Topology Optimisation of High Heat Flux Cooling

PhD Student: Amirhossein Bayat
Principal supervisor: Joe Alexandersen
Co-supervisor: Hao Li

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Introduction

- Topology optimisation is still a young field when applied to fluid dynamics and heat transfer
- Thermal management is critical for both large industrial equipment and microelectronic devices
- The full governing equations for conjugate heat transfer must be solved. The goal is then to optimise the fluid-solid interface

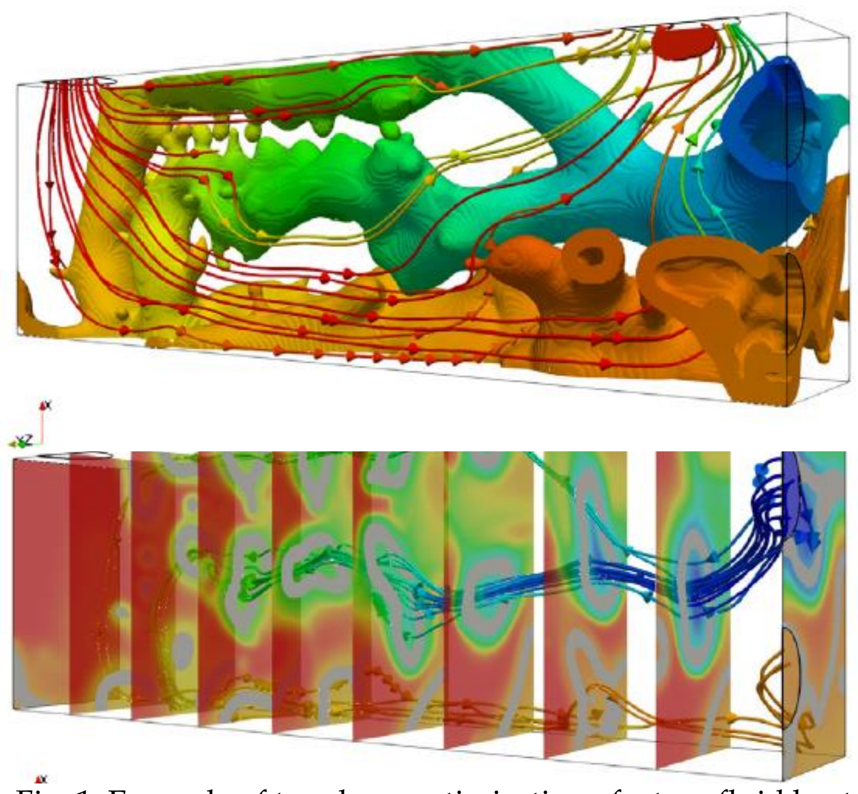

Fig. 1: Example of topology optimisation of a two-fluid heat exchanger.
[Høghøj et al. (2020)]

Cooling channel insert design

- Twisted tape inserts in cooling channels can increase heat transfer, e.g. in the Wendelstein 7-X stellarator
- Fusion reactors generate heat fluxes up to 5–10 (MW/m^2)
- Topology optimisation generates a novel design improving thermal energy extraction by 29% at a 11% smaller pressure drop compared to benchmark twisted tape

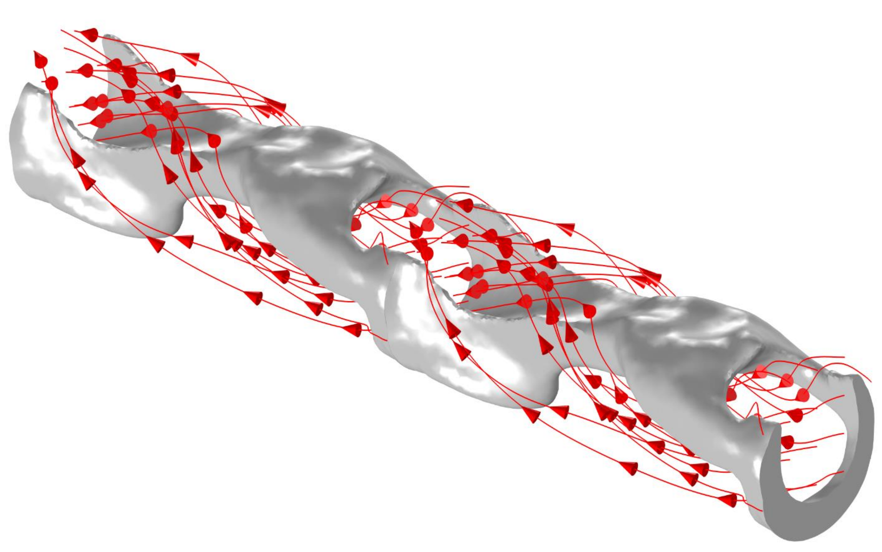

Fig. 2: Topology-optimised cooling channel insert.

