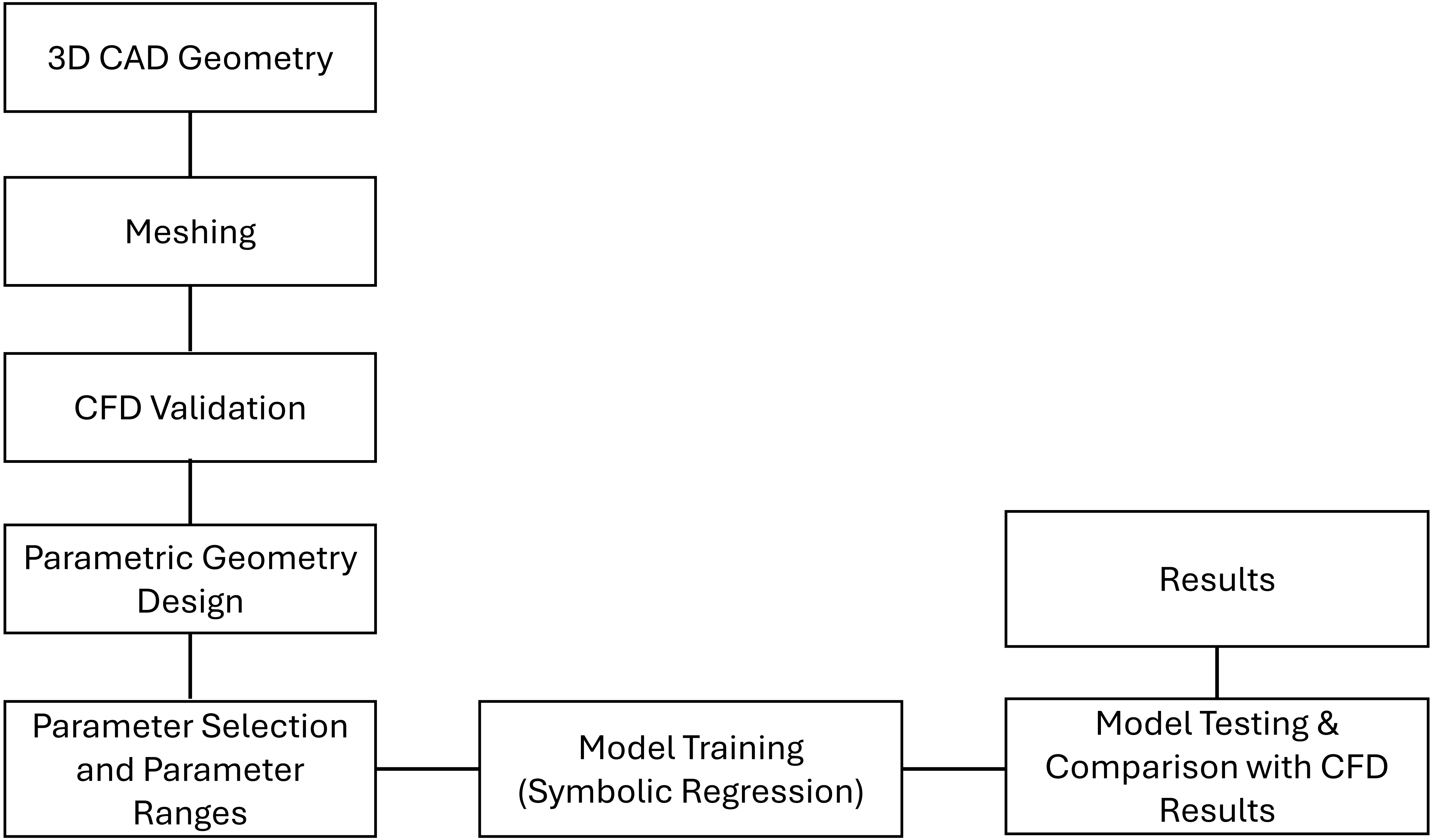
Development of a Symbolic Regression-Based Model for Leading Edge of Film Cooled Gas Turbine Blade

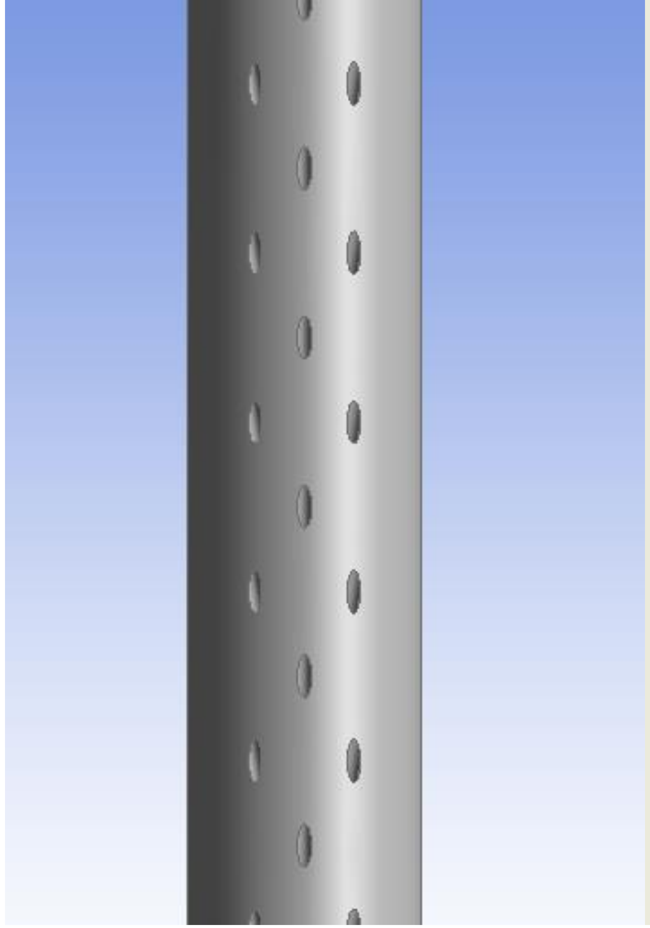
Project Workflow

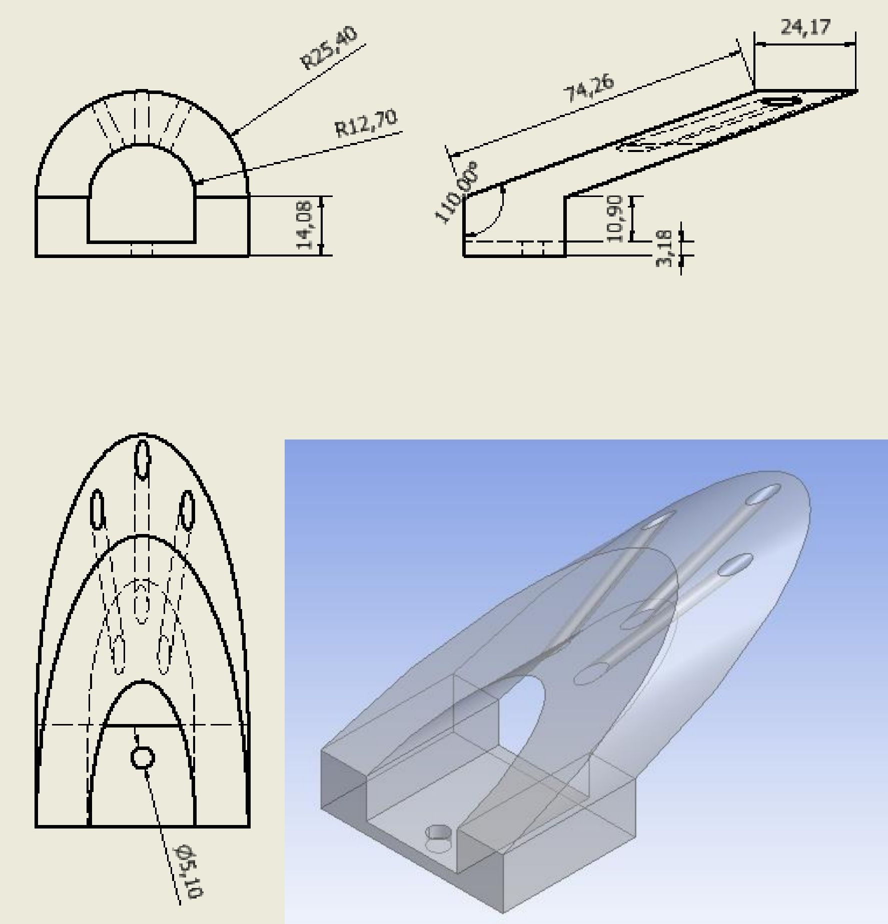


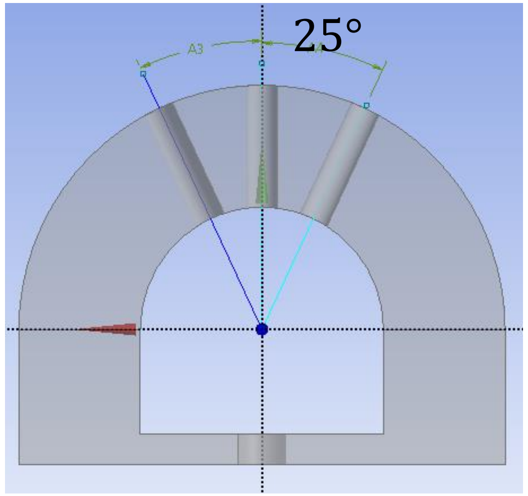
3D CAD Geometry

- The validation is based on the study “Overall Effectiveness for a Film-Cooled Turbine Blade Leading Edge With Varying Hole Pitch. ”

- The geometry was designed to enable periodic analysis, since the paper does not specify the number of holes.

