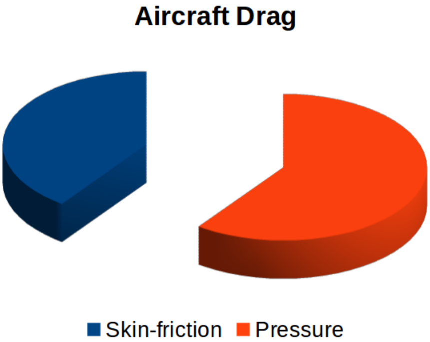
Drag reduction of a wing-body configuration via spanwise forcing

Andrea Gadda, Jacopo Banchetti, Giulio Romanelli, Maurizio Quadrio

Dipartimento di Scienze e Tecnologie Aerospaziali
Politecnico di Milano

Drag components of Transport Aircraft in Cruise:

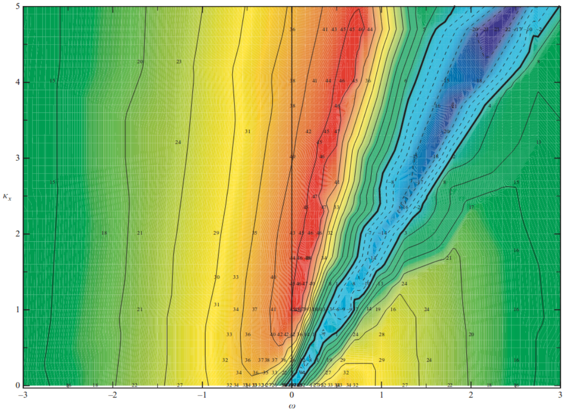


Mele *et al.*, *J. of Aircraft*, 2016

Quadrio, Ricco & Viotti, *JFM*09

Potential for large energy savings

Low-Re, incompressible flows in simple geometry.



[QRV09]

What about an airplane?

Background (Gatti & Quadrio, *JFM*16)

Waves can be assimilated to drag-reducing roughness

- Streamwise travelling waves produce a vertical shift ΔB of the logarithmic portion of the mean velocity profile
- Drag reduction rate R is linked to ΔB
- ΔB^+ at non-low *Re* becomes Reynolds independent

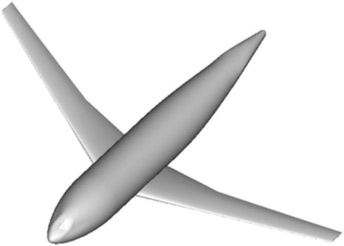
$$U^+ = \frac{1}{\kappa}\log(y^+) + B + \Delta B^+$$

Case of study

AIAA Second Drag Prediction Workshop (DLR-F6)

DLR-F6 is a modern transport aircraft, with a **transonic design**

- Wing-body configuration
- RANS
- Spalart-Allmaras Turbulence model
- Fully turbulent boundary layer
- $Re = 3 \cdot 10^6$ based on reference chord
- $M = 0.75$
- Flight lift coefficient 0.5



Present work

- Forcing is introduced by a modified wall function

$$U^+ = \frac{1}{\kappa} log(y^+) + B + \Delta B^+$$

- Coarse mesh available in Drag Prediction Workshop website

- Forcing applied over the entire aircraft

AeroX

A GPU-CPU compressible RANS solver

- Finite volumes
- Compressible (transonic)
- Speedup by GPU:

