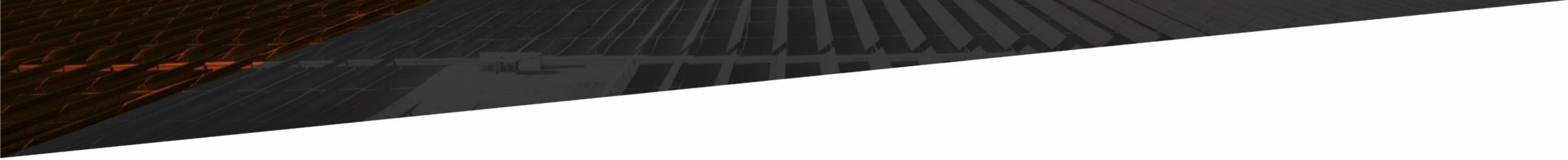
Soltec

Making Tracks, Building Trust



Our Company

Soltec specializes in the manufacture and supply of single-axis solar trackers with global operations and a workforce of over 1600 people, blending experience with innovation.

Our Situation

10 GW
Track Record
Worldwide

3.6 GW
Solar Trackers
Sold 2019

#1 LATAM
30% Market Share
#2 Europe 18%

20 GW
Annual Production
Capacity

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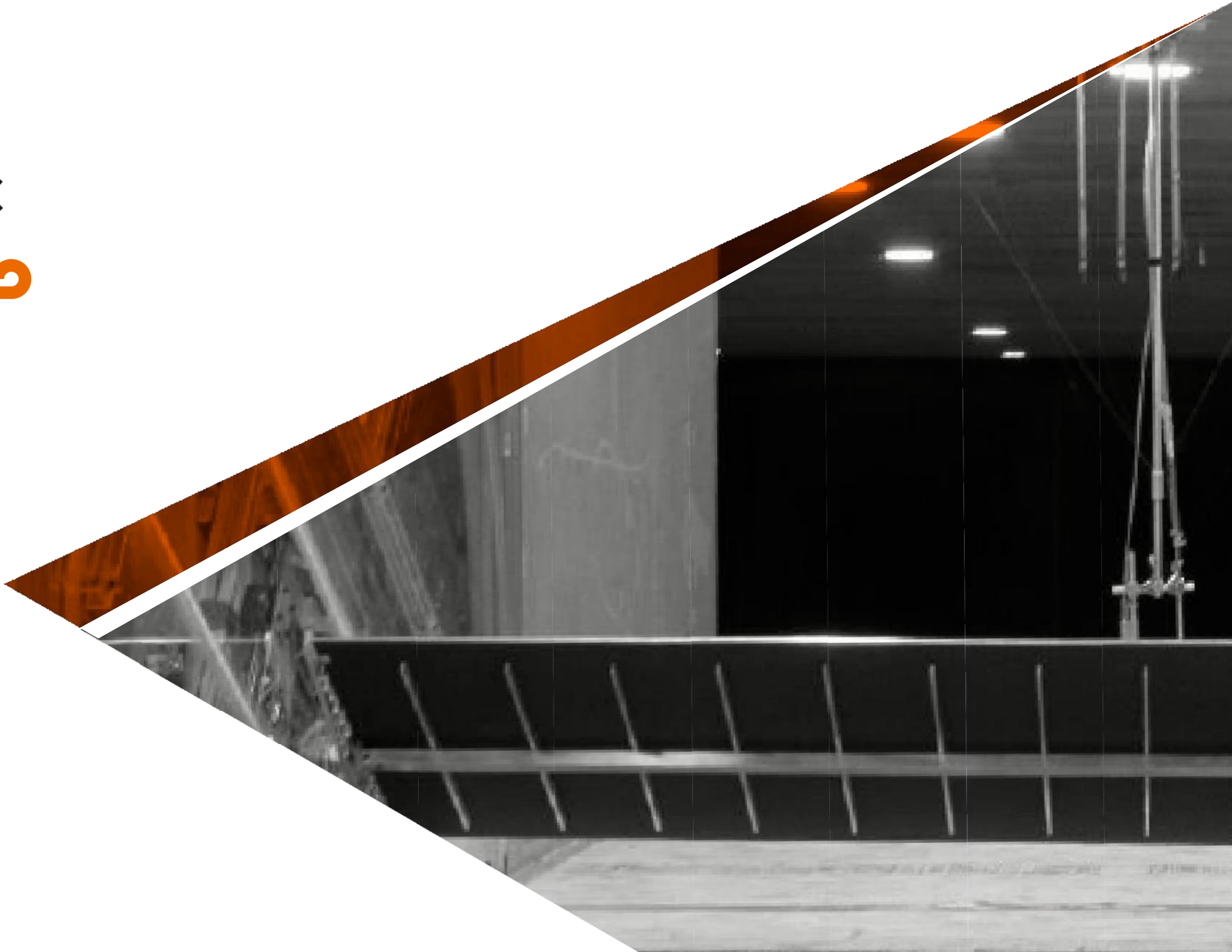
Dy-WIND

