CFD Heat Exchanger Simulation with porous media as surrogate material

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Mentor Graphics

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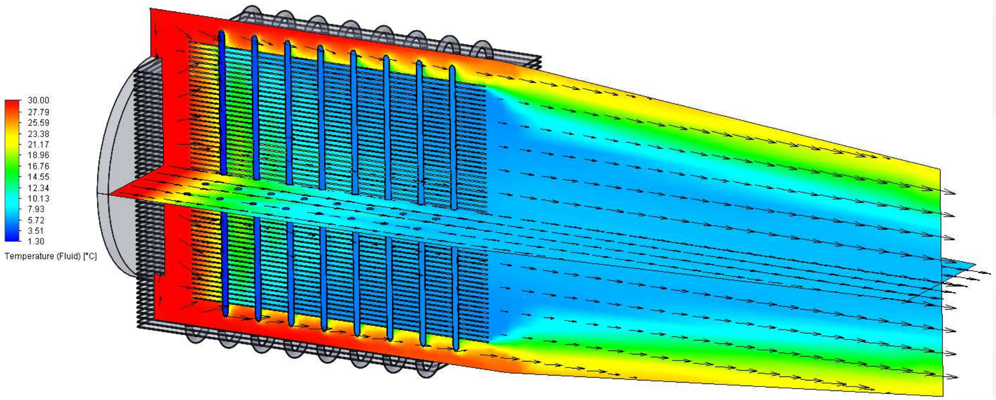
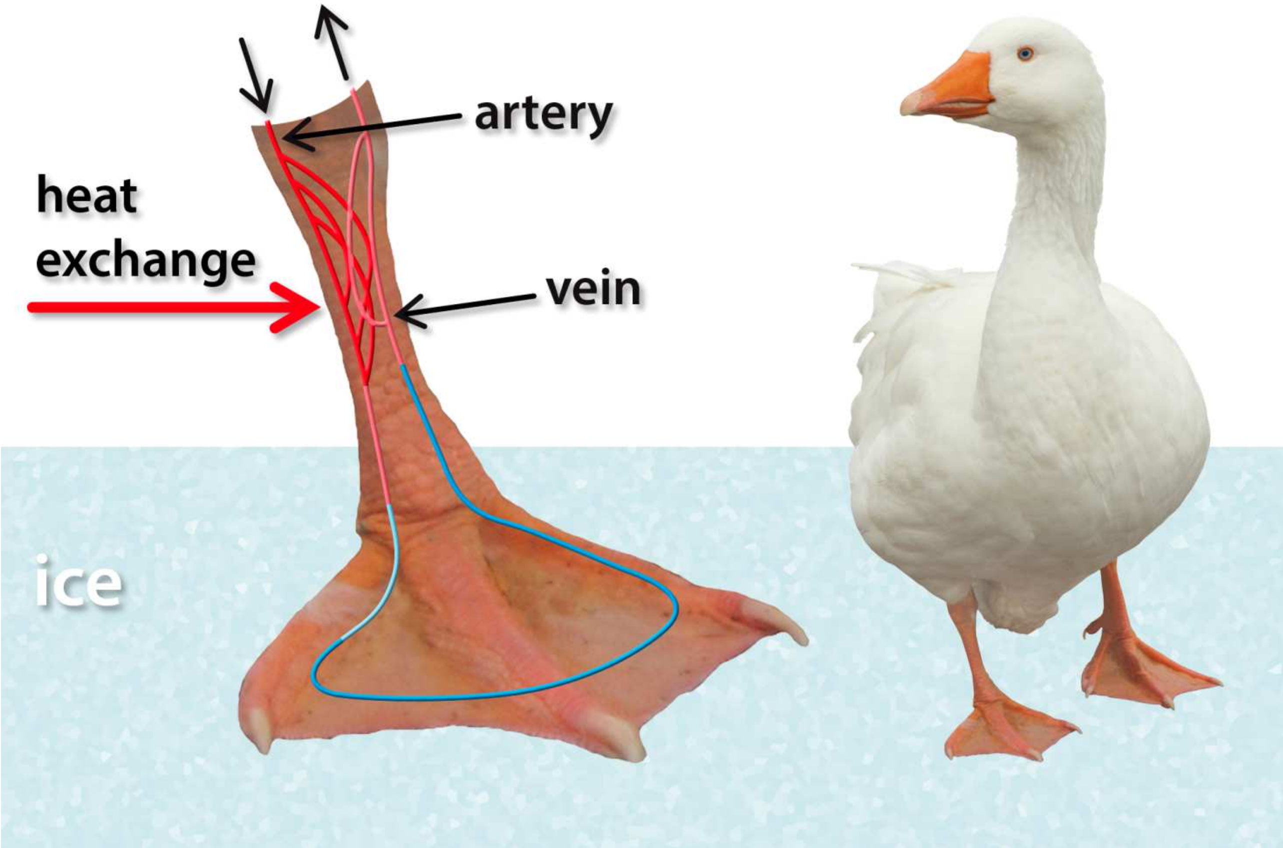
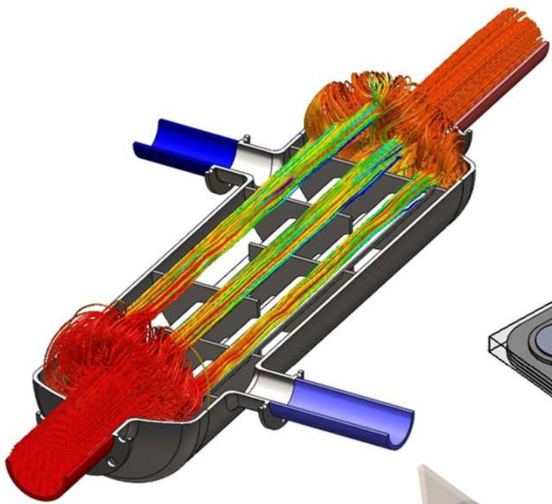
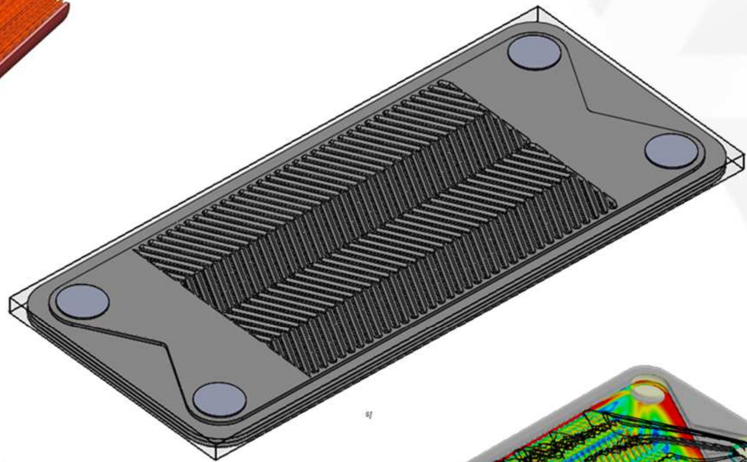
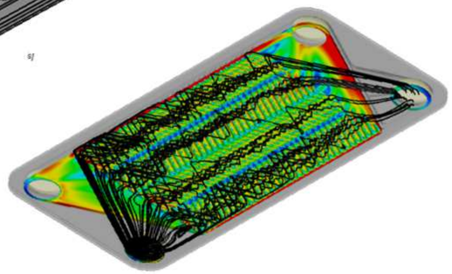
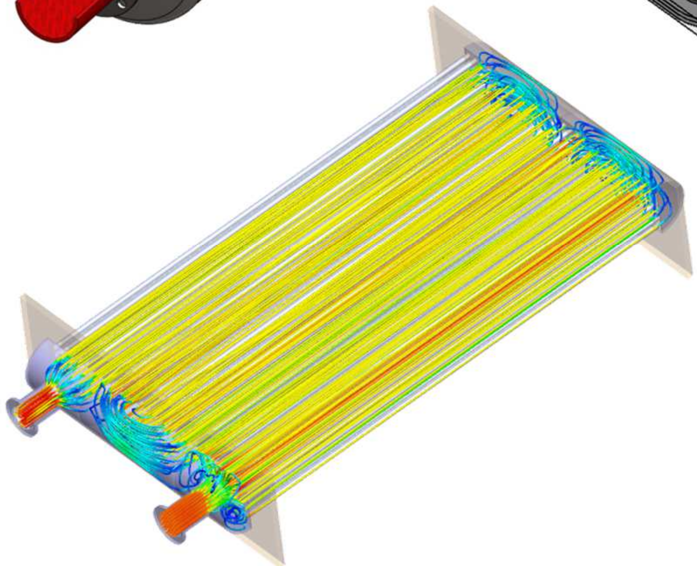
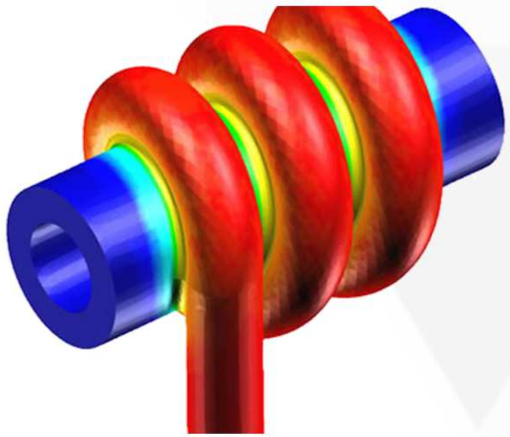


Introduction:
An Example from Nature



Introduction:
Types of Heat Exchanger

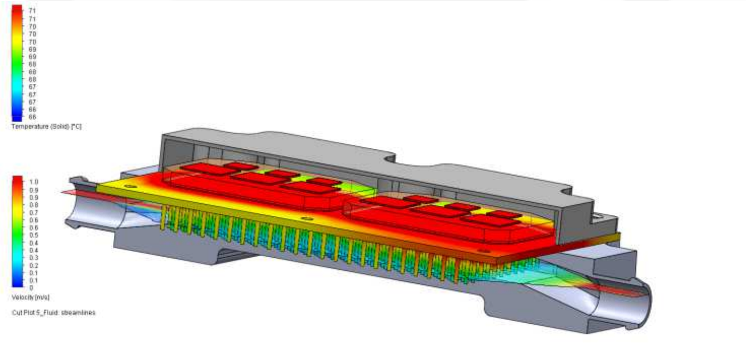



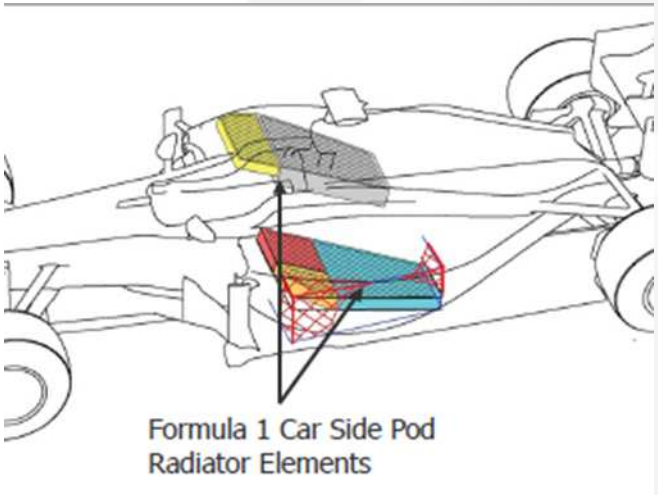




Introduction

- Key Industry sectors
  - – Automotive
  - – Aerospace
  - – Process Industries
  - – Electronics
  - – Power Electronics

