A fluid solver for studying torsional galloping in solar-tracking PV panel arrays

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Motivation

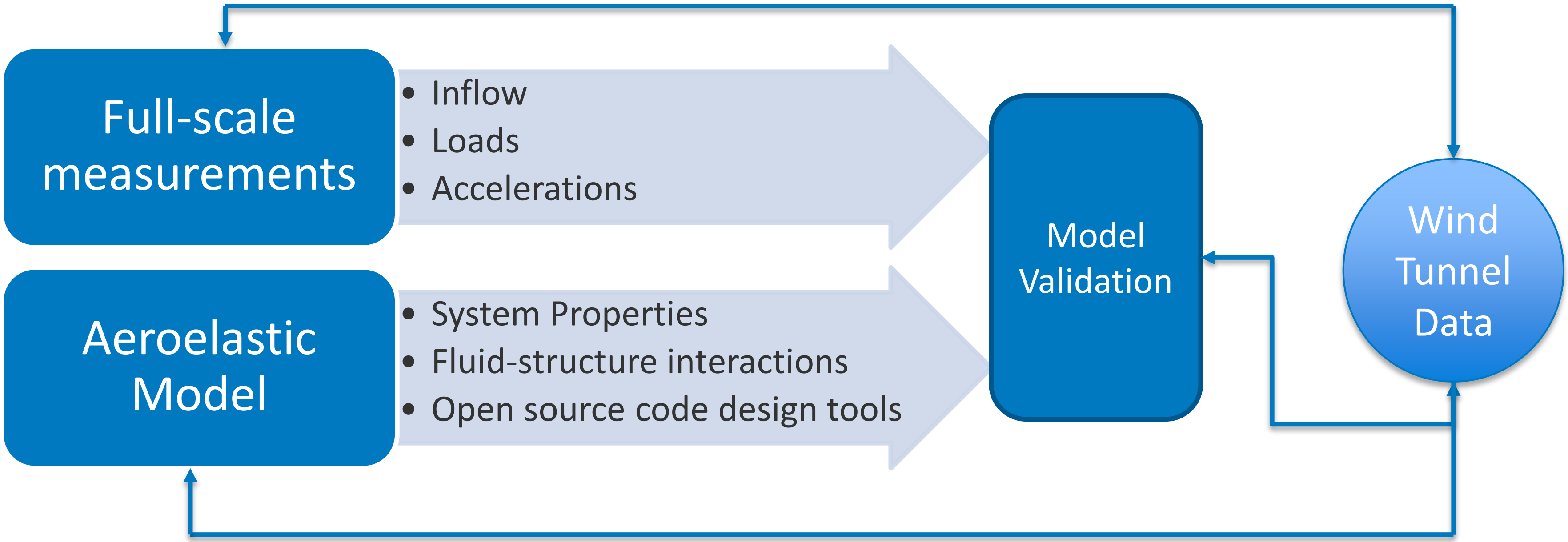
- **Complicating factors for tracker failure**
  - Range of wind speeds and geographic locations
  - Unclear sources (galloping vs divergence)
  - Unclear stow guidance

- Understanding the **fluid-structure interaction** driving this instability using an **open-source, validated model** can improve panel stow guidelines and inform stabilizing designs.

