

# Shape optimisation using computational fluid dynamics and evolutionary algorithms

Steven Daniels

Alma Rahat, John Fieldsend, Gavin Tabor, and Richard Everson

College of Engineering, Mathematics and Physical Sciences, University of Exeter, UK

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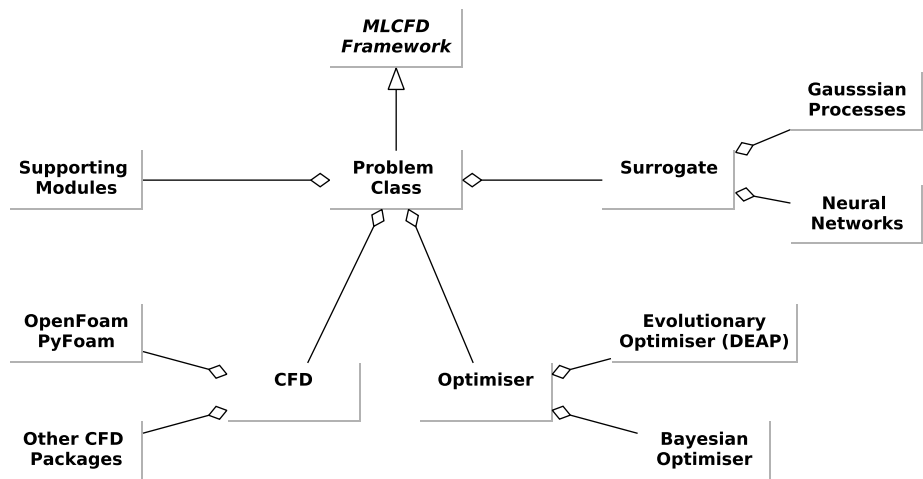


## Presentation outline

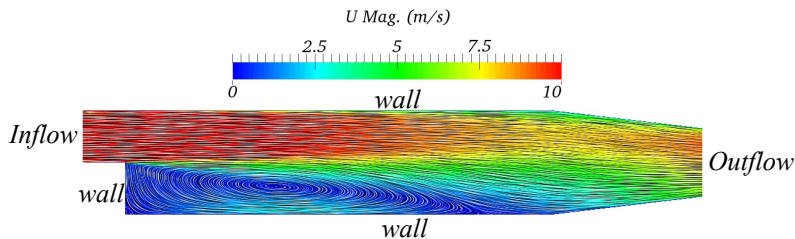
A summary of the progress made in coupling OpenFOAM into the ML-CFD framework for shape optimisation.

- Outline a few ideas for the 'representation' of shape optimisation.
- Apply the framework to a couple of benchmark test cases:
  - 1 PitzDaily
  - 2 Cross-flow heat exchanger

