Optimization of an Additively Manufactured Inverter Cooling Plate for an Electric Vehicle

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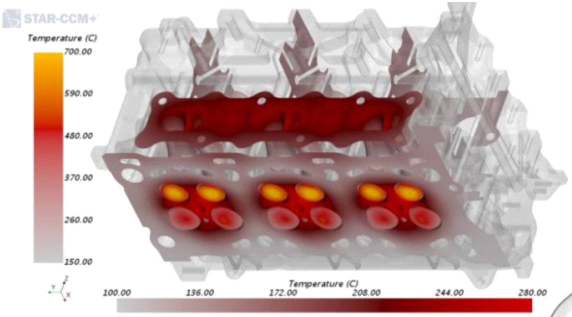
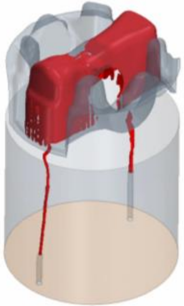
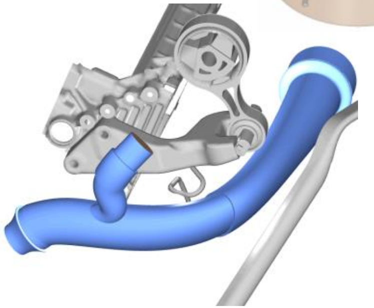
- ✓ 500+ core HPC systems
- ✓ 4 funded PhD positions in 5 years
- ✓ engineering services for some of the most renowned automotive, food&beverage, healthcare, fluid-power companies
- ✓ Partner of FRIENDSHIP SYSTEMS since 2016

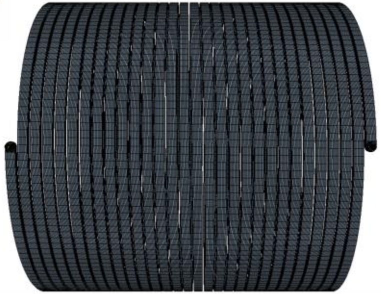


Simulation Portfolio

- Diesel and Gasoline Combustion
- Multiphase Flows
- Heat Transfer
- Fluid Power
- Design Optimization
- Alternative Fuels
- Fuel Cells
- Electrification





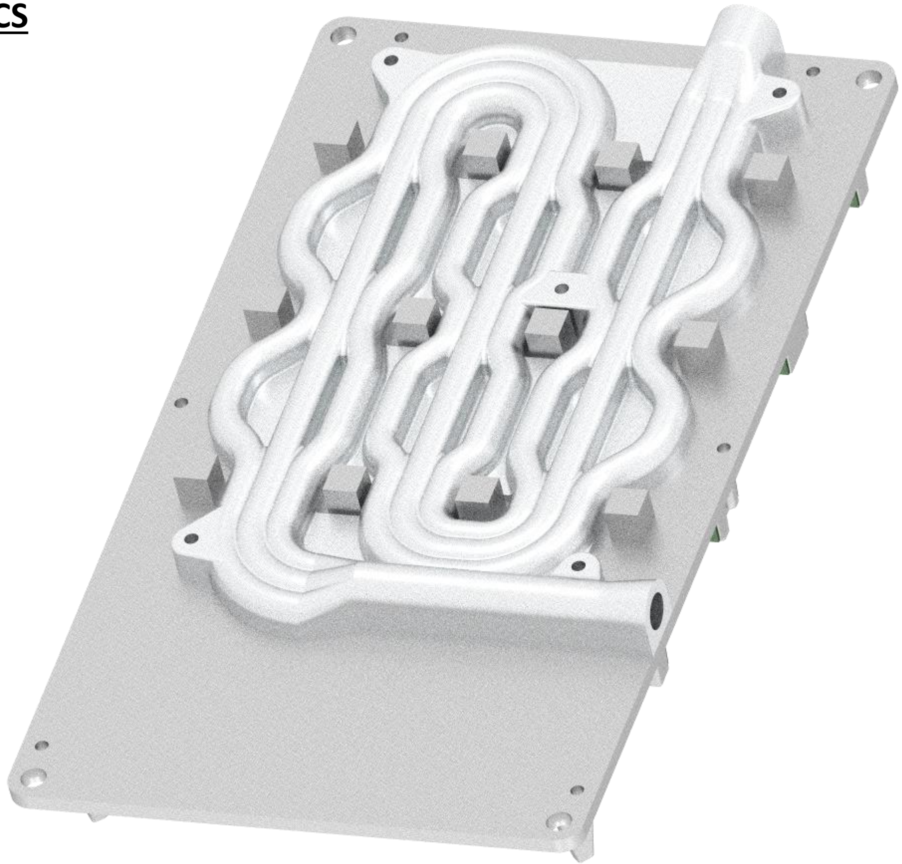


MMR HYBRID F-SAE CAR: THE COOLING OF POWER ELECTRONICS

- MMR Hybrid is the team of University of Modena and Reggio Emilia participating in Formula SAE Hybrid
- The inverter devoted to control electrical power fluxes was originally intended to be cooled by air
- To increase its performance, a cold plate fed with water is purposely devepoled

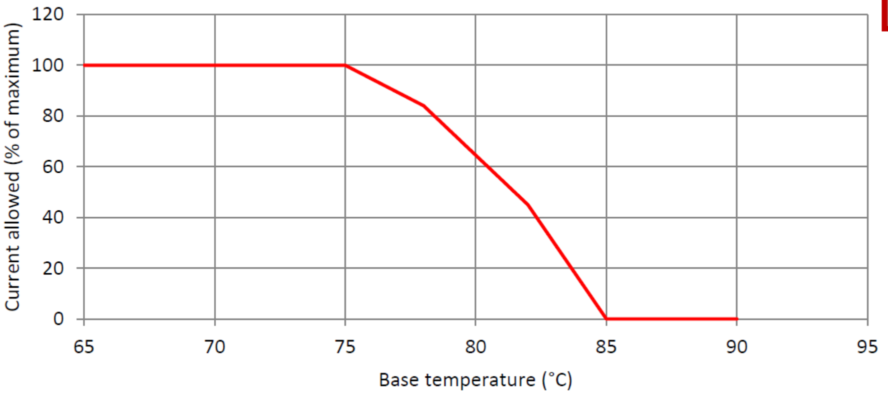
MMR HYBRID F-SAE CAR: THE COOLING OF POWER ELECTRONICS

- The original cold plate was already enhanced through the testing of different layouts
- Thanks to additive manufacturing the design costraints are very limited (mainly related to minimum thickness of the metal and wall inclinations)
- Inlet and outlet locations are fixed due to the layout of the components

