ON THE NEED AND AVAILABILITY OF TIME RESOLVED EXPERIMENTAL RESULTS FOR VALIDATION PURPOSES

Tony ARTS

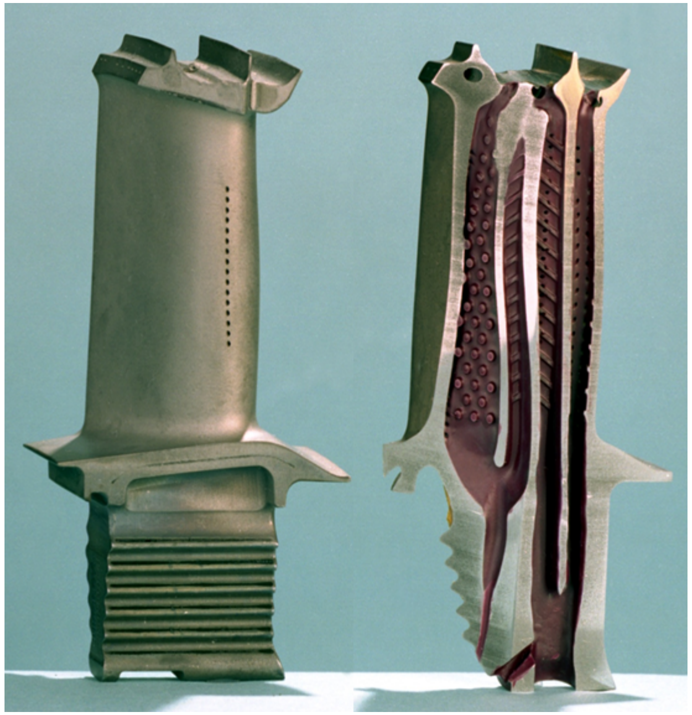
Filippo COLETTI – Thomas MAURER – Irene CRESCI

