Drag reduction on a transonic airfoil

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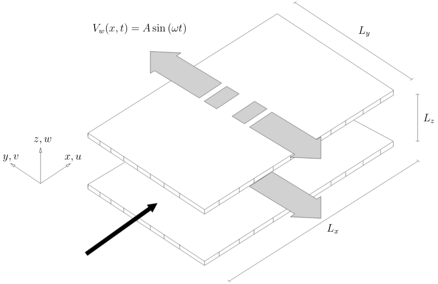
Flow control for skin friction drag reduction

- Flow control for skin-friction drag reduction largely investigated for flows over planar walls, where friction is the only drag contribution



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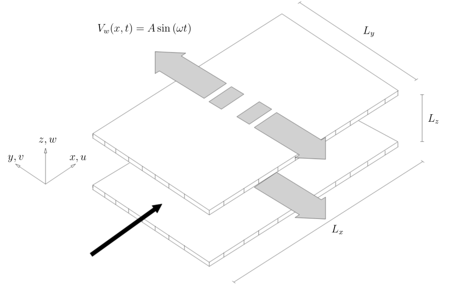
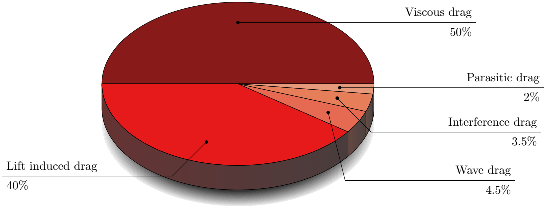


- ◇ In non-planar walls drag includes additional contributions



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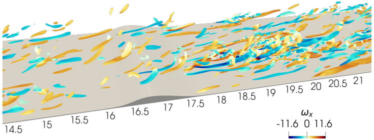
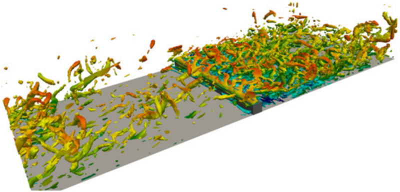
- Banchetti et al. (JFM, vol. 896): a distributed reduction of friction via spanwise forcing reduces the pressure drag in a channel flow with a wall-mounted bump



- Nguyen et al. (JFM, vol. 912): a temporally spanwise-oscillating pressure gradient reduces both pressure and friction drag in a channel flow with transverse bars at the wall



Taken from Nguyen et al.

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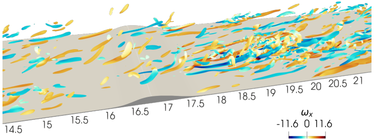

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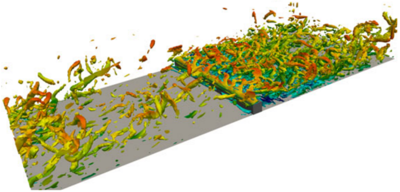

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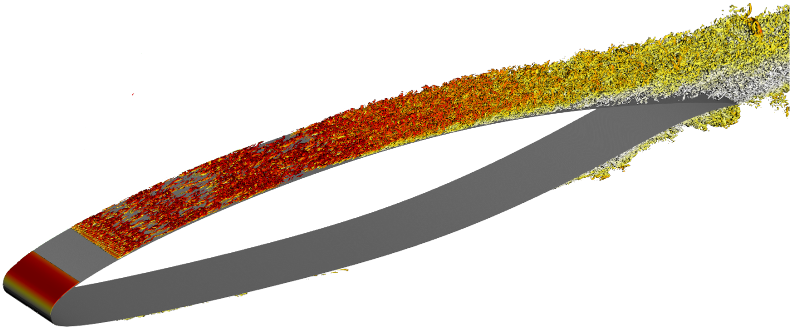
What about the other contributions to the total drag?

Effect of skin friction drag reduction on a transonic airfoil

- First Direct Numerical Simulation (up to 1.8 billions cells)
- Supercritical V2C airfoil
- The control is applied on a portion of the suction side only
- Streamwise travelling waves of spanwise velocity
- $Re_\infty = 3 \times 10^5$, $M_\infty = 0.7$, $\alpha = 4^\circ$



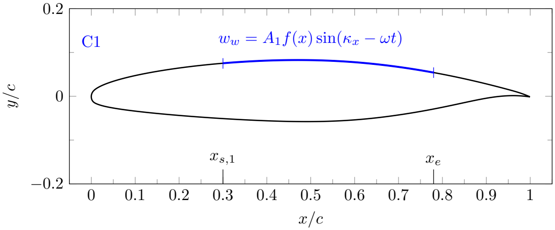
Numerical Simulation

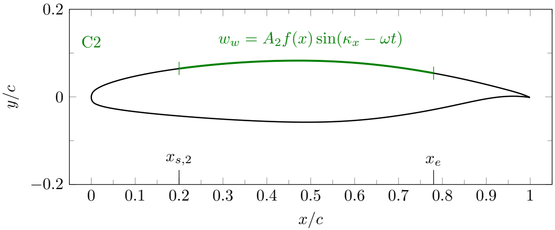
For C1:

- ◇ $A_1 = 0.5$, $\omega = 11.3$, $\kappa_x = 161$
- ◇ $x_{s,1} = 0.3c$, $x_{e,1} = 0.78c$

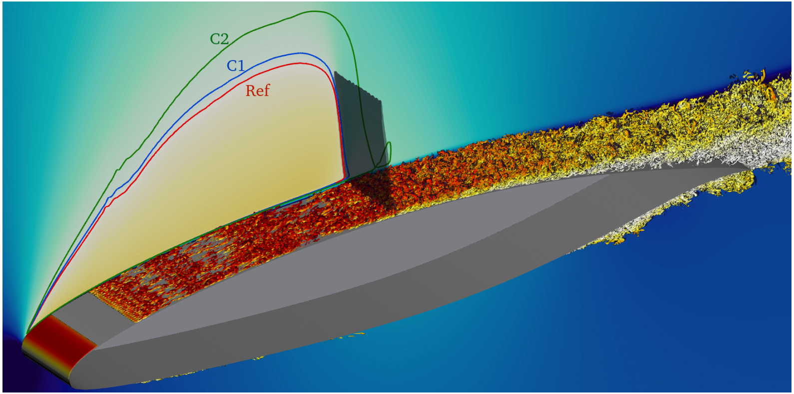
For C2:

- ◇ $A_2 = 0.684$, $\omega = 11.3$, $\kappa_x = 161$
- ◇ $x_{s,2} = 0.2c$, $x_{e,2} = 0.78c$



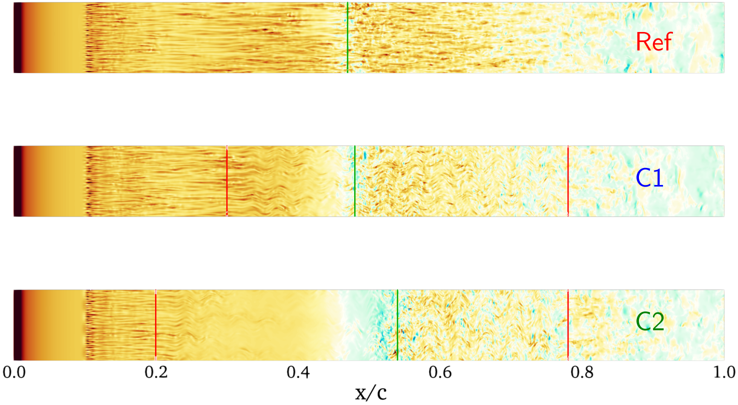


Mean flow



— $M = 1$ (Ref)
— $M = 1$ (C1)
— $M = 1$ (C2)

