

# On the coupled integration of ducted heat-exchanger systems for aviation

Presenter Erik Hasselwander, PhD Student | 14-10-2025

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# Agenda

- Introduction to the project INTEHEX
- Introduction to the study
- Methodology
- Results
- Conclusions

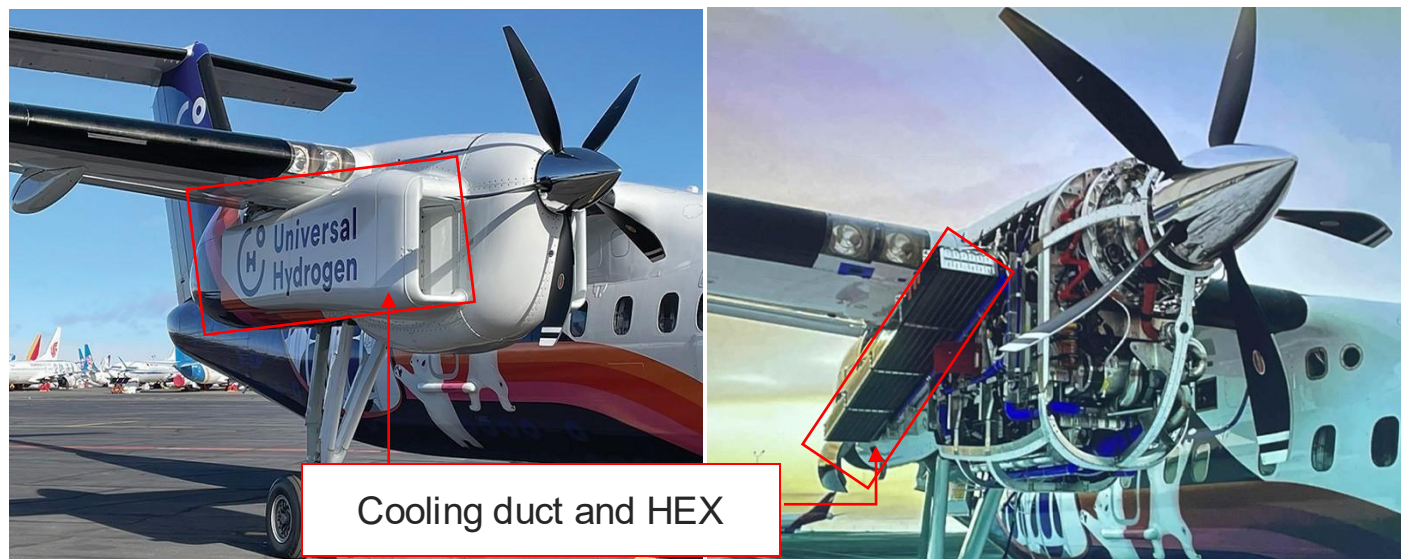


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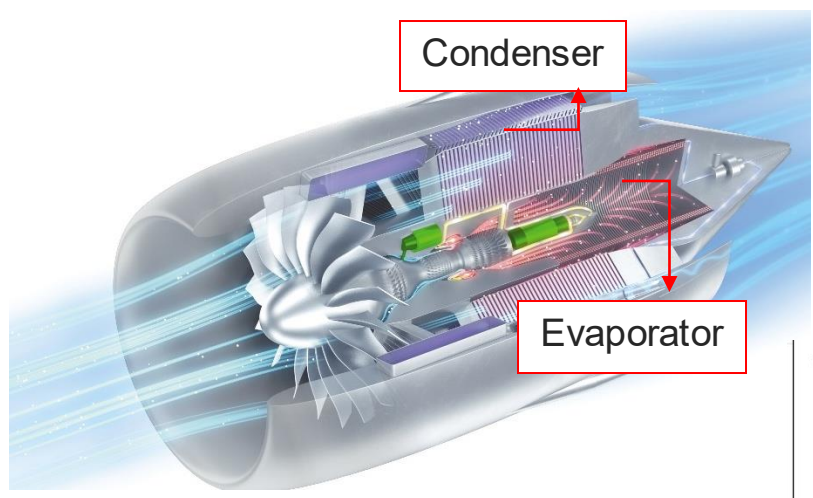
# Project Introduction