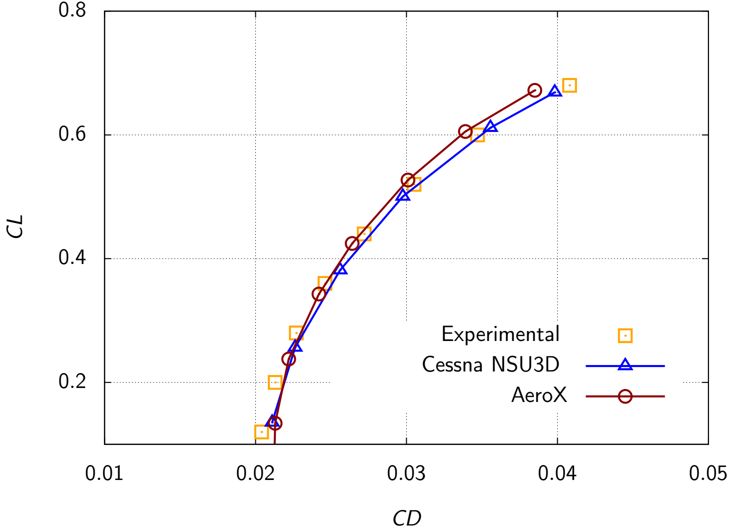
(2015)	AMD 380X $\sim 230\,USD$	FURY X $\sim 650\,USD$
i7 5930k-6 $\sim 600\,USD$	$4.3x$	$8.7x$

In the present work:

- GPU: AMD 380X
- $2 \cdot 10^6$ elements: convergence in ~ 45 min

Validation

DLR-F6 Polar curve



Drag Reduction

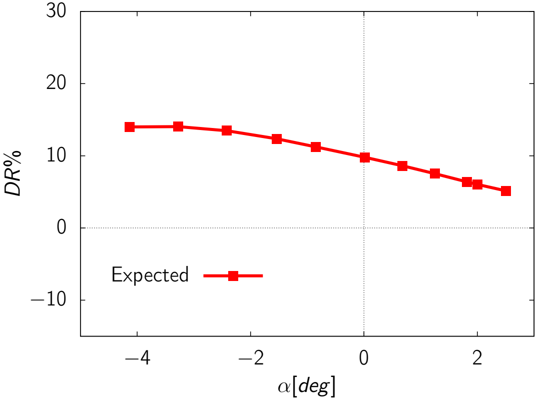
Friction and Pressure drag decomposition

Drag Reduction

Friction and Pressure drag decomposition

Expected

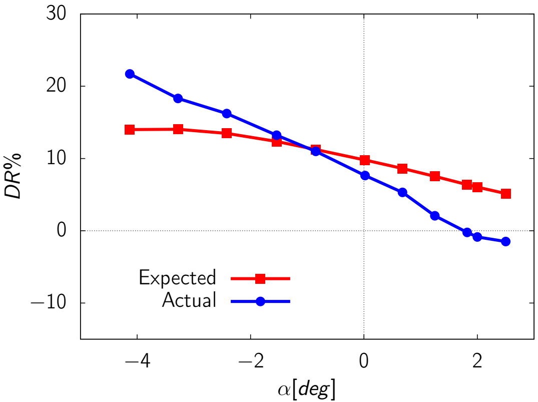
- Friction drag reduces by 23%
- Pressure drag is unchanged
- Total drag reduces by at most 14%



Drag Reduction

Friction and Pressure drag decomposition

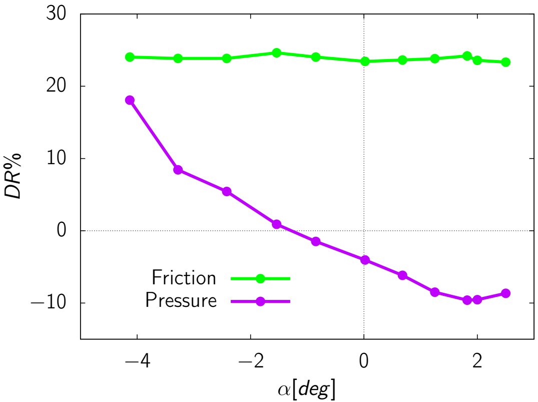
Expected	Actual
• Friction drag reduces by 23%	
• Pressure drag is unchanged	
• Total drag reduces by at most 14%	• 22%



