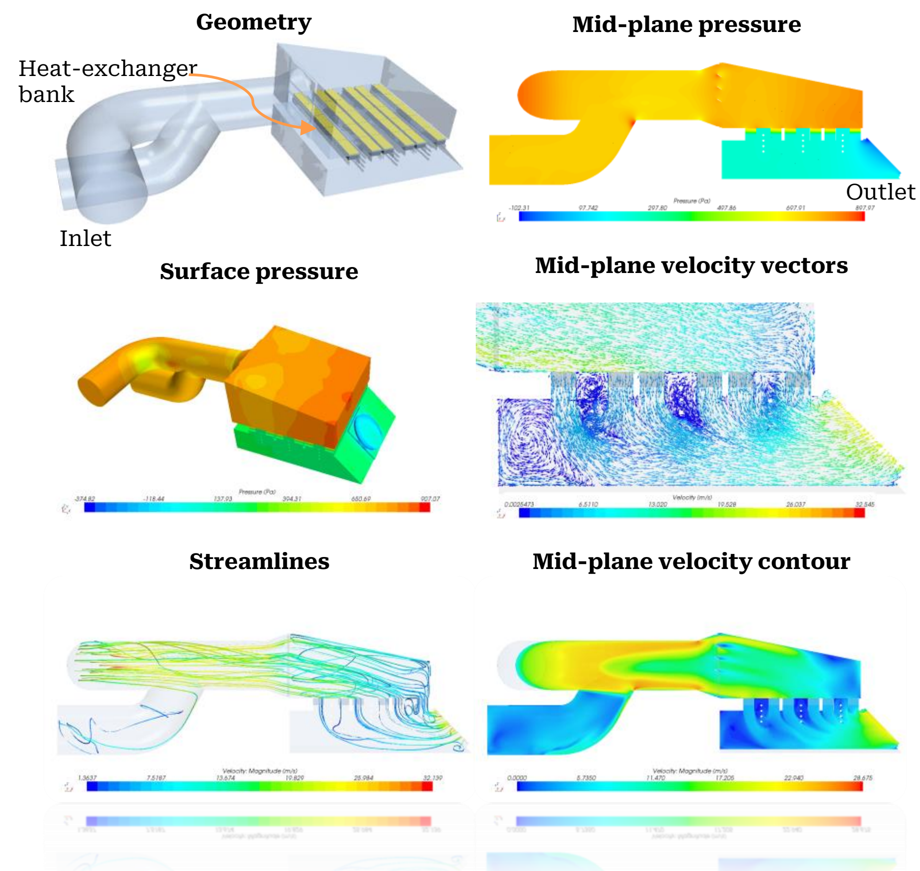


Aluminum temperature: hot inlet air side. Note the higher temperature gradient in the outermost tubes.

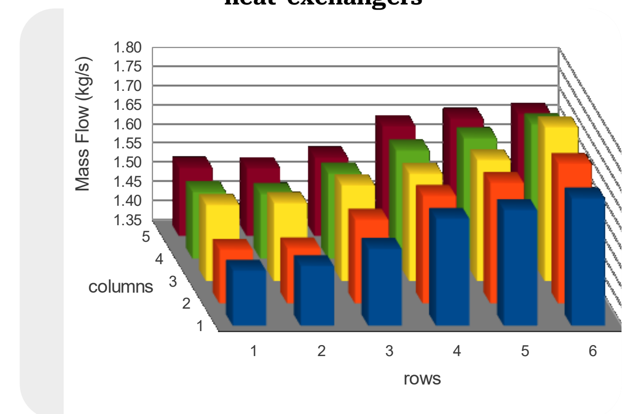


Industrial Waste Heat Recovery

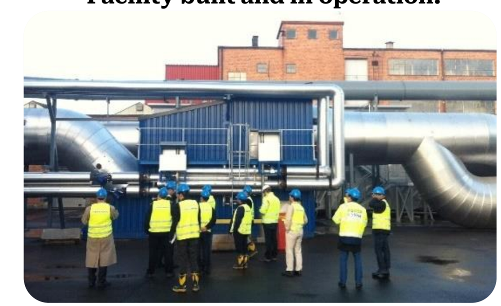
Objective →
Optimize flow distribution across heat-exchanger bank for maximum efficiency



Mass-Flow distribution across heat-exchangers



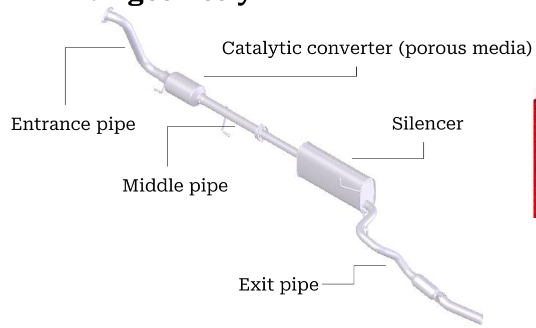
Facility built and in operation.



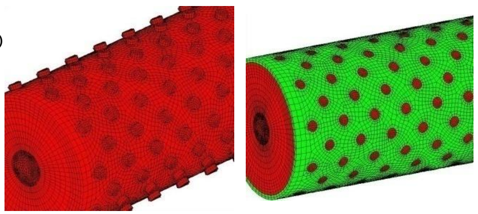
Automotive Exhaust Systems

Objective → Determine pressure drop and heat-transfer on exhaust system

Full geometry



Mesh at the silencer tubes, inc/holes.

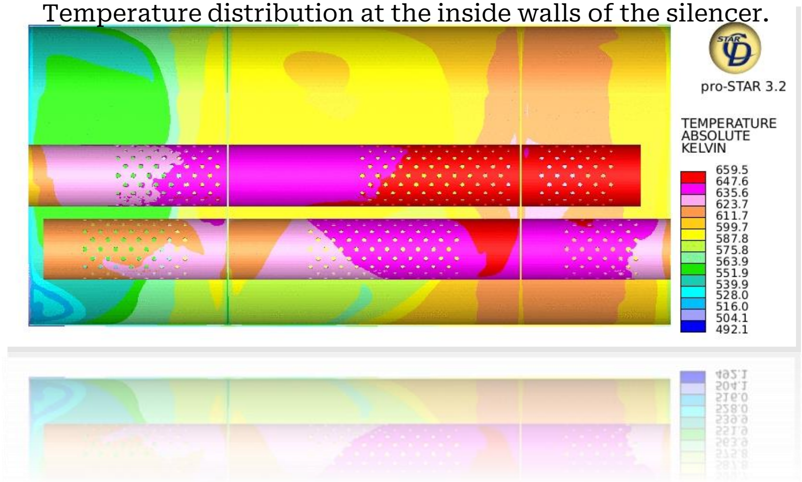


Range of turbulence models tested
Mesh studies for results independence

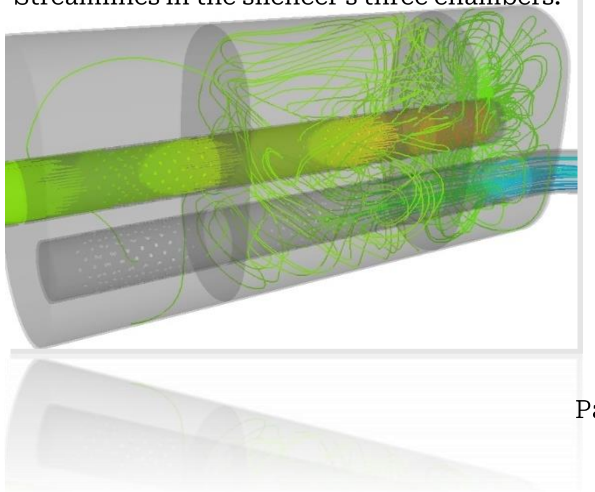
Pressure drop along the system

Component	Δp (bar)	%
System	0,353	100
Entrance pipe	0,005	1,4
Catalytic converter	0,057	16,1
Middle pipe	0,073	20,5
Silencer	0,198	55,9
Exit pipe	0,021	6,0

Temperature distribution at the inside walls of the silencer.



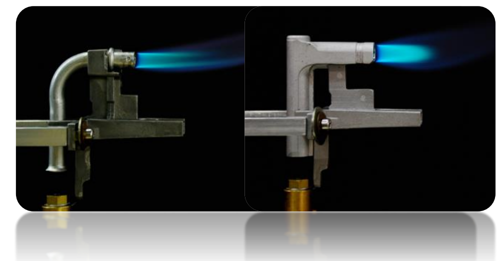
Streamlines in the silencer's three chambers.

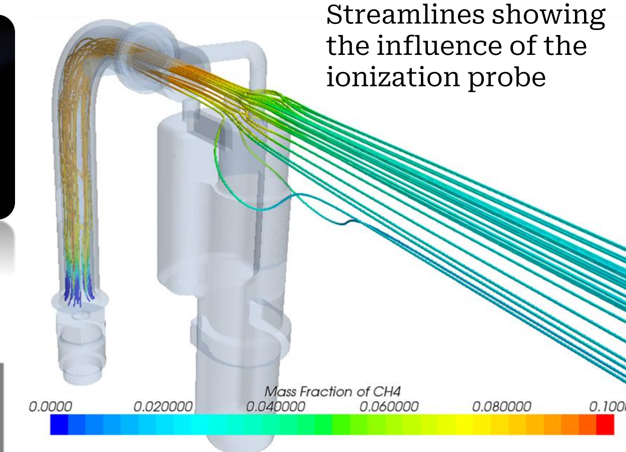


Boiler Pilot Flame Optimization – I

Objective → Improve mixture fraction uniformity at pilot outlet

Parameters:
Geometry
Different injector distances
Presence of ionization probe
Different gases → methane/propane

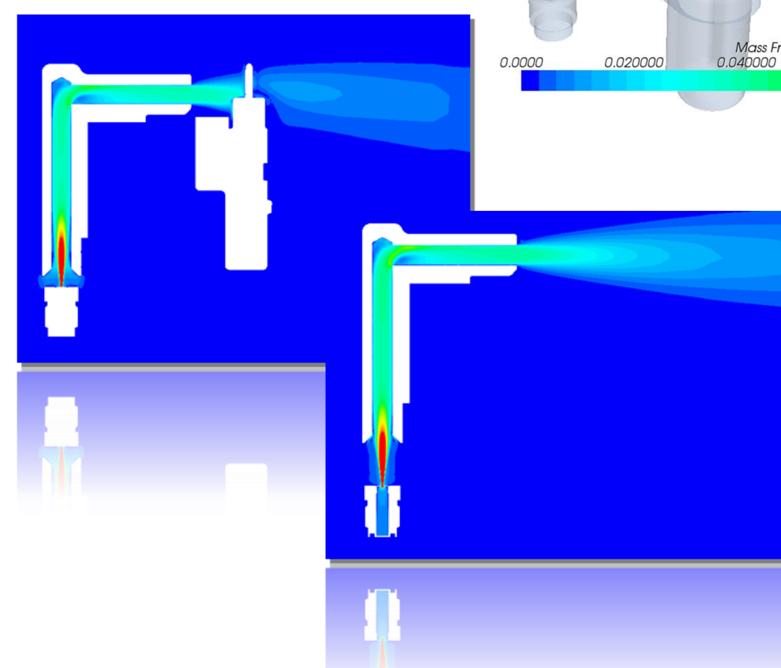




Streamlines showing the influence of the ionization probe

Original geometry

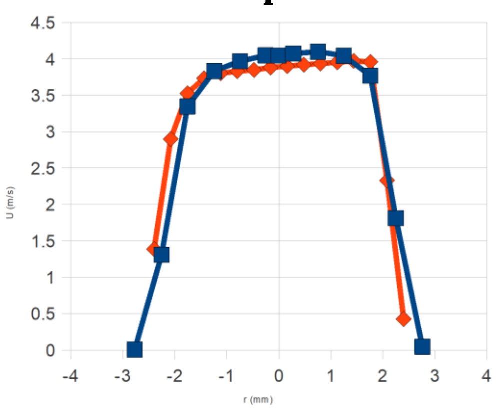
New geometry

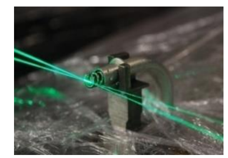


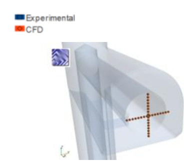
Boiler Pilot Flame Optimization – II

Objective →
Improve mixture fraction uniformity at pilot outlet

CFD vs experimental data





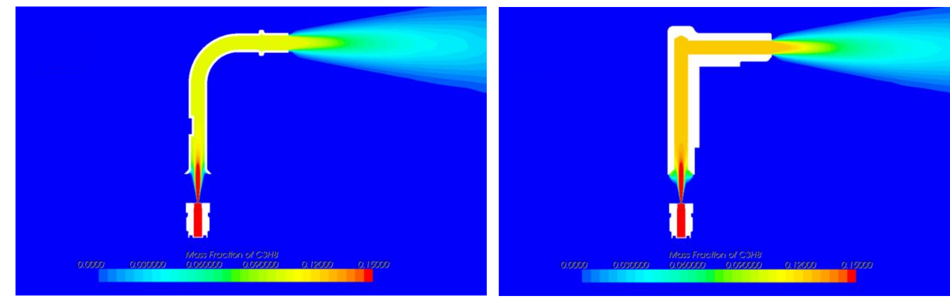


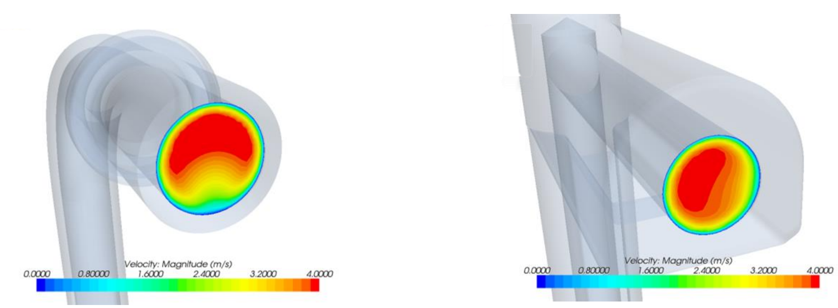
Velocity along vertical centerline (z)

	Experimental	CFD	Diff (%)
Pilot 1	1.74	1.79	2.98
Pilot 2	1.97	2.04	3.62

CH_4 equivalence ratio Φ at pilot outlet

Methane Mass fraction



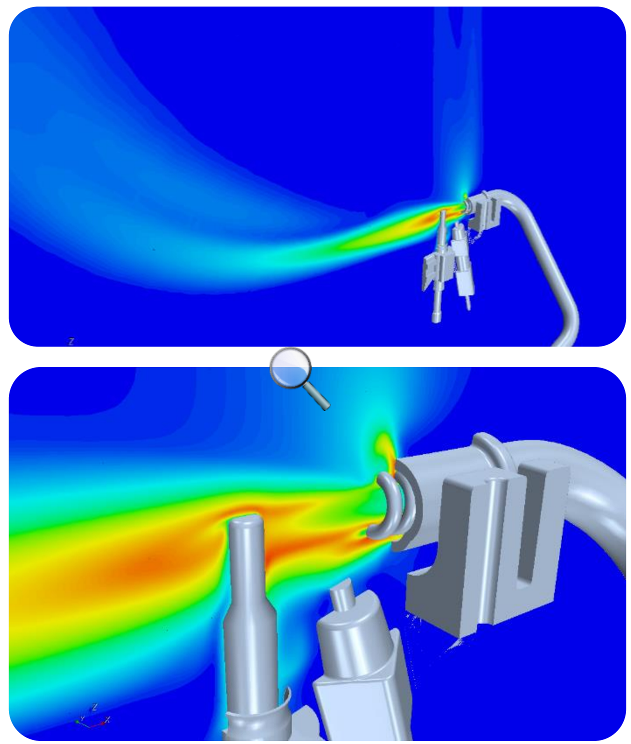


Velocity magnitude at pilot outlet

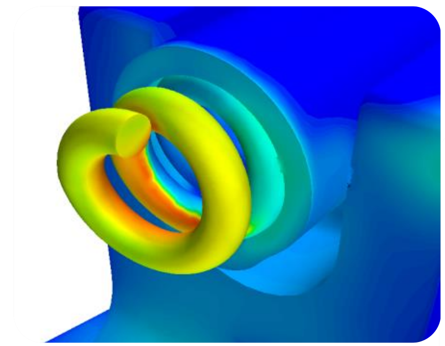
Very good agreement with experimental data

Boiler Pilot Flame Optimization – III

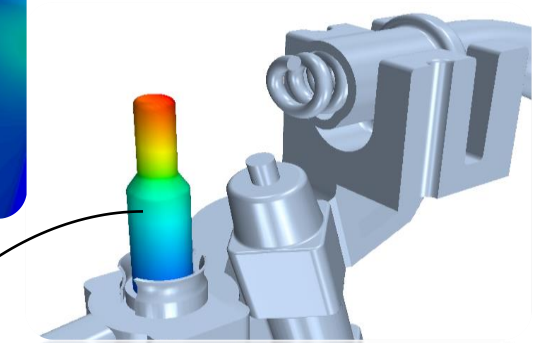
Objective → Temperature analysis of piezometric element under operating conditions/verification of material compliance with operating limits established by manufacturer.



Gas temperature contour at symmetry plane.



Coil temperature during operation.

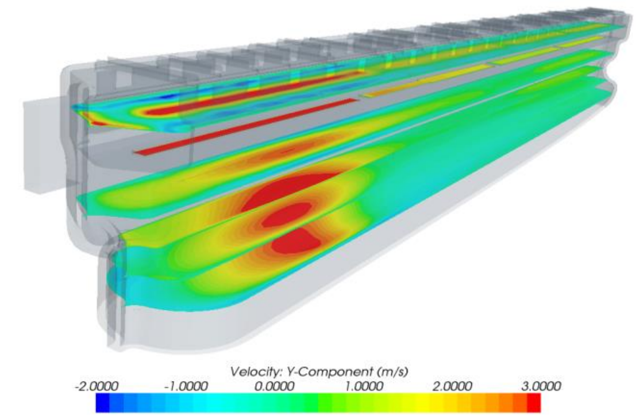


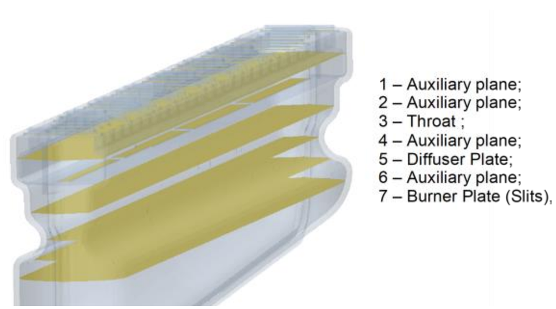
Piezometric element (gas flow control device) temperature contour, as it is impinged by pilot flame.

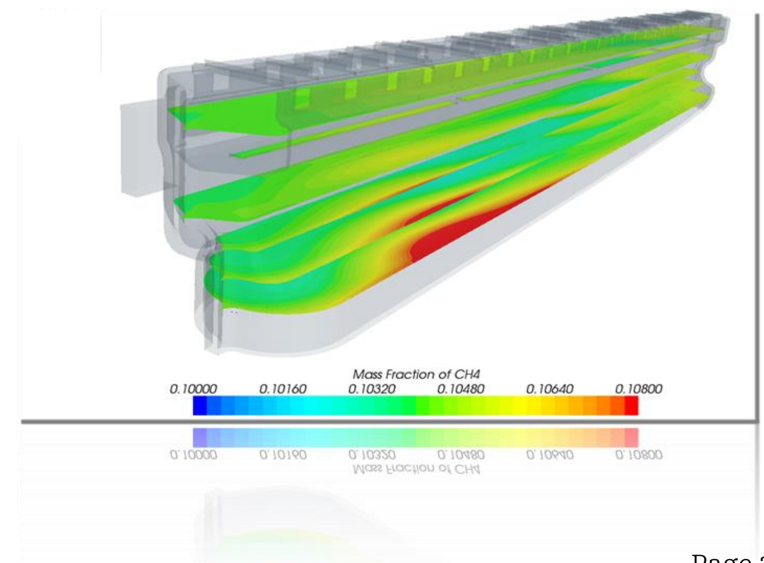
Material complied with specs, surface temperature below threshold.

Burner Flute Optimization – I

Objective → improve equivalence ratio distribution at flute exit with new burner shape to reduce cost



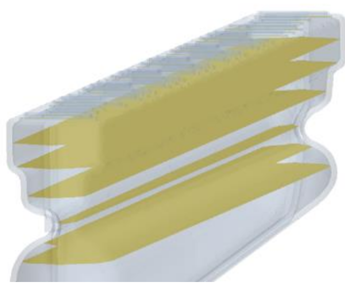




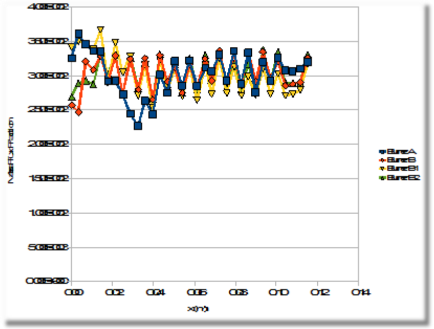
Burner Flute Optimization – II

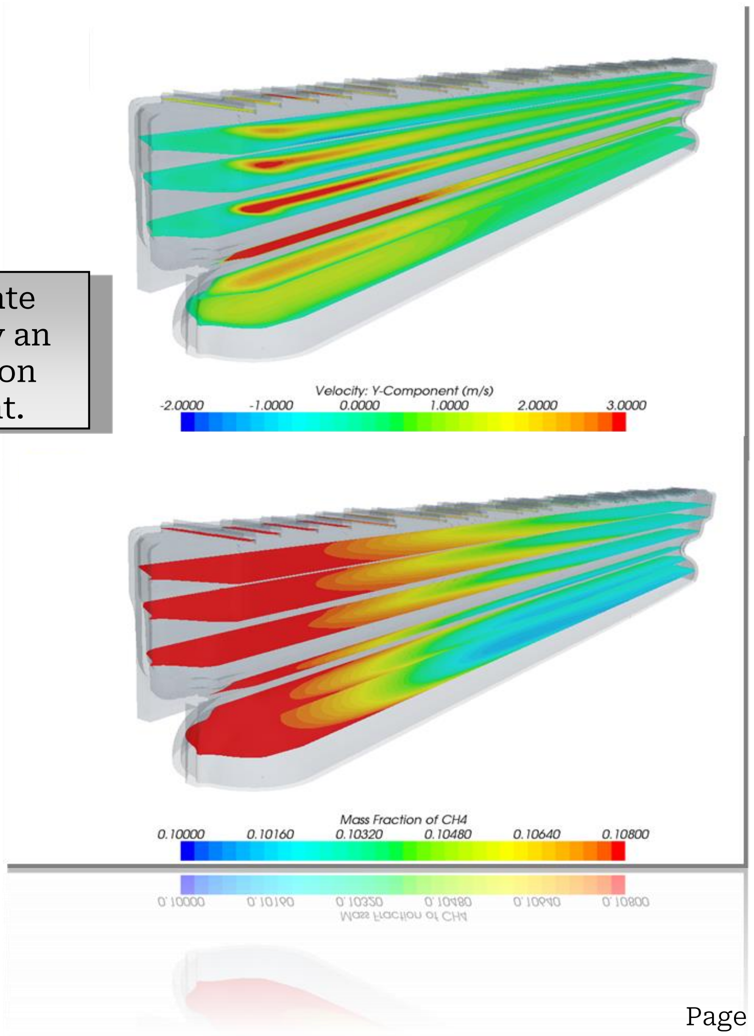
Objective → improve equivalence ratio distribution at flute exit with new burner shape

Diffuser plate replaced by an area variation in the throat.