# INTEHEX

aero engine INTEgration of Heat EXchangers

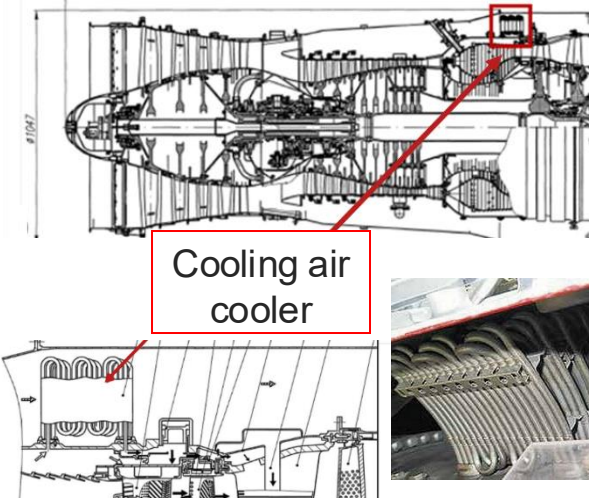


Cooling duct and HEX



Condenser

Evaporator

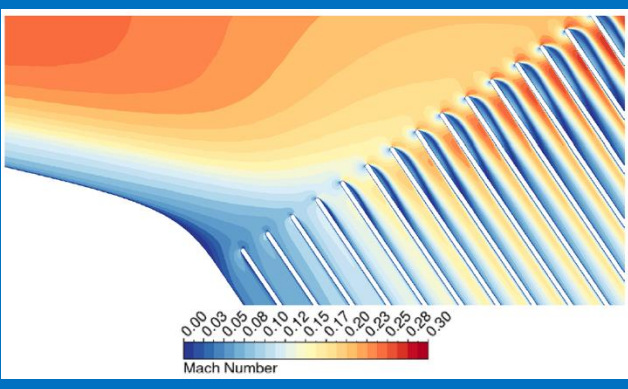
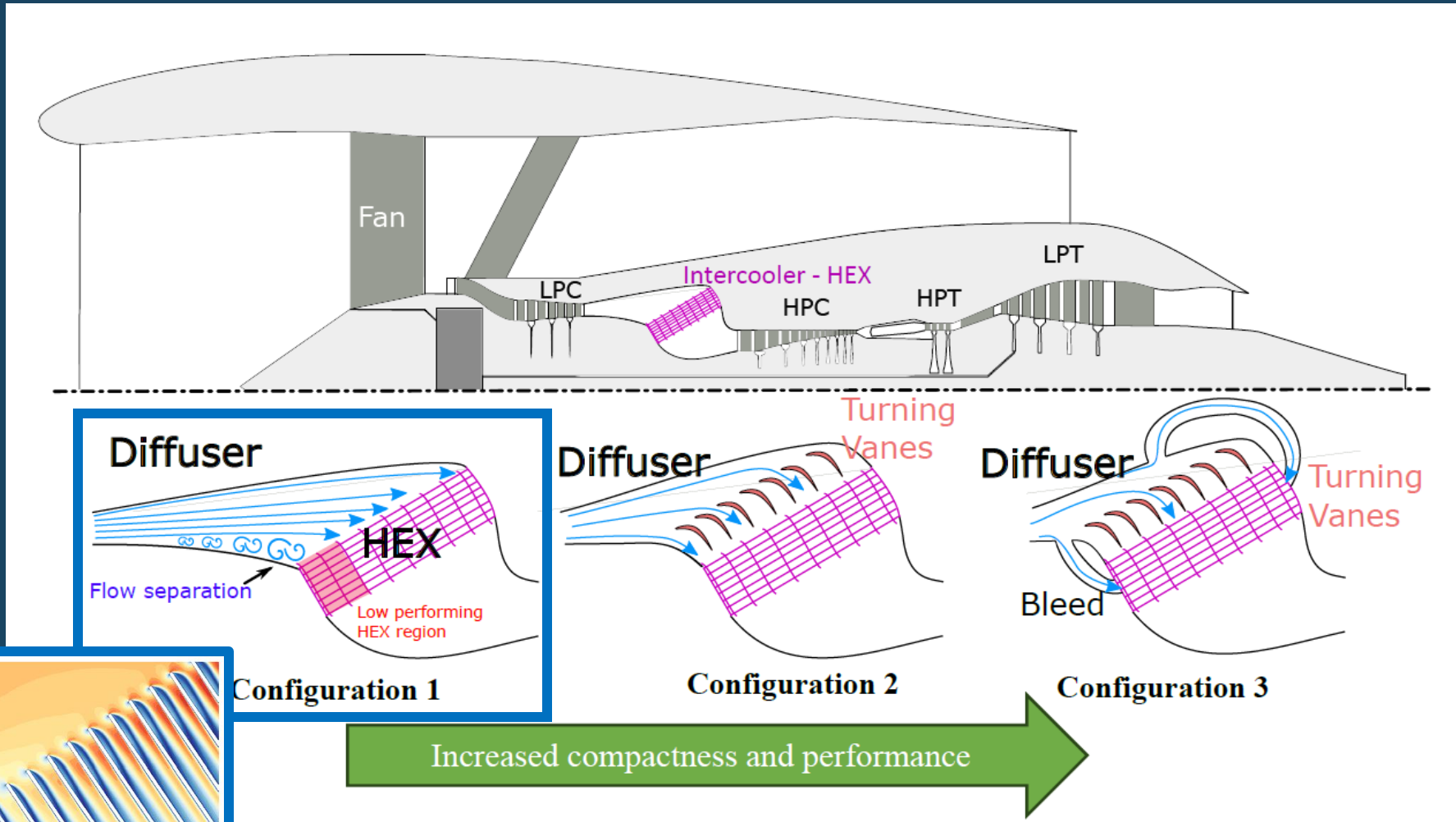


Cooling air cooler

# Motivation

- Heat exchangers are not new to aircraft.
- Today's range is tens of kW
- Future requirements are 100's – 1000's kW
- Design must be compact
- No established practice

# Example - Intercooler

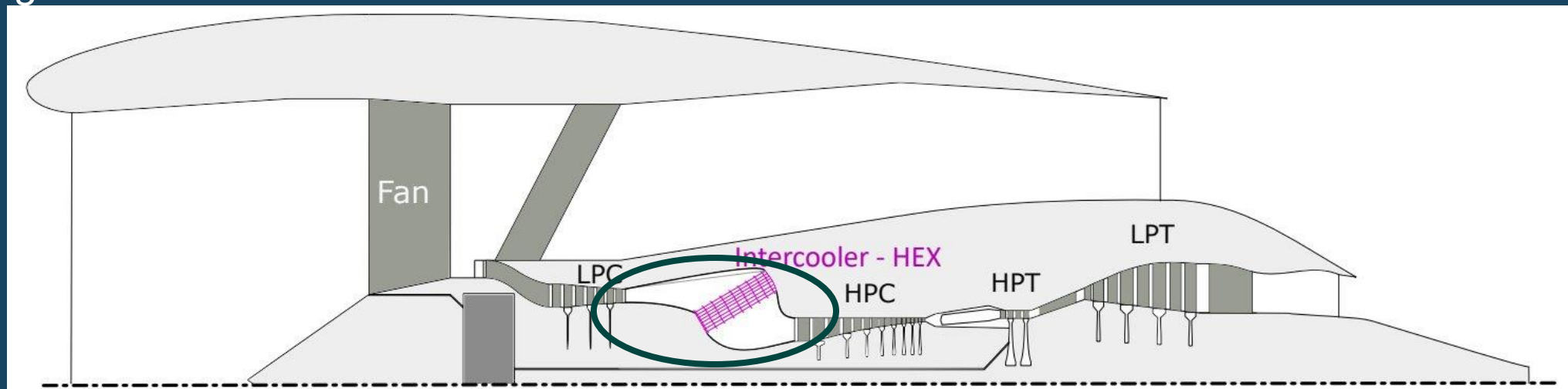


# Project goals

- Develop a structured **design framework for HEX integration in aircraft propulsion systems**
- **Understand and quantify the impact** of different heat-exchanger configurations on the upstream diffuser ducts.
- Propose and **investigate passive and active systems** for a more controlled and stable flow deceleration towards the heat-exchanger.
- **Design and investigate the performance and stability** of innovative compact configurations for commercial and military applications.

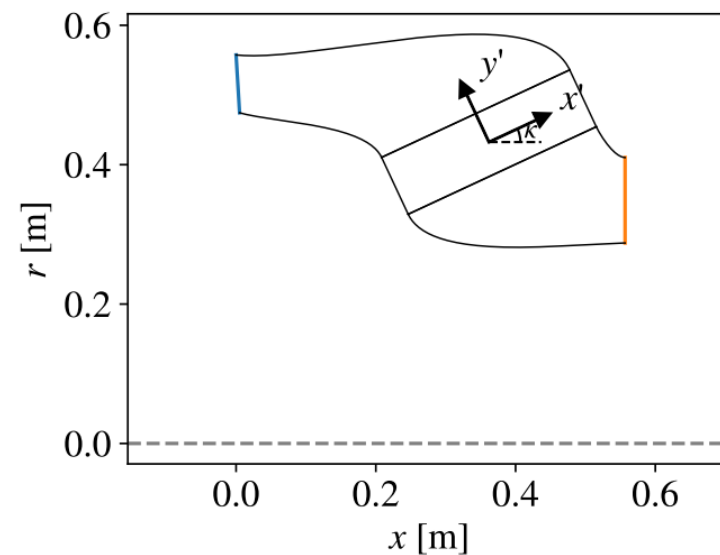
# Present study - Goals

- Investigate a design for an ICD with an integrated HEX
  - Realistic inlet conditions
  - Passive control
- Understand the trade factors in the integration
- Develop new design methods
  - Integrate GenHEX into commercial CFD software