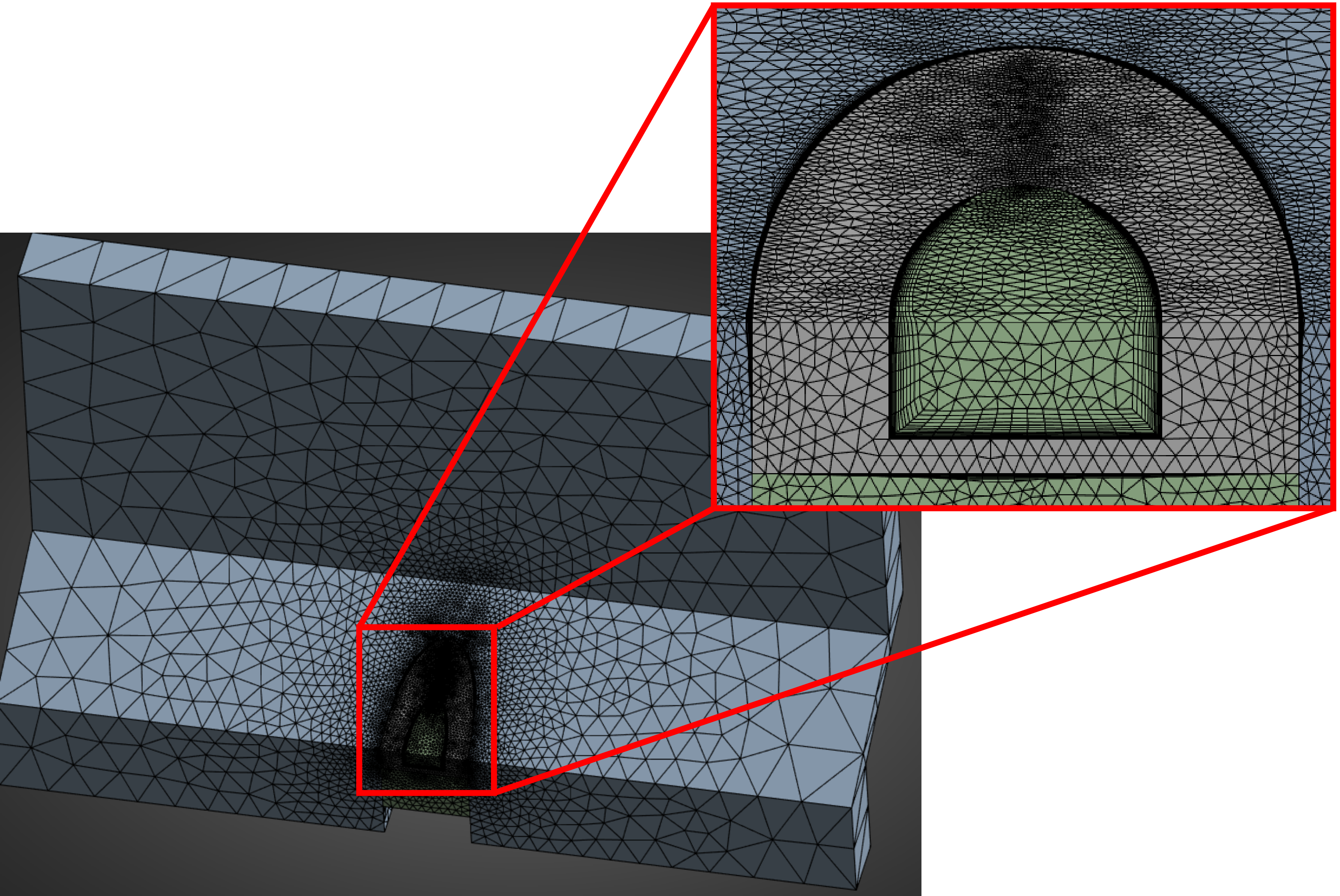




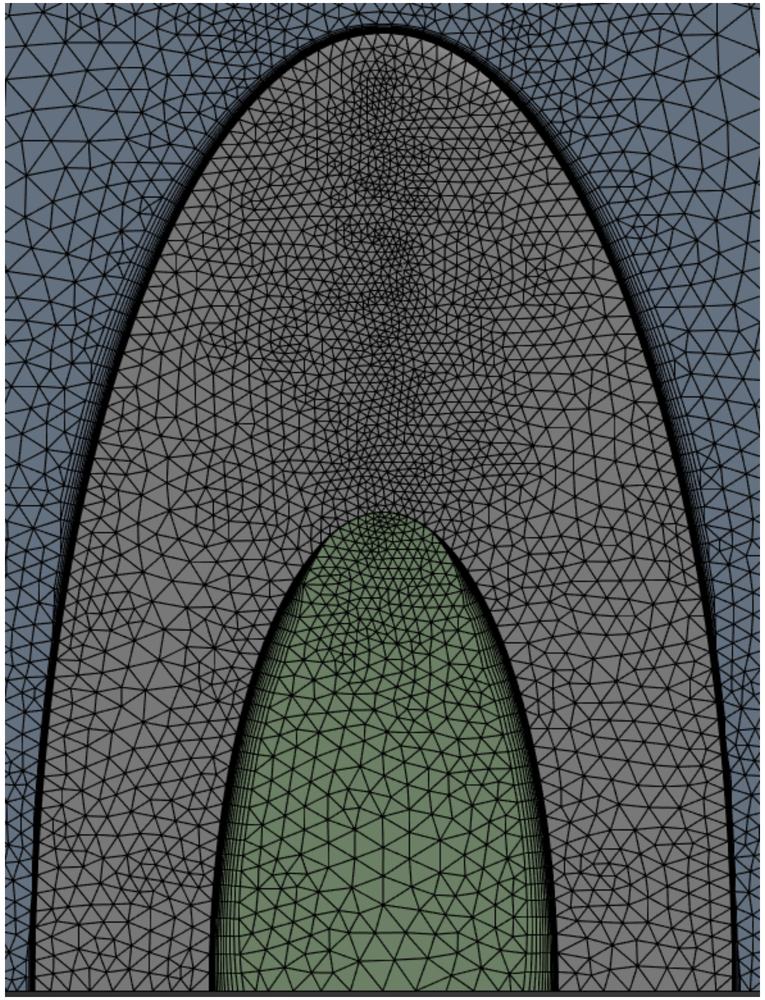


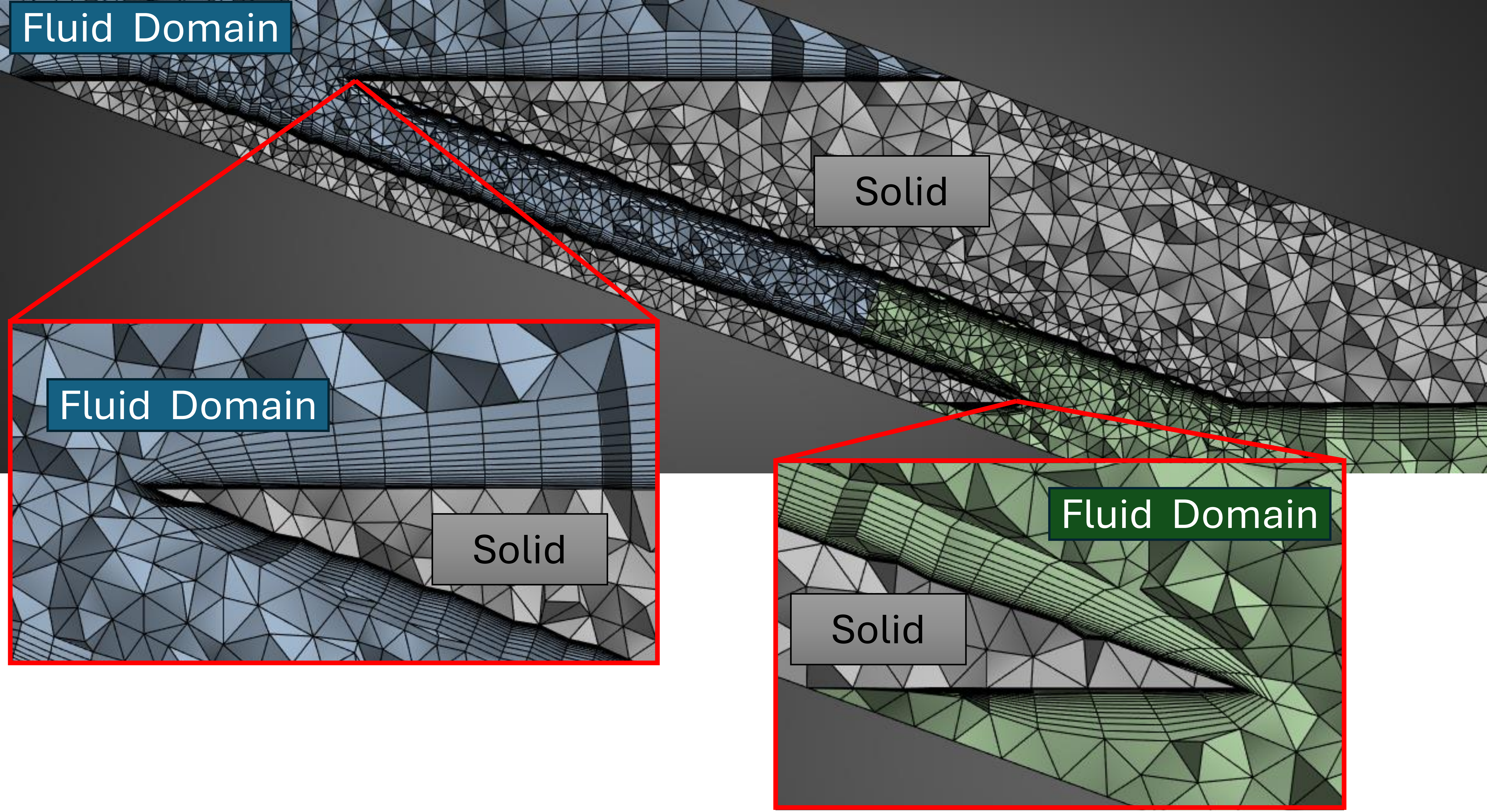
K = 1.04 ± 0.06 W/m.K (Polycast 287)