1 – Auxiliary plane;
2 – Auxiliary plane;
3 – Throat ;
4 – Auxiliary plane;
5 – Auxiliary Plane;
6 – Auxiliary plane;
7 – Burner Plate (Slits)



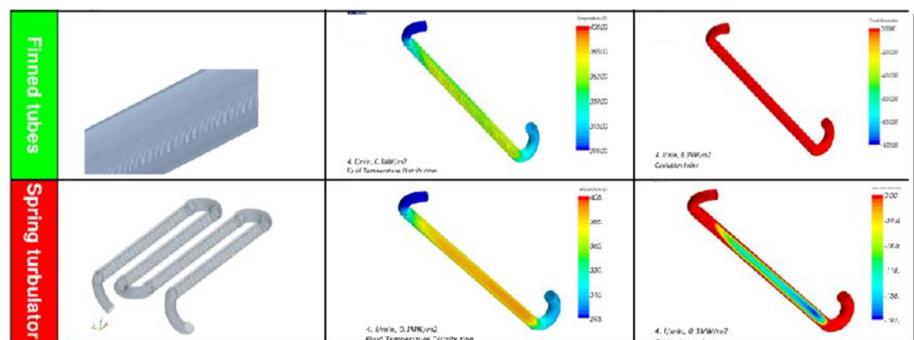


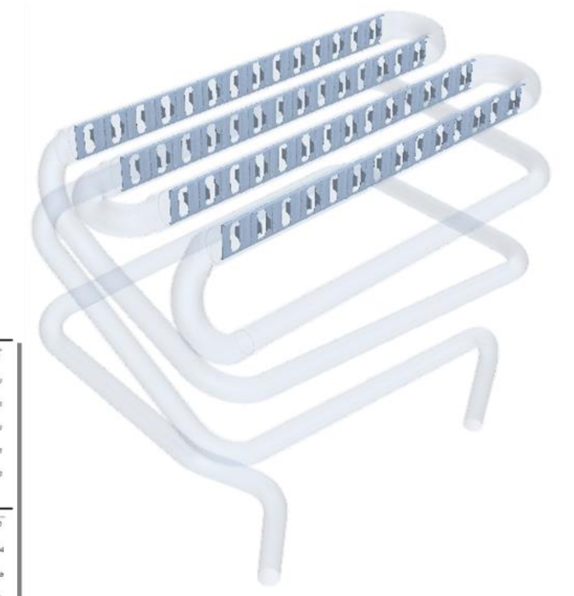
Boiler Turbulator

Objective → Replace/Remove Turbulator, proposing or trying out new shapes to reduce cost on a home appliance gas-liquid heat exchanger

Turbulator function:

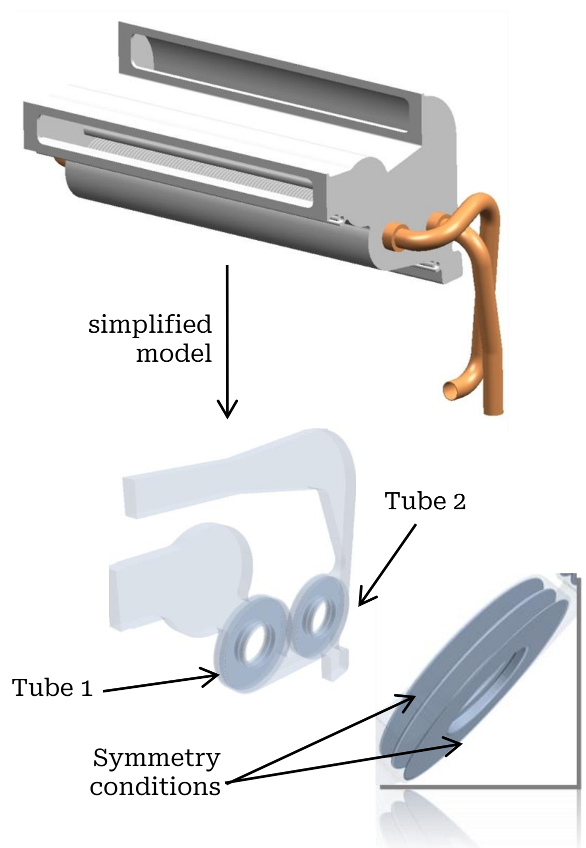
- **Heat transfer enhancement**
- Reduce cavitation/boiling inside the tubes
- Reduce vibration and acoustic noise
- Increase durability

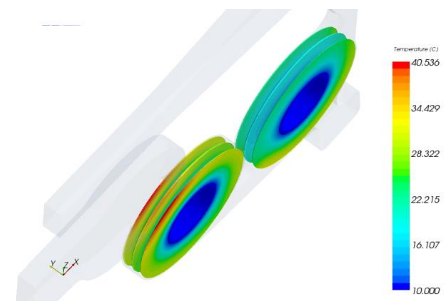




Condensation Heat Exchanger – I

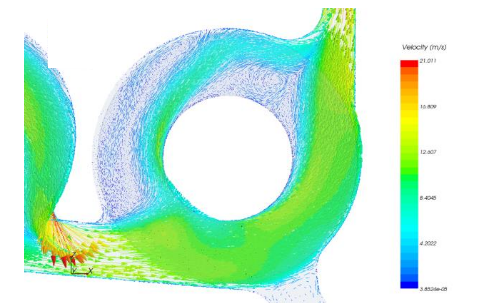
Objective → Improve efficiency of condensing heat-exchanger





Copper tube and aluminum fins detail - temperature

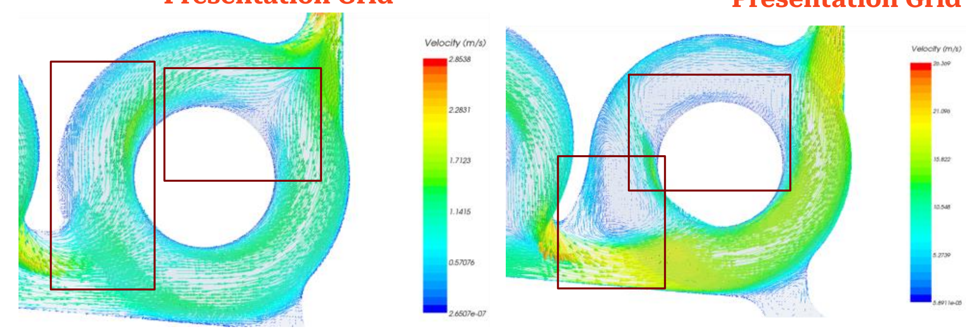
Presentation Grid



Velocity vectors in second tube showing recirculation

Presentation Grid

Presentation Grid



Different Throat Geometry between tubes

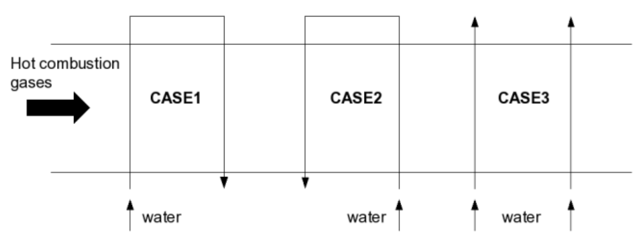
Condensation Heat Exchanger – II

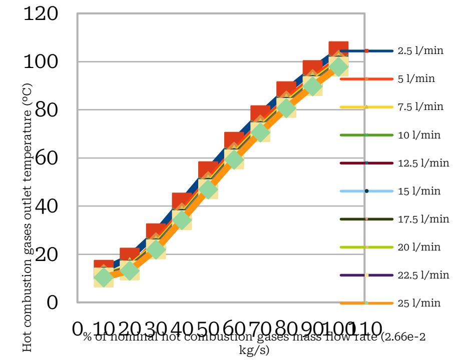
Objective → Improve efficiency of condensing heat-exchanger when CFD is too expensive through alternative design approach: study water flow influence and overall heat exchanger performance for several water and hot combustion gases flow rates.

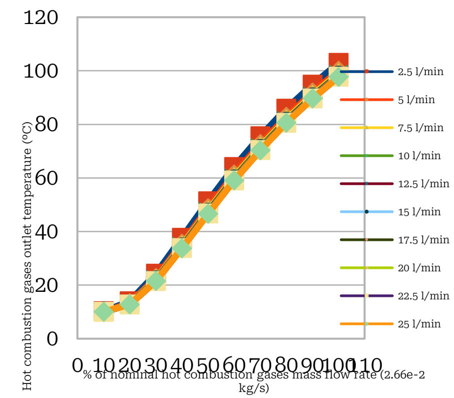
	Exchanged Heat (W)					
	$T_w=10$	% Total	$T_w=20$	% Total	$T_w=40$	% Total
Tube 1	53.53	61.71	51.17	61.78	46.48	61.78
Tube 2	33.21	38.29	31.66	38.22	28.76	38.22
Total	86.74	100	82.82	100	75.24	100

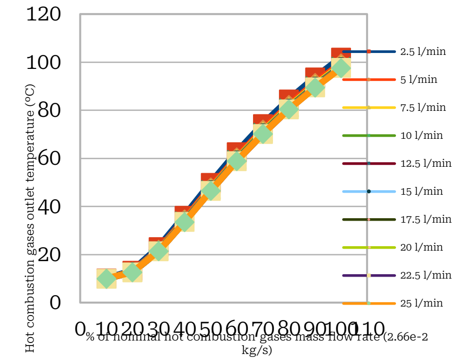
	Heat Transfer Coefficient *U* (W/m²-K)		
	$T_w=10$	$T_w=20$	$T_w=40$
Tube 1	46.36	46.53	46.97
Tube 2	45.38	45.60	46.46

While exploring the possible design envelope for the heat exchanger, CFD results were used as inputs to ε-NTU **analytical** methodology





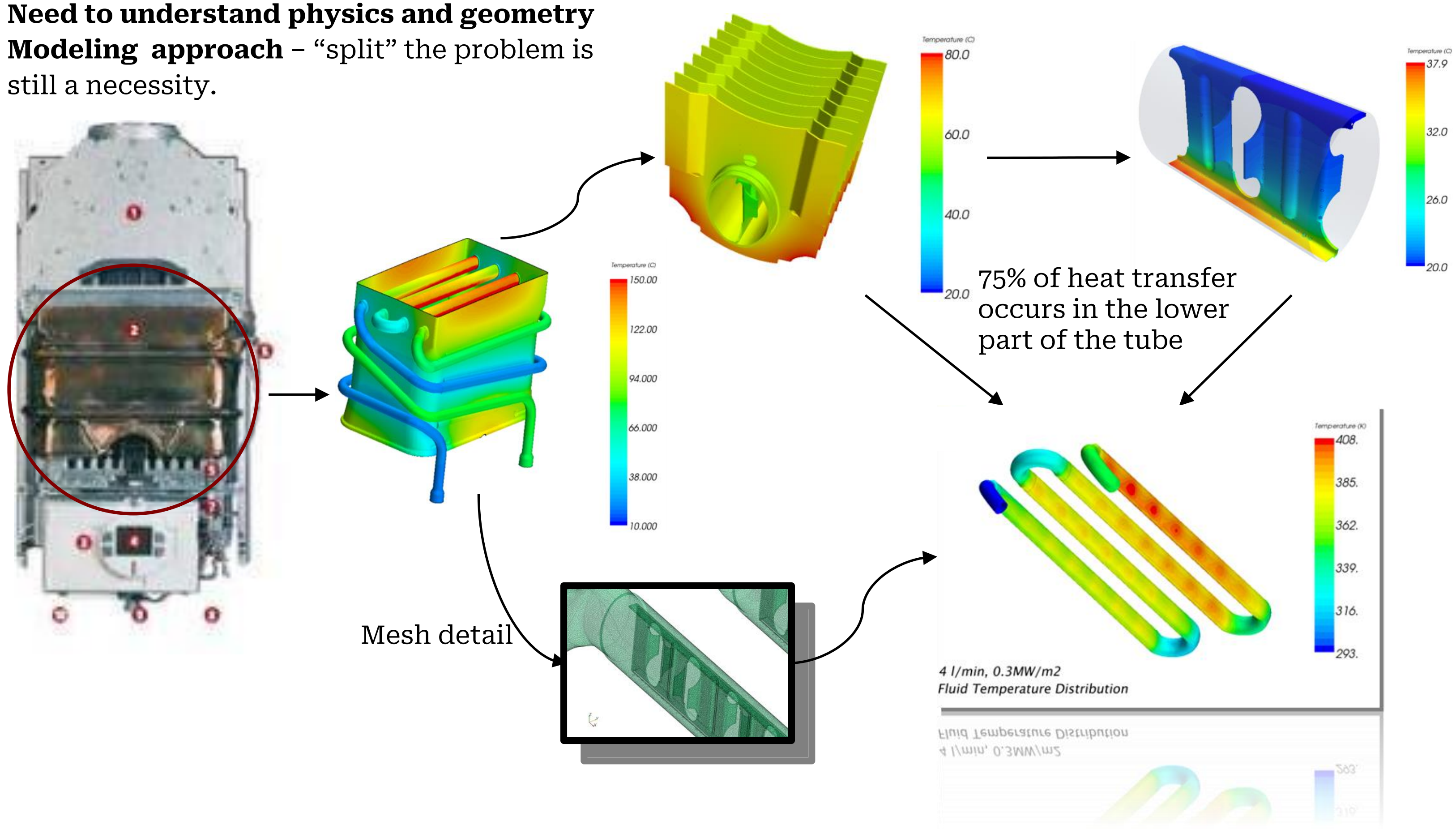




Combustion Chamber

Objective →
Full representation of a wall-standing domestic water heater

Need to understand physics and geometry
Modeling approach – “split” the problem is still a necessity.

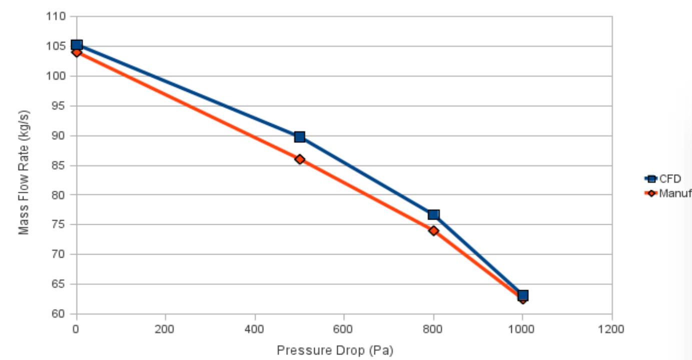


Mechanical Air Supply Simulation

Objective →
Evaluate ventilator performance and include its effects on downstream components

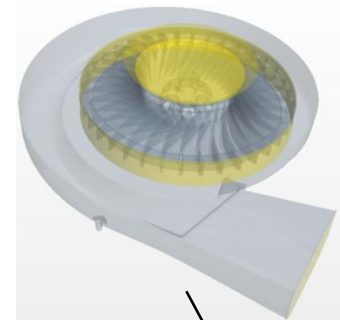
	Mass Flow Rate (kg/s) through ventilator			
	0 Pa	500 Pa	800 Pa	1000 Pa
CFD	105.26	89.74	76.66	63.15
Manufacturer	104.00*	86.00	74.00	62.50
Diff (%)	1.21	4.35	3.59	1.04

** Extrapolated from manufacturer's curve*

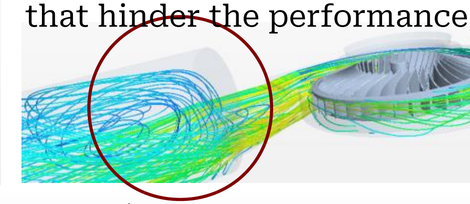


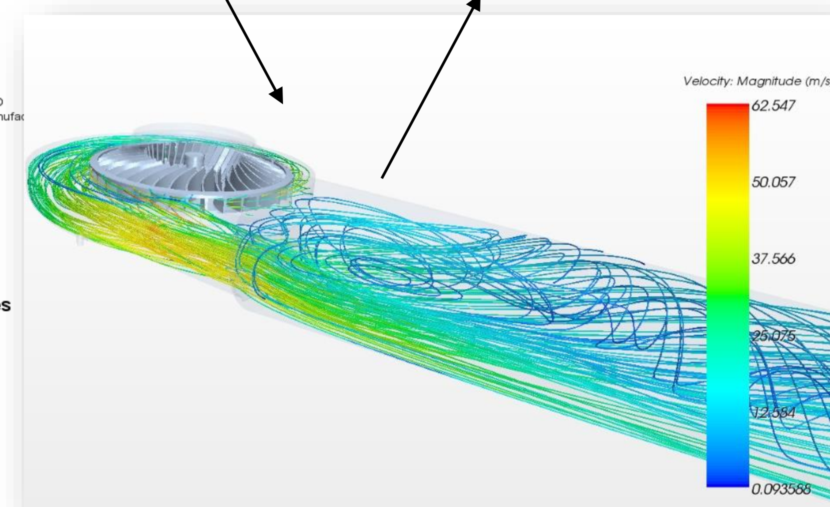
Comparison between CFD predicted mass flow rate and manufacturer curves

Validation of methodology by comparison with manufacturer's experimental data.



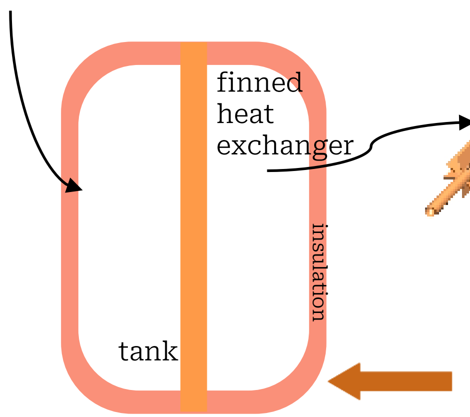
Identification of critical flow regions that hinder the performance



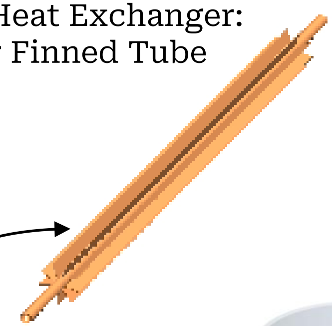


Long Run Thermal Simulations

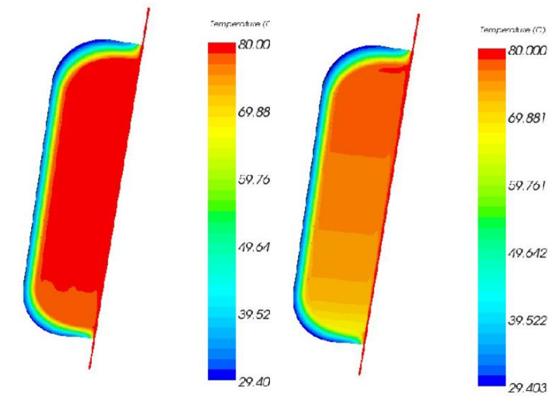
Objective → Study transient thermal performance of a Hot Water Storage tank and characterize stratification.



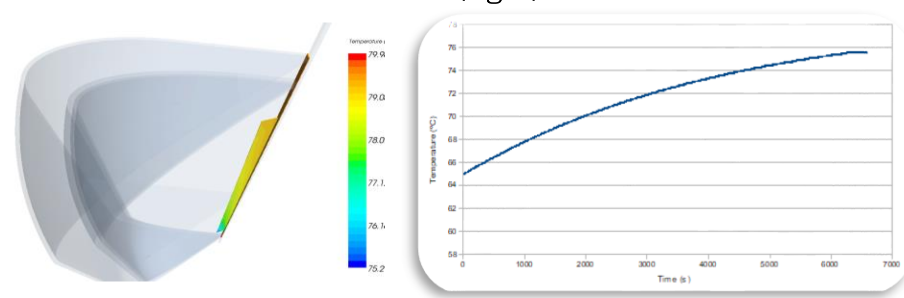
Novel Heat Exchanger: Copper Finned Tube



Thermal inertia very high. A new approach was necessary to simulate 24h of real time. Matlab/Simulink based



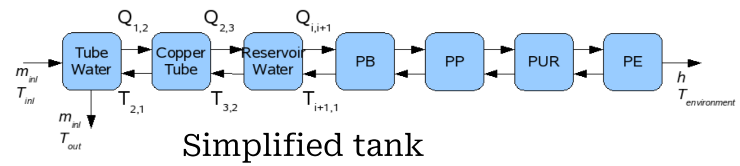
Tank temperature results – steady state simulation (left); transient simulation after 1h50m of simulated time (right)



Transient simulation after 1h50m of simulated time: finned tube temperature (left) and evolution of reservoir water averaged temperature (right).

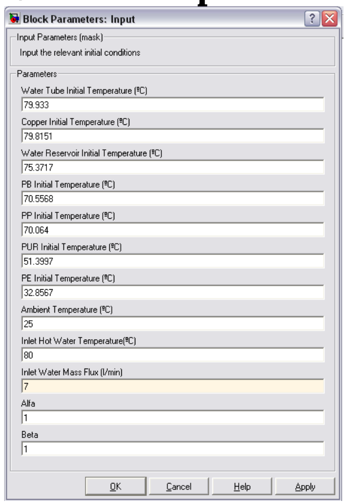
1D Thermal Simulations

Objective →
A simplified **Matlab/Simulink** model was developed to represent the tank and simplify transient calculations.