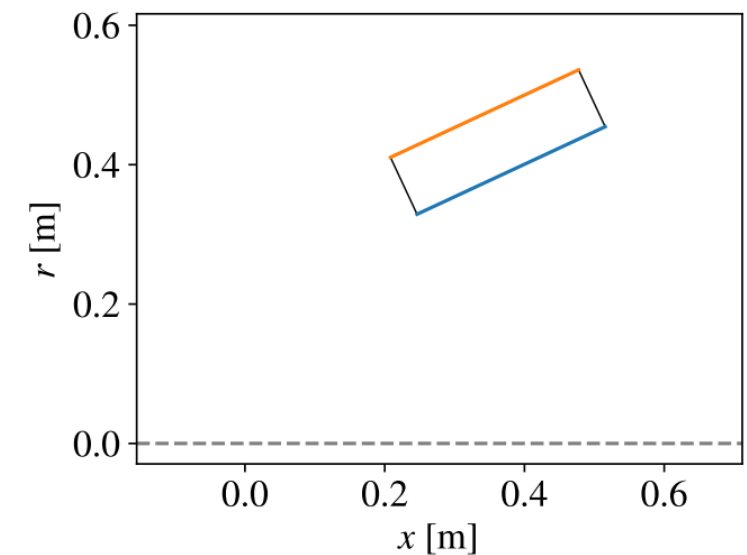


# Geometry

- Two flow fields



(a) Air side (hot)



(b) Water side (cold)

**Figure 3.1:** Meridional view of an intermediate compressor duct with an integrated heat exchanger. The blue lines represents the respective domain inlets and the orange lines represent the outlets.

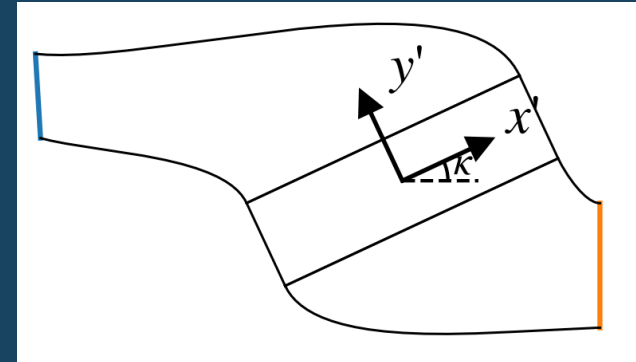
# Methodology overview

- Generate parametrized ducts using optimizer
- Solve for two different flow fields
  - Hot (air) and cold (water) side of HEX
- Use GenHEX and a variable HEX geometry to:
  - Estimate aerothermal performance for the HEX
- Match a target temperature drop within the CFD simulations
  - Keep aerothermal performance constant between designs
- Use Bayesian optimization to minimize pressure drop

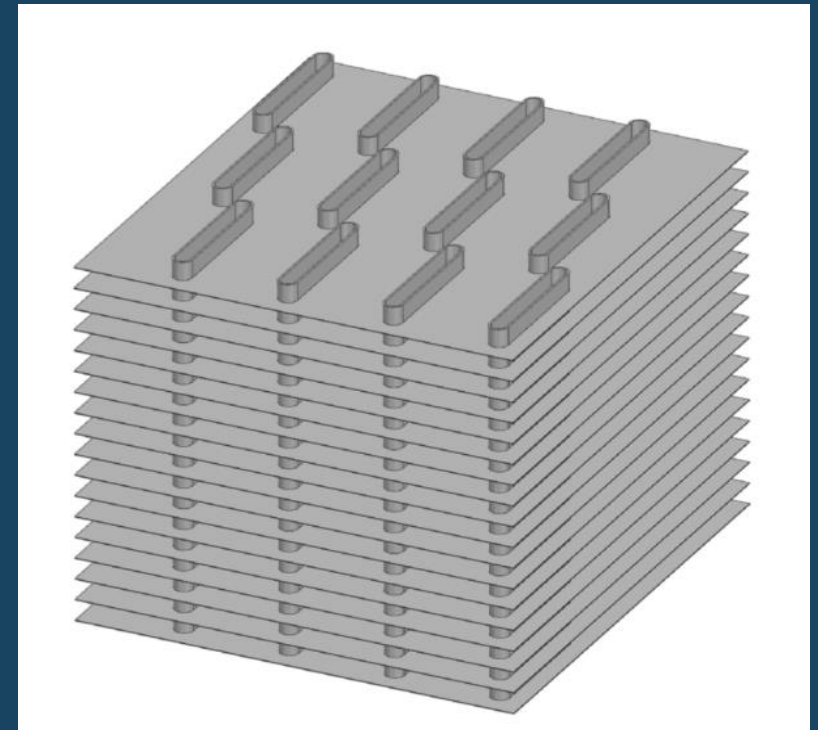
CFD

Python,  
BO-GP

# Reference heat exchanger

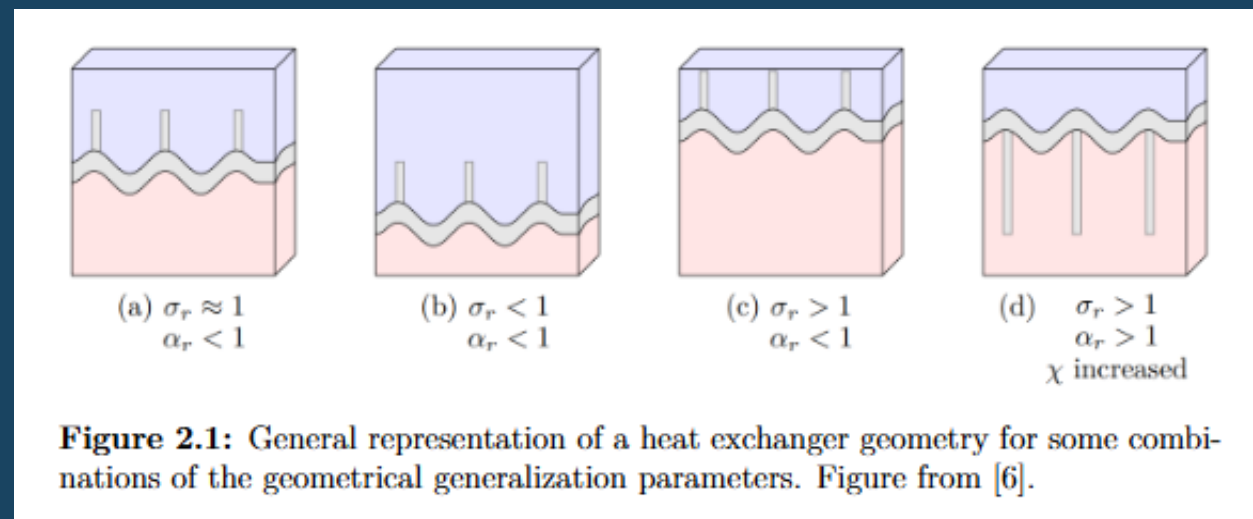


- Based on 9.1-0.737-S
  - Finned flat-tube HEX
- Cold side geometry constant, tubes
- Hot side geometry varies through the fin spacing to match target temperature drop
- Fins are normal to the  $x'$ -direction
- Used to obtain initial geometry generalization
  - Aerothermal performance is estimated using GenHEX for both fluids



