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

Wind Tunnel Study on the Effects of Ground Clearance Ratio on Heliostat Dynamic Wind Loads

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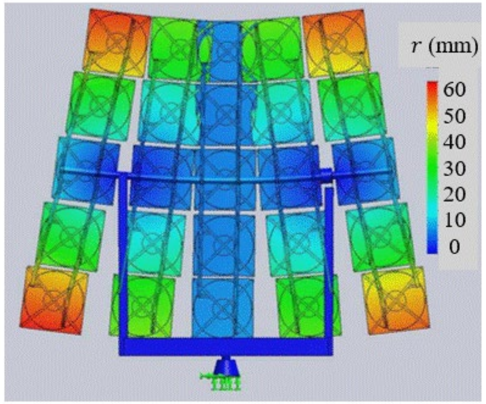
conceptual design • components • integration • mass production • heliostat field

Introduction

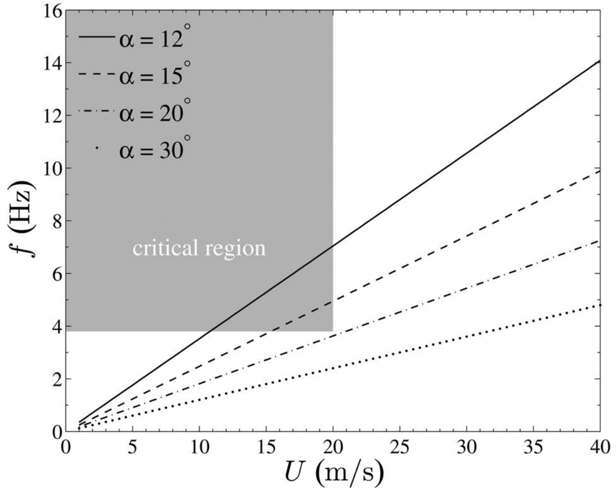
- Dynamic wind loads on operating heliostats
  - Torque bending at modal frequency of 3 Hz corresponds to maximum displacements of 60mm of corner facets (Griffith *et al.* 2015)
  - Out-of-plane torsion and rigid body modes of the mirror frame due to oscillation about the elevation axis cause deflections of the order of 1% of the heliostat characteristic length (Vásquez-Arango *et al.* 2015)
  - Truss member to torque tube interfaces due to out-of-plane bending modes due to wind cause maximum beam deviations of 0.17m and 1.58m, compared with 0.1m and 0.25m due to gravity in the absence of wind (Ho *et al.* 2012)
  - Modal frequencies largely dependent on heliostat size (Ho *et al.* 2012)



NSTTF heliostat FEA simulation (adapted from Griffith *et al.* 2015)

- Vortex-induced vibrations induced by wind load fluctuations on a heliostat "flat plate" model depend on elevation angle α, flat plate geometry c and inflow conditions

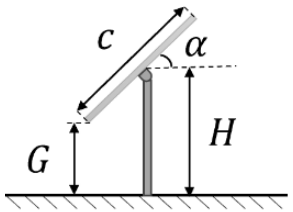
$$St = fc/U$$



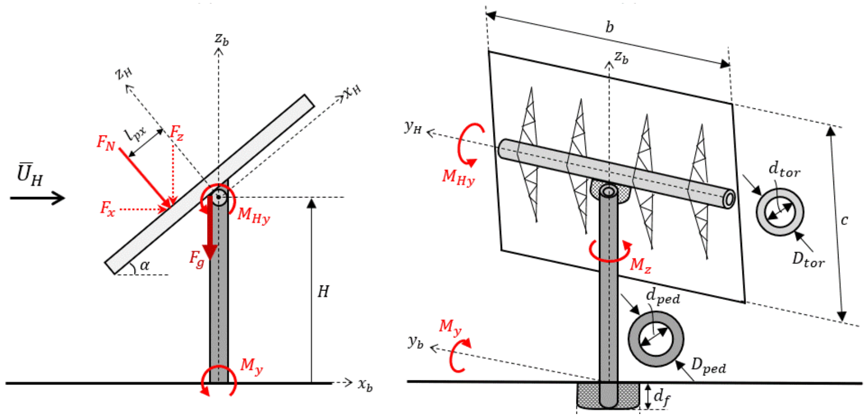
Vortex shedding frequencies (Vásquez-Arango *et al.* 2015)

