U.S. Department of Energy
HelioCon
Heliostat Consortium for Concentrating Solar-Thermal Power

Impact of Heliostat Array Density on Boundary Layer Characteristics and Wind Loading

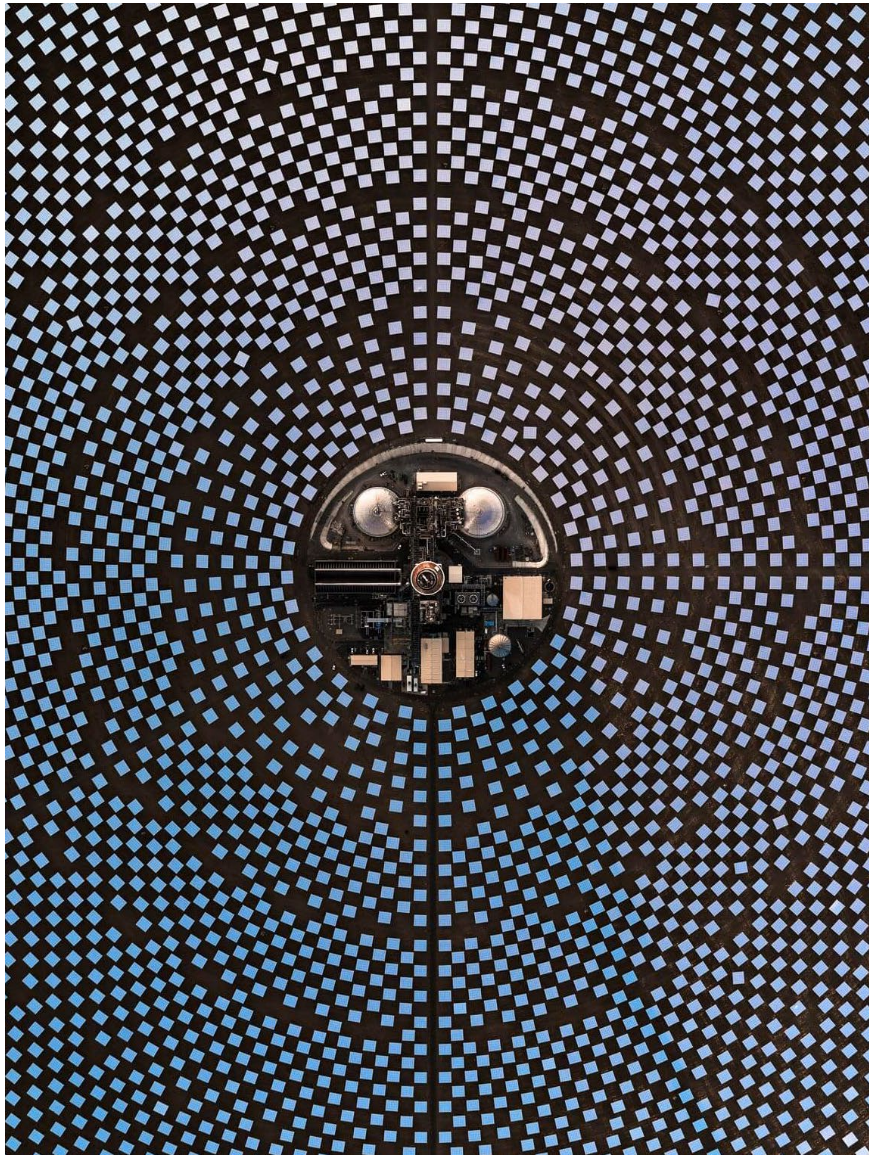
Matthew Marano, Matthew Emes, Azadeh Jafari, Maziar Arjomandi
The University of Adelaide, Australia

16 July 2024 • ASME ES2024 • Anaheim

conceptual design • components • integration • mass production • heliostat field

Introduction

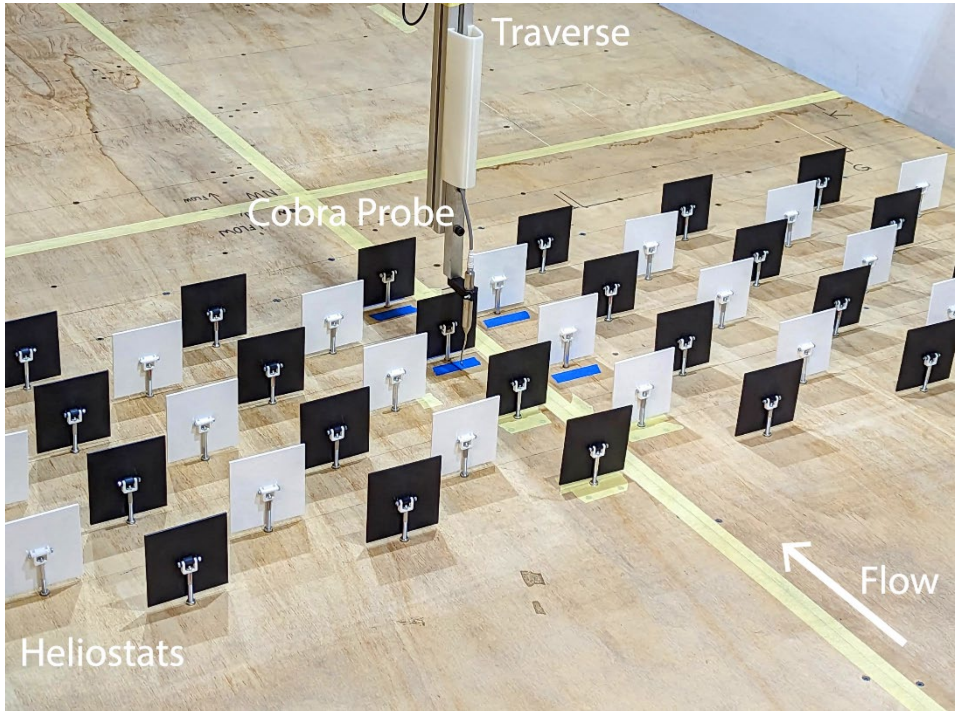
- Heliostat arrangement optimised for optical performance
- Arrangement based on wind loading is not considered
- Heliostat structure overdesigned
- Significant proportion of capital cost
- Heliostats identical in design throughout field
- Change in density with distance from tower and field layout