von Karman Institute for Fluid Dynamics

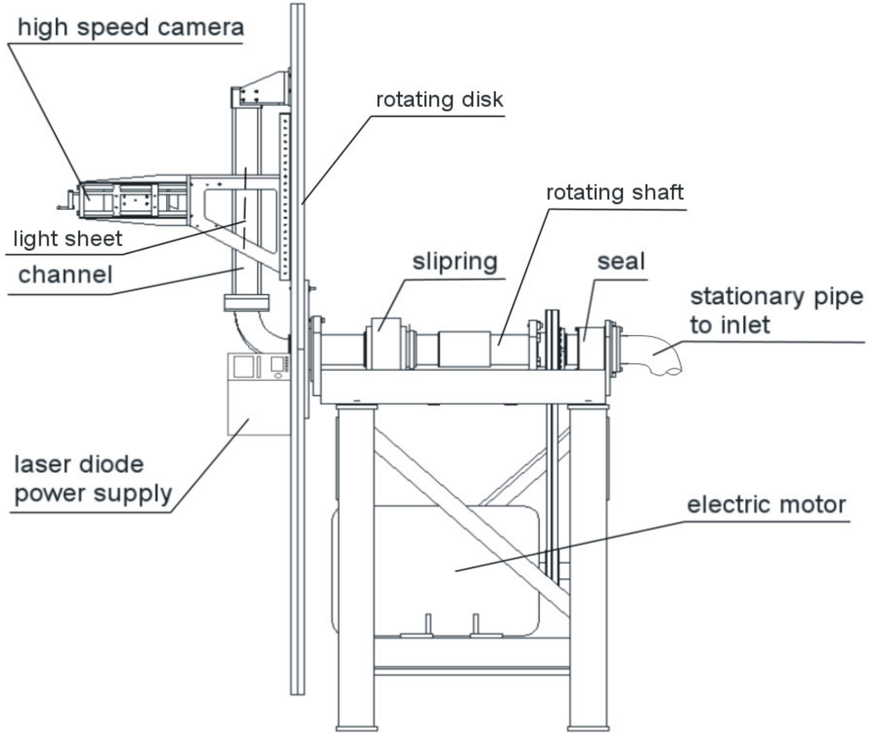
Turbomachinery & Propulsion Department

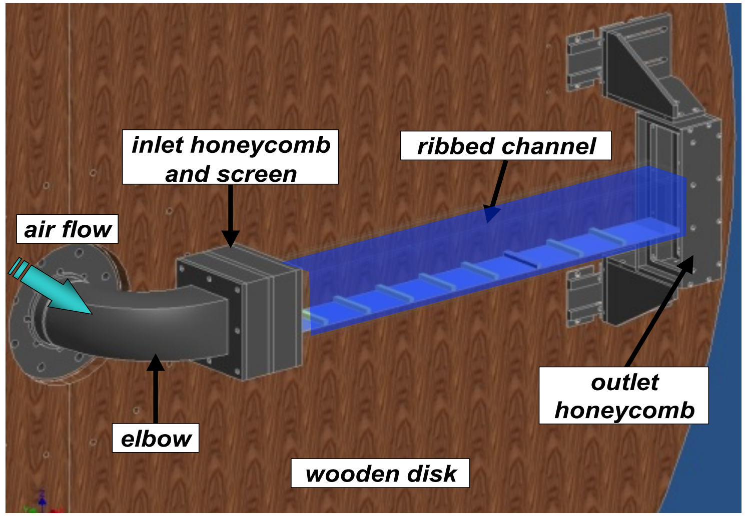
"Jacques Chauvin" Laboratory

THE ENVIRONMENT – THE TEST CASE



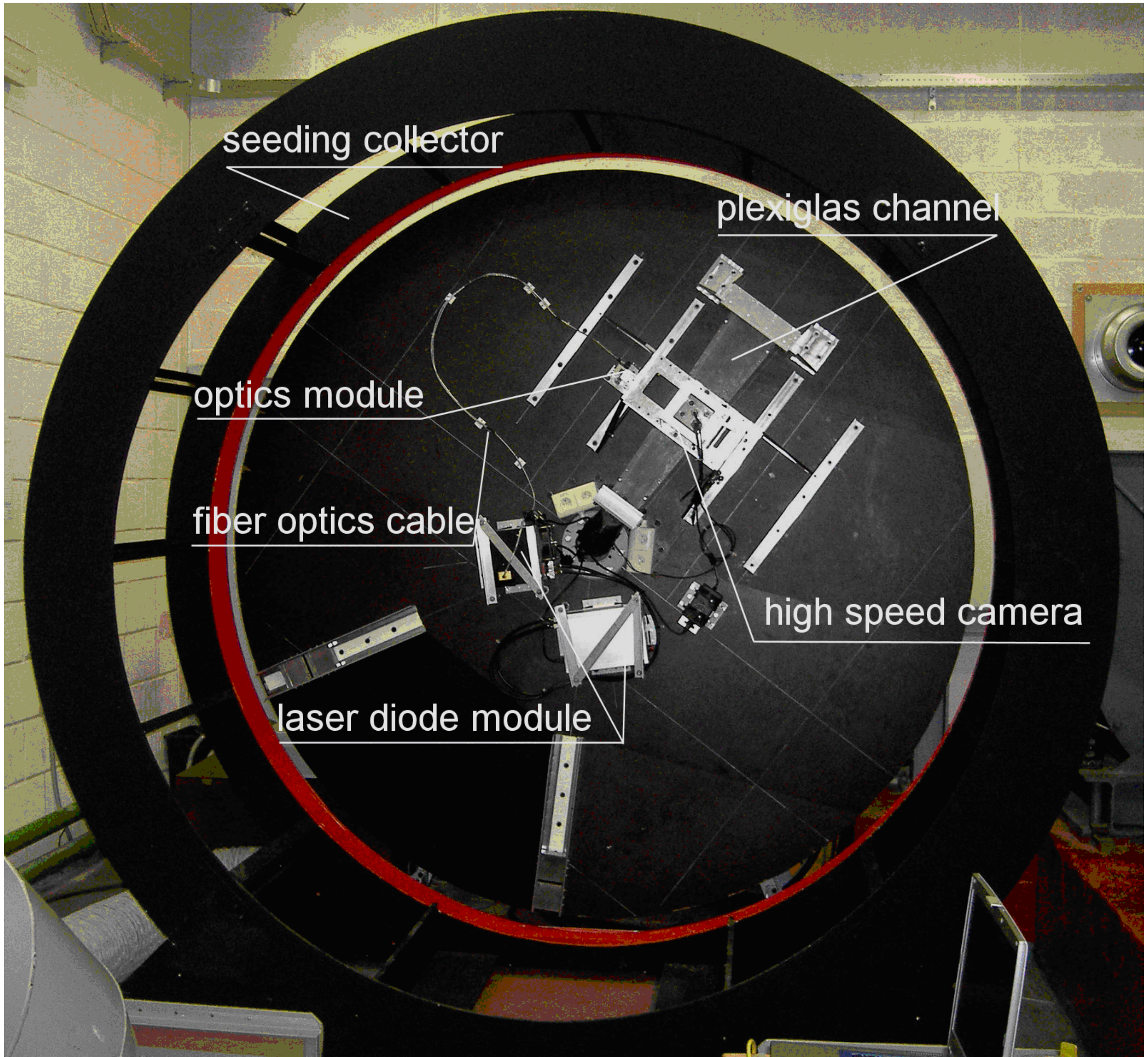
SIMILARITY





Geometrical and flow similarity conditions

Rib height : 8 mm	Re=15000	Uo = 3 m/s
Test section : 80 x 80 mm^2	Pr = 0.7 (air)	Ro=0 … 0.3 (=ΩD/U)


seeding collector
plexiglas channel
optics module
fiber optics cable
high speed camera
laser diode module

