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The Science of Compliance: Continuous Fiber Angle Topology Optimization with Stress Constraints and Path-Planning

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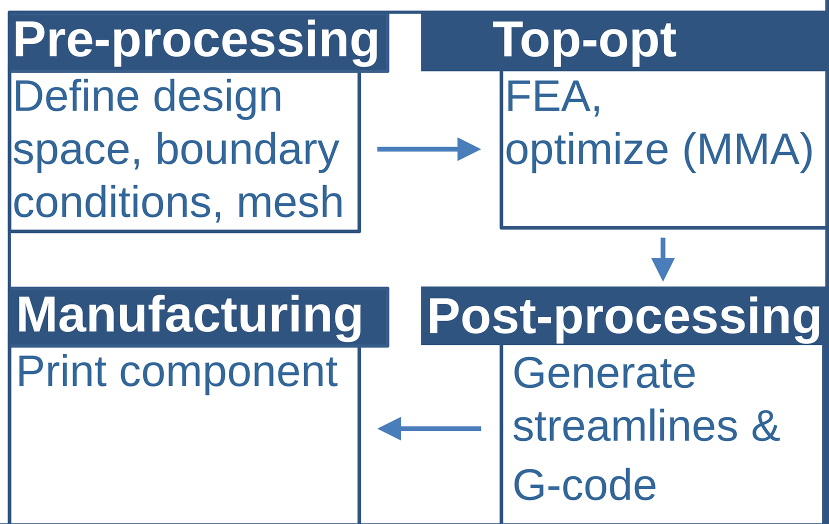
1. Introduction

Continuous Fiber Co-Extrusion (CFC) has the potential to be the preferable manufacturing method in the **aerospace** or other high-performance industries. CFC provides an extended design freedom for engineers to design and manufacture **lightweight components**. To utilize the advantages provided by CFC, this project has developed a tool to generate **optimized designs,** post-process and manufacture the designs by the CFC-process.

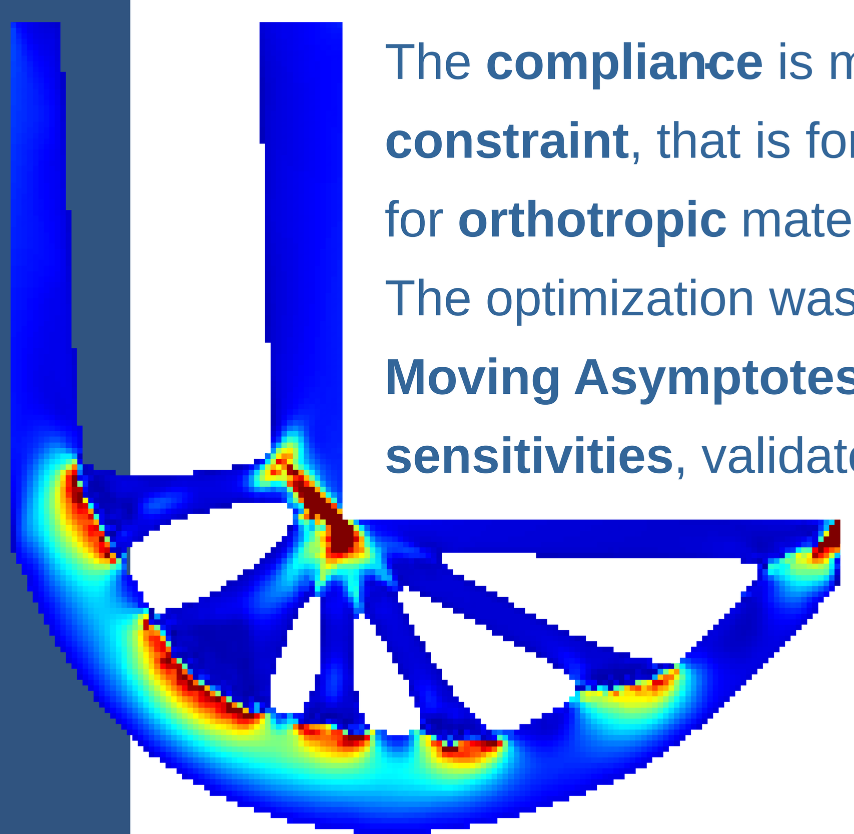
2. Project Scope

A user-specified **design domain** is discretized and exported to the program that is developed in this project.
Continuous fiber angle topology-optimized designs are generated using **density-based topology optimization** with **stress** and **mass constraints.** "Free" manufacturing constraints are introduced in the optimization through a **fiber angle filter** and two **density filters**. Furthermore, the 2D **finite element analysis** program uses a **bi-linear isoparametric element** formulation**.**

Post-processing:
The optimized fiber angles are converted to a vector field and post-processed using **stream-lines** to obtain **manufacturable fiber paths**. **G-code** is generated to manufacture the part.

