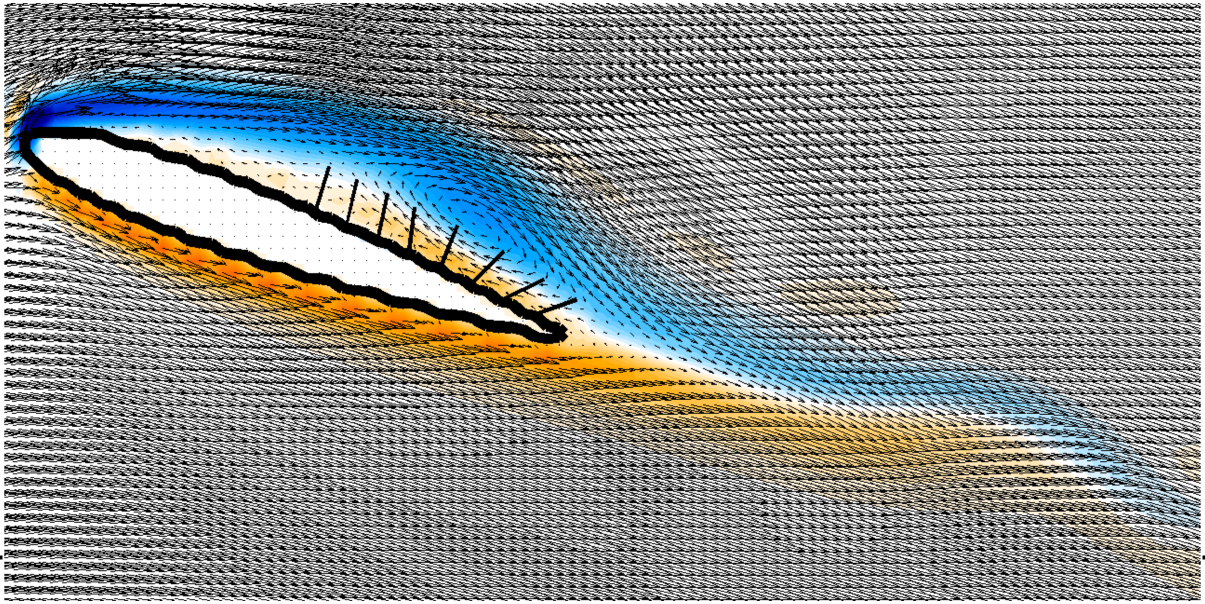
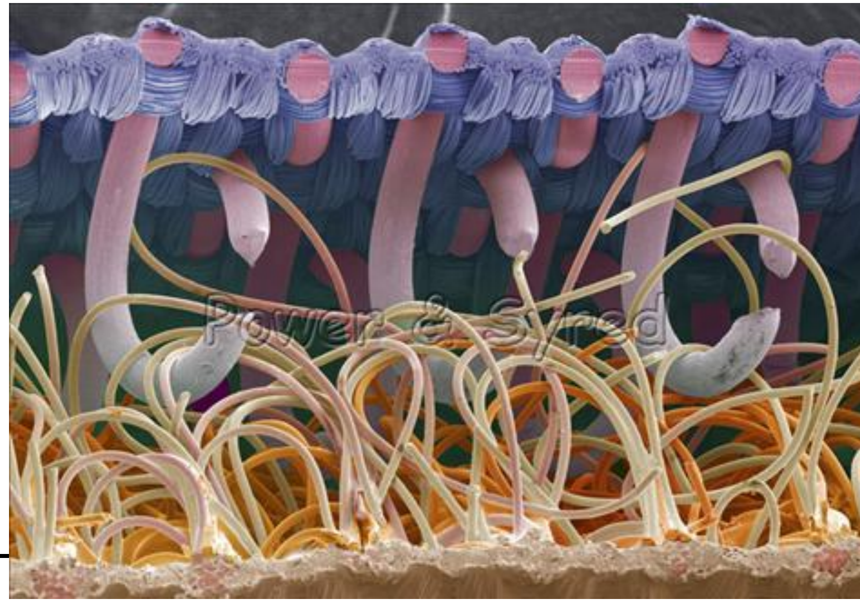


BIOMIMETISME ET AERONAUTIQUE:

Pourquoi rugueux, flexible et accidenté est mieux que lisse, rigide et régulier ?

A. Bottaro (DICCA, Université de Gênes)

Petit déjeuner **du RTRA, Toulouse, 6 june 2012**



BIOMIMETISME:
ça demarre avec le velcro …

Georges de Mestral, 1941

Petit déjeuner **du RTRA, Toulouse, 6 june 2012**

BIOMIMETISME:
pas seulement le velcro !!!

Petit déjeuner **du RTRA, Toulouse, 6 june 2012**

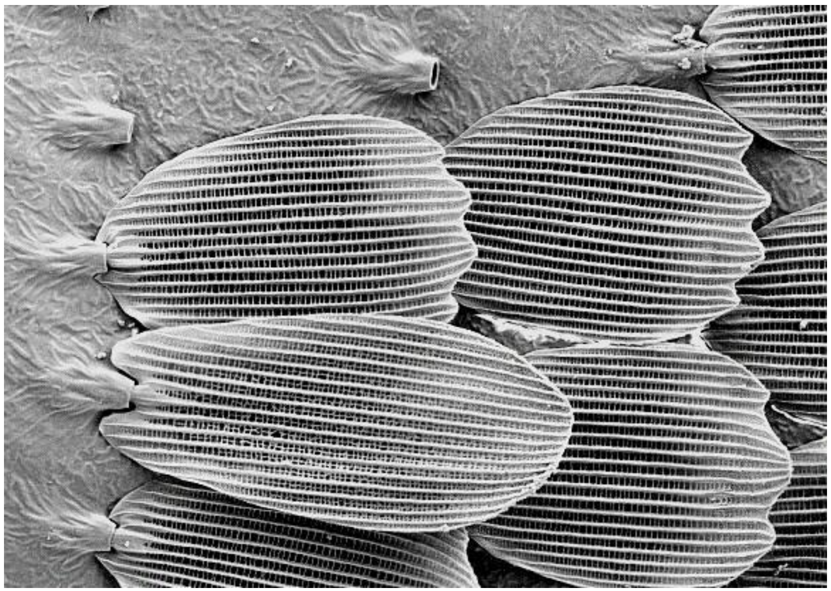
Focus: passive/active flow control

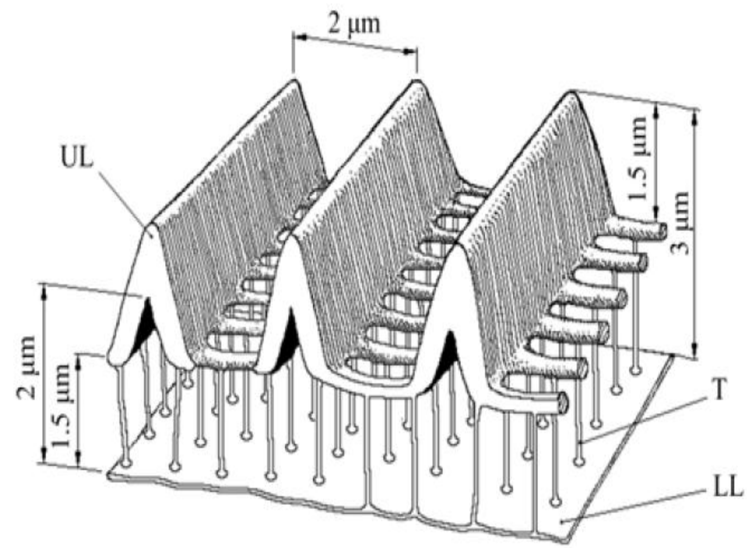
Known techniques of passive/active flow control:

- **Injection of micro-bubbles and/or polymers**
- **Riblets**
- **Compliant walls**
- **Viscosity modifier**
- **Vortex generators**
- **…**

Less known techniques of passive/active flow control:

- Butterfly and moth wings microstructure



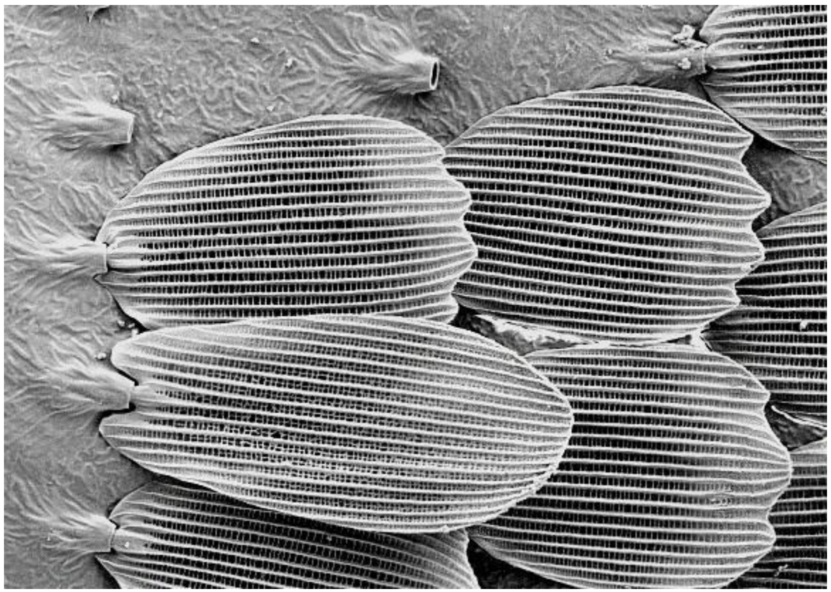


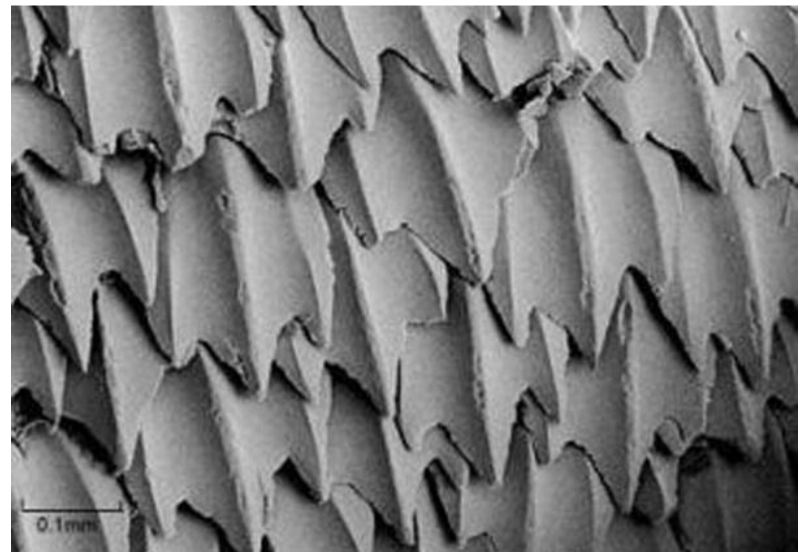
Left: electron microscope image of butterfly scales.
Right: perspective view (with dimensions) with details of a scale.
UL: upper lamina; LL: lower lamina; T: trabecula.

Less known techniques of passive/active flow control:

- **Shark skin paint!**

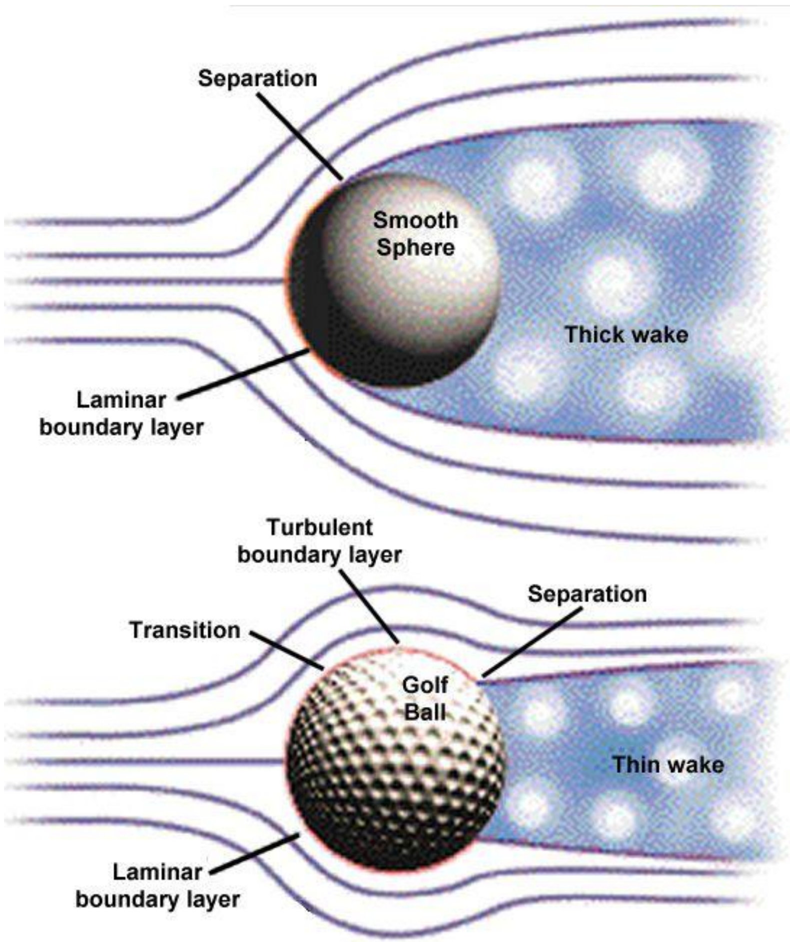
The coating that reduces drag (Fraunhofer, Bremen)

