Turbulent drag reduction for a wall with a bump

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Outline

Motivation

DNS of bump flow with StTW

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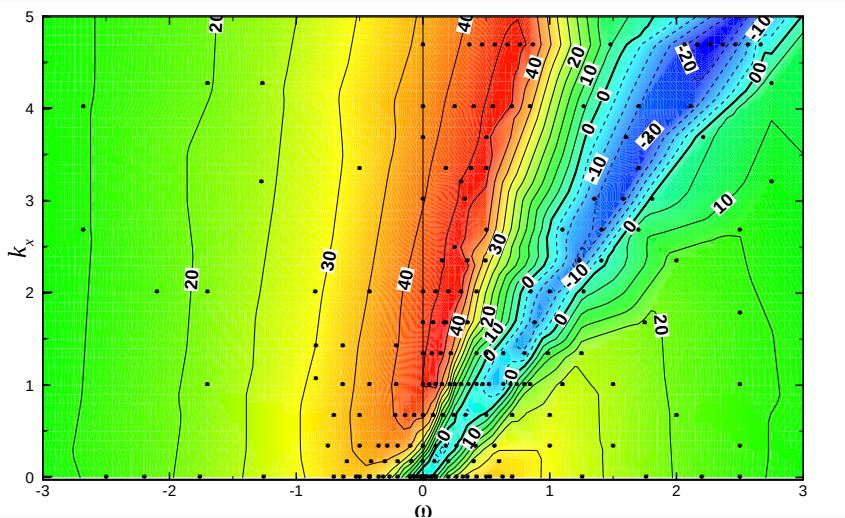
DNS of bump flow with StTW

The streamwise-traveling waves

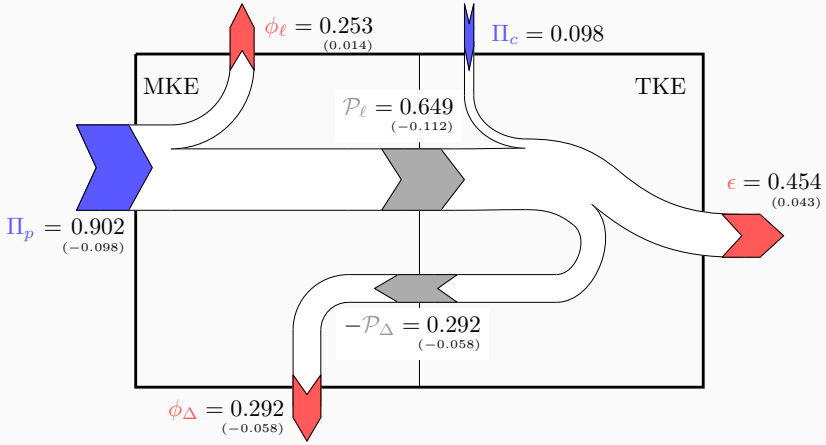


The next steps

Besides lacking a suitable actuator, of course!

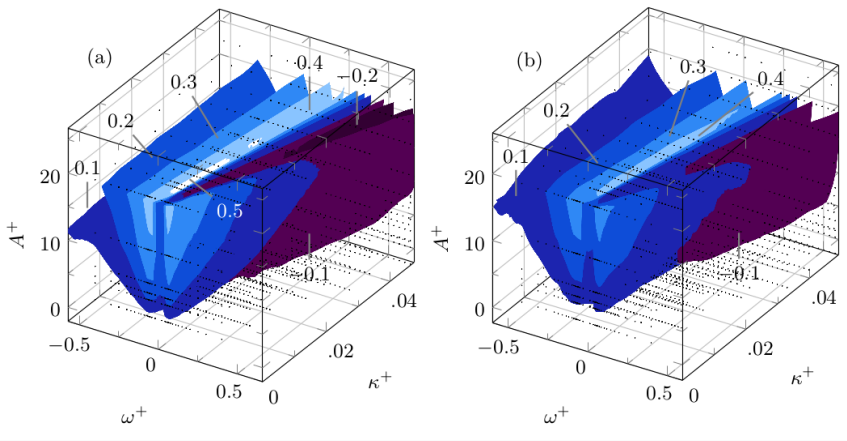
- Q1 How to interpret results?
- Q2 Effect of *Re*? Gatti & Quadrio, JFM 2016
- Q3 What about total drag?

Q1: The energy box



Gatti, Cimarelli, Hasegawa, Frohnapfel & Quadrio, JFM 2018

Q2: effectiveness is constant with *Re*

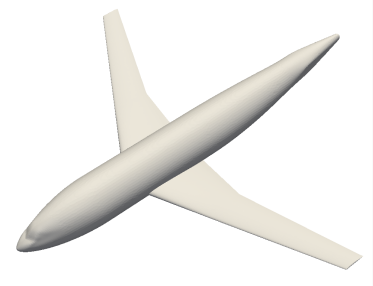


Gatti & Quadrio, JFM 2016

Q3: What about the airplane total drag?