Dynamic Wind Analysis in Tracker Array Design



Challenge

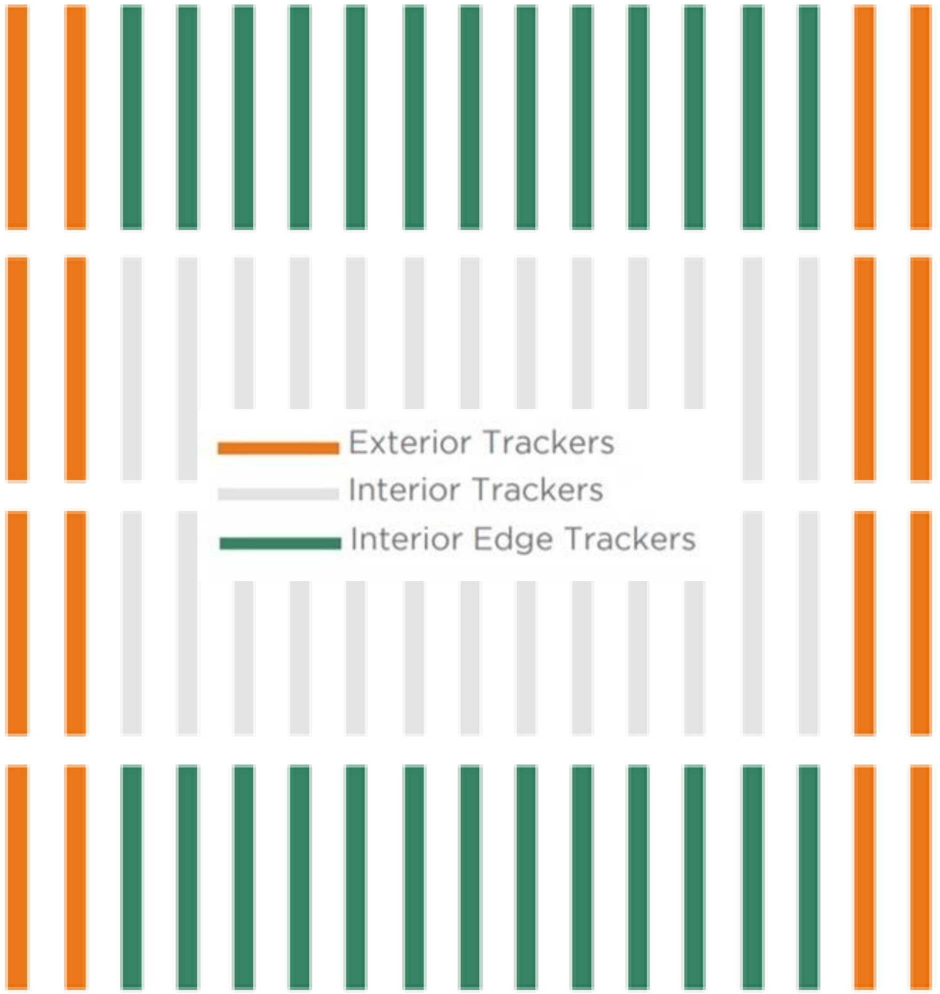
- Experience has shown that applying building codes to solar trackers is insufficient. Codes do not consider the tracker specific aeroelastic effects produced by the action of wind.
- A more advanced analysis method is necessary for reliable tracker design.

Solution

- Method to predict the wind loads on the flexible tracker structure considering geometry as well as mass inertia and stiffness properties of the tracker.
- Dynamic wind load component that includes the static load amplification due to buffeting AND instability effects.

Tracker Field Layout

- To withstand strong winds Soltec used 3 different tracker types.
- Exterior trackers are fully exposed.
- Interior trackers are fully shielded.
- Interior edge trackers are partially shielded but exposed for oblique wind.



Components of Total Wind Load

$$I\cdot\ddot{\alpha} + k\cdot\alpha + c\cdot\dot{\alpha} = M_{SE} + M_{BUFF}$$

Tracker Inertia x angular acceleration

α, Angle of Rotation of the Tracker (maximum moment M used to dimension tracker structural elements)

Torsional Stiffness x angle of rotation

Structural Damping x Angular velocity. c is obtained from:

$$c = 2\cdot\xi\cdot\omega_n\cdot I$$

ξ must be obtained experimentally in the field by means of free vibration tests to obtain the natural frequency:

$$\omega_n = 2\cdot\pi\cdot f_n$$

being f_n the natural frequency in the torsional vibration mode.

M_{SE} & M_{BUFF} are the moments produced by self-excited forces and the moment of buffeting. These values are considered to reproduce tracker movement as realistically as possible and amplify the response. The associated method for obtaining these values is described in the following section.

