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TESI DI LAUREA MAGISTRALE
INGEGNERIA MECCANICA

Goal driven multi-objective shape optimization for conjugate heat transfer in an effusion cooling system of a combustion chamber, through a CFD-mesh-morphing based approach.

Relatore
Prof. Marco E. Biancolini

Correlatore
Prof. G.E. Andrews (University of Leeds)
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Walter Savastano
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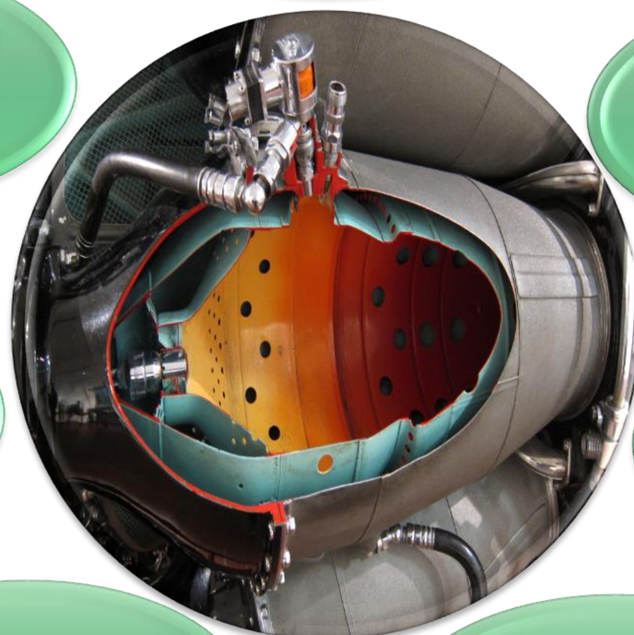
Effusion Cooling

