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OPTIMAL CONTROL OF TURBULENT JETS USING AN UNSTEADY ADJOINT SOLVER

Asim Önder, Johan Meyers

Department of Mechanical Engineering, KU Leuven, Celestijnenlaan 300A, B3001 Leuven, Belgium, asim.onder@mech.kuleuven.be

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The current work aims to develop optimal open-loop controls for turbulent round jet flows using direct numerical simulations (DNS) in combination with adjoint based gradient estimation. The main goal is to achieve better mixing properties which can be measured with various cost functionals (J) such as radial kinetic energy, enstrophy, etc. One of the most popular active control means is the time-periodic fluidic actuator, i.e. the so-called synthetic jet or zero-net mass flux (ZNMF) actuator. We study the effect of optimized ZNMF actuation on the near field of a transitional axisymmetric jet with $Re_D = 2000$.

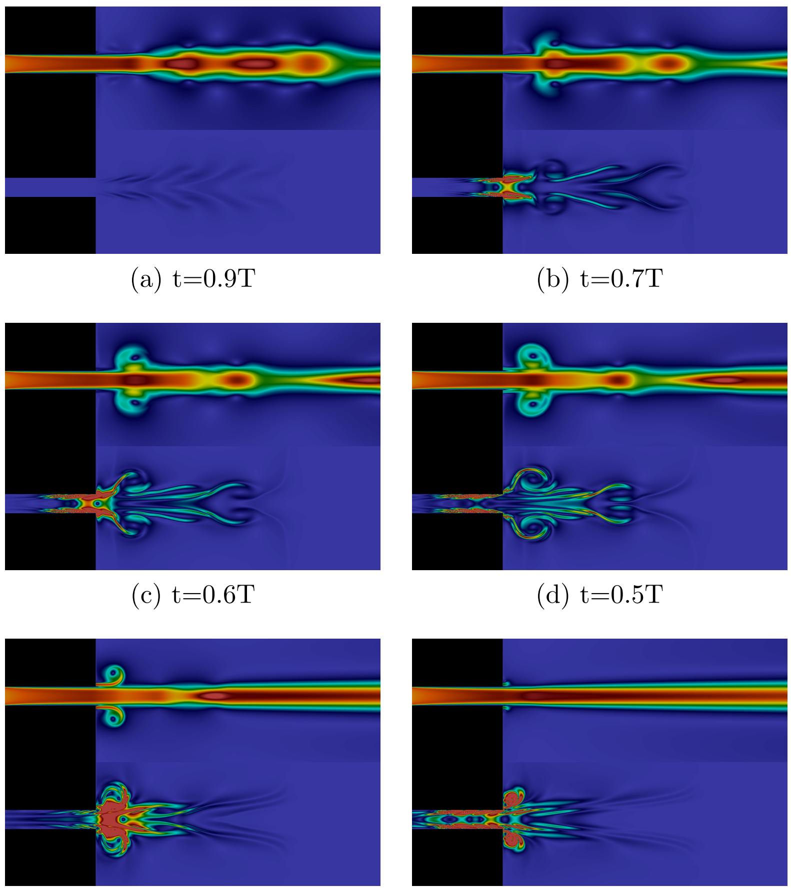
A parametric study is initially conducted using various control frequencies driving in phase three ZNMF actuators and certain characteristic frequencies are determined [1]. In order to explore the combined effect of these characteristic frequencies we designed following control signals for each actuator $k \in \{1, .., M\}$:

$$u_c^k(t) = \sum_{n=1}^{N} \alpha_{2n-1}^k \sin(2\pi f_n t) + \alpha_{2n}^k \cos(2\pi f_n t) \qquad (1)$$

where M is the total number of ZNMF actuators distributed evenly in the circumferential direction, N is the dimension of frequency space and the control vector is $\alpha \in \mathbb{R}^{2MN}$. To find an optimal value for α using a gradient based algorithm then gradient $\partial J/\partial\alpha$ has to be calculated at each optimization iteration. Since a regular first order finite difference calculation of the gradient would require an excessive cost of 2MN+1 DNS evaluations, the continous adjoint methodology is selected for this process.

To this end, an unsteady backwards in time solver using adjoint linearized incompressible Navier-Stokes equations is implemented into the open-source FVM toolbox OpenFOAM v2.1.x [2]. The cross-convection term which couples all the adjoint velocity components has been implemented using the form $(\nabla\mathbf{u})^T\mathbf{w}$ instead of $-(\nabla\mathbf{w})^T\mathbf{u}$ where $\boldsymbol{u}$ and $\boldsymbol{w}$ is the velocity and adjoint velocity respectively. The latter version is commonly employed in optimization studies using steady adjoints(e.g.[3]), but has been found to be very unstable in transient setting.

The optimization framework is validated using two-dimensional Bickley jets (Fig.1) and is being employed in the optimal control of fully turbulent three-dimensional jets.



(a) t=0.9T (b) t=0.7T

(c) t=0.6T (d) t=0.5T

(e) t=0.3T (f) t=0.1T

Figure 1: Snapshots of velocity magnitude $|\boldsymbol{u}|$ (upper part) and its adjoint counterpart $|\boldsymbol{w}|$ (lower part) for a controlled Bickley jet. T is the optimization horizon and cost functional J is the radial kinetic energy.

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