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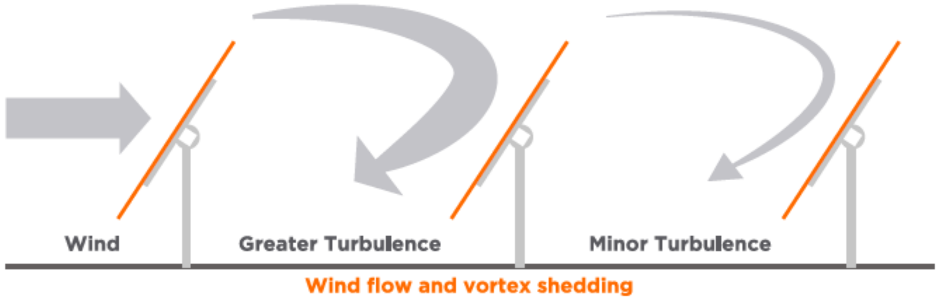
Dynamic Effects

Mechanism 1: Resonant Vibration

Resonant vibration is caused by either general wind buffeting or the wake resonance effect caused by the turbulence generated from the upwind rows of a tracker field.

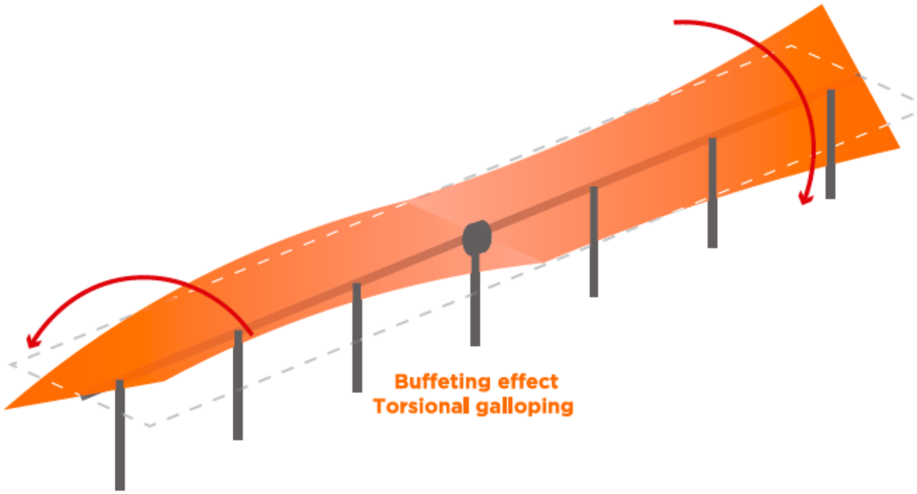


Mechanism 2: Torsional Flutter (Higher Tilt Angles)

Flutter is a self-excited aerodynamic instability in which the aerodynamic forces depend on the rotation and angular velocity of the structure itself, and it can lead to very large amplitudes in torsional motion or coupled torsional and vertical motion.

Mechanism 3: Torsional Galloping (Lower Tilt Angles)

This instability depends on the rotation of the structure and can lead to large responses in the structure due to variations in the aerodynamic pitching moment. At its onset, the increasing pitching moment reduces the overall structural stiffness, resulting in either unidirectional twisting of the structure or oscillatory motion depending on the remaining stiffness of the structure.



The Hybrid Method

Rigid Model Tests + Sectional Model Tests + Numeric Simulations = Flexible Design Approach

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Dynamic Wind Analysis in Tracker Array Design

Obtain Pressure Coefficients and DAF

Rigid model wind tunnel test

- Static wind load coefficients are obtained from the wind tunnel pressure tests.
- The coefficients do not include an allowance for resonant loading caused by resonant vibration.
- Dynamic Amplification Factors (DAF) account for the load amplification due to these effects, depending on the natural frequency of vibration of the structural system, wind speed, chord length, as well as the damping in the system.
- They assume small displacements and do not include fluid-structure interaction effects (or aeroelastic effects).

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Obtain Aerodynamic Properties

Sectional aeroelastic wind tunnel test

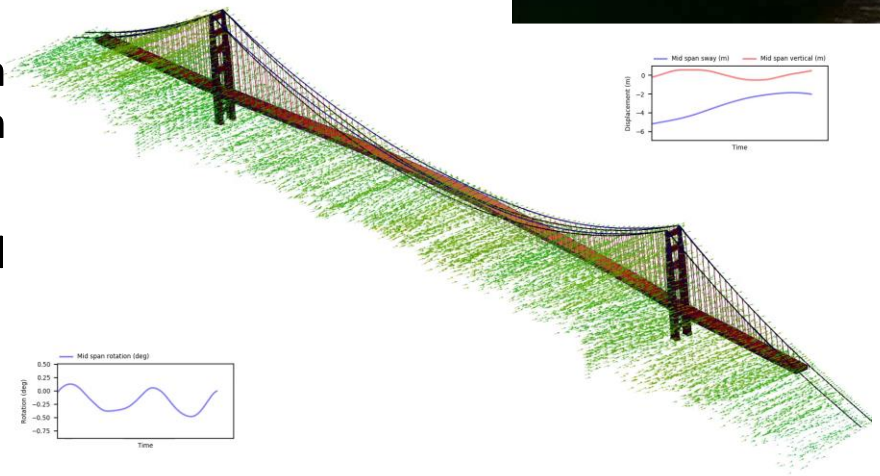
Aerodynamic derivatives obtained allow accurate knowledge of the change in damping and stiffness of the tracker as a function of wind speed. Such parameters are used in numerical models to obtain Flutter and Buffeting Analysis Methods:

- **FAM:** Predicts the maximum allowable wind speed before instability.
- **BAM:** Predicts the tracker response (load/deflection) due to wind action.