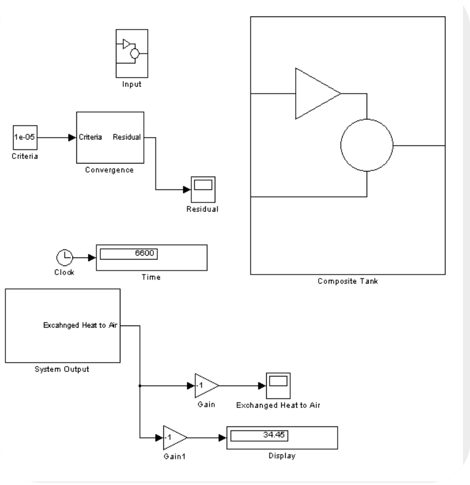


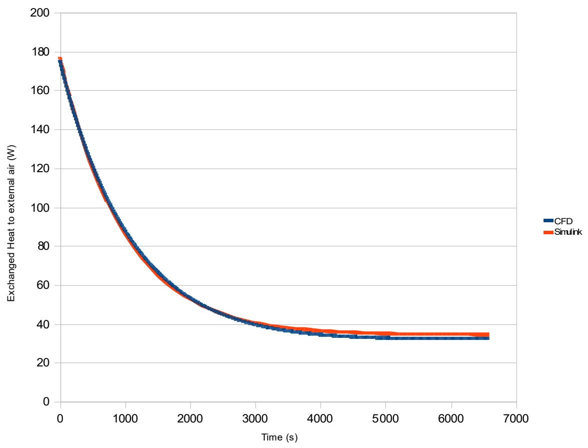
Simplified tank model

Simulink input


Block Parameters: Input
Input Parameters (mask)
Input the relevant initial conditions
Parameters
Water Tube Initial Temperature (ºC)
79.933
Copper Initial Temperature (ºC)
79.8151
Water Reservoir Initial Temperature (ºC)
75.3717
PB Initial Temperature (ºC)
70.5568
PP Initial Temperature (ºC)
70.064
PUR Initial Temperature (ºC)
51.3997
PE Initial Temperature (ºC)
32.8567
Ambient Temperature (ºC)
25
Inlet Hot Water Temperature(ºC)
80
Inlet Water Mass Flux (l/min)
7
Alfa
1
Beta
1
OK Cancel Help Apply

Simulink model





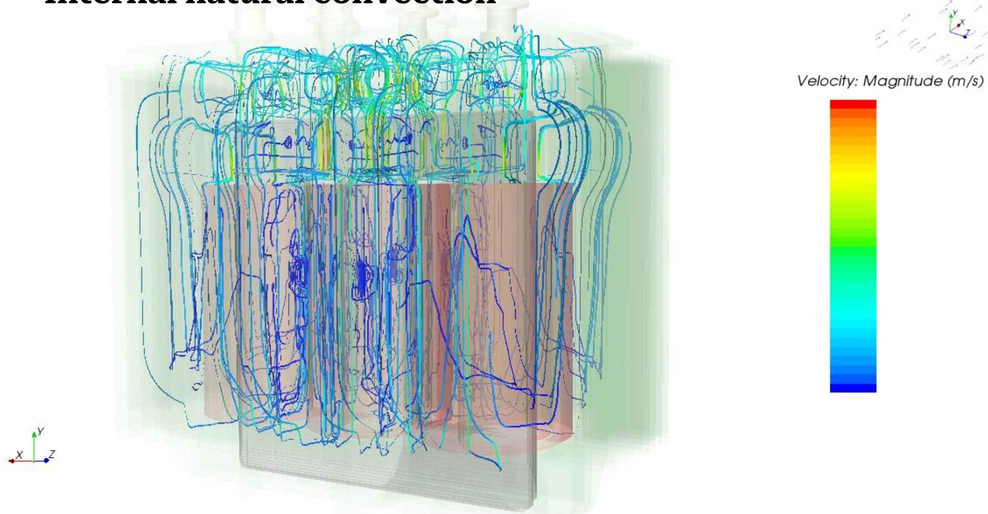
Model validation: Exchanged Heat to External air, CFD *vs* Simulink results for 1h50m of simulated time.

Allows substantial savings in simulation time (hours *vs* weeks).

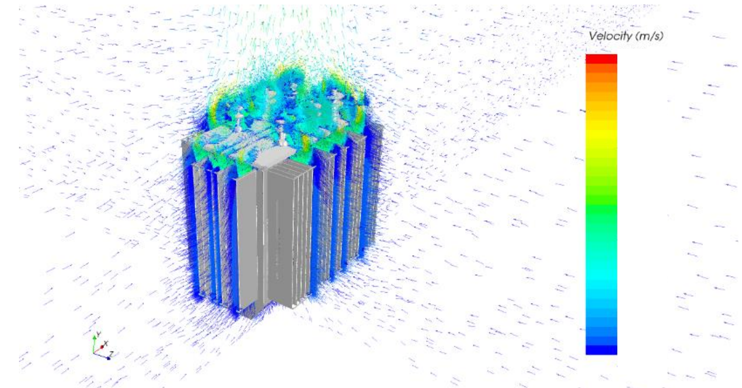
Transformer

Objective →
Manage thermal load of power transformer, considering all heat transfer modes and physical domains

Internal natural convection

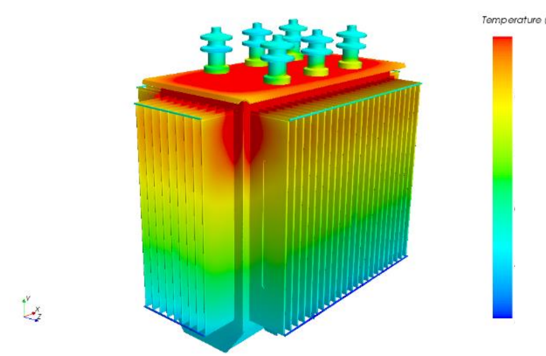


Electromagnetic effects were not considered but all heat dissipation and insulation components were modelled to adequately model reality.



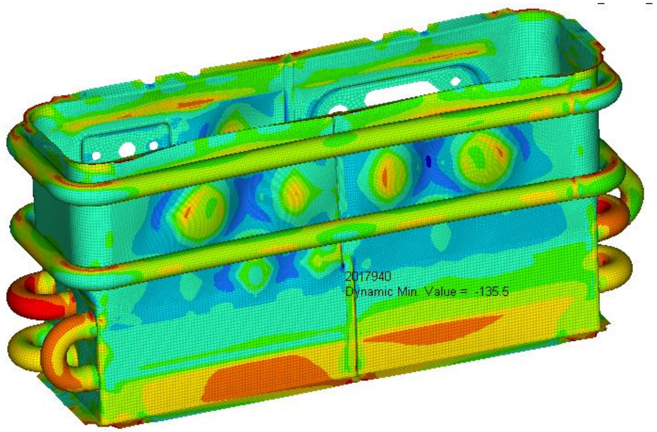
External heat-transfer

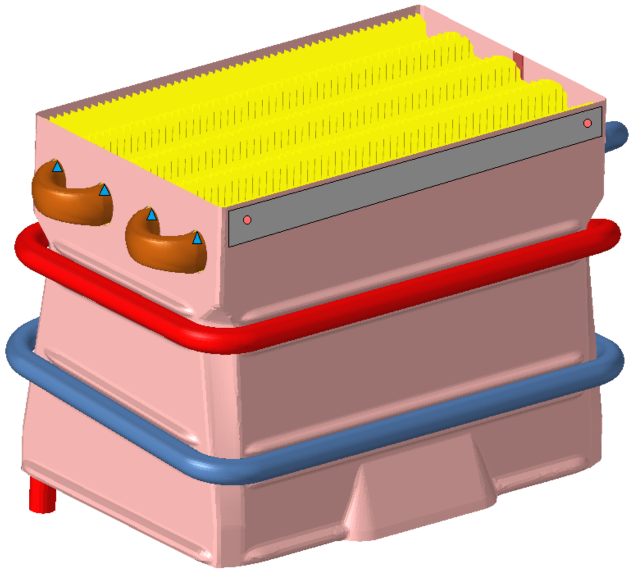
Conduction through steel enclosure

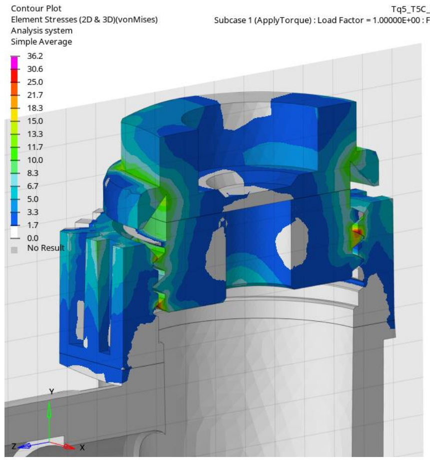


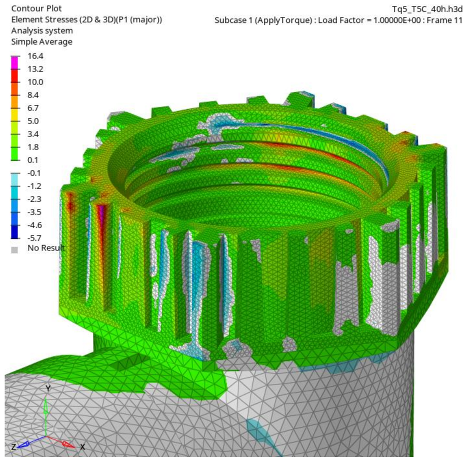
Water heater - FEM

Objective
Thermal and structural optimization, fatigue life analysis of water heaters and hydraulic components.



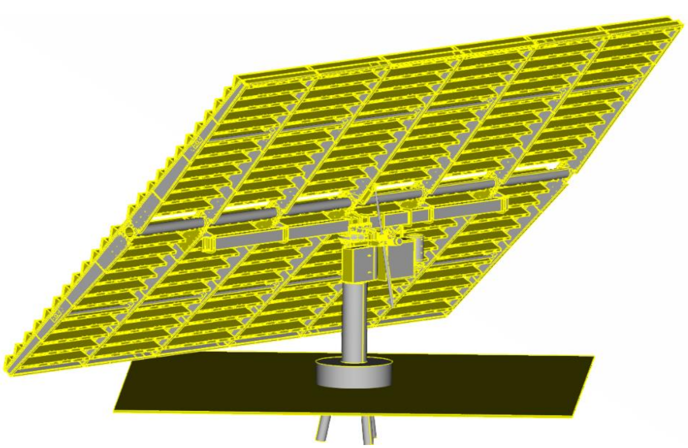


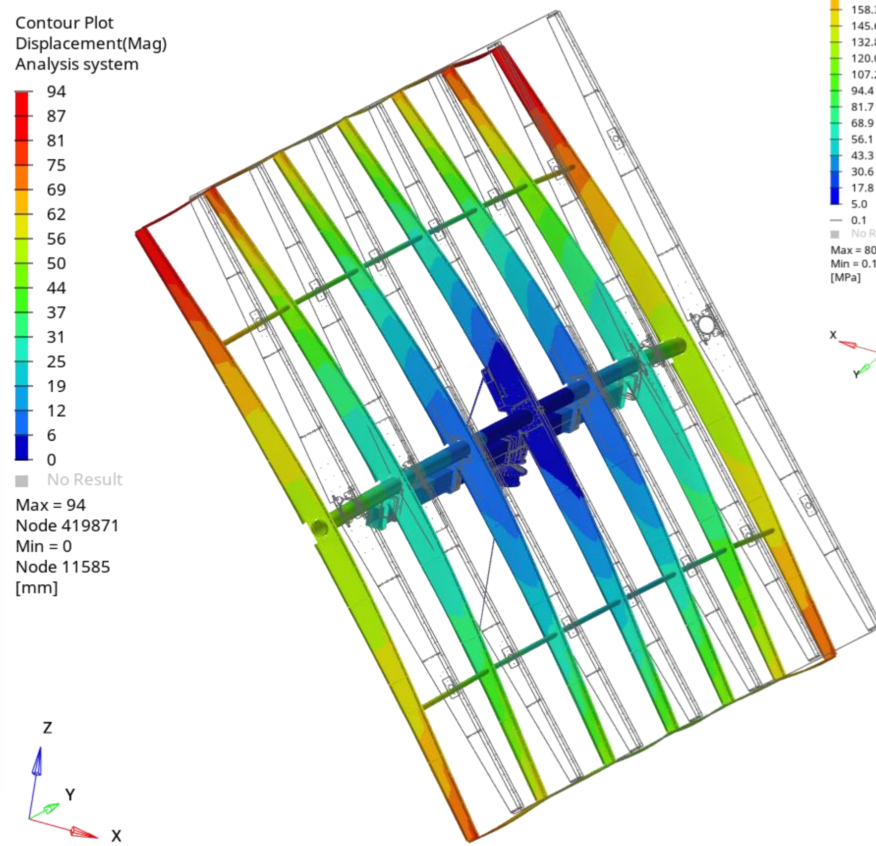


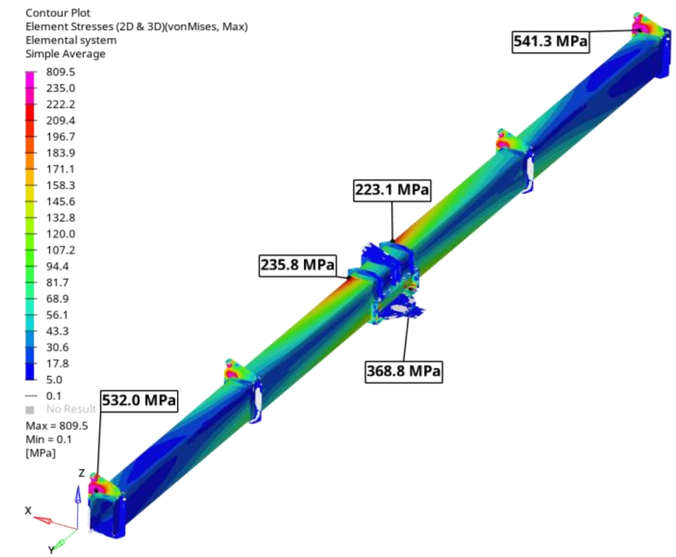


Hydrogen generator - FEM

Objective
Structural validation and optimization of an innovative semi-movable solar hydrogen generator concept.

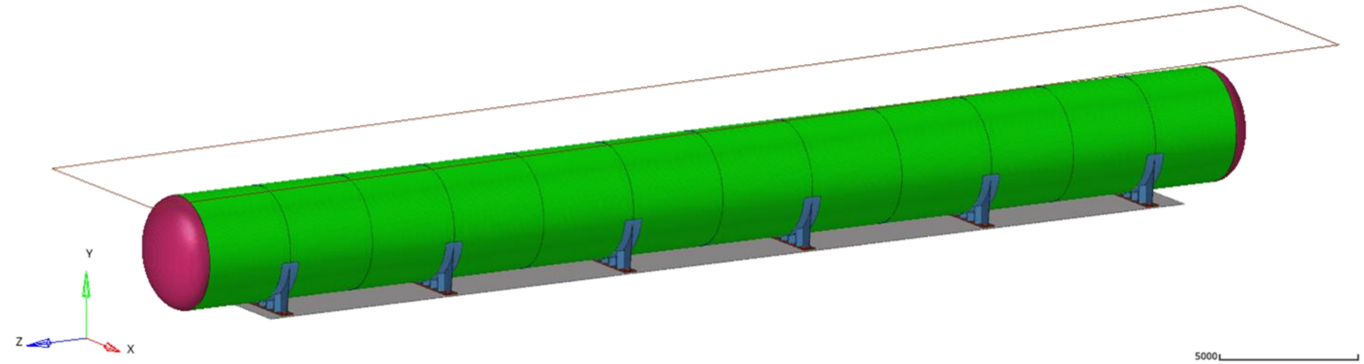




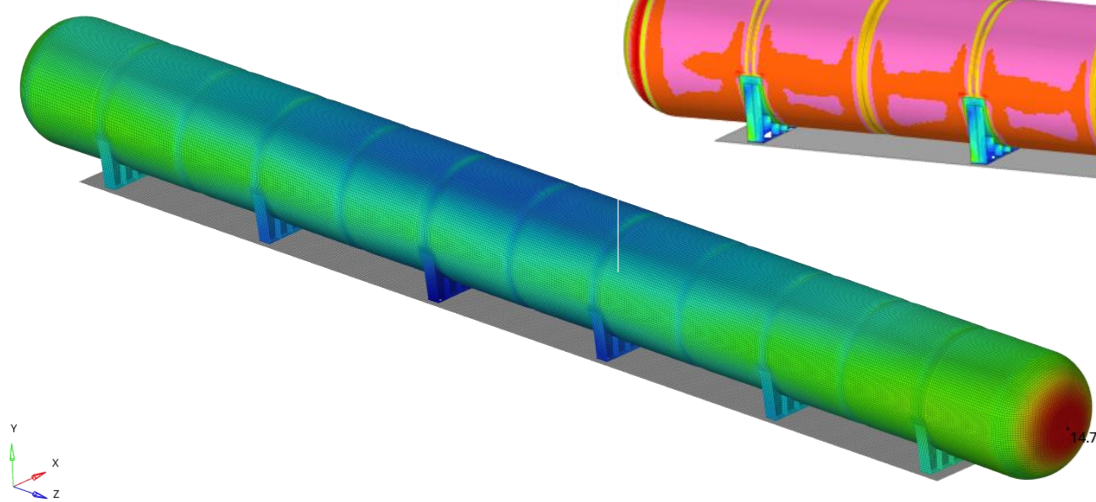


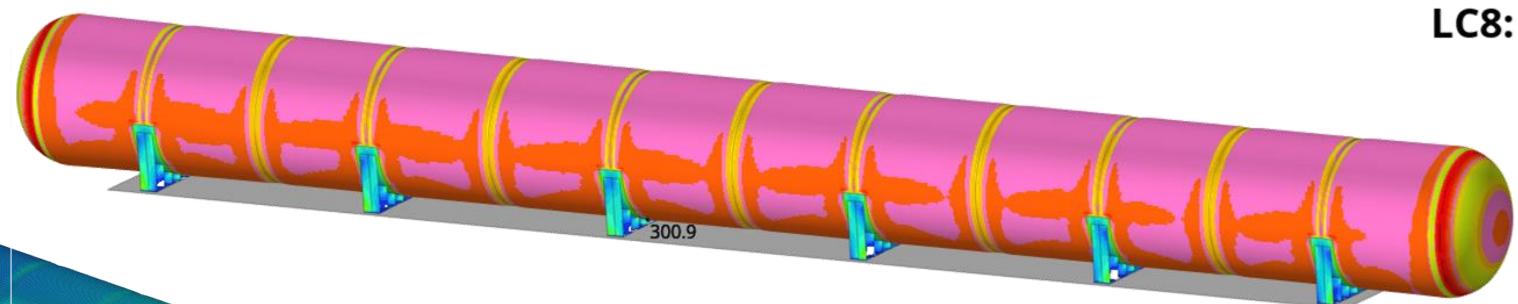
Mounded pressure vessels - FEM

Objective
Mounded pressure vessels structural validation for test loads, operative loads and seismic loads.

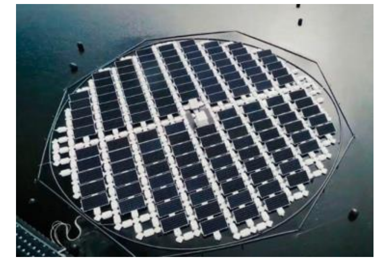


LC8:

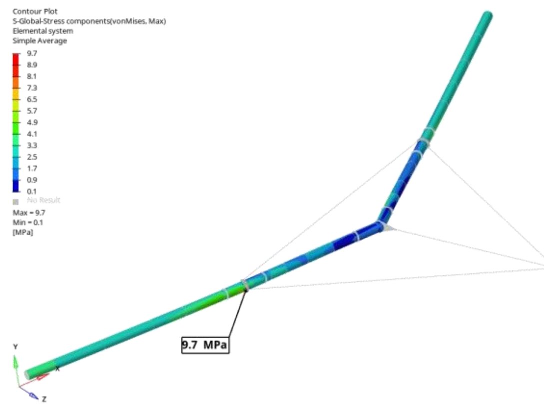


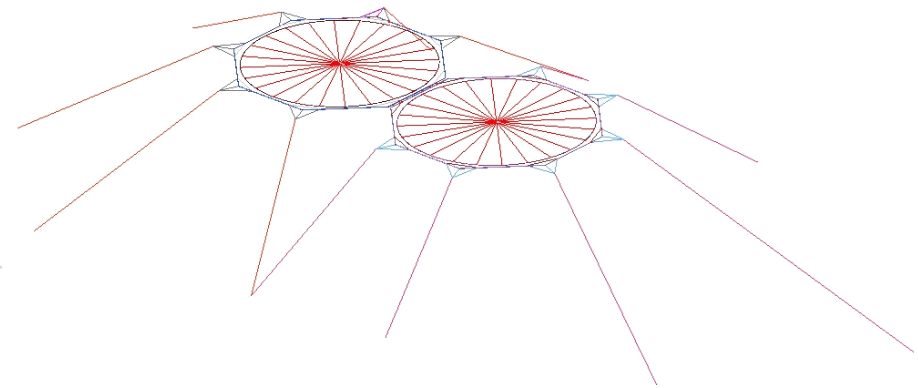


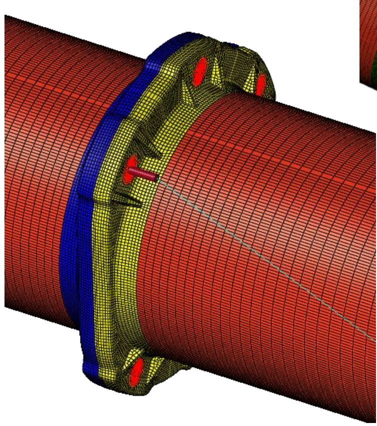
Floating solar plant - FEM

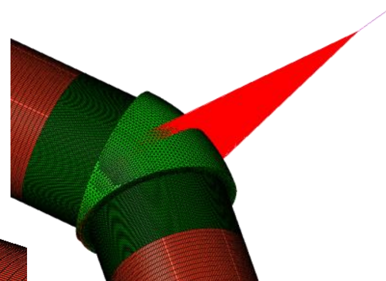


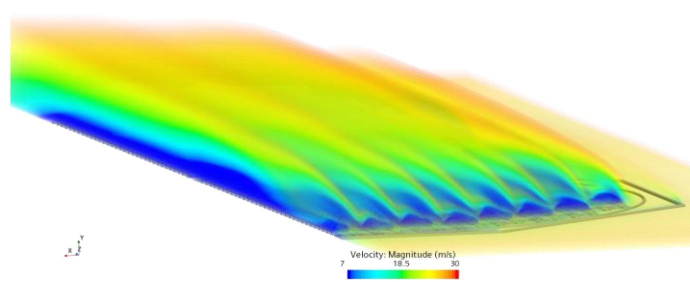
Objective
Aerodynamic and hydrodynamic forces calculation (CFD), mooring reaction forces and structural calculations of an innovative floating solar plant concept.

