Imperial College London

Department of AERONAUTICS

THE “BIG AND SLOW” SURFACE WAVE EXPERIMENT

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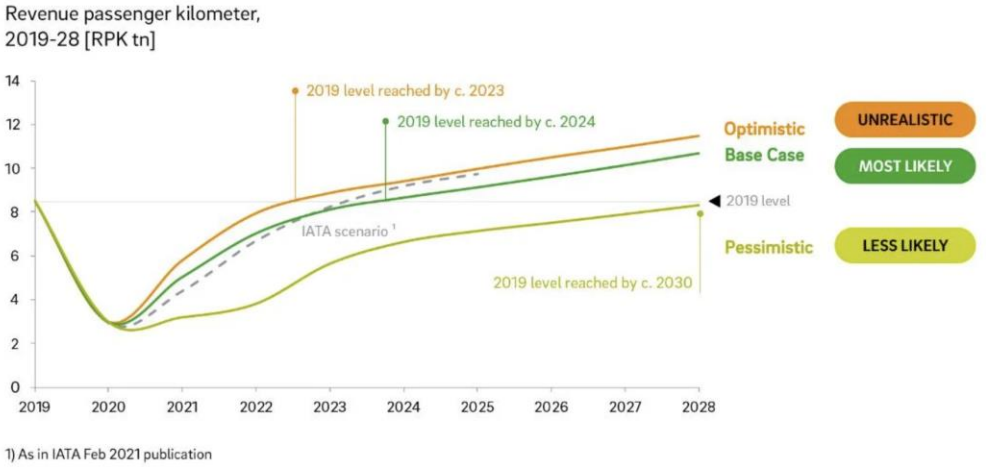
NWTF

EPSRC
Engineering and Physical Sciences Research Council

Green aviation

- The aviation industry contributes to pollution and climate change.

- There has been a significant growth in demand for air travel.



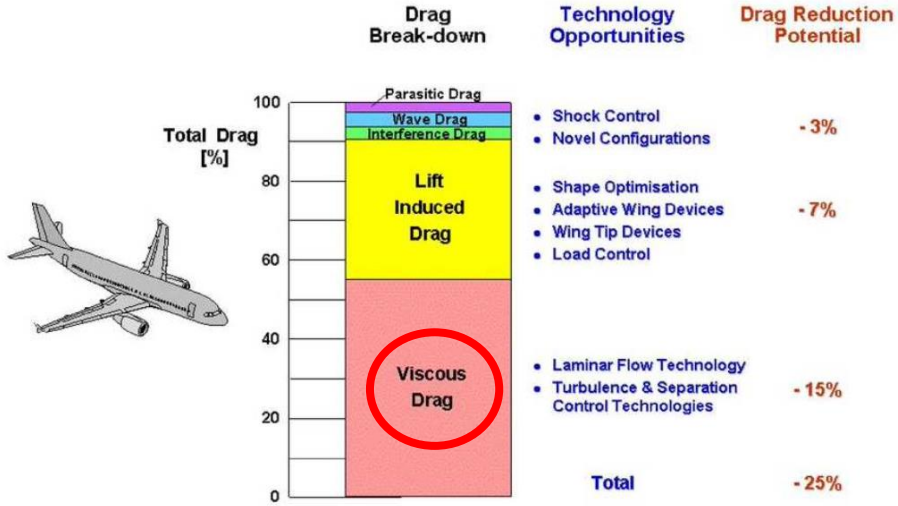
<u>OUR GOAL:</u>

Meeting this demand while ensuring the environment is protected.

https://insideclimatenews.org/news/27102020/hydrogen-fueled-aircraft-clean-energy-emissions/

https://www.rolandberger.com/en/Insights/Publications/A-flight-path-to-post-Covid-success.html

What can we do?

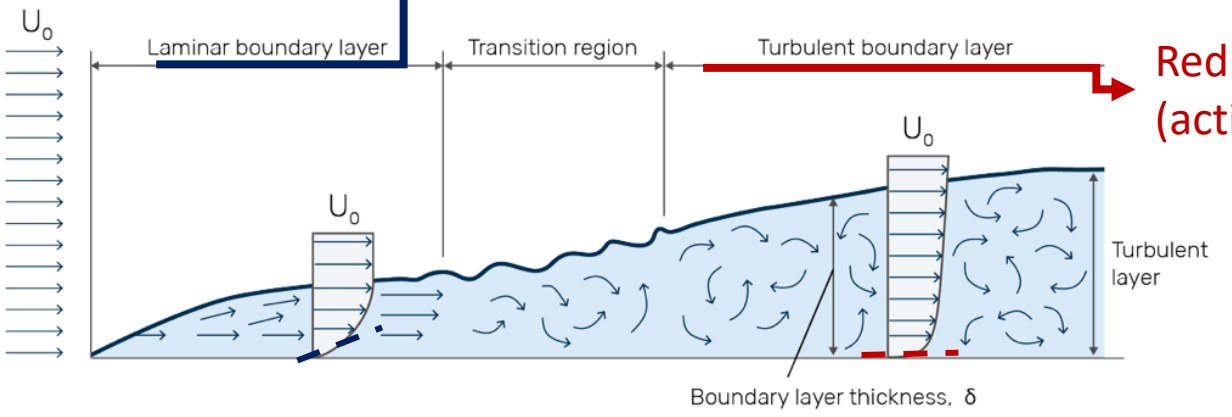


Abbas et al. 2017

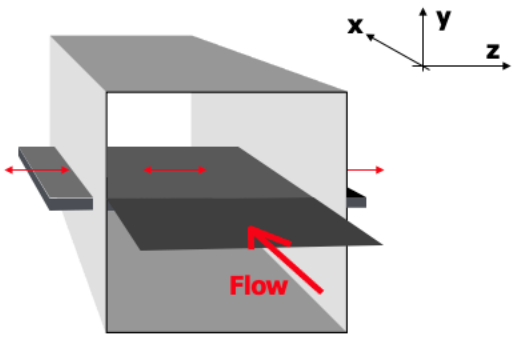
- How can we reduce skin friction drag?

$$\tau = \mu \frac{\partial U(y)}{\partial y}\Big|_{y=0}$$

Delay transition
(Ideally laminar flow wing)