The Roots of Flutter & Buffeting Analyses in Wind Engineering

- The eigenvalue-based flutter analysis can be traced back to Theodore Theodorsen (1935) with use in wind engineering pioneered by Robert Scanlan (1968)
- Buffeting methodology used today in wind engineering can be traced back to Professors Alan Davenport (1961) and Robert Scanlan (1971)
- Long-span bridge design relies heavily on buffeting analysis to predict the ultimate design wind loads
- Buffeting analysis is continuously validated against physical aeroelastic models

Tacoma Narrows Bridge



RWDI’s buffeting analysis of the Golden Gate Bridge

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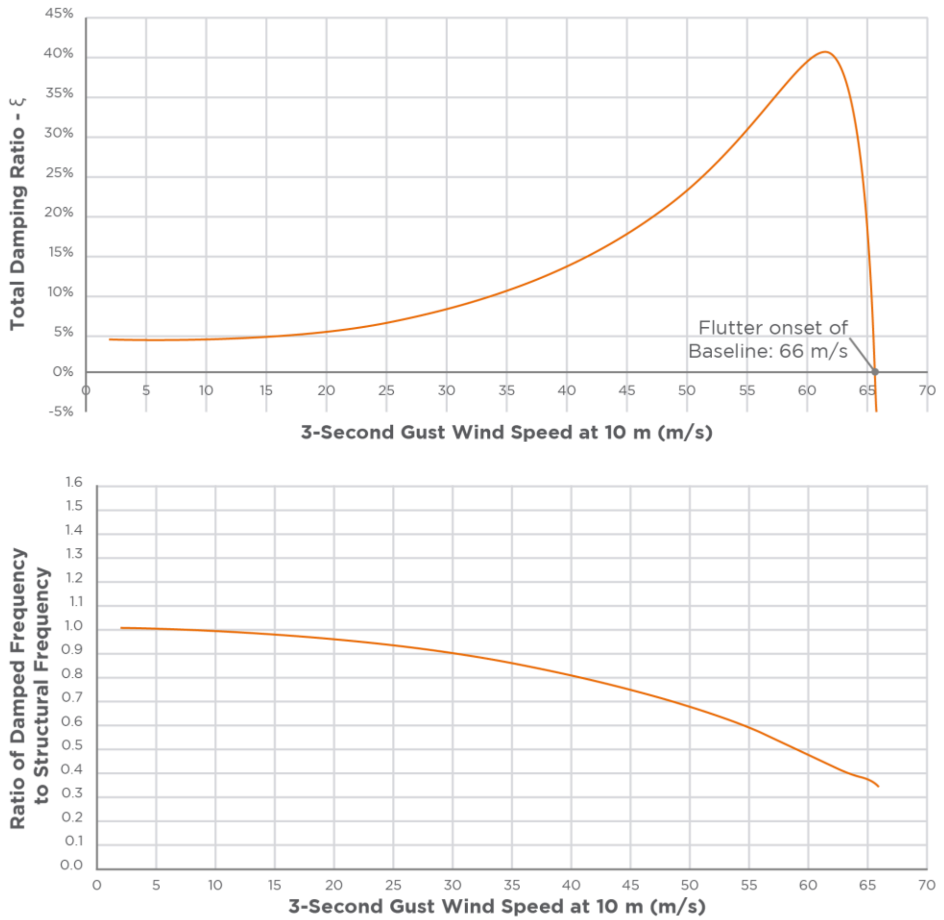
Obtain Onset Wind Speed (FAM)