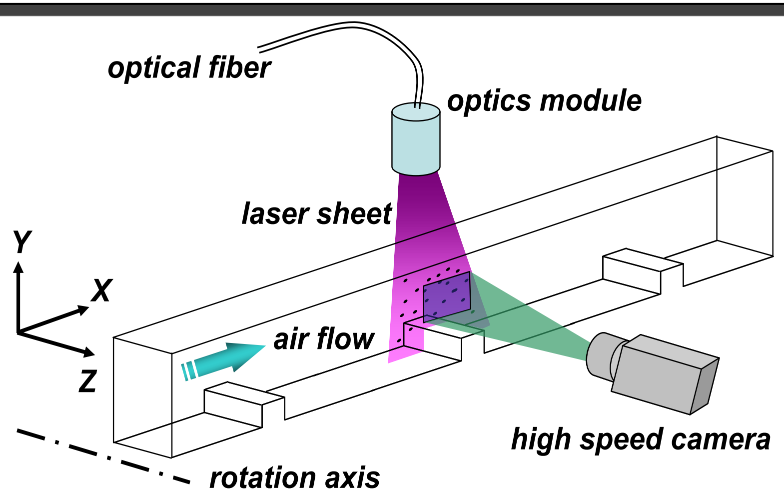
RC-1 Facility

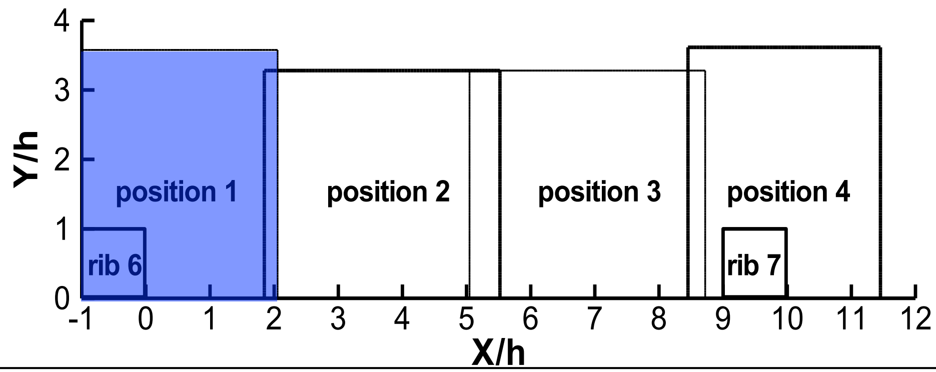
von Karman Institute

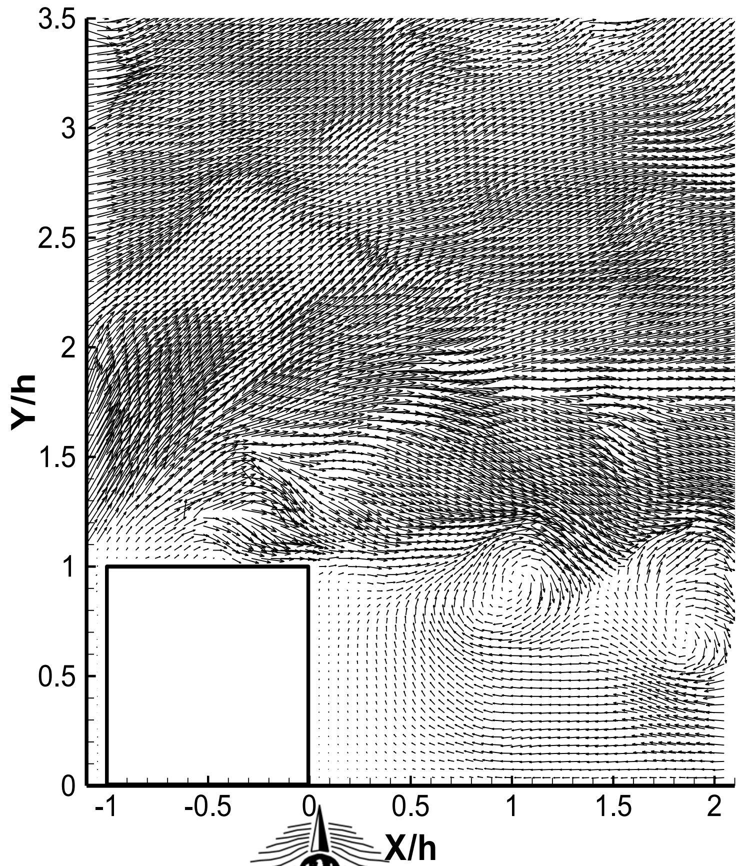
Rhode-Saint-Genèse / Belgium

ON-BOARD PIV (1/2)

- XY symmetry plane: 4 stations (28 x 32 mm^2)
- Magnification: 13.6 pixel/mm
- Windows of 80 x 64 pixels^2, 2 refinements, 75% overlap → vector spacing 0.04*h*
- 2000 realizations → uncertainty = 2% on <*U*>, 4% on *rms*(U) (95% confidence)

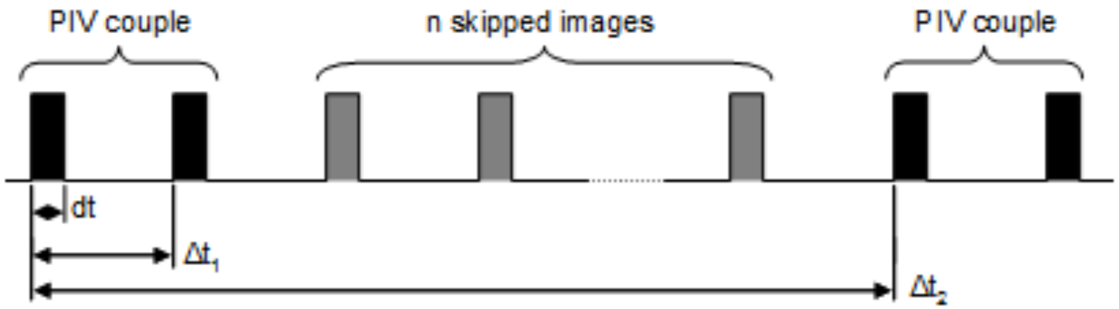






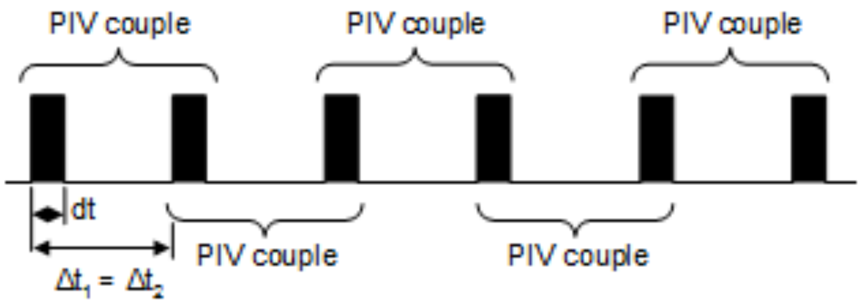
ON-BOARD PIV (2/2)

High speed camera operation mode for ensemble-averaged measurements



Exposure time dt = 80 µs
Separation time Δt1 = 300 µs
Sampling frequency f = 3 Hz
2000 uncorrelated realizations

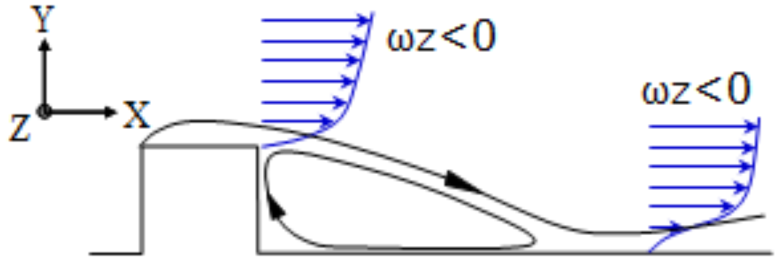
High speed camera operation mode for time-resolved measurements



Exposure time dt = 80 µs
Separation time Δt1 = 300 µs
Sampling frequency f = 3.3 kHz
4000 time-resolved realizations

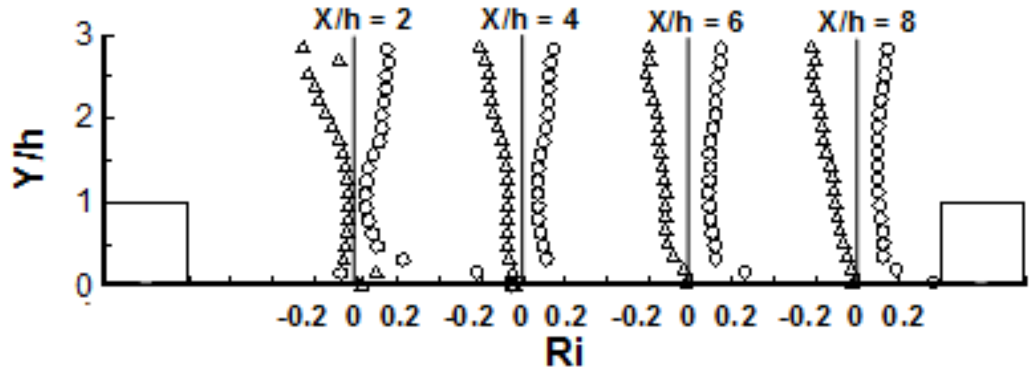
FLOW STABILITY

$S = 2\Omega/\omega z$ = background vorticity/flow vorticity
Bradshaw-Richardson number: $Ri = S(S+1)$



- ωz < 0 both in separated shear layer and boundary layer
- clockwise rotation (○)→ $S > 0$ → $Ri > 0$ → stabilizing rotation (ribbed leading side)
  (cyclonic)
- counter-clockwise rotation (Δ) → $S < 0$ →
  - $Ri < 0$ → destabilizing rotation (ribbed trailing side)
  - $Ri > 0$ → re-stabilizing rotation ($Ro > 0.5$, not the case here)

