Convegno sulle Applicazioni della
Computational Fluid Dynamics alla Progettazione Navale

# *UNA NUOVA TECNICA DI AZIONAMENTO PER IL CONTROLLO DELLA SCIA – E LA RIDUZIONE DELLA RESISTENZA AL MOTO – DIETRO UN CORPO TOZZO IMMERSO*

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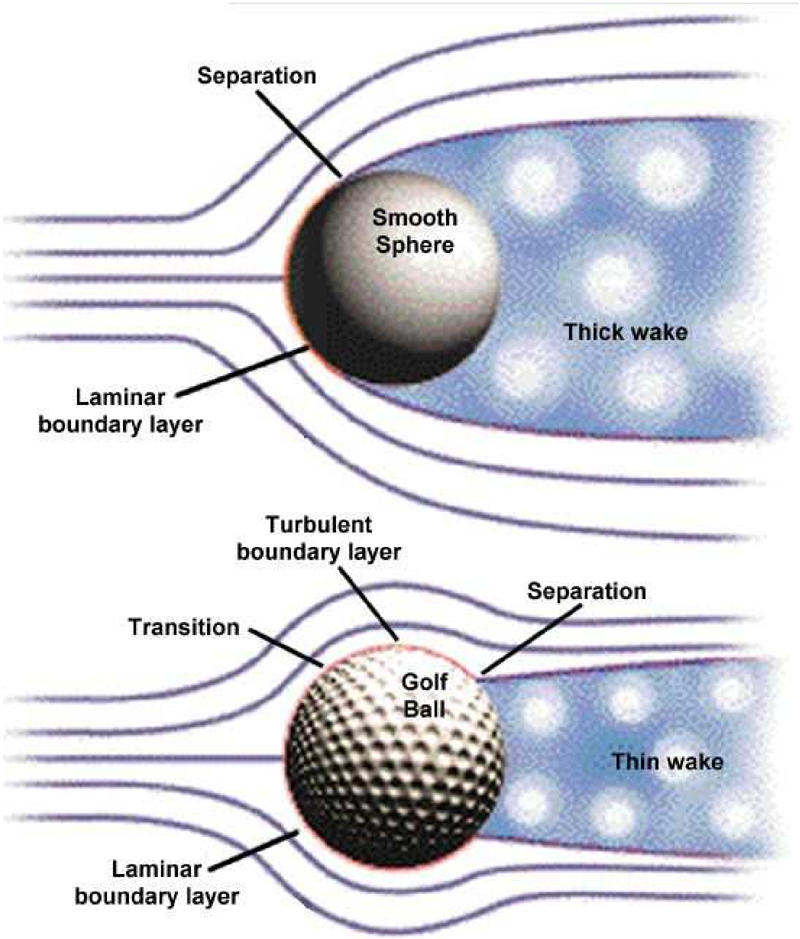
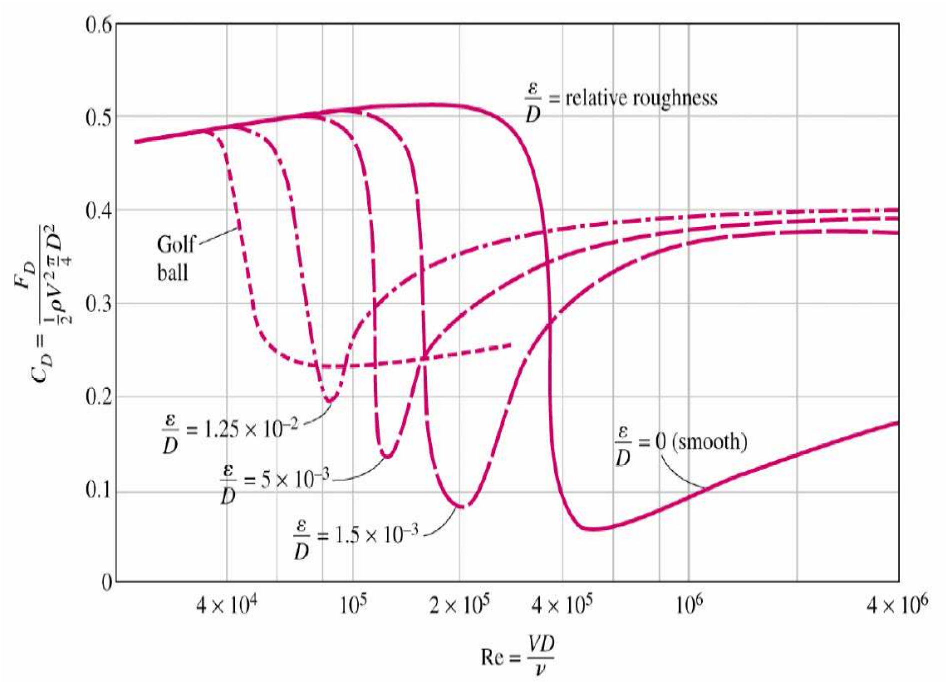
## How can we reduce pressure drag behind a solid bluff body by a passive technique?

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



## Known techniques of passive/active flow control:

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

## Known techniques of passive and/or active flow control:

- Injection of micro-bubbles and/or polymers
- Riblets
- Compliant walls
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- Vortex generators
- ...

## The approach used here:

**Passive hairy coating**

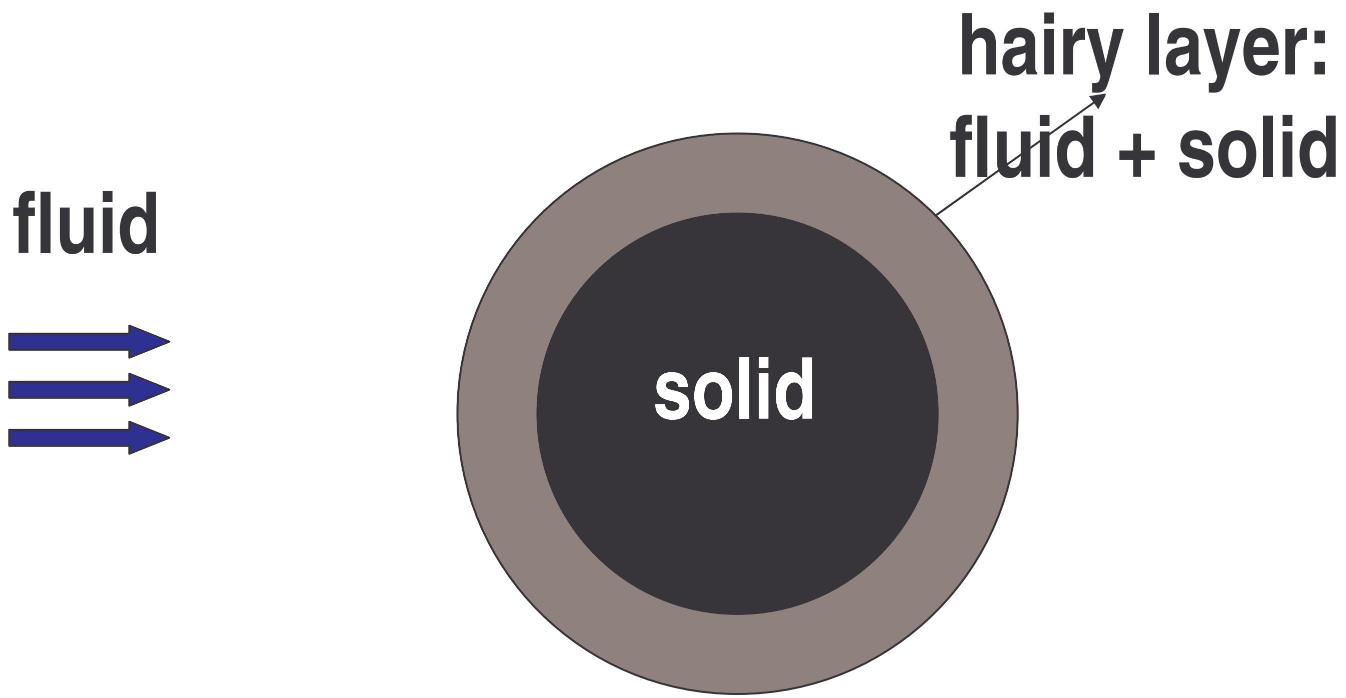
sea otter

# Scientific challenges to modeling a hairy surface

- *Mechanical properties of the biological surfaces*
- *Large displacements and rotations of structures*
- *Multiple interactions between structures*
- *Coupling fluid and structure*

