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Effect of Bypass on Overall Performance of Pin-Fin Heat Sinks

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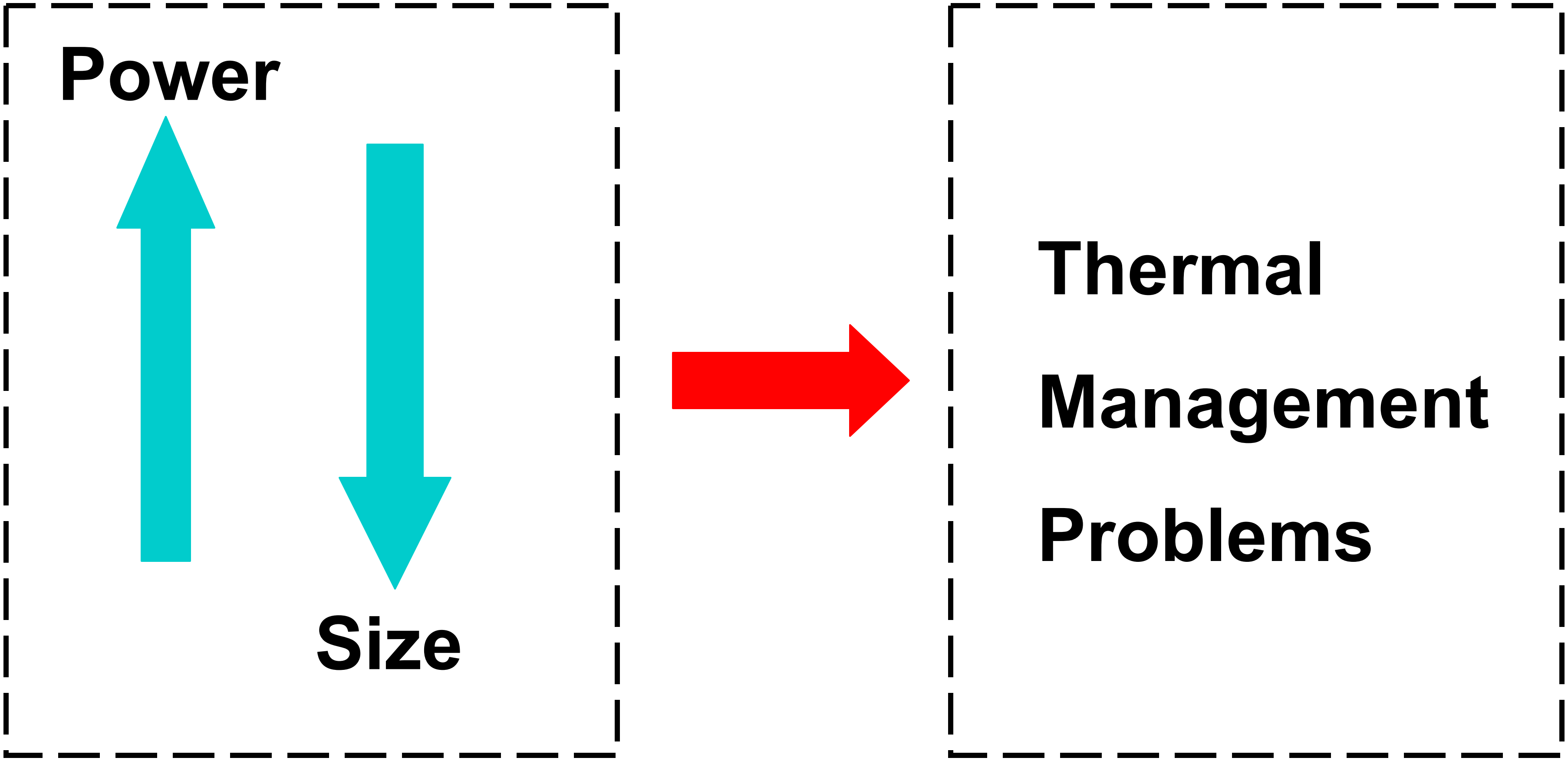
Outline

- Introduction
- Literature Review
- Objectives
- Analysis
- Results
- Conclusions
- Acknowledgments

Introduction



Power

Size

Thermal

Management

Problems

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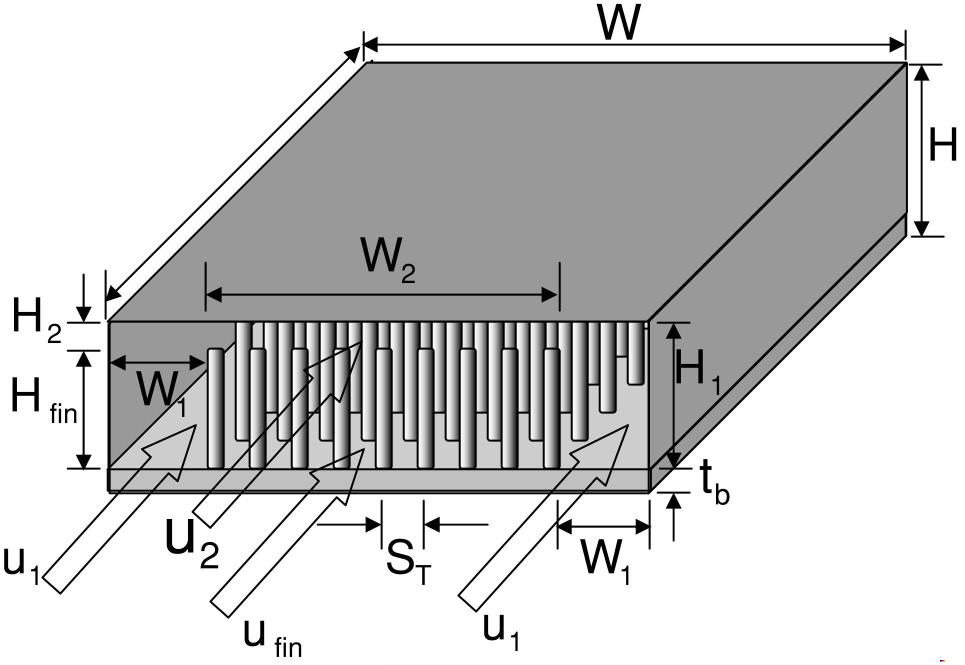
Physical Model (In-Line PFHS)

Fixed:

- ✓ Heat sink geometry
- ✓ Pin-fin dimensions
- ✓ Volume flow rate
- ✓ Pitch ratios (S_L, S_T)
- ✓ Heat load
- ✓ Fluid properties



Variables:

$$CL_s = \frac{2W_1}{W_2}$$

$$CL_t = \frac{H_2}{H_1}$$

Literature Review (PFHS)

- Experimental: Ortega group (SPFHS)
  Rizzi group (CPFHS, SPFHS)
  Jonsson group (CPFHS, SPFHS)
- Numerical: Jonsson and Moshfegh (CPFHS)