The 2014 F1 car - keeping it cool - The Racer's Edge 41 Part 5
https://www.youtube.com/watch?v=gmWp1jPhbu4





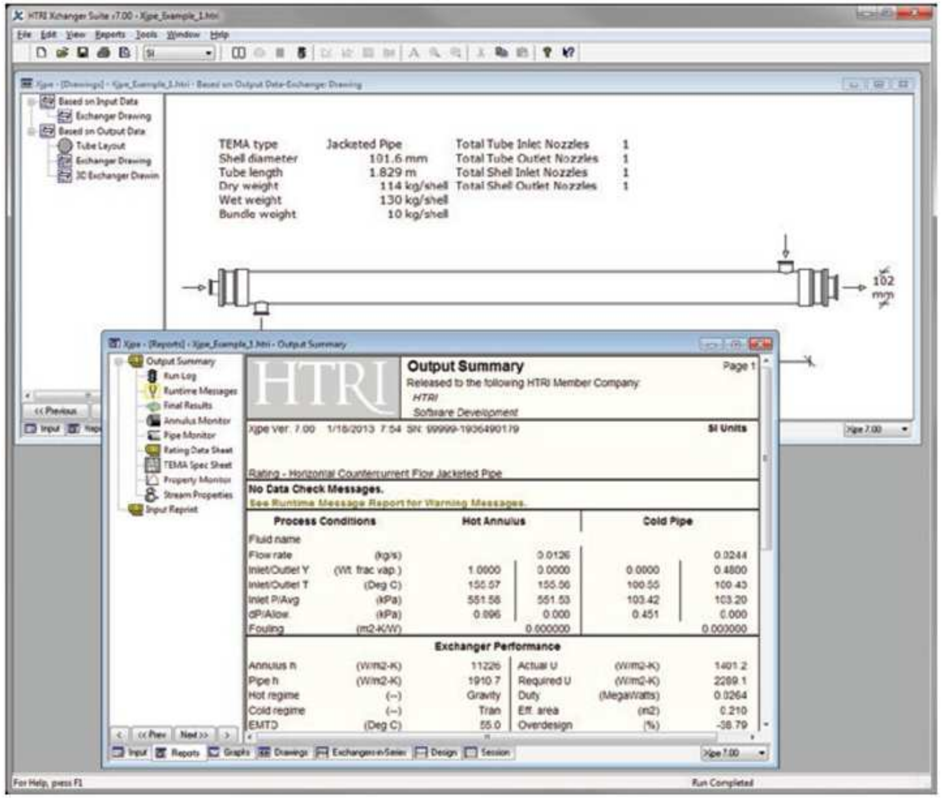
Introduction

- Reliable dimensioning programs are available, e.g.
  - HTRI (www.htri.net/)
  - Lauterbach Verfahrenstechnik (www.lv-soft.de/)

- Good for standard designs, especially in the process industries.

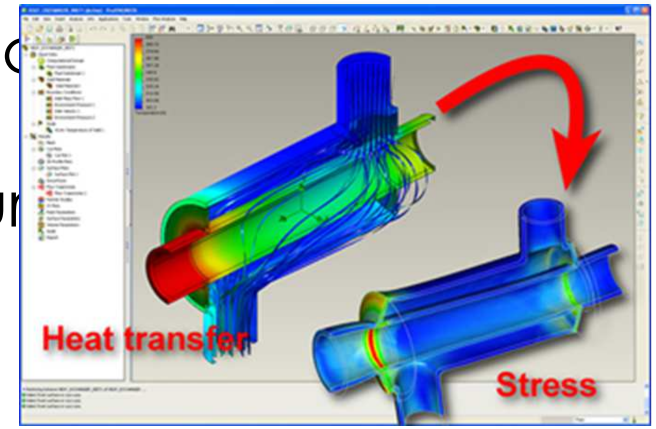
- Allows alternatives to be evaluated

- Designs put out to competitive tender.



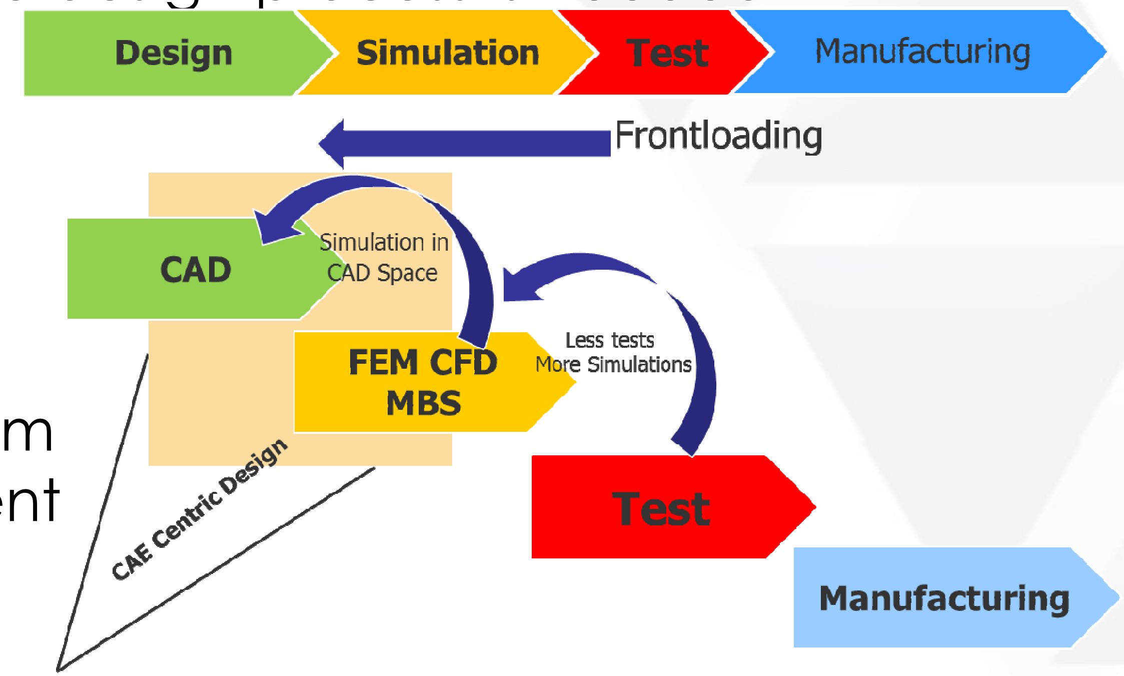
CFD For Heat Exchangers

- Analysis of flow distribution problems
- Detailed analysis of specific areas (e.g. flow distributors, plenum chamber)
- Evaluation of operating points that differ greatly from the designed for conditions
- Transient considerations
- Calculations with boundary conditions that lie (far) beyond range of the empirical correlations
- Special designs for which no empiric dimensioning programs exist
- Evaluating pressure and temperatur distributions for stress analysis (FEA)



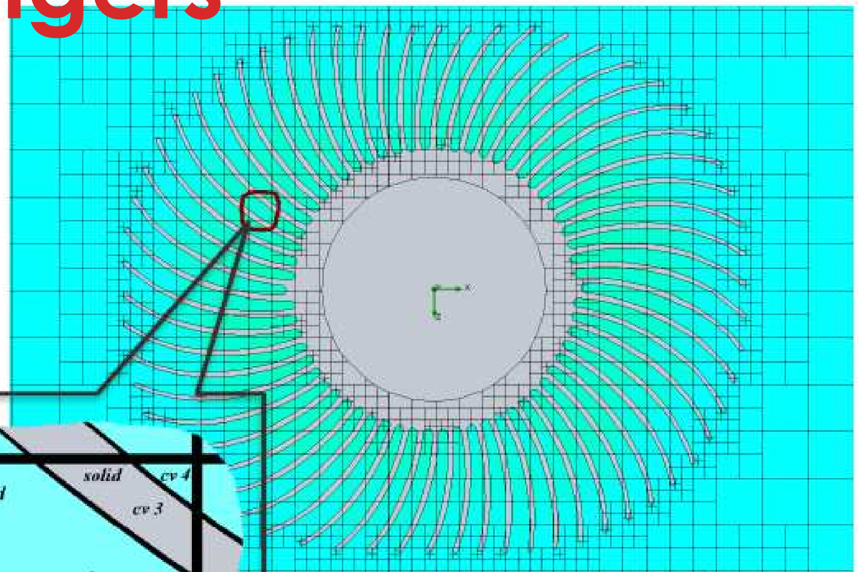
CFD For Heat Exchangers

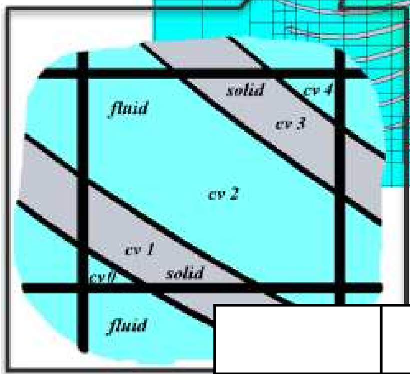
- Near infinite choice of design detail; presumably only one optimum for a given application & duty, hence:
- Need for optimization – where performance vs. volume or weight is critical, .e.g. motorsport
- Early assessment in the design process is needed
- Frontloading of CFD within the design process:
- CFD is performed within the CAD environment, upstream of the CAE department

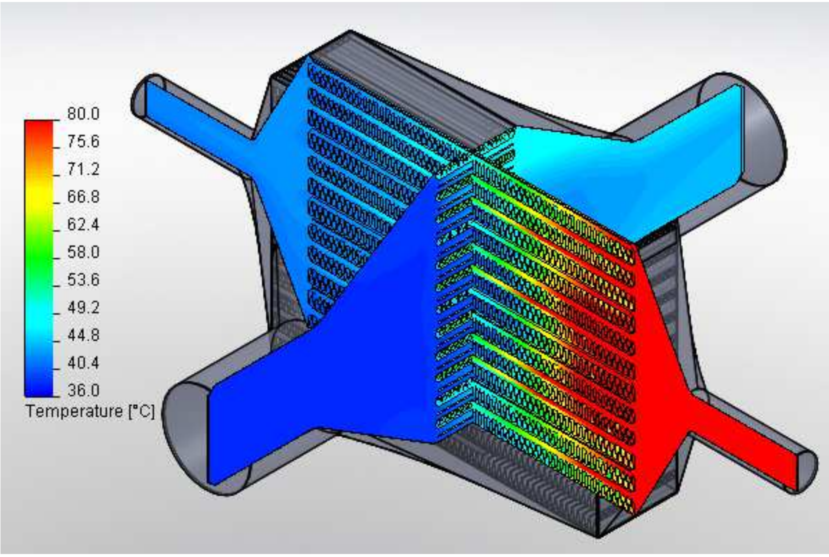


CFD For Heat Exchangers

- **Option 1:**
  - Model geometry directly
  - Possible with SmartCells & "Engineering" models:





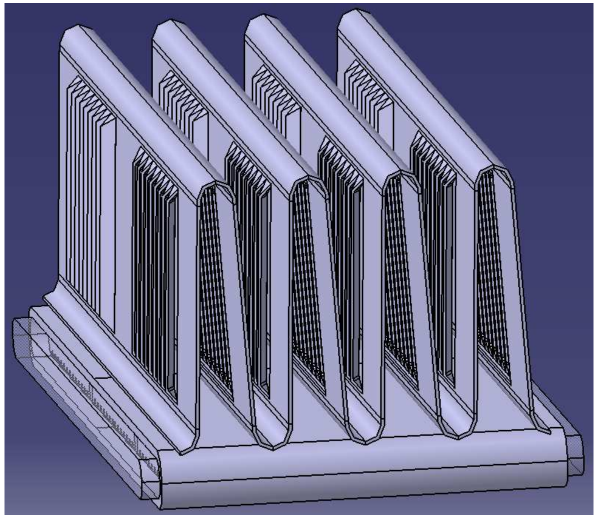


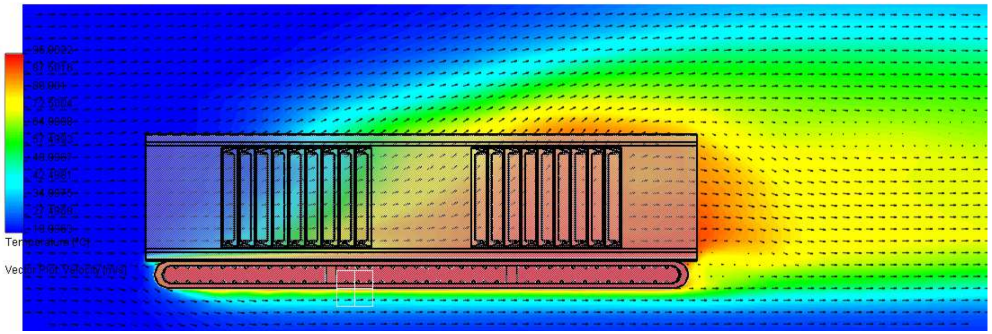
	Level 3*	Level 5**	Test data
T^{cold}_{in}	38.0	38.0	38.0
T^{cold}_{out}	48.3	48.3	45.4
T^{hot}_{in},	159.7	159.7	159.7
T^{hot}_{out}	41.6	43.9	42.2

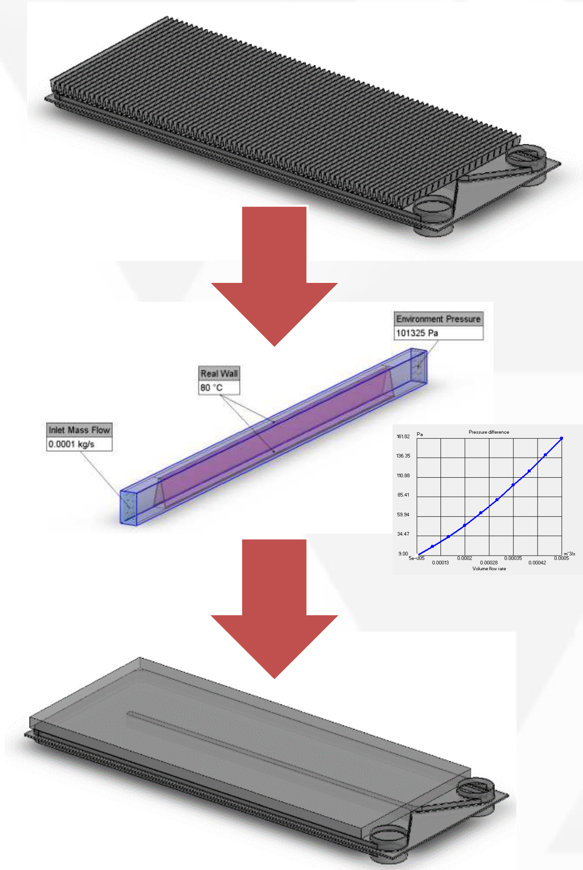
* #Cells = 159,836; ** #Cells = 1,000,272

CFD For Heat Exchangers

- **Option 2:**
  - Use a porosity approach for the finned region:

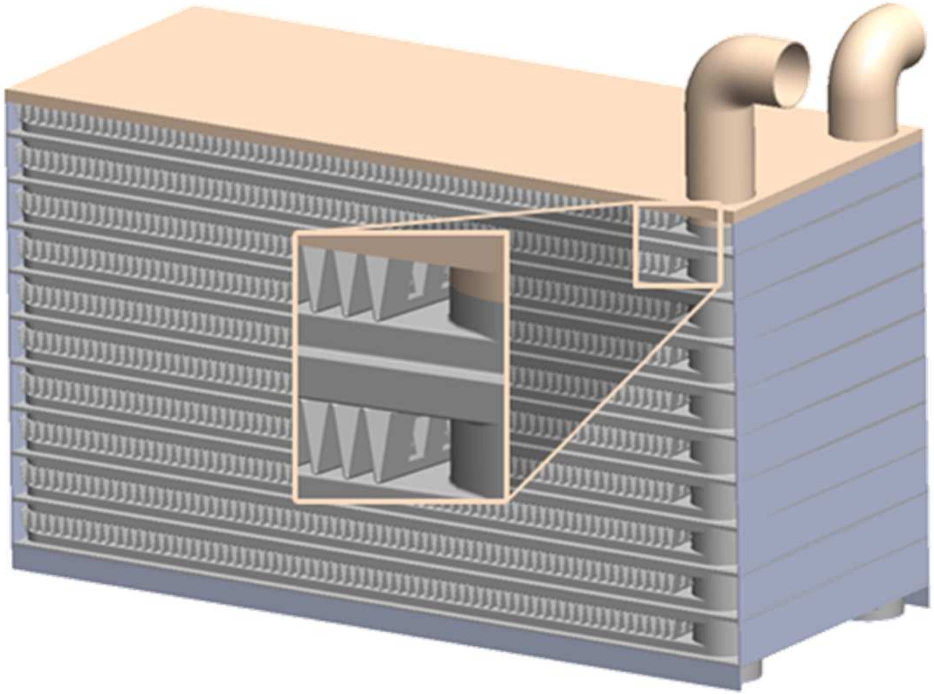


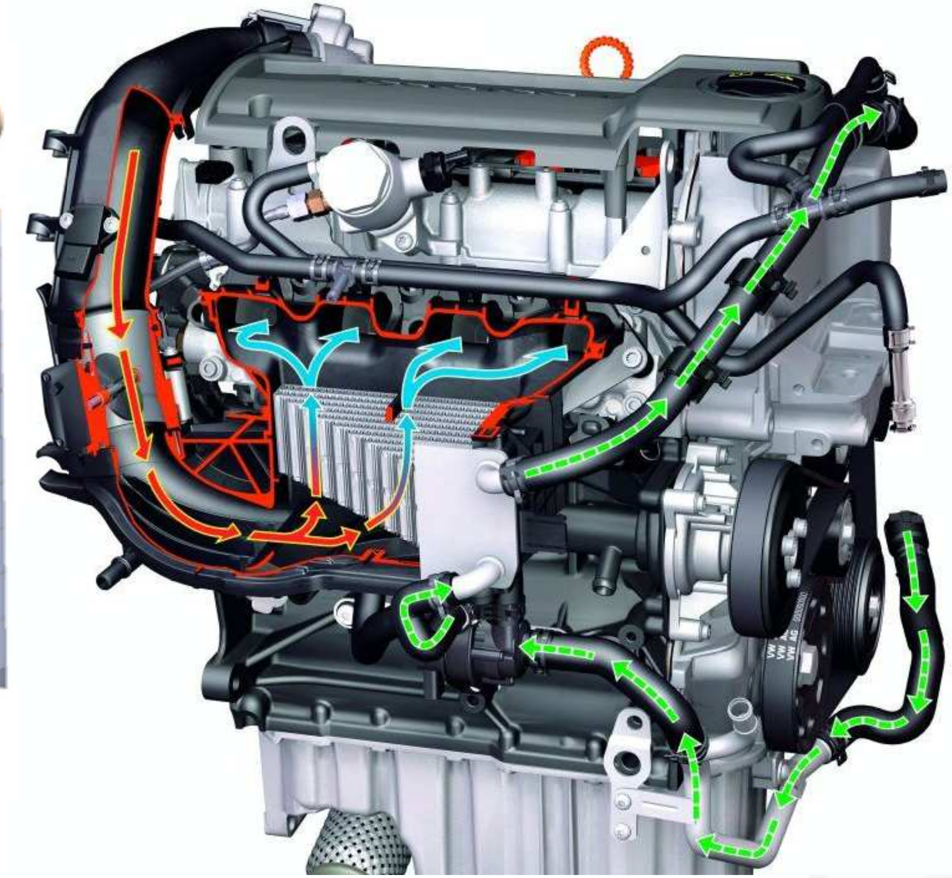




Example: Context

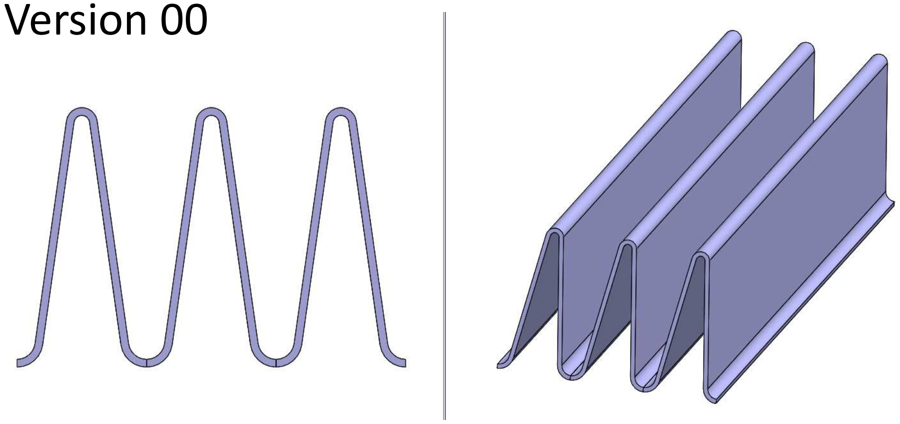
- Study focuses on Option 2 for this example:



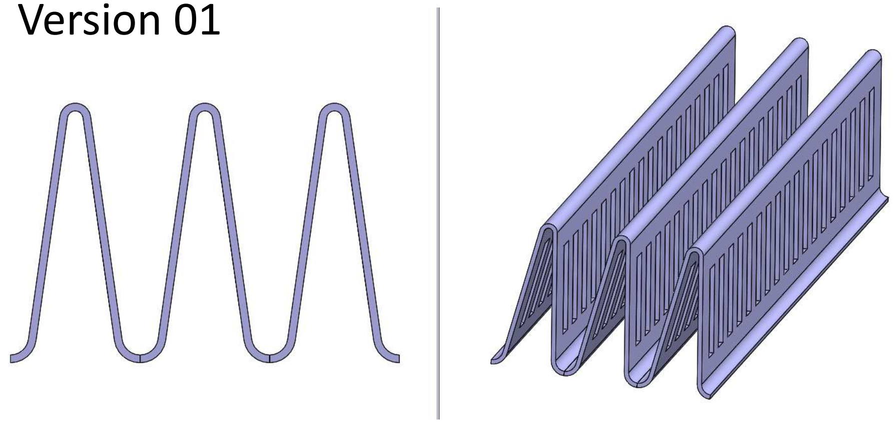


Example: Fin Geometries

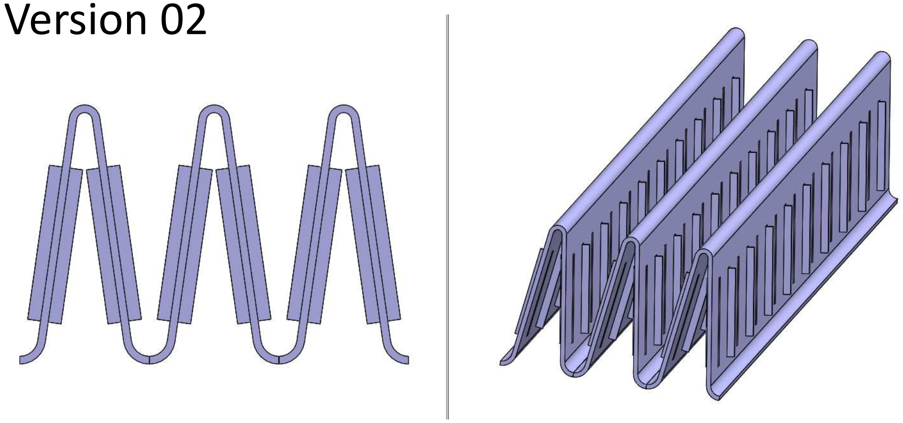
Version 00



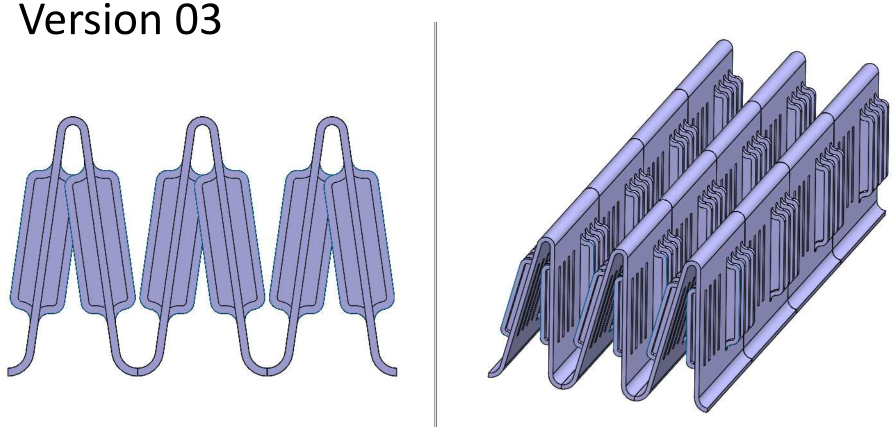
Version 01



Version 02

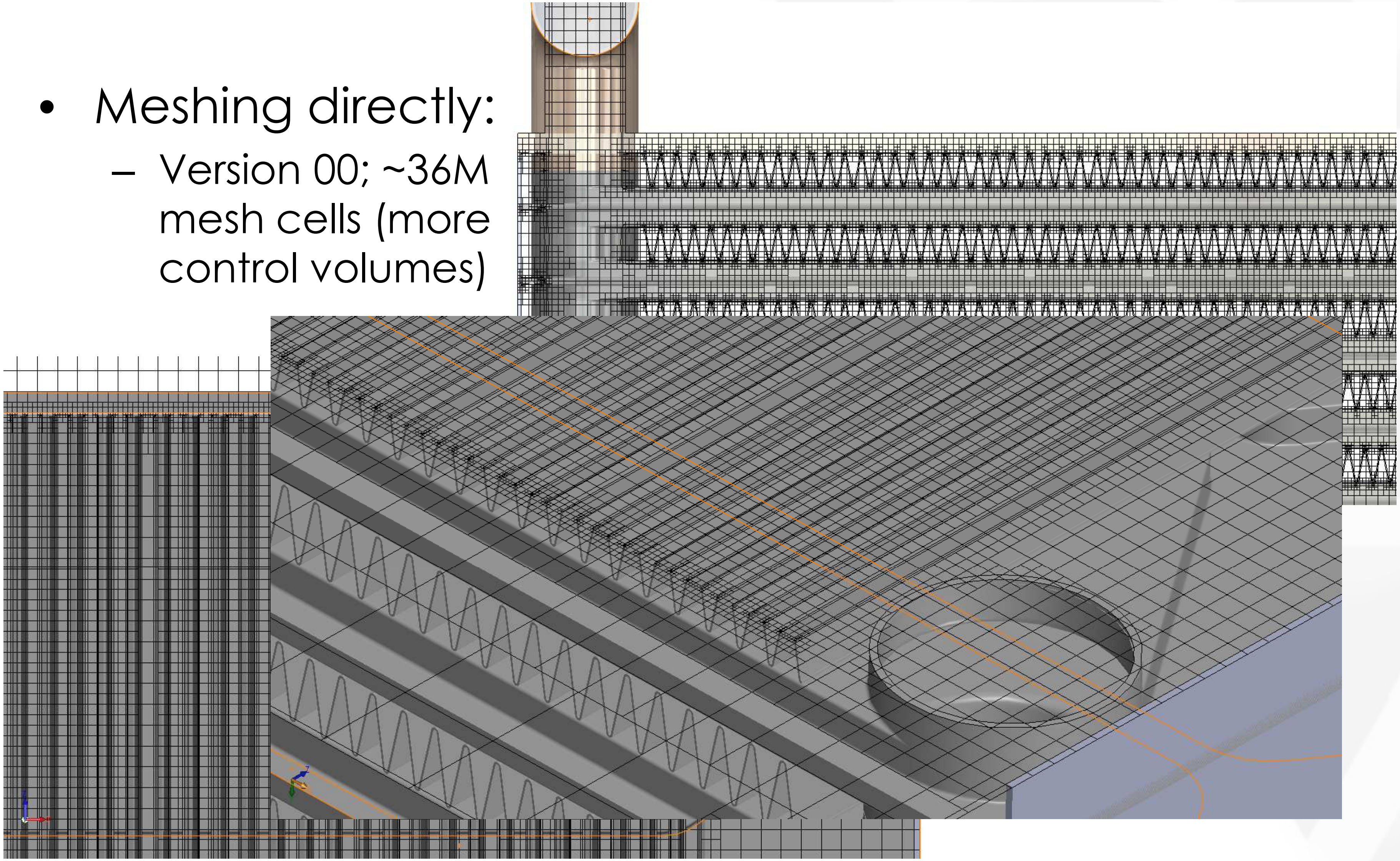


Version 03



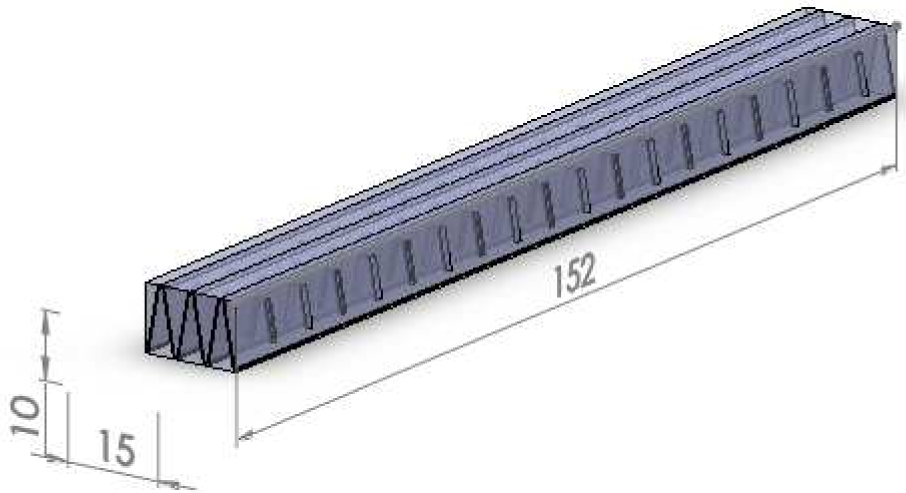
Example: Meshing

- Meshing directly:
  - Version 00; ~36M mesh cells (more control volumes)

