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Wind loads on heliostats in stow position

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Stowed heliostats are exposed to gusty wind conditions from large-scale vortices within the atmospheric boundary layer (ABL). The vortices around the stowed heliostat have various shedding frequencies with can lead to highly unsteady wind loads and vibrational responses through galloping and buffeting of the wind. Consideration of the maximum dynamic wind loads on stowed heliostats from the effects of large-scale eddies can lead to significant savings in costs due to the reduced design wind loading.

Objectives

- Investigate the effect of the design wind speed for stowing heliostats on the levelised cost of electricity (LCOE) of a concentrating solar thermal (CST) plant.
- Determine the integral length scales of vortices in the ABL for heliostat loads.
- Determine the relationship between gust factor and turbulence intensity within the ABL.
- Generate and characterise a well-defined large-scale spanwise vortex.
- Determine the effect of the length scales of vortices on the wind loads and frequency response of heliostats in stow position.

Methods

- Six sites were selected for assessment based on the joint criteria of a good solar resource with an annual average DNI greater than 2000 kWh/m^{2}yr.
- The solar energy input was calculated from historical time series of direct normal irradiance (DNI) measured using a pyrheliometer, which can achieve an accuracy of 15 W/m^2 on a regional scale [1].

Table 1. Details of the six sites selected for analysis of hourly average DNI and hourly average wind speed data [2]

Station	Latitude (°)	Longitude (°)	Elevation (m)	Barometer height (m)	Annual average DNI (kWh/m^{2}yr)
Alice Springs, AUSTRALIA	–23.7951	133.8890	546	1	2771
Mildura, AUSTRALIA	–34.2358	142.0867	50	2.8	2251
Darwin, AUSTRALIA	–12.4239	130.8925	30.4	4.6	1970
Las Vegas, USA	36.0719	–115.1634	664.5	1.5	1875
Bakersfield, USA	35.4344	–119.0542	149	1.5	2387
Phoenix, USA	33.4277	–112.0038	337.4	1.5	1964

- The accuracy of the previous semi-empirical relationship [3] between turbulence intensity and gust factor using field experiment velocity data in a low roughness ABL has been investigated.

$$\text{Gust factor} = 1.0+0.42\, I_u \ln(3600/t)$$

  Here t (s) is the gust period and I_u is turbulence intensity.
- The gust factors were calculated from the velocity data collected by Hutchins et al. [4] during a field experiment at the SLTEST facility in the Great Salt Lake desert in western Utah.
- The generation of a large spanwise vortex is investigated by the forcing of periodic motions behind a bluff body.
- Controlled generation of a spanwise vortex with a defined size and defined frequency is achieved using a surface-mounted oscillating fence connected to a servo motor.
- Small oscillations of the fence are used to force the spanwise vortex structures to become periodic and enable characterisation of the coherent flow structures through phase-averaging of the velocity data collected at different positions behind the fence using a high-frequency Cobra probe.

