Heliostat Wind Load – Decade of Research at the University of Adelaide

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make history.

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- ANU
- UoM
- COtL
- Vast Solar, Raygen
- 1414 Degrees
- DLR
- NREL
- DTU
- Sandia National Laboratories
- Solar Dynamics
- Sundrop Farms
- Heliostat SA

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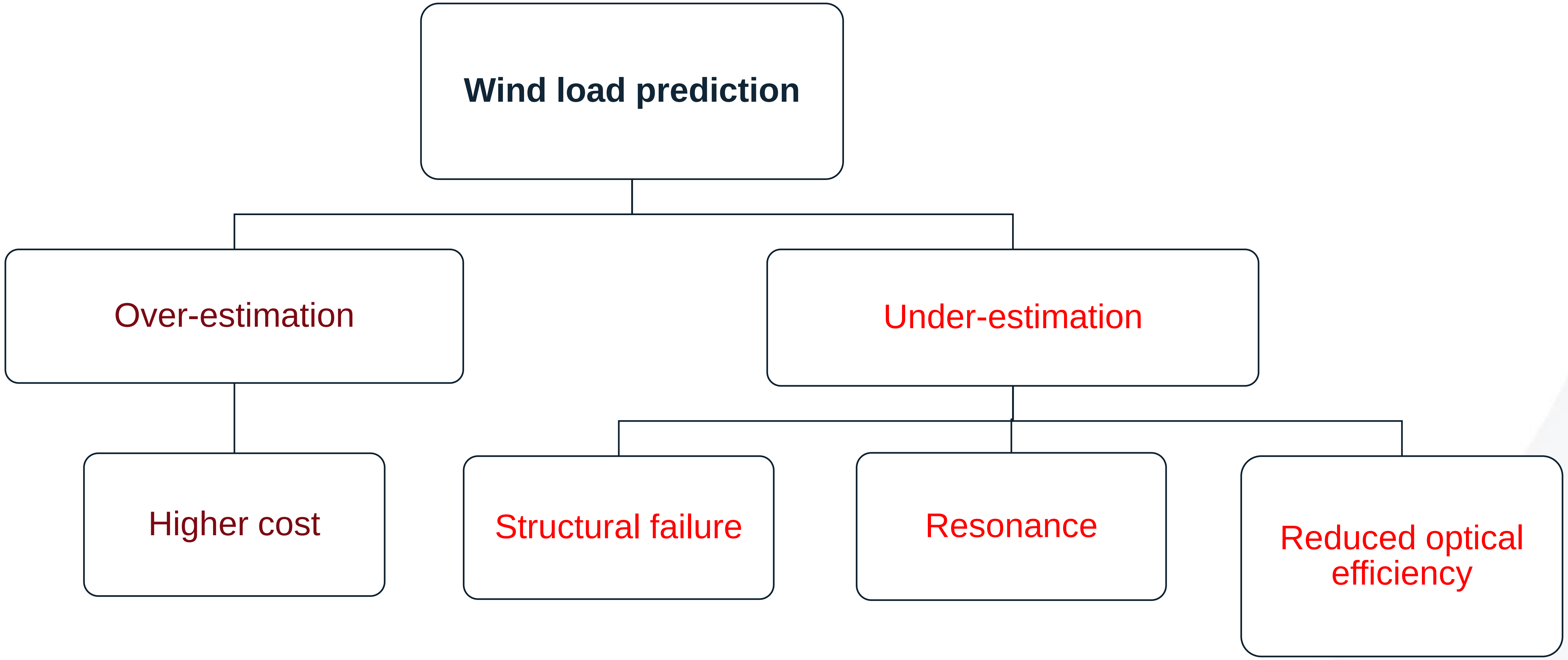
Why wind load?



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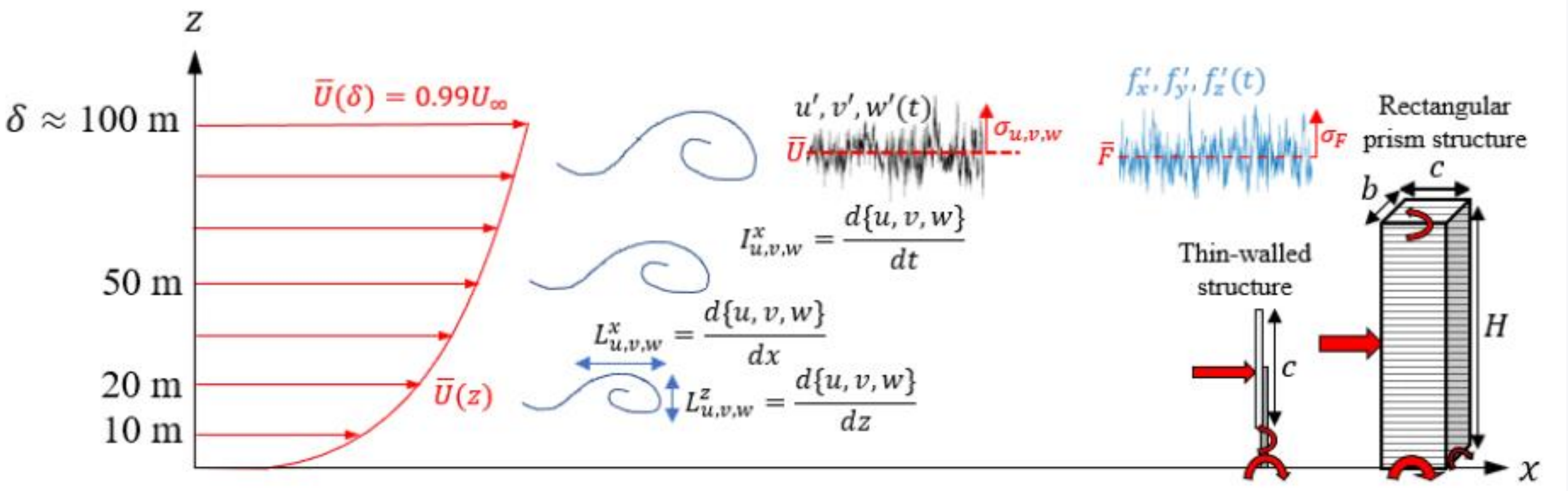
What are the gaps?



- Design standards – current standards have been developed for large civil infrastructure such as buildings with natural frequencies less than 1 Hz. Also, the impact of thermal gradient must be considered
- Flow structure interaction – peak of vertical turbulence occurs at frequencies close to the natural frequencies of heliostats which is one order of magnitude higher than longitudinal component
- Atmospheric boundary layer data – heliostats are installed at the bottom of roughness sublayer <10m where the flow is dominated by coherent structures
- Gusts - wind loads will be at higher frequencies and closer to the heliostat natural frequencies during high wind speed gusts
- Impact of atmospheric stratification - the impact of thermal gradient on turbulence must be better understood

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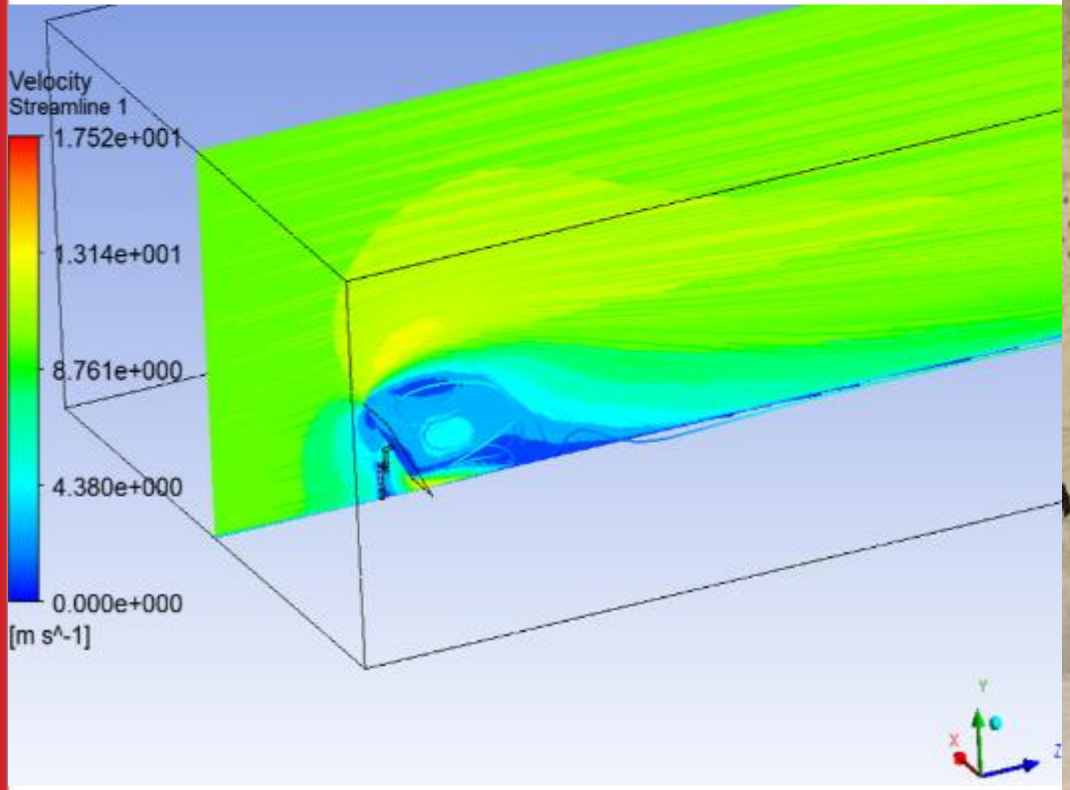
How to estimate wind load?

- CFD modelling
- Wind tunnel experiments
- Field experiments



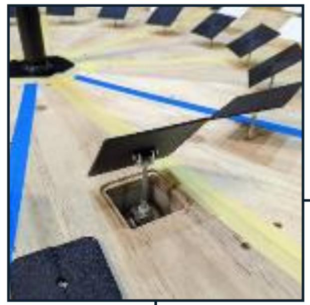
What are the requirements?

Atmospheric boundary layer data

- Velocity components: u, v, w
- Fluctuating velocity components: $u' = \frac{\partial u}{\partial t}, v' = \frac{\partial v}{\partial t}, w' = \frac{\partial w}{\partial t}$
- longitudinal and vertical integral length scales: L_x^u and L_x^w
- Long term data for evaluation of 30 year structure design life

Single heliostat aerodynamics

- Flow similarity and scaling: longitudinal and vertical power spectral density functions, boundary layer depth and …
- Heliostat geometry: aspect ratio, ground clearance and …
- Pressure distribution
- Force and moment coefficients
- Different elevation and azimuth angles



Heliostat field aerodynamics

- Heliostats in tandem
- Impact of field layout: density, staggered, tower, access roads
- Optical errors
- Dust and maintenance strategy
- Filed partial stow strategy
- Wind control techniques: perimeter fences, different heliostat sizes, wind barriers and …