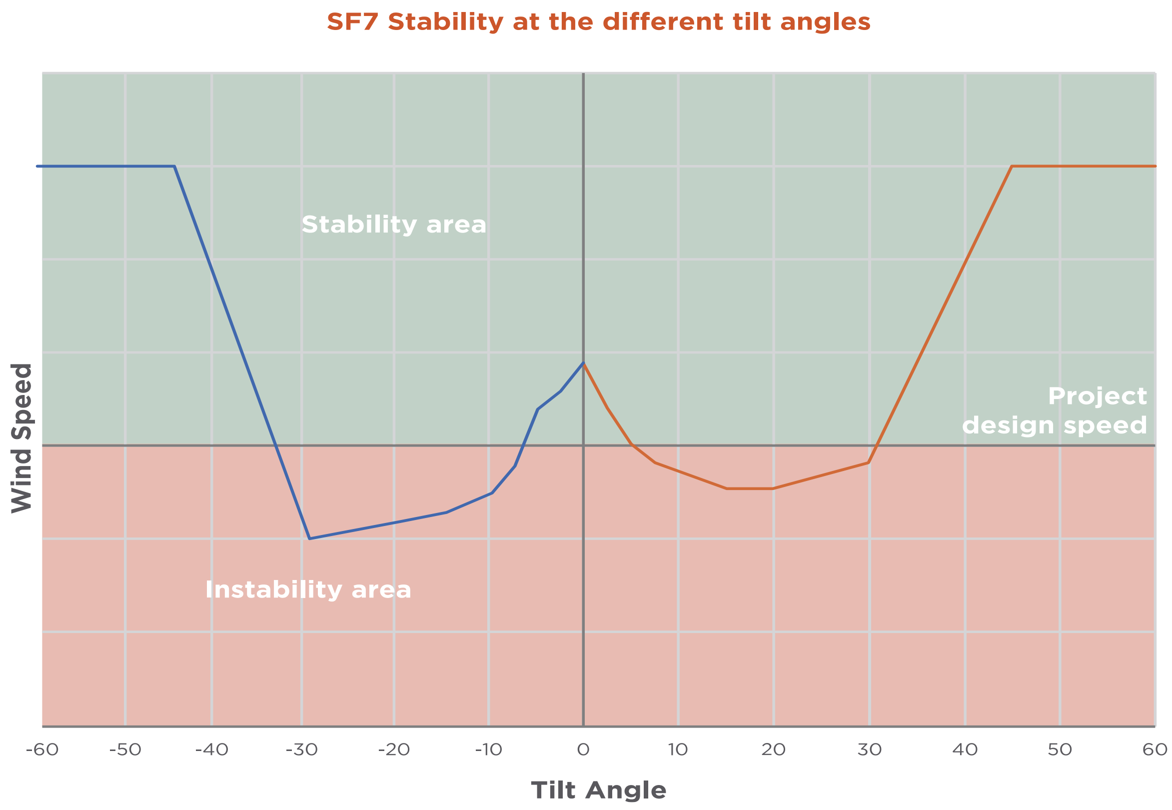
- The stability of the tracker is analyzed to obtain onset wind speeds for torsional instabilities.
- It is important that instability phenomenon, such as torsional galloping and torsional flutter, are considered when designing trackers and predicting their behavior.
- The results of this analysis provide the variation of total damping (structural + aerodynamic) and stiffness/frequency as a function of wind speed.
- Instability occurs when the total damping crosses 0.



Flutter Analysis Method (FAM)

Plot Onset Wind Speed Curve

- The onset wind speed curve shows the onset wind speed for each tilt angle
- According to its dynamic properties (geometry, mass inertia, stiffness, damping, position) each tracker type has its own characteristic curve.
- The plot shows that the onset wind speed reduces dramatically in vicinity of 0°.
- Tilt angles of approx. 45° and higher are typically stable.



Onset wind speed curve (FAM)

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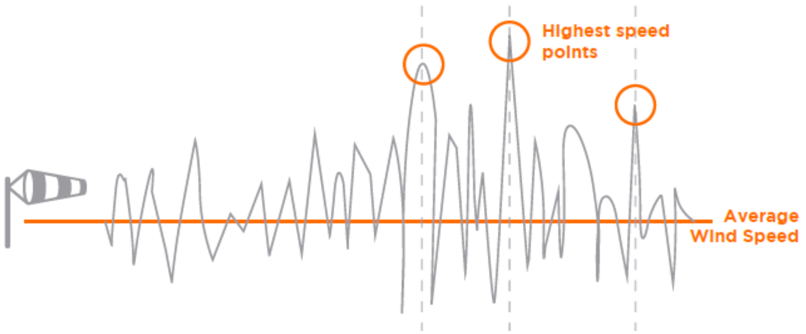
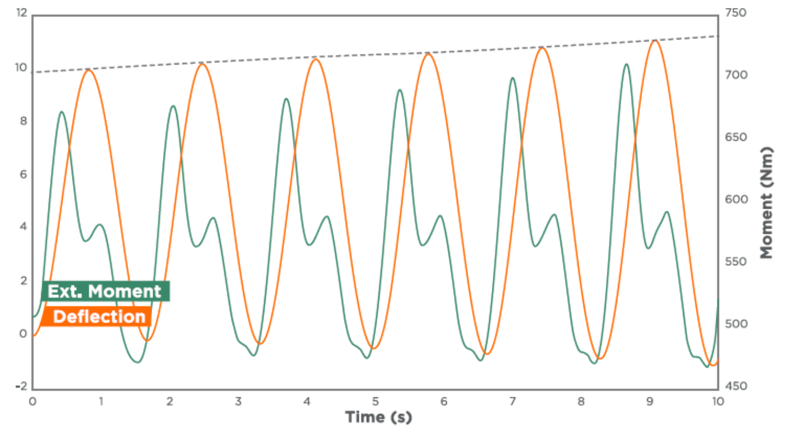
Dynamic Wind Analysis in Tracker Array Design

Obtain Twist incl. Aeroelastic Effects (BAM)