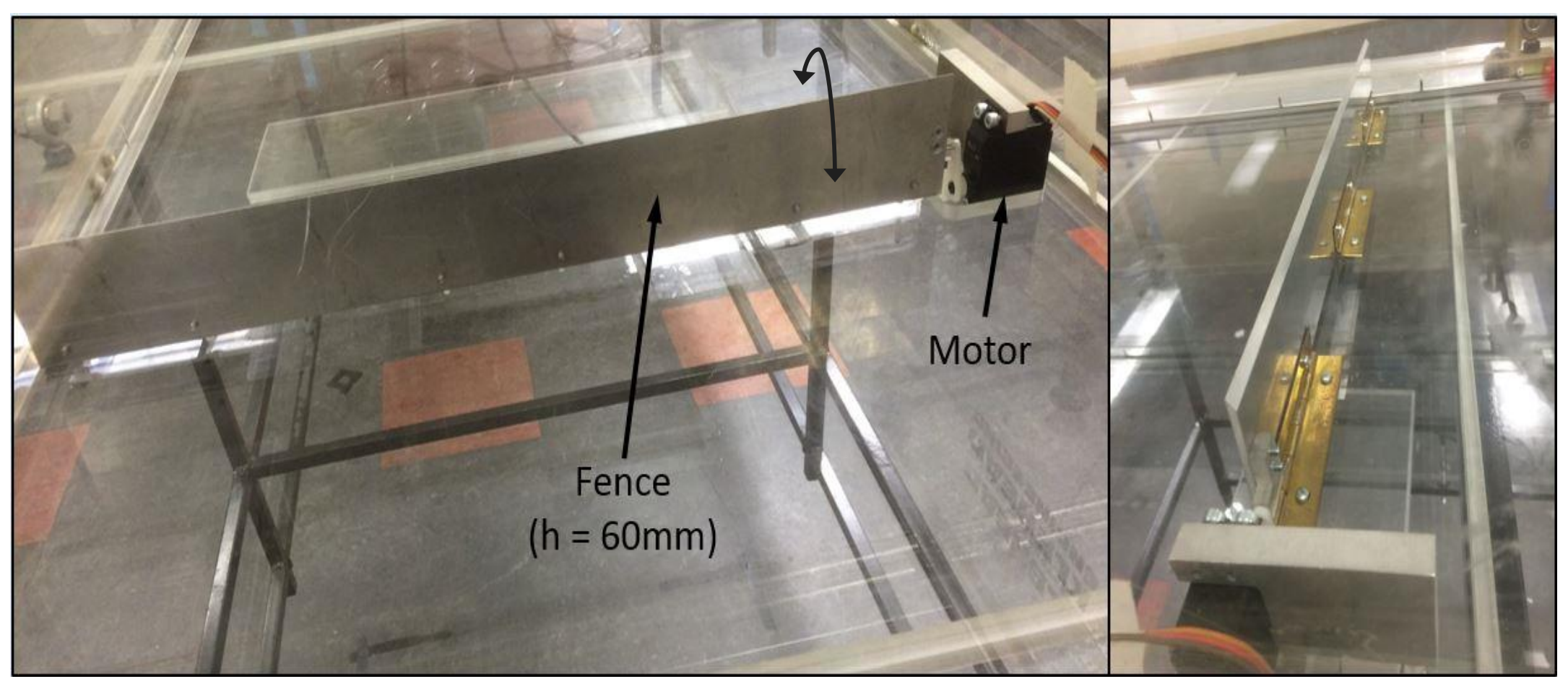

Figure 1. Experimental setup of oscillating fence in the wind tunnel

Results

- The optimal design wind speed is less than 12 m/s while, in cases such as Phoenix, it is as low as 6 m/s.
- Lowering the design wind speed from the maximum recorded at the three Australian sites is found to yield a significant economic benefit, such that the LCOE of a PT plant at Alice Springs, Mildura and Darwin can be reduced by 9%, 10% and 8%, respectively.

