

ONE-SHOT TOPOLOGY OPTIMIZATION FOR LARGE-SCALE DESIGN OF FLUID MANIFOLDS

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Abstract

This work presents a one-shot framework for large-scale density-based topology optimization of fluid manifolds that significantly reduces the computational cost of CFD-constrained optimization. Fluid manifold design remains an active research area because the distribution or combination of flow streams strongly affects the performance of many industrial systems. Modern manifold engineering pursues design objectives that extend beyond pressure drop minimization. Examples include achieving flow uniformity in microchannel reactors and cooling plates, ensuring phase distribution in hydrogen fuel cells and solar panels, minimizing refrigerant charge in heat pumps and air-conditioning systems, reducing size in compact heat exchangers, and controlling turbulence in mixing devices. Consequently, numerical optimization has become indispensable, yet the field continues to seek methods that remain robust across diverse physical models, operating conditions, and large number of design variables.

Topology optimization has proven particularly effective for manifold design, not only for minimizing viscous dissipation but also for revealing non-intuitive features such as internal baffles or optimized asymmetric layouts. Recent developments in large-scale optimization and adaptive remeshing have enabled the treatment of industrial-scale problems involving millions of design variables. Nevertheless, the iterative nature of traditional nested optimization algorithms—where the forward and adjoint problems must reach full convergence before every design update—results in extreme computational costs.

The proposed one-shot topology optimization framework addresses this bottleneck by fundamentally altering the iteration architecture. Instead of the traditional nested approach, the one-shot method performs alternating updates of the state, adjoint, and design variables within a segregated fixed-point solver. By leveraging an existing flow solver based on a pseudo-time stepping scheme, the optimization stably converges toward the stationary point of the Lagrangian in a fraction of the time typically required. Our results demonstrate that the total number of iterations required for full optimization is comparable to that required for a single fully

converged forward simulation. An Augmented Lagrangian formulation is employed to incorporate volume and flow-rate constraints directly into the one-shot cycle, ensuring that the computational cost of sensitivity calculations remains independent of the number of constraints.

The methodology is applied to large-scale topology optimization problems with millions of design variables. In a benchmark manifold with two outlets, the one-shot framework achieved convergence in about 2.5 equivalent forward simulation. This highlights the potential of the one-shot paradigm, as traditional nested topology optimization approaches for manifold design typically require 100 to 1000 optimization cycles, each requiring a sequence of converged forward and adjoint solves.

To further validate the method, we present a more challenging case involving the simultaneous optimization of inlet, outlet, and intermediate manifolds within a single integrated system. Furthermore, we improve convergence rates through a refined update scheme for the Augmented Lagrangian parameters. Since the proposed one-shot framework leverages standard fixed-point solvers and adjoint-based sensitivity analysis, it is readily compatible with existing nested topology optimization platforms. The proposed methodology can also be extended to more complex manifold design problems involving turbulent flow and heat transfer.