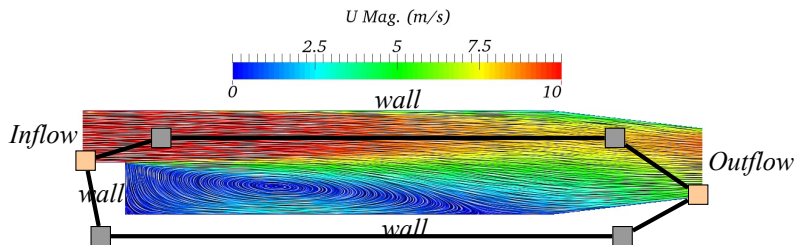
# ML-CFD Framework



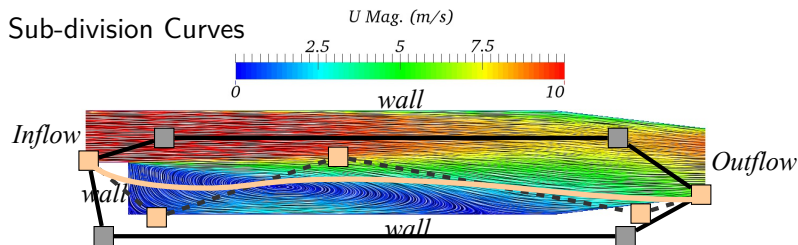
# Snappy-Hex Mesh method



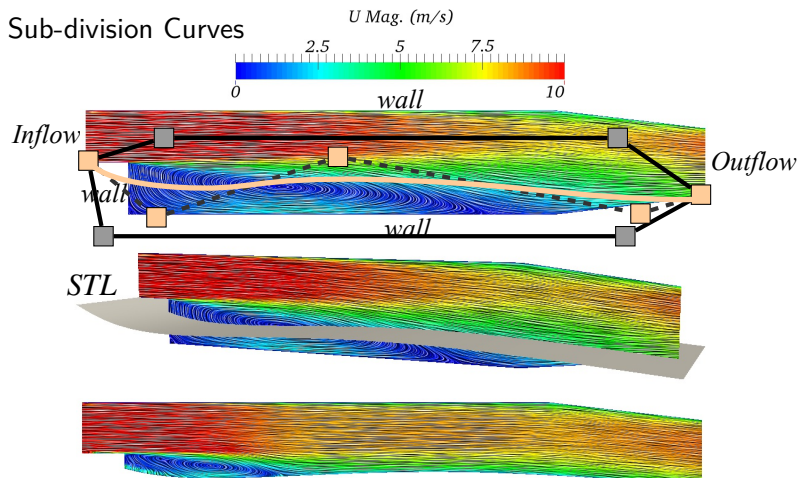
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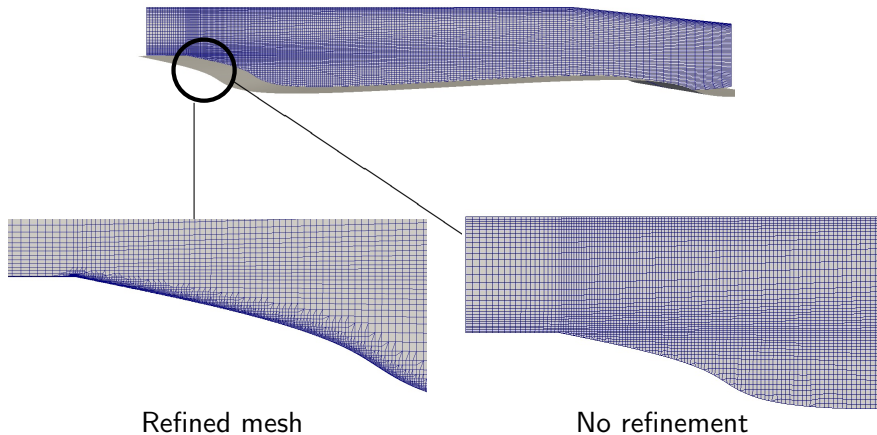
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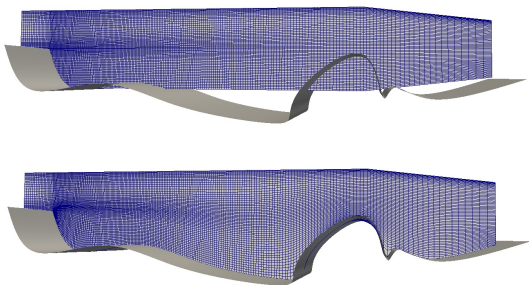
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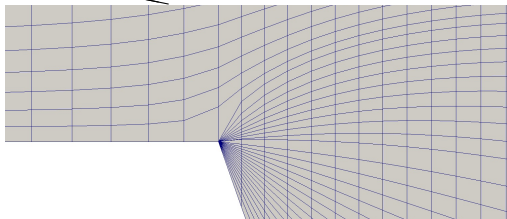
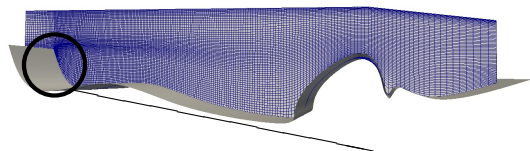
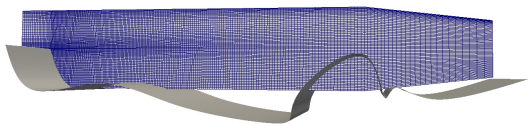
## Snappy Hex Mesh Refinement Method



