A-LES: WORKSHOP ON ACTIVE FLOW CONTROL, WWW.A-LES.ORG

Chalmers, Gothenburg, 13-14 Sept 2009

CHALMERS

ALES for Drag Reduction of Truck-Trailers

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Acknowledgments

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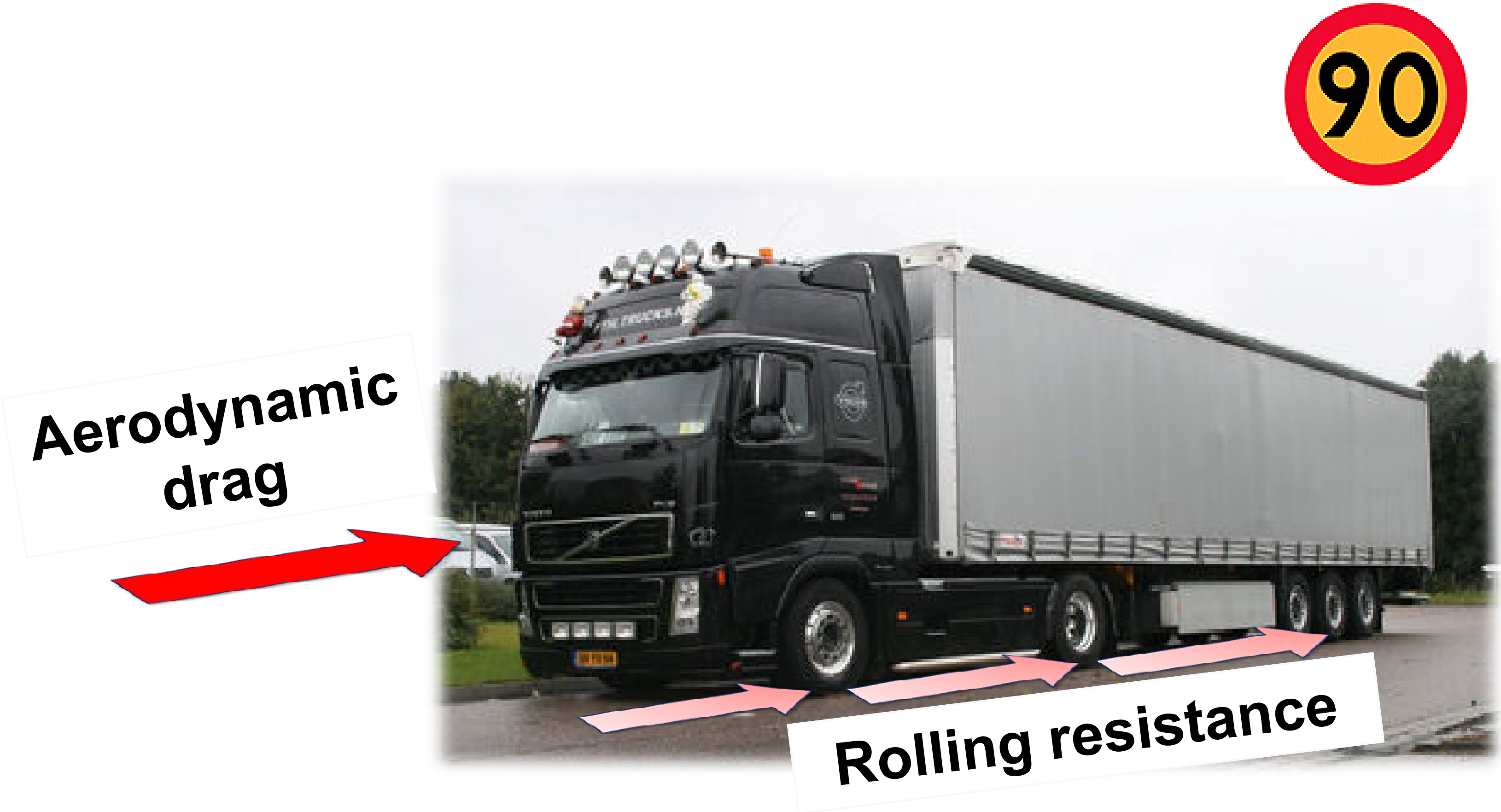
Co-supervisor:	**Per Kjellgren**
VOLVO 3P:	**Linus Hjelm**
SKAB:	**Bengt Karlsson**

