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SVT Air Thermal System and Flow Distribution

ePIC SVT Working Meeting

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Stony Brook, NY

7/9/2025

Topics

1. Cooling air requirements for 1 channel: CFD+FEA study
2. System total air requirements
3. System air handling and pressure estimation

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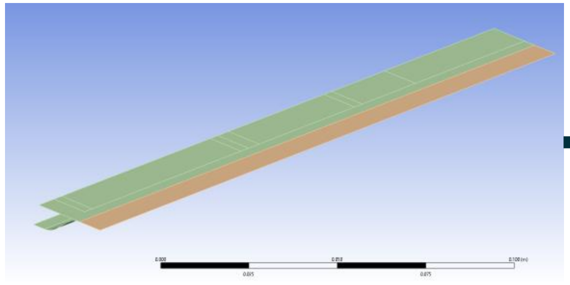

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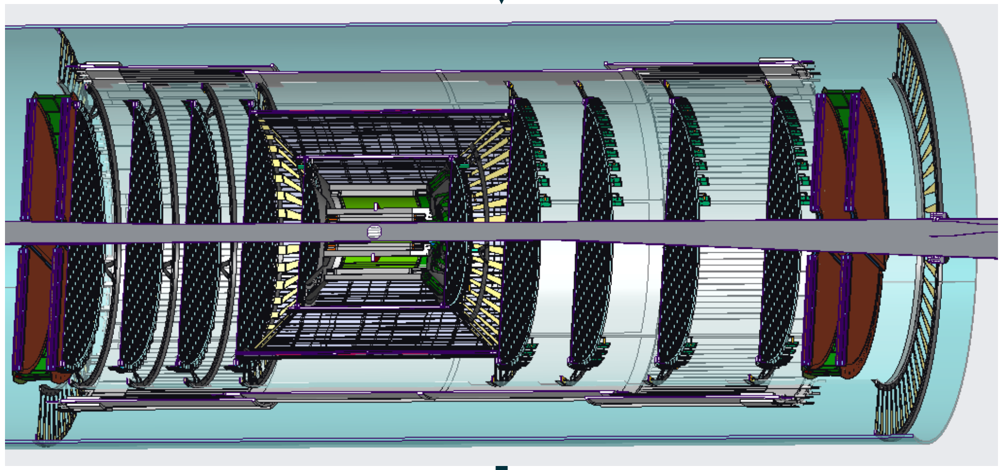

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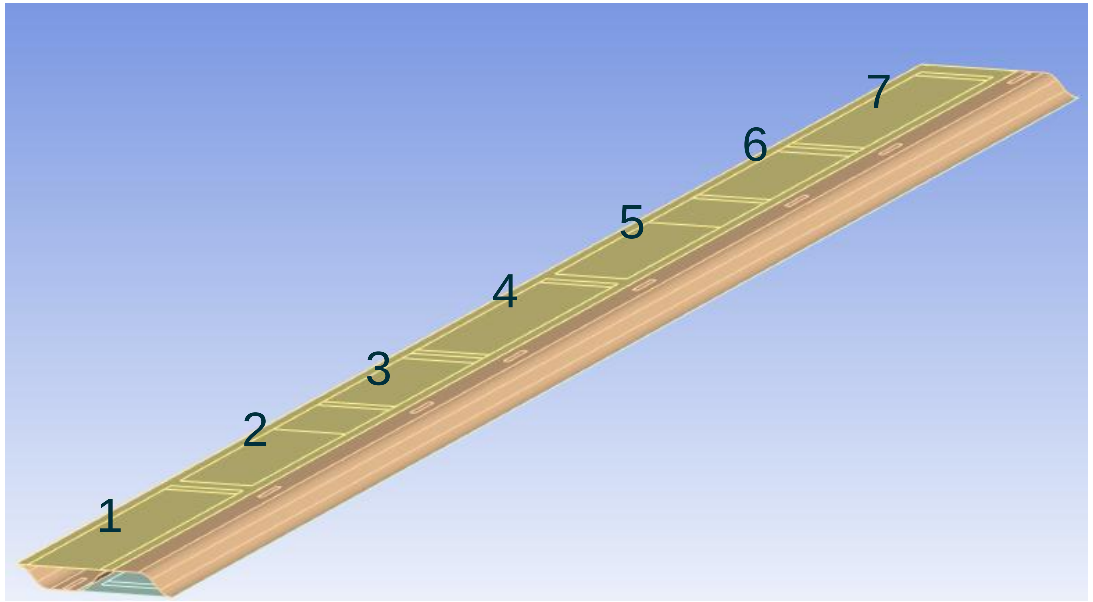
Model Approach

FEA Configuration: 7 sensor modules - single channel

Nusselt number correlations for uniform wall temperature and uniform heat flux did not fit well.