Meshing



View from top



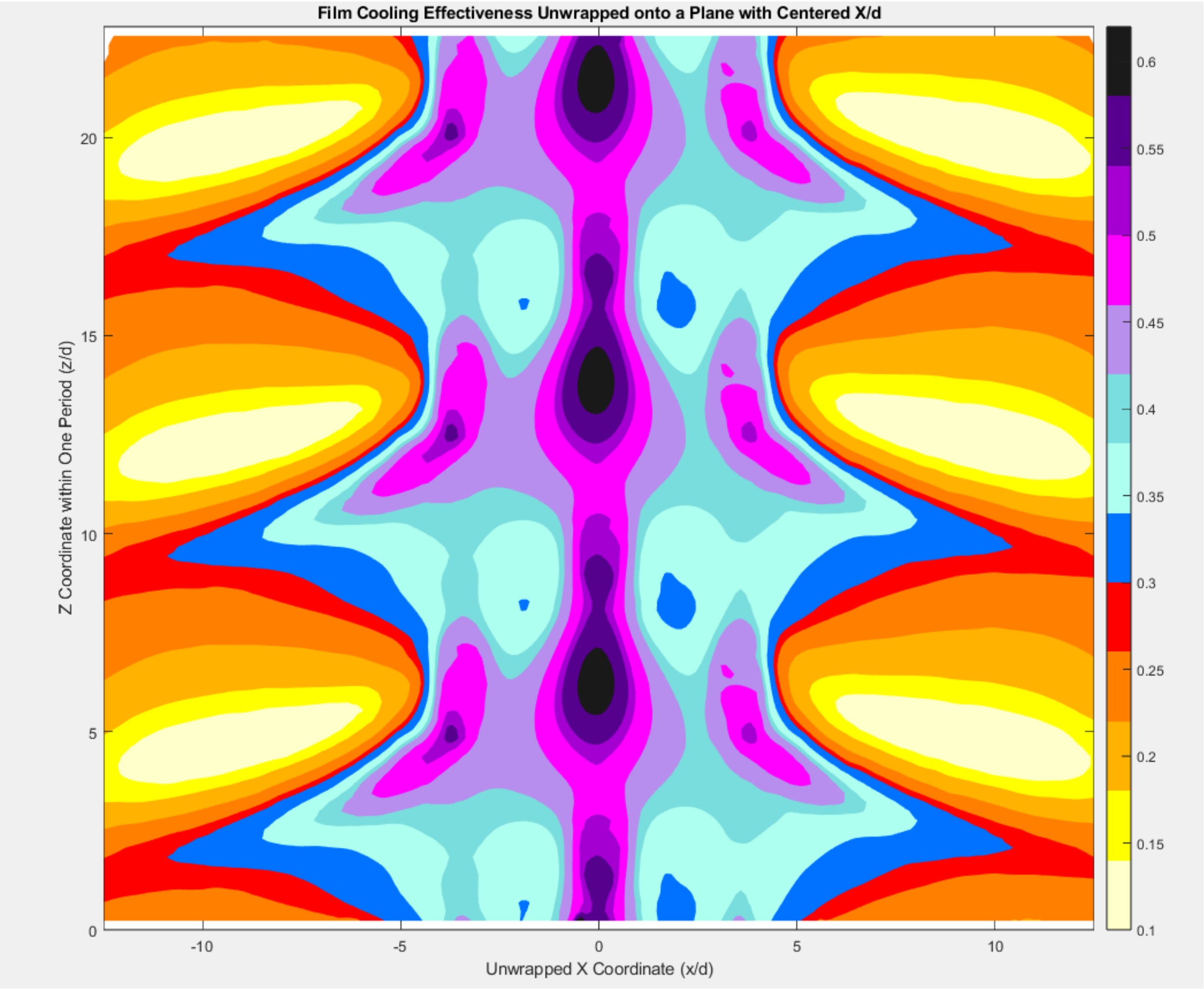

Fluid Domain
Solid
Fluid Domain
Solid
Fluid Domain
Solid

Boundary Conditions

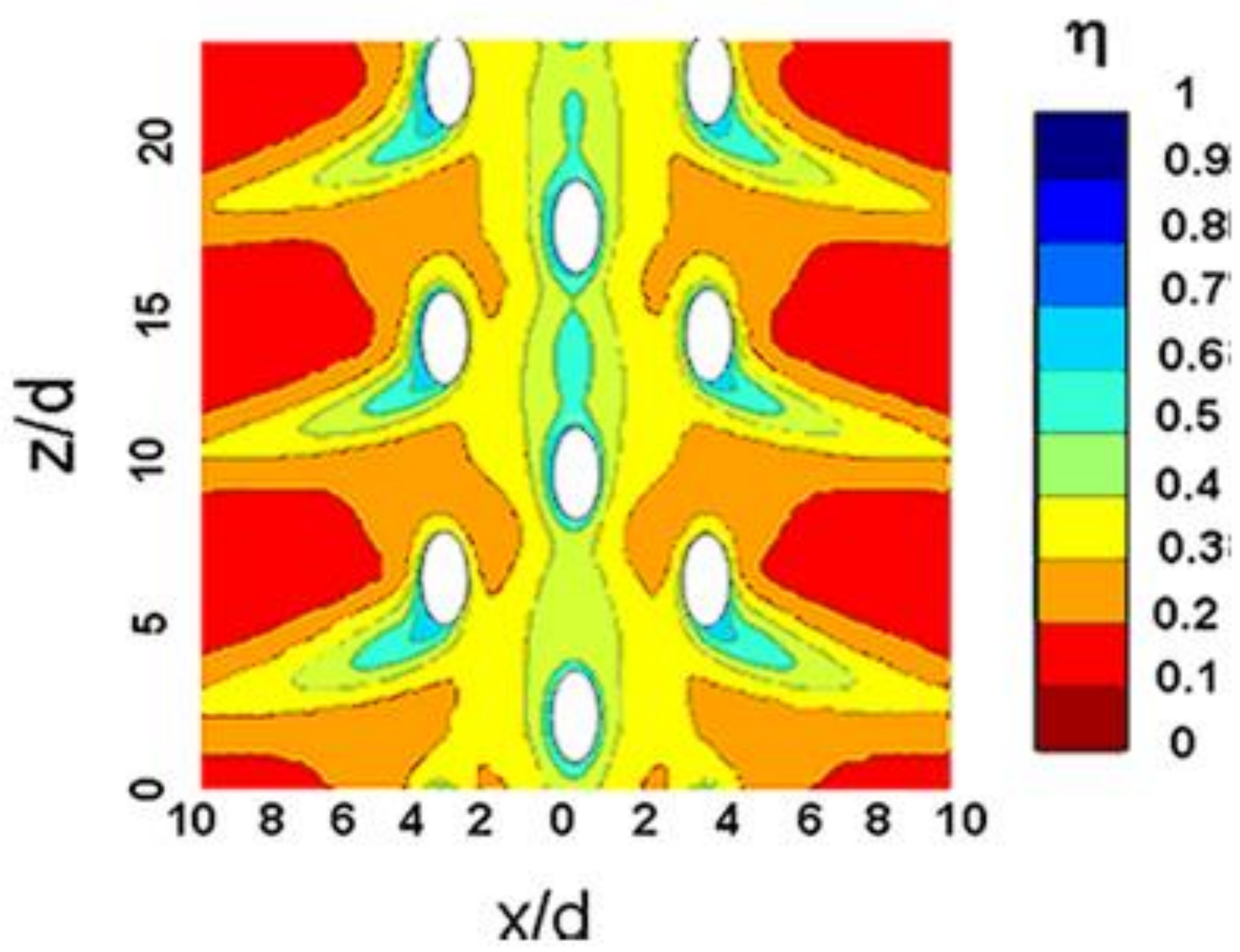
- Mainstream velocity was maintained at a nominal value of 15 m/s.
- Tu levels measured at 5%, with a turbulence length scale of 2.3 cm at the location of the model
- Typical T_∞ values were near 300 K. The coolant was simulated using N_2 gas at 200 K in order to maintain a constant DR of 1.5 for all test conditions.
- The cold gas then passed through a plenum which served to evenly distribute the gas along the span of the model.
- turbulence effects were modeled with the Realizable k–ε and Menter SST k–ω approaches
- (Blowing ratio) M = 2