*We use a partitioned explicit approach. The fluid and the structures communicate via* ***volume forces****.*

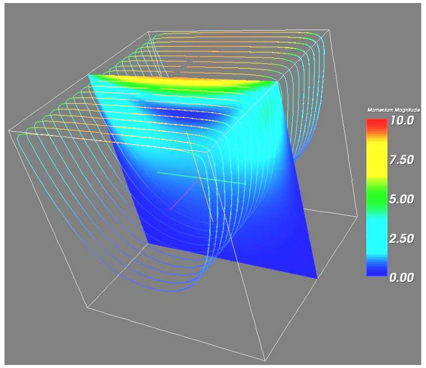
# *Flow configuration*




Circular cylinder at Re=200
Influence on the unsteady separated wake

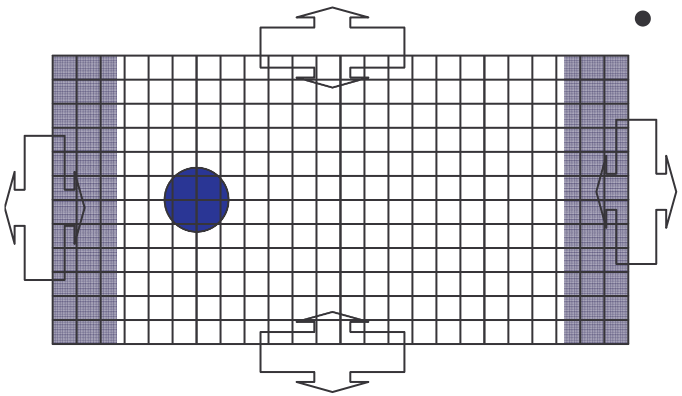
**porous**, **anisotropic**, **compliant** coating

# *Fluid model*




- Navier Stokes solver for uncompressible, unsteady laminar flows, with a volume force, 2nd order in space and time

$$\begin{aligned} \nabla \cdot \mathbf{u} &= 0 \\ \frac{\partial \mathbf{u}}{\partial t} + \nabla(\mathbf{uu}) &= -\nabla p + \nu \nabla^2 \mathbf{u} + \mathbf{f} \end{aligned}$$



- 2D Mesh is regular, periodic Cartesian, staggered, (typically 800x400). Obstacles, sources and damping terms imposed by the **IMMERSED BOUNDARY METHOD**.

Chorin A.J. *Math. Computation* 1968

Peskin C.S. *Acta Numerica* 2002

# *Interaction model: homogenized approach*

Modeling every cilium is numerically impossible:
→ reduction of the dimensions of the problem

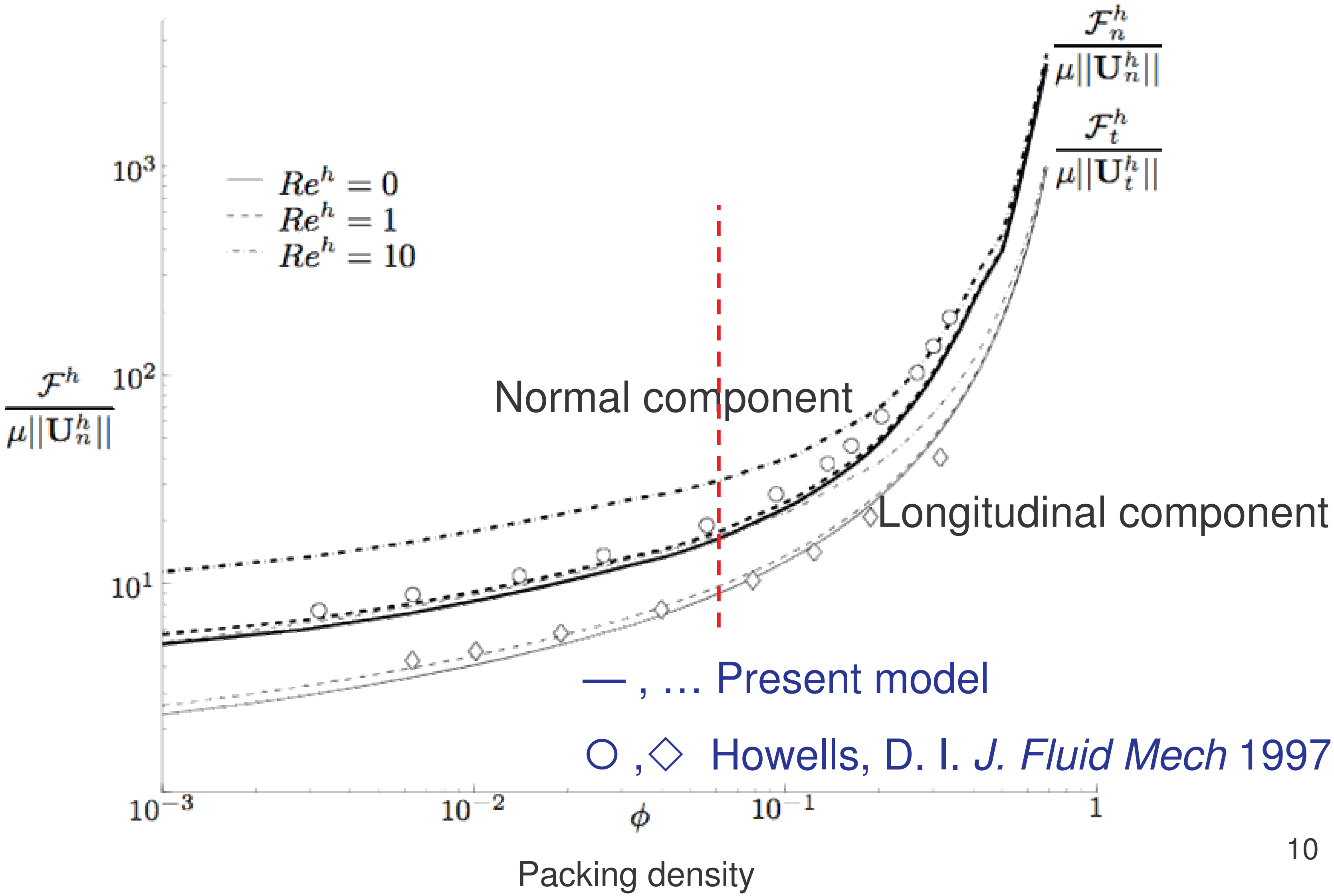
- The volume of hair is considered as an homogenized anisotropic porous medium, with porosity varying in time and space.
- Locally, a drag force is applied on fluid (and its reaction on the structure)

- $\eta$ local porosity
- ***d*** hair direction
- ***u-u***$_{hair}$ relative velocity of fluid

$$\mathbf{F}_{drag} = \mathcal{F}(\eta, \mathbf{d}, \mathbf{u} - \mathbf{u}_{hair})$$

Howells, D. I. *J. Fluid Mech* 1997

# *Interaction model: homogenized approach*

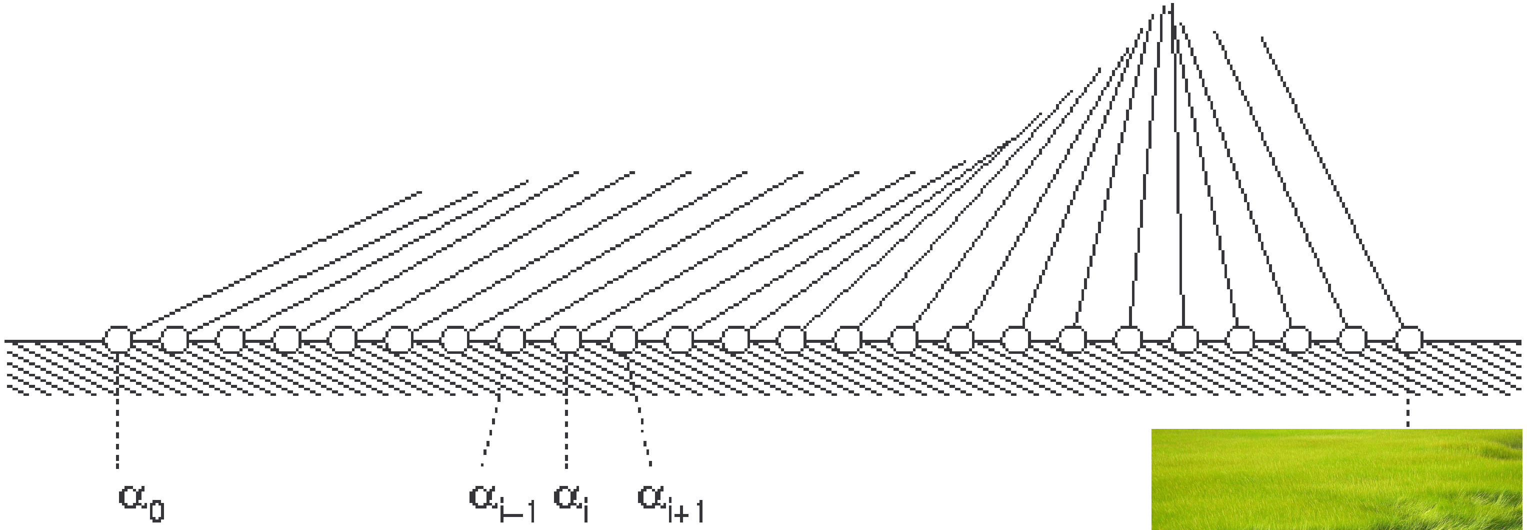


# Structure model

- Hair layer motion is modeled by a group of rods. Each rod represents a cluster of hairs