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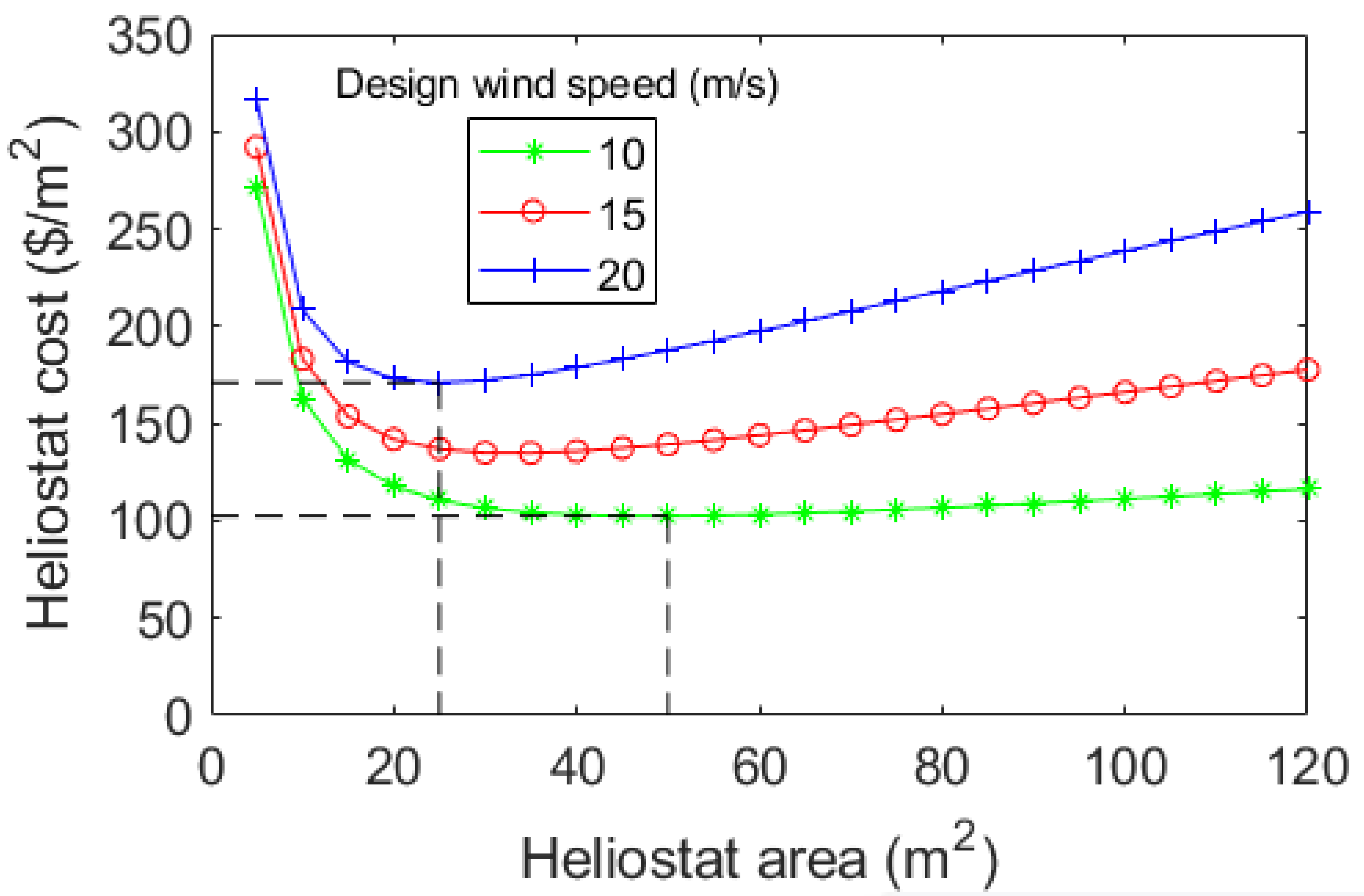
What we have learnt: Lesson 1

- **Stow wind speed is an important parameters affecting the heliostat design and cost.** For example:
  - Heliostat cost can be reduced by 40% by lowering the stow design wind speed from 20 m/s to 10 m/s
  - Annual field operation increased by 6% with increasing stow design wind speed from 6 m/s to 12 m/s



(Emes et al., Solar Energy, 2015)

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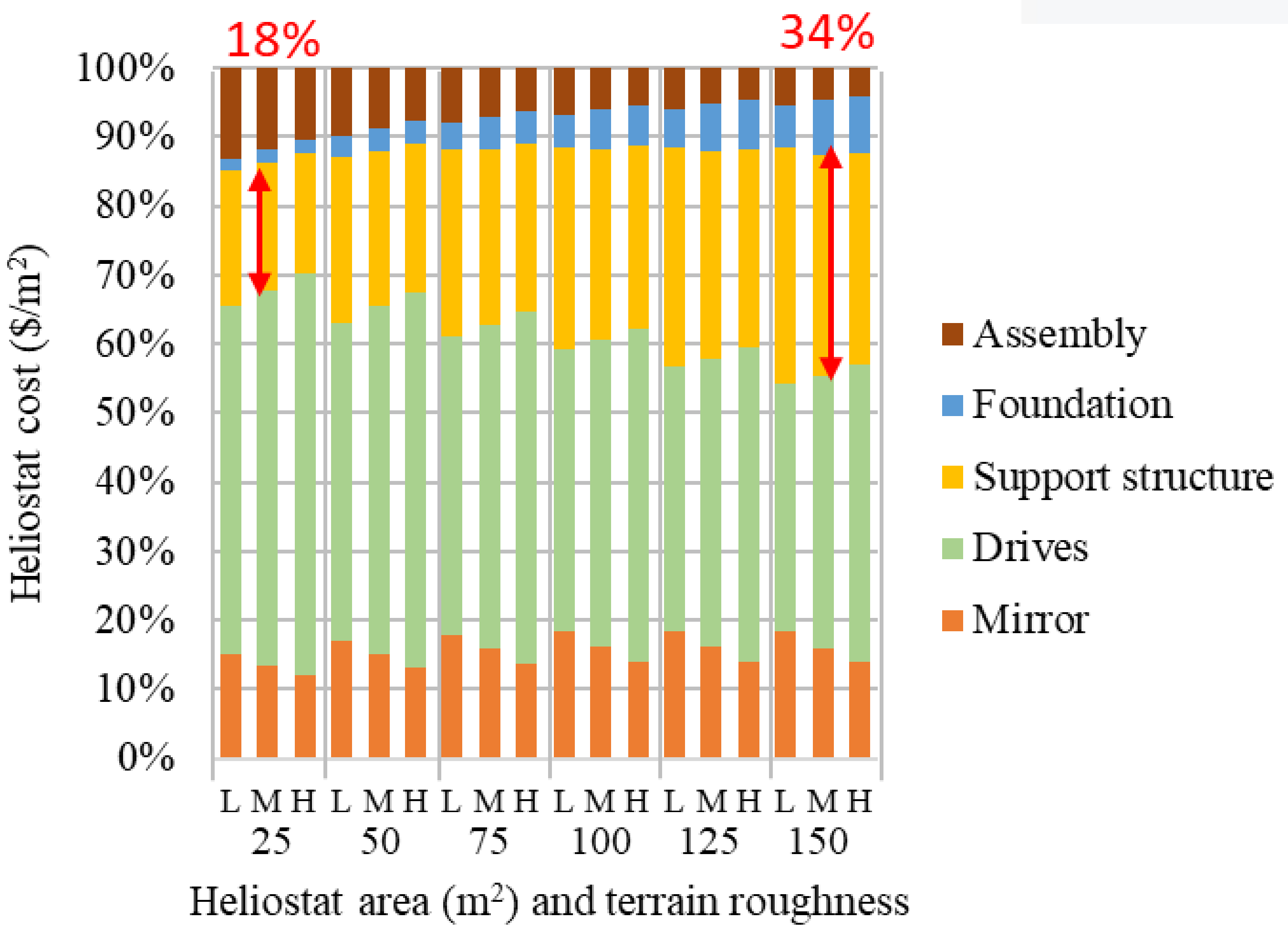
What we have learnt: Lesson 2

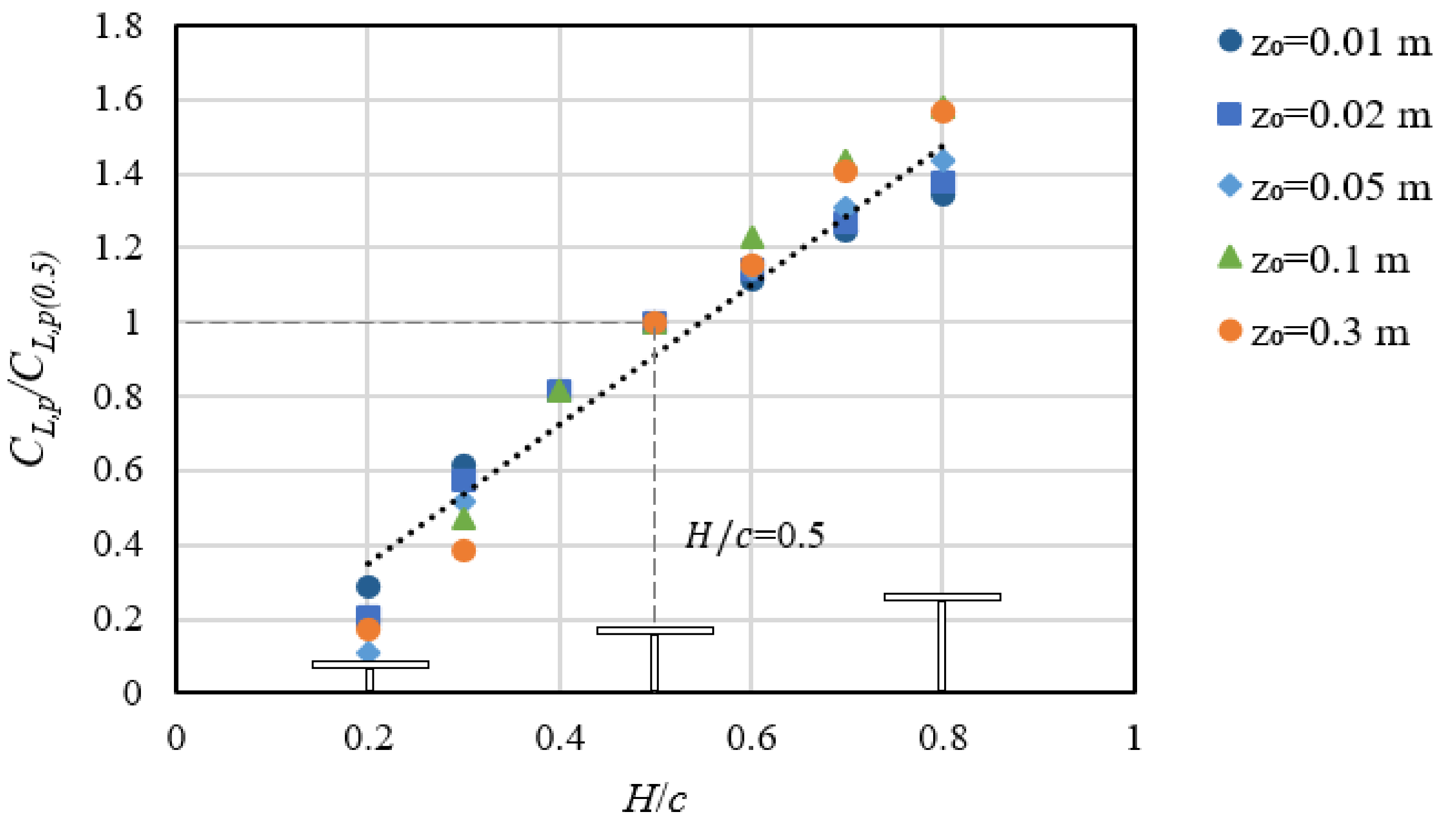
- **Terrain roughness and wind velocity must be considered when heliostat geometry is selected.** For example:
  - Increasing turbulence in a high-roughness terrain results in 10% increase in cost of a 25 m^2 heliostat and 13% increase in cost of a 150 m^2 heliostat



(Emes et al., Solar Energy, 2020)