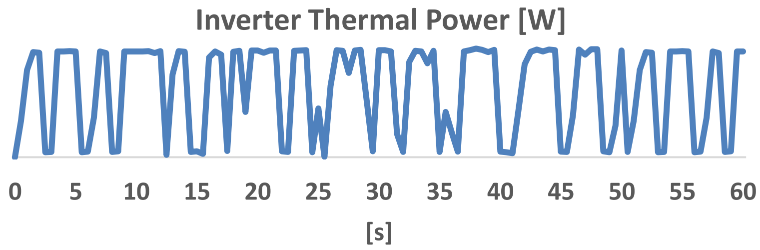


The role of thermal management

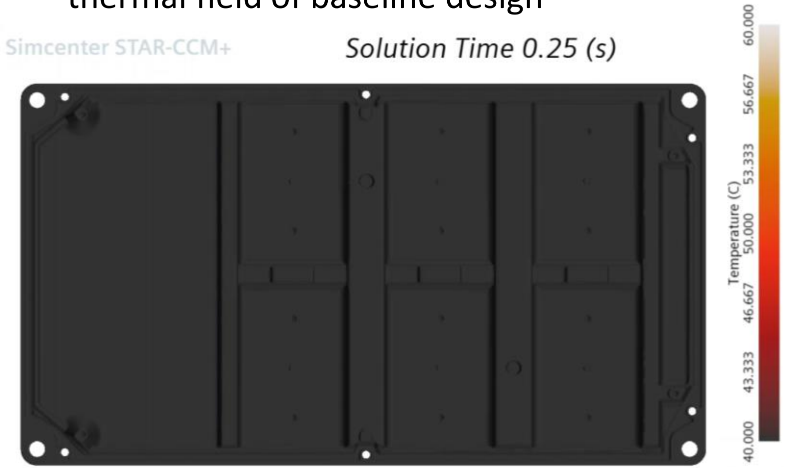
- Power electronics performance depend on the thermal management of the components
- Max junction temperature for transistors: in-between 125 °C and 150 °C
- The base temperature of the inverter must not exceed 75 °C to avoid a huge reduction of the current



① Estimate of the power dissipated by the inverter by means of a Simulink model of the hybrid powertrain



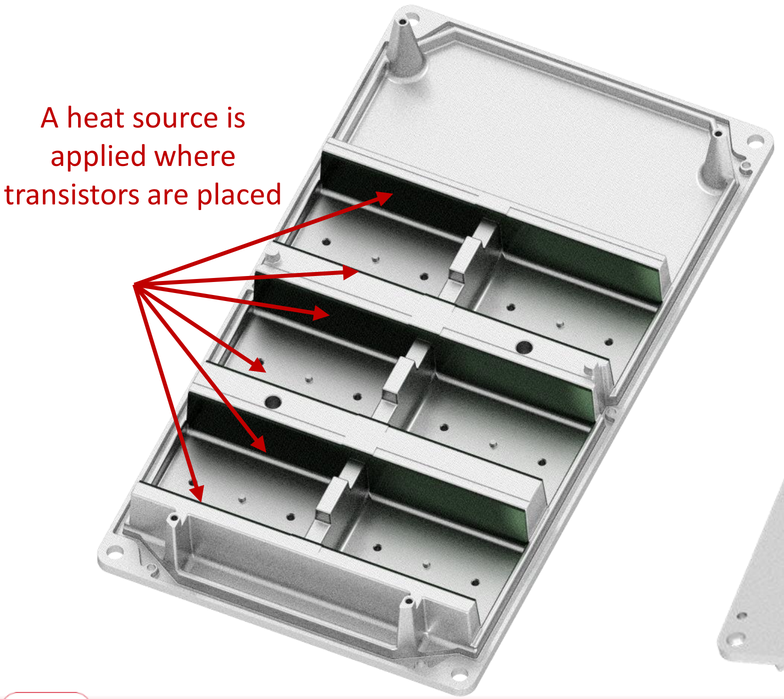
② CFD simulation of 3 consecutive laps to monitor the thermal field of baseline design

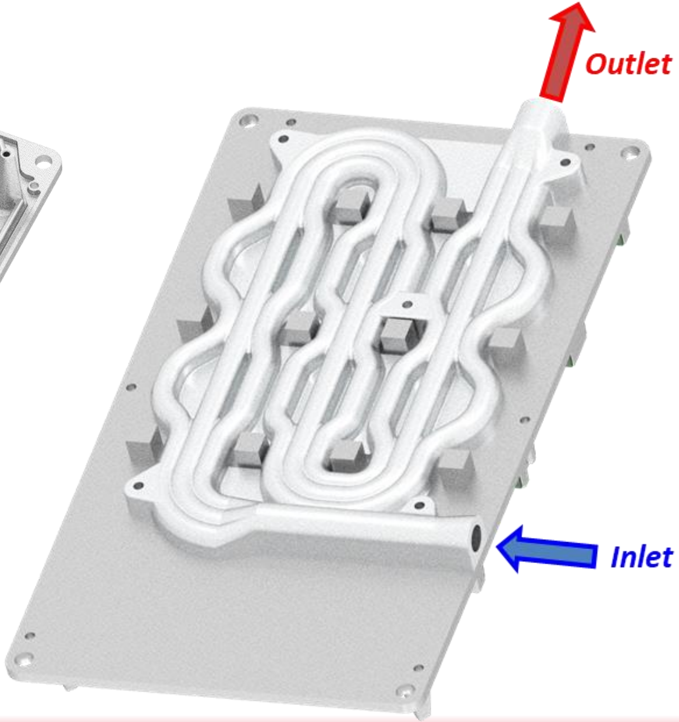


1. From unsteady to steady framework

- A steady state CHT CFD model is generated to speed up investigations → neglection of thermal inertia

