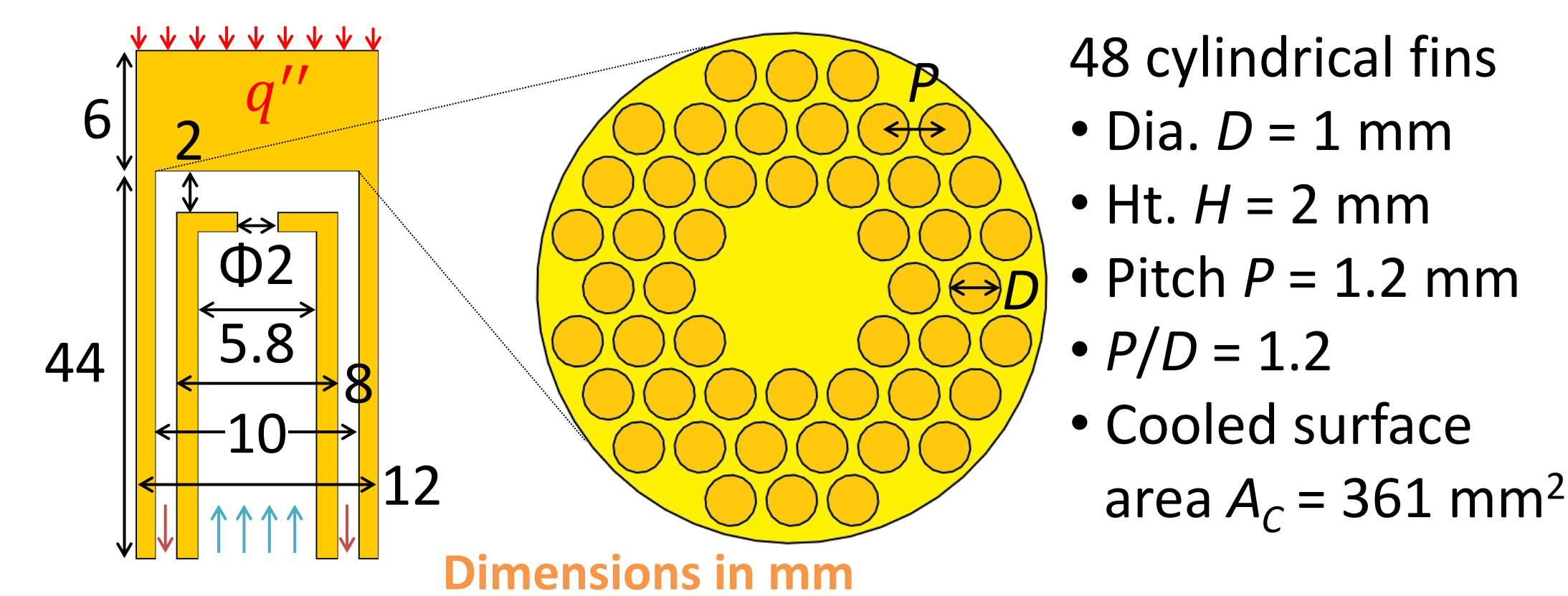


Optimization of Pin-Fin Arrays for Helium-Cooled Finger-Type Divertor

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Introduction and Objectives

- He-cooled divertor with multi-pin array (HEMP)**
 - FZK design¹ used array of fins (vs. jet impingement) to cool surface
 - Complex geometry made fin array difficult to fabricate²
- Combine pin-fin array and impinging jet cooling in finger-type divertor**
 - Experimental and numerical studies³⁻⁵ of Georgia Tech design showed that maximum heat flux accommodated q''_{max} increased by 19% at the cost of a 16% increase in coolant pumping power
 - Array geometry not optimized



- Research Objective:** Use numerical simulations to optimize fin-array geometry to achieve similar improvements in q''_{max} while minimizing increase in pumping power
 - Keep uniform pin-fin geometry to minimize fabrication issues
 - Determine how variations in fin-tip contact affect thermal performance
 - Evaluate how geometric variations (e.g. due to neutron-induced swelling or thermal expansion) affect thermal performance

