TOPOLOGY OPTIMIZATION OF INCOMPRESSIBLE TURBULENT FLOW CONSIDERING THE CONTINUOUS ADJOINT METHOD

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Topology optimization of turbulent flow has been tackled at the continuous adjoint approach by considering frozen turbulence and the Spalart Allmaras turbulence model without solving the near-wall distance calculation. At this research, the method is extended by including not only the Eikonal equation for the near-wall distance calculation but also, replacing the steepest descent optimizer by considering advanced optimization techniques used at structures optimization: the method of moving asymptotes (MMA) and Topology Optimization of Binary Structures (TOBS), which behaves in the discrete form to improve the solid-fluid boundary definition. Promissory results are obtained at incompressible turbulent regime, by optimizing pipes in 2D and 3D considering coarse meshes. It diminishes considerably the computational cost of previous assumptions and extends the Topology Optimization of fluids applications to industrial regimes.

1. INTRODUCTION

"Topology optimization (TO)\textsuperscript{1}" has achieved efficient designs of fluid slow passages by changing the permeability of the volume cells in a domain considering a material distribution (ALEXANDERSEN [1]). The technique combines Computational Fluid Dynamics (CFD) and optimization method libraries based on derivatives that maximize objective functions like minimizing the energy dissipation through the domain. The adjoint code obtained by the continuous adjoint approach is performed by hand, and considering the developments of PAPOUTSIS [2], YOON [3], BUENO [4], KIYONO [5], and PICELLI [6], the method is extended at the current research for incompressible turbulent regime in FVM. The scientific contribution is given by considering TOBS optimizer and 3D optimization in coarse meshes.

1.1. Topology Optimization Formulation for Incompressible Turbulent Flow

$$\begin{align*}
\text{Minimize } & \left\{ F = \int_{\Omega} \left[ p + \frac{1}{2} \left( u \cdot \nabla u \right)^2 \right] \, d\Omega \right. \\
\text{subject to } & R^p = \frac{\partial \bar{u}_i}{\partial x_i} = 0 \\
& 0 < y < 1 \\
& \bar{R}^a = \frac{\partial (\bar{u}_i \bar{u}_j)}{\partial x_j} + 1 \frac{\partial \bar{p}}{\partial x_j} - \left[ \left( \frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} \right) - u_i^0 u_j^0 \right] + \alpha a \bar{u}_i = 0 \\
& \bar{R}^v = \frac{\partial \bar{v}}{\partial x_j} \frac{\partial \bar{v}}{\partial x_i} \left[ \left( \frac{\partial \bar{v}}{\partial x_j} + \frac{\partial \bar{v}}{\partial x_i} \right) - \frac{\partial u_j}{\partial x_i} \right] - \alpha P = 0 \\
& \bar{R}^s = \frac{\partial \bar{v}}{\partial x_j} \frac{\partial \bar{v}}{\partial x_i} \left[ \left( \frac{\partial \bar{v}}{\partial x_j} + \frac{\partial \bar{v}}{\partial x_i} \right) - \frac{\partial u_j}{\partial x_i} \right] - \alpha a \Delta = 0 \\
& \nabla_f r_a \geq \int_{\Omega} f_a d\Omega - V_{\text{tar}}
\end{align*}$$

2. METHODOLOGY

![Figure 1: Topology Optimization Flowchart](Author)
3. RESULTS
The Diffuser case from literature (Yoon, [7]) is tested, which consists of a horizontal straight channel with an inlet/outlet ratio of 3 discretized by a 100x100 hexahedral mesh (Figure 2). It considers a fluid with $Re_{inlet} = 3 \times 10^3$, and TO parameters of $\bar{V}_{target} = 0.3$, $q = 0.1$, $\bar{a}_u = 1 \times 10^6$, $\bar{a}_\Delta = 25$, $\bar{a}_\phi = 1 \times 10^{-3}$ and $\bar{a}_\phi = 0$ (Figure 2).

![Diffuser Domain](image1)

**Figure 2.** (a) Diffuser Domain (Yoon, [7]), and optimized topologies considering (b) MMA and (c) TOBS optimizer

Finally, a 3D case is tested considering TOBS optimizer and the following fluid properties: $u_{inlet} = 1 [m/s]$, $v = 8 \times 10^{-5} [Pa \cdot s]$, $Re_{inlet} = 3125$. The result is shown at Figure 3.

![3D Domain](image2)

**Figure 3.** (a) 3D Domain and (b) Optimized Topology considering TOBS optimizer.

4. CONCLUSION
The use of TOBS and MMA optimizers at topology optimization of turbulent flow is successfully achieved. TOBS optimizer allows a clear boundary solid-fluid definition due to its discrete behavior, and despite its computational cost overcomes by 80% MMA iterations, the 3D optimization is not restricted and achieved by using coarse meshes.

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**References**