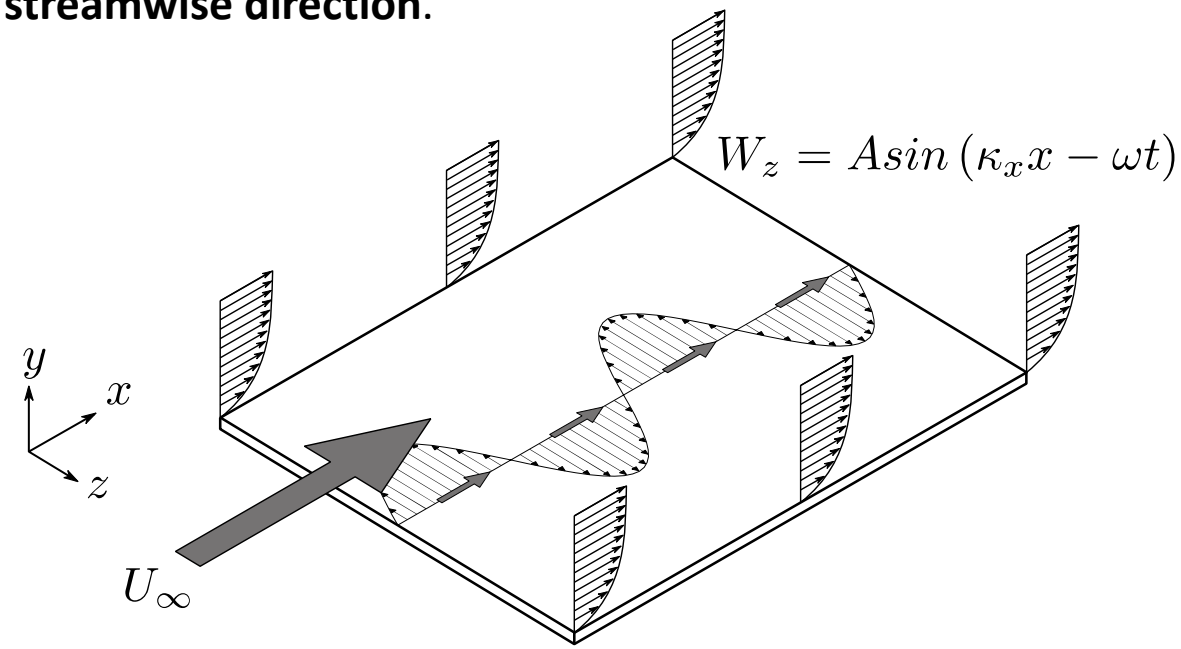


Reduce skin friction
(active/passive flow control)

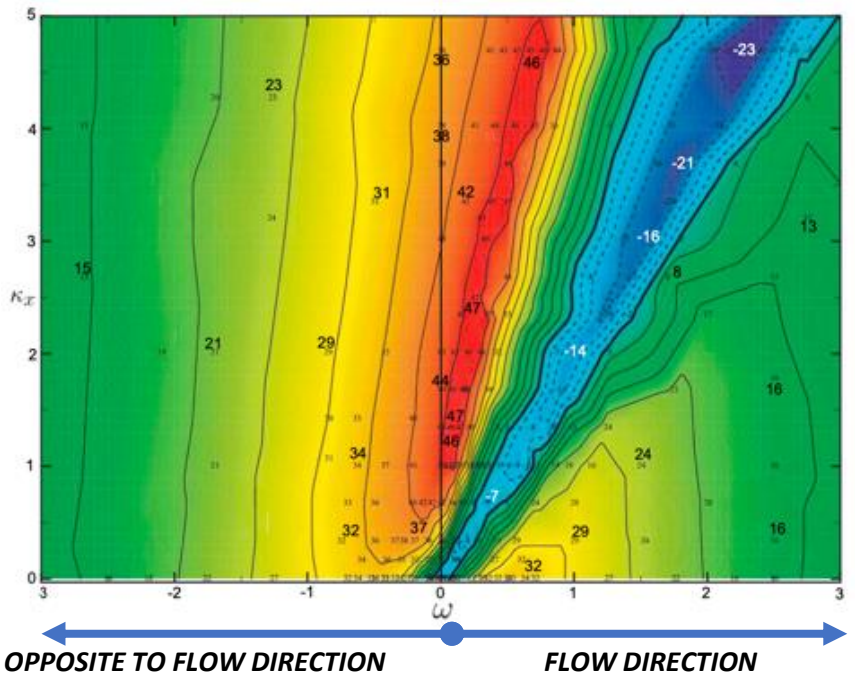


Skin friction drag reduction

Skin friction drag can be reduced through spanwise motion of the wall, in particular generating **spanwise waves travelling in the streamwise direction**.



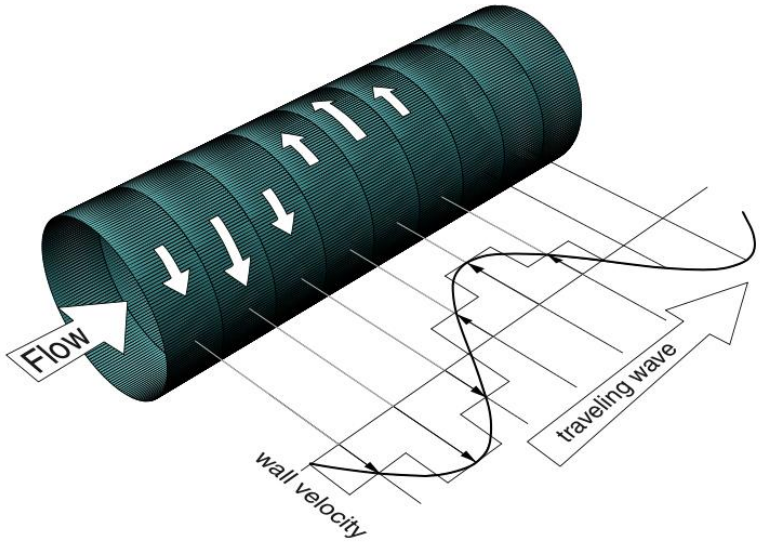
$Re_\tau = 200$ at $W^+ = 12$



M. Quadrio, P. Ricco, and C. Viotti. Streamwise−travelling waves of spanwise wall velocity for turbulent drag reduction. J. Fluid Mech., 627:161–178, 2009.

