Evolutionary optimization of a compliant surface for turbulent friction drag reduction

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We introduce our recent attempt to numerically optimize the parameters of compliant surface for skin-friction drag reduction in turbulent channel flow [1]. We consider a passive control using an anisotropic compliant surface model [2]: due to the restriction of the inclined arms, this anisotropic compliant surface always moves so as to create a negative Reynolds shear stress on the wall, from which the friction drag is expected to reduce [3].

Turbulent channel flow under a constant flow rate ($Re_b = 3300$) is solved by using the direct numerical simulation (DNS) code [4], coupled with the solver for the surface equation of motion via the velocity coupling. The surface equation of motion has several parameters that have to be determined. The inverse design problem is formulated as an optimization problem. Our objective is to minimize the friction drag coefficient, which is a function of the surface parameters under the restriction of wall-deformation amplitude. Therefore, the cost function can be defined here as the friction drag. We also added a penalty term in order to avoid solutions lading to large deformation. We implement an Evolution Strategy with Covariance Matrix Adaptation (CMA-ES) [5]. The CMA-ES was initialized with sets of parameters distributed over the initial search domain. The available computation time permitted about 1000 evaluation trials of the cost function, each one involving two simulations with different initial turbulent fields (viz., about 2000 DNS runs were made in total).

The optimization led to a maximum drag reduction rate of 8%. The primary mechanism for drag reduction is attributed to the decrease of the Reynolds shear stress (RSS) near the wall induced by the kinematics of the surface. The resultant wall motion is a uniform wave traveling downstream. The compliant surface, with the parameters found in the optimization study, is also tested in a computational domain that is doubled in the streamwise direction. The drag, however, is found to increase in the larger computational domain due to excessively large wall-normal velocity fluctuations.

References