Objectives

- Investigate the sensitivity of Strouhal number of a single heliostat to:
  - Elevation angle α
  - Ground clearance ratio $GR = G/H$
  - Inflow turbulence



- Spectral analysis of wind load fluctuations measured on a single heliostat using a six-axis load cell and differential pressure sensors



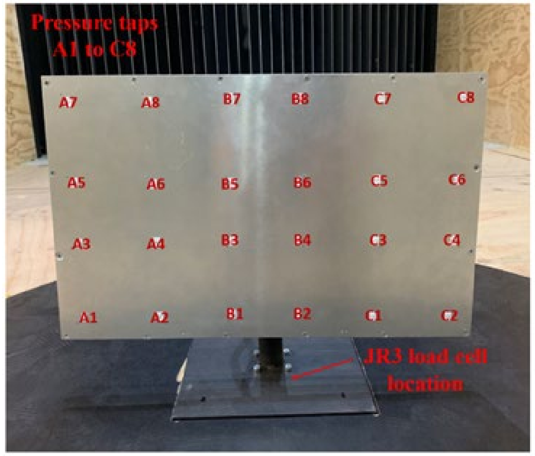
Wind loads on a heliostat (Emes *et al.* 2020)

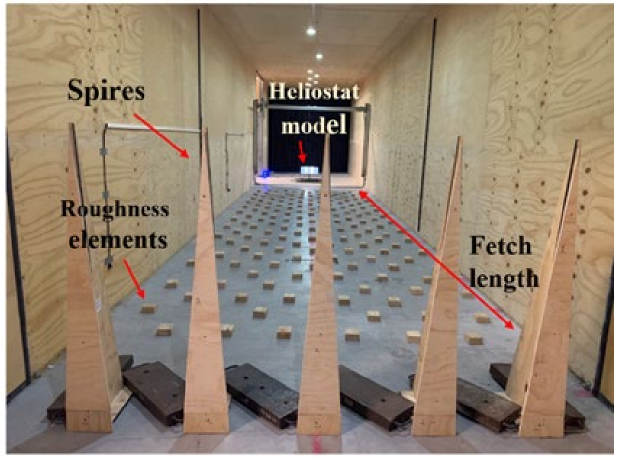
Wind tunnel experiments – instrumentation

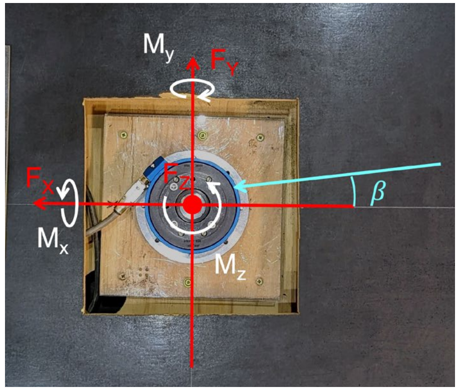
- Two inflow conditions: (1) uniform flow (2) turbulent ABL
- 1:6 scale heliostat model
  - b = 0.33 m, c = 0.53 m, H = 0.2-0.325 m (G/H = 0.106-0.485)
- JR3 six-axis load cell

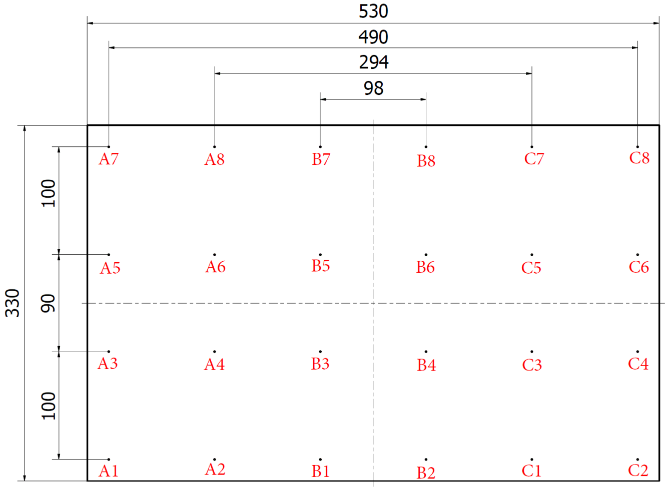
  ±100 N F_x, F_y, ±200 N F_z, ±12 Nm M_x, M_y, M_z with ±0.25% accuracy
- 24 differential pressure sensors