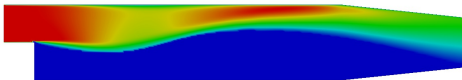
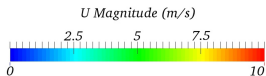
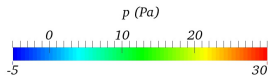
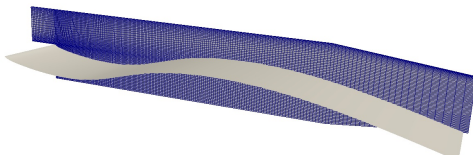
## Moving Boundary Method



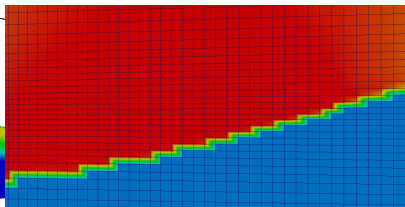
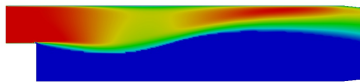
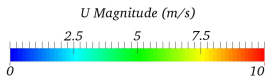
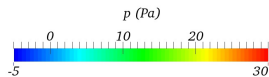
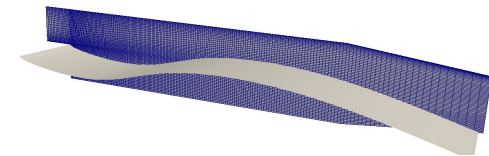
## Moving Boundary Method



## Cell Blocking Method



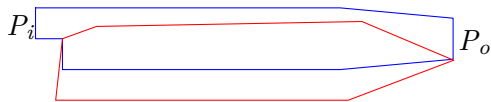
## Cell Blocking Method



## Multi-Objective Optimisation

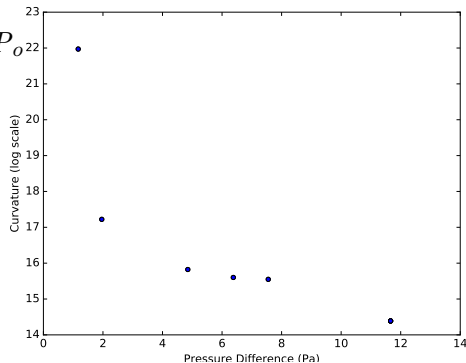
Pressure difference,  $f_1 = |P_o - P_i|$

Curvature,  $f_2 = \int [f''(x)]^2 dx$



Used NSGA-II (multi-objective)  
algorithm in Deap.

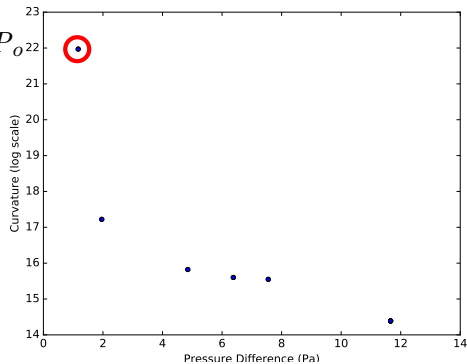
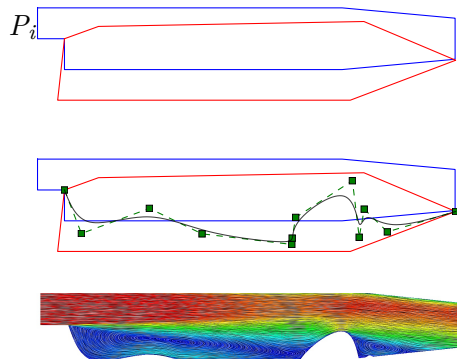
SimpleFoam tutorial case  
reference.