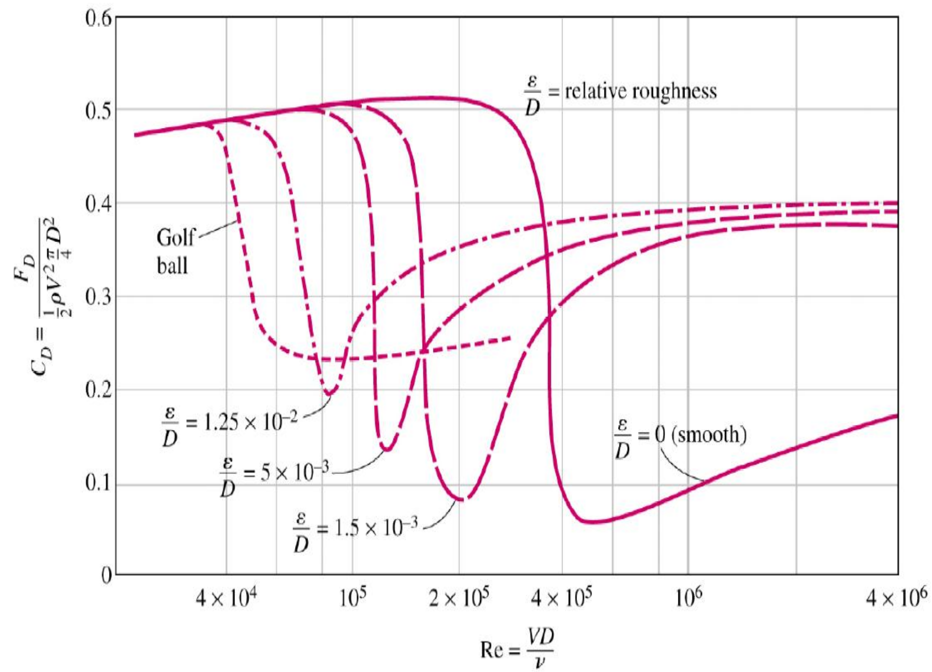




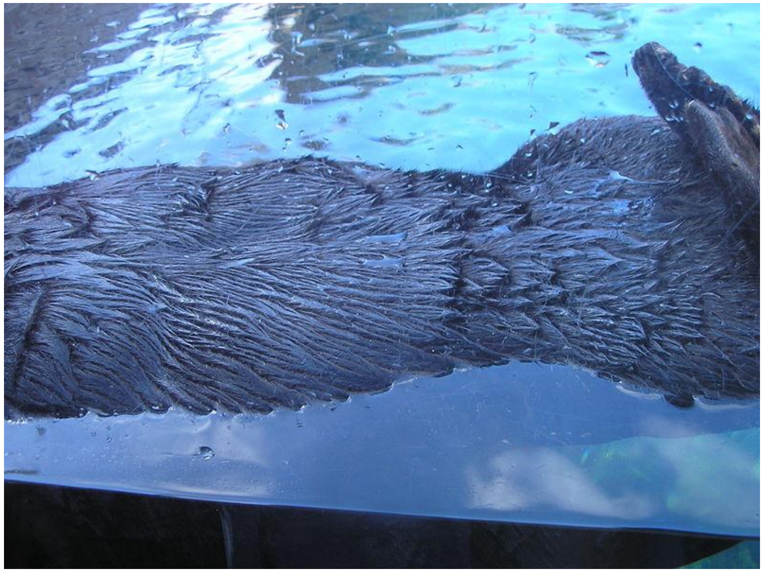
How can we increase lift over a streamlined body at incidence by a passive technique?

How can we reduce pressure drag behind a solid bluff body by a passive technique?





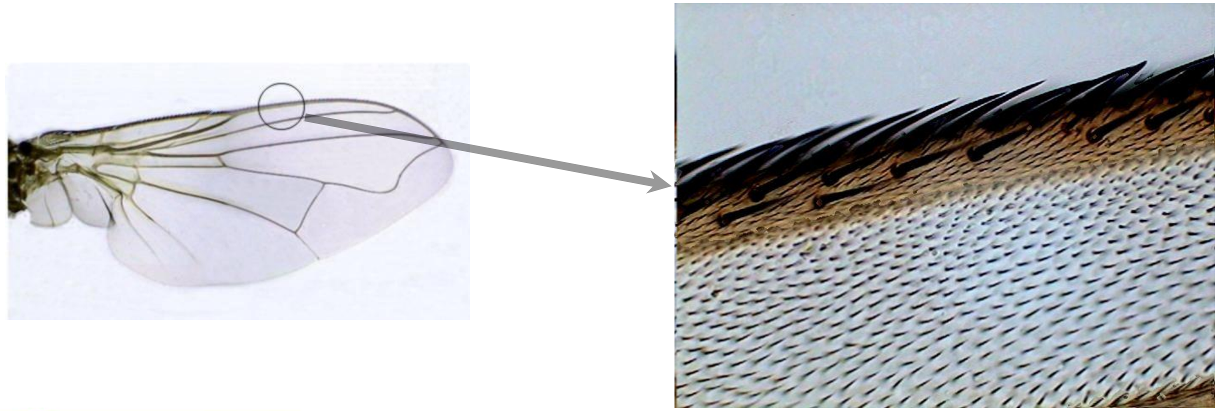
Less known techniques of passive/active flow control:

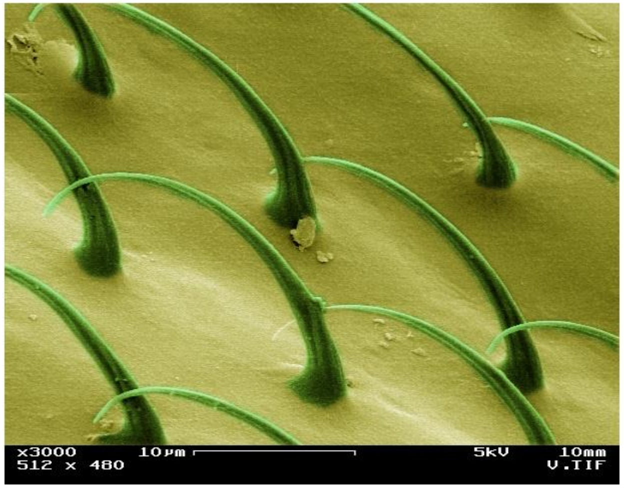


sea otter
(*loutre de mer*)

Passive, compliant hairy coating

How can we increase lift over a streamlined body at incidence by a passive technique?



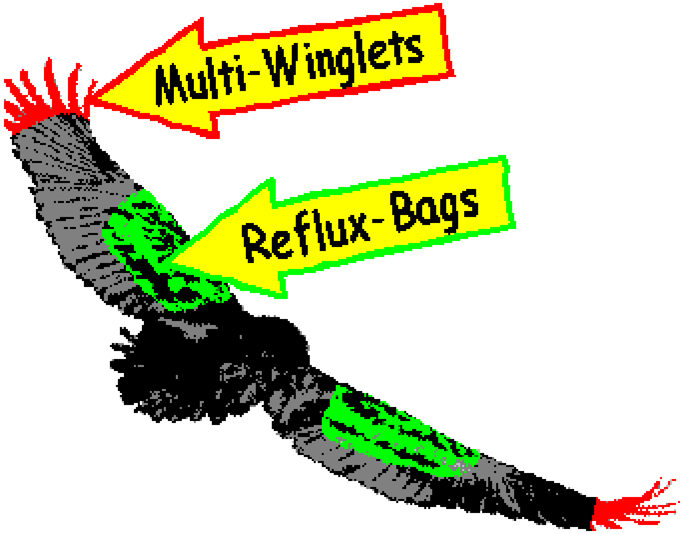


How can we increase lift over a streamlined body at incidence by a passive technique?

How can we increase lift over a streamlined body at incidence by a passive technique?

Coverts have also a aerodynamic role ...

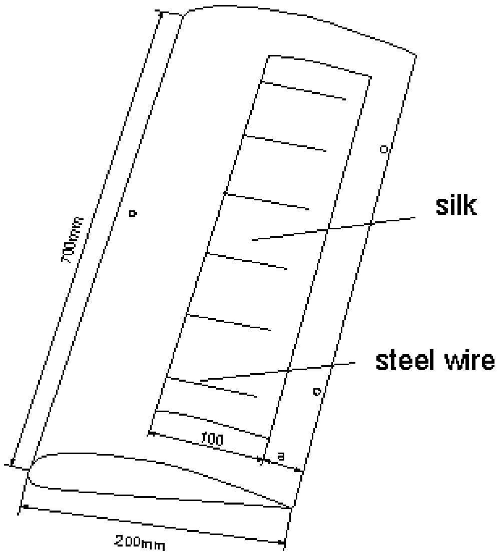
How can we increase lift over a streamlined body at incidence by a passive technique?



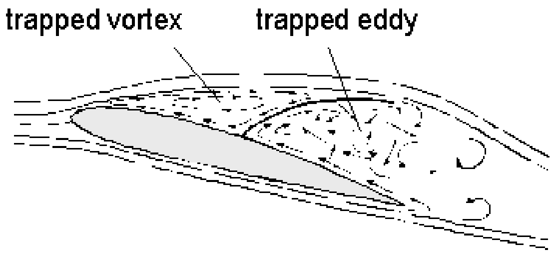
Prof. Ingo Rechenberg, TU Berlin
http://www.bionik.tu-berlin.de/institut/xs2vogel.html

How can we increase lift over a streamlined body at incidence by a passive technique?

aerofoil with silk flaps



flow visualisation



Prof. Ingo Rechenberg, TU Berlin
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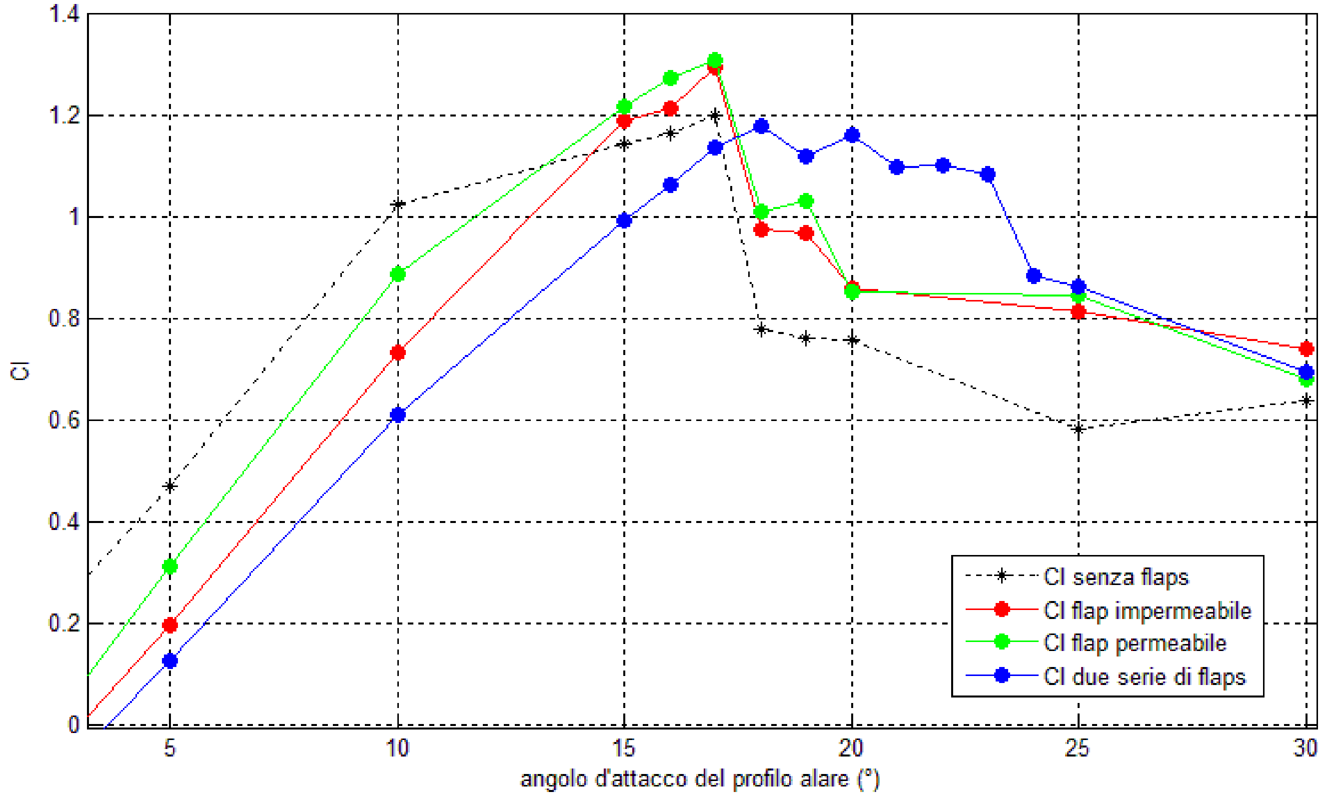
Wind tunnel tests in Genova

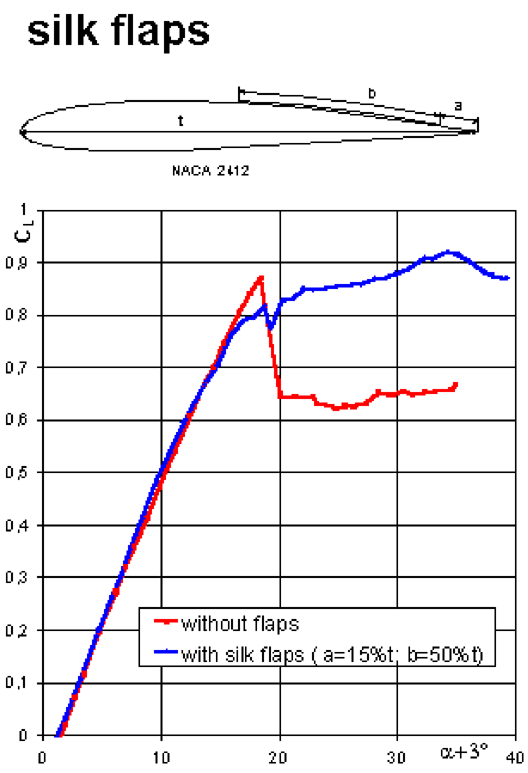
F. Negrello, Engineering Diploma work, 2010

Wind tunnel tests in Genova



F. Negrello, Engineering Diploma work, 2010

How can we increase lift over a streamlined body at incidence by a passive technique?