References

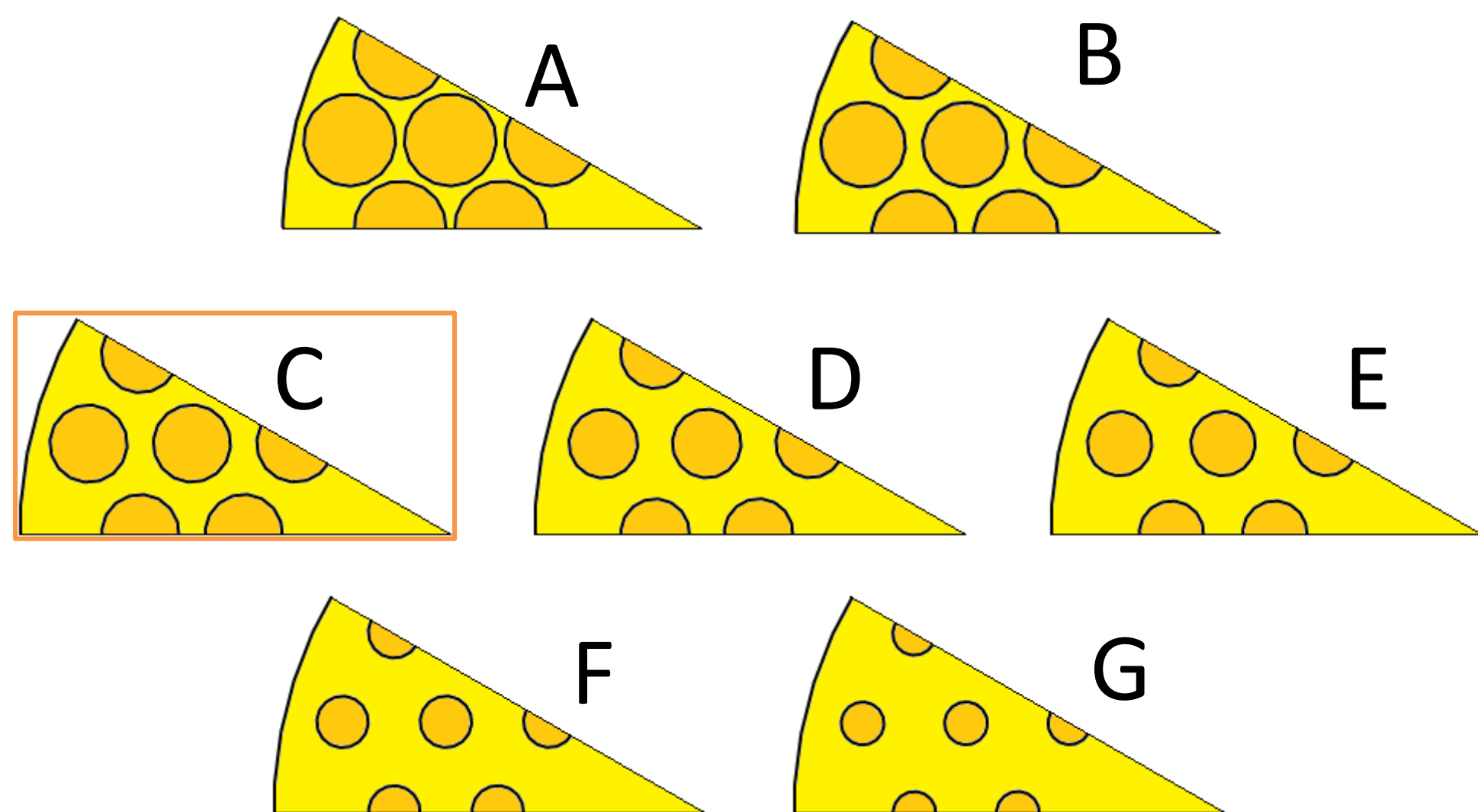
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Numerical Simulations

