Project MaKoS - Manipulation and Control of Turbulent Flow

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Contents

The Objective of MaKoS

The **overall objective of the project** is to develop methods leading to an effective drag minimization by an active, energy-efficient and robust manipulation and control of the turbulent flow which leads to a reduction in fuel consumption of commercial aircrafts.

Scientific aims:

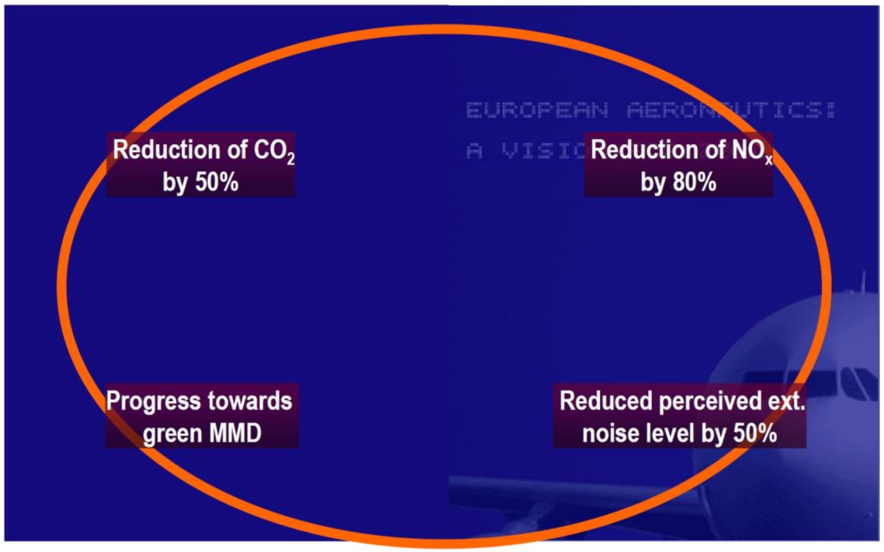
- Understanding of the action mechanism and interactions of turbulent structures
- Research of effective methods for manipulating very-large structures in the turbulent flow which have an effect on total drag reduction

Technological aims:

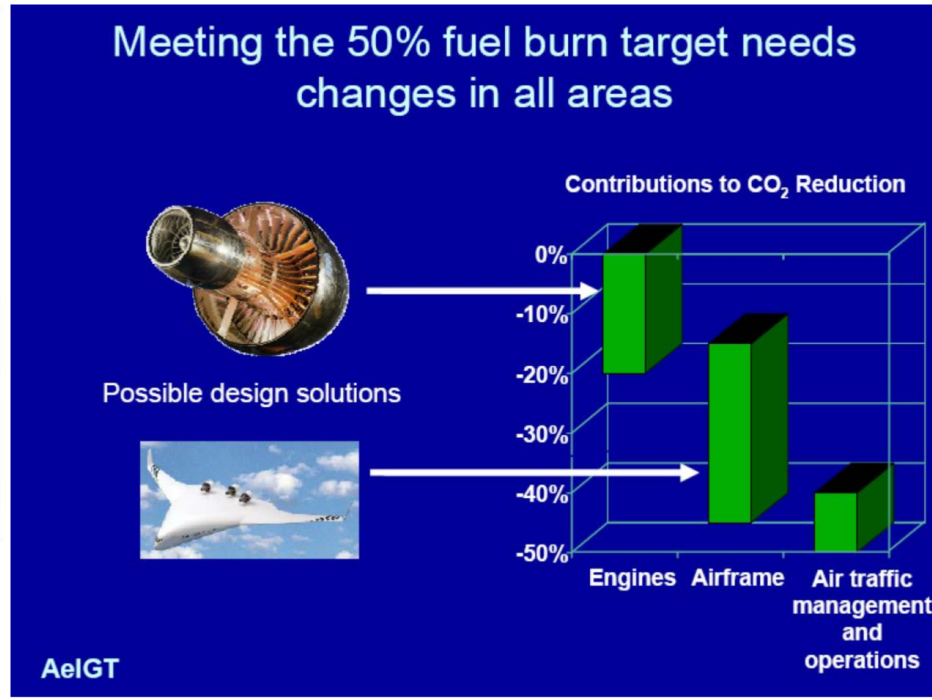
- The development of actuators for active manipulation of the turbulent flow
- The development of suitable sensor technology establishing a close loop control
- Demonstration of the system's efficiency regarding the total drag reduction

The Objective of MaKoS
ACARE Vision 2020 - Environment

Goals for the environment



Die Zukunft der Luftfahrt, Joachim Szodruch 2006



Potential for fuel burn reduction:

Engine: ~20%
Airframe: ~25%
ATM: ~10%

ACARE goals C.-C. Rossow 2007

Flightpath 2050

The Objective of MaKoS

55% of total drag = viscous drag

⇩

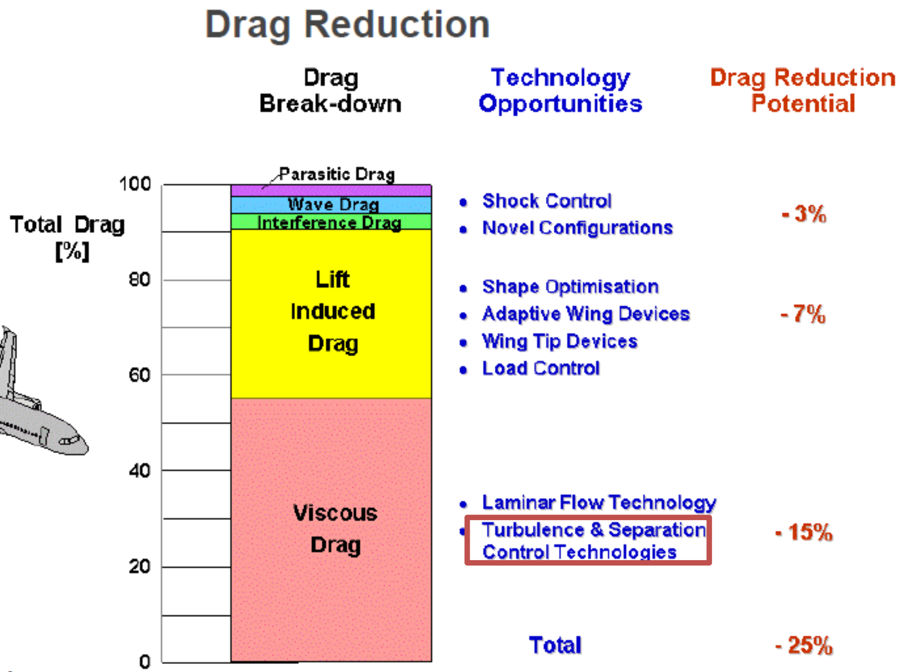
Drag reduction by active flow control

⇩

Fuel reduction

⇩

CO_2 reduction

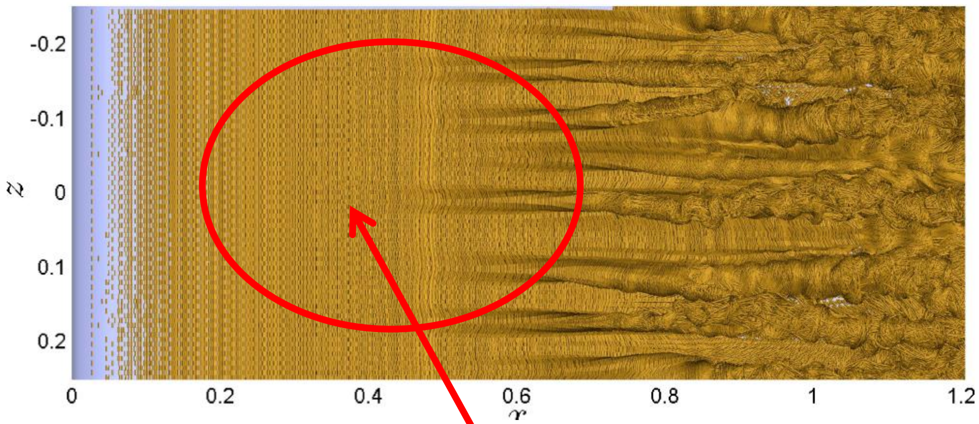


Source:
Geza Schrauf,
KATnet
Key Aerodynamic Technologies

ACARE goals C.-C. Rossow 2007

Flightpath 2050

Delimitation of other projects



FOR 1779

EU-China DRAGY

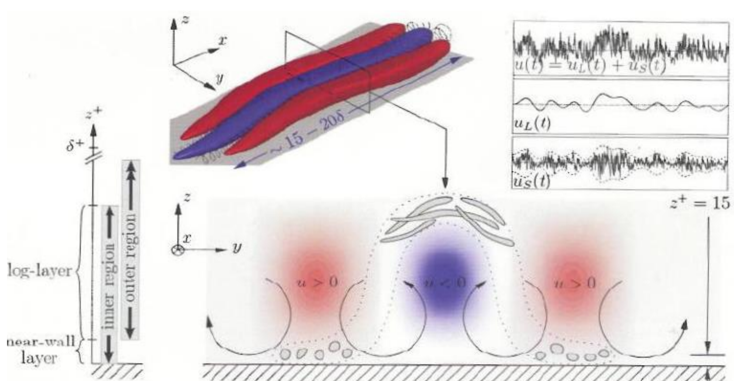
AKSA

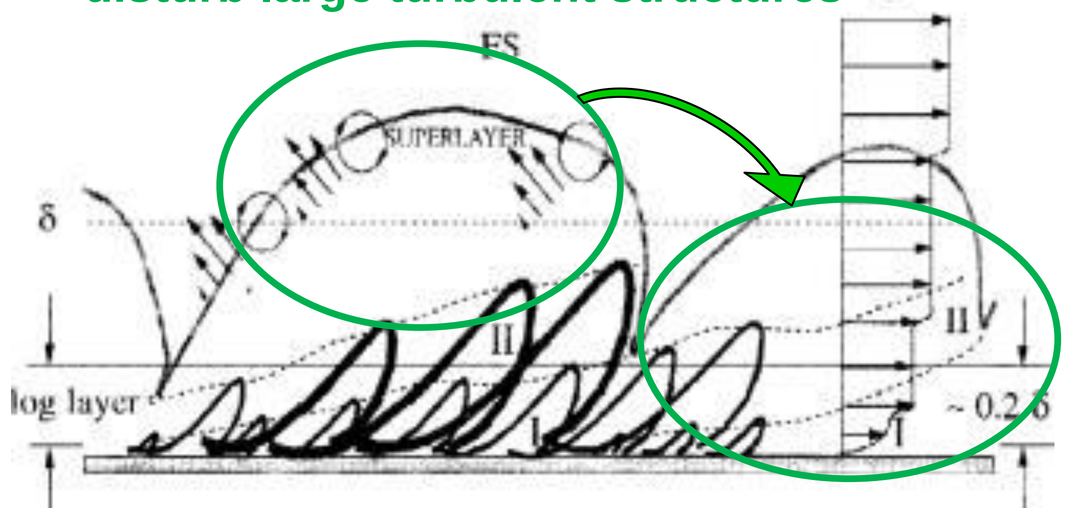
„Active Control of Disturbances in Aerodynamics“

MaKoS:

disturb large turbulent structures

Marusic 2008

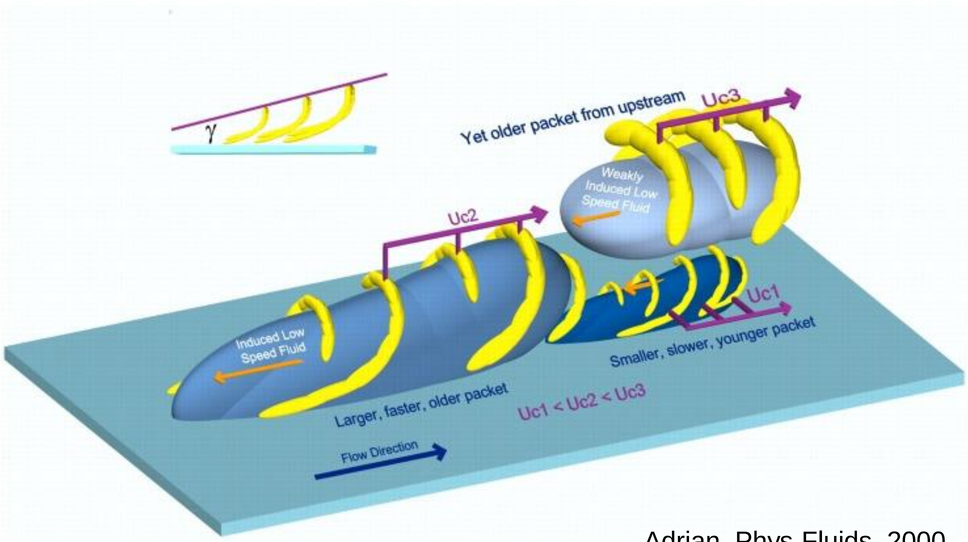




MaKoS: also spanwise forcing of large scale turbulent structures

Physical background
Very large structures

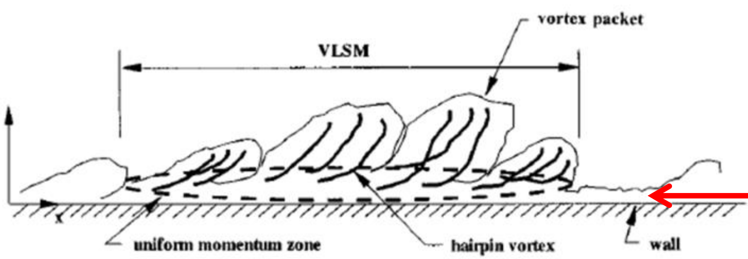
Overlaying "packets" collapse
→ New „hairpin vortices“ arise
→ The cycle repeats from the beginning