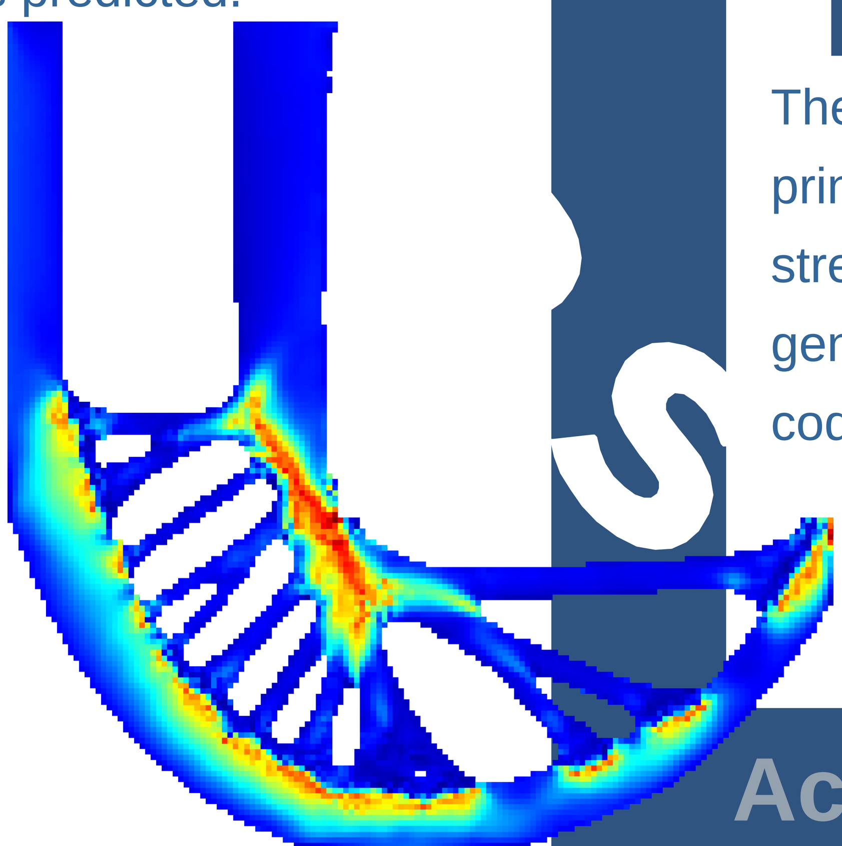


3. Optimization



The **compliance** is minimized subjected to a **stress constraint**, that is formulated using a **static failure criterion** for **orthotropic** materials – the **Tsai-Wu failure index**.
The optimization was accomplished using the **Method of Moving Asymptotes** with analytically determined **sensitivities**, validated with forward difference approximation.

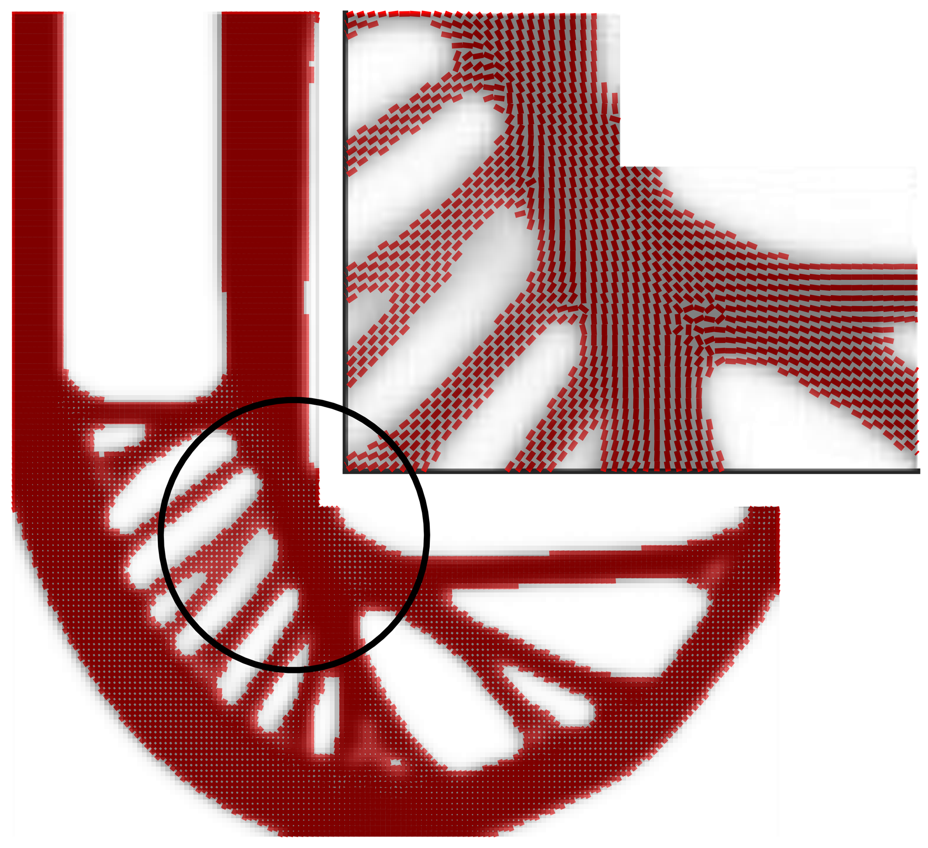
Mass-constrained optimization minimizes the compliance. However, it results in a stress concentration, where failure is predicted.