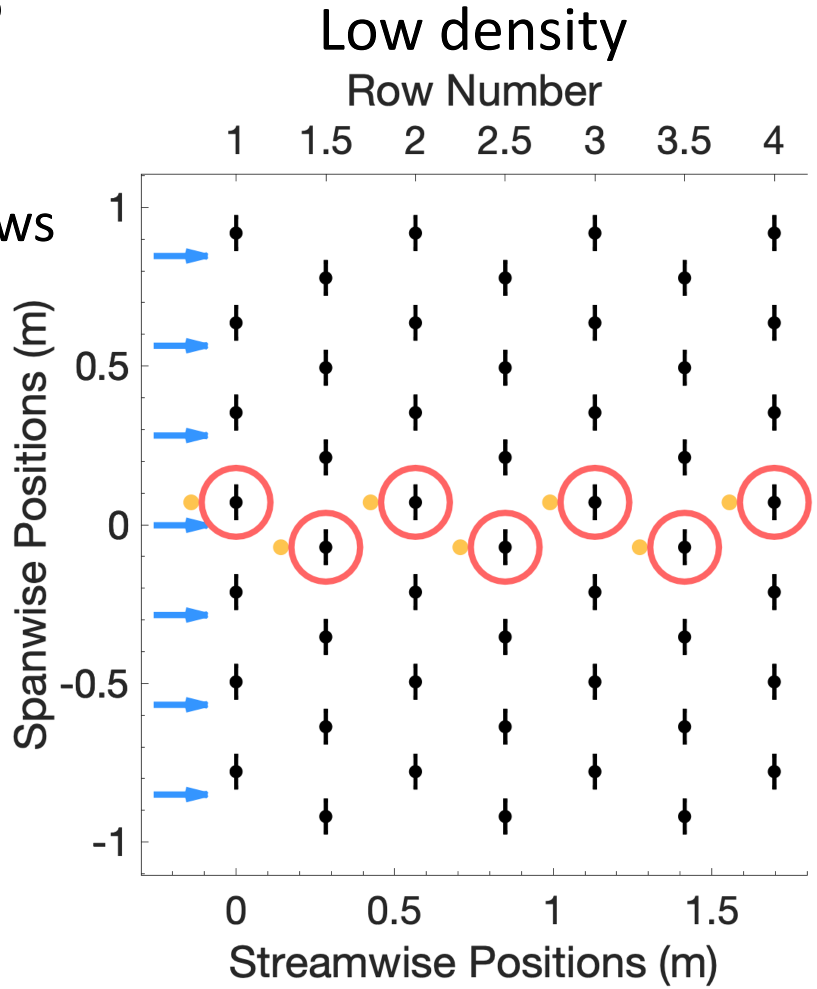


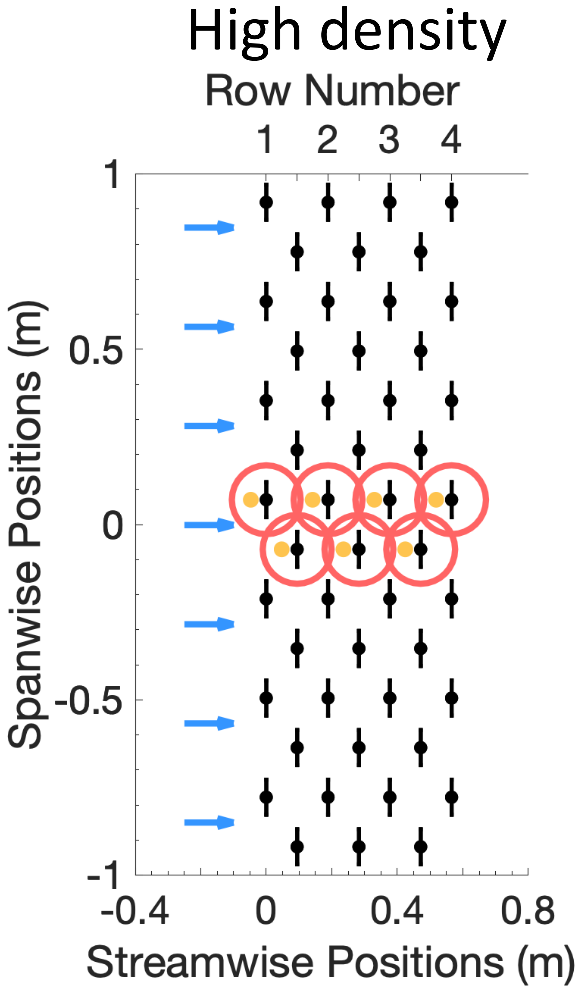
Crescent Dunes 110MW. Photo captured by Hegen (2016)