# Discretized GenHEX

- HEX performance estimation tool
  - Developed by Petter Miltén at Chalmers
- Generalized geometry + aerothermal performance
- Each cell is a tiny heat exchanger
- Calculate  $h$ ,  $\Delta p_0$ ,  $\Delta T$  for each flow field
- Fins are captured through source term



$$\frac{dq}{dA} = U(T_h - T_c) \longrightarrow \frac{q_h}{V} = U\alpha_h(T_c - T_h)$$

$$\Delta p_0 = \frac{\dot{m}^2}{2\rho_{in}A_{fr}^2} \left( \left( \frac{1}{\sigma^2} + 1 \right) \left( \frac{\rho_{in}}{\rho_{out}} - 1 \right) + 2fL \frac{\alpha}{\sigma^3} \frac{\rho_{in}}{\rho_m} \right) \longrightarrow \frac{\Delta p_0}{u^2 L} = \frac{\alpha \rho f}{2\sigma^3}$$

$$\frac{1}{U_h} = \frac{1}{\eta_{o,h} h_h} + \frac{\alpha_r}{\eta_{o,c} h_c} + \frac{2t}{\left(1 + \frac{1}{\alpha_r}\right) k}$$

$$h = \frac{k\alpha_h \text{Nu}}{4\sigma_h} = \frac{k\alpha_h j \text{RePr}^{1/3}}{4\sigma_h}$$

# Matching a target temperature drop

- Update the spacing between the fins between every iteration in the CFD simulation
- The spacing is controlled by  $\chi$
- As the difference goes to 0  $\chi$  becomes constant
- $\Delta T_{\text{target}} = 10\text{K}$
- Every design does the same thermal work
  - Easy comparison of losses

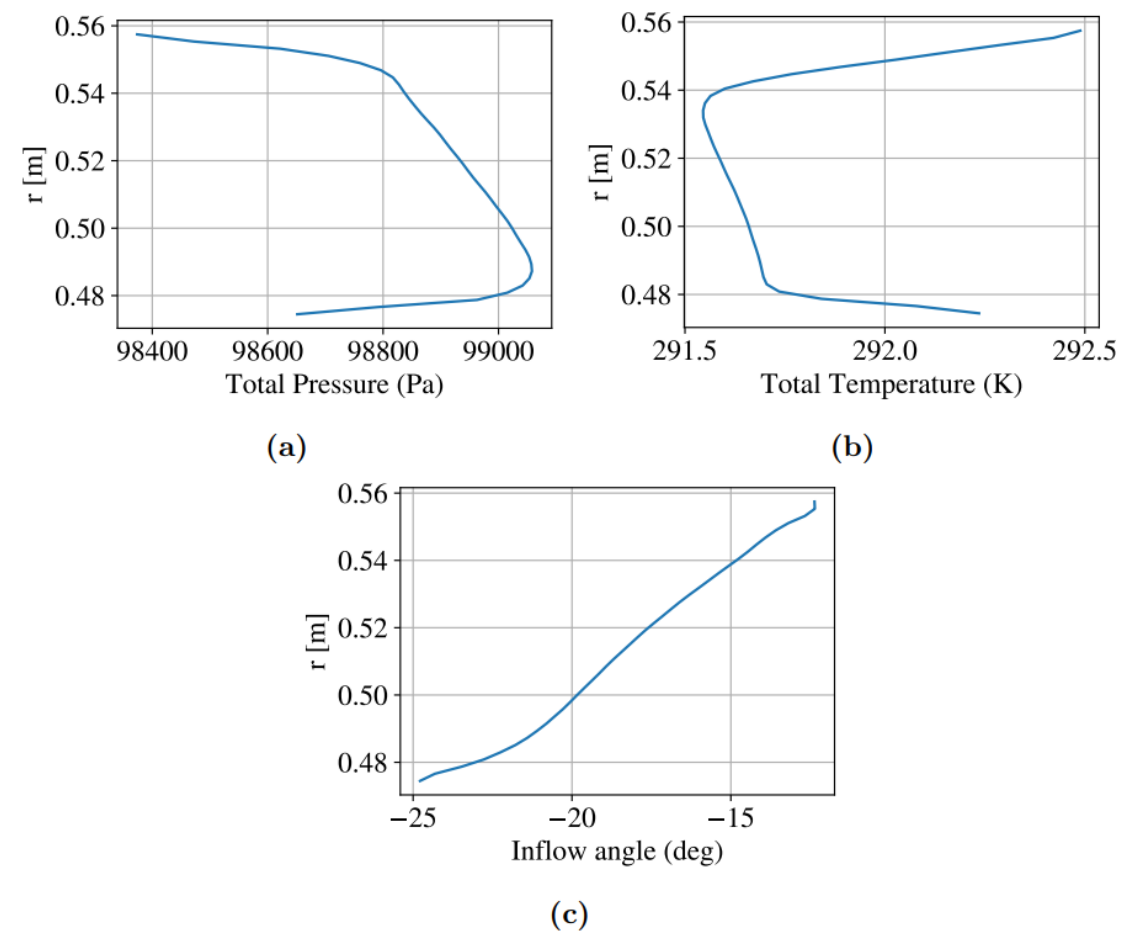
$$\chi = \chi_{\text{old}} \left( 1 - \psi \frac{\Delta T_{\text{current}} - \Delta T_{\text{target}}}{\Delta T_{\text{target}}} \right)$$

# Boundary conditions

- Extracted from the Chalmers experimental compressor facility
- Pressure outlet to obtain target massflow of 12.866 kg/s

**Table 3.2:** Summary of inlet boundary conditions.

Parameter	Value
Total temperature, $T_0$	291.73 K
Total pressure, $p_0$	98.907 Pa
Reynolds number, Re	366.262
Mach number, Ma	0.129
Velocity, $v$	44.13 m s <sup>-1</sup>
Blockage ratio, $B_T$	24 %



# Numerics

## Air side

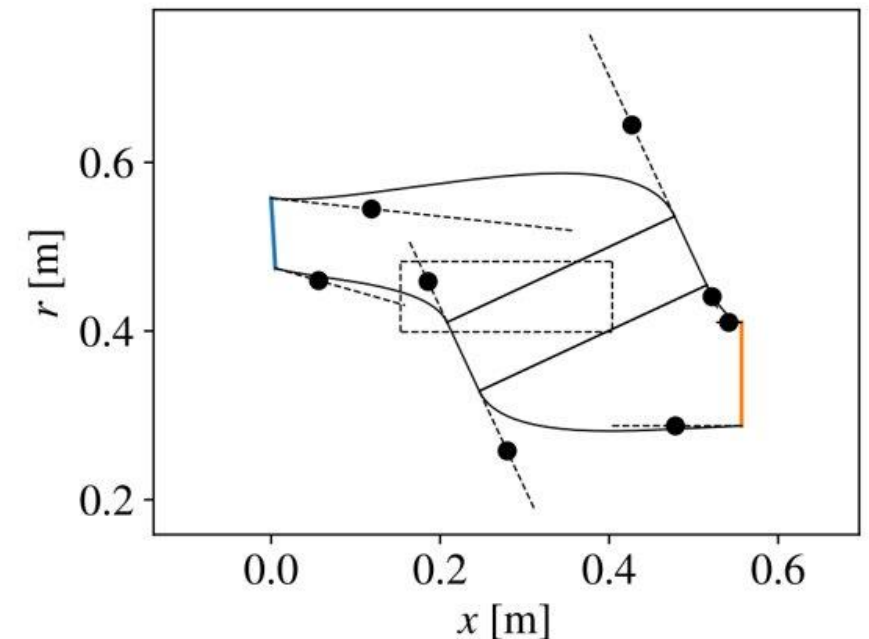
- 2D axisymmetric
- Compressible RANS
- k-omega SST
- Coupled flow
- 2nd order discretization