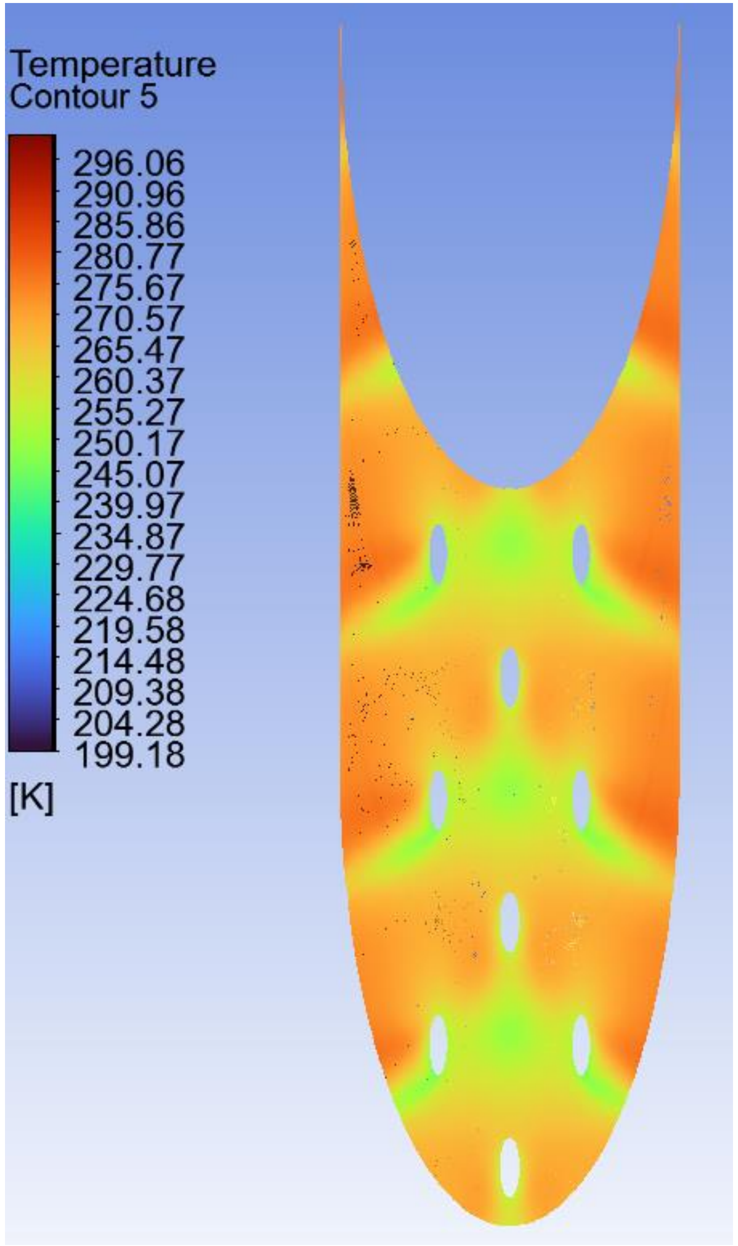
Results

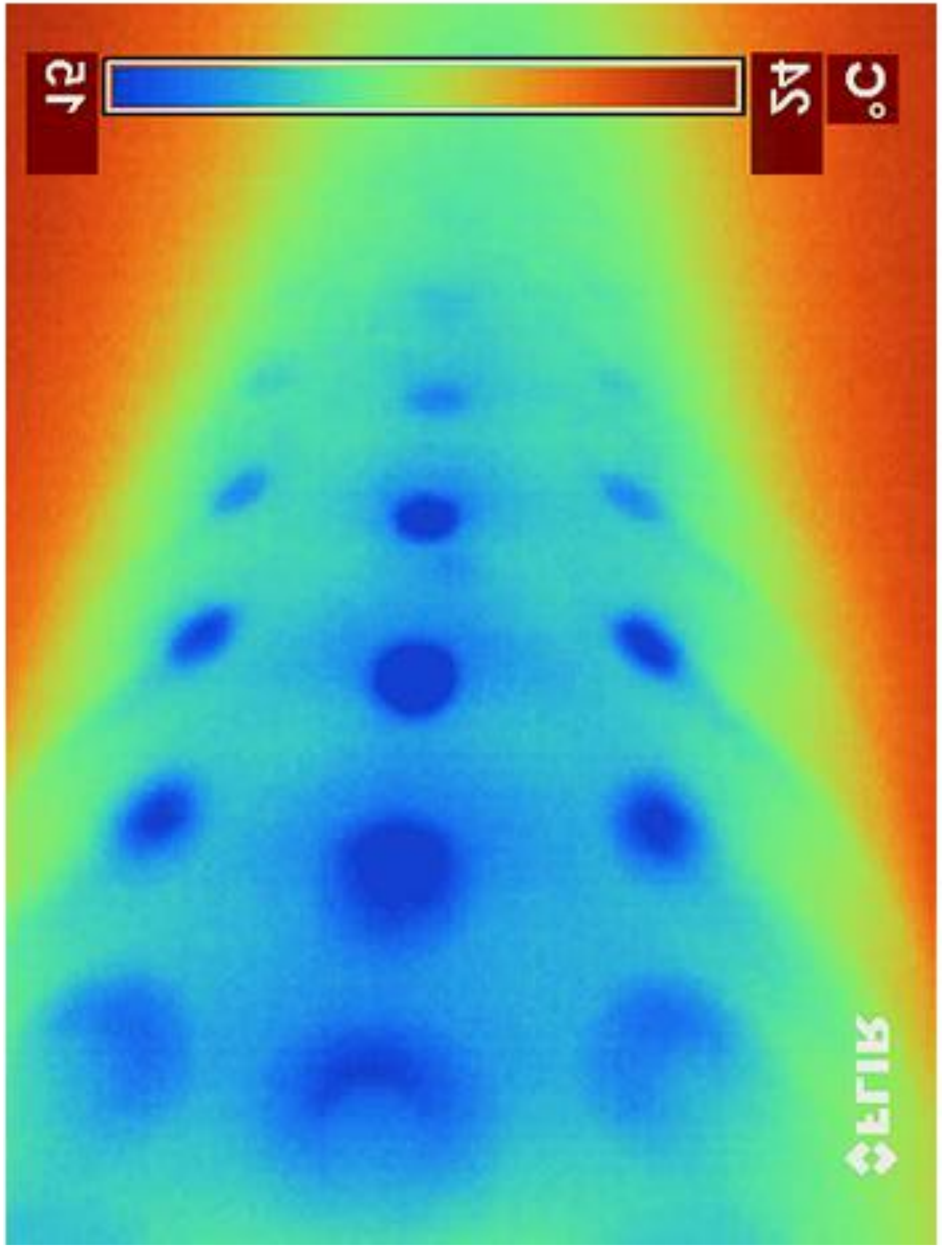
CFD

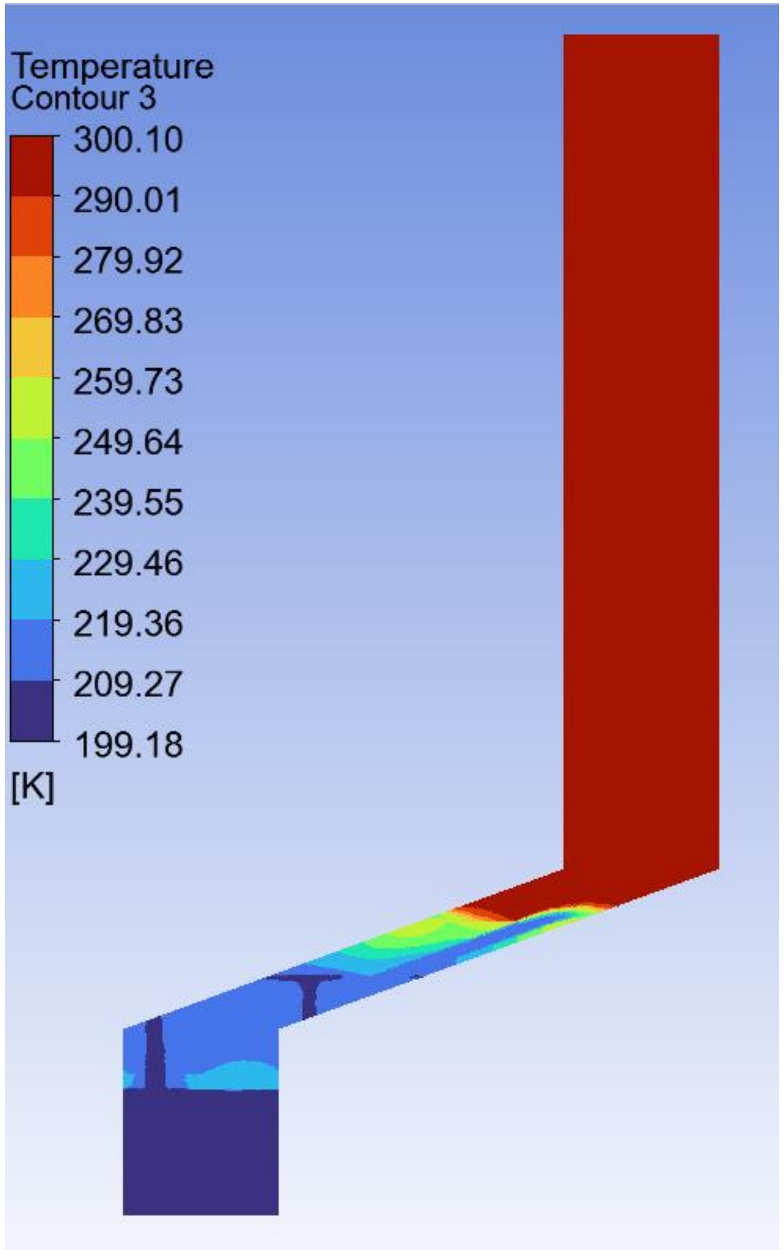


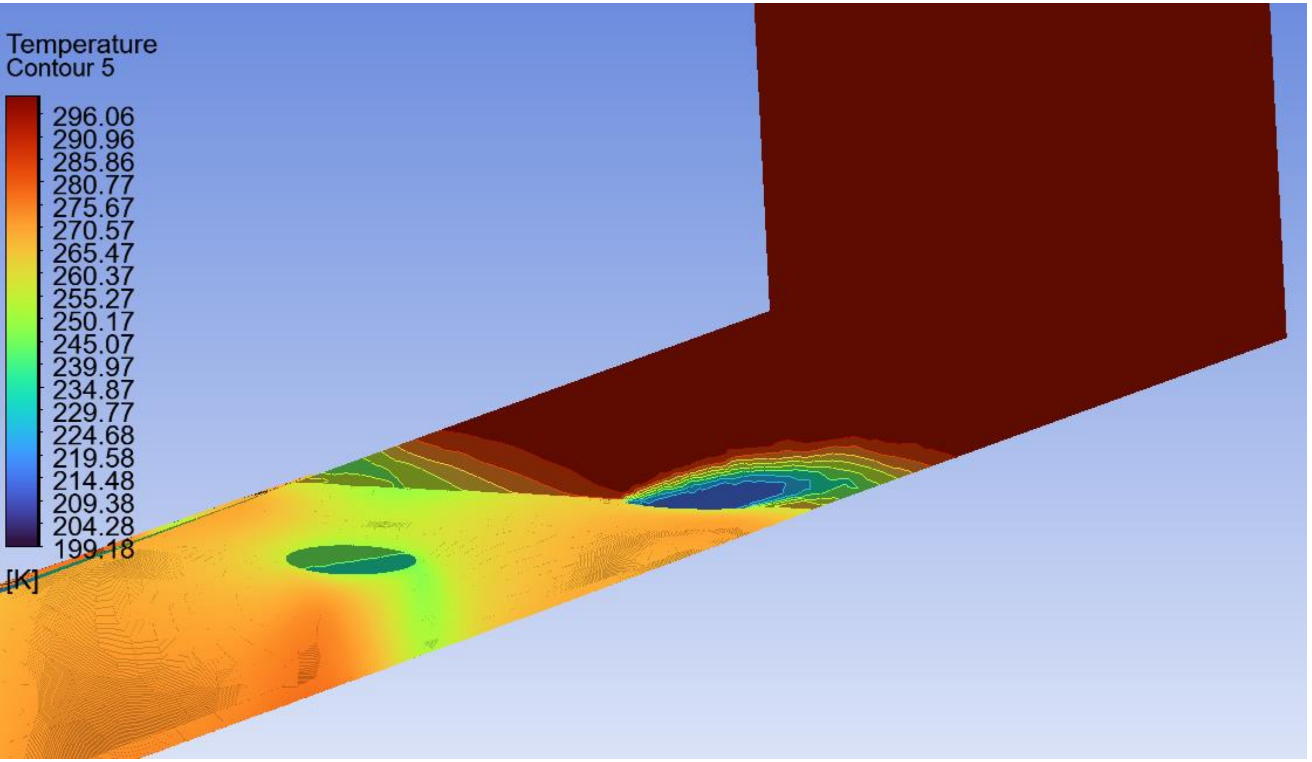
Experiment




Temperature
Contour 5
296.06
290.96
285.86
280.77
275.67
270.57
265.47
260.37
255.27
250.17
245.07
239.97
234.87
229.77
224.68
219.58
214.48
209.38
204.28
199.18
[K]




Temperature
Contour 3
300.10
290.01
279.92
269.83
259.73
249.64
239.55
229.46
219.36
209.27
199.18
[K]