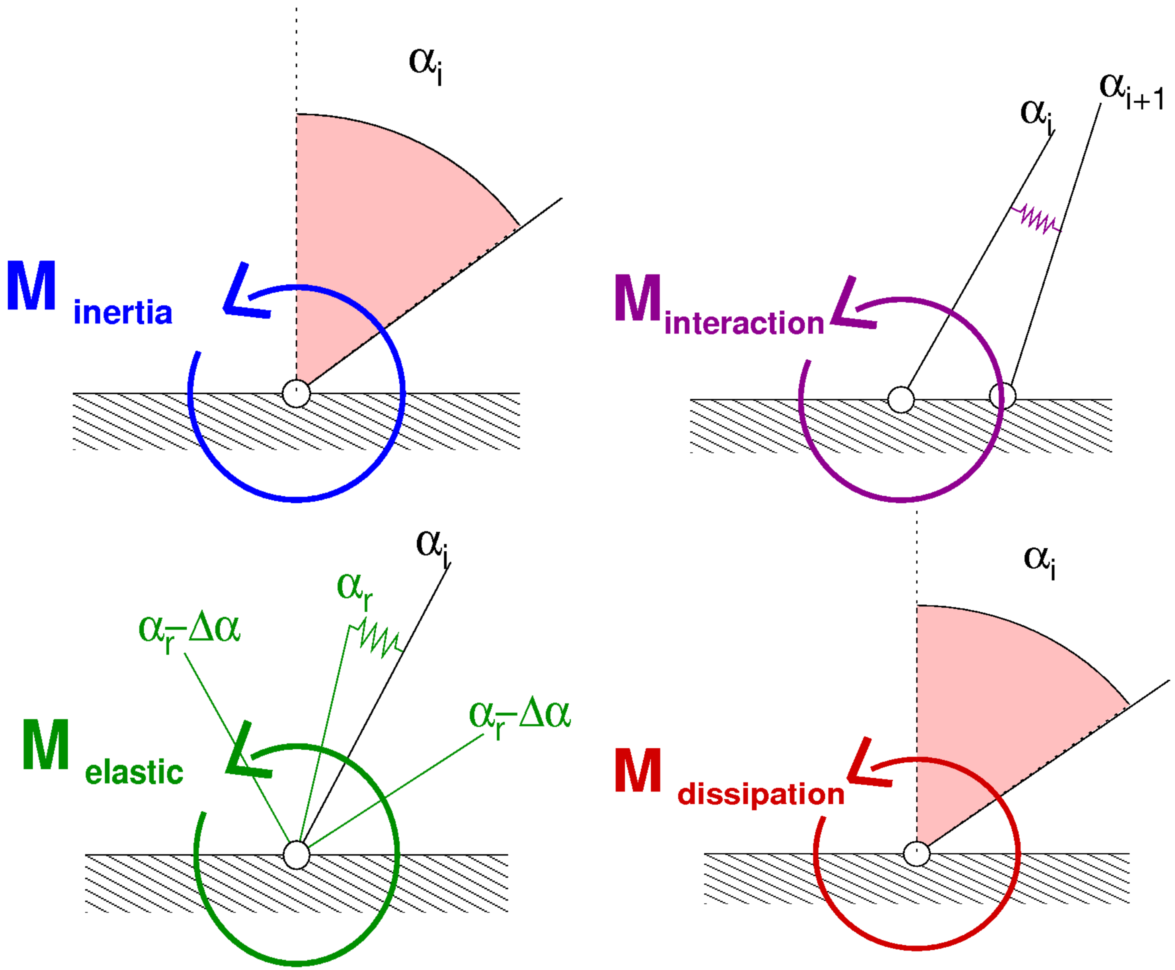
$$0 \quad = \quad M_{ext.}(\mathbf{x}_k) + M_{inter.}(\alpha_{k-1,k,k+1}) + M_{flex.}(\alpha_k) + M_{dissip.}(\dot{\alpha_k}) + M_{inertia}(\mathcal{I}\ddot{\alpha_k})$$

- Non linear system solved implicitly (NLCG) or explicitly (RK4)



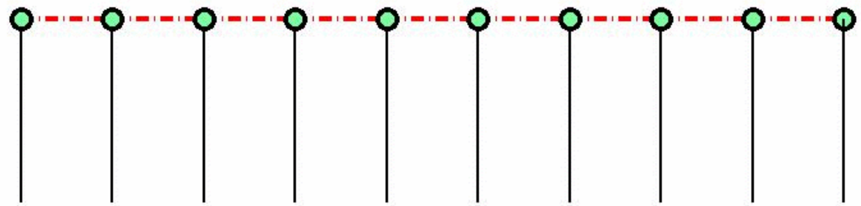

De Langre E, *Ann. Rev. Fluid Mech.* 2008

# Restoring forces in the structural model



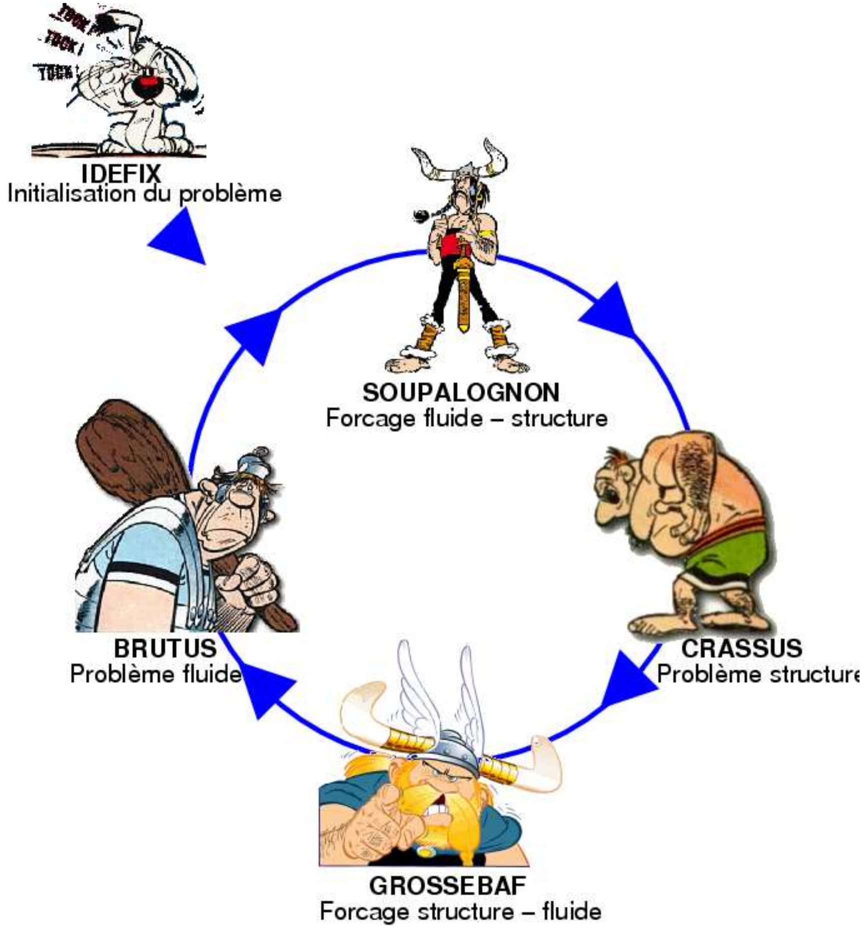
# *Structure model: parameters*

1. **Density** of hair, related to porosity *(0.006, modifies fluid flow without blocking)*
2. **Flexibility** related to material elasticity
3. **Interaction** between hair during a compression
4. **Dissipation** by deformation and hair-to-hair contacts
5. **Inertia** of the hair *(low)*