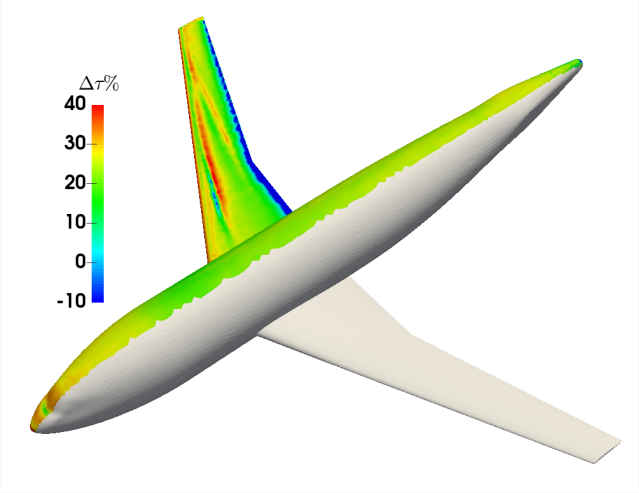
Prelim results presented at last EDRFCM in Frascati

- Transonic DLR-F6 transport aircraft
- RANS, Spalart-Allmaras model
- $Re = 3 \times 10^6$, $M = 0.75$
- StTW accounted for via wall functions



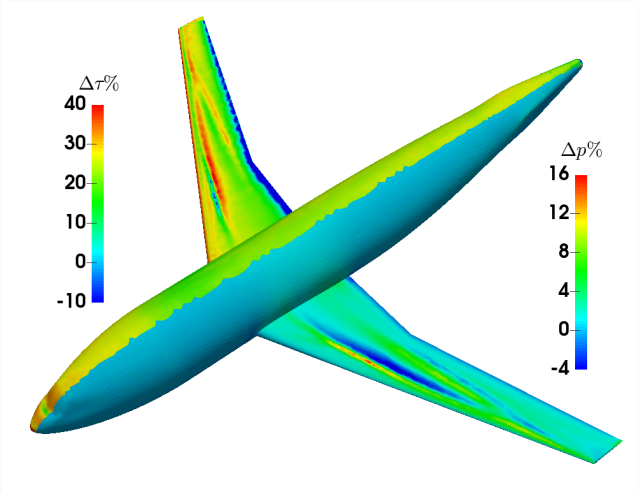
Changes in friction AND pressure

Friction drag reduces by 23%, as expected...



Changes in friction AND pressure

… but total drag reduces by the same amount!



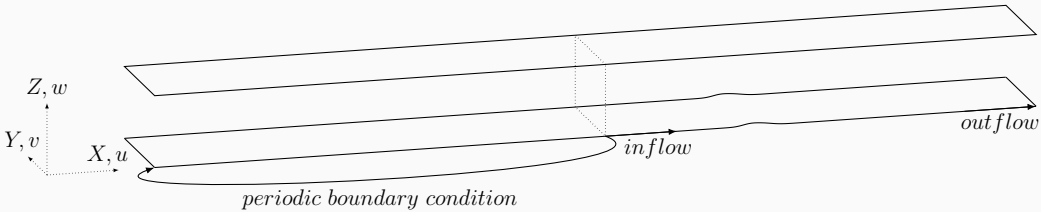
Outline

Motivation

DNS of bump flow with StTW

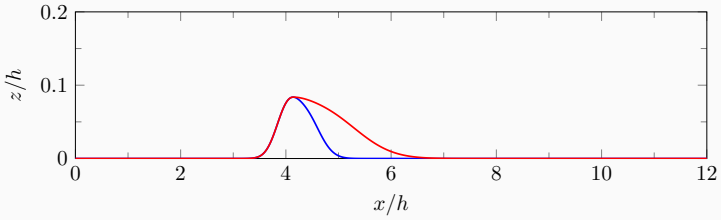
Back to fundamentals: a low-Re, incompressible DNS study