- Simulations of the generated designs can be used to understand how to improve simpler manufacturable designs

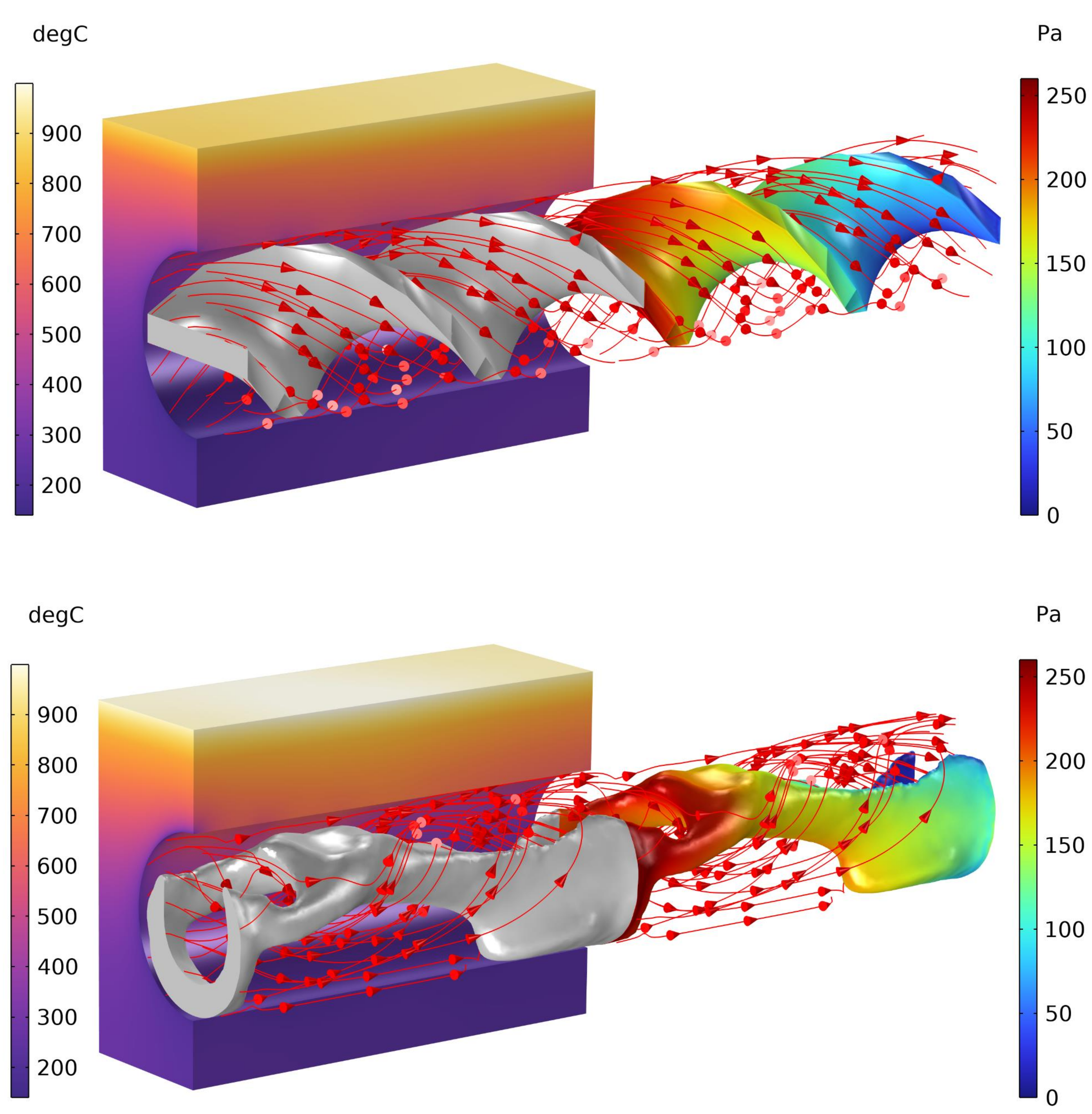

Fig. 3: Conjugate heat transfer simulations of:
(a) reference twisted tape; and (b) topology-optimised design

Methodology

- Coupling conjugate heat transfer with topology optimisation can be the solution to handle high heat dissipation requirements
- We will use topology optimisation to design cooling channel layouts and tube inserts for improved heat transfer
- Process consists of four main parts:

1. Initial design
2. Solving equations
3. Checking if the design is optimal
4. Improve the design

- We will use the finite element method to solve fluid-based and heat transfer partial differential equations

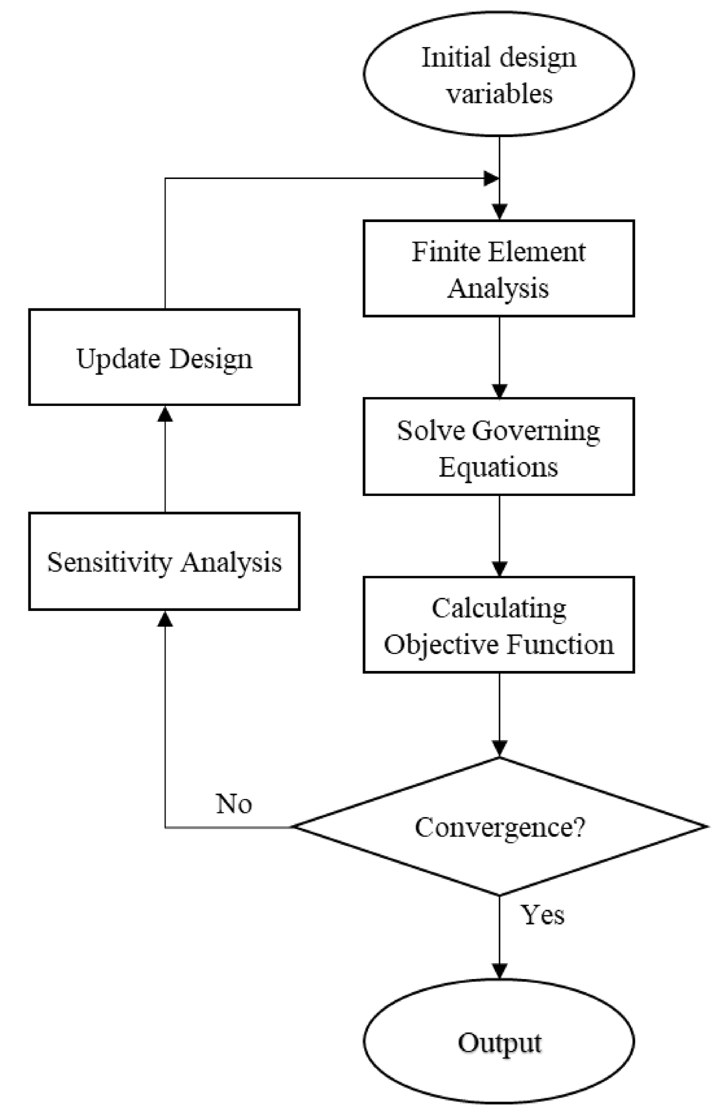

Fig. 4: Flow chart of topology optimisation

- For the definition of solid and liquid domains, we will use the density-based method