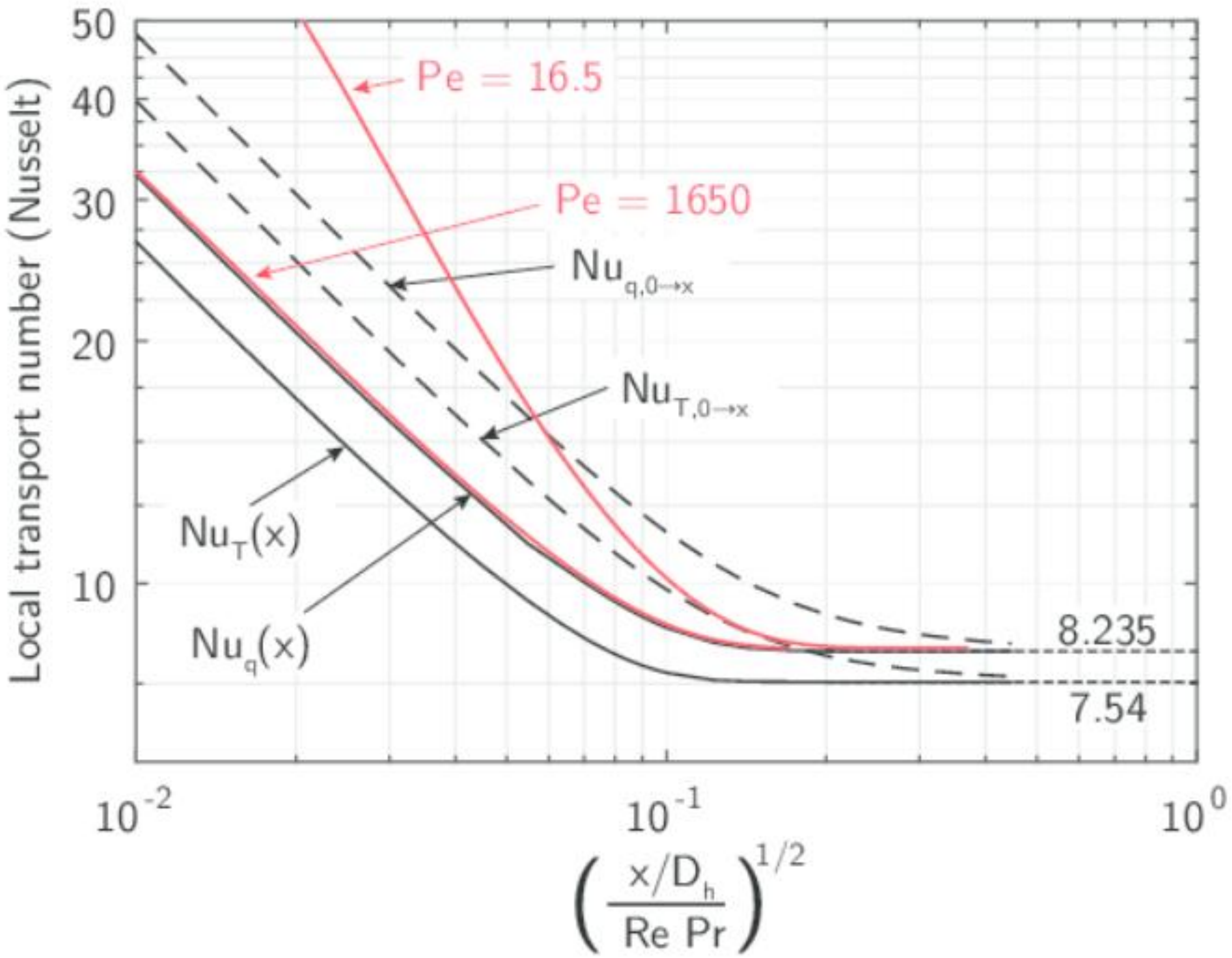
CFD + FEA coupled thermal fluid simulation

- CFD model resolves the cooling air flow and HTC.
- FEA model computes the heat transfer of the channel structure.



Entrance Region

- Nusselt number is inherently higher at the entrance of the duct.
- Temperature of air changes by about 5°C during passage through the channel.



CFD Model Details

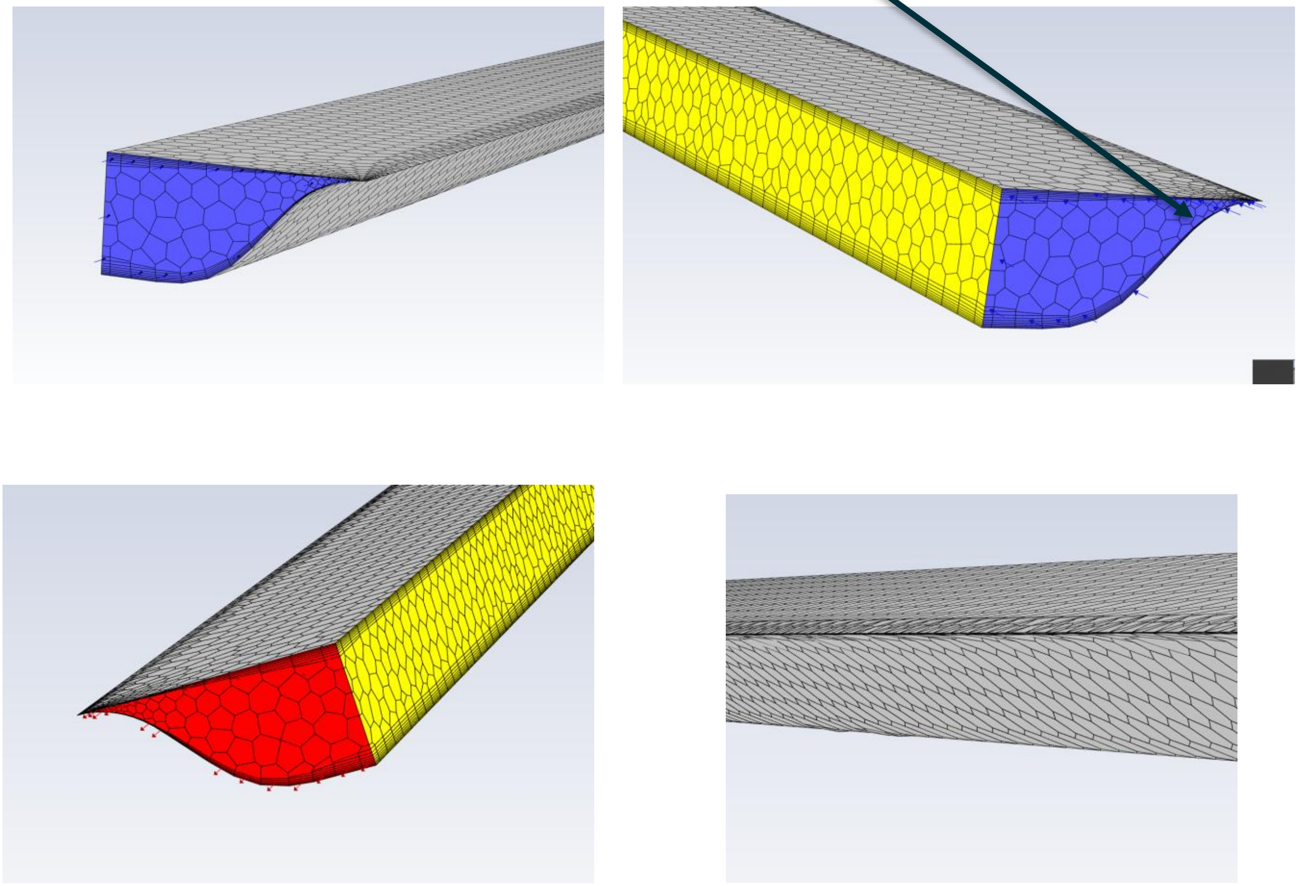
Coarse mesh in corners, high y+.
Relatively little flow in this region.