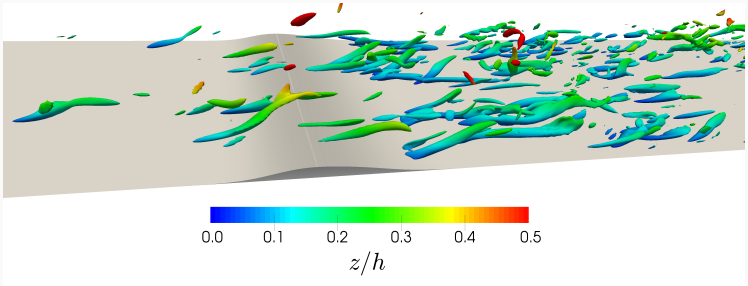
- Incompressible DNS of a channel with a small bump
- Periodic + non-periodic domain
- Second-order FD, immersed boundary
- $Re_\tau = 200$, $(L_x, L_y, L_z) = (25h, 3.2h, 2h)$, $(N_x, N_y, N_z) = (800, 312, 241)$
- With and without StTW



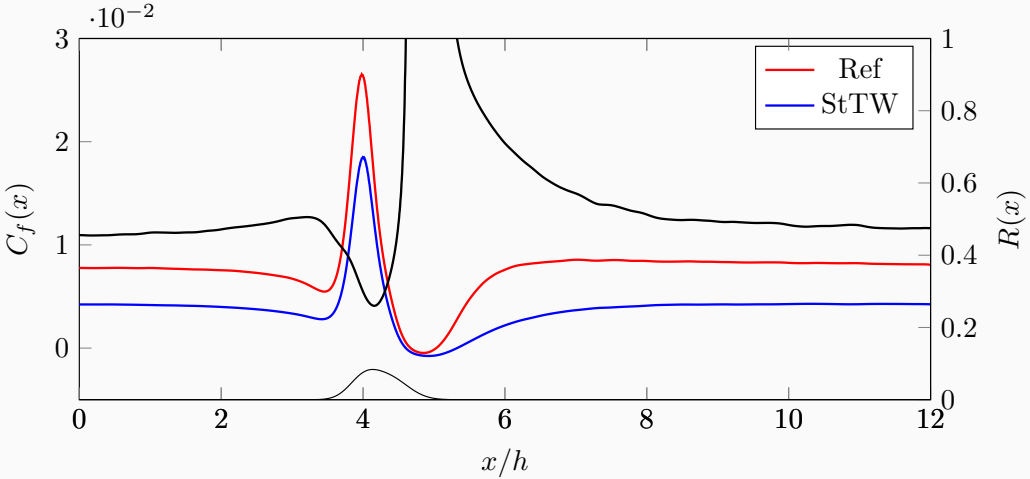
Bump instead of a wing profile

Two (small) bump geometries, one inducing mild separation



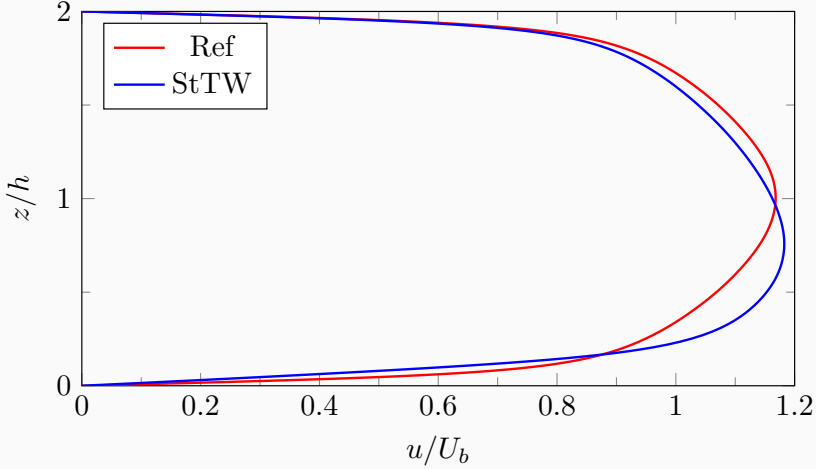


Friction coefficient (and a poll)

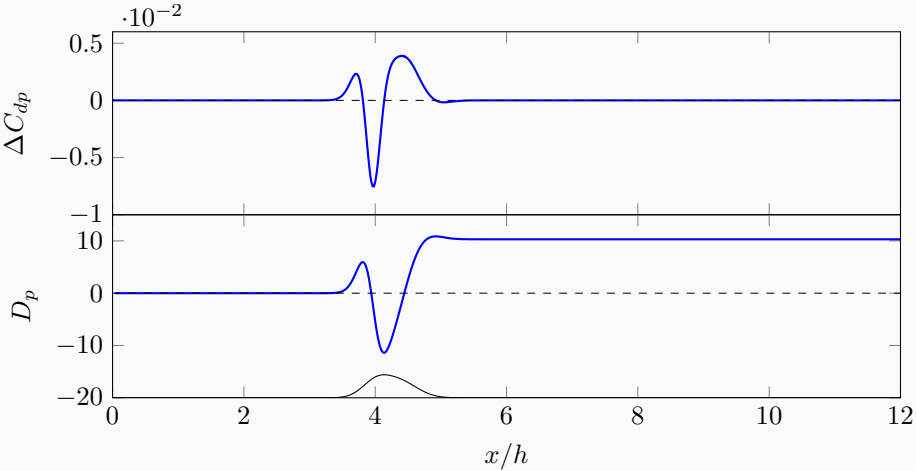


The mean velocity profile (no bump)

The maximum velocity shifts towards the actuated side and produces 4% additional drag reduction on the unactuated side!