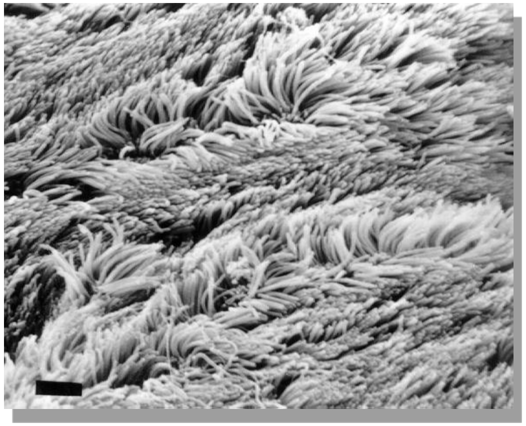


Flexible, porous flaps delay stall …

Prof. Ingo Rechenberg, TU Berlin
http://www.bionik.tu-berlin.de/institut/xs2vogel.html

GOAL: instead of a single flexible flap, let's model a continuous *hairy/feathery* coating to affect lift and drag

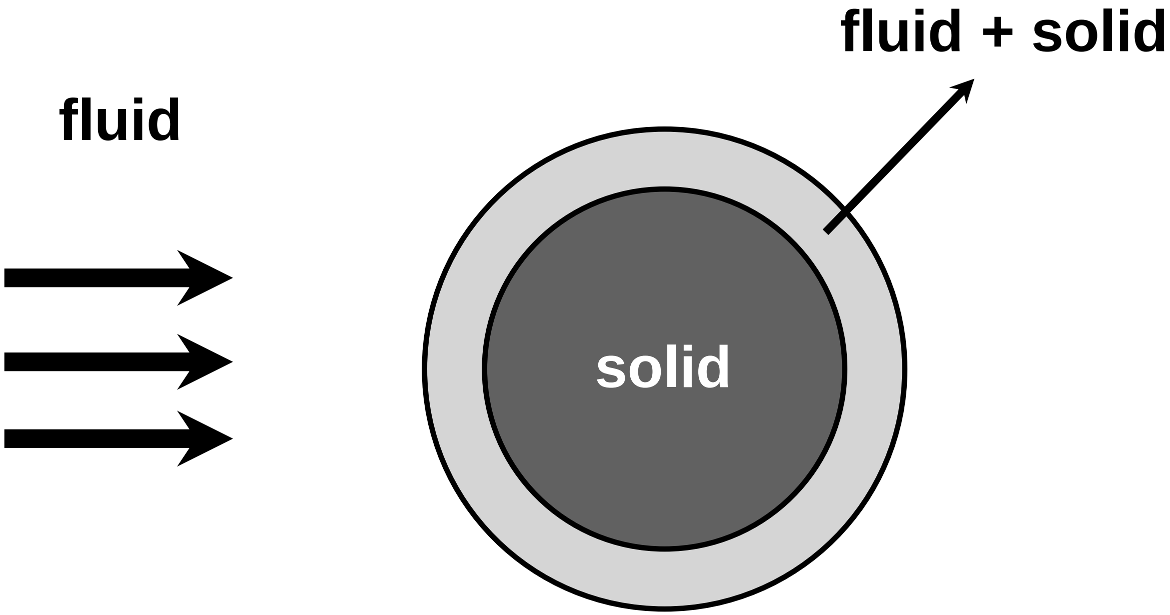
Numerical challenges



- **Model** mechanical properties **of biological surfaces**
- Structures with **large displacements** and **large rotations**
- Interaction between **multiple structures**

Coupling between a layer of oscillating densely packed structures and a unsteady separated boundary layer

The initial configuration

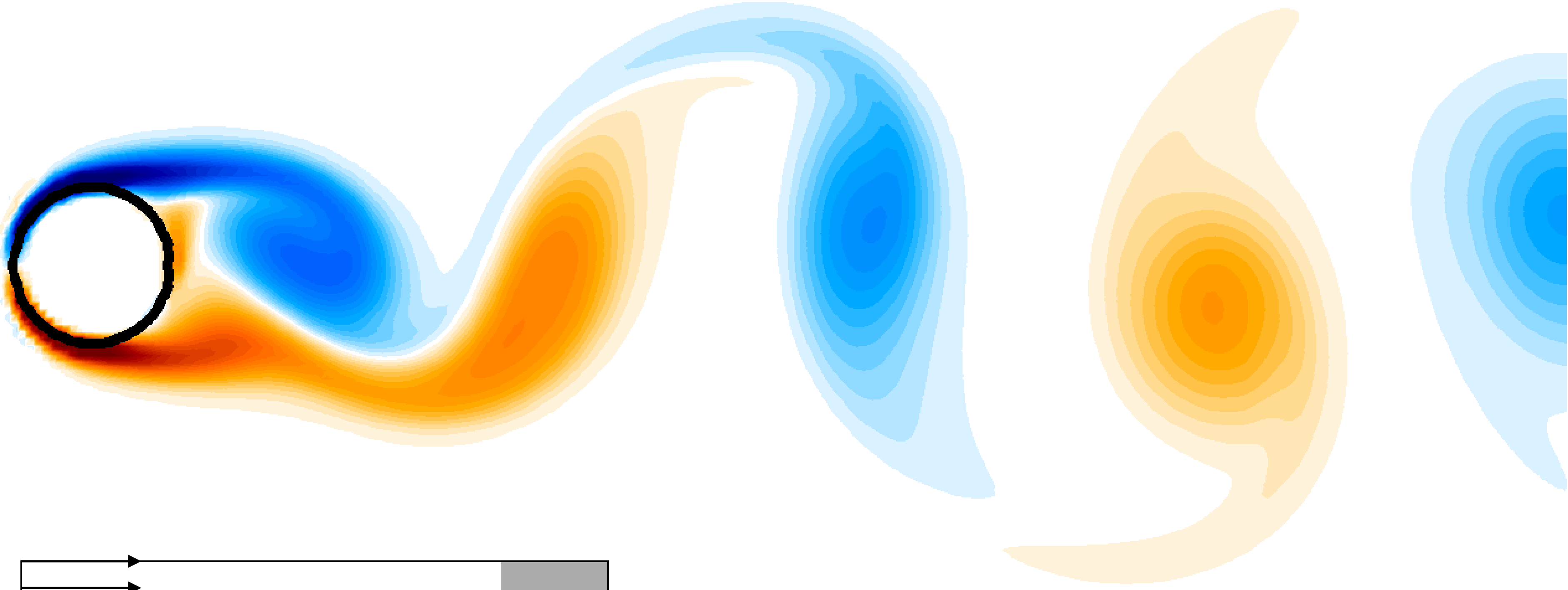


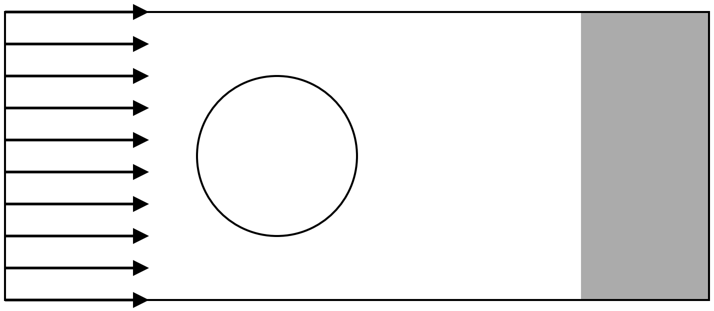
Circular cylinder, Re=200

Model of the layer?