It was verified on single cases that the improvements emerge in a steady state framework as well

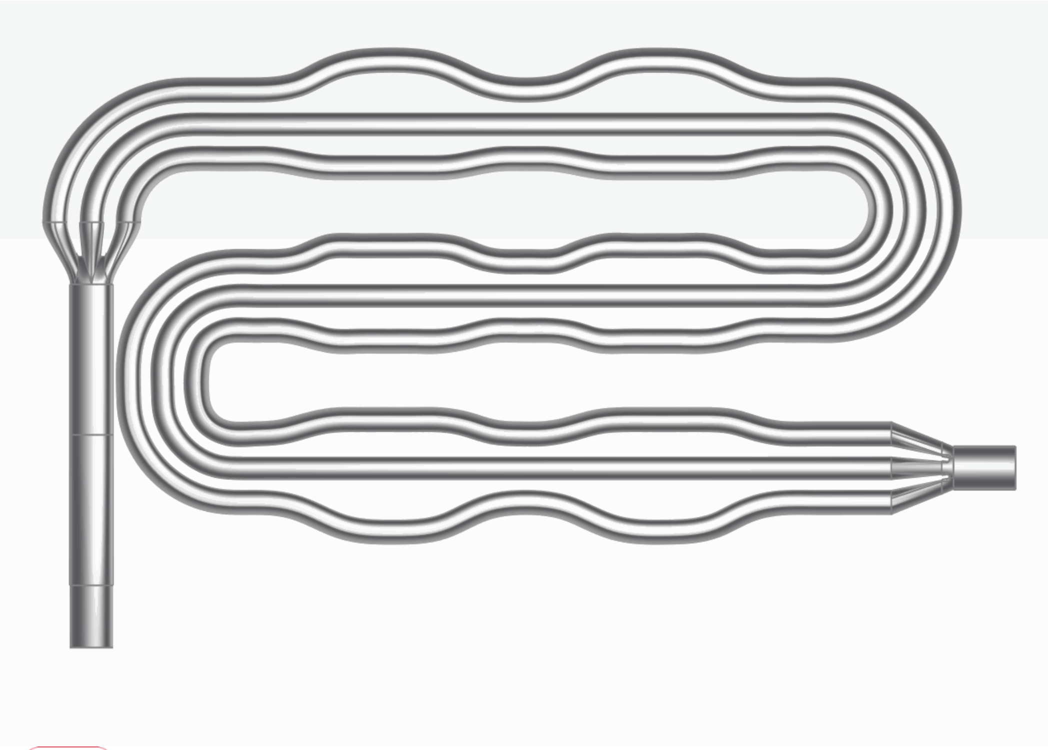


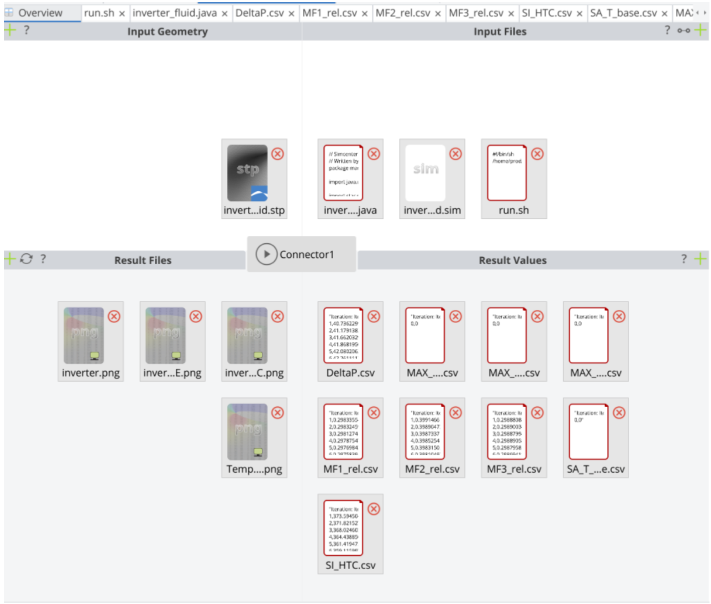


- 3 different materials
- Contact resistances
- Heat can be removed only by the coolant

2. Creation of a parametric model

CAESES® is connected to STAR-CCM+® for the execution of CFD simulations

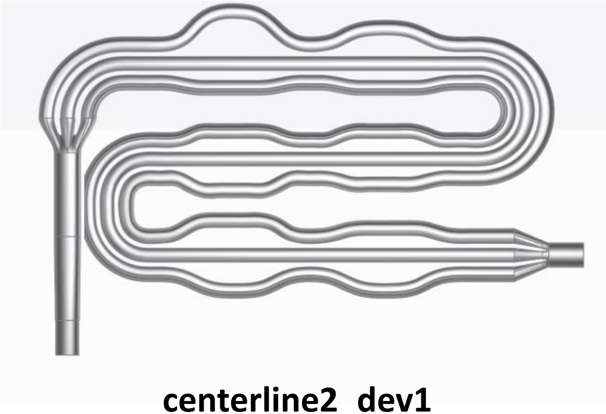




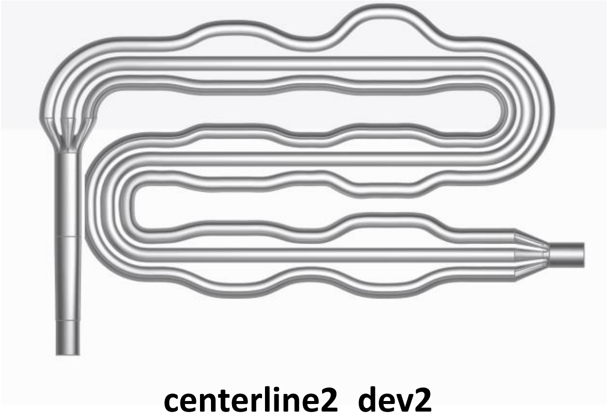
2. Creation of parametric models

Centerline parameters affect the way the cold plate surrounds the bolt seat of the inverter