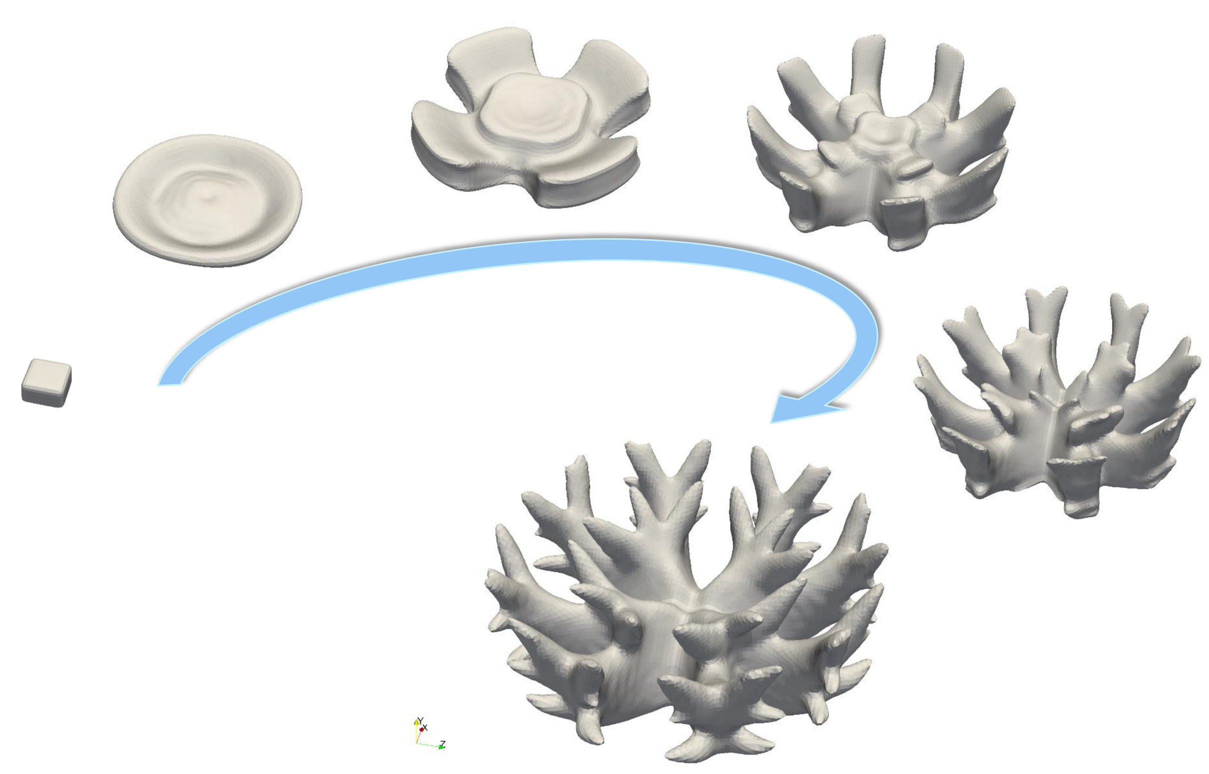

Fig. 5: Design evolution from nothing to novel high-performing passive heat sink for electronics cooling. [Alexandersen et al. (2016)]

Objectives

- Apply topology optimisation algorithms to complex fluid and heat transfer problems, such as turbulence and two-phase fluids
- Find more efficient ways to cool the high heat fluxes, which is beneficial to the fusion, industrial and electronics industries
- Mitigate the heat-related obstacles for new emerging technologies

Challenges

- Extreme Temperatures separated only by a few centimeters
- Complicate nature of turbulent fluid
- Extreme computational costs of optimization
- Need of high-quality meshes for complex geometries
- Deformation of plasma facing surface

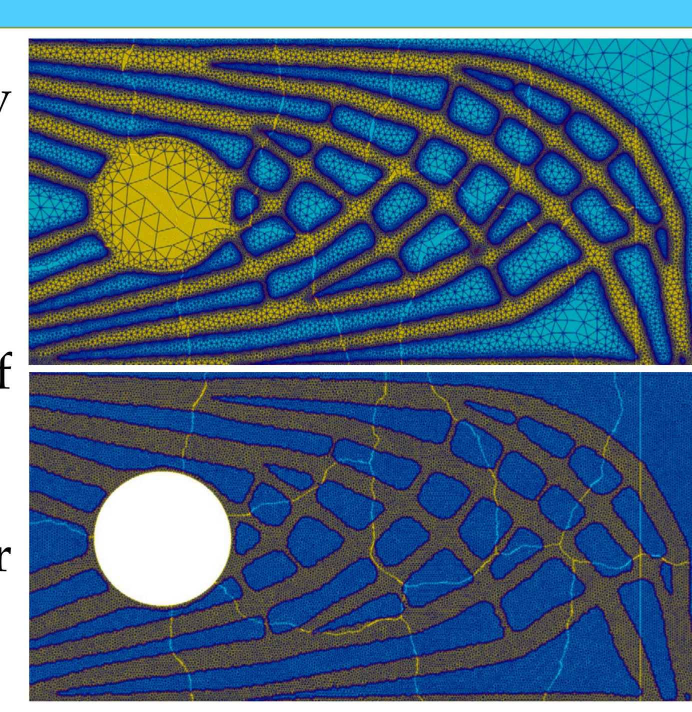

Fig. 6: Comparing the mesh adaptation and fixed mesh for simplification of numerical evaluation [Hao Li et al. (2023)]

References:

- *Alexandersen (2016), International Journal of Heat and Mass Transfer 100:876-891, doi:10.1016/j.ijheatmasstransfer.2016.05.013*
- *Hao Li et al. (2023), Advances in Engineering Software180: 103457, doi.10.1016/j.advengsoft.2023.103457*
- *Høghøj et al. (2020), International Journal of Heat and Mass Transfer 163:120543, doi:10.1016/j.ijheatmasstransfer.2020.120543*

Amirhossein Bayat
PhD student
University of Southern Denmark
abay@sdu.dk

SDU Mechanical Engineering
Department of Mechanical and Electrical Engineering