# Catching the SUN

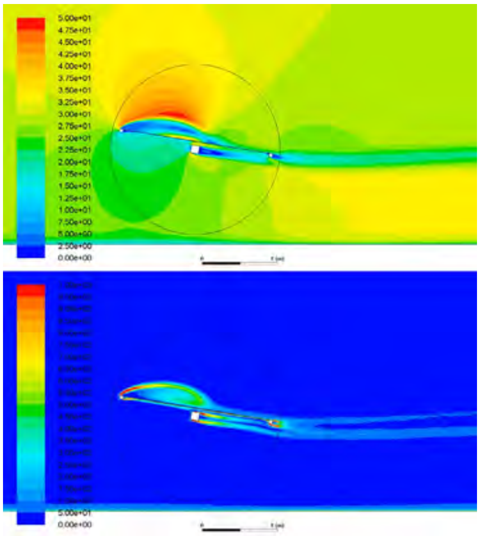
**By rotating solar panels to follow the sun across the sky,** solar trackers can generate more power. These solar power plants can be damaged by aeroelastic instability at modest wind speeds. CPP Wind Engineering used simulation to determine the nature of the instability and to identify operating procedures and design changes that can prevent them.

By **Christian Rohr**, CFD Manager and **Peter Bourke**, Operations Manager, CPP Wind Engineering, St. Peters, Australia

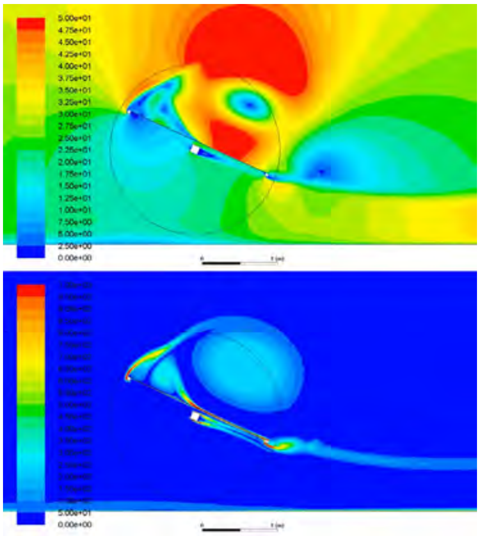
**Single-axis solar trackers that automatically rotate to follow the sun from east to west** can generate 10 percent to 30 percent more power than stationary or "fixed tilt" solar panels. Certain wind conditions can cause a torsional instability that damages solar trackers. CPP was commissioned by several tracking companies, including NEXTracker, to investigate these kinds of failures and develop a solution. CPP used ANSYS Fluent computational fluid dynamics (CFD) software in conjunction with wind tunnel testing to re-create the conditions under which the trackers became unstable. CPP identified the cause of the problem and demonstrated how it could be solved through adjustments in operating conditions and design changes.

## SOLAR TRACKERS

Single-axis trackers consist of photovoltaic panels mounted to a long shaft, called a torque tube, that rotates the panels. The torque tube provides stiffness to resist wind forces, and some trackers also have torsional dampers that look like automotive shock absorbers to reduce vibration. Most single-axis trackers are mounted so that the axis of rotation is horizontal to the ground. The torque tube is supported by vertical piers or posts at intervals along its span that are mounted to the ground.

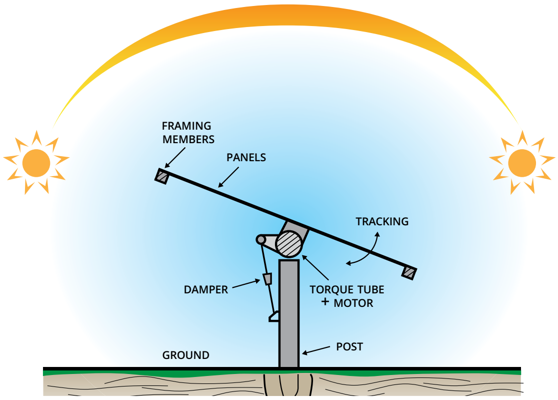


A vortex forms along the upper side of the panel during the simulation at 0.30 seconds.



At 0.55 seconds, a vortex separates from the panel, and upward moment drops to zero.