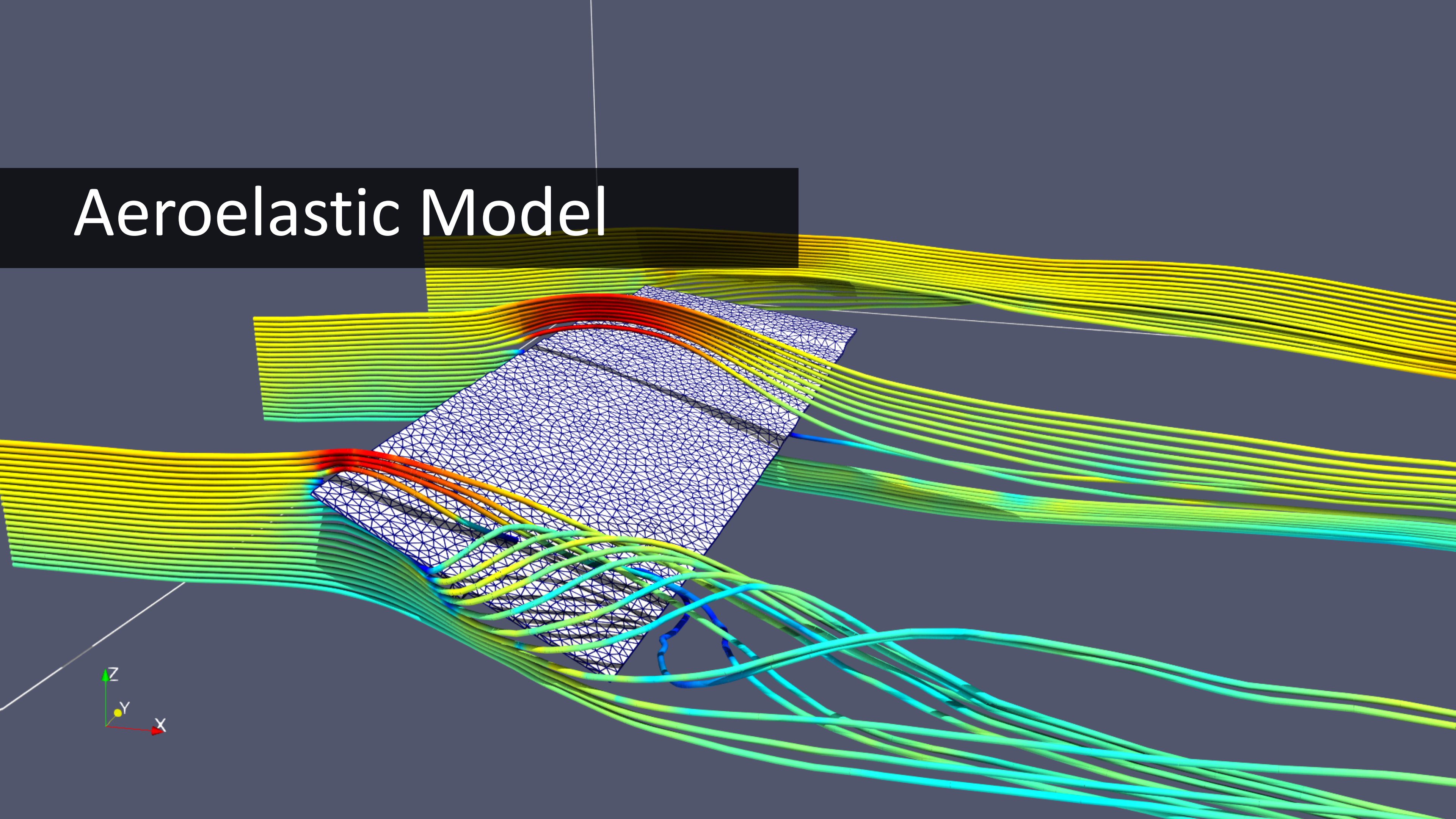
[1] GTM and NEXTracker Webinar, *Driving the Standard: Wind Testing, Solar Trackers, and Peer Review*, December 10th, 2019
[2] PV Magazine Webinar, *Can a tracker be as stable as a fixed tilt?* , December 10th, 2019
[3] PV Magazine Webinar, *High or low tilt angles for single-axis trackers in extreme winds – different approach*, December 16th, 2019

DuraMAT Enabled Parallel Study

Goal: Address PV resilience and dynamic instability



Aeroelastic Model

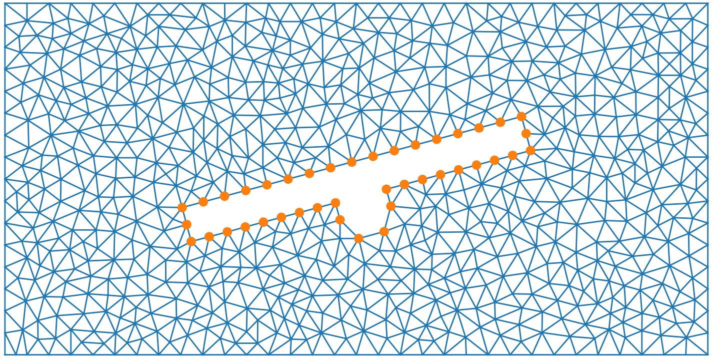


Methodology

- A pressure correction scheme is used to solve the Navier-Stokes equations while enforcing incompressibility.