Turbulence model: **SST k-omega**, target y+ measure is on the order of **1**.

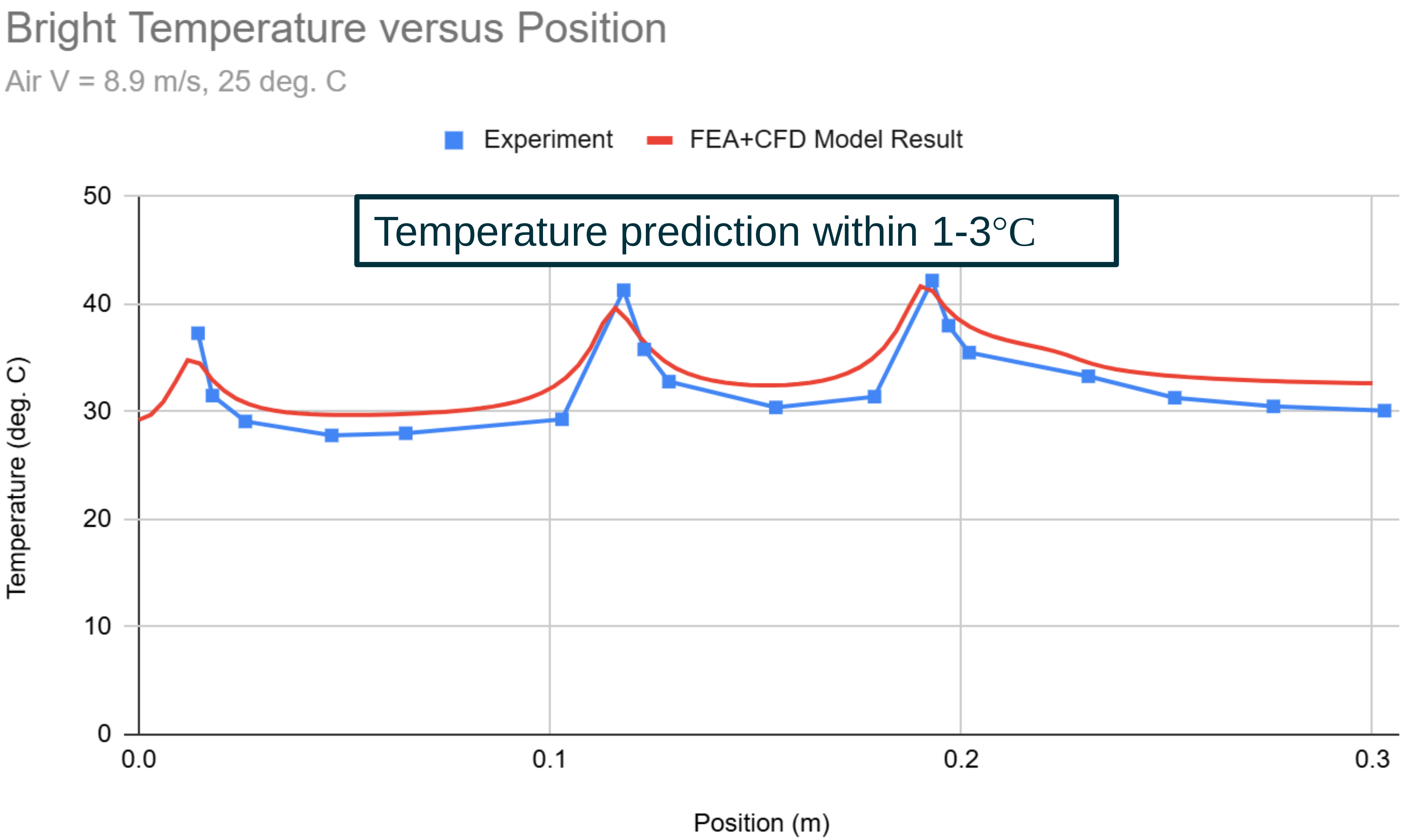
Fluid material model: air, Ideal gas

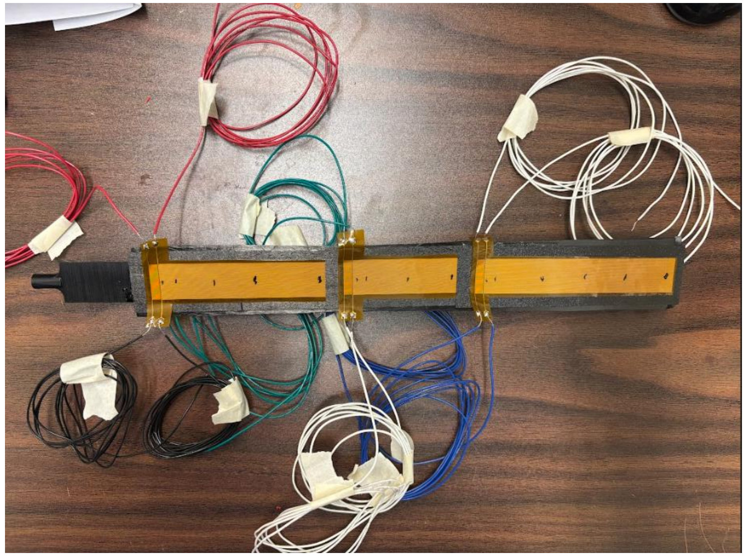
Boundary conditions:

1. Inlet (blue) 8.9 m/s air
2. Outlet (red) 0 psig
3. Symmetry (yellow) no mass, thermal flux
4. Wall (gray) fluid velocity = 0

