Imperial College London

In-plane travelling waves for turbulent skin friction drag reduction

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Workshop on Turbulent Skin Friction Reduction

EPSRC
Engineering and Physical Sciences Research Council

Imperial College
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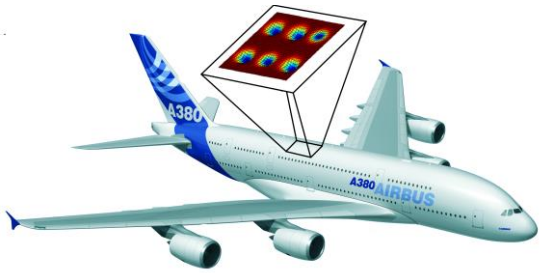
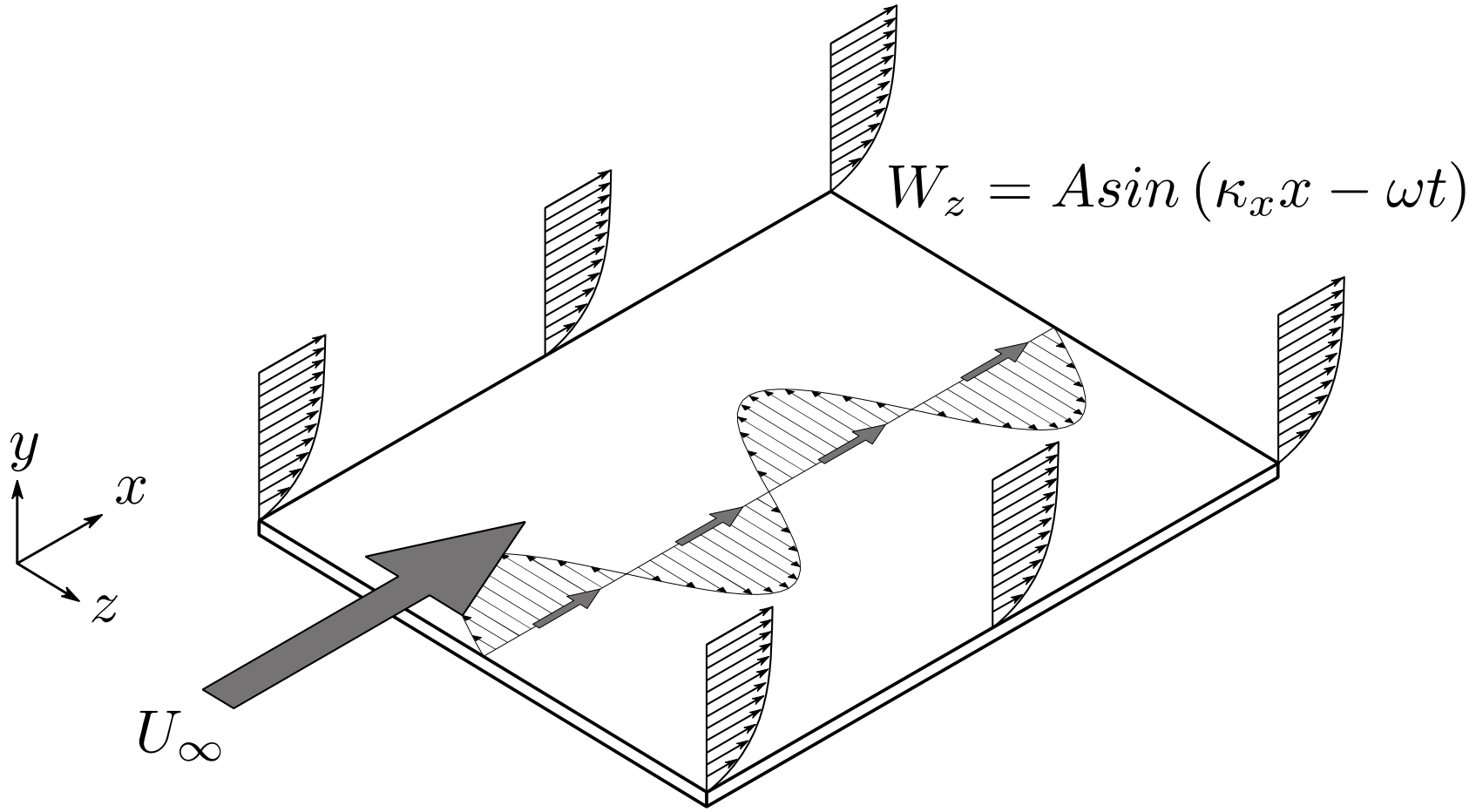
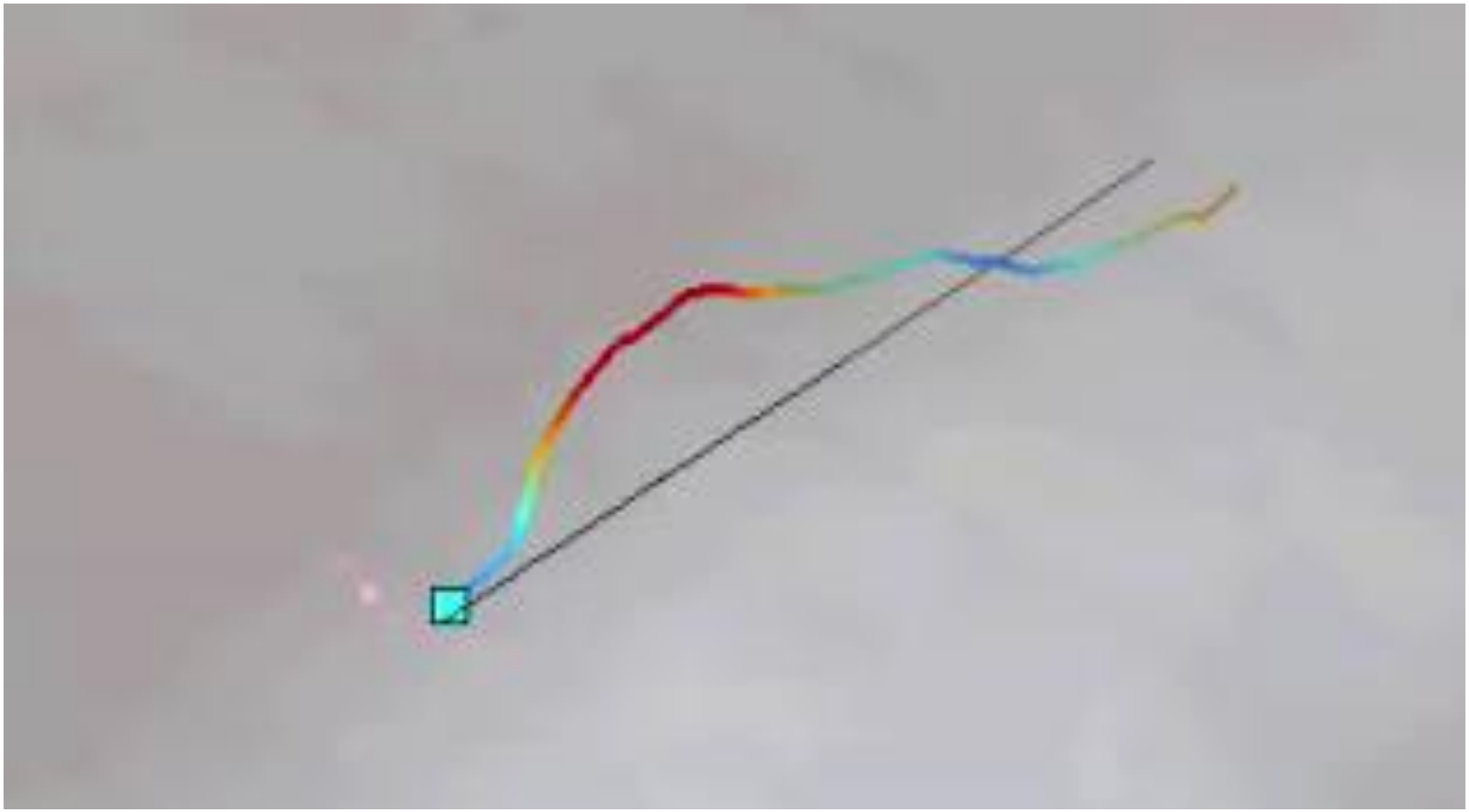