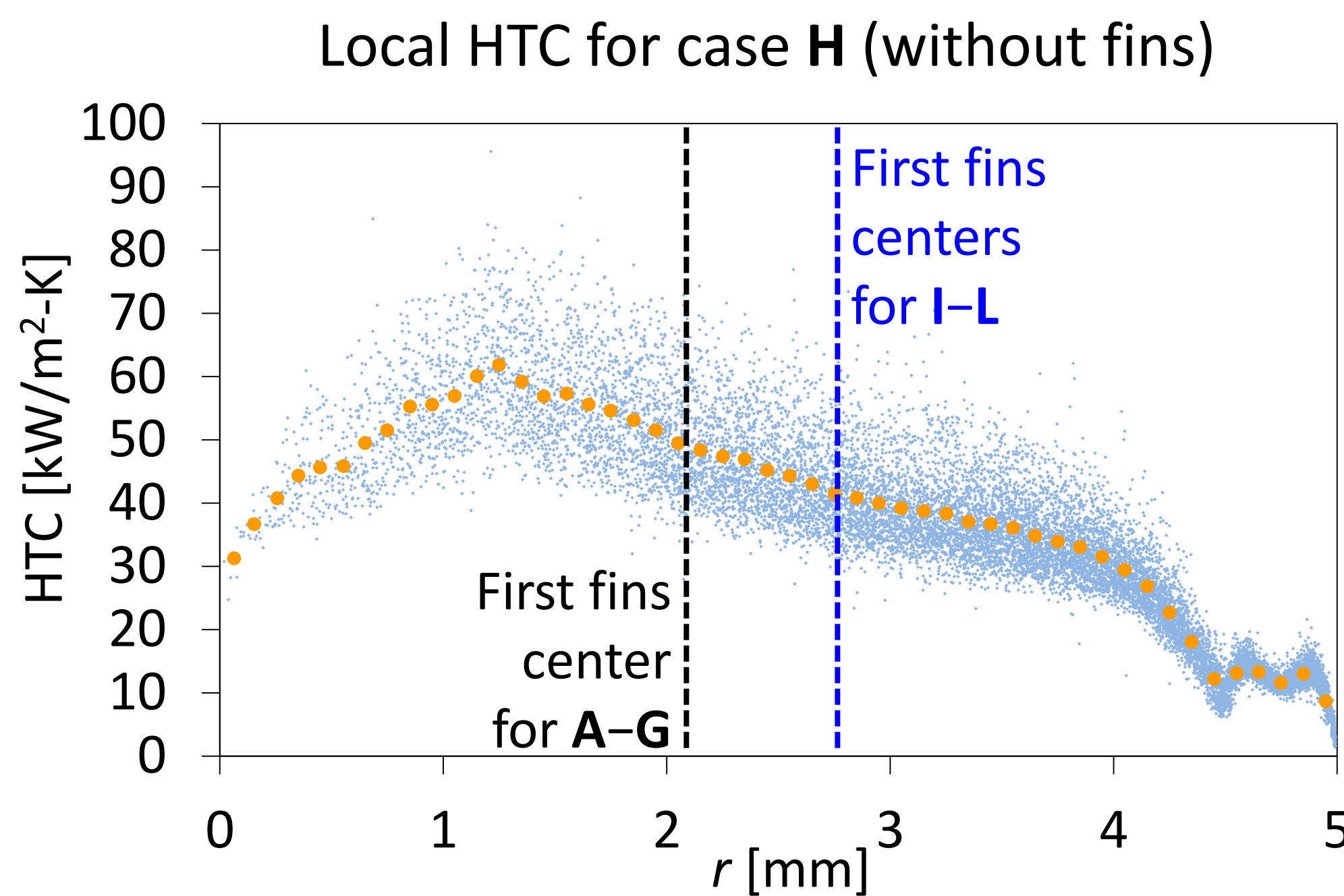
- ANSYS® FLUENT® 14.0**
 - Model: 30° "wedge" of finger-type divertor with axial extent of 45 mm made of WL-10 (W-1%La₂O₃): exploit 12-fold symmetry
 - ~3×10⁶ unstructured tetrahedral cells
 - Uniform incident heat flux of 10 MW/m²
 - Simulations: realizable k - ϵ turbulence model, enhanced wall treatment
 - Coolant mass flow rates corresponding to Reynolds numbers $Re = 4.5 \times 10^4, 6 \times 10^4, 7.5 \times 10^4, 9 \times 10^4$
- Optimization objective**
 - Minimize average heated surface (pressure boundary) temperature $\bar{T}_s$ and pressure drop over divertor test section Δp
 - Compare results with two baseline cases:
 - Divertor without fin array (minimum Δp)
 - Experimentally studied array of 48 cylindrical fins with pitch-to-diameter ratio $P/D = 1.2$
- Effect of fin-tip boundary condition**
 - For fins of fixed $H = 2$ mm, tip of fins may only partially contact end of cartridge due to machining variations, neutron-induced swelling, thermal expansion
 - Results from two extremes: adiabatic and perfectly conducting fin tips indicate that $\bar{T}_s$ varies by <2 °C with negligible change in Δp (B*)

