Turbulent drag reduction via spinning discs

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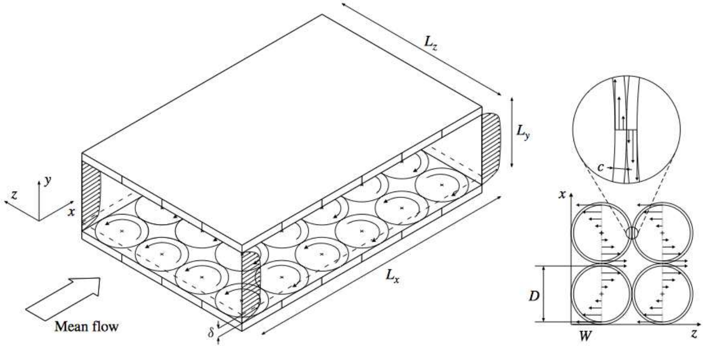
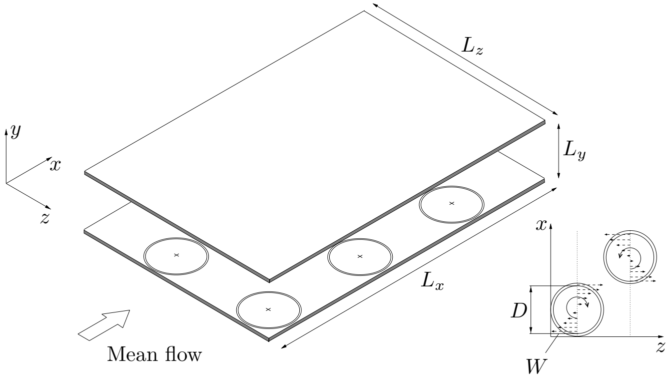
European Drag Reduction and Flow Control Meeting,
Cambridge, UK, March 23-26 2015

Turbulent drag reduction via spinning discs
Ricco and Hahn (2013)



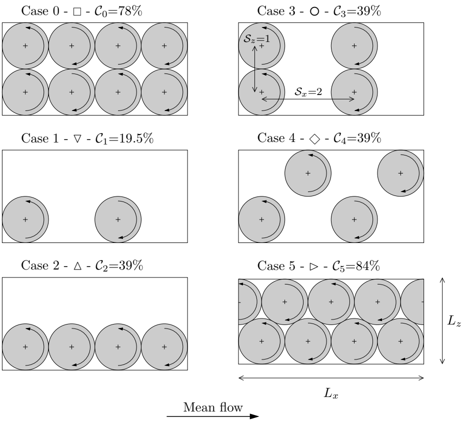
- Keefe (1998), no results until Ricco and Hahn (2013) (RH13).
- Fully developed channel flow, $R_\tau = 180$.
- Key parameters: disc diameter D and tip velocity W $\Rightarrow \mathcal{R} = 23\%$.
- Discs are square packed.

Outline



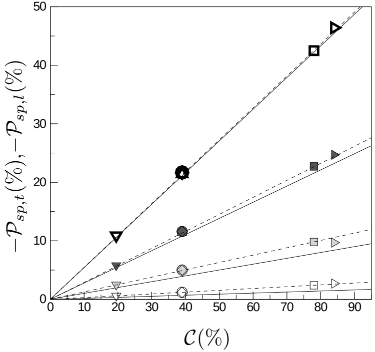
- Effect of disc layout on $\mathcal{R}$ and $\mathcal{P}_{sp,t}$.
- Half-disc actuators.

Disc layout and performance quantities



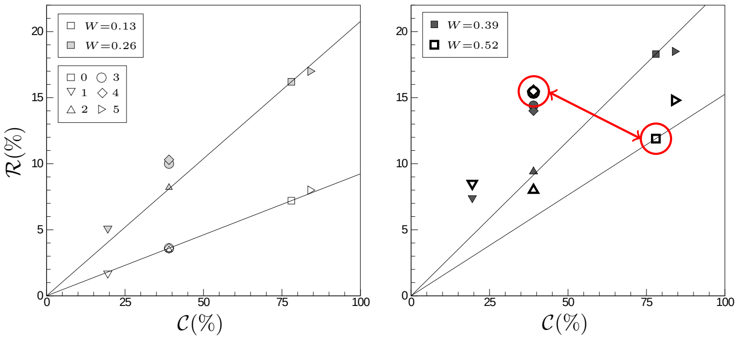
- Coverage $\mathcal{C}$ = % of the wall surface that is in motion.
- Drag reduction $\mathcal{R}(\%) = 100\frac{C_{f,s} - C_f}{C_{f,s}}$.
- Power supplied to the discs to activate them.