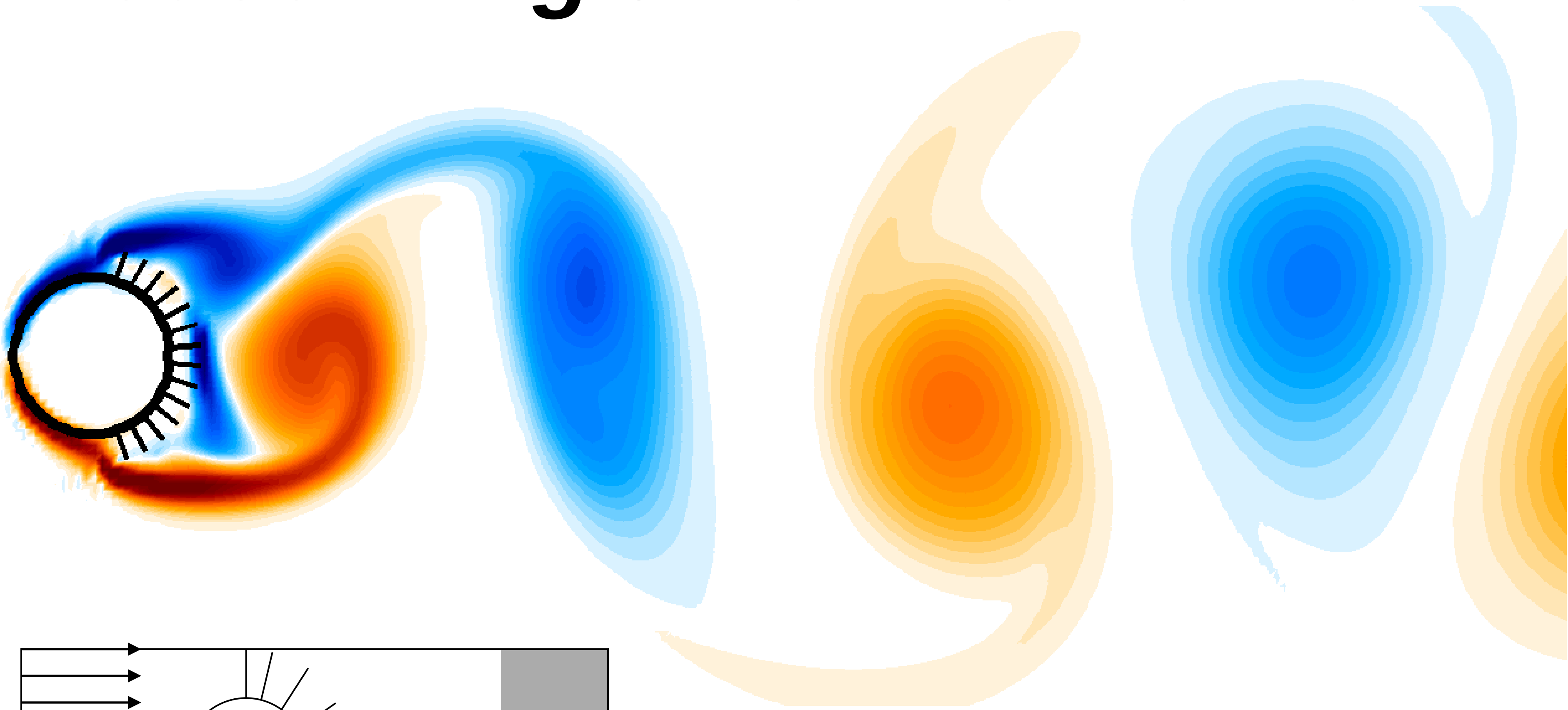
Porous, anisotropic and compliant

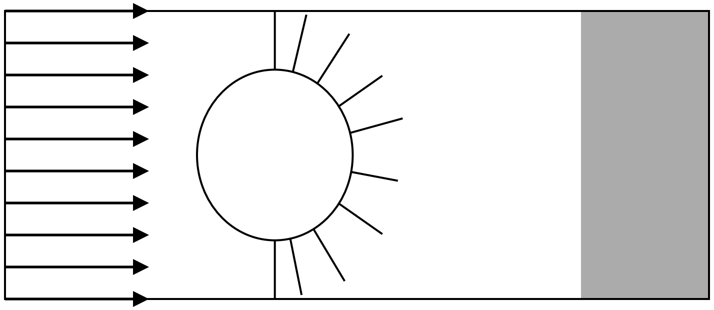
Case 1: bare cylinder



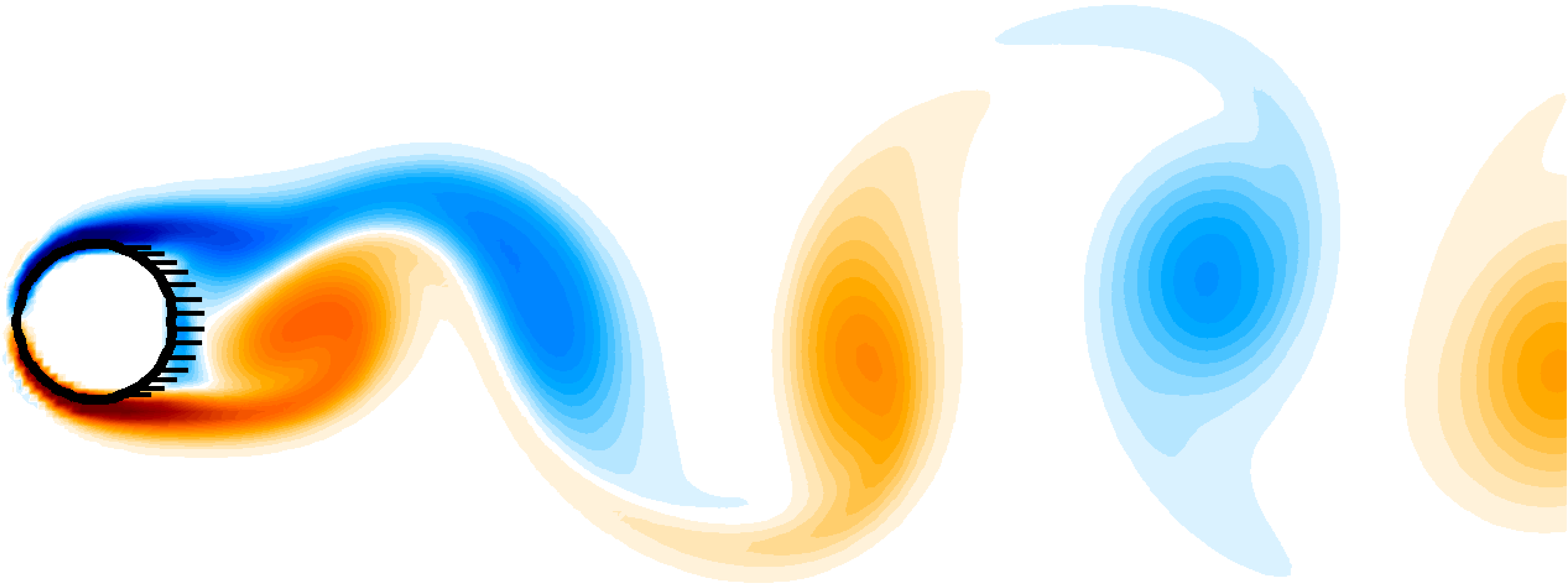


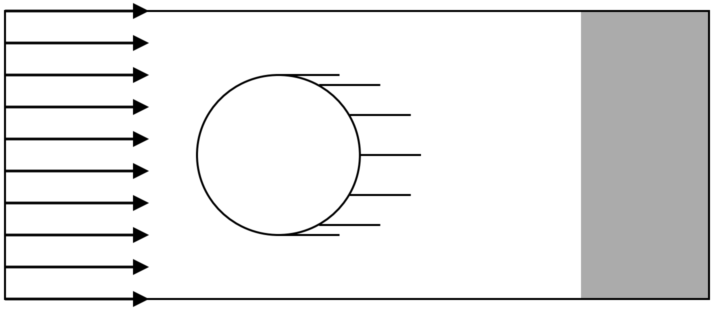
Case 2: rigid wall-normal hair



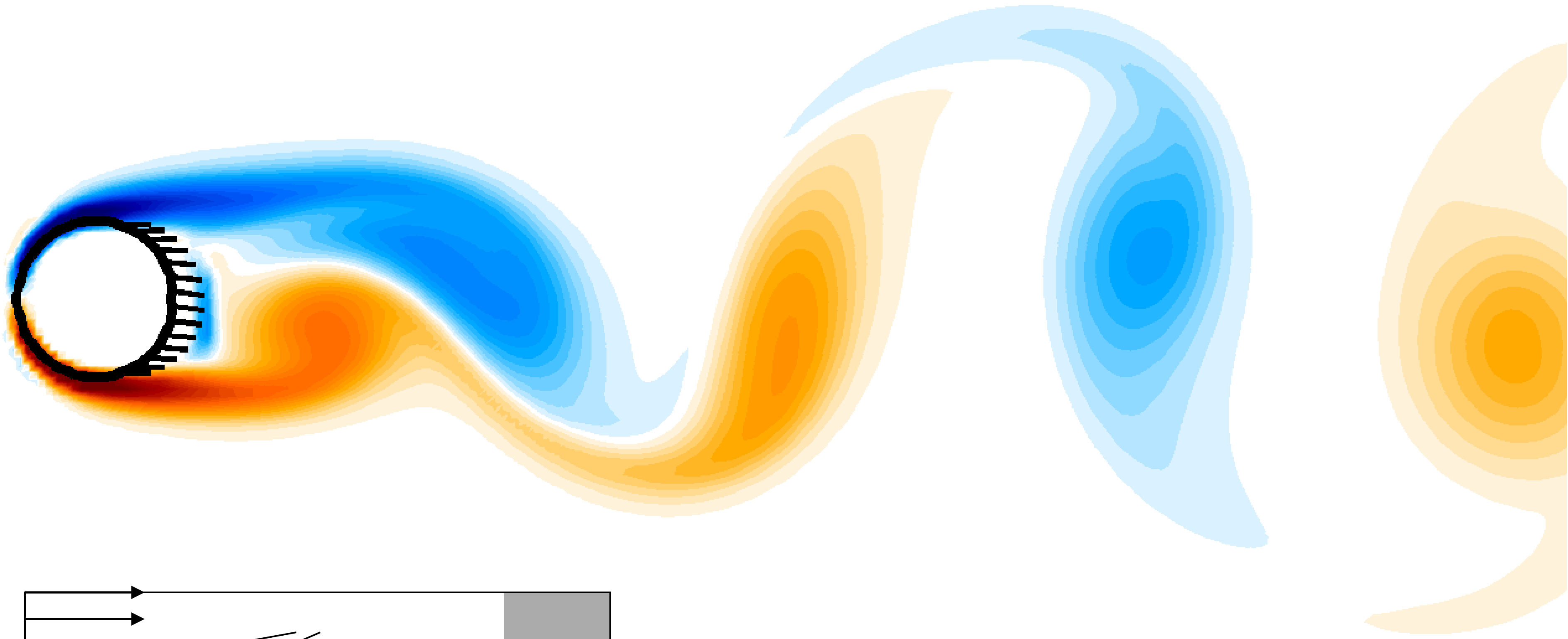


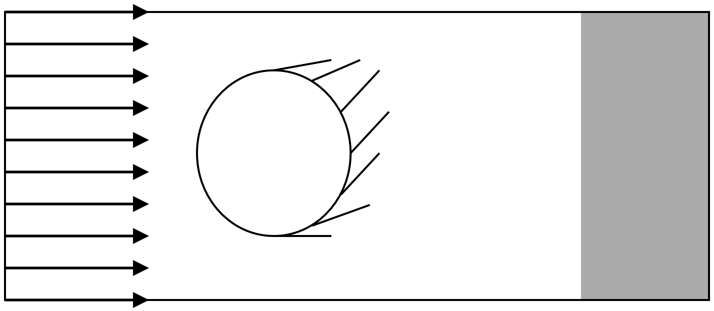
Case 3: rigid longitudinal hair



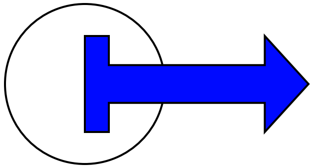


Case 4: moving hair

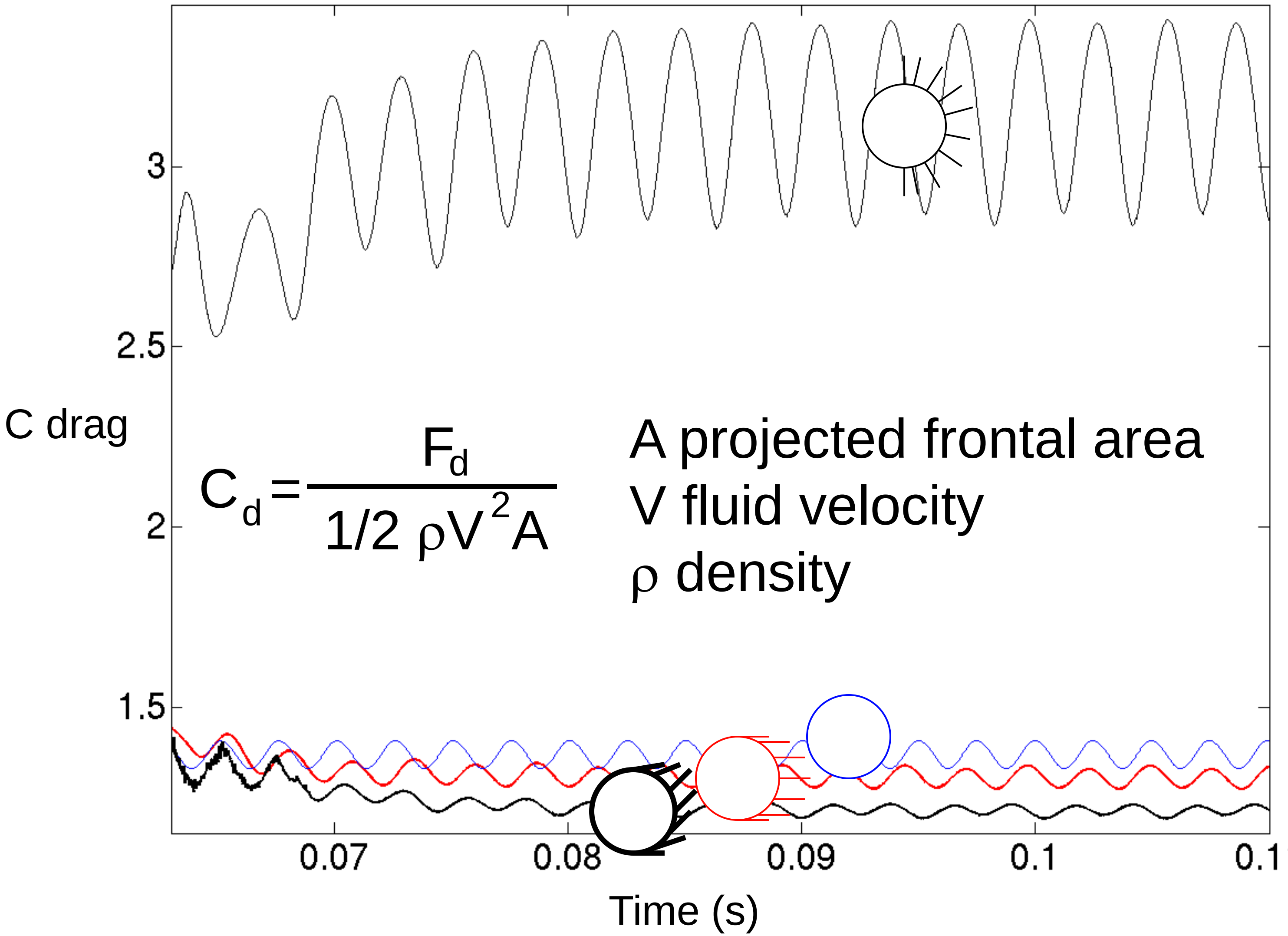




$T_{fluid} \approx 4\ T_{structure}$



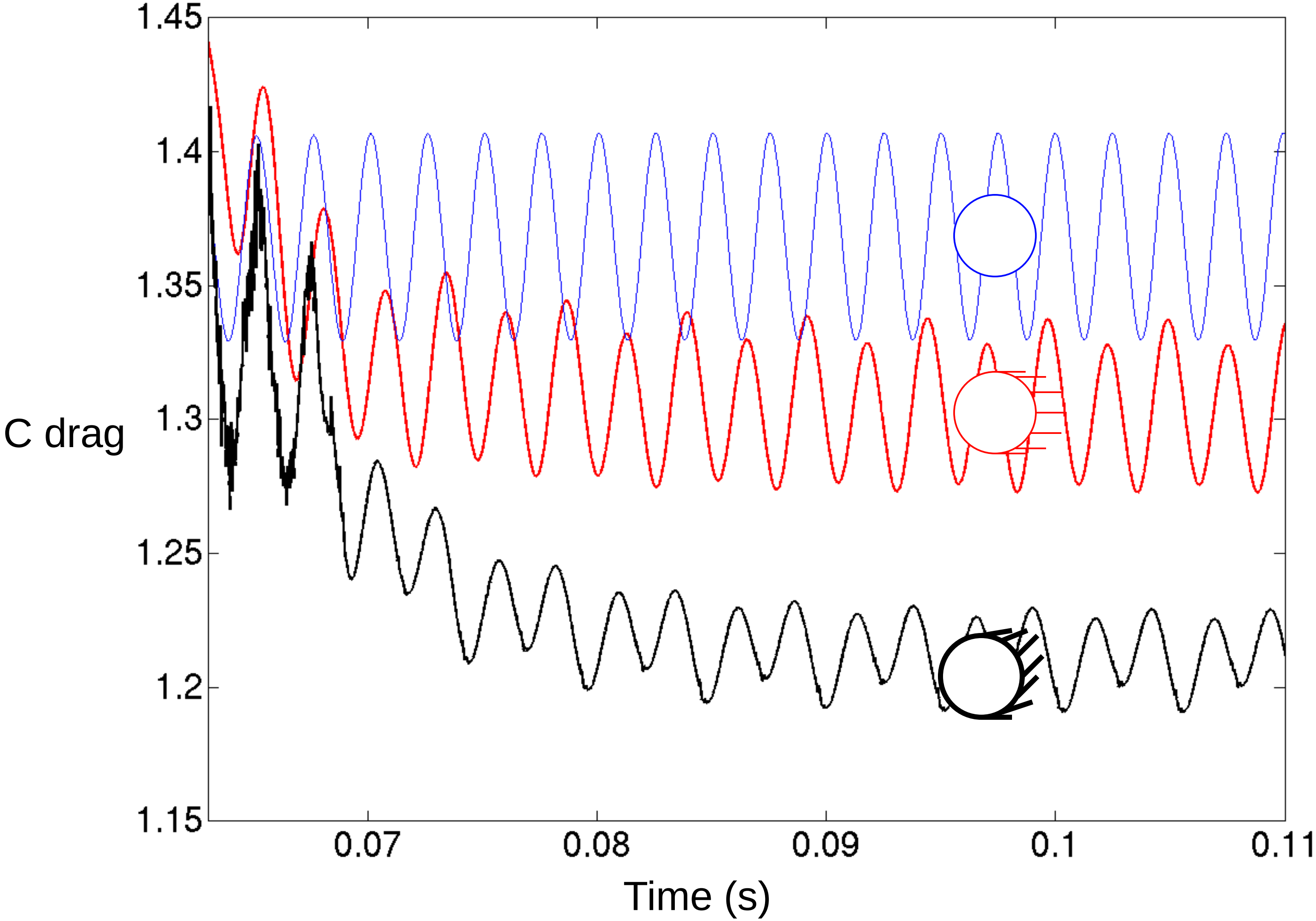
Drag



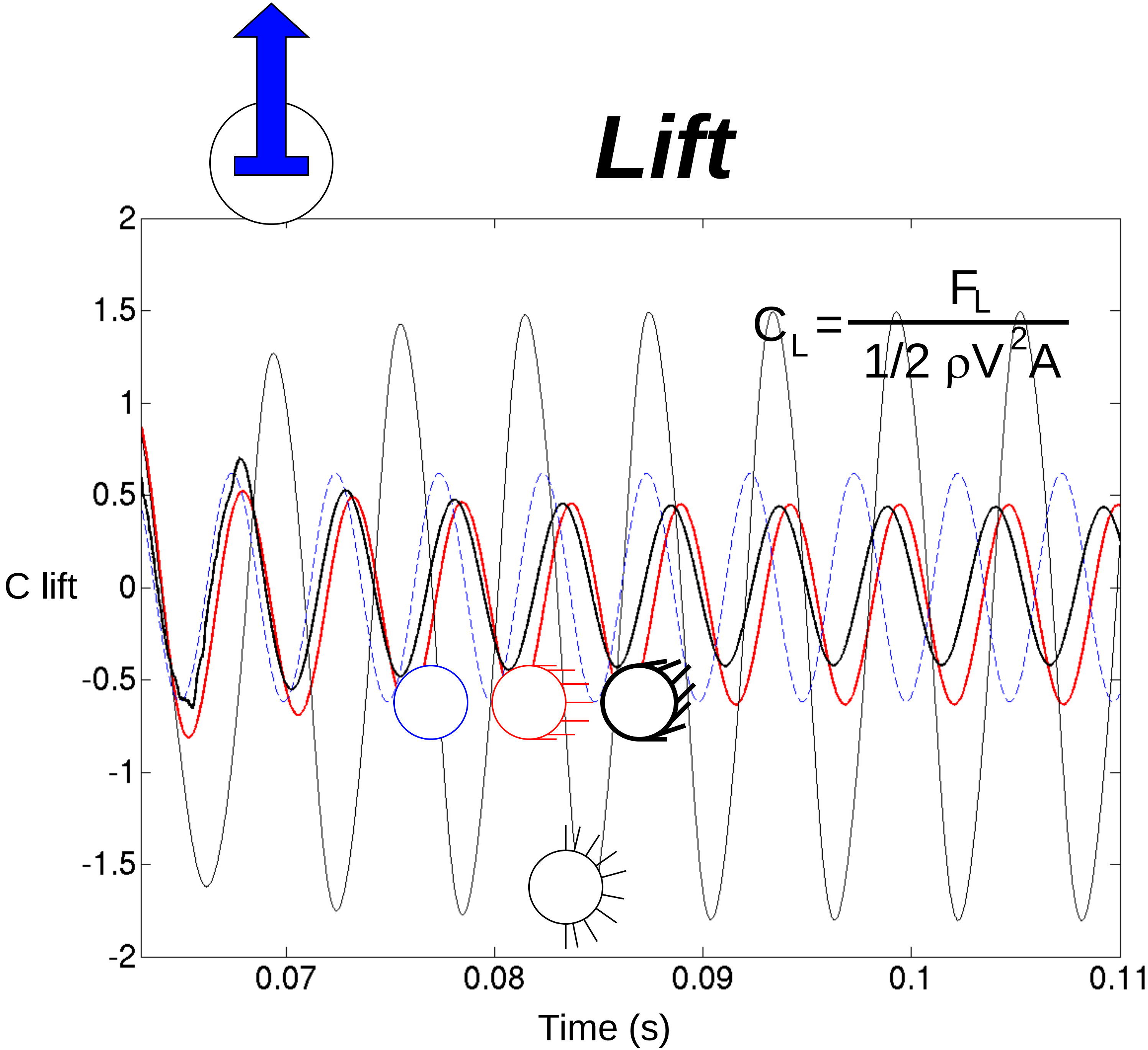
$$C_d = \frac{F_d}{1/2\ \rho V^2 A}$$

A projected frontal area
V fluid velocity
ρ density

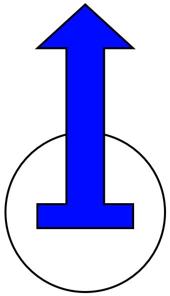
Drag (ctd.)