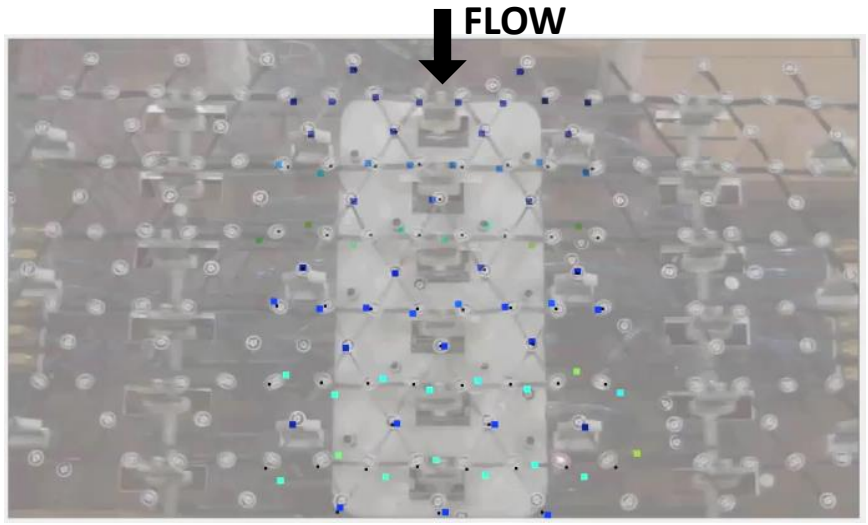
Skin friction drag reduction

$Re_\tau = 175$



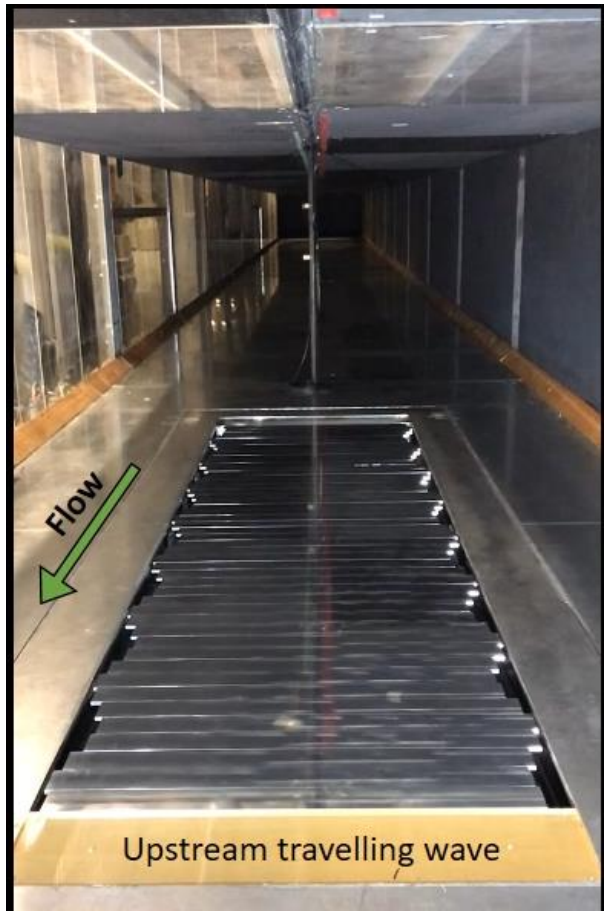
Auteri et al. (2010) "Experimental assessment of drag reduction by traveling waves in a turbulent pipe flow"Physics of fluid 22

$Re_\tau \sim 1000$



Bird, J., Santer, M. & Morrison, J.F. 2018 Experimental control of turbulent boundary layers with in-plane travelling waves. Flow, turbulence and combustion 100 (4), 1015– 1035

$Re_\tau \sim 10000$



Marusic, Ivan, et al. "An energy-efficient pathway to turbulent drag reduction." Nature communications 12.1 (2021): 1-8.

What is drag reduction mechanism at high Re?

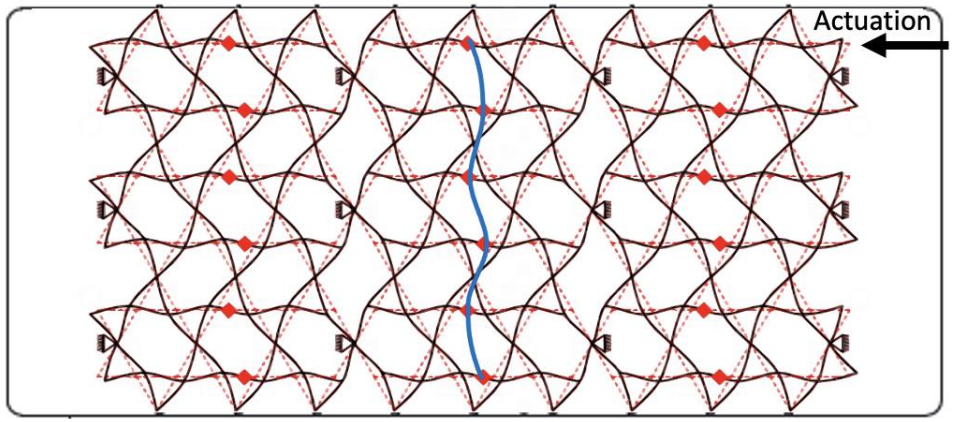
- The “big and slow” experiment: active surface (3 m x 1m) to be mounted in the 10x5 wind tunnel ($Re_\tau \sim 8000$).
- Variable well-resolved waveforms using Kagome lattice.
- Is large-structure control energy saving (as well as drag reducing)?

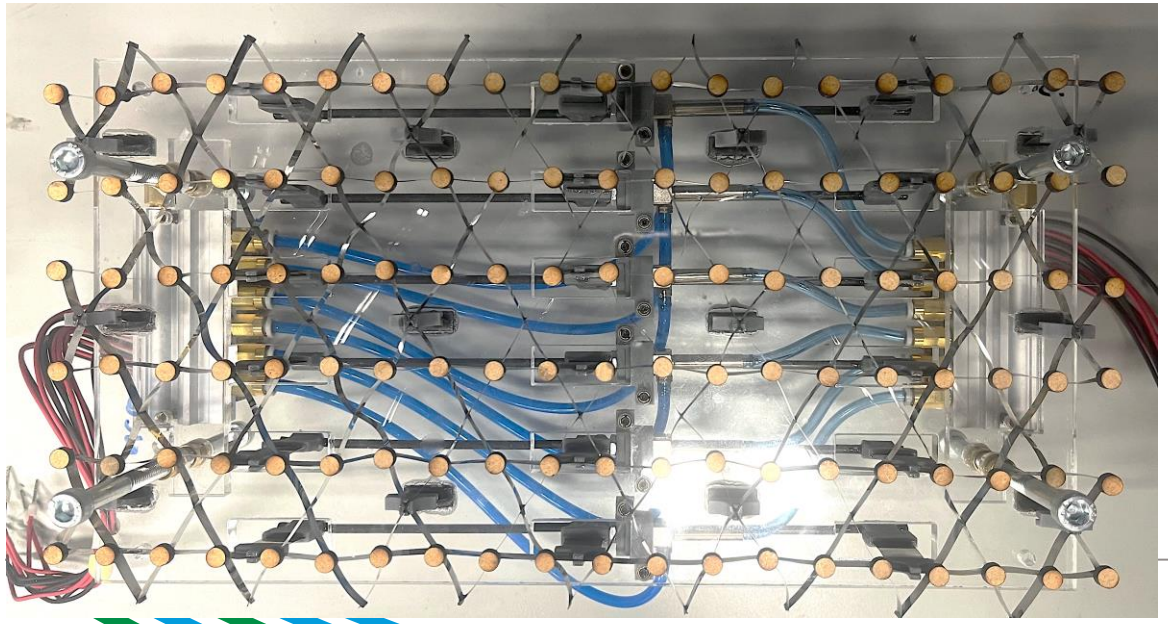
Two test sections:

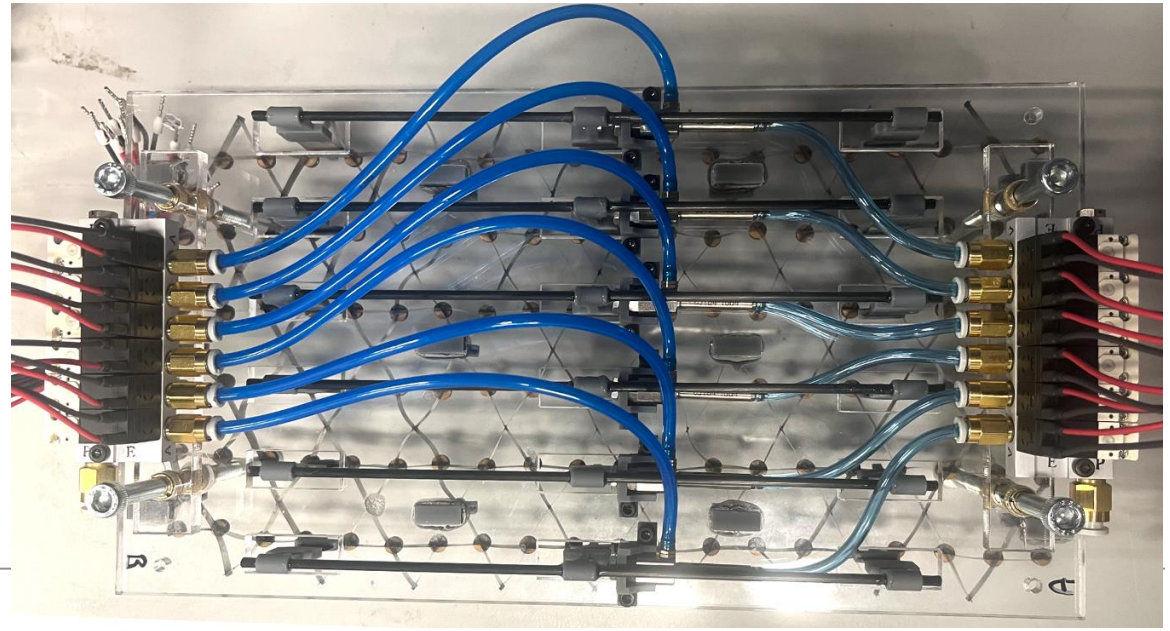
- **3 m × 1.5 m × 20 m** with a speed range up to 40 m/s, and Turbulence Intensity below 0.15%.
- **5.8 m × 2.7 m × 18 m** with a speed range up to 11 m/s.

The model

- Based on the Kagome lattice designed by Bird et al., 2017.
- Pneumatically actuated.
- Rig can run up to 40 Hz with a minimum wavelength of 57 mm and a spanwise displacement of 10mm.