Drag Reduction

Friction and Pressure drag decomposition

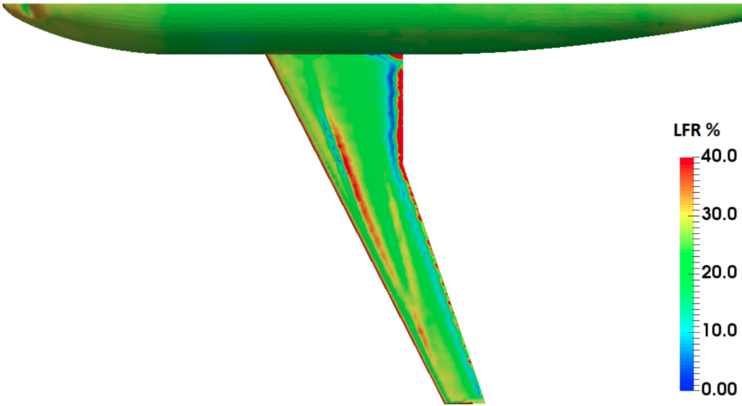
Expected	Actual
Friction drag reduces by 23%	$\sim$ 23%
Pressure drag is unchanged	changed
Total drag reduces by at most 14%	22%



Local Friction Reduction

Upper view

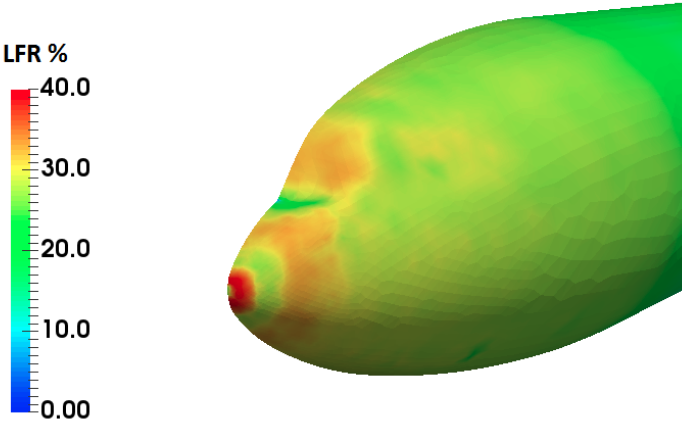
- Local Friction Reduction close to 23% where the configuration is clean
- Strong variations on the upper wing surface



Local Friction Reduction

Frontal view

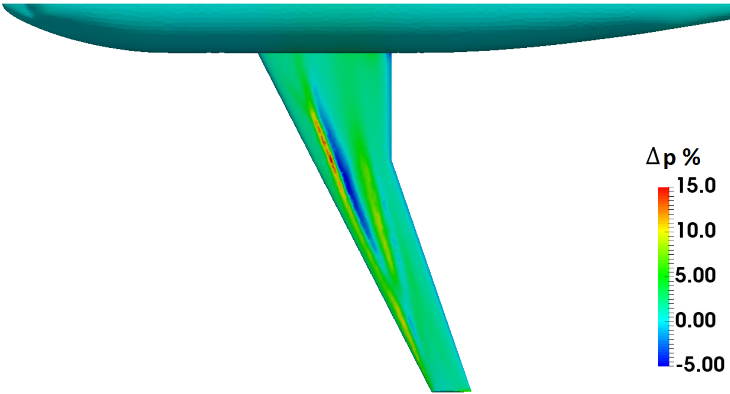
Local Friction Reduction unexpectedly high in the front fuselage