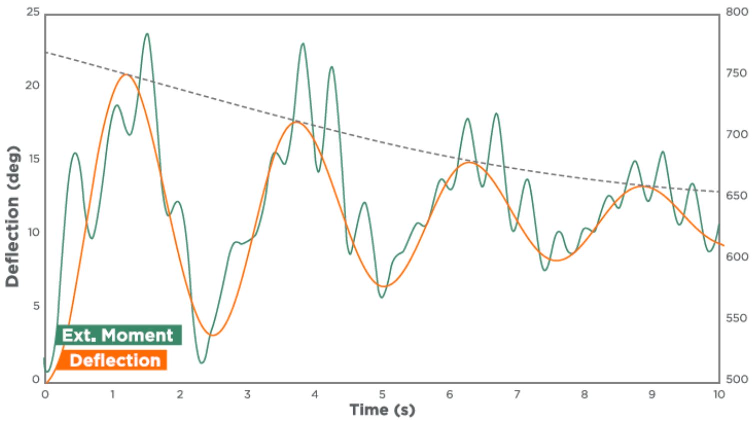
- The Buffeting Analysis Method (BAM) predicts the behavior of a multi-row tracker array under wind action.
- This method can simulate both the full spectrum of wind turbulence fluctuations and the response of the tracker due to buffeting and self excited forces.
- With this method, maximum loads due to wind actions including all dynamic effects can be analyzed in each member of the tracker.



Instability Response (structural issues expected)



Stability Response (damped signal)



The extra damping provided by dampers is not sufficient to mitigate the torsional stresses in solar trackers (for two-up portrait module configurations)

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3D Buffeting Response Analysis (“BAM”): Multi-Row Array

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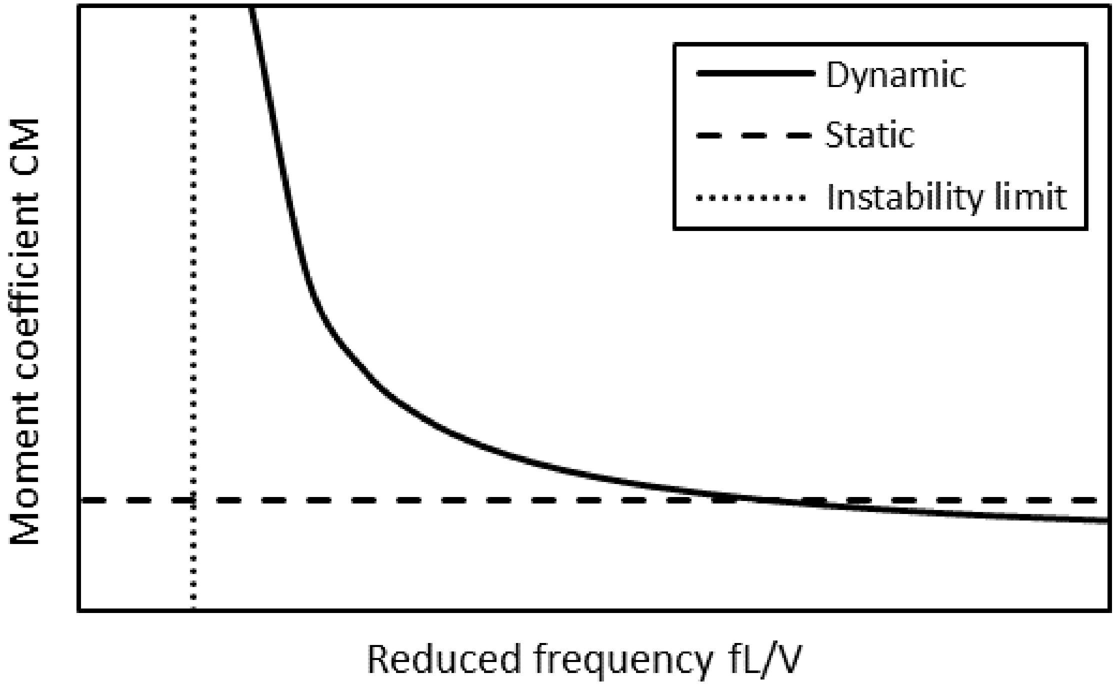
Using Dy-Wind for Tracker Design

- Dy-WIND includes STATIC + DAF + FAM + BAM.
- BAM predicts maximum tracker deflections and forces due to wind action considering all aeroelastic effects.
- Note: Dynamic torque moment can be significantly higher than STATIC + DAF while the tracker is still stable.



