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# The Effect of an Increased Ground-Clearance on Peak Wind Loads on a Single-Axis Solar Tracking System

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**SUMMARY:**
The effect of an increased ground-clearance on peak wind loads on a single-axis PV tracking system is investigated. Boundary layer wind tunnel measurements are conducted at a total of three heights for four different tilt angles and two row spacings. Torque and normal force acting on the rows were calculated as equivalent-static pressure coefficients and dynamic amplification factors. Results showcase the behaviour of recent agrivoltaics structures and were compared with wind loads on a traditional tracking system.

*Keywords: single-axis tracker, ground-mount, agrivoltaics*

## 1. INTRODUCTION

Single-axis PV tracking systems (SATs, trackers) have long been the focus of commercial and scientific interest. Static and more importantly dynamic loads play a key role in designing these systems. Over the past years a new concept draws attention to it which is known as agrivoltaics i.e. the simultaneous use of land for both agriculture and solar power. Among others one approach to this is the use of traditional tracker designs with an increased ground-clearance resulting in mean heights of 5 m or more. The effect of the ground-clearance on wind loads in the published literature is only covered with regard to freestanding walls or signboards (Leder and Geropp, 1993; Letchford, 2001; Giannoulis et al., 2012), yet it is unclear how this relates to tracking systems with tilt angles smaller than 90°. A recent study (Browne et al., 2020) on generalized wind loads on ground-mounted solar panels was limited to a mean height of 75% of the chord length, i.e. h/c=0.75. The present study aims at closing this gap and provide details on wind load behaviour up to h/c=2.1 in order to enable a safe but also efficient design of agrivoltaics system.

## 2. EXPERIMENTAL PROCEDURE

### 2.1. Wind tunel set-up

The wind tunnel tests were conducted in the large I.F.I. boundary layer wind tunnel in Aachen, Germany. For the present study, an upwind terrain with a power law exponent of 0.14 was simulated. The wind tunnel model at 1:60 geometrical scale consisted of an array of 7 rows each equivalent to 90 m length in full-scale with a chord length of 4.1 m. Model rows were tilted to

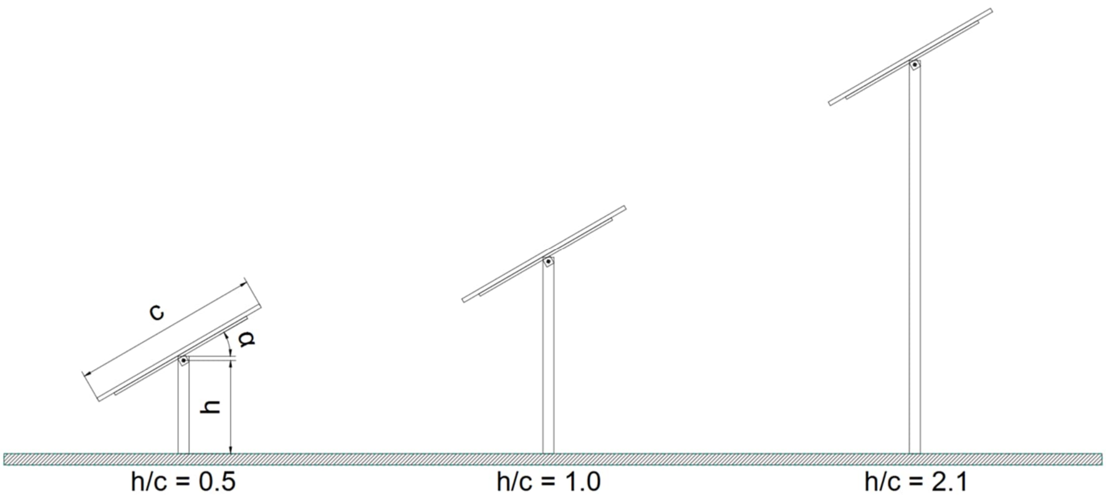


**Figure 1.** Tested geometries with different height ratio h/c

the west at four different tilt angles of 0°, 10°, 30° and 60°. Moreover, two different row spacings of 8 m and 15 m, corresponding to ground-coverage-ratios (GCR) of 0.50 and 0.28, respectively, were examined. Wind tunnel testing was conducted at 15° intervals for 13 wind directions from 90° to 270° where 90° corresponded to wind blowing from the east. In this way the effects of corner vortices, flow detachment and reattachment were accounted for. Using brass tubes and flexible tubes the pressure taps were connected to PSI DTC-Initium pressure scanners. The number of sampling values per data series was set such that a 24 minute sampling in full-scale was achieved. The model rows were measured with rotation center heights of each row at 2.0 m and 4.2 m, corresponding to ratios of height to chord of h/c=0.5 and h/c=1.0. Measurements with a third height of 8.5 m or h/c=2.1 are planned for February 2023. Figure 1 shows the tested geometries.