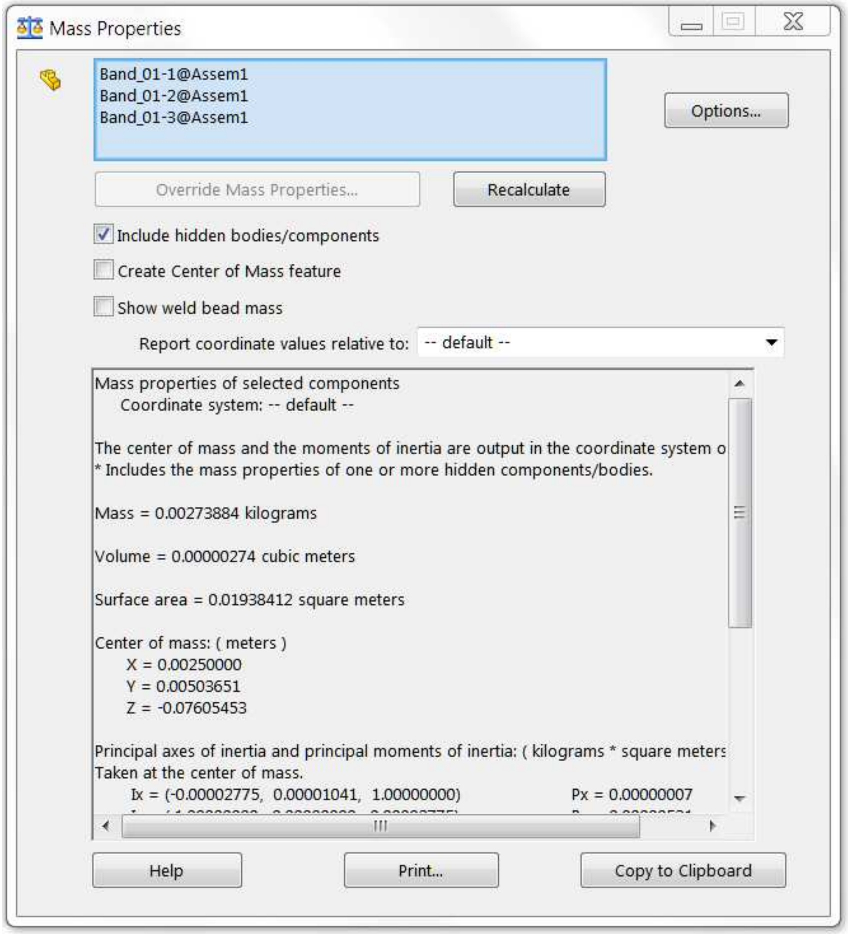


Example: Porous Media

- Porosity, dimensionless: $$\epsilon = \frac{V_{por}}{V_{total}}$$

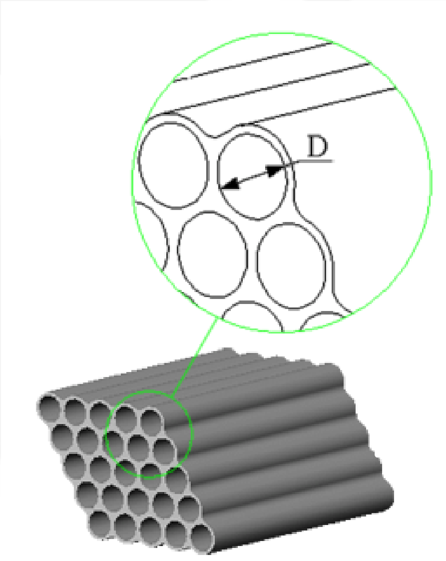


- CAD system provides:
  - Mass
  - Volume
  - Surface Area, etc.



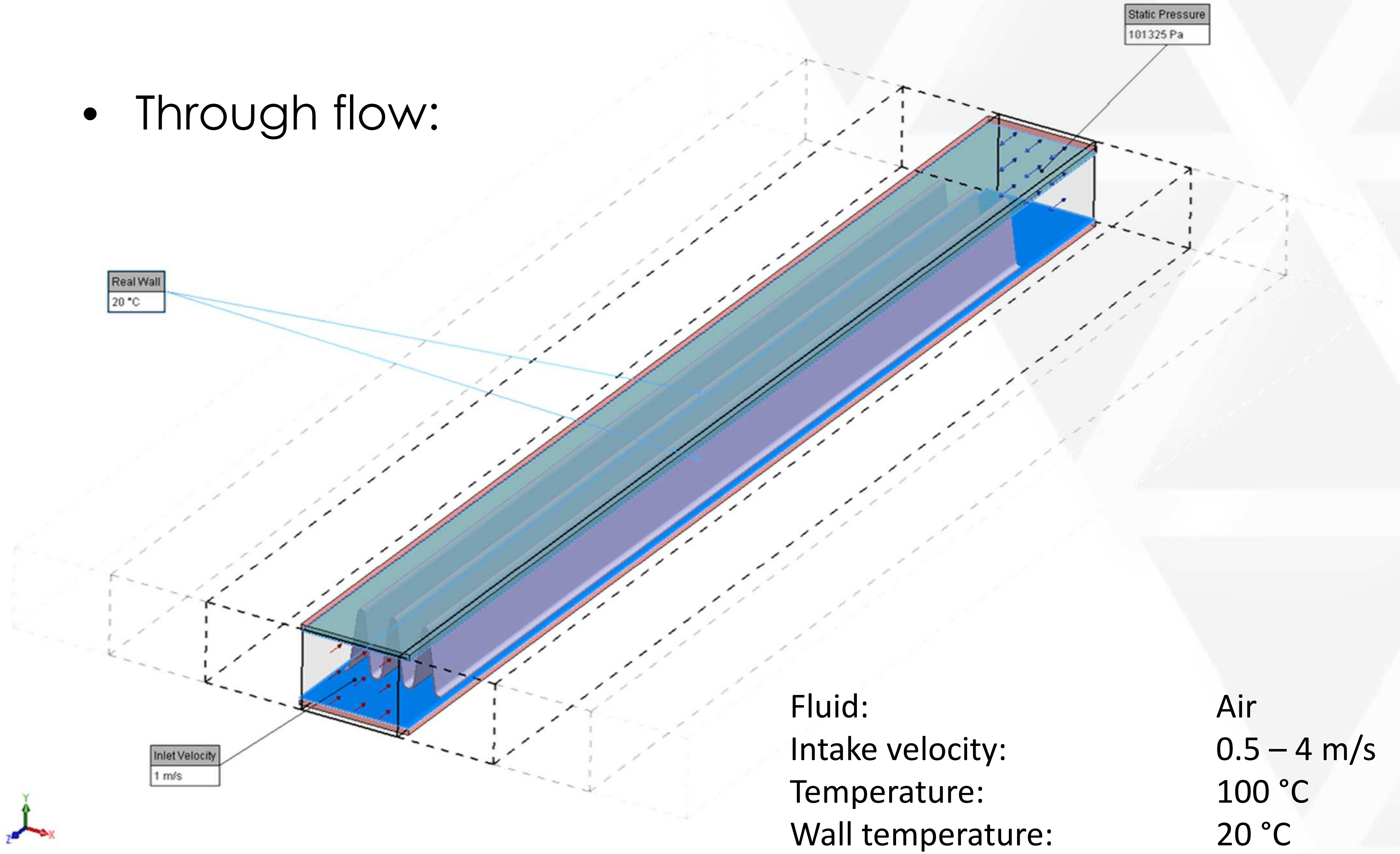
Example: Porous Media

- Isotropic:
  - permeability is independent of direction within the medium
- Unidirectional:
  - The medium is permeable in one direction only:
- **Orthotropic:**
  - Permeability different in each direction
- Anisotropic:
  - Permeability varies throughout medium



Example: Characterization

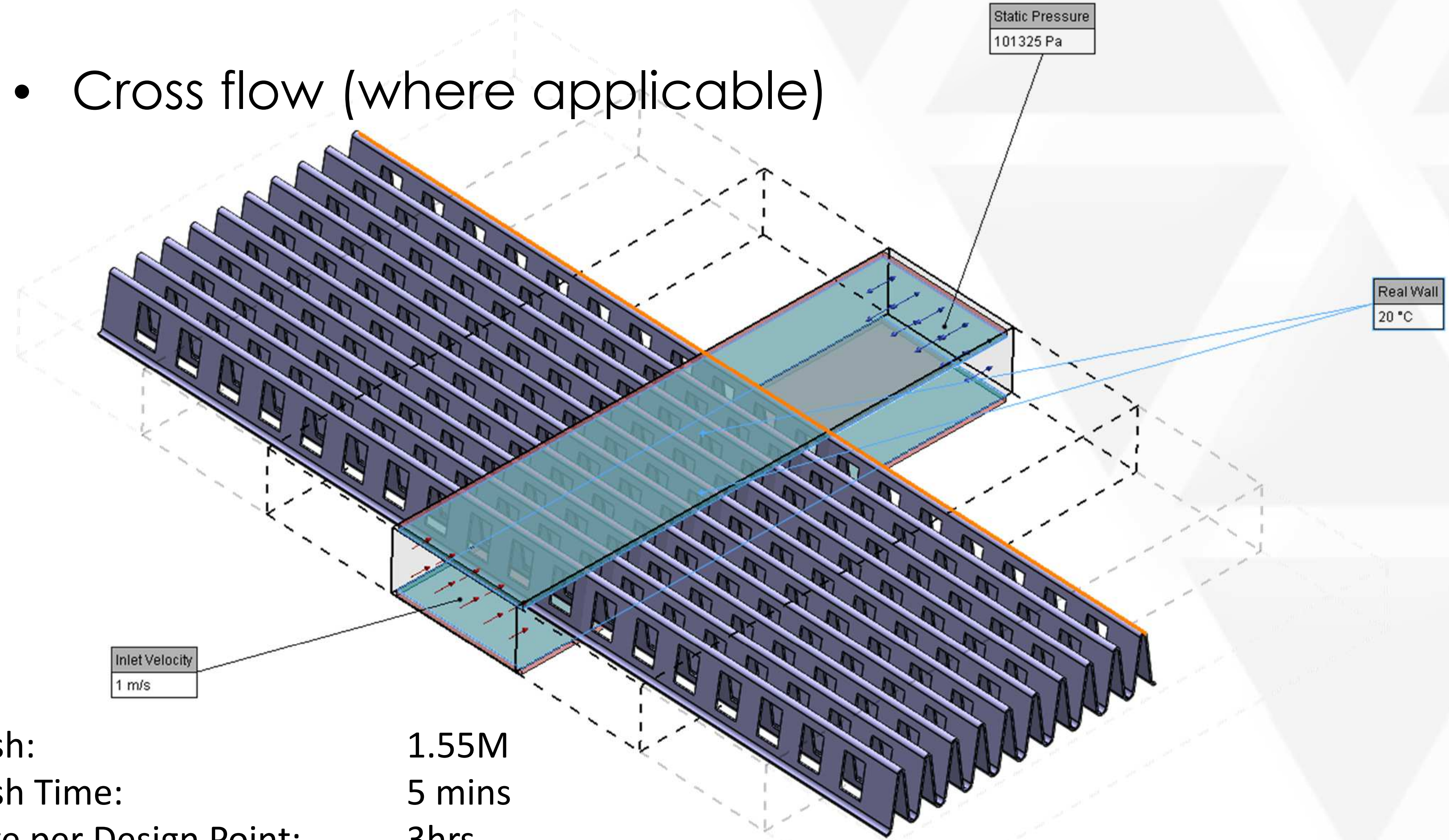
- Through flow:



Fluid:	Air
Intake velocity:	0.5 – 4 m/s
Temperature:	100 °C
Wall temperature:	20 °C

Example: Characterization

- Cross flow (where applicable)



Mesh:	1.55M
Mesh Time:	5 mins
Solve per Design Point:	3hrs
Configuration (4 cores):	1 Core/DP

Example: Characterization

- Parametric study:
  - Mass Flow Rate (m)
  - Pressure drop (ΔP)
  - Av. Solid Temp. (Ts)
  - Enthalpy Difference (ΔQ)
- Usually select to run on different computers on the network; or
- One run per core on a single machine
- Localization for different languages – needed for Frontloading, .e.g.
  - French, German, Japanese,
  - Russian and Chinese.