- No theoretical study exists which investigates the effects of side and top bypass on the overall performance of PFHS

Objectives

- ❖ Investigate effects of side and top bypass on overall performance of PFHS for :
  - In-line and
  - Staggered arrangements

- ❖ Compare thermal and hydraulic performances for both arrangements

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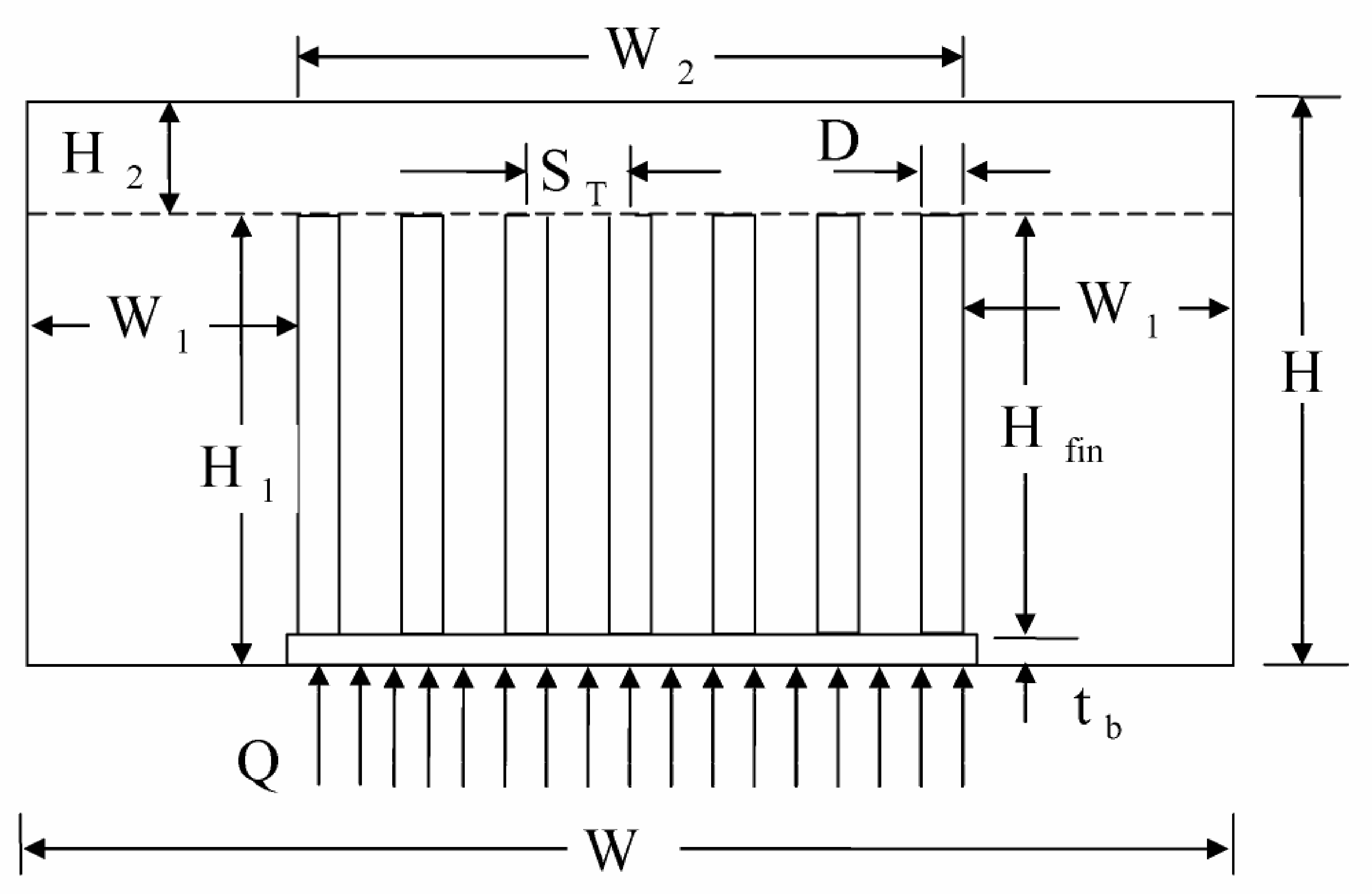
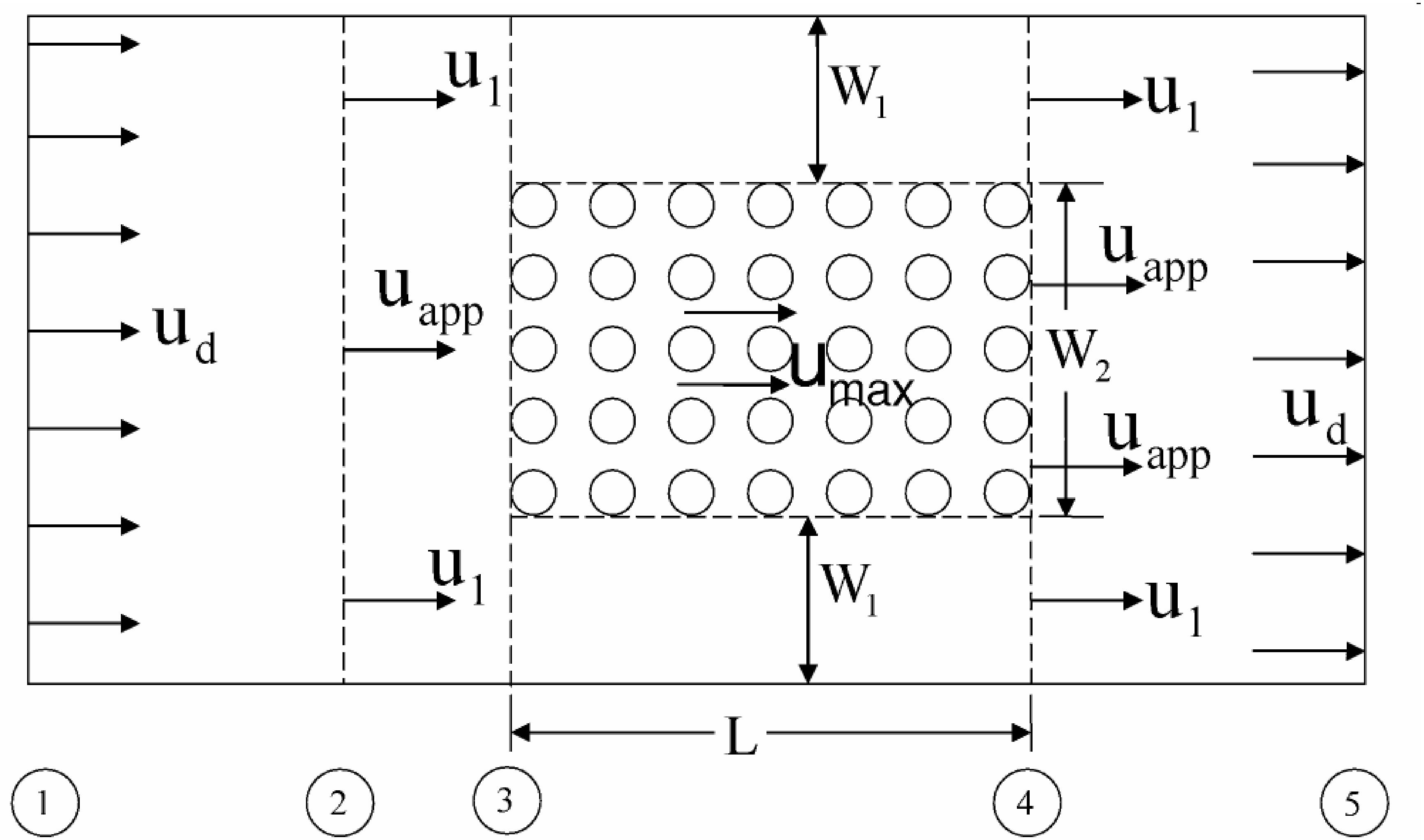
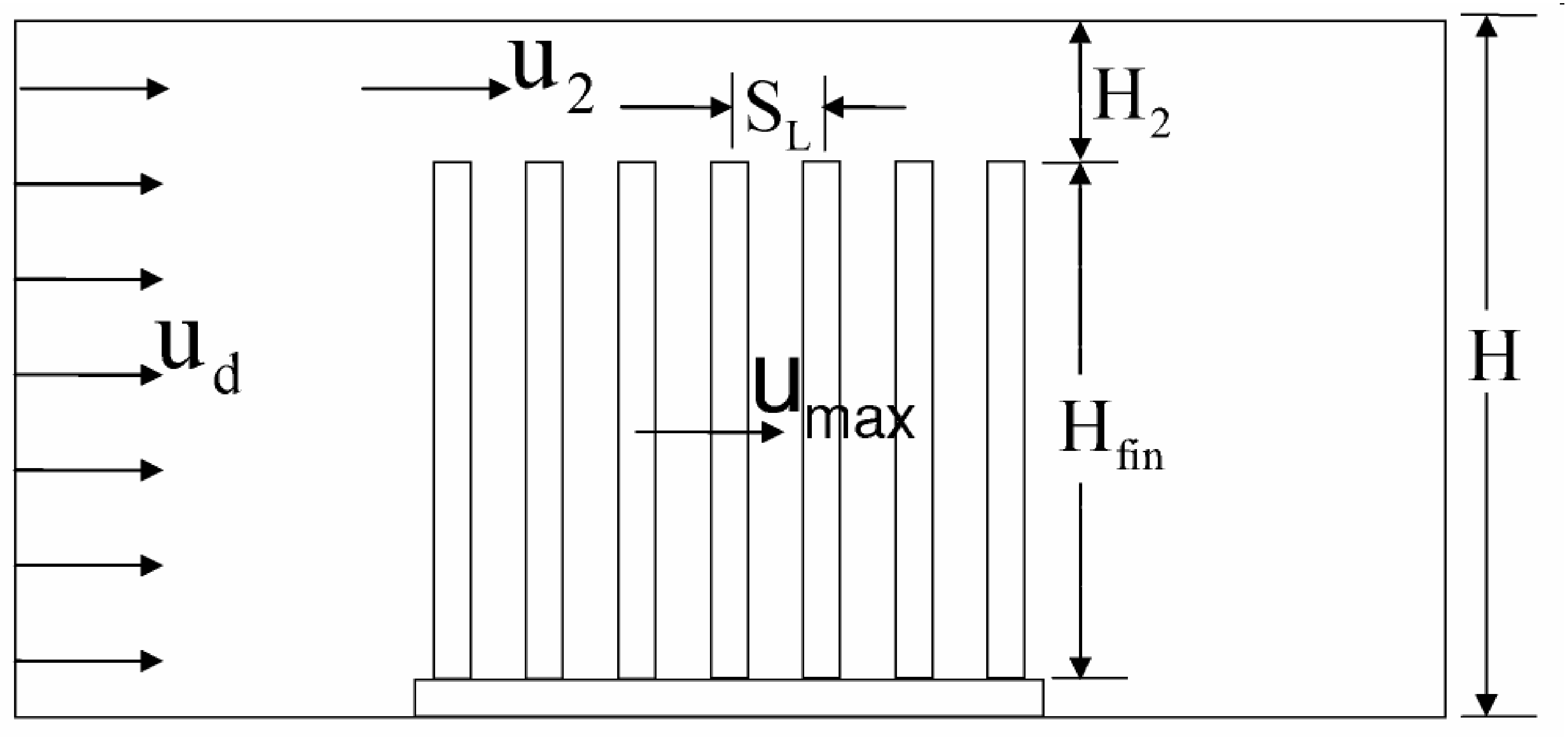
Front View (In-Line PFHS)