Metallurgical Limits

Right Design of Layout of the Holes

Reach Higher Temperature



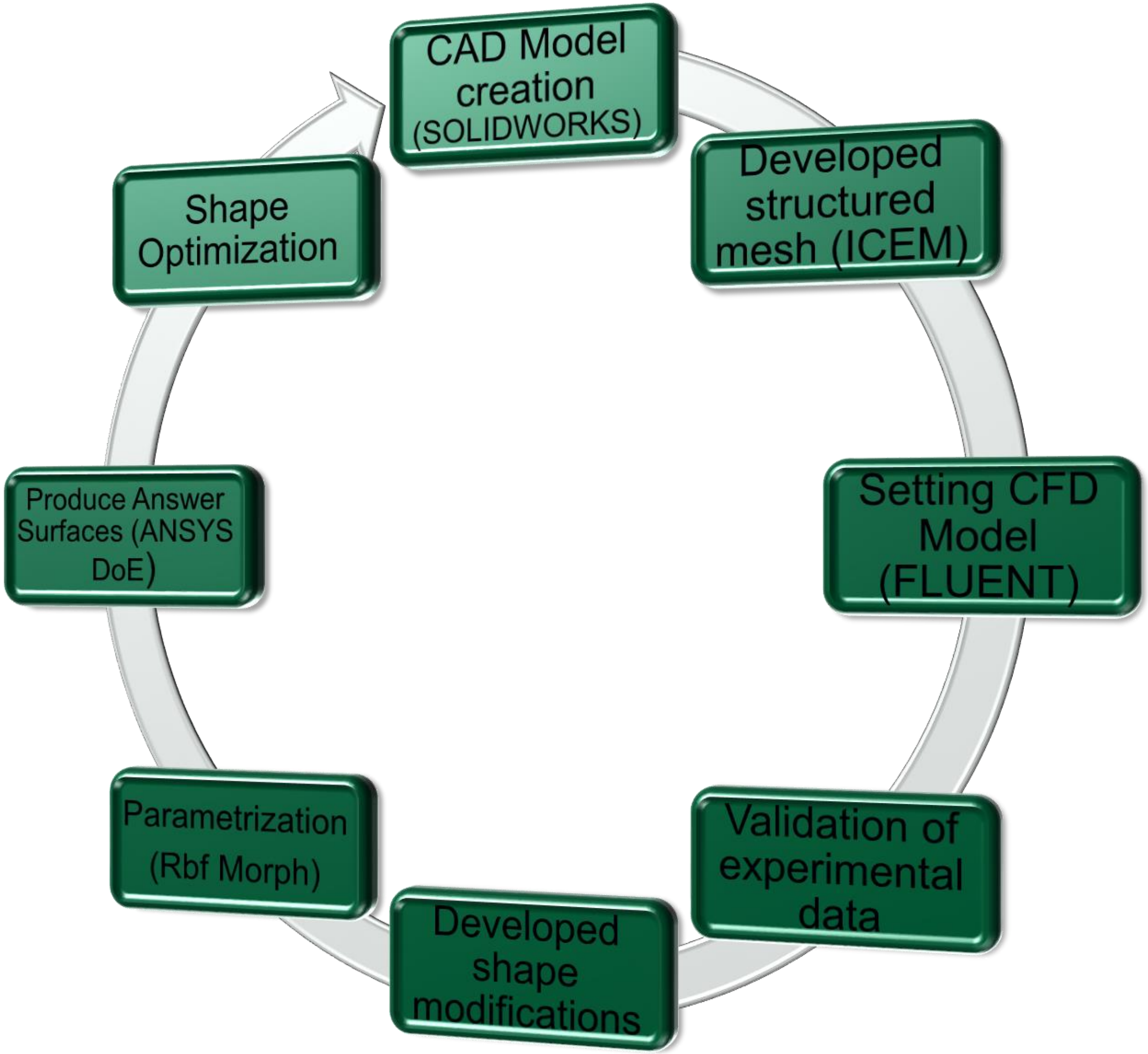
Ensure right combustion

Better efficency

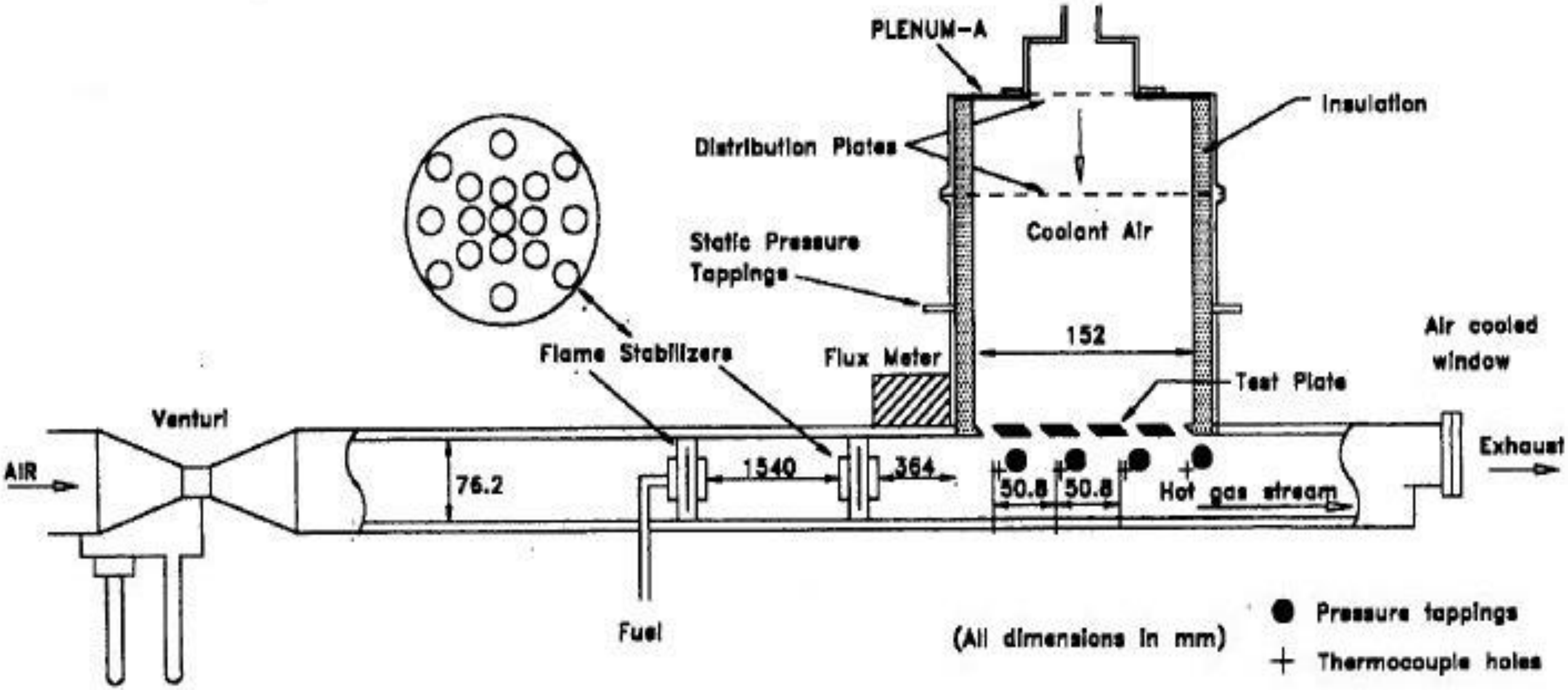
Minimize cooling flow

Avoid high thermal stress

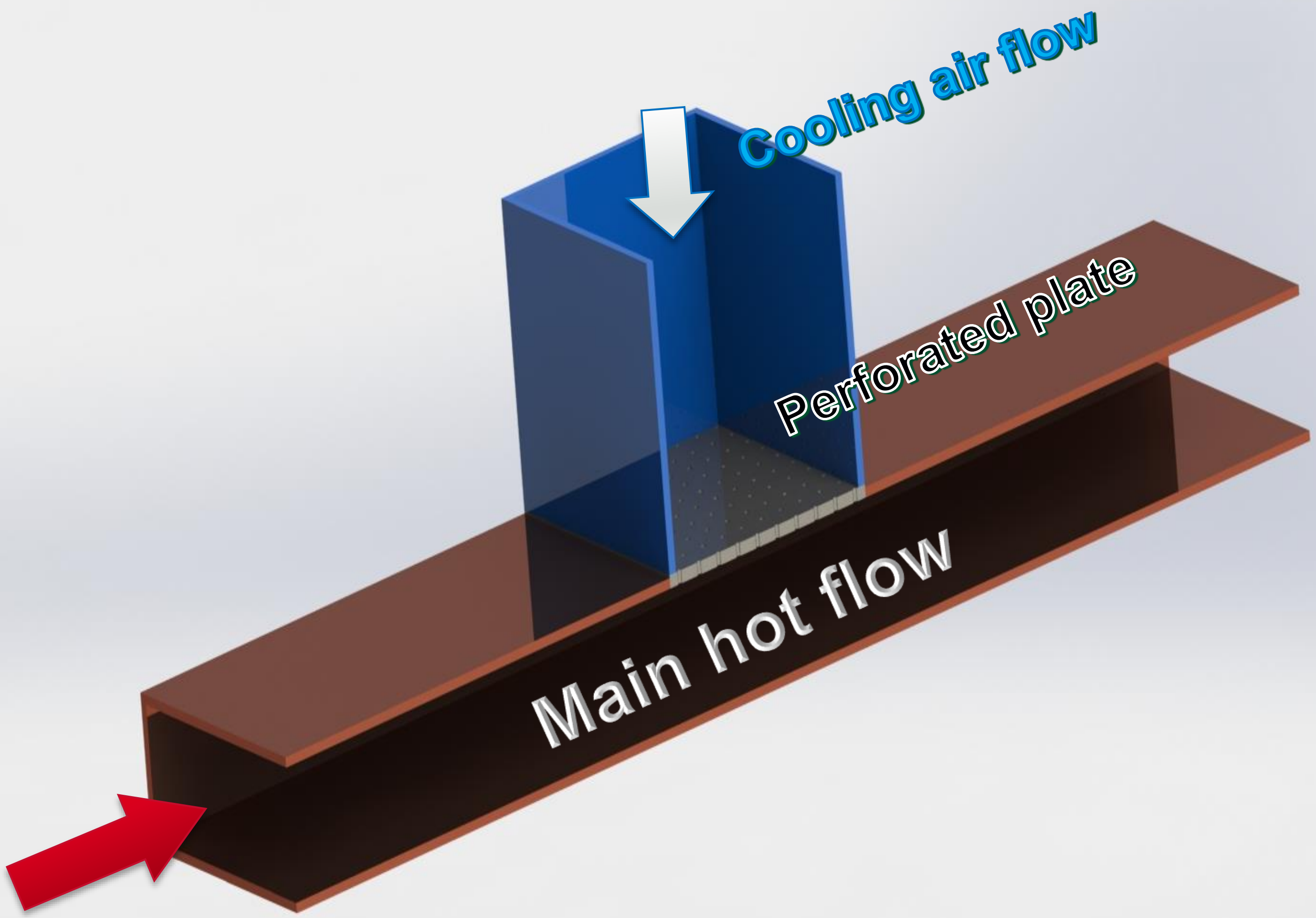
Introduction



Experimental Apparatus



Solidworks Model



ANSYS ICEM: Structured mesh

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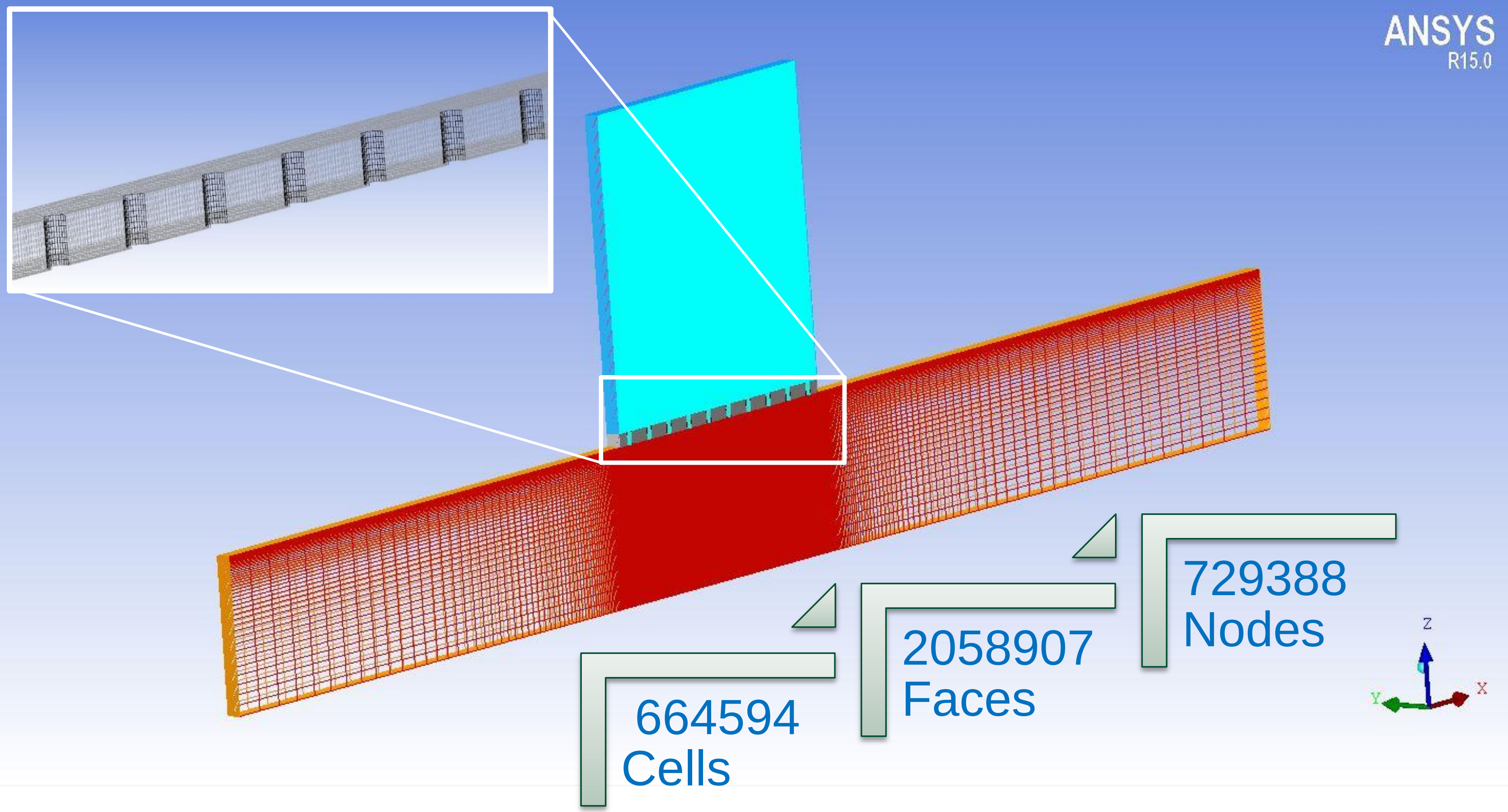