What we have learnt: Lesson 3

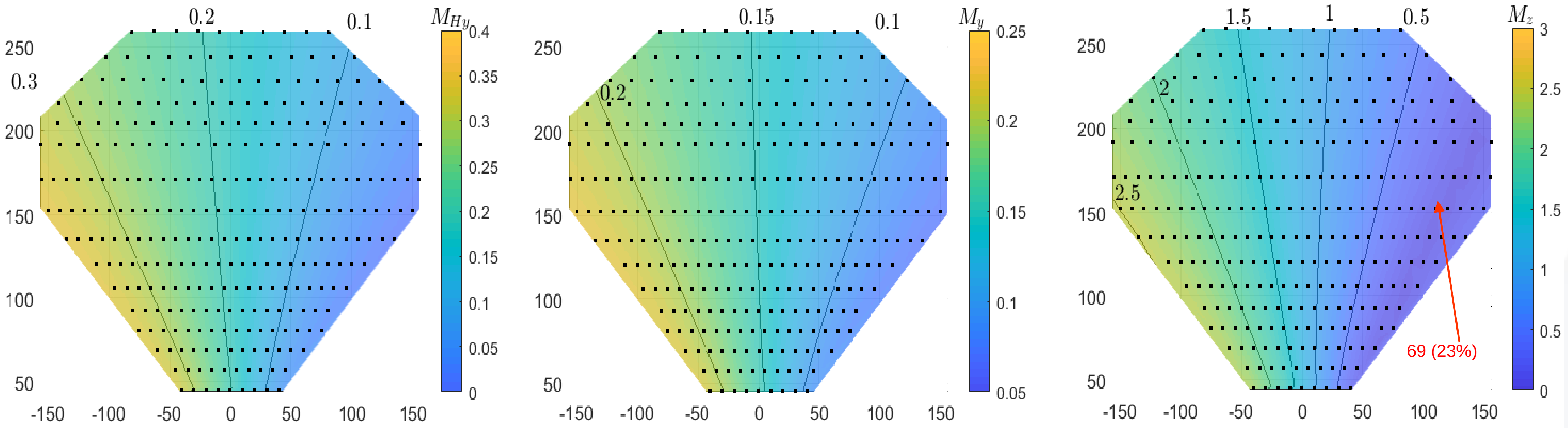
- **Stow height can significantly reduce the cost of heliostats but hard to achieve.** For example:
  - Stow loads are reduced by 80% if H/c is reduced from 0.5 to 0.2



(Jafari *et al.* 2019)

What we have learnt: Lesson 4

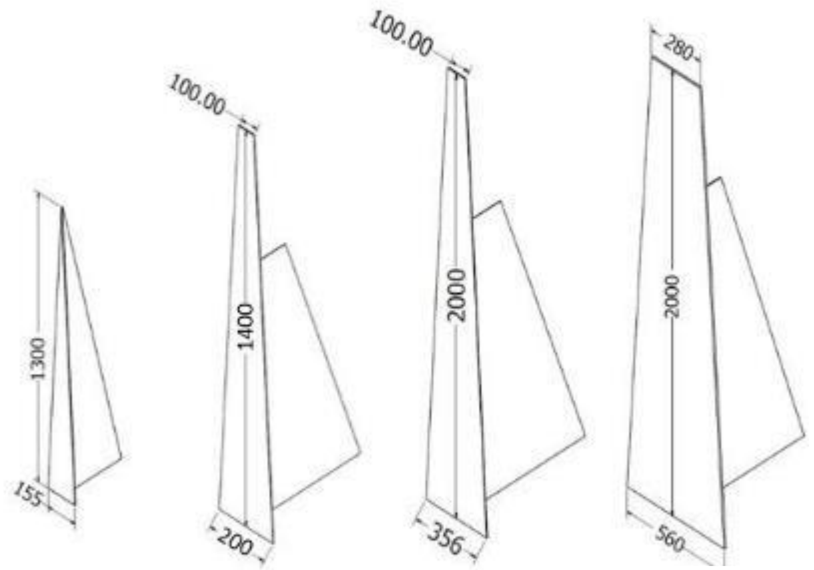
- **Partial stow strategy can increase the power output from a field.** For example, if partial stow strategy is applied:
  - Based on statistical correlation of DNI, tracking angles and CSAT3 wind data at PSA CESA-I field of 300 heliostats the annual thermal energy capture can be increased by 1.2% with β= 90 ± 15° stowing strategy at wind speeds exceeding 10 m/s



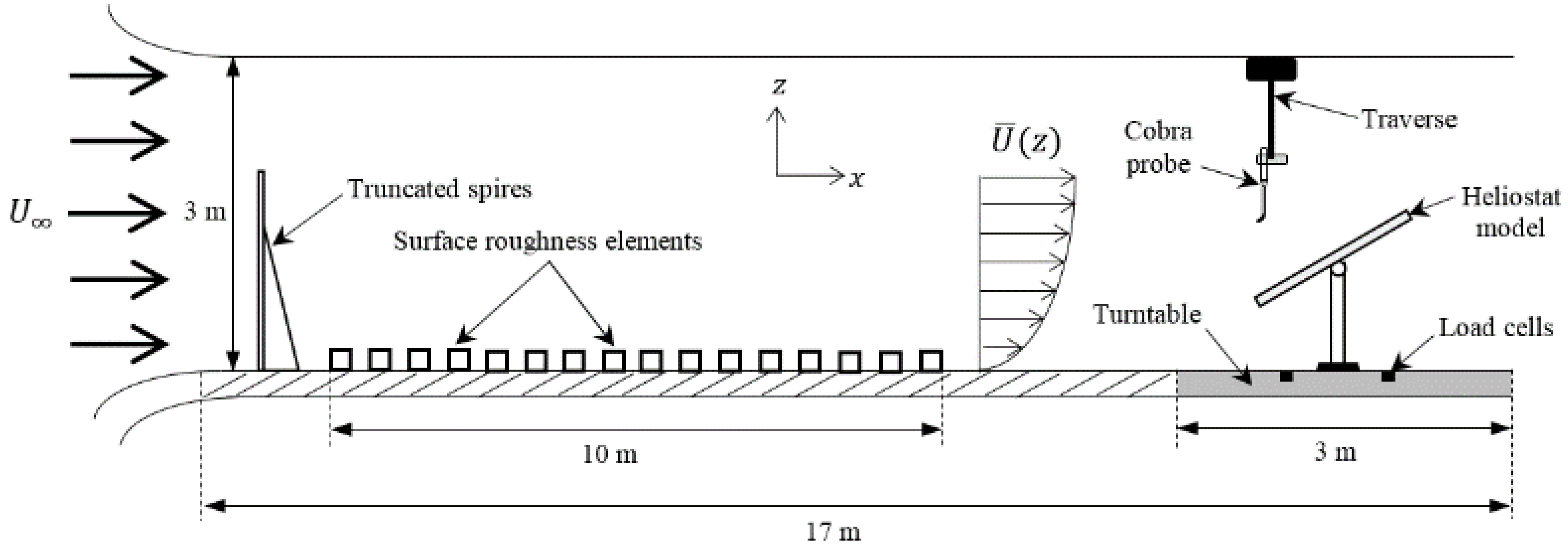
(Emes *et al.* 2022)

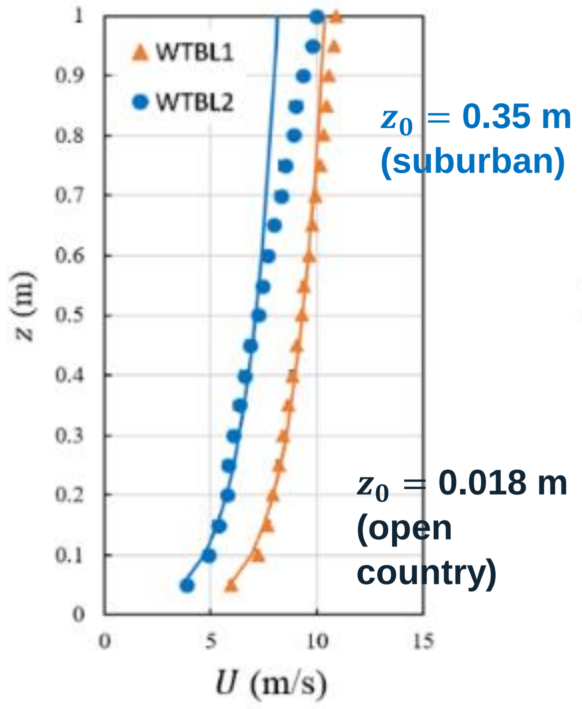
What we have learnt: Lesson 5

- **Wind tunnel experiments must be properly scaled.**

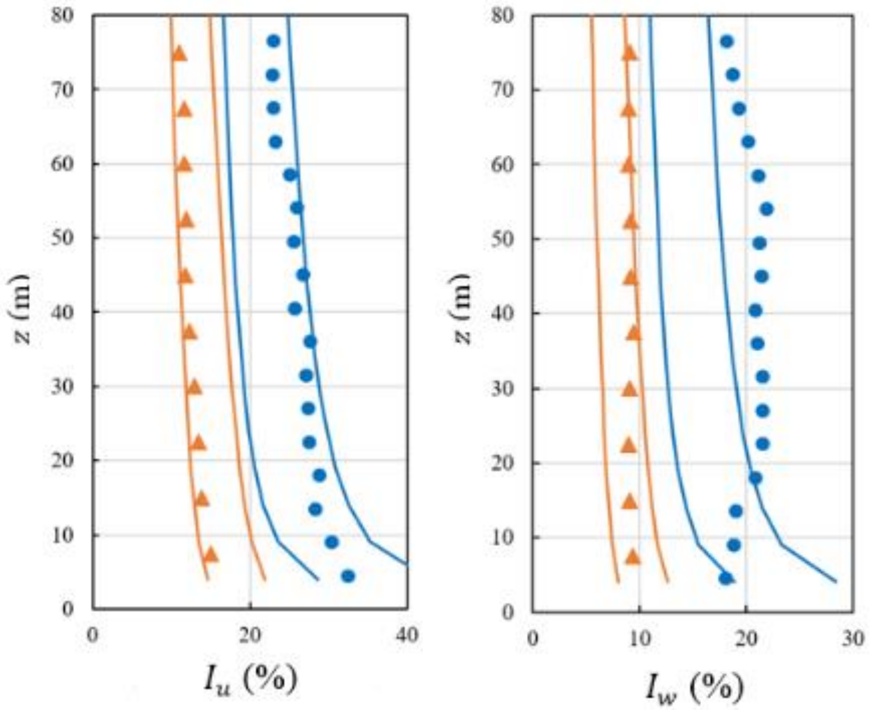


SR1 SR2 WTBL1 WTBL2

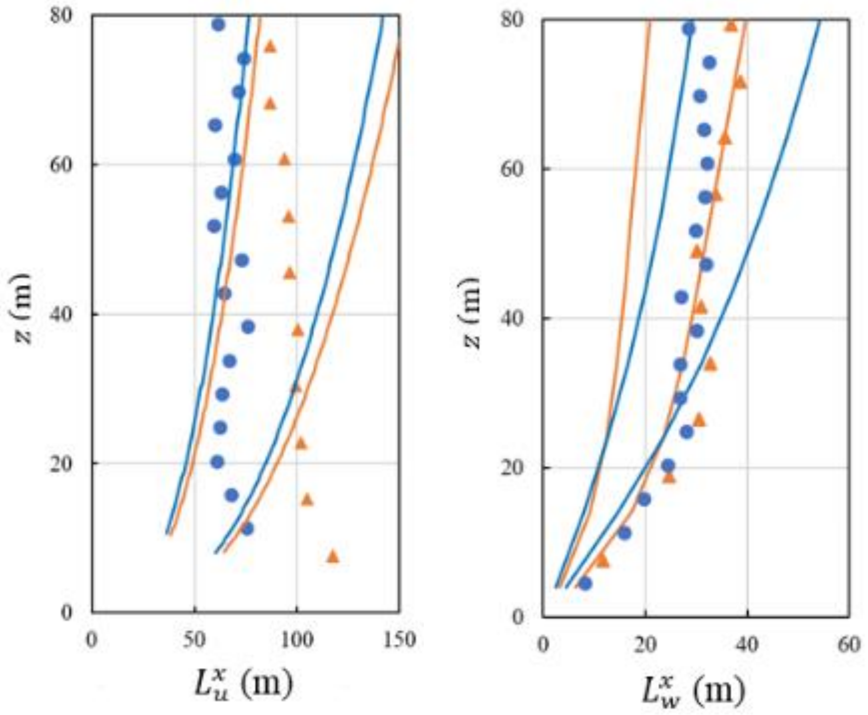




Mean velocity compared with logarithmic profiles



Turbulence intensities in longitudinal (left) and vertical (right) directions compared with upper and lower bounds of ESDU 85020