Mass- and stress-constrained optimization reduces the stress concentration, at the cost of a slightly higher compliance. It results in a more complex design, with intricate details and more iterations to convergence.

Stress concentrations are observed at the load introduction, causing large failure indices that are removed from the optimization.

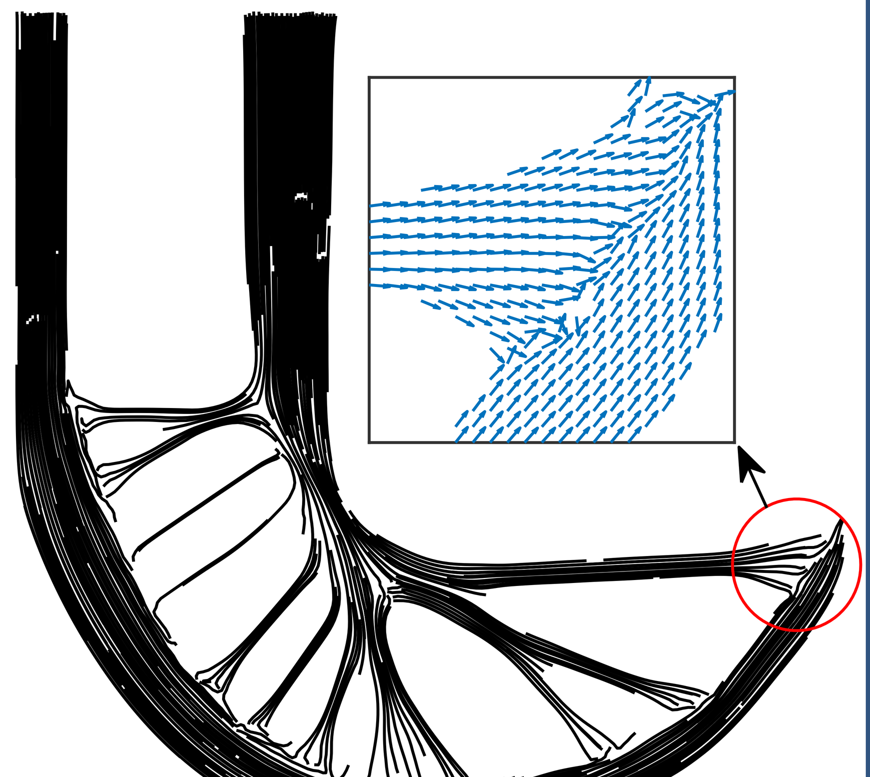
4. Path Planning



The **fiber angle filtering** smooths fiber orientations, resulting in increased **manufacturability.**
The principal stress directions and fiber orientations are primarily aligned.

In the interfaces, with biaxially stressed elements, the fiber angles are irregular.

Path-planning via streamlines generates **manufacturing-tolerant paths,** that follow optimized orientations.
Gaps and discontinuities are present and should be minimized by novel techniques.
From the **streamline method**, a specimen of the **optimized design** was printed in **carbon fiber reinforced polymer.**



5. Conclusions

Results from the optimized geometries show that both the enforced stress and mass constraint are satisfied. The results indicate that **simultaneous topology and fiber angle optimization** can be a great design tool for **3D printed fiber reinforced composites.**

	Compliance [mm/N]	Max failure index	Iterations to convergence
Non stress-constrained	1607	5.5	108
Stress-constrained	1855	0.991	1230
Change	+15.4%	-454%	+1122

The proposed framework utilizes the freedom provided by new 3D printing technologies and **synthesizes** designs. The generated streamlines have been 3D printed using a custom G-code generator. A video of the workflow can be seen by scanning the QR-code. While the current implementation may be preliminary, it demonstrates the potential for it to be a powerful design tool for CFC-manufactured structures.

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