Wind tunnel experiments – field array layout

- Field densities of 12.5% (low) and 37.5% (high)
  - Heliostat aperture area / Ground area
- Flow measurement midway between rows
- Load measurements at each row

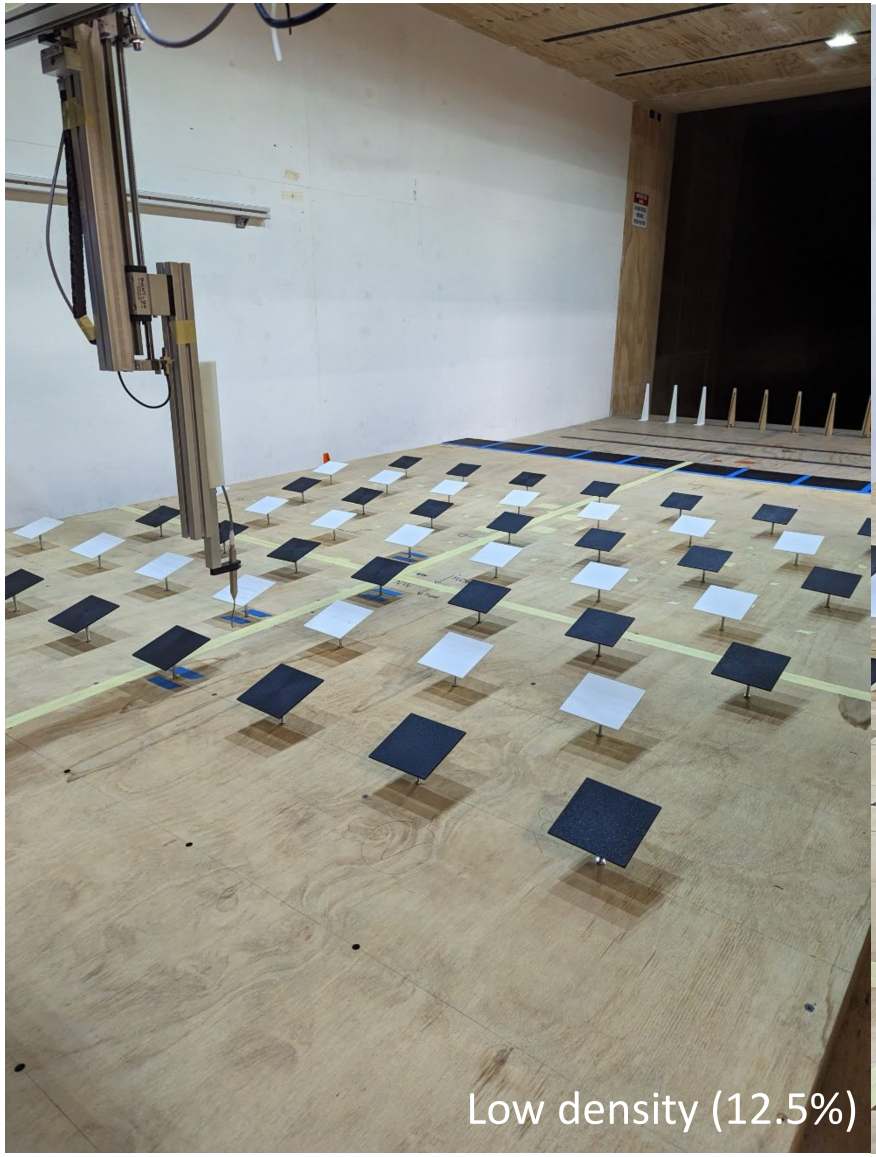


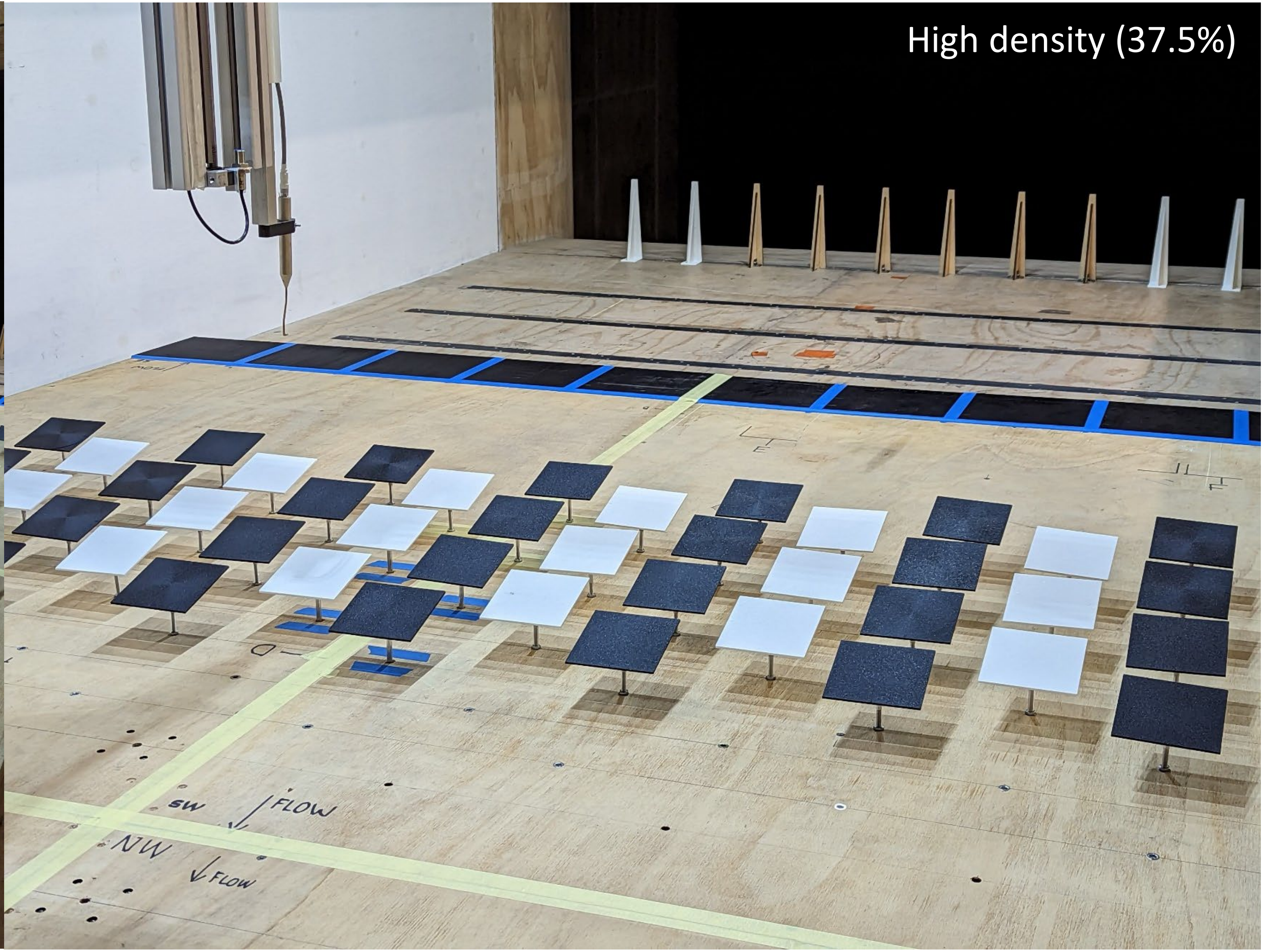