Turbulence length scales of longitudinal (left) and vertical (right) velocity compared with upper and lower bounds of ESDU 85020

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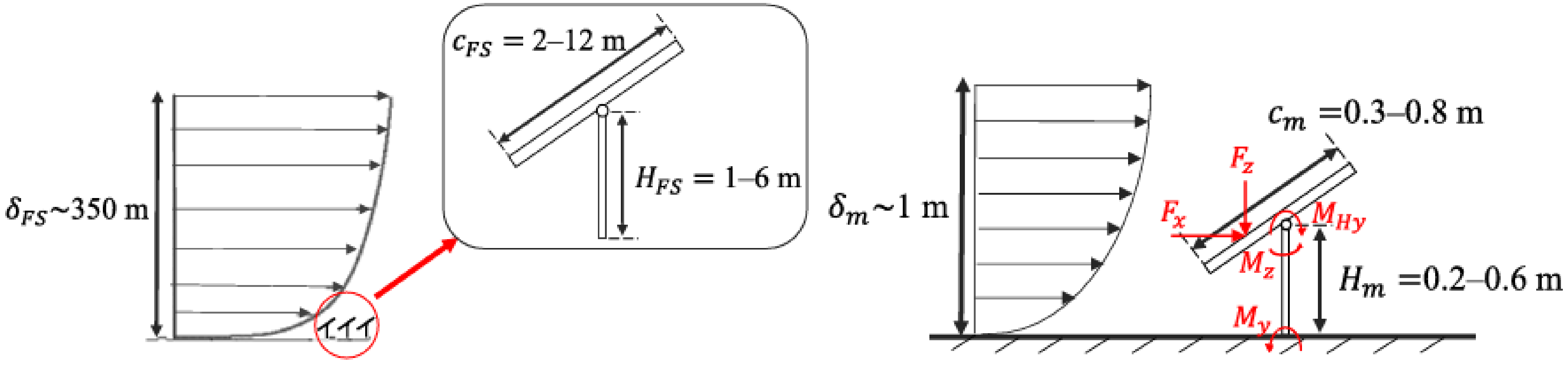
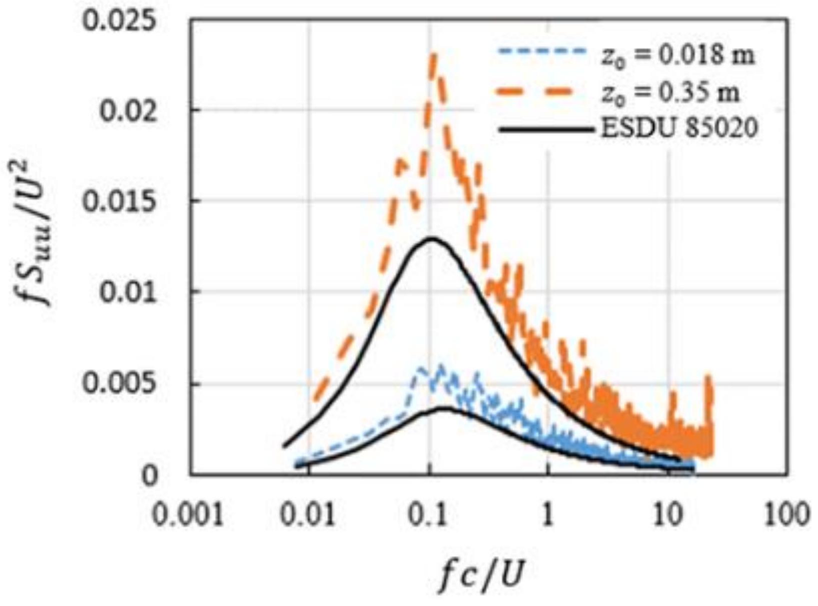
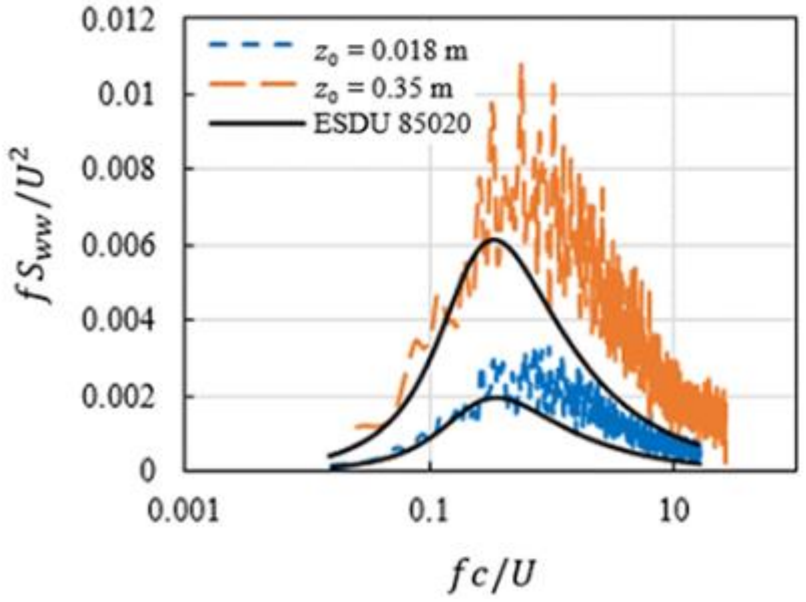
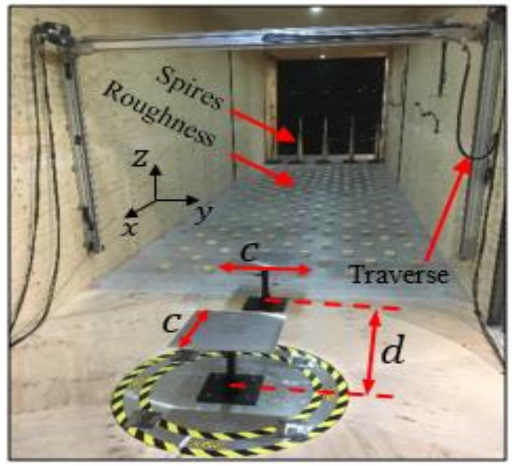
What we have learnt: Lesson 5 (cont.)

- **Wind tunnel experiments must be properly scaled.**

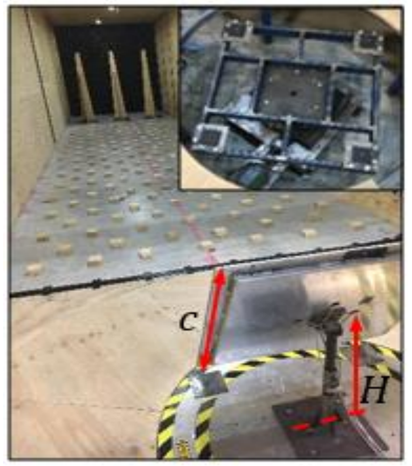




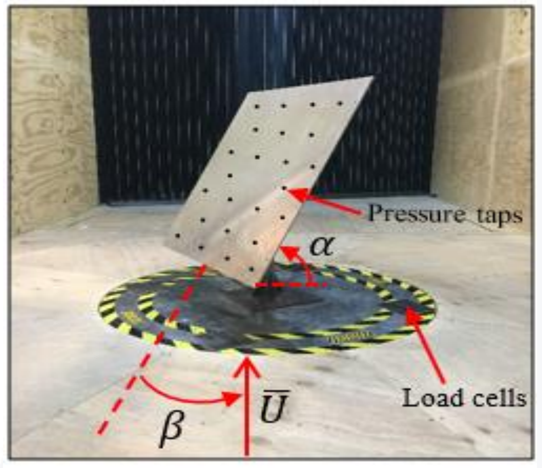




d/c = 2-8



c = 0.2-0.8 m
H = 0.15-0.5 m



α = 0-90°
β = 0-180°

(Jafari *et al.* 2019, Emes *et al.* 2021)

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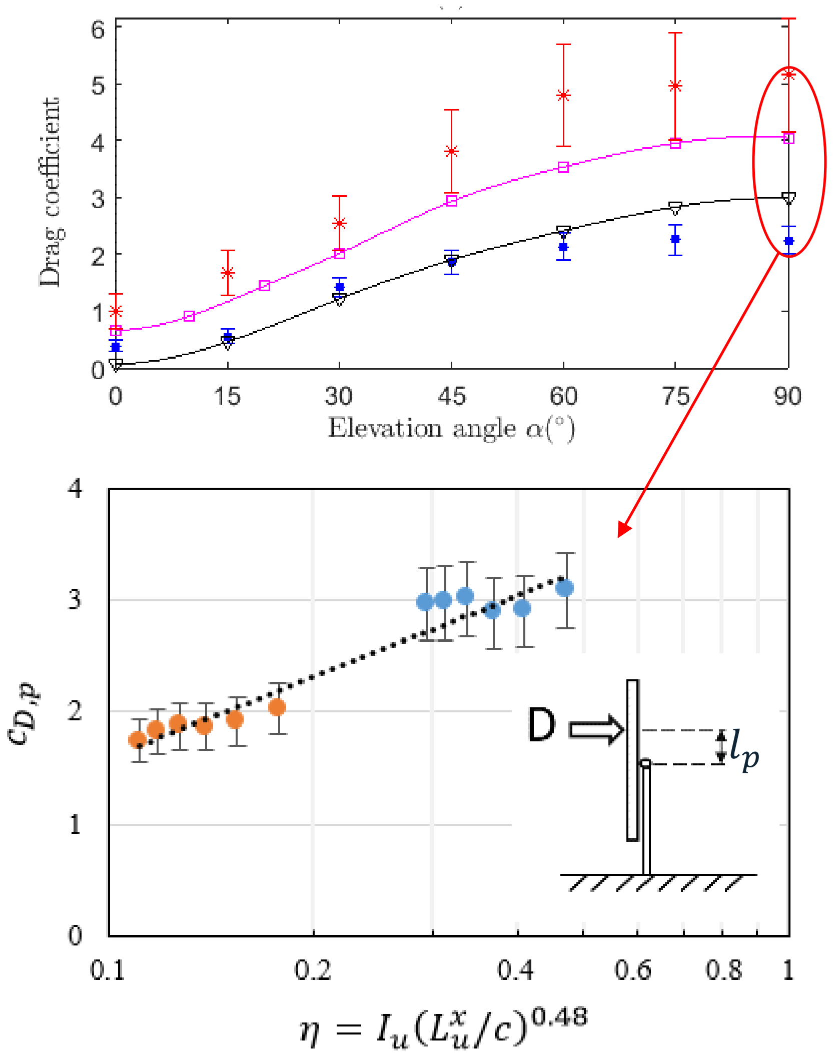
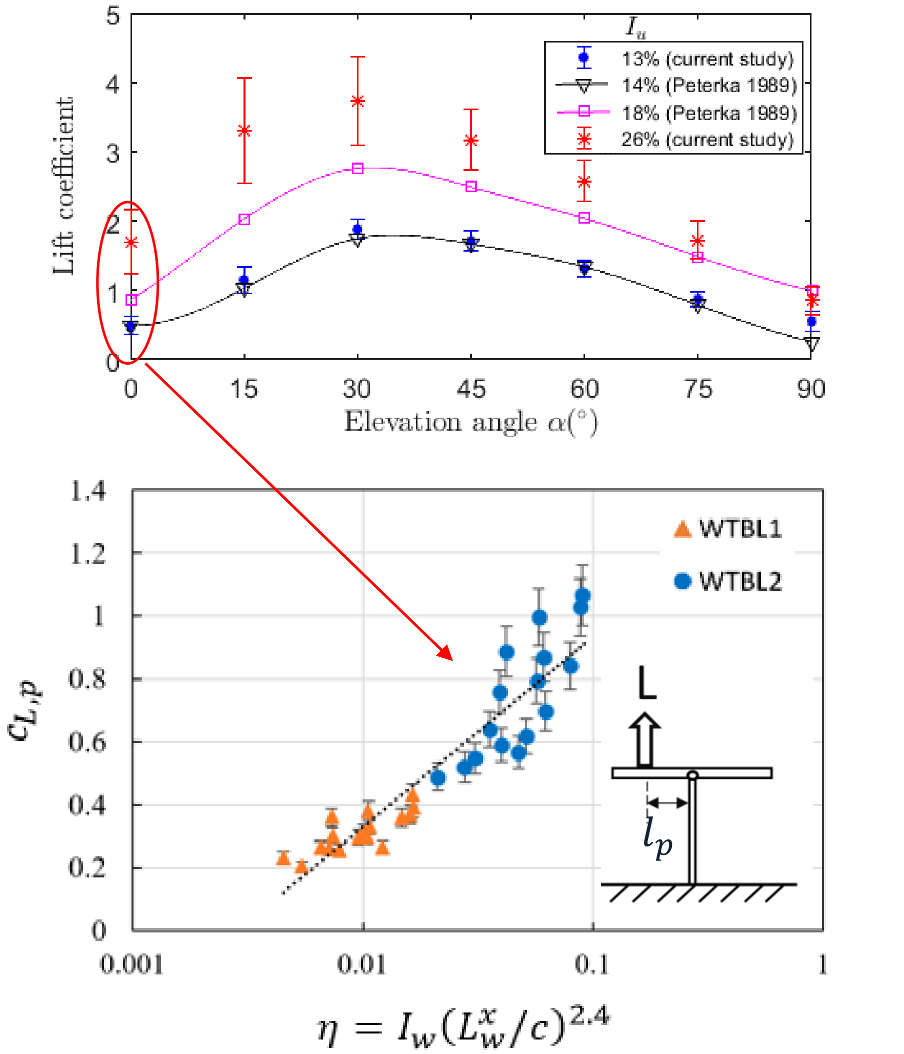
What we have learnt: Lesson 6