  (anti-cyclonic)



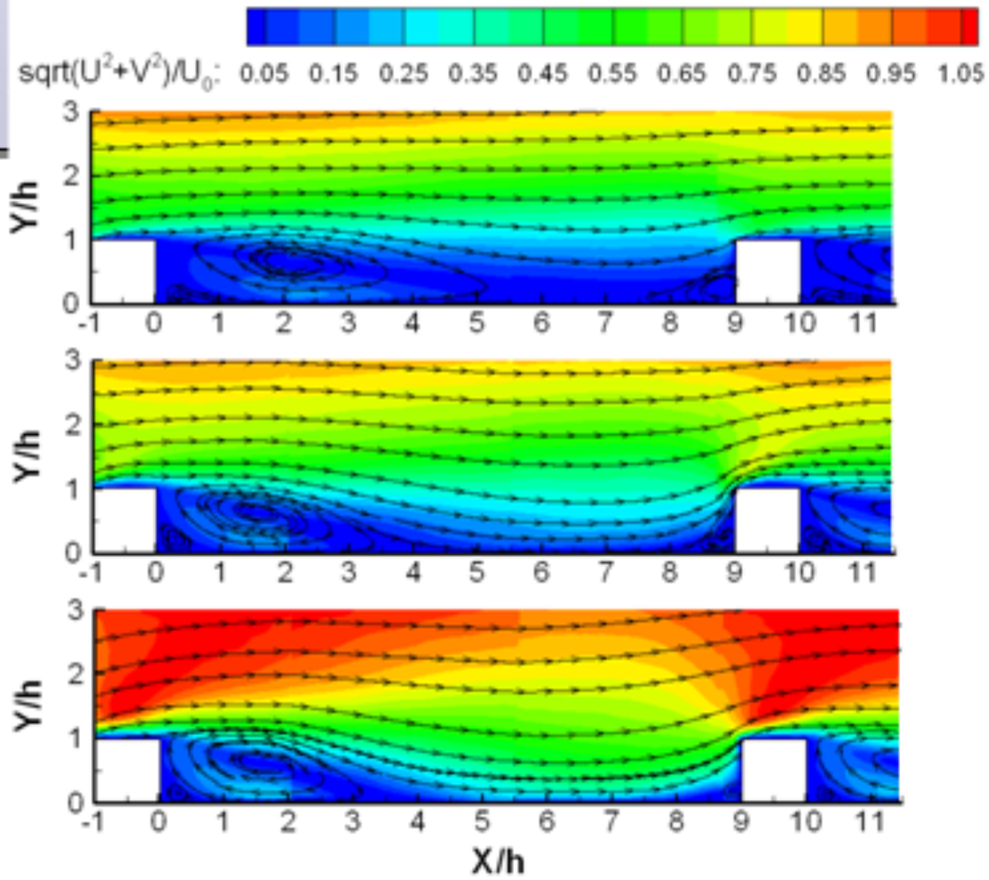
TIME-AVERAGED FLOW FIELD (1/2)

- Destabilizing rotation
  - higher through-flow velocity due to secondary flows
  - more shear entrainment
    - → transverse pressure gradient
    - → shear layer curvature
    - → earlier reattachment
- Vice versa for stabilizing rotation

Stabilizing rotation: **X_R/h= 5.65**
Abdel-Wahab and Tafti, 2004 – LES: **5.4**

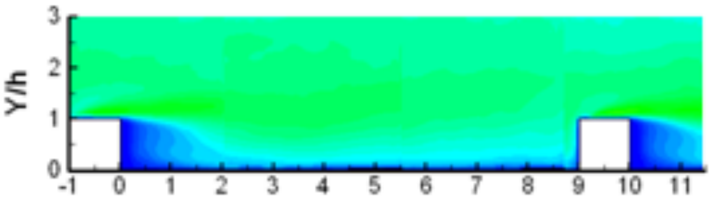
Non rotating: **X_R/h= 3.85**
Rau et al., 1998 (LDV): 3.7
Casarsa and Arts, 2007 (PIV): **3.95**

Destabilizing rotation: **X_R/h= 3.45**
Abdel-Wahab and Tafti, 2004 (LES): **3.4**

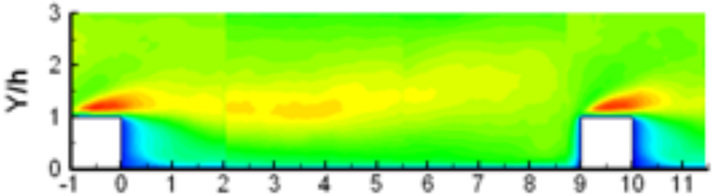


TIME-AVERAGED FLOW FIELD (2/2)

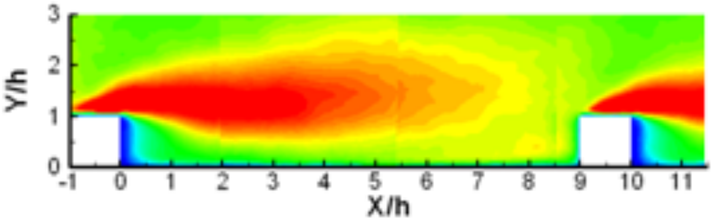
- Destabilizing rotation → increases indirectly the production of $\overline{u^2}$ through mean shear
  → increases directly the production of $\overline{v^2}$
- Stabilization/destabilization → reduces/increases turbulence levels