Temperature
Contour 5
296.06
290.96
285.86
280.77
275.67
270.57
265.47
260.37
255.27
250.17
245.07
239.97
234.87
229.77
224.68
219.58
214.48
209.38
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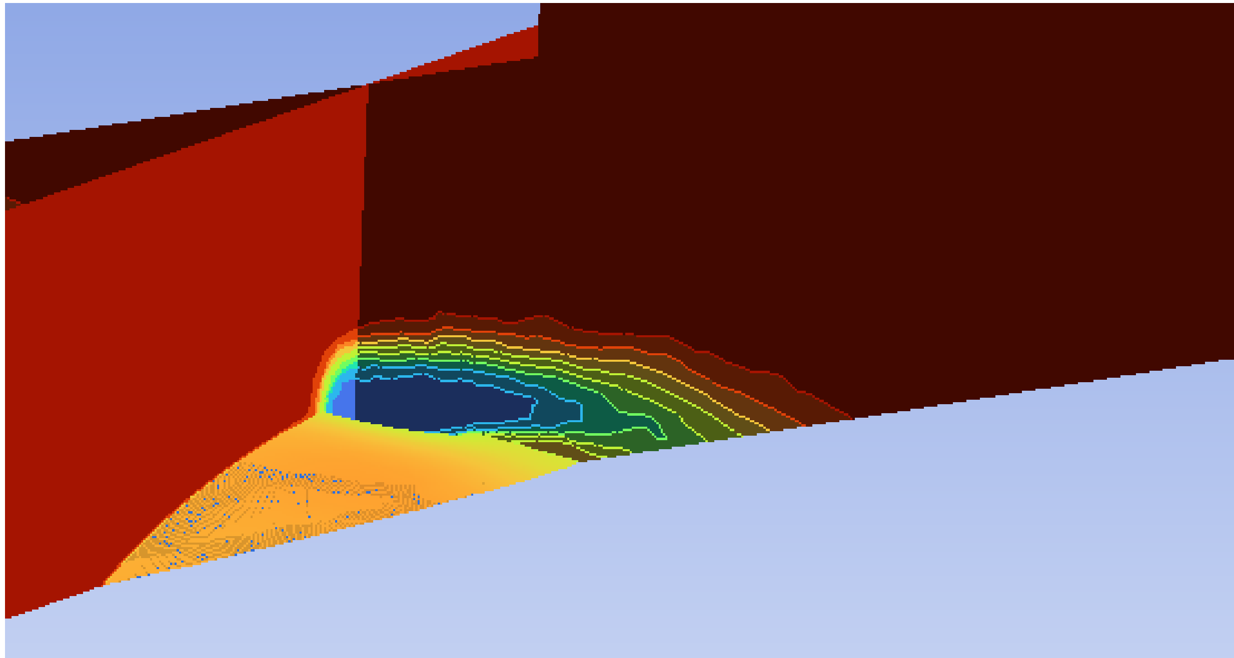
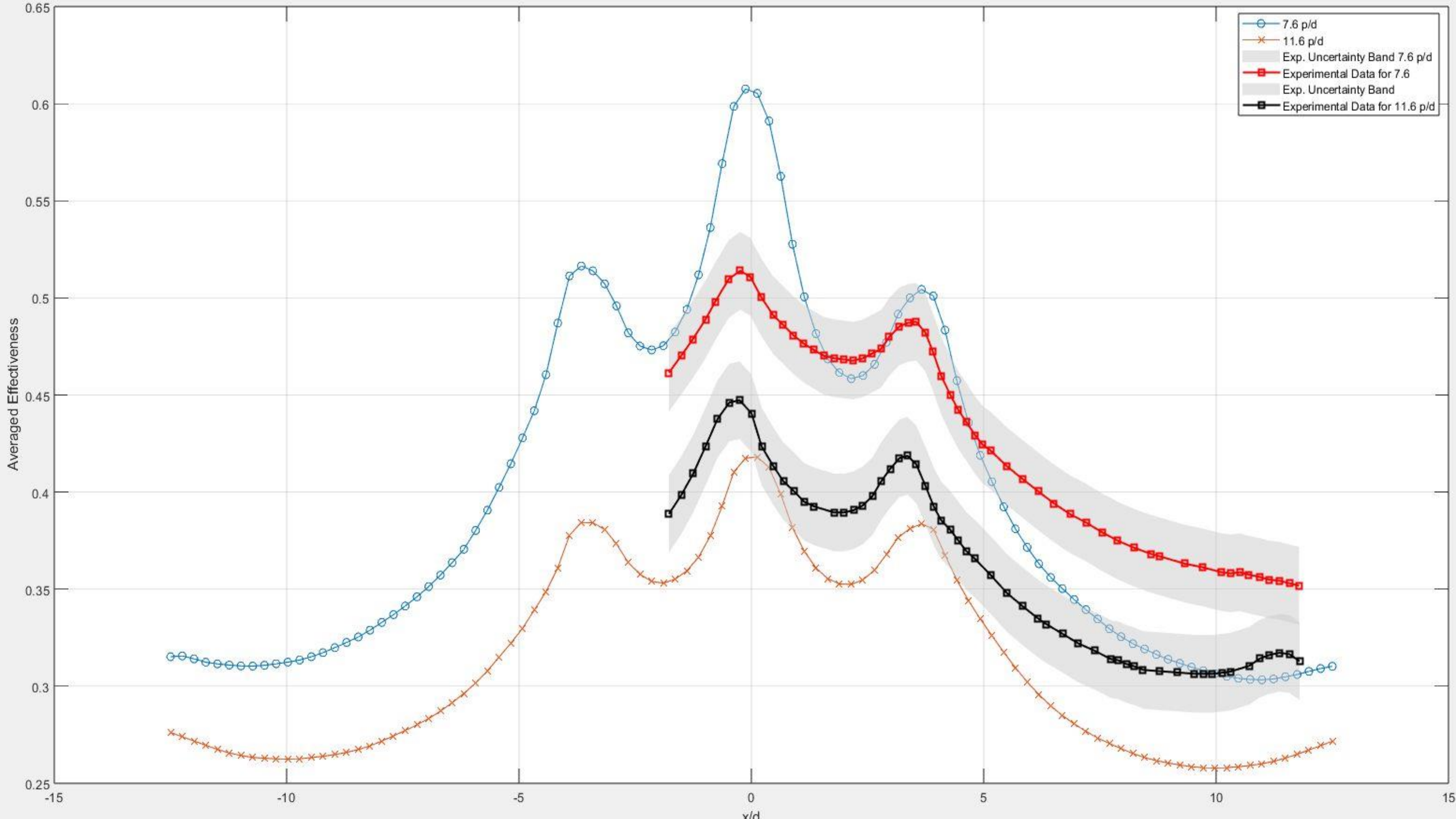
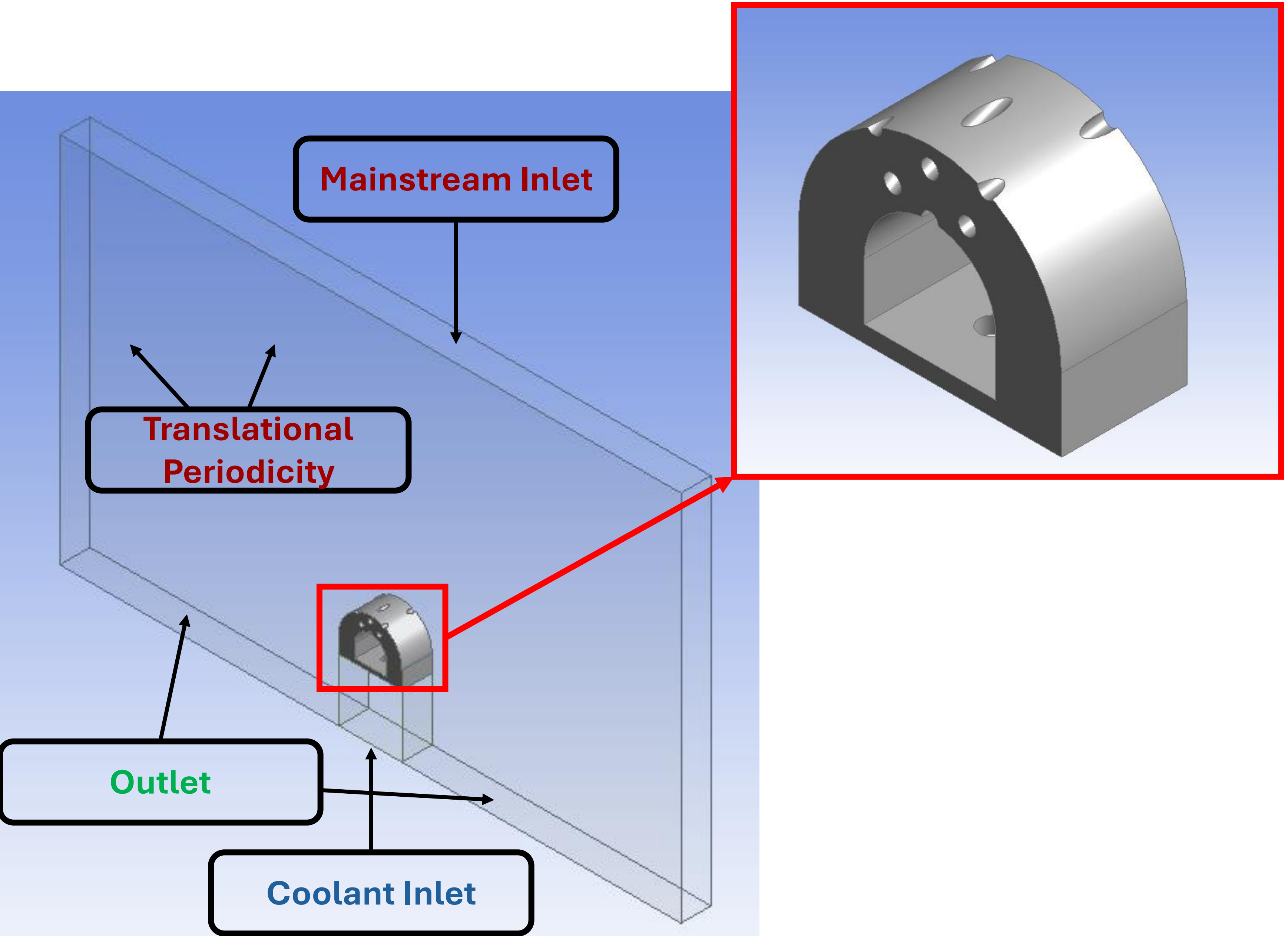
199.18
[K]

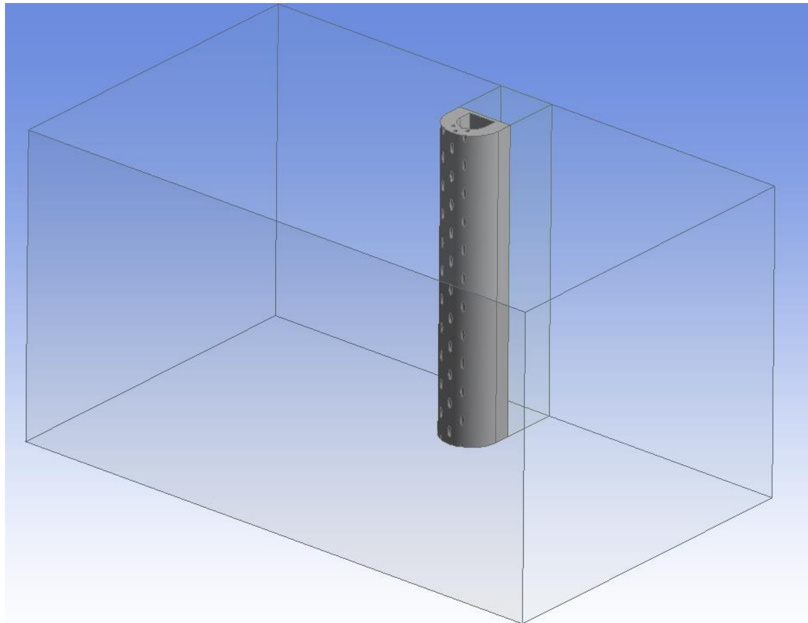




0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
Averaged Effectiveness
-15
-10
-5
0
5
10
15
x/d
7.6 p/d
11.6 p/d
Exp. Uncertainty Band 7.6 p/d
Experimental Data for 7.6
Exp. Uncertainty Band
Experimental Data for 11.6 p/d