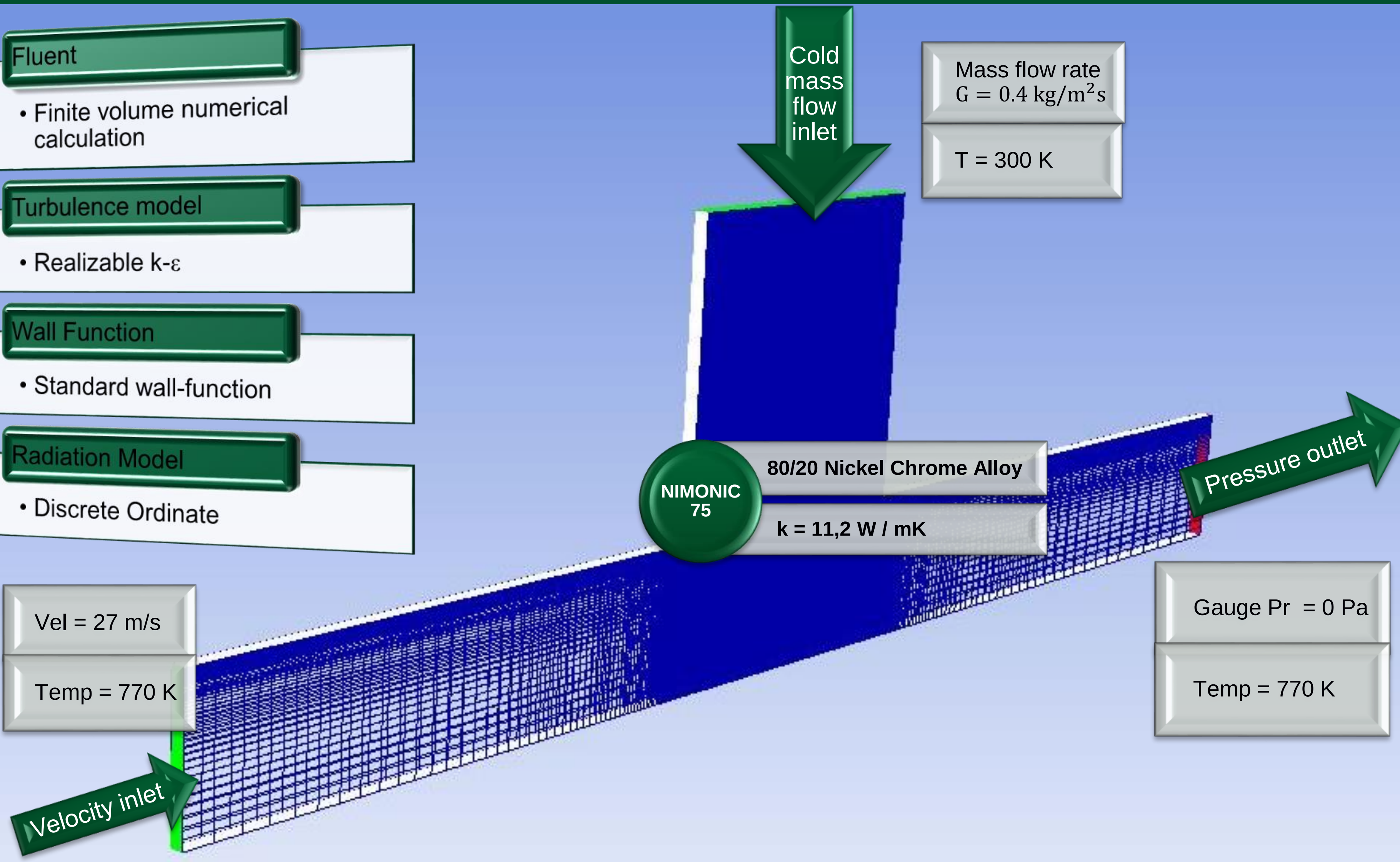
Fluent Model

Fluent
- Finite volume numerical calculation

Turbulence model
- Realizable k-ε

Wall Function
- Standard wall-function

Radiation Model
- Discrete Ordinate



Validation: Mesh Sensibility

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Overall effectiveness

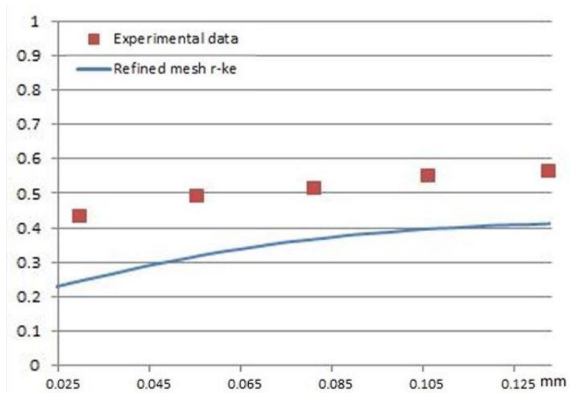
$$\eta_{ov} = \frac{T_g - T_w}{T_g - T_c}$$

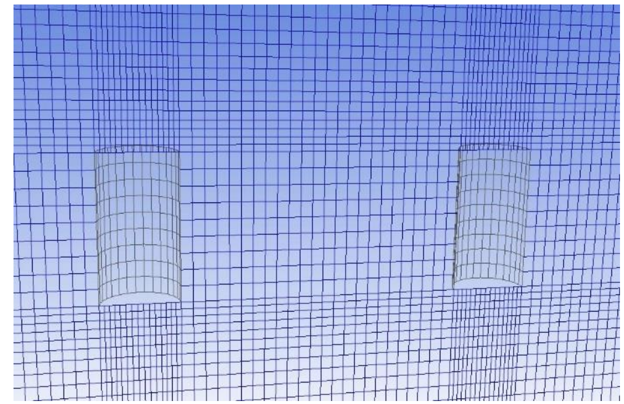
T_g= Hot gas Temperature

T_w=Wall temperature

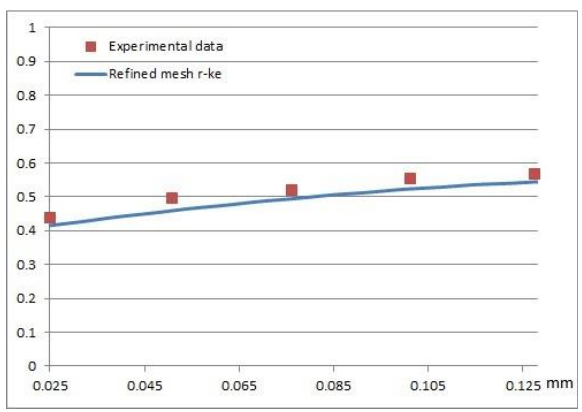
T_C= Cooling air Temperature

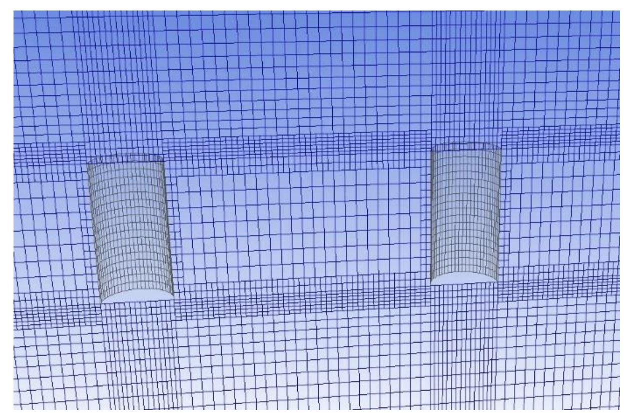
Coarse Mesh (700k cells)





Refined Mesh (1mln cells)





Turbulence Model Sensibility

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Overall effectiveness

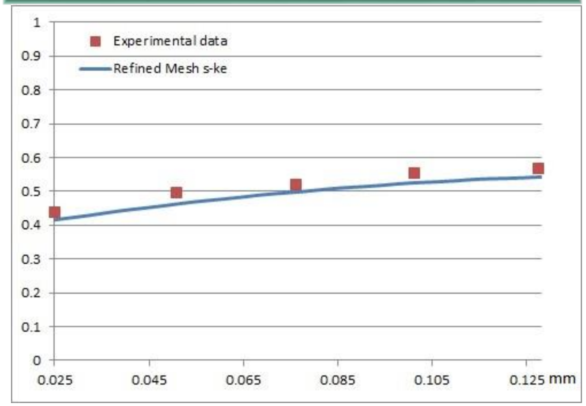
$$\eta_{ov} = \frac{T_g - T_w}{T_g - T_c}$$

T_g= Hot gas Temperature

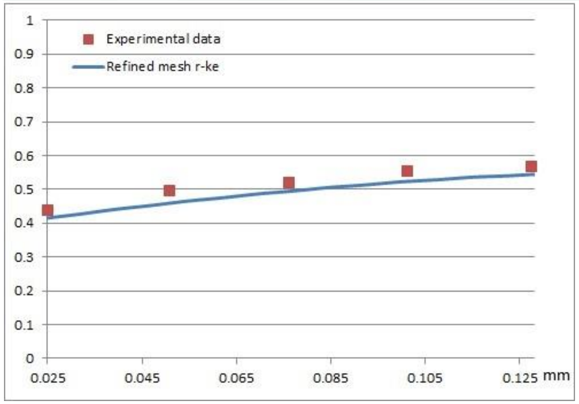
T_w=Wall temperature

T_C= Cooling air Temperature

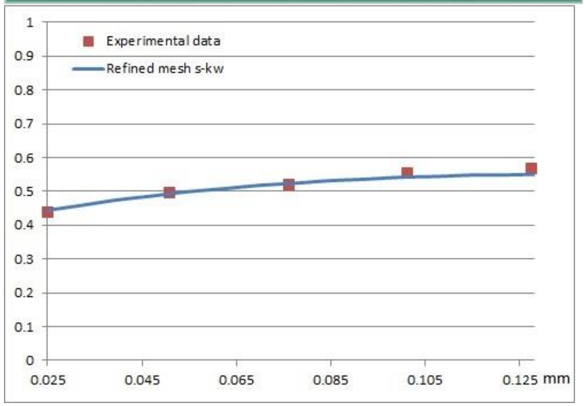
Standard k-e



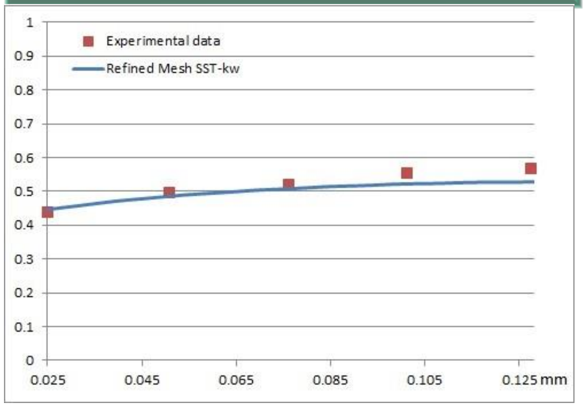
Realizable k-e



Standard k-w

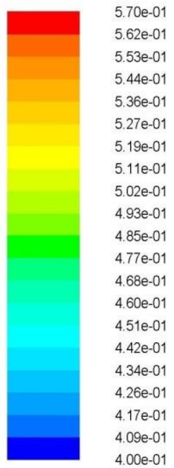


SST k-w

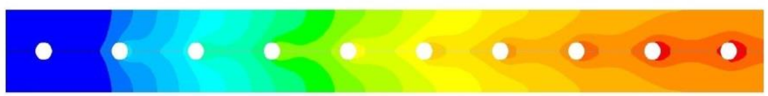


Baseline results

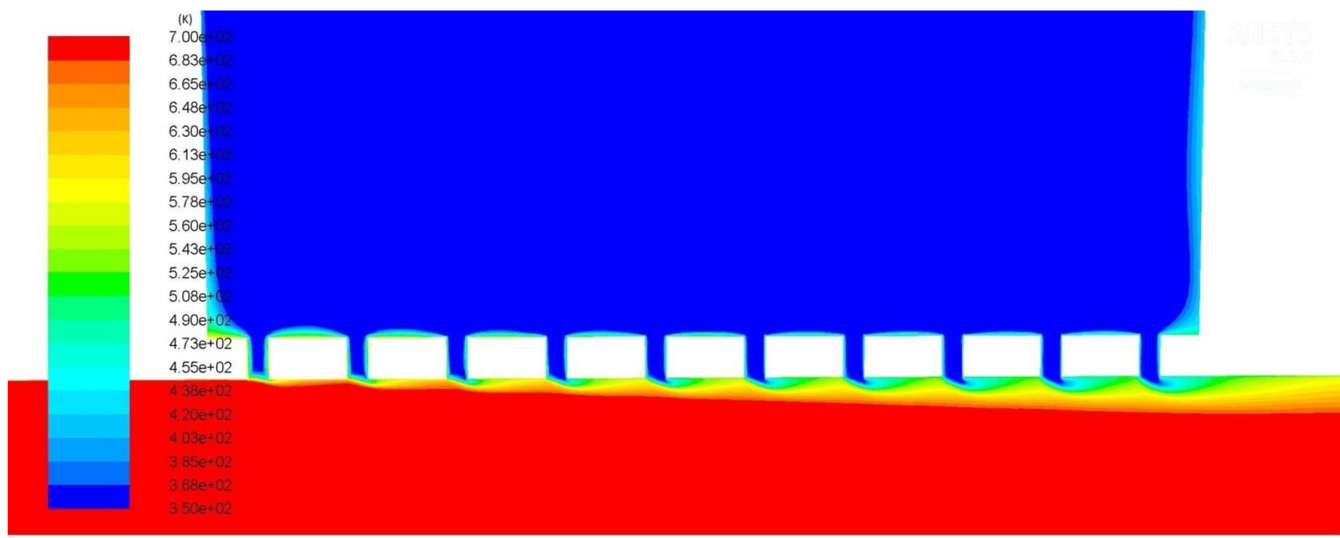
Overall Effectiveness:
Contour on the plate