Adrian, Phys Fluids, 2000

Kima, Adrian, Phys Fluids, 1999

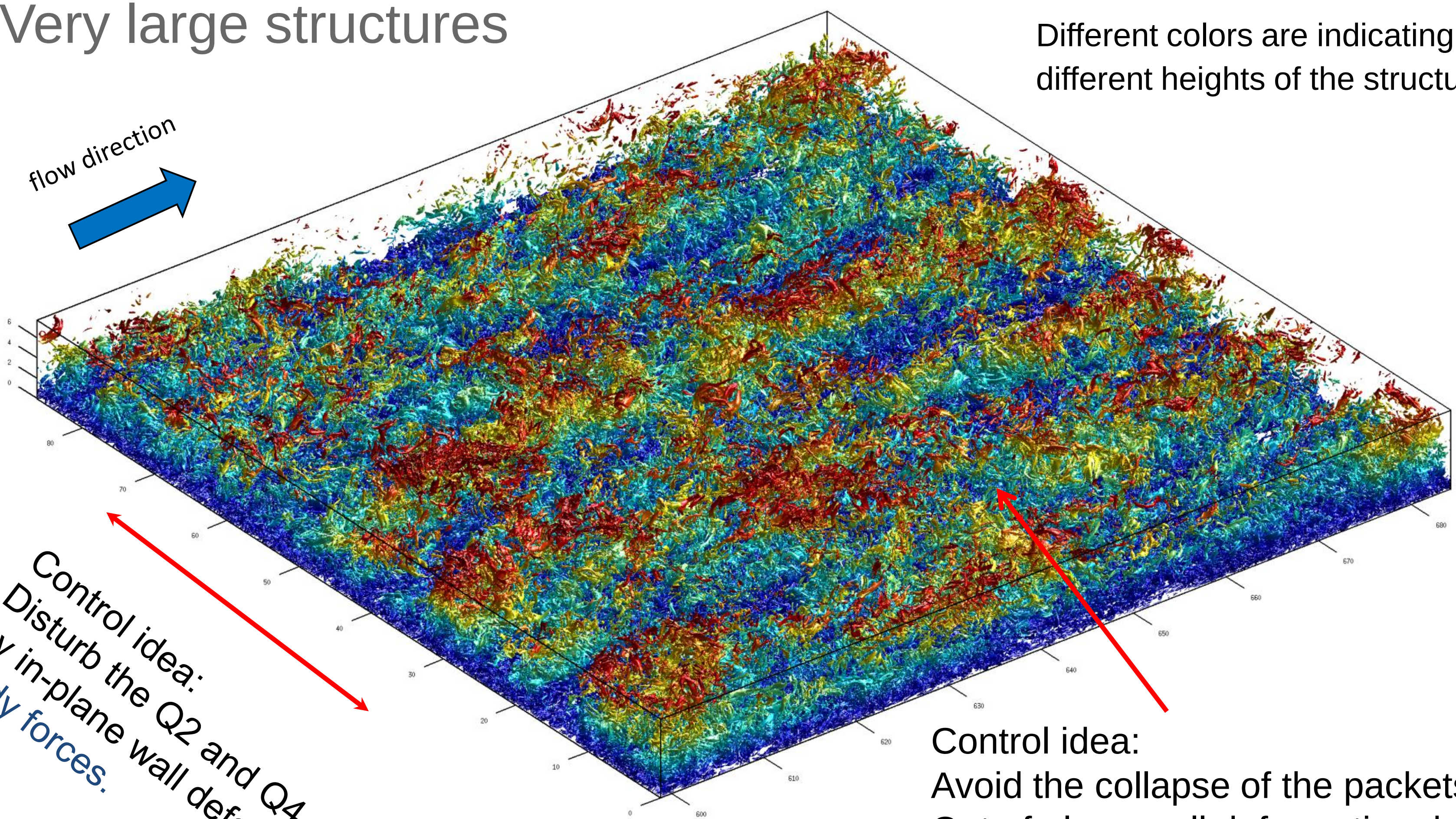
Control idea:
Avoid the collapse of the packets.
Out of plane wall deformation, forces, fluid jets, synthetic jets …



Control idea:
Change „globals“ $\nu_t \downarrow$

Physical background
Very large structures

Different colors are indicating different heights of the structures.



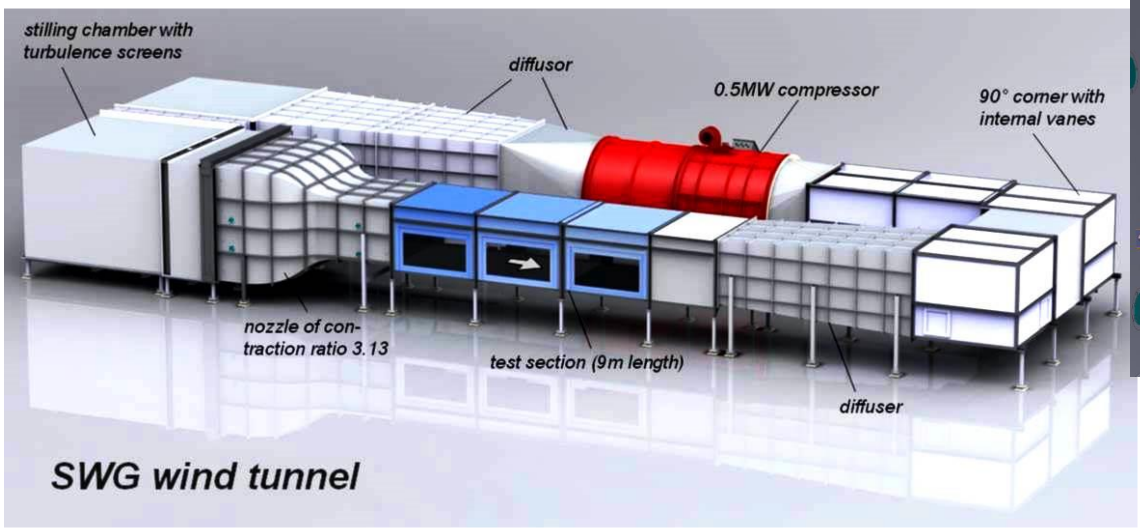
Control idea:
Disturb the Q2 and Q4 effects by in-plane wall deformation, body forces.

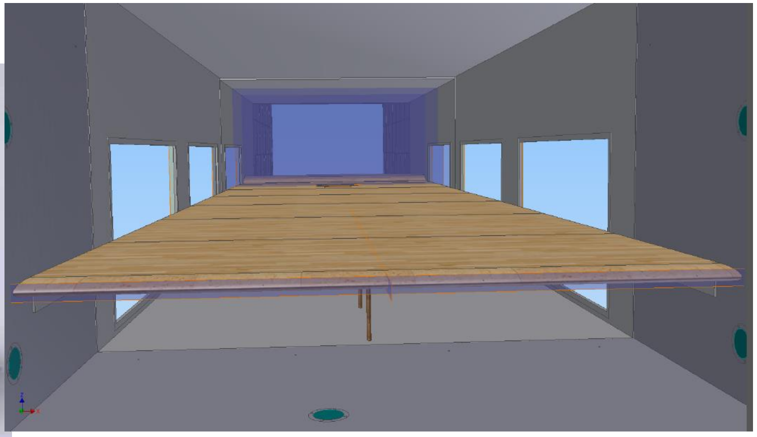
Schlatter, EJM, B/Fluids 2014

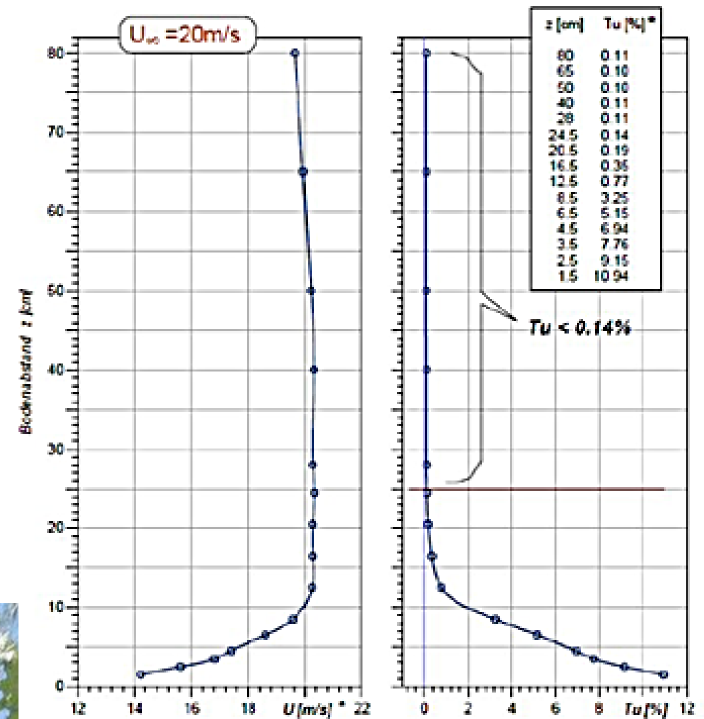
Control idea:
Avoid the collapse of the packets.
Out of plane wall deformation, body forces, fluid jets, synthetic jets …

Experimental setup

Cross Wind Facility Göttingen (SWG)







- test section 9 m x 2.4 m x 1.6 m
- freestream velocity $U_\infty = 15\ \frac{m}{s}$
- $Re_x = 7 \cdot 10^6,\ x = 6.5\ m$
- $Re_\theta = 10{,}000$
- boundary layer thickness $\delta = 105\ mm$
- y+ ~ 19 µm

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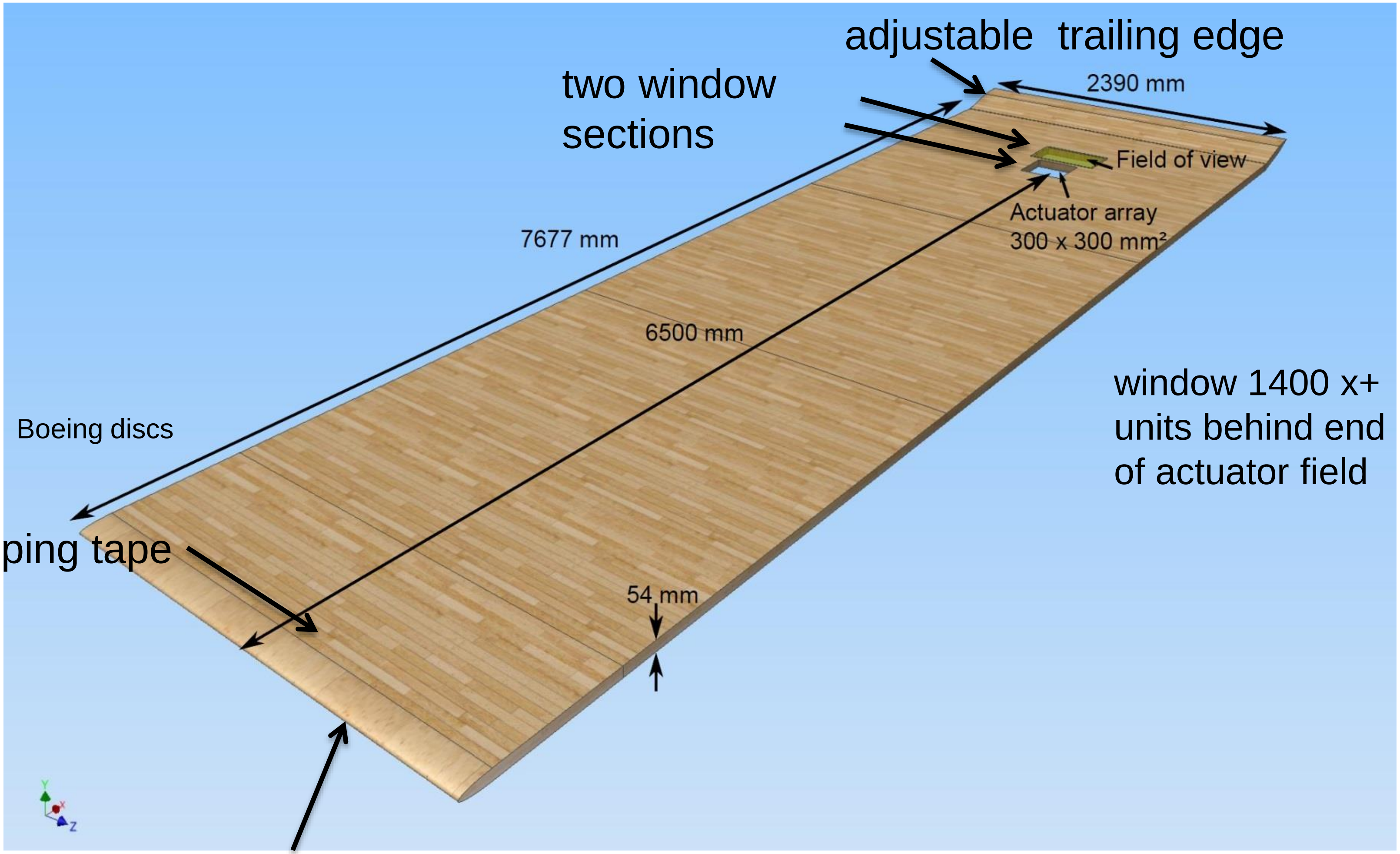
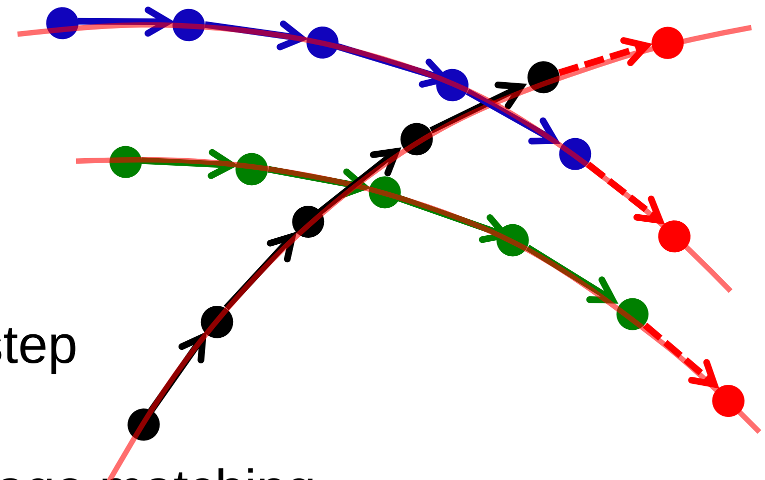
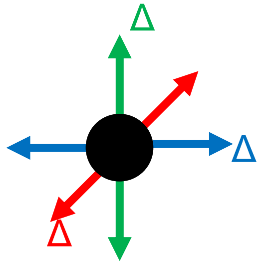
Experimental setup
Flat plate model