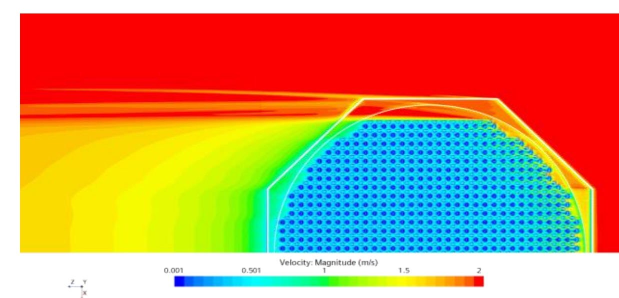












Transport
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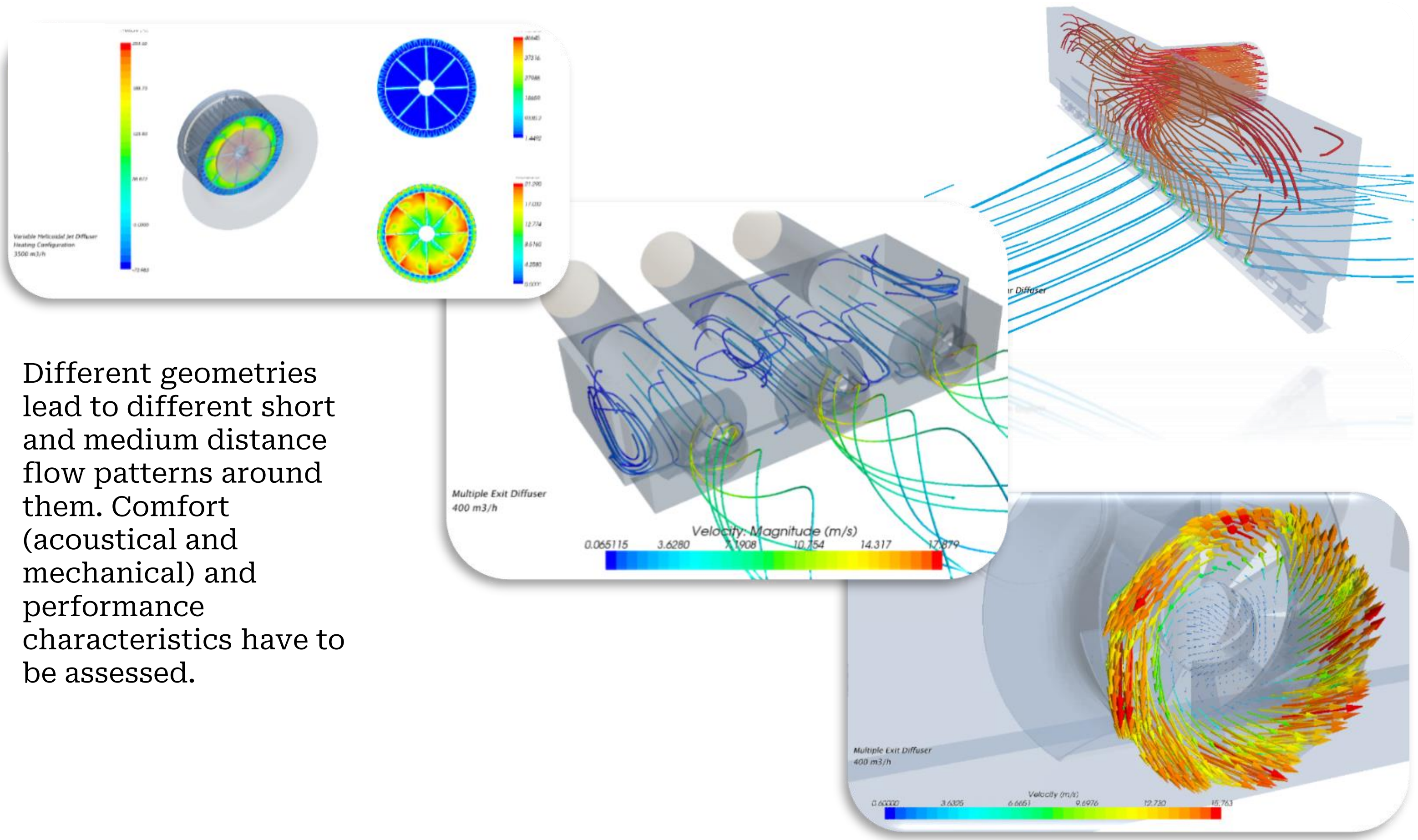
Electronics
Wastewater
H.V.A.C.
Biomedical
Process
Machinery

Ventilation Components

Objectives →

- Provide detailed insight into convective and diffusive transport mechanisms;
- Aid in the development of new, high-tech, insuflation registers.

Different geometries lead to different short and medium distance flow patterns around them. Comfort (acoustical and mechanical) and performance characteristics have to be assessed.



Underground Car Park Ventilation

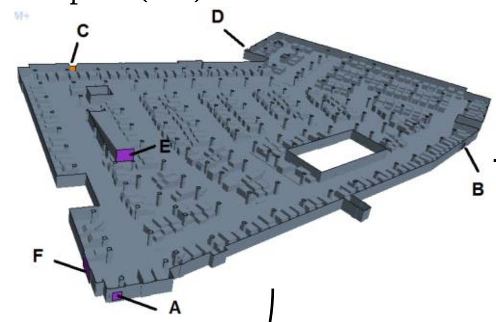
Objectives →

- Validate simulation methodology against experimental values;
- Develop and deploy automatic optimization technique to better explore design space

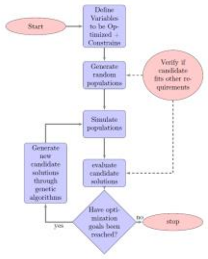
Level of interest in car park, zoned

Underground car parks are normal fixtures in large commercial spaces. Besides insuflation and extraction fans, full-scale air motion can be secured through additional fans placed in the ceiling. Their number and placement is critical.

Car park (full) with inlet and outlet boundaries

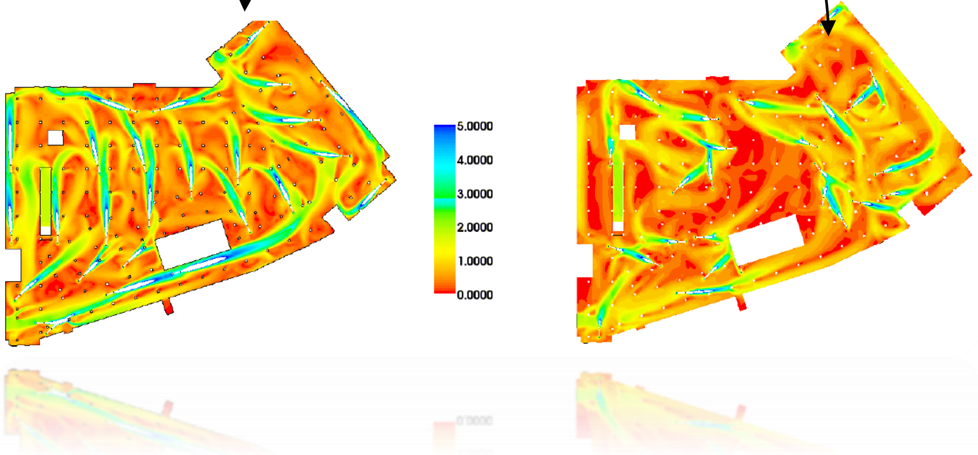


Automatic Optimization



Usual iterative design approach

Optimization based on minimizing maximum air-age.

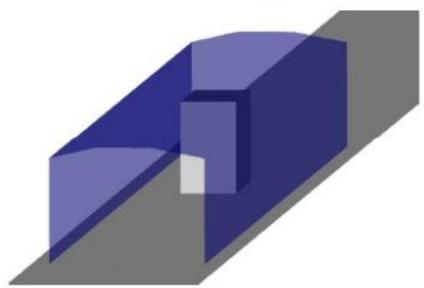


Road Tunnel Safety

Objective → Benchmark CFD simulation approach as a Design Tool for Tunnel Engineers

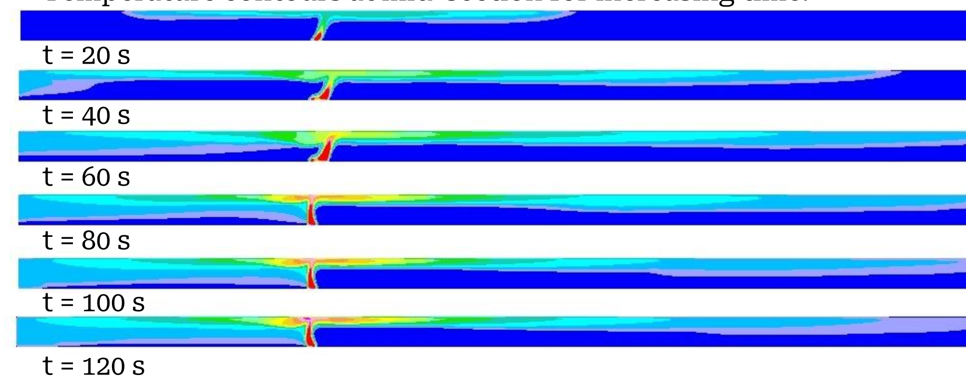
Runehamar Fire Tests Simulations

Fire source and protective lining

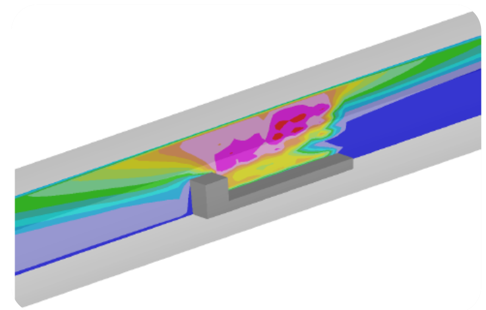


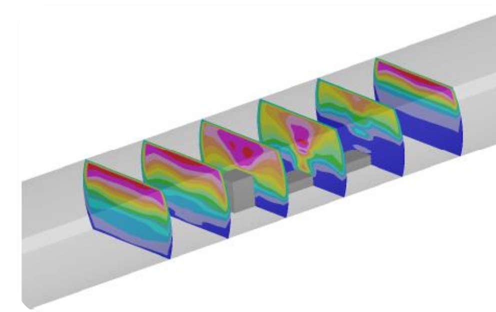
HGV with wood pallets load on fire:
1. Peak HRR of 200MW;
2. T_{max} ~ 1300°C

Temperature contours at mid-section for increasing time:



Good agreement with experimental results!





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CFD: Particle Flows

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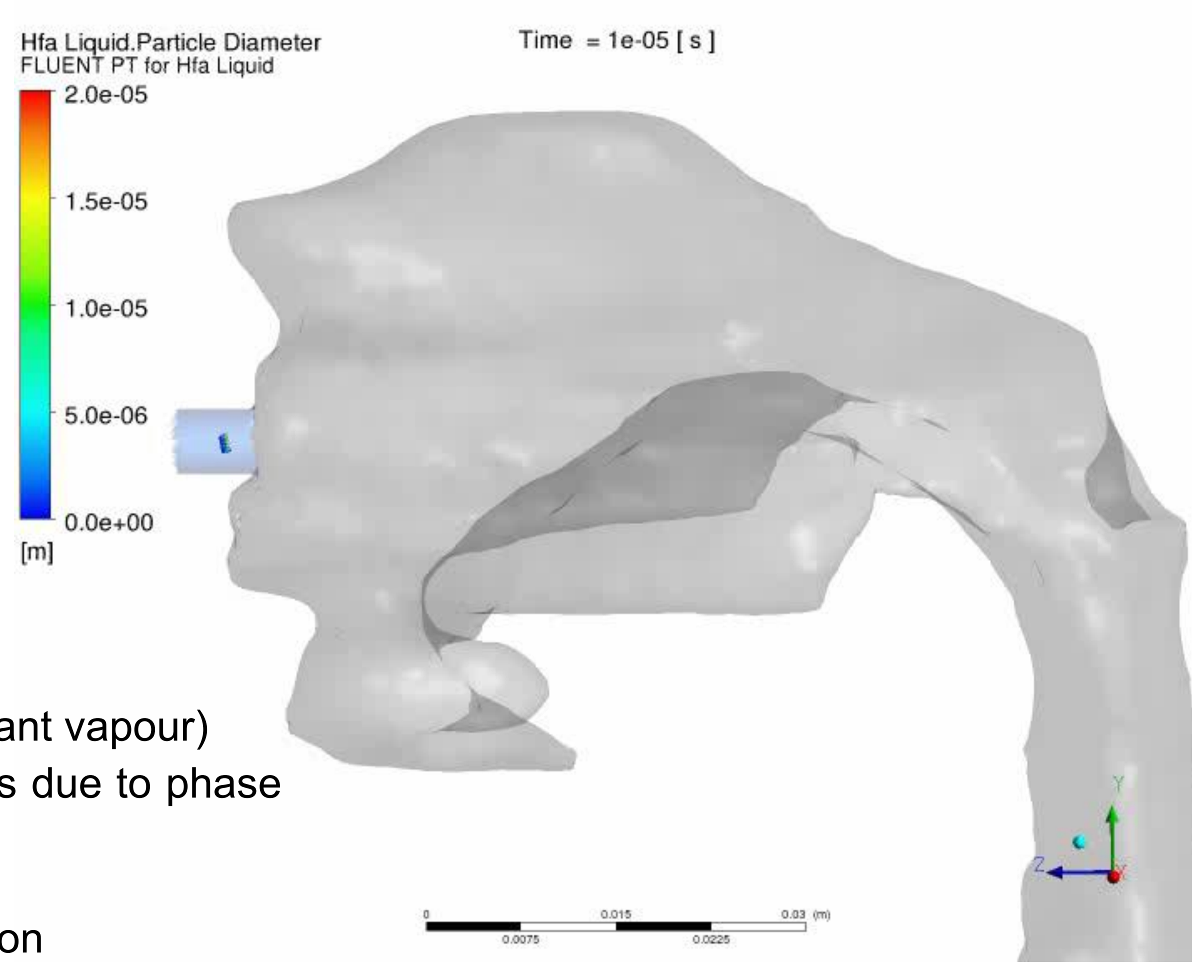
pMDI spray

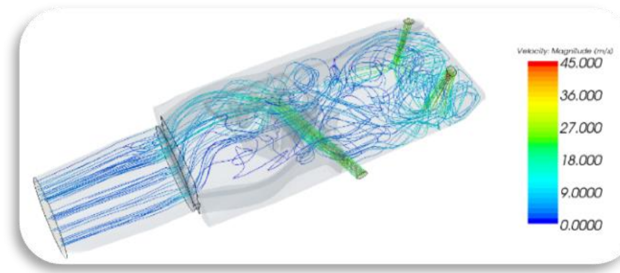


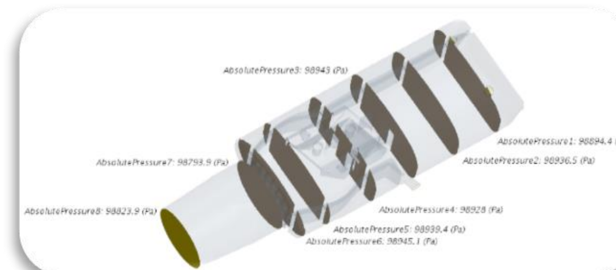
- 2-way coupling (droplets also affect carrier fluid)
  - Momentum transfer (in both directions)
  - Mass transfer (droplets evaporate into propellant vapour)
  - Heat transfer (heat is taken from surroundings due to phase change)
- Gas mixture (air + propellant)
- Models available for droplet break-up and collision
- Atomization process is very complex (assume particle size distribution at nozzle exit)

Dry Powder Inhaler (DPI)

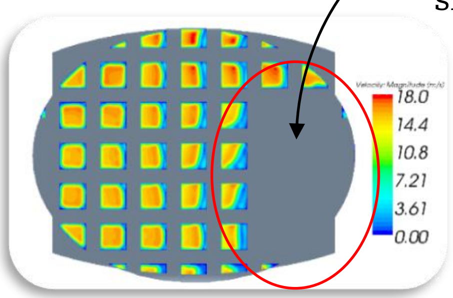
Objectives →

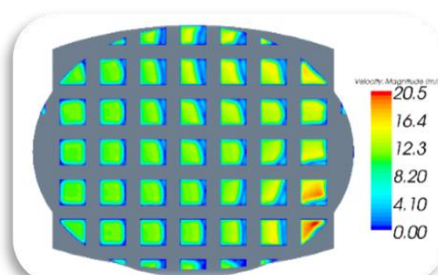
- In-depth analysis of fluid flow pattern, totally impossible otherwise;
- Insure effectiveness and stringent efficiency targets;
- Meet cost targets with simplest solution possible.





Blockage is easily incorporated into the simulation process.

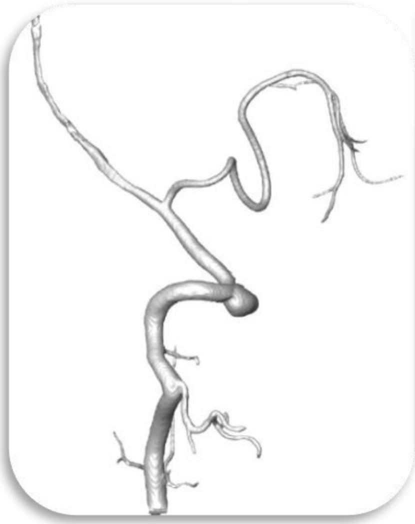




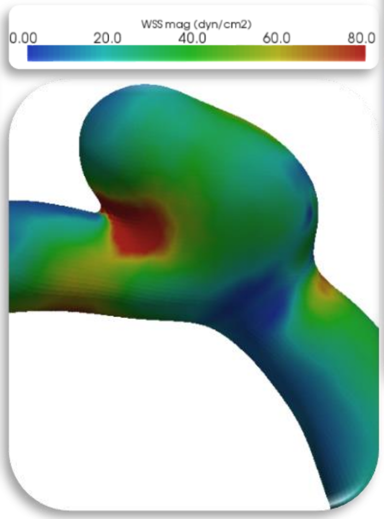
Aneurysm Hemodynamics

Objective →
Assess impact of biomechanical parameters on and near vessel walls in the genesis, development and rupture of cerebral aneurysms using patient-specific 3D geometries.

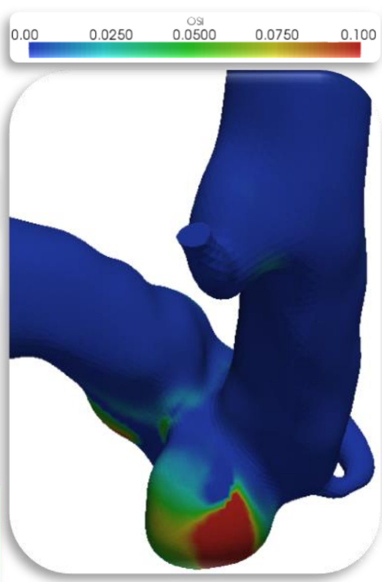
Cerebral aneurysms are more likely to arise at regions with a combination of high WSS and its gradients, such as bifurcations and strong curvatures.



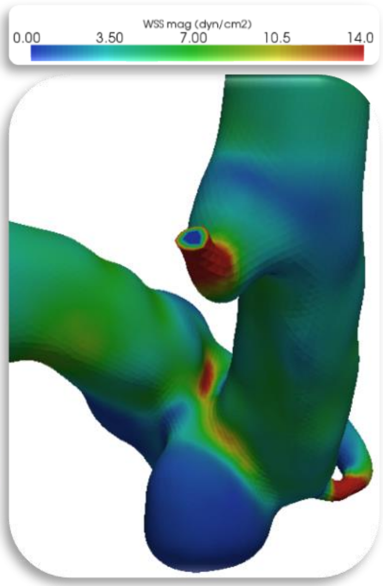
Real life geometry.



Wall shear-stress (WSS)



Oscillatory Shear Index (OSI)



Wall shear-stress (WSS)

Generally, WSS is higher in the neck region and minimal inside the aneurysm, whereas OSI reaches high values both in the neck region and in the aneurysm.

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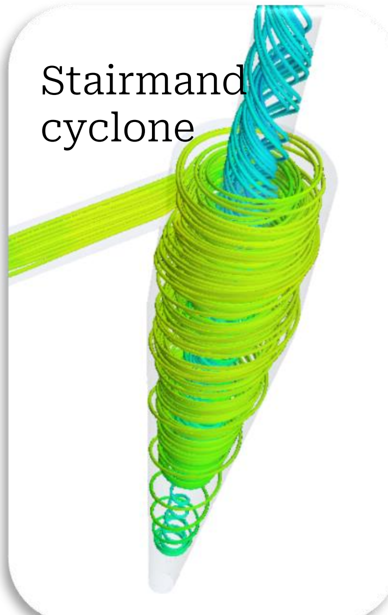
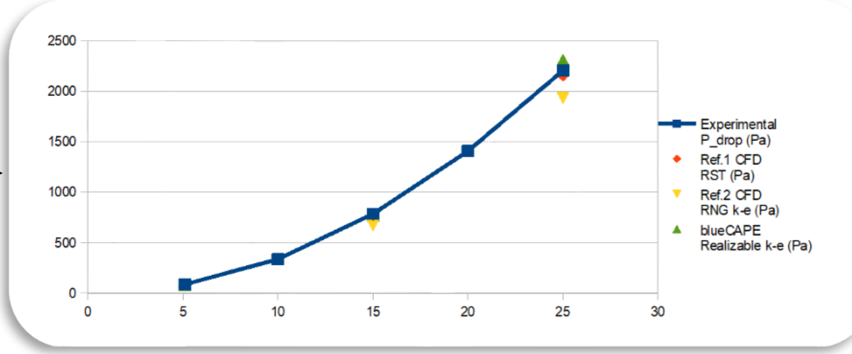
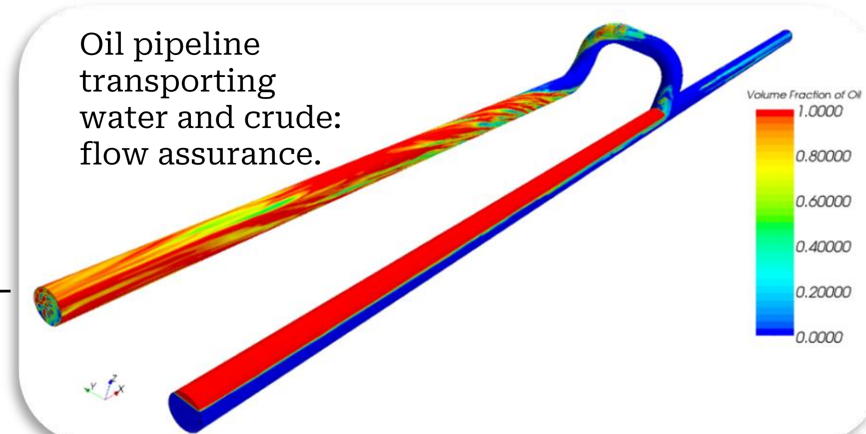
Separation Processes

Objective → Evaluate efficiency of separation processes





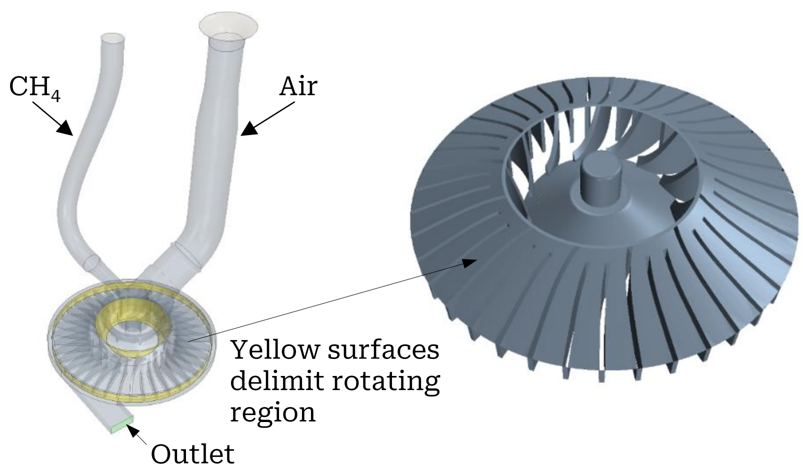
Accurate Results!