$$\eta_{ov} = \frac{T_g - T_w}{T_g - T_c}$$

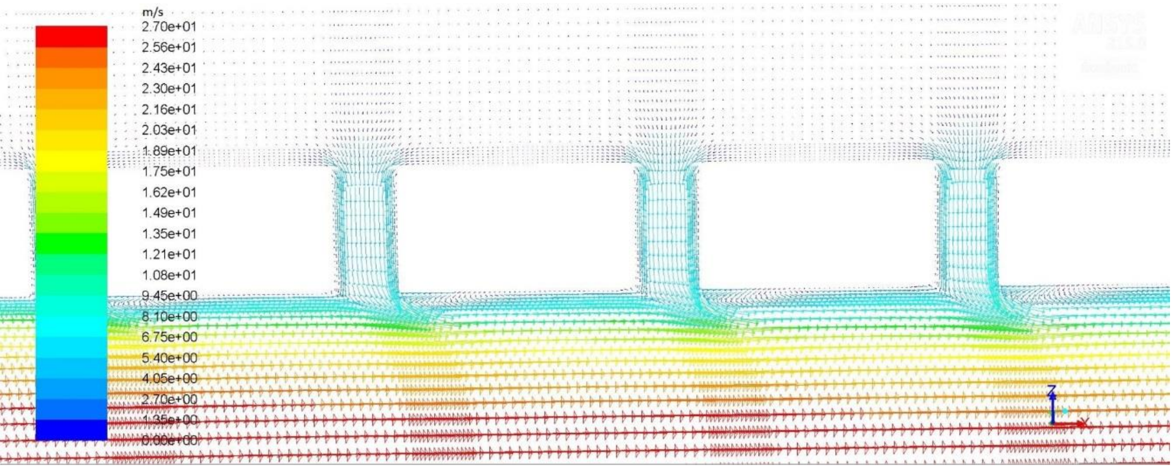


Temperature profile
on symmetry plane



Baseline results

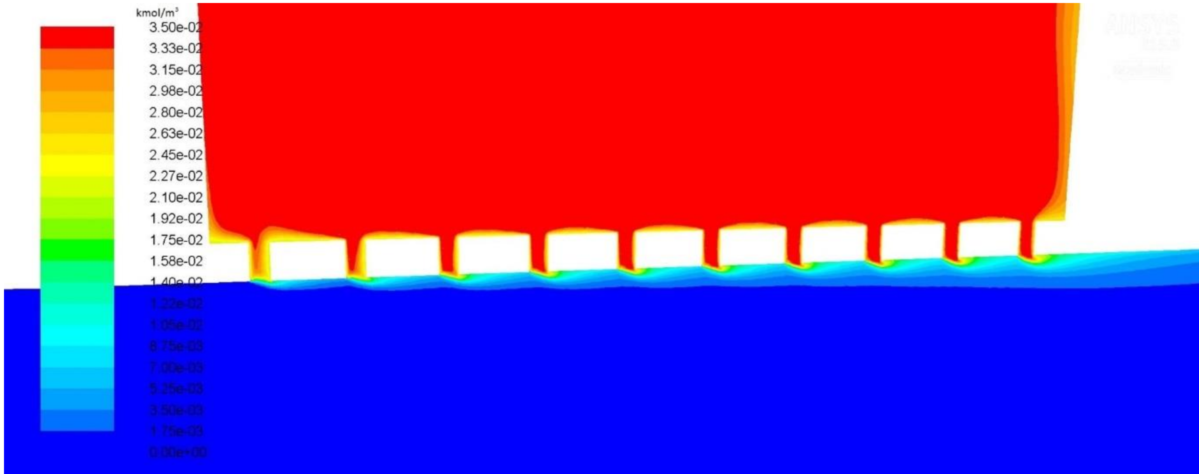
Velocity vectors on symmetry plate



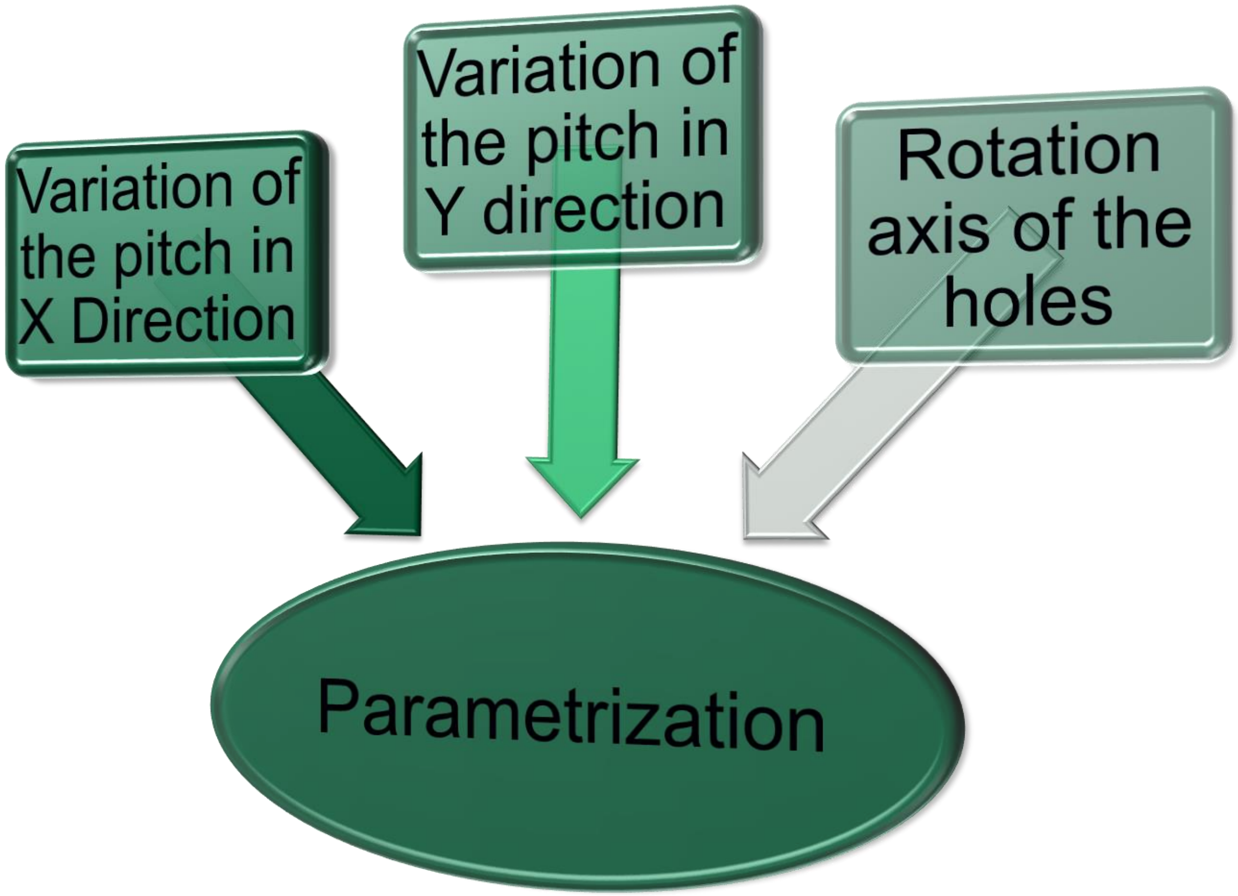
Flow separation at the exit of the holes