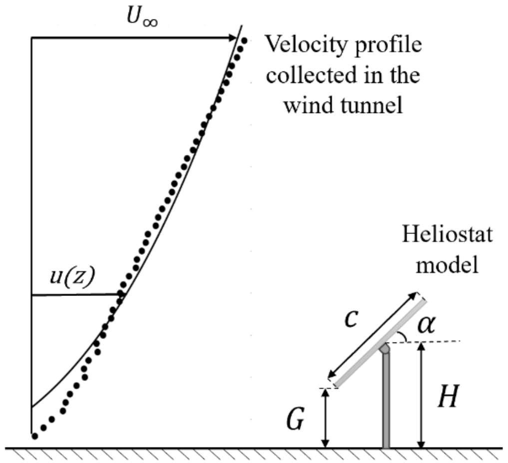
  ±1” H2O (±248.84 Pa) with ±0.25% accuracy











Wind tunnel experiments – inflow profiles

- Uniform flow

  U_∞ = 10.5 m/s, δ = 0.2 m

- Turbulent ABL flow
  - Mean velocity profile

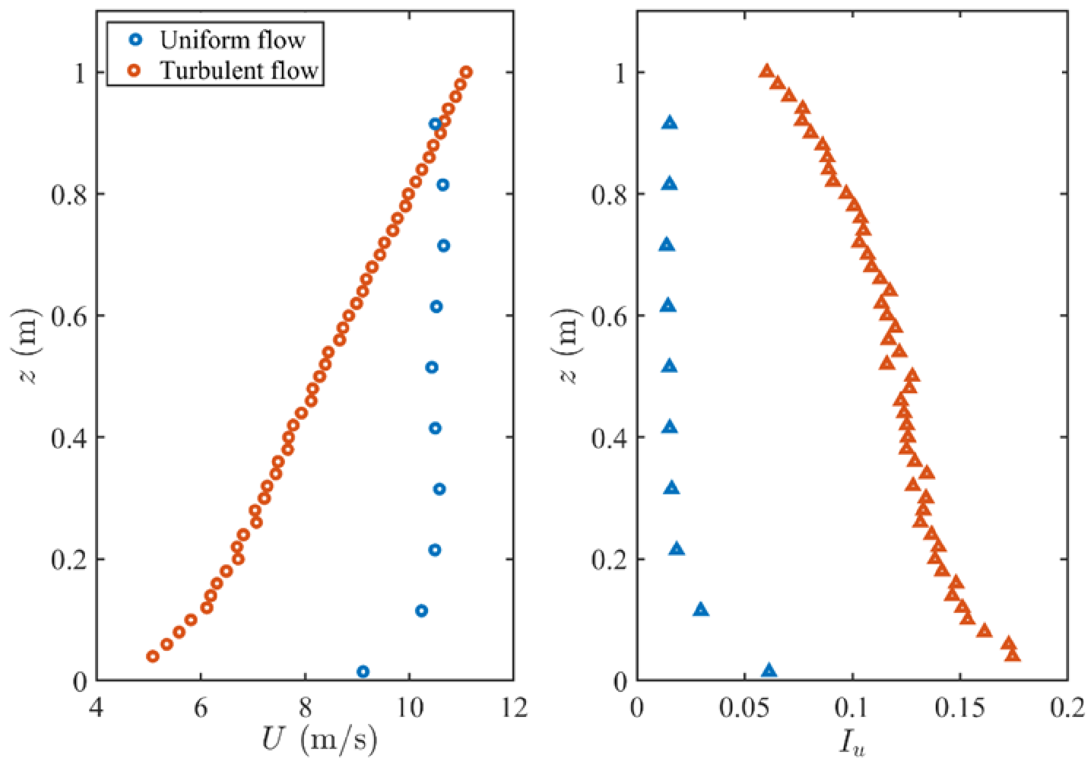
    $$U(z) = \frac{u_\tau}{k} \ln \frac{z}{z_0} + d$$