Introduction

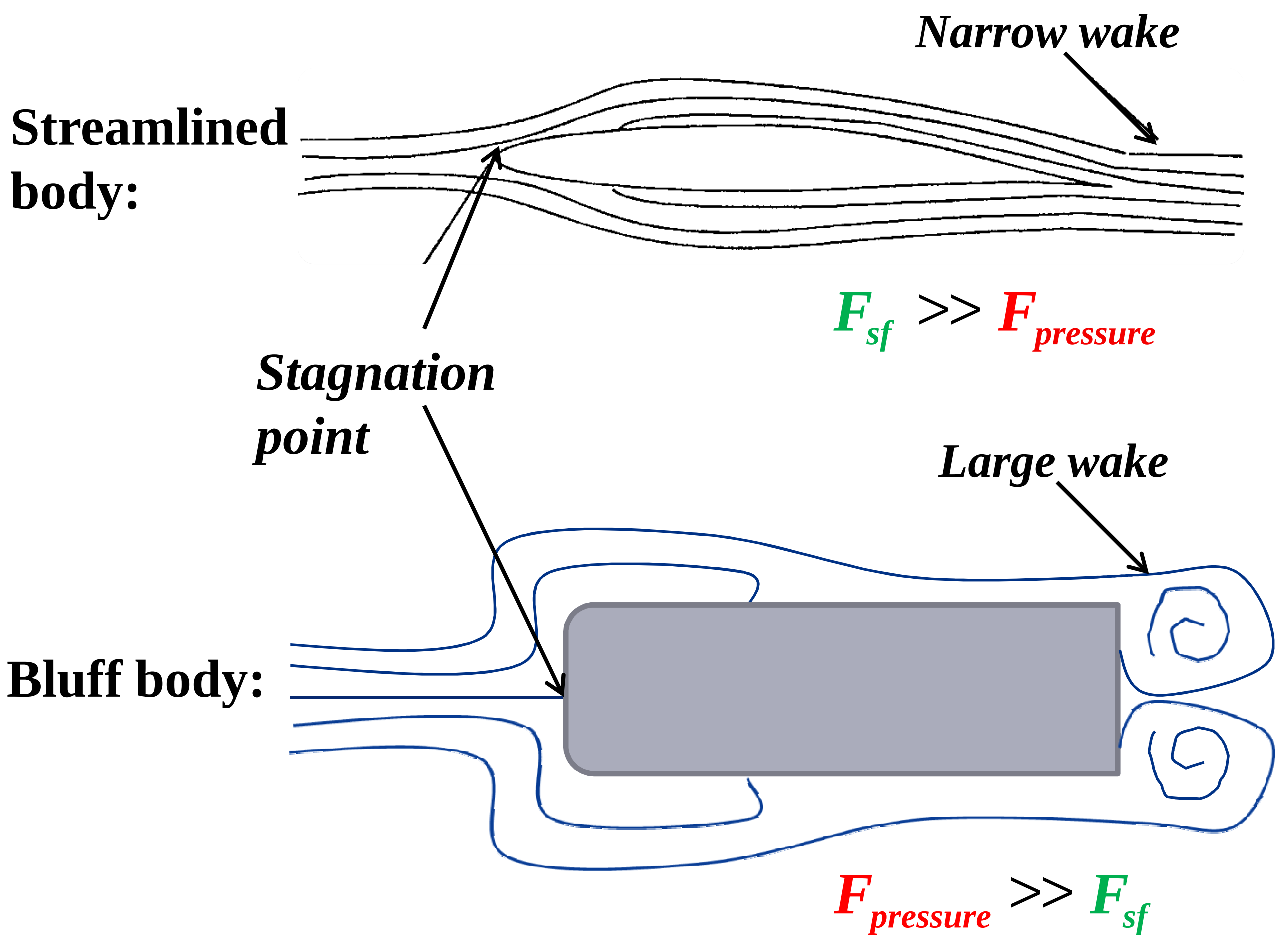


Aerodynamic drag > Rolling resistance

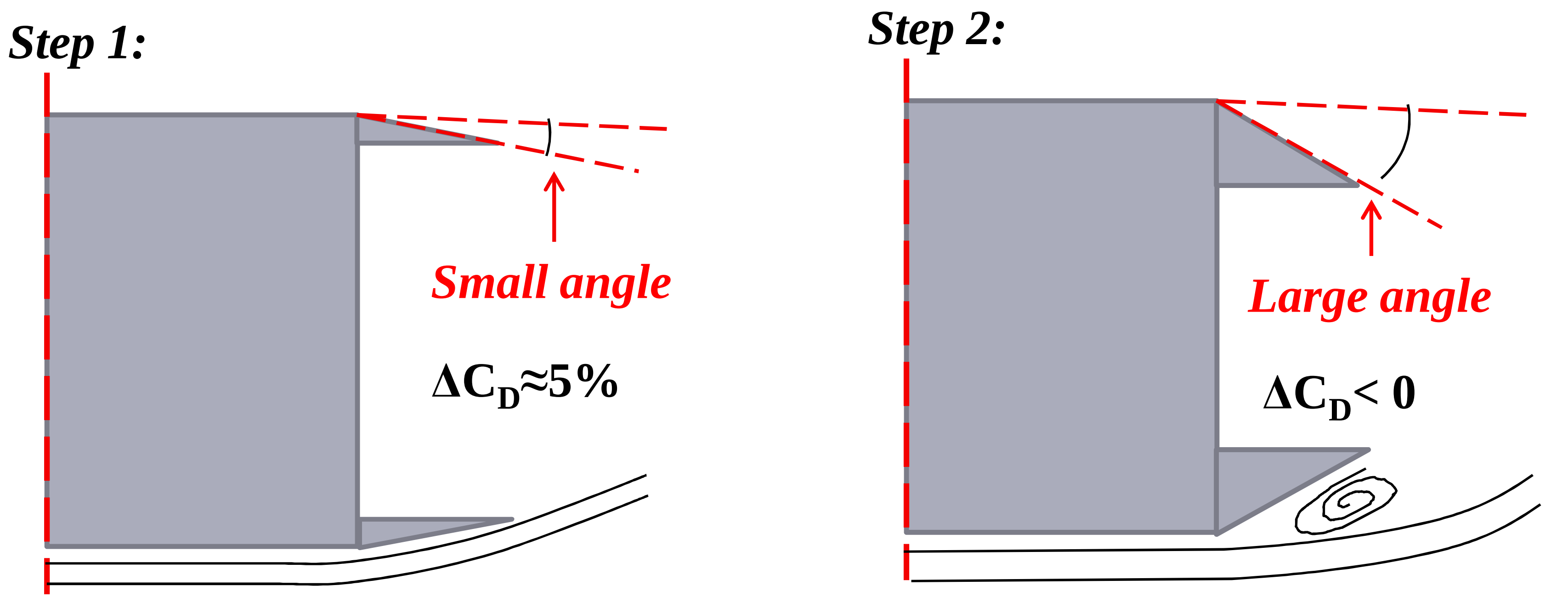
Introduction

Aerodynamic drag =
Pressure +
Skin friction

$$\boxed{F_D = \frac{1}{2}\rho A U_\infty^2 C_D}$$



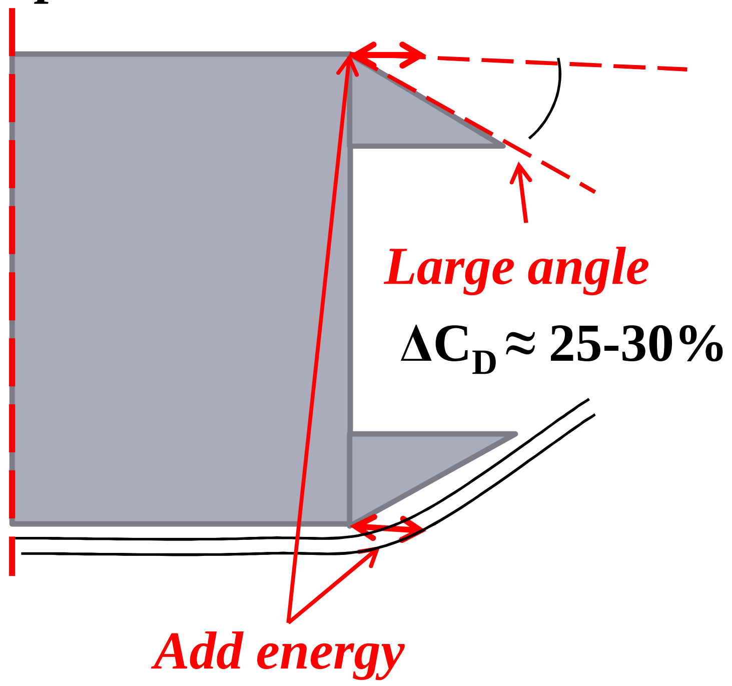
Idea: Passive Flow Control



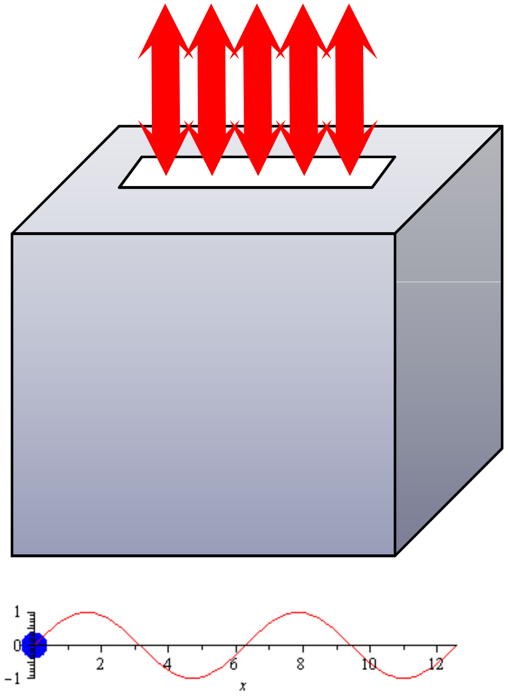
Rear end of a Bluff body

Idea: Passive + Active Flow Control

Step 3:



Actuator

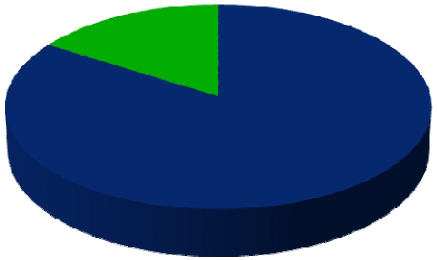


$\Delta C_D \approx$ 25-30% $\longleftrightarrow$ 15% Fuel save

$$u(t) = A\sin(2\pi F t)$$

Background

How much can we save in Sweden?



Average Heavy truck

# heavy trucks	80 000
Fuel consumption :	28 liters /100 km
Annual driving distance:	50 000 km

Source: SCB

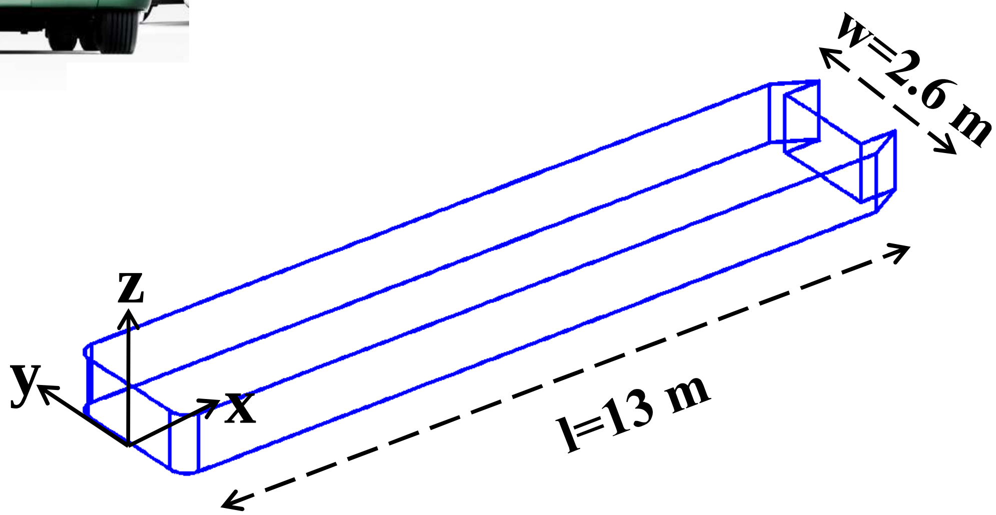
Fuel save

1% → **12 million €**

15% → **180 million €**

First step: Truck-trailer model

Vertical spanwise slice,
dz=0.2, 0.4, 0.8 and 1.0 m



Numerical method (1/5)

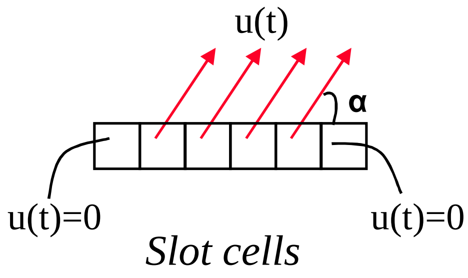
- Parameters to investigate/optimize
  - Flap length, FL
  - Flap angle, FA
  - Slot location / width
  - Slot angle, SA
  - Slot strength, C_μ
  - Slot frequency, F^+

- Two codes investigated for LES
  - STAR-CD v4
    - 1 sim. sec ~ 1 week
  - FlowPhys v2
    - 1 sim. sec ~ 1 day
- Re = 200 000, modified viscosity.

Our choice

Numerical method (2/5)

- Actuation modeling
  - Transient velocity-inlet
  - Constant spatial profile



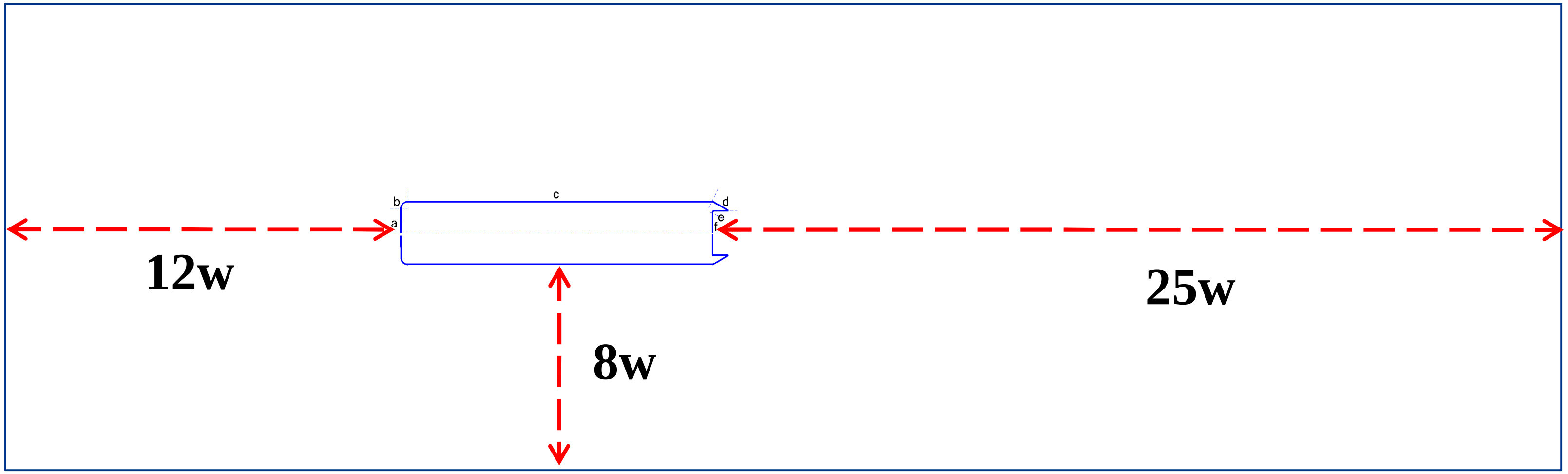
$$J_{rms} = \int \rho u_{rms}^2 \, dh = \rho u_{rms}^2 \Delta h$$

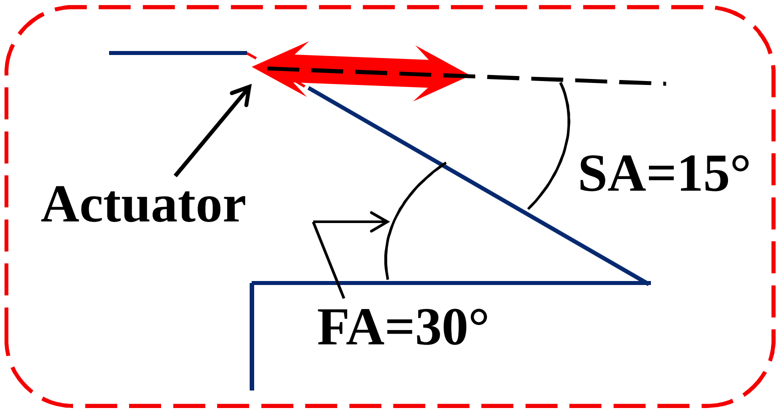
$$C_{\mu \ rms} = \frac{u_{rms}^2 \Delta h}{chord \frac{1}{2} u_\infty^2}$$

$$F^+ = \frac{F \cdot X_{TE}}{U_\infty}$$

$$\boxed{u(t) = \sqrt{2} u_{rms} \sin(2\pi F t)}$$

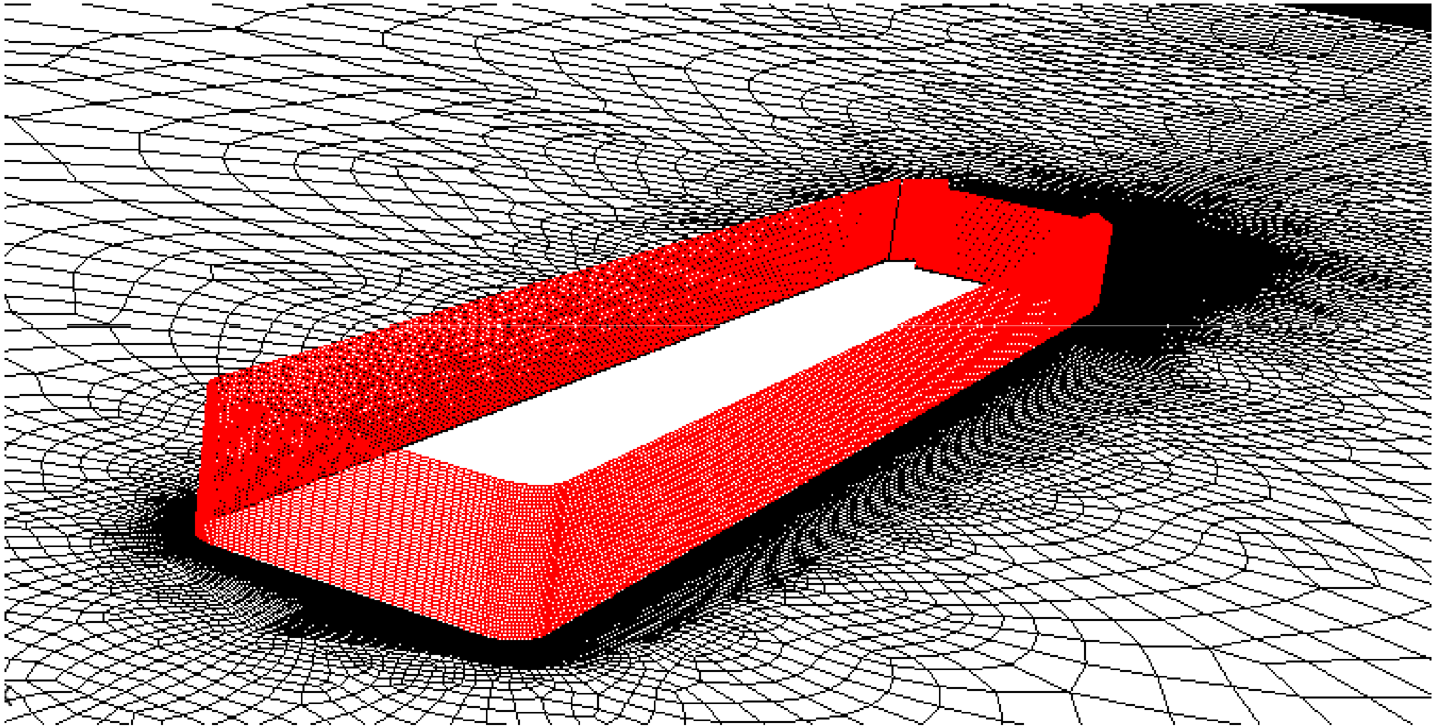
Numerical method (3/5)