Pressure drag

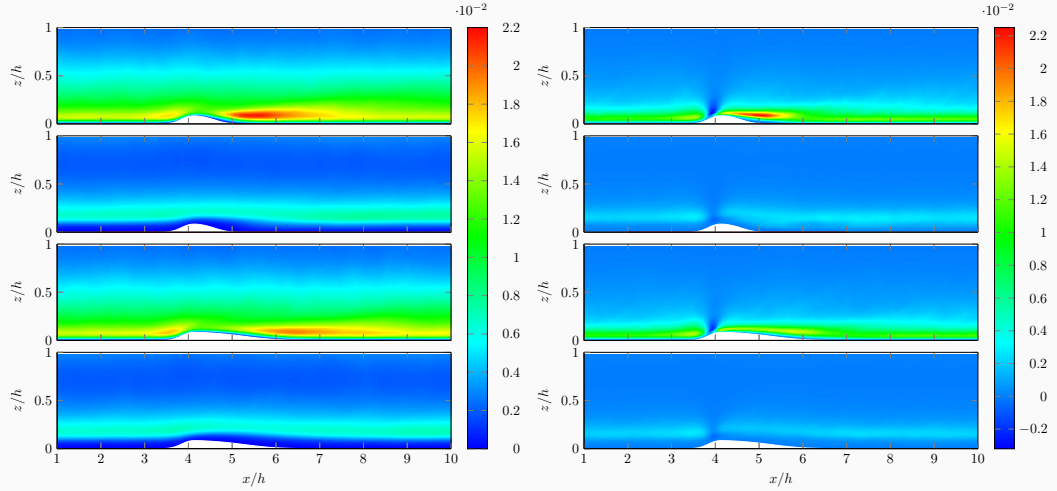


Power budget

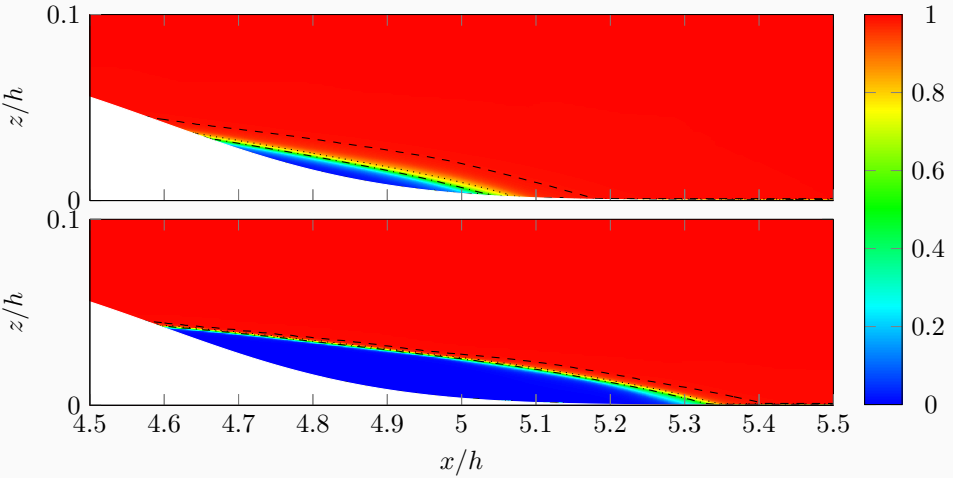
	Periodic			Non-Periodic			
	Ref	StTW	Δ%	Ref	StTW	Δ%	Expected
P_f	1	0.545	−45.5%	1	0.504	−49.6%	−45.5%
P_p	-	-	-	0.088	0.080	−10.3%	0%
P_{tot}	1	0.545	−45.5%	1.088	0.575	−46.4%	−42.2%
P_{req}	-	34.1%P_{tot}		-	31.2%P_{tot}		31.3%P_{tot}
Net	-	11.4%P_{tot}		-	15.3%P_{tot}		11%P_{tot}

Table 1: Power per unit area, bump wall with G_1

TKE (left) and TKE production (right)



The separation bubble



Conclusions

- Interaction between friction drag reduction and overall drag
- Benefits of skin-friction drag reduction techniques may be underestimated
- Compressible DNS may reveal larger effects