Tracer concentration on symmetry plane

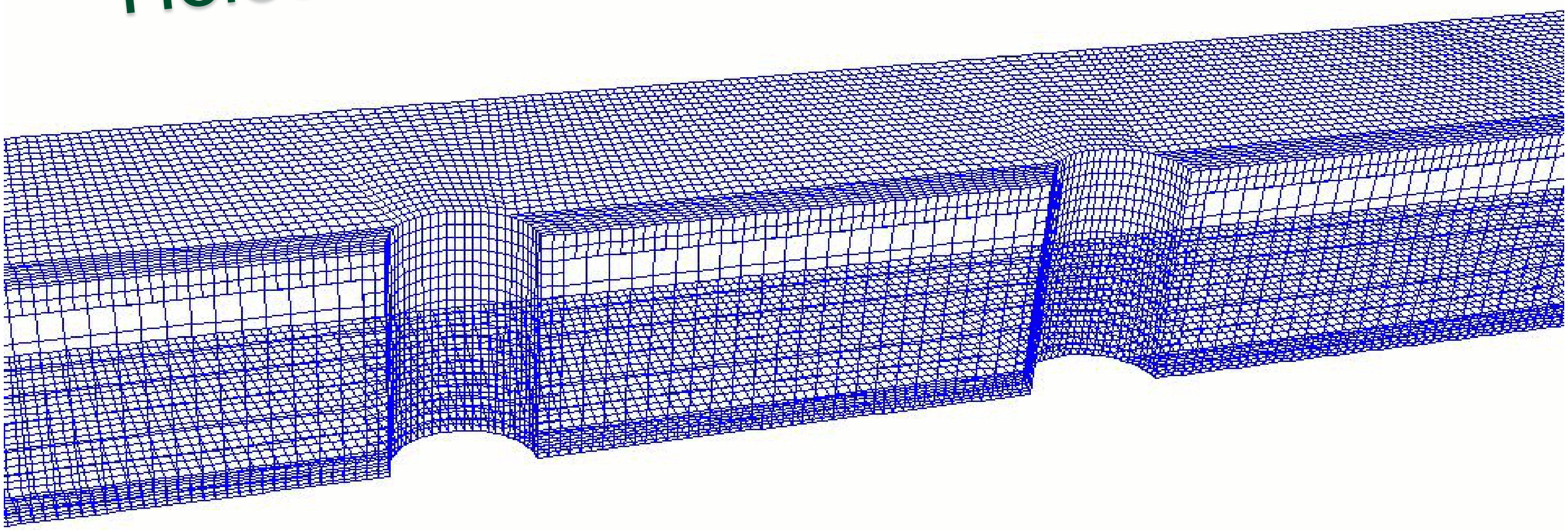
No mix between the flows



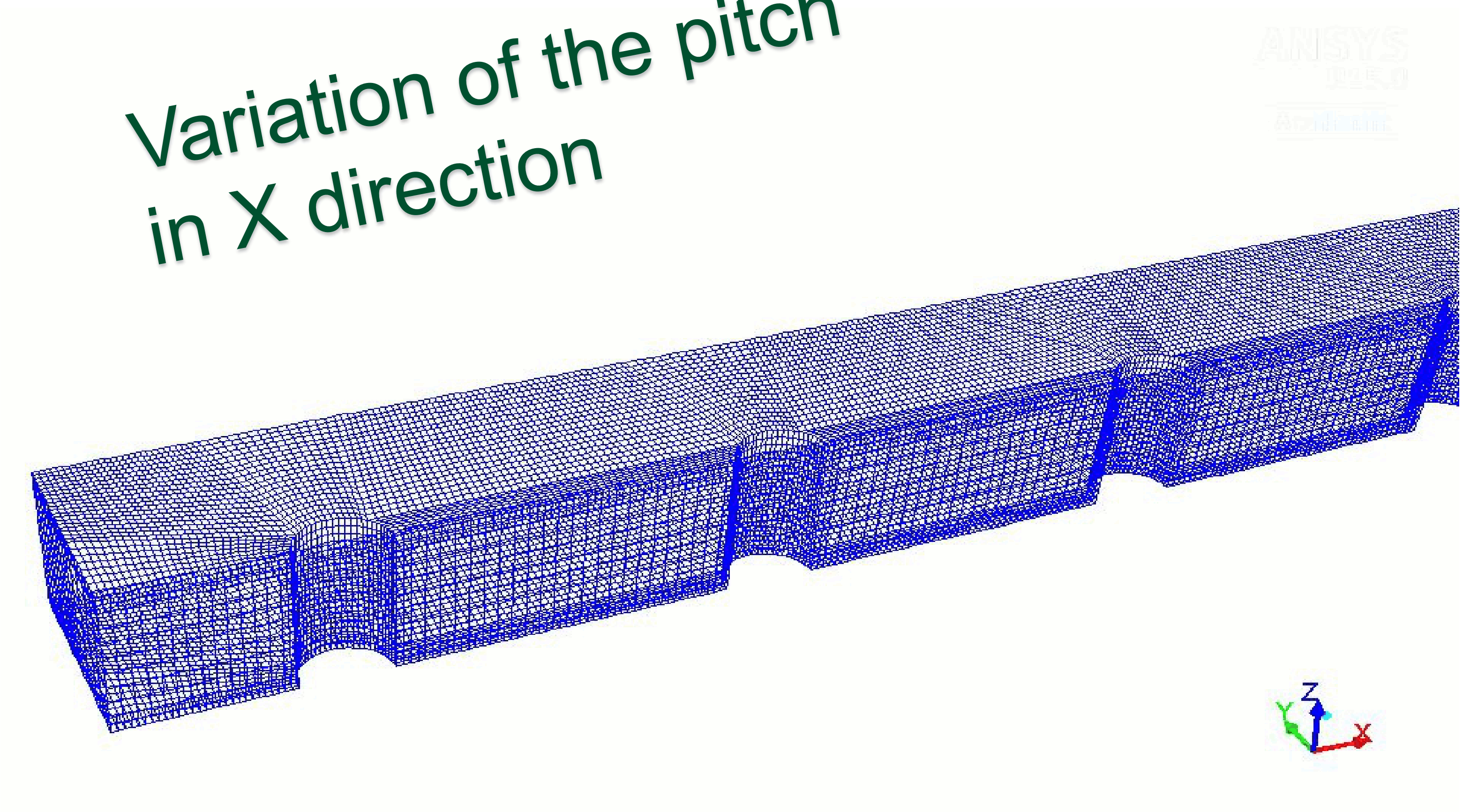
RBF Morph Parametrization



Holes' Axis rotation

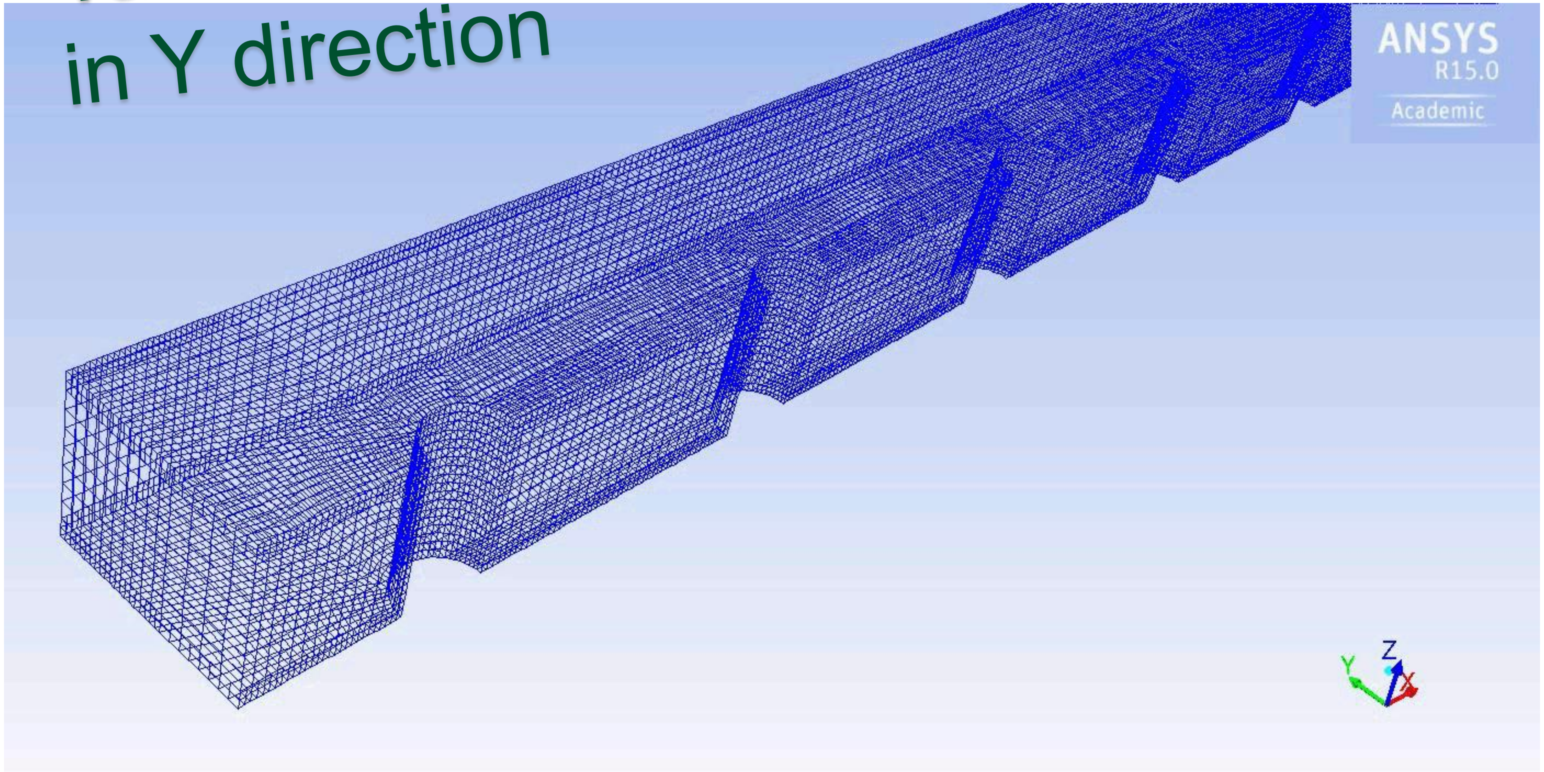


Variation of the pitch in X direction



RBF Morph Parametrization

Variation of the pitch in Y direction



Parametrization

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Input

- Rotation
- Pitch in X
- Pitch in Y

Output $\left(\frac{T_g - T_w}{T_g - T_c}\right)$

- Overall effectiveness Average
- Overall effectiveness Min >0,4
- Overall effectiveness Max
- Adiab. effectiveness Average (at 0,2 mm from the plate)
- Adiab. Effectiveness Max (at 0,2 mm from the plate)