## Water side

- 2D axisymmetric
- Steady state
- Laminar
- Coupled flow

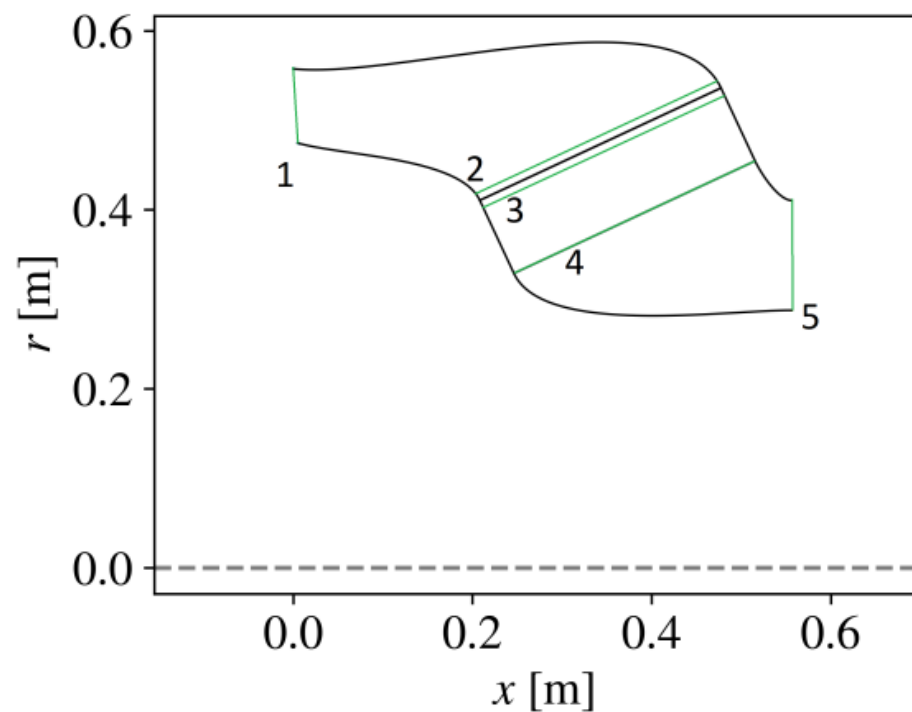
# Optimization

- Generate geometry inputs using BO-GP based on the existing data.
- Generate the duct geometry from the geometry inputs.
- Create a computational mesh.
- Solve for the flow fields
- Post-process the results to get target quantity
  - Total pressure drop over the entire domain
- Add the target quantity to the database.
- Repeat



# Geometry definitions

- Diffusing duct: 1-2
- HEX entry: 2-3
- HEX core: 3-4
- Contracting duct: 4-5

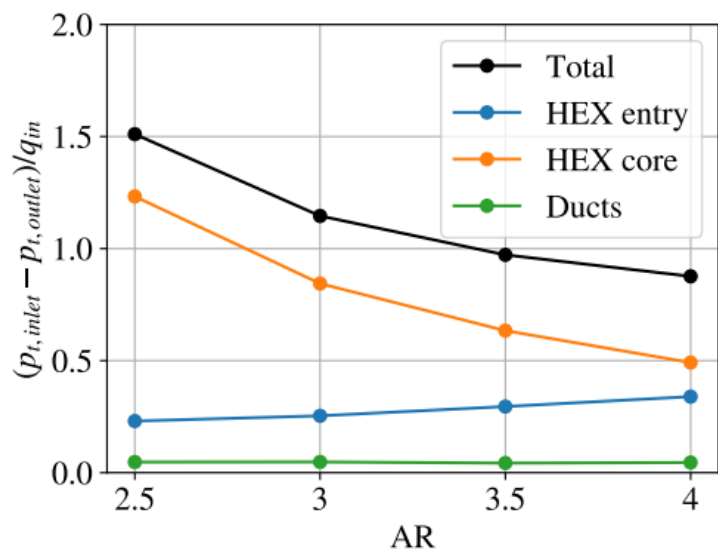


**Figure 3.3:** The boundaries, in green, used to distinguish between different sources of losses.

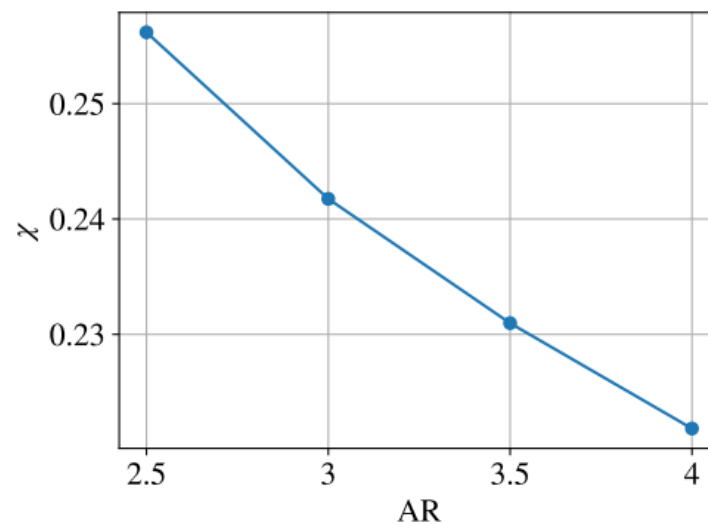
# Results

- Three main investigations
  - Effects of area ratio on performance
  - Effects of length on performance
  - Effects of fins on performance