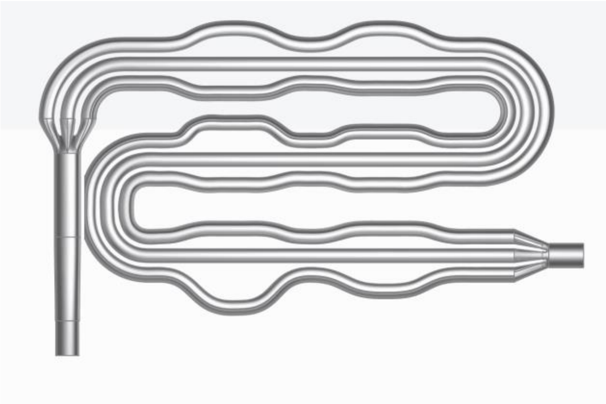
centerline1_dev1



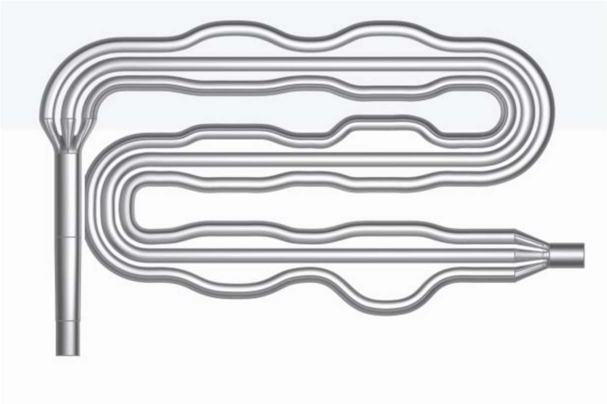
centerline1_dev2



centerline2_dev1

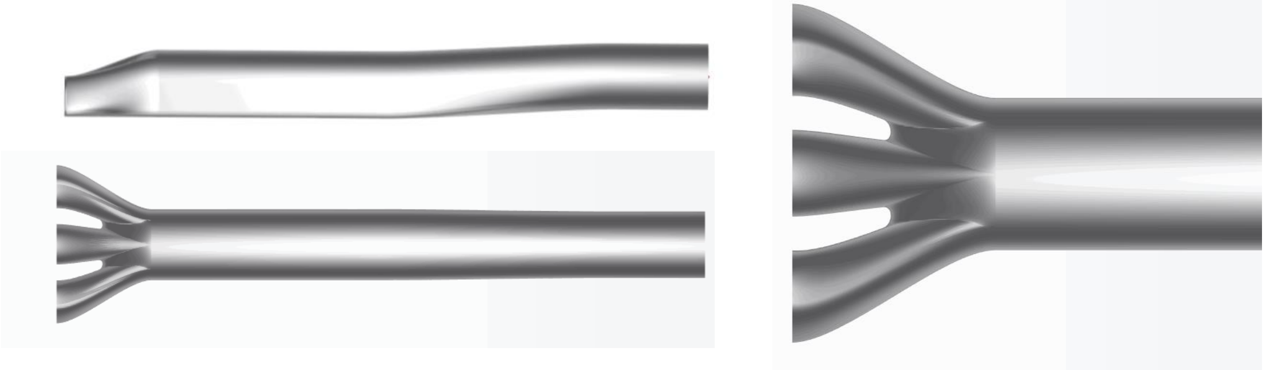


centerline2_dev2

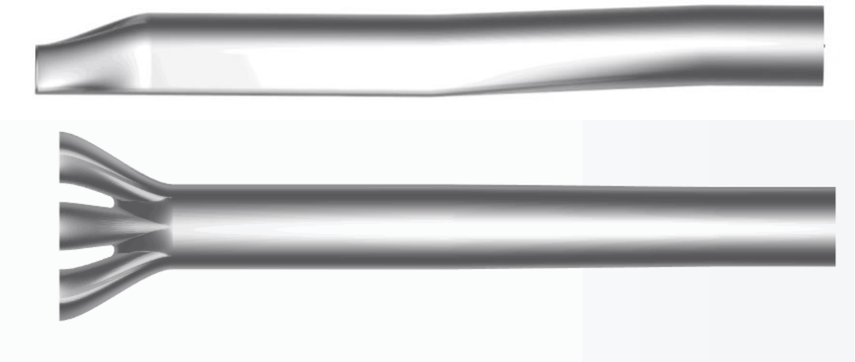


2. Creation of parametric models

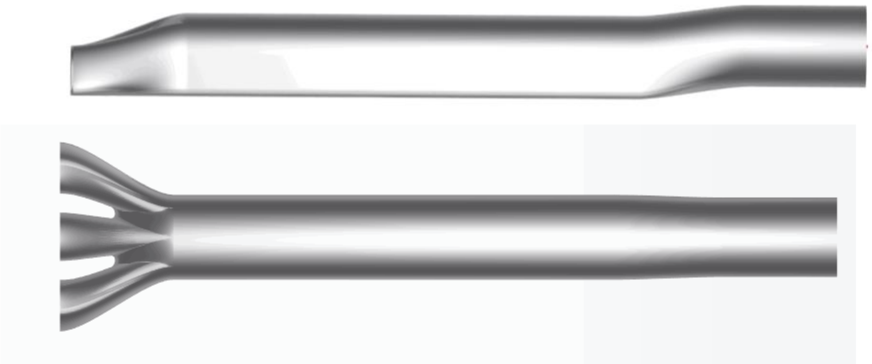
Inlet_AR: affects the transition from inlet to channels