Aim of the project



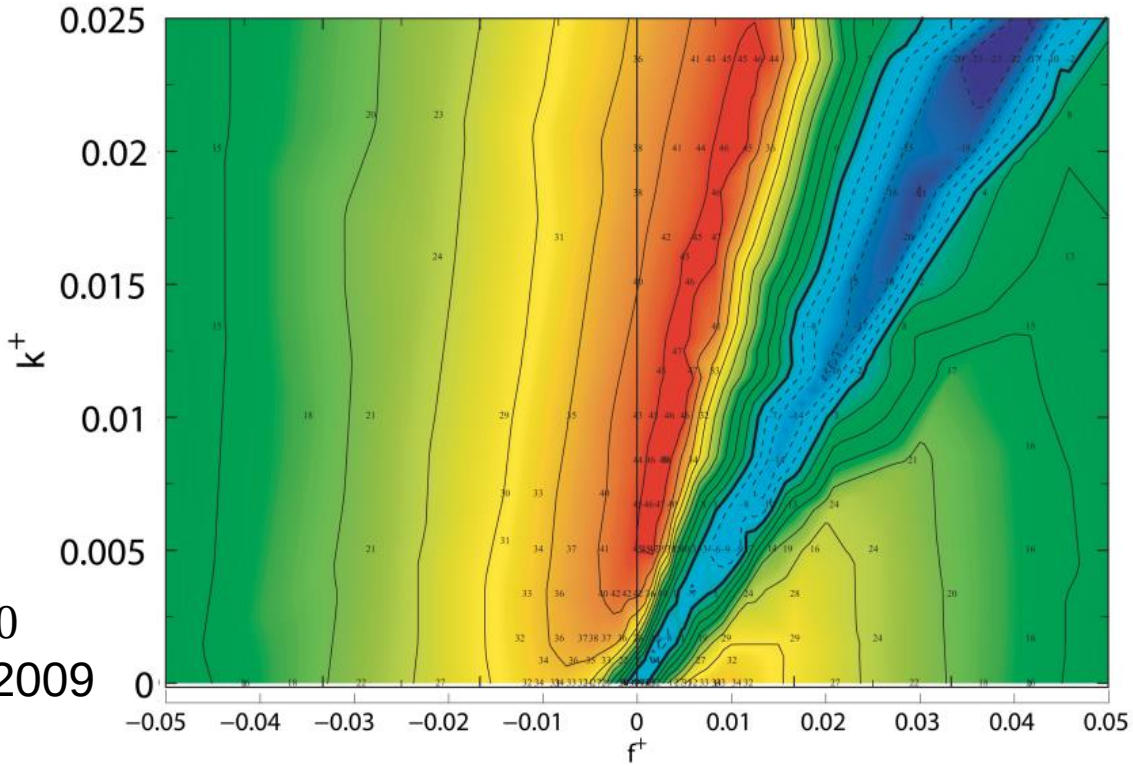
Standing wave - surface

Travelling wave - surface



Requirements of an experimental surface: skin friction drag

- Always aim to maximise wave velocity, W^+ .
- Try and achieve the largest wavenumber, κ^+, as possible.
- Match suitable frequency to map, but use T^+ = 100 as a good starting point.
- Practical application (higher Re, $U_\infty \longrightarrow$ higher frequencies).