# Coupling

- The flow and structure solvers, developed at DICAT, are written in FORTRAN 77 and 90
- The partitioned coupling is controlled by the PALM software developed at CERFACS




Buis S. , Piacentini A., Declat D. *Concurrency Comp.: Pratice and Experience* 2005

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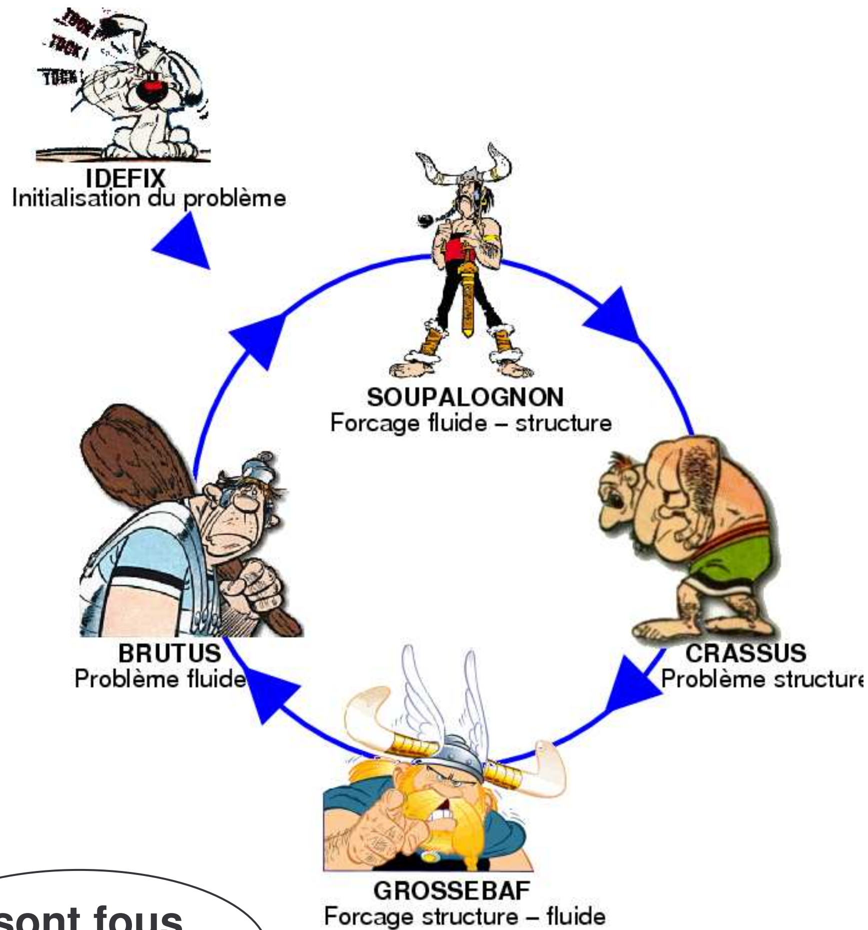
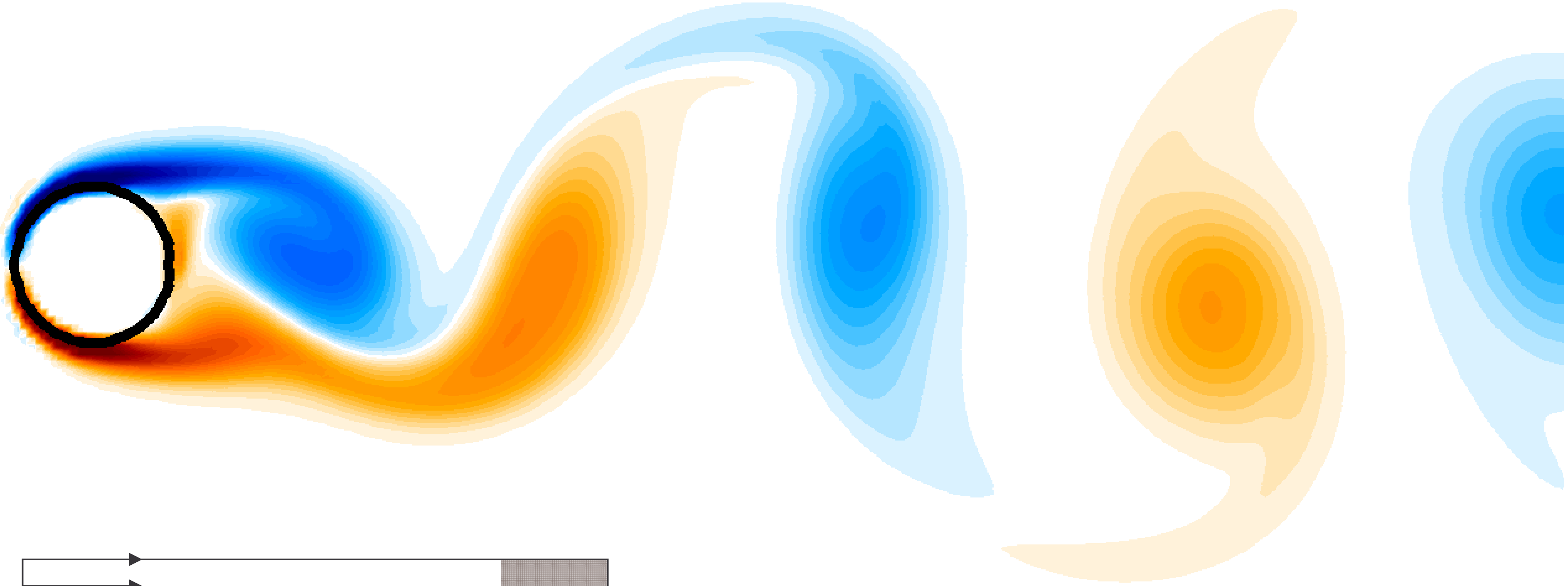
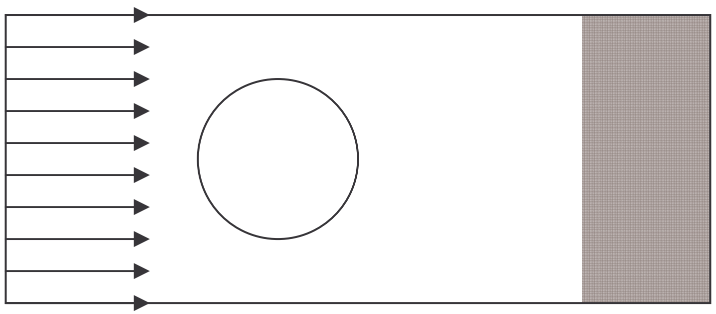