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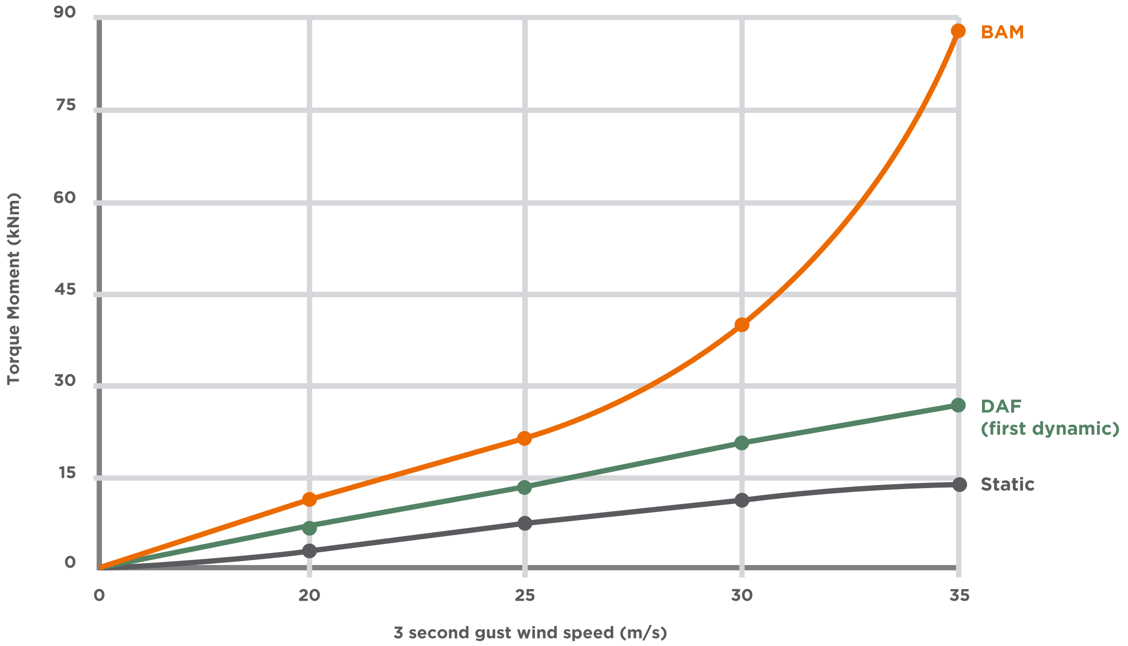
Comparing Static and Dynamic Wind Loads



Wind Speed	Static	DAF	Buffeting	Δ from Static
20 m/s	4.8kNm	7.4 kNm	11.8 kNm	x2.45
25 m/s	7.5kNm	13.6 kNm	22.1 kNm	x 2.95
30m/s	10.9 kNm	20.4 kNm	40.6 kNm	x 3.72
35m/s	14.8 kNm	27.8 kNm	88.5 kNm	x 5.98

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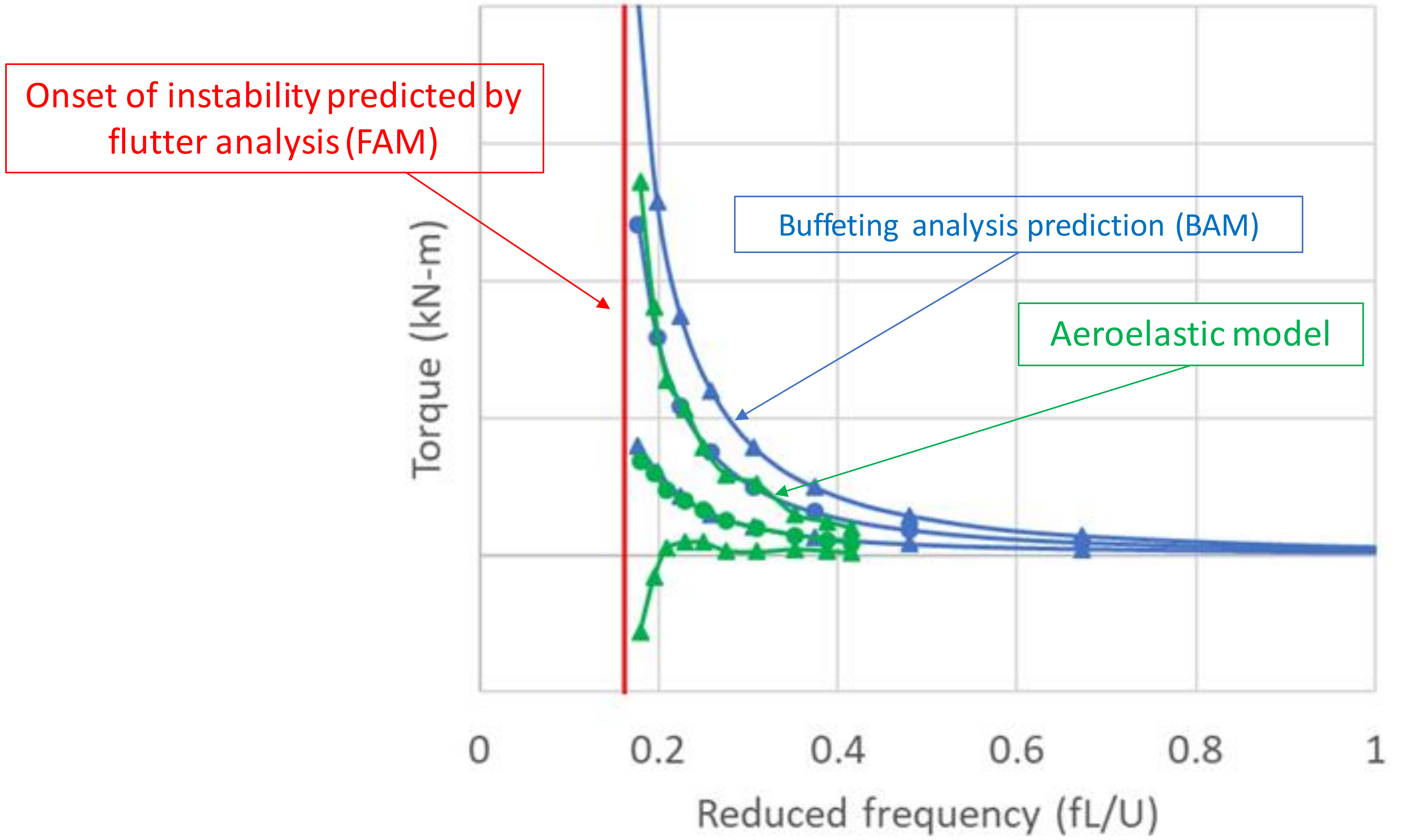
Verify Dy-Wind Results Using 3D Aeroelastic Model Test