inlet_dev_factor

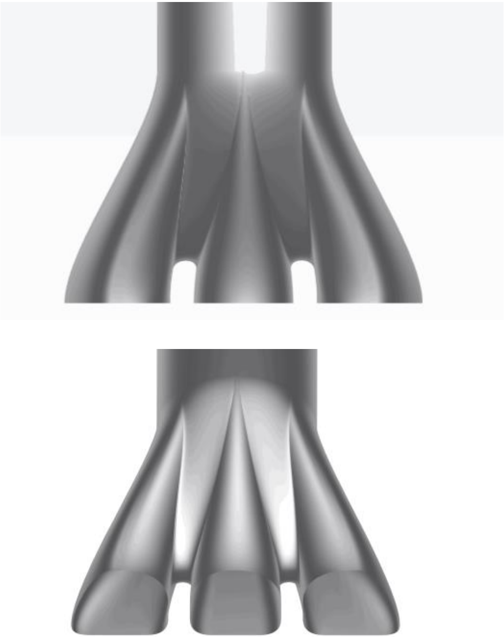


inlet_dev_length

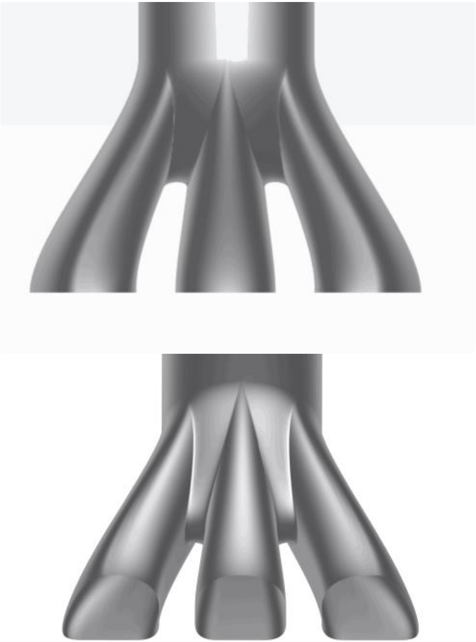


2. Creation of parametric models

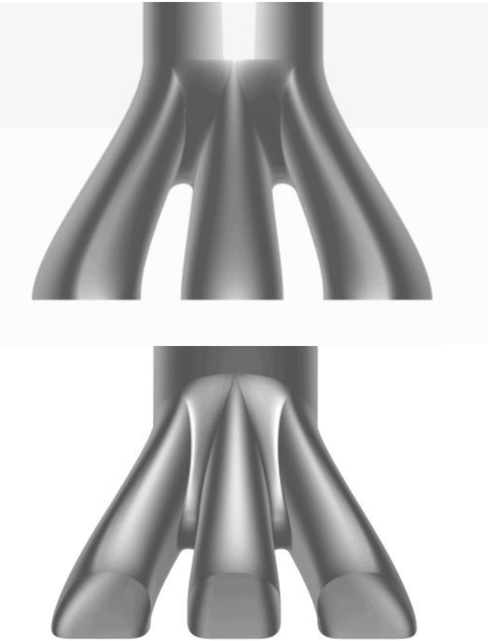
Junction_Gap



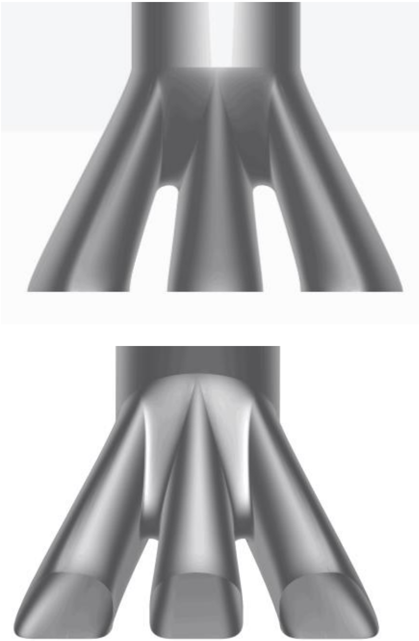
Junction_Tongue



junction_tongue_verLoc

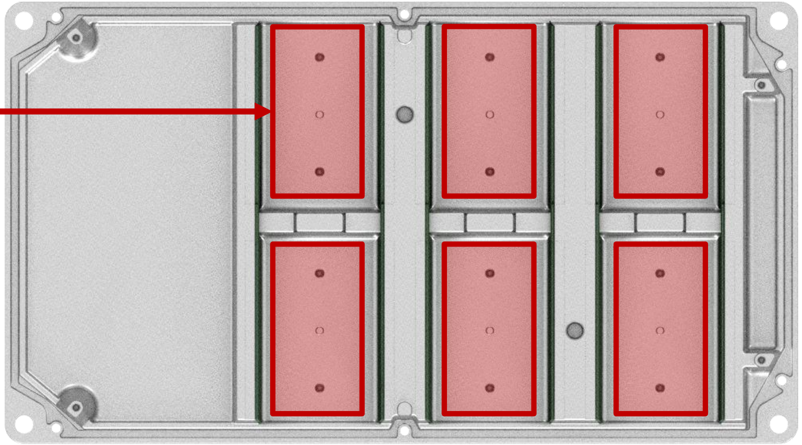


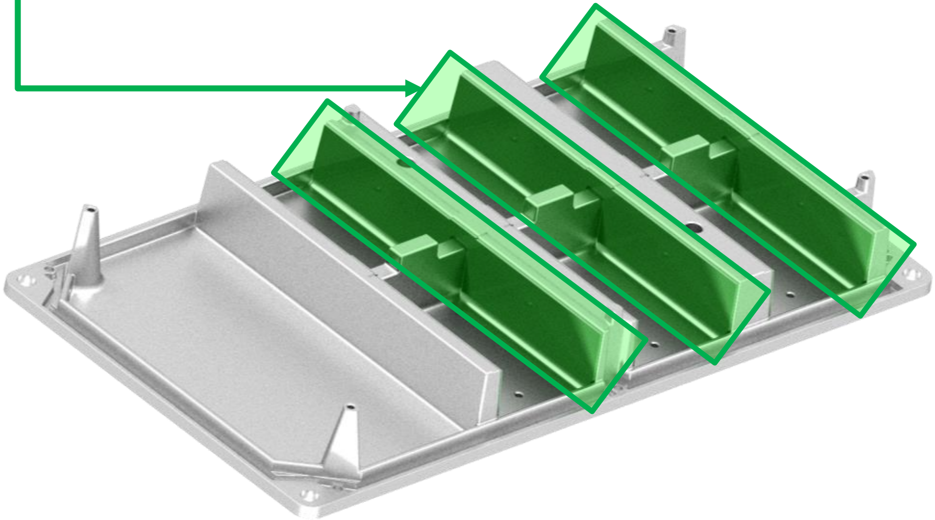
junction_tongue_horSF



3. Monitored quantities

- Pressure Drop across the coldplate
- Mass flow through each pipe
- Surface Average and Max temperature of inverter base
- Max temperature of transistors