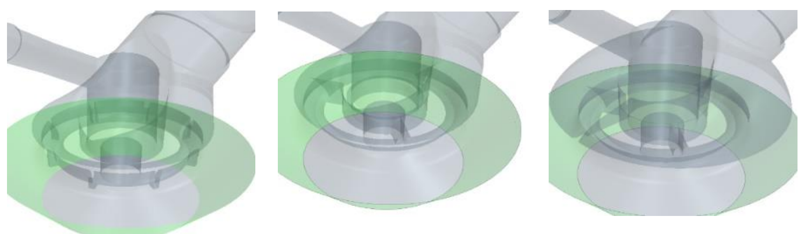


Provides insight into exhisting or planned networks, thus validating solutions and saving costs.

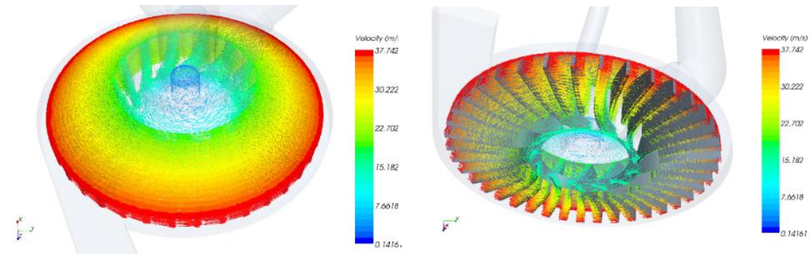
Advanced Mixing

Objective →
Evaluate suction and mixing ability of Methane injector

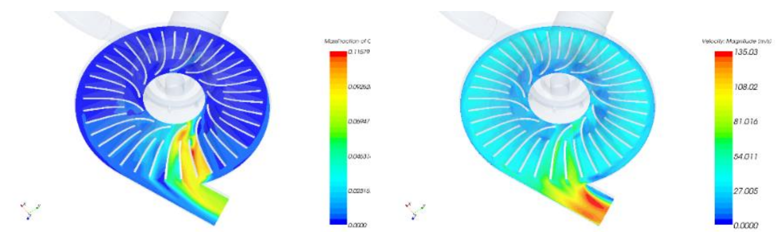




Evaluation of different mixer concepts:
→ Pressure drop
→ Mixture quality



6000 rpm rotation velocity

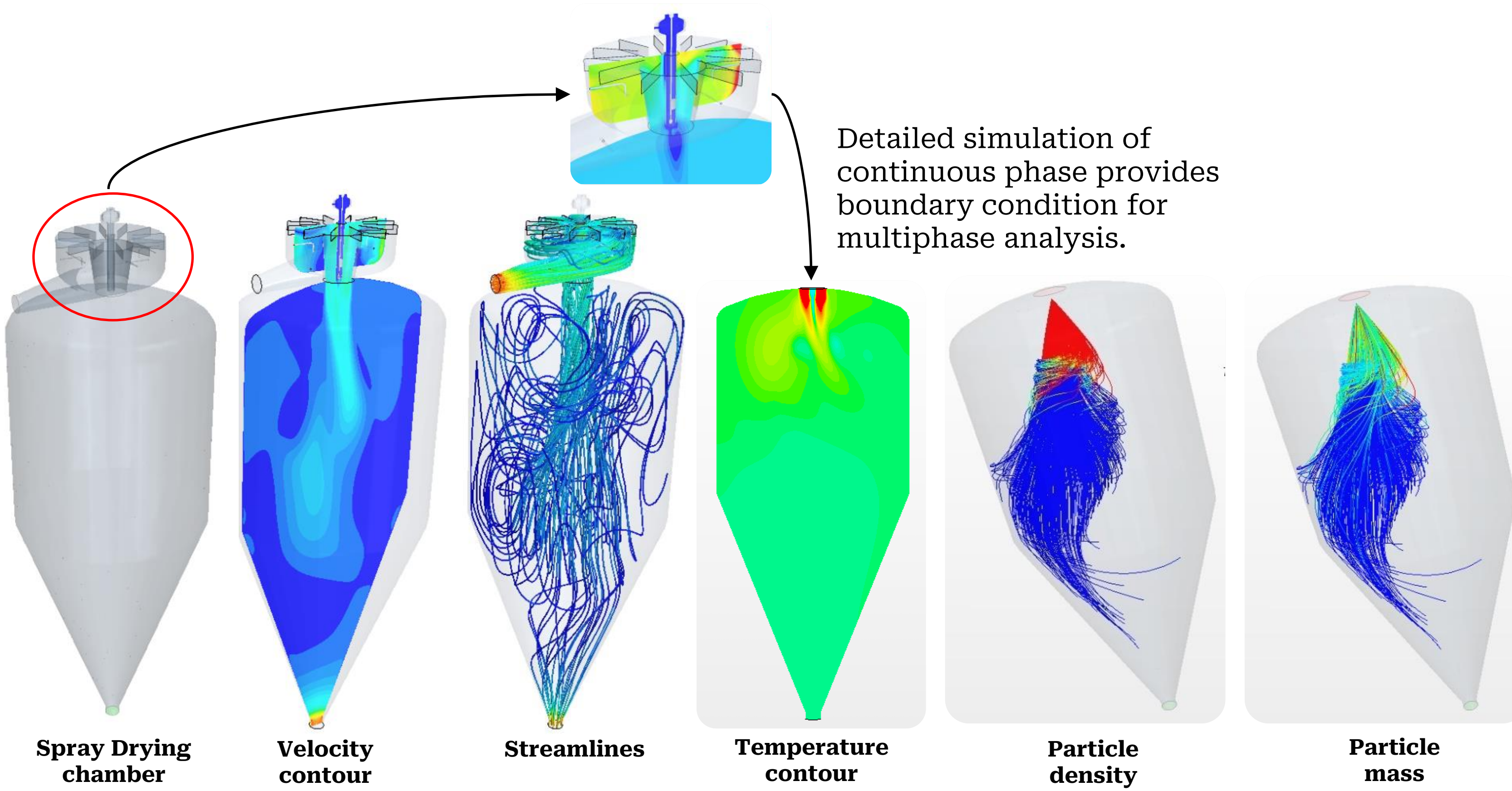


Mass fraction of CH4 (left) and Velocity Magnitude (right) contour at ventilator middle plane

Two methodologies to simulate rotation:
MRF – Moving Reference Frames
RBM – Rigid body motion (moving mesh)

Spray Drying

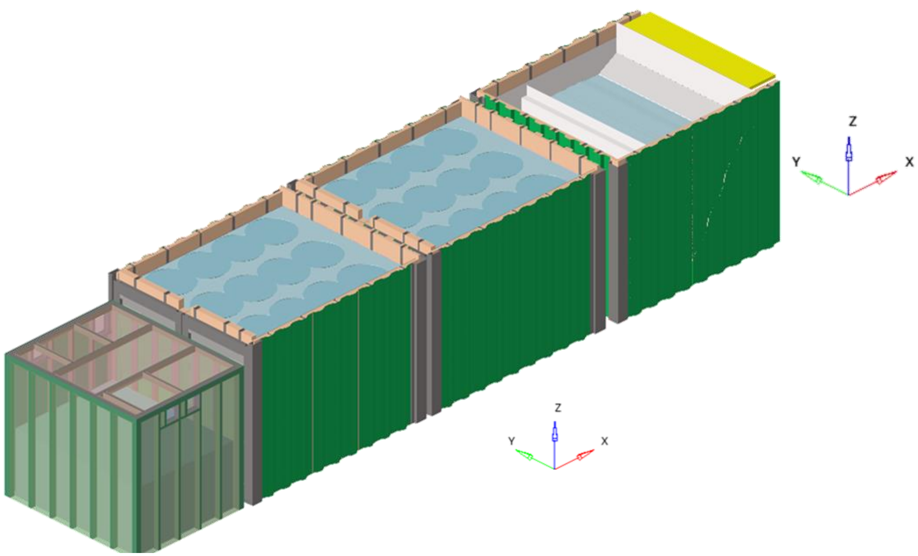
Objective → Evaluate efficiency of spray drying chamber with two-way coupling between continuous and disperse phases.

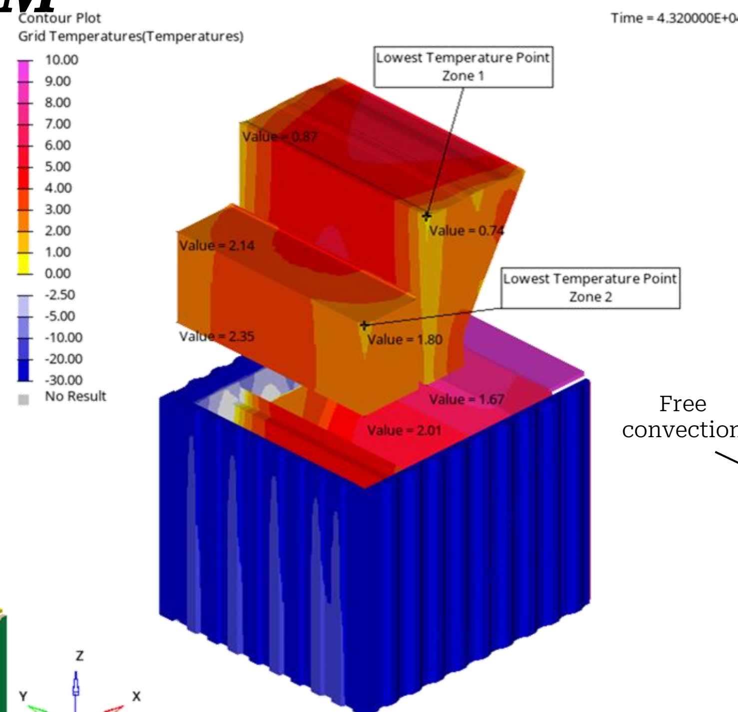


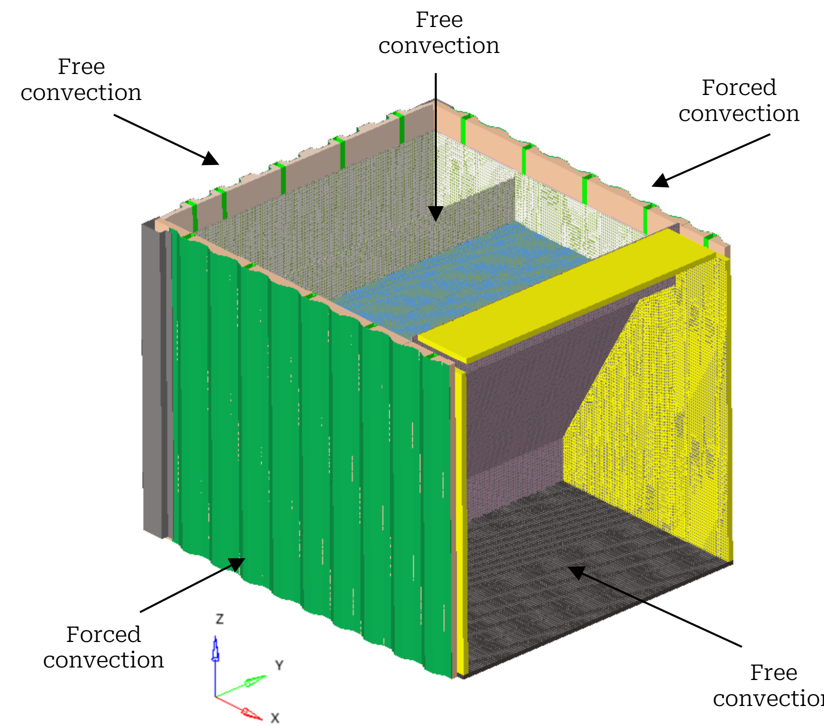
Portable water tank - FEM

Objective

Study the temperature evolution of the water in a portable water tank and guarantee that no freezing occurs during the required field operation.



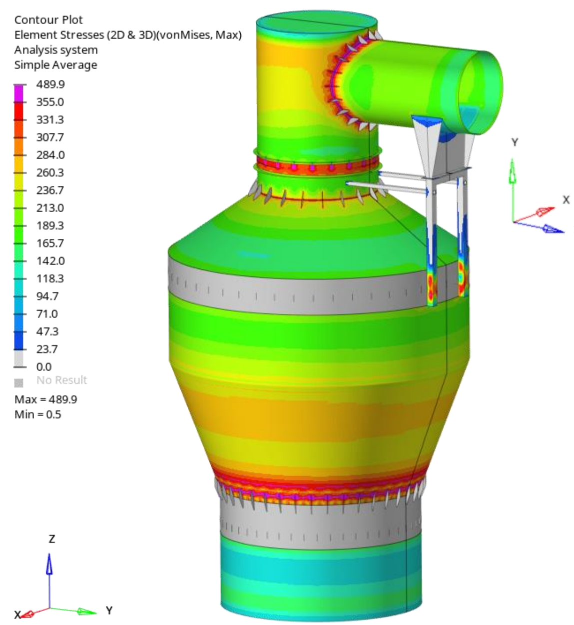


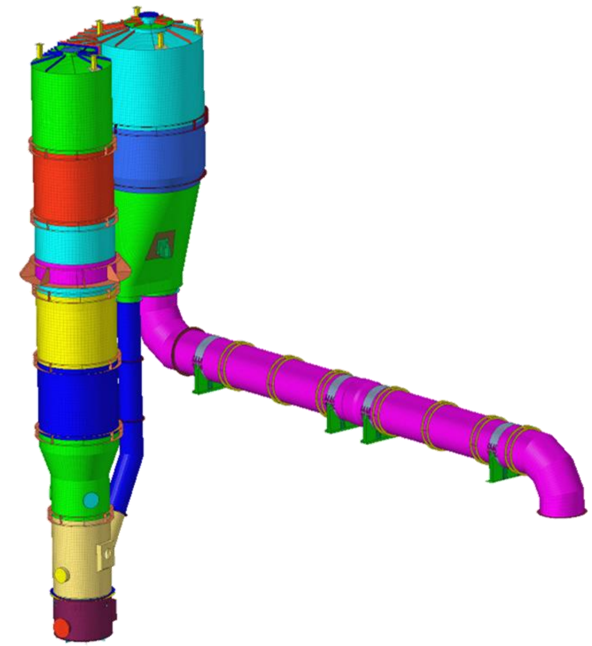


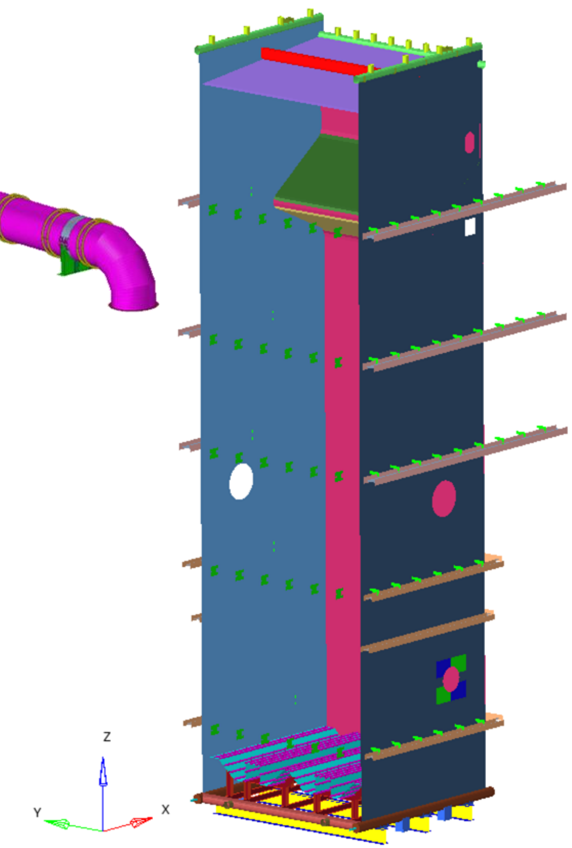
Industrial furnaces - FEM

Objective
Evaluate the structural integrity and stability of big structures under thermal loads, seismic loads and other loads.

FEA simulations coupled with CFD simulations or subject to the Eurocode norms.

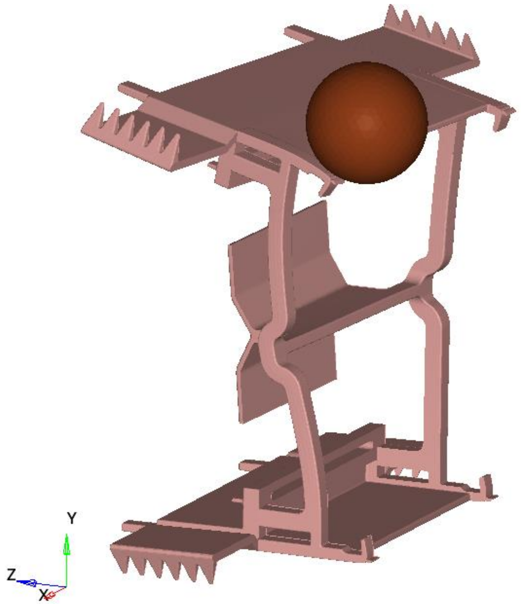


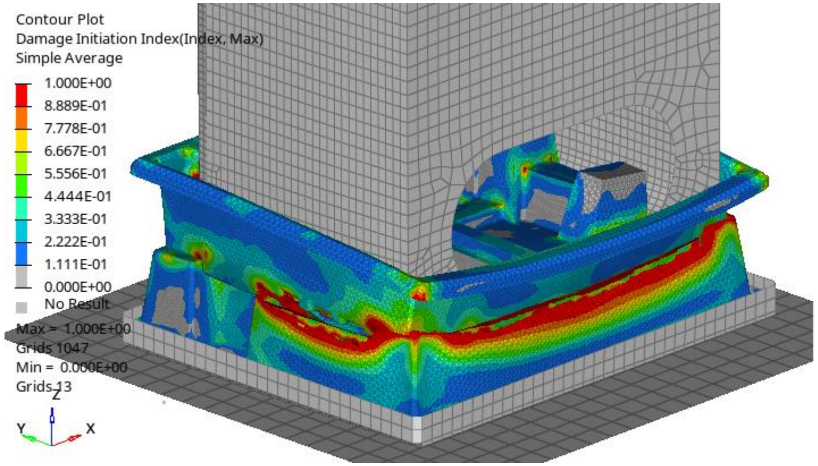


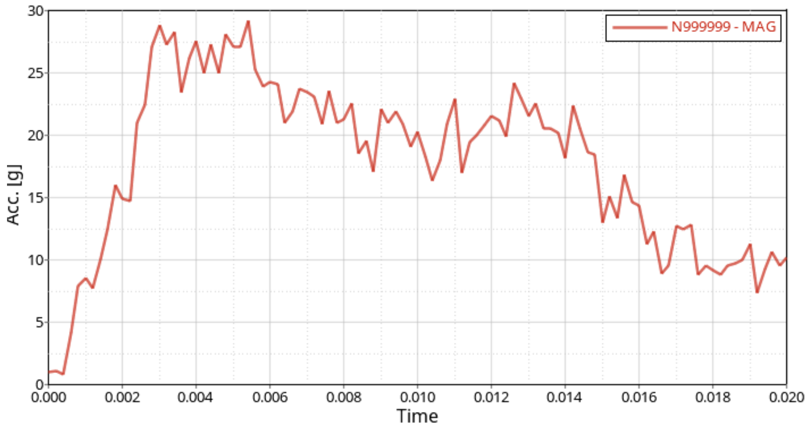


Packaging – Drop test - FEM

Objective
Evaluate different packaging and parts performances simulating dropping scenarios through explicit dynamic analyses.