Top View (In-Line PFHS)



Side View (In-Line PFHS)



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Mass and Force Balance

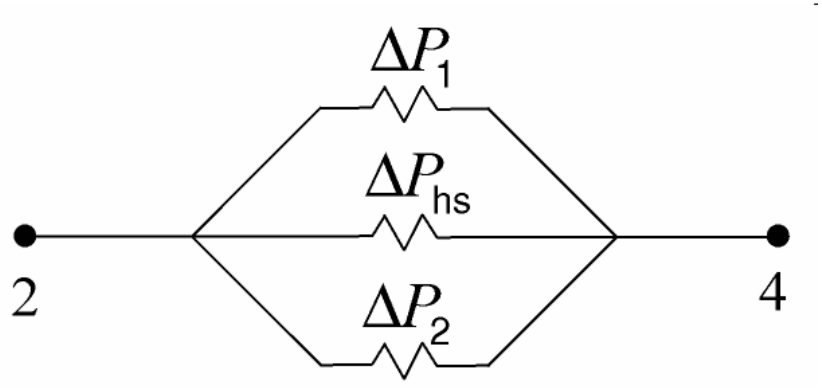
Mass balance between 1 and 2

$$U_d A_d = U_1 A_1 + U_2 A_2 + U_{app} A_f$$

Force balance between 1 and 4

$$\begin{array}{lcll}
P_1 + \frac{1}{2}\rho U_d^2 & = & P_4 + \frac{1}{2}\rho U_1^2 + \Delta P_1 & \text{Side bypass} \\
P_1 + \frac{1}{2}\rho U_d^2 & = & P_4 + \frac{1}{2}\rho U_2^2 + \Delta P_2 & \text{Top bypass} \\
P_1 + \frac{1}{2}\rho U_d^2 & = & P_4 + \frac{1}{2}\rho U_{app}^2 + \Delta P_{hs} & \text{Heat sink}
\end{array}$$