Load cell location   Flow measurement location

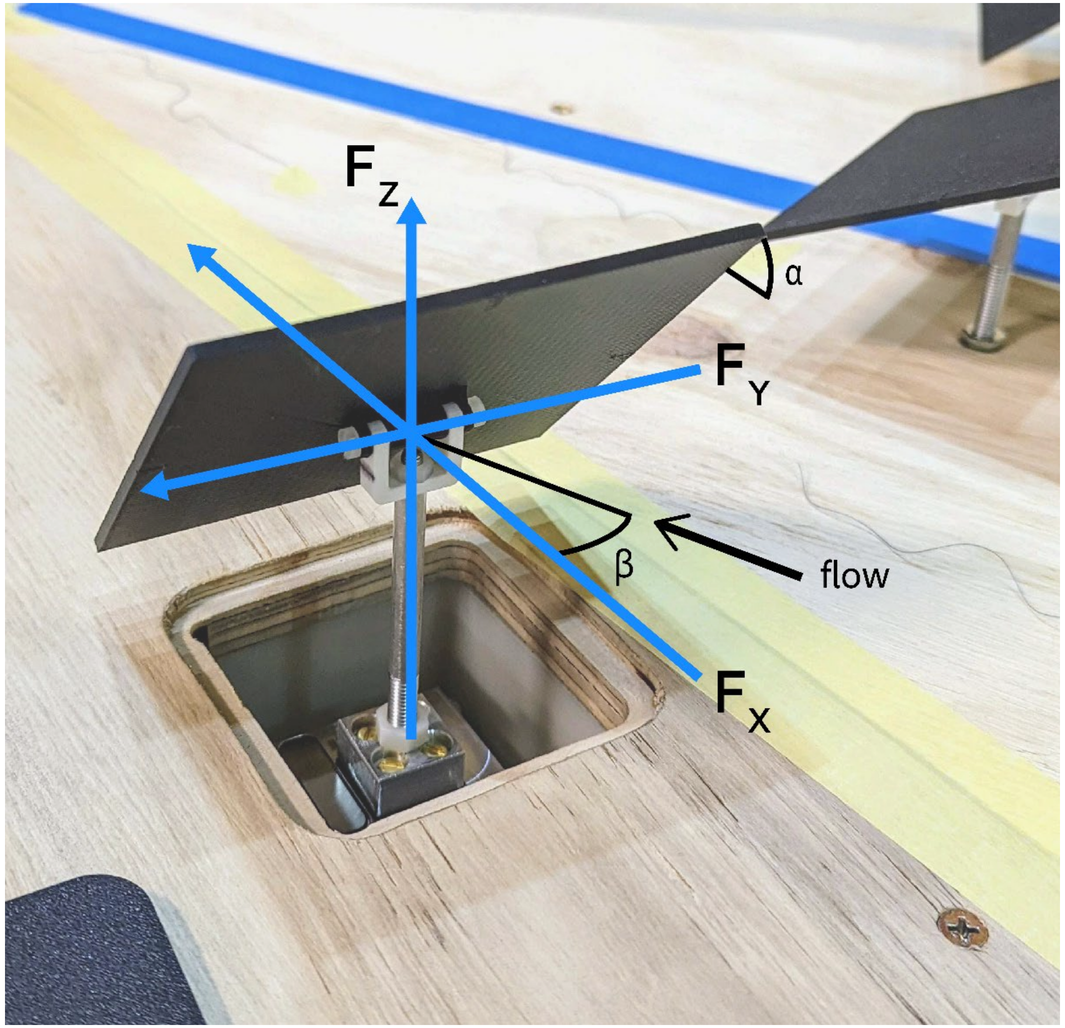
Comparison of densities





Wind tunnel experiments – instrumentation

- 3D printed heliostat models with
  - Chord = 0.1 m, Hinge height = 0.075 m
- Adjustable about 3-axes
  - Azimuth (β)
  - Elevation angle (α)
  - Hinge height