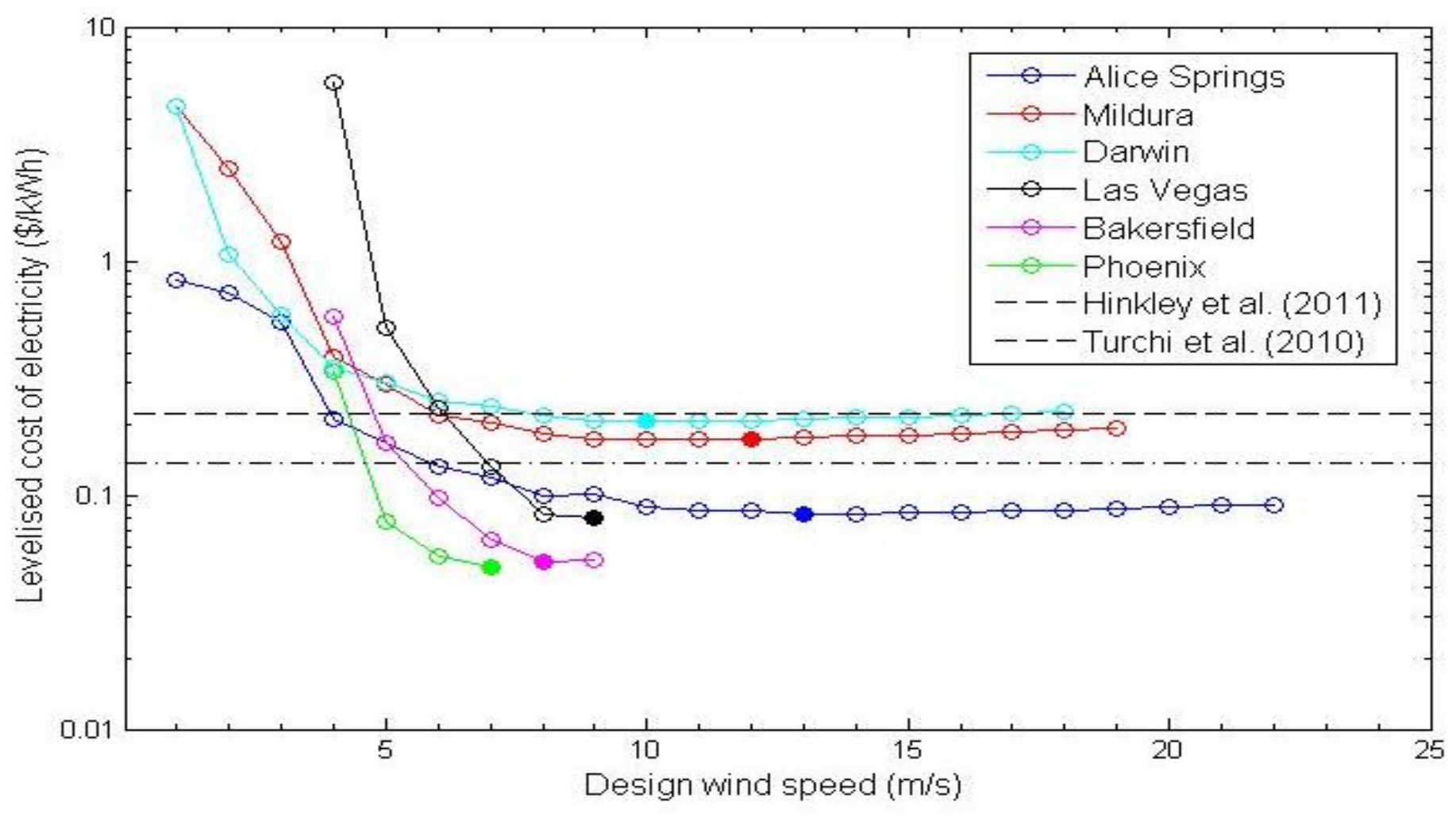

Figure 2. Effect of LCOE on the design stow wind speed [5]

- The peak wind loads are overestimated by as much as 5% on structures positioned close to the ground at heights below the 10m reference height
- Maximum gust wind speeds increase by an additional 50% in an urban terrain of double the turbulence intensity than in a rural terrain when lowering the gust period from 3s to 1s.
- Sonic anemometers are preferred for turbulence measurements in the ABL including spectral analysis, integral length scales and turbulence intensity.