Experimental setup
Multi-pulse Shake the Box (STB) **3D Particle Tracking**



- Lagrangian particle tracking at high particle image density
- Seizing temporal information:
  Prediction of particle positions in next step
- **Correction** of the prediction error by image matching
  ‚shaking' the particle in 3D space until residual is minimized



STB group:
Andreas Schröder, Daniel Schanz,
Mateo Novara, Reinhard Geisler

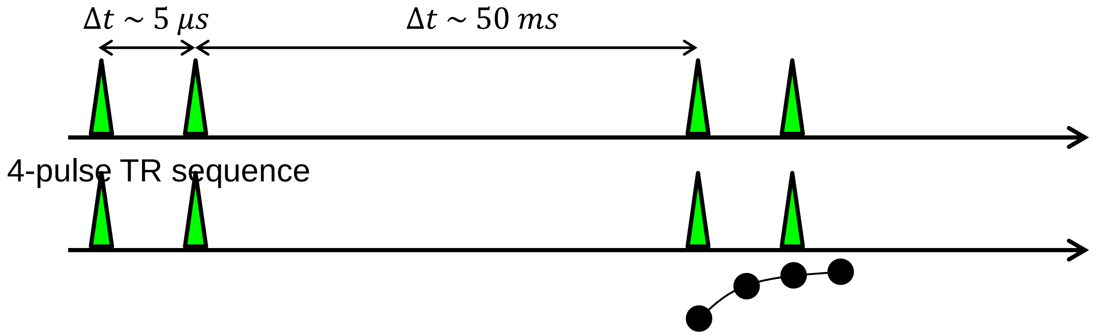
Schanz D. et al. “Shake-The-Box: Lagrangian particle tracking at high particle image densities” Exp. Fluids **57:70**

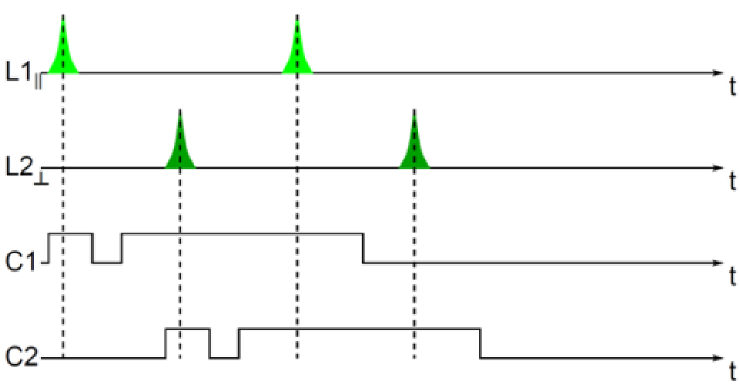
Wieneke B. “Iterative Reconstruction Of Volumetric Particle Distribution” Meas. Sci. Technol. **24** 024008 (2013)

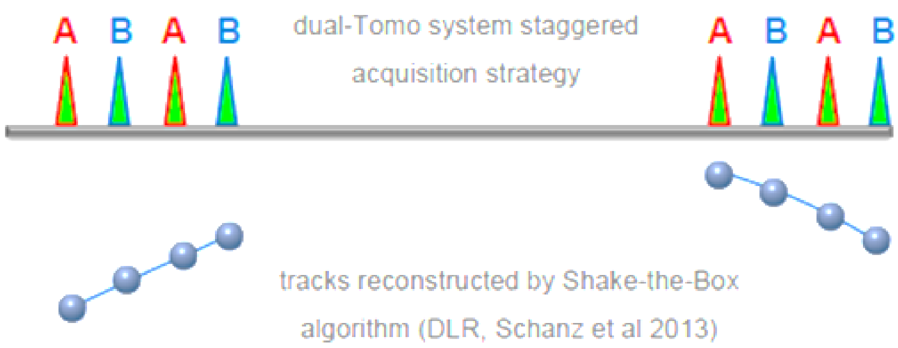
Experimental setup
Multi-pulse STB

High-speed applications:

❖ multi-pulse systems







slide prepared by Matteo Novara

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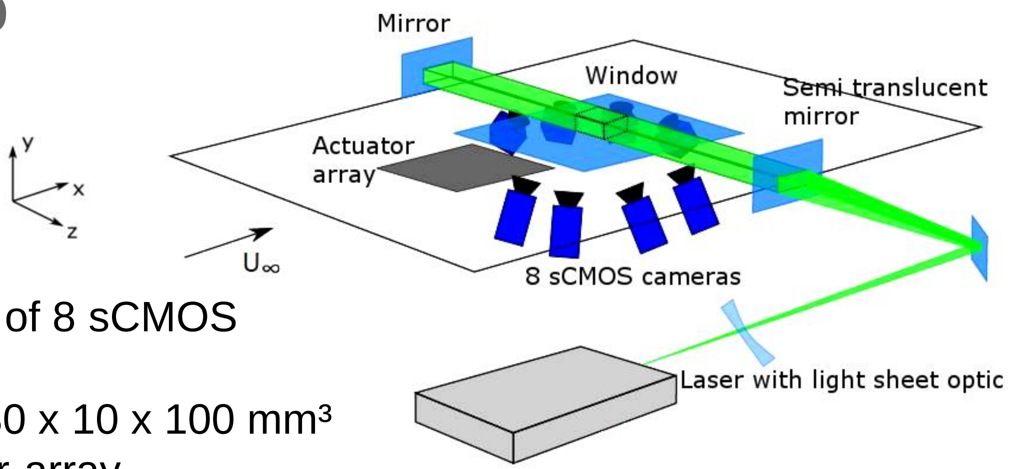
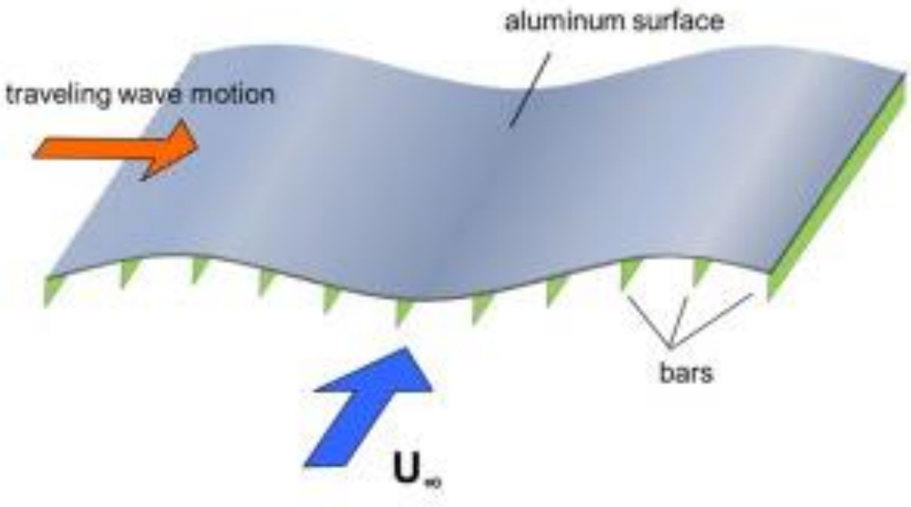
Experimental setup
Multi-pulse STB



- Multi-pulse-system consisting of 8 sCMOS cameras
- Field of view (FOV) of about 80 x 10 x 100 mm³ (x, y, z), 8 mm behind actuator-array
- Recording frequency: 10 Hz

Experimental setup

Actuation concept: spanwise travelling wave at y+~ 12-15
Institut für Mikrosystemtechnik der Universität Freiburg (IMTEK)



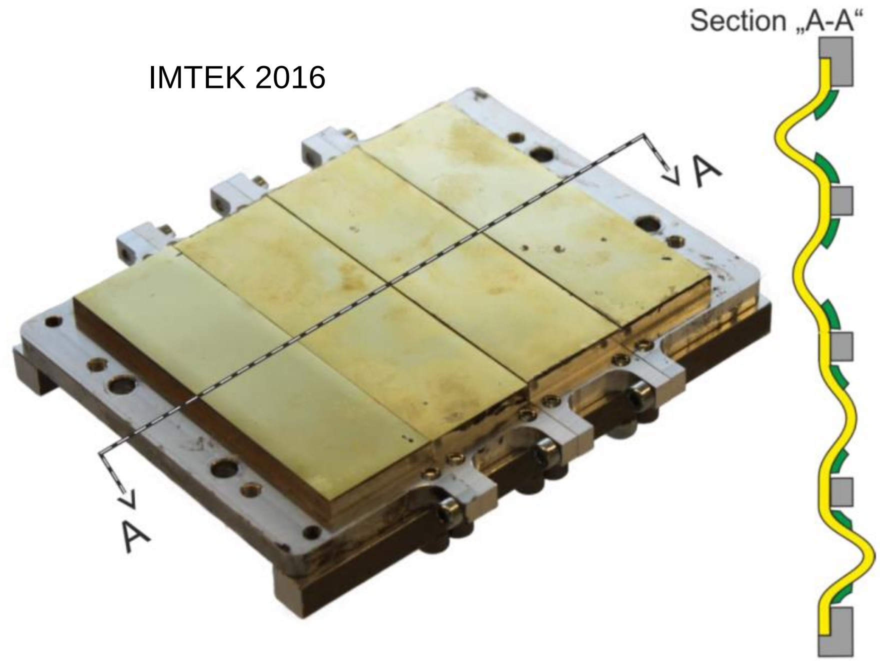
Li, Europ. J. Mechanics B/ Fluids, 2015

- Drag reduction by spanwise traveling wave having an impact on the near-wall streaks
- Spanwise-oriented volume forcing caused by waves traveling in spanwise direction
- Weakening and flattening of the quasi-streamwise vortices
- Drop in shear stress and skin friction due to rising three-dimensional skewing (Touber & Leschziner, J. Fluid Mechanics, 2012)

Experimental setup

Actuator type: piezo resonance actuator IMTEK

- piezo – actuator consisting of 4 modules
- brass membrane is put into resonance by the piezo-stack actuator
- high resonance frequency
- small mechanical stroke which can be maximized by using the resonance of the cover plate