- Four 3-axis ±2N load cell (K3D40)
  - Sampled at 1 kHz simultaneously
  - F_x, F_y, F_z with ±0.5% accuracy



Wind tunnel experiments – inflow ABL profiles

- Incoming turbulent flow
  - Mean velocity profile

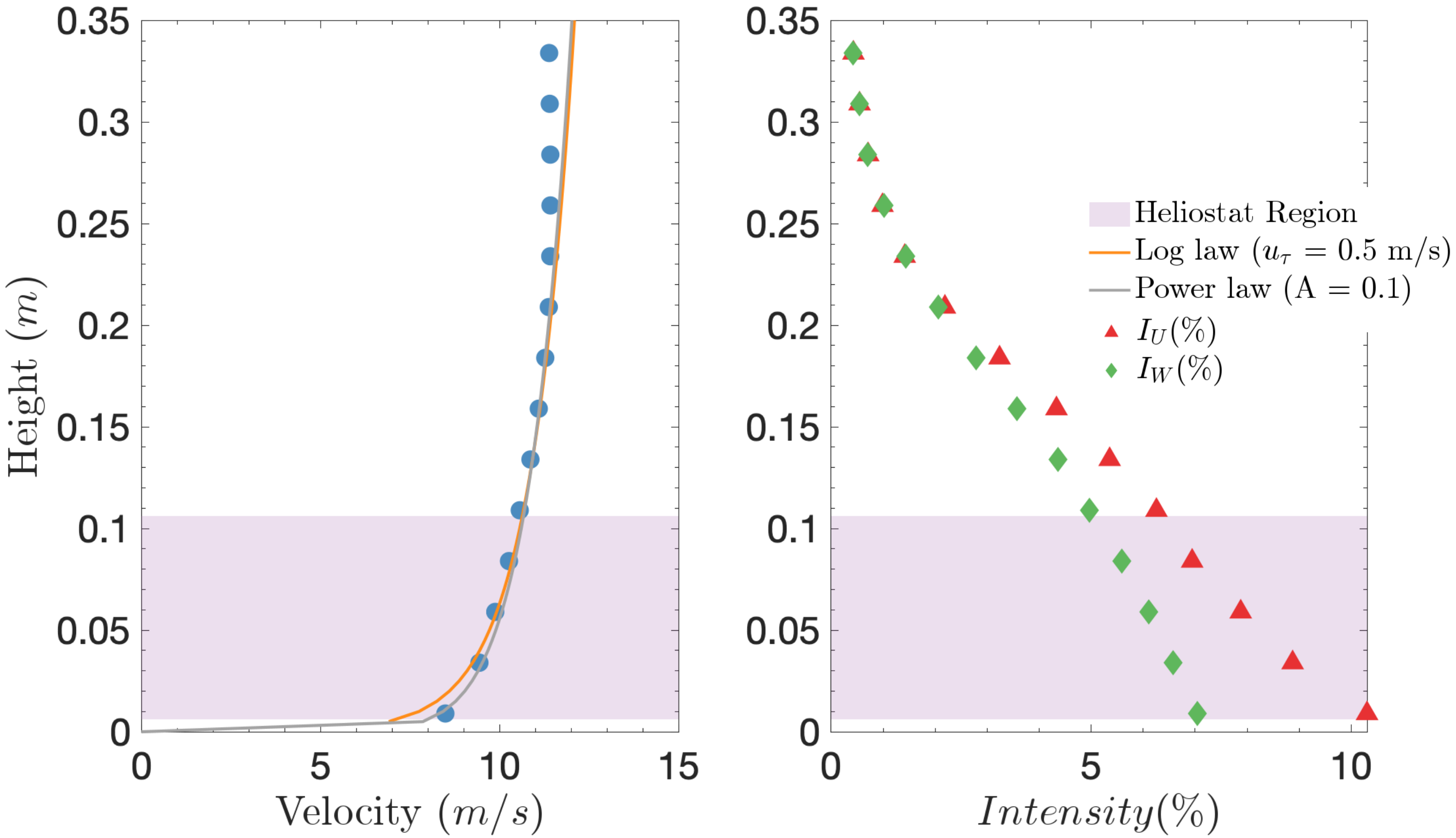
$$U(z) = \frac{u_\tau}{k} \ln \frac{z}{z_0} + d$$