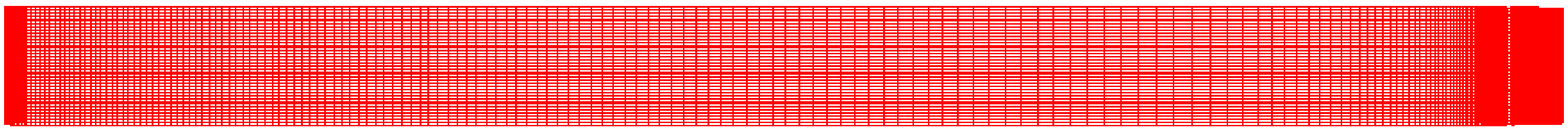


AFC Parameter	Value
FL	0.75 m
FA	30 deg
SA	15 deg
C_μ	1.0%
F^+	0.3

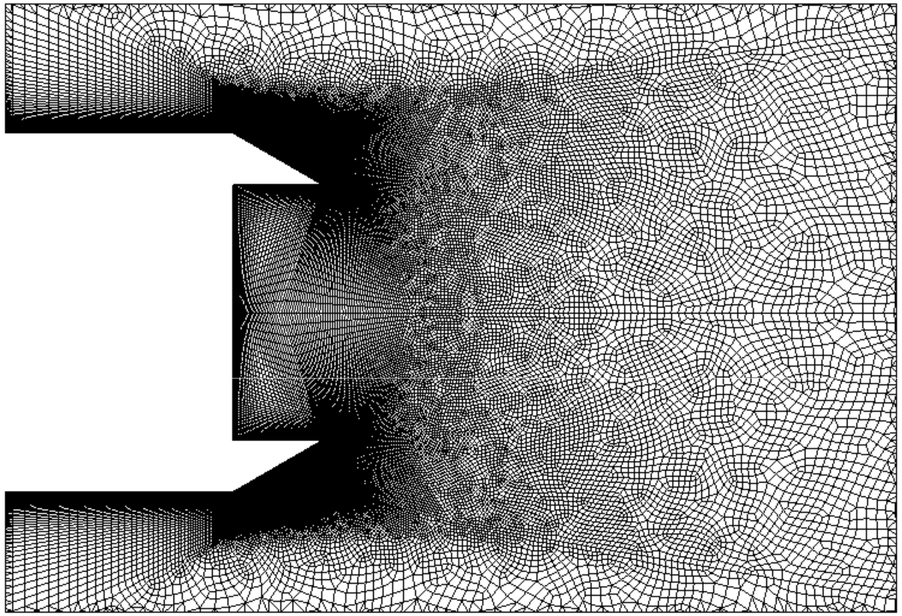
Numerical method (4/5)



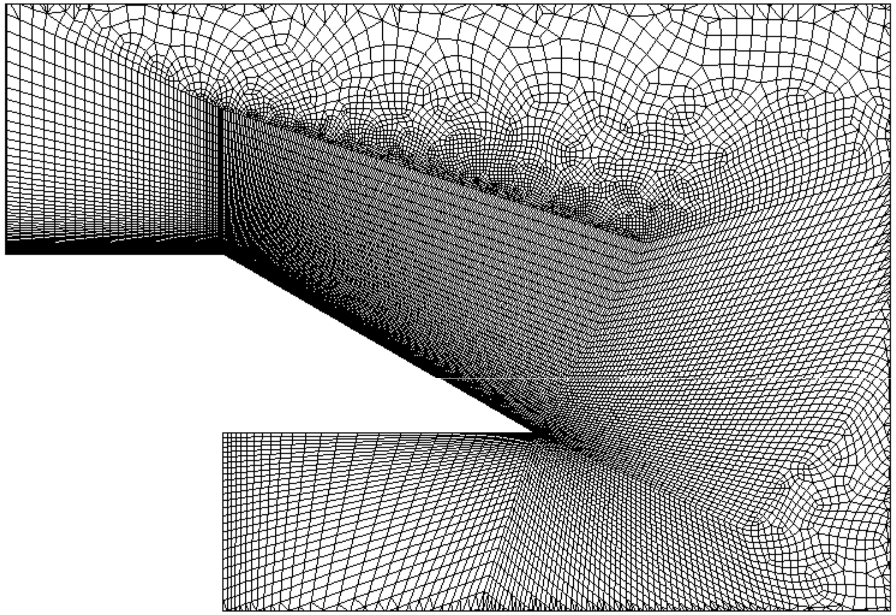
#cells: 1.5-3.3 million



Numerical method (5/5)



Wake region



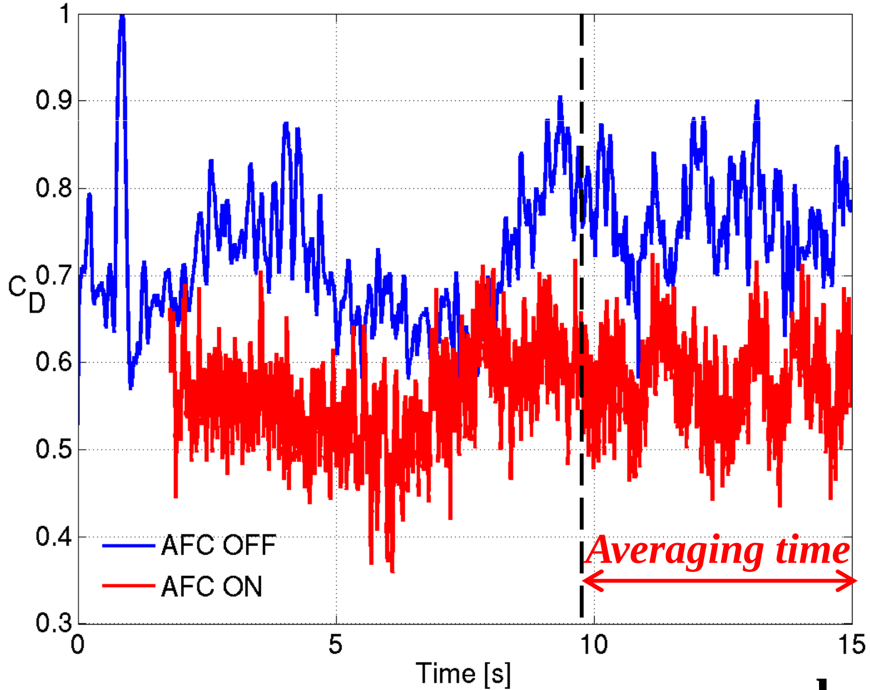
Flap region

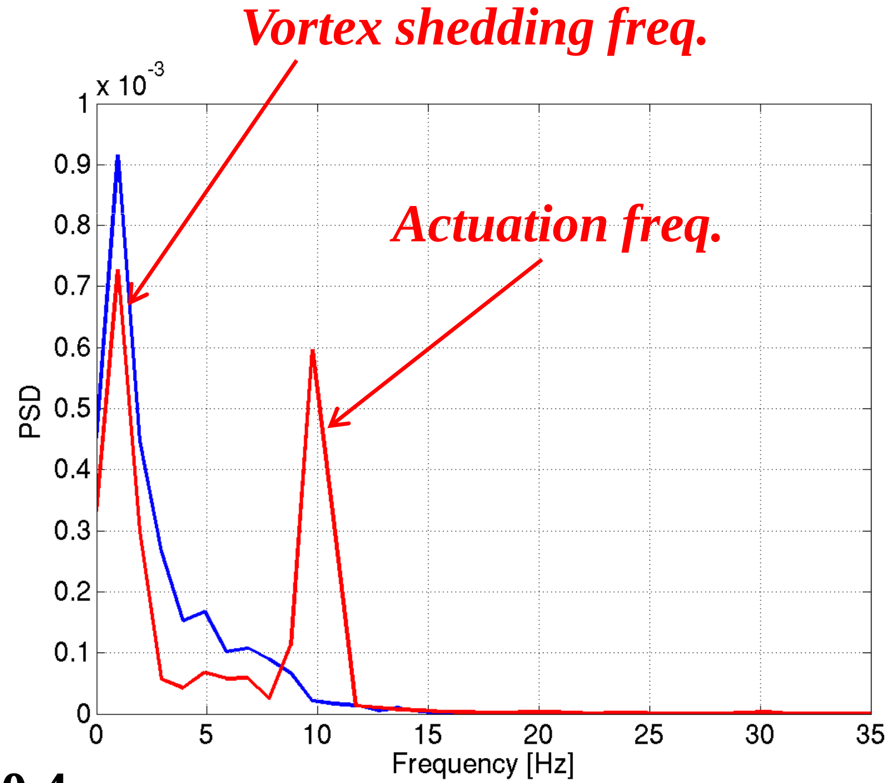
	y^+	Δx^+	Δz^+ *LR*	Δz^+ *HR*
Max	2	30	150	75
Mean	1	20	100	50