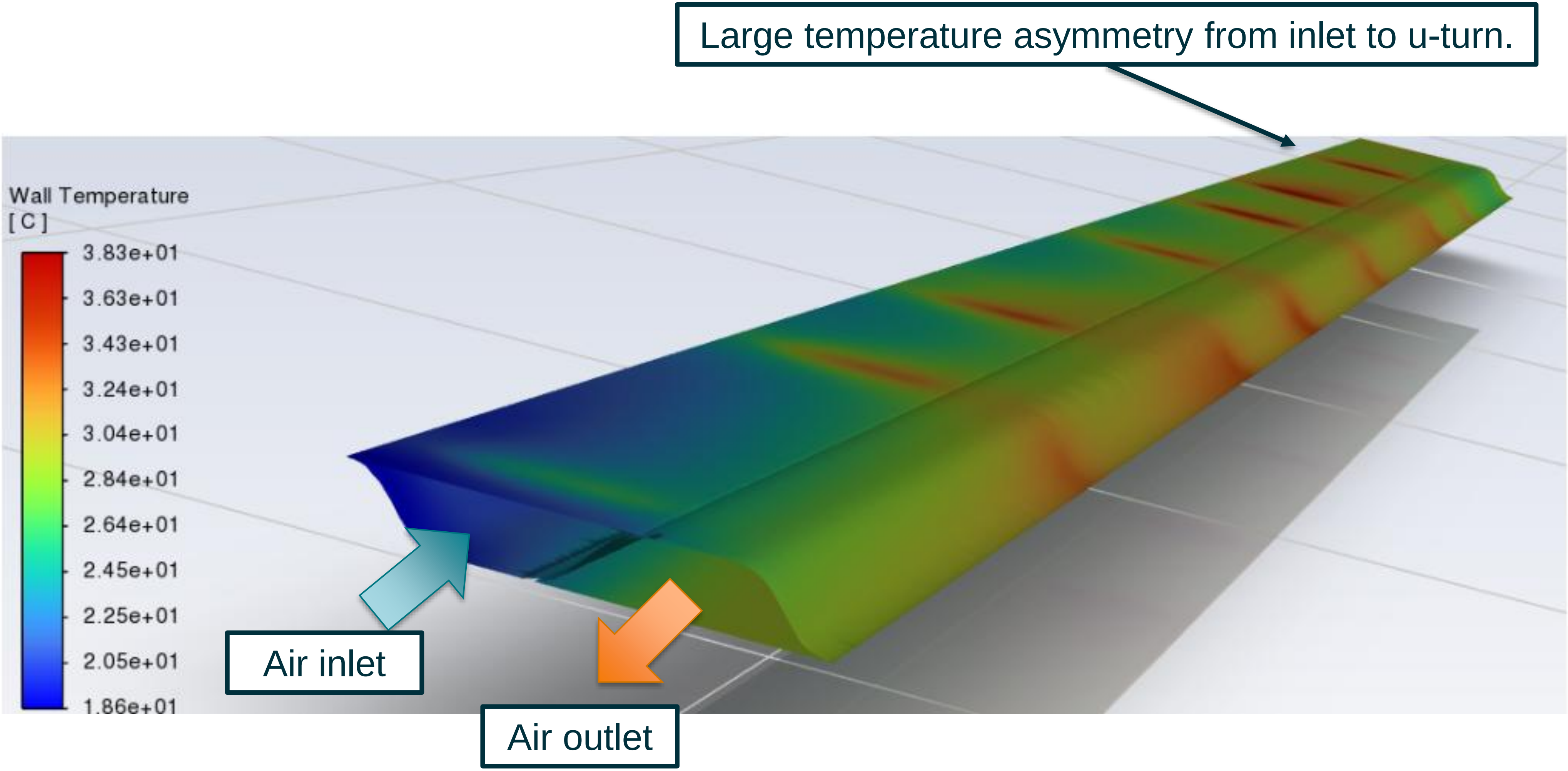


Model Validation

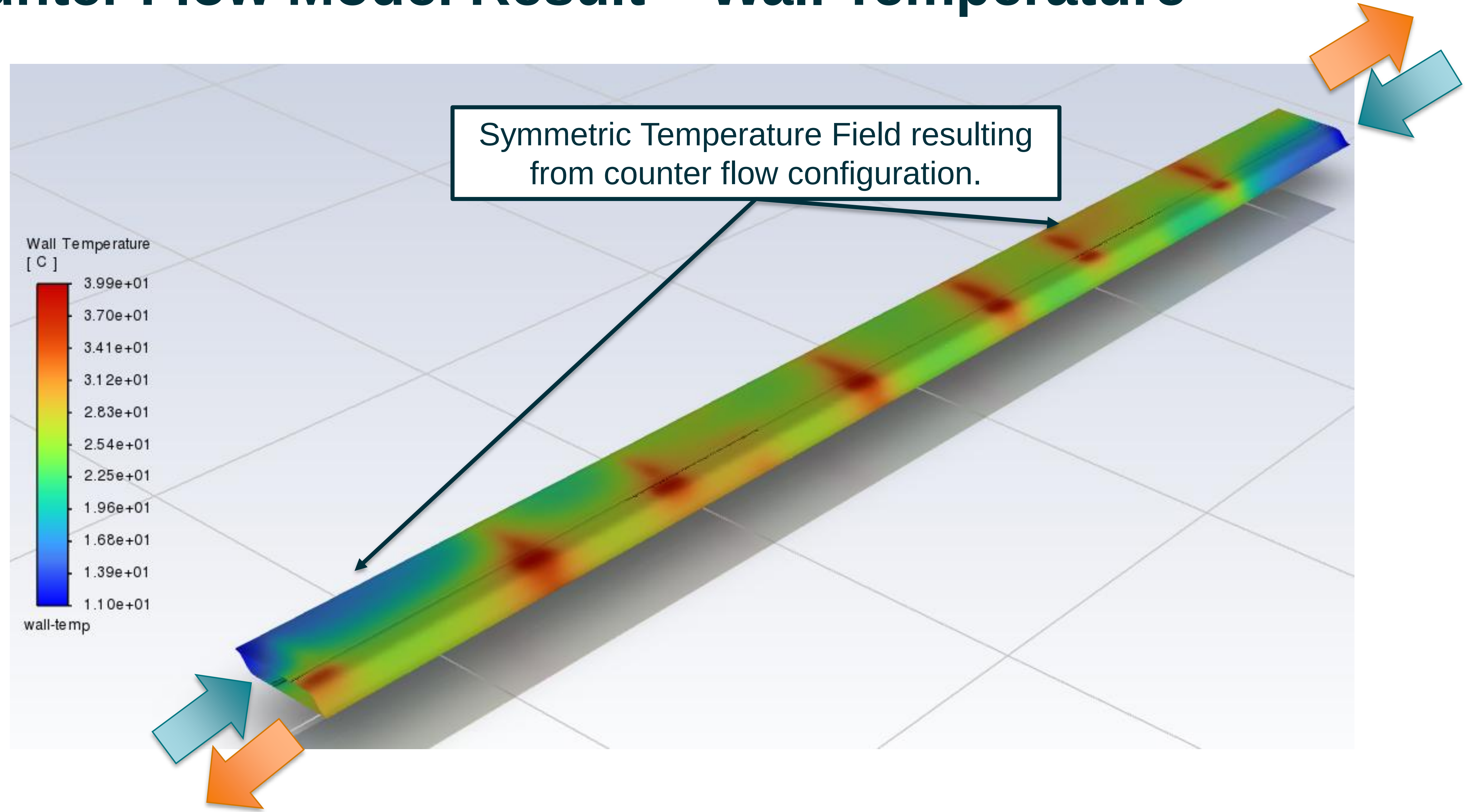