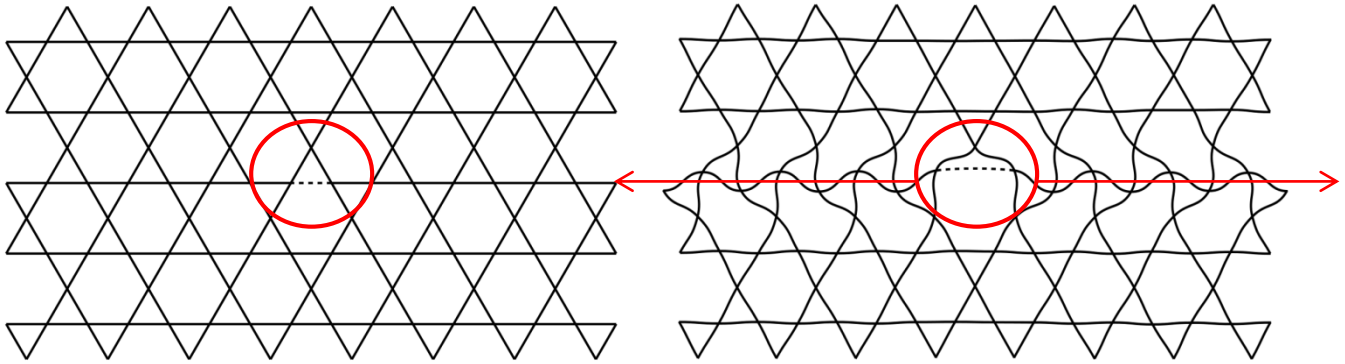
: decrease 46%

: increase 20%

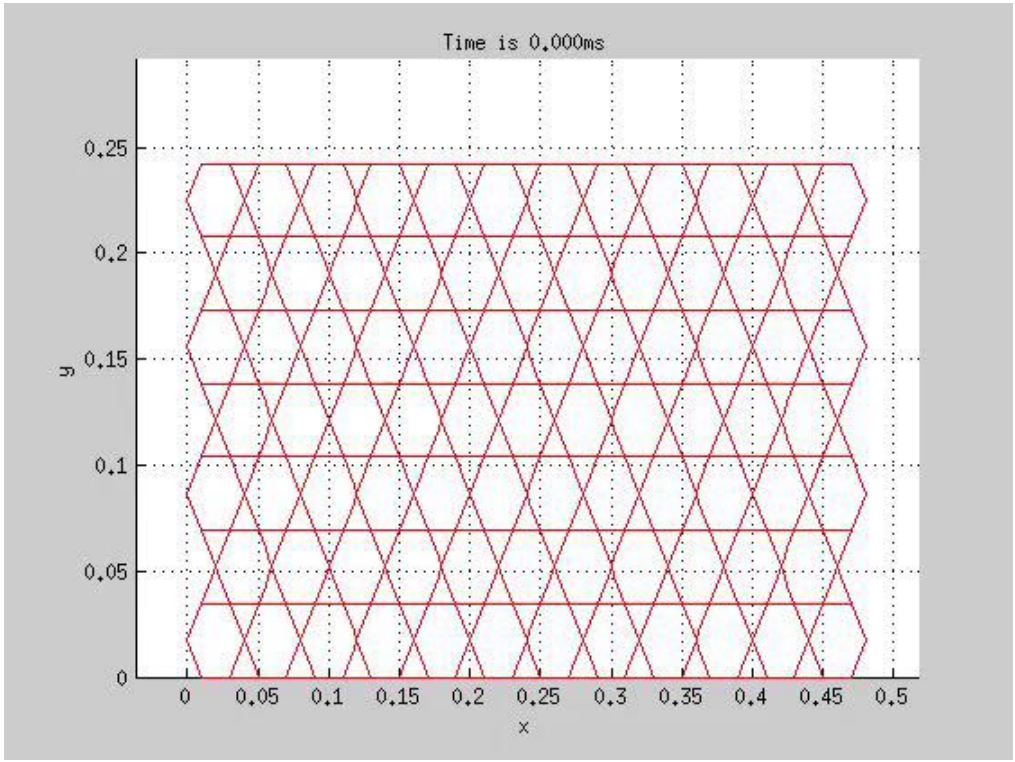
DNS at Re_τ=200
Quadrio *et al*. 2009

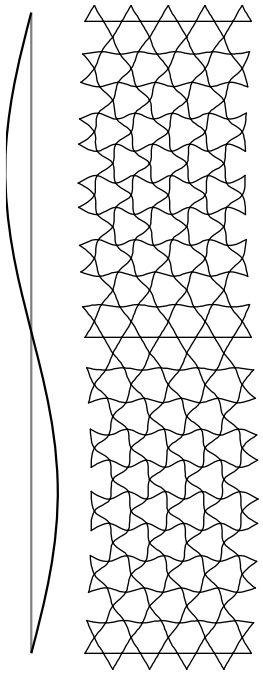
The Kagome lattice

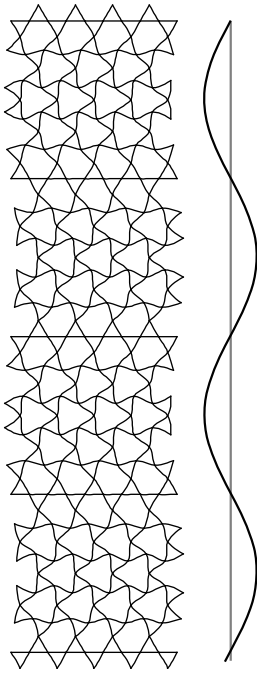
- The Kagome lattice is a structure which propagates displacements along discrete “corridors”.
- These corridors can then be driven independently to discretise waveforms.
- By varying the phase between adjacent corridors, a travelling or standing wave can be created.



Kagome lattice



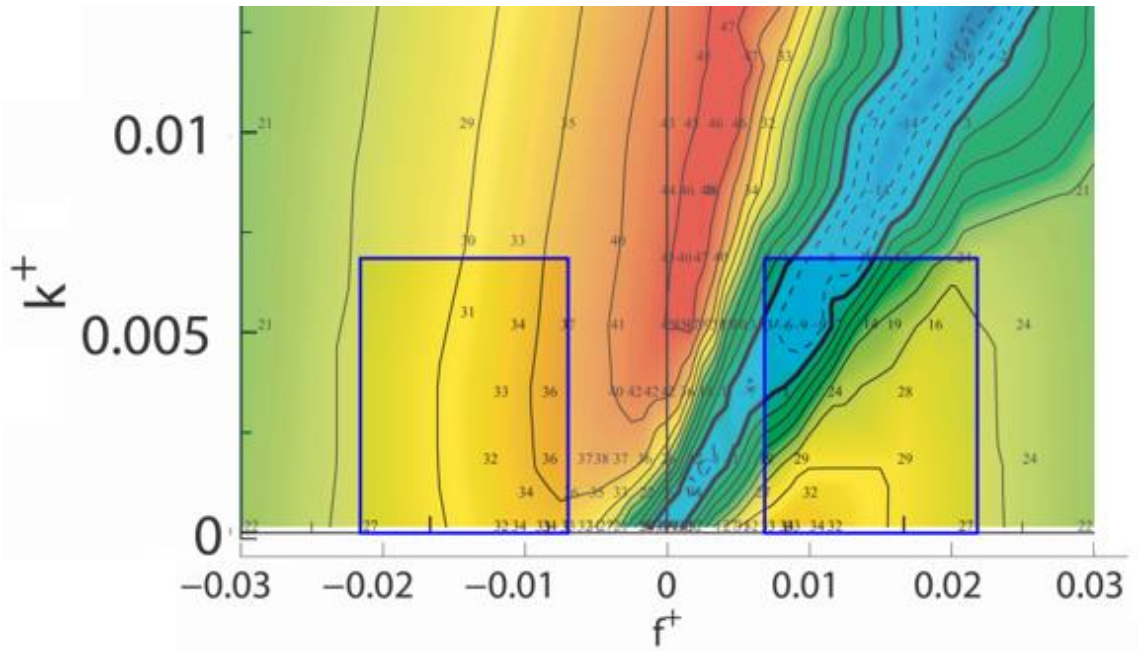




Bird *et al.* Int. J. Solids & Struct. 2017
Bird *et al.* Int. J. Solids & Struct. 2017 (submitted)

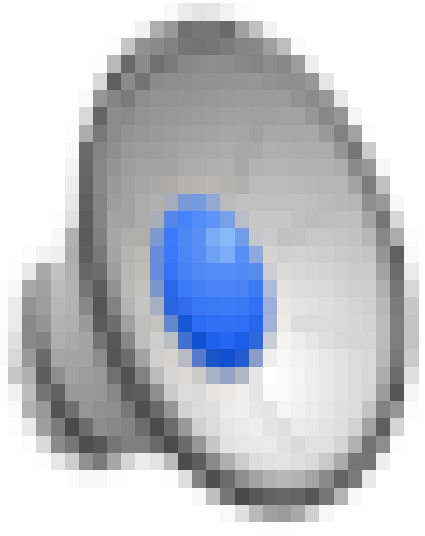
Experimental scope

- Based on the structural limitations of the lattice, a fluids experiment can be carried out with:
- $5 < U_\infty < 8$ ms^{-1}
- $Re_l \sim 1000$
- $0 < \kappa^+ < 0.0069$
- $f_{max} = 70$ Hz