Methodology

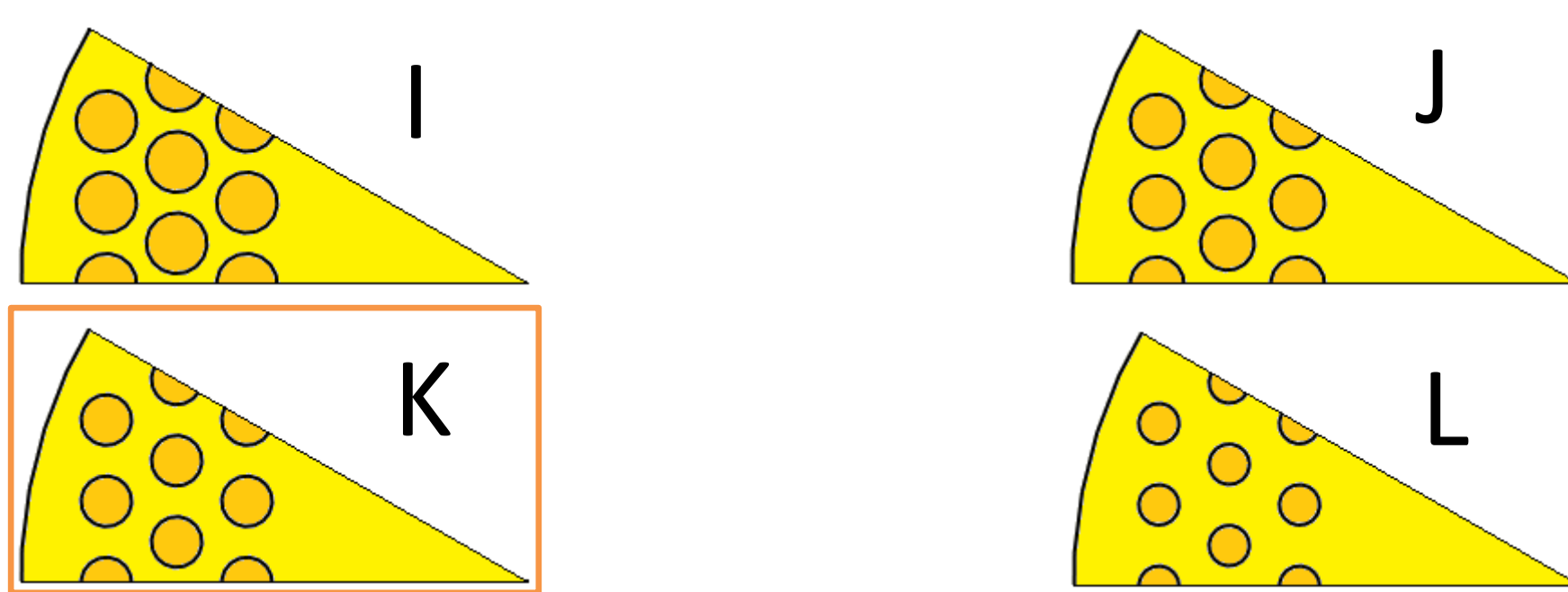
- First test: 48 fins at $P = 1.2$ mm; change D**
 - Smaller fins decrease A_c , may decrease Δp
 - $P/D = 1.1$ (A), 1.2 (B), 1.33 (C), 1.5 (D), 1.6 (E), 2.0 (F), 2.4 (G)



- Second test: 84 fins starting 2.7 mm out from center at $P = 0.8$ mm: change D**
 - First test results $\Rightarrow$ larger Δp for larger D and smaller P/D
 - Increasing gap between fins $\Rightarrow$ smaller Δp , but $\bar{T}_s$ higher due to decrease in A_c
 - More smaller fins to restore A_c
 - Simulation with no fins (H) $\Rightarrow$ max. heat transfer coefficient (HTC) 1.3 mm from center, so fins at least 2.7 mm from center: may also reduce Δp since fins will not affect cooling due to impinging jet



- $P/D = 1.33$ (I), 1.5 (J), 1.6 (K), 2.0 (L)