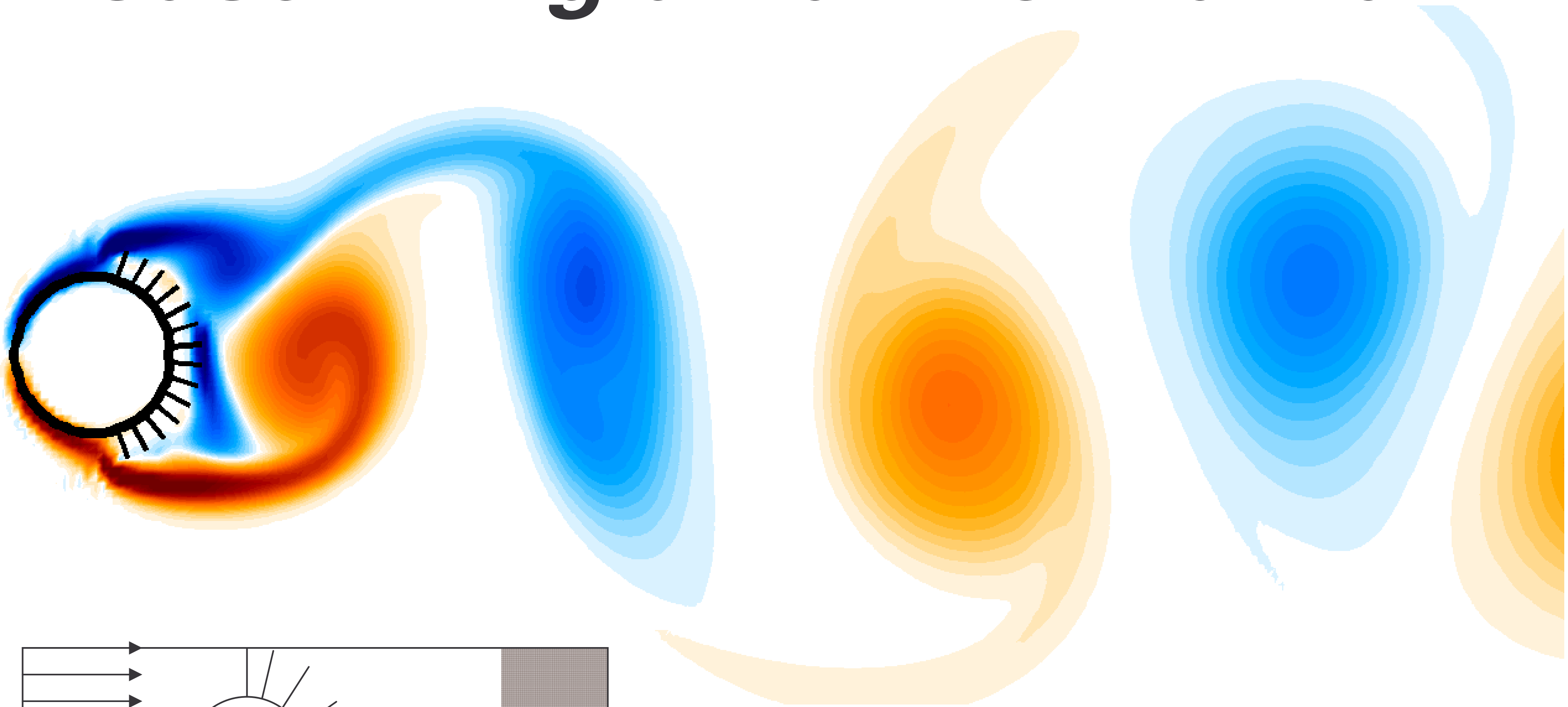
Buis S. , Piacentini A., Declat D. *Concurrency Comp.: Pratice and Experience* 2005