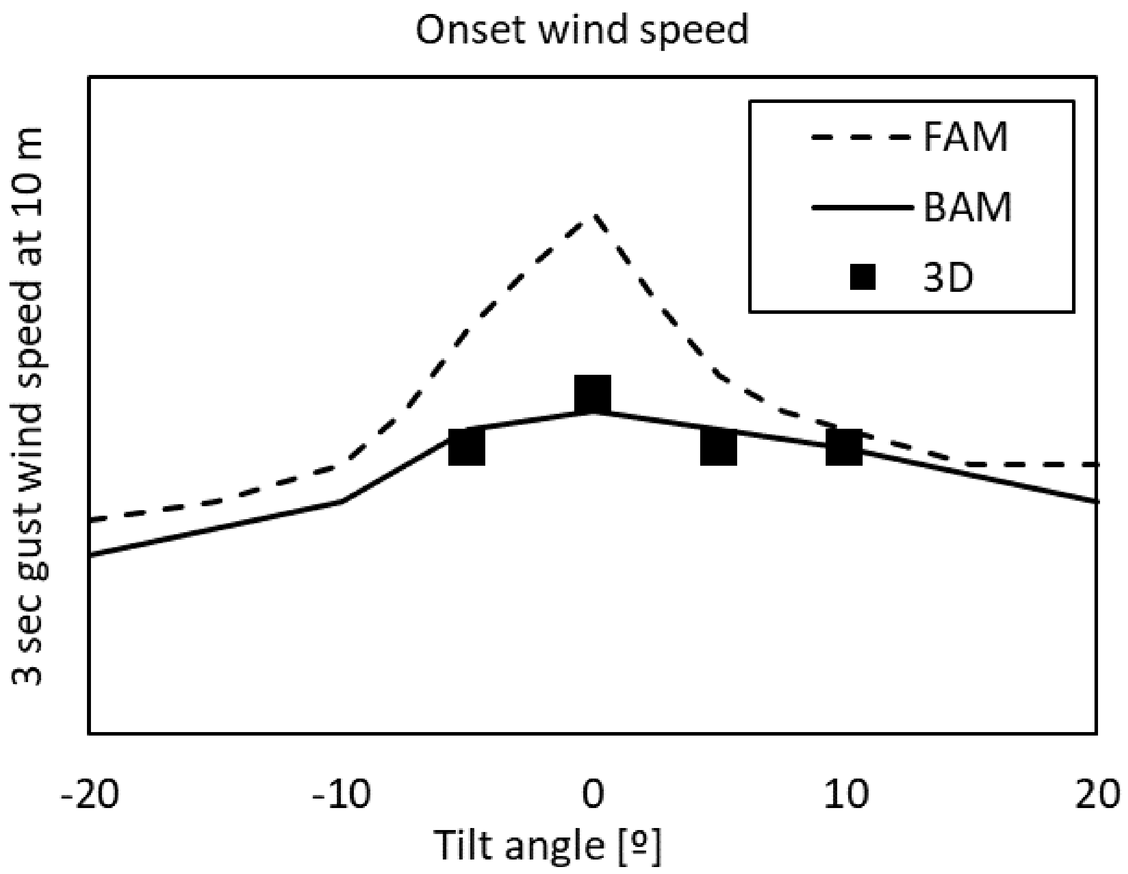
- A recommended practice is to validate the numerical buffeting approach with physical aeroelastic model research.
- Specific configuration (tracker types, stiffness, geometry) used for full 3D aeroelastic wind tunnel test.
- 17 rows to consider behavior of interior tracker.
- Perpendicular and oblique wind directions.
- Preliminary results show generally good agreement between numerical and physical 3D results.

Aeroelastic Model Results for Low Tilt Angle



Comparison between Dy-Wind and 3D aeroelastic test

- BAM results are in accordance with 3D full aeroelastic results
- FAM (sectional test without buffeting analysis) seems to overestimate the stability at small tilt angles BUT
- FAM and BAM have different instability criteria which cause the deviation at small tilt angles (zero system damping vs. twist angle limit)



Conclusion

- Major effort in wind tunnel testing and design method
- Tracker design beyond building code requirements
- High tilt angle stow policy to mitigate instability risk
- Client specific individual tracker solution for each project

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