Design of Experiment

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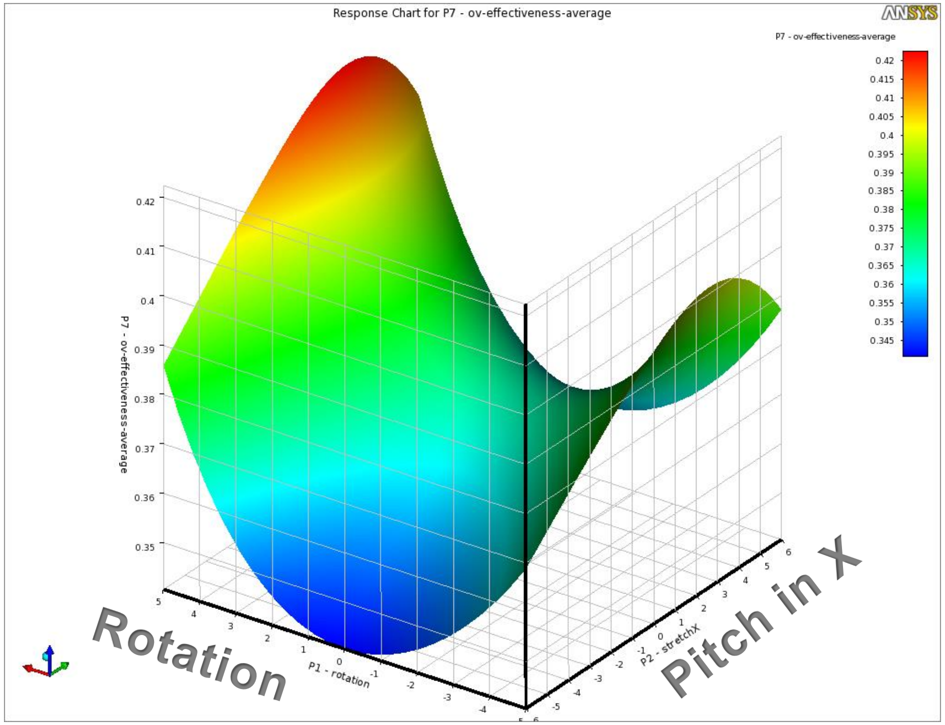
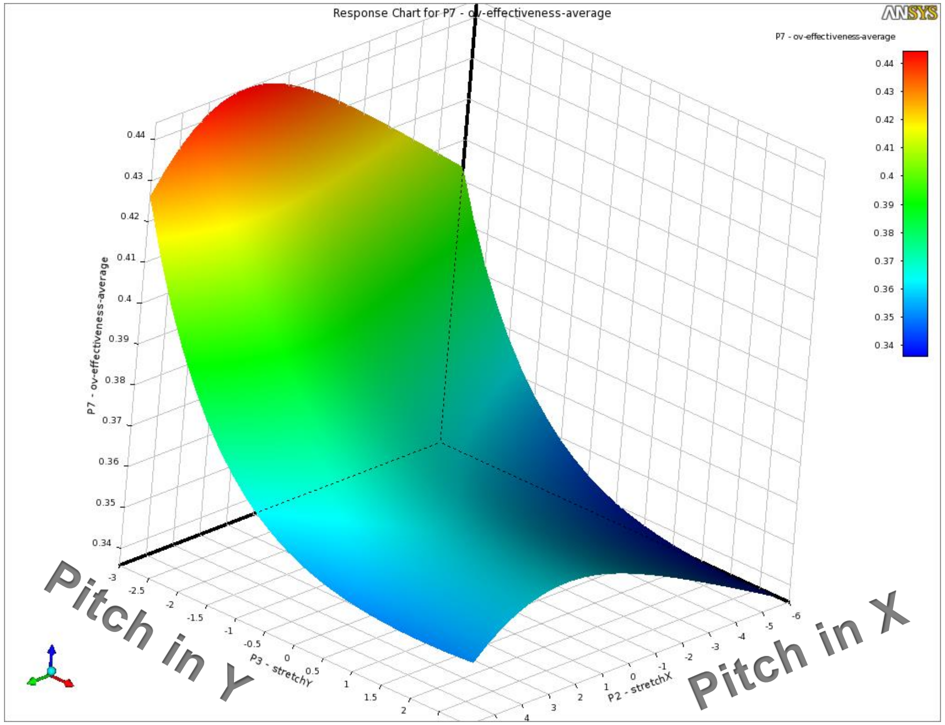
Input			Output				
Injection angle (deg)	Pitch in x (mm)	Pitch in Y (mm)	Overall Effectiveness Min	Overall Effectiveness Average	Overall Effectiveness max	Adiabatic Effectiveness Average	Adiabatic Effectiveness Max
43°	18.8	19.5	0.408	0.468	0.616	0.243	0.356
90°	23.7	15.2	0.358	0.409	0.514	0.216	0.29
-51°	15.2	12.8	0.367	0.383	0.550	0.223	0.314
-43°	6.7	13.4	0.405	0.413	0.650	0.249	0.388
-78°	22.5	16.4	0.275	0.351	0.573	0.204	0.323
57°	10.3	18.8	0.369	0.416	0.548	0.220	0.310
-57°	21.3	11.6	0.284	0.351	0.557	0.210	0.319
-66°	17.6	17.6	0.424	0.445	0.643	0.258	0.382
-39°	7.9	17.0	0.381	0.389	0.576	0.228	0.319
51°	9.1	15.8	0.279	0.360	0.546	0.209	0.308
-35°	12.8	14.0	0.285	0.366	0.654	0.213	0.354
35°	11.6	10.9	0.338	0.407	0.596	0.242	0.342
66°	16.4	18.2	0.327	0.411	0.640	0.245	0.382
39°	14.0	14.6	0.393	0.480	0.563	0.232	0.315
78°	18.8	19.5	0.344	0.363	0.557	0.220	0.332

Answer surfaces

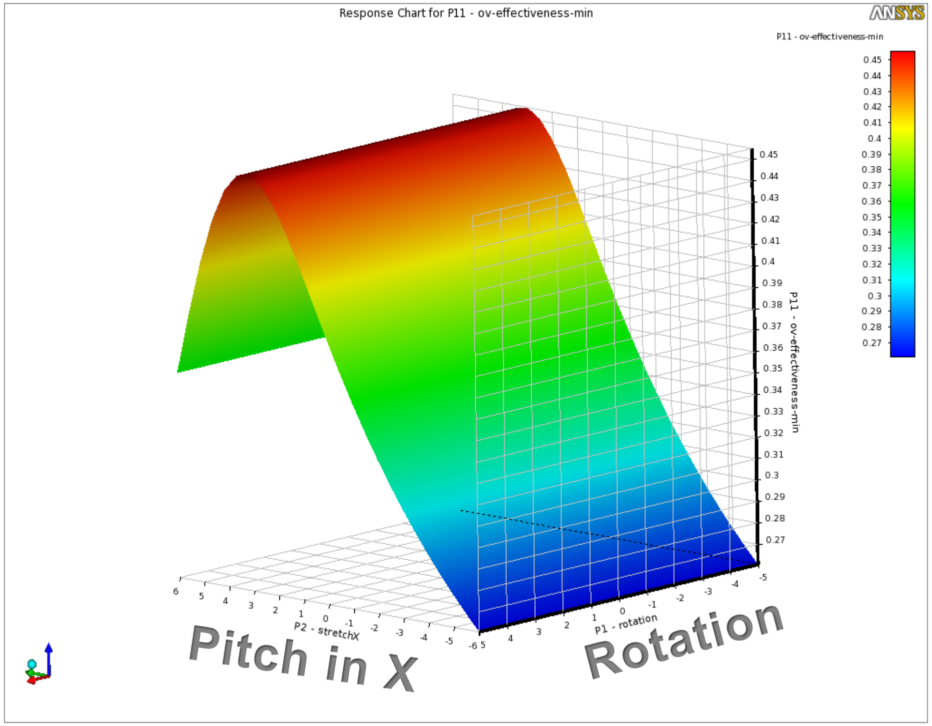
Optimization parameter
Overall effectiveness average = f (Input1, Input2)

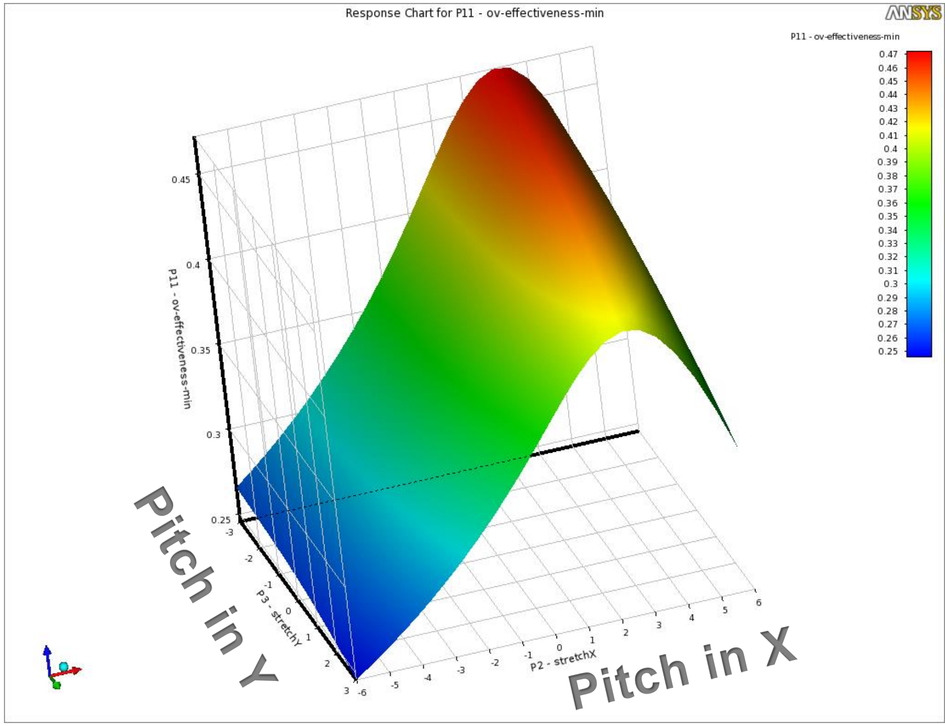




Answer surfaces

Constraint parameter > 0,4
Overall effectiveness min = f (Input1, Input2)