Pressure Drops



$$\Delta P_1 = \left(\frac{1}{2}\rho U_1^2\right) f_1(L/D_{h1})$$

$$\Delta P_2 = \left(\frac{1}{2}\rho U_2^2\right) f_2(L/D_{h2})$$

$$\Delta P_{hs} = \left(\frac{1}{2}\rho U_{max}^2\right) [k_c + k_e + N_L f_3]$$

$$f_1 = \frac{24}{Re_{Dh_1}} \qquad f_2 = \frac{24}{Re_{Dh_2}}$$

$$Dh_1 = \frac{4W_1H_1}{2W_1 + H_1} \qquad Dh_2 = \frac{2WH_2}{W + H_2}$$

$$Re_{Dh_1} = \frac{U_1Dh_1}{\nu} \qquad Re_{Dh_2} = \frac{U_2Dh_2}{\nu}$$

Friction Factors

Khan (2004):

$$f = \begin{cases} K_1 \left[0.233 + 45.78/(\mathcal{S}_T - 1)^{1.1} Re_D\right] & \text{In-Line arrays} \\ K_1 \left[378.6/\mathcal{S}_T^{13.1/\mathcal{S}_T}\right] / Re_D^{0.68/\mathcal{S}_T^{1.29}} & \text{Staggered arrays} \end{cases}$$

$$K_1 = \begin{cases} 1.009 \left(\dfrac{\mathcal{S}_T - 1}{\mathcal{S}_L - 1}\right)^{1.09/Re_D^{0.0553}} & \text{In-Line arrays} \\ 1.175(\mathcal{S}_L/\mathcal{S}_T Re_D^{0.3124}) + 0.5 Re_D^{0.0807} & \text{Staggered arrays} \end{cases}$$

Average Velocities in Different Regions

$$U_1 = \frac{C_2 U_d}{a_1 C_2 + a_2 C_1 + a_f C_1 C_2}$$

$$U_2 = \frac{C_1 U_d}{a_1 C_2 + a_2 C_1 + a_f C_1 C_2}$$

$$U_{app} = \frac{C_1 C_2 U_d}{a_1 C_2 + a_2 C_1 + a_f C_1 C_2}$$

$$a_1 = \frac{A_1}{A_d} \qquad a_2 = \frac{A_2}{A_d} \qquad a_f = \frac{A_f}{A_d}$$

$$C_1 = \sqrt{\frac{1+K_1}{1+\sigma_3^2 K_3}} \quad \text{and} \quad C_2 = \sqrt{\frac{1+K_2}{1+\sigma_3^2 K_3}}$$

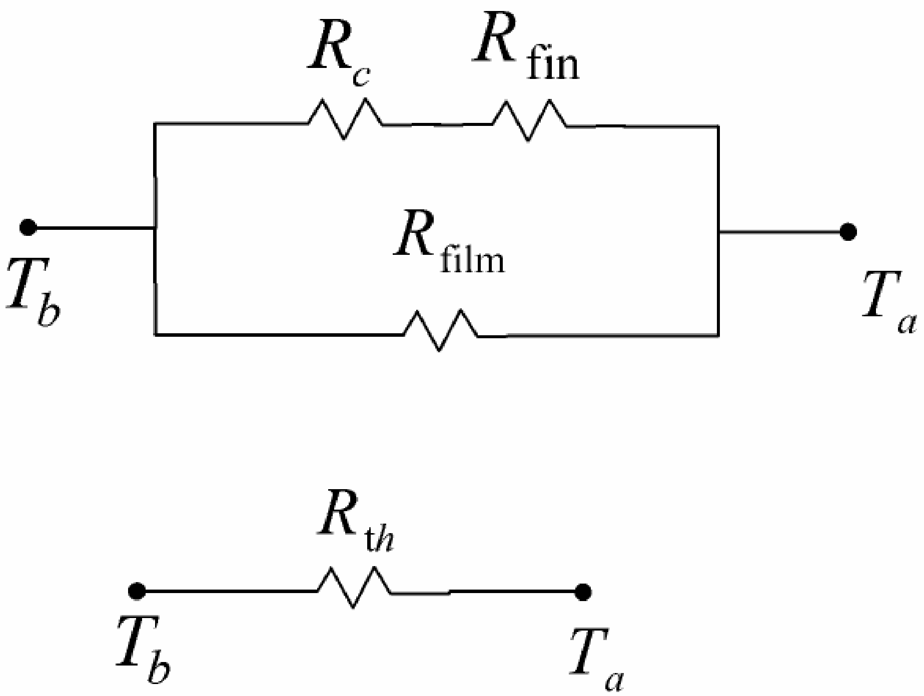
$$K_1 = f_1 \frac{L}{Dh_1} \qquad K_2 = f_2 \frac{L}{Dh_2} \qquad K_3 = f_3(k_c + k_e + f_3 N_L)$$

Thermal Resistance Network

$$R_{fin} = \frac{1}{(hA\eta)_{fin}}$$

$$R_c = \frac{1}{(hA)_c}$$

$$R_{film} = \frac{1}{h_b\left(LW_2 - N\frac{\pi D^2}{4}\right)}$$



$$R_{th} = \frac{1}{\frac{N}{R_c + R_{fin}} + \frac{1}{R_{film}}}$$

Heat Transfer Coefficients

Khan (2004):