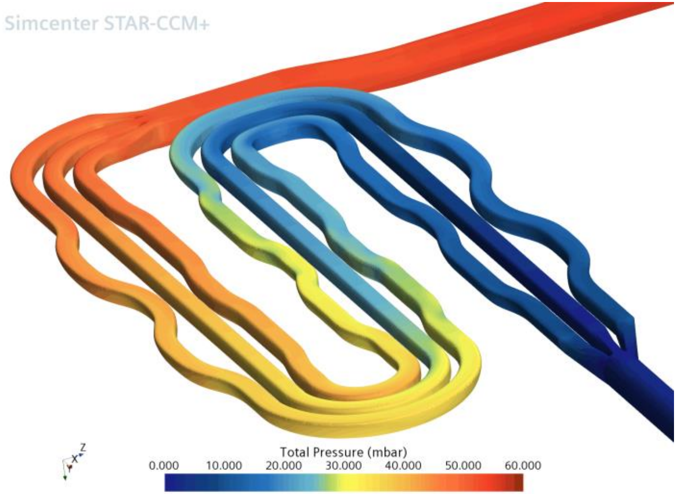


DOE | **OPTIMIZATION**

A «Sobol» algorithm with 100 designs is run to extract Pearson's Correlation Coefficients

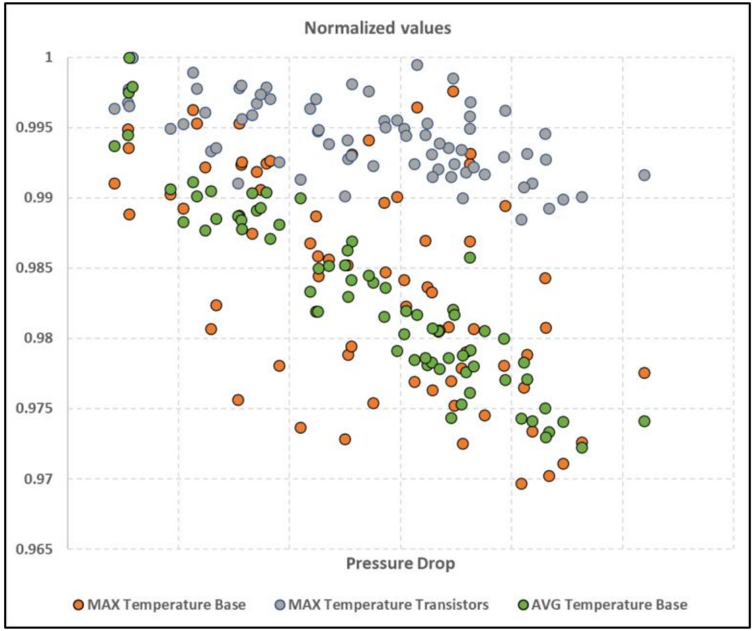
	Pressure Drop	MFR Channel 1	MFR Channel 2	MFR Channel 3	HTC	MAX Temperature Base	MAX Temperature Transistors	AVG Temperature Base
centerline1_dev1	-0.39	-0.28	-0.37	0.58	0.31	-0.05	-0.06	0.39
centerline1_dev2	-0.43	-0.23	-0.41	0.55	0.29	0.07	0.11	0.48
centerline2_dev1	-0.57	0.59	-0.59	-0.23	0.17	0.13	0.20	0.57
centerline2_dev2	-0.49	0.67	-0.49	-0.39	0.08	0.95	0.83	0.48
inlet_AR	0.19	-0.03	0.10	-0.05	-0.02	-0.14	-0.07	-0.18
inlet_devFactor	0.07	0.03	0.07	-0.09	-0.09	0.03	0.04	-0.03
inlet_devLength_par	-0.09	0.07	0.00	-0.08	0.04	0.01	-0.01	0.18
junction_h_SF	0.08	0.01	0.06	-0.06	-0.07	0.04	0.05	0.05
Tongue_SF	0.00	0.08	0.02	-0.10	0.12	-0.01	-0.05	-0.03
Tongue_vLoc_par	0.08	-0.23	0.18	0.12	-0.18	-0.12	-0.09	-0.08
junction_gap	0.20	0.14	0.13	-0.26	-0.08	0.18	0.21	-0.03

The monitored quantities are mainly affected by channel paths more than other parameters



DOE | OPTIMIZATION

	Pressure Drop	MFR Channel 1	MFR Channel 2	MFR Channel 3	HTC	MAX Temperature Base	MAX Temperature Transistors	AVG Temperature Base
Pressure Drop	1.00	-0.44	0.98	-0.22	-0.40	-0.58	-0.58	-0.94
MFR Channel 1	-0.44	1.00	-0.48	-0.77	-0.04	0.69	0.66	0.41
MFR Channel 2	0.98	-0.48	1.00	-0.20	-0.38	-0.59	-0.60	-0.92
MFR Channel 3	-0.22	-0.77	-0.20	1.00	0.33	-0.34	-0.31	0.21
HTC	-0.40	-0.04	-0.38	0.33	1.00	0.04	-0.03	0.39
MAX Temperature Base	-0.58	0.69	-0.59	-0.34	0.04	1.00	0.96	0.59
MAX Temperature Transistors	-0.58	0.66	-0.60	-0.31	-0.03	0.96	1.00	0.59
AVG Temperature Base	-0.94	0.41	-0.92	0.21	0.39	0.59	0.59	1.00