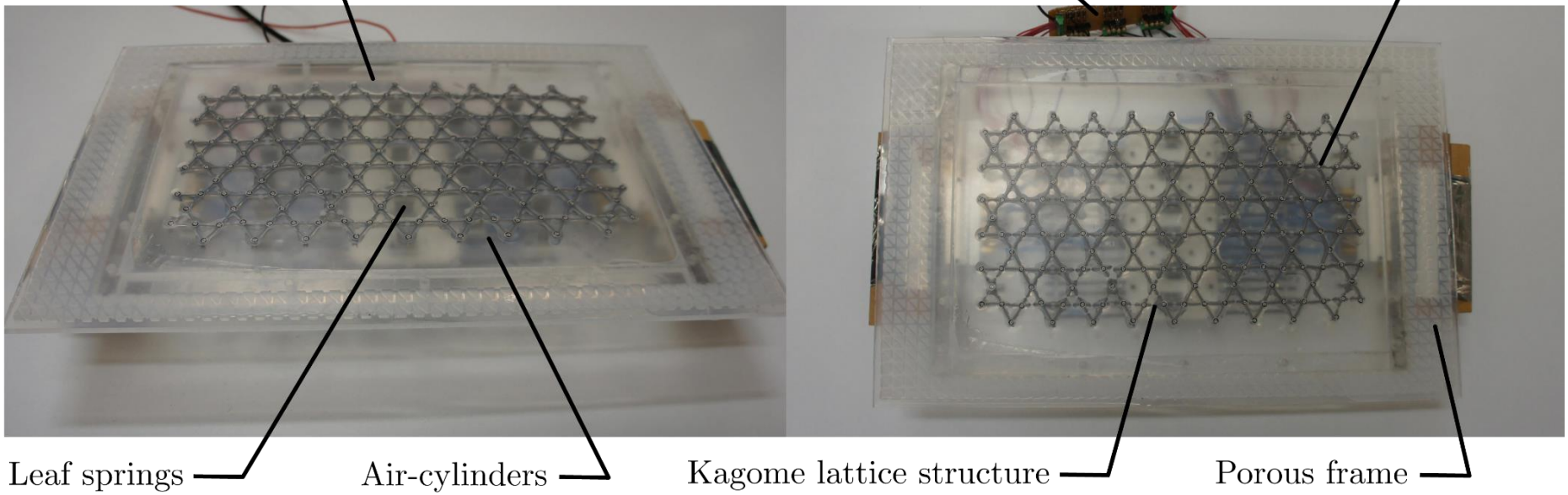


(Assuming W^+ is always greater than 5)