    u_τ = 0.48 m/s, z_0 = 0.01 m, d = 4.4

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

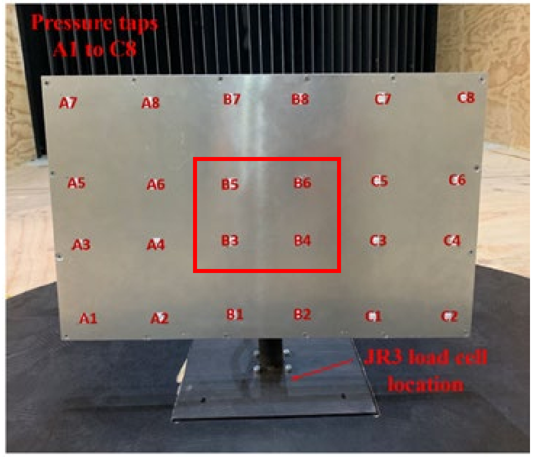
    U_∞ = 11.1 m/s, δ = 1.3 m, α = 0.35

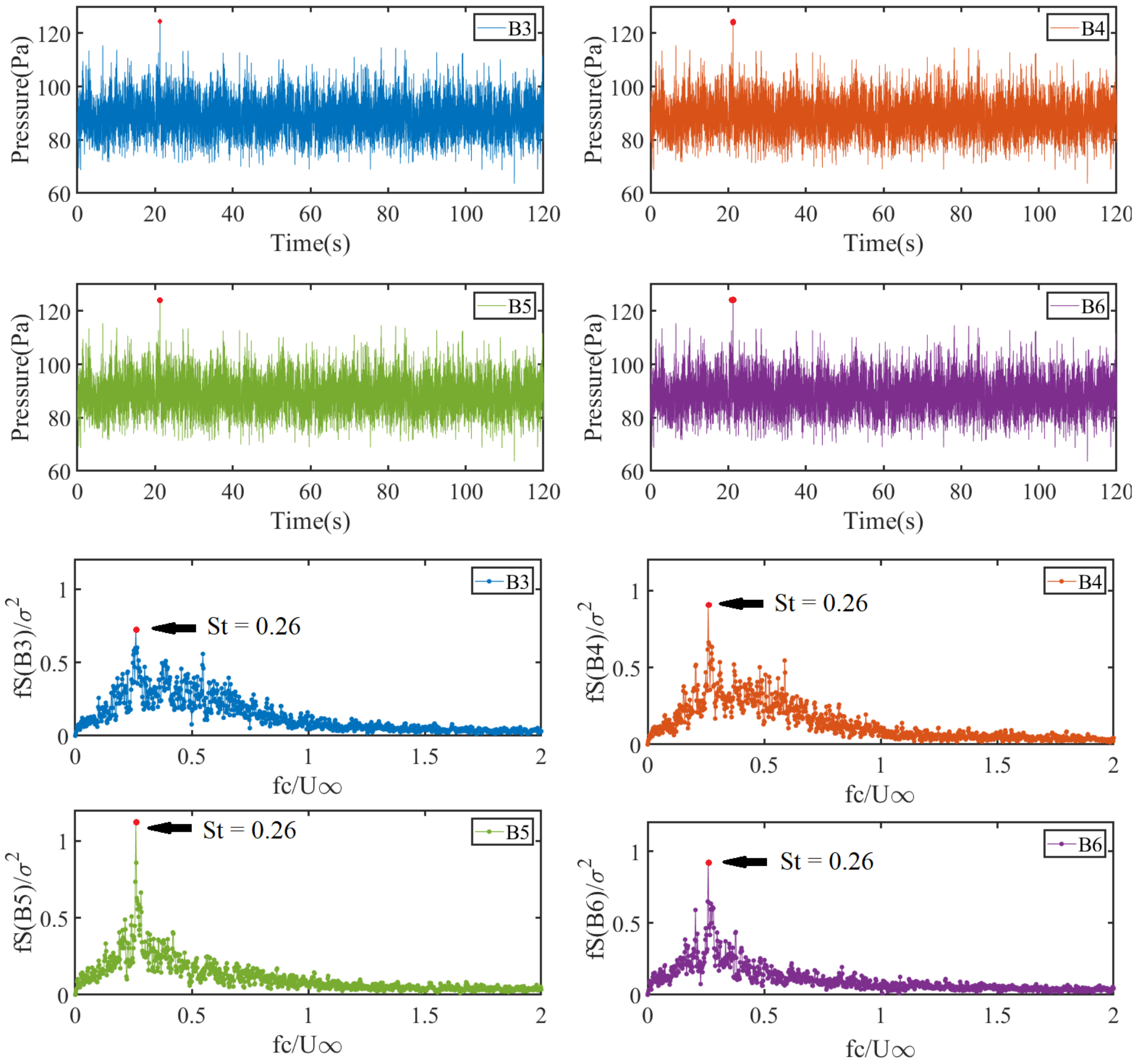
  - Turbulence intensity profiles
    - Open country terrain