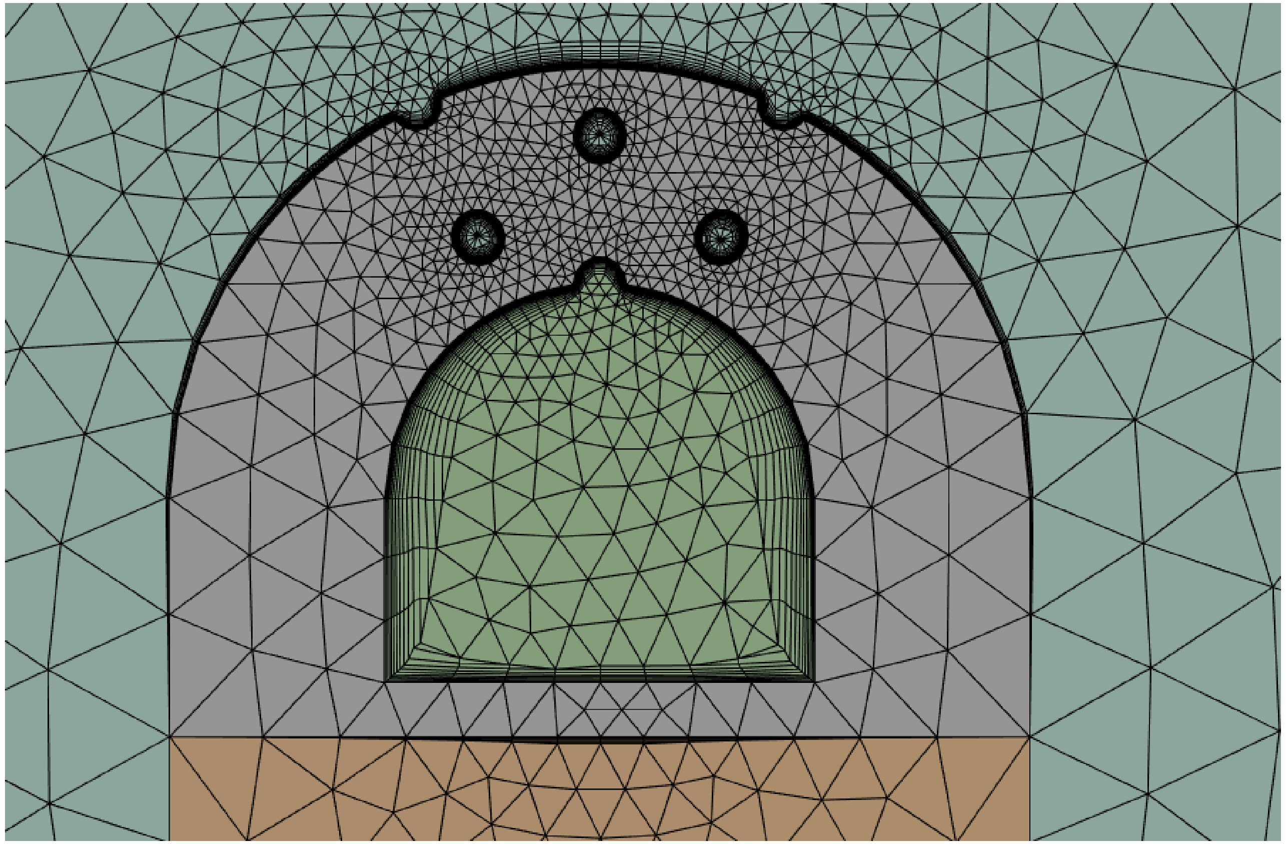
Parametric Study



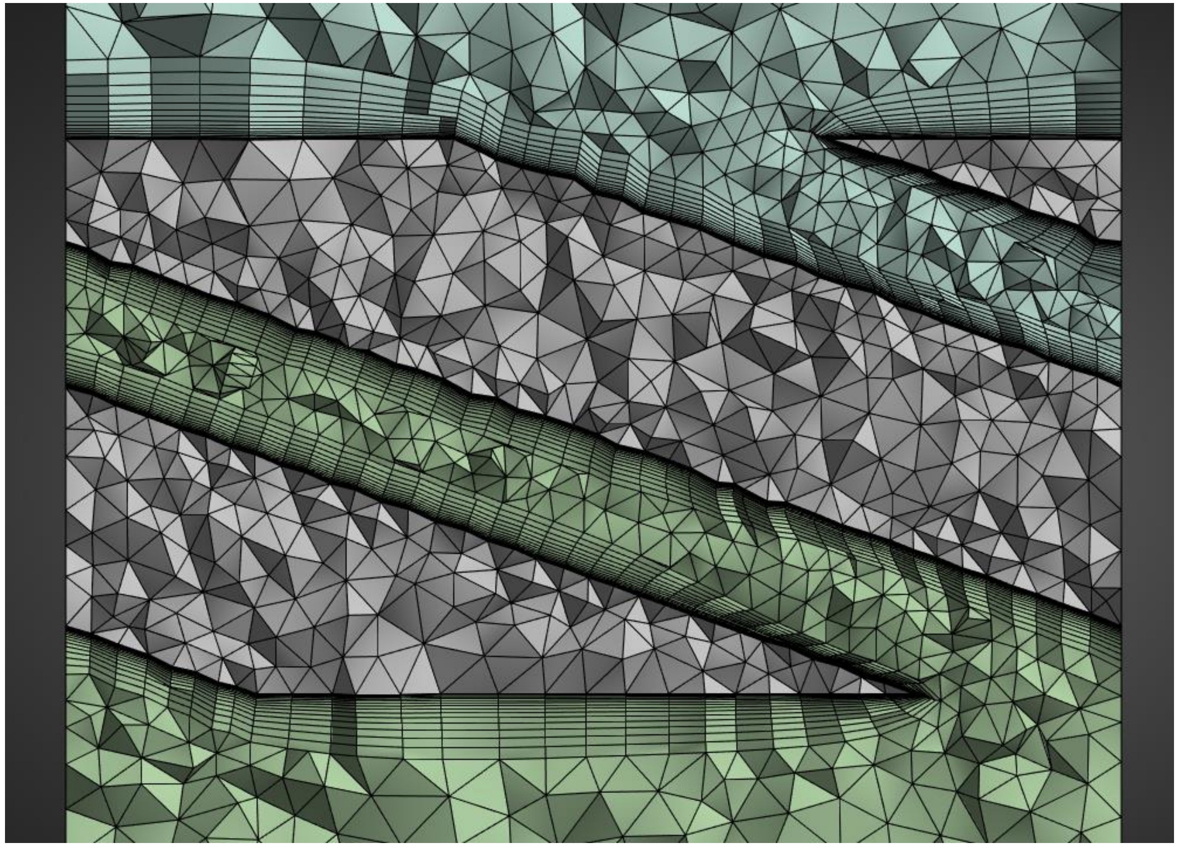


Meshing For Parametric Geometry

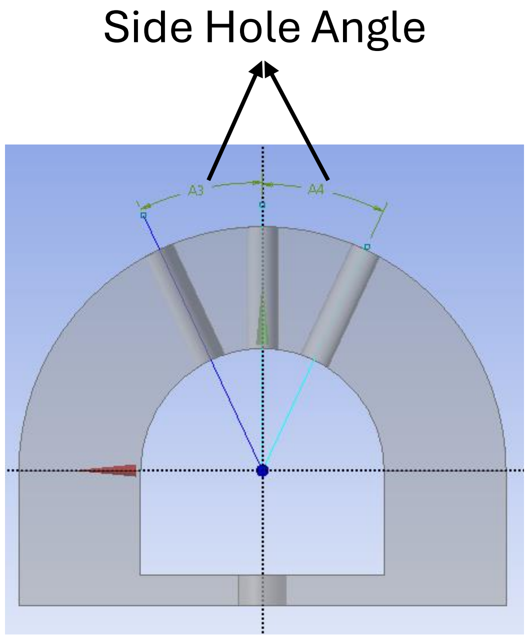
View From Front

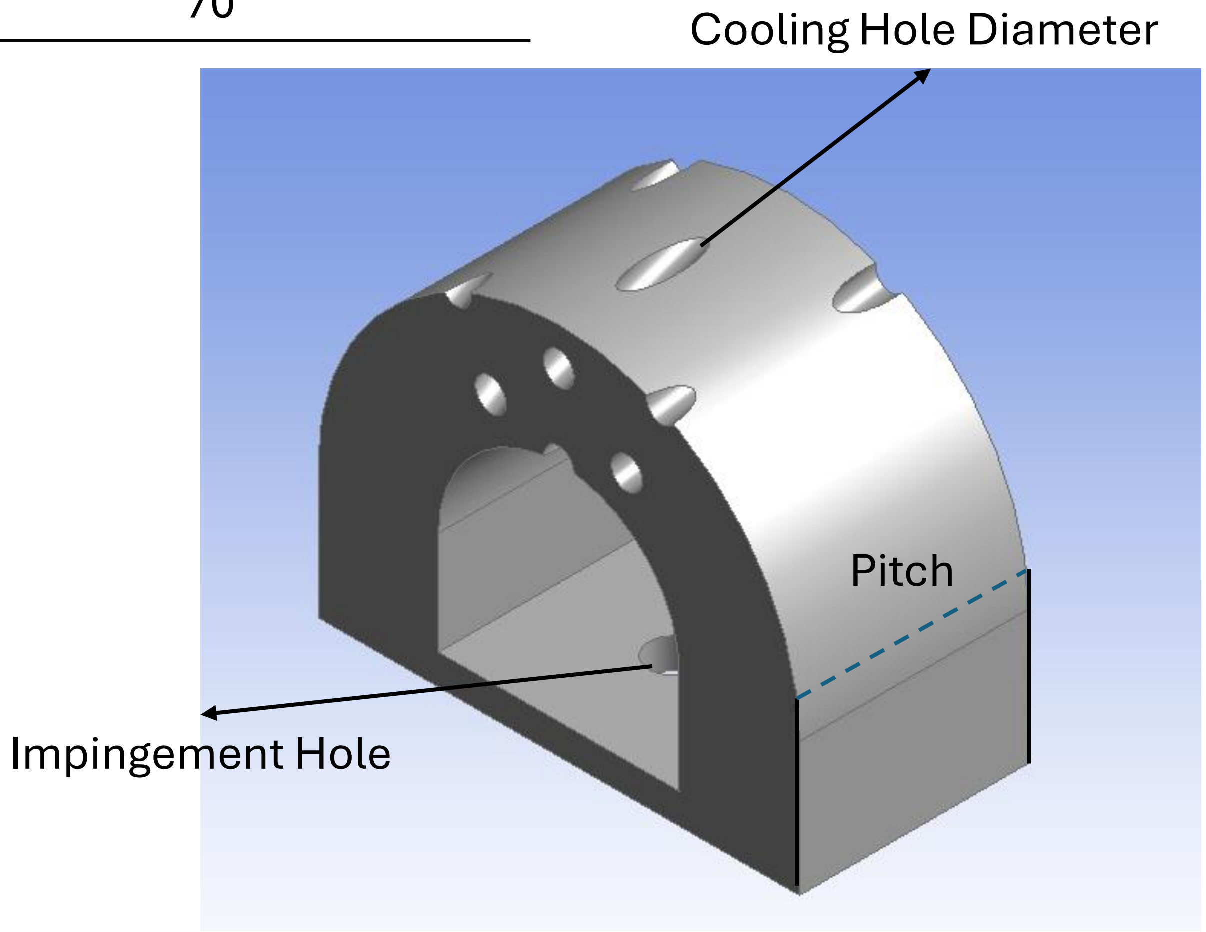


View From inside of the Geometry



Design variable	Symbol	Unit	Lower bound	Upper bound
Cooling Hole Diameter	D	mm	2	6
Pitch	P	mm	22	50
Impingement Hole Diameter	ID	mm	3	12
Side Hole Angle	Ø	°	15	70





Training Samples

D	P	ID	ø	Surface Temperature
5.1	24.168	3.18	25	296.8727
3	22	2	15	296.9487
3	22	2	45	297.4766
3	22	2	70	296.9168
3	22	4	15	297.0906
3	22	4	45	296.7818
3	22	4	70	295.8082
3	22	6	45	295.5831
3	22	6	70	297.9099
3	36	2	15	297.7951
3	36	2	45	297.2733
3	36	2	70	297.1273
3	36	4	15	297.8079
3	36	4	45	297.5459
3	36	4	70	298.6457
3	36	6	15	299.3115
3	36	6	45	295.982
3	36	6	70	272.3987
3	50	2	15	297.137
3	50	2	45	297.8616
3	50	2	70	297.2641
3	50	4	15	297.3921
3	50	4	45	297.4096
3	50	4	70	297.4233
3	50	6	15	293.9666
3	50	6	45	297.1769
3	50	6	70	297.5532
7	22	2	15	297.477
7	22	2	45	297.3758
7	22	2	70	297.6703
7	22	4	15	296.5115