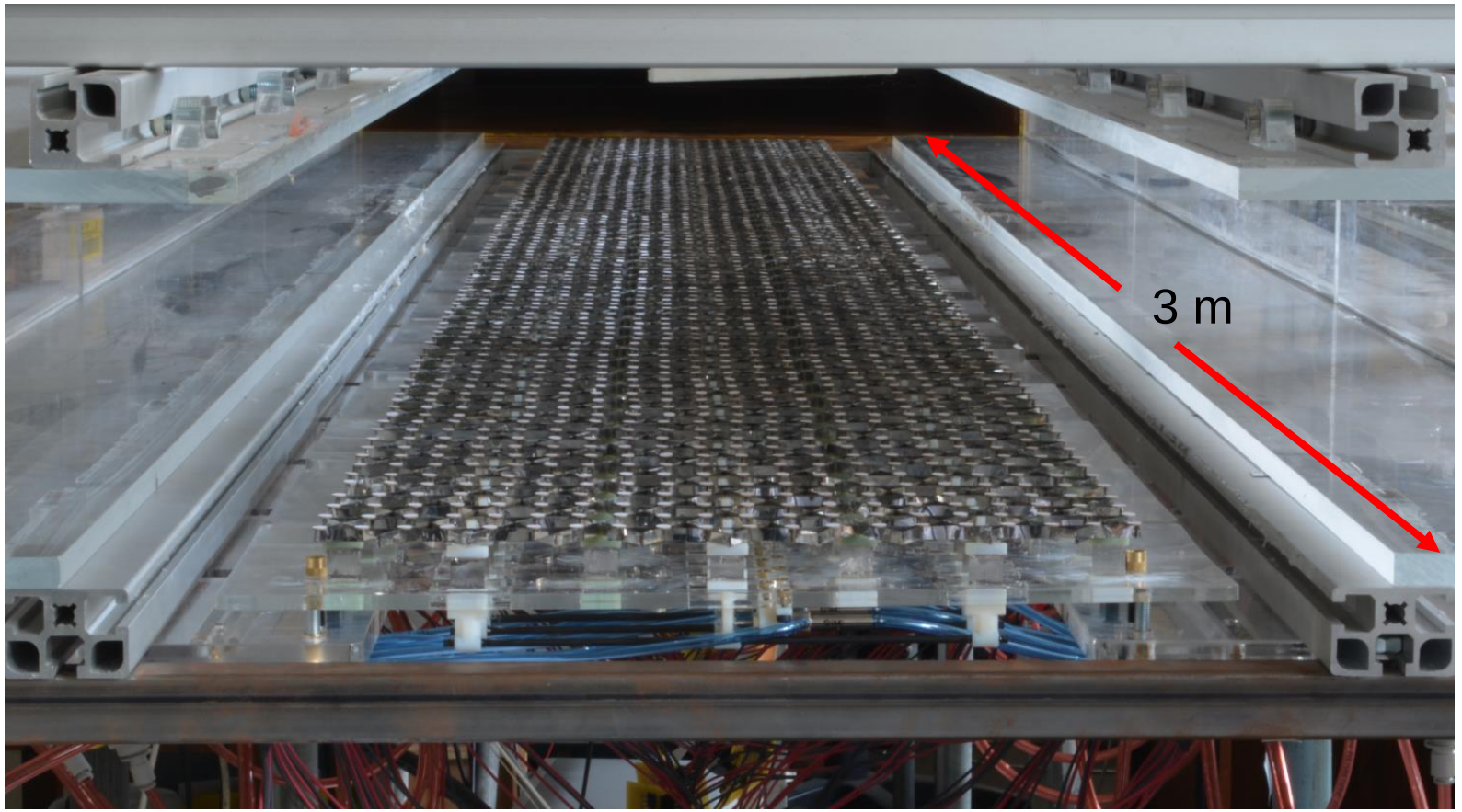
Initial module



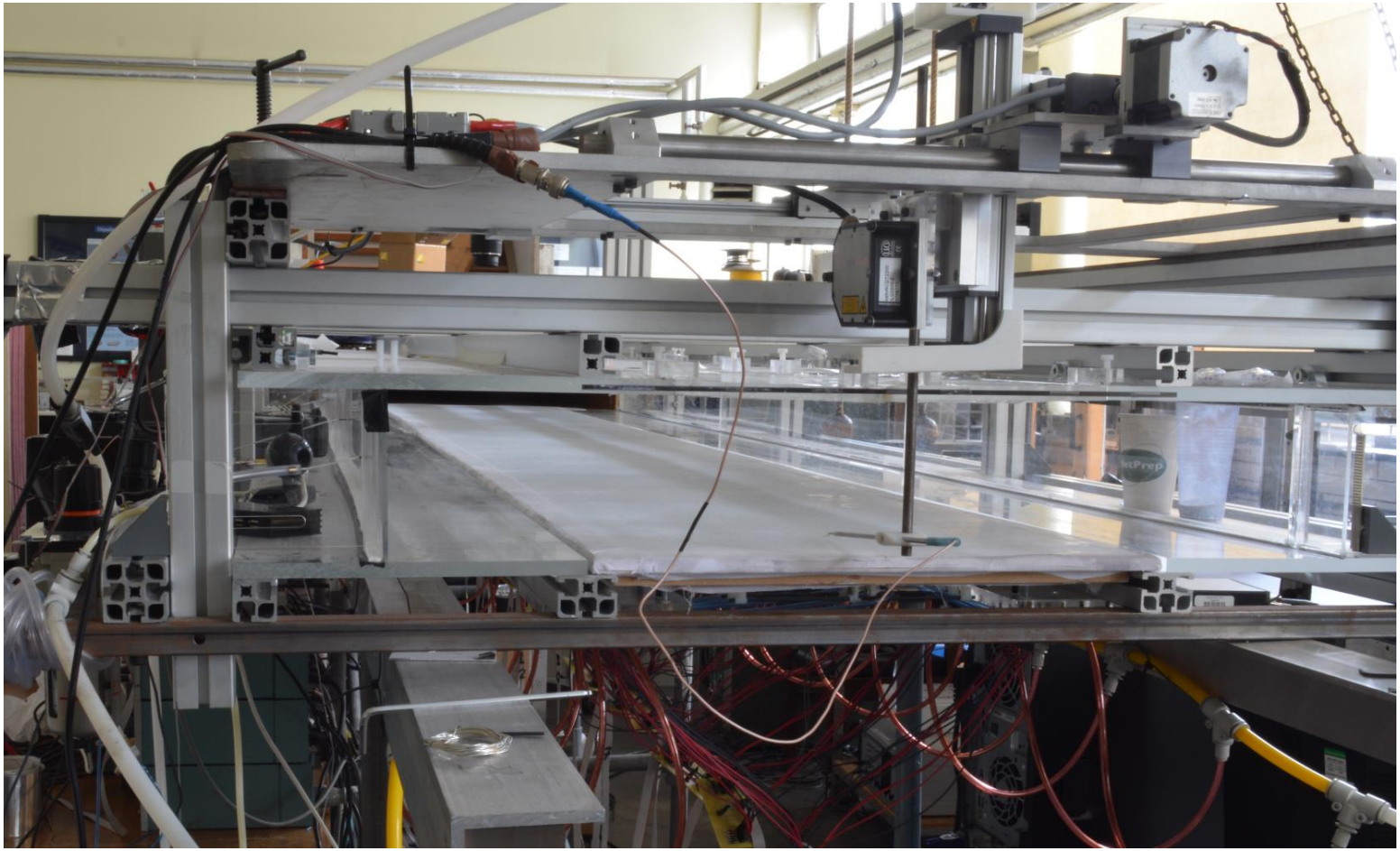
Latest module built



Instrumented tunnel showing Kagome structure



With pre-tensioned silicone skin

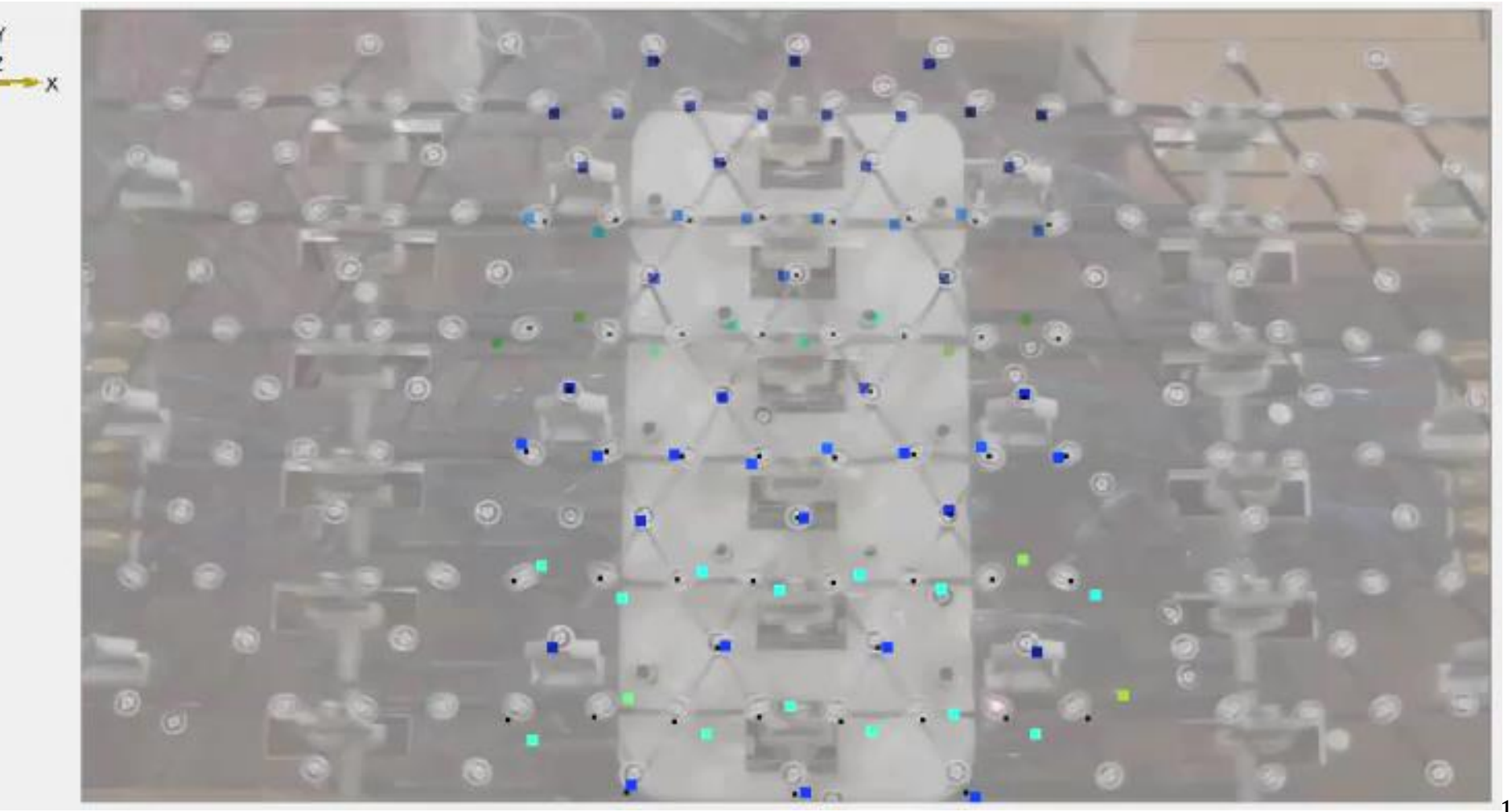