Velocity and spectra time series

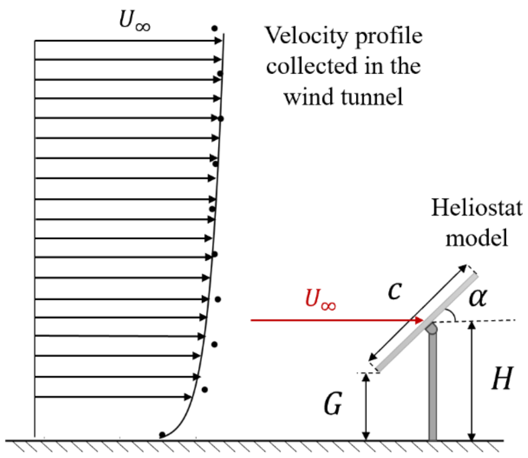
- Case study: $\alpha = 45°$ uniform flow
  - Time series pressure data collected at 1 kHz for 120 seconds
  - PSD (pwelch) of time series data
  - Determine frequency f corresponding to first peak in PSD
  - Determine St as non-dimensional frequency with $c = 0.33$ m and $U_\infty = 11.1$ m/s

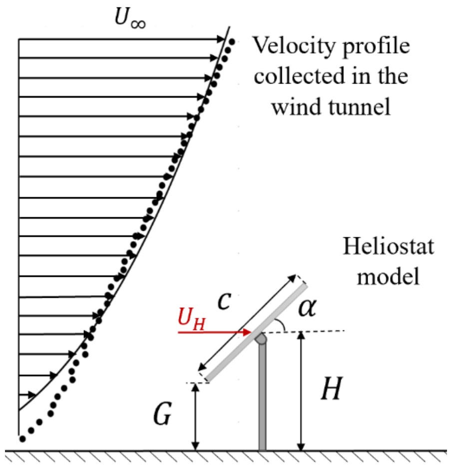


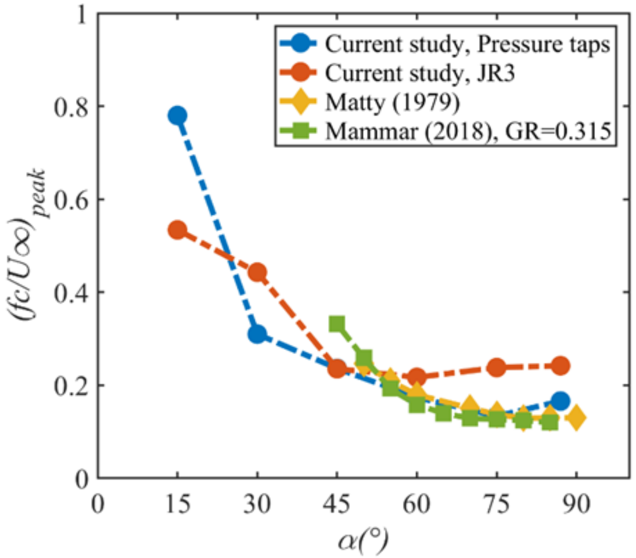


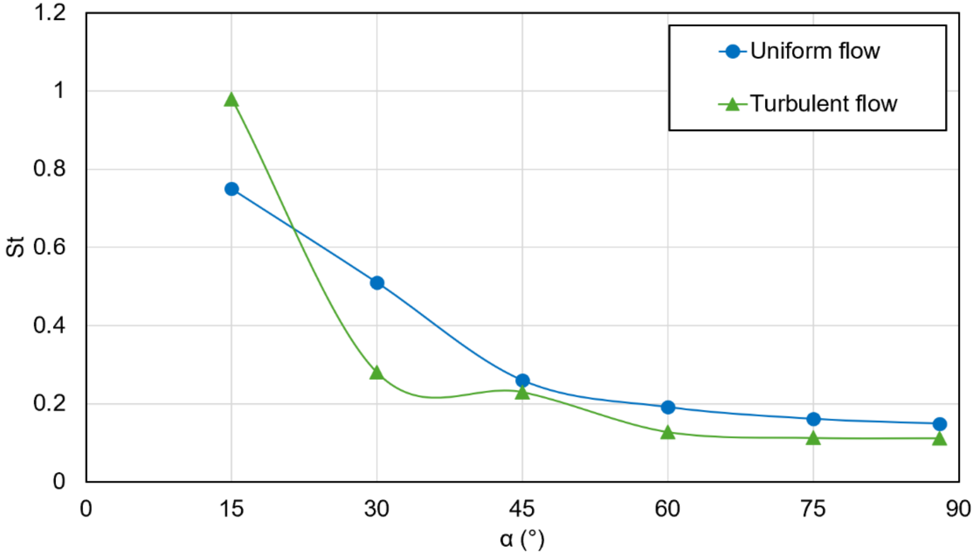
Effect of inflow turbulence

- Impact of inflow turbulence on Strouhal number most significant at $\alpha \leq 30°$
- Strouhal number of flat plate model at $\alpha = 88°$ smaller in turbulent flow than in uniform flow