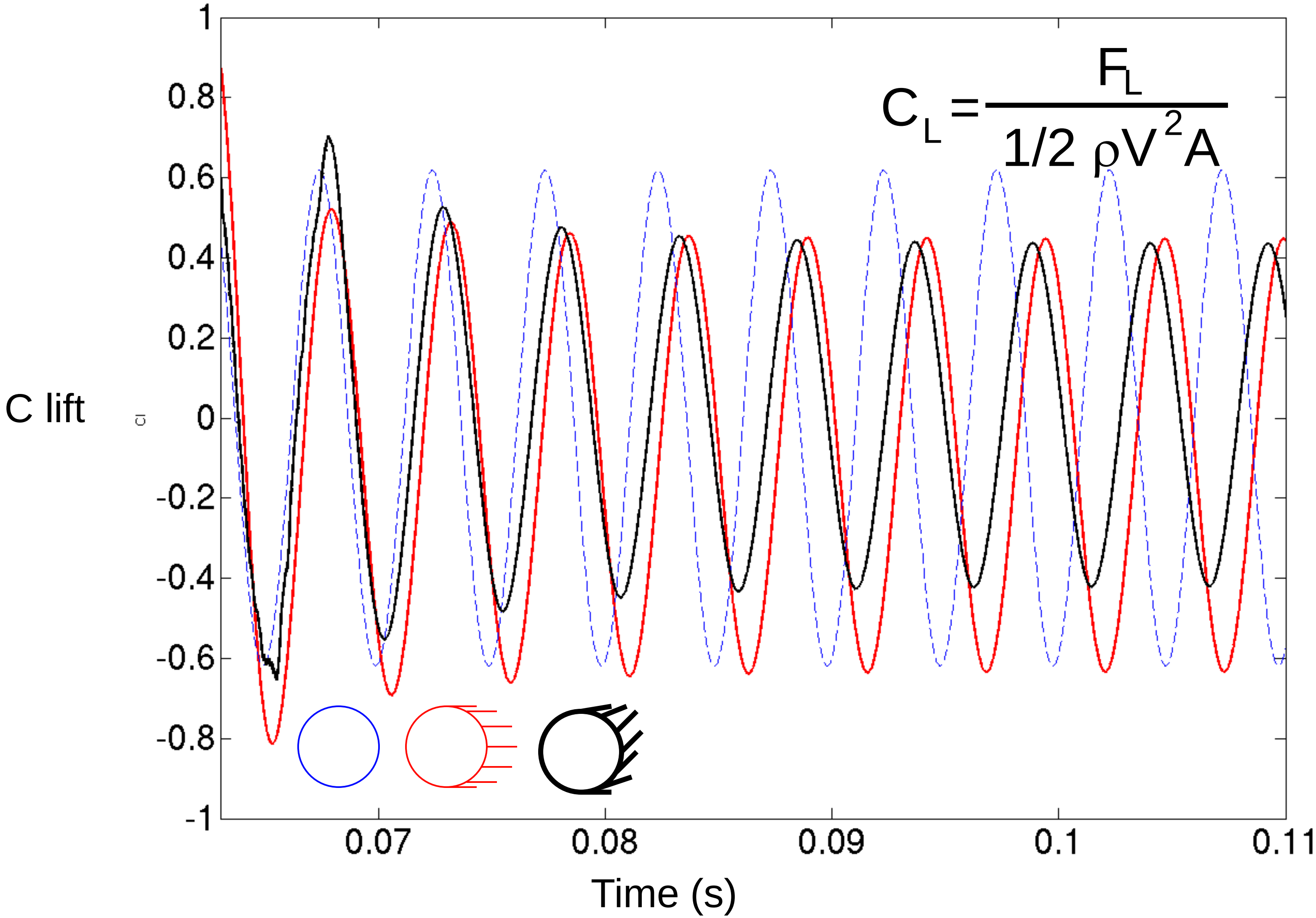
Lift



$C_L = \frac{F_L}{1/2\ \rho V^2 A}$
C lift
Time (s)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0.07
0.08
0.09
0.1
0.11

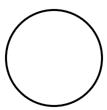
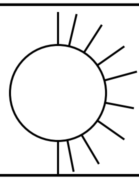
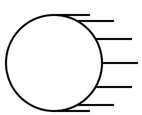
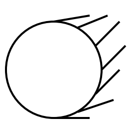


Lift (ctd.)



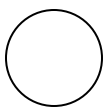
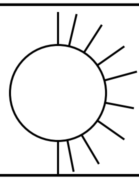
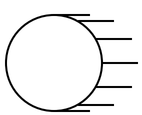
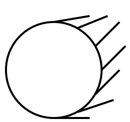
$$C_L = \frac{F_L}{1/2\ \rho V^2 A}$$
C lift
cl
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0.07
0.08
0.09
0.1
0.11
Time (s)

Aerodynamic performances

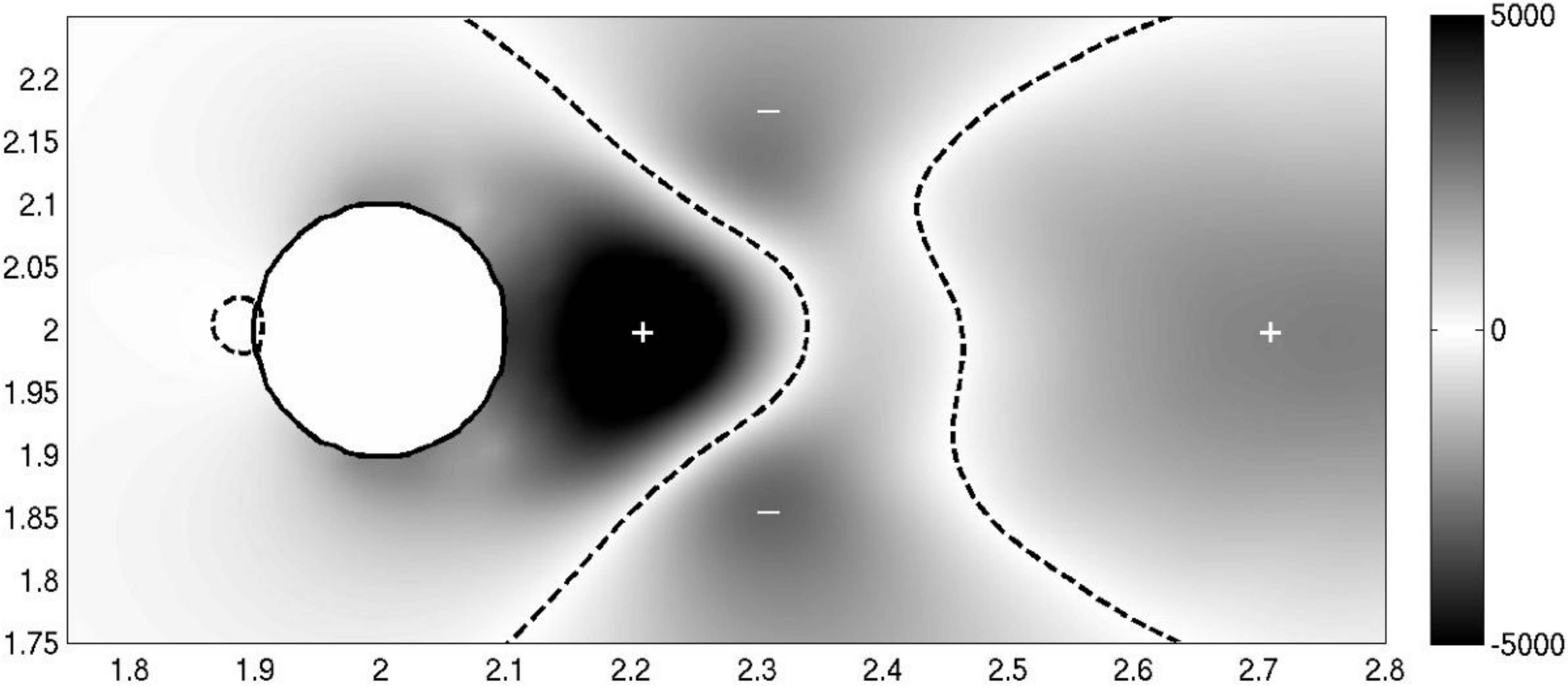
	Cd	Cd'	Cl'	St
Case 1 	1.3689 (1.39;1.356)	0.0274	0.4381	0.199 (0.199;0.198)
Case 2 	3.1464	0.1943	1.1376	0.1946
Case 3 	1.3035	0.0207	0.3839	0.1916
Case 4 	1.2109	0.012	0.3008	0.1661

(Bergmann et al. Phys. Fluids 2005 ; He et al J. Fluid Mech. 2000)

Aerodynamic perf.(ctd.)

	Cd	Cd'	Cl'	St
Case 1 	ref	ref	ref	ref
Case 2 	+130%	+608%	+160%	-2.21%
Case 3 	-4.78%	-24.54%	-12.37%	-3.71%
Case 4 	-11.54%	-56.09%	-31.34%	-16.53%

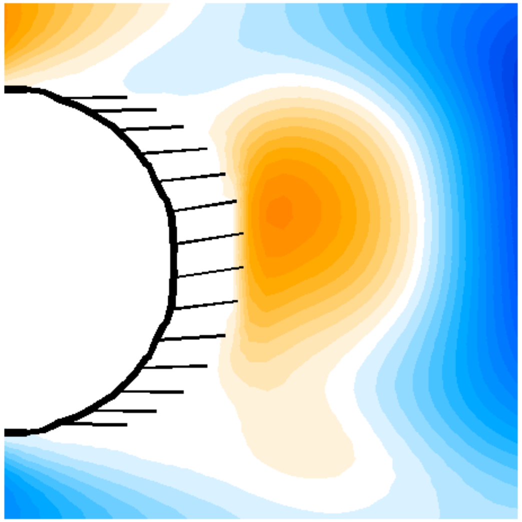
Physical mechanism



Difference of time-averaged pressure field

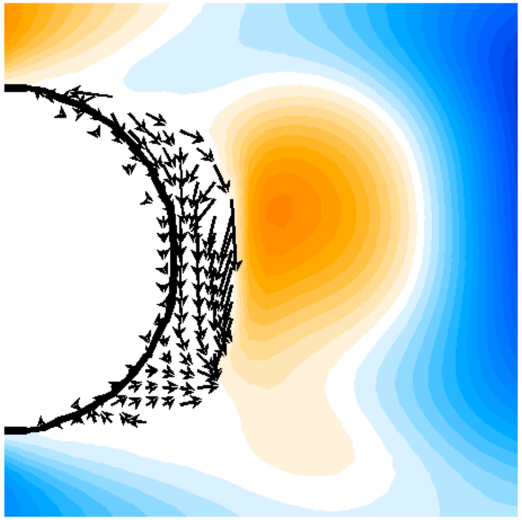
<P with hair>-<P ref>

Physical mechanism



Contours of vertical velocity

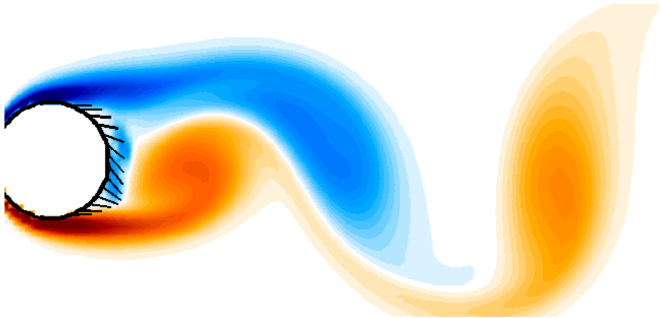
Movements of *reference* cilia



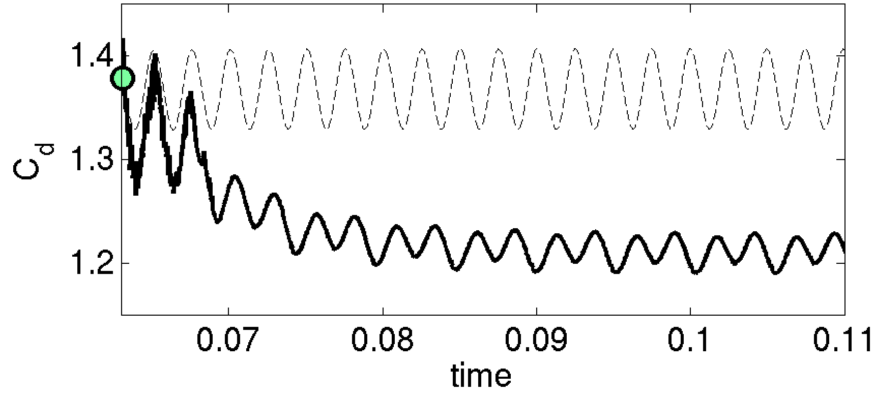
Contours of vertical velocity

Force field

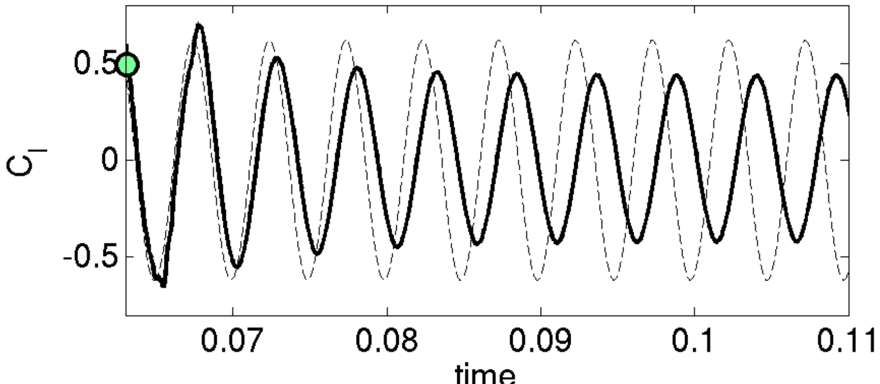
The hairy layer counteracts flow separation