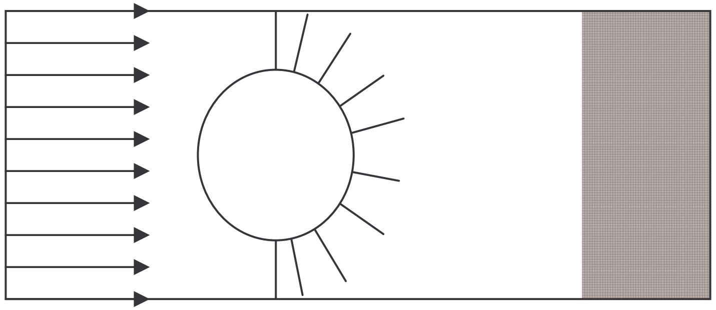
# Case 1 : bare cylinder



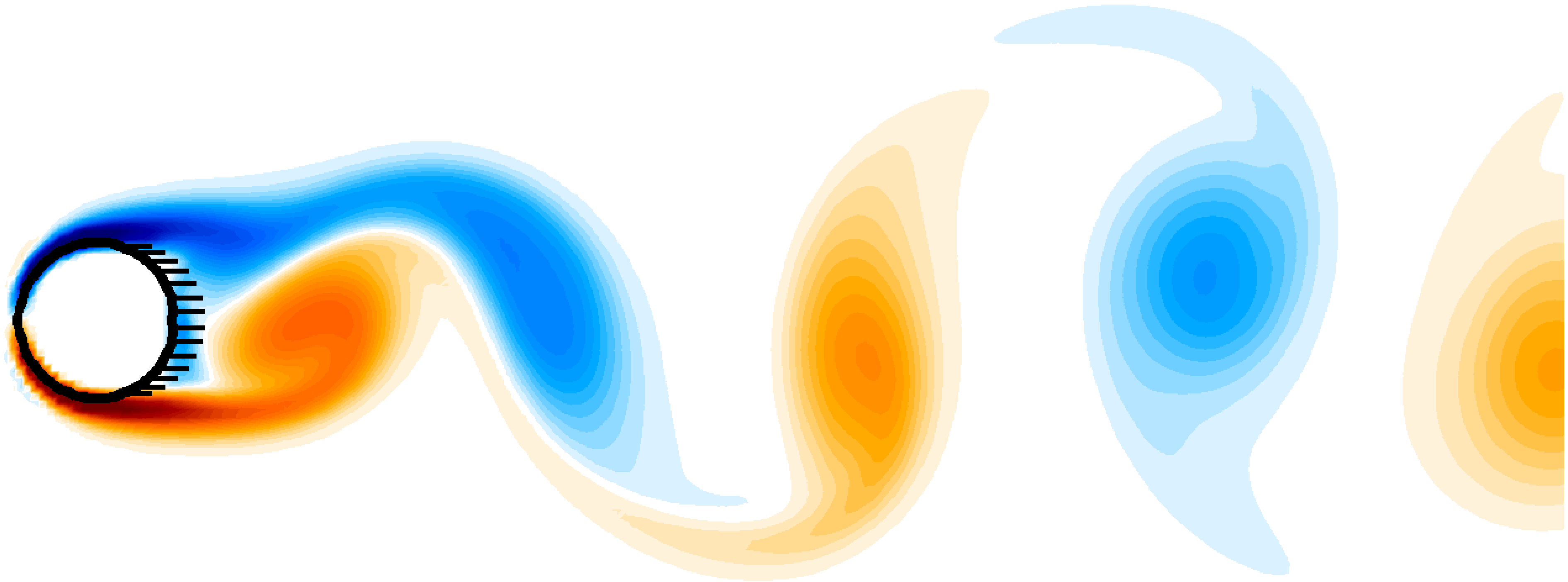


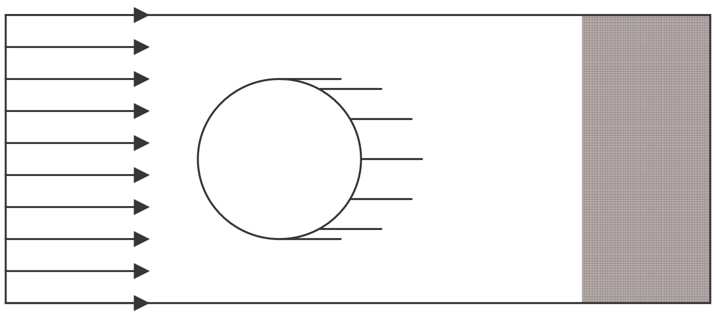
# Case 2 : rigid wall-normal hair



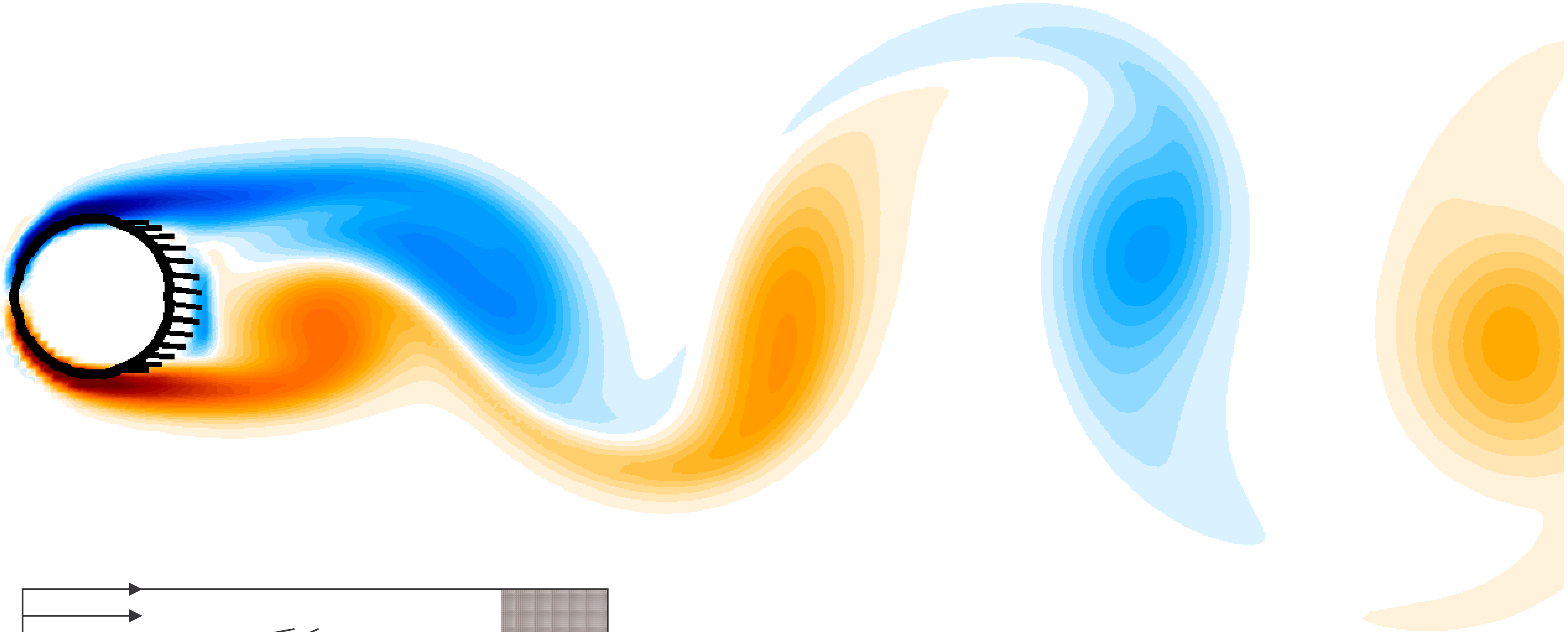


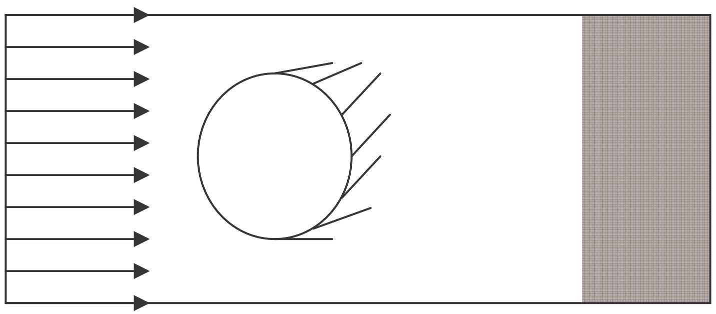
# *Case 3 : rigid longitudinal hair*



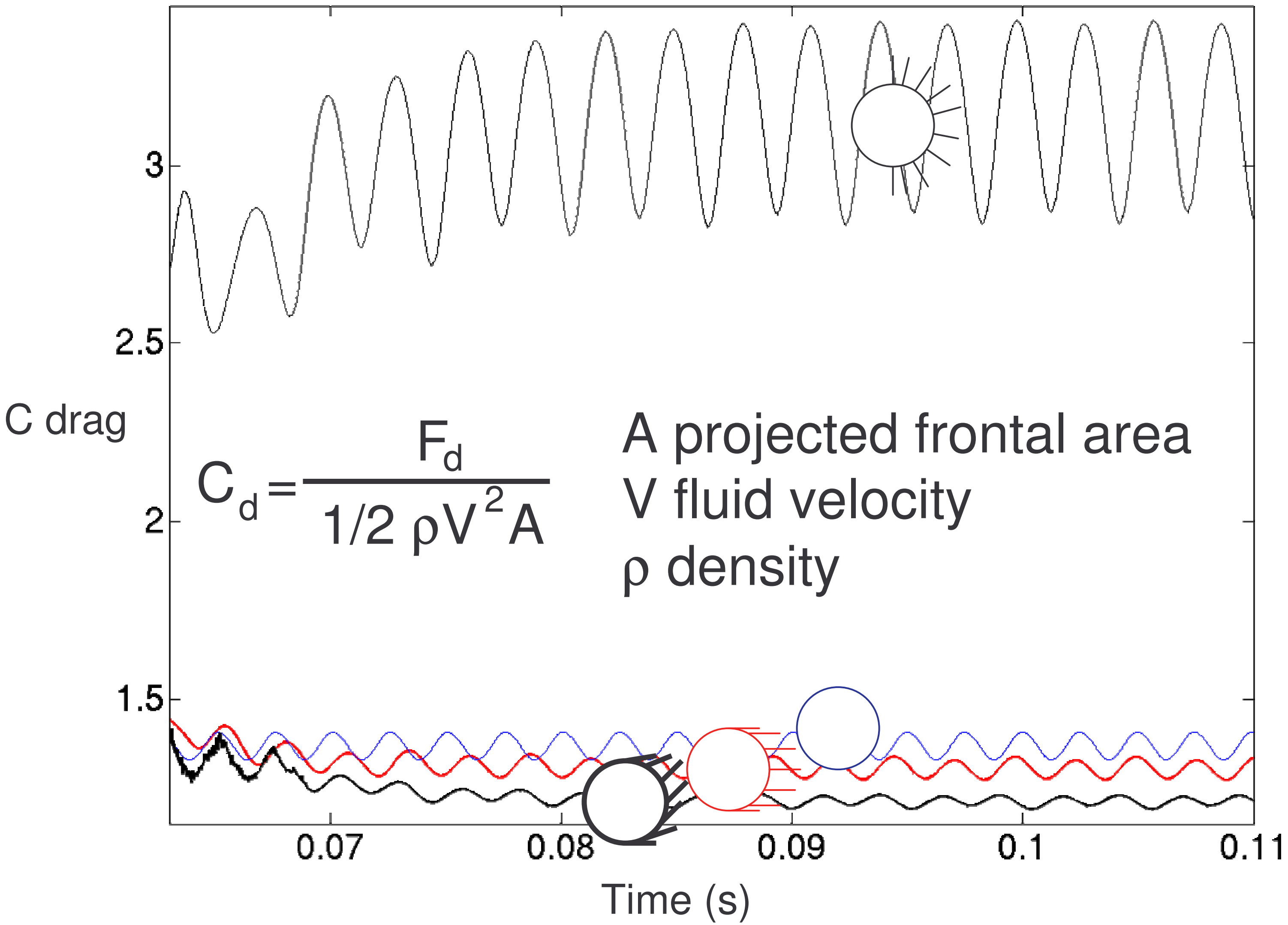


# Case 4 : moving hair

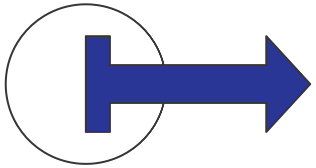




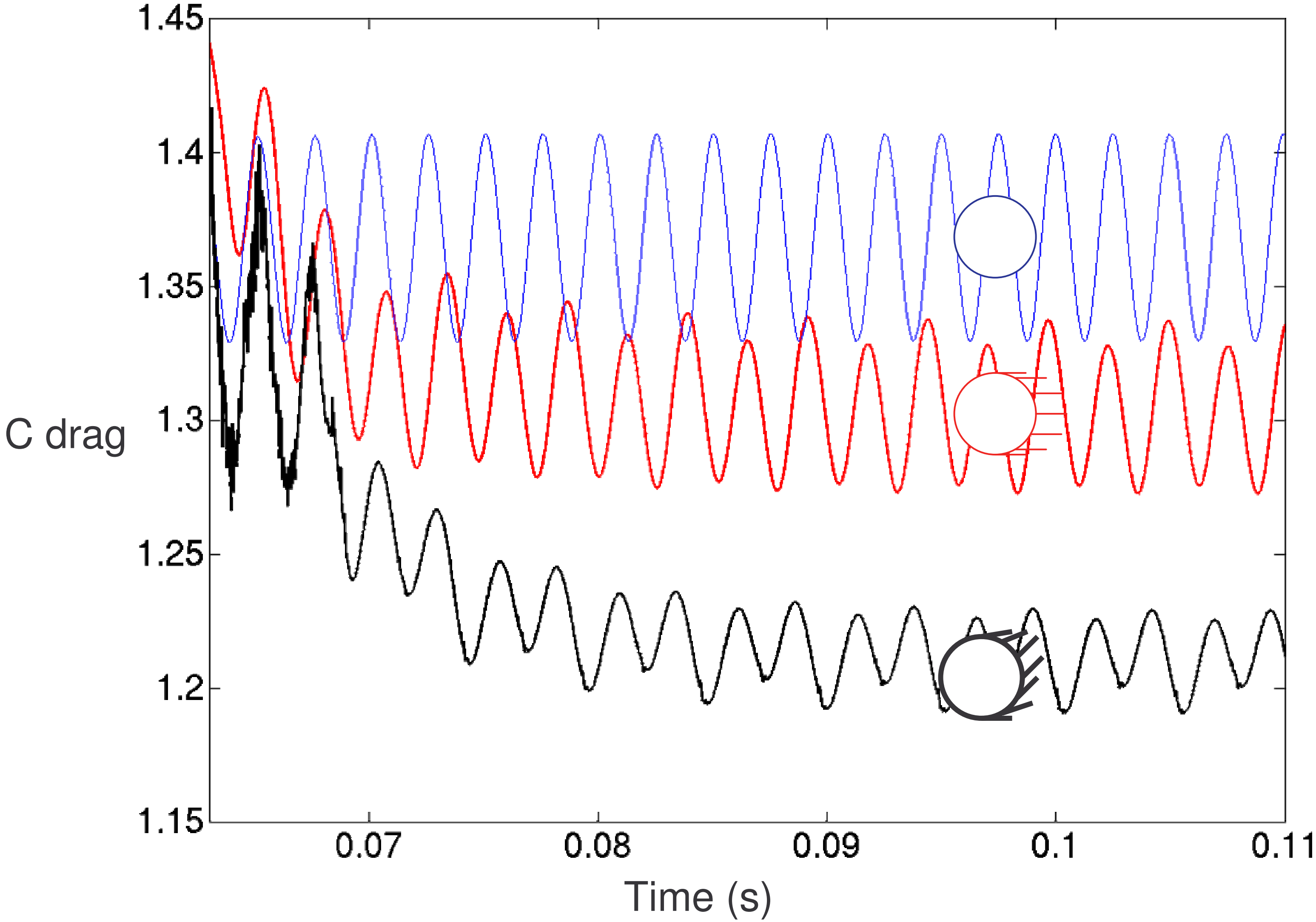
# *Drag*



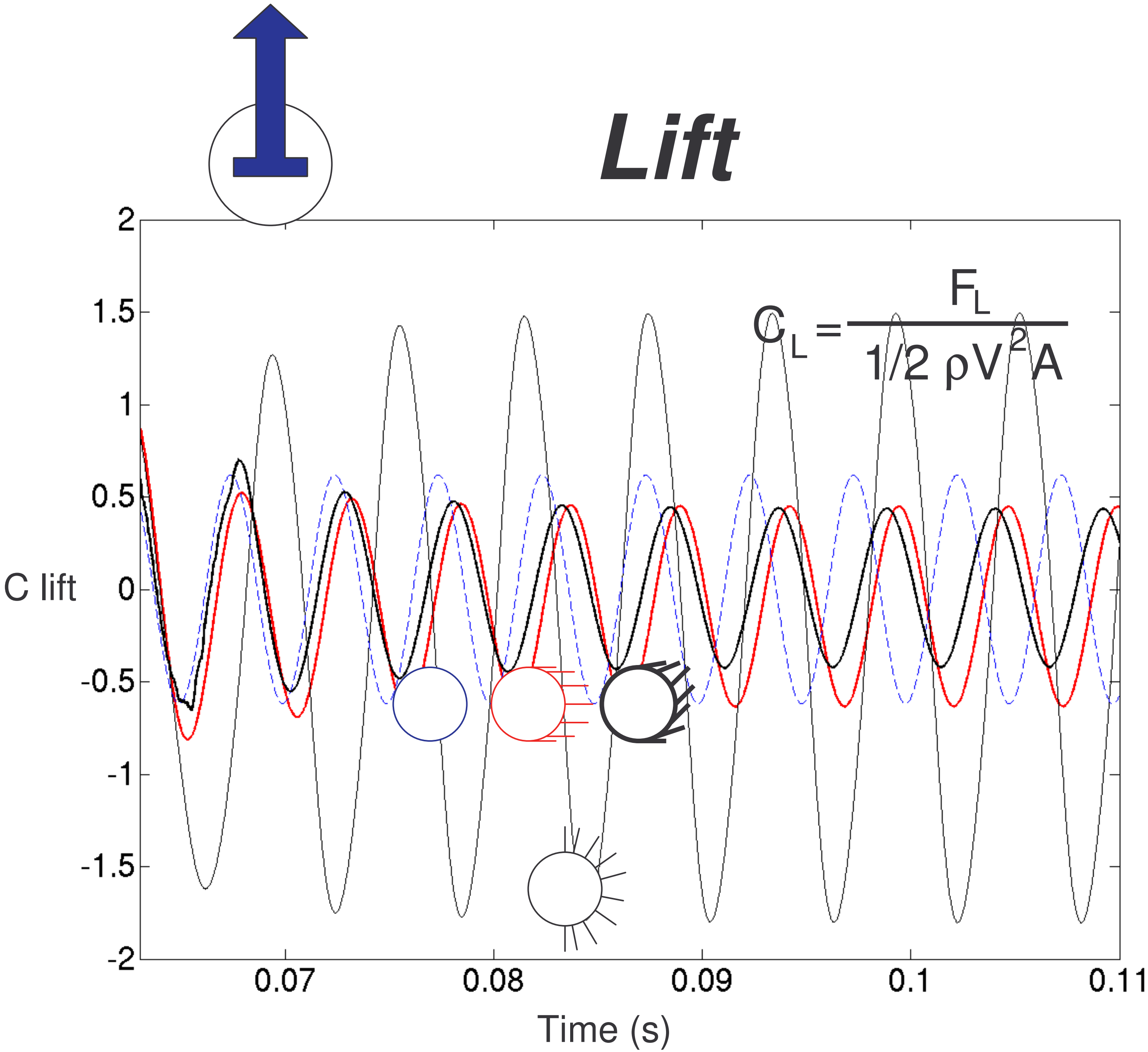

$$C_d = \frac{F_d}{1/2\,\rho V^2 A}$$



# Drag (ctd.)

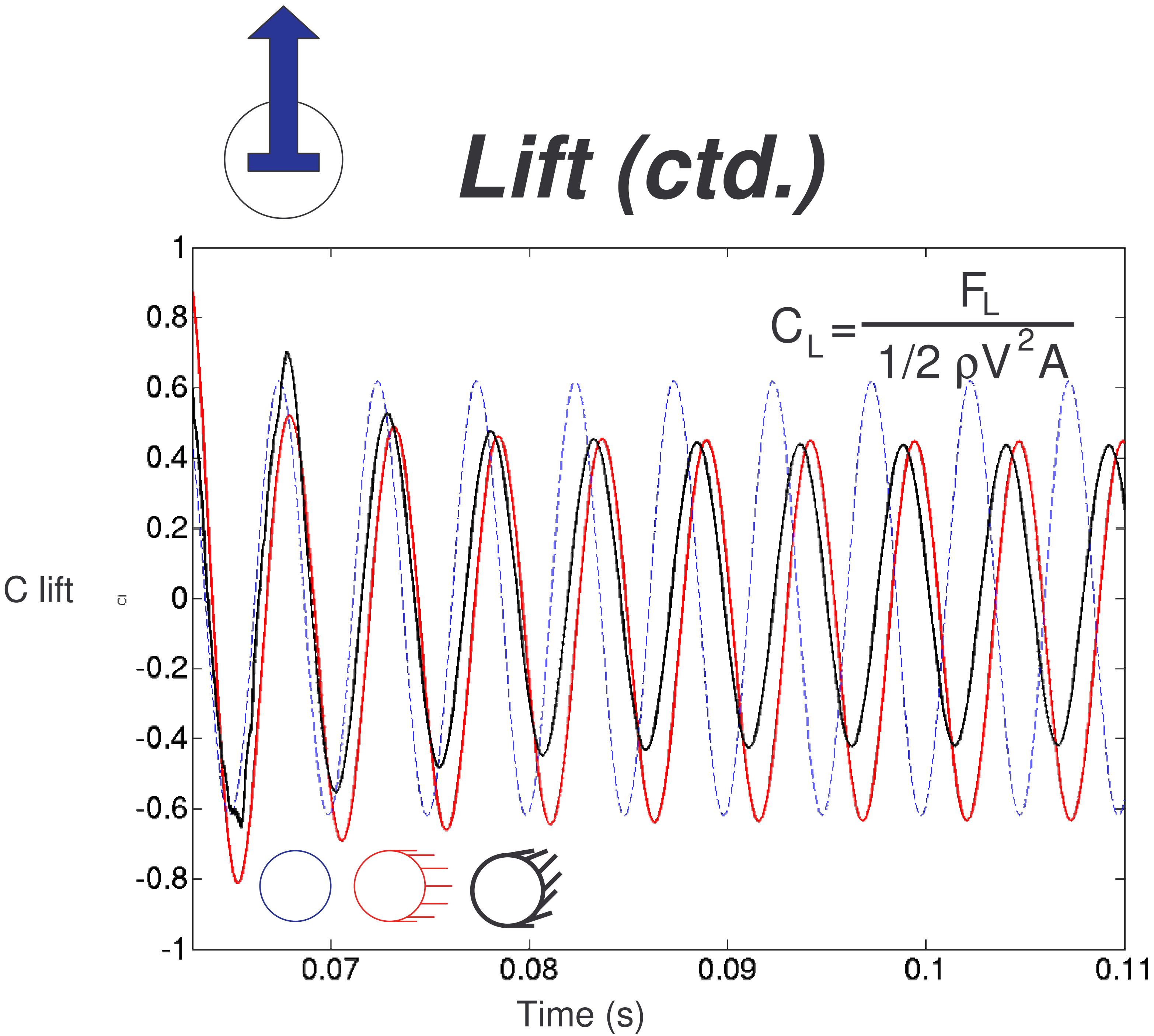


# *Lift*



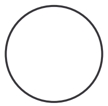
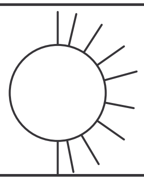
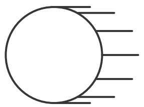
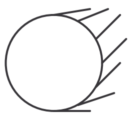
$C_L = \frac{F_L}{1/2\,\rho V^2 A}$
C lift