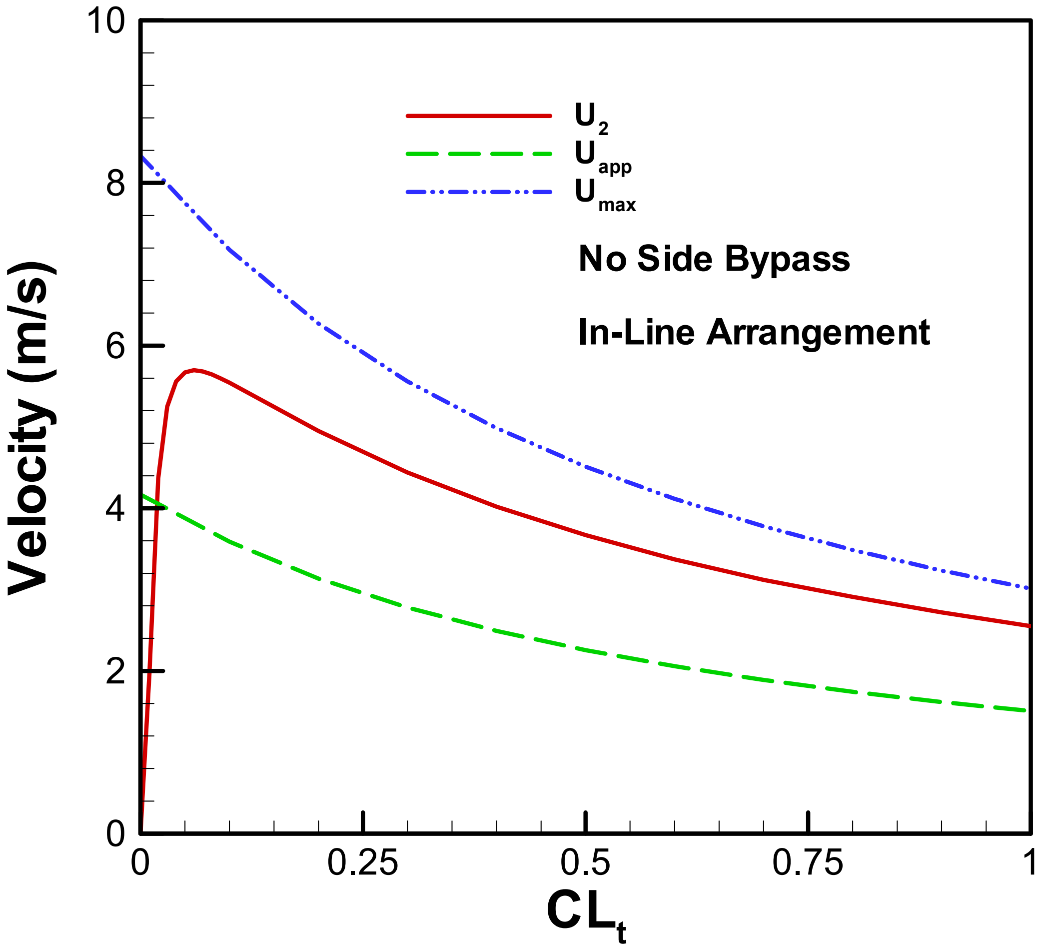
$$\begin{cases} h_b = 0.75 \dfrac{k_f/D}{\sqrt{N_L \mathcal{S}_L}} Re_D^{1/2} Pr^{1/3} \\[2ex] h_{fin} = C_3 \dfrac{k_f}{D} Re_D^{1/2} Pr^{1/3} \end{cases}$$

$$C_3 = \begin{cases} [0.2 + \exp(-0.55\mathcal{S}_L)]\mathcal{S}_T{}^{0.285}\mathcal{S}_L{}^{0.212} & \text{In-Line arrangement} \\[2ex] \dfrac{0.61\,\mathcal{S}_T{}^{0.091}\mathcal{S}_L{}^{0.053}}{[1 - 2\exp(-1.09\,\mathcal{S}_L)]} & \text{Staggered arrangement} \end{cases}$$

Assumed Parameter Values

Quantity	Parameter Values
Footprint, (mm^2)	50×50
Source Dimensions, (mm^2)	50×50
Baseplate Thickness, (mm)	2
Pin Diameter, (mm)	1.5
Overall Height of Heat Sink, (mm)	50
Duct Flow Rate, (m^3/s)	0.01
Thermal Conductivity of Solid, $(W/m \cdot K)$	210
Thermal Conductivity of Fluid, $(W/m \cdot K)$	0.026
Thermal Contact Conductance, $(W/m^2 \cdot K)$	10^4
Density of Fluid, (kg/m^3)	1.1614
Specific Heat of Fluid, $(J/kg \cdot K)$	1007
Kinematic Viscosity, (m^2/s)	1.58×10^{-5}
Prandtl Number	0.71
Heat Load, (W)	10
Ambient Temperature, (^0C)	27

Velocities in Top Bypass and Heat Sink Regions



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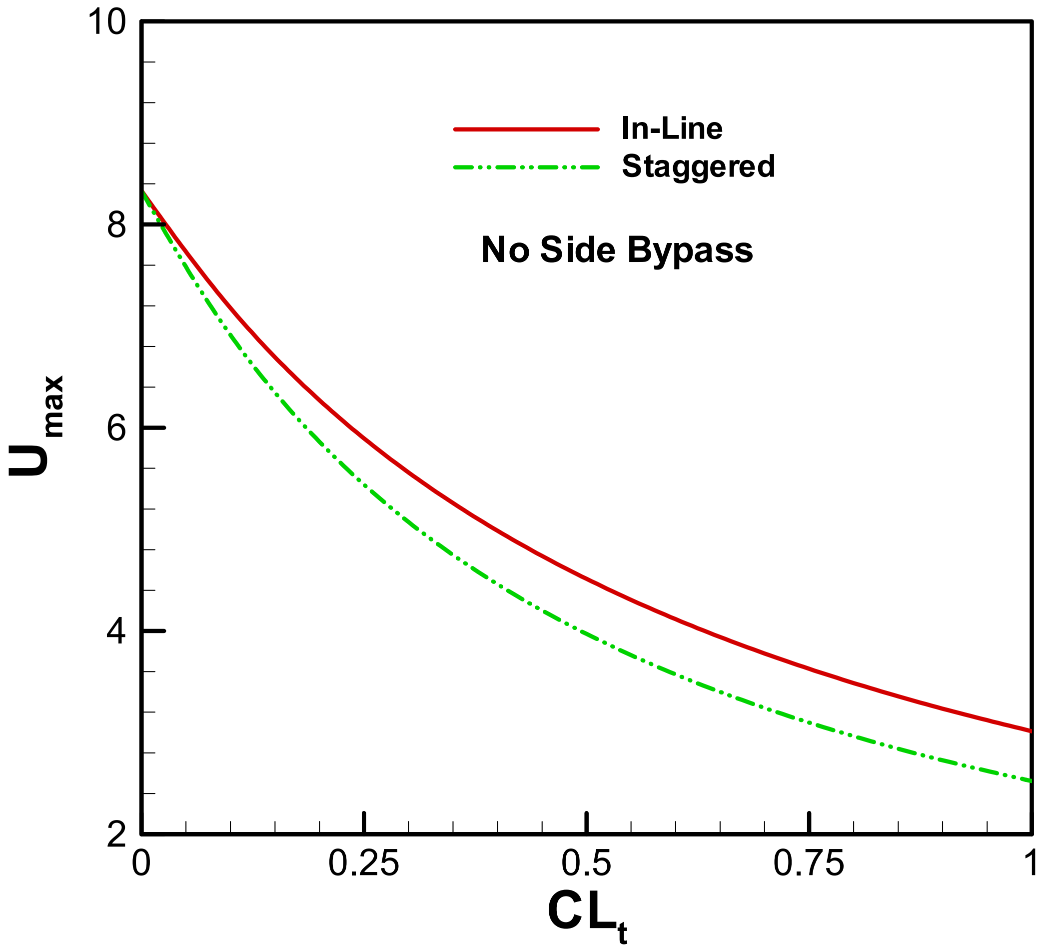
U_{max} (Top Bypass Only)