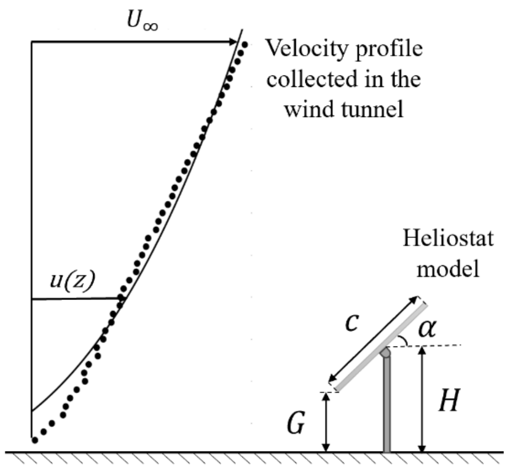


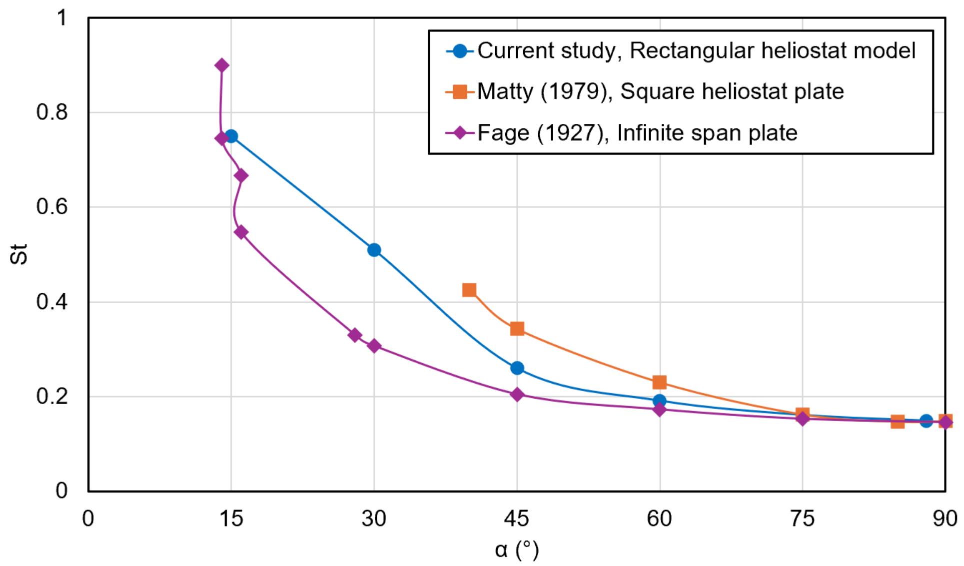




Effect of heliostat elevation angle

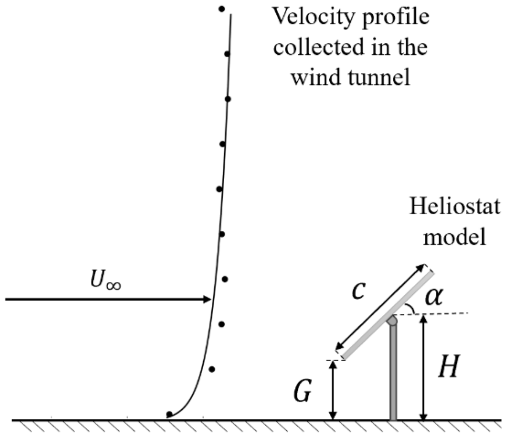
- Strouhal number of a rectangular flat plate