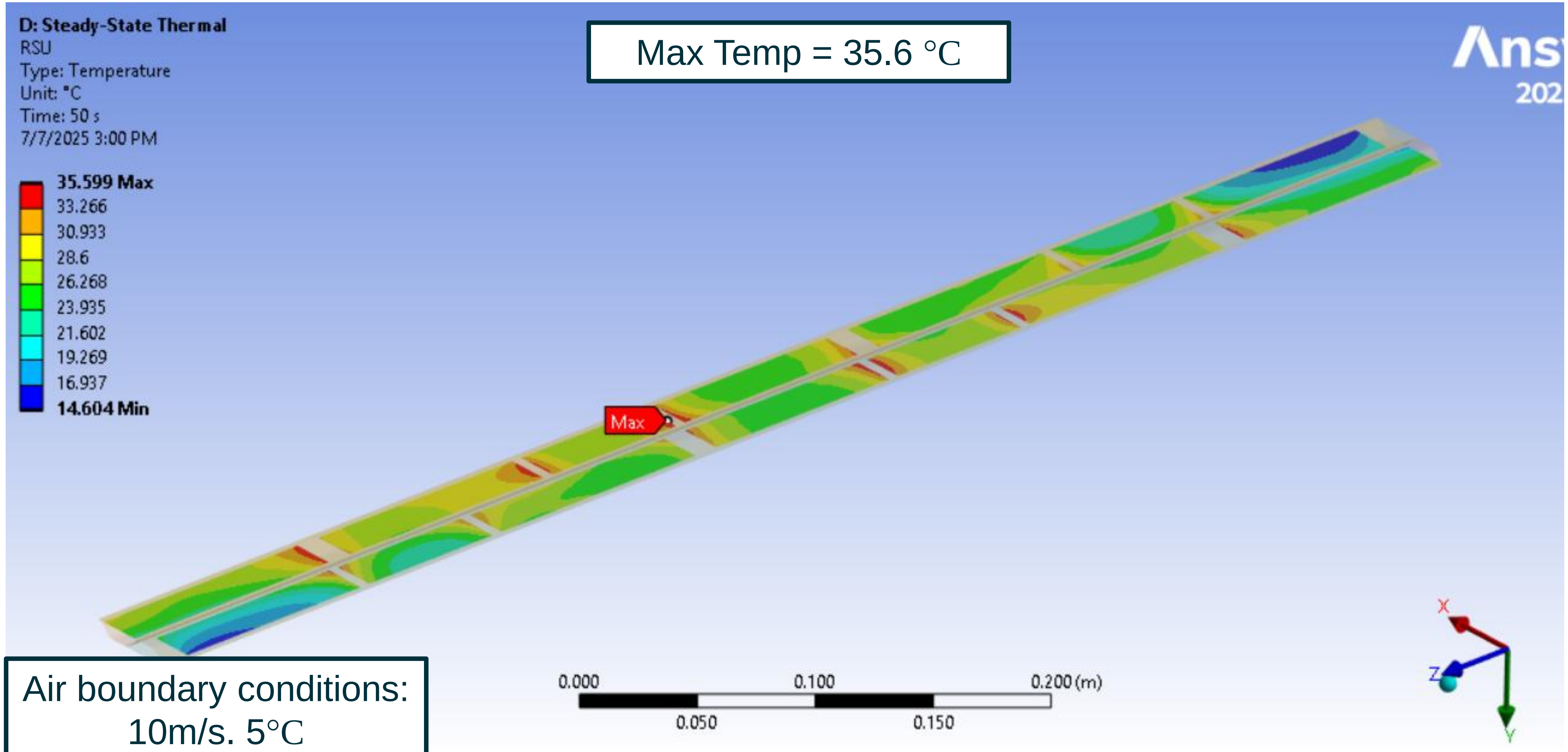
“U-turn” Model Result – Wall Temperature