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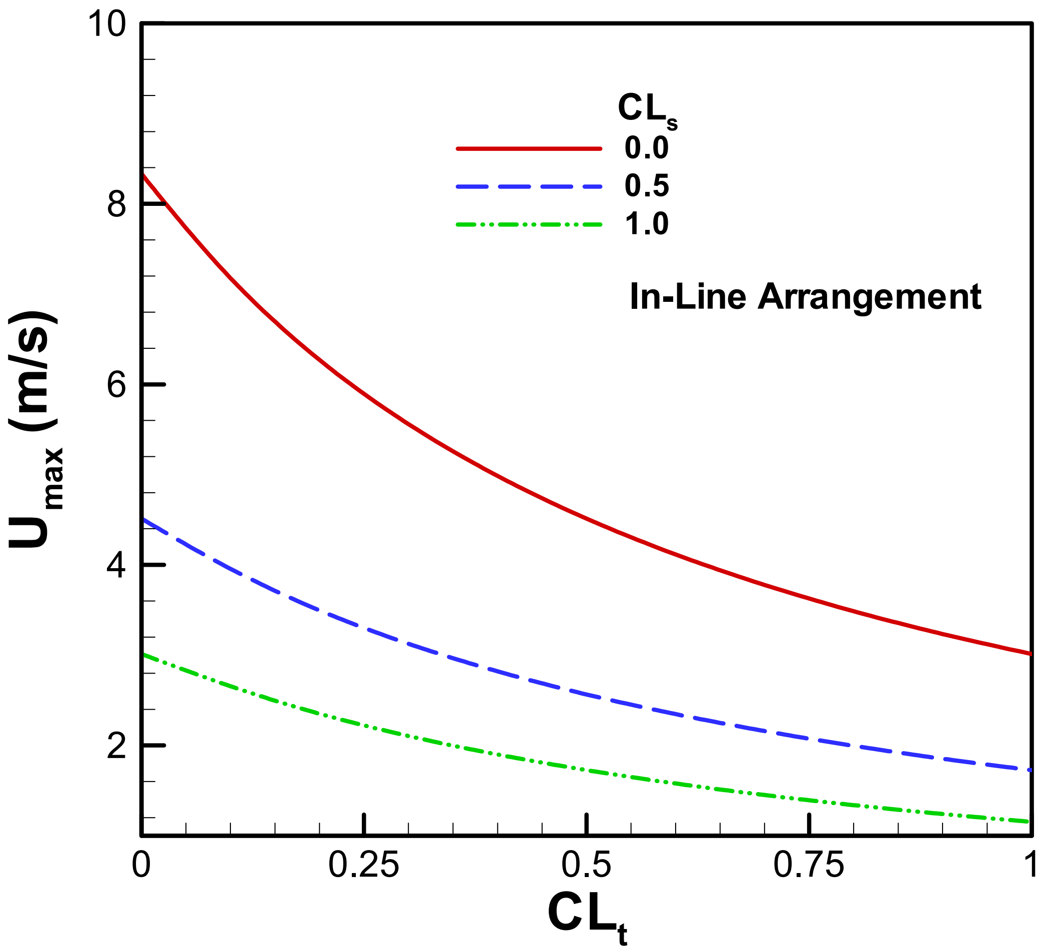
U_{max} (With Side and Top Bypass)