Optimization
Candidate Points

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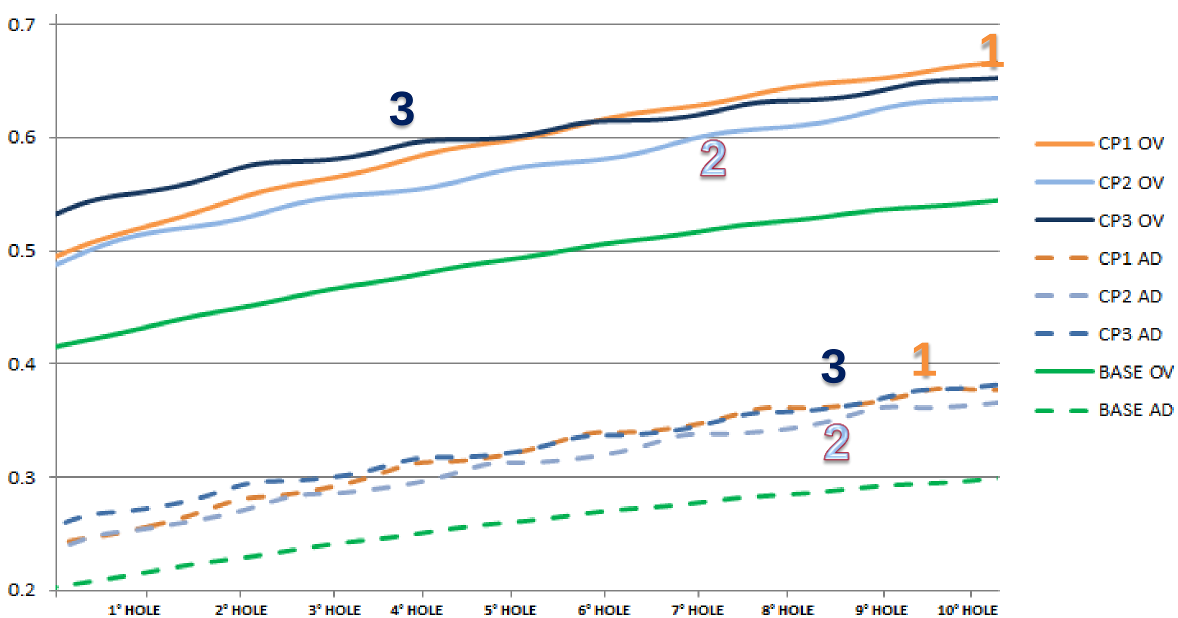
N°	Injection Angle (deg)	Pitch in x (mm)	Pirch in Y (mm)	Overall Effectiveness Min	Overall Effectiveness Average	Overall Effectiveness Max	Adiabatic Effectiveness Average	Adiabatic Effectiveness Max
BASE	90°	15,24	15,24	0.411	0.453	0.540	0.216	0.309
1	-32,7°	17,03	12,92	0.483	0.591	0.681	0.316	0.392
2	-33,2°	18,31	12,90	0.482	0.563	0.652	0.304	0.383
3	-74,6	16,72	12,90	0.524	0.603	0.668	0.338	0.403



- Improvement of 30% in overall effectiveness
- Improvement of 50% in adiabatic effectiveness
- Candidate Point N°3 :
  - Overall Effectiveness higher
  - Lower Temperature gradient along the plate
  - Ad Effectiveness higher

Candidate Points

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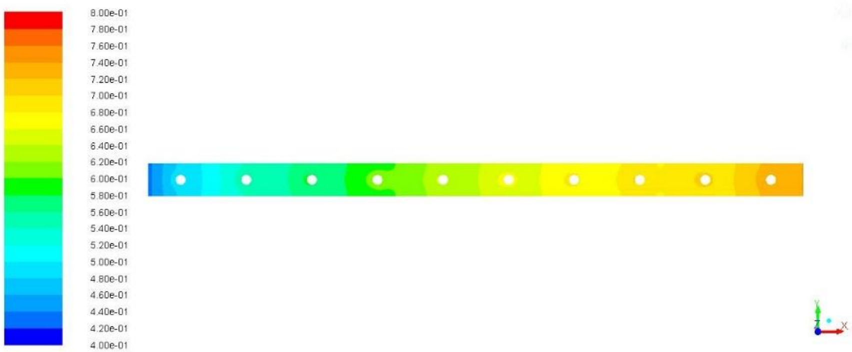
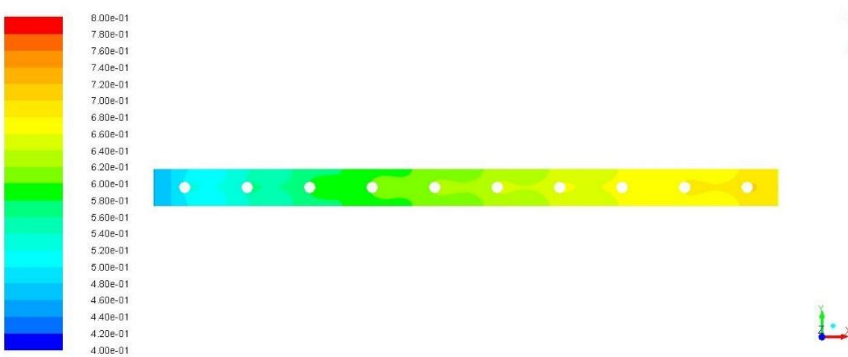
Overall effectiveness on the Plate

Candidate Point N°1

Candidate Point N°2



Candidate Point N°3

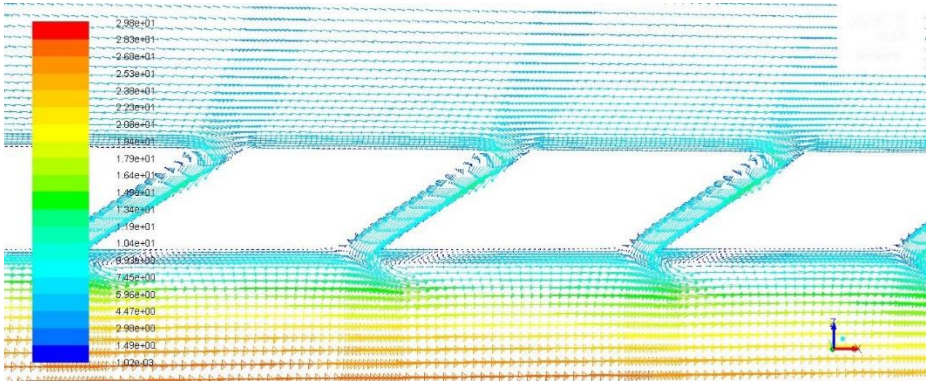


- **More homogeneous effectiveness**
- **Higher minimum effectiveness**

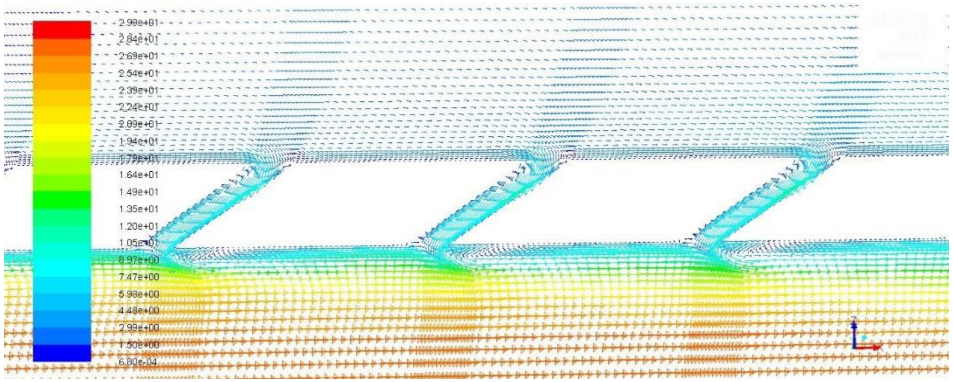
Candidate Points

Velocity vectors on symmetry plane

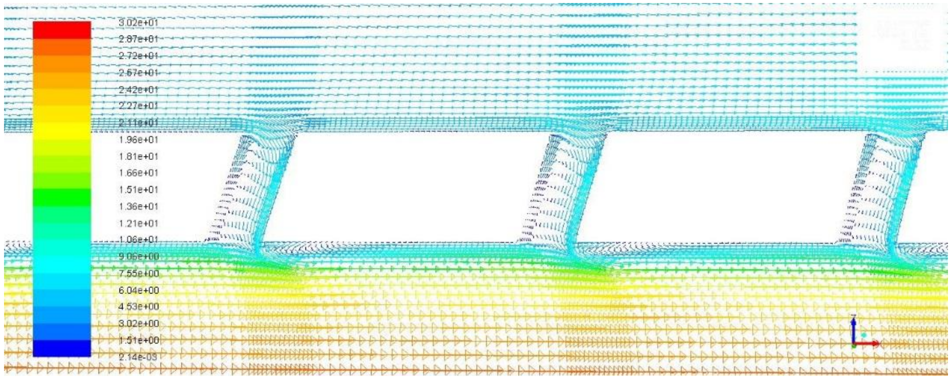
Candidate Point N°1



Candidate Point N°2



Candidate Point N°3



Smaller detachment and recirculation zone

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Candidate Points

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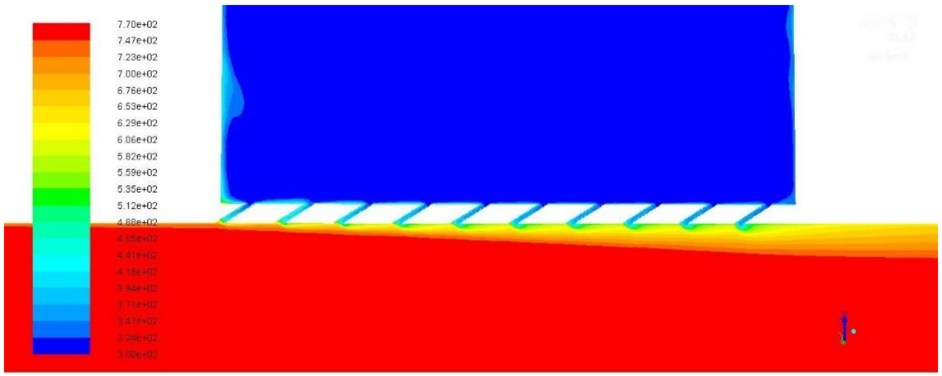
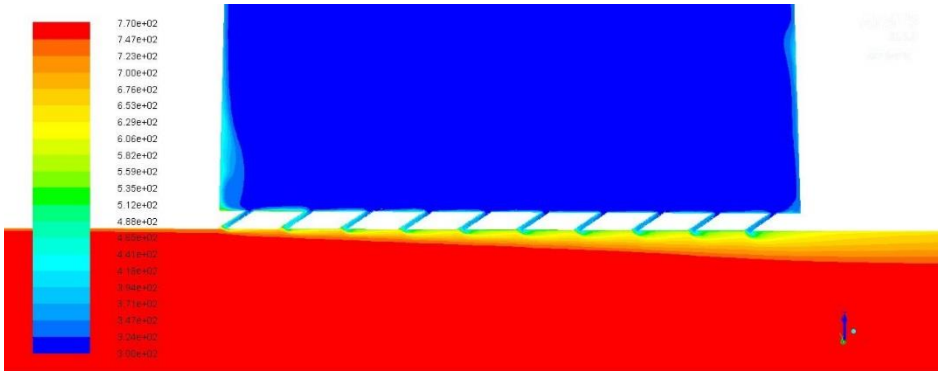
Temperature profile on symmetry plane