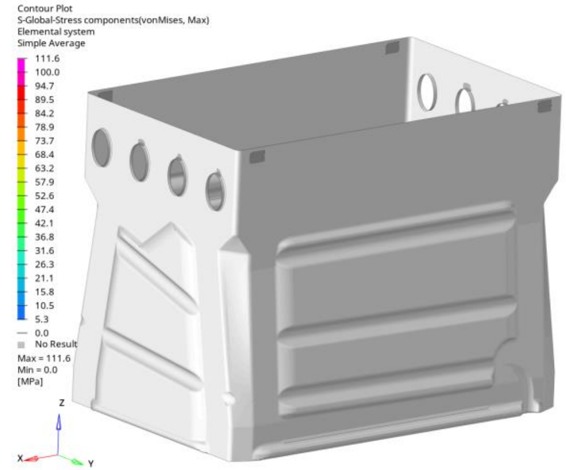


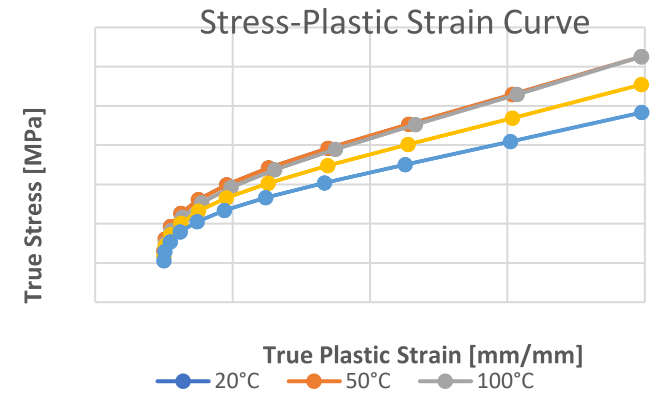


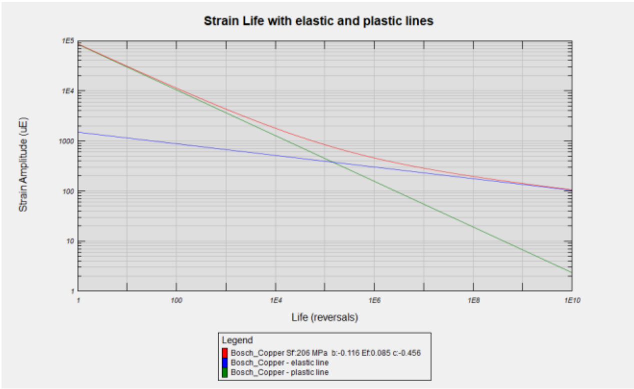


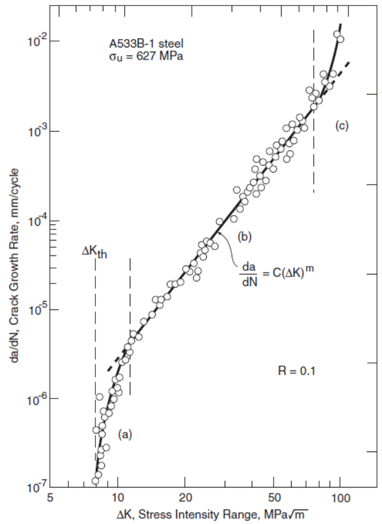
Heat exchangers - FEM

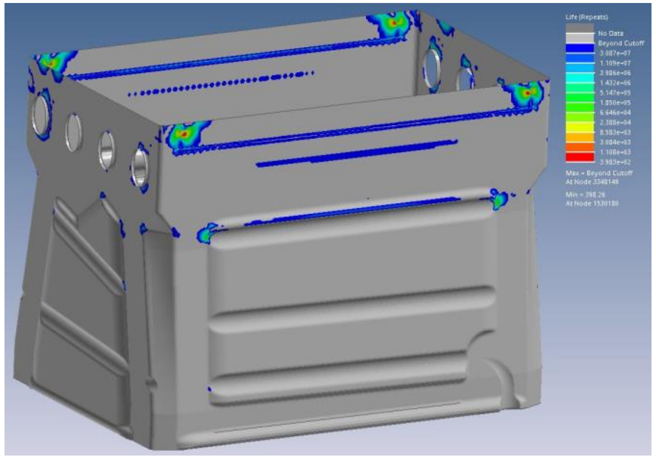
- Transient Heat Transfer analysis
  - 1-way coupled with CFD simulations
- Transient non-linear structural
  - Temperature dependent material's properties
- Low cycle fatigue analysis
- Crack propagation





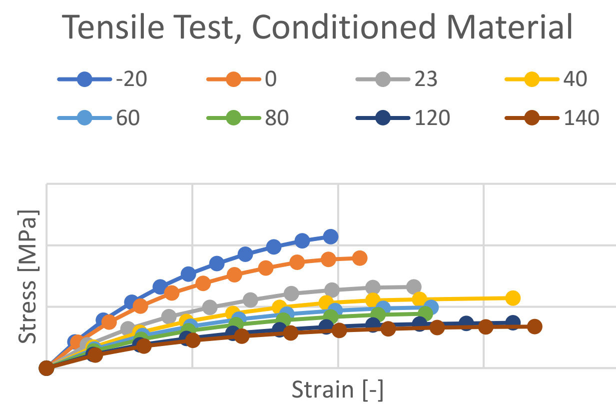


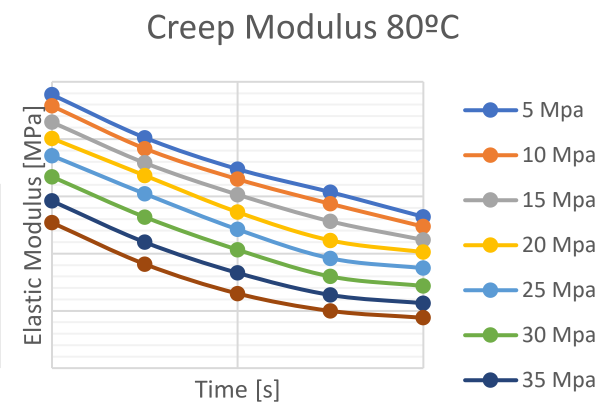


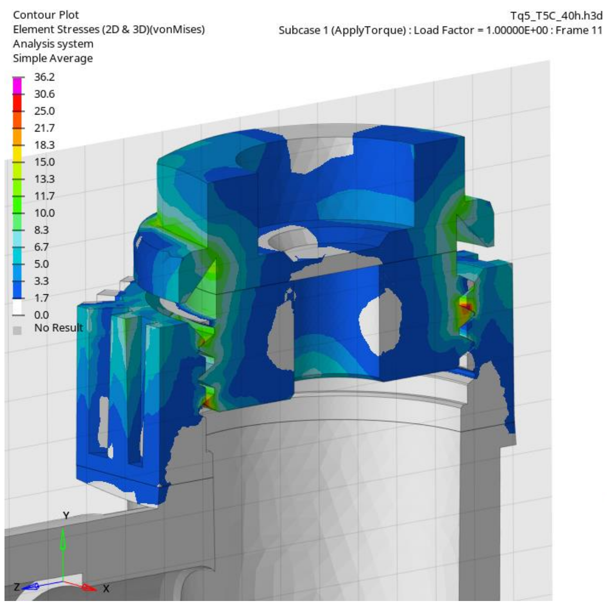


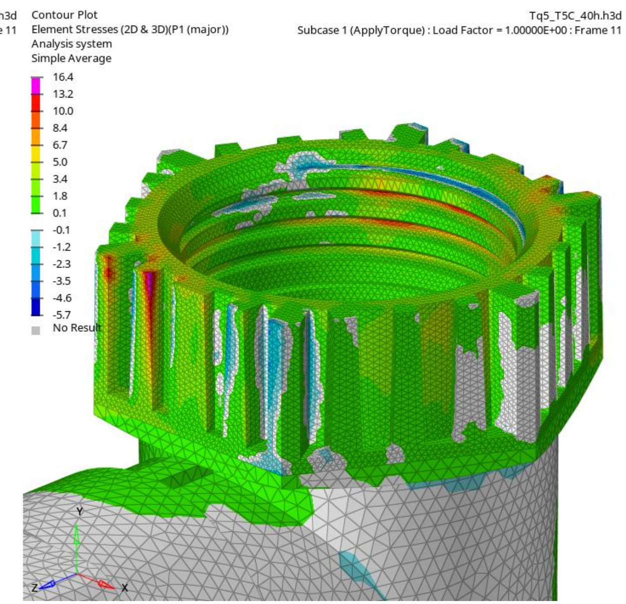
Polymeric components - FEM

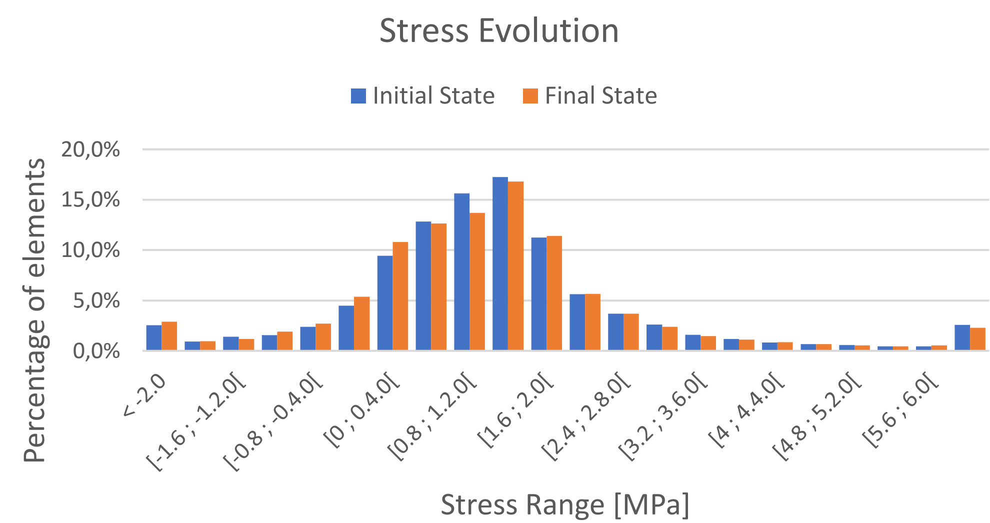
- Visco-elasto-plastic material modelling
- Steady-state thermal analysis
- Static non-linear structural
    - Contacts
    - Pre-loaded threaded connection
- Creep and stress relaxation transient









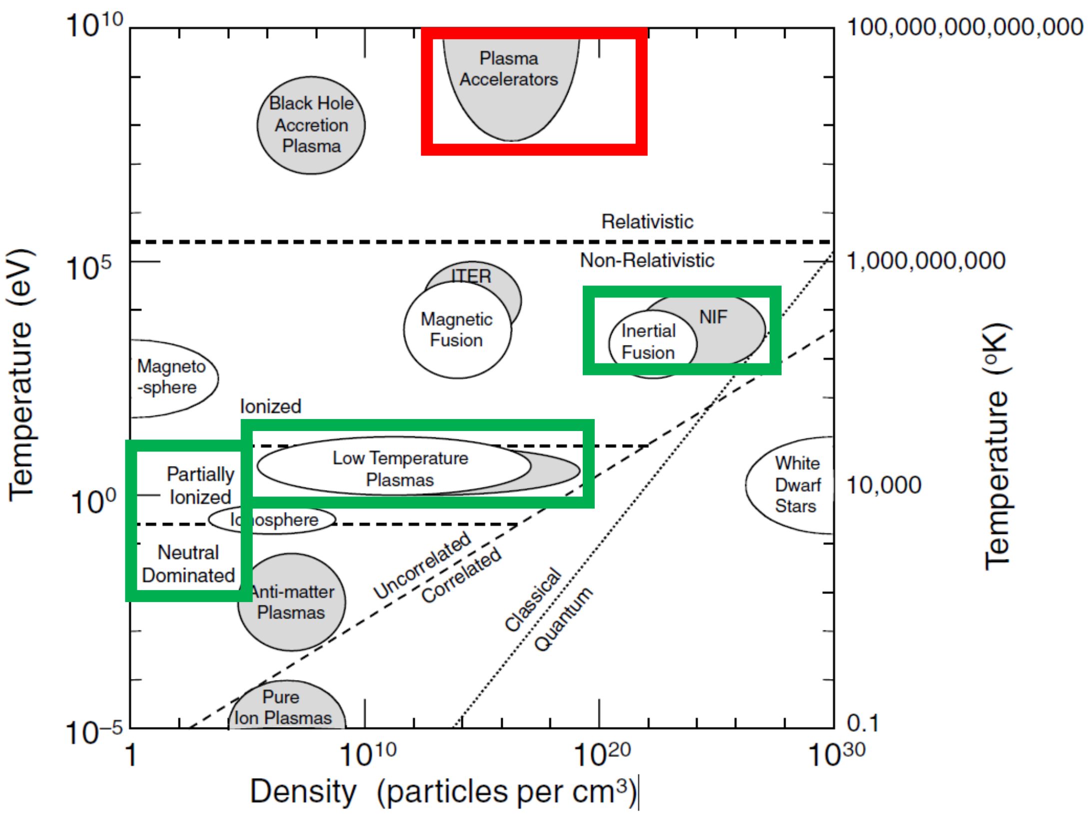


Processes - Plasma Modelling

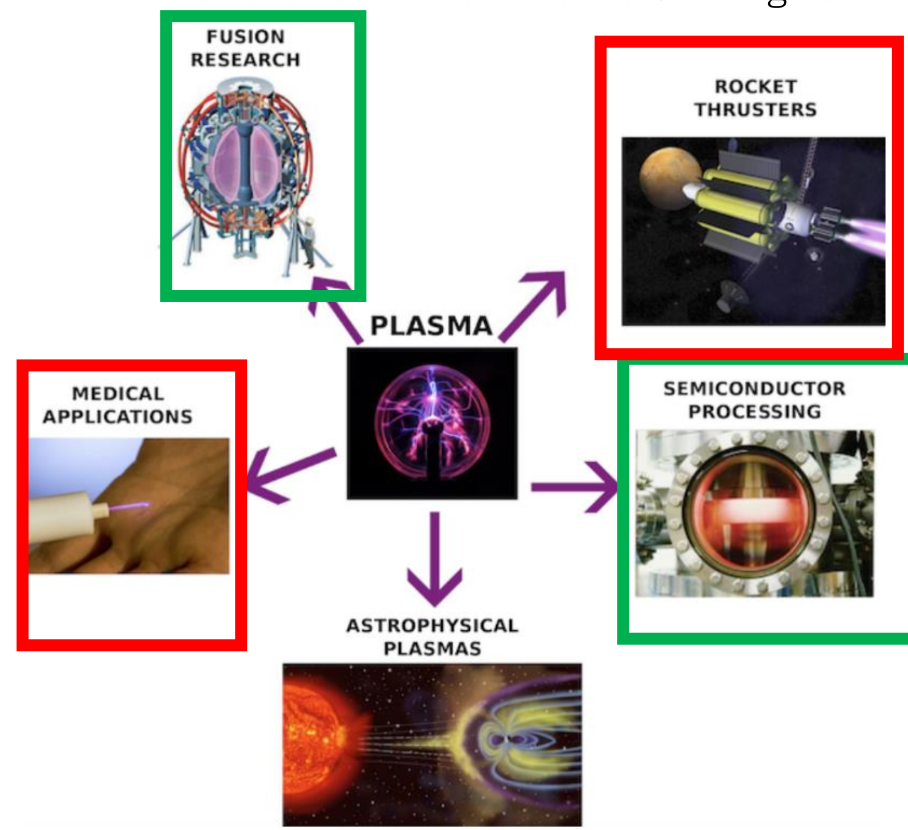
FS × DYNAMICS

Plasma competence: Modelling of plasma sources and plasma based technologies

Plasma can occur in different conditions



Plasma is used for different technologies



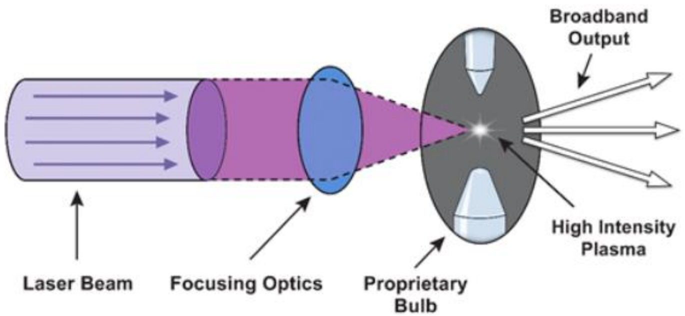
FSD past projects

Work in progress

FS × DYNAMICS

Laser produced plasma sources for broadband emission

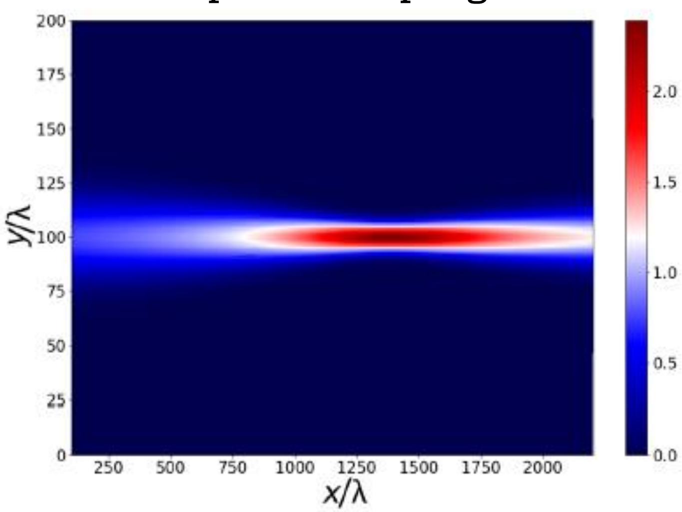
Improvement of source emission via radiative hydrodynamics simulations



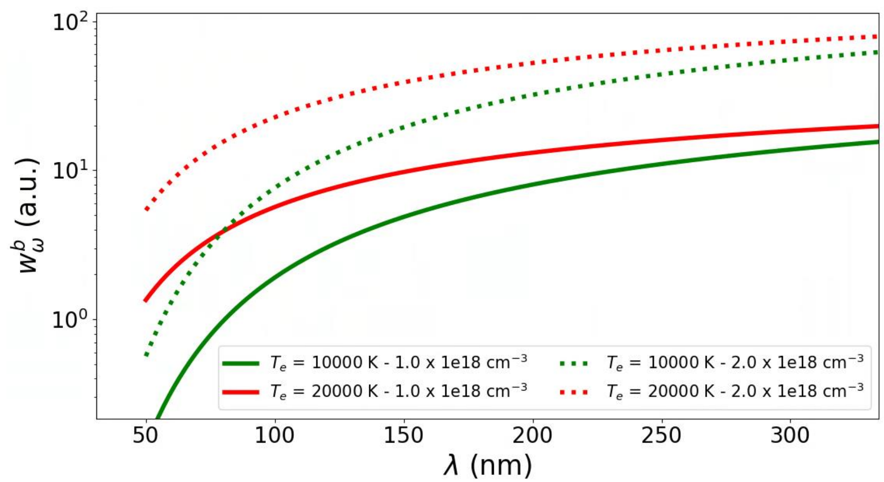
Plasma: single fluid conservation equations
Laser light: ray-tracing equations
Radiation: multigroup equations

Plasma-laser coupling: inverse Bremsstrahlung
Plasma-radiation: EOS and opacity

Laser plasma coupling evolution



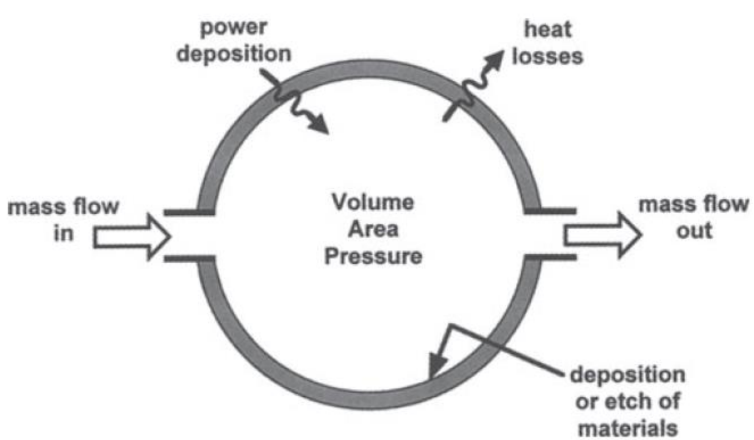
Plasma emission in the VUV regime

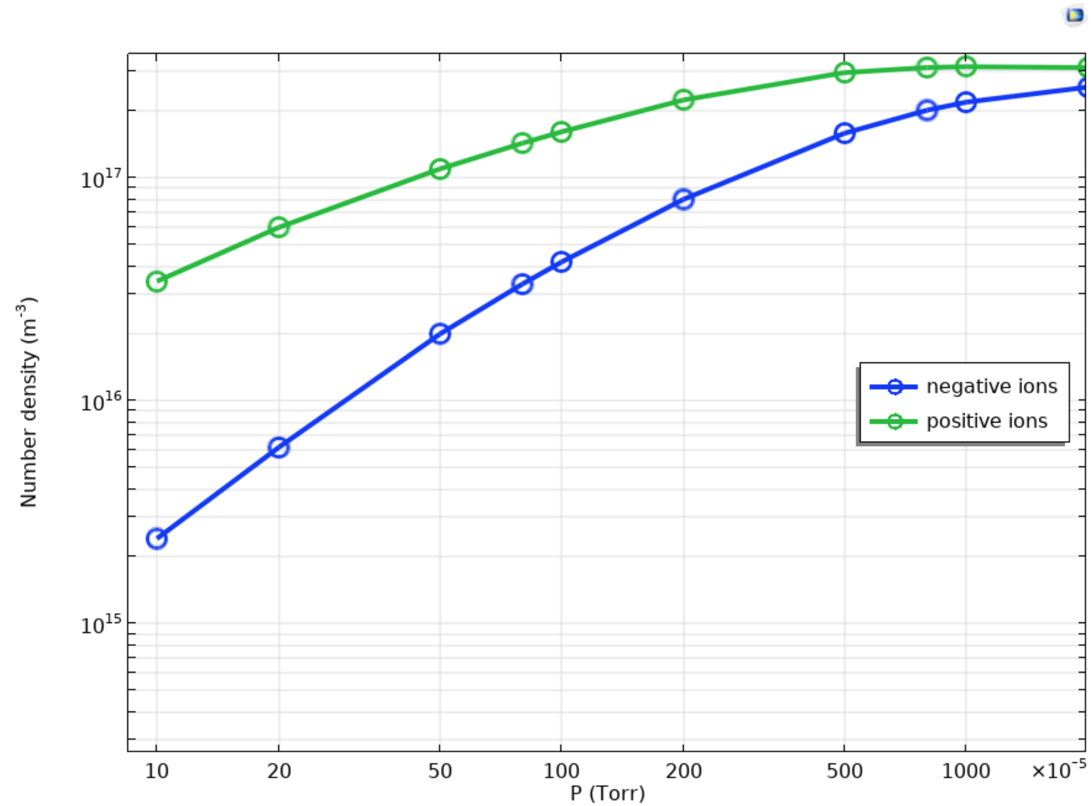


Best combination of initial gas density and laser parameters to increase VUV emission

Chlorine etching of silicon with ICP reactors

0d modelling: Finding the range of parameter operation over large interval of pressure





Numerically cheap for large parameter study
Good if chemistry is complicated to understand trends