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} - \hat{\mathbf{u}}) \cdot \nabla \mathbf{u}\right) = -\nabla P + \mu \nabla^2 \mathbf{u}$$

$$\nabla \cdot \mathbf{u} = 0$$

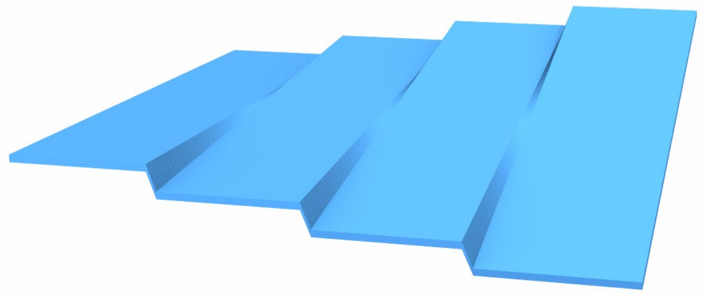


- The fluid stress around the immersed surface creates a torque, τ, at each node on each panel.

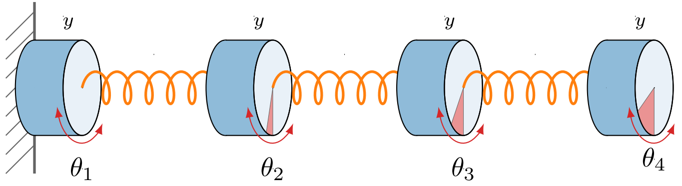
$$\mathrm{T}_j = \int_{S_j} \tau \, dS \qquad \text{for } j = 1, 2, \ldots, N$$

Methodology

- Panels are treated as **rigid masses** linked with **rotational springs**.
- This mass-spring approximation is used to model the fluid-structure dynamics.

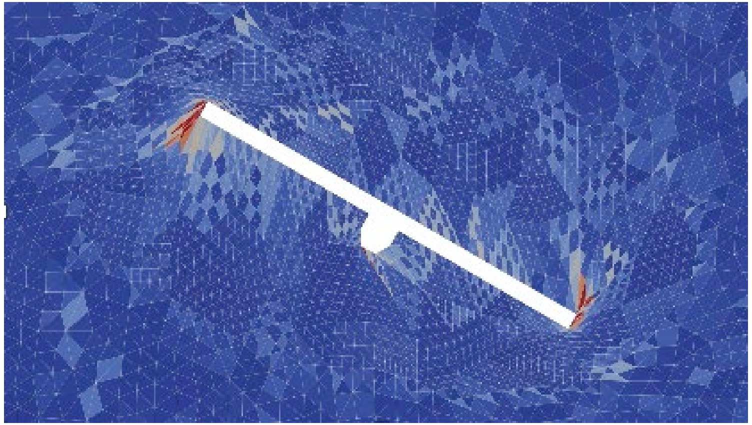


$$I_y \frac{d^2}{dt^2}\begin{bmatrix}\theta_1\\ \theta_2\\ \vdots\\ \theta_{N-1}\\ \theta_N\end{bmatrix} + \kappa \begin{bmatrix} 1 & -1 & 0 & \dots & 0\\ -1 & 2 & -1 & \dots & 0\\ & & \ddots & & \\ 0 & \dots & -1 & 2 & -1\\ 0 & \dots & 0 & -1 & 1\end{bmatrix}\begin{bmatrix}\theta_1\\ \theta_2\\ \vdots\\ \theta_{N-1}\\ \theta_N\end{bmatrix} = \begin{bmatrix}\mathrm{T}_1\\ \mathrm{T}_2\\ \vdots\\ \mathrm{T}_{N-1}\\ \mathrm{T}_N\end{bmatrix}$$