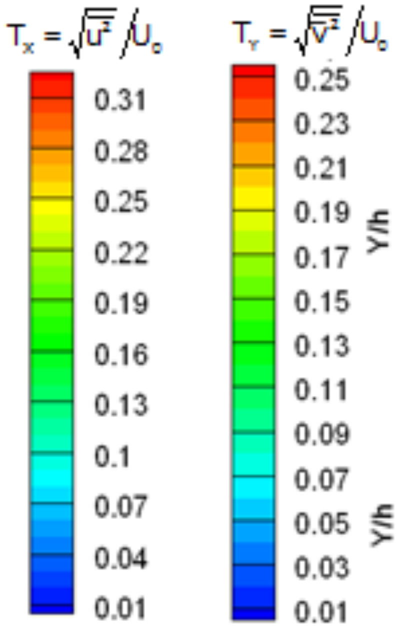
stabilizing rotation

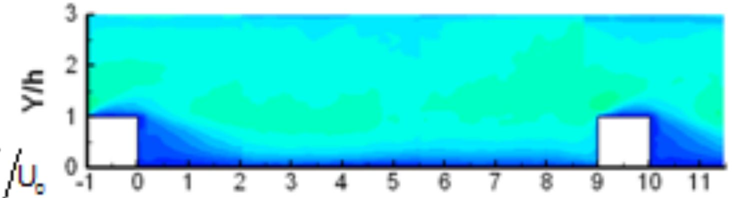


non-rotating

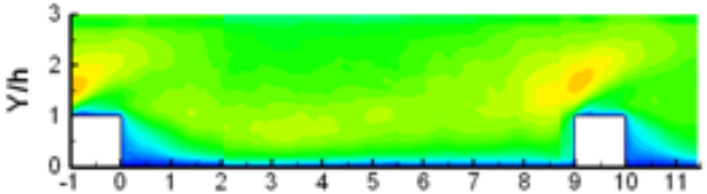


destabilizing rotation

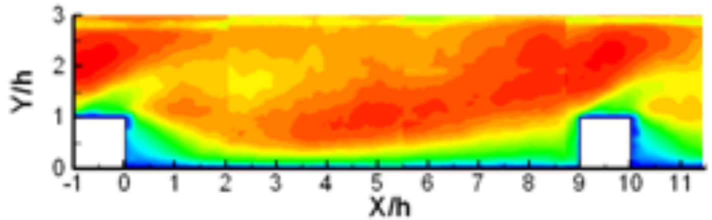




stabilizing rotation



non-rotating

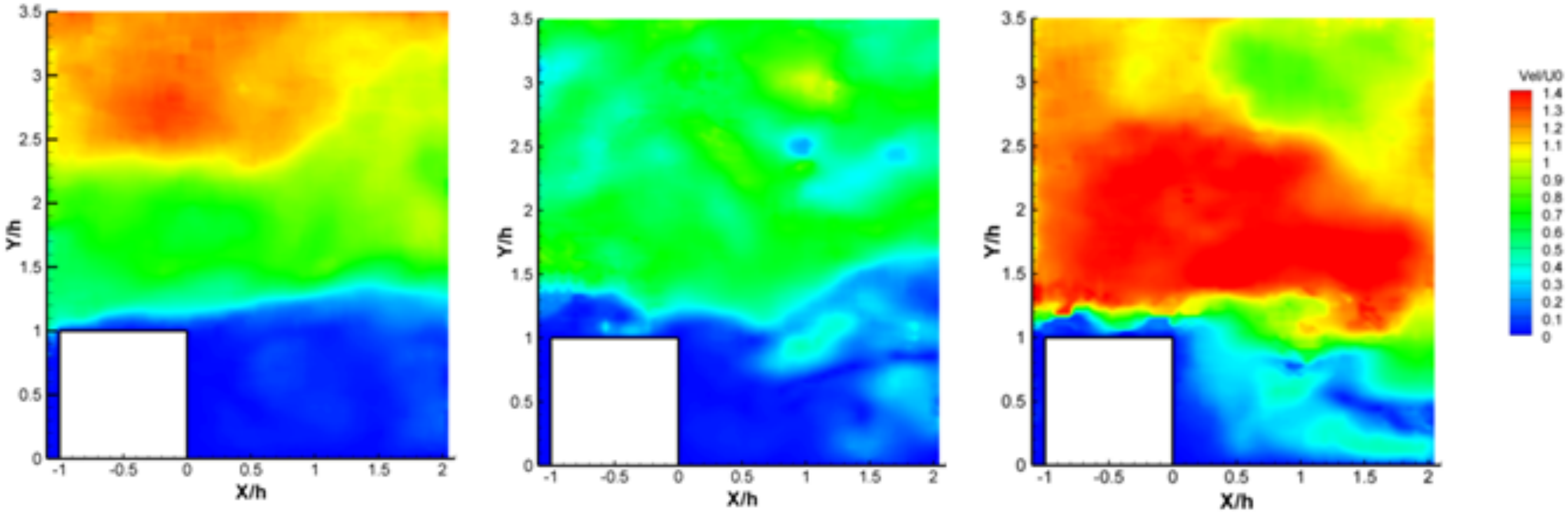


destabilizing rotation

TIME-RESOLVED FLOW FIELD

- Stabilizing rotation → slow shear layer flapping, stable flow inhibits mixing
- Destabilizing rotation → fast fluid is ingested in recirculation area, high mixing

stabilizing rotation | non-rotating | destabilizing rotation

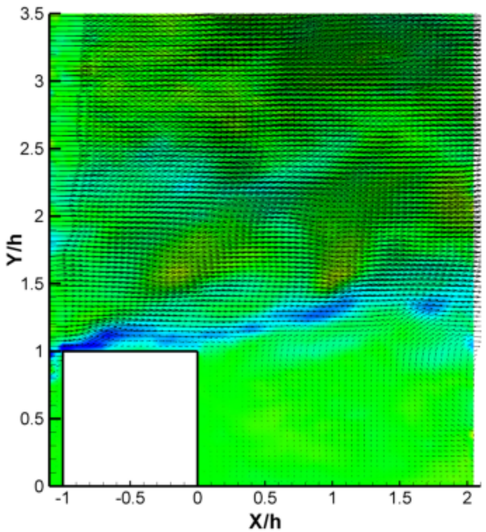


in-plane velocity

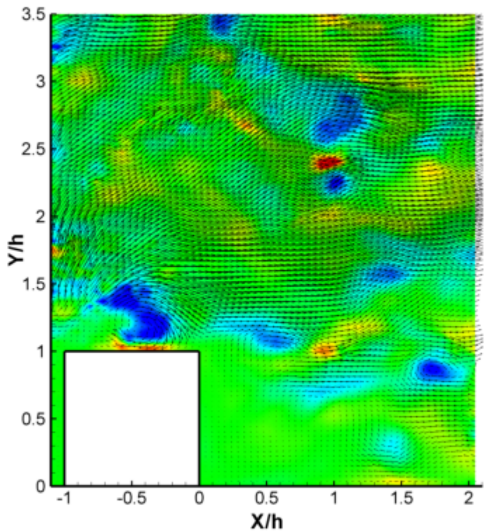
TIME-RESOLVED VORTICITY

- Stabilizing rotation suppresses 3D turbulence → reinforces Kelvin-Helmholtz rollers (2D)
  → slow shear layer flapping
- Destabilizing rotation → vortices are ingested in the recirculation area