Time (s)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0.07
0.08
0.09
0.1
0.11

# Lift (ctd.)



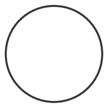
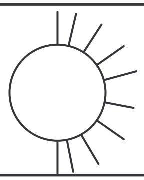
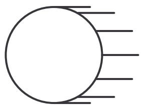
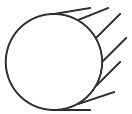
$C_L = \frac{F_L}{1/2\ \rho V^2 A}$
C lift
cl
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0.07
0.08
0.09
0.1
0.11
Time (s)

# *Aerodynamic performances*

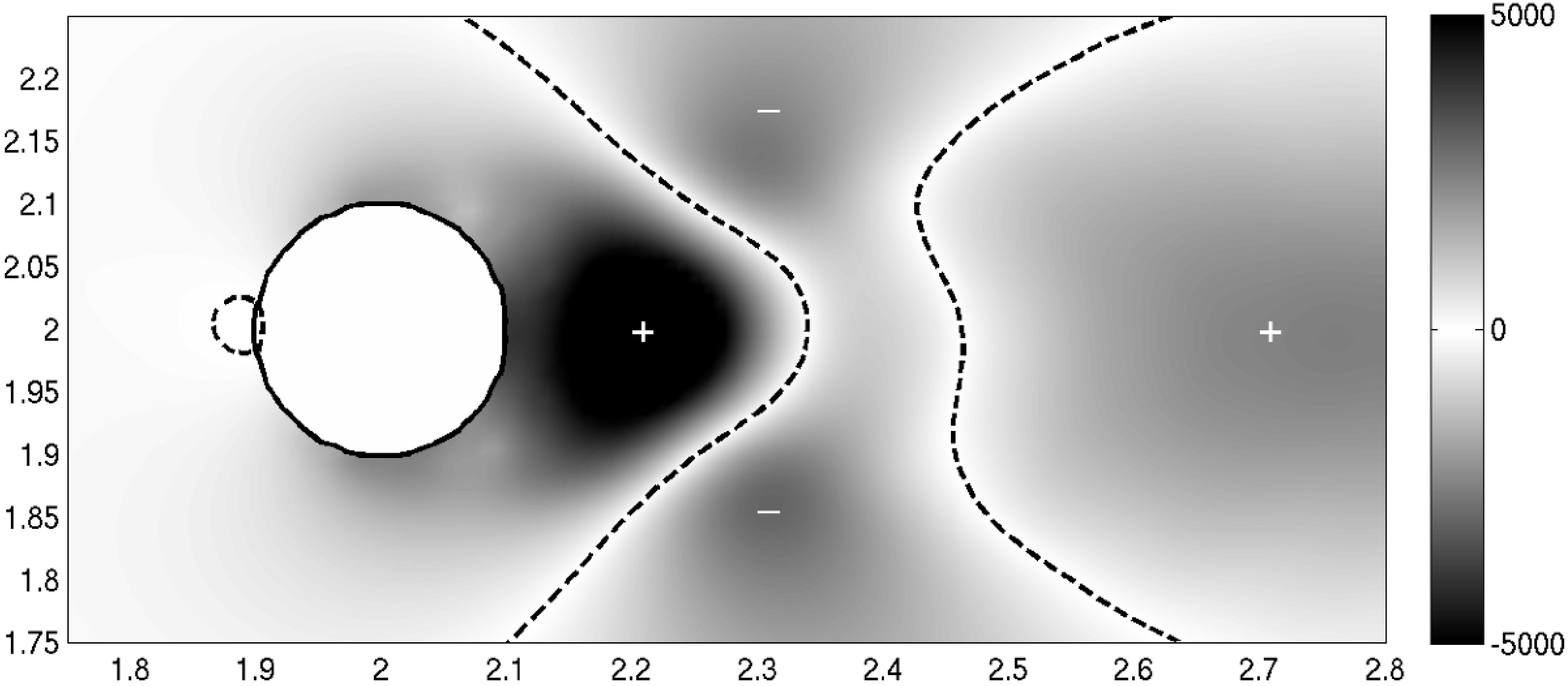
| | Cd | Cd' | Cl' | St |
|---|---|---|---|---|
| Case 1  | 1.3689 (1.39;1.356) | 0.0274 | 0.4381 | 0.199 (0.199;0.198) |
| Case 2  | 3.1464 | 0.1943 | 1.1376 | 0.1946 |
| Case 3  | 1.3035 | 0.0207 | 0.3839 | 0.1916 |
| Case 4  | 1.2109 | 0.012 | 0.3008 | 0.1661 |

(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% |

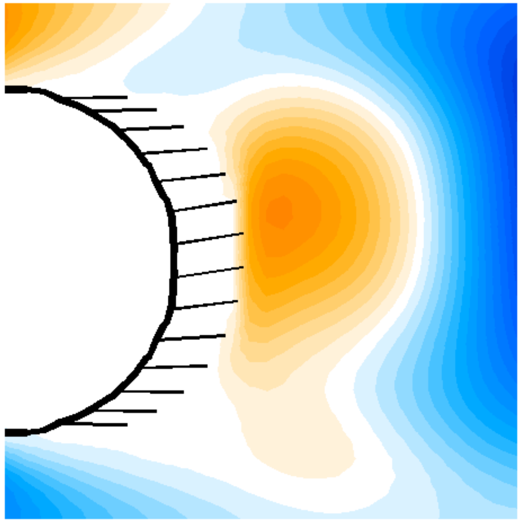