Results

Drag history and frequency spectra

C_D=0.76 C_D=0.57 ΔC_D=25%



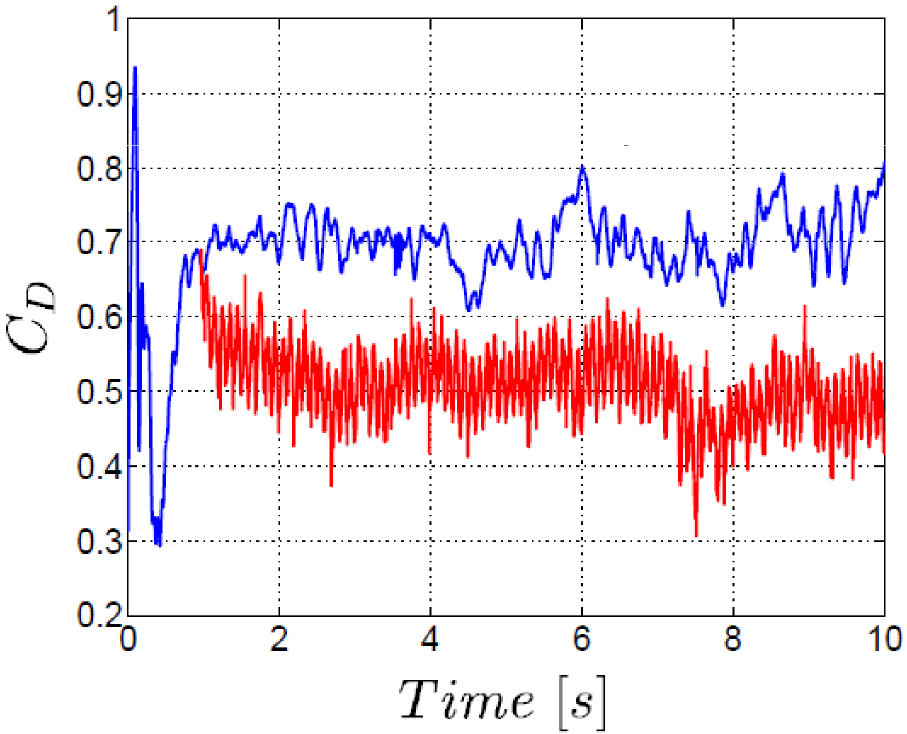


dz=0.4m

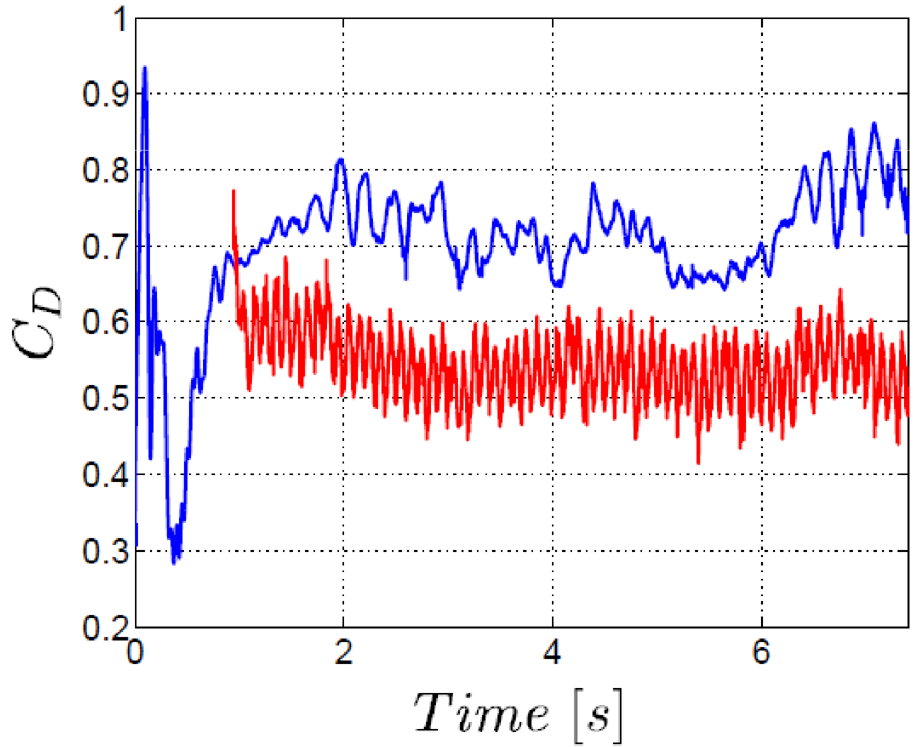
Results

Drag history of different spanwise domain sizes

dz=0.8m, ΔC_D=30%



dz=1.0m, ΔC_D=25%

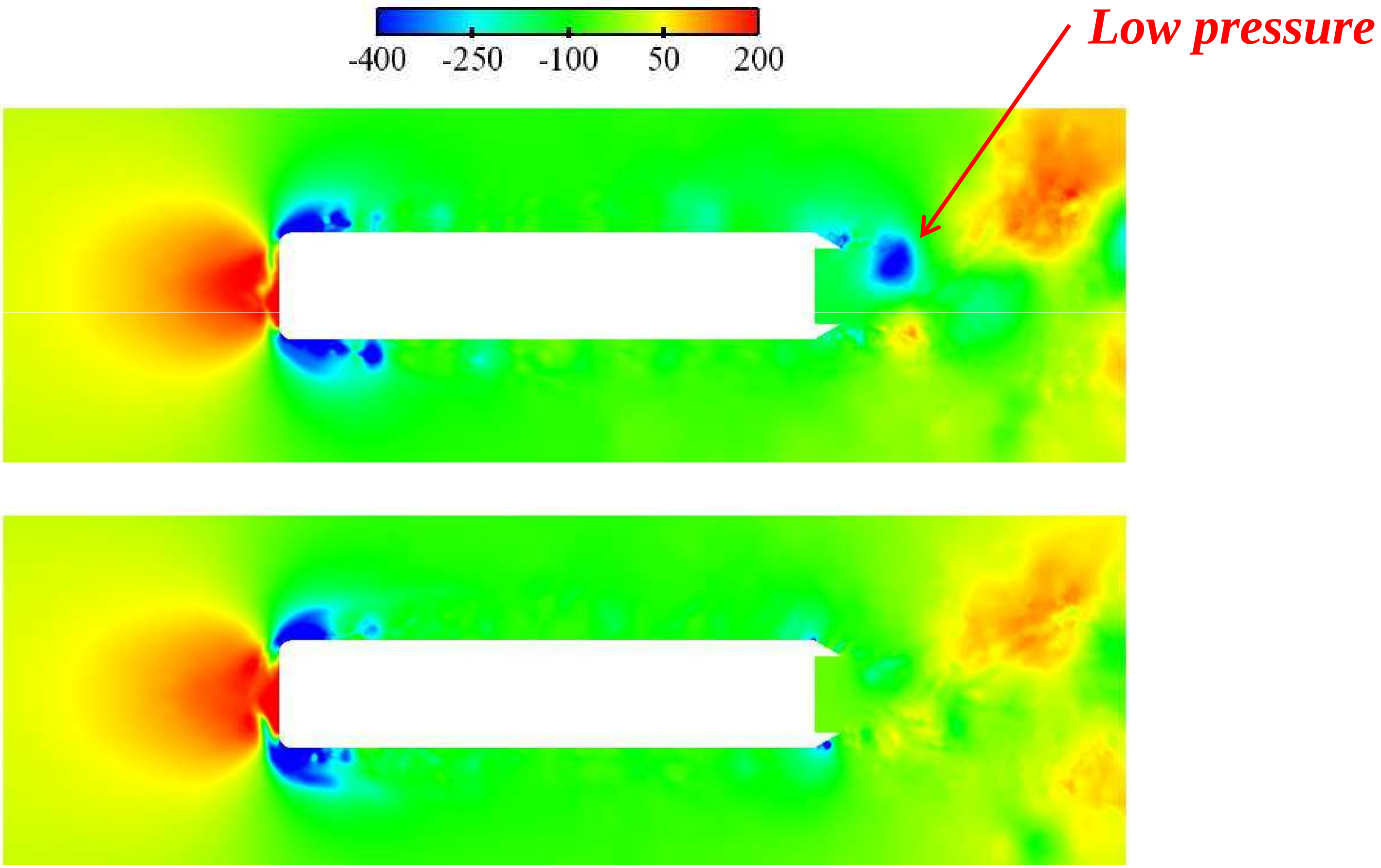


Results

Instantaneous pressure

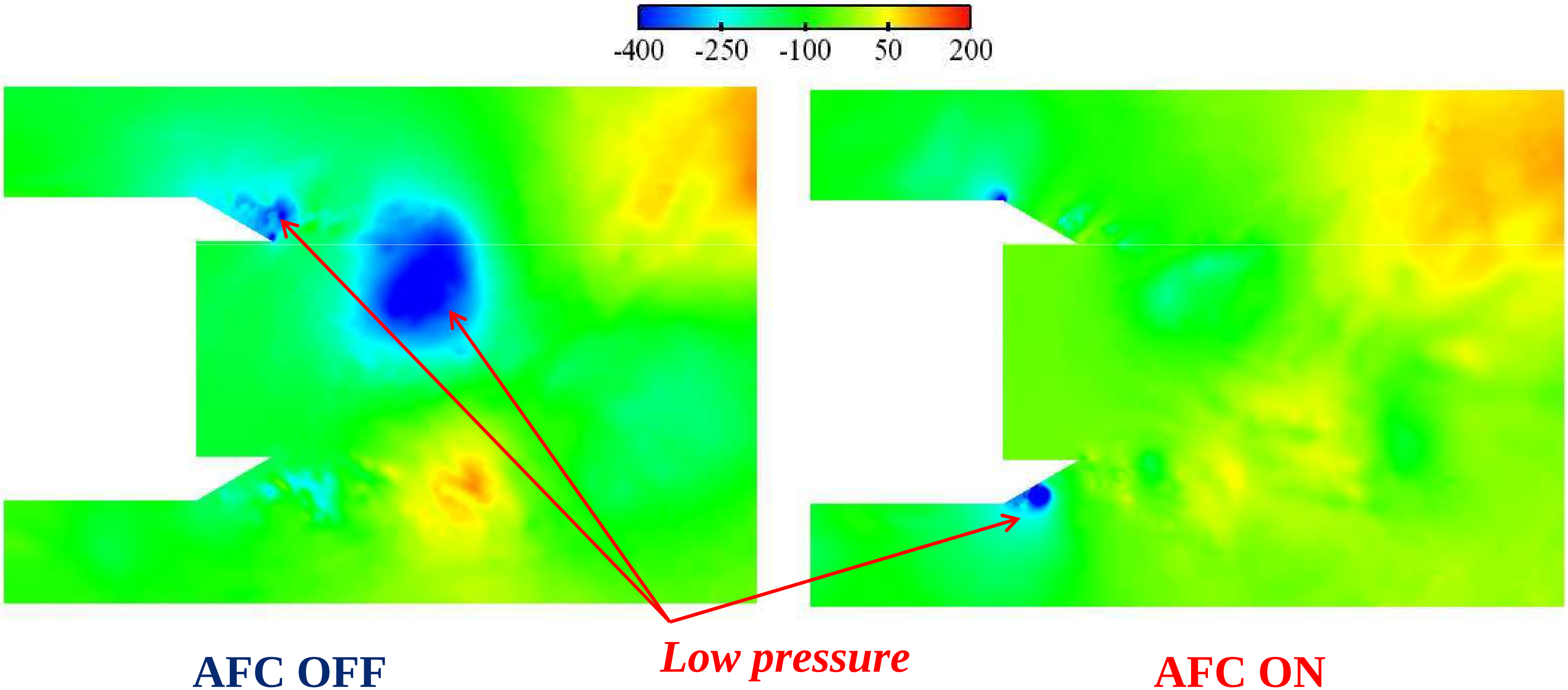
AFC OFF

AFC ON



Results

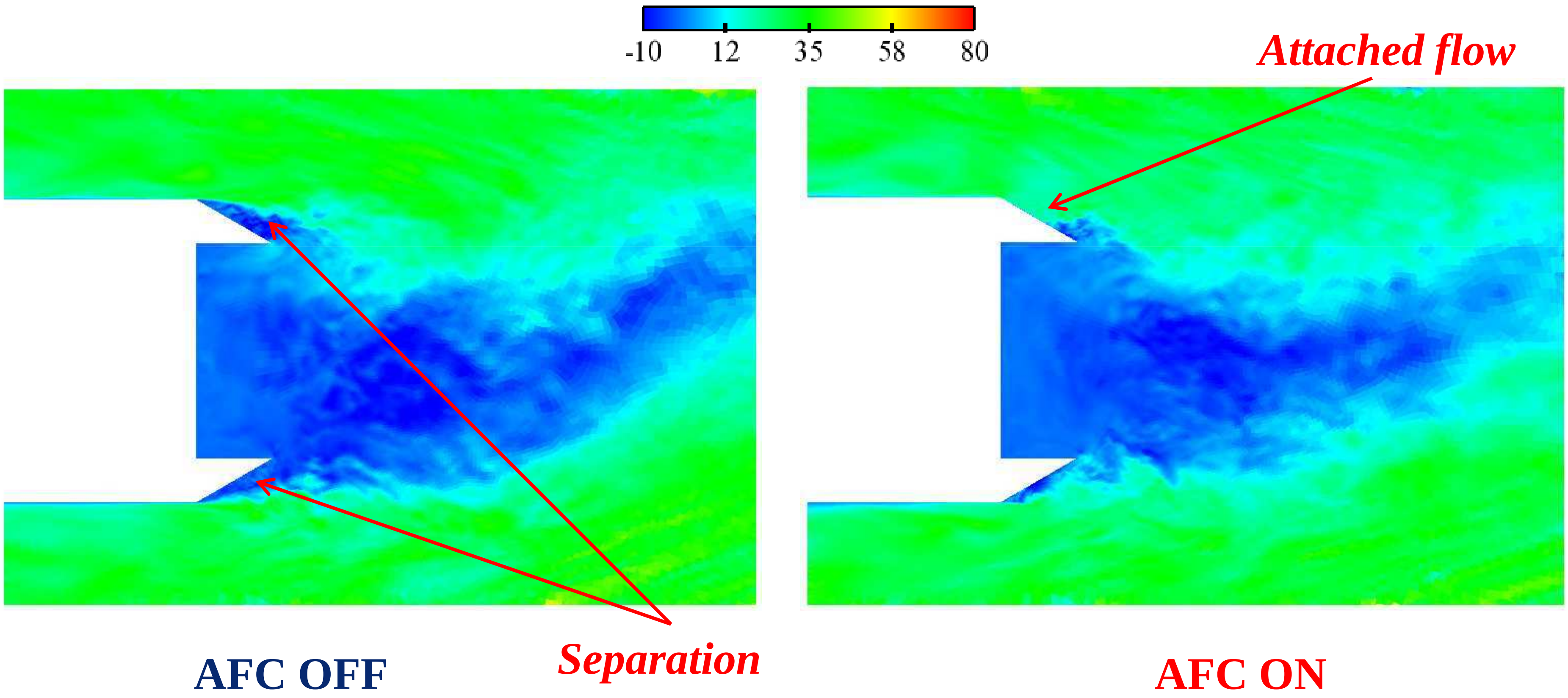
Instantaneous pressure, zoom around wake region