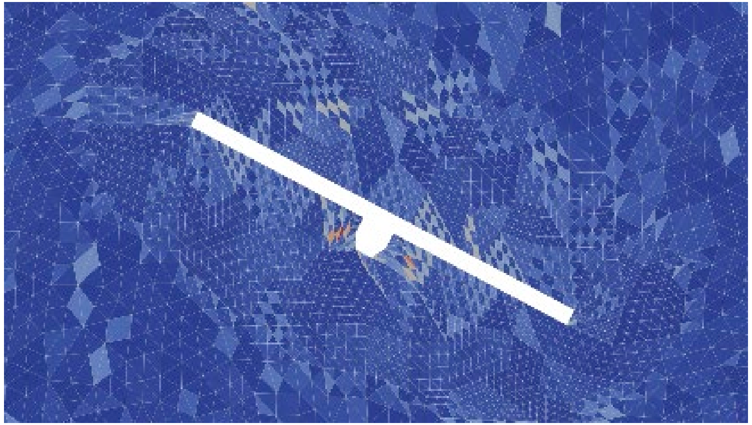


Methodology

- A Laplacian smoothing strategy **preserves cell quality** near the panel surface during mesh motion.



Constant diffusivity: $\nabla^2 \hat{x} = 0$

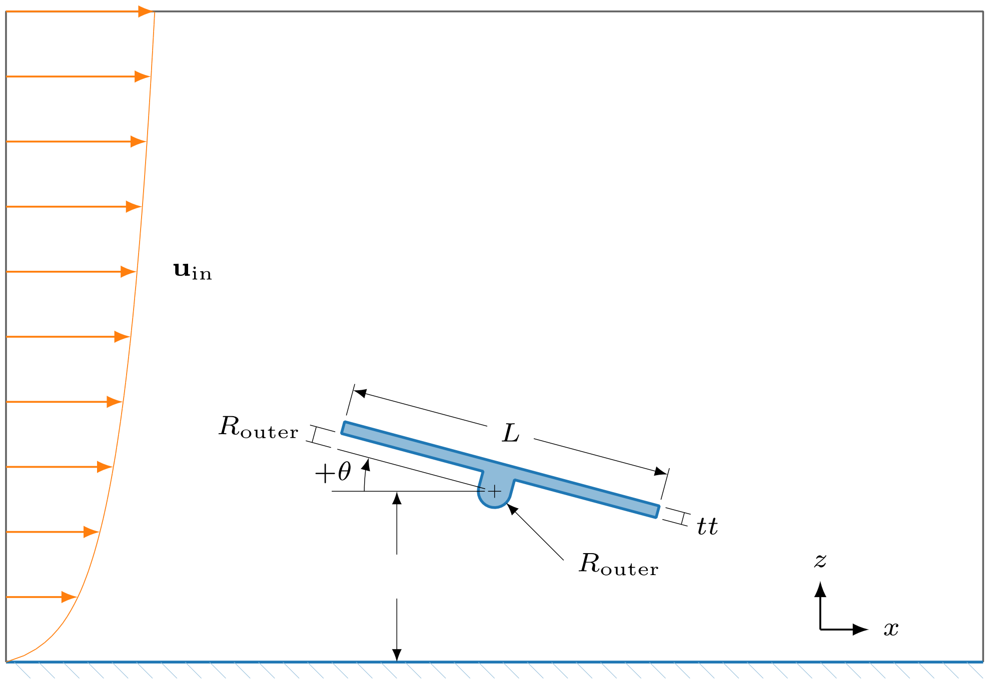


Quadratic diffusivity: $\frac{1}{d^2} \nabla^2 \hat{x} = 0$

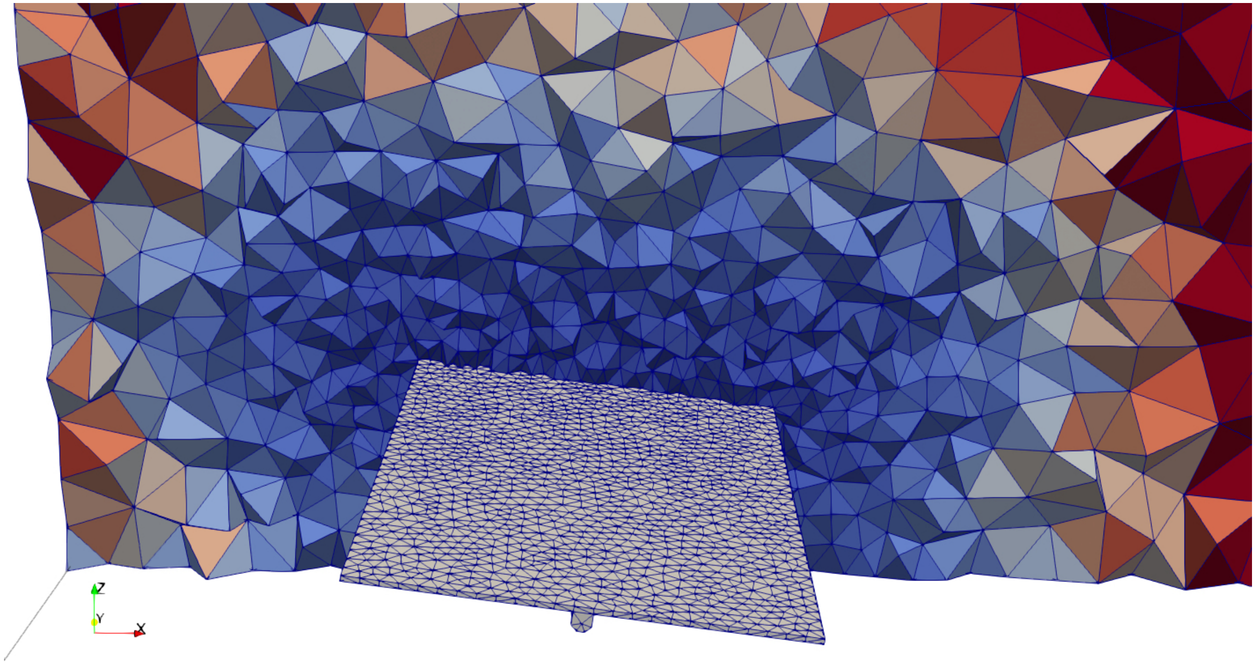