# *Physical mechanism*




Difference of time-averaged pressure field

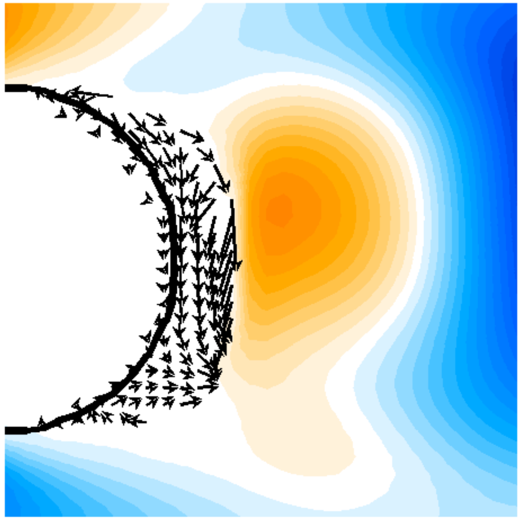
<P with hair>-<P ref>

# *Physical mechanism*



Contours of vertical velocity

Movements of *reference* cilia



Contours of vertical velocity

Force field

The hairy layer counteracts flow separation

# *Conclusions and perspectives*

- ✓ Simulations show a reduction of pressure drag on a cylinder for a unsteady laminar flow (Re=200).
- ✓ The motion of the hairy structure can improve aerodynamic performances
- ✓ The passive control structural parameters have been optimised
- ✓ Direct perspectives concern flexible rods and turbulent configurations; possible applications to small underwater vehicles and to UAV/MAV (in the aeronautical field)
- ✓ Experimental investigations seem justified on this topic

# Thank you for your attention