AFC OFF **AFC ON**

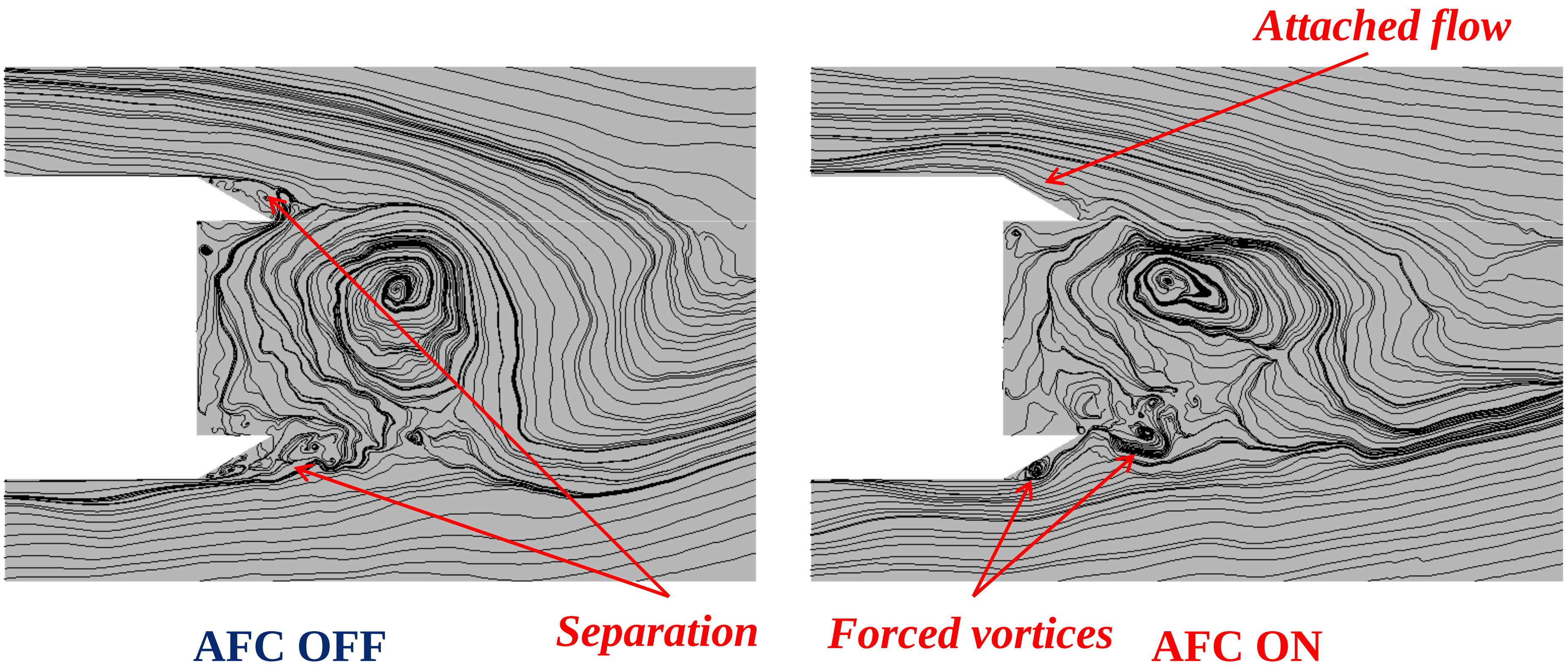
Results

Instantaneous u-velocity, zoom around wake region



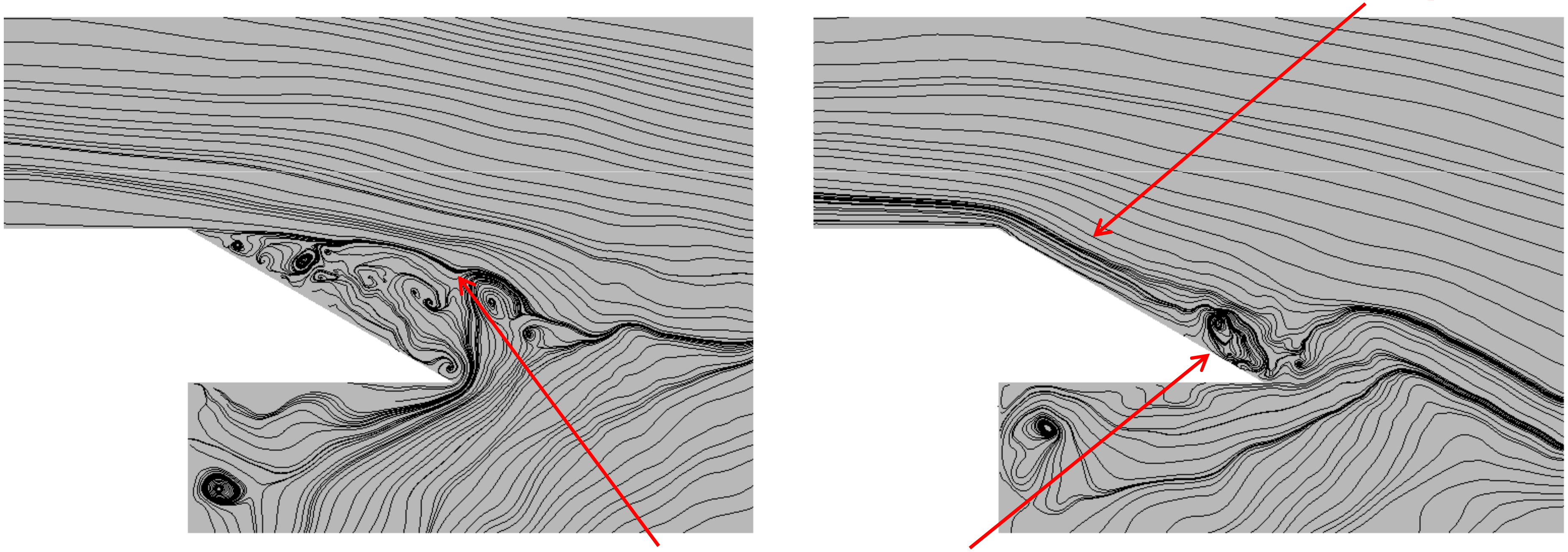
Results

Instantaneous streamlines, zoom around wake region



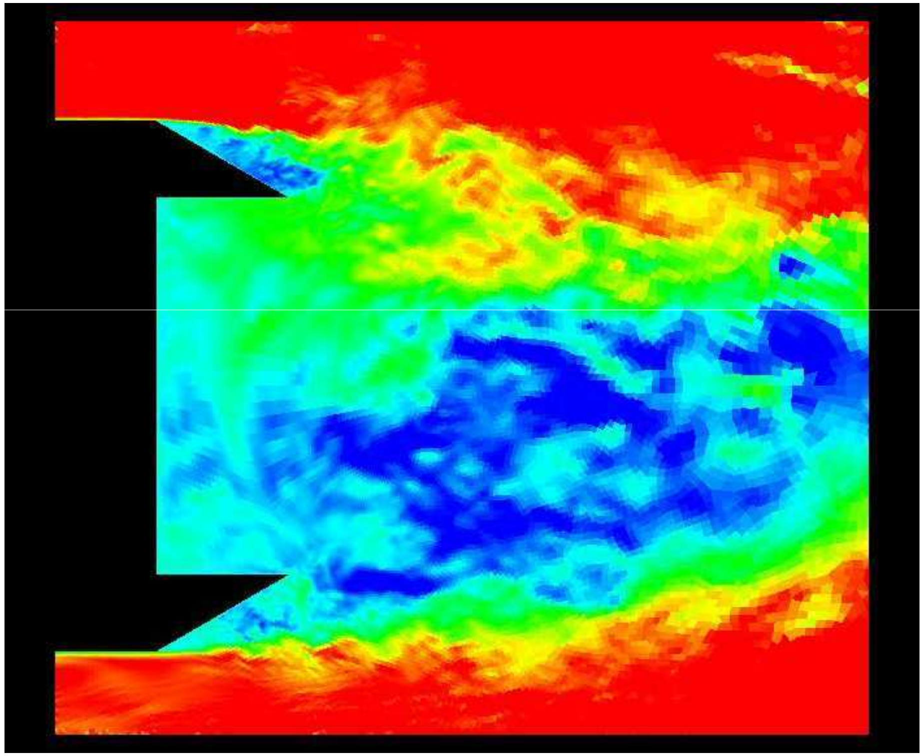
Results

Instantaneous streamlines, zoom around flap region

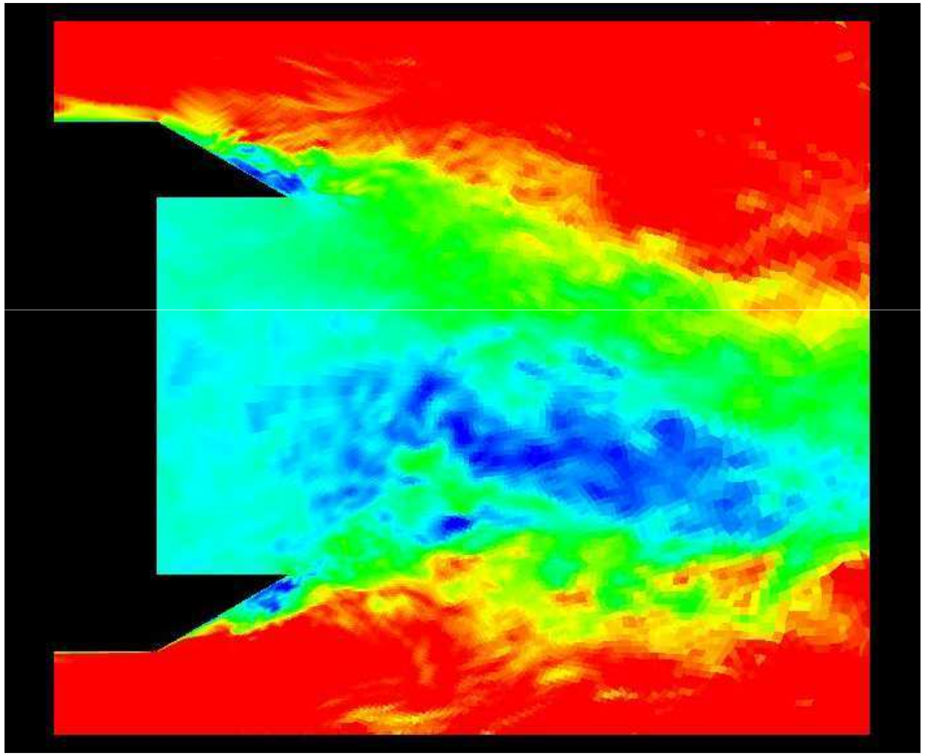


Results

Movie: u-velocity, zoom around wake region



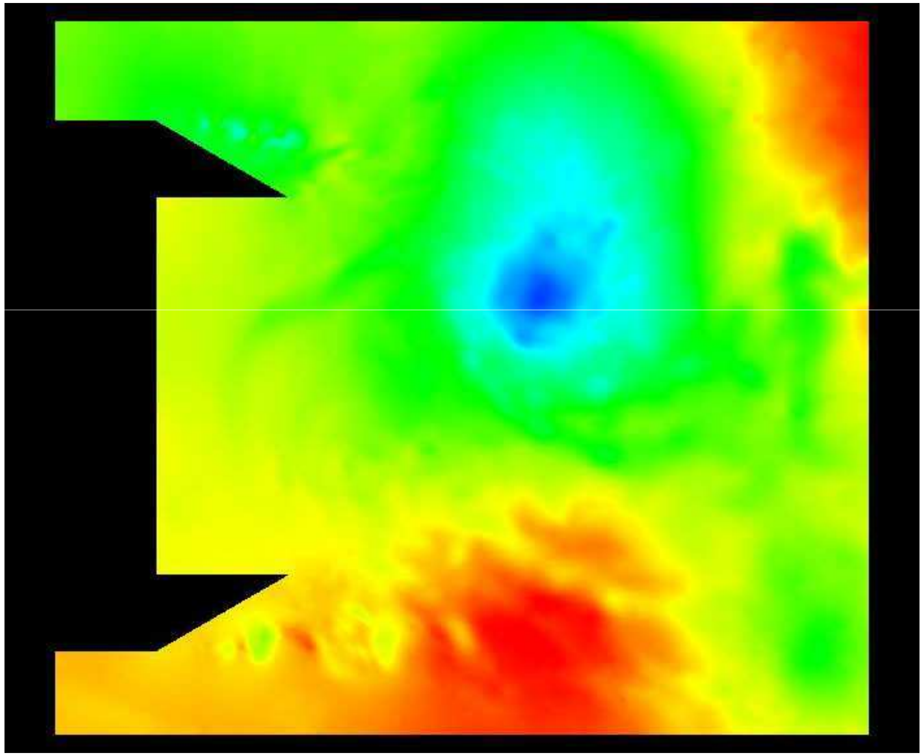
AFC OFF



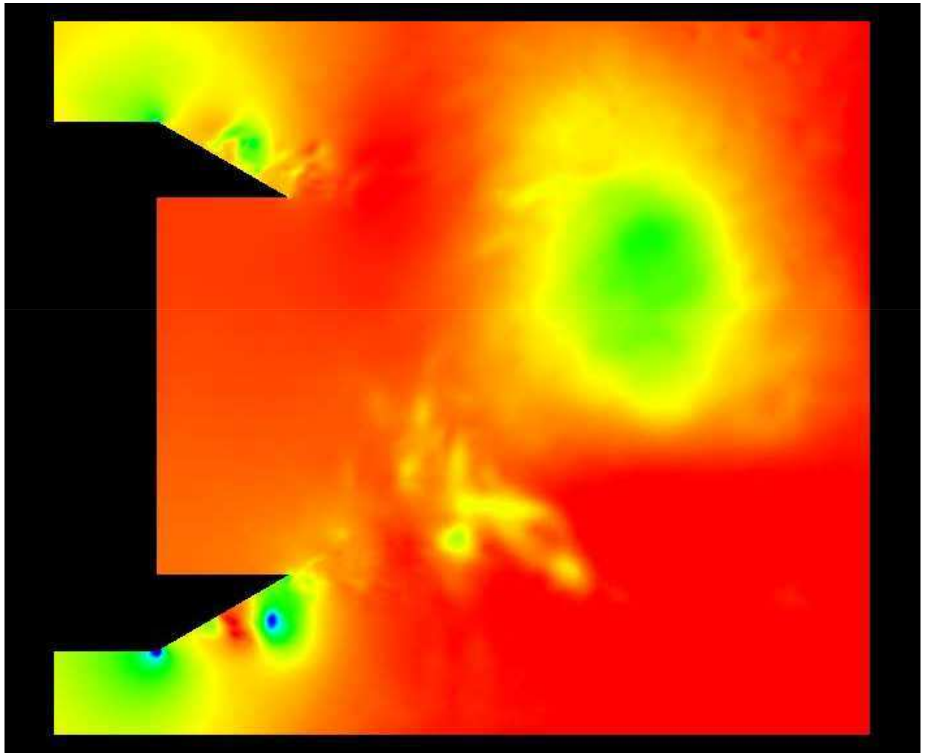
AFC ON

Results

Movie: pressure, zoom around wake region



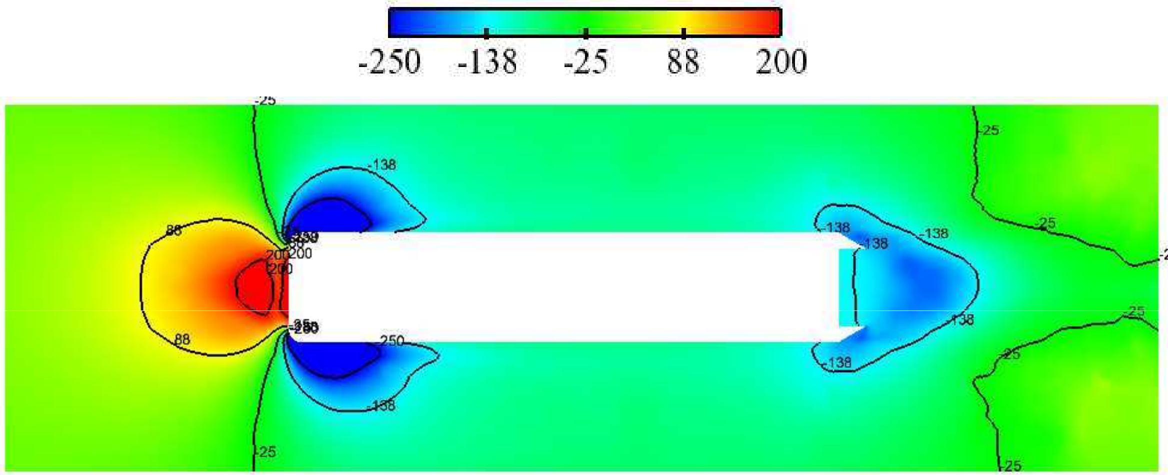