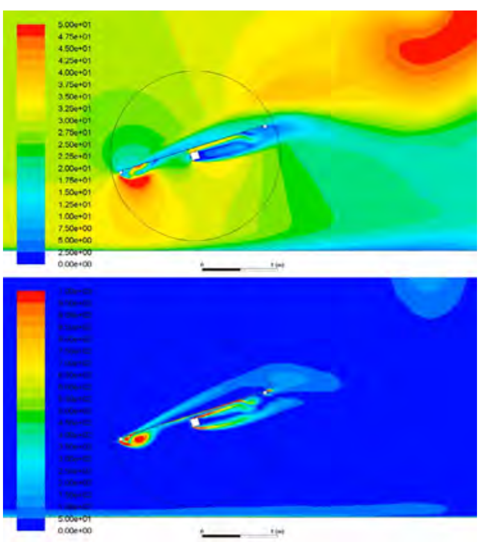
When winds are high, trackers are often rotated into a stow position. Traditionally, this stow position places the panels parallel to the ground to reduce horizontal wind forces. In a series of incidents, trackers from multiple suppliers stowed in this manner have experienced large deflections in their first mode of vibration, a helical twisting mode with opposite ends of the solar panel rotating in opposite directions. Reports from the field indicate that the panels were oscillating more than 20 degrees in the positive and negative directions, causing damage.



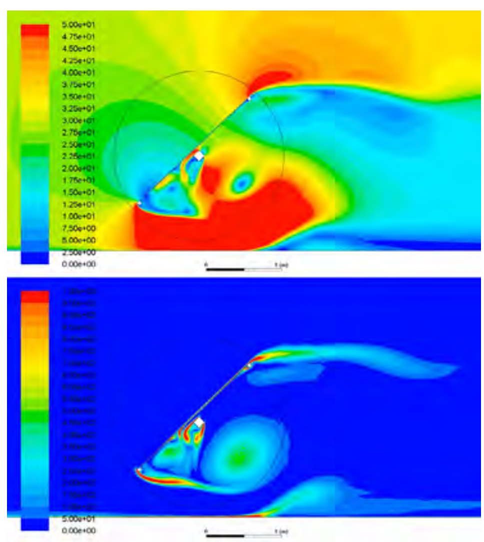

**Typical solar tracker configuration**

In the flat stow position (parallel to the ground), the trackers bear a resemblance to an airplane wing, so CPP engineers postulated that their instability might be caused by flutter, which occurs when aerodynamic response amplifies the vibration of blades. Calculations with handbook equations indicated that classical flutter was not likely because the trackers cannot heave up and down while twisting because vertical motion is constrained at regular intervals by the support posts. Furthermore, handbook equations could not supply adequate results because they rely on assumptions that were not true for field conditions. For example, most of the handbook equations pertaining to flutter are based on oscillations that are much smaller than what was reported in the field with the solar trackers.

Neither CFD nor wind tunnel testing alone can provide a complete understanding of these phenomena. Aeroelastic wind tunnel testing does not reveal the flow mechanism that causes the instability, and the geometries and conditions that can be tested in this way are limited. CFD is well-suited to simulating many different design points and virtually any geometry or condition but requires validation comparison to physical testing when applied to a new problem. CFD also provides a deeper dive into the physics than can be obtained with wind tunnel testing, providing full-field pressure and velocity patterns that reveal the flow structures responsible for the tracker's motion.



**At 0.77 seconds, the leading edge of the tracker's panel has rotated downward and a vortex has formed on the lower edge.**



**At 0.90 seconds, a vortex has separated and the leading edge is about to rotate upward.**

### CFD MODELING OF A SECTION

CPP engineers wanted to evaluate many different design points in order to tell their clients which were stable and which were unstable. To obtain short solution times, they used a 2D CFD model. While this model was not able to reproduce the 3D twisting seen in real solar trackers, CPP engineers calibrated the stiffness and damping of the 2D model to match the behavior of real 3D trackers as observed in the wind tunnel and in the field.

In the CFD model, the panel was mounted just barely high enough above the ground to spin without contacting the ground. The domain was meshed with approximately half a million quadrilateral cells with refinement around the panel and wake regions. Engineers applied the realizable k-ε turbulence model to observe the threshold at which instability occurs. They ran a 10-second transient simulation with minimal computing resources to determine the stability of the tracker.

Engineers substantially reduced the computational effort required to perform the simulation by embedding the equations of motion for this model into a user-defined function (UDF), and using the UDF to calculate the deflection of the structure at each time step in the simulation. This information feeds back to the CFD solver, which adjusts a rotating mesh to alter the position of the tracker to account for the deflection. This approach provided reasonable results quickly.

Engineers created a table of design points in ANSYS Workbench by varying the windspeed, wind direction, elevation angle, structural stiffness and damping of the tracker. They then entered values in the table of the design parameters that they were interested in exploring. Next, engineers used Workbench to automatically generate models and execute CFD simulations to evaluate each of the design points and store the results.

**Model used for wind tunnel testing**

### NATURAL VENTILATION STRATEGIES

The complementary benefits of wind tunnel testing and CFD have also been used by CPP engineers on several occasions to improve comfort levels in interior locations. Although wind tunnel testing is the most appropriate tool for accurately measuring wind speeds and turbulence in urban environments, it is primarily limited by Reynolds number effects to outdoor spaces. CPP engineers used a combination of wind tunnel pressure measurements and CFD studies of internal spaces to determine comfort levels in interior locations not accessible to wind tunnel testing. The computational models also enabled evaluation of thermal loads generated by occupants, equipment and solar heating that cannot be measured in the tunnel.