Travelling wave – short wavelength

Laser scanning Doppler vibrometer

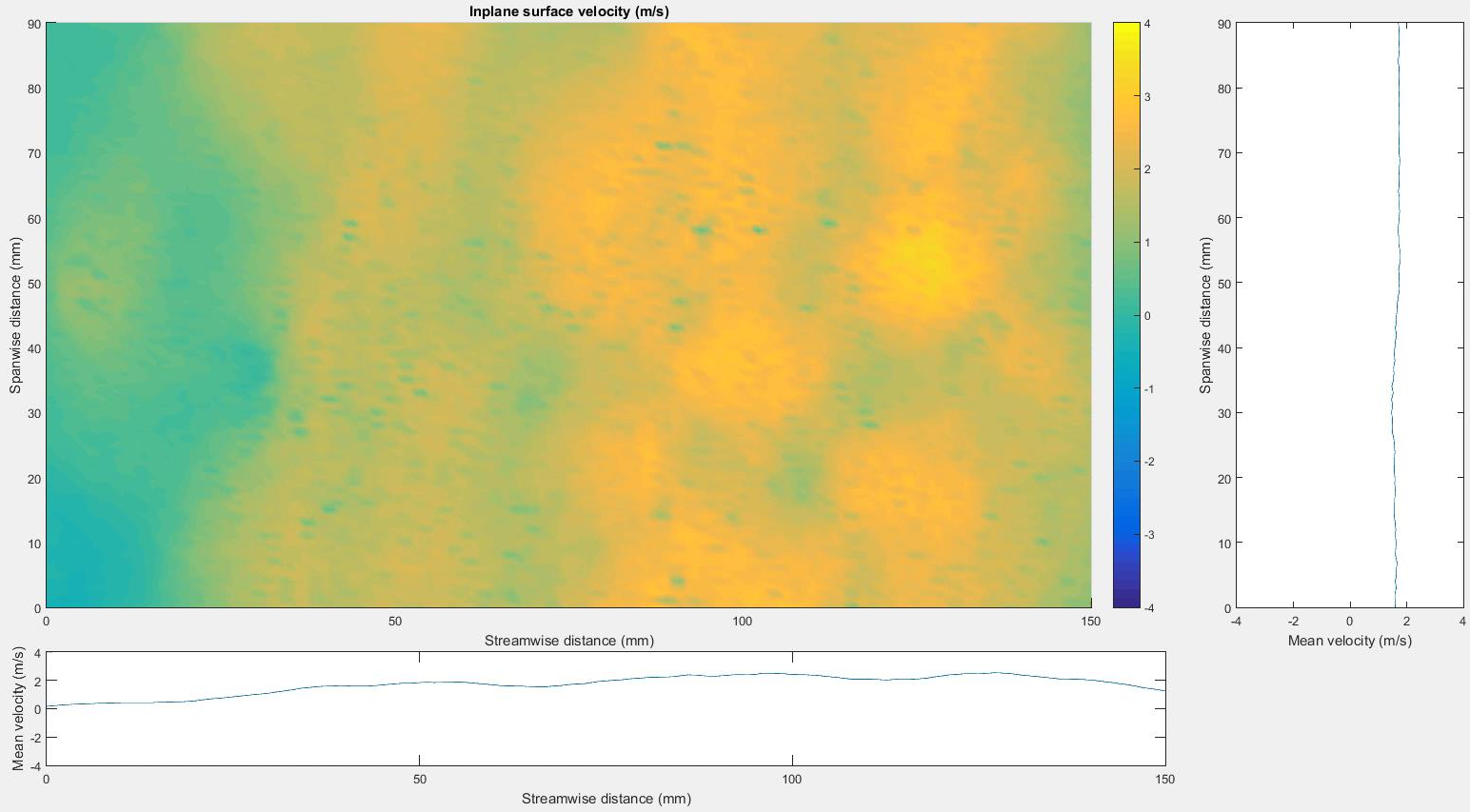
Travelling wave – long wavelength

Laser scanning Doppler vibrometer



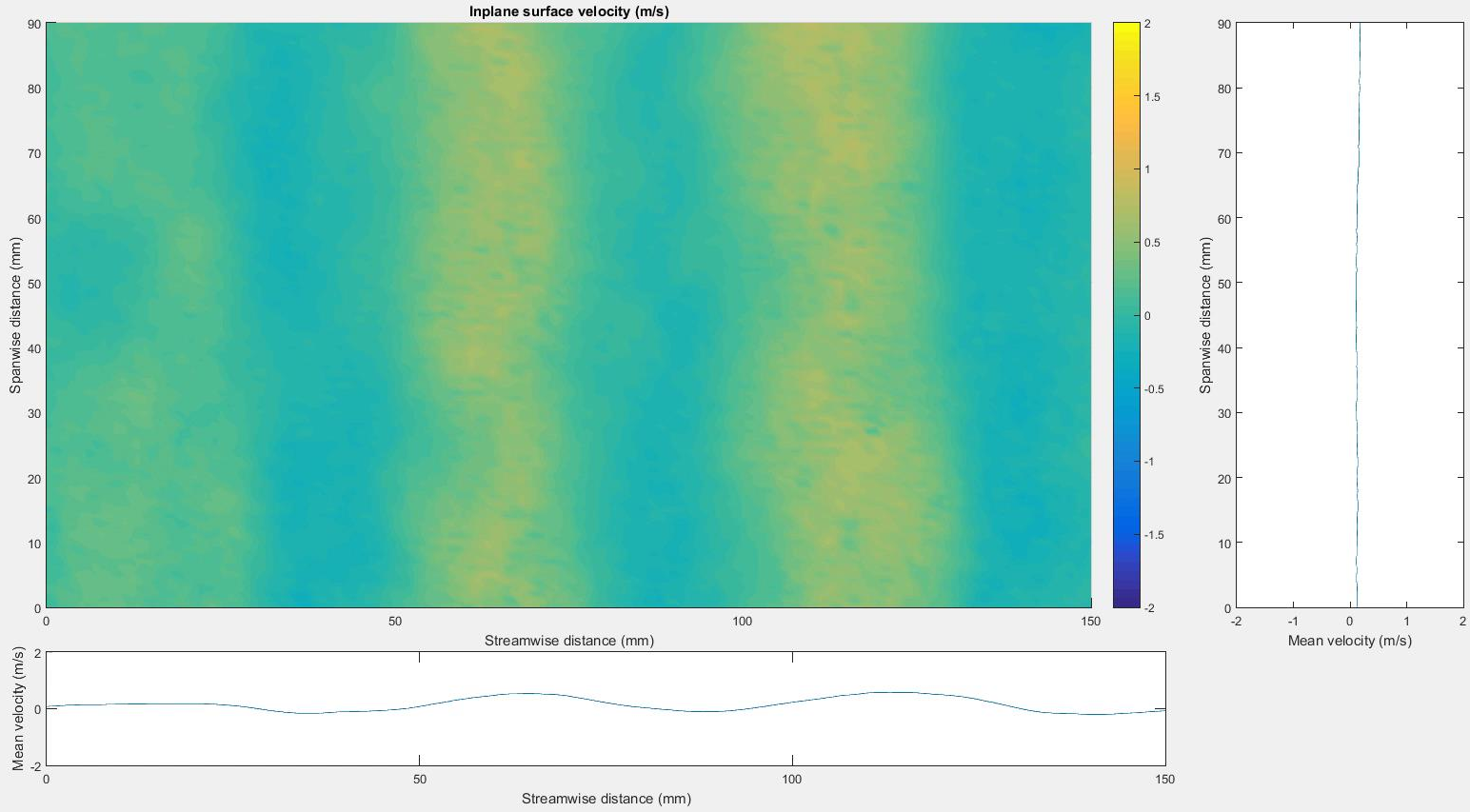
Digital image correlation wall oscillation