AFC OFF



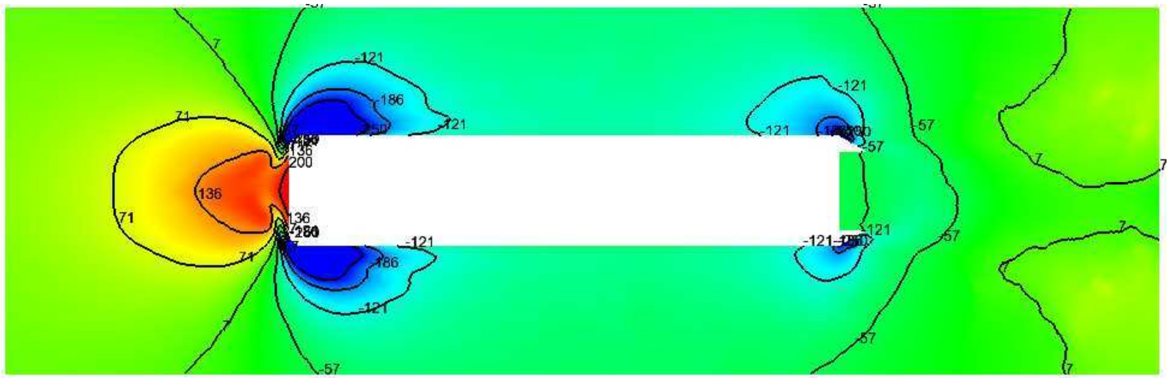
AFC ON

Results

Time-averaged pressure, zoom around wake region



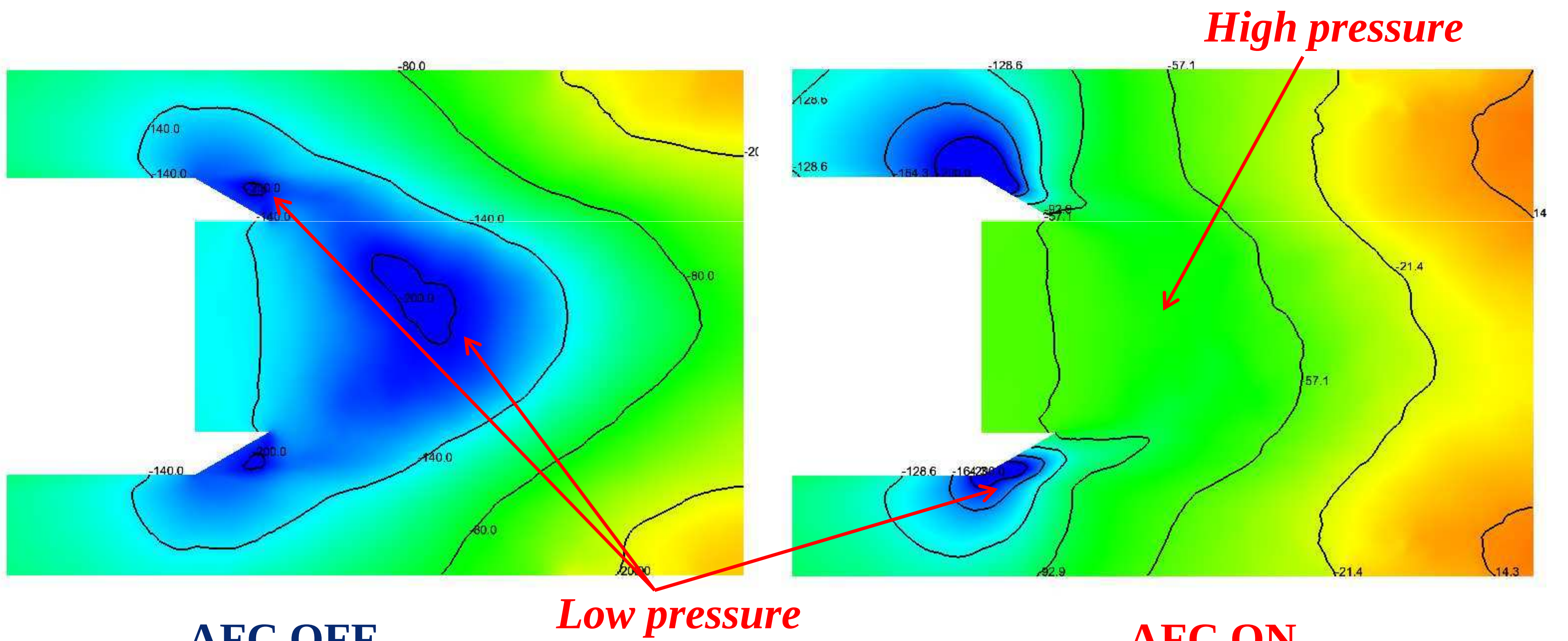
AFC OFF



AFC ON

Results

Time-averaged pressure, zoom around wake region

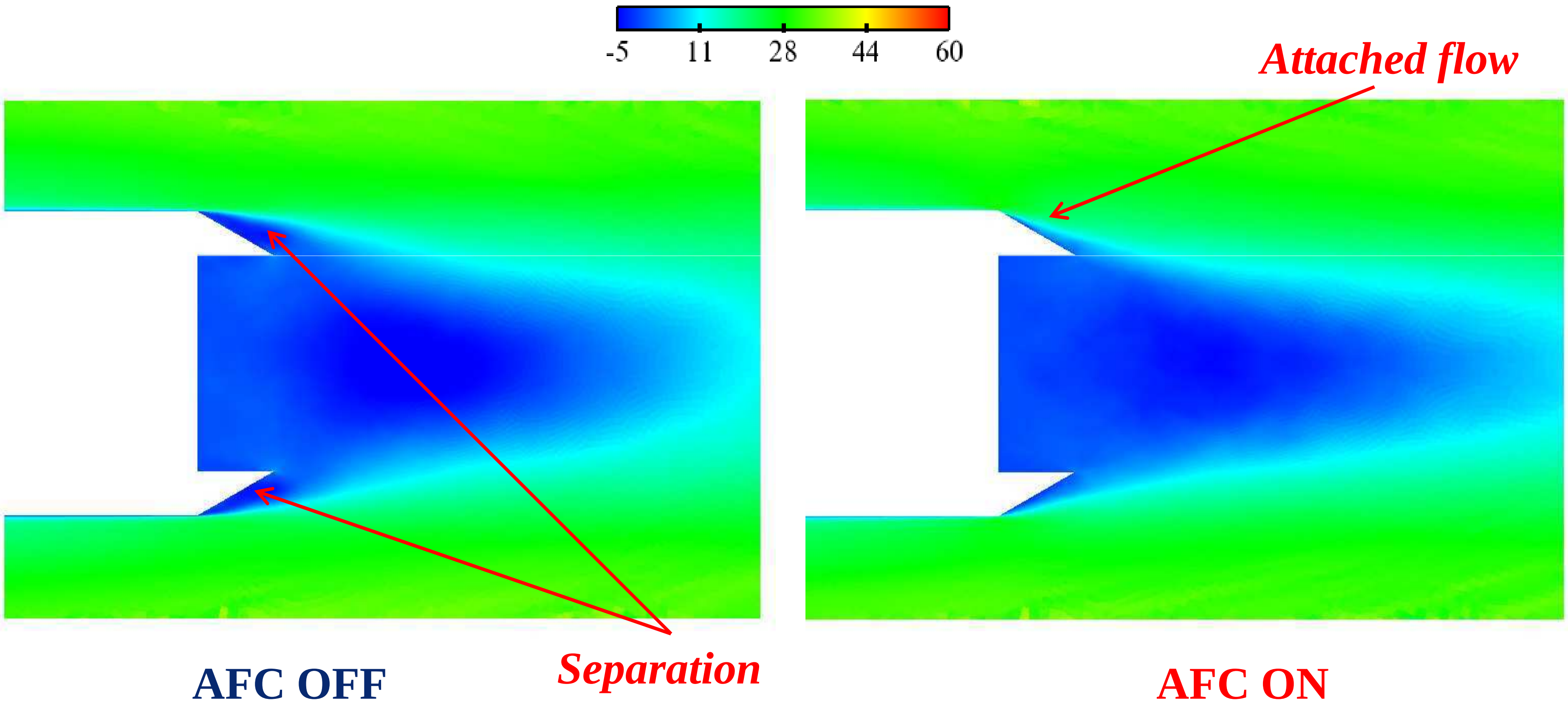


AFC OFF

AFC ON

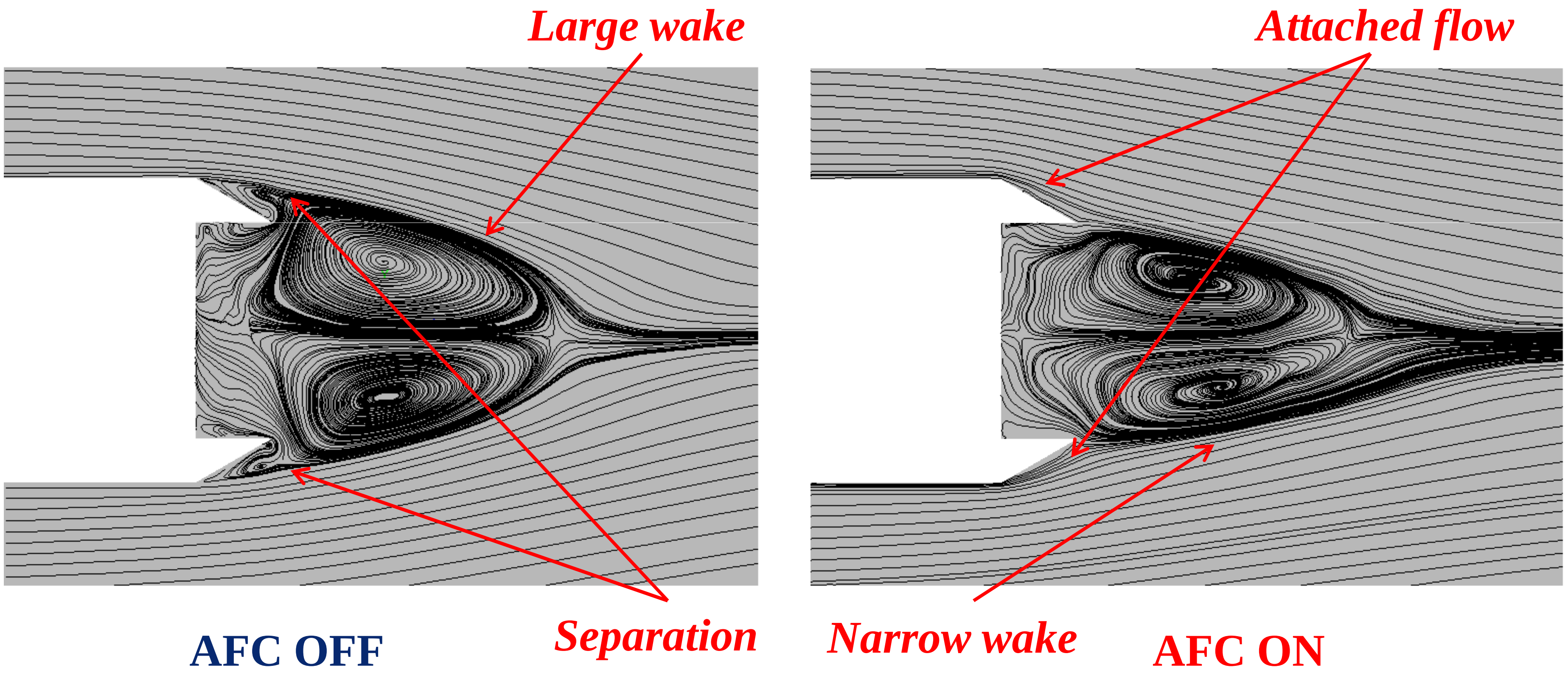
Results

Time-averaged u-velocity, zoom around wake region



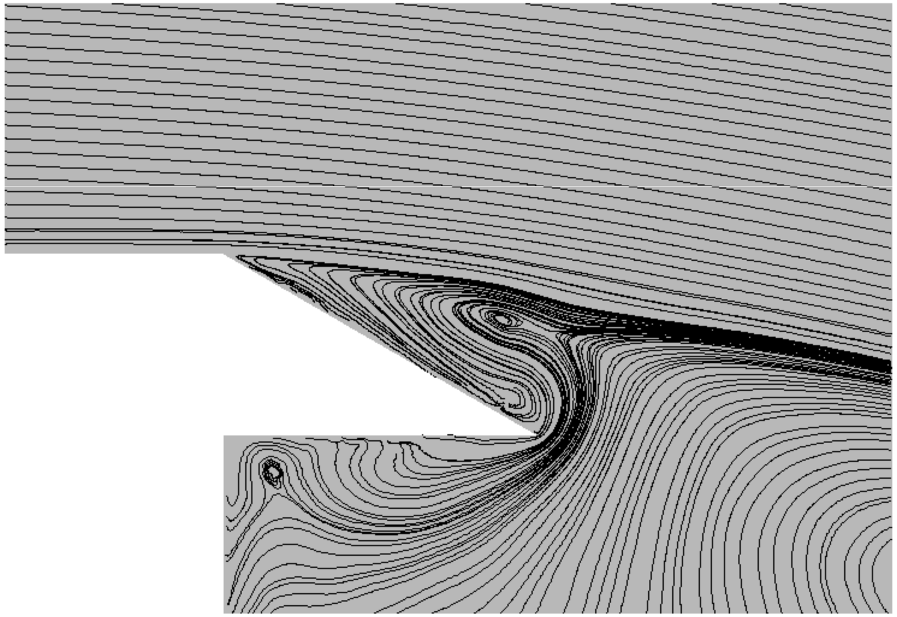
Results

Time-averaged streamlines, zoom around wake region

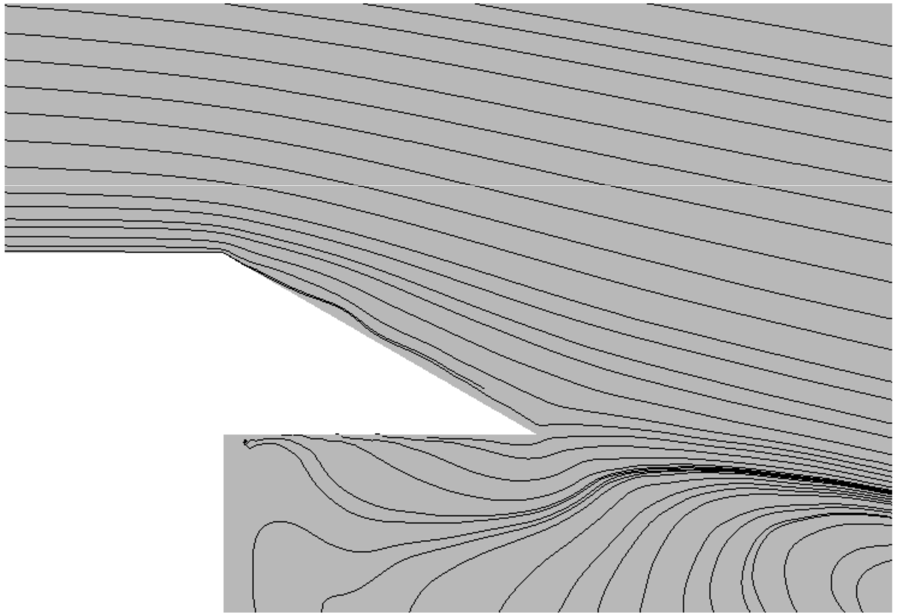


Results

Time-averaged streamlines, zoom around flap region