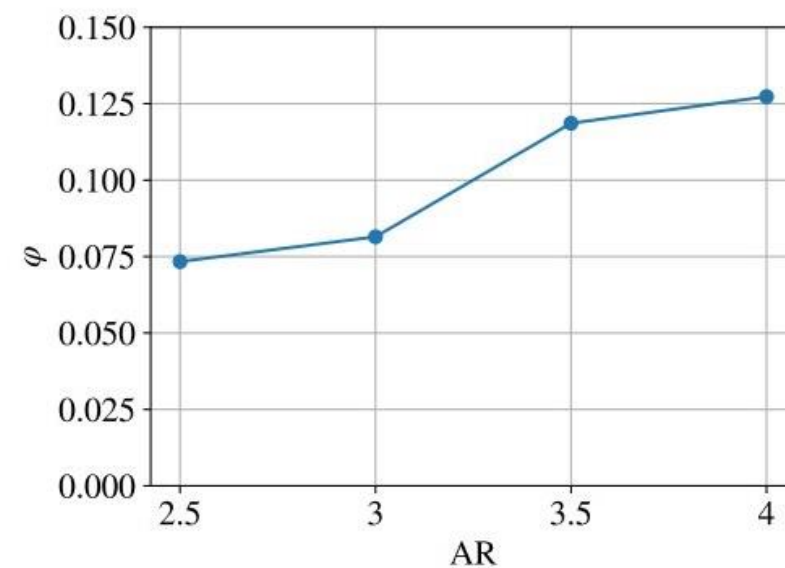
# Effects of area ratio on performance



**Figure 4.7:** Total, HEX entry, HEX core and duct losses against area ratio for the optimal designs.

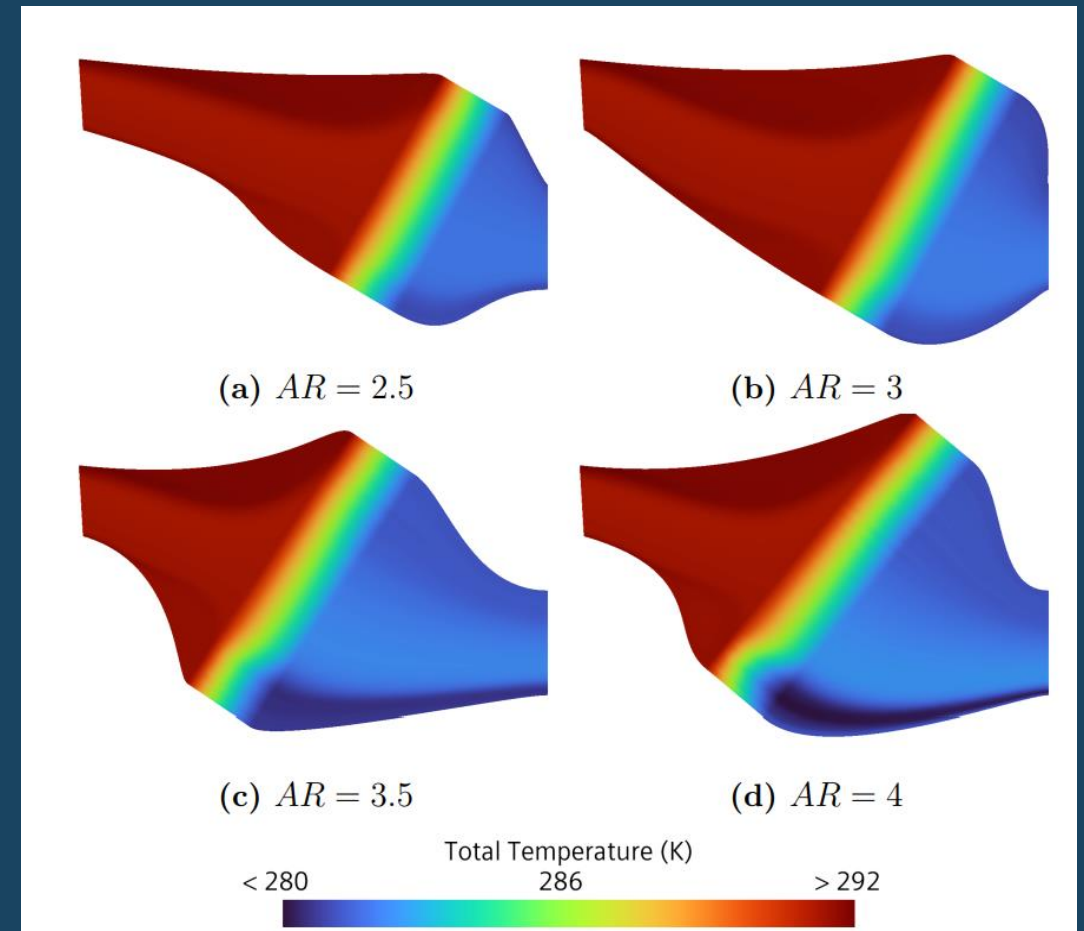
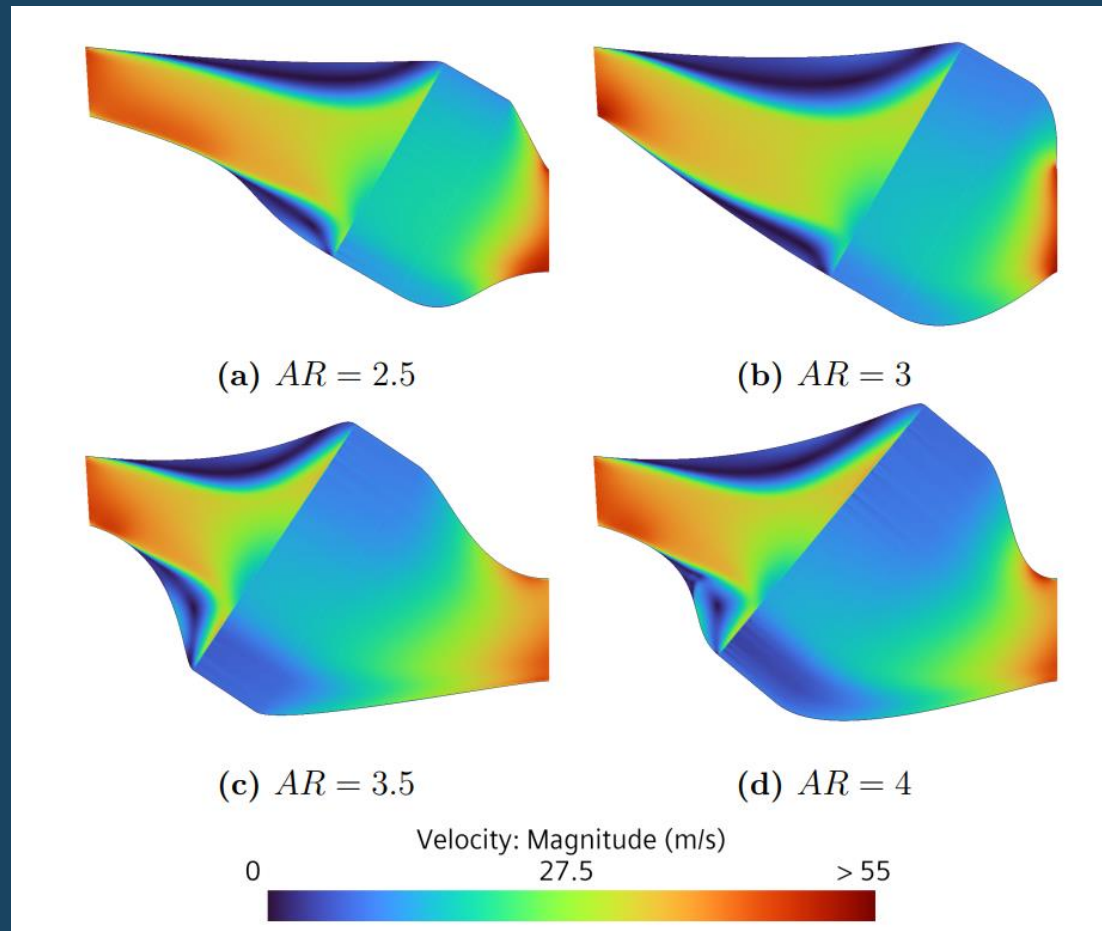