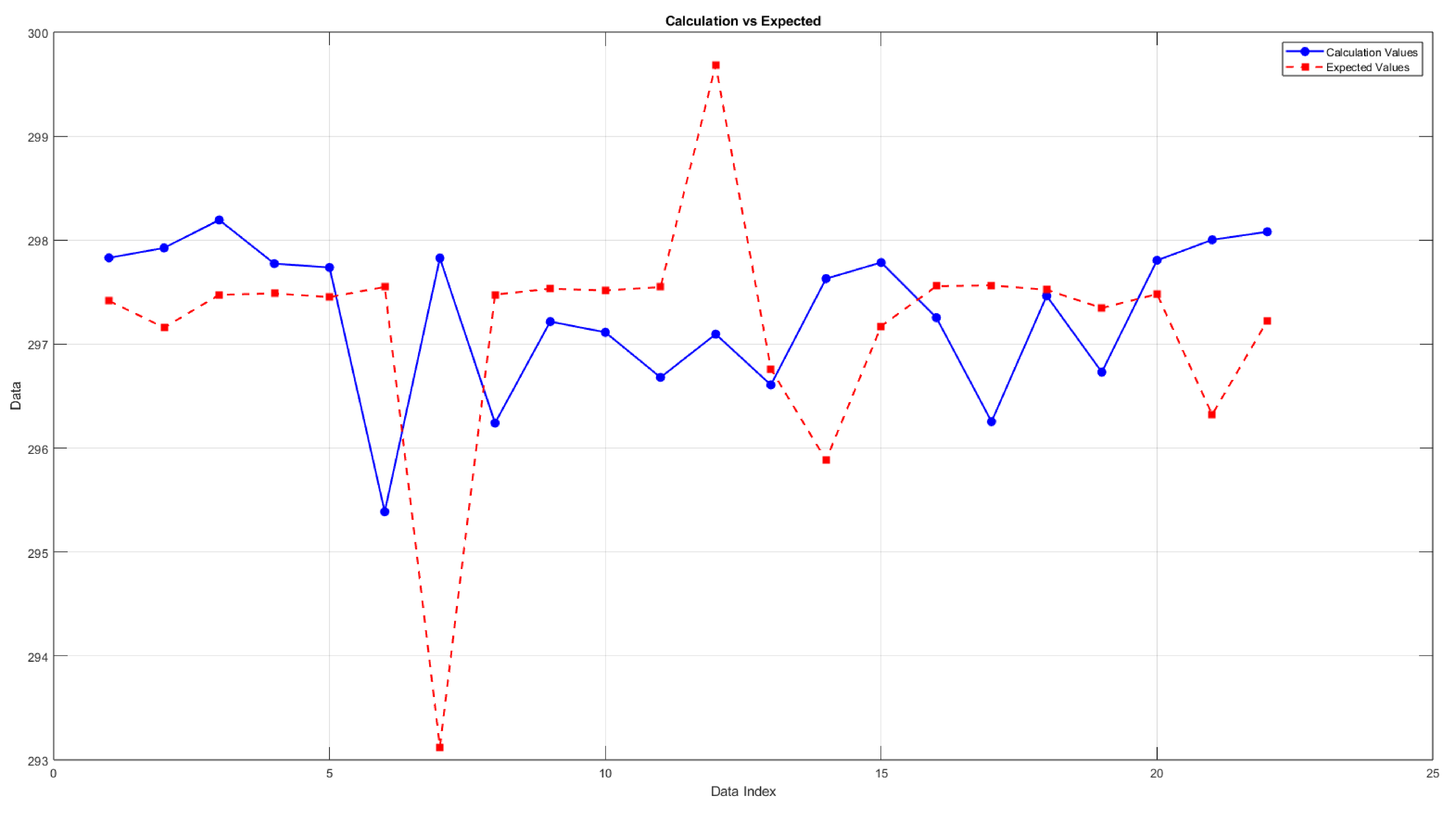
- The dataset consisting of these samples was utilized to train the symbolic regression-based model.
- These are only the first 31 samples. In total, there are 79 samples.
- The model was built in Python using the PySR library.

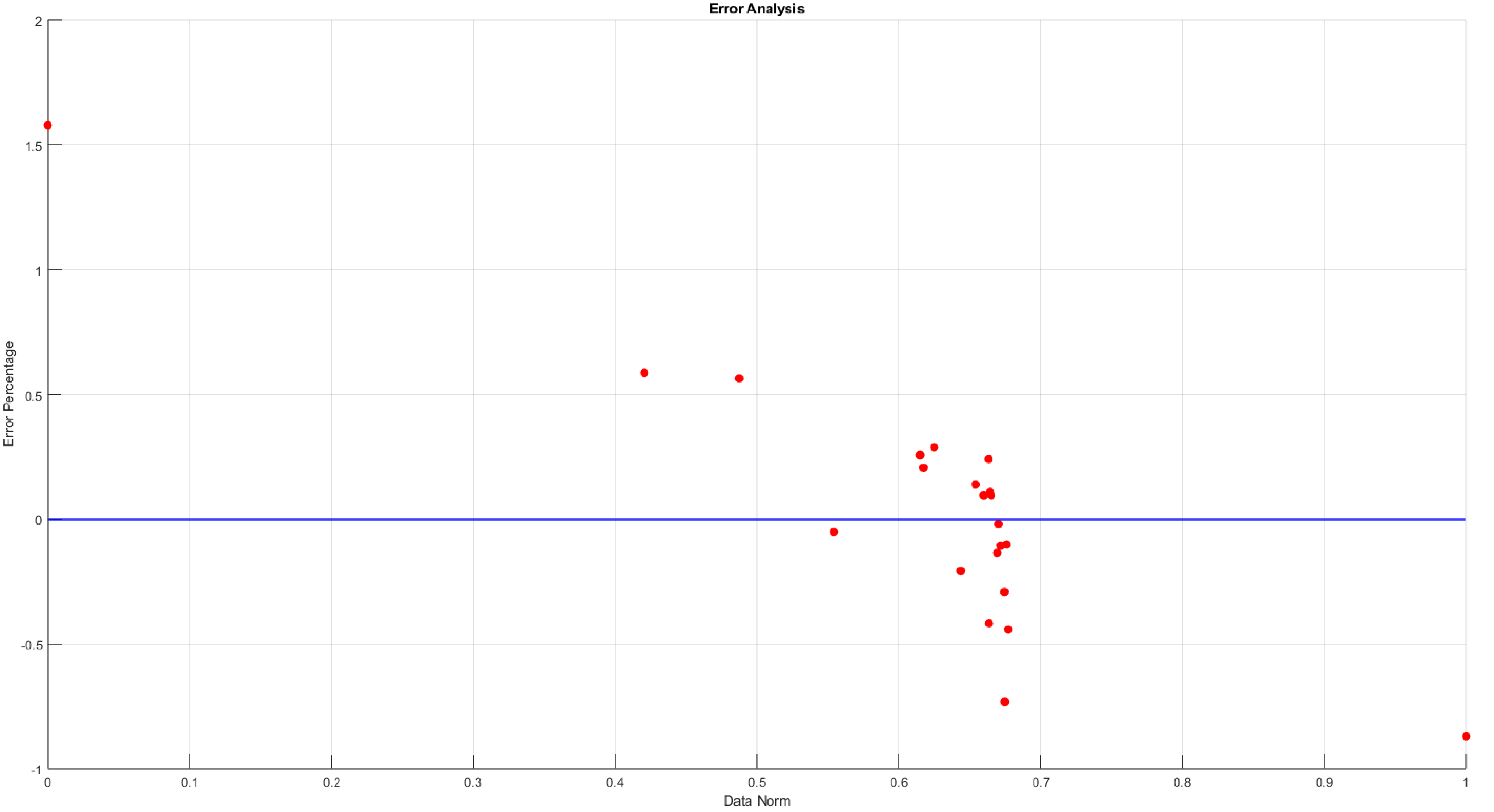
$$T_s = \left| 0.80867 \times \tan\left(\frac{e^D}{ID \times \left(\left(\frac{A}{P} \right)^{5.9273} + P \right)} \right) \right|$$

Testing Samples

D	P	ID	ø	Surface Temperature
7.5	36	4	42.5	297.8294
3	36	4	42.5	297.925
12	36	4	42.5	298.1937
7.5	22	4	42.5	297.7734
7.5	50	4	42.5	297.7365
7.5	36	2	42.5	295.3878
7.5	36	6	42.5	297.8272
4.331073	26.14112	2.591588	23.13434	296.2405
10.66893	26.14112	2.591588	23.13434	297.2165
4.331073	45.85888	2.591588	23.13434	297.1129
10.66893	45.85888	2.591588	23.13434	296.6797
4.331073	26.14112	5.408412	23.13434	297.0956
10.66893	26.14112	5.408412	23.13434	296.6072
4.331073	45.85888	5.408412	23.13434	297.6294
10.66893	45.85888	5.408412	23.13434	297.7846
4.331073	26.14112	2.591588	61.86566	297.2544
10.66893	26.14112	2.591588	61.86566	296.2538
4.331073	45.85888	2.591588	61.86566	297.4633
4.331073	26.14112	5.408412	61.86566	296.7302
10.66893	26.14112	5.408412	61.86566	297.8053
4.331073	45.85888	5.408412	61.86566	298.0026
10.66893	45.85888	5.408412	61.86566	298.0803

- Testing samples were used to compare the CFD results with the model predictions obtained from the training samples.

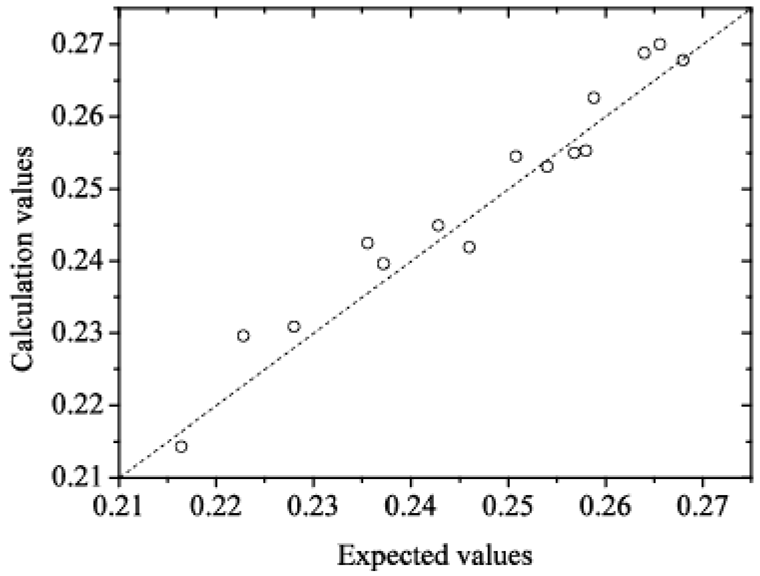

Calculation vs Expected
Calculation Values
Expected Values
Data
Data Index
300
299
298
297
296
295
294
293
0
5
10
15
20
25