Local Pressure

Upper view

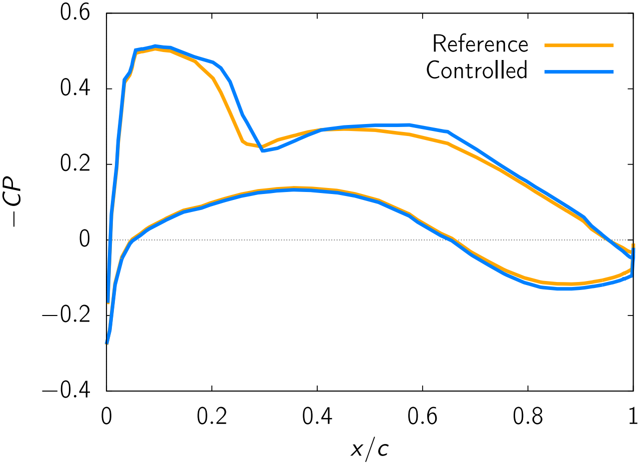
- Fuselage and lower wing surface unchanged
- Changes on upper wing surface



Local Pressure

Pressure coefficient distribution

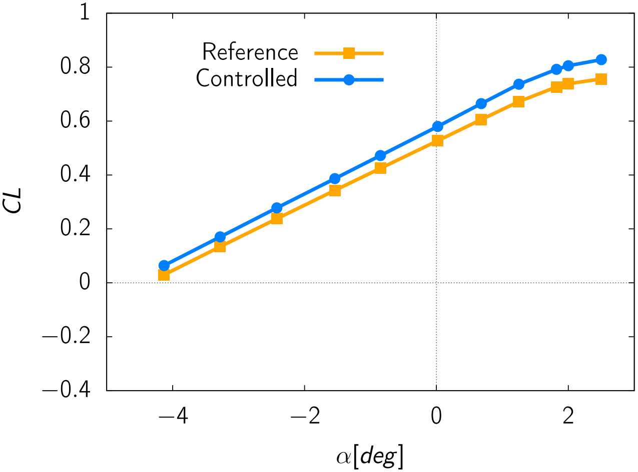
Secondary effect: Shock delay



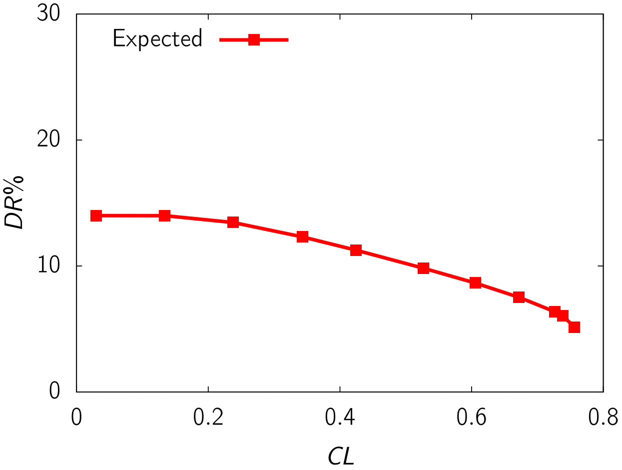
Lift Coefficient

$CL - \alpha$ curve

Secondary effect: Lift increase

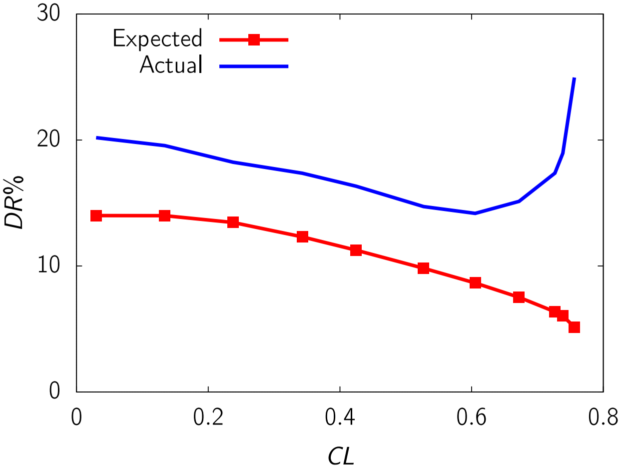


Drag reduction at constant lift



Drag reduction at constant lift

- Drag reduction is always higher than expected
- Lift increase - Stall begins at higher CL