Counter Flow Model Result – Wall Temperature



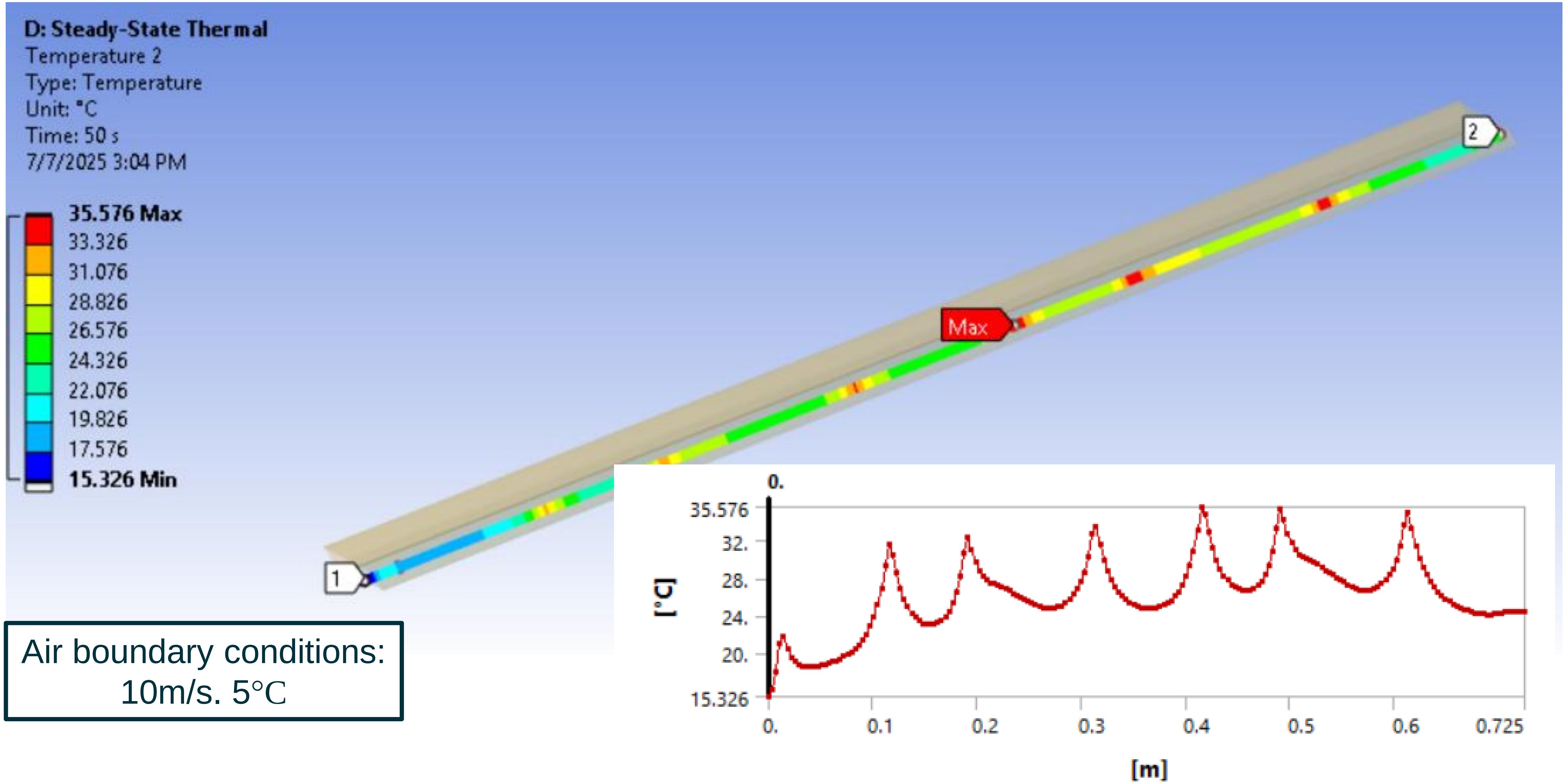
FEA Model - RSU Maximum Temperature



Max Temp = 35.6 °C

Air boundary conditions: 10m/s. 5°C

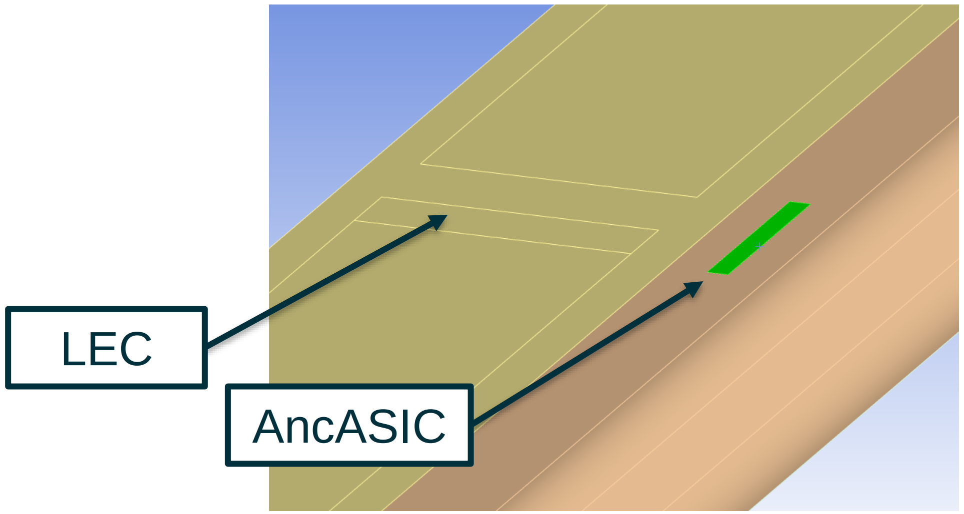
Temperature versus Channel Position



Air boundary conditions:
10m/s. 5°C

Overall Study Findings

1. Required cooling air velocity per channel is **≈10 m/s.**
2. Air inlet temperature required to be **5°C**.
3. AncASIC required to be placed away from the LEC to avoid high power density region.