Photogrammetry



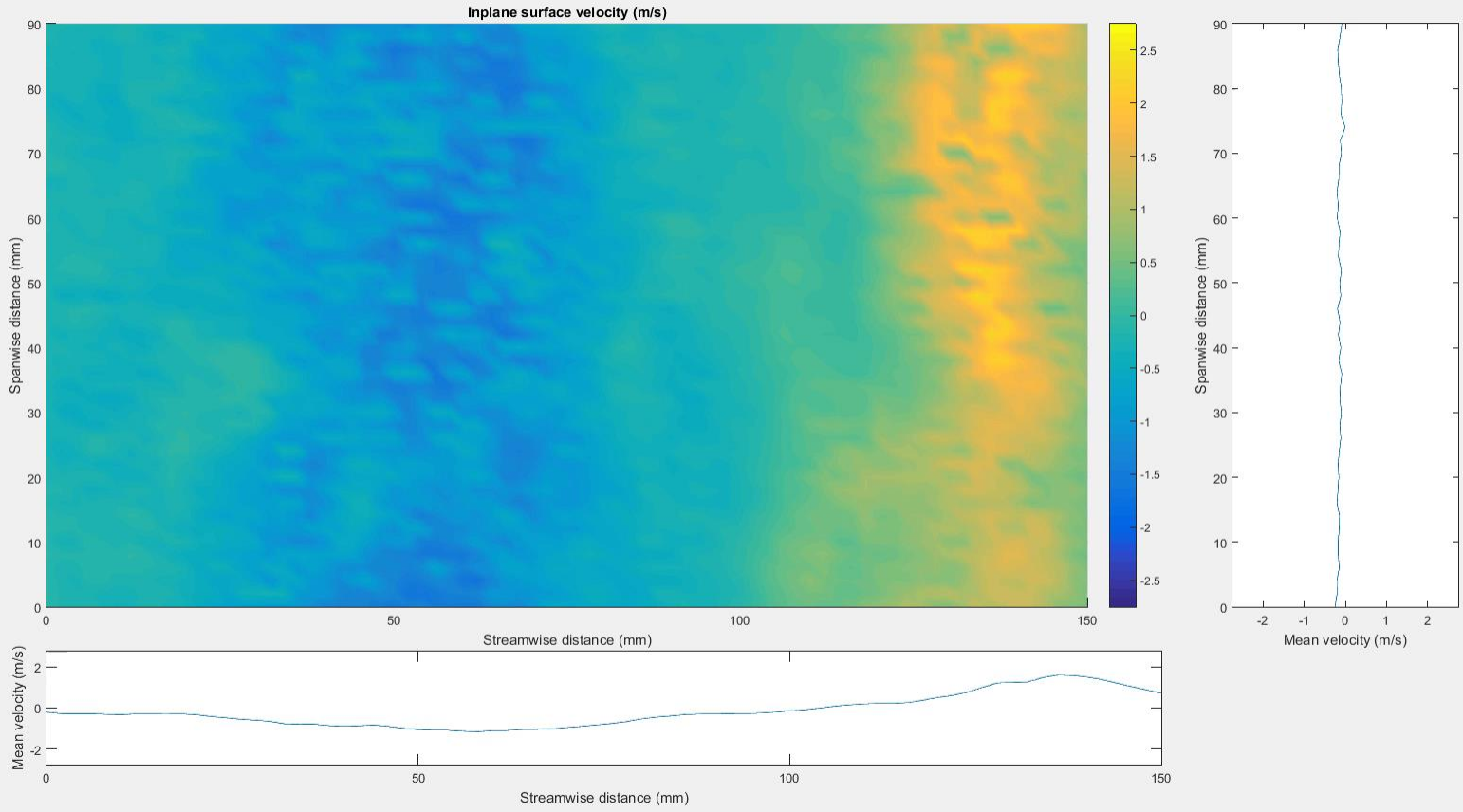
Digital image correlation standing wave

Photogrammetry

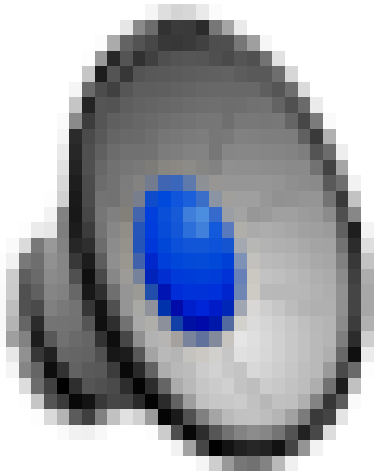


Digital image correlation travelling wave

Photogrammetry

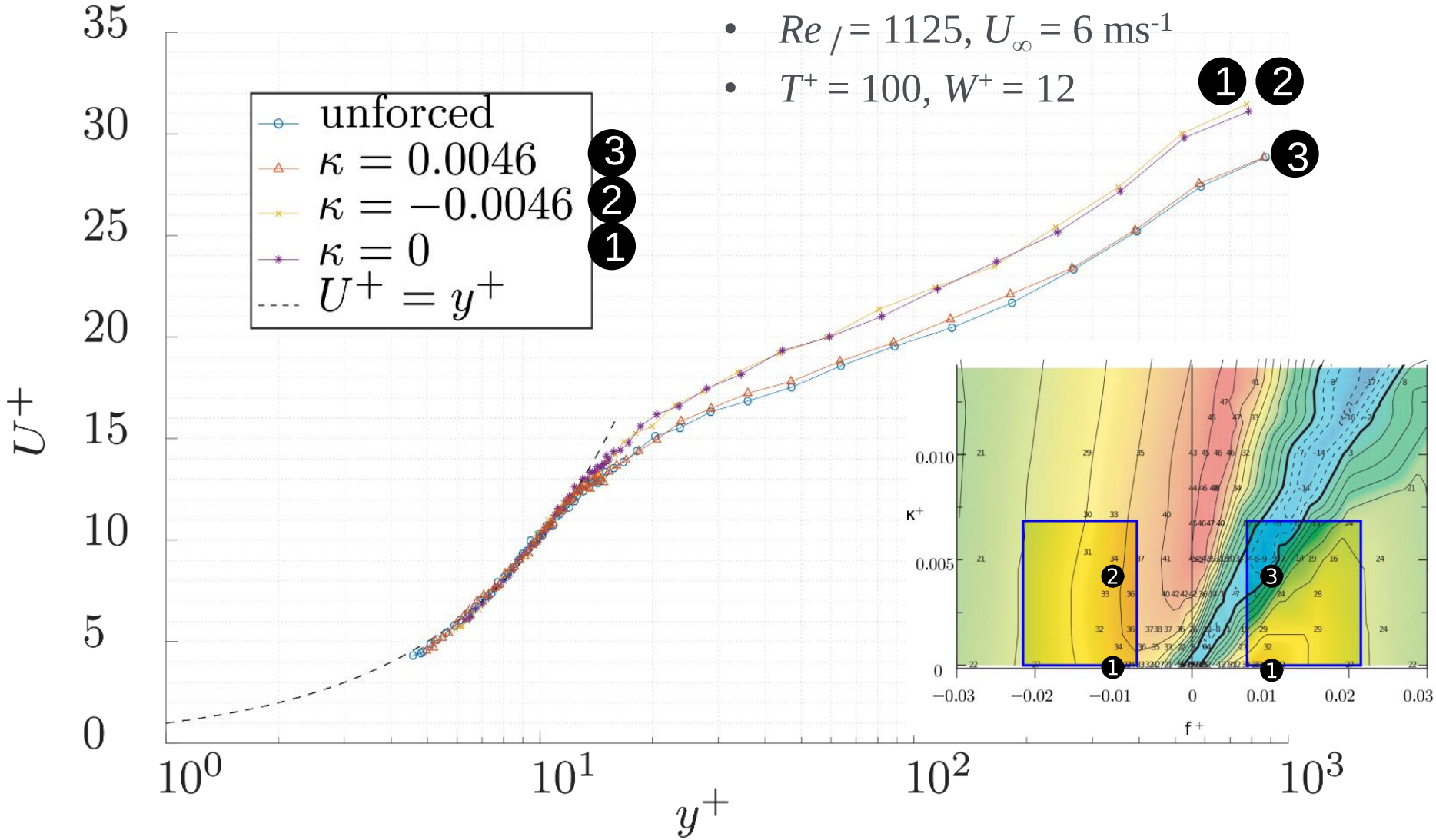


Phase-averaged hot-wire measurements

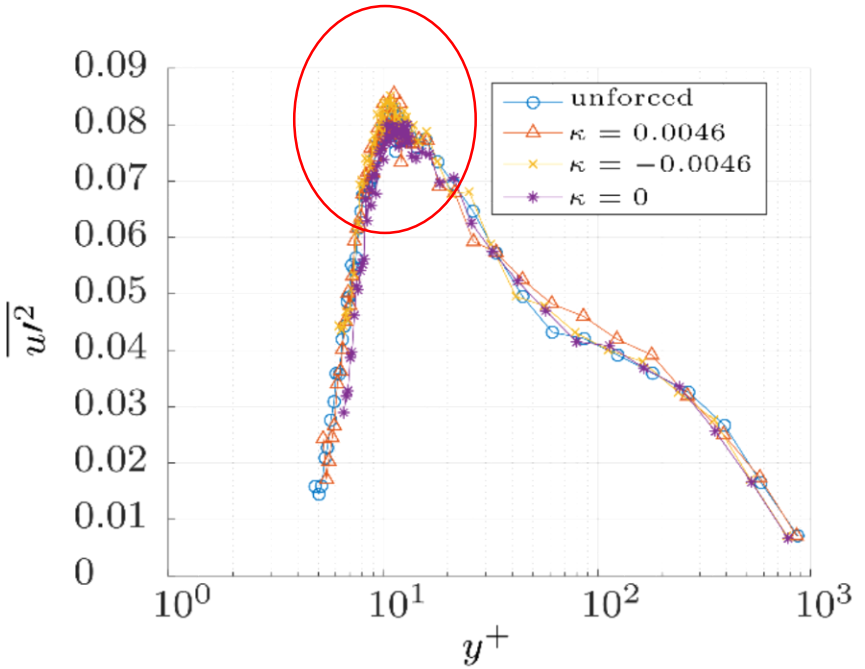


- Phased locked to the surface velocity recorded with the vibrometer.

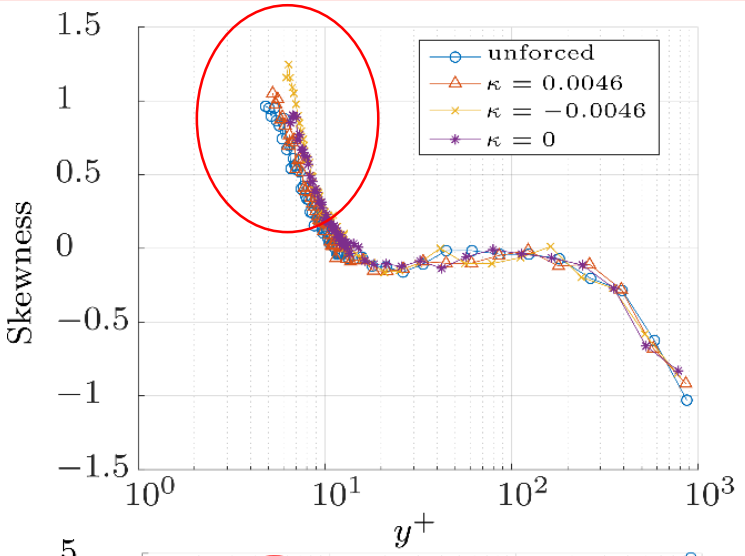
Mean velocity 1.5 metre fetch
DR_{max} = 21.5%

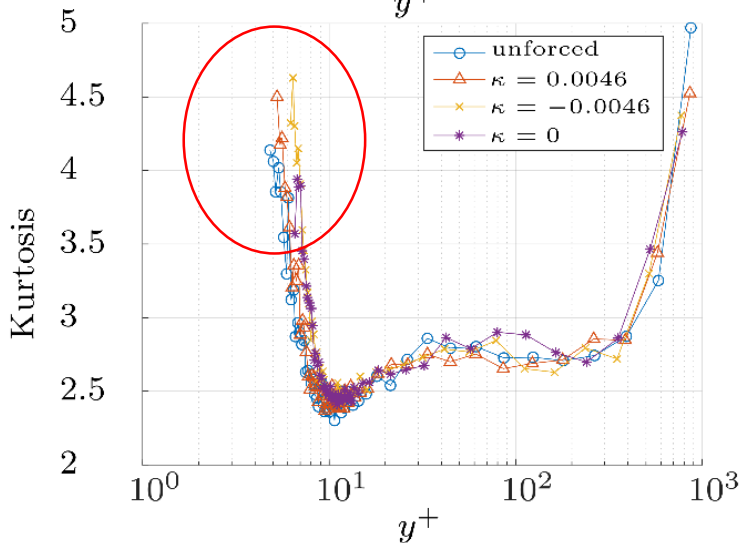


u-statistics 1.5m metre fetch