Optimal **self-adaptive hairy layer**



15% drag reduction



40% reduction in lift fluctuations

Reducing pressure drag:

- ✓ Simulations show a reduction of pressure drag on a cylinder for a unsteady laminar flow (Re = 200).
- ✓ The motion of the hairy structures can improve aerodynamic performances
- ✓ The structural parameters of the actuators have been optimised
- ✓ Immediate perspectives concern flexible filaments and turbulent configurations; possible applications to small underwater vehicles and to UAV/MAV (in the aeronautical field)

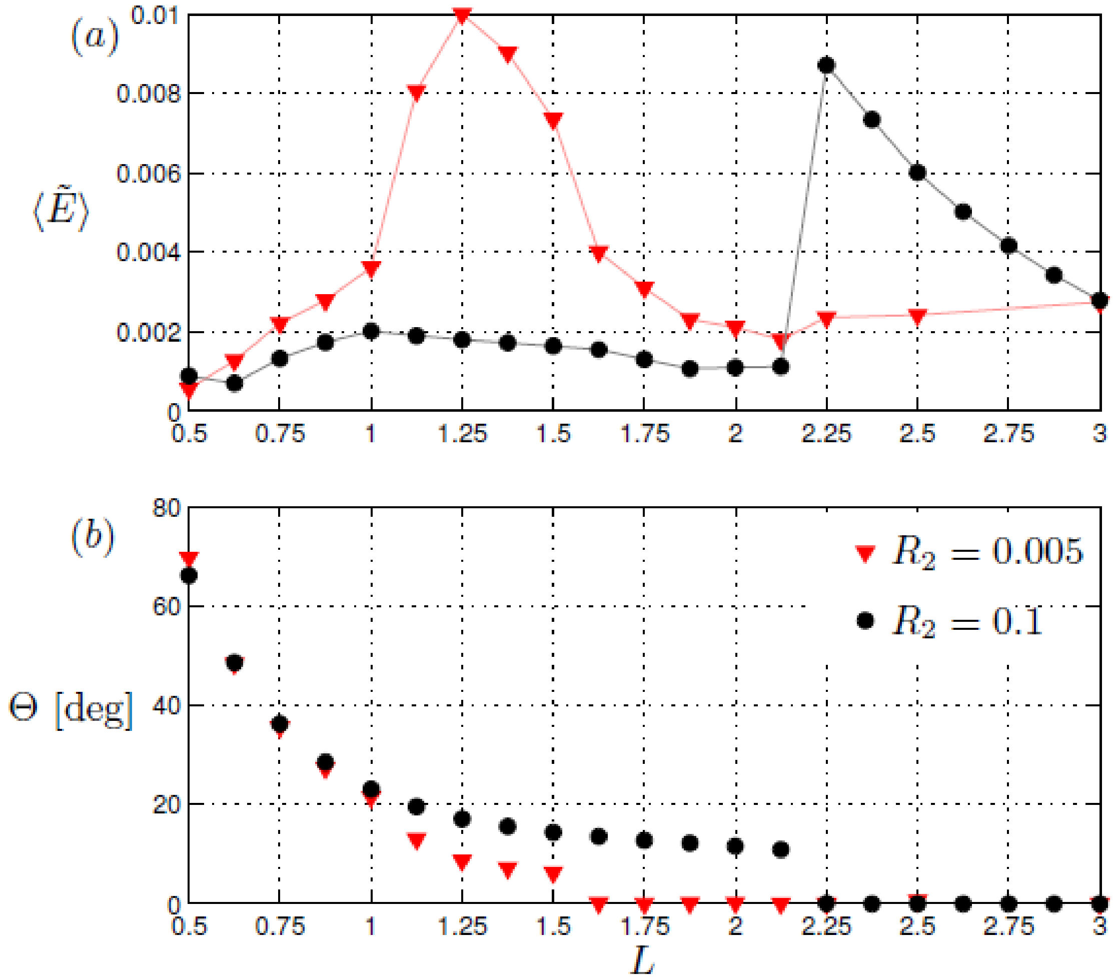
Favier *et al*., **JFM** 2009

In fact, a single flexible filament can do much already!!

Bagheri *et al*., **PRL**, 2012 (submitted)

In fact, a single flexible filament can do much already!!

Bagheri *et al*., **PRL**, 2012 (submitted)

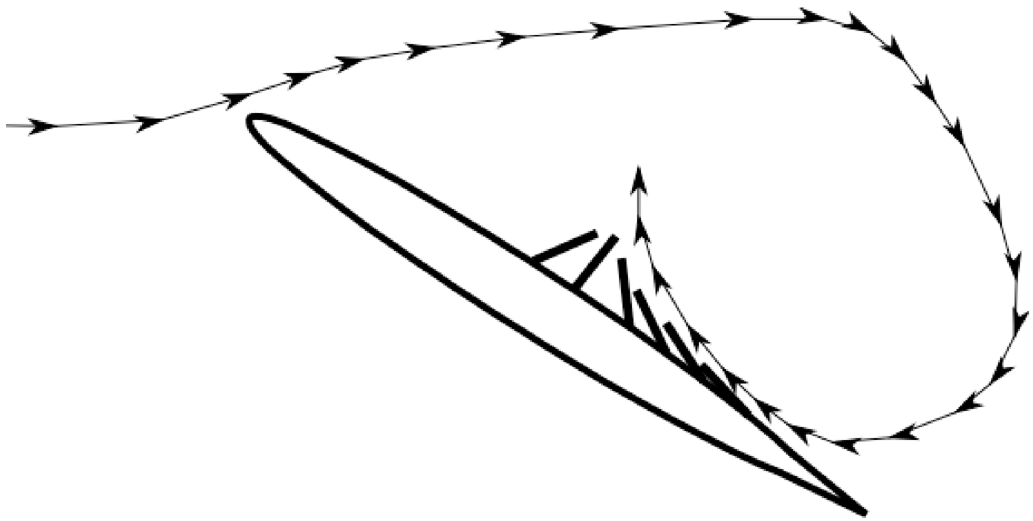


A symmetry-breaking bifurcation occurs when vortices and structures resonate …

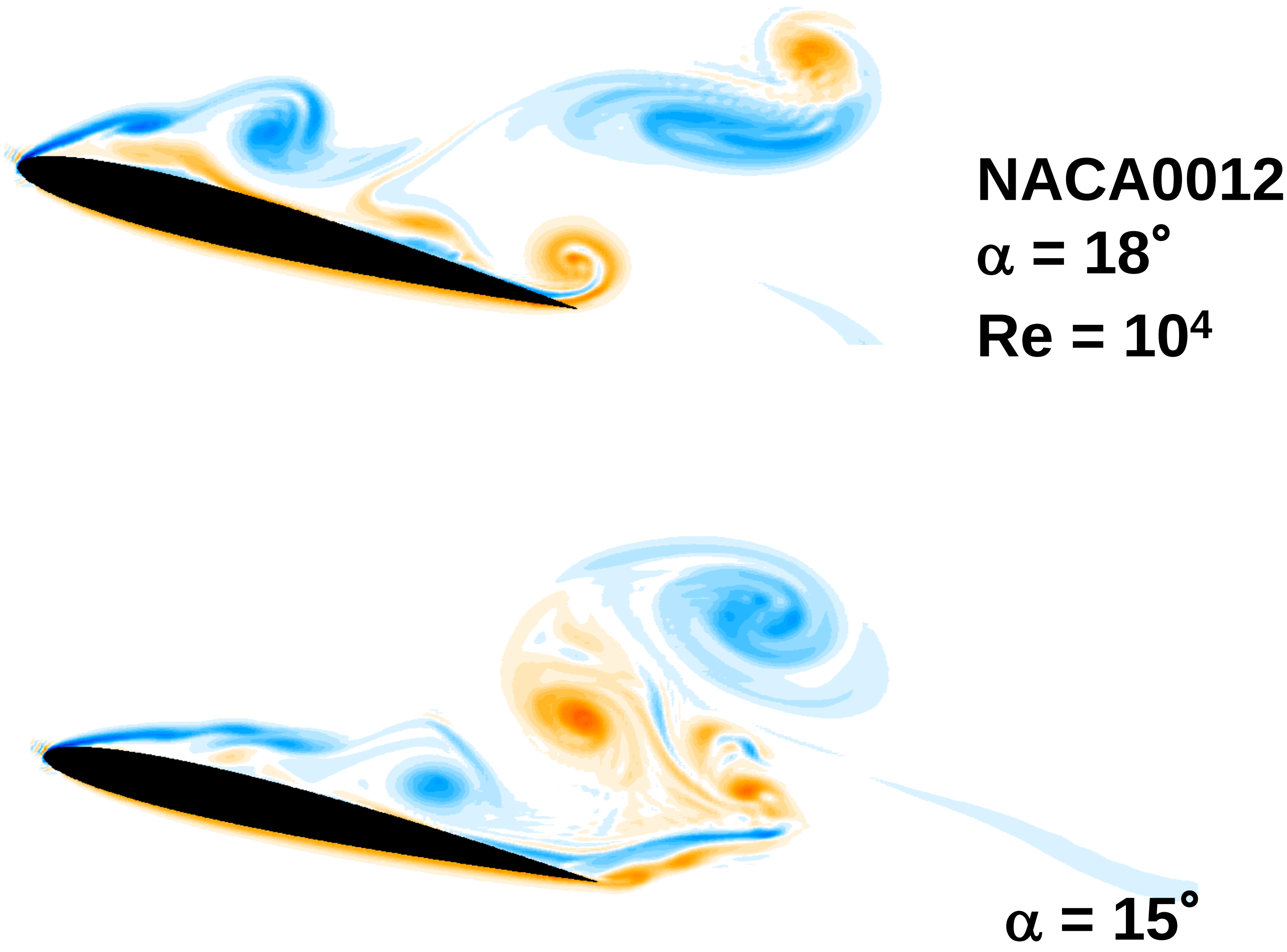
L	R_2	C_d	C_l	f_c	y_m
0.0		1.36 ± 0.01	0.00 ± 0.34	0.164	
1.5	0.005	1.32 ± 0.08	0.18 ± 0.28	0.159	0.16 ± 0.43
3.0	0.005	1.28 ± 0.06	0.00 ± 0.23	0.157	0.00 ± 0.64
1.5	0.100	1.23 ± 0.05	0.21 ± 0.24	0.145	0.37 ± 0.13
3.0	0.100	1.24 ± 0.08	0.00 ± 0.32	0.139	0.00 ± 0.54

increasing R_2 → increased rigidity of the structure

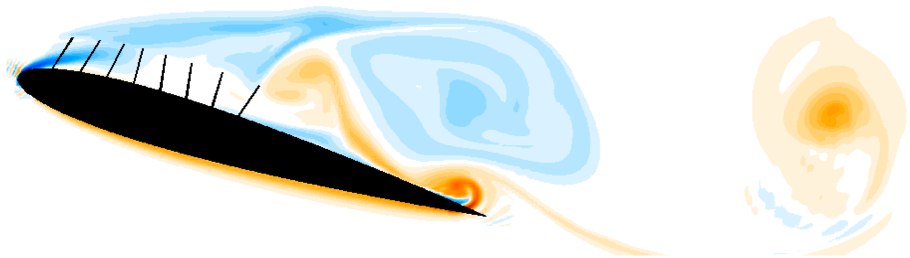
Hairfoils



Consider a **h**airfoil: the control elements (the "feathers") must be placed in the position of largest *sensitivity* to achieve an effect

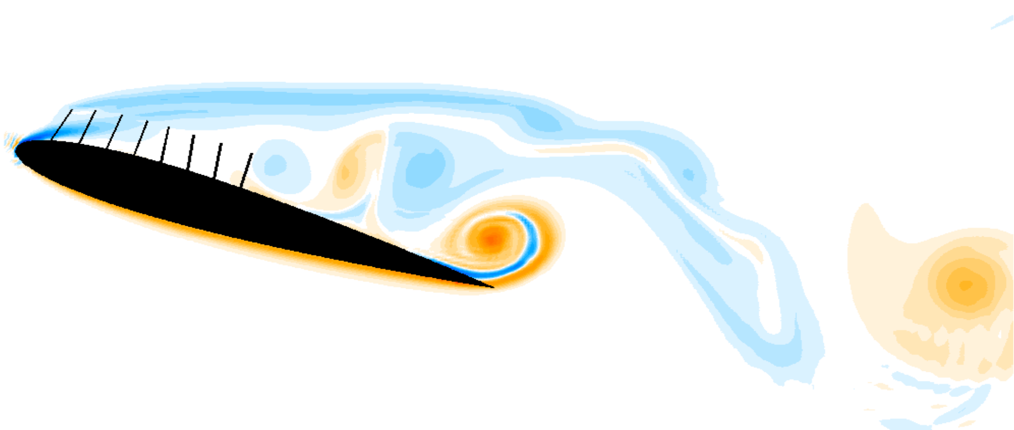


NACA0012
α = 18°
Re = 10^4
α = 15°



$\alpha = 18^\circ$

$\rho_{feathers}$ = 890 Kg/m^3 (keratin)