Disc layout: effect on $\mathcal{P}_{sp,t}$



- Excellent linear scaling with $\mathcal{C} \rightarrow \mathcal{P}_{sp,t}$ only depends on wall motion.
- __ $\mathcal{P}_{sp,l}$, prediction from laminar solution (von Kármán).
- _ _ $\mathcal{P}_{sp,t}$, rescaling RH13 $\mathcal{P}_{sp,t}$ with $\mathcal{C}$.

Disc layout: effect on $\mathcal{R}$



- **Low W**: linear scaling applies.
- **High W**: linear scaling is lost.
  $\rightarrow$ Additional drag reduction for cases with a streamwise fixed-wall space.
  $\rightarrow$ Higher $\mathcal{R}$ upon removal of half of the discs.

Prediction of $\mathcal{R}$

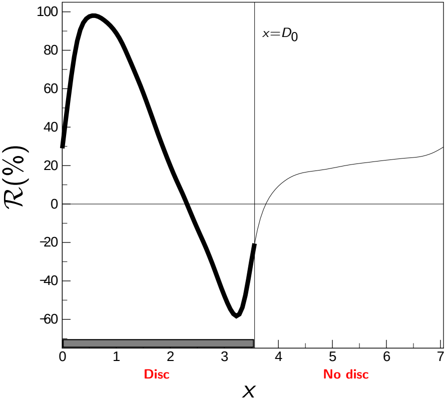
$\rightarrow$ **Low W** $\rightarrow$ linear scaling with coverage.

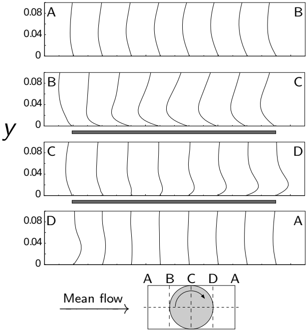
- Assumptions: wall forcing similar to triangular wave with $\lambda_x = 2D_0$ and amplitude W.
- $R_{pred} = C_w \cdot C_\theta \cdot \mathcal{C} \cdot \mathcal{R}_{sw}$ where
  - $C_w = 85\%$: waveform, Cimarelli *et al.* (2013).
  - $C_\theta = 75\%$: orientation, Zhou and Ball (2008).
  - $\mathcal{C}$: coverage.
  - $\mathcal{R}_{sw}$: $\mathcal{R}$ in standing-wave case proposed by Viotti, Quadrio and Luchini (2009).

Case	D	W	$\mathcal{R}_{sw}(\%)$	$\mathcal{R}_{pred}(\%)$	$\mathcal{R}(\%)$
0	3.38	0.26	33	16.4	16.2
2	3.38	0.26	33	8.2	8.2
5	3.38	0.13	16	8.6	8.7

Radial streaming

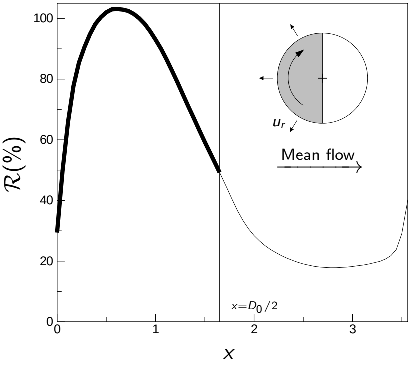
→ **High W** → coverage scaling breaks down. WHY?





- Region of additional $\mathcal{R} = 20\%$ between discs
  → interaction between disc flow and mean flow.
- Radial flow: retards the mean flow in the upstream part of the disc (drag reduction) and enhances it downstream (drag increase).

Half-disc actuators



	D=3.38	
W	$\mathcal{R}_0(\%)$	$\mathcal{R}_h(\%)$
0.26	16.2	13.7
0.39	18.3	21.8
0.52	11.9	**25.4**

	D=5.07	
W	$\mathcal{R}_0(\%)$	$\mathcal{R}_h(\%)$
0.26	17.5	13.0
0.39	22.3	21.1
0.52	18.5	**25.6**

- Downstream half of the disc has zero wall-velocity:
  - Negative effect of downstream radial flow eliminated.
  - Positive effect of azimuthal flow eliminated.
- **Low W**: $\mathcal{R}$ decreases $\rightarrow$ azimuthal flow is more important.
- **High W**: $\mathcal{R}$ increases (26%) $\rightarrow$ the radial flow effect is more important.
- Limitation: disc housing neglected.

Conclusions and summary

- The disc layout has unexpected effects: $\mathcal{R}$ increases upon removal of discs.
- Radial flow is responsible for additional $\mathcal{R}$.
- Half-disc actuators $\rightarrow$ maximum $\mathcal{R} = 26\%$.

D.J. Wise, C.Alvarenga, P. Ricco, "Spinning out of control: wall turbulence over rotating discs", Phys. Fluids (2014).

We acknowledge the Department of Mechanical Engineering at the University of Sheffield for funding this research.

THANK YOU!