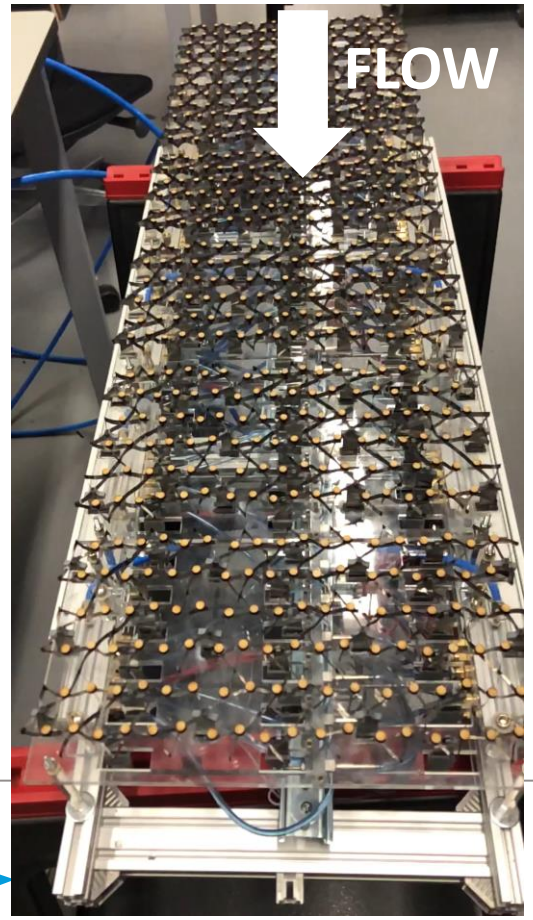




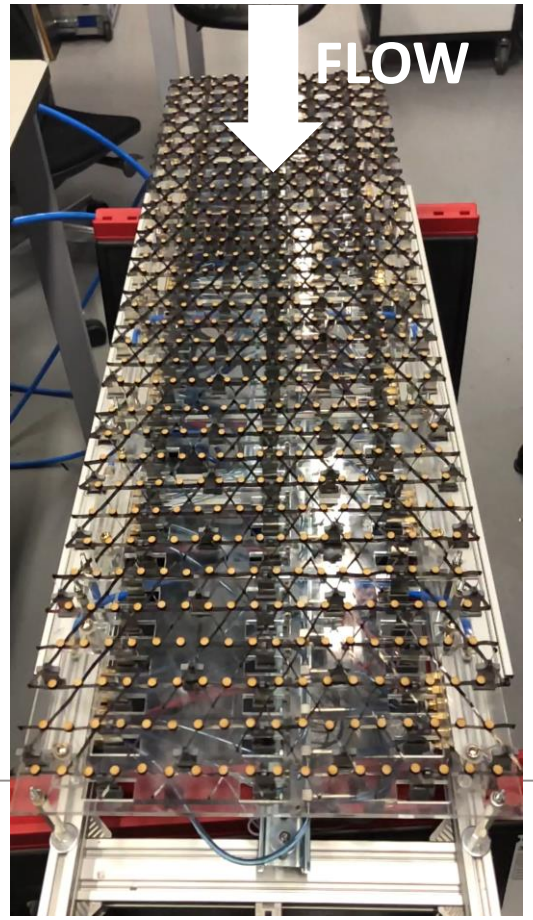


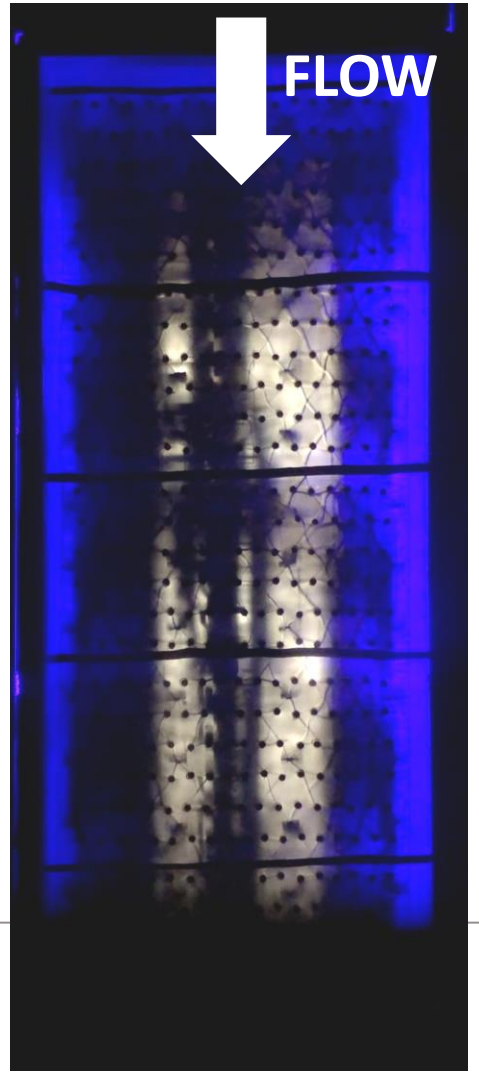
The model

Upstream travelling

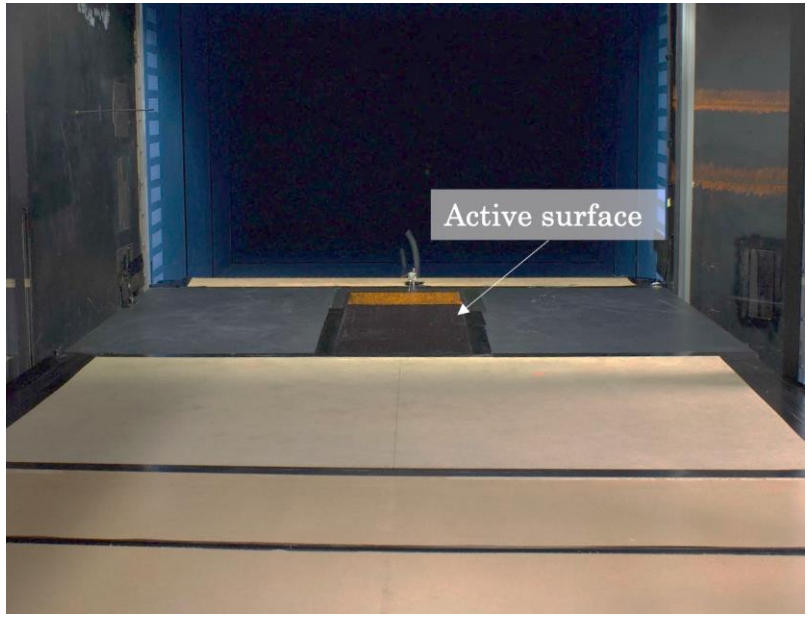