Simulation Setup

Fluid Property	Value
ρ	$1.0\,\mathrm{kg\cdot m^{-3}}$
μ	$1.8\times10^{-5}\,\mathrm{Pa\cdot s}$

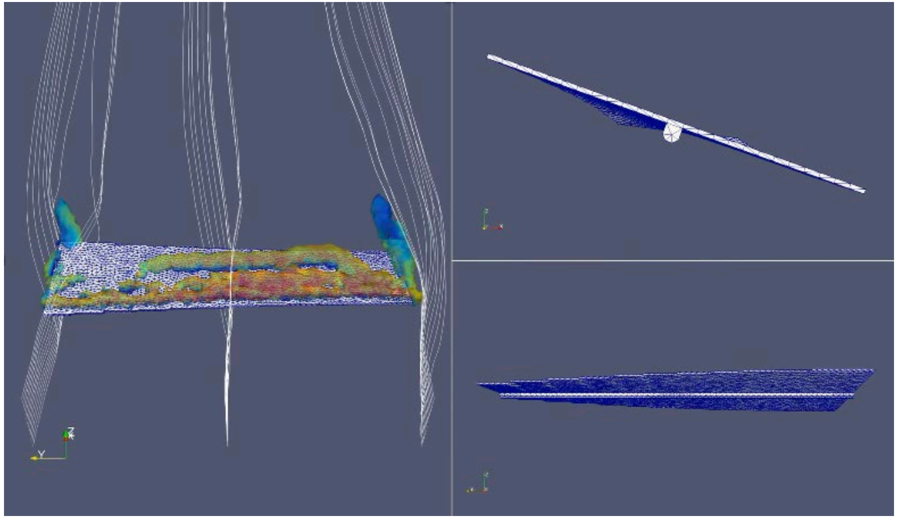
Structure Property	Value
$L\times W\times tt$	$4\,\mathrm{m}\times12\,\mathrm{m}\times0.05\,\mathrm{m}$
h	$2.1\,\mathrm{m}$
R	$0.085\,\mathrm{m}$
E	$148\,\mathrm{GPa}$
m	$50.8\,\mathrm{kg}$

