IN-VENTO 2026
International Conference of the Italian Association for Wind Engineering
Bari, September 13th – 16th, 2026

BARI

Assessment of simulated ground proximity effects in sectional wind tunnel tests of photovoltaic trackers

G. Frontini[1], S. Muggiasca[2]

[1]Politecnico di Milano, Milan, Italy, giorgio.frontini@polimi.it
[2]Politecnico di Milano, Milan, Italy, sara.muggiasca@polimi.it

SUMMARY
Ground mounted single-axis photovoltaic trackers may operate close to the terrain and, especially at large pitch angles between 45° and 60°, the lower panel edge can be only 0.5m to 0.7m above ground. This condition is usually not reproduced in sectional wind tunnel tests, where models are tested in uniform flow away from the floor. This work presents an exploratory forced-motion wind tunnel study on the influence of simplified ground simulation on a sectional photovoltaic tracker model. A scaled flat plate, with a square hollow section underneath, representative of a single-panel tracker, was tested in a 1.0m×1.5m section with and without a thin horizontal plate installed beneath the model. Results show that ground proximity mainly changes the magnitude of the aerodynamic response, while preserving its dependence on pitch angle. The effect is limited for nose-down configurations but becomes more relevant for nose-up angles, especially in stall and post-stall conditions.

Keywords: single-axis photovoltaic trackers, wind tunnel testing, aerodynamic coefficients

1. INTRODUCTION

Single-axis photovoltaic trackers are lightweight, torsionally flexible structures with large surfaces, characteristics making their response sensitive to dynamic and aeroelastic effects (Taylor et al., 2024; Frontini et al., 2025). Unlike elevated bridge decks or isolated airfoils, photovoltaic panels are installed close to the terrain and may reach large inclination angles, up to 60°, during operation. In these configurations, the lower edge of the panel may approach the ground: the flow field generated by the inclined panel can interact with the nearby ground boundary, modifying the pressure distribution and the resulting loads.

The influence of ground proximity is particularly relevant for sectional wind tunnel testing. Conventional sectional tests are usually performed with the model placed near the center of the test section, sufficiently far from the tunnel floor and ceiling to reduce direct boundary interference. While this configuration is convenient for identifying aerodynamic derivatives and comparing aerodynamic behavior, it removes a geometric feature that is present in real photovoltaic installations. The absence of ground proximity may affect both static and unsteady aerodynamic measurements.

Recent studies on solar tracker sections have shown that ground clearance can influence aerodynamic derivatives and aeroelastic stability margins. In particular, the aerodynamic damping-related derivative may depend on the clearance ratio H/B, where H is the torque tube height above the ground and B is the panel chord (Cárdenas-Rondón et al., 2023). This suggests that sectional configurations tested far from the ground may not fully reproduce the static aerodynamic coefficients and derivative trends relevant to full-scale operation.

This work investigates whether the ground-clearance sensitivity highlighted in previous studies can be observed in the present sectional wind tunnel setup, by comparing static aerodynamic coefficients and aerodynamic derivatives with and without simulated ground.

2. METHODOLOGY

The experimental campaign was conducted in the Aerospace Engineering Department wind tunnel at Politecnico di Milano, using a 1.0 m wide and 1.5 m high test section. This facility allowed the installation of a local horizontal ground plane beneath the sectional model.

The model consisted of a carbon-fiber flat plate with chord length 0.39 m, representative of a single-panel single-axis photovoltaic tracker at a geometric scale of 1:5.83. Acrylic end plates were installed to improve flow two-dimensionality, while a 20 mm × 20 mm aluminum square hollow section reproduced the torque tube beneath the panel. The model was equipped with 16 pressure taps at mid-span, arranged as 8 taps per side, and two six-component ATI force balances installed at the model extremities.

Forced-motion tests were performed by imposing harmonic torsional oscillations about the torque tube axis, resulting in a controlled single-degree-of-freedom torsional motion.