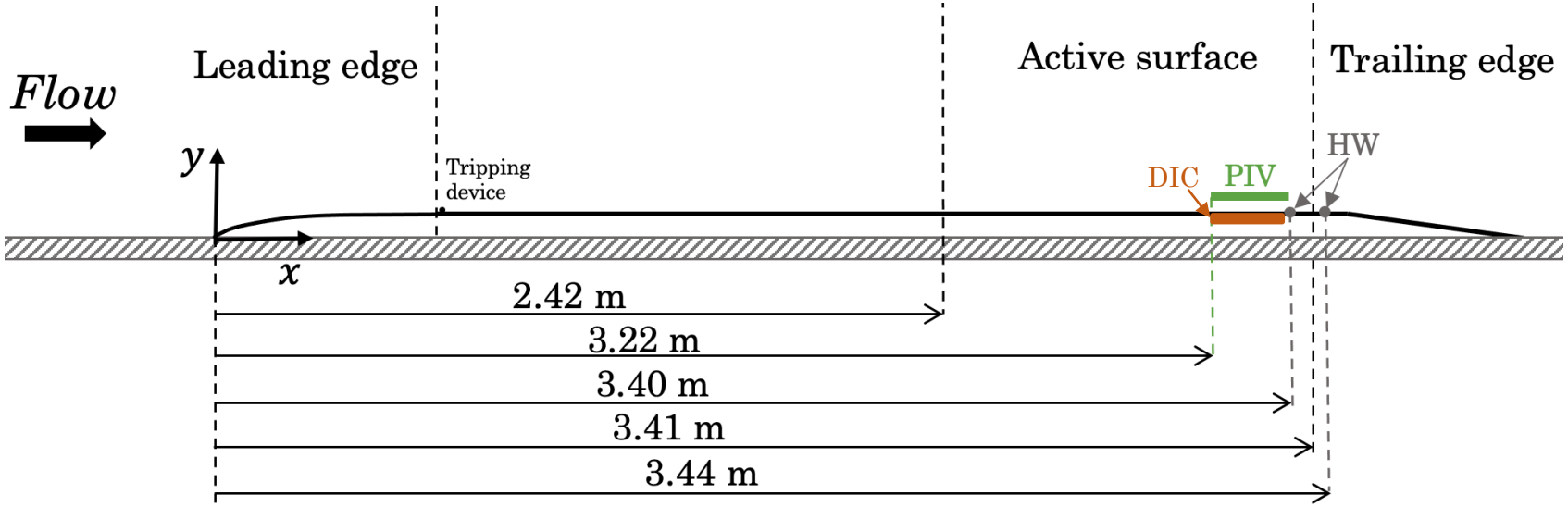
Downstream travelling



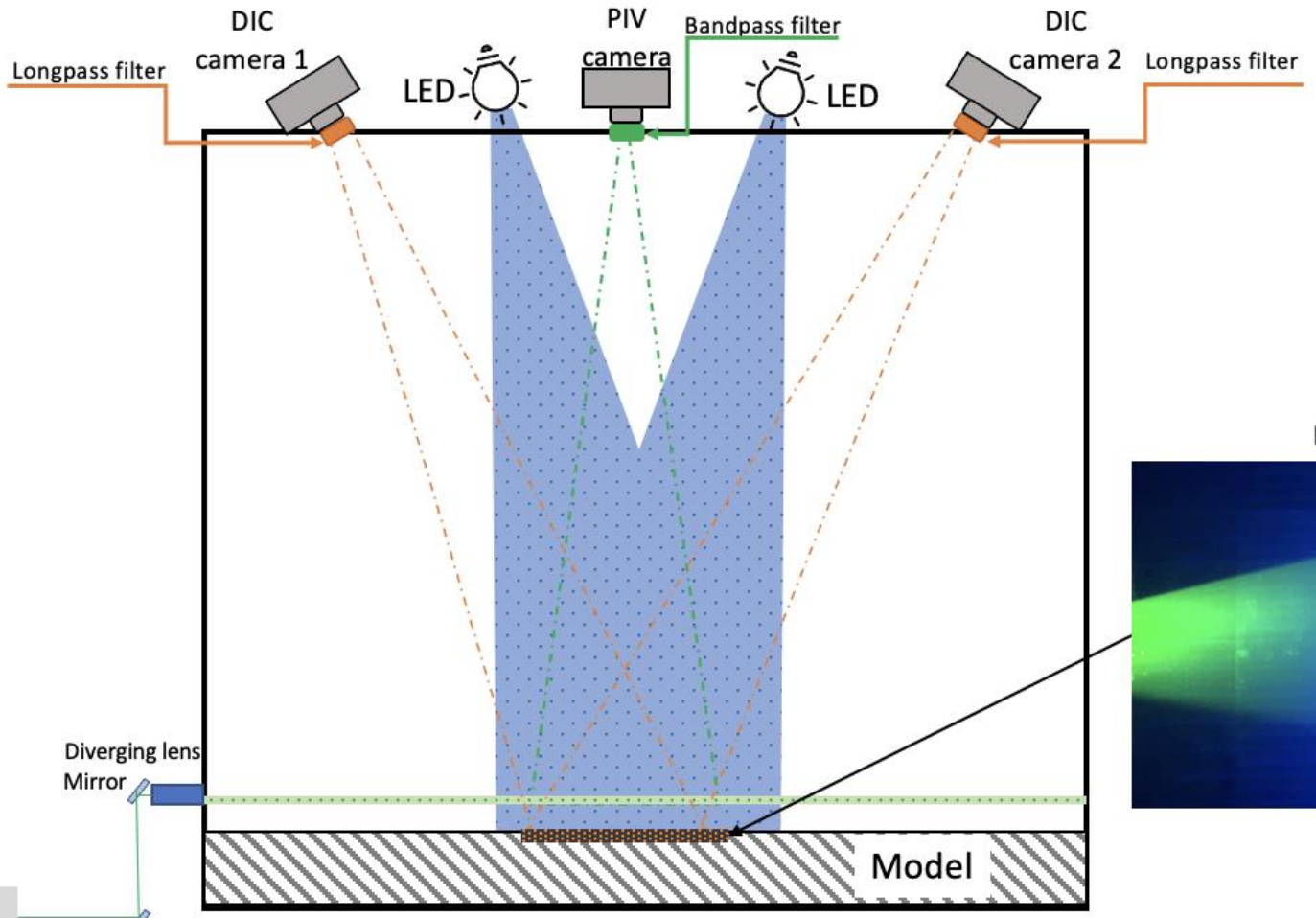


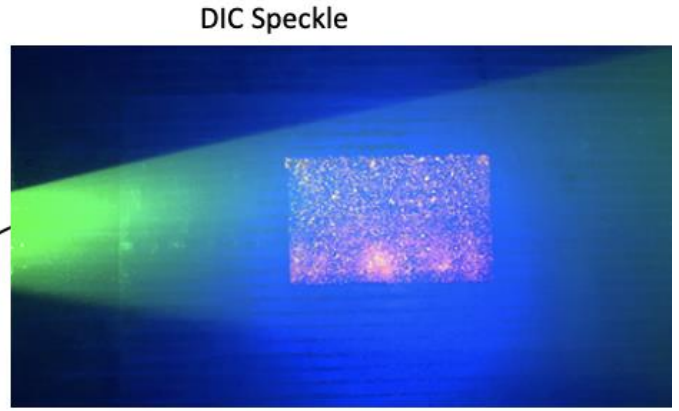
Preliminary experiment





Simultaneous DIC/PIV