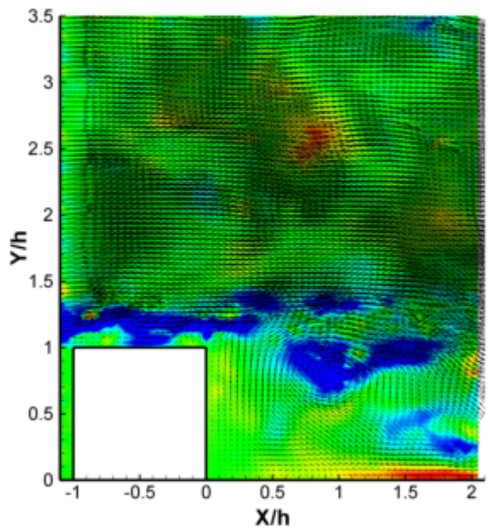
stabilizing rotation



non-rotating

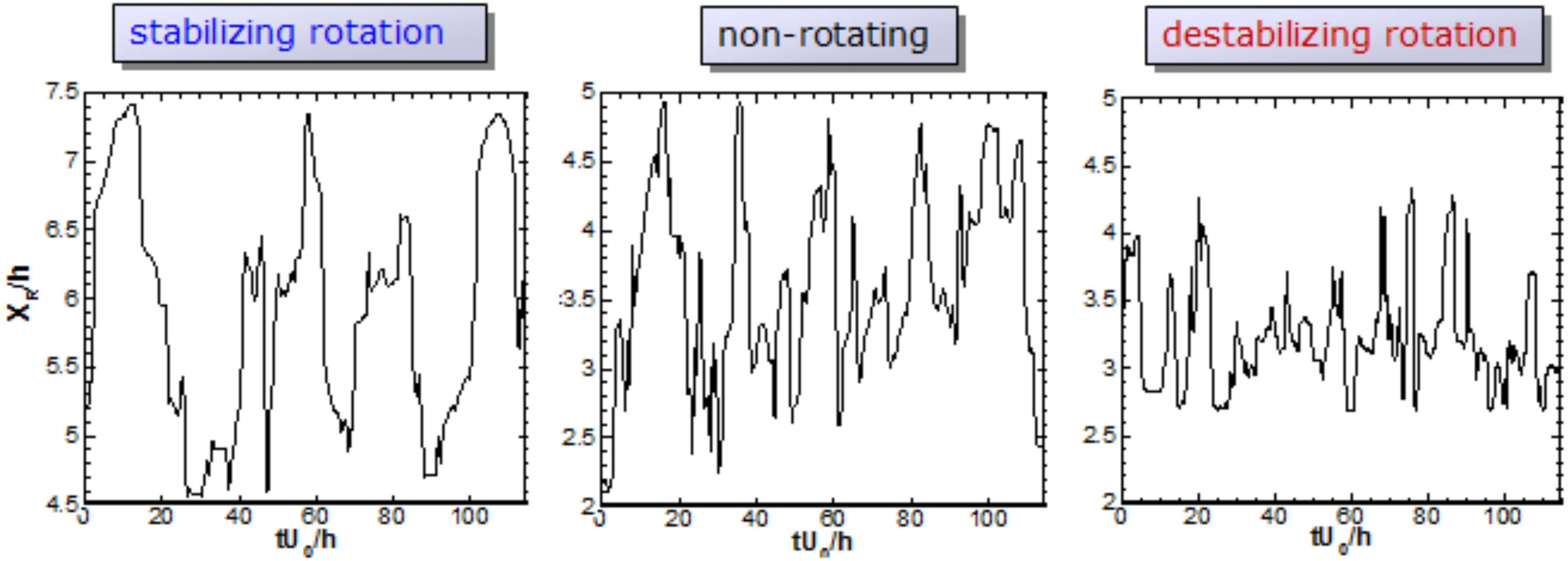


destabilizing rotation



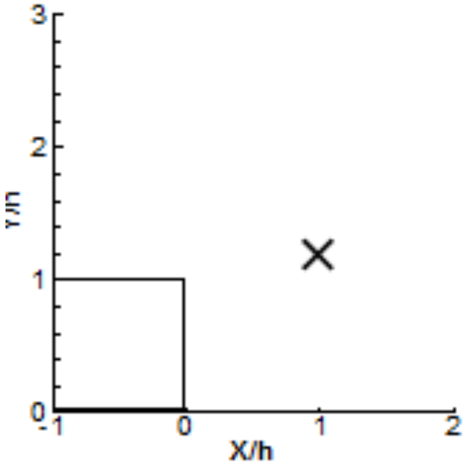
REATTACHMENT POINT (Time-resolved)

- Instantaneous time traces of the reattachment point (near-wall *U* changing sign)
- Stabilizing rotation pushes reattachment point further
- Oscillations are slower and span almost 3 rib heights
- Vice versa in destabilizing rotation (spanning about 1 rib height)

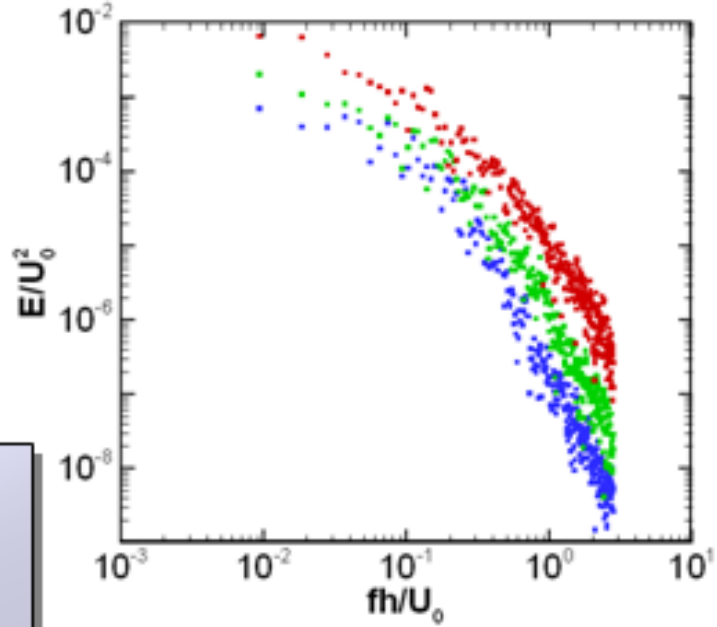


TURBULENCE SPECTRUM

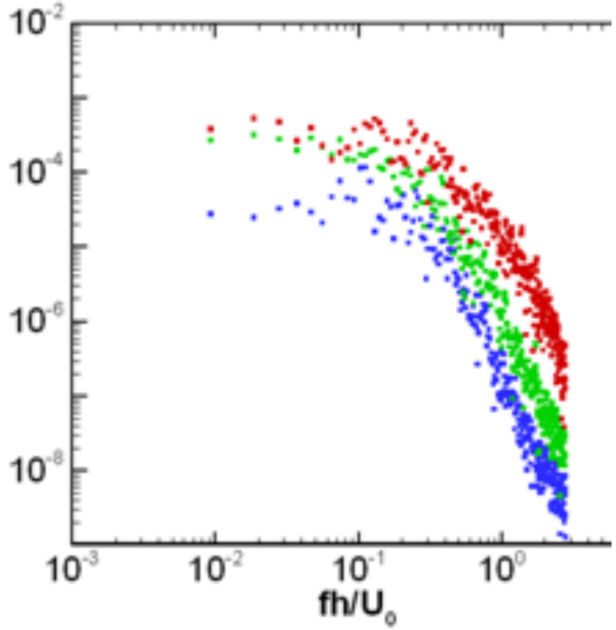
- Time series extracted in the middle of the shear layer
- Rotation affects the whole spectrum of frequencies
- No dominant frequency excited by rotation