Plasma chemistry
38 bulk reactions + 8 surface reactions

Negative and positive ions density saturates when approaching 0.1 Torr

Processes - Plasma Modelling

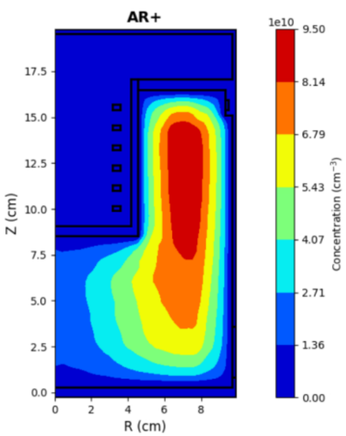
FS × DYNAMICS

Capacitive coupling of ICP coils at low current

Hybrid modelling of ICP including capacitive coupling retrieves theoretical results

I = 0.1 A – W = 4 W

CC on



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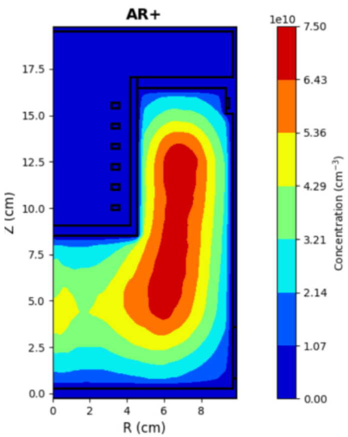
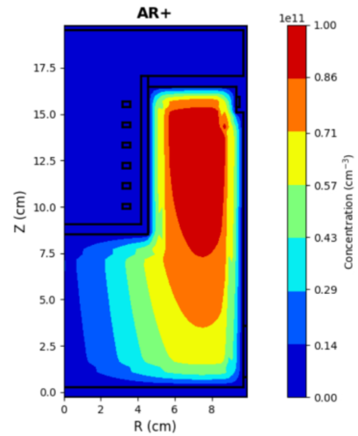


I = 10 A – W = 400 W

CC on



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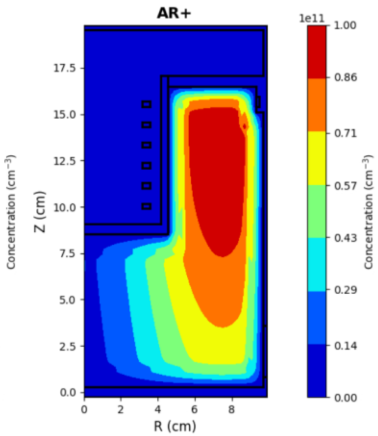
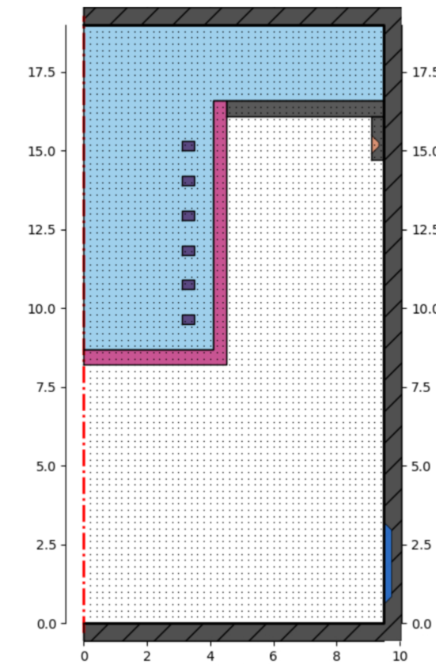
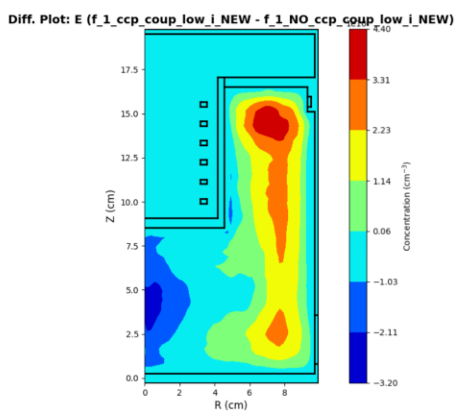
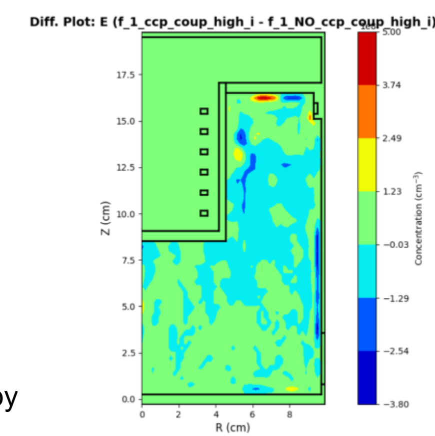


Reactor geometry





Max difference ~50%



Max difference ~0.05%

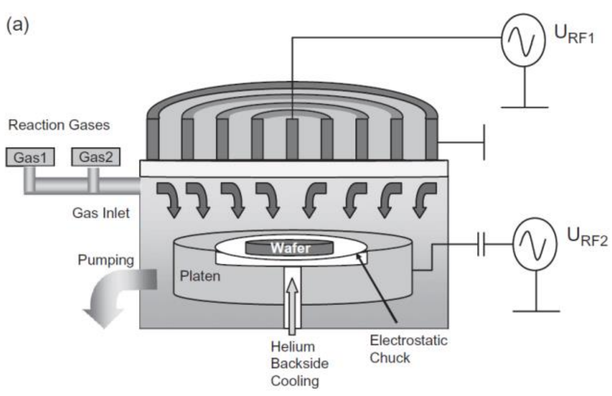
Capacitive coupling plays important role at low currents, observed via hybrid modelling

Processes - Plasma Modelling

FS × DYNAMICS

Multi-scale modelling of plasma etching – JUST STARTED

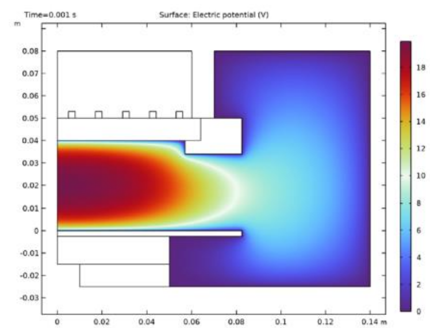
Copling MHD and molecular dynamics tools to obtain information on feature profile modification



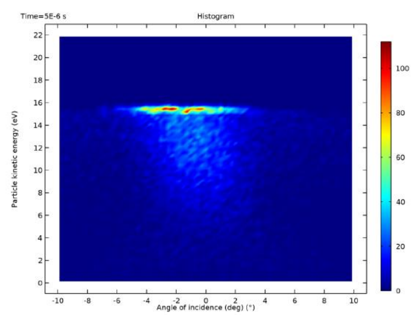
COMSOL/
EDIPIC/
HYBRID?

ICP Fluid/kinetic model → Heavy particle tracing

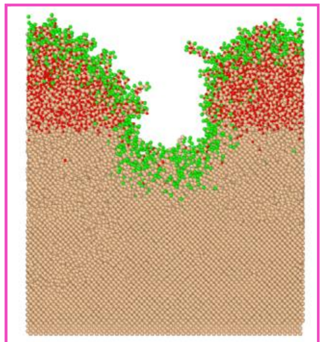
Info on fields



Downstream particle flux



Varying gas flow and density, and RF power



Etching profile

LAMMPS

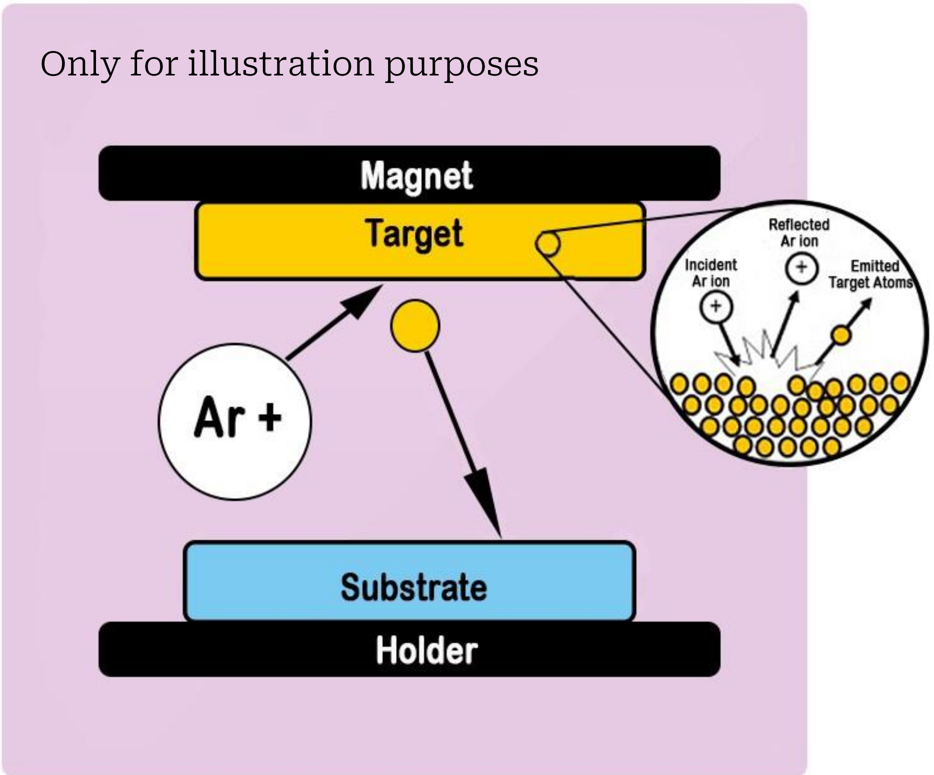
Molecular dynamics simulation predicting the profile modification based on molecular interaction among substrate, coating and ions.

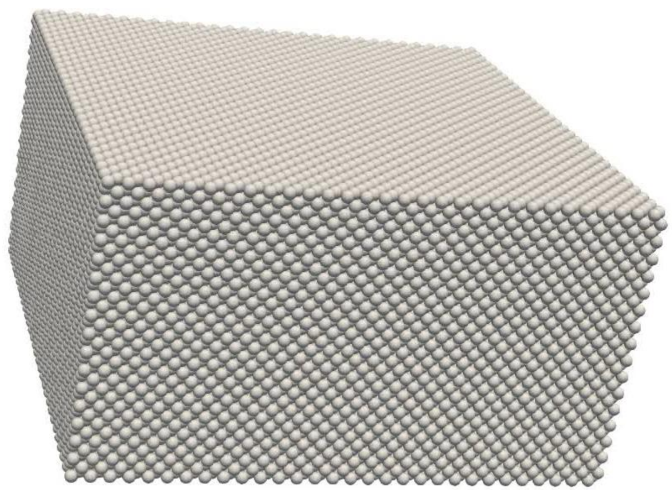
How much is etching profile sensible to reactor ou

Molecular Dynamics for PVD with Sputtering

FS x DYNAMICS

Sputtering is a physical vapor deposition (PVD) process used to create thin films on a substrate. In this project, FS Dynamics experts analyze different parameters to improve the thin film deposition of titanium on top of the nickel substrate.





Simulation is performed using Opensource code LAMMPS. However, different applications might require different software solutions. And our team of expert can advise.

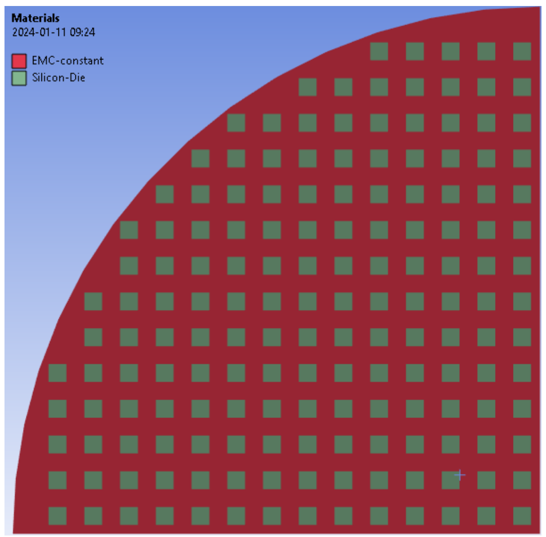
Transport
Energy
Electronics
Wastewater
H.V.A.C.
Biomedical
Process
Machinery

Wafer Warpage Prediction

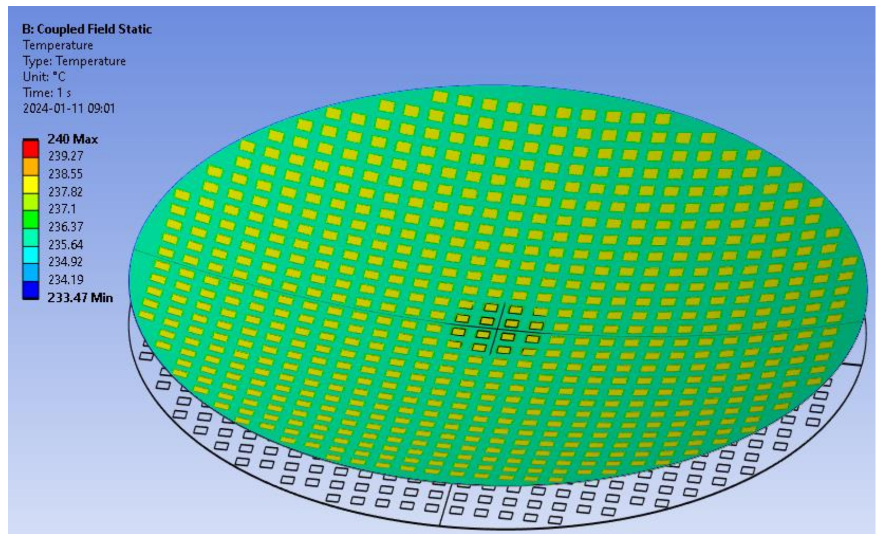
FS × DYNAMICS

Prediction of wafer warpage has emerged as a critical aspect in ensuring the success of the chip packaging process. Understanding and accurately predicting this warpage is essential for several reasons:
reliability and performance, yield enhancement, advanced packaging technologies, Cost Efficiency and Process Optimization.

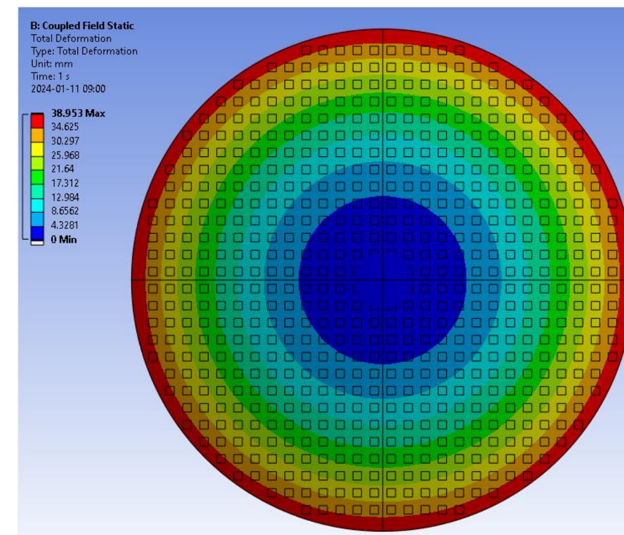
Geometry/Layout



Temperature



Deformation



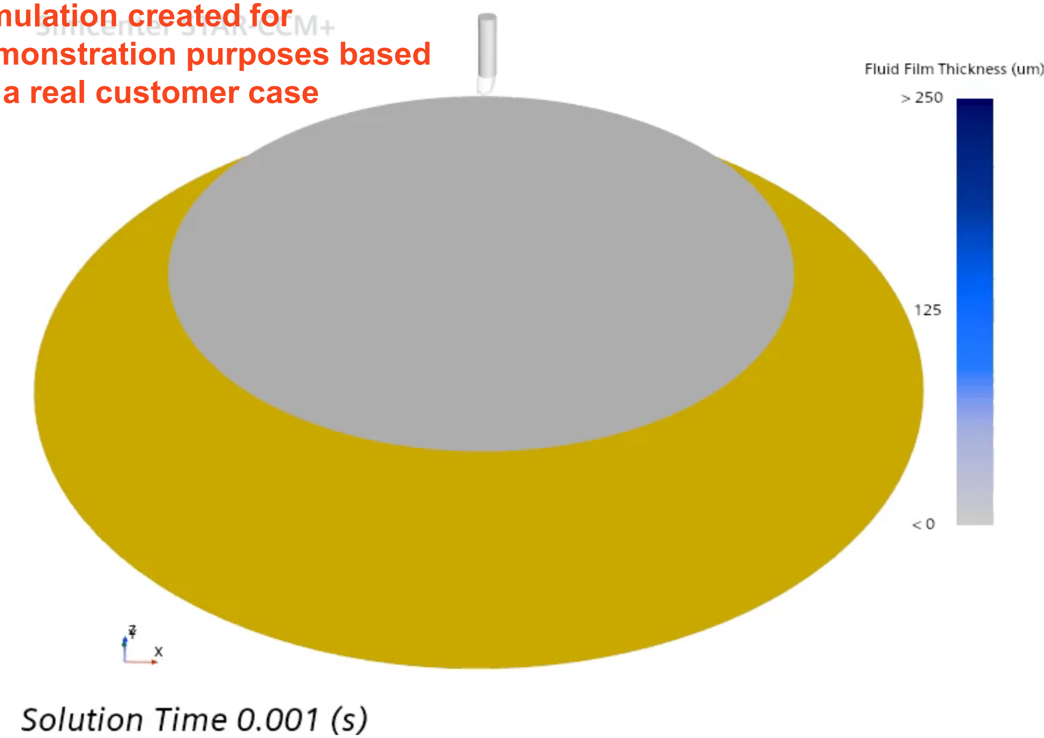
Finite element analyses (FEA) facilitate prediction with high confidence by use of high fidelity in geometrical models, material characteristics, process and environmental boundary conditions. FEA also serves as a foundation for validation with experimental data.

CFD: Spin coating

FS × DYNAMICS

Objective → Evaluate the film thickness as function of different parameters.

Simulation created for demonstration purposes based on a real customer case

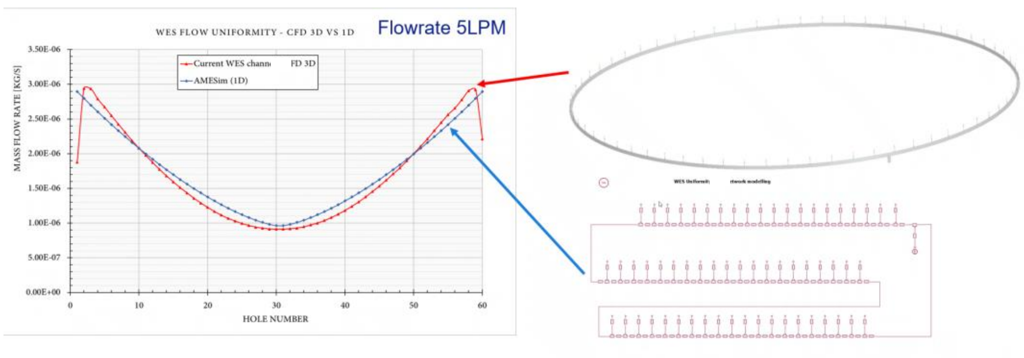


In this study, it was evaluated the fluid film thickness as function of angular speed of wafer, liquid flow velocity, nozzle motion and distance from the wafer.

CFD: 1D Network Multiphysics Modelling

FS × DYNAMICS

The 1D network Multiphysics modelling are powerful and fast tools to assess performance of the system. In the examples below, the focus is on flow. However, it can be easily extended to flow with heat transfer, mechanical actuators and more.

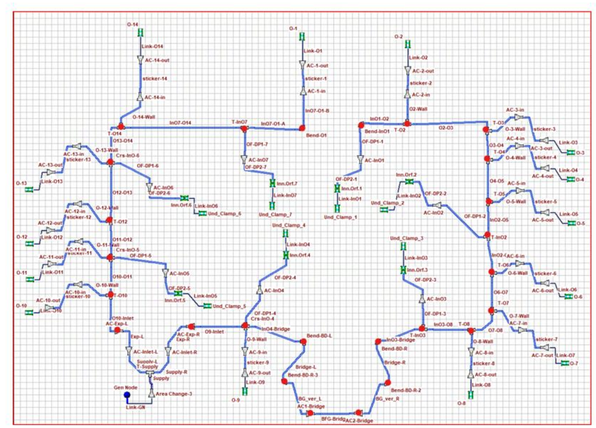


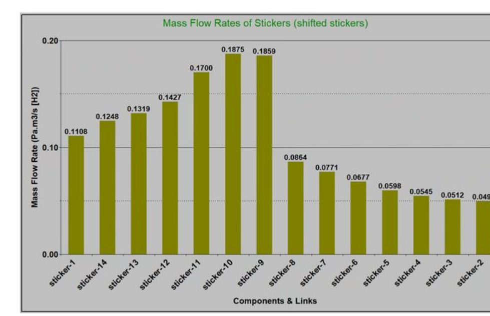
<< In this example, flow uniformity is critical for the performance of the system. In order to verify if the 1D approach would be enough, a 3D CFD was performed and compared with the 1D tool.

- The 1D approach provides an **averaged** mismatch of 4% wrt 3D CFD;
- The higher deviation are present in the extremities due to 3D effect which cannot be captured by the 1D approach;
- 1D approach is very flexible, allowing us to make sensitivity analysis/optimization of multiple parameters in seconds (depending on the complexity of the model).

In this case, a more complex network of channels, flow restrictions and volumes are created in 1D to represent the 3D design.

The objective was to assess the level of uniformity.