Instantaneous flow: near-wall fluctuations

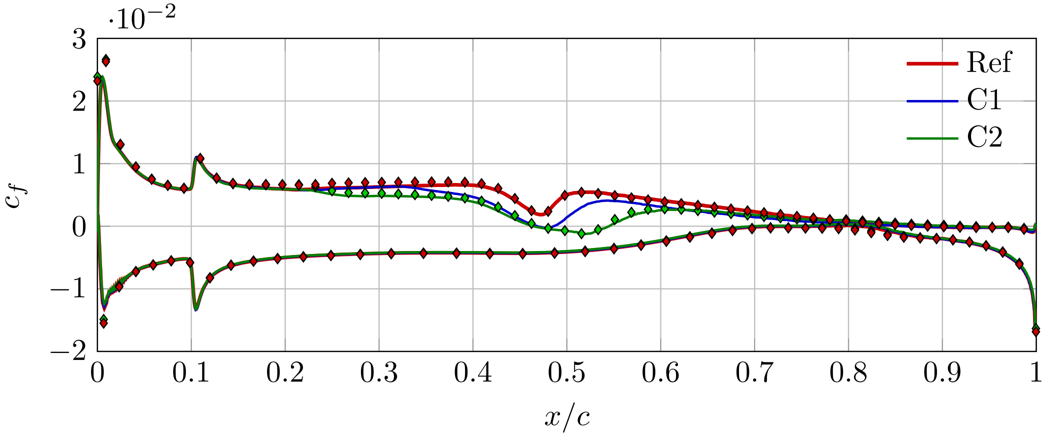


— shock position

— x_s and x_e

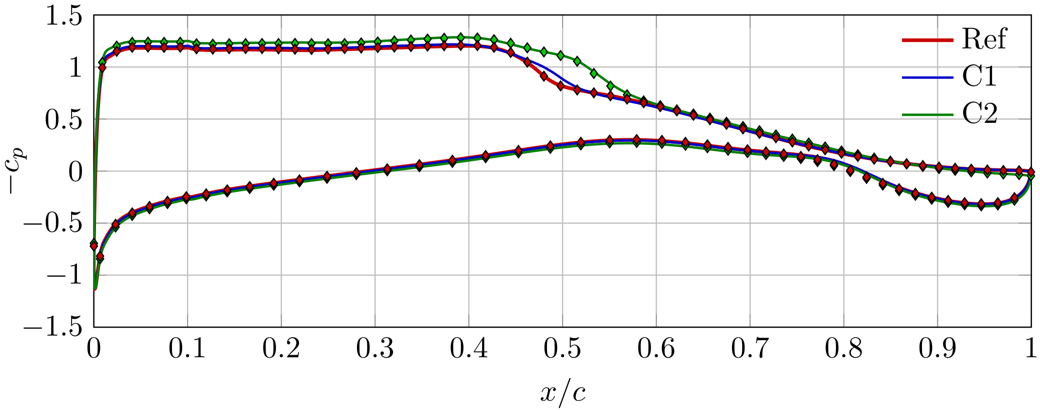
Friction coefficient

$$c_f = \frac{2\tau_w}{\rho_\infty U_\infty^2}$$



Pressure coefficient

$$c_p = \frac{2(p_w - p_\infty)}{\rho_\infty U_\infty^2}$$



Aerodynamics forces

At the same incidence angle $\alpha = 4^\circ$

	Reference	C2	Δ_2	C2 ($\alpha = 3.45^\circ$)	Δ_2
C_ℓ	0.740	0.825	+11.3%	0.730	-1.3%
C_d	0.0247	0.0245	-0.8%	0.0210	-15.0%
$C_{d,f}$	0.0082	0.0071	-13.4%	0.0074	-9.7%
$C_{d,p}$	0.0165	0.0174	+5.5%	0.0136	-17.6%
C_ℓ / C_d	29.7	33.7	+13.5%	34.8	+17.2%

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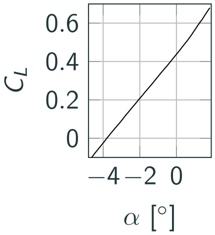
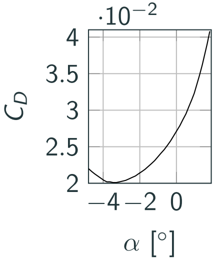
Assumptions:

- The wing is responsible for the entire lift and $1/3$ of the total drag
- ΔC_ℓ and ΔC_d due to the control do not change along the wing span
- ΔC_ℓ and ΔC_d due to the control do not change with α, Re_∞ and M_∞

How does it scale to a full aircraft?

- DLR-F6 (Second AIAA CFD drag prediction workshop)
- Flight condition: $M_\infty = 0.75$, $Re_\infty = 3 \times 10^6$
- Control C2 applied to both wings





taken from https://aiaa-dpw.larc.nasa.gov/Workshop2/DPW_forces_WB_375

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α	0.52°	0.0125°
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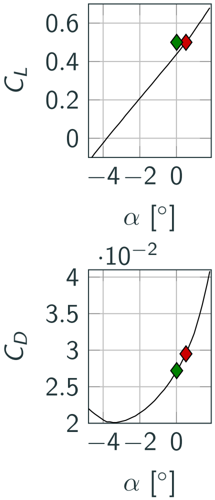

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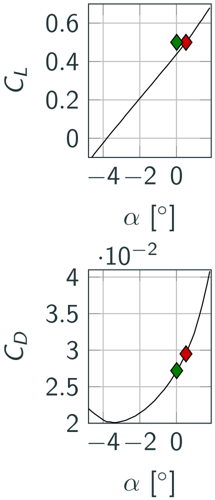
actuation power $\approx 1\%$ of the overall power expenditure



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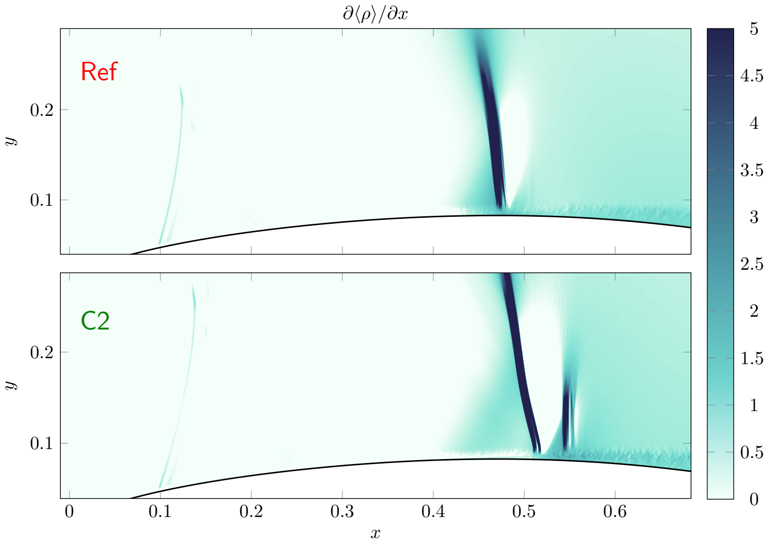
Conclusion

- The global aerodynamic performance of the wing is improved by locally reducing skin friction over a portion of the suction side
- For the present case we measure $\Delta C_d \approx 15\%$ (but even more is possible!)
- For the full aircraft we estimate $\Delta C_D \approx 8.5\%$
- Skin-friction drag reduction should be considered as a tool and not only as a goal

Reference: Quadrio et al. (J. Fluid Mech, vol. 942, R2)

Thanks for the attention!

Mean flow: downstream shift of the shock



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