Aeroelastic tests on solar tracker models built with different techniques

Arturo Carboné [a], Mikel Ogueta-Gutiérrez [b,c], Sebastián Franchini [b,d], Jose Luis Ruiz Moral[b,e], Carlos Carbajosa[b,f]

[a]Escuela Técnica Superior de Ingeniería Aeronáutica y del Espacio, Universidad Politécnica de Madrid, Madrid, Spain, arturo.cmejias@alumnos.upm.es
[b]Instituto Universitario de Microgravedad Ignacio da Riva, Universidad Politécnica de Madrid, Madrid, Spain
[c]mikel.ogueta@upm.es
[d]s.franchini@upm.es
[e]joseluis.ruiz.moral@upm.es
[f]c.carbajosa@alumnos.upm.es

SUMMARY: (10 pt)
Solar energy is one of the renewables energies that are growing more rapidly. The main loads in the tracker structure are aerodynamic loads. Due to the optimization in the structures, aeroelastic phenomena play now a significant role in their design. Wind tunnel tests have been performed in three-dimensional models of trackers. Models have been manufactured with different techniques. The results show good agreement for all the configurations tested.

Keywords:solar trackers, aeroelastic tests, wind tunnel.

1. INTRODUCTION

In the growing concern about climate change, renewable energies play a significant role. They can potentially produce a big amount of energy with very low CO2 emissions. In the past years, renewable energy systems have expanded throughout the world. One of the most promising renewable energy is solar energy. The most used system in solar energy field is the solar tracker. These devices follow the sun through the day, so the energy production is always optimized.

However, some problems have risen. Because of the competitive characteristic of the sector, optimization has led to lighter and less stiff structures. Because of that, aeroelastic phenomena have appeared in several cases and have caused the destruction of a significant number of trackers around the world (Gifford, 2019; Valentín et al, 2022).

The approach to reduce the aeroelastic phenomena in trackers is to perform wind tunnel tests. Aeroelastic tests require the scaling of not only the geometry, but also the inertial characteristics. The scale factor of the inertial characteristics is linked to the geometrical scale selected (Martínez-García et al., 2021). Many aspects of this instability need research. Several approaches have been used, such as the extraction of the flutter derivatives (Cárdenas-Rondón et al., 2023) or three dimensional tests (Martínez-García et al., 2021). In this work, the latter has been used.

2. MODEL MANUFACTURE AND EXPERIMENTAL SETUP

Three different models have been manufactured with different techniques. The first model has been manufactured by 3D printing a small part of the solar panel and then covering it with plywood. The second model has been totally manufactured by 3D printing. The last model has been manufactured by covering a wood strip structure with a shrink wrap cover. The geometry of all three models is the same, but their inertial characteristics are slightly different. A view of all three models is shown in figure 1.

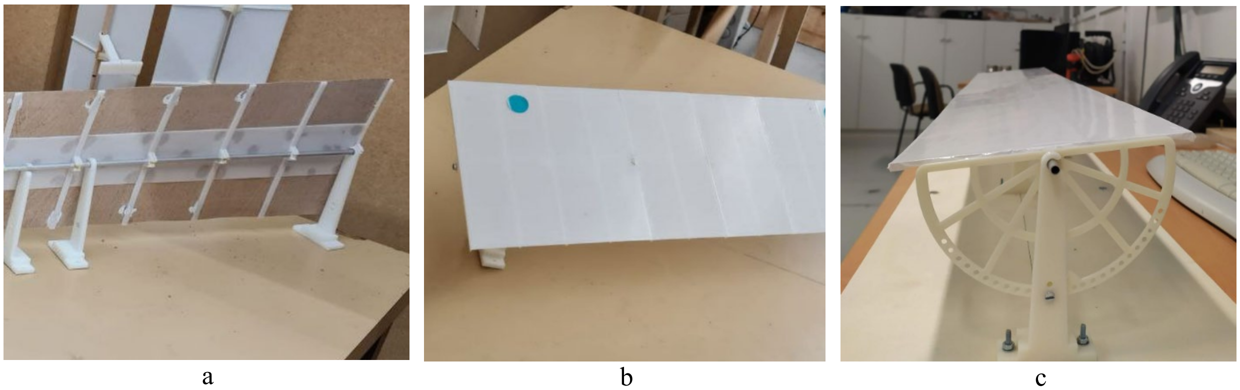

Figure 1. Images of the three models manufactured: a) 3D printing and plywood (Model #1); b) 3D printing (Model #2); c) Shrink wrap (Model #3).