Two configurations were compared: a reference case without ground simulation and a second case with a plywood plate installed beneath the model reproducing the geometric proximity of the ground. Since flow remained possible beneath the plate, it is better interpreted as a splitter plate rather than as a full ground boundary condition. The clearance was selected to represent a full-scale lower edge distance of about 0.66 m at a pitch angle of 45°, corresponding at model scale to a minimum panel edge clearance of about 11 cm, or equivalently to about 25 cm between the torque tube axis and the simulated ground.

3. RESULTS

3.1. Static coefficients

The static response was evaluated in terms of drag, lift, and torsional moment coefficients, considering both force-balance measurements and pressure-based integration. The corresponding trends are shown in Figure 1. The simulated ground does not substantially alter the overall pitch-angle dependence of the coefficient curves, but it modifies their magnitude and, above about β = 10°, slightly changes the slope in the stall and post-stall region. The effect depends on the pitch sign, remaining limited for nose-down configurations and becoming more significant for nose-up configurations. This behavior is further examined through the coefficient differences between the simulated-ground and no-ground configurations, as shown in Figure 2.

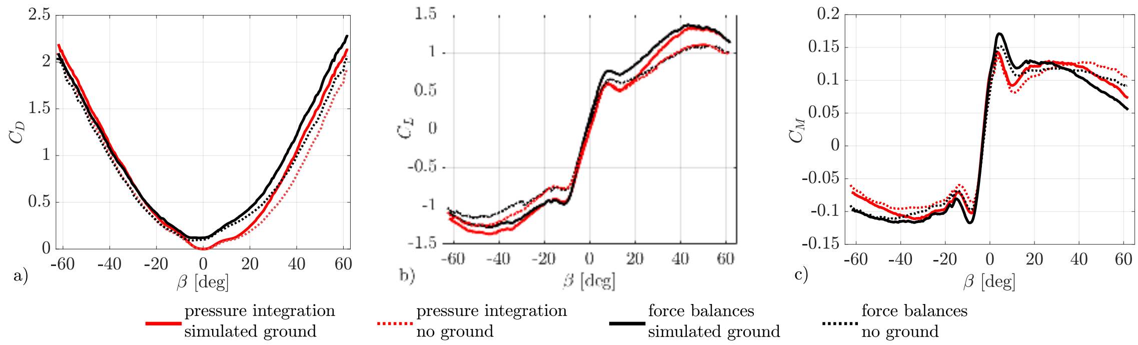

Figure 1. Static aerodynamic coefficients as a function of pitch angle: (a) drag, (b) lift, (c) torsional moment. Comparison for pressure integration and force-balance measurements, with and without simulated ground.

The drag coefficient, shown in Figure 1(a) and Figure 2(a), is not significantly affected by ground proximity in nose-down conditions. At $\beta = -60°$, the drag increment ΔC_D is about 0.07, corresponding to approximately 4% of the reference value. For nose-up configurations, the effect becomes more evident, with ΔC_D increasing rapidly and reaching a plateau of about 0.3 between $\beta = 40°$ and $60°$, corresponding to an increase of roughly 15%. This behavior is attributed to the stronger interaction between the deflected flow, the simulated ground, and the confined wake. Near $\beta = 0°$, differences between force-balance and pressure-based estimates are mainly associated with the torque tube contribution, which is captured by the balances but not by the panel pressure taps.

The lift coefficient, shown in Figure 1(b) and Figure 2(b), preserves its expected pitch angle dependence, including stall, post-stall reduction, and recovery. Ground-induced differences are observed at larger angles. For negative pitch angles, ΔC_L is negative and reaches approximately -0.20 between $\beta = -10°$ and $-30°$. For positive pitch angles, ΔC_L becomes positive and follows the main features of the lift curve, with an increase of about 20%–30% near $\beta = 40°$, and about 15% at $\beta = 60°$. Although force-balance and pressure-based estimates show a systematic offset, their ΔC_L trends remain similar, suggesting that both approaches capture the same underlying aerodynamic effect.