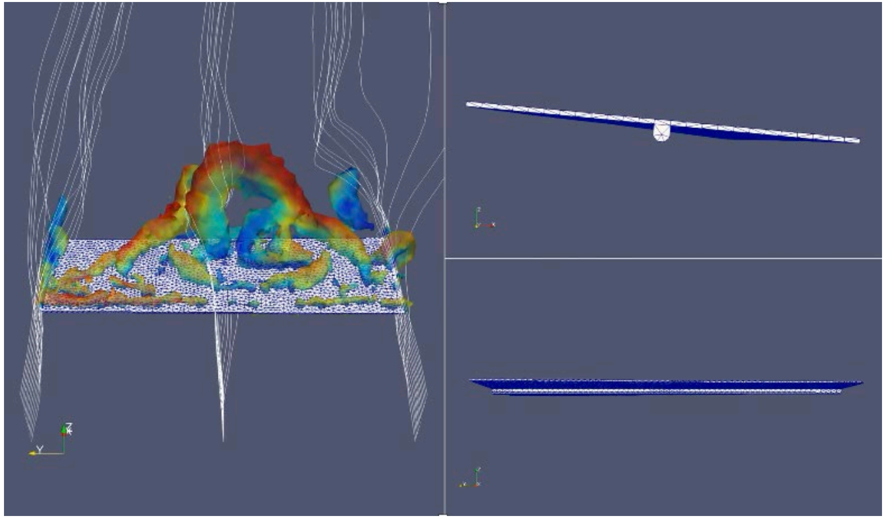


Simulation Setup



Fluid-Structure Response





$$\theta = +7.5, \qquad \overline{U}_{in} = 40.5\,\mathrm{m\,s^{-1}}$$

Pressure Interpretation

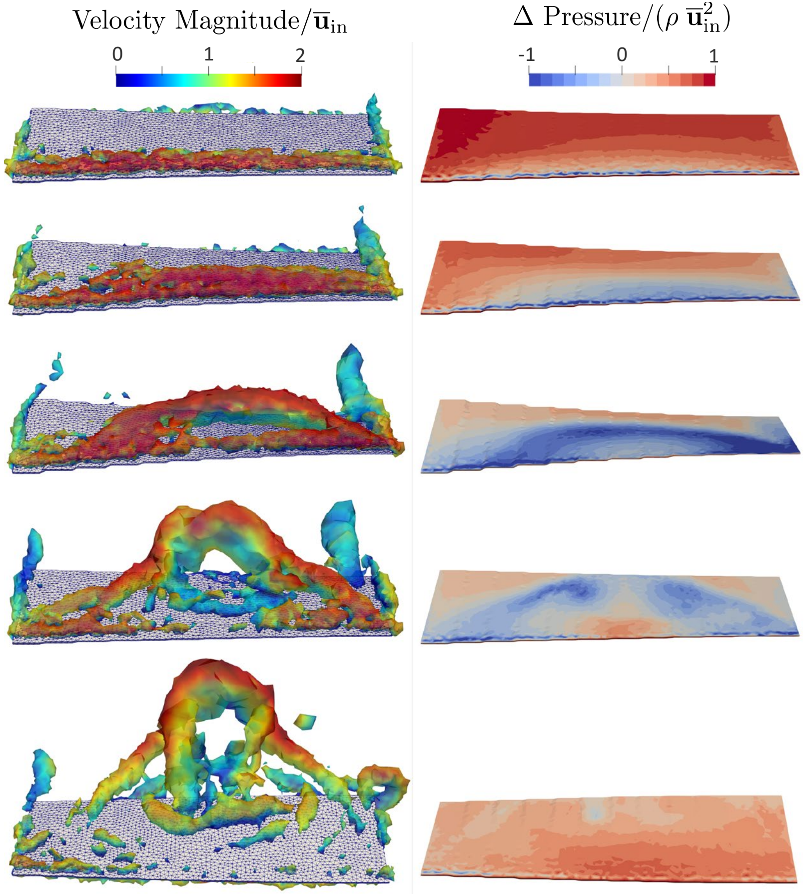
$t_1 = 1.22$ s
$\theta_{\text{free}} = 15.25°$