Each model has been mounted in an aluminium tube, which provide the stiffness. A piece for fixing the nominal angle of attack of the model has been also manufactured (see figure 1 d).

Wind tunnel tests have been performed in ACLA16 wind tunnel. The test chamber is closed, being the section a square of 2.2 meters each side of the square. Overall, the length is 20 meters, so the atmospheric boundary layer can be reproduced. In the midpoint of the test chamber, the flow can reach up to 32 m/s, with a level of turbulence of 2 %. The wind tunnel is equipped with 16 fans. Overall, the power of the wind tunnel is 120 kW.

2.1. Characterization of the models

Before the tests in the wind tunnel, the stiffness of the aluminium tubes has been studied For that, different torques have been applied to the tubes, and the torsional displacement has been recorded. The stiffness is important to calculate the mass moment of inertia of the model by measuring the natural frequency of the tracker model. Characteristics of each model and the nominal angles of attack at which they have been tested are shown in table 1.

Table 1. Characteristics of the models tested and nominal angles of attack.

Model #	Material	Natural frequency [Hz]	Inertia [kg·m^2]	α[º]
1	3D printing and plywood	16.8	$1.75\cdot10^{-4}$	-15, -6, 0, 10
2	3D printing	13.5	$2.55\cdot10^{-4}$	-30, -15, -6, 0, 10
3	Shrink wrap	18.3	$1.50\cdot10^{-4}$	-30, -15, -6, 0, 10

For different wind flow velocities, the displacement of the solar tracker models has been recorded with two laser sensors. One of the lasers is placed pointing to the middle of the length of the tracker and the other one is placed pointing in the end of the tracker. The sampling frequency of the lasers is 1000 Hz, and the sampling time is 30 seconds. Simultaneously, the dynamic pressure of the flow has been measured with a Pitot tube. The displacements are measured for increasing velocities and also for decreasing velocities, in order to find possible hysteresis phenomena.

The setup of the fully 3D printed model in the wind tunnel can be seen in figure 2. In that figure, wind is coming from right to left.

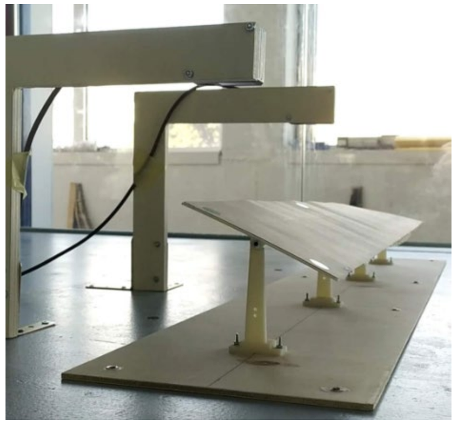

Figure 2. Solar tracker model in the wind tunnel. Laser supporting bars can be seen. The static deflection can also be observed. The nominal angle of attack is fixed in the other end of the model.

3. RESULTS

The output of the lasers is the distance measured. It is easily converted to torsional time series of the tracker. The RMS of the time series of the torsional movement, $\alpha(t)$ is calculated to estimate the critical velocity at which the instability appears.

As an example, the RMS of the torsional movement against the reduced velocity is displayed in figure 3. Reduced velocity has been calculated as $U_{red} = \frac{U_\infty}{bf}$, where U_∞ is the velocity of the upcoming flow, b is the tracker chord and f is the model frequency.