**Figure 4.8:** The value of  $\chi$ , which correlates with fin density, against area ratio for the optimal designs.

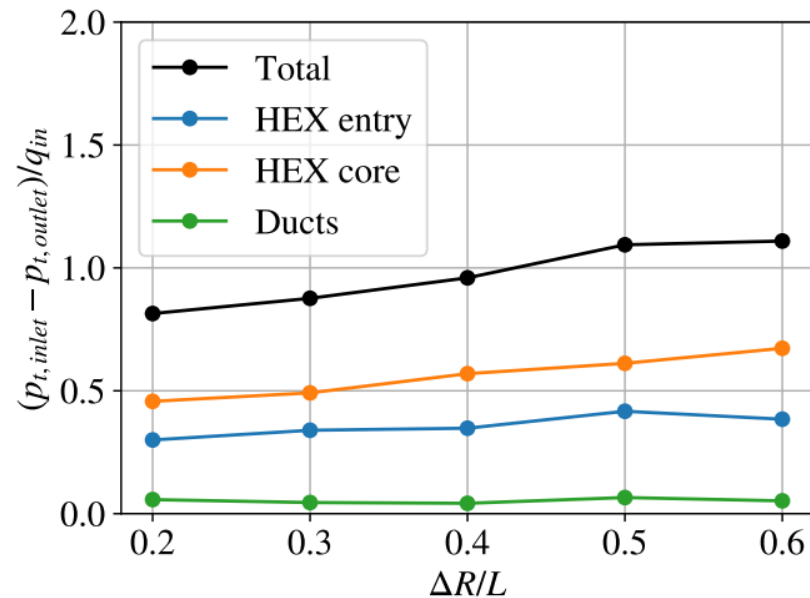


**Figure 4.9:** y'-velocity non-uniformity at HEX inlet

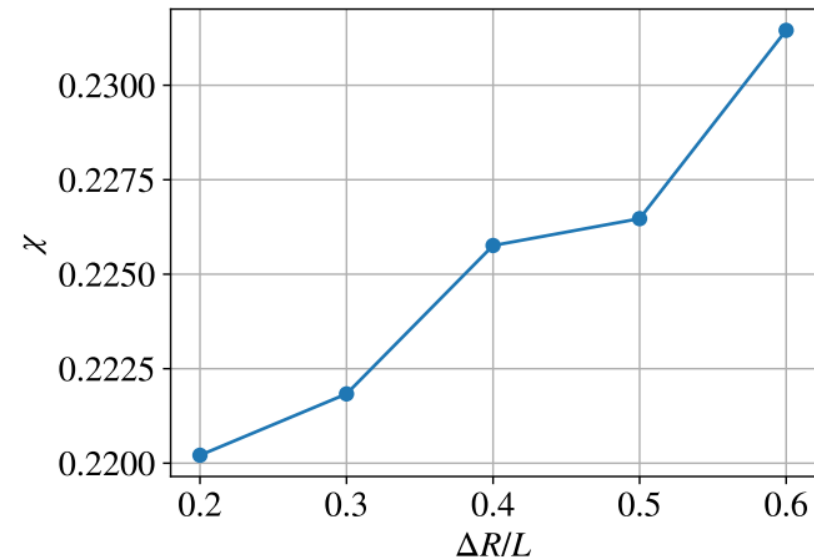
# Effects of area ratio on performance Fields



# Effects of length on performance

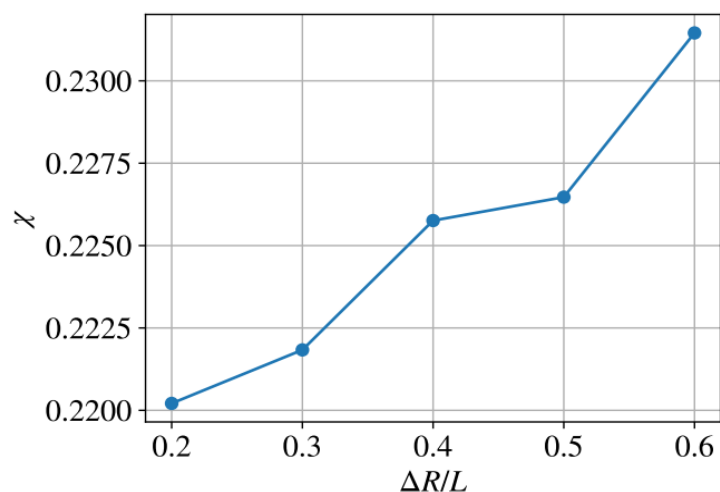


**Figure 4.13:** Total, HEX entry, HEX core and duct losses against area ratio for the optimal designs.

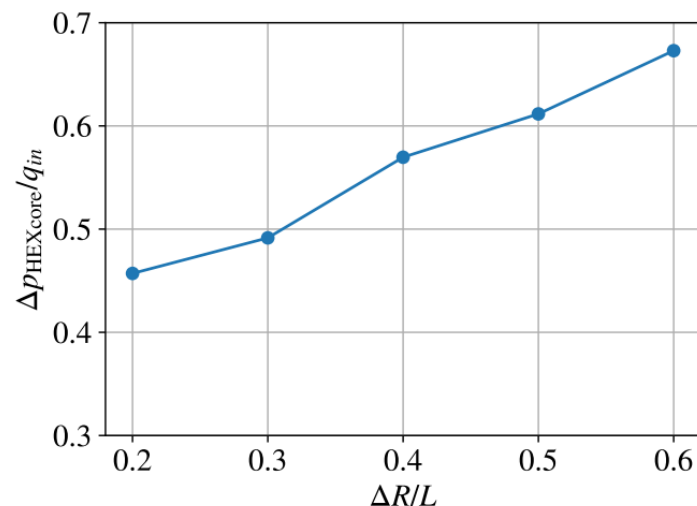


**Figure 4.14:** The value of  $\chi$ , which correlates with fin density, against area ratio for the optimal designs.

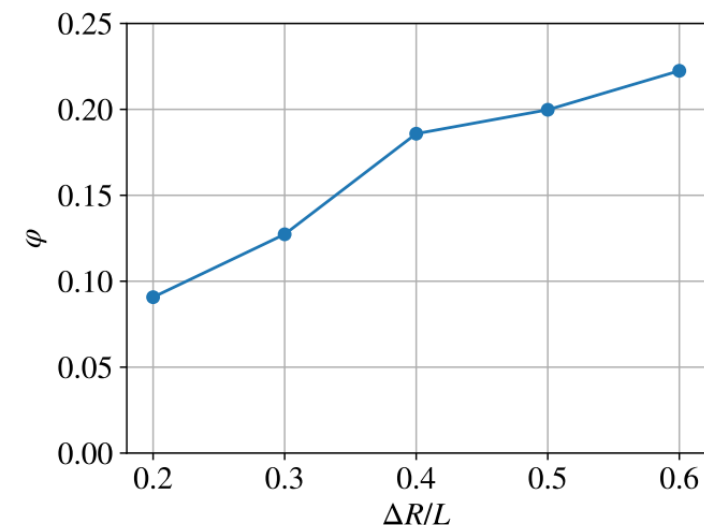
# Effects of length on performance



**Figure 4.14:** The value of  $\chi$ , which correlates with fin density, against area ratio for the optimal designs.



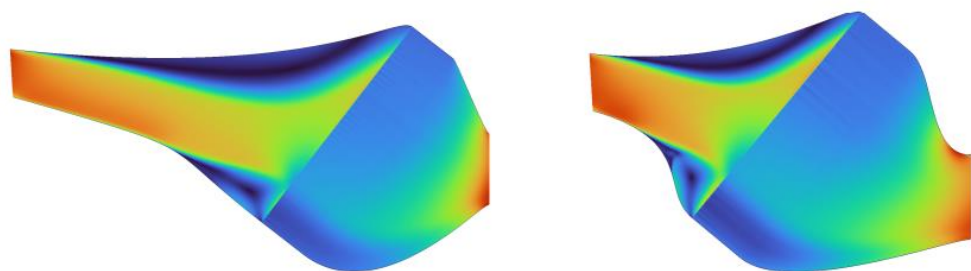
**Figure 4.15:** Heat exchanger core pressure losses against  $\Delta R/L$  for the optimal designs.