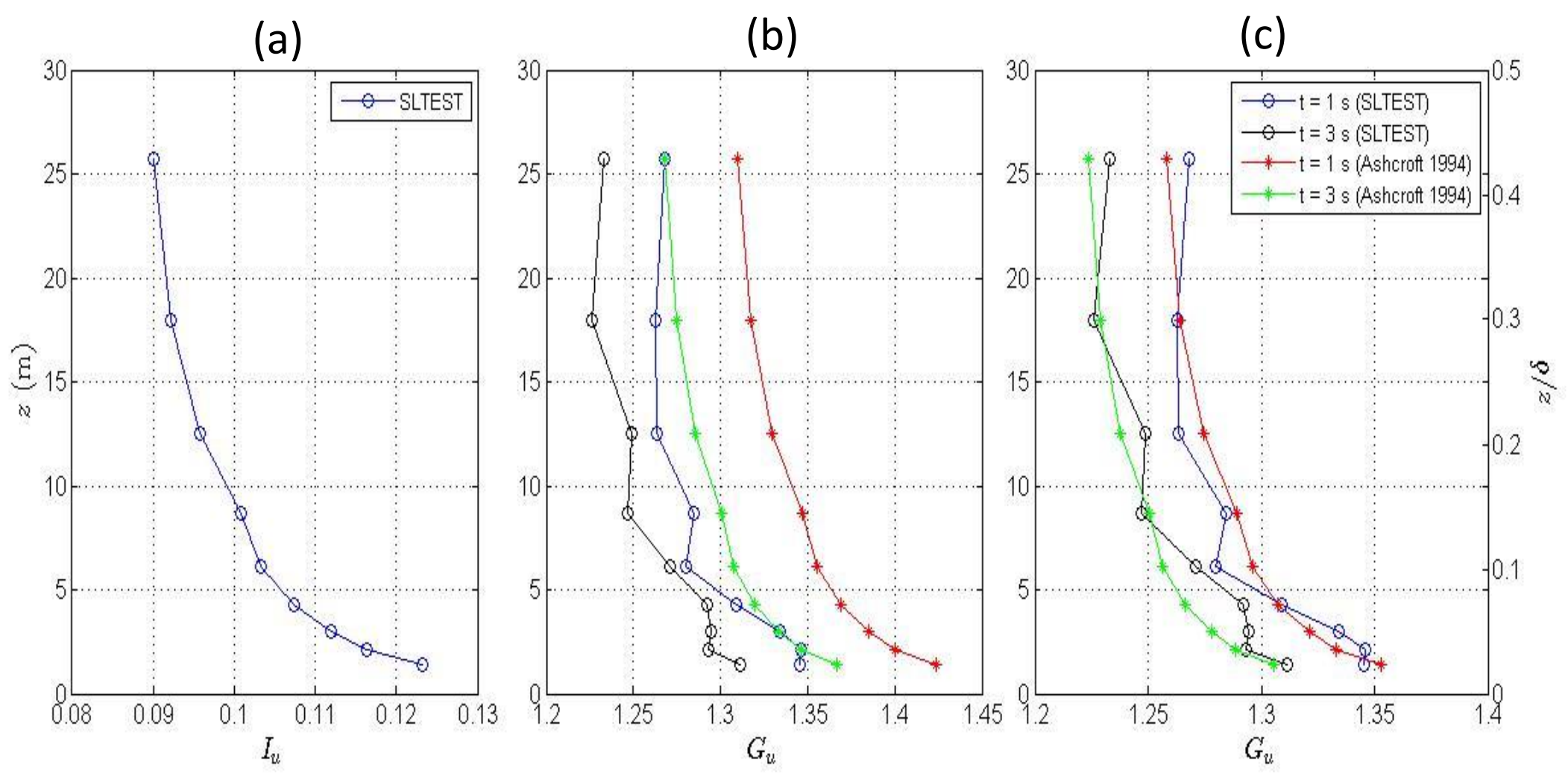

Figure 3. (a) Calculated turbulence intensity as a function of height within the SLTEST field experiment ABL; (b) Calculated gust factor as a function of height in the SLTEST field experiment ABL and comparison with semi-empirical relationship for gust periods of 1s and 3s; (c) Calculated gust factor as a function of height in the SLTEST field experiment ABL and comparison with semi-empirical relationship using a modified coefficient for gust periods of 1s and 3s

- The large-scale vortex structure behind the fence is characterised in terms of its length scale and power spectral density.
- The maximum peak Reynolds shear stress occurs at *x/h* = 5, which is in an indication of turbulent stress production and rapid shear layer growth from the direct roll-up of large-scale eddies.