Net power saving at constant lift

- Active techniques require input power
- Input power is estimated via known trends in channel flow

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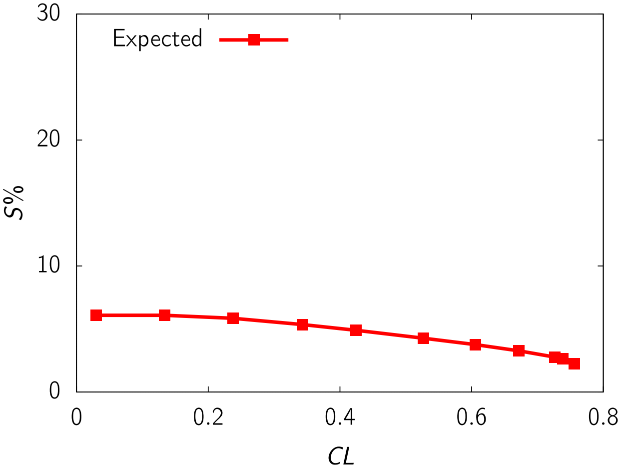
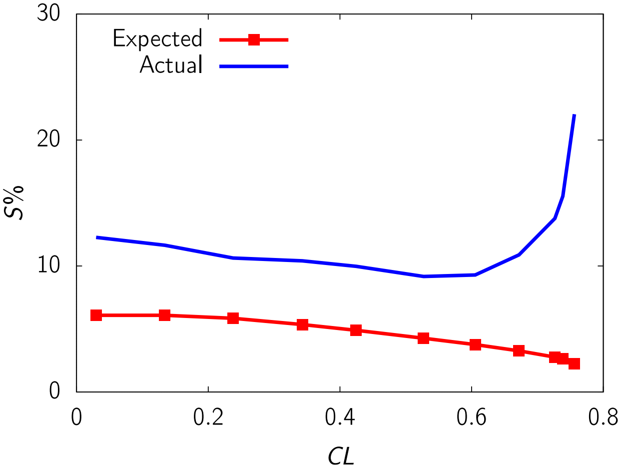


Net power saving at constant lift

Net power saving S higher than 10%



Comparison with MTC 2016

Despite the differences

	MTC16	Actual
Solver	UZEN / FLOWer	AeroX
Aircraft	CRM	DLR-F6
Re	$5 \cdot 10^6$	$3 \cdot 10^6$
M	0.85	0.75
Turbulence model	SST	Spalart-Allmaras
DR technique	Riblets	Spanwise forcing
Forcing formulation	ω at wall	Wall function

Same qualitative results:

- Direct effects: R close to the expected value
- Indirect effects: Shock delay - Lift increase

Doubts?

Do we trust these results?

Further investigations needed:

- Transition?
- Log Law?

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"One coincidence is just a coincidence. Two coincidences are a clue. Three coincidences are a proof." (A. Christie)

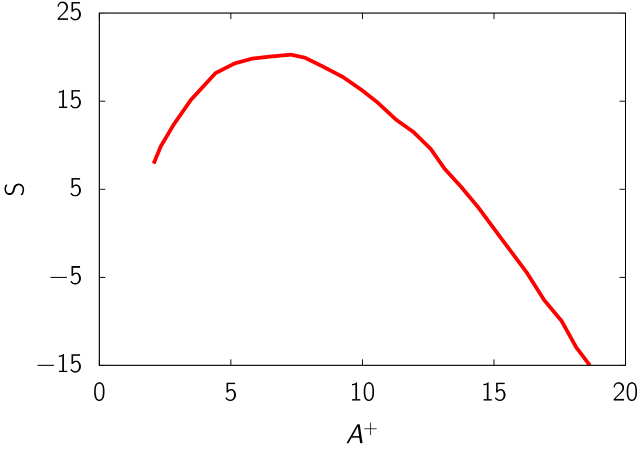
Thank you for your attention

Questions?