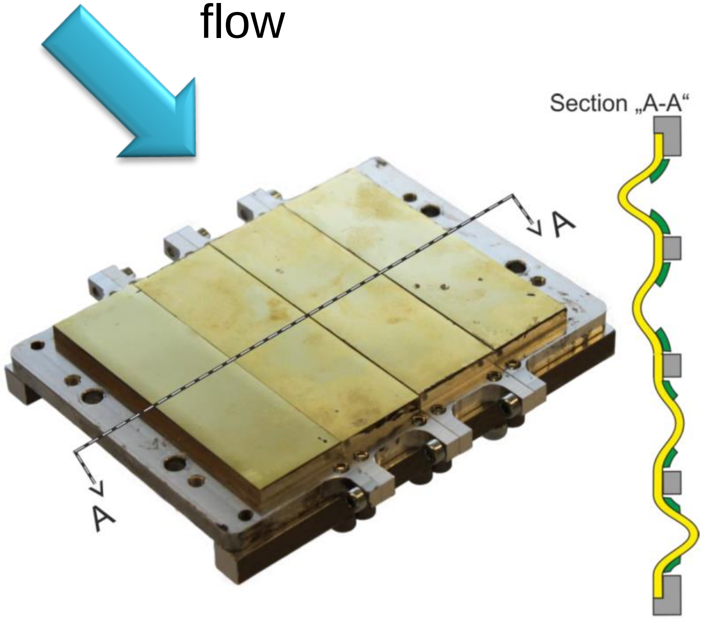


Experimental setup

Actuator type: piezo resonance actuator IMTEK

Re_θ	phase between modules	frequency	amplitude
10000	0°	1,2 kHz	150 µm
10000	90°	1,2 kHz	150 µm
10000	120°	1,2 kHz	150 µm
10000	180°	1,2 kHz	150 µm
10000	90°	1,2 kHz	230 µm
10000	0°	1,2 kHz	230 µm

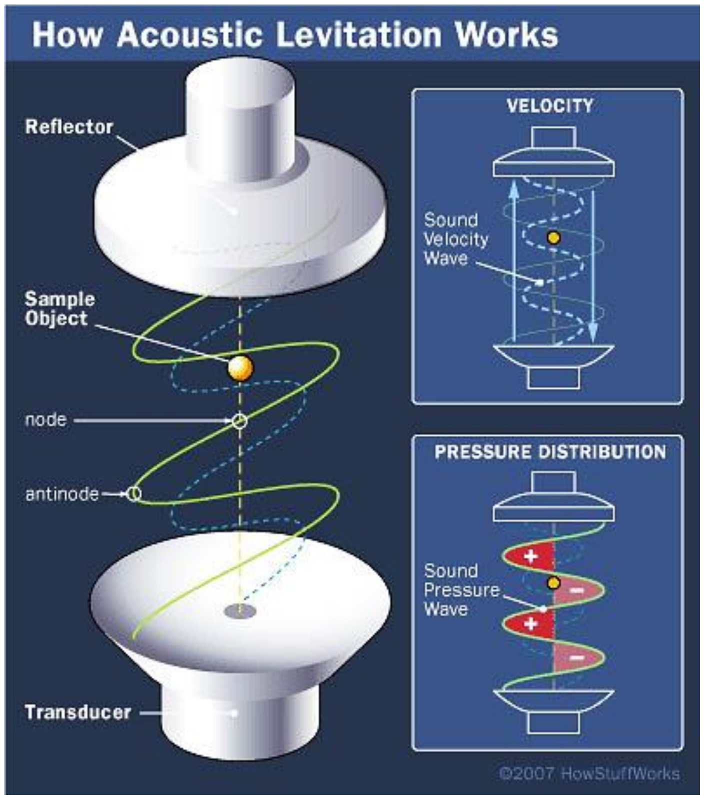
y+ ~ 19 µm



gaps between the four elements

Experimental setup

Actuation concept: Blocking large scale structures at y+ 150 - 300
Lehrstuhl für Mikromechanik, Mikrofluidik/Mikroaktorik der Universität des Saarlandes (LMM)



http://science.howstuffworks.com/acoustic-levitation1.htm

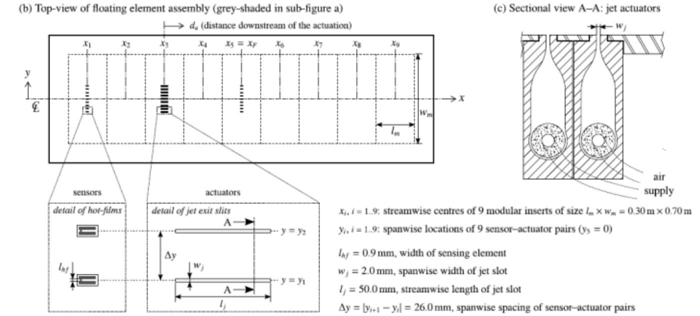


Fig. 2. (a) Schematic of the boundary layer facility at the University of Melbourne with an open view (sidewalls and ceiling removed) of the test section, indicating the floating element assembly (Baars et al., 2016b). (b) Top-view of the floating element assembly with the real-time control hardware implemented in the wind tunnel surface. (c) Cross-sectional view A–A, indicated in sub-figure (b), of the jet actuators.

M.R. Abbassi, W.J. Baars, N. Hutchins, I. Marusic: „Skin-friction drag reduction in a high-Reynolds-number turbulent boundary layer via real-time control of large-scale structures", International Journal of Heat and Fluid, Vol. 1, pp. 1–12 (2017)

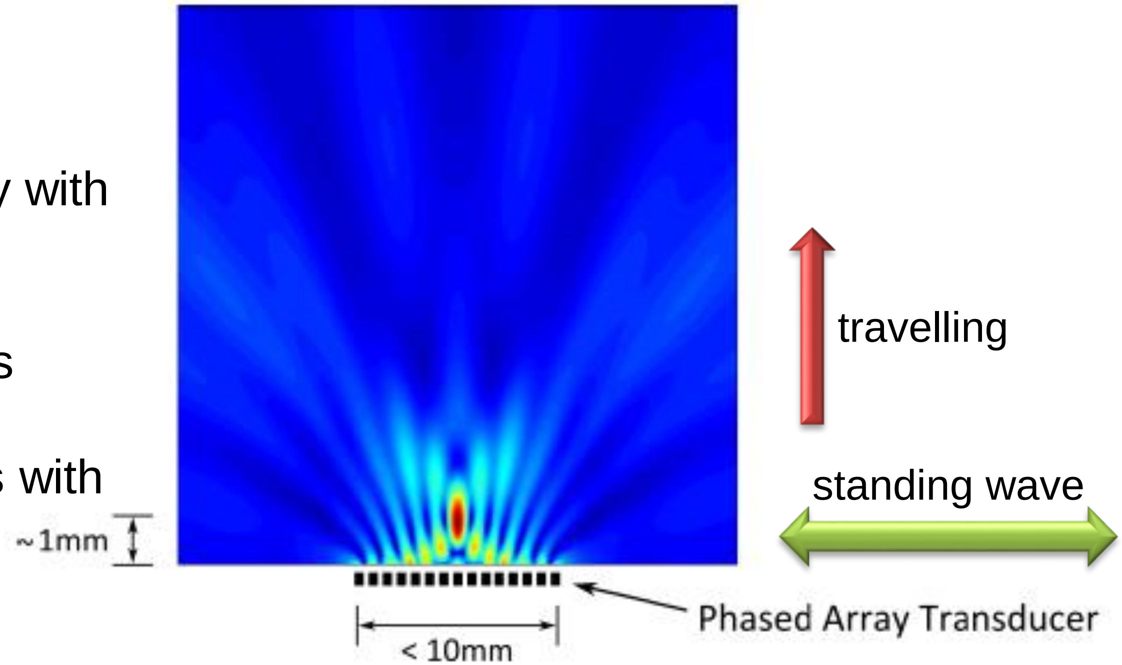
- Creation of a standing wave between loudspeaker and reflector
- Acoustic levitation leads to manipulation of the turbulent flow
- High frequency achievable

Control idea:
blocking / destroying very large scale turbulent structures

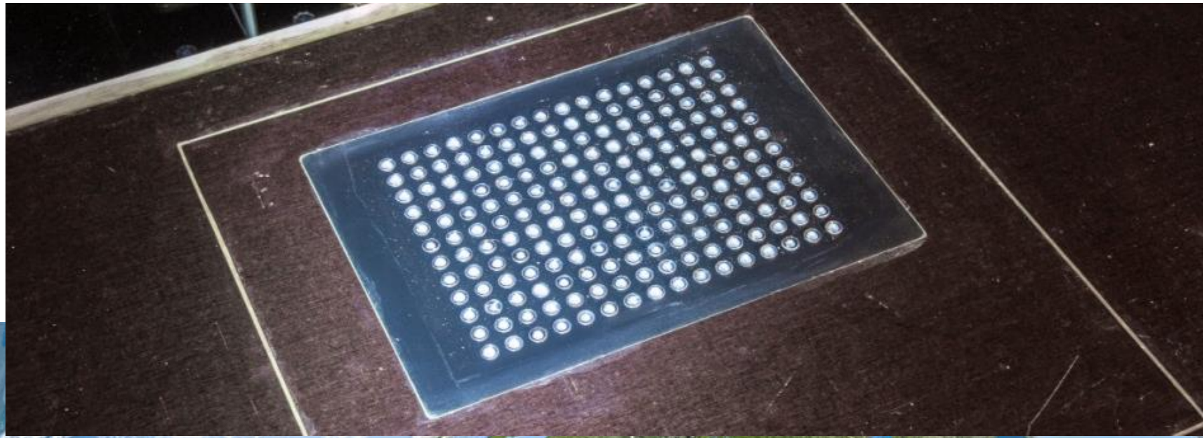
Experimental setup

Actuator type: acoustic ultrasonic knot field
LMM

- In – plane loudspeaker array with 192 ultrasonic transmitters
- 4 synchronized control cards
- Modelling of standing waves with different properties



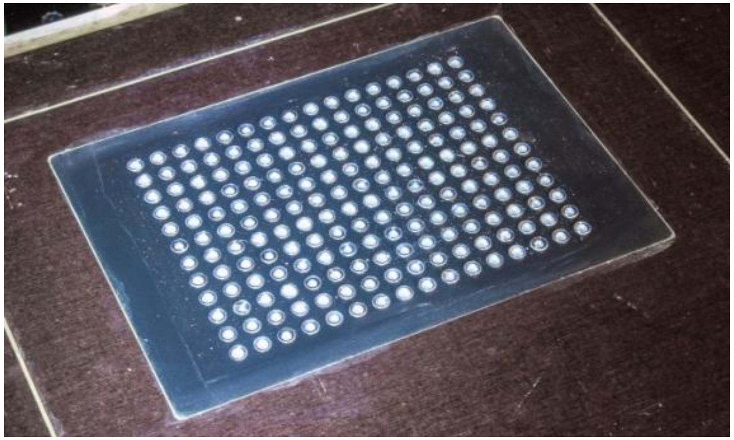
Christian Kiefer, LMM (2015)



Experimental setup

Actuator type: acoustic ultrasonic knot field
LMM

Re_θ	focal point position	voltage
10000	4x4 foci, 1cm wall distance	13,5 V
10000	2 foci in the mid of arrays	13 V
10000	maximal focus in array-mid	13 V
10000	convergent wave with wall reflection	13 V
10000	standing wave with wall reflection	13 V
10000	focus in measurement volume (without reflection)	13 V