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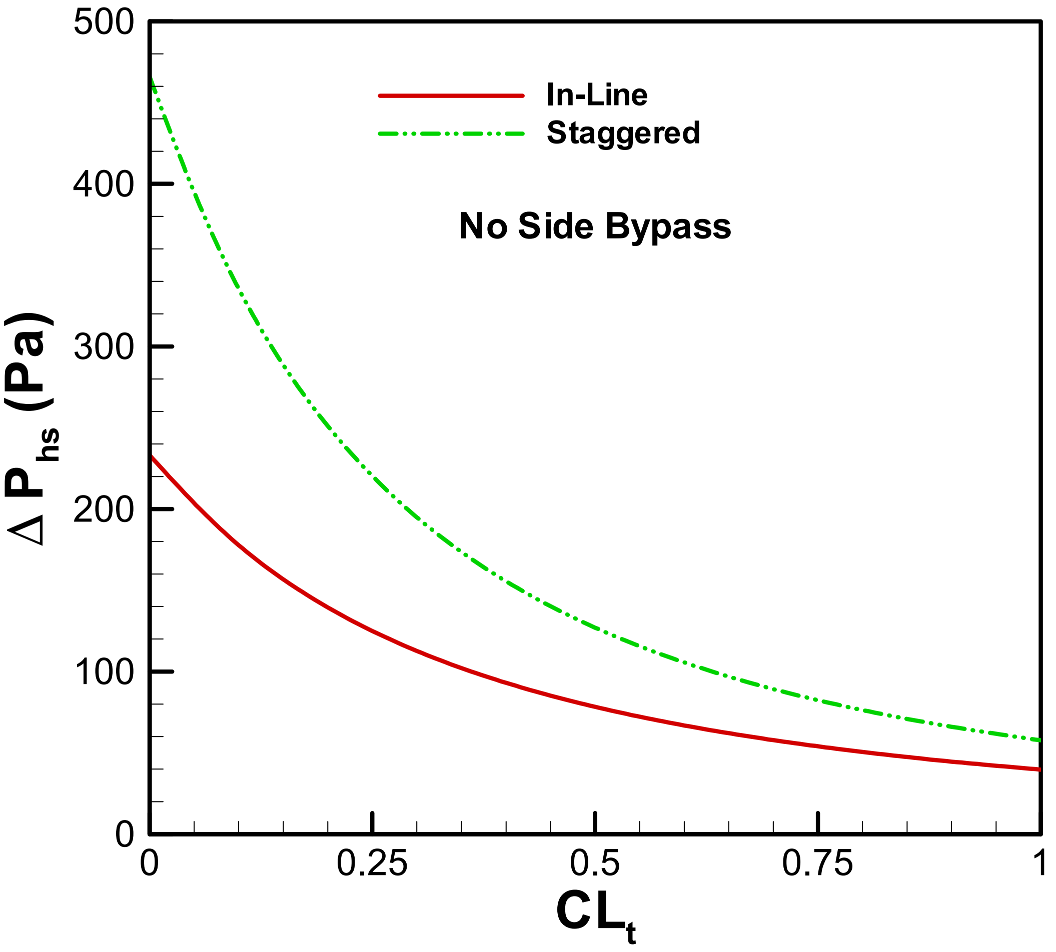
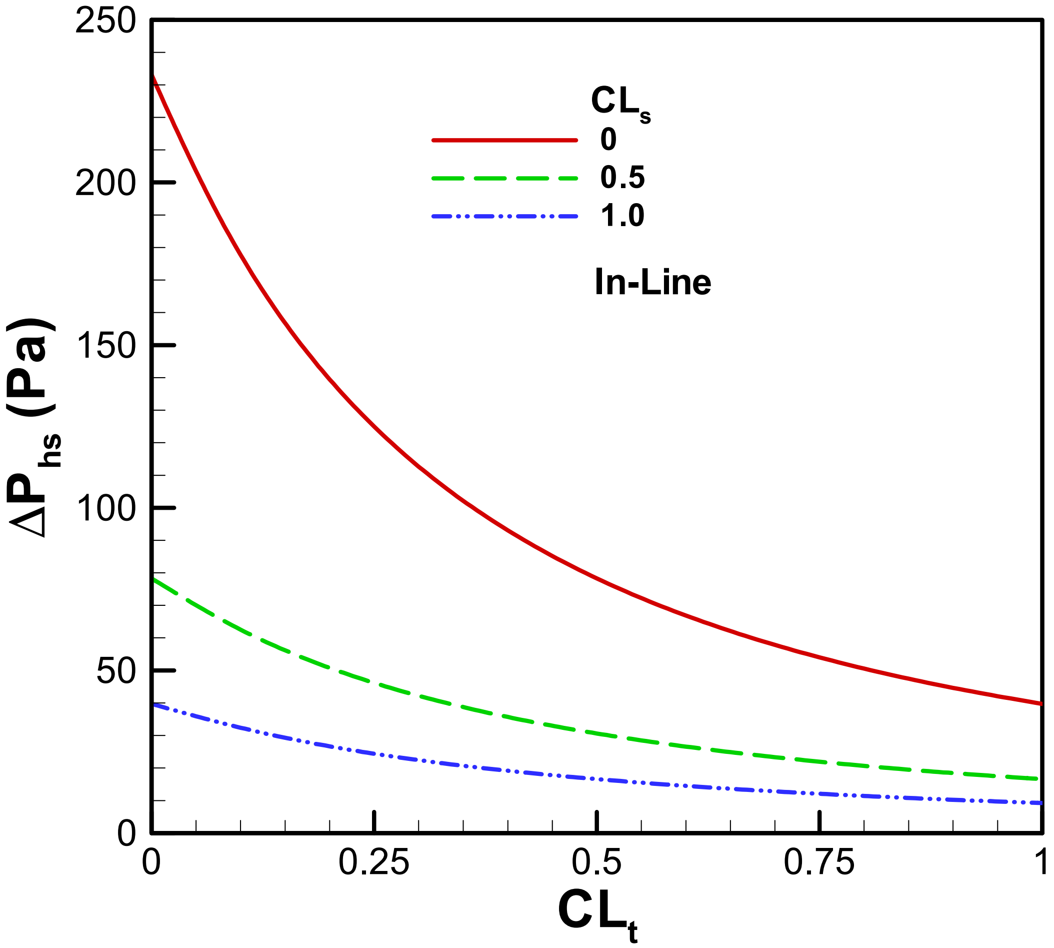
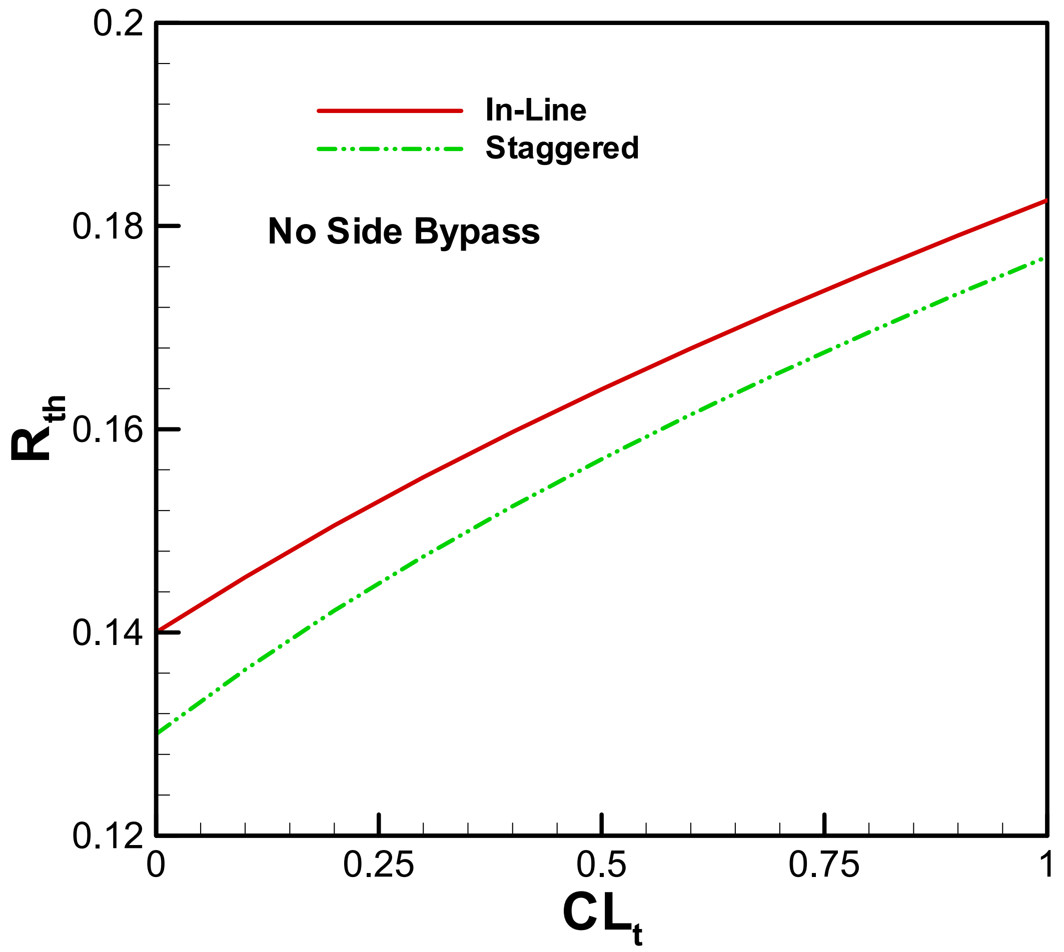
ΔP_{hs} (Top Bypass Only)