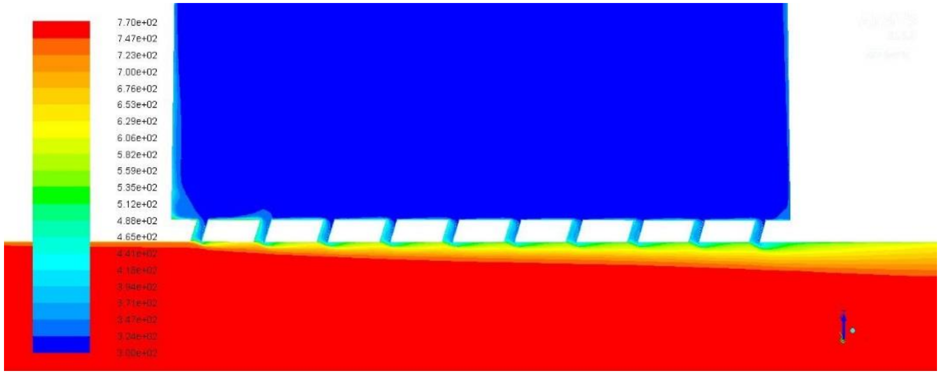
Candidate Point N°1



Candidate Point N°2



Candidate Point N°3

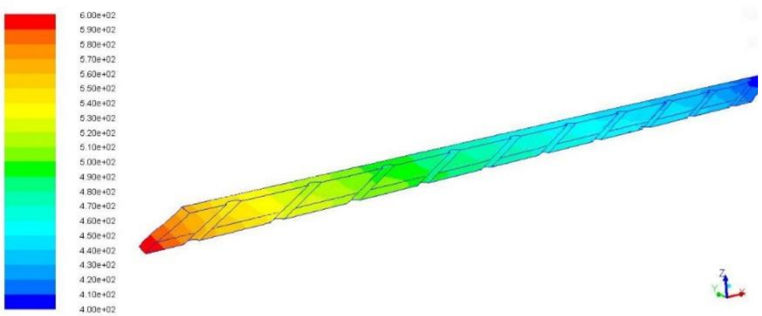


Better Coverage of the plate

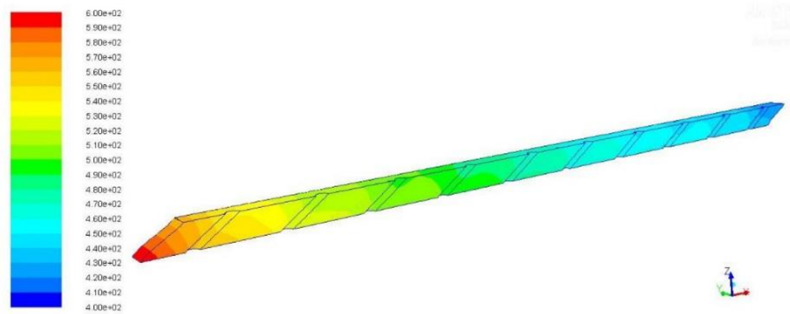
Candidate Points

Temperature gradient on the plate

Candidate Point N°1



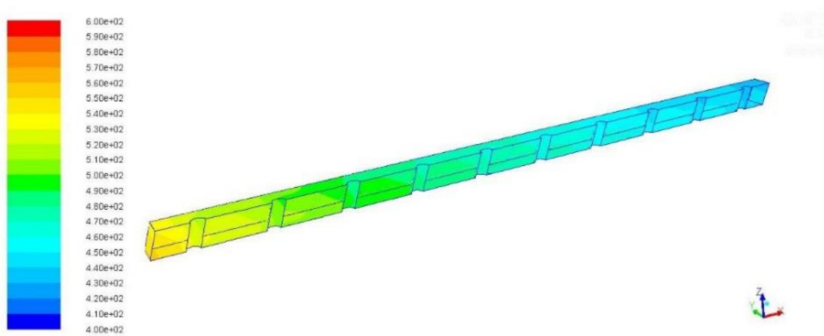
Candidate Point N°2



$\nabla T_X \approx 200\ K$

$\nabla T_Z \approx 30\ K$

Candidate Point N°3



$\nabla T_X < 130\ K$

$\nabla T_Z < 10\ K$

Candidate Point N°3

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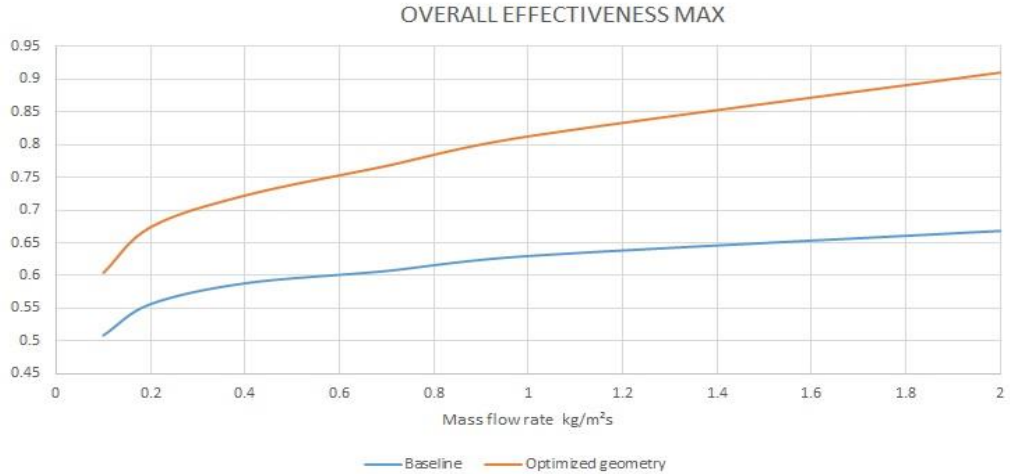
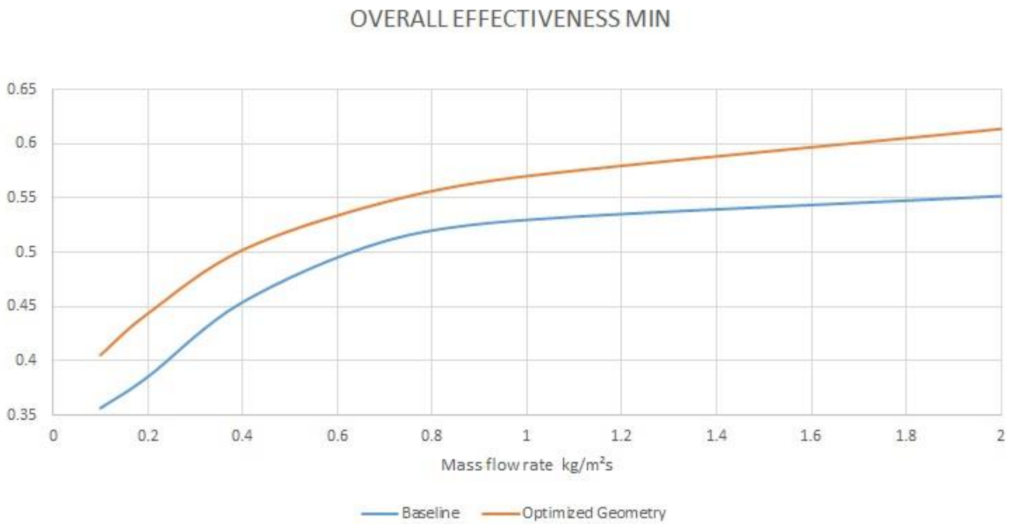
Overall effectiveness as a function of cooling air mass flow (G)





- New geometry is better than baseline for all G
- Get same effectiveness with lower G
- Plateaux for high G

Conclusions

- CFD numerical study of an effusion cooling system developed at ***University of Leeds***

- Model validation matching experimental data obtained from:
  G E Andrews, A A Asere, M L Gupta and M C Mkpadi,
  "Effusion cooling: the influence of the number of holes"
  Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 1990

- Shape optimization performed by means of Rbf Morph and Ansys Workbench suite

- Results analysis to get influence of the shape parameters on the effusion cooling effectiveness, improvement of 30%

- Found an optimal geometry reducing up to 10 times cooling air flow, without reducing effectiveness.

W. Savastano, A. Pranzitelli, G. E. Andrews, M. E. Biancolini, D. B. Ingham, M. Pourkashanian,

“Goal driven shape optimisation for conjugate heat transfer in an effusion cooling plate”,

Asme Turbo Expo, Montreal, Québec 2015

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Thank you for your attention

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