$t_2 = 1.28$ s
$\theta_{\text{free}} = 22.08°$

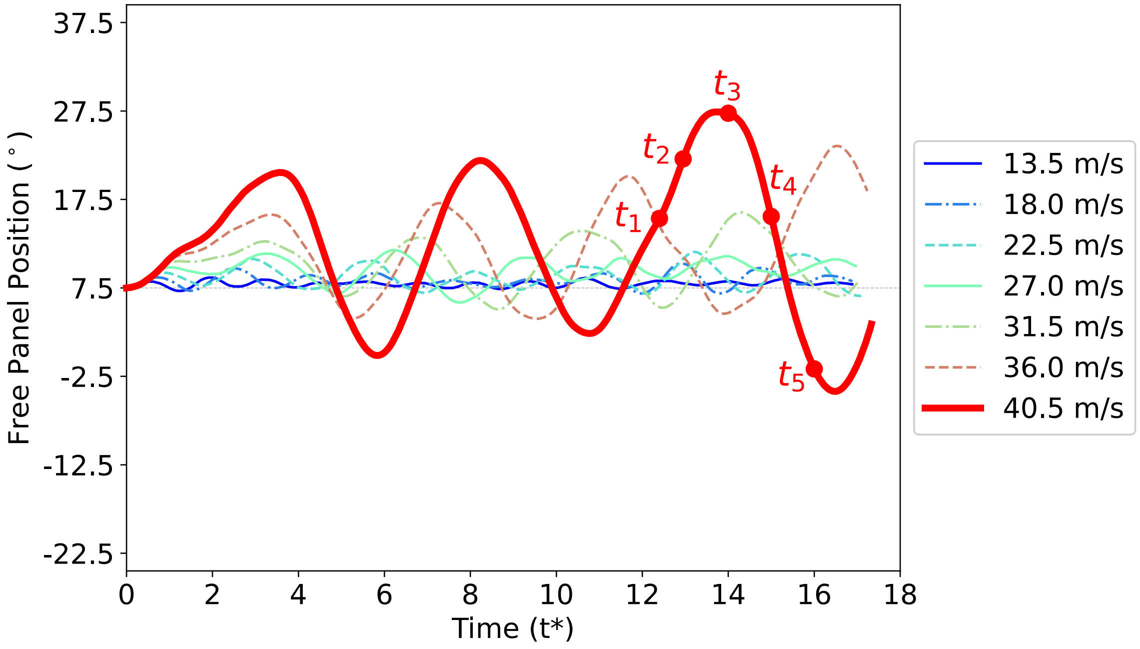
$t_3 = 1.38$ s
$\theta_{\text{free}} = 27.24°$

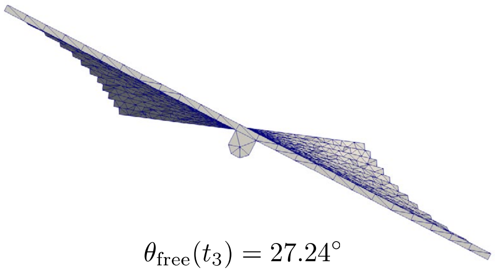
$t_4 = 1.48$ s
$\theta_{\text{free}} = 15.57°$