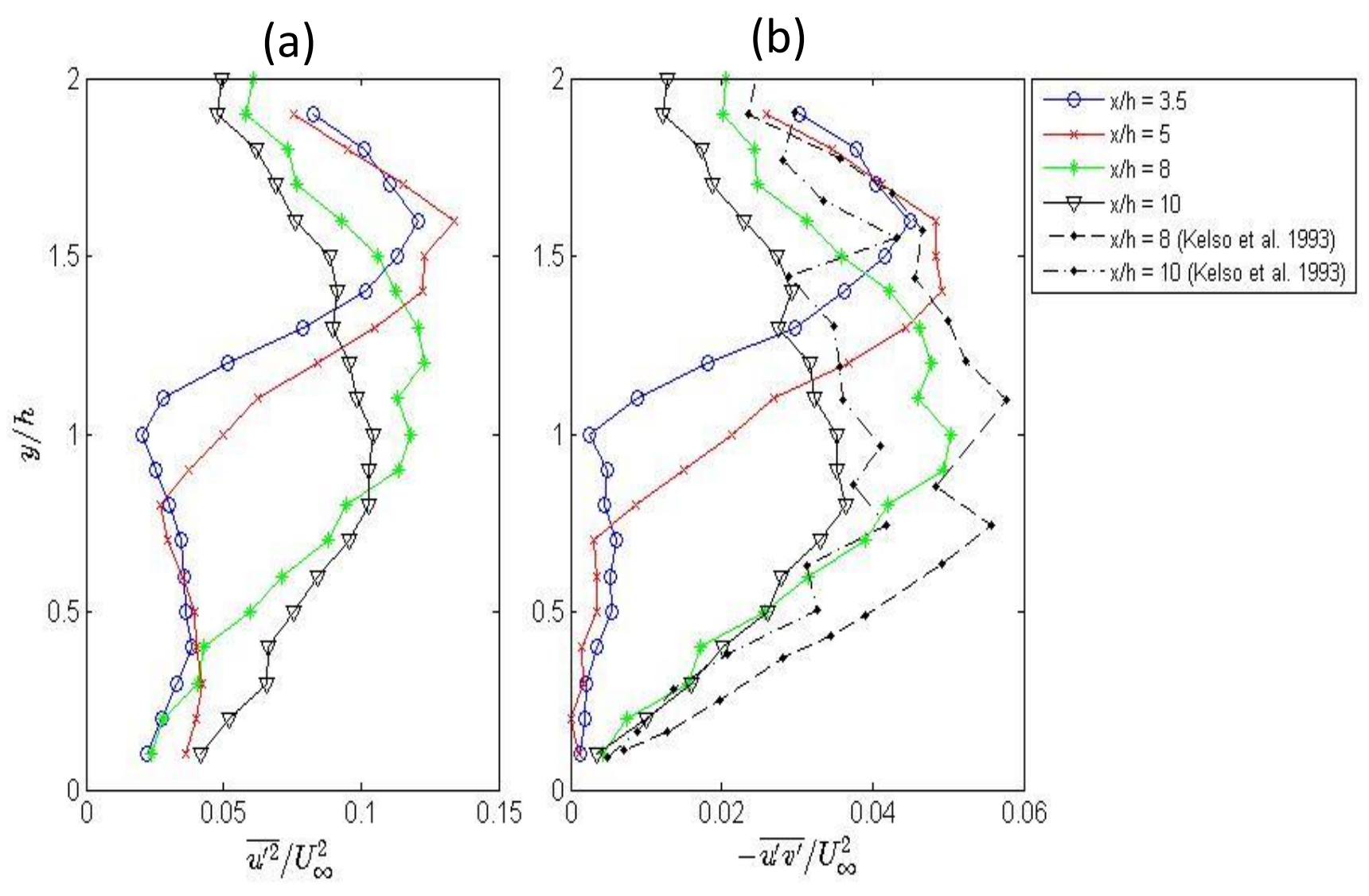

Figure 4. Time-averaged profiles of the Reynolds (a) streamwise (b) shear stresses at four positions downstream of the oscillating fence and comparison with a forced fence experiment [6]

Future work

- Characterise a well-defined spanwise vortex and develop a validated CFD model for oscillating fence.
- Force and surface pressure measurements on stowed heliostat exposed to a large vortex in the wind tunnel.

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