stabilizing rotation
non-rotating
destabilizing rotation

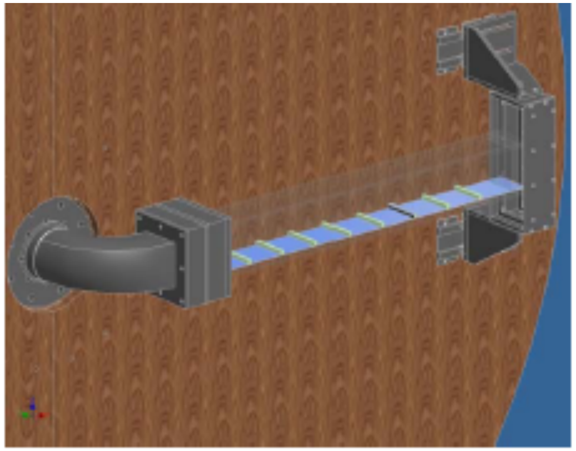


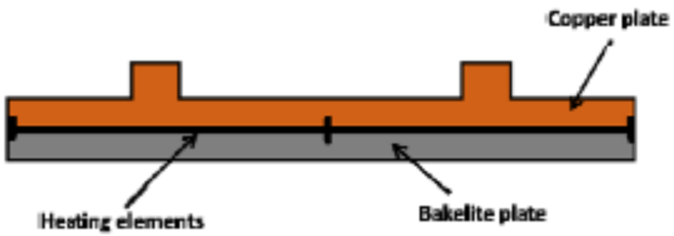
longitudinal direction

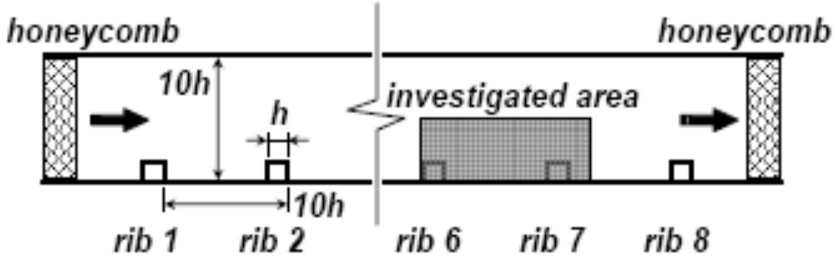


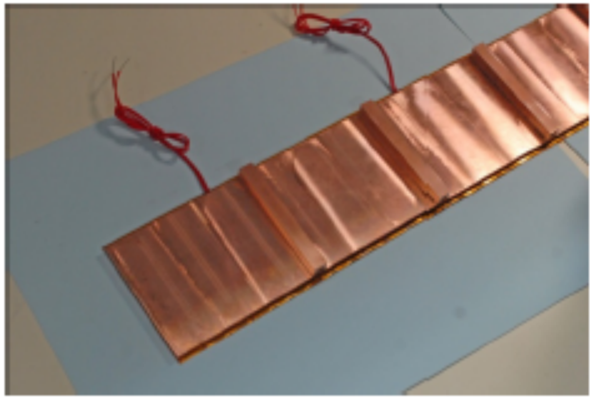
transversal direction

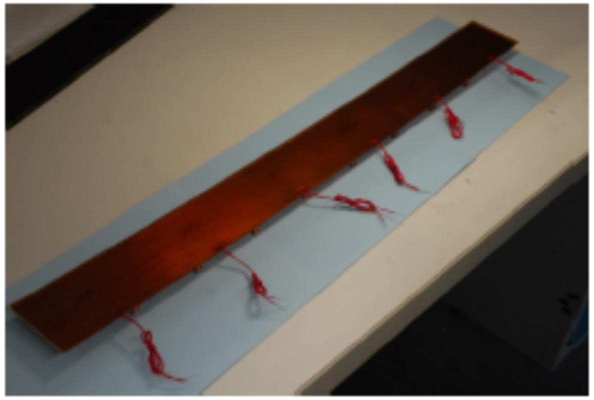
- Plexiglass channel (aspect ratio = 0.9)
- 8 ribs
- Measurement area between the 6th and the 7th rib
- Blockage ratio (rib height/hydraulic diameter) = 0.1
- Copper ribbed wall heated by 6 resistances with a bakelite plate

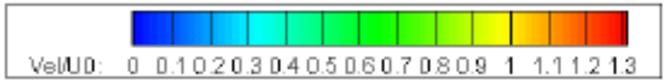






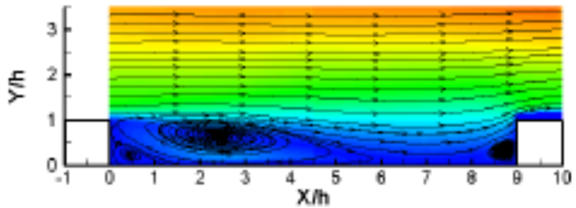




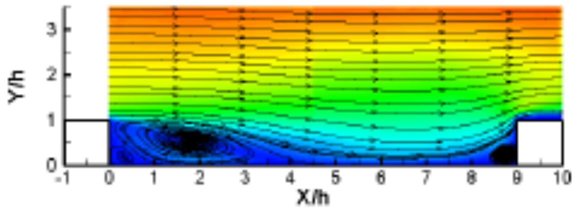


Rotation effect

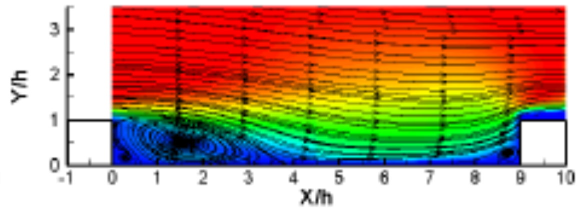
Leading side (Ro=0.38, Bo=0)