The mean velocity fluctuations squared with boundary layer height.

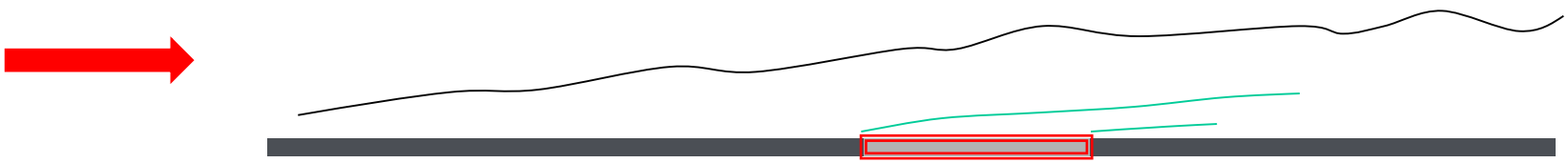




Summary

- Developed an optimised compliant structure.
- Can withstand frequency, displacement and forcing required.
- Structure drives a surface to create discretised waveforms of (almost) arbitrary wavenumber.
- Low Reynolds number experiment – measured 22% drag reduction.
- But not quite the right experiment!

New internal layer generated from leading edge of active surface



- Further experiments with fully actuated surface $Re_\tau \longrightarrow 20{,}000$

Further details: Bird *et al. FTaC* 2017 (to appear)