u_τ = 0.5 m/s, z_0 = 0.01 m, d = 7.75

$$U(z) = U_\infty \left(\frac{z}{\delta}\right)^\alpha$$

U_∞ = 11.4 m/s, δ = 0.2 m, α = 0.1

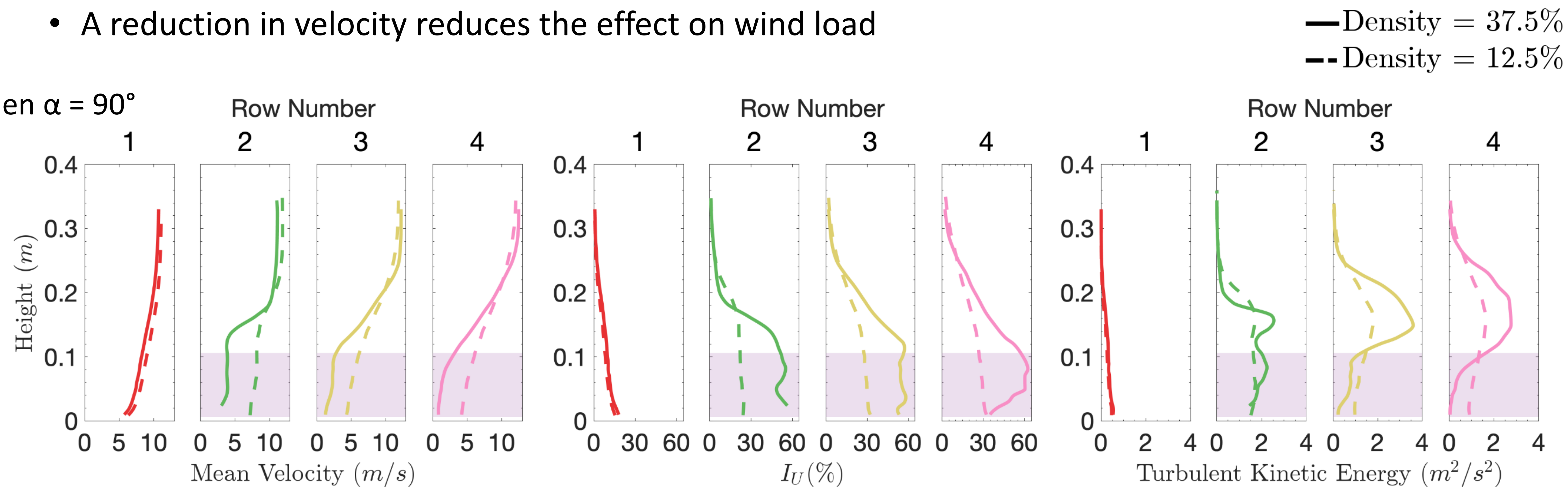
  - Turbulence intensity profiles
- At hinge height
  - 9.8 m/s flow velocity
  - 8% streamwise turbulence
  - 6% vertical turbulence



Effect of field density on flow characteristics

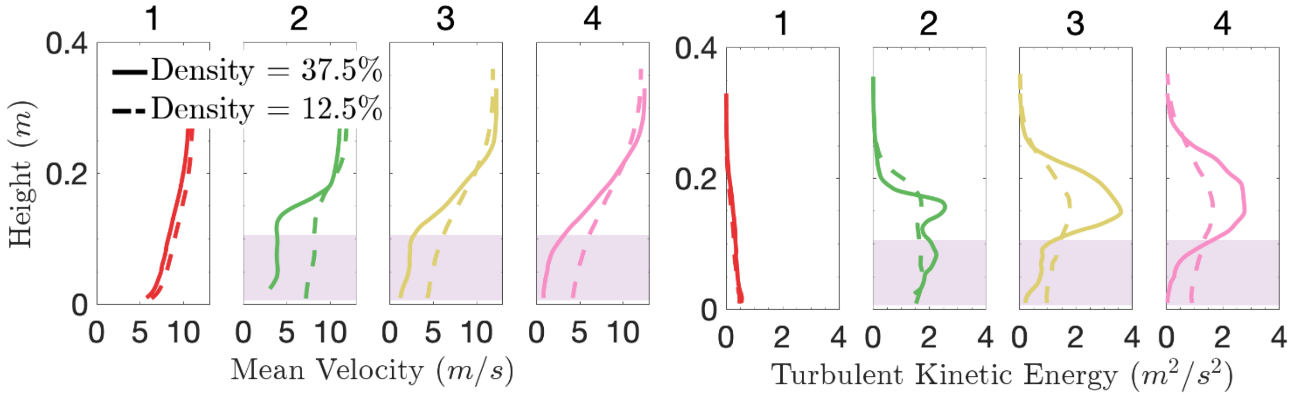
- Reduction in flow velocity within array – similar to canopy flow
- Increase in streamwise turbulence intensity with distance
  - Significant increase for high density case
- Increase in turbulent kinetic energy downstream
  - A reduction in velocity reduces the effect on wind load