The torsional moment coefficient, reported in Figure 1(c) and Figure 2(c), is the most sensitive quantity to ground proximity. Despite differences in the absolute C_M curves obtained from force balances and pressure integration, the corresponding ΔC_M trends are consistent. Around stall, ΔC_M reaches approximately 0.03, which corresponds to about 30% of the peak absolute moment coefficient. For nose-down configurations, the effect decreases and becomes negligible near $\beta = -60°$. For nose-up configurations, ΔC_M changes sing around $\beta = 35°$ to $40°$, and at $\beta = 60°$, the ground-induced moment variation approaches 40% of the absolute C_M value.

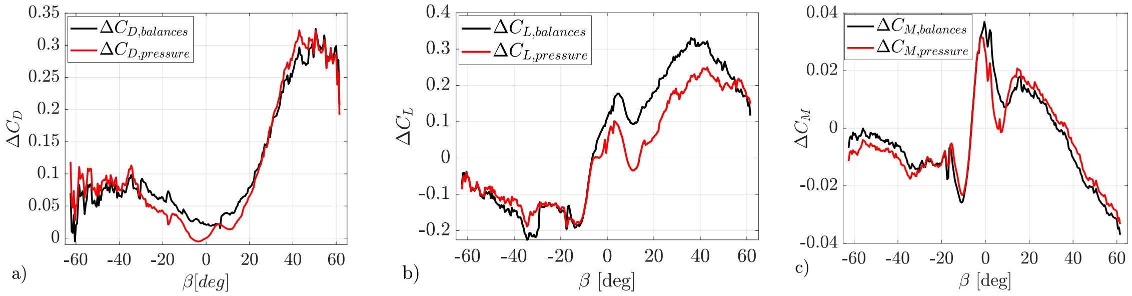

Figure 2. Ground-induced variations of the static aerodynamic coefficients as a function of pitch angle: (a) drag, (b) lift, (c) torsional moment. Differences defined as simulated-ground value minus no-ground value.

3.2. Aerodynamic derivatives

The aerodynamic derivatives, defined according to the notation of (Zasso, 1996), are identified from forced-motion tests and reported in terms of reduced velocity $U^* = U/(f_{FM}B)$, where U is the mean wind velocity, f_{FM} is the imposed oscillation frequency and B is the panel chord. The coefficient a_2^* is associated with the aerodynamic damping, while a_3^* is associated with the aerodynamic stiffness, consistently with formulations adopted in previous solar tracker studies (Taylor et al., 2024; Frontini et al., 2025).

Results are reported in Figure 3 for selected fixed pitch angles, specifically $\beta = -45°, -2.5°$, and $0°$, for both the no-ground reference and simulated-ground configurations. The comparison of the two results suggests that ground proximity can modify both the magnitude and the evolution of the derivative curves.