commercial loudspeakers with cavities - not smooth enough

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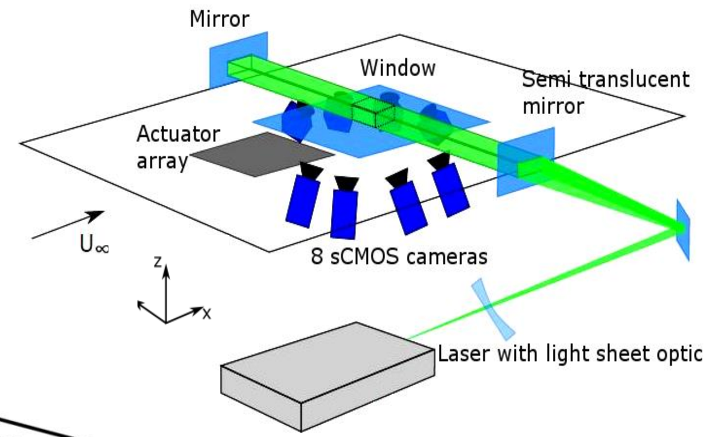
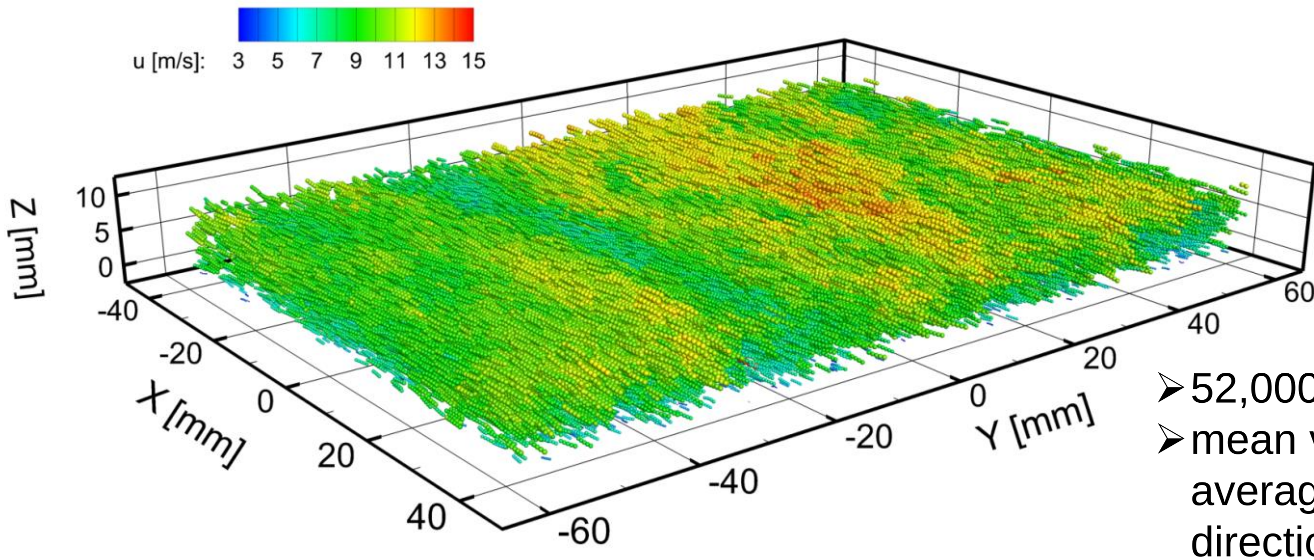
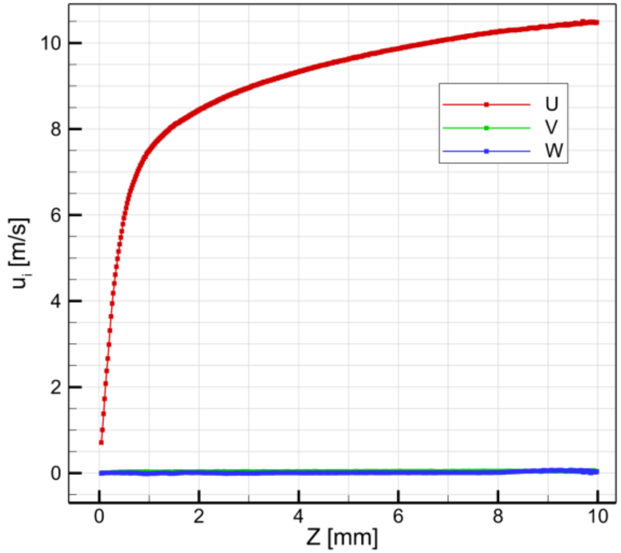
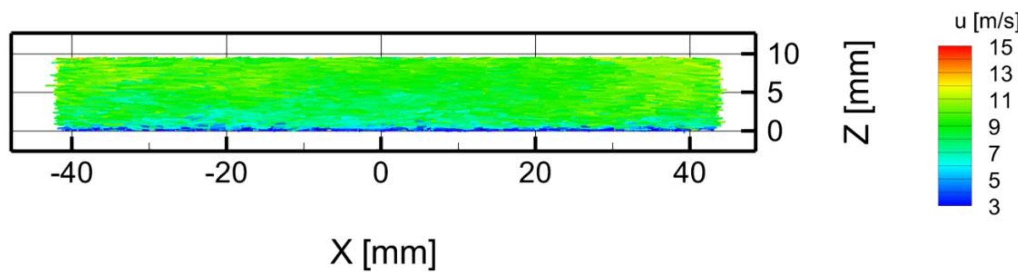
Results
Clean case

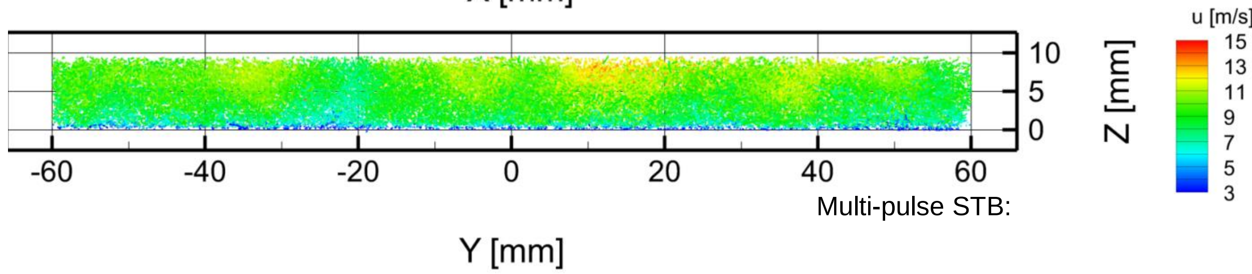




- 52,000 instantaneous tracks
- mean velocity profile, averaged with a bin size in z - direction of 0.5 pixel

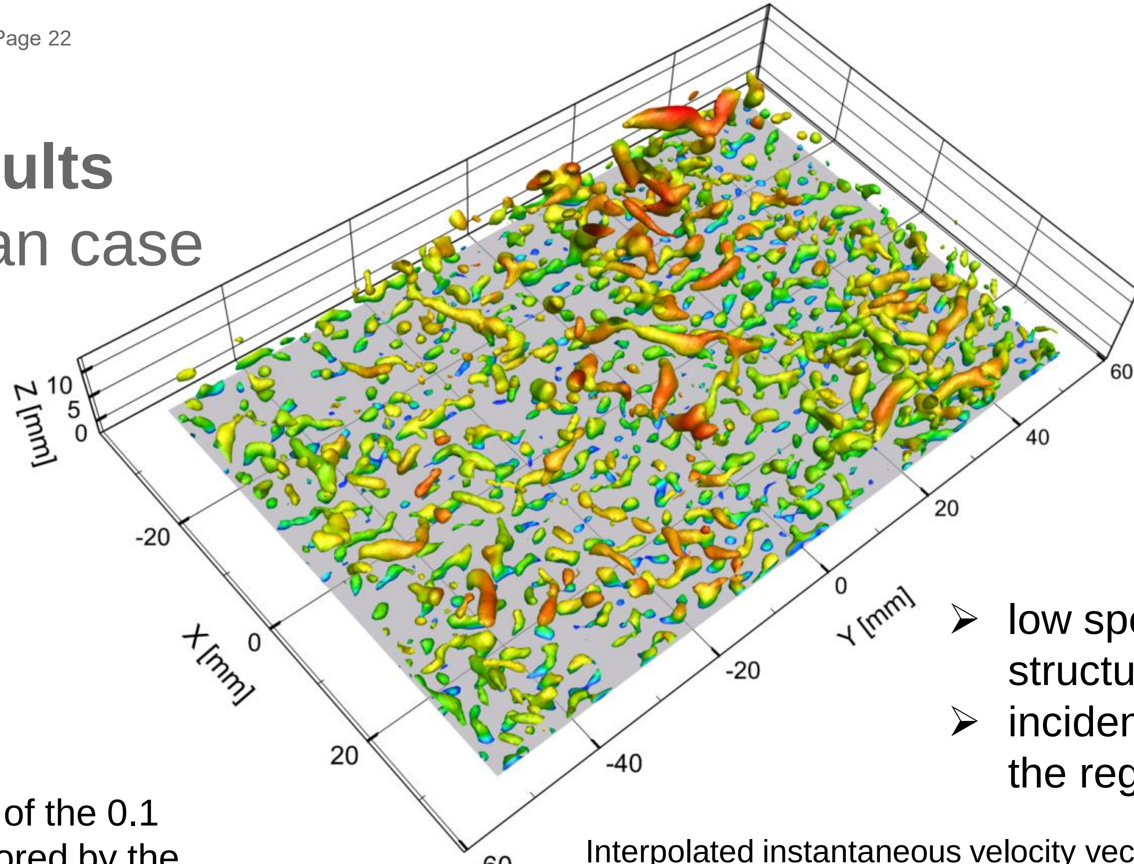


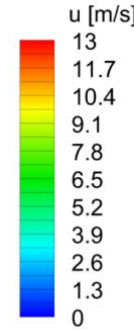




Multi-pulse STB:

Results
Clean case



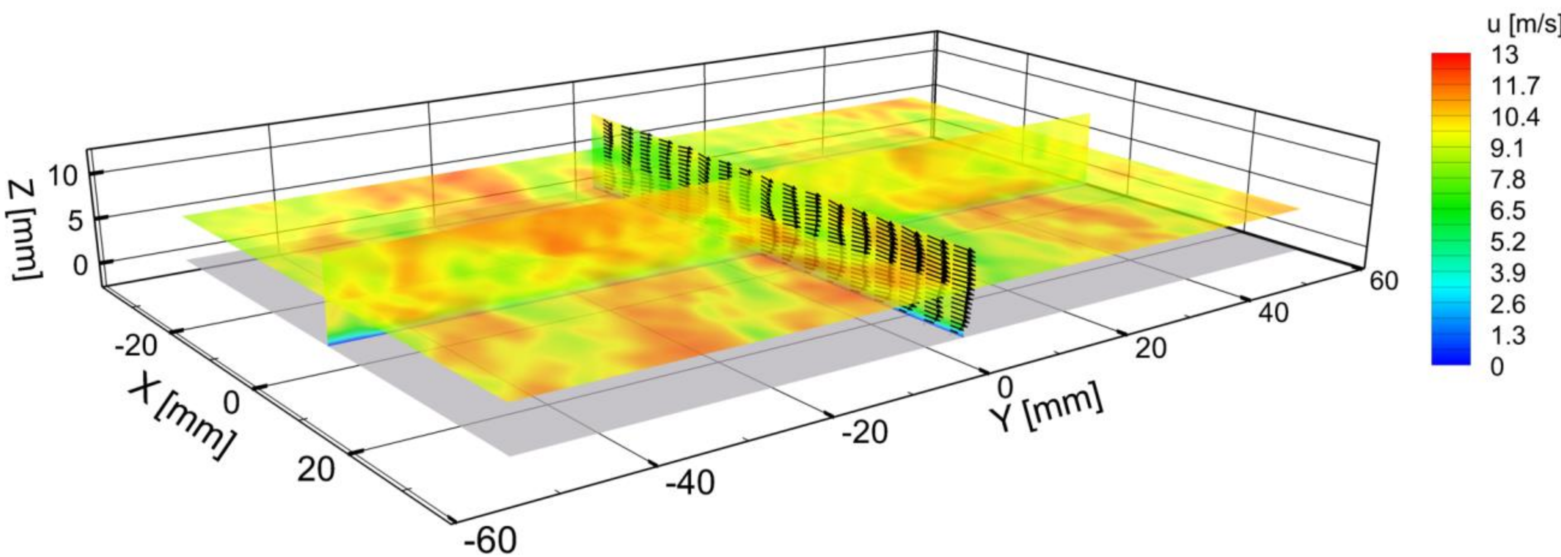


We do not observe hairpins!! (never)

- low speed and high speed streaky structure detectable
- incidence of hairpin-like vortices in the region of low speed streaks

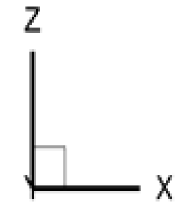
isosurfaces of the 0.1 Q-value colored by the streamwise velocity component

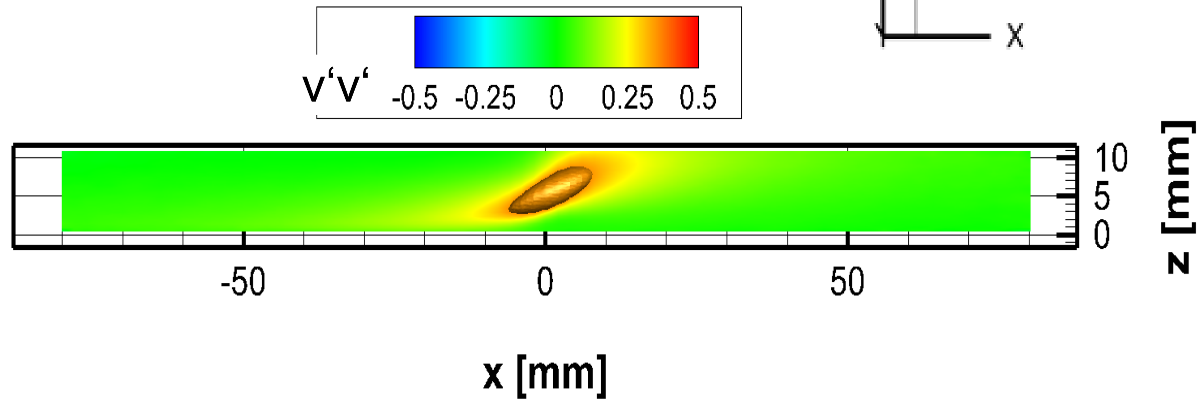
Interpolated instantaneous velocity vector volume from non-linear FlowFit