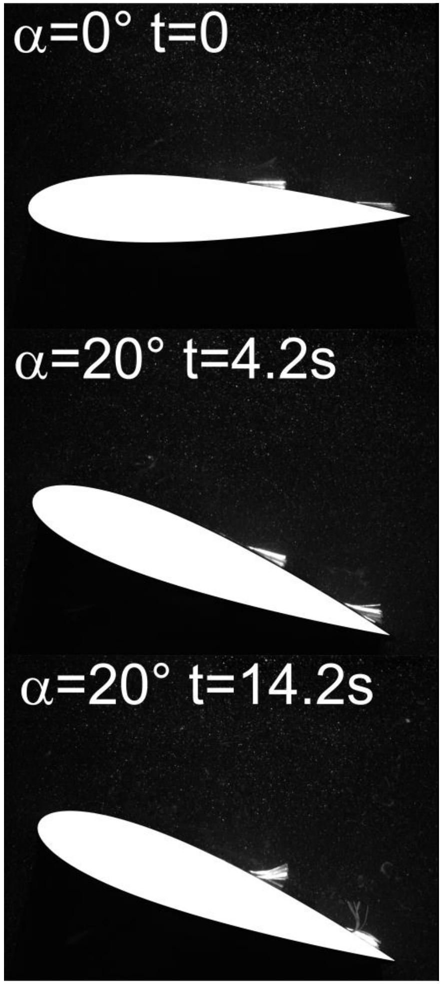


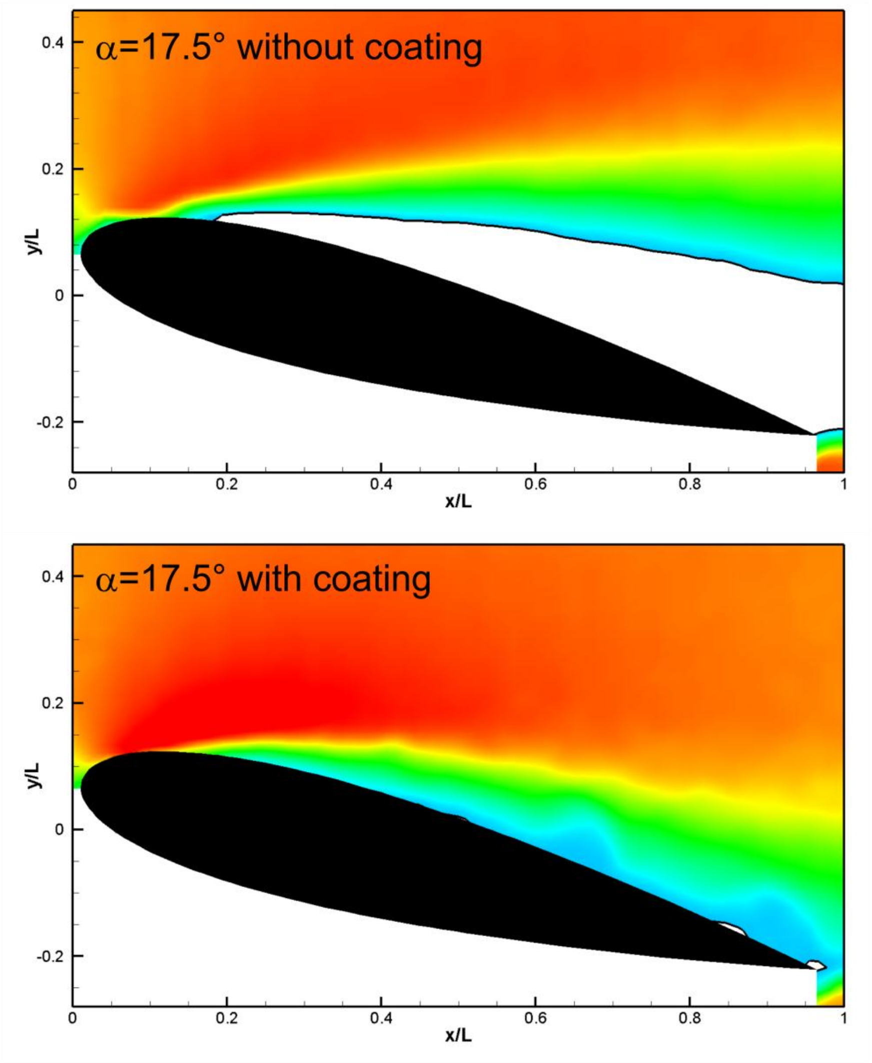
$\alpha = 18^\circ$

Summary of runs

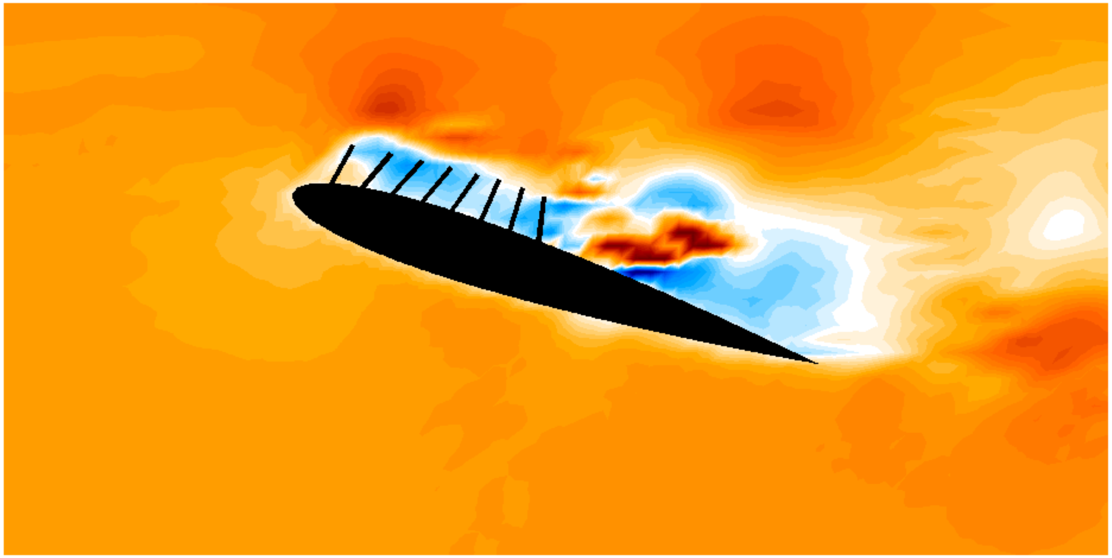
$\alpha = 15^\circ$	$\langle C_D \rangle = 0.284$	$\langle C_L \rangle = 0.579$
$T_{fluid} = 0.5\ T_{structure}$	*+ 1.35%*	*- 13%*
$T_{fluid} = T_{structure}$	+ 2 %	- 10%
$T_{fluid} = 2\ T_{structure}$	+ 3%	- 9%
$T_{fluid} = 4\ T_{structure}$	- 0.2 %	+ 2.5%
$T_{fluid} = 8T_{structure}$	-7 %	- 11%

Results are similar when $\alpha = 18^o$, except that now $\langle C_L \rangle$ increases the most when $T_{fluid} = 2\ T_{structure}$





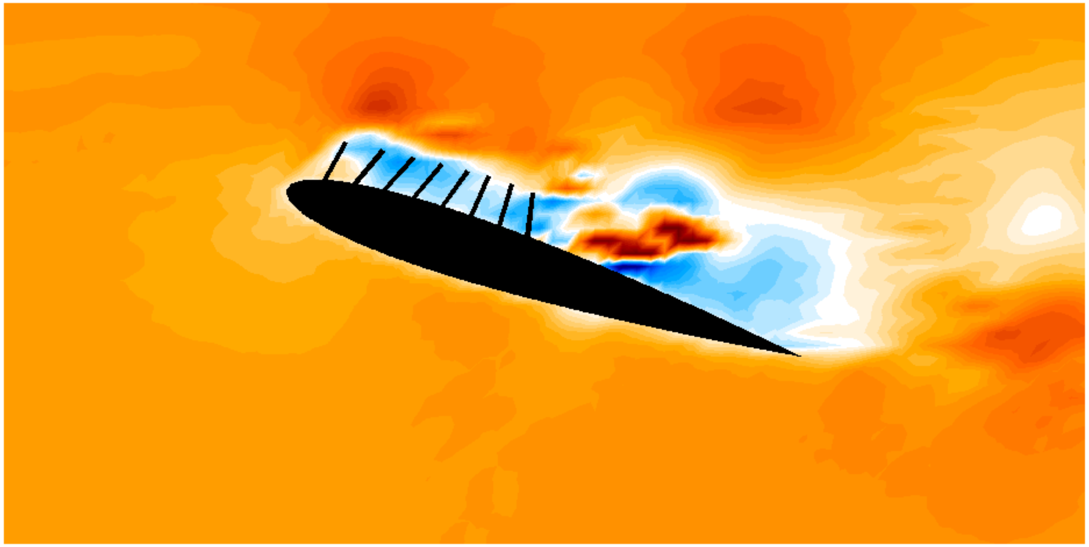
Kunze & Brücker, **CRAS** 2012



The amplitude of the oscillations decreases (the system's stability improves) as $T_{structure} \nearrow$

$(i.e.\quad m \nearrow \quad l \nearrow \quad K_r \searrow)$

A parametric resonance must be triggered to optimise the response of the system

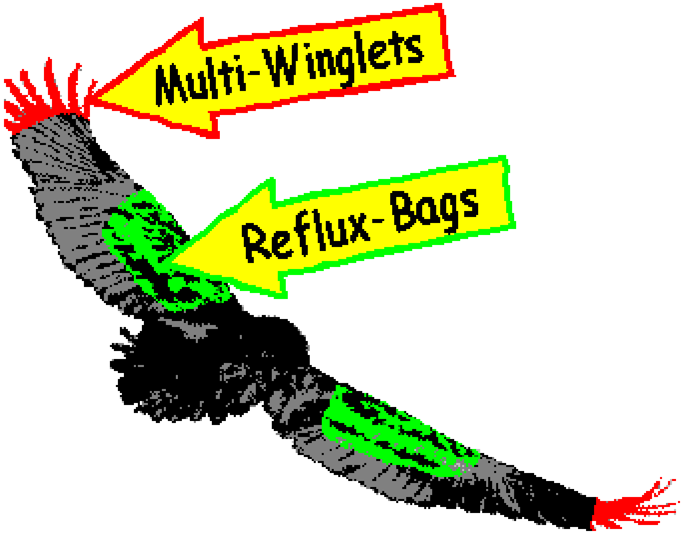


Engineering perspectives

MAV/UAV
Wind turbines
Hydraulic machines (cavitation?)
Sound mitigation

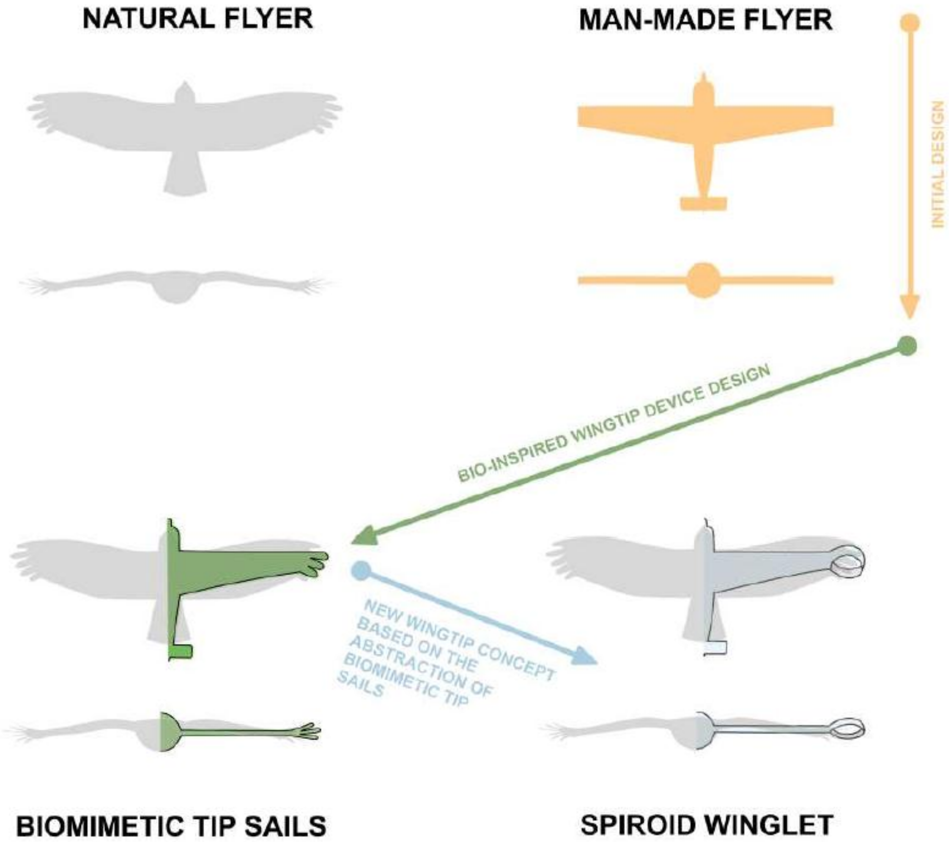
Ajit Ninan

How can we increase lift over a streamlined body at incidence by a passive technique?