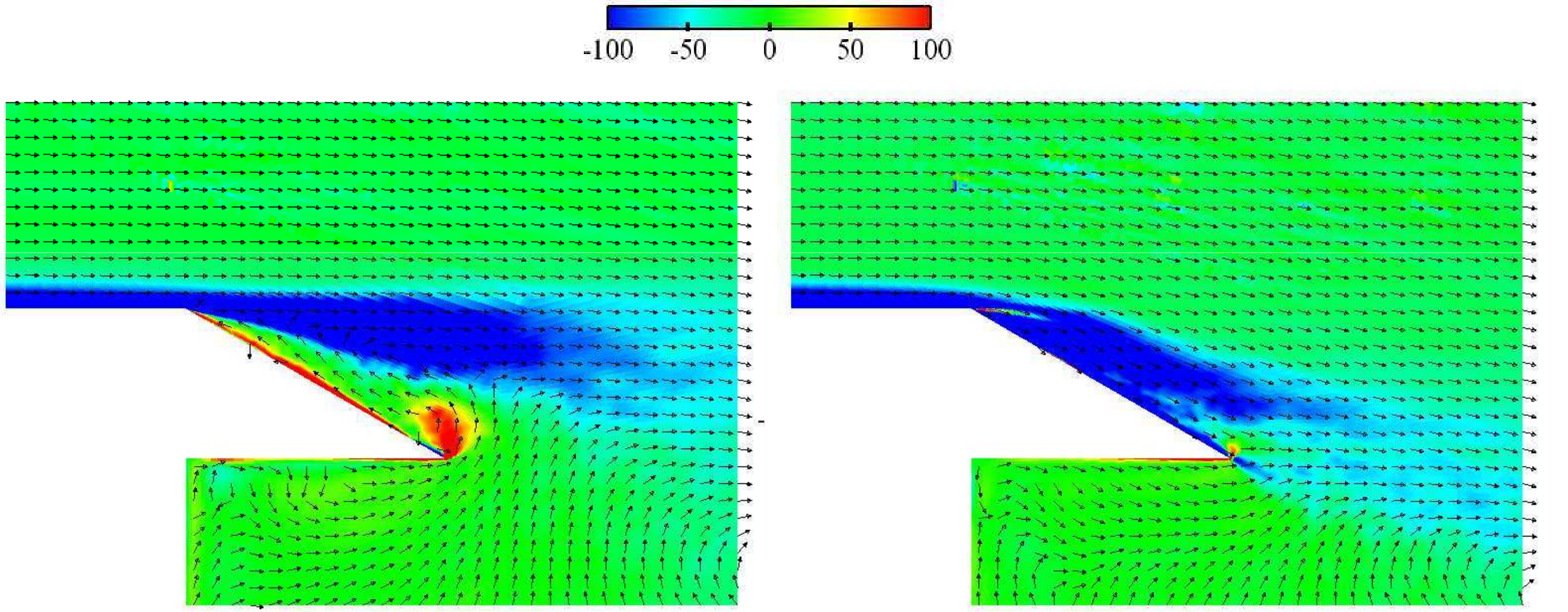
AFC OFF



AFC ON

Results

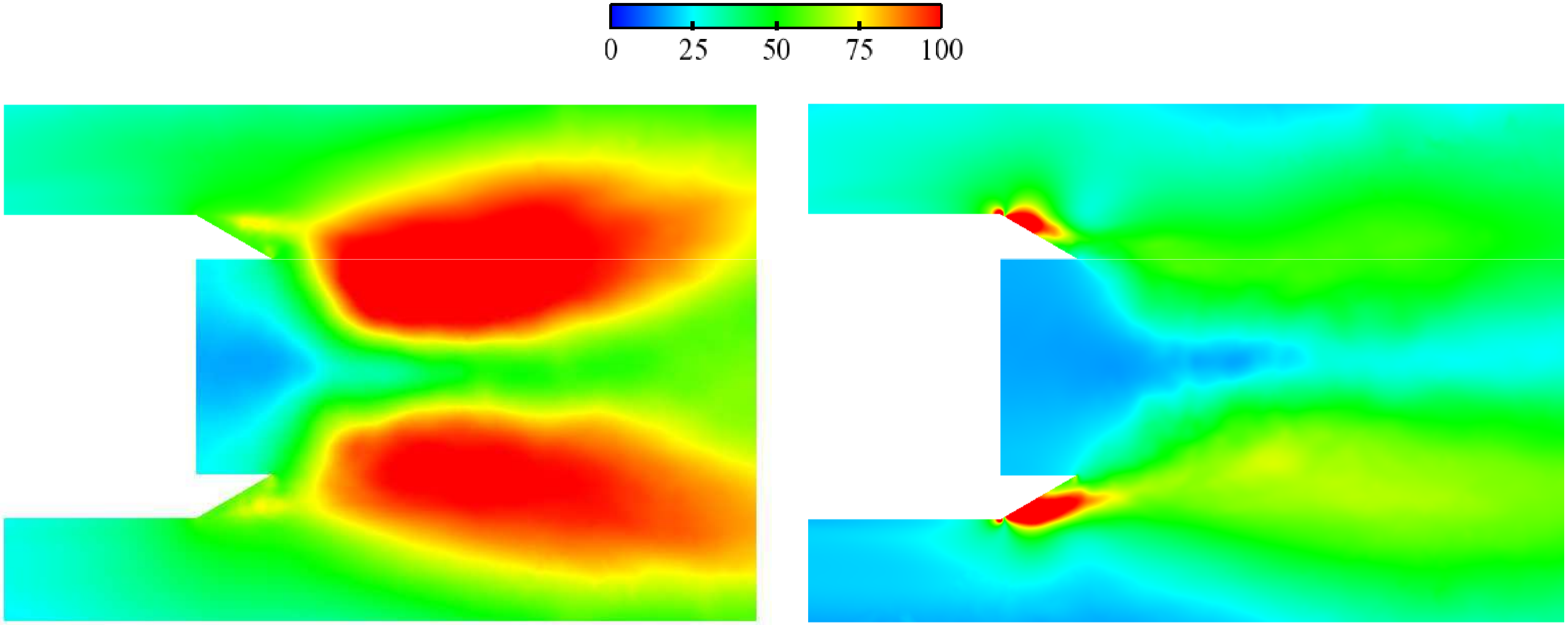
Time-averaged vorticity, zoom around flap region



AFC OFF **AFC ON**

Results

RMS of pressure, zoom around wake region

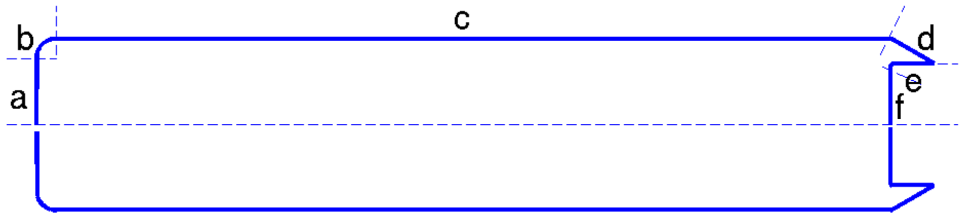


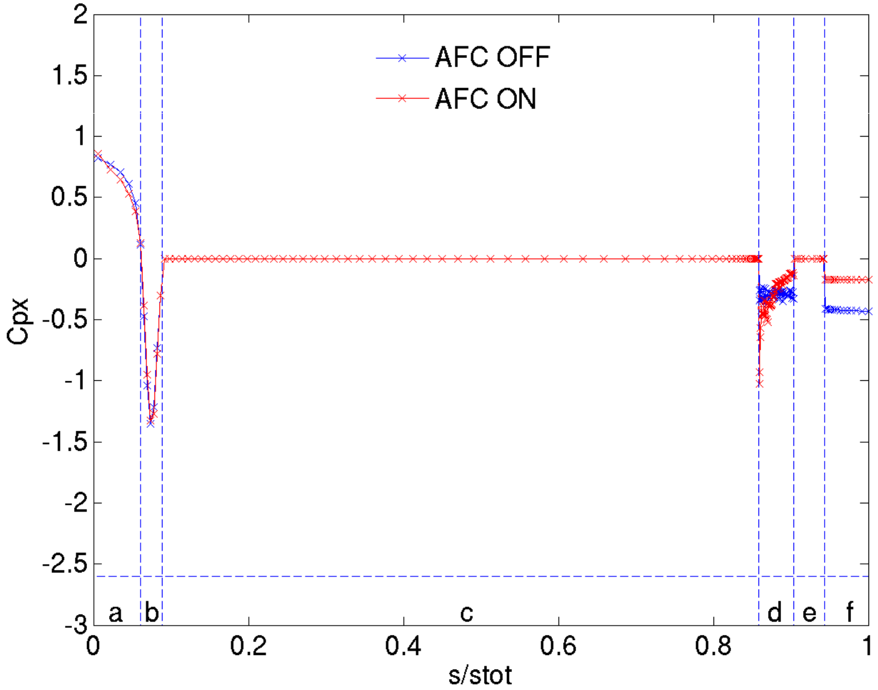
AFC OFF

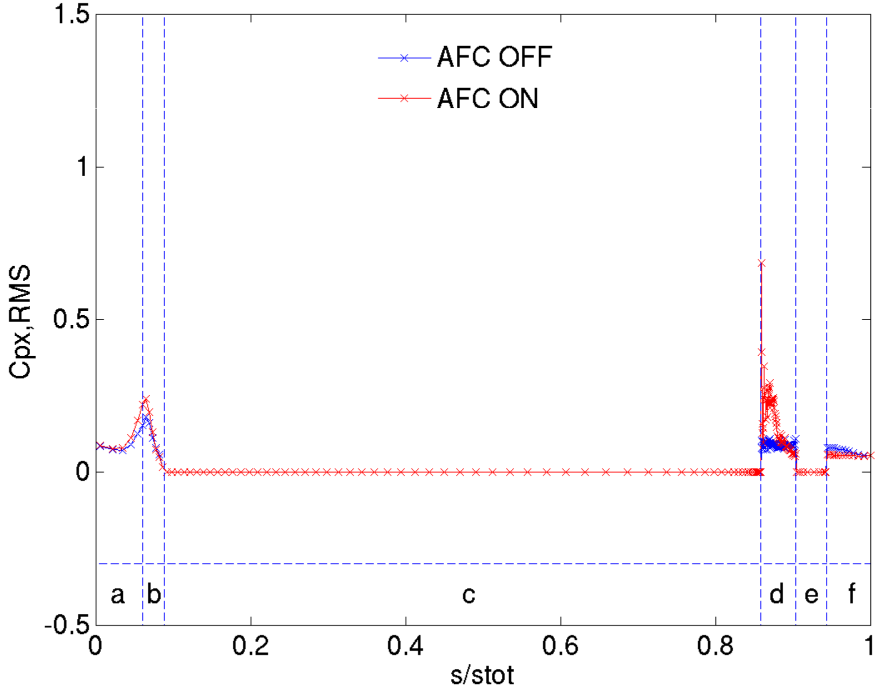
AFC ON

Results

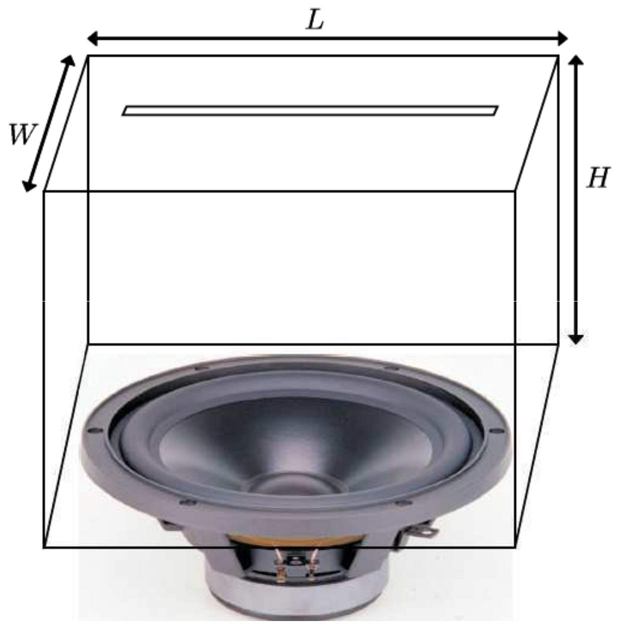
Surface pressure distribution







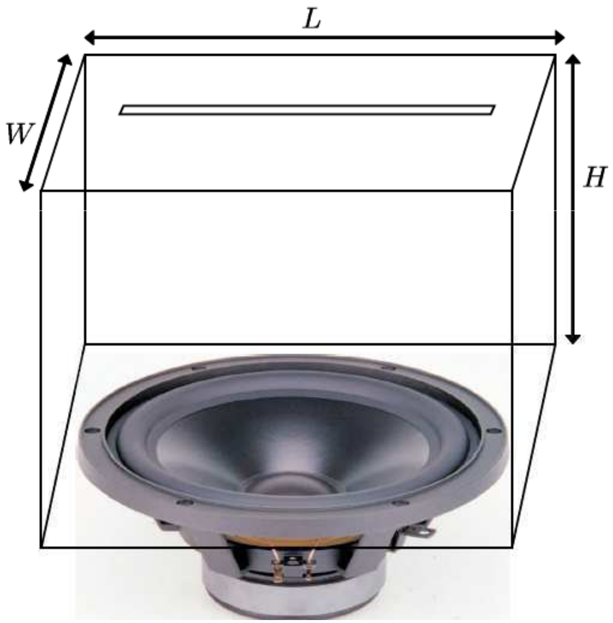
Second step: Built and test of actuator



Simple synthetic-jet actuator

Max velocity – max C_μ?
Slotwidth, speaker, cavity volume?

Third step: Build the prototype model



Simple synthetic-jet actuator

Forth step: Full scale test of the prototype model

VOLVO

November 2009

Hällered proving ground

Conclusions

- Drag reduction of 25-30%
  - Flow reatachment
  - Narrower wake size
  - Less intensive wake
  - Increased base pressure
- AFC works well for bluff bodies

Future work

- Optimization using RSM
- Parallellizing FlowPhys and/or using DES with STAR-CD
  - Fully 3D bluff body with AFC
  - Fully detailed truck-trailer with AFC
- More analysis on the drag reduction mechanism
- Study more applications of AFC

Thank you!

Questions