is between that of an infinite flat plate and a square flat plate and aspect ratio becomes significant at $\alpha \lesssim 30°$



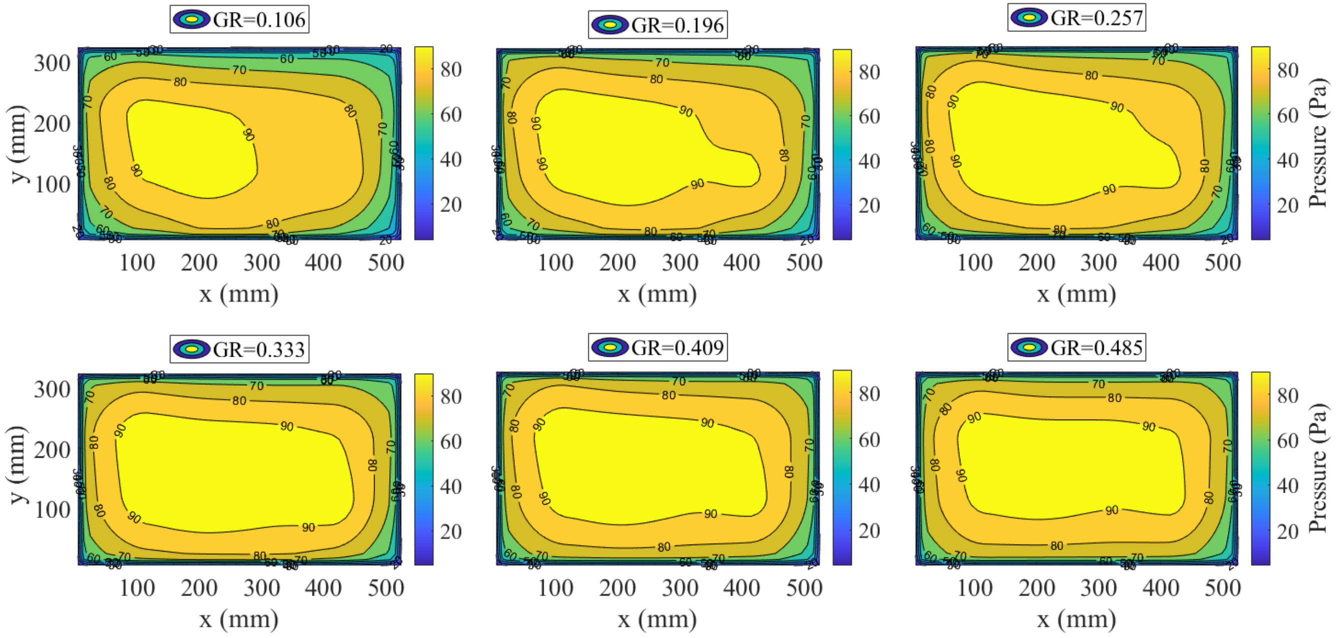


Effect of ground clearance ratio (GR)

