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TURBULENT DRAG REDUCTION VIA SPINNING DISCS AND RINGS.

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An active method for turbulent drag reduction in a pressure-driven channel flow is investigated by direct numerical simulations. The actuation strategy is based on arrays of flush-mounted discs steadily rotating on both walls, first introduced by [2] and recently further investigated by [3] (referred to as RH13 in the following) and [4]. Full details have recently been published in [5].
In RH13, the discs are arranged in a square packing manner, i.e. next to each other in both streamwise and spanwise directions. The work herein presented is aimed at the study of the effects of different disc layouts on the drag reduction $\mathcal{R}$, the power spent $\mathcal{P}_{sp,t}$ and the interdisc structures. The discs are now arranged in columns or rows (that is, aligned in the streamwise and spanwise directions, respectively), in a checkerboard and hexagonal-like fashions, as shown in figure 1. This results in surprising effects on the flow. For low disc-tip velocities it is found that drag reduction is proportional to coverage $\mathcal{C}$, i.e. the percentage of actuated area, meaning that drag reduction occurs because of the shearing effect of the flow over the disc surfaces.

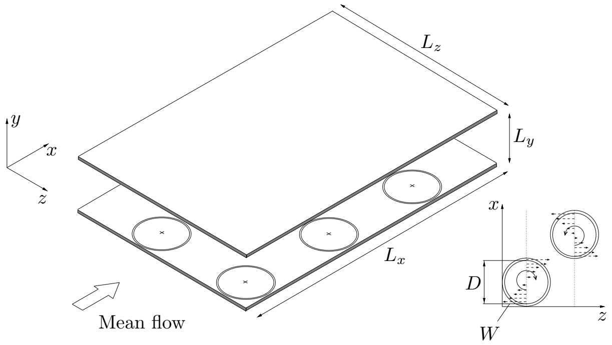

Figure 1: Channel flow geometry. The discs arrangement shown here is the checkerboard-like layout.

This linear behaviour starts to deteriorate at moderate disc tip velocities and is completely lost at higher velocities, whereby drag reduction is higher even when the number of discs is halved, to an optimal value of an additional 5% drag reduction relatively to the layout used in RH13, for an optimal distance between neighbouring disc centres of 1.5 disc diameters.
With regards to the power spent to activate the discs, an excellent linear scaling with $\mathcal{C}$ is found, as shown in figure 2. The power spent does not depend on the discs arrangement. This result is expected, as $\mathcal{P}_{sp,t}$ does not depend on the turbulence dynamics but it is only related to the wall motion. For the half disc actuators, $\mathcal{P}_{sp,t}$ decreases almost linearly as a is increased.

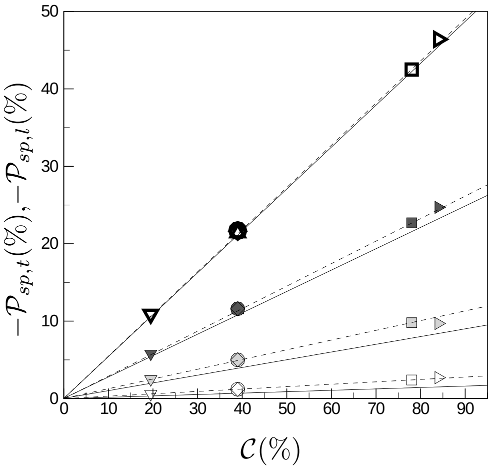

Figure 2: Power spent vs. coverage. Different symbols correspond to different discs arrangements and different colours to different disc tip velocities. The solid lines represent the prediction of power spent via the laminar solution. The dashed lines are found by rescaling the RH13 power spent value with respect to coverage.

Flow visualizations and the Fukagata-Iwamoto-Kasagi (FIK) identity [1] have shown that the additional drag reduction is obtained with those arrangements that present a streamwise fixed-wall space of the extent of one disc diameter between two discs, as this leads to the formation of turbulent structures between the discs, i.e. jets of streamwise motion in the opposite direction relatively to the mean flow. Therefore, the flow between discs is studied to gain more insight on this phenomenon. It is found that a region of $\mathcal{R} \simeq 20\%$ in the downstream disc area is responsible for the additional drag reduction and it must be created through interaction between the mean flow and the disc flow. The radial flow created by the von Kármán pumping effect generates a boundary layer in the fixed wall area between the discs. Dramatic drag increase occurs on the downstream disc region, caused by the radial flow induced by the downstream half of the discs.
To avoid this effect, half-disc actuators are studied, whereby only the downstream half of the disc is covered. As seen in figure 3, this serves to eliminate the drag increase in the downstream half of the disc, but it also results in the removal of the azimuthal flow which enhances drag reduction. The resulting effects on the flow are a trade-off between these two effects. At low disc-tip velocities, drag reduction decreases as the radial flow effect is less significative than the benefit of the azimuthal flow.

As the disc-tip velocity is increased, the opposite mechanism is in place and drag reduction increases up to a maximum of $\mathcal{R} \simeq 26\%$.

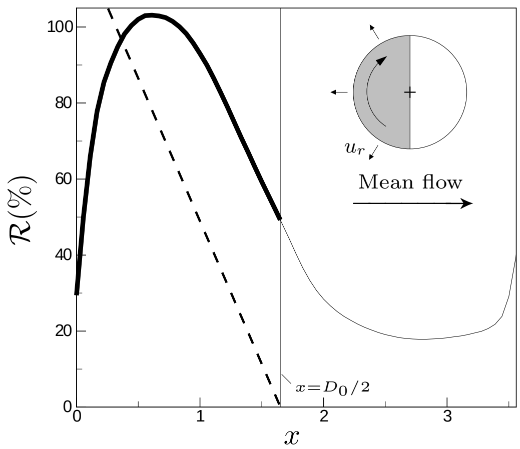

Figure 3: Streamwise development of $\mathcal{R}$ along the discs centrelines for the half-disc actuators. Inset: schematic of a half-disc actuator. The thick lines represent the profile for the flow over the disc and half-disc surface respectively and the dashed lines indicate drag reduction predicted by the laminar solution.

In order to eliminate the detrimental effect of drag reduction created in the low velocity area in the surrounding of the discs centre, annular actuators shown in the inset of figure 4 are studied. The ratio of internal and external radii $a = r_i/R$ is changed from 0 to 1 and the effects on drag reduction are shown in figure 4. For $a < 0.375$, drag reduction remains constant at about 19%, then reaches an optimum value of $\mathcal{R} = 20\%$ at $a = 0.6$ and then dramatically drops to a null value for $a = 1$. This result supports the foresight that the low velocity flow around the disc centre has an overall negative effect on drag reduction.

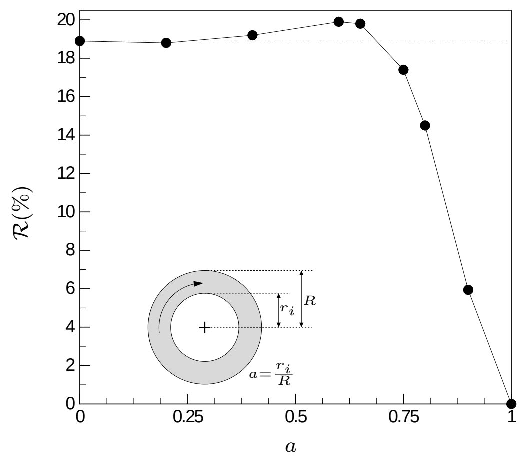

Figure 4: Drag reduction vs. annulus ratio.

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