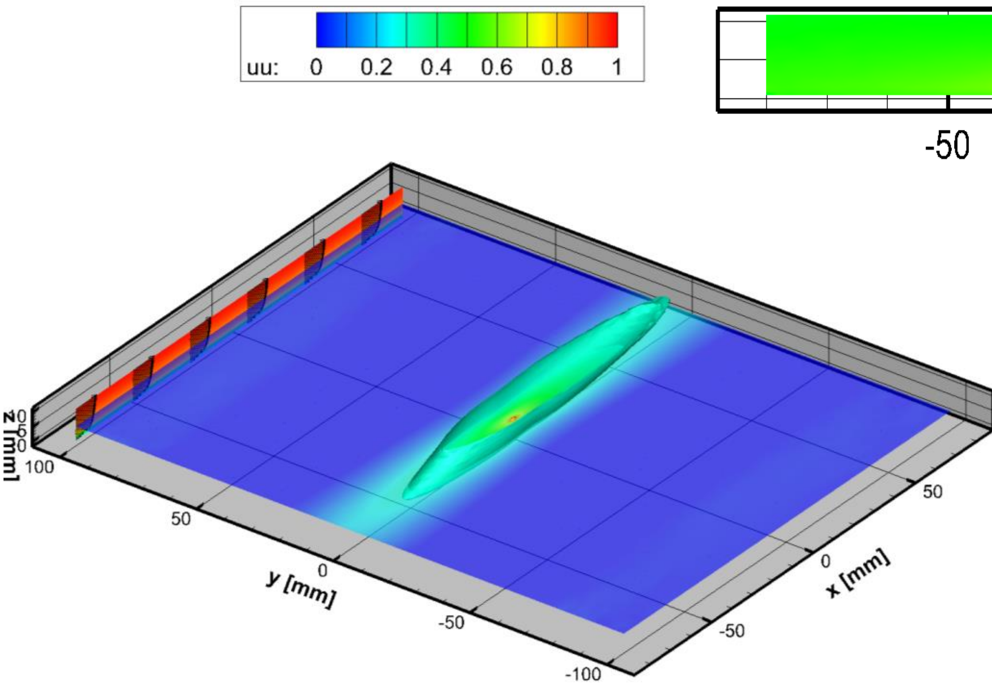


Results
Clean case

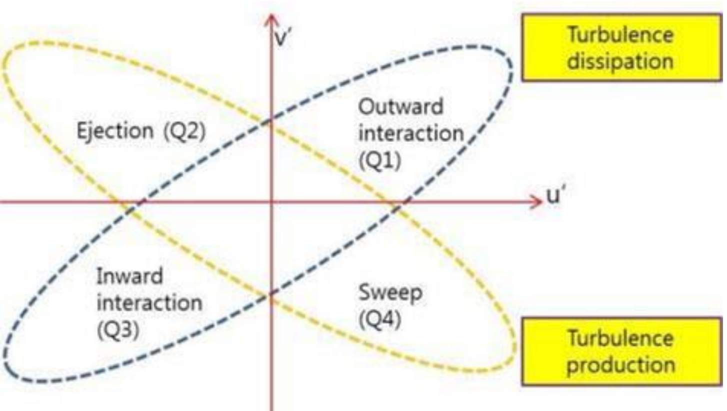
slice through the 2–point–correlation field

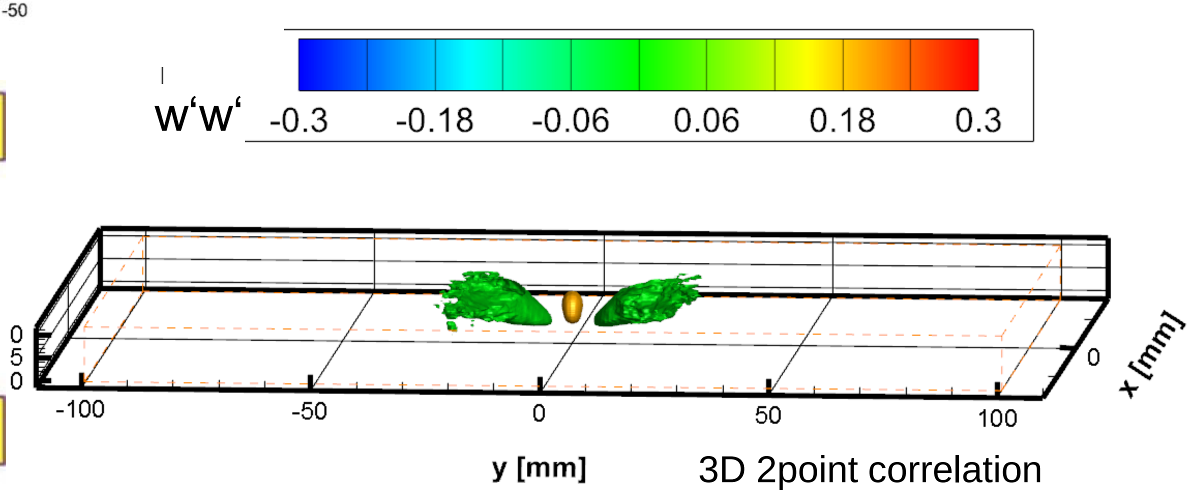




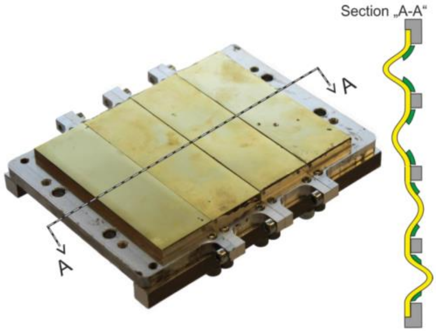


- 2 – point – correlation of u' –, v' – and w' – component at a height of $z^+ = 140$
- elongation of correlation region due to different velocity at increasing heights





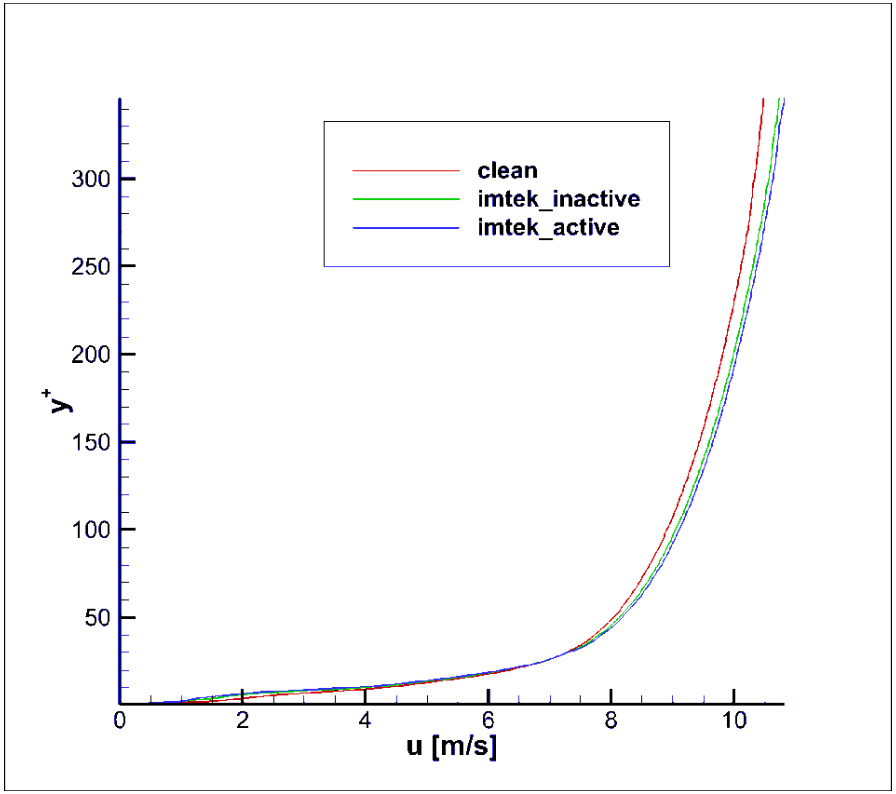
3D 2point correlation

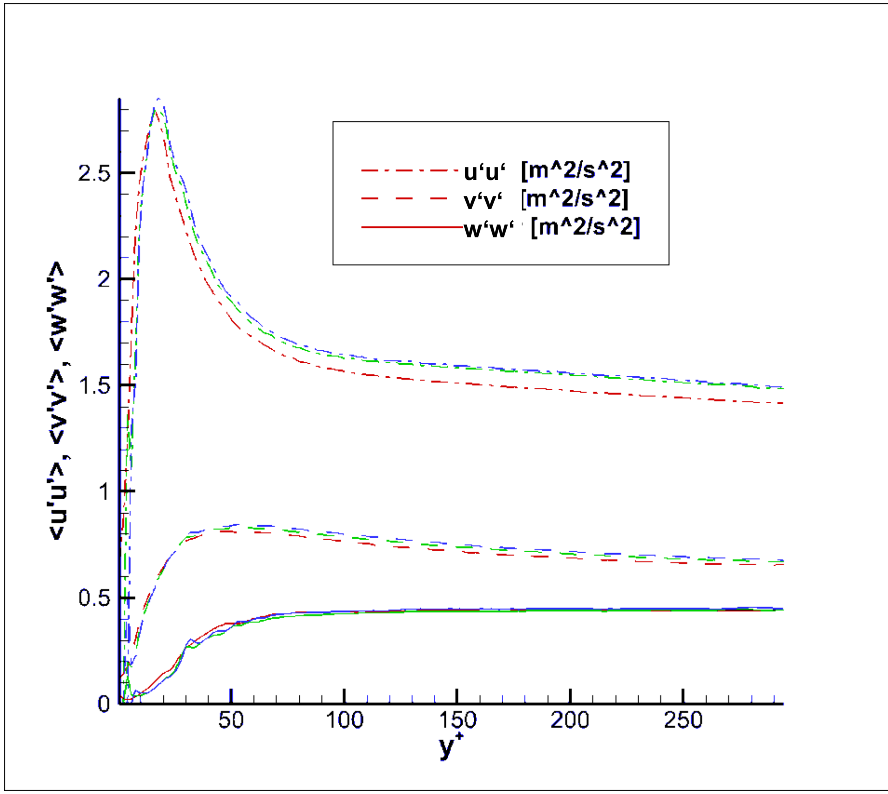


Results

IMTEK moving wall actuator

Configuration: 230 µm amplitude, (~12 y+ units), 90° phase





profiles are indicating increased drag due to installation and actuator gaps

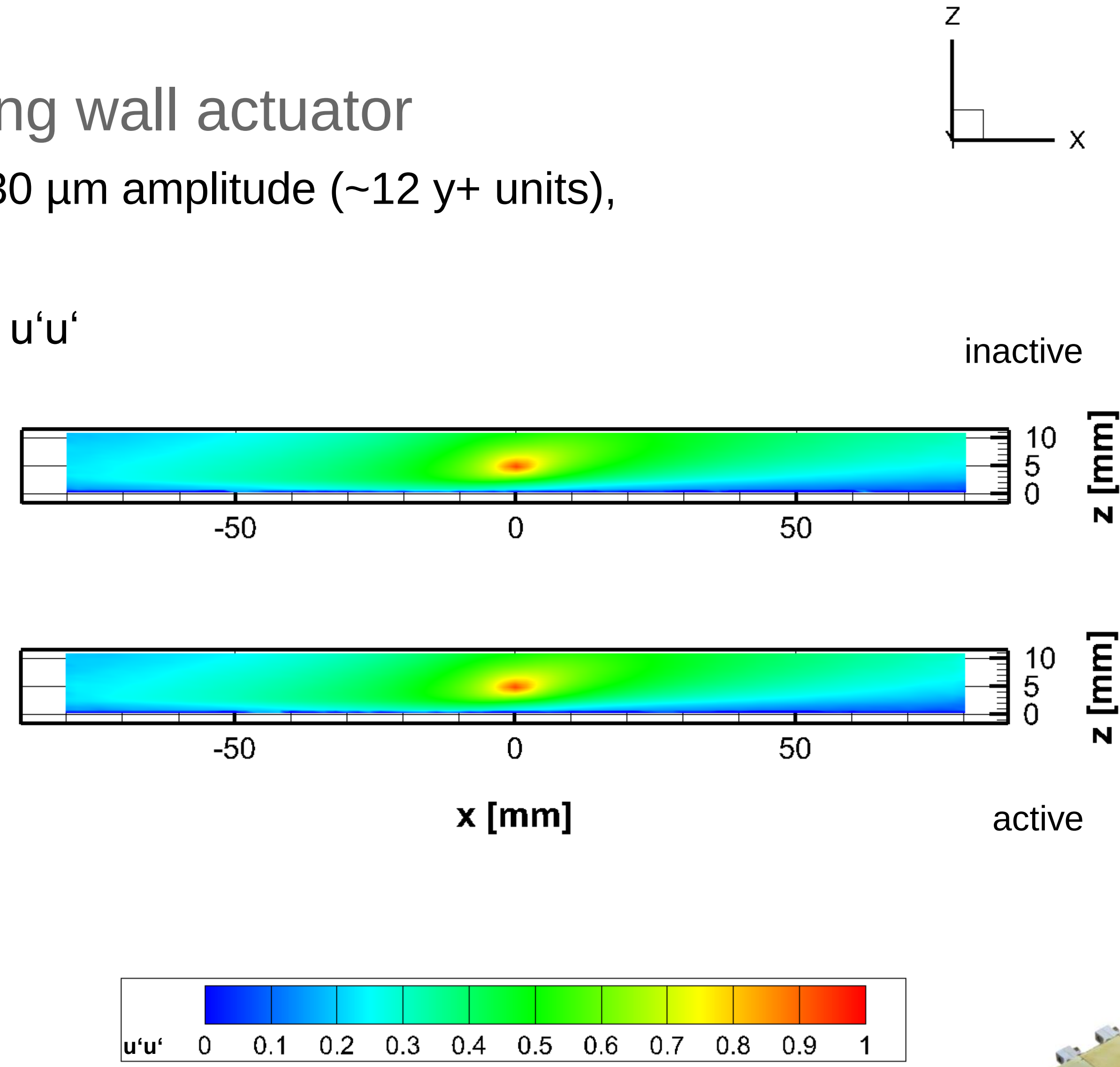
activation of the actuator seems to increase drag

