

TOPOLOGY OPTIMIZATION OF HYDROGEN HEAT EXCHANGERS

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Abstract

The rapid advancement of hydrogen-powered aircraft requires lightweight, high-performance heat exchangers capable of efficiently heating cryogenic liquid hydrogen to gaseous conditions suitable for combustion or fuel cell use, while operating under extreme high-altitude environments with stringent constraints on weight and pressure drop.

This work develops a multi-physics, multi-fluid topology optimization framework for heat exchanger design, considering two separate fluid streams. Fluid flow is modeled using the incompressible Navier–Stokes equations augmented with a Darcy term to simulate the presence of solid material in the design domain. The thermal problem is addressed via a conjugate heat transfer formulation, solving a unified energy equation that transitions from convective transport in fluid regions to conduction (Fourier's law) in solid regions. Thermophysical properties of the fluids are interpolated as continuous functions of temperature, pressure, enabling the representation of strong property variations typical in cryogenic hydrogen applications.

The optimization is implemented in OpenFOAM using a discrete adjoint formulation, with the objective of minimizing power loss (pressure drop) between inlet and outlet while maximizing inter-fluid heat transfer. The framework is first verified against established benchmark problems from the literature on topology optimization. Subsequently, it is applied to an industrial-relevant case of designing heat exchangers in aircraft fuel systems.

Results demonstrate performance improvements over conventional designs, including enhanced heat transfer rates and reduced pressure penalties.