## Multi-Objective Optimisation

Pressure difference,  $f_1 = |P_o - P_i|$

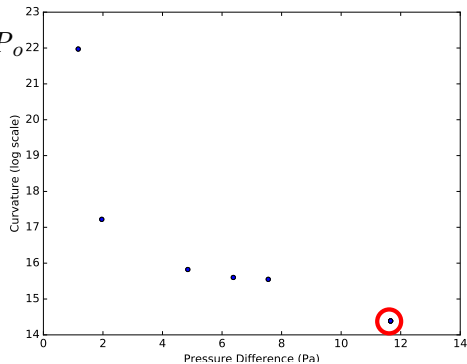
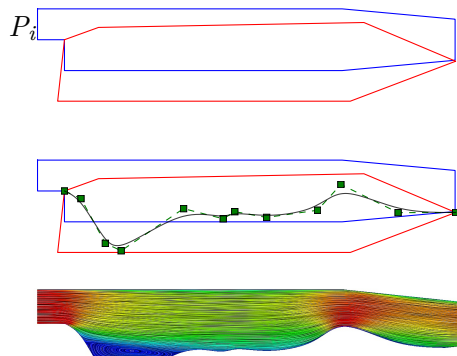
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## Multi-Objective Optimisation

Pressure difference,  $f_1 = |P_o - P_i|$

Curvature,  $f_2 = \int [f''(x)]^2 dx$



## Analysis of a cross-flow heat exchanger

- Performance of cross-flow heat exchanger measured by heat transfer and pressure drop across the domain.
- Considering a small section of the array to save computational cost.
- Variables for the position and radius of the pipes

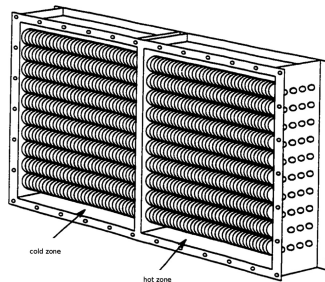
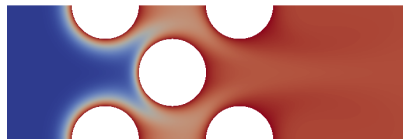


Diagram source: Selma et al. (2013).



Heat exchanger element.

## Outline of CFD set-up

$$\frac{\partial T}{\partial t} + \nabla \cdot (UT) = \nabla^2(\alpha T)$$

- Passive scalar transport equation to represent temperature recovery.
- $Re = 100$ , based on diameter of base pipe and freestream velocity - considered steady-state.

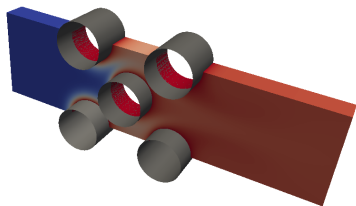
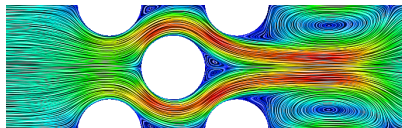


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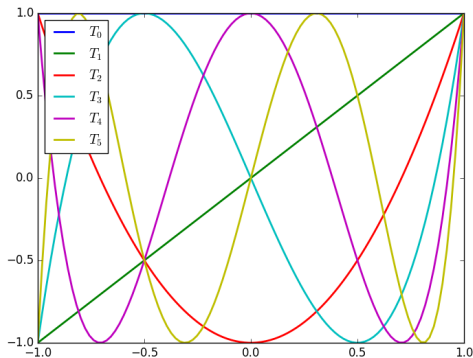


Heat exchanger element.

## Representation

$$p(x) = c_0 T_0(x) + c_1 T_1(x) + \dots c_n T_n(x)$$

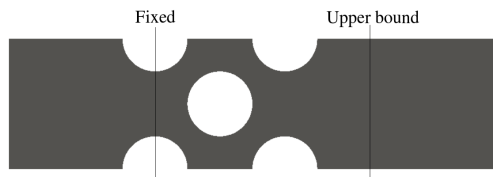
- Chebyshev polynomials to describe the position and radius of the pipes.
- Using function of degree 3.
- SnappyHexMesh representation method.
- Total of 12 variables (coefficients).



Chebyshev polynomials of different degrees.