$$S(A^+)$$

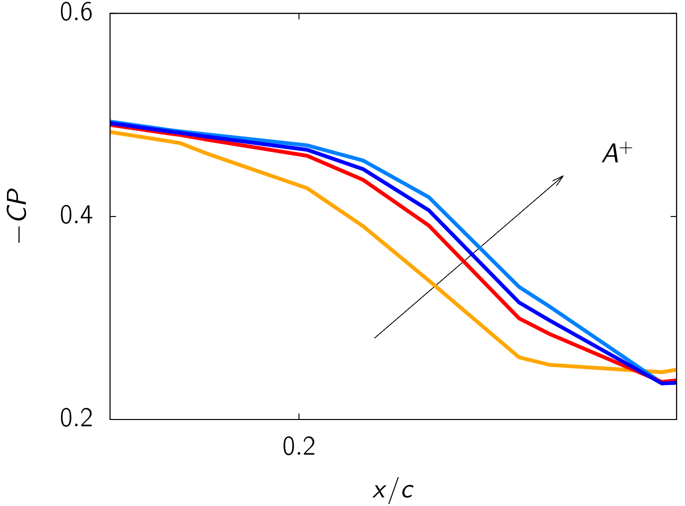
How does S changes with forcing amplitude?

S at low-Re incompressible channel flow rapidly decreases after $\sim A^+ = 7$



How does S changes with forcing amplitude?

Shock delay increase with A^+



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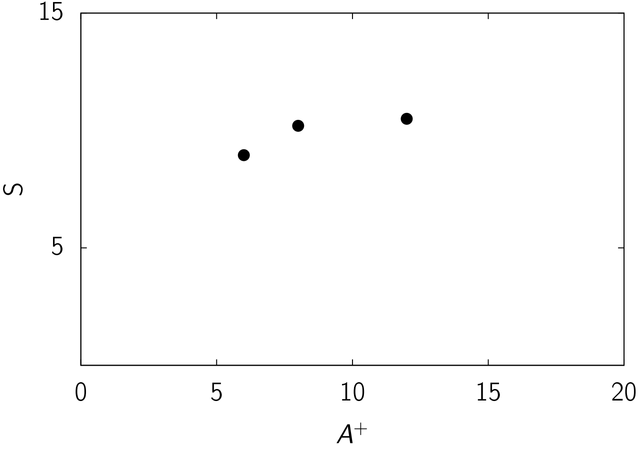

Actual S slightly increases until $A^+ = 12$

$$\Delta LFR \ \& \ -\nabla p?$$

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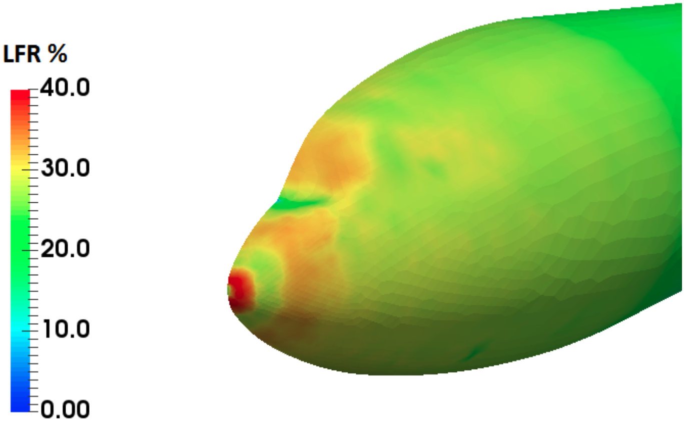

Local Friction Reduction

Pressure gradient and Local Friction Reduction

$$(LFR - LFR_{expected}) \propto -\nabla p?$$