- **Horizontal and vertical integral length scales are as important as turbulence intensity when heliostat wind loads are estimated.**



Peak **drag** coefficient a function of *longitudinal* turbulence intensity and integral length scale

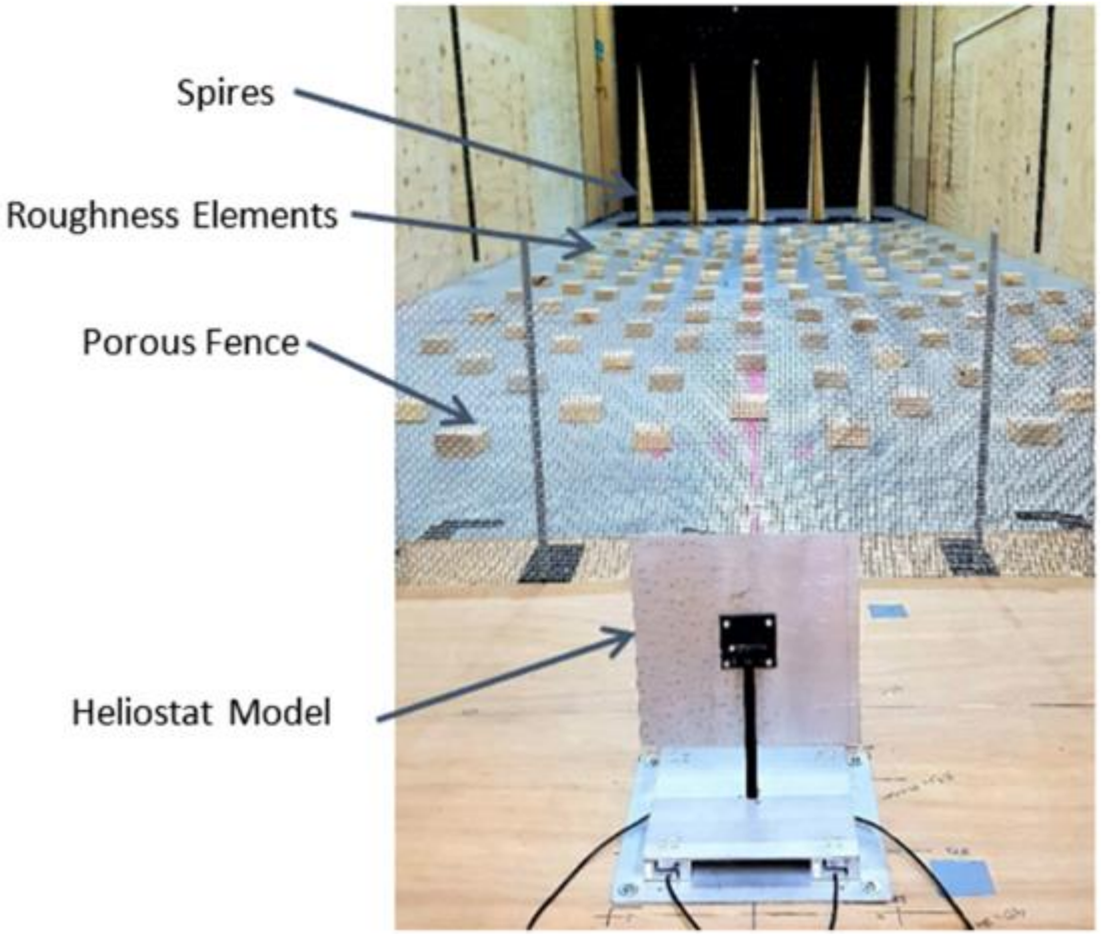


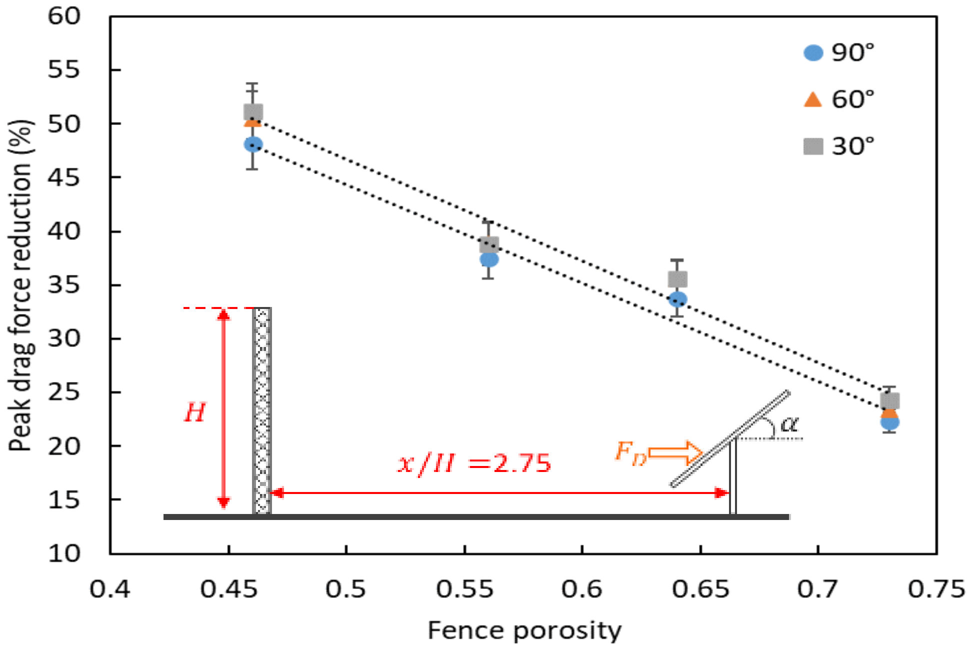
Peak **lift** coefficient a function of *vertical* turbulence intensity and integral length scale

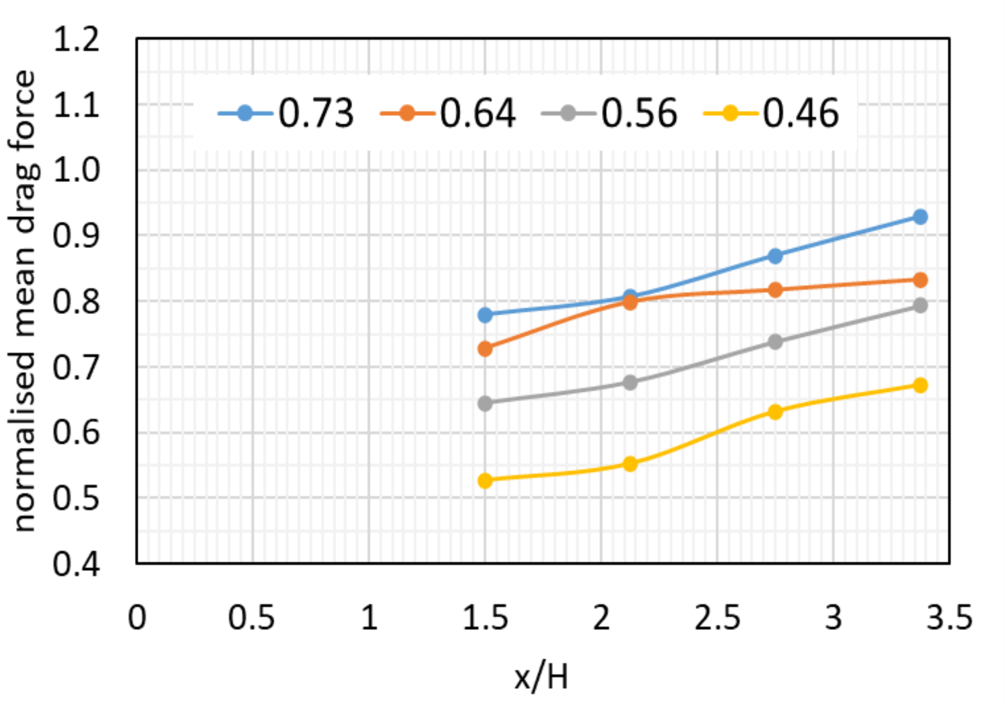
(Jafari *et al.* 2018 and 2019, Emes *et al.* 2021)

What we have learnt: Lesson 7

- **Perimeter fences and wind barriers can reduce wind loads on heliostats. Their application depends on the field layout and terrain roughness**