- Asymmetric pressure distribution at $GR \leq 0.257$ in **uniform flow** due to ground effect generating a jet flow with alternate vortex shedding and asymmetric wake



$$GR = G/c$$



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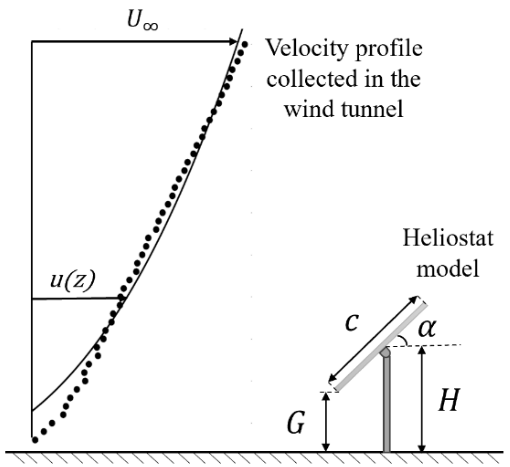
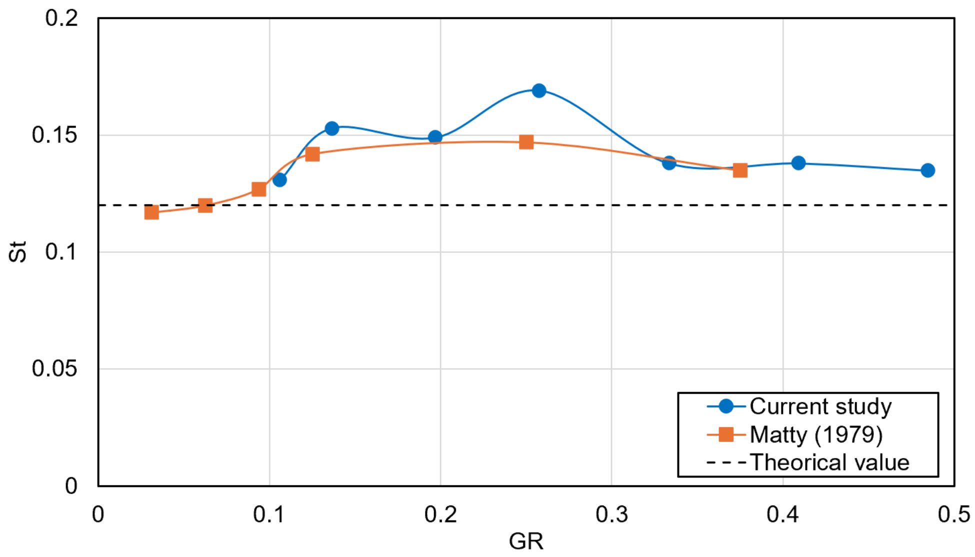


$GR = G/c$

- Ground effect causes asymmetric flow and a decrease in Strouhal number at smaller GR
- Flow becomes symmetric at higher GR and Strouhal number approaches a nearly constant value of St = 0.135 (0.125 without considering flow effects)



Conclusions and next steps

- Strouhal number of a heliostat model is sensitive to inflow ABL turbulence at elevation angles smaller than 30°
- Strouhal number of a heliostat model is smaller in a turbulent ABL inflow than in a uniform flow for ground clearance ratios of less than 0.4. At larger values of ground clearance ratio, Strouhal number becomes almost constant at 0.15
- As heliostat ground clearance ratio decreases, asymmetric wake is formed in vertical plane and Strouhal number increases while for higher values of ground clearance ratio a symmetric wake is formed and Strouhal number stabilizes at a constant value of 0.135
- Ground clearance effects on Strouhal number at elevation angles of 15° and 30° and the influence of inflow turbulence and azimuth angle on dynamic loads requires further investigation

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