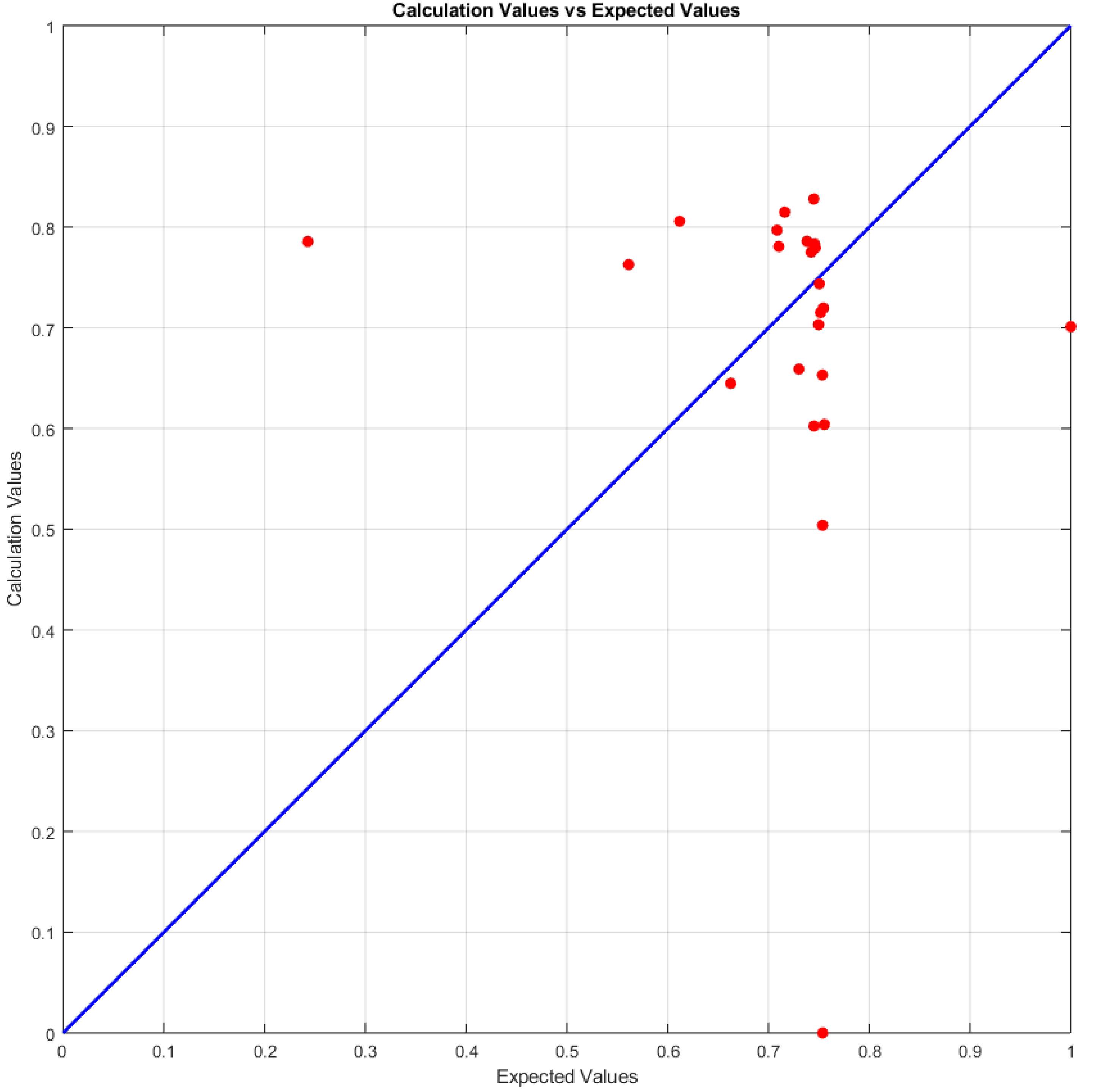


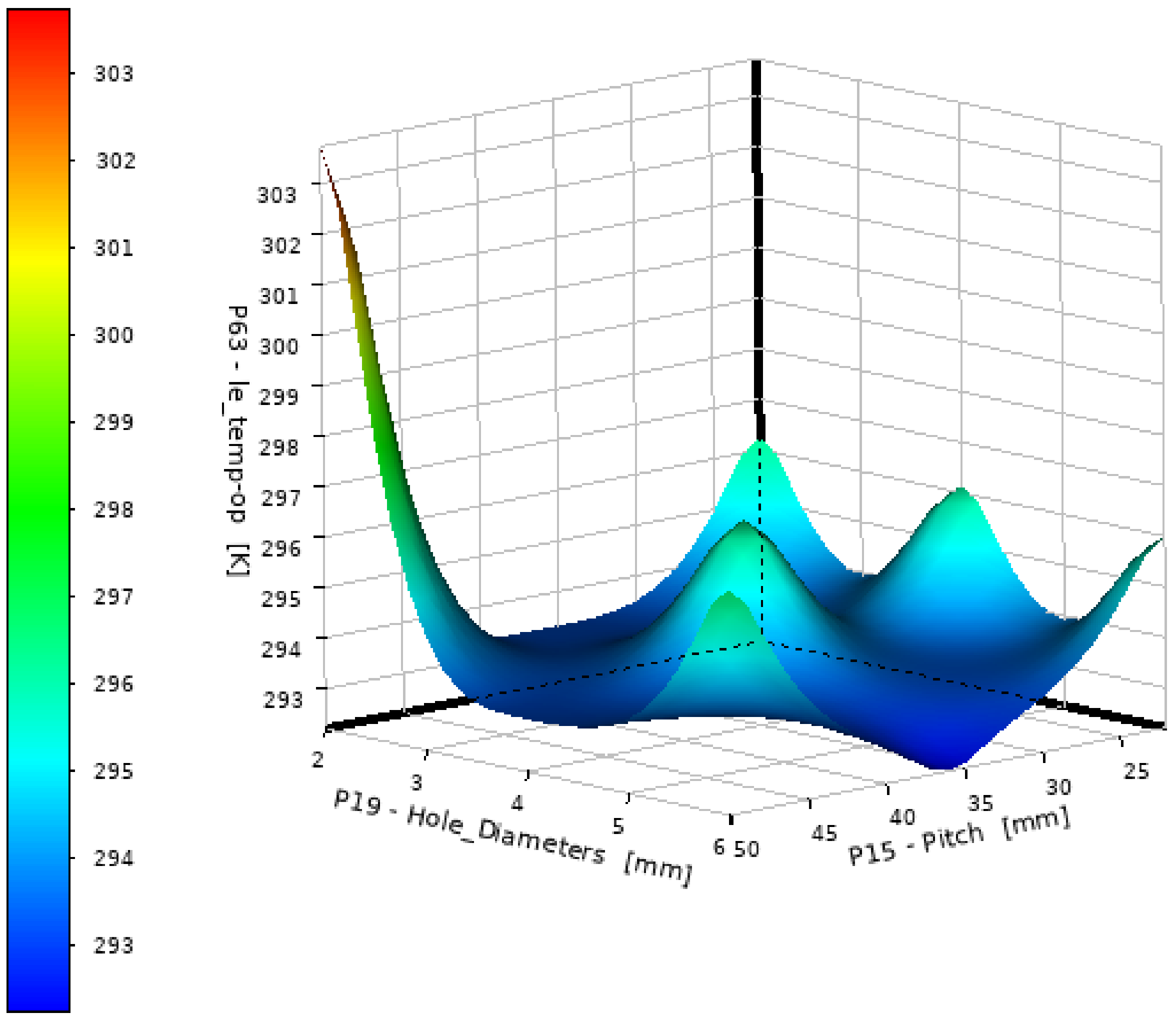
Error Analysis
Error Percentage
Data Norm
2
1.5
1
0.5
0
-0.5
-1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

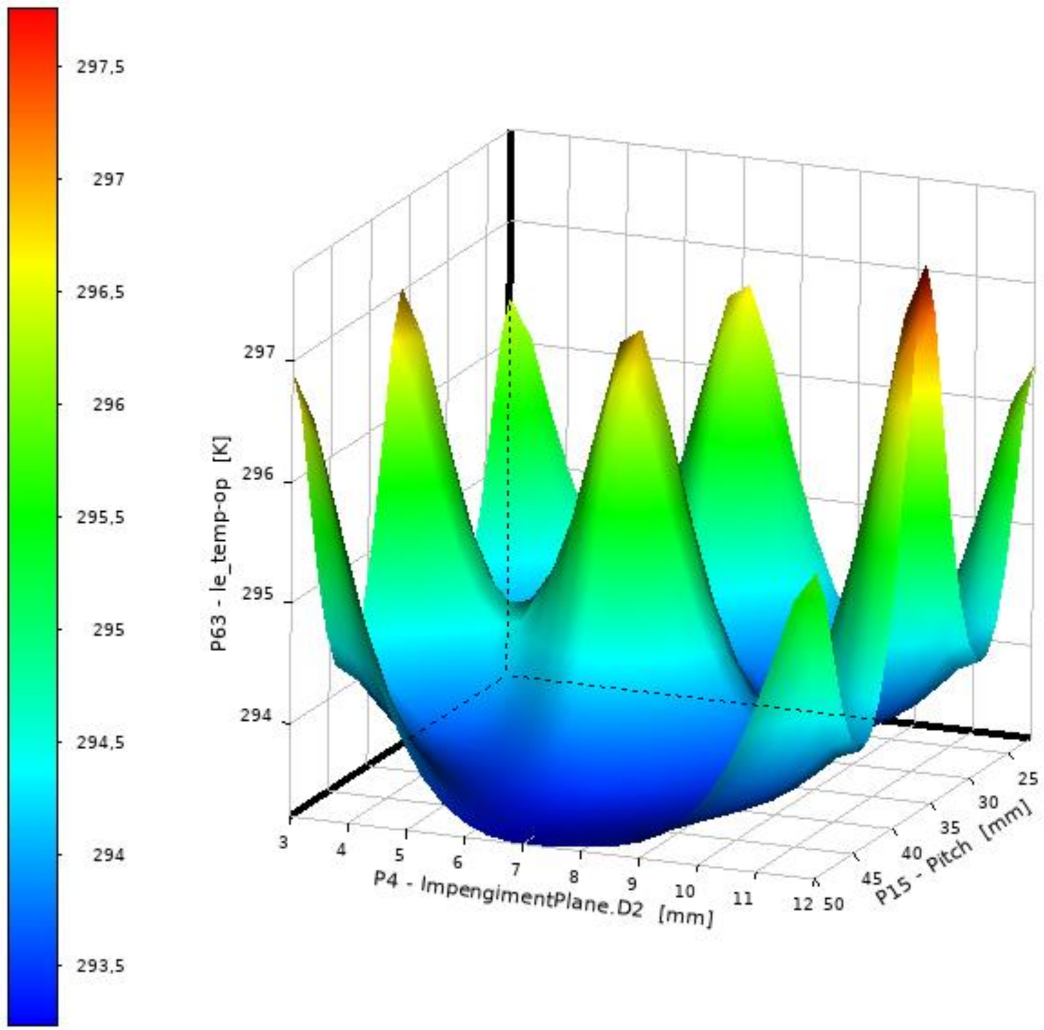
- The graph did not turn out as expected. I aimed for a result similar to the example below, but it did not work as intended. Although I would like to continue working on this project, I currently do not have enough time. I plan to complete it after my internship.

Example






303
302
301
300
299
298
297
296
295
294
293
P63 - le_temp-op [K]
2
3
4
5
6
P19 - Hole_Diameters [mm]
50
45
40
35
30
25
P15 - Pitch [mm]


297,5
297
296,5
296
295,5
295
294,5
294
293,5
P63 - le_temp-op [K]
3
4
5
6
7
8
9
10
11
12
P4 - ImpengimentPlane.D2 [mm]
50
45
40
35
30
25
P15 - Pitch [mm]

What I have read

[1] İ. Tunçil and M. T. Çakır, *Analysis and Optimization of Film Cooling Parameters for Turbine Blades Using CFD*.

[2] Jianran Ren and Zhongran Chi, *Multi-Dimensional Platform for Cooling Design of Air-Cooled Turbine Blades*.

[3] Y. Wang and J. Cui, *Two-Dimensional Film-Cooling Effectiveness Prediction Based on Deconvolution Neural Network*.

[4] C. Wang, J. Zhang, and J. Zhou, *Optimization of a Fan-Shaped Hole to Improve Film Cooling Performance by RBF Neural Network and Genetic Algorithm*.

[5] *Overall Effectiveness for a Film-Cooled Turbine Blade Leading Edge With Varying Hole Pitch*.