假设分析 ▾ | dp_HT_z_v00_160302_03

输入变量 | 输出参数 | 方案 | Goals

运行

摘要	设计点 1	设计点 2	设计点 3
Velocity normal to face (Geschwindigkeit (Ein	1	1	0.5
Temperature (Geschwindigkeit (Einlass) 1) [°C	70	100	70
Inlet_Massenmittelw. Temperatur (Fluid) 1 [°C	70	100	70
Outlet_Massenmittelw. Temperatur (Fluid) 1 [°	23.8955777	25.1164517	20.77822
IN por Bulk Av Temperature (Fluid) 1 [°C]	62.7706181	87.6572584	59.9922683
OUT por Bulk Av Temperature (Fluid) 1 [°C]	24.1860882	25.5255457	20.8751131
dT_z [°C]	46.1044223	74.8835483	49.22178
dQ_z [W]	7.17091127	10.7219486	3.82737241
TLuft_m [°C]	46.9477888	62.5582258	45.38911
dTm [°C]	26.9477888	42.5582258	25.38911
alfa_z_m2 [W/m^2/K]	49.2784988	46.6548135	27.9164047
alfa_z_m3 [W/m^2/K]	9855.69975	9330.9627	5583.28095
dP_por_z [Pa]	6.65733917	6.23833071	3.137383
dT_por_z [°C]	38.58453	62.1317127	39.1171552
TLuft_m_por_z [°C]	43.4783531	56.5914021	40.4336907
dTm_por [°C]	23.4783531	36.5914021	20.4336907
dQ_z_por [W]	7.03669071	10.0275165	3.52218853
alfa_z_por_m2 [W/m^2/K]	65.7258235	60.0965523	37.8007939
alfa_z_por_m3 [W/m^2/K]	13145.1647	12019.3105	7560.15879
dp_z [Pa]	7.17462179	6.69505381	3.30425636
状态	已完成	已完成	已完成
运行位置:	本计算机	本计算机	本计算机
线程数量	4	4	4
重新计算	☐	☐	☐
采用之前的结果	☐	☐	☐
保存全部结果	☑	☑	☑
关闭监视器	☐	☐	☐

Example: Characterization

- Volumetric Heat Exchange Coefficient α (W/m³K) and thermal conductivity of porous media λ (W/mK):

$$1 = \frac{mC_p}{\Delta Q}\left(T_w - T_{fluid}^{IN}\right)\left(1 - e^{-\beta A\left(\sqrt{\delta}\right)}\right)$$

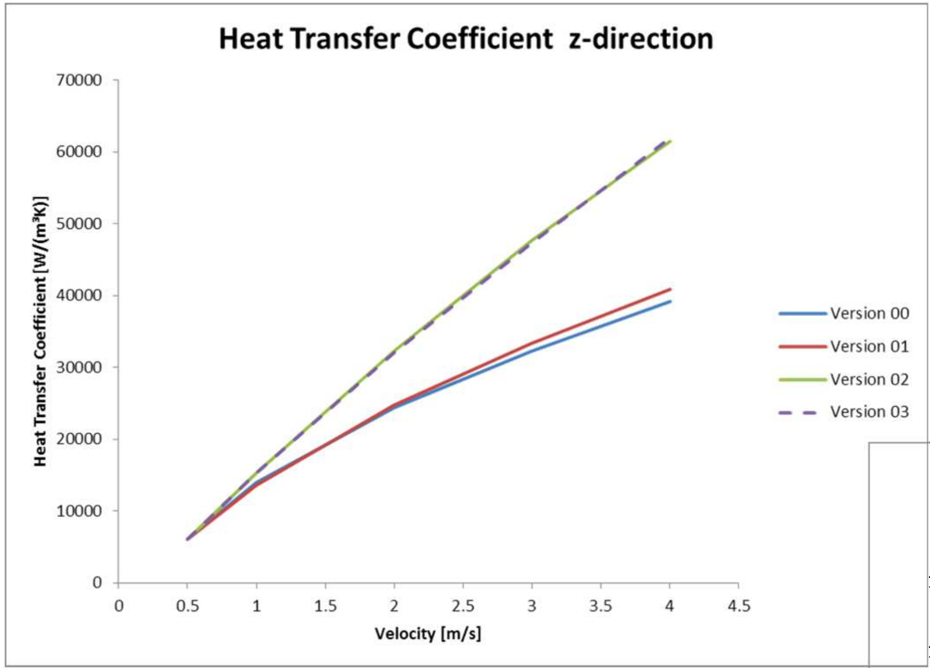
Where:

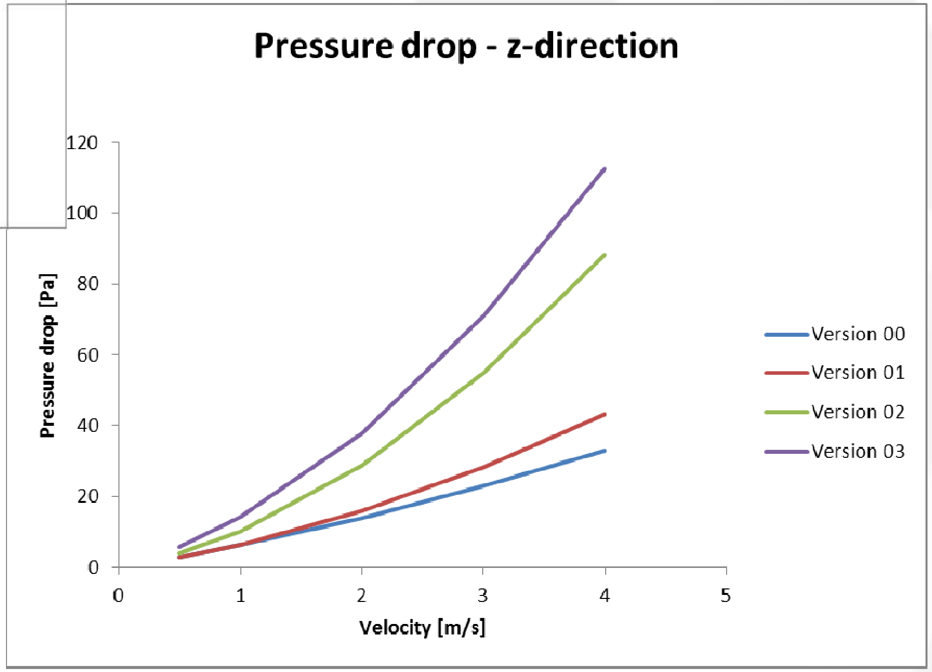
$$\beta = \frac{\alpha_v S_1 L}{mC_p}, A\left(\sqrt{\delta}\right) = \frac{1}{\sqrt{\delta}} th\left(\sqrt{\delta}\right),$$

$$th\left(\sqrt{\delta}\right) = \frac{e^{\sqrt{\delta}} - e^{-\sqrt{\delta}}}{e^{\sqrt{\delta}} + e^{-\sqrt{\delta}}}, \delta = \frac{\alpha_v h^2}{\lambda_k}$$

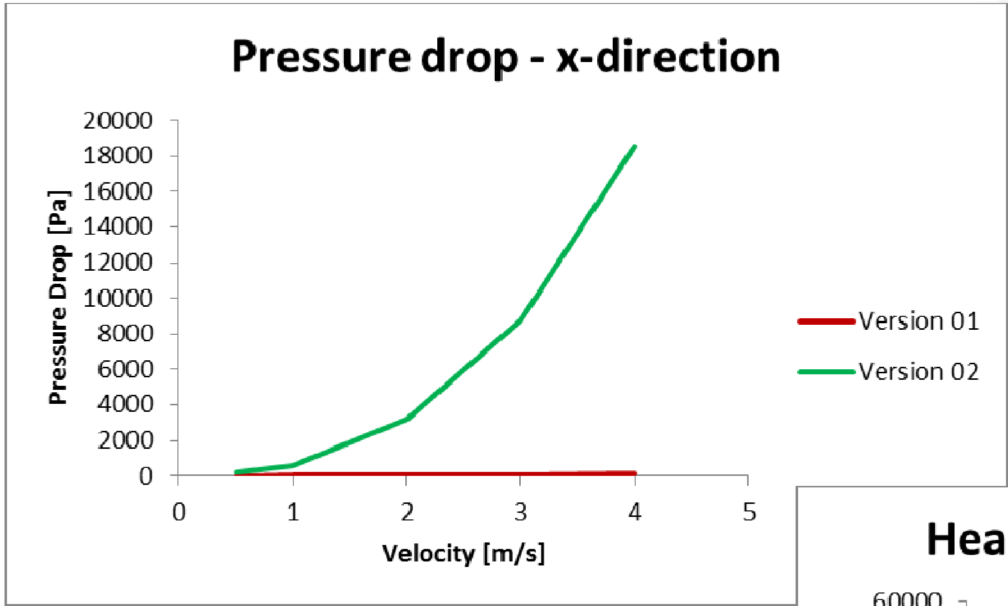
- Calculation performed by a utility program

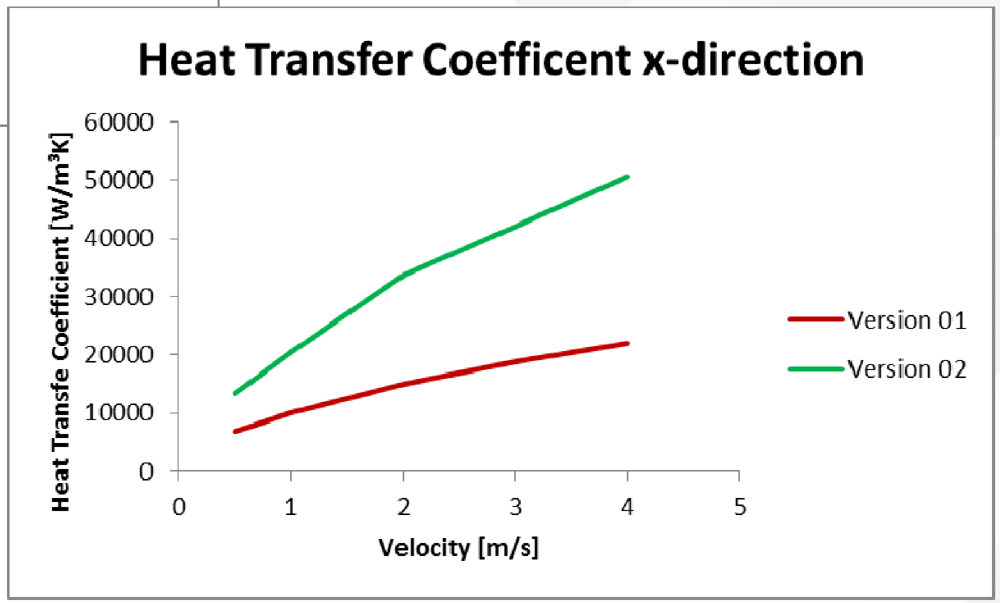
Example: Calibration





Example: Calibration



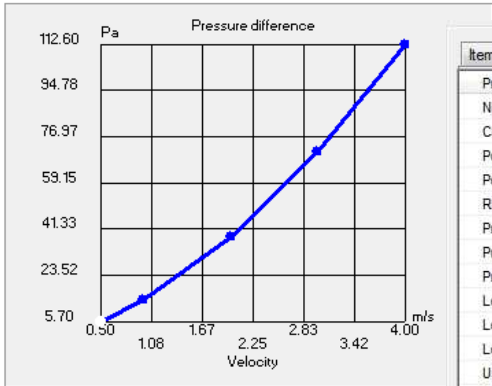


Example: Porous Media Definition

Property:

Pressure drop vs. velocity in Z

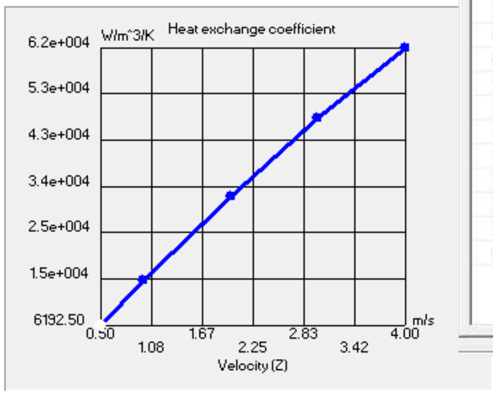
Velocity	Pressure difference
0.5 m/s	5.7 Pa
1 m/s	14.1 Pa
2 m/s	38 Pa
3 m/s	70.9 Pa
4 m/s	112.6 Pa



Property:

Hv (Vz)

Velocity (Z)	Heat exchange coefficient
0.5 m/s	6192.5 W/m^3/K
1 m/s	15237.9 W/m^3/K
2 m/s	32049.4 W/m^3/K
3 m/s	47625.5 W/m^3/K
4 m/s	61923 W/m^3/K

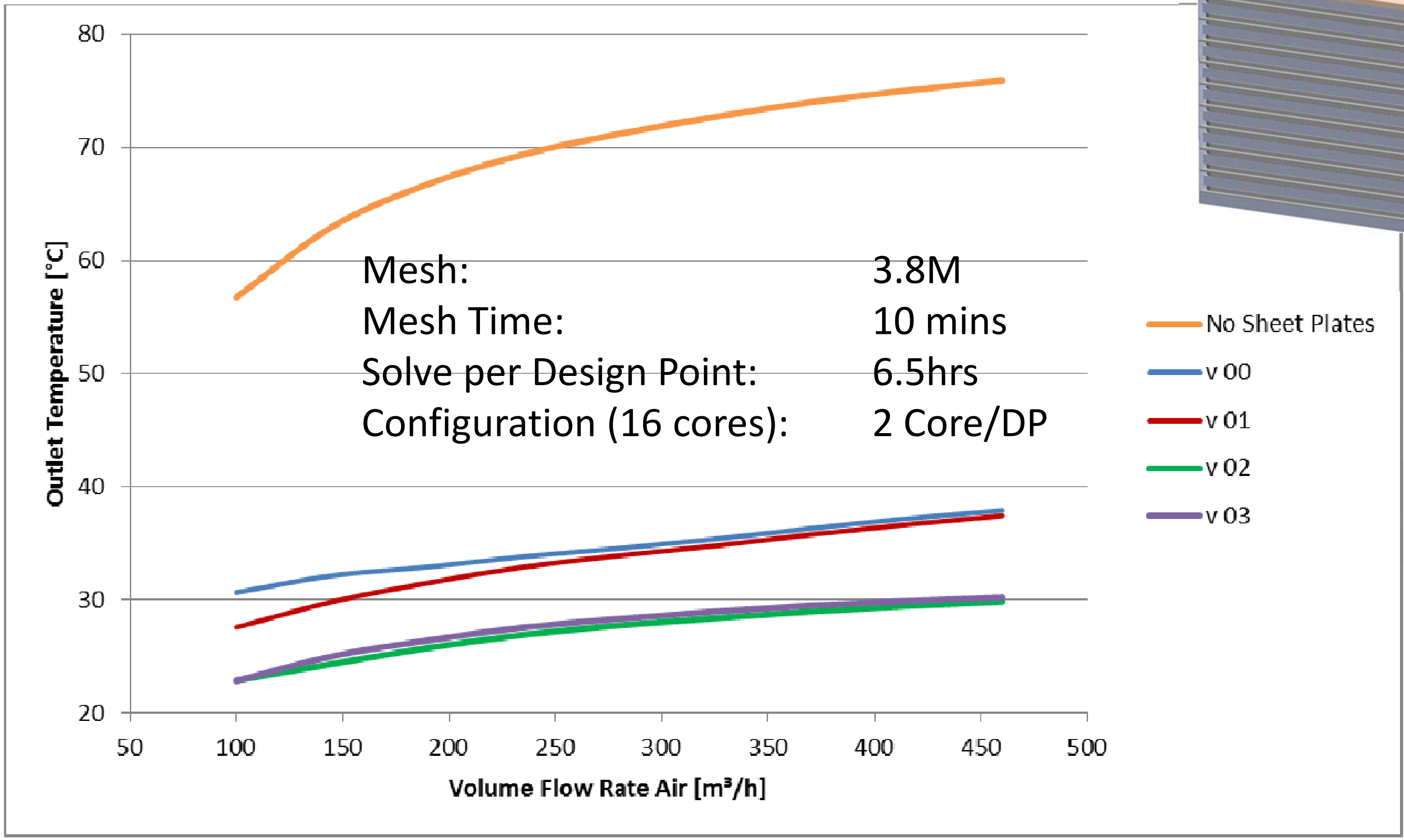


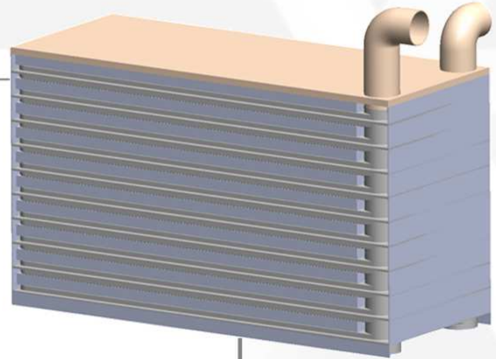
Items | Item Properties | Tables and Curves | Formula

Property	Value
Name	160411_Ver 03_01_orthotrop
Comments	Formula corrected
Porosity	0.8579
Permeability type	Orthotropic
Resistance calculation formula	Pressure Drop, Velocity, Dimensions
Pressure drop vs. velocity in X	(Table)
Pressure drop vs. velocity in Y	(Table)
Pressure drop vs. velocity in Z	(Table)
Length in X	0.05 m
Length in Y	0.05 m
Length in Z	0.152 m
Use turbulent scale	☐
Use calibration viscosity	☐
Use calibration density	☐
Heat conductivity of porous matrix	☑
Use effective density and capacity	☐
Density of porous matrix	2689 kg/m^3
Specific heat capacity of porous matrix	(Table)
Conductivity type	Isotropic
Thermal conductivity	(Table)
Melting temperature	933.4 K
Matrix and fluid heat exchange defined by	Volumetric heat exchange coefficient
Volumetric heat exchange coefficient type	Orthotropic
Hv (Vx)	(Table)
Hv (Vy)	(Table)
Hv (Vz)	(Table)
Formula	({Hv (Vx)}^2+{Hv (Vy)}^2+{Hv (Vz)}^2)^0.5

Example: Overall Results

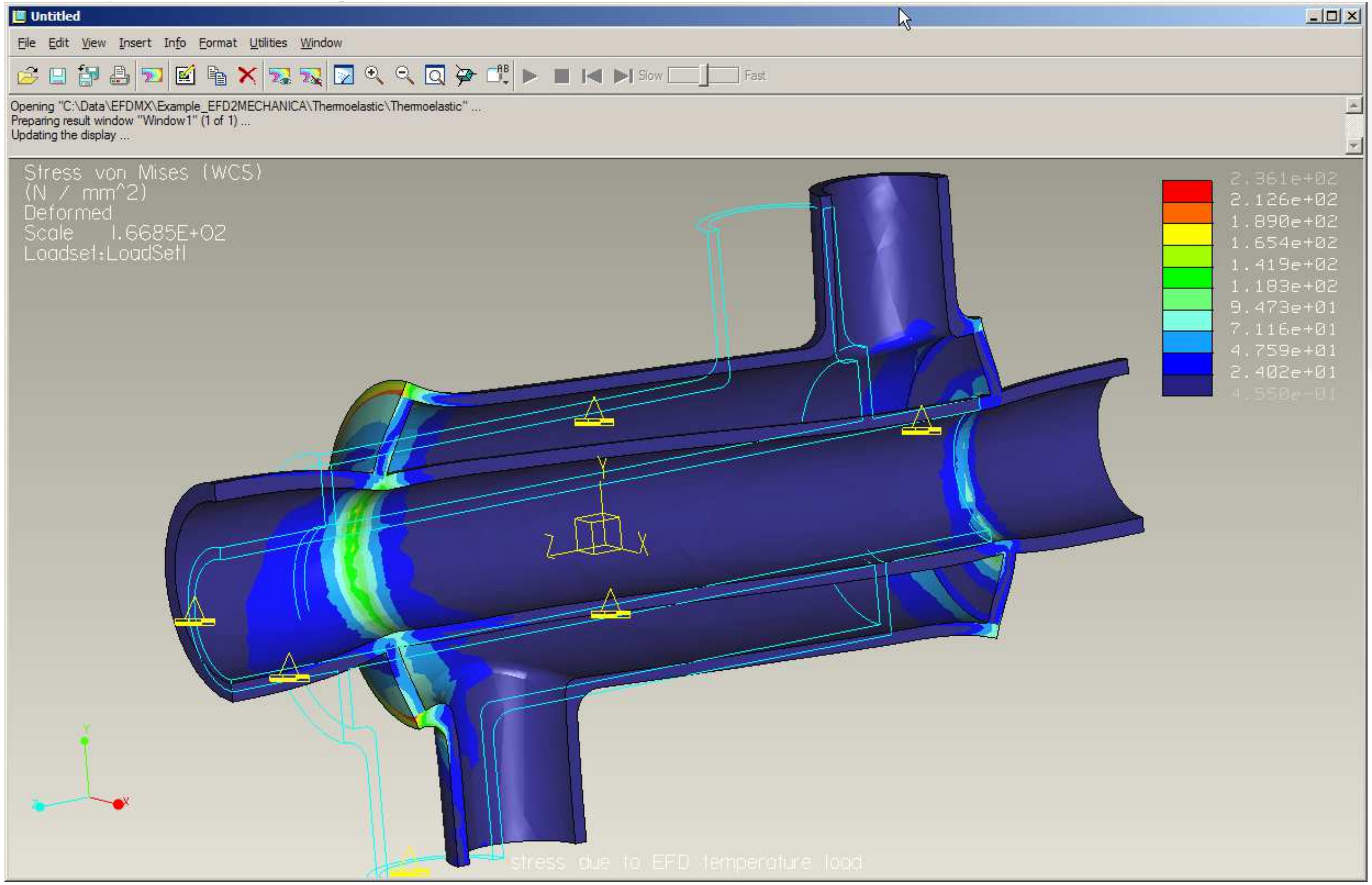
- Air outlet temperature for several volume flow rates