**Figure 4.16:** The value HEX inlet-normal velocity uniformity  $\Delta R/L$  for the optimal designs.

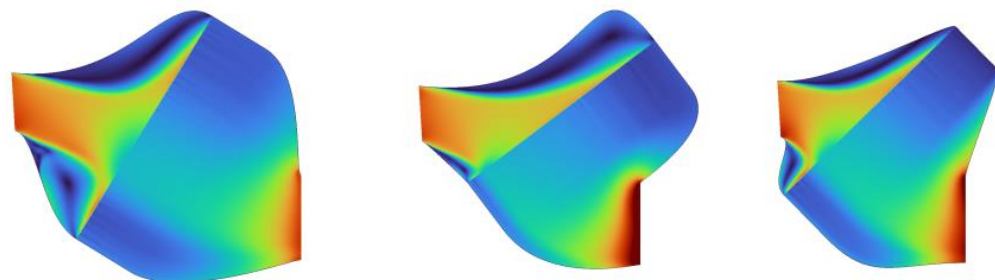


# Effects of length on performance Fields



(a)  $\Delta R/L = 0.2$

(b)  $\Delta R/L = 0.3$

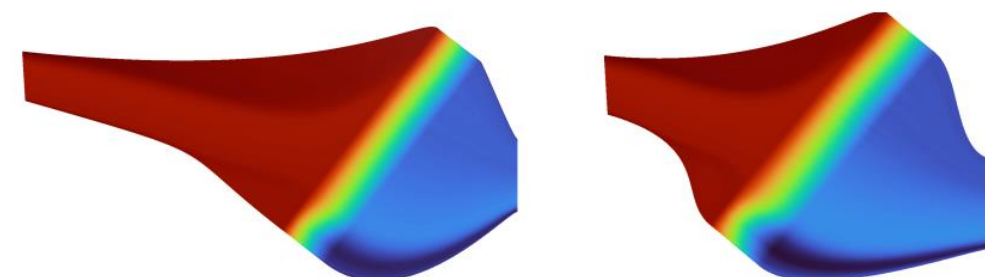


(c)  $\Delta R/L = 0.4$

(d)  $\Delta R/L = 0.5$

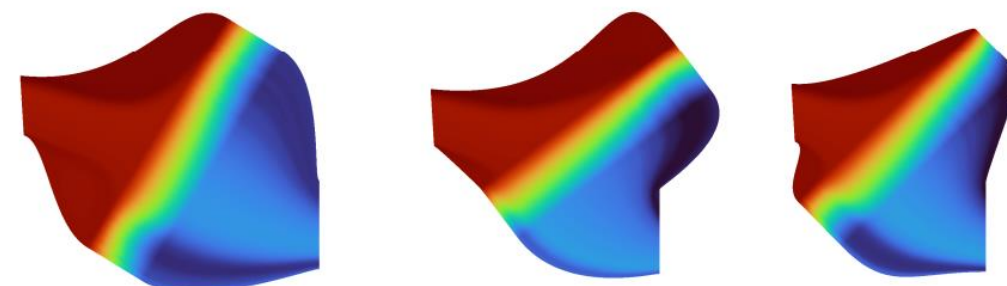
(e)  $\Delta R/L = 0.6$

Velocity: Magnitude (m/s)



(a)  $\Delta R/L = 0.2$

(b)  $\Delta R/L = 0.3$



(c)  $\Delta R/L = 0.4$

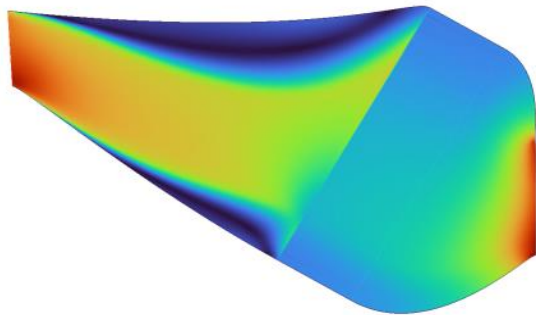
(d)  $\Delta R/L = 0.5$

(e)  $\Delta R/L = 0.6$

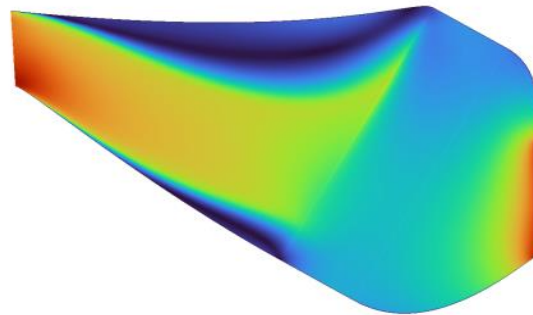
Total Temperature (K)



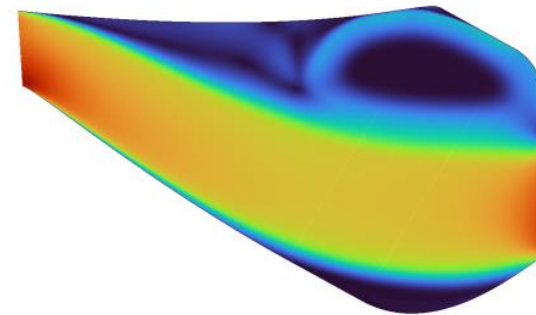
# Isotropic heat exchanger Constant geometry



(a) Finned heat exchanger.

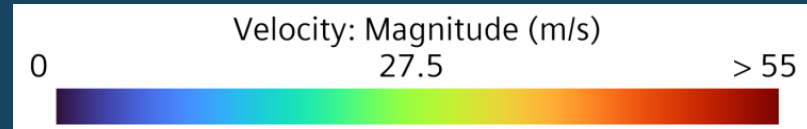


(b) Isotropic heat exchanger.



(c) No heat exchanger.

Heat exchanger type	Finned	Isotropic	No HEX
$\Delta T$	10 K	10 K	0 K
$\Delta p_{0,HEX} / q_{in}$	1.146	1.159	0.037
$\Delta p_{0,HEX \text{ entry}} / q_{in}$	0.254	0.143	N/A
$\Delta p_{0,HEX \text{ core}} / q_{in}$	0.844	0.97	N/A
$\Delta p_{0,ducts} / q_{in}$	0.048	0.046	N/A
Non-uniformity	0.081	0.226	0.565
$\chi$	0.242	0.234	N/A



# Conclusions

- Discretizing the GenHEX method allows realistic modelling of the aerothermal performance of heat exchangers
- Losses in aggressive designs are split evenly between entry losses and core losses
  - Reducing entry losses could lead to significant gains
- Isotropic heat exchangers result in largely unchanged performance
  - The pressure drop over the heat exchanger drives diffusion, not the fins
- Future work could implement a parametrization with more DOFs to improve pressure recovery of the diffusing duct
- Future work could investigate the tradeoff between HEX inclination and size



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