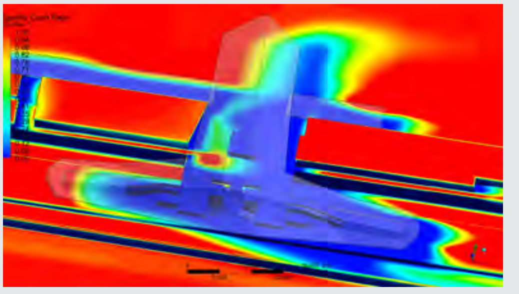
### WIND TUNNEL TESTING VALIDATES SIMULATION

At the same time, engineers built a physical section model that matched the geometry of the 2D CFD model and used a variable stiffness torsional spring to match the stiffness and damping of the CFD model. The physical model was placed horizontally in CPP's atmospheric boundary layer wind tunnel. The spring was attached to the axis of rotation, and angular displacement was measured with a laser sensor. The wind tunnel model showed good agreement with the CFD results, providing assurance that the CFD model could be used to accurately evaluate alternative designs.

Next, the engineers built a 3D CFD model to run steady-state simulations of several key design points, allowing them to check whether the behavior of these points matched 2D CFD. They also built a fully three-dimensional aeroelastic wind tunnel model to further validate both the 2D and the 3D CFD models. All of these simulations and tests correlated well with each other.

## WIND-DRIVEN RAIN

CPP engineers also synergistically combined CFD with wind tunnel testing to determine the extent of wet patches under awnings and close to building entries. They used both discrete particle models and Eulerian multiphase strategies in ANSYS Fluent and matched the predicted flow field against concurrent pedestrian-level wind tunnel testing to validate or scale the CFD results.

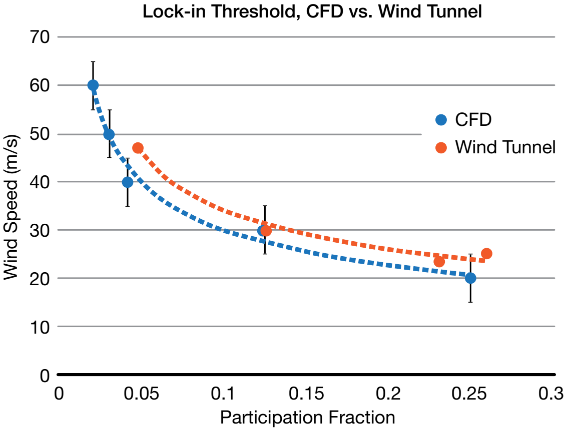


**CFD results for wind-driven rain**

## IDENTIFYING THE CAUSE OF THE INSTABILITY

The simulation showed that, in flat stow, a vortex forms above the leading edge of the tracker, creating a substantial moment across the central chord. This causes the tracker to twist and, as it does, the size of the flow separation increases and the zone of significant uplift crosses the midpoint of the chord. As the vortex is shed by the tracker, the moment suddenly drops to zero. The tracker then bounces back past the flat position so that its leading edge is twisted downward into the wind. A vortex then forms on the underside of the leading edge, and the process described above is repeated. The simulations showed that this instability is based on torsional divergence, and is not easily treated with damping.

Simulation showed that it is possible to excite twisting in the first mode shape with only a fraction of the full span participating in the vortex shedding, and that significant amplitudes can be reached in just a few cycles. Simulations were run at different conditions, and the time series was examined to determine whether the tracker was stable or unstable.




**Critical wind speed determined by simulation vs. wind tunnel testing**

Simulating the tracker over a wide range of conditions showed that the system has a critical velocity above which instability will always occur. The results revealed that, in many cases, instability could be avoided by stowing the trackers at an angle rather than parallel to the ground. However, the results also showed that tilting the tracker introduces the potential for vortex lock-in instability (where alternating vortices are shed from the leeward face of the tracker). Greater static loads and greater dynamic excitation due to buffeting also result from higher tilt stow. These issues can be addressed by increasing the stiffness and damping of the tracker.

CPP engineers provided their clients with maps of tracker angles, wind speeds and directions that indicate which types of trackers work under which weather and operating conditions. They also provided guidance on what results could be expected by upgrading the stiffness and damping of trackers. This project provides a good example of how CFD and wind tunnel testing can be combined to solve problems that would have been difficult or impossible to solve with either testing or simulation alone. Wind tunnel testing was also used to validate both 2D and 3D CFD models. CFD, on the other hand, made it possible to identify the exact cause and solve the problem. Engineers were able to evaluate many different design points in a reasonable amount of time while providing voluminous diagnostic information on each point.

*CPP Wind is supported by ANSYS Channel Partner LEAP Australia.*

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