## 2.2. Analysis of wind loads

Load effects studied in the present work are the peak torque around the center chord axis and the peak normal force acting on the PV modules of the tracker. These load effects are given in terms of dimensionless coefficients. For the calculation of peak aerodynamic coefficients the method of Cook was adopted and coefficients were converted into the pseudo-steady format. Aerodynamic coefficients are referenced to the 3-second-gust pressure at 10 m height in full-scale. Distributions of pressure coefficients which represent the peak load effect in question were reconstructed using the Load-Response-Correlation method. A 59% probability of non-exceedance was adopted for the calculation of all aerodynamic coefficients. To account for resonant dynamic effects due to vortex shedding or gust buffeting, the determination of dynamic amplification factors (DAFs) is a well-established approach. Resonant dynamic responses were calculated based on power density spectra of the load effects in question, employing Miles' equation. For each zone the worst overall load, i.e. the sum of the 'static only' load effect and the resonant dynamic response, was determined from all wind directions. The DAF for a given damping ratio $\zeta$ and frequency f is then given via the ratio of the worst overall load and the worst static load.

## 3. RESULTS AND DISCUSSION

As with other wind tunnel studies on solar trackers data has been reduced by grouping into zones of similar loads. In this way, a total of three different zones for each of the load effects results. For the peak torque around the center chord axis this is the ‘Perimeter-1’ which comprises the two outermost rows, ‘Perimeter-2’ which is rows No. 3 and 4 and the remaining ‘Interior’ rows. Static wind loads gradually decrease from perimeter to interior while dynamic effects are usually more pronounced for the interior rows as they experience more array-generated turbulence from upstream rows (Kray and Markus, 2019).

Figure 2(a) shows the torque coefficients due to uplift forces for the Perimeter-1 and Interior zone for two different ground-clearances corresponding to h/c=0.5 as the reference case and h/c=1.0 as a geometry with increased height. The row spacing in both cases corresponds to a GCR of 0.50 and the effective wind area is one entire row of 90 m. As observed in earlier studies the peak torque increases from a parallel position to any non-zero tilt angle before it gradually decreases with tilt. Torque coefficients in Figure 2(a) are referenced to a gust pressure in 10 m height in both cases, i.e. coefficients are representative for the overall load. It can be seen that the overall load for a geometry with h/c=1.0 is always larger with a relative increase of 10% to 20% at 0° tilt and 60% to 70% at 60° tilt. However, this was anticipated as an increased height also means a greater exposure and an overall increased velocity pressure acting on the structure. Figure 2(b) shows torque coefficients corresponding to the previous situation but now re-referenced to the respective mean height according to the wind profile of the wind tunnel in order to eliminate the effect of the velocity pressure. It can be noted that for small tilt angles an increased ground-clearance actually leads to slightly lower torque coefficients while at higher tilt angles, torque increases for the higher system. This is attributed to additional vortex shedding at the lower edges of the solar modules i.e. between the tracker and the ground, which is expected to be more pronounced for larger ground-clearances.