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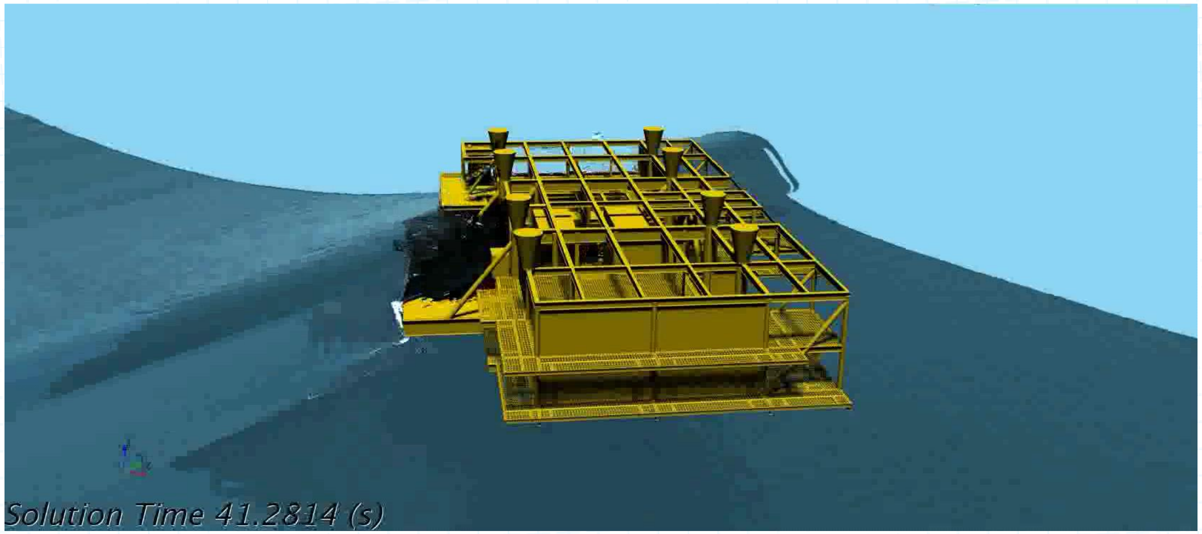
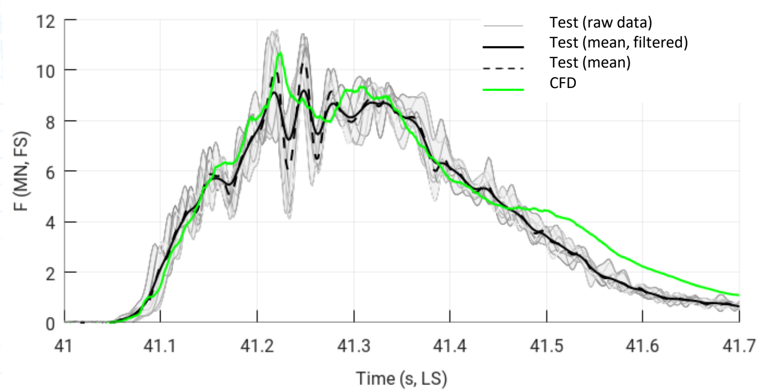
FS × DYNAMICS

CFD Wave load validation for complex structures

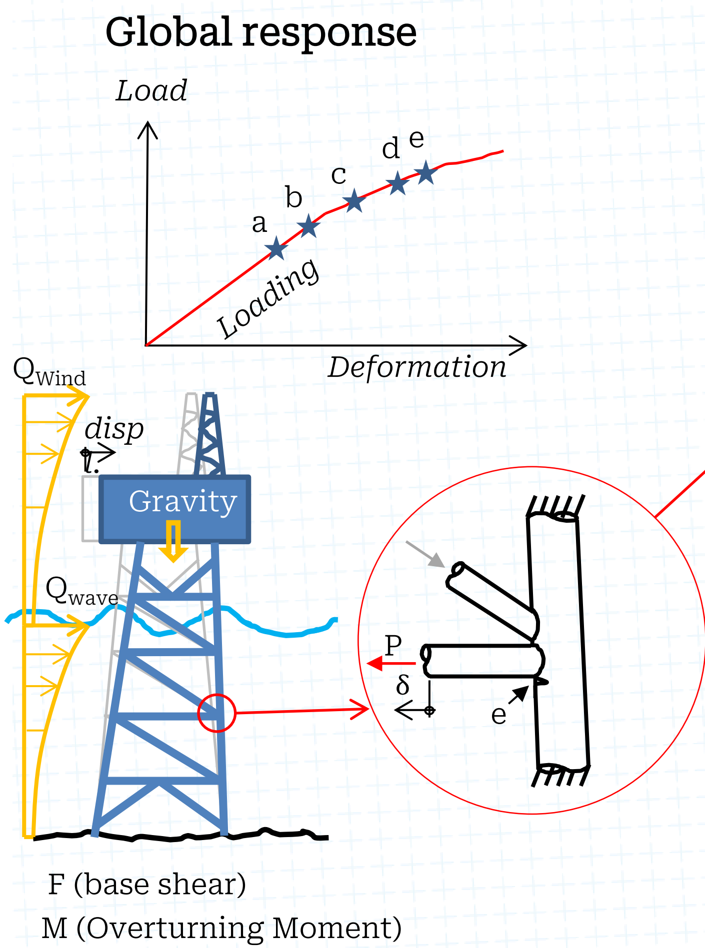


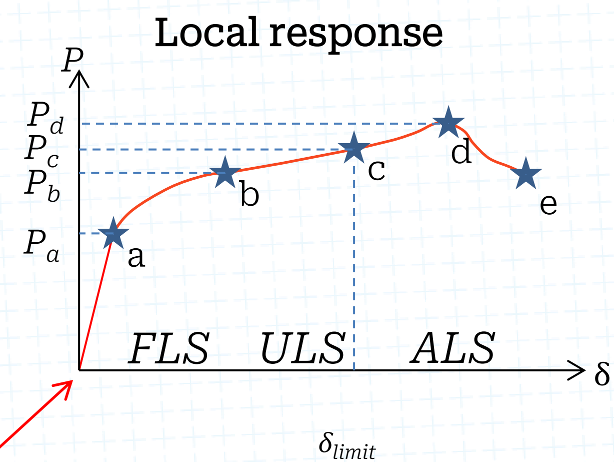


Validated CFD methodology for Wave loads

- Method
  - Numerical schemes for discretization and time integration
  - Meshing approach and resolution
  - Time step optimization
- Surface elevation
  - Comparisons with measured wave gauges (2D flume and 3D basins with regular, irregular and breaking waves)
  - Comparisons with HD video
  - Comparisons with theoretical linear irregular waves (spectrum)
- Kinematics
  - Comparisons with PIV and LDA data
- Loads
  - Comparisons with measured loads on scale models (regular and breaking waves)

Structural response modeling



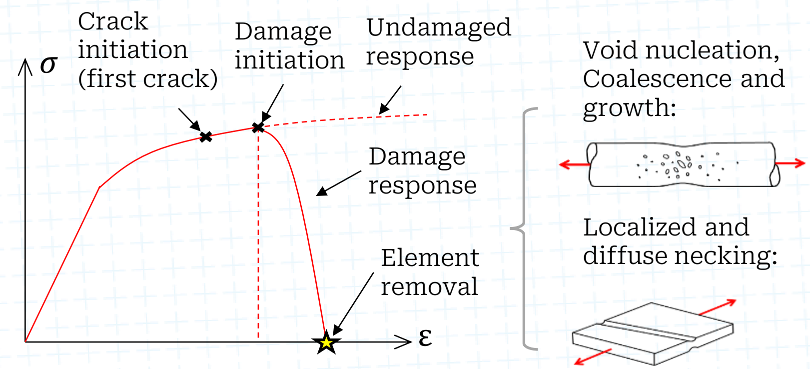


Failure limits:

a) initiation of material yielding
b) crack initiation
c) deformation limit
d) ultimate capacity
e) tensile failure

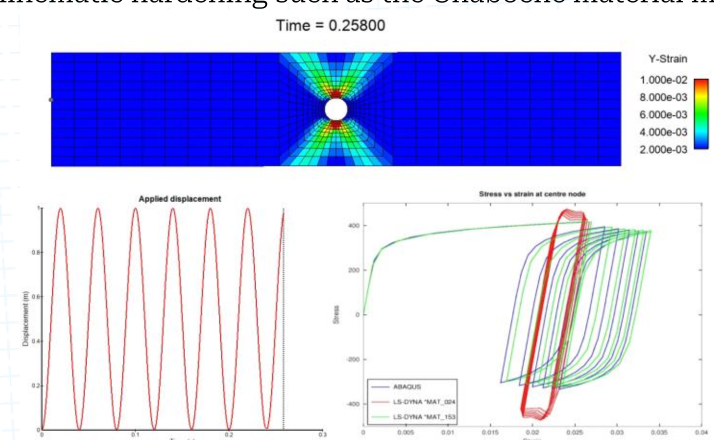
Structural damage evolution

Capturing effects of material degradation with use of damage initiation and damage evolution



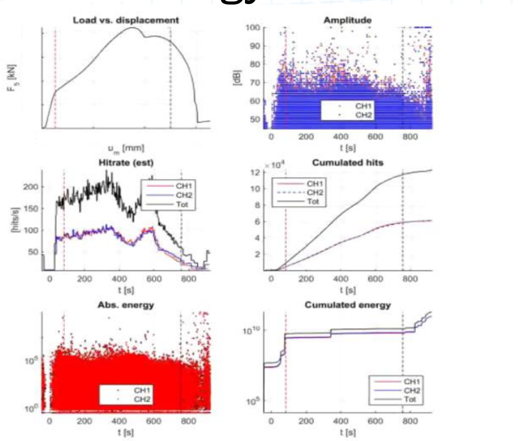
Non-linear Material modeling

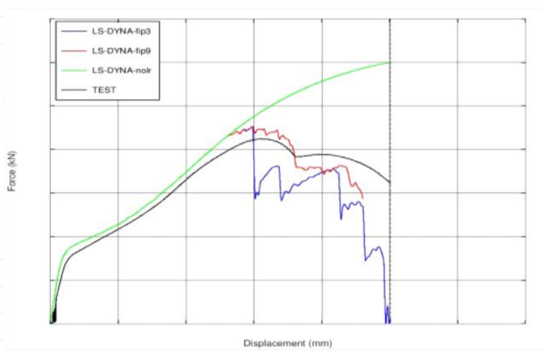
Capturing effects of cyclic loading with use of Non-linear kinematic hardening such as the Chaboche material model

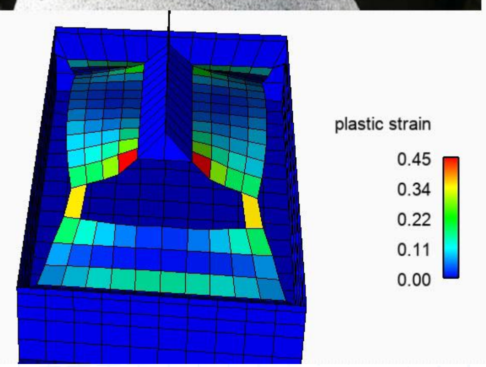


Validation of Structural response – methodology calibration

Methodology Calibration







Calibration and Validation: *© Eriksson M., Nyberg M., Andersen M., Tychsen J. and Nielsen J., "Validated Methodology for Assessment of Welded Steel Structures by Nonlinear Finite Element Analysis", International Journal of Offshore and Polar Engineering, Vol. 34, No. 2, June 2024, pp. 191–198.*
https://doi.org/10.17736/ijope.2024.ty14

Validated FEA methodology for welded details

- Based on an extensive testing campaign involving
  - *16 test series with various failure mechanisms*
  - *Varying levels of Bending in combination with Tension*
  - *In-plane shear failures*
- Calibration adhering to ISO 19902:2020

Calibration includes

- Material
  - *Stress-strain curve*
  - *Failure strain (eroding)*
  - *Number of layers to element failure*
- Shell definition
  - *Element formulation*
  - *Number of through thickness integration points*
- Mesh resolution
  - *Along welds*
  - *Over gaps*
  - *At weld terminations*
- Weld modelling

Failure criteria/limits

- Mean and characteristic strain limits:
  - *Crack initiation / Local necking (degrading fatigue properties)*
  - *Ultimate tensile failure*

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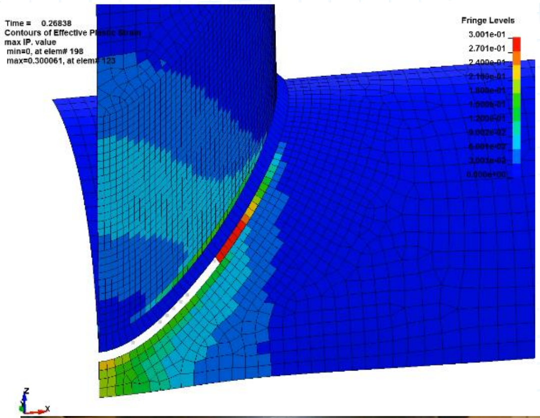
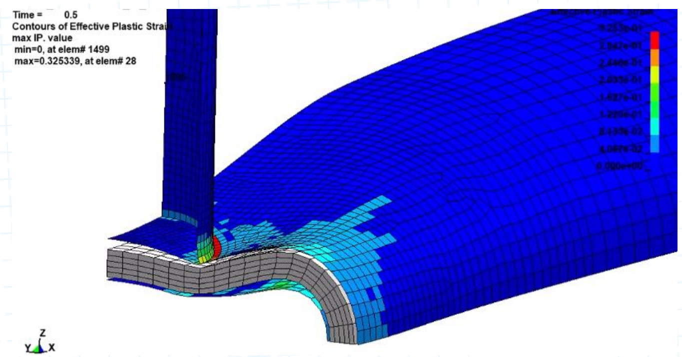
Validation of Structural response – methodology validation

Methodology Validation

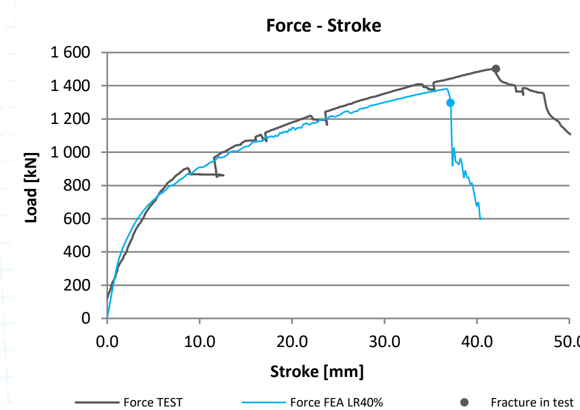




Calibration and Validation: *© Eriksson M., Nyberg M., Andersen M., Tychsen J. and Nielsen J., "Validated Methodology for Assessment of Welded Steel Structures by Nonlinear Finite Element Analysis", International Journal of Offshore and Polar Engineering, Vol. 34, No. 2, June 2024, pp. 191–198.*
https://doi.org/10.17736/ijope.2024.ty14

Validation of the methodology´s performance and generalizability

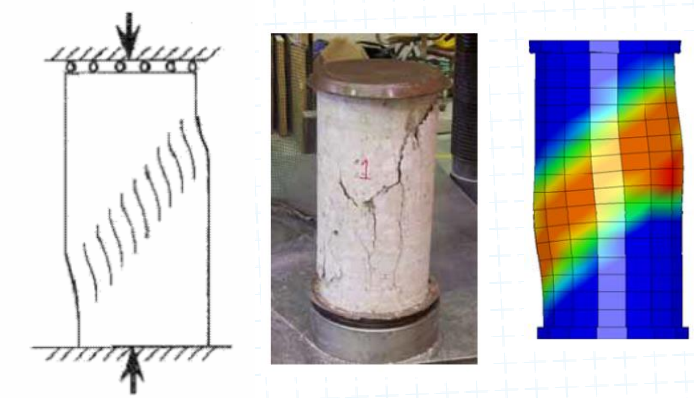
- Reassessment of independent dataset from previously performed validation of Tubular joints and members
- Confirmation of welded section modelling and failure criteria/limits
- Weld modelling rules for tubular joints
  - *Both with and without grout*

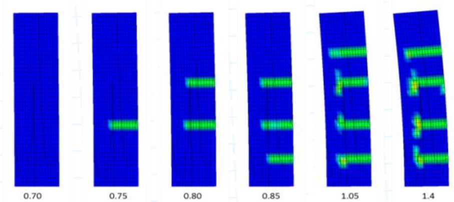


Grout model calibration for grout reinforced jacket legs

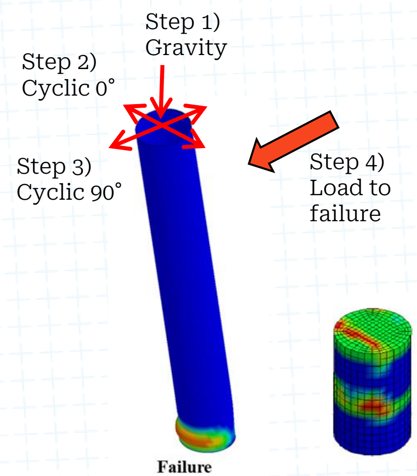
Project description:
Enhance the accuracy of the grout representation in grout reinforced jacket legs analysis models. Correlation against test with and without grout.

Compression

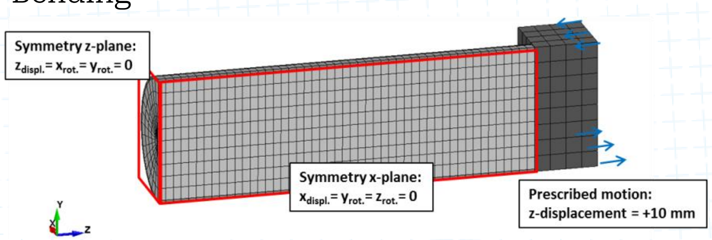




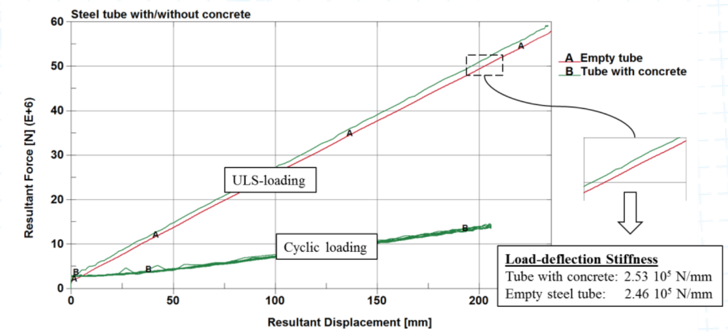
Cracks progressing with increasing load



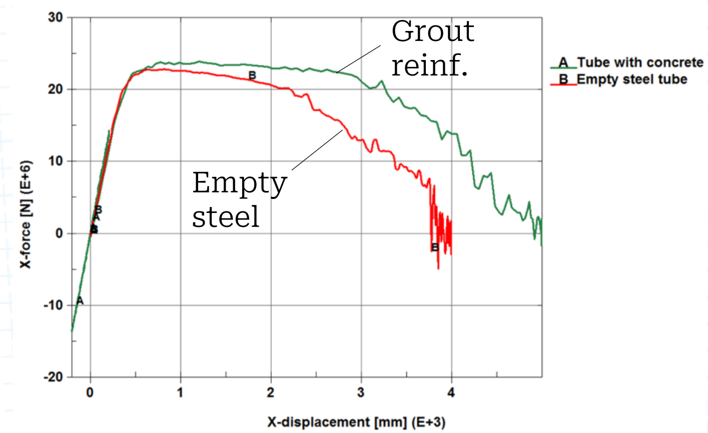
Bending



Ultimate load scenario:



Ultimate load capacity:



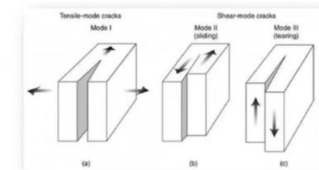
Crack growth assessment within tubular joint weld detail

Project description:
In case when structures are subject to cyclic loading, it is of interest to know the interaction between crack extension rate and the number of load cycles. Preexisting cracks may propagate when certain loading conditions are reached or when certain localized conditions are met.

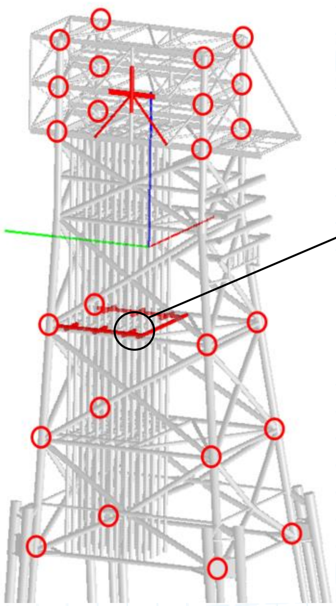
Fracture Mechanics Modes

Three primary modes of fracture:

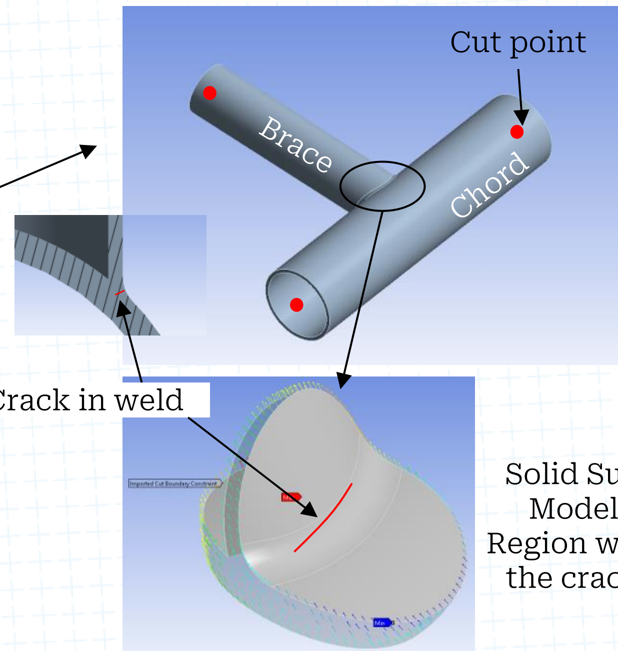
- Mode I: tensile or opening mode
  - generally most critical
- Mode II: sliding or shear mode
- Mode III: tearing mode



Global model –
Beam elements

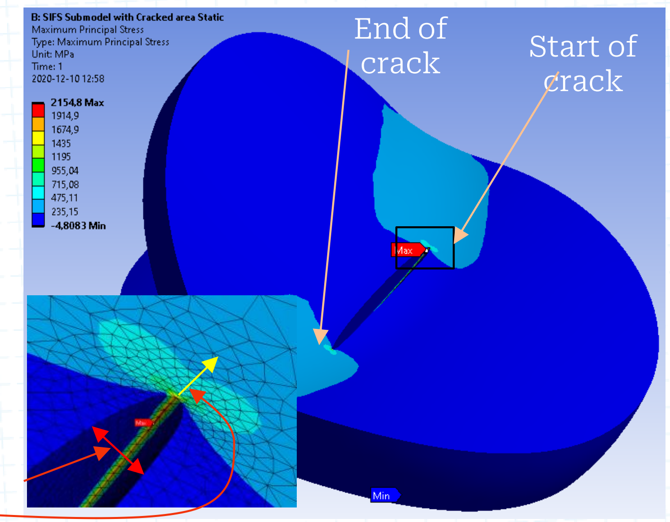


Local model -
Solid or shell elements



Solid Sub
Model
Region with
the crack

Solid Sub Model
Crack growth results



Crack
opens and
propagate

THANK YOU!

contact: jose.fonseca@fsdynamics.de

Phone: +49 151 4315 7230

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