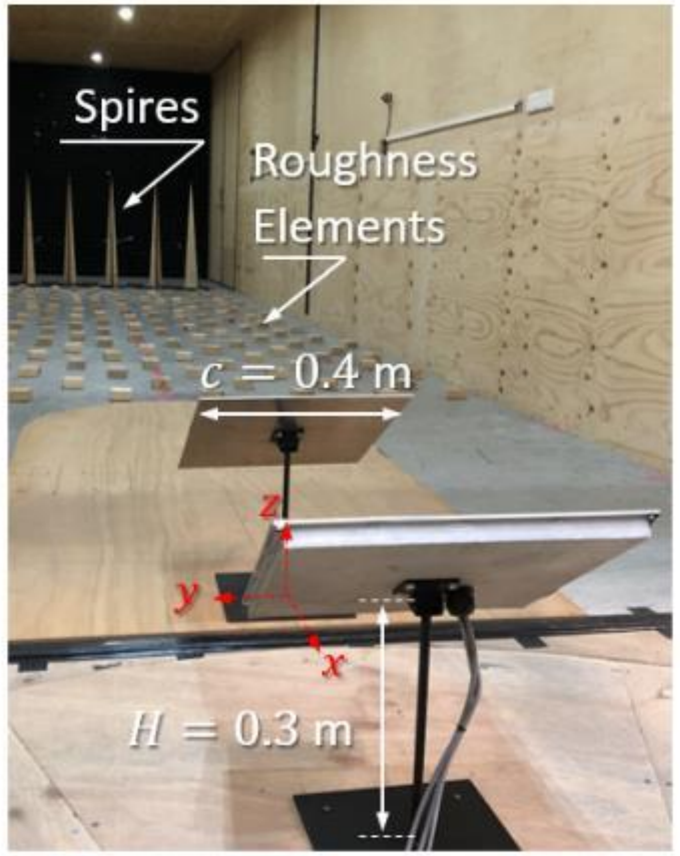


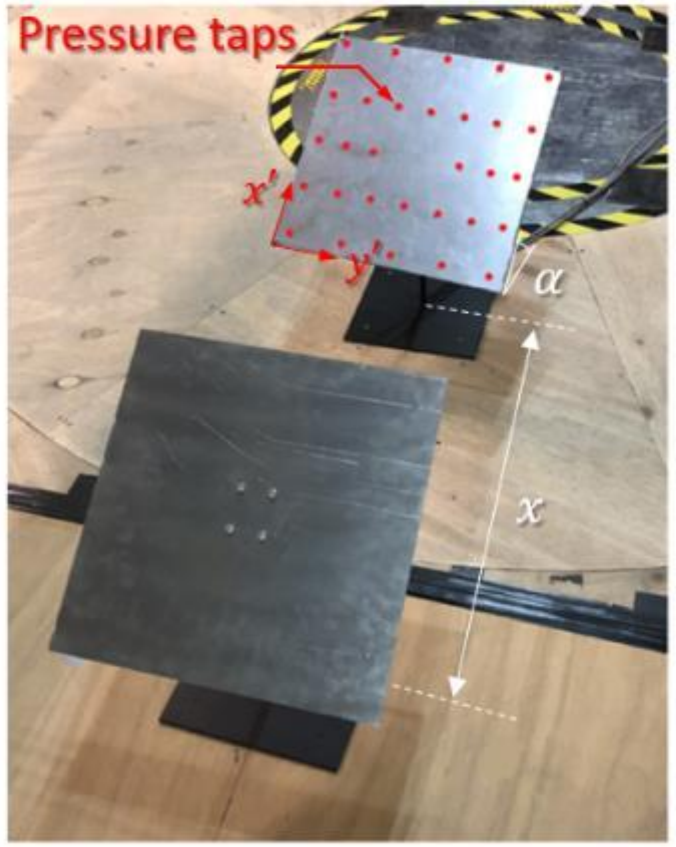


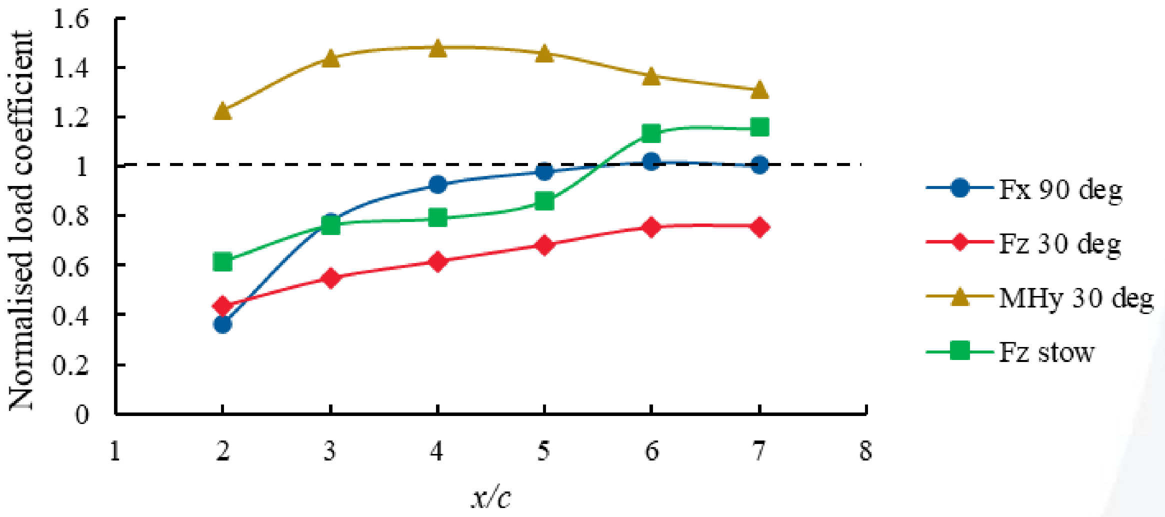
(Emes *et al.* 2022)

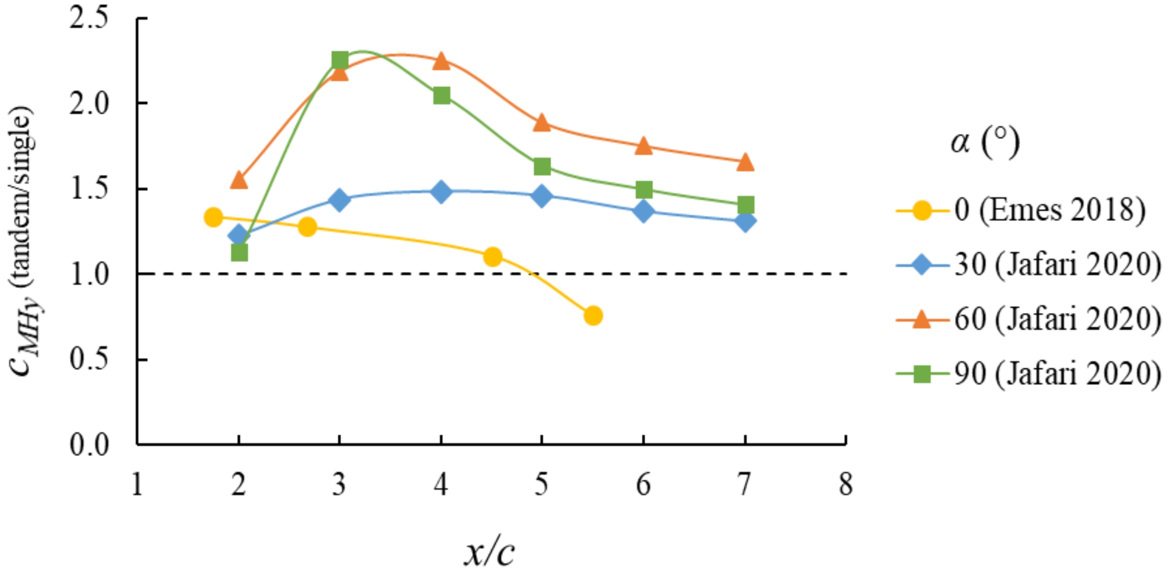
What we have learnt: Lesson 8

- **While positioning heliostats in tandem configuration may result in reduced lift and drag forces on the downstream heliostat at some elevation angles and distances, the peak hinge moment of the downstream heliostat is always larger**









(Emes *et al.* 2022, Jafari *et al.* 2020)

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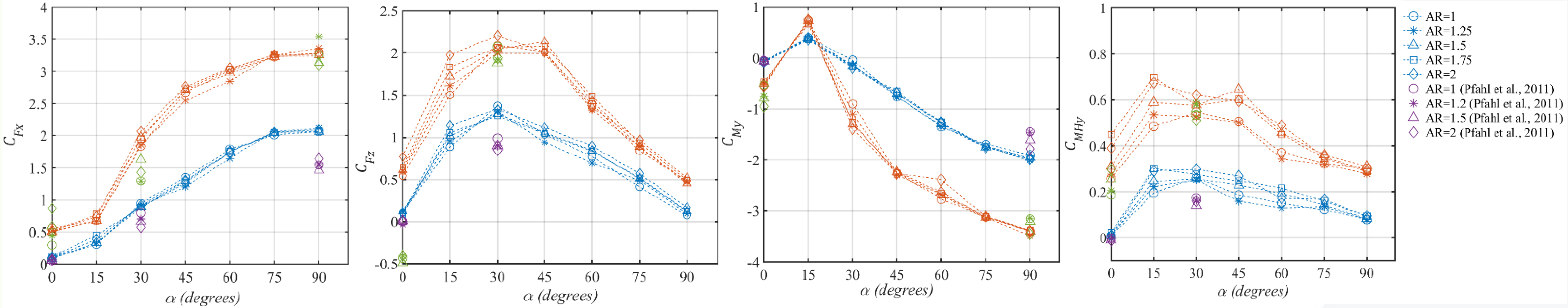
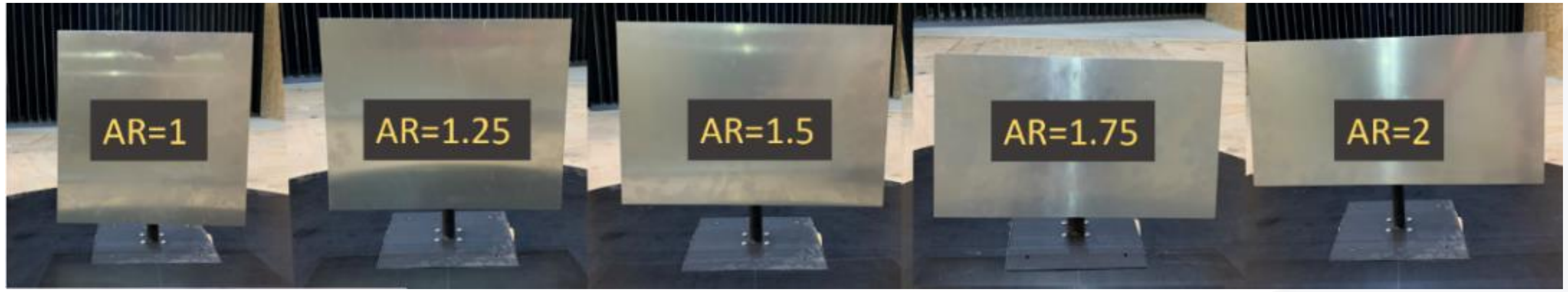
What we have learnt: Lesson 9

- **Heliostat aspect ratio has no significant effect on lift, drag and moment coefficients. If the ground clearance ratio is maintained constant increasing aspect ratio results in a larger hinge moment coefficient.**





(Bakhshipour *et al.* 2023)