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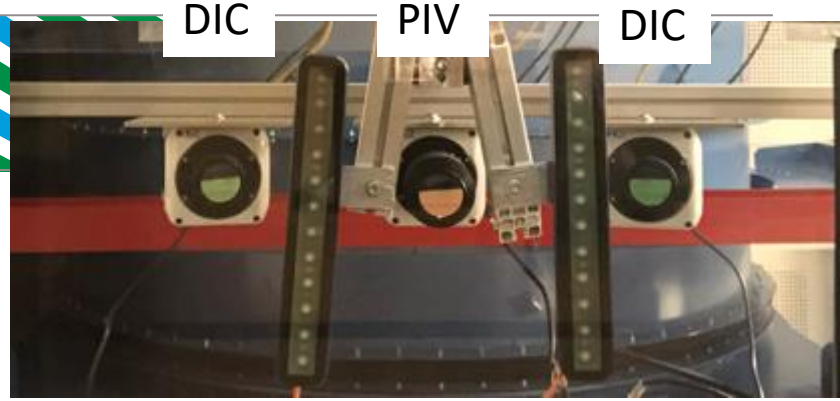
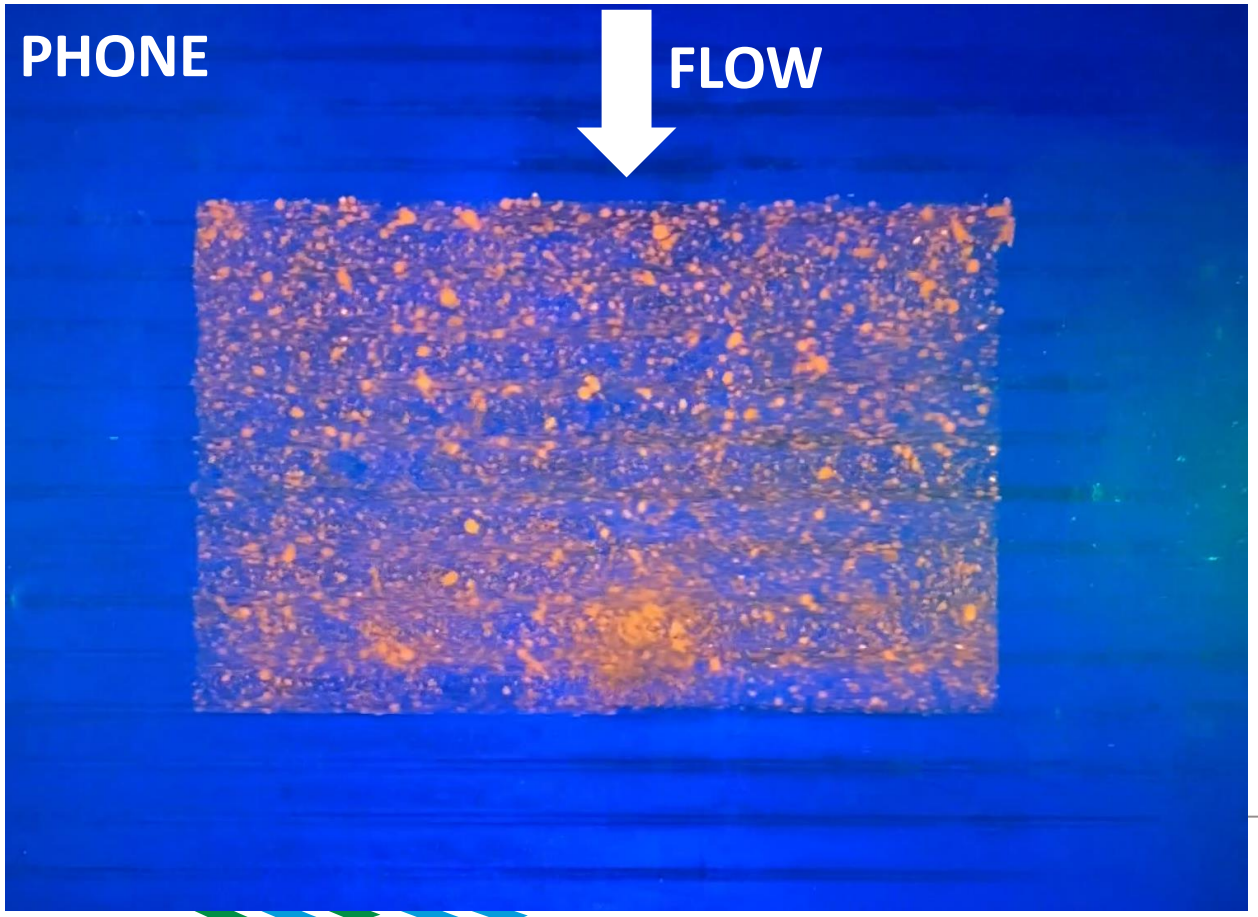
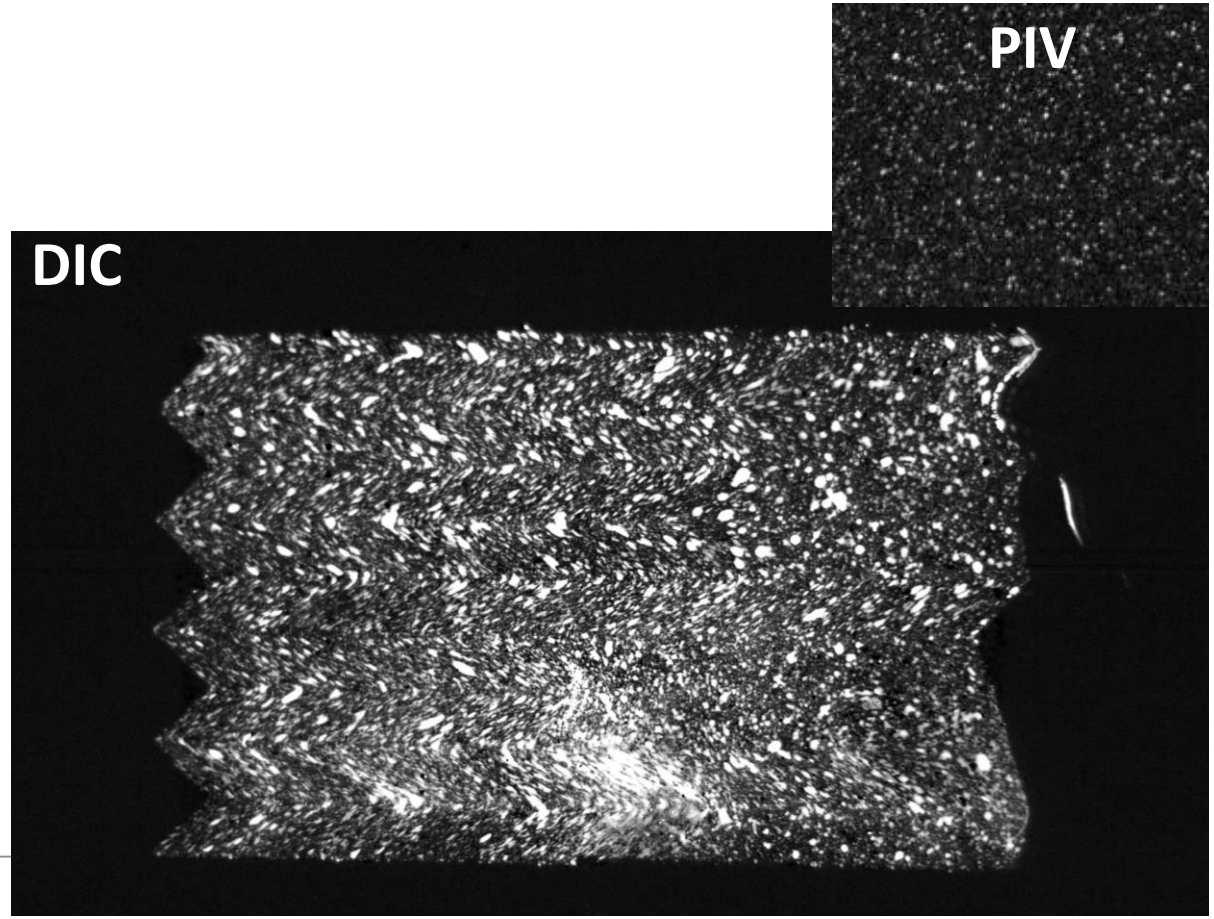
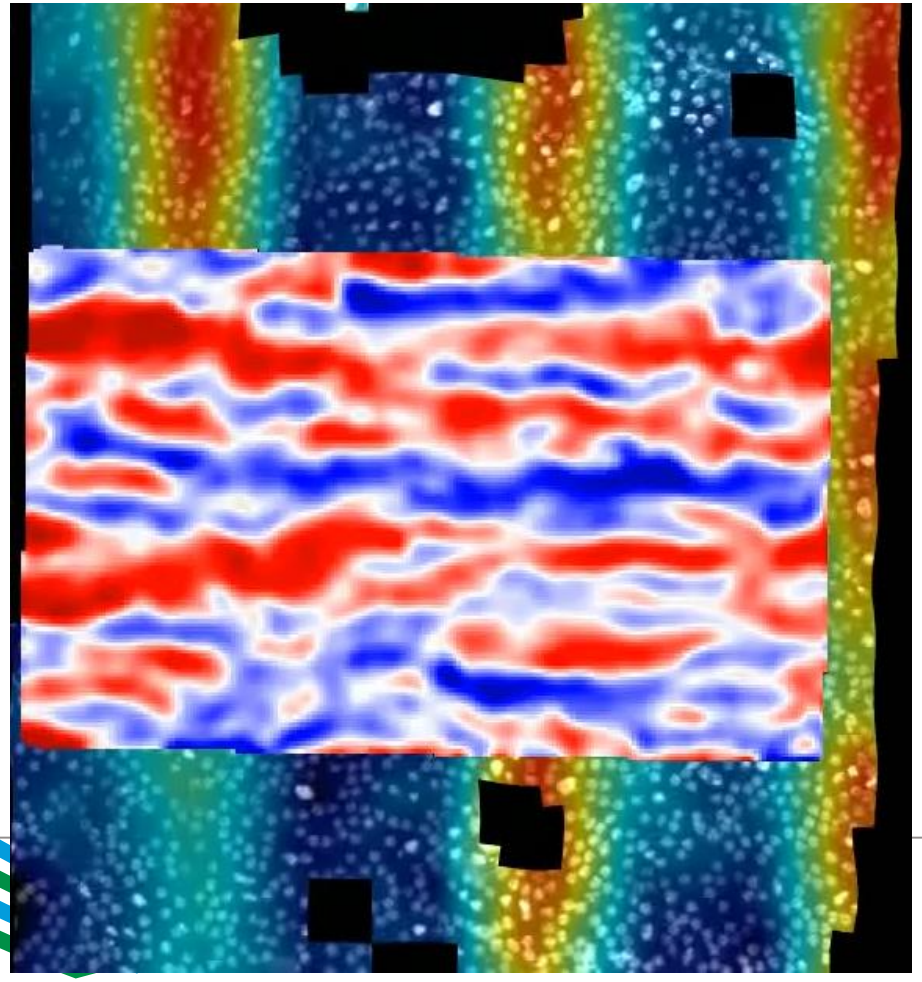