4. Flow configuration: Alternating flow directions in neighboring channels minimize temperature gradient in the channel.



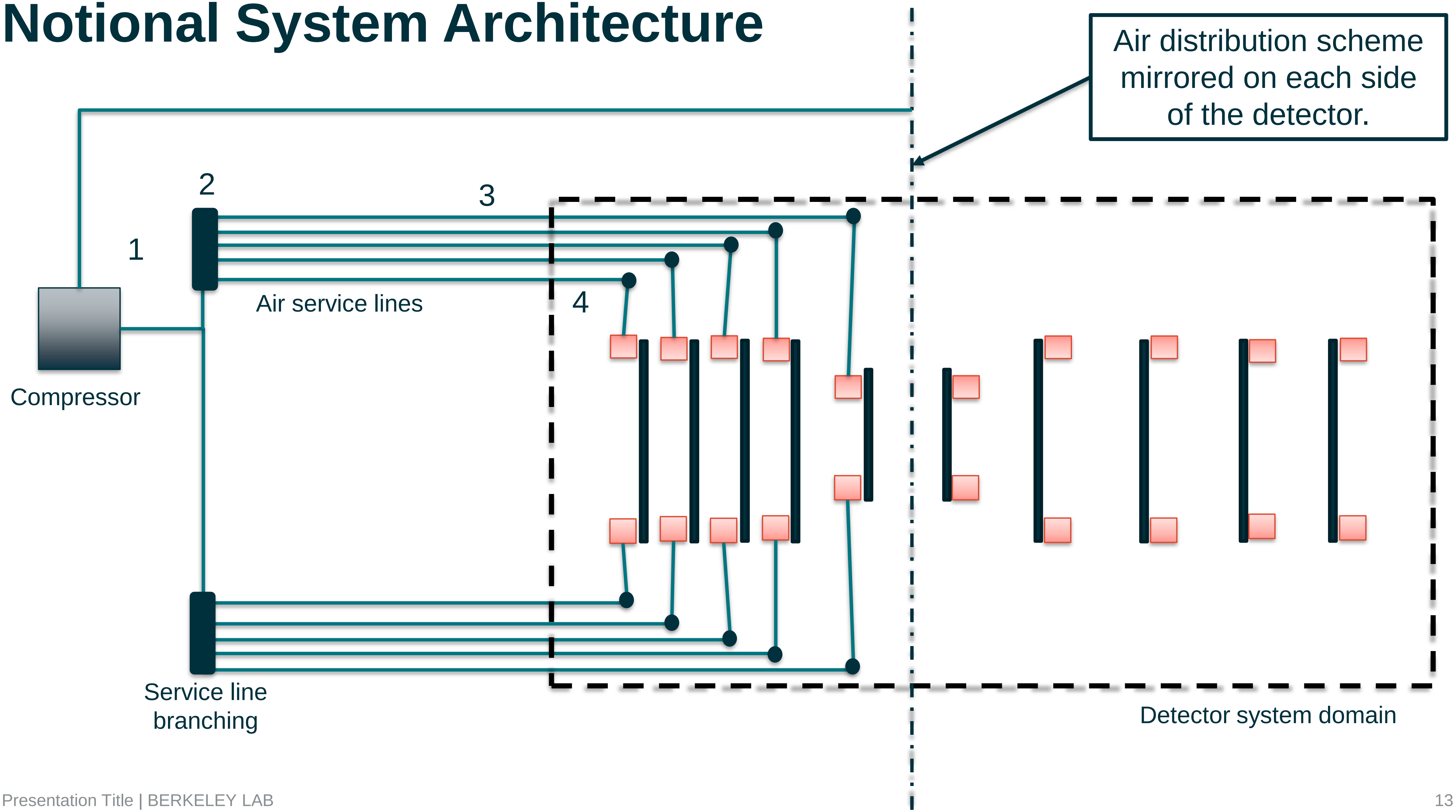
Total Disc Air Requirements

Variable	Value	Units	Description
T_supply	5.00	°C	Temperature of air supplied for cooling
n_sensors	2316		Total number sensors
n_5total	204		Total number of 5-unit sensors
n_6total	2112		Total number of 6-unit sensors
q_outer	7180.8	W	Total power for outer discs
q_inner	615.1	W	Total power for inner discs
air_outer	883.9	cfm	Total air flow for outer discs
air_inner	119.3	cfm	Total air flow for inner discs