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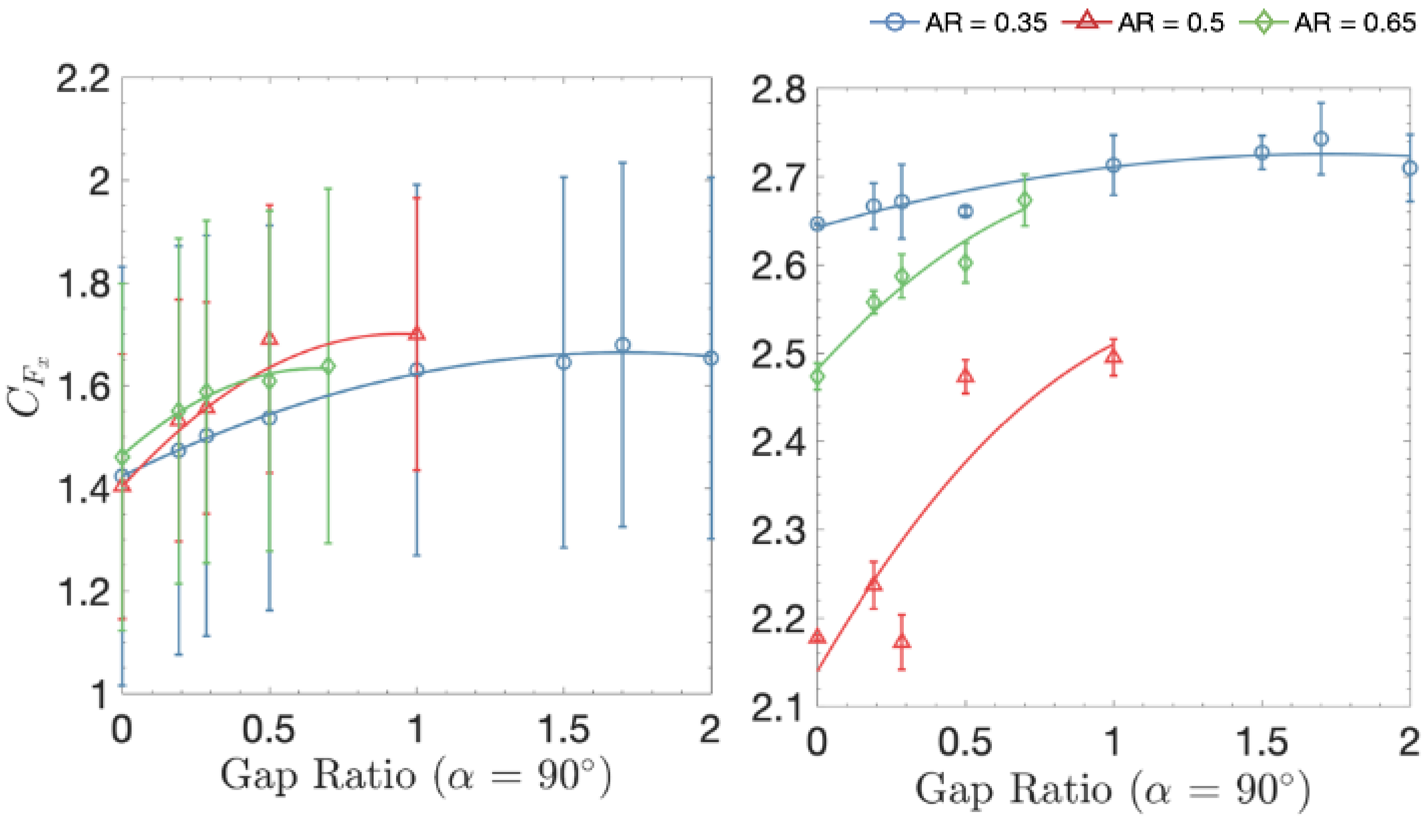
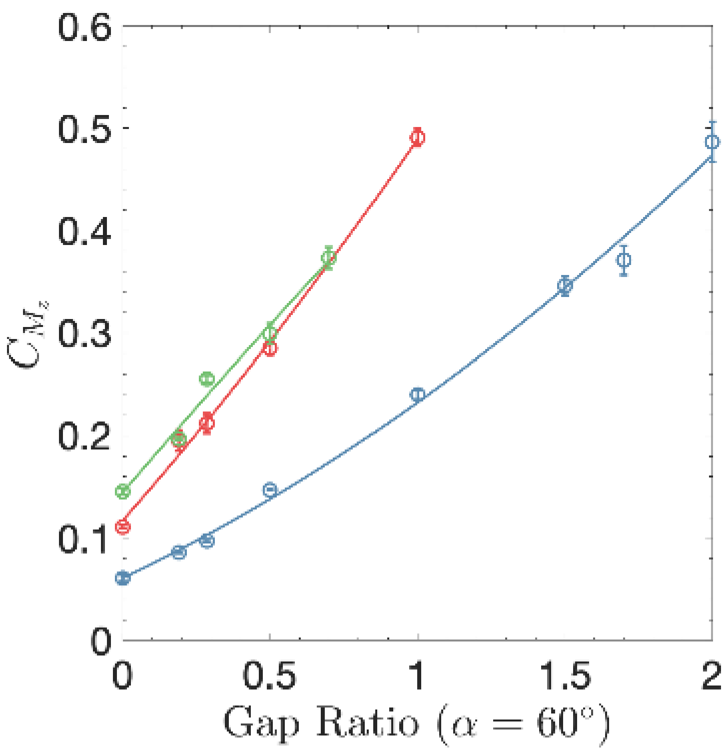
What we have learnt: Lesson 10

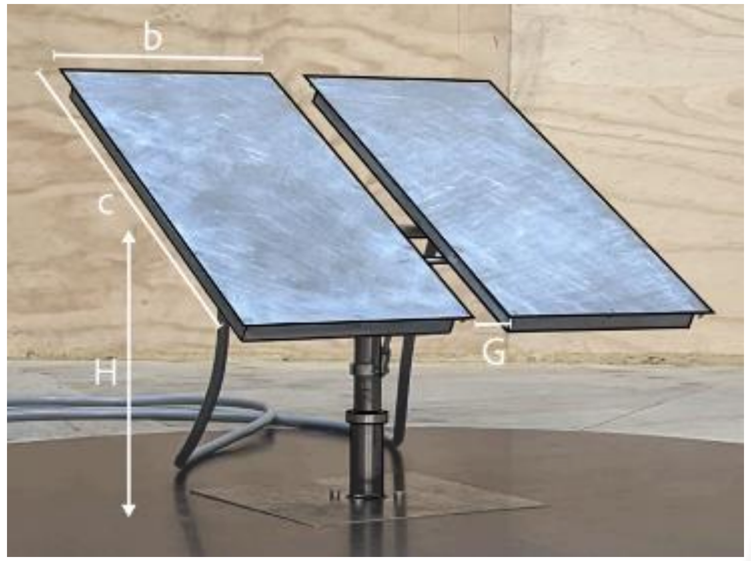
- **Facet gap, in general, results in a slight increase in force and moment coefficients, with larger increases for peak azimuthal moment**



Mean and peak drag coefficient at α = 90°



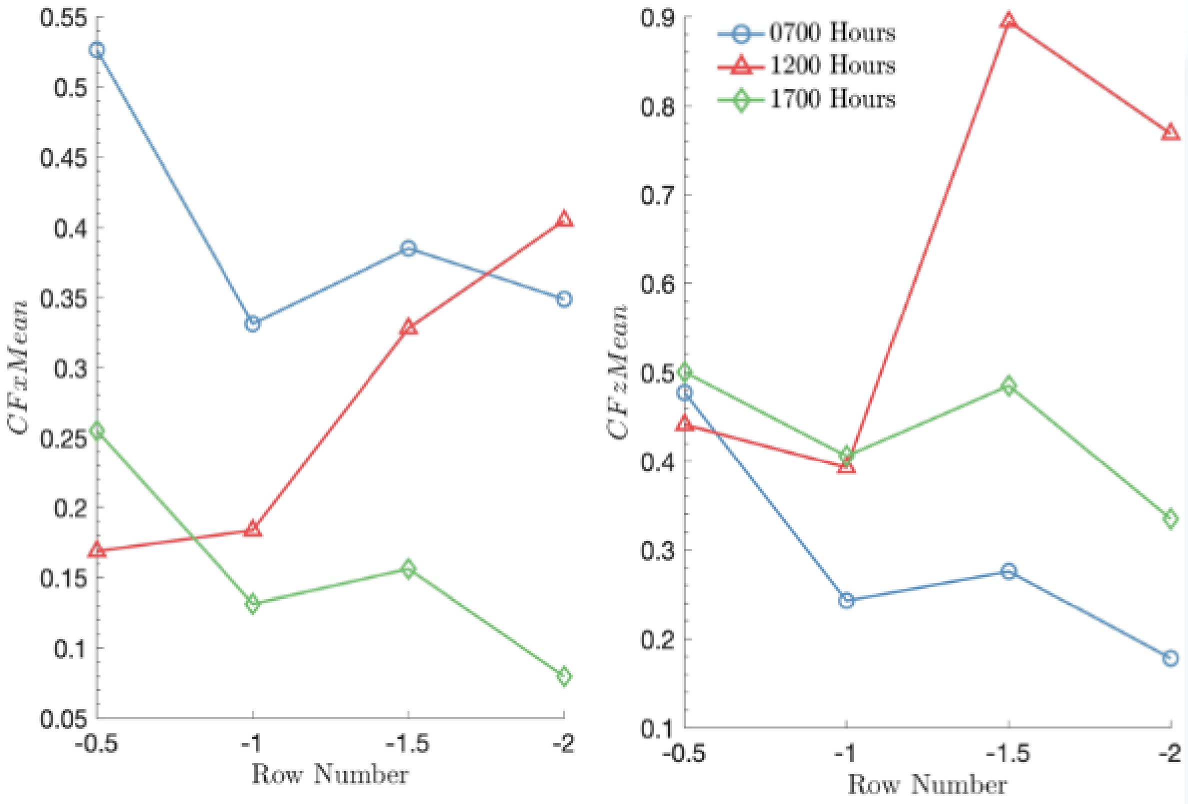
Peak azimuthal moment coefficient at α = 60°



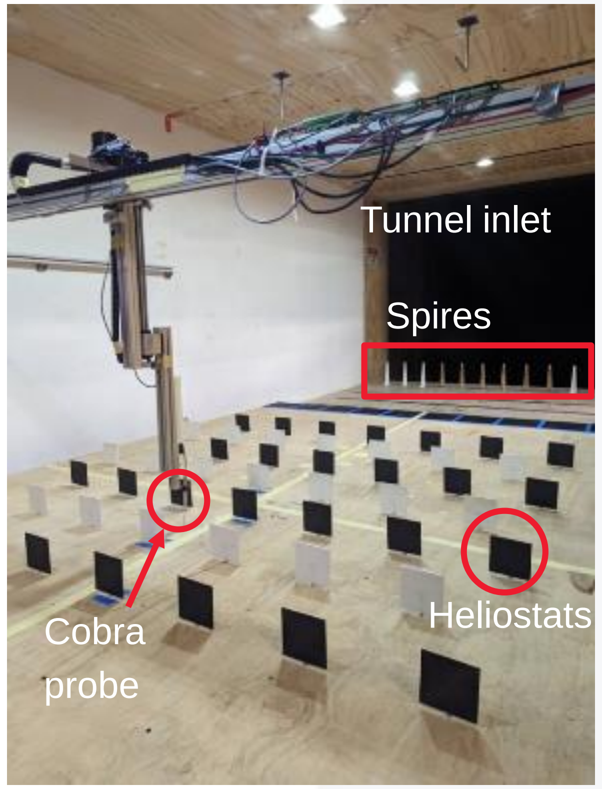
(Marano *et al.* 2023)

What we have learnt: Lesson 11

- **In an array configuration:**
  - Drag coefficient generally decreases with distance into the field due to the high blockage upstream and decreasing elevation angle of the heliostats further into the field
  - Decrease in load magnitude is observed at 7am and 5pm, however at 12pm there is an observed increase in both drag and lift coefficients further downstream
  - Tower has effect on peak loads