## Constraints

- We need to make sure the pipes don't overlap!
- The first row of pipes are fixed, but their radius can change.
- Vertical positions of all pipes are fixed.
- Minimum diameter =  $D/2$ .

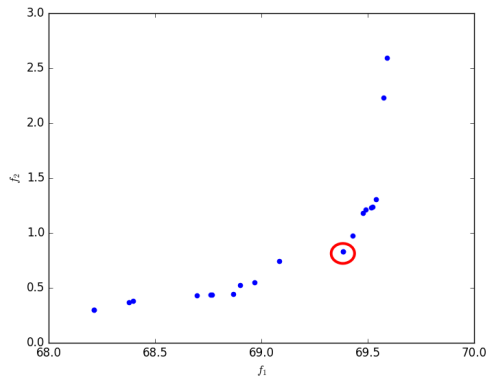
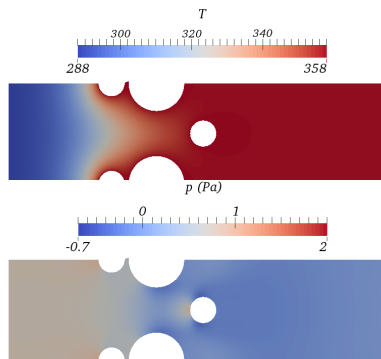


Domain constraints for optimisation.

## Multi-Objective Optimisation

$$f_1 = T_o - T_i$$

$$f_2 = |P_o - P_i|$$

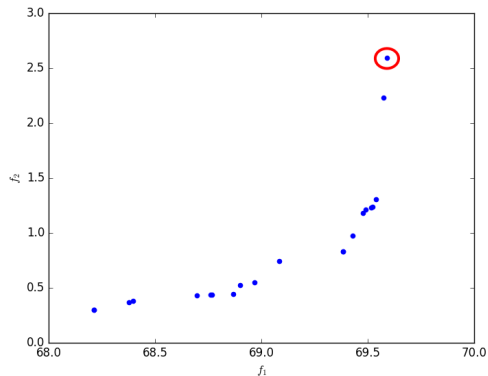
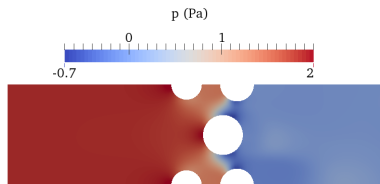
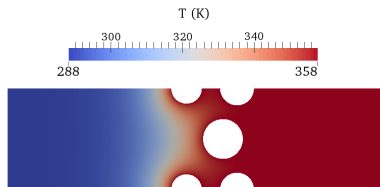


Parental front of multi-objective optimisation.

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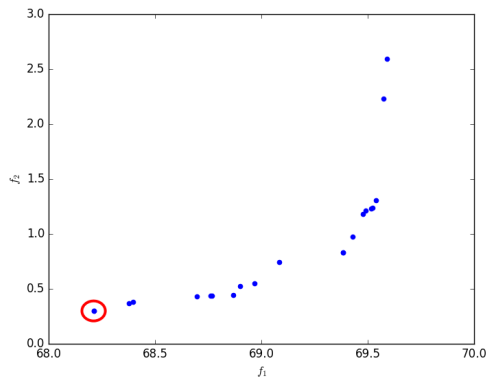
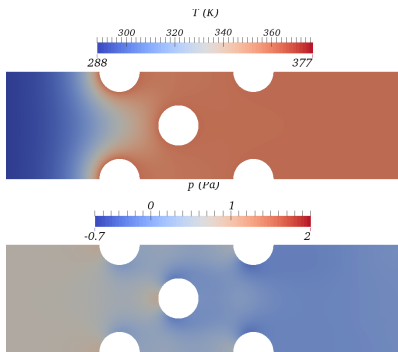


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Parental front of multi-objective optimisation.

## Conclusions and future work

### Conclusions

- A base framework has been established to automate shape optimisation in CFD using evolutionary algorithms.

### Future work

- Considering other methods for optimisation, e.g. Surrogate modelling, Bayesian optimisation.