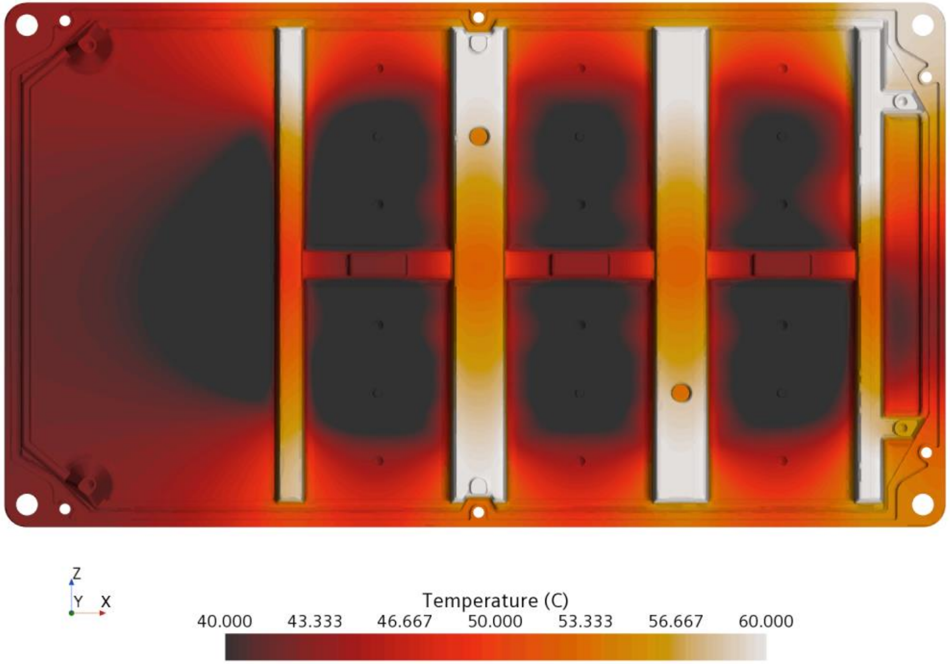
Main outcomes:

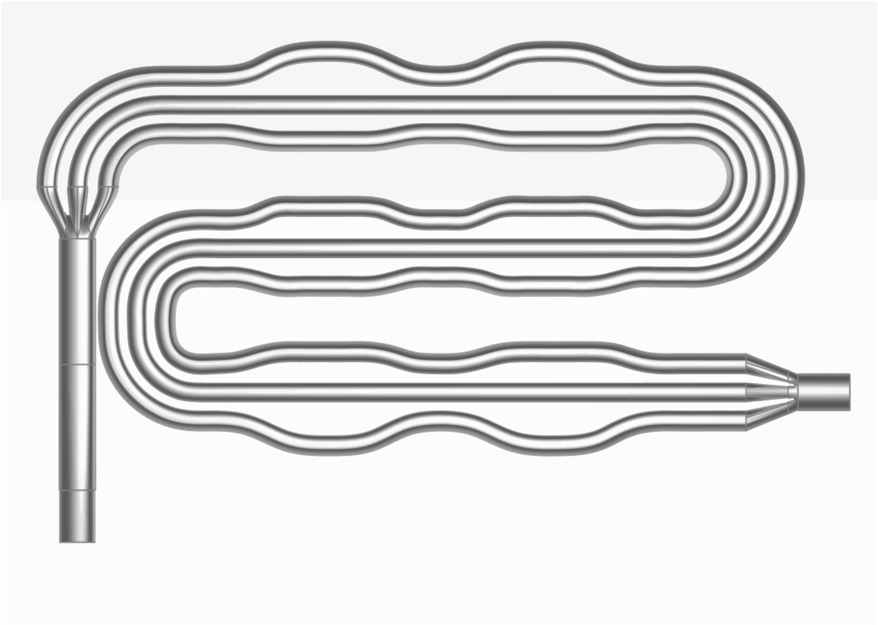
- Pressure drop ↑ Temperatures ↓
- Pressure drop ↑ MFR in channel 2 ↑
- All the temperatures all very well correlated → just one can be picked to be minimized

DOE

OPTIMIZATION

Simcenter STAR-CCM+



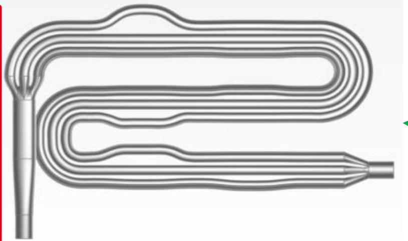


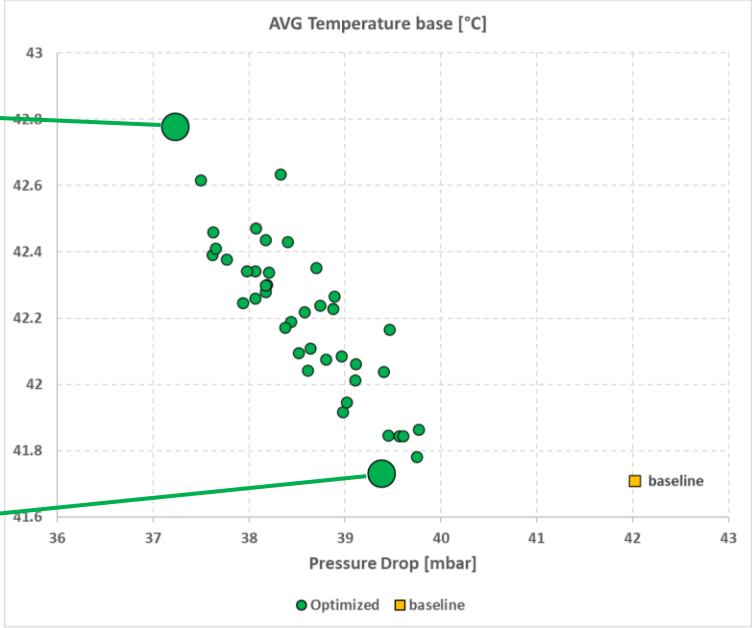
DOE | **OPTIMIZATION**

Response surface optimization

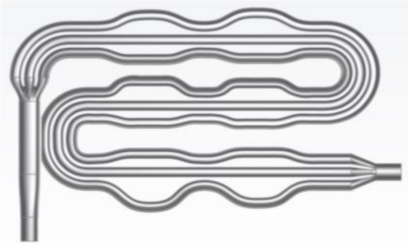
- Two objectives: minimization of pressure drop and AVG Temperature base

Pressure drop reduction by more than **10%** in the most permeable configuration. Hence, in the actual operations, the flow rate through the cold plate will increase with a further reduction of temperatures.