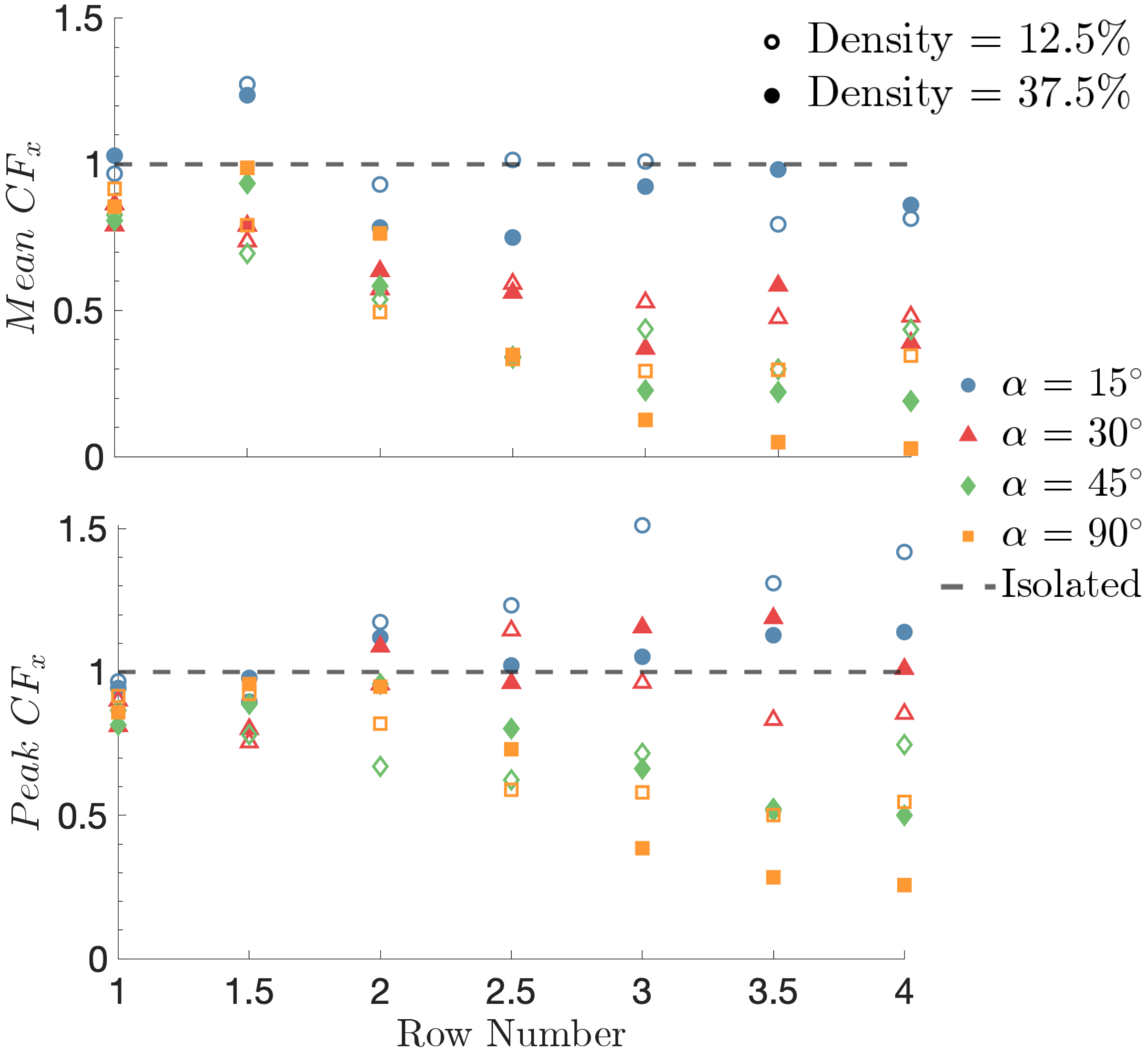
When α = 90°



Effect of field density on drag forces

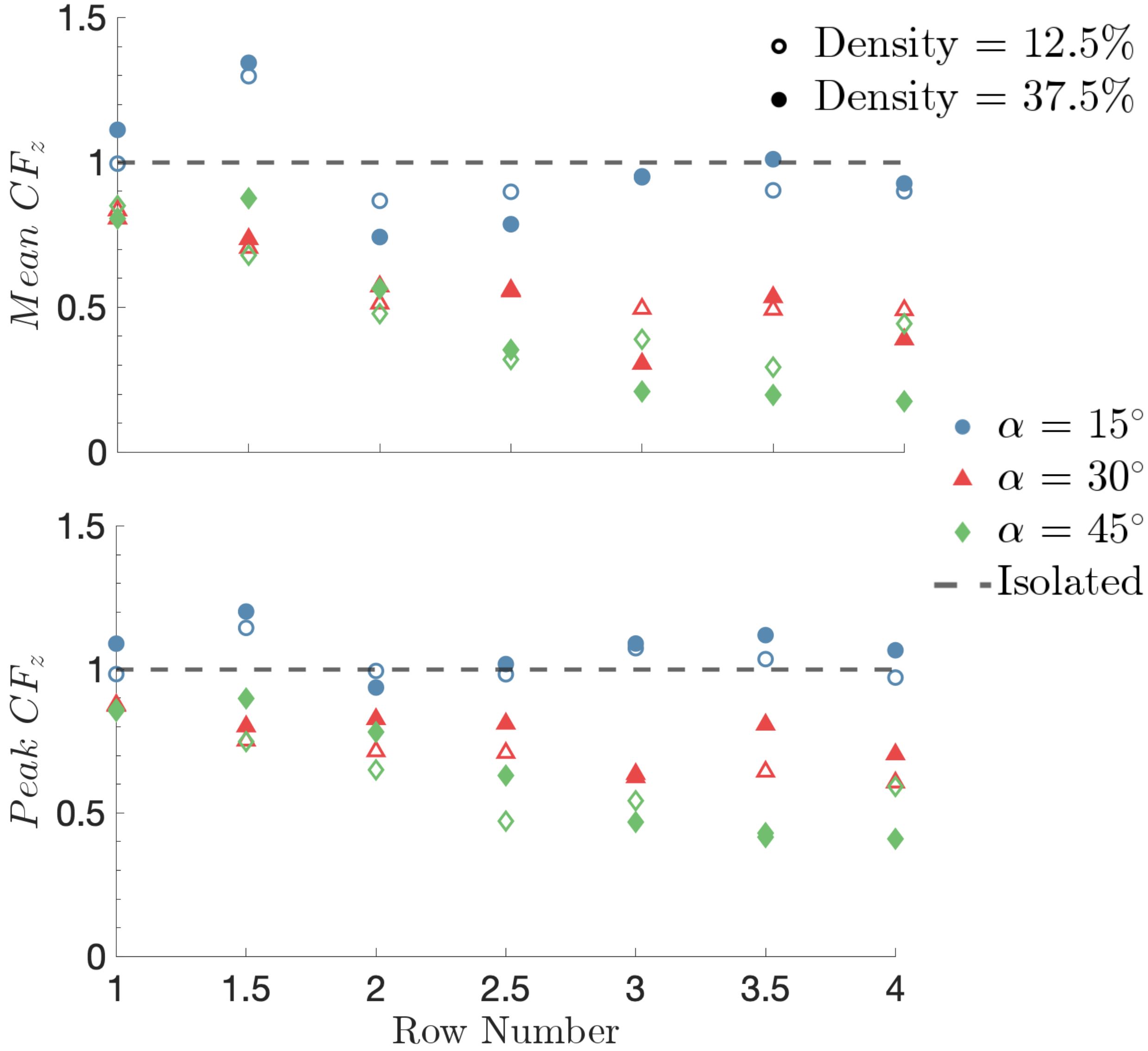
- Normalised to isolated heliostat drag
- From row 3:
  - Mean and peak reduced by up to 50% (α = 90°)
  - Increase in density → reduction in drag ($\alpha \geq$ 45°)
  - Similar drag coefficients at $\alpha \geq$ 30° (low density)
- Increased peak drag at $\alpha \leq$ 30°
- Maximum mean drag at row 1.5, when velocity and turbulent kinetic energy is high





Effect of field density on lift forces

- Normalised to isolated heliostat lift
- Mean and peak lift at $\alpha \leq 15°$ remain similar to isolated heliostat
  - Minimal upstream flow blockage
- Amplification of peak lift forces at $\alpha \leq 15°$ due to channeling flow



Conclusions and next steps

- Reduction in drag compared to isolated heliostat
- Fluctuation in mean lift beyond isolated heliostat
- Alternative heliostat design conditions for inner regions
  - Potential for cost reduction
- Investigation into potentially increased hinge moments
- Development of a transformation formula to estimate loads within an array based on individual heliostat investigations

Acknowledgements

- Heliostat Consortium (HelioCon)

  US Department of Energy (DOE) Solar Energy Technologies Office Award DE-EE00038488/38714

- Australian Solar Thermal Research Institute (ASTRI)

  Australian Renewable Energy Agency (ARENA) Grant 1-SRI002

- University of Adelaide fabrication and instrumentation teams

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
SOLAR ENERGY TECHNOLOGIES OFFICE

NREL Transforming ENERGY

Sandia National Laboratories

ASTRI Australian Solar Thermal Research Institute

ARENA

Australian Government
Australian Renewable Energy Agency

THE UNIVERSITY of ADELAIDE

CSIRO