No rotation (Ro=0.38, Bo=0)

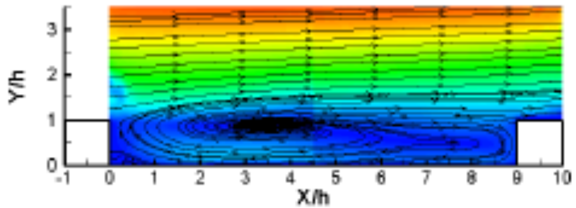


Trailing side (Ro=0.38, Bo=0)

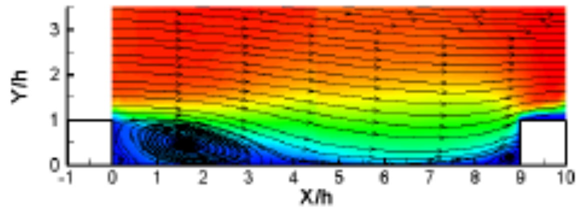


Buoyancy effect

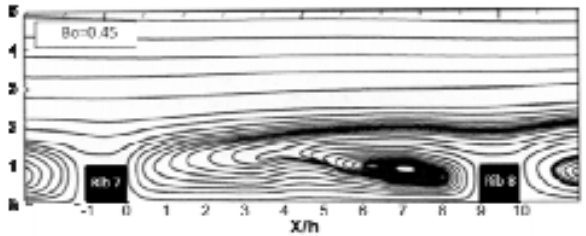
Leading side (Ro=0.38, Bo=0.31)

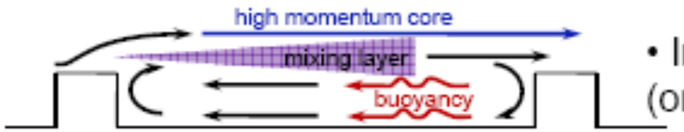


Trailing side (Ro=0.38, Bo=0.31)



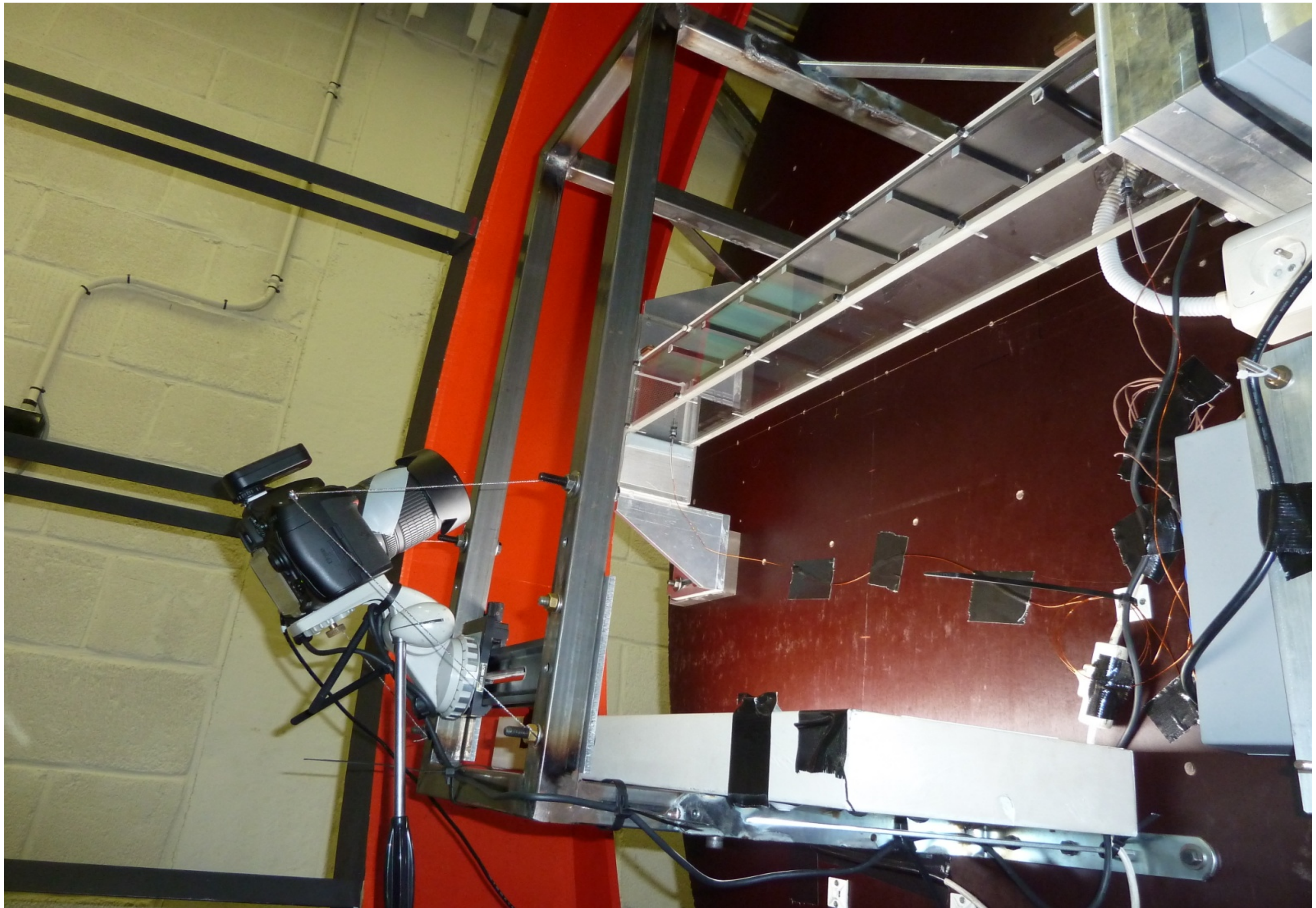
Sewall and Tafti, Ro=0.3, Bo=0.45





- Rotation effect
  - Stabilizing/destabilizing effect on the leading/trailing side
  - Flow driven toward the trailing side by secondary flows
- Buoyancy effect
  - Upstream motion near the leading side
  - Negligible effect on the trailing side
- Influence of thermal boundary condition (only ribbed wall heated)

HEAT TRANSFER IN ROTATION



PERSPECTIVES

- Numerical predictions : RANS versus LES
  A difficult test case for CFD ?
  Conjugate problem modeling ?

- Identification of coherent structures
  Wavelet analysis
  Contribution to turbulence modeling

- Industrial geometries - optimisations
  (inclined ribs, extractions, impingement …)