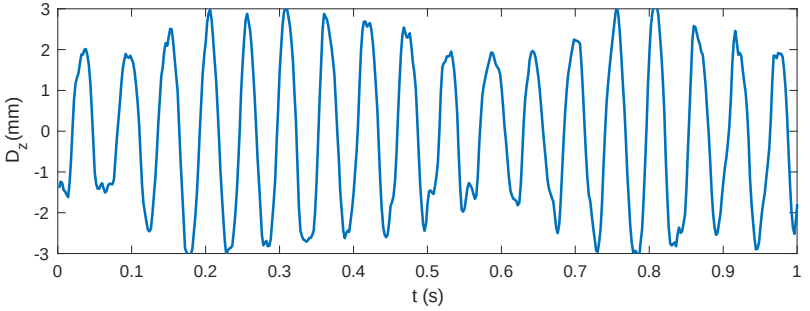


Simultaneous DIC/PIV

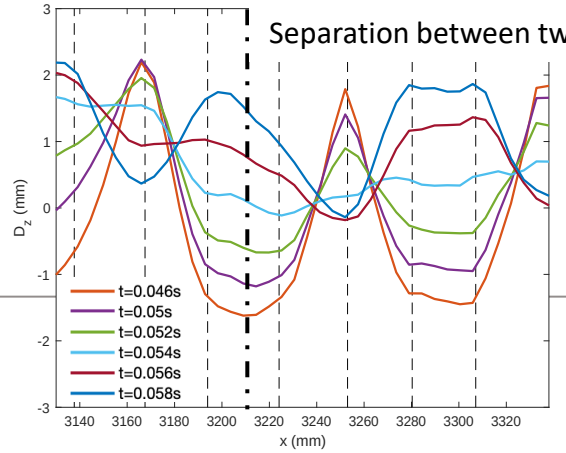


PIV $y{\sim}3mm$ $(y^{+}{\sim}30)$

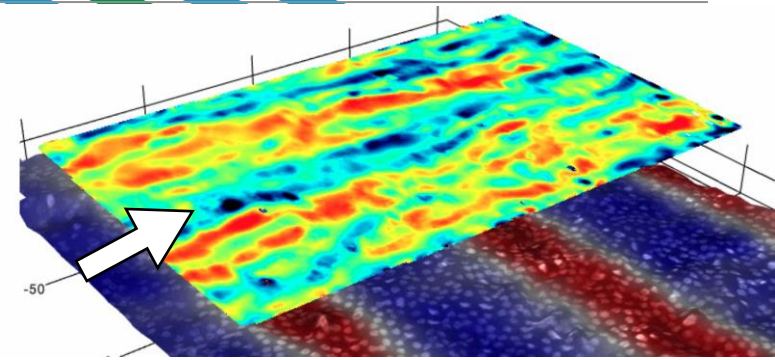
Example of spanwise displacement: wave definition in time at 20 Hz.



Example of spanwise displacement in time in the streamwise direction.



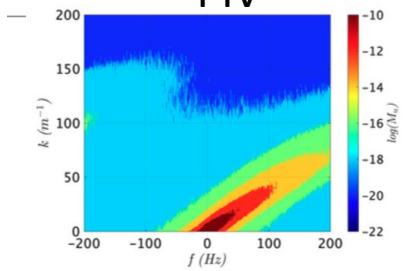
What comes next?



- Experiment at 20 Hz: square wave vs sine wave.

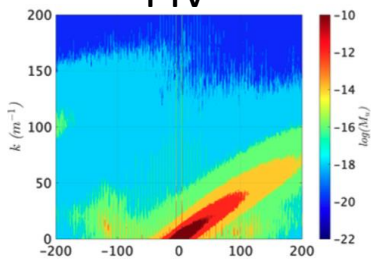
- PIV and DIC: frequency-wavenumber 2D spectrum; cross-correlation in time, advanced input/output analysis.

PIV



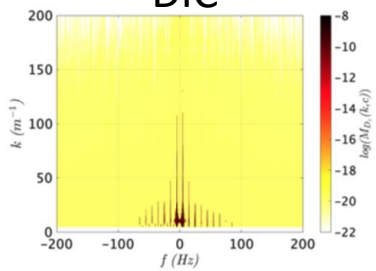
(a) streamwise without actuation

PIV



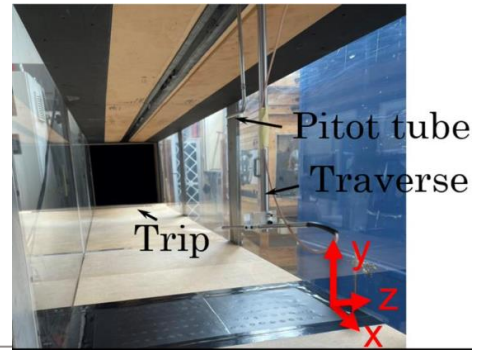
(b) streamwise with actuation

DIC

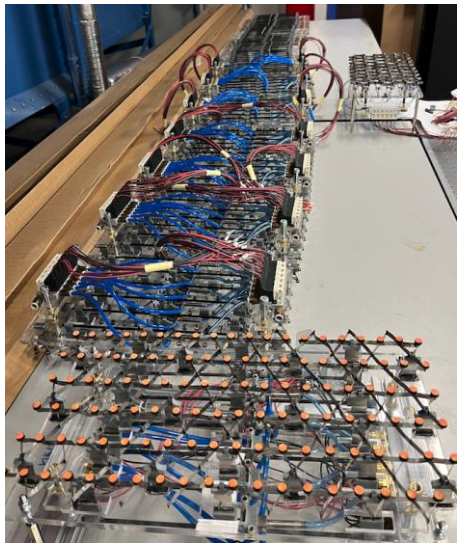


(e) spanwise wall displacement

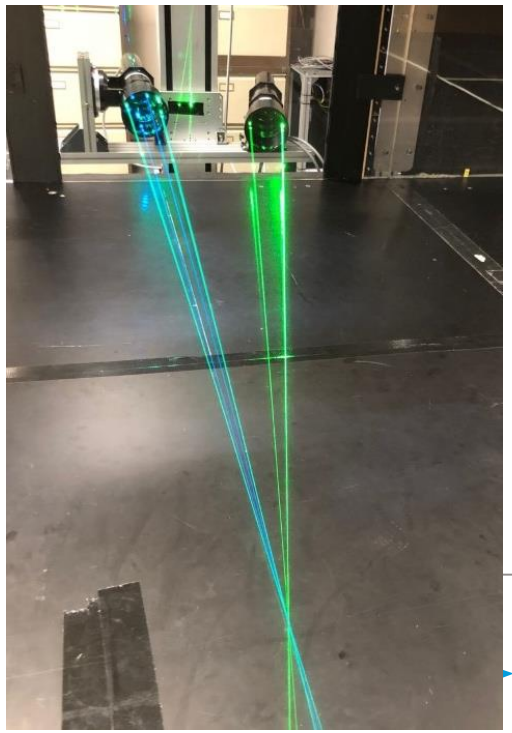
- Experiment in the 18’’ wind tunnel (thinner boundary layer so shorter test length with one tile) with one tile.



What comes next?



- Experiment in the 10x5 model on a 3mx1m active surface, this summer!
- 51 modules (3 rows of 17actuators) for full development and 2D in the mean along centre line.



- 3D LDA measurements to characterise the boundary layer.
- Oil-film interferometry for direct measurement of skin friction.