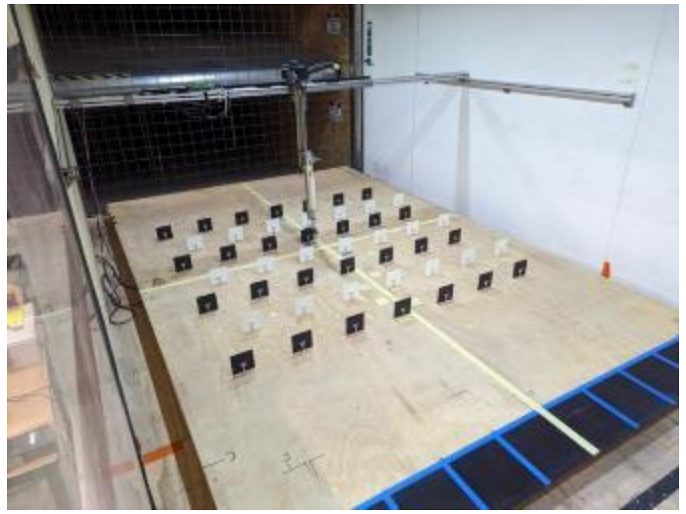


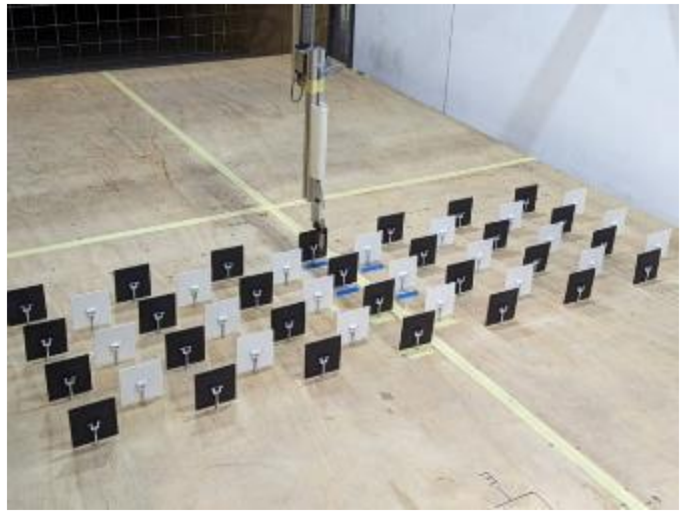
(Marano *et al.* 2023)

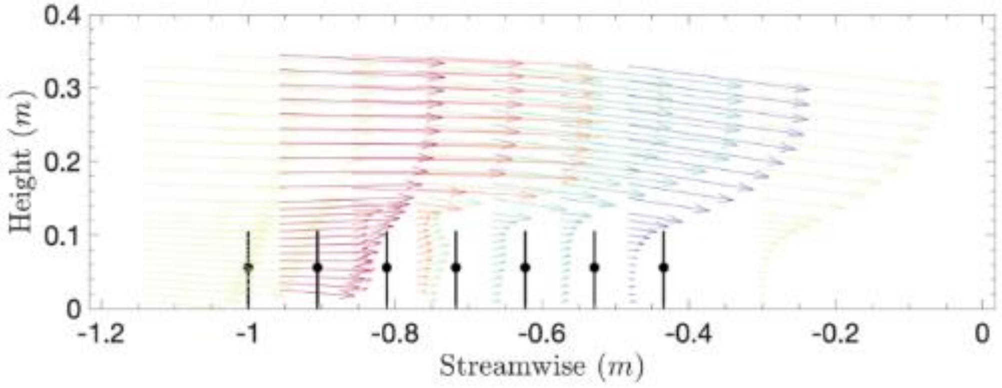


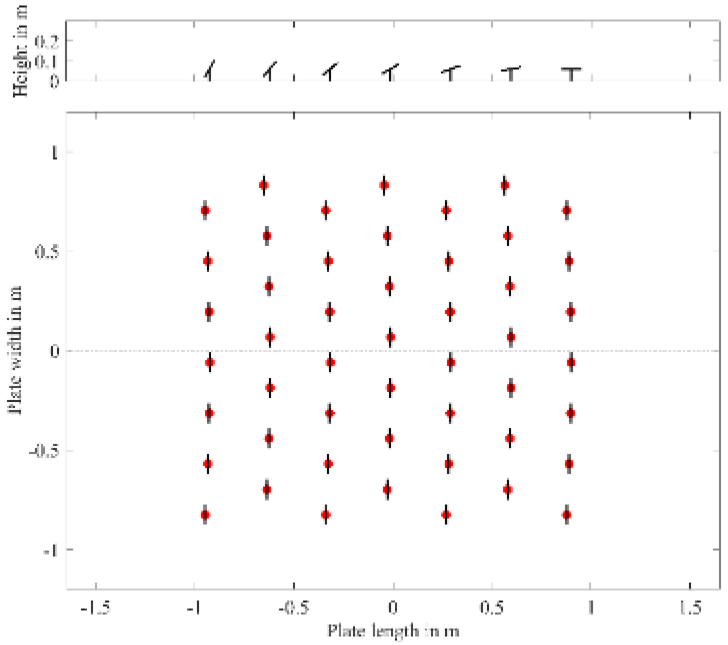
What we have learnt: Lesson 12

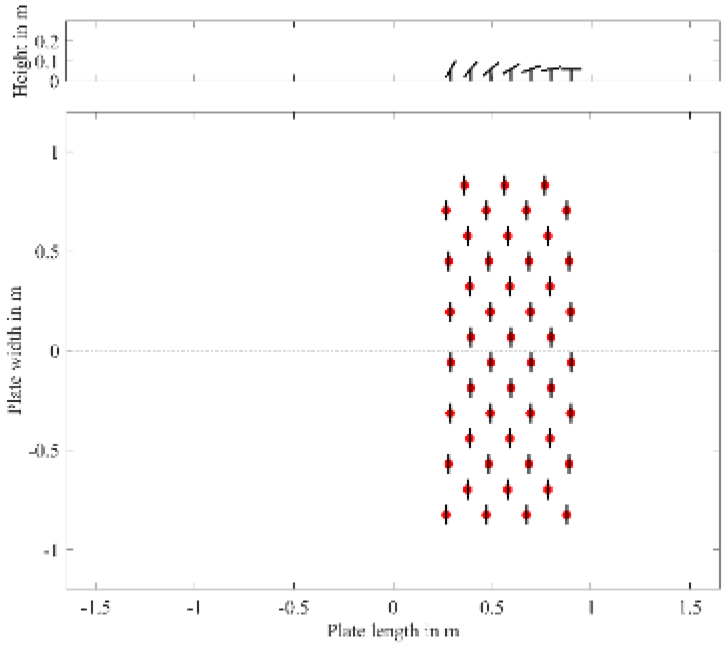
- **ABL over a heliostat field is like a rough wall boundary layer. The field density changes the wall roughness**

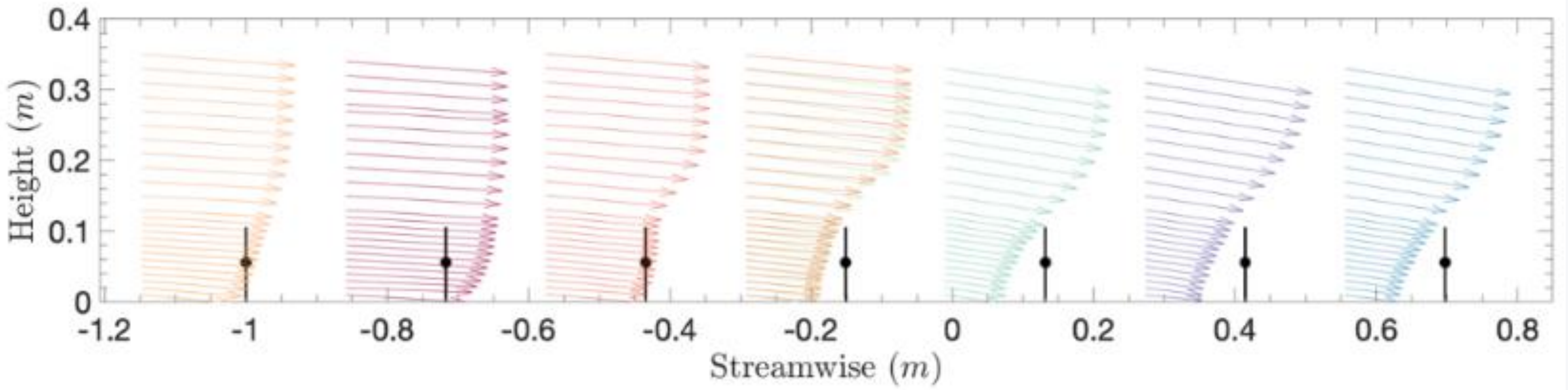












(Marano *et al.* 2023)

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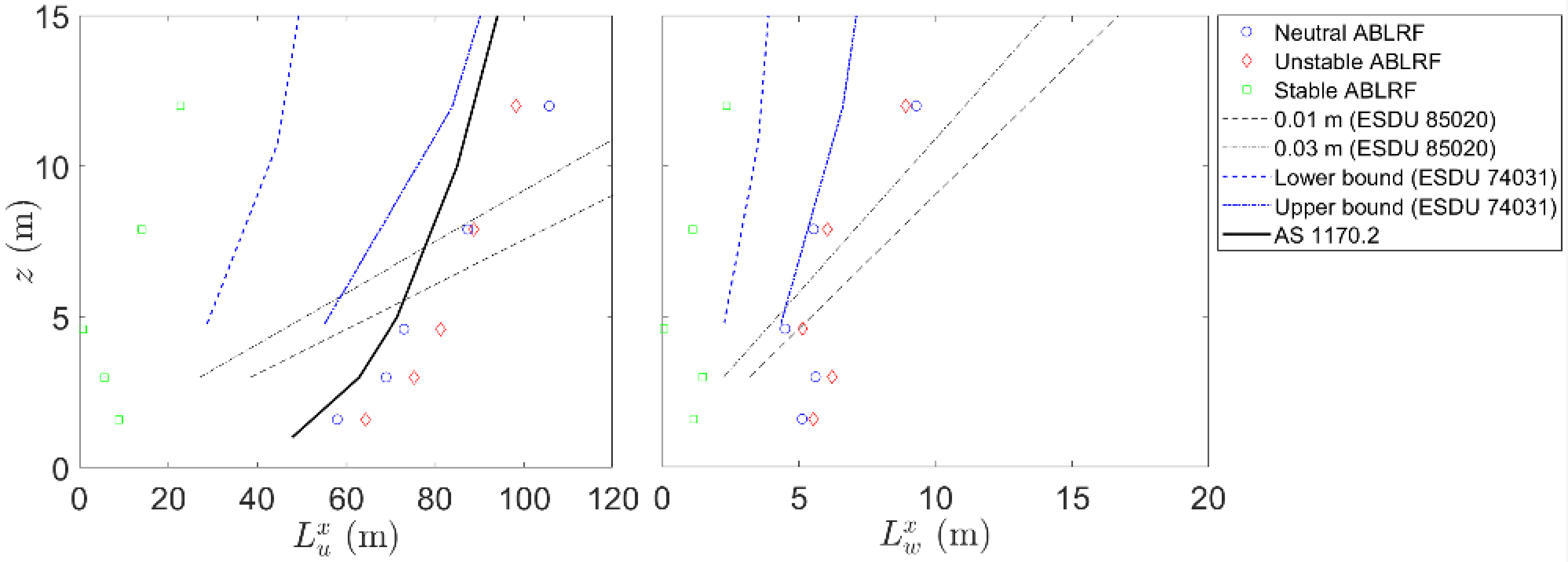
What we have learnt: Lesson 13

- **Outdoor experiments are critical. Better ABL data is necessary. The effect of temperature gradient on the stability of the eddy surface layer must be better understood.**
  - Longitudinal (I_u, L_u^x) and vertical (I_w, L_w^x) turbulence dependent on height, surface roughness and atmospheric stability
  - Anisotropic turbulence in ESL increased in unstable ABL with vertical heat flux due to temperature gradients in lower atmosphere



(Emes *et al.* 2023)

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Conclusions and Future Work

- **Wind loads have a significant effect on the heliostat field CAPEX, OPEX and LCOE**
- **There is an urgent need to develop wind load standards for heliostats**
- **Wind loads must be considered at the feasibility study stage**
- **Better understanding of atmospheric surface layer is necessary**
- **Turbulence spectrum, integral length scales and velocity gradients must be carefully modelled in wind tunnel experiments and numerical models**
- **High-fidelity ABL data is necessary to better understand the effect of thermal stratification on wind loads.**
- **Dust deposition and cleaning schedule are highly dependent on atmospheric surface layer behaviour**

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