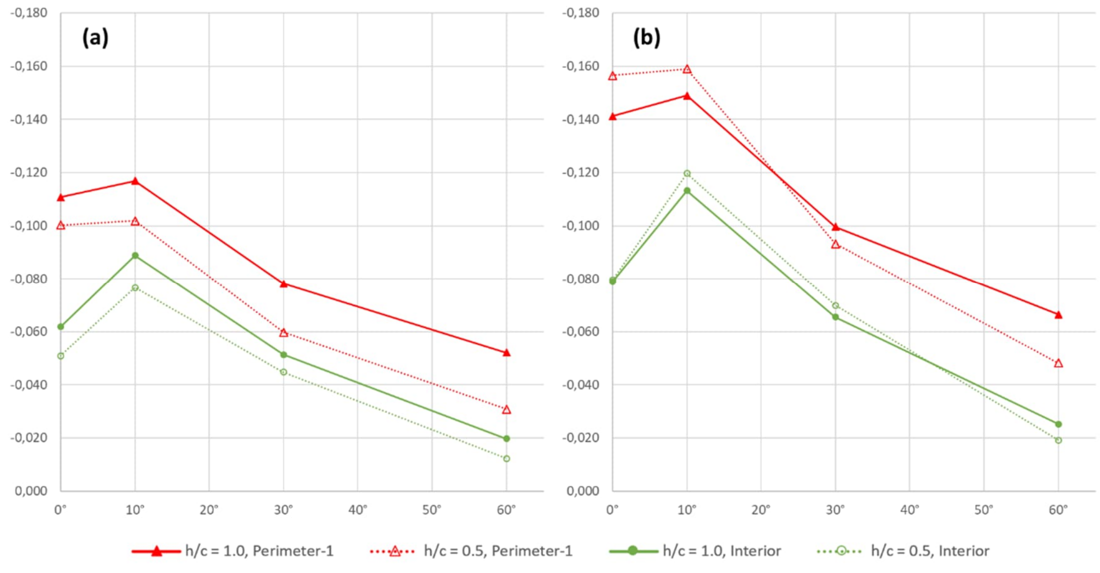


**Figure 2.** Torque coefficient vs. tilt angle for different zones and ground clearances; (a) all referenced to a gust pressure at 10m height; (b) re-referenced to the respective mean system height

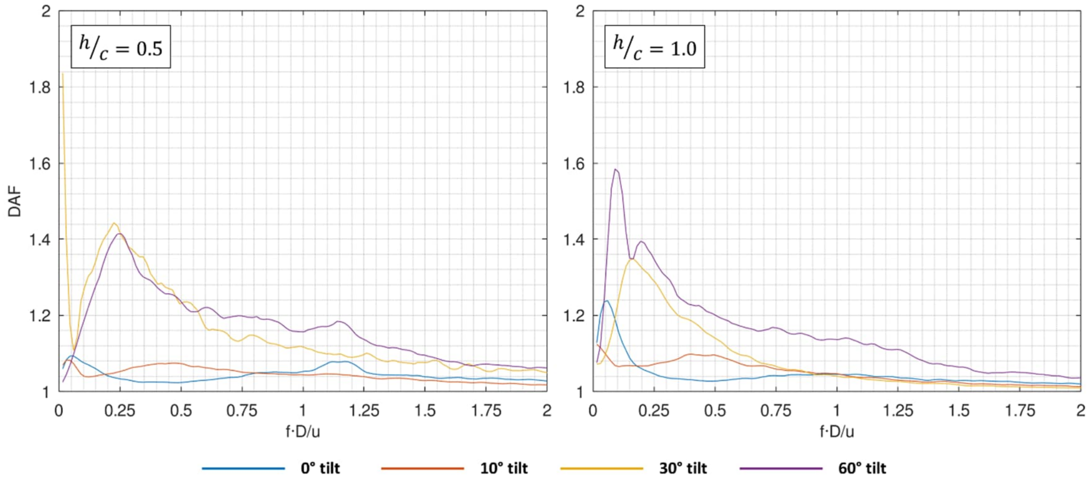


**Figure 3.** DAFs vs. Strouhal number for different tilt angles and different ground-clearances for Interior rows

A look at the DAFs underlines that assumption. Figure 3 shows DAFs corresponding to the data in Figure 2 for a 2% damping ratio. At 0° tilt DAFs are quite similar, 10° show an increase for the higher system at low frequencies but reduced DAFs at higher frequencies. At 30° tilt, DAFs are also reduced compared to the reference system at lower ground clearance. Corresponding to the behavior of static loads in Figure 2(b), 60° tilt is the only position at which DAFs are similar or larger in magnitude for the higher system and we see an additional peak at the low frequency end.

## 4. CONCLUSION AND OUTLOOK

First data and analysis of an increased ground-clearance indicate complex flow behavior. Normalized torque loads vary substantially with tilt angle and preliminary analysis shows that systems with increased ground-clearance have higher loads at higher tilt angles. This is most likely due to a changed gap flow between the tracker and the ground and an increased vortex-shedding. The planned measurements and analyses of a third variant with an increased height of 8.5 m corresponding to h/c=2.1 will provide further data to probe the above assumptions and observed trends, which will be included in a full paper.

**REFERENCES**


Browne, M. T. L., Taylor, Z. J., Li, S., and Gamble, S., 2020. A wind load design method for ground-mounted multi-row solar arrays based on a compilation of wind tunnel experiments. Journal of Wind Engineering and Industrial Aerodynamics 205, 104294.

Giannoulis, A., Stathopoulos, T., Briassoulis, D., and Mistriotis, A., 2012. Wind loading on vertical panels with different permeabilities. Journal of Wind Engineering and Industrial Aerodynamics 107-108, 1-16.

Kray, T. and Markus, D., 2019. Peak wind loads on single-axis PV tracking systems. Proc. 15th International Conference on Wind Engineering, Beijing, China.

Leder, A. and Geropp, D., 1993. Analysis of unsteady flows past bluff bodies. Journal of Wind Engineering and Industrial Aerodynamics 49, 329–338.

Letchford, C. W., 2001. Wind loads on rectangular signboards and hoardings. Journal of Wind Engineering and Industrial Aerodynamics 89, 135–151.