$t_5 = 1.58$ s
$\theta_{\text{free}} = -1.67°$



Effect of Wind Speed



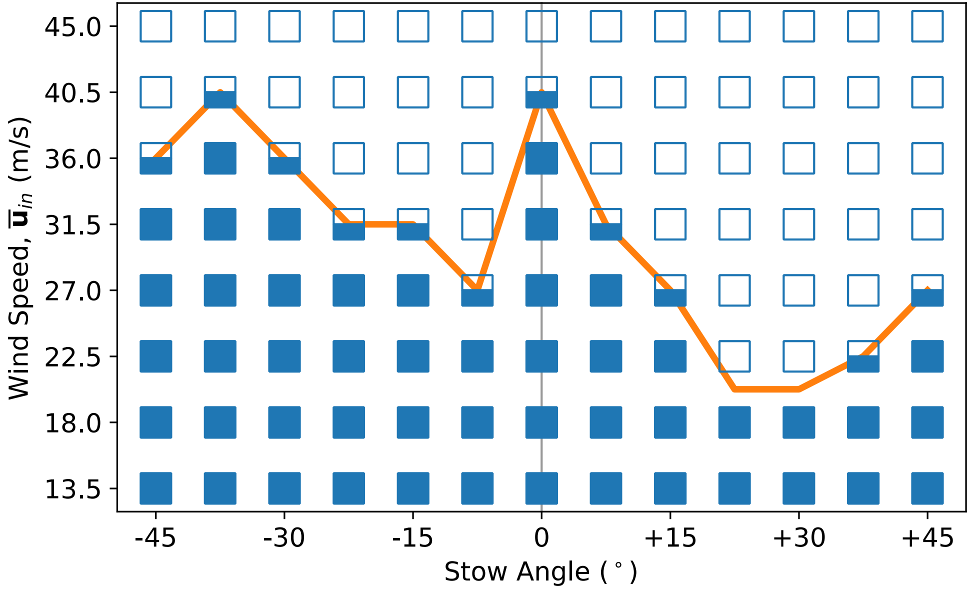


$\theta_{\text{free}}(t_3) = 27.24°$

$\theta_{\text{free}}(t_5) = -1.67°$

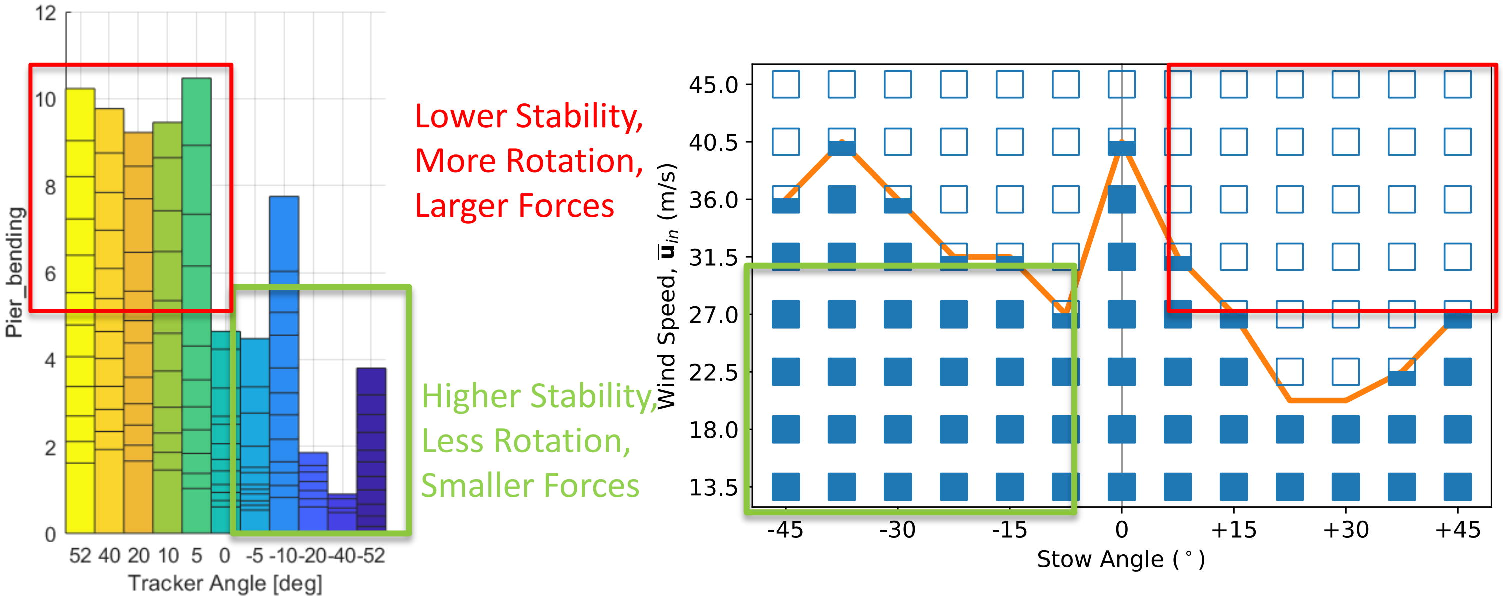
Panel stability at $\theta = +7.5$

Panel Stability



Panel stability across a range of wind speeds and stow angle pairs;
■ = stable pair, ⬓ = conditionally stable pair, □ = unstable pair.

Field & Model Convergence



- Both the field campaign and the computational model indicate **increased stability at negative stow angles**.

Next Steps

- **Modeling Approach**
  - Implement improved stability criterion.
  - Compounding effect of multiple panel rows.
  - High-fidelity model to capture deformation effects.
- **Field-Model Validation**
  - Current simulations show good *qualitative* agreement to field measurements.
  - Still have a wealth of data to mine for the further refinement of both approaches.