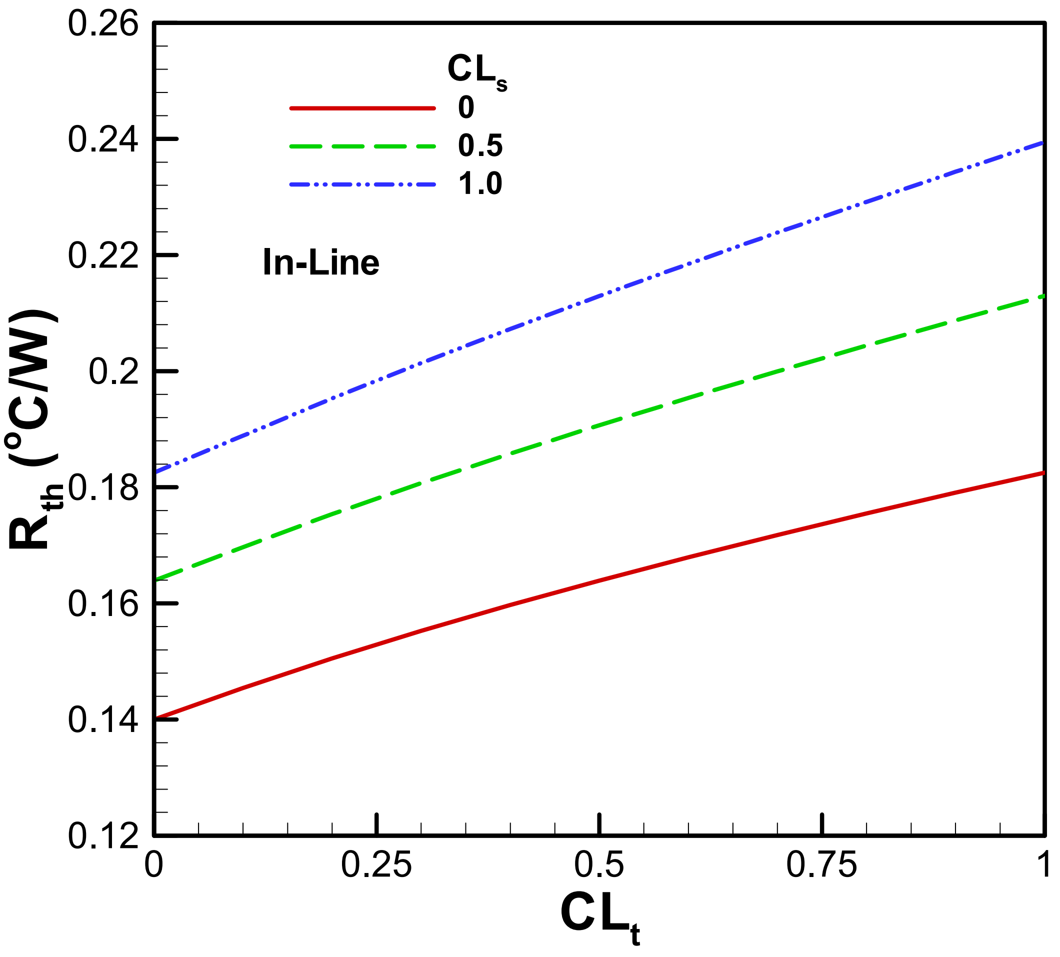
ΔP$_{hs}$ (With Side and Top Bypass)



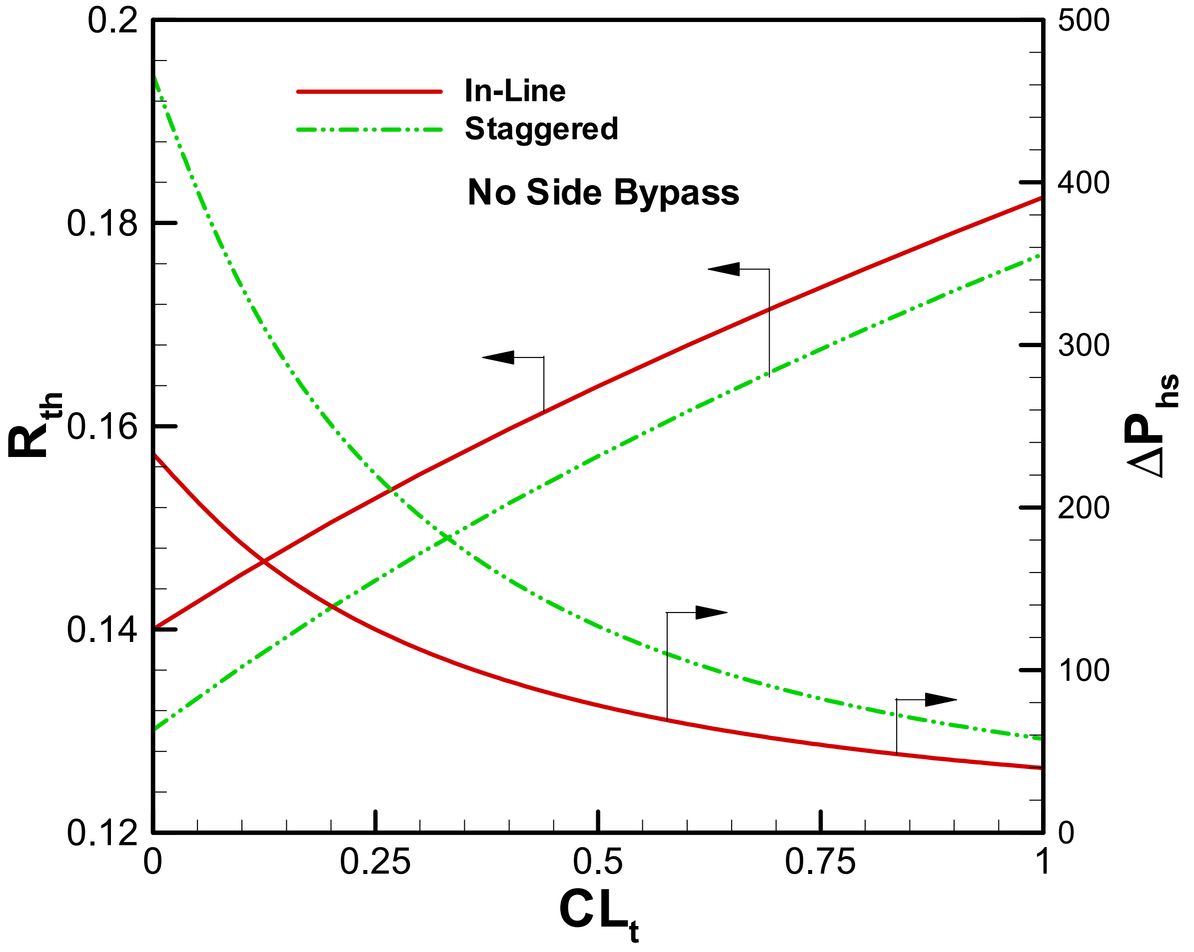
R_{th} (With Top Bypass Only)



R_{th} (With Side and Top Bypass)



R_{th} and ΔP_{hs} (Top Bypass Only)



Conclusions

- R_{th} increases whereas ΔP decreases with the increase in side and top clearance ratios.

- Comparisons show that In-line arrangement has higher R_{th} but lower ΔP than staggered one.

Acknowledgements

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