Total number of channels: 454

7795.9	W	Total disc power	
1007.2	cfm	Total disc volume air flow	at 1 atm.
0.72	kg/s	Total disc mass air flow	
7.85	in^2	Total air tube cross sectional area	Assuming pressure < 100 psig

Notional System Architecture



Flow Branching and Pressure Estimation

Assumptions:

- All flow is balanced at every junction.
- Only pipe friction losses incorporated.
- Adiabatic process.
- Isentropic process.
- Approximately incompressible (M<0.3)

Compressor Pressure Estimation

Author: Joseph Silber, LBNL

Boundary conditions			
source temperature	T_s	K	287
source pressure	P_s	bar	3.530
"	"	Pa	357,668
"	"	psi	51.9
source mass flow rate	$\dot{m}_s$	kg/s	0.73
final exit pressure (atmosphere)	P_e	bar	1.0

stage index	-	-	0	1	2	3
num channels (per parent channel)	n	-	1	10	1	50
mass flow per channel	$\dot{m} = (\dot{m}_s$ or previous stage $\dot{m}) / n$	kg/s	0.730	0.073	0.073	0.001
length	L	m	20.000	3.000	0.500	0.500
hydraulic diameter (mm)	D_mm	mm	50	25	25	11.5
hydraulic diameter	D	m	0.050	0.025	0.025	0.012
cross-sectional area along length L	$A_{12} = \pi D^2 / 4$	m^2	1.96E-03	4.91E-04	4.91E-04	1.04E-04
interior height for "squashed" tube in annulus	hs	mm	12	8	8	n/a
interior width for "squashed" tube in annulus	ws	mm	**163.6**	**61.4**	**61.4**	-
entrance temperature	$T_1 = T_s$ or previous stage T_3	K	287	282.4	282.4	**277.9**
entrance pressure	$P_1 = P_s$ or previous stage P_3	Pa	357,668	278,488	161,442	120,841
entrance density (ideal gas law)	$\rho_1 = P_1 / (R * T_1)$	kg/m^3	4.342	3.436	1.992	1.515
entrance dynamic viscosity	$\mu_1 = \mu_0 * (T_1/T_0)$^0.76	Pa*s	1.78E-05	1.76E-05	1.76E-05	1.74E-05
Reynold's number	$Re = 4 \dot{m} / (\pi D \mu_1)$	-	1.04E+06	2.11E+02	2.11E+02	9.28E+00
friction factor (Blasius)	f = 64/Re, Re < 2300 = 0.316/Re^0.25 otherwise	-	0.010	0.303	0.303	6.895
friction pressure drop (Darcy-Weisbach)	$\Delta P_{12} = -f * (L/D) * \dot{m}^2 / (2 \rho_1 A_{12}^2)$	Pa	-62,954	-117,046	-33,651	-19,438
downstream pressure	$P_2 = P_1 + \Delta P_{12}$	Pa	294,714	161,442	127,791	101,402
downstream temperature (assume minimal heating)	$T_2 \sim T_1$	K	287.0	282.4	282.4	277.9
downstream density (ideal gas law)	$\rho_2 = P_2 / (R * T_2)$	kg/m^3	3.578	1.992	1.577	1.271
average density	$\rho_a = (\rho_1 + \rho_2)/2$	kg/m^3	3.960	2.714	1.784	1.393
average volumetric flow	$V_a = \dot{m} / \rho_a$	m^3/s	0.184	0.027	0.041	0.001
average volumetric flow (cfm)	V_a_cfm	cfm	390.6	57.0	86.7	2.2
average air speed	$u_a = V_a / A_{12}$	m/s	93.9	54.8	83.3	**10.1**
cross-sectional area on other side of outlet	$A_3 = \infty$ or next stage's $(A_{12} * n)$	m^2	4.91E-03	4.91E-04	5.21E-03	1E+99
area change pressure drop (non-choked)	$\Delta P_{23n} = \dot{m}^2/(2*\rho_2) * (1/A_3^2 - 1/A_{12}^2)$	Pa	-16,226	0	-6,951	-77
outlet pressure if non-choked	$P_{3n} = P_2 + \Delta P_{23n}$	Pa	278,488	161,442	120,841	101,325
outlet pressure if choked	$P_{3x} = P_2 * \beta_x$	Pa	155,692	85,287	67,510	53,569
pressure ratio calculated with non-choked eqn	$\beta_{3n} = P_{3n} / P_2$	-	**0.945**	**1.000**	**0.946**	**0.999**
is choked?	$\beta_{3n} < \beta_x$	boolean	FALSE	FALSE	FALSE	FALSE
outlet pressure	$P_3 = P_{3n}$ or P_{3x}	Pa	278,488	161,442	120,841	101,325
outlet pressure (bar)	P_3_bar	bar	2.75	1.59	1.19	1.00
outlet temperature (isentropic expansion)	$T_3 = T_2 * (P_3 / P_2)^k$	K	282.4	282.4	277.9	277.9

Concluding Remarks and Future Work

- Compressor required likely somewhat large for these conditions
  - 3.5 bar @ 390 cfm for discs only. Additional capacity will be needed for the inner and outer barrels.
- Approximate cross section for air tubing: 7.85 in^2 (5065 mm^2)
- Thermal system interlocks needed during startup.
- Solution needed to prevent over-pressure condition.
- Air return area required.