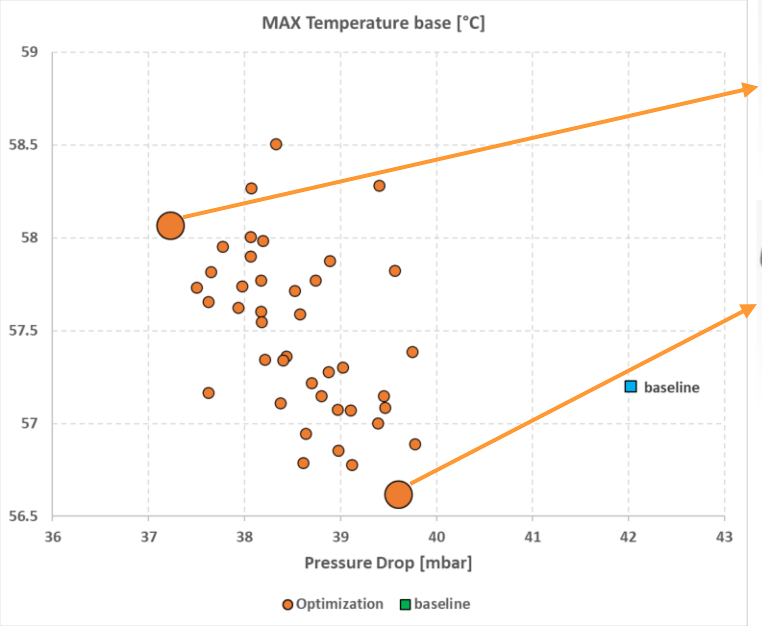
The design with the minimum AVG temperature has the same temperature of baseline design with a reduction of pressure drop by more than 5%. Increased MFR is expected

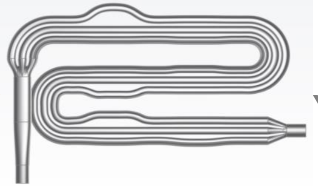


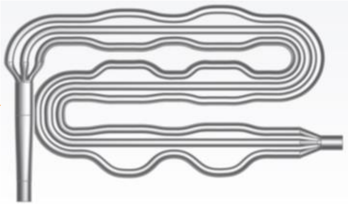
DOE | **OPTIMIZATION**

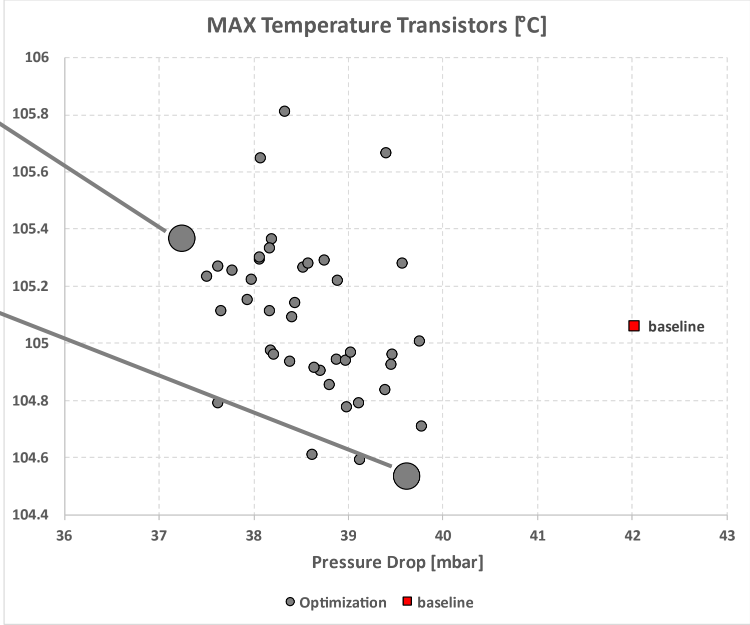
Response surface optimization

- The same rationale is valid looking at the best designs for MAX Temperature of base and transistors.





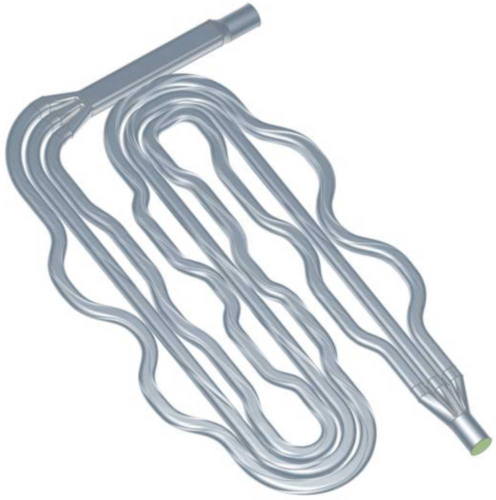




- *Was the optimization process successful?*
  - Yes, it was! The pressure drop reduction is the main outcome of the activity, which in turn leads to an increase of coolant flow rate and to a further temperature reduction

- *Why the temperature reduction was pretty limited?*
  - HTC x Area variation is limited, hence the heat removal capability of the coolant is unaltered

- *Are the shown designs feasible?*
  - Yes, they are! The cold plate will be engineered and pinted to be tested on the Formula SAE car



- *Are there any other options?*
  - Yes, for sure! These results are of course influenced by the rationale of the model generation. Other kind of paths, pipe shapes, etc. can be tested: e.g., we tried to introduce parametric grooves on the pipe surface, but the increased pressure drop did not justify the minimal temperature decrease.

Thank you for your attention!

FRIENDSHIP SYSTEMS

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