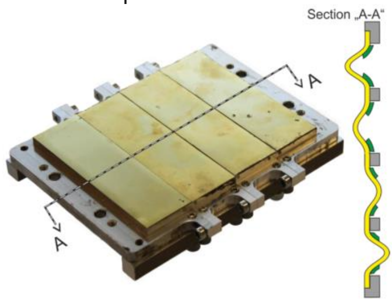
Results

IMTEK moving wall actuator

Configuration: 230 µm amplitude (~12 y+ units), 90° phase,

no significant change in 2-point correlation results

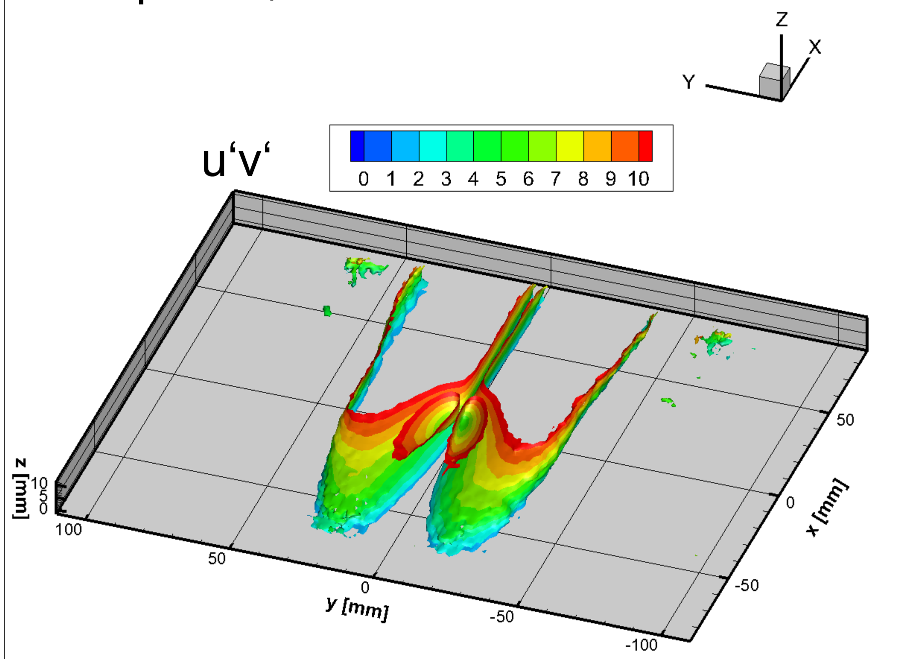




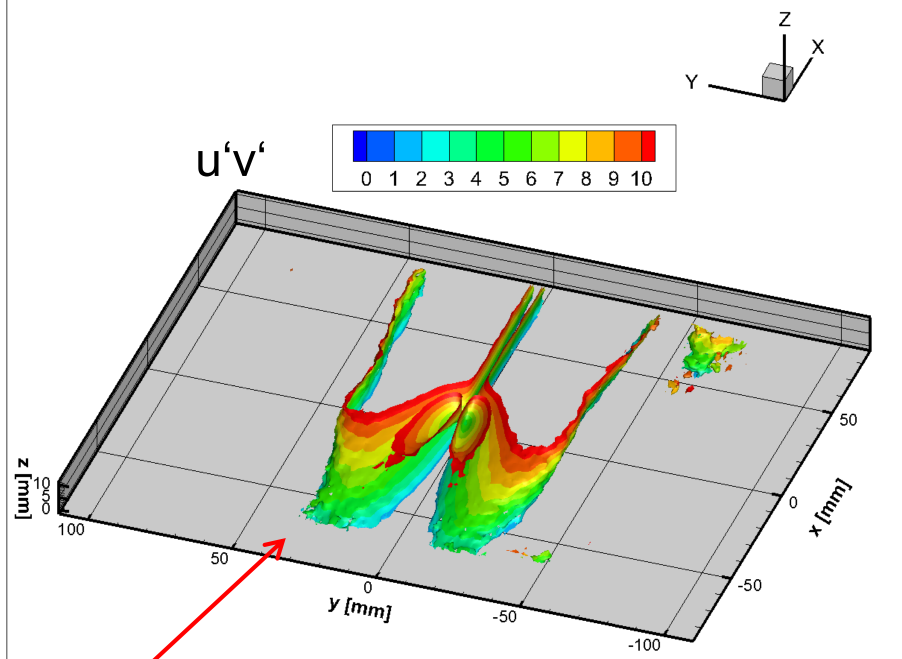
remind coordinate system
v is spanwise

Results
IMTEK moving wall actuator

Configuration: 230 µm amplitude (~12 y+ units),
90° phase,

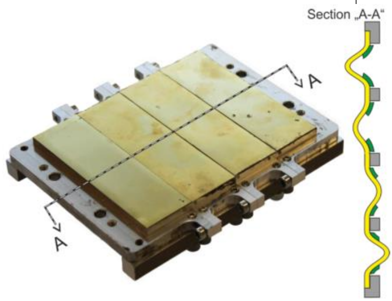


inactive



active

a slight change in 2-point correlation indicating
a small stretching of streaks outwards



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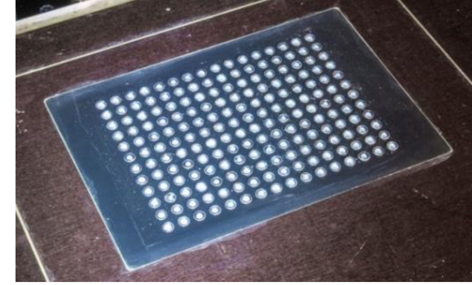
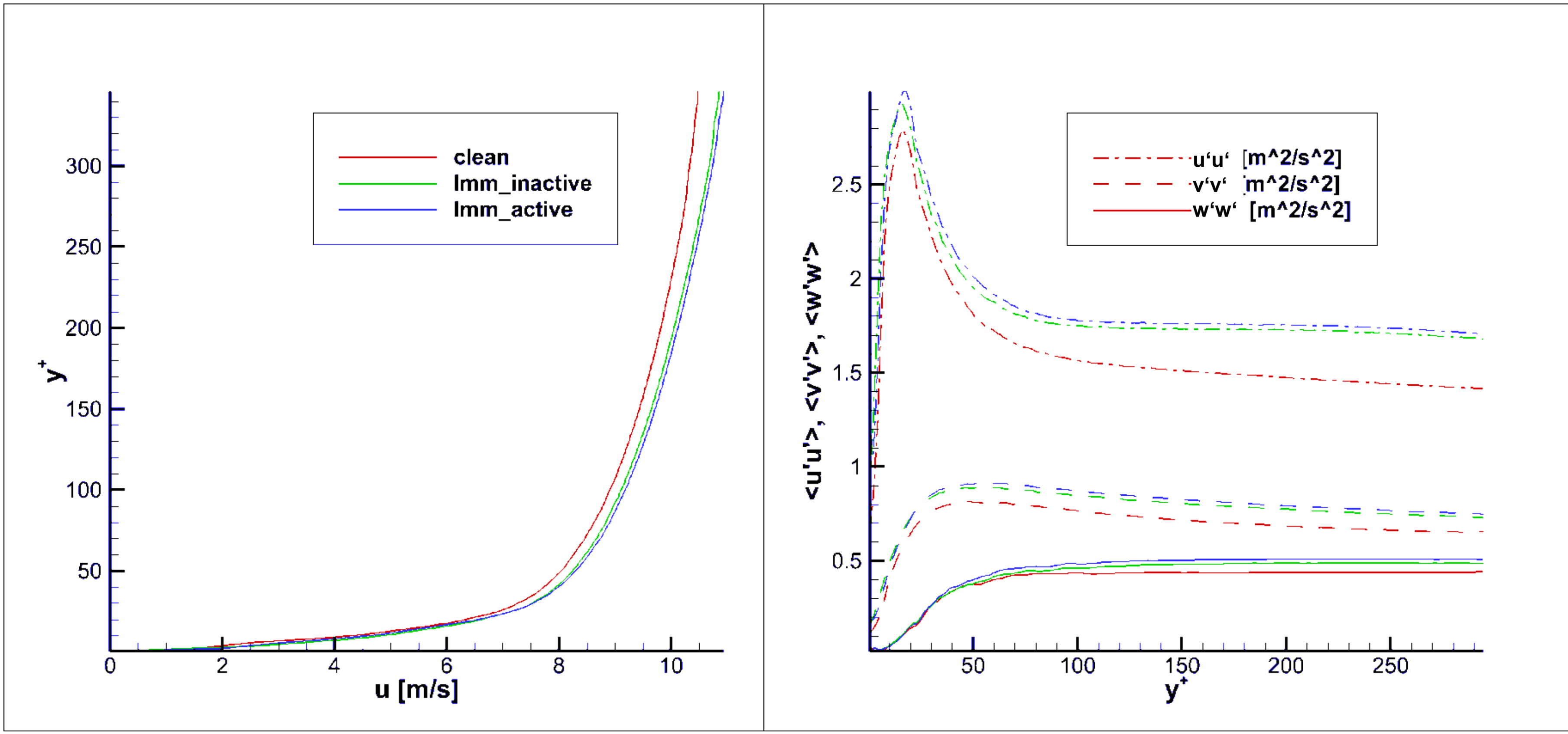


Results
LMM acoustic actuator

Configuration: one maximal focal point in the center of the actuator field



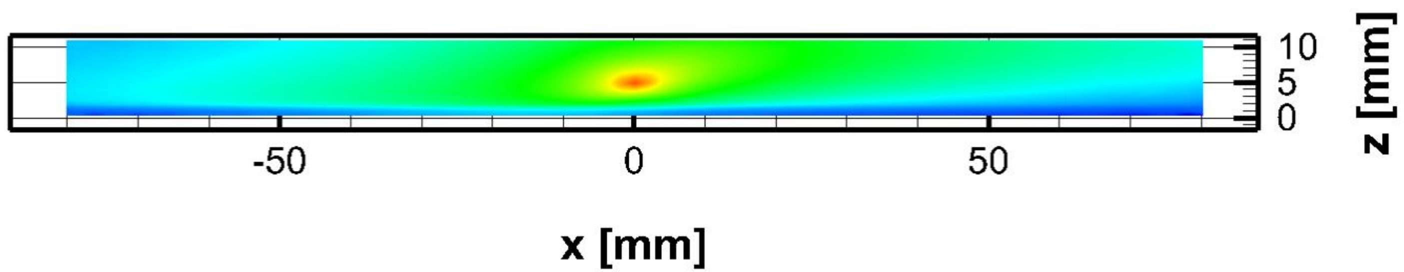
indication of drag increase

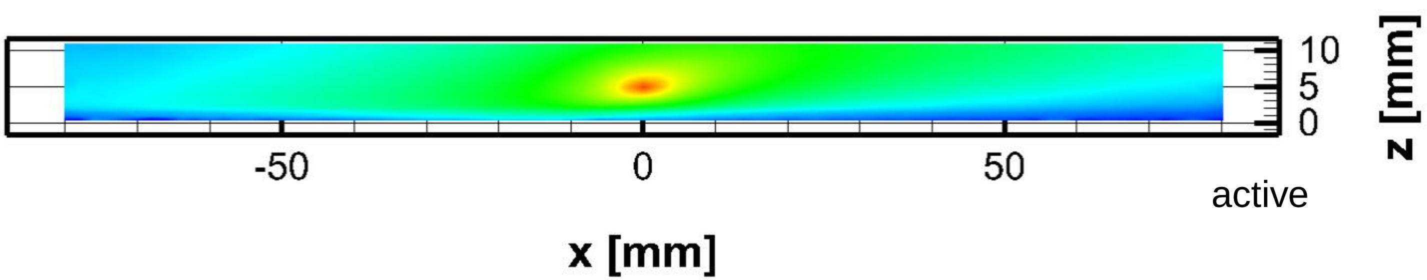
Results
LMM acoustic actuator

Configuration: one focal point (maximal intensity)
in the center of the actuator field

u‘u‘ two point correlation

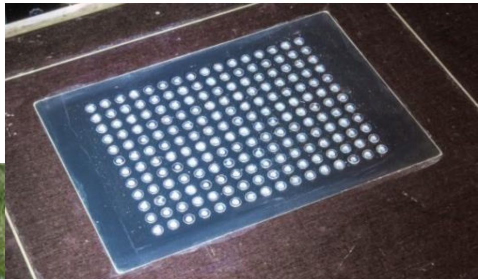
inactive





active

no visible change: no blocking of large scale
turbulent structures, no stretching or compressing