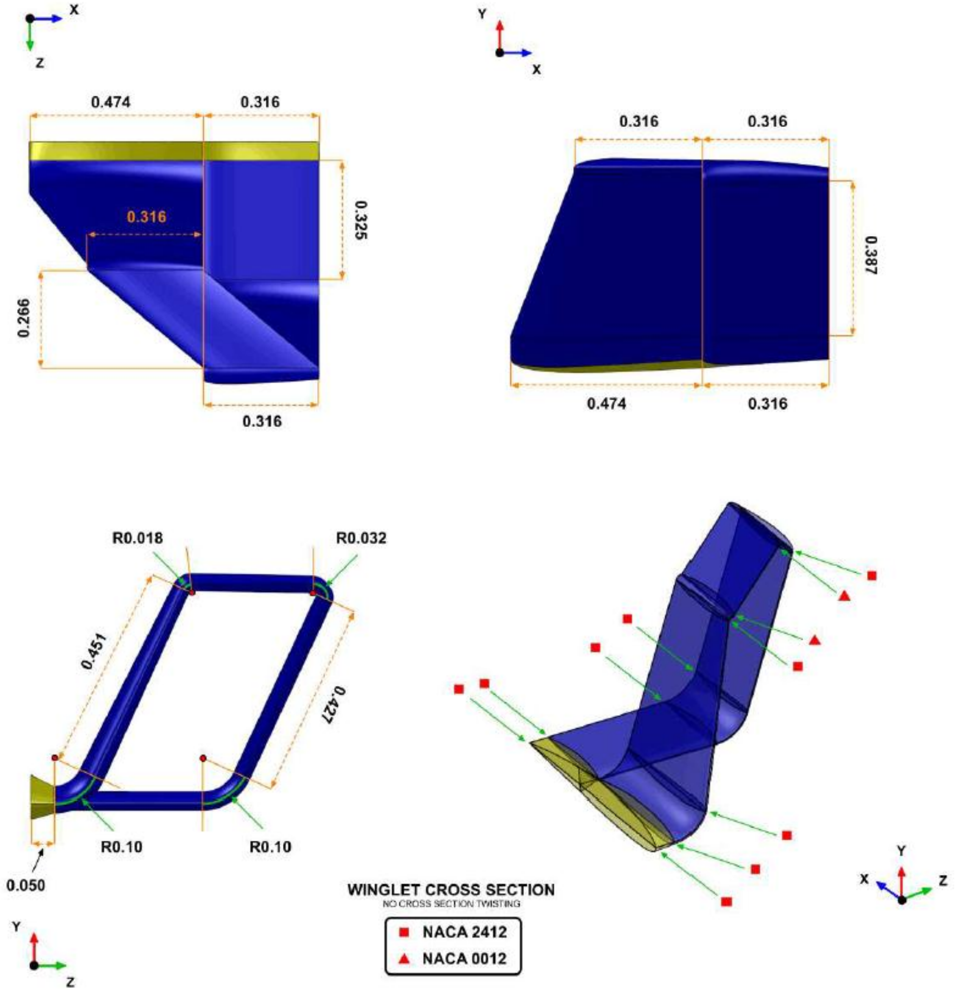
Prof. Ingo Rechenberg, TU Berlin
http://www.bionik.tu-berlin.de/institut/xs2vogel.html

Biomimetic winglets



Guerrero *et al*., ***CRAS***, 2012

Biomimetic winglets



Biomimetic winglets

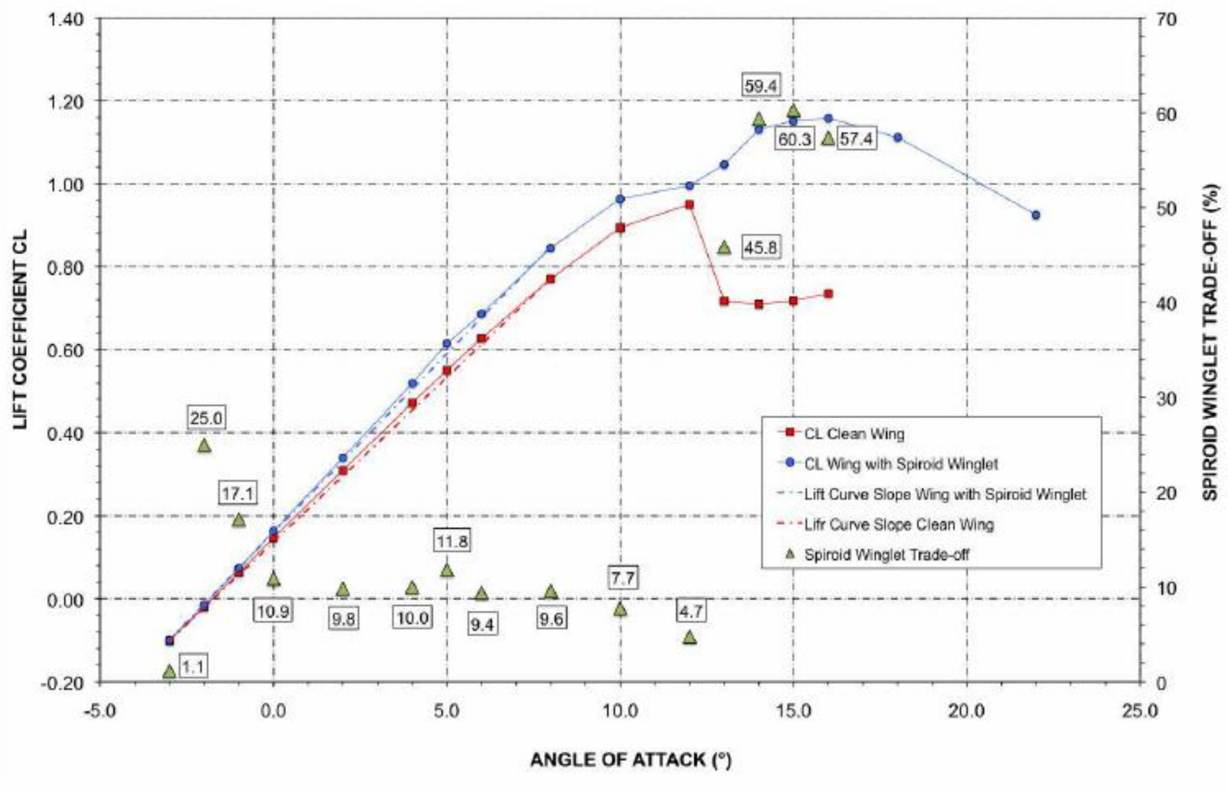


Figure 10. Lift coefficient versus angle of attack for the clean wing (CW) and the wing with the spiroid wingtip (WSW).

Biomimetic winglets

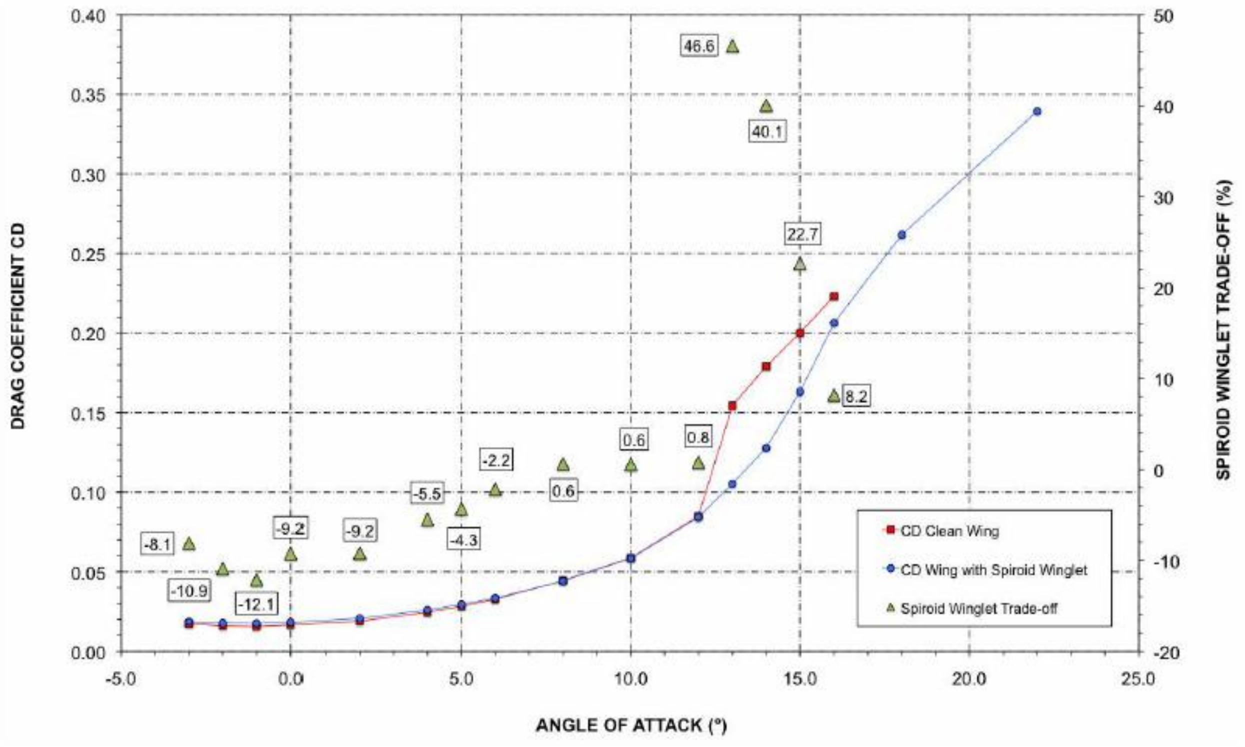


Figure 11. Drag coefficient versus angle of attack for the clean wing (CW) and the wing with the spiroid wingtip (WSW).

Biomimetic winglets

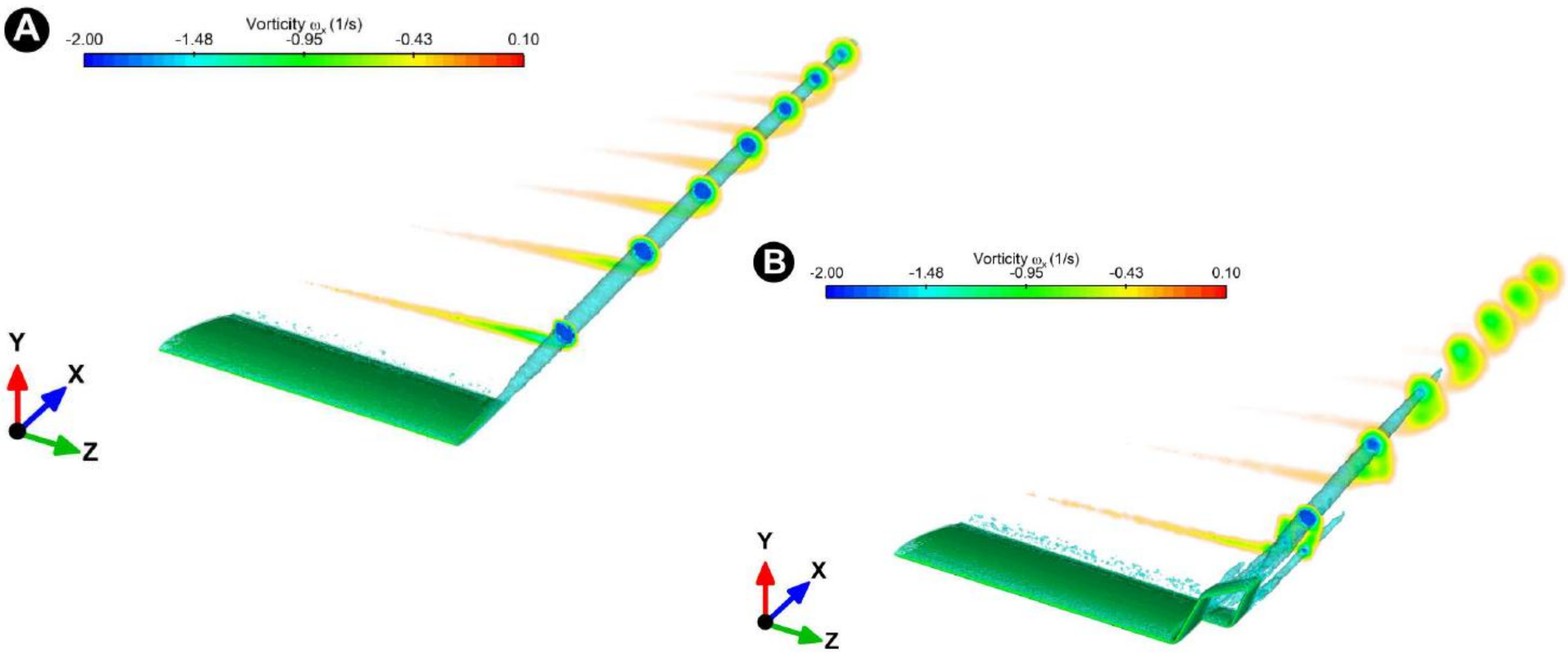


Figure 15. Wingtip vortices (in light blue), visualization by iso-surfaces of Q-criterion ($Q = 0.5\ 1/s^2$). The equally spaced planes behind the wing are colored by vorticity ω_x. A) Perspective view of the clean wing at $AOA = 5.0°$. B) Perspective view of the wing with spiroid winglet at $AOA = 5.0°$.

Advantages

- Lift-induced drag reduction. As much as 75.0% at $C_L = 0.95$, 35.0% at $C_L = 0.55$ and 28.0% at $C_L = 0.40$.
- Lift production enhancement. C_L is higher for the whole lift curve and its slope is increased by approximately 9.0%.
- Total drag reduction for C_L values above the crossover point $C_L = 0.47$. As much as 50.0% at $C_L = 0.95$, 20.0% at $C_L = 0.90$ and 7.0% at $C_L = 0.60$.
- Lift-to-drag ratio enhancement. The trade-off at $(C_L/C_D)_{max}$ is nearly 7.1% and the maximum trade-off value in no-stall configuration is close to 10.0% $(AOA = 8.0°)$.
- Wing stall delay.
- Better post-stall behavior.

… which translate into:

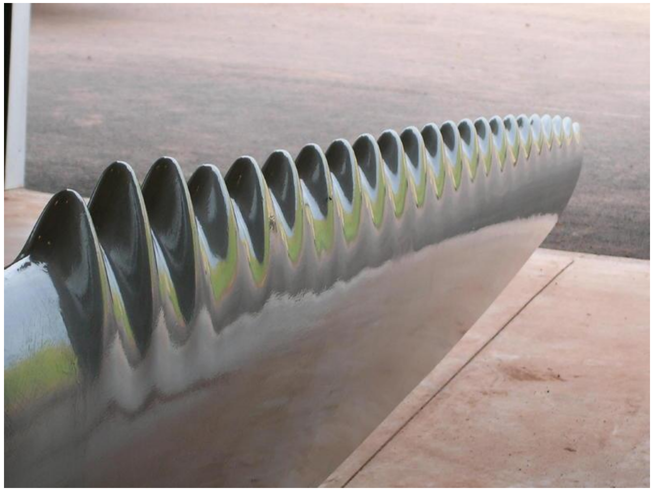
- Increased operating range.
- Improved take-off performance.
- Higher operating altitudes.
- Improved aircraft roll rates.
- Shorter time-to-climb rates.
- Less take-off noise.
- Increased cruise speed.
- Reduced engine emissions.
- Meet runaway and gate clearance with minimal added span and height.
- Reduced separation distances and improved safety during take-off and landing operations due to wake vortex turbulence reduction.

Other biomimetics secrets currently under investigation include:

- owl silent flight

"It was just because of the surface of owl's body have a lot of coupling interaction such as special surface morphology, unique wing configuration, special internal structure and highly flexible material. They can delay the separation of turbulent boundary layer around the airfoil profile, reduce pulsating pressure of the surface of wings, and reduce the production of sound energy. Above all the feature make the surface have function of noise elimination." (Liang *et al*., *Adv. Natur. Sciences*, 2010)

Other biomimetics secrets currently under investigation include:
- owl silent flight
- tubercles on whale flipper, effect on stall, lift and drag …



Tubercle technology!

Whalepower Corp., Canada

Other biomimetics secrets currently under investigation include:
- owl silent flight
- tubercles on whale flipper, effect on stall
- skin friction drag reduction with superhydrophobic surfaces

Leaves retain a air film underwater, using hydrophobic hairs with hydrophilic tips: 10% drag reduction in a large-scale ship model (Nees Institute, University of Bonn)

… and many others …