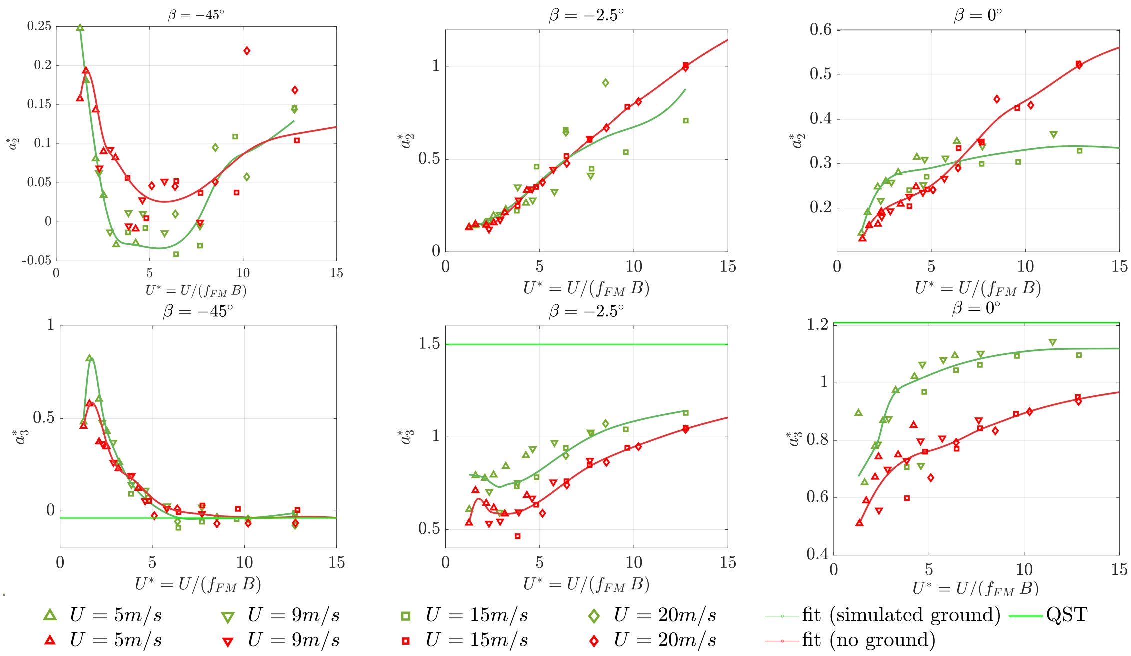

Figure 3. Aerodynamic derivatives a_2^* and a_3^* as functions of reduced velocity for selected pitch angles, comparing no-ground and simulated-ground configurations. Quasi-steady estimate is reported where applicable.

4. CONCLUSIONS

The results show that ground proximity produces measurable changes in the aerodynamic response. For the static coefficients, the main pitch-dependent trends are preserved, but their magnitude is modified. The effect is asymmetric with respect to pitch angle: it is limited in nose-down configurations and more evident in nose-up configurations, especially at large pitch angles where the interaction with the simulated ground becomes more relevant. At smaller pitch angles, ground-proximity effects are comparatively limited. The comparison between force-balance measurements and pressure-based integration supports the robustness of these incremental trends, despite some differences in the absolute coefficient values.

Among the static coefficients, drag is the least affected, with a maximum increase of about 15% at large positive pitch angles. Lift shows larger variations, especially at positive pitch angles, reaching approximately 30% near $\beta = 40°$. The torsional moment is the most sensitive quantity, with ground-induced variations of about 30% near stall and 40% at 60°.

The aerodynamic derivatives also show differences between the reference and simulated-ground configurations.

These results indicate that the presence of a nearby ground boundary can affect sectional tracker measurements, particularly for positive pitch angles and for quantities related to torsional response. A more detailed discussion of the static and dynamic results will be provided in the full contribution.

REFERENCES

Cárdenas-Rondón, J.A., Ogueta-Gutiérrez, M., Franchini, S., Manzanares-Bercial, R., 2023. Stability analysis of two-dimensional flat solar trackers using aerodynamic derivatives at different heights above ground. Journal of Wind Engineering and Industrial Aerodynamics 243, 105606. doi:10.1016/j.jweia.2023.105606.

Frontini, G., Calamelli, F., Muggiasca, S., Argentini, T., 2025. Key parameters influencing wind-induced aeroelastic responses of single-axis solar trackers in photovoltaic plants. Solar Energy 287, 113232. doi:10.1016/j.solener.2024.113232.

Taylor, Z.J., Feero, M.A., Browne, M.T., 2024. Aeroelastic instability mechanisms of single-axis solar trackers. Journal of Wind Engineering and Industrial Aerodynamics 244, 105626. doi:10.1016/j.jweia.2023.105626.

Zasso, A., 1996. Flutter derivatives: Advantages of a new representation convention. Journal of Wind Engineering and Industrial Aerodynamics 60, 35–47. doi:10.1016/0167-6105(96)00022-0.