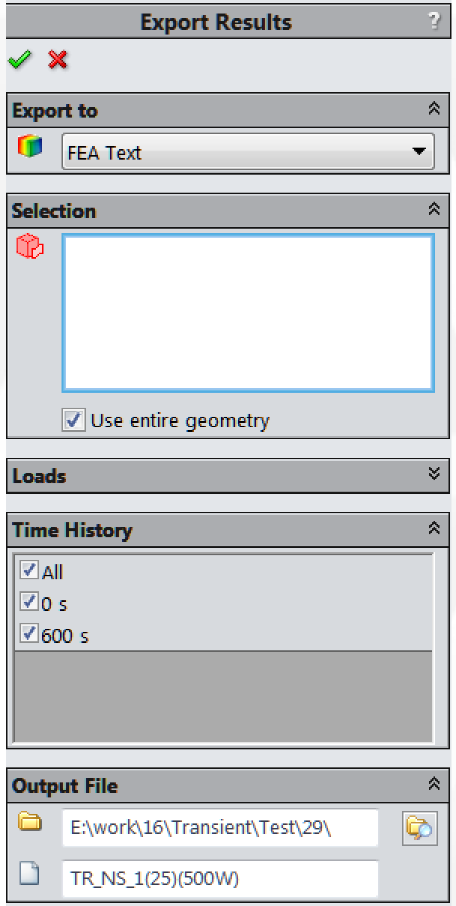




Downstream: Stress Analysis

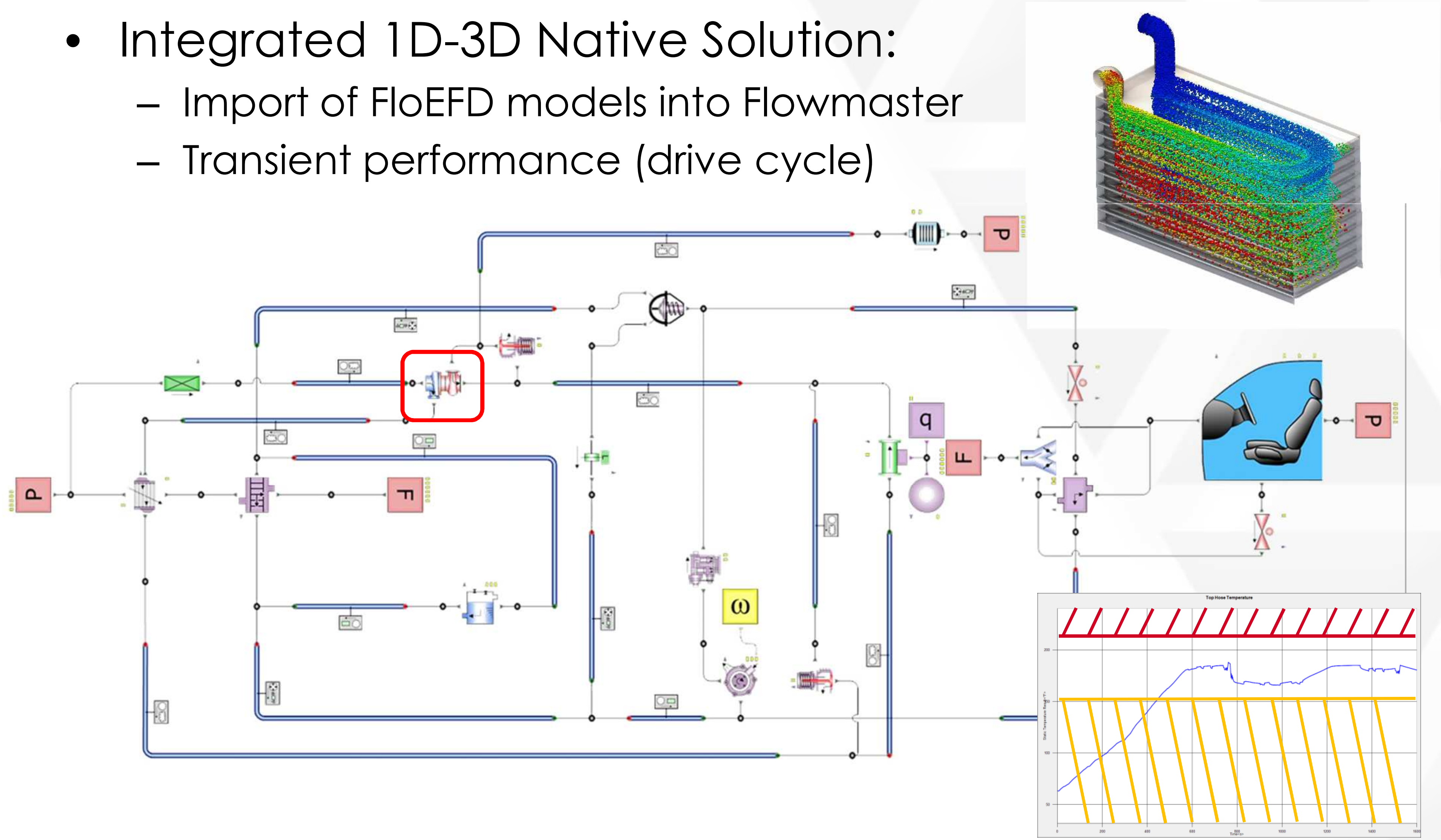
- Export Porous Matrix Temperature (vs. time) e.g. for ANSYS
- Or calculate directly in CAD suite (e.g. PTC Creo





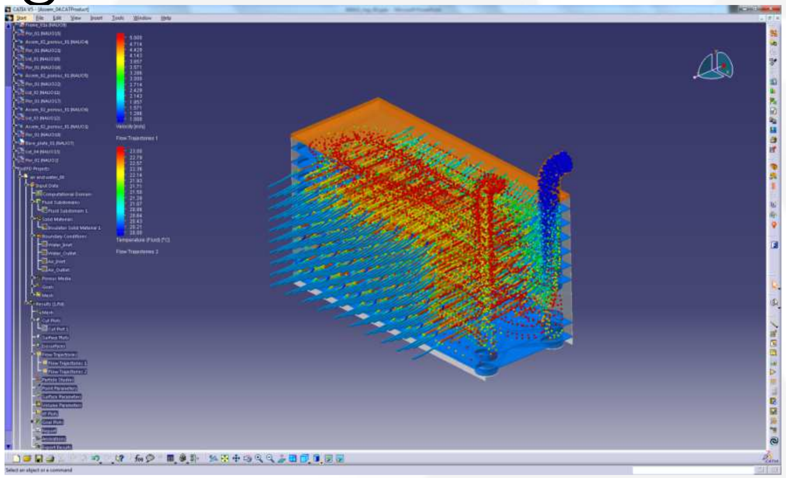
Downstream: System CFD

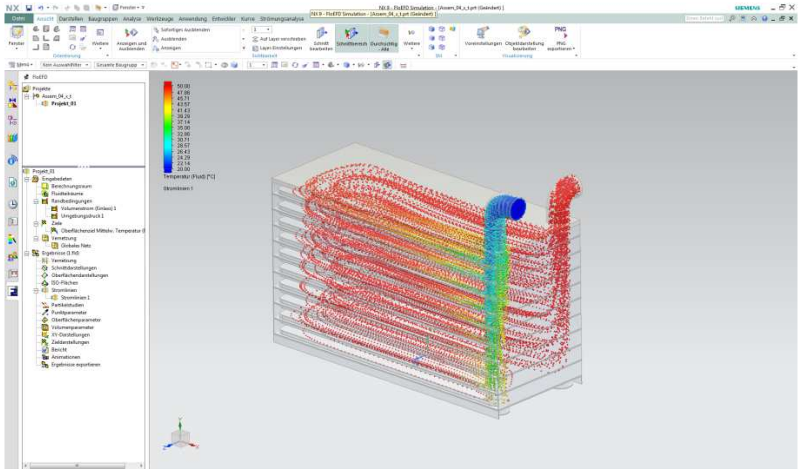
- Integrated 1D-3D Native Solution:
  - Import of FloEFD models into Flowmaster
  - Transient performance (drive cycle)

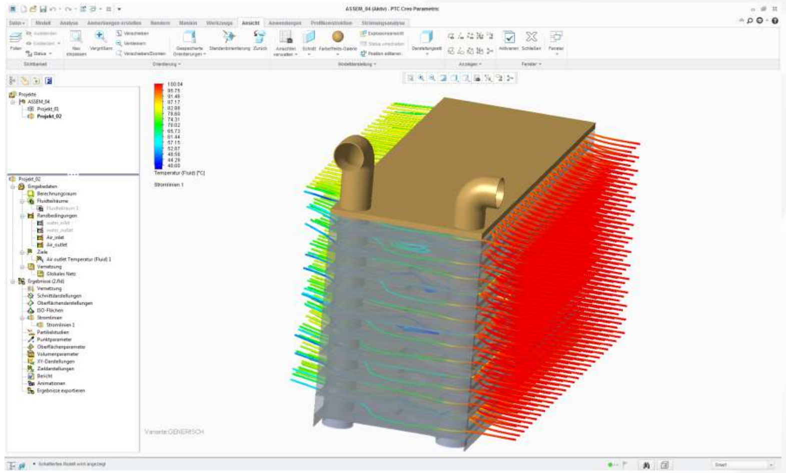


Summary

- Frontloading for early design evaluation
  - Made possible by embedding CFD into CAD:
    - FloEFD for Siemens NX
    - FloEFD for PTC Creo
    - FloEFD for CATIA V5
  - Also
    - Solid Edge







Summary

- Frontloading fits simulation into customer's design flow
- Efficient and engineer-suitable simulation process:
  - CAD-embedding allows automatic recognition of fluid regions, etc.
  - Fully automatic meshing of the complex geometry happens directly on the CAD model
  - Parametric CAD allows rapid geometry changes
- Cost-optimized and resource-efficient simulation workflow for Heat Exchangers:
  - Parametric study capability enables a fast characterization of the actual geometry
  - Porous media replaces complex sheet metal structure in full heat exchanger simulation

Thanks For Your Attention