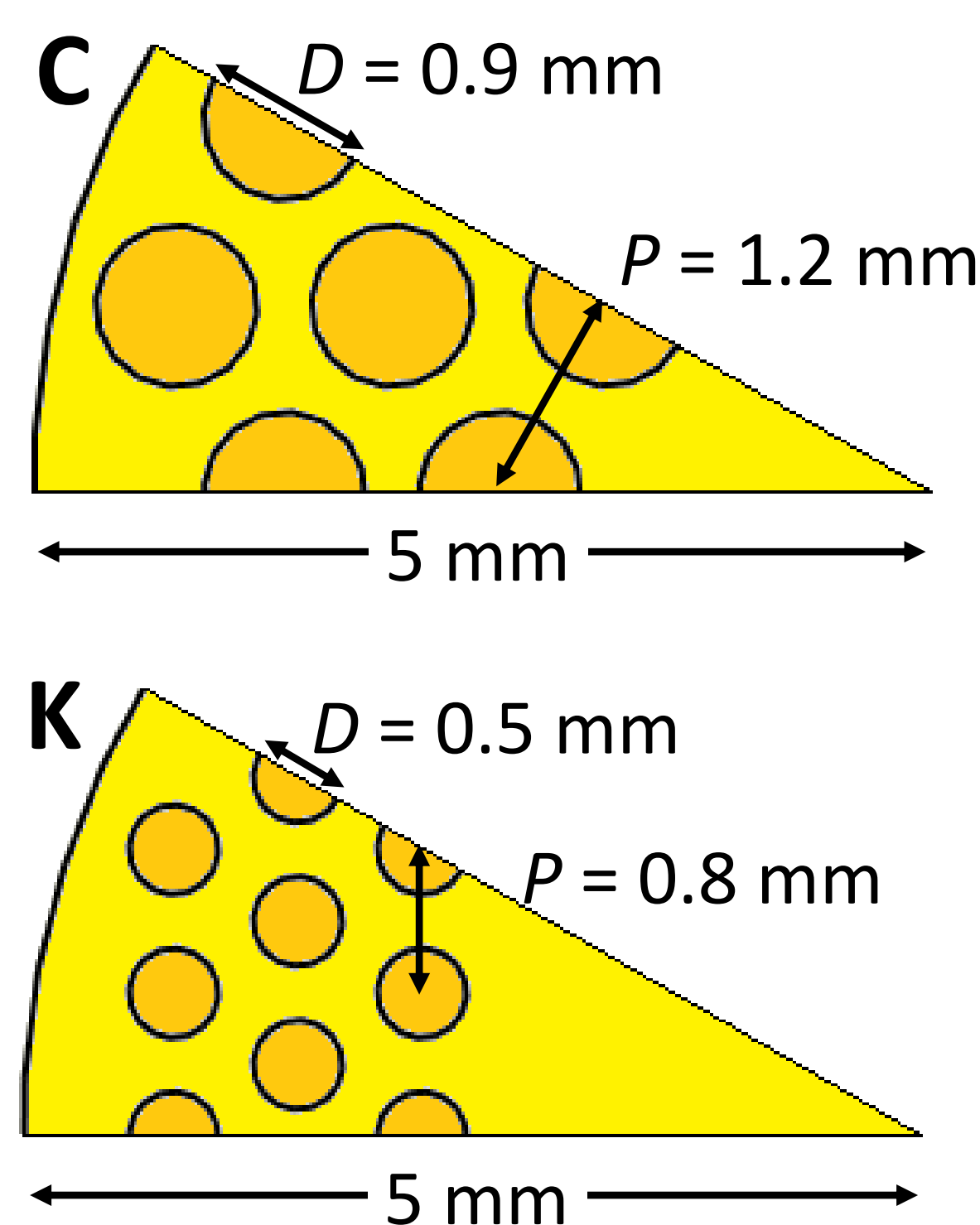
Summary of Simulation Results

Case	# Fins	P/D	A_c [mm²]	Re_i [10^4]							
				4.5	6	7.5	9	4.5	6	7.5	9
				$\bar{T}_s$ [°C]				Δp [kPa]			
A	48	1.1	388	879	853	836	827	277	482	729	1049
B	48	1.2	361	900	868	848	835	192	342	531	771
B*	48	1.2	361	901	868	848	835	191	342	530	769
C	48	1.33	329	872	842	823	809	182	325	506	736
D	48	1.5	304	887	850	828	814	179	321	498	726
E	48	1.6	292	896	862	836	820	179	322	500	726
F	48	2.0	251	907	866	839	823	179	323	502	725
G	48	2.4	223	916	874	842	825	184	327	501	732
H	0	---	79	976	915	875	848	163	294	459	669
I	84	1.33	380	906	869	845	824	178	321	499	727
J	84	1.5	348	900	865	838	822	178	320	500	727
K	84	1.6	332	897	861	838	822	178	320	499	725
L	84	2.0	283	906	868	842	822	177	319	497	724

Summary

- Performance improved by optimizing geometry of cylindrical fin array**
 - Compared to baseline case B (48 fins) at prototypical flow rate, case C gives 25 °C decrease in $\bar{T}_s$ and 4.7% decrease in Δp
 - Case K (84 fins) gives 10 °C decrease in $\bar{T}_s$ and 6.0% decrease in Δp
 - Variations in extent of fin tip contact has little effect on performance
 - Inter-fin gap for B and K (0.3 mm) may still cause fabrication issues: similar cases with slightly bigger gap have similar performance, however $\Rightarrow$ small geometric variations in changes unlikely to significantly affect thermal performance
 - Next step: experimental validation of optimized geometries

Optimum Designs



Pressure Boundary Surface Temperatures