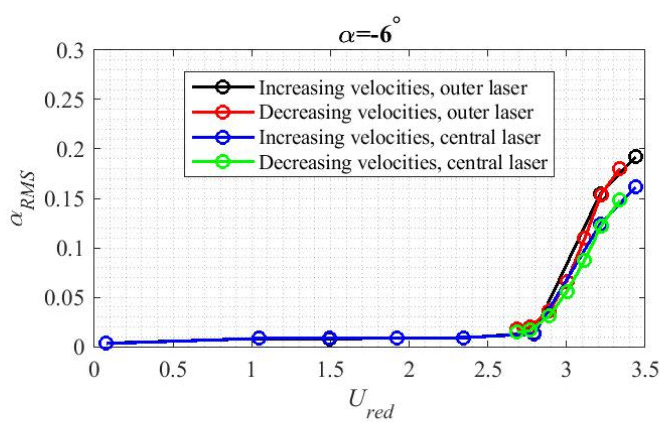

Figure 3. RMS of the torsional movement for a nominal angle of attack of -6º plotted against the reduced velocity for model #1.

With the RMS values, the critical velocity of each case can be extracted. The critical velocity is the velocity at which the motion starts (RMS increases significantly). No significant hysteresis phenomenon has been found. Critical velocities of all the cases tested can be seen in figure 4.

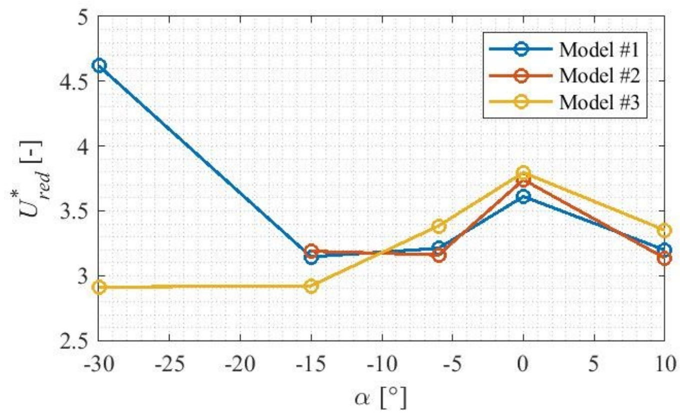

Figure 4. Critical reduced velocities for different nominal angles of attack and for the three different construction techniques.

In the range of low angles of attack, the behaviour is very similar. The discrepancy for $\alpha = -30°$ may be explained by the twist of the axis of the Model #1, that led to a higher friction between axis and pylons. Therefore, that result should not be considered.

4. CONCLUDING REMARKS

Three dimensional models of solar trackers are a very useful tool to determine their aeroelastic conditions. In this research, three models manufactured with three different techniques have been tested. The results between them seem to agree significantly. However, some differences still appear. The origin of the differences may be the difference of the inertias. Further research is needed to confirm it.

ACKNOWLEDGEMENTS

The research would have been impossible without the work of Manuel Ortega, Javier Pascual, Carlos Pascual and Guillermo Banús manufacturing and assembling the models. This work is part of the project TED2021-130541B-C21 funded by MCIN/AEI/10.13039/501100011033, the European Union “NextGenerationEU”/PRTR and project PID2022-137630OB-C21 financed by MCIN/AEI /10.13039/501100011033/FEDER, UE.

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.

Gifford, J., 2019. What broke at Oakey. PV Magazine. https://www.pv-magazine-australia.com/2019/12/07/long-read-what-broke-at-oakey/

Martínez-García, E., Marigorta Blanco, E., Parrondo Gayo, J., Navarro-Manso, A., 2021. Experimental determination of the resistance of a single-axis solar tracker to torsional galloping. Structural Engineering and Mechanics 78 (5) 519-528.

Valentín, D., Valero, C., Egusquiza, M., Presas, A., 2022. Failure investigation of a solar tracker due to wind-induced torsionall galloping. Engineering Failure Analysis, 135, 106137.