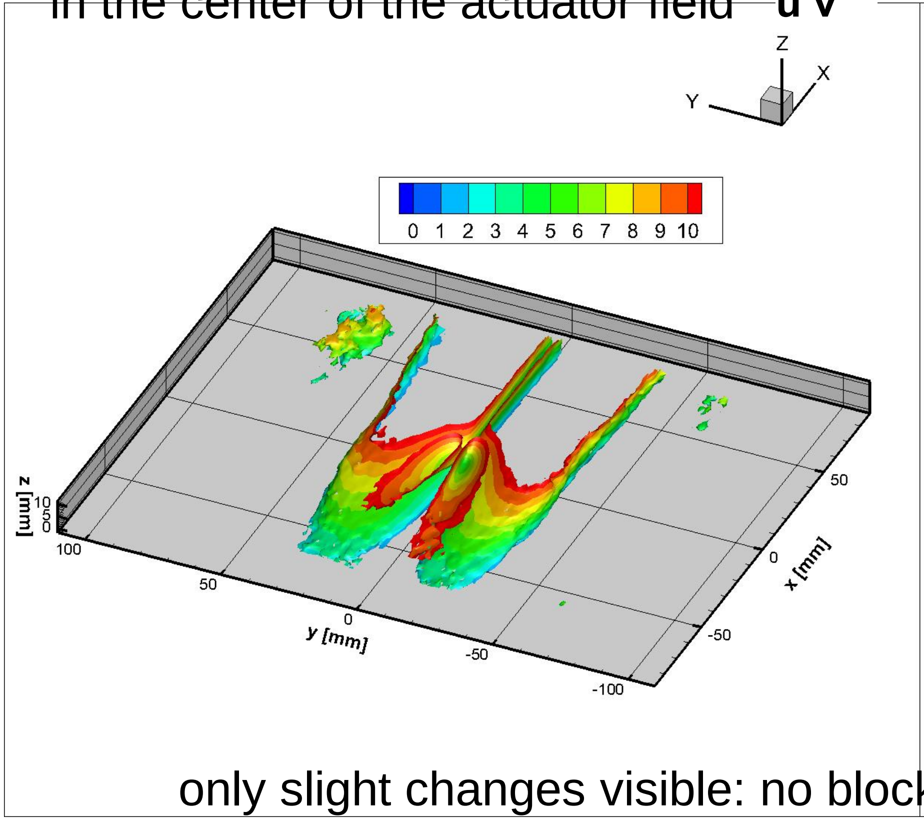


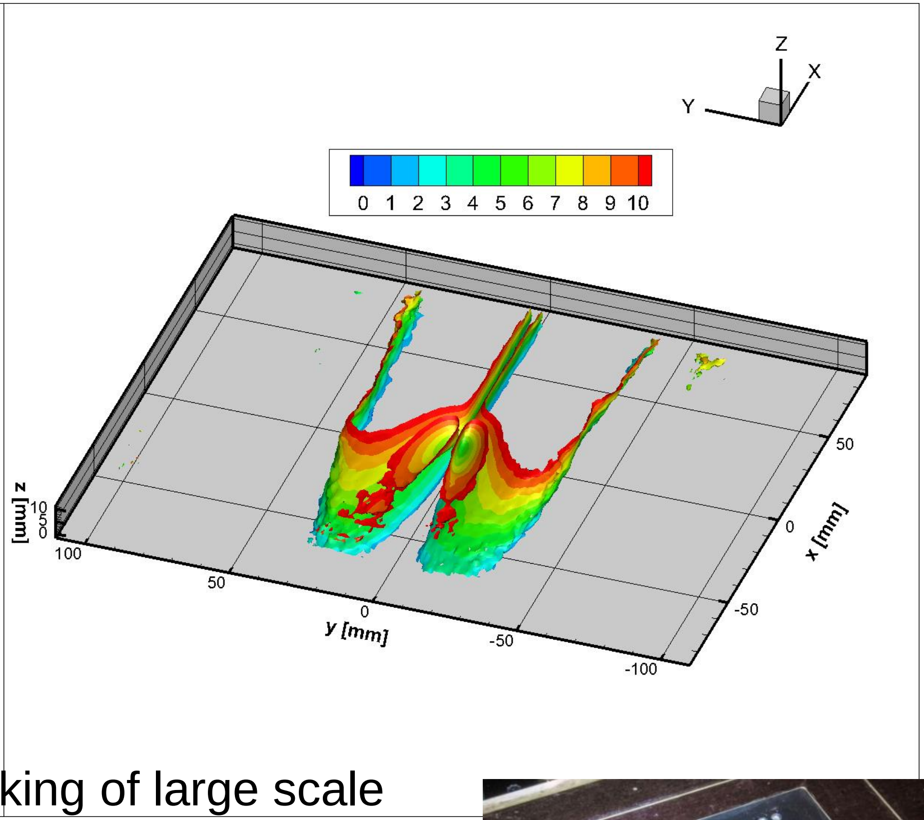
remind coordinate system
v is spanwise

Results
LMM acoustic actuator

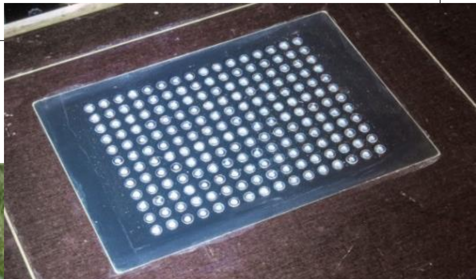
Configuration: one focal point (maximal intensity)
in the center of the actuator field

u‘v‘



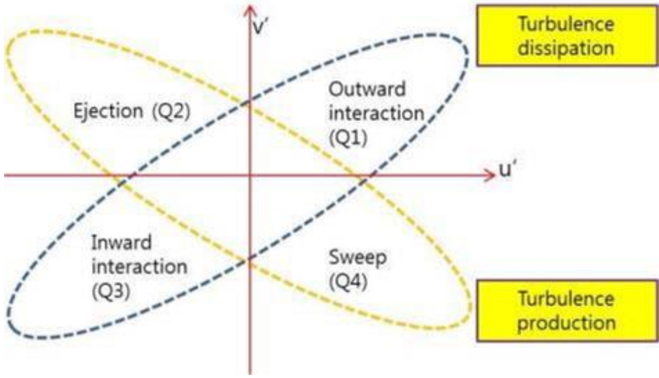


only slight changes visible: no blocking of large scale turbulent structures, no stretching or compressing, a little bit more symmetric streaks…

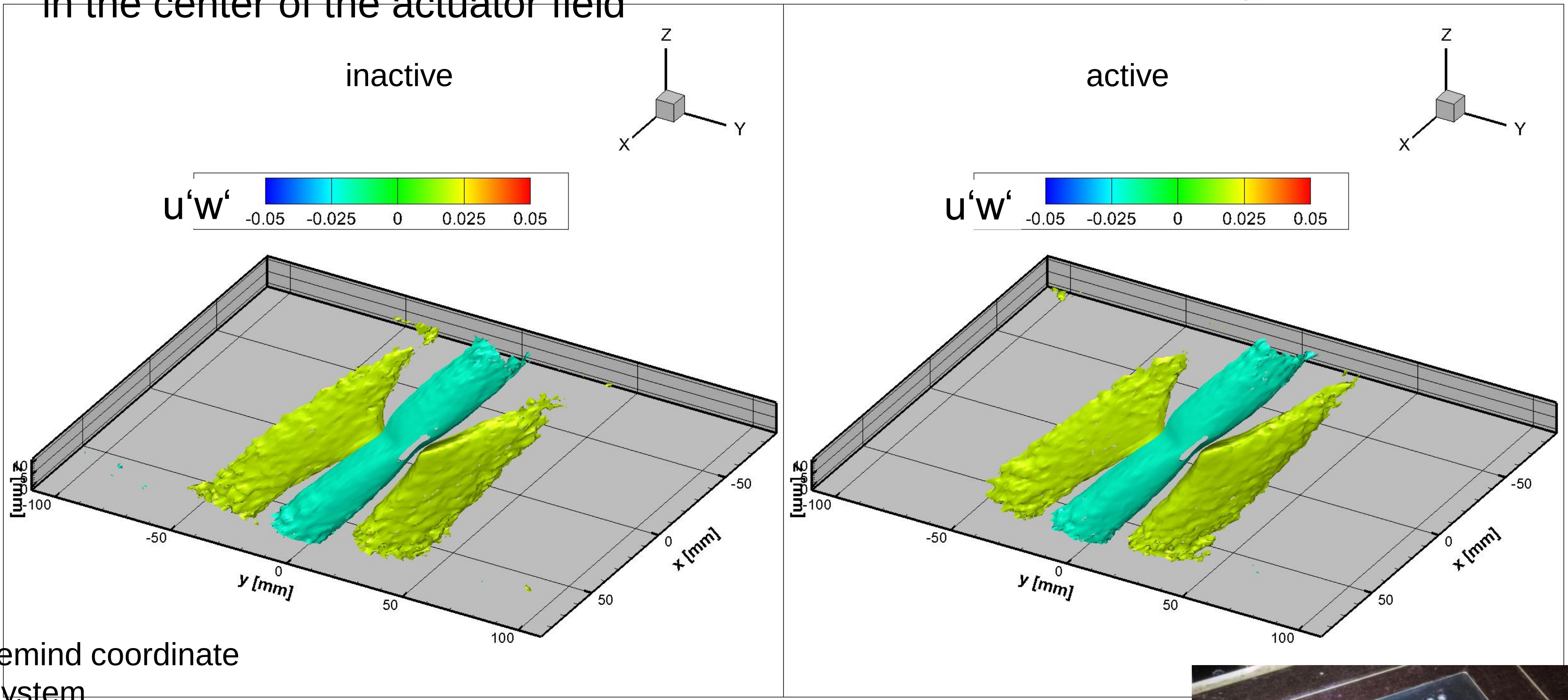


DLR

Results
LMM acoustic actuator

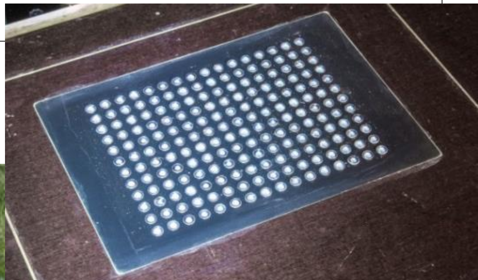


Configuration: one focal point (maximal intensity) in the center of the actuator field



remind coordinate system
v is spanwise

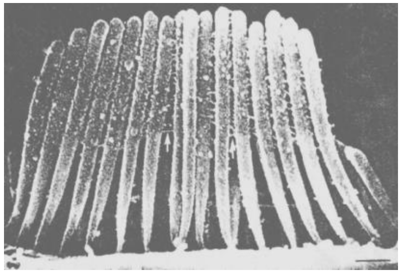
a slight change in 2-point correlation indicating
a small stretched outward interaction region (Q1)



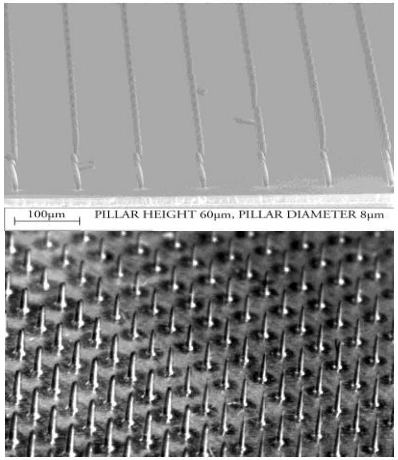
Conclusions

- Two types of actuation concepts have been tested.
- Results do not show drag reduction
  - profiles are indicating that drag is increased
  - small changes of in fluctuations have been observed showing actuation effects in correlation plots
- Main critical points – learning lessons:
  - although communicated: actuators show gaps and geometry discrepancies.
  - installation issues have to be addressed more carefully
- Potential of the technology could not be fully explored
  - developing better strategies for the experimental investigation

The Next Steps…



THE MICRO-PILLAR SHEAR-STRESS SENSOR MPS³
from the AIA, RTWH Aachen, Prof. W. Schröder



- Developing new actuation techniques
  - smooth surface acoustic actuator fields
  - magnetized “cilia” – type of waving actuator fields
  - magnetized waving riblet actuator fields

- New experiments with smoother actuation integration
  - smoothing the large area of surface actuators outside the wind tunnel
  - usage of new coatings

- Improvement of Software on HPC
  - faster experimental data to result management

    -> results over night for enabling corrections / changing the experiment…

DLR

Thank you for your attention!

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