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Extreme damping – A new wind mitigation strategy for trackers

15 September 2021

11:00 am – 12:00 pm | EST, New York
10:00 am – 11:00 am | Mexico, Colombia
5:00 pm – 6:00 pm | CEST, Berlin

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Extreme Damping - A new wind mitigation strategy for trackers

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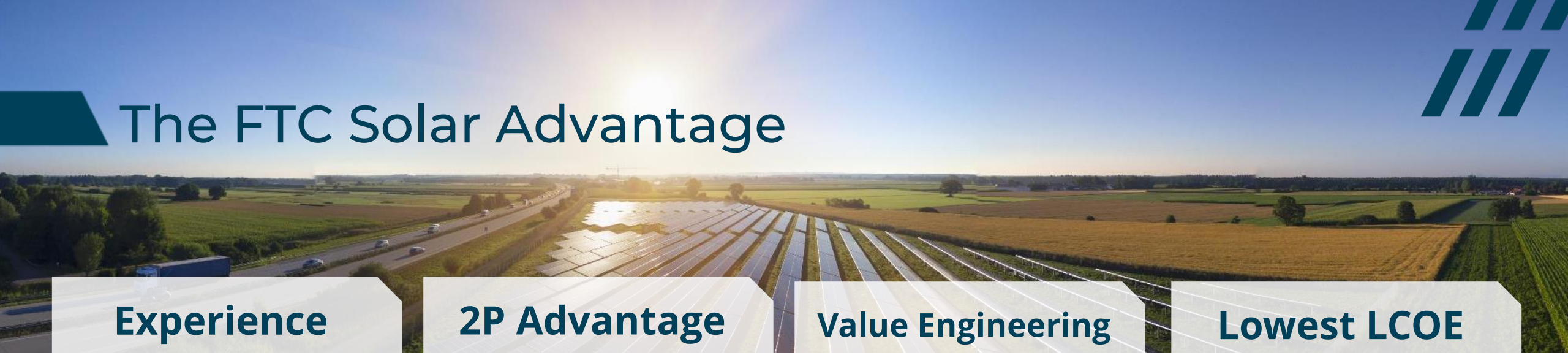
The FTC Solar Advantage



Experience

20+ Years of experience — As developers, EPCs, and asset owners

1.9 GW delivered — Highest 2P market share in the US

260% — YoY growth

2P Advantage

46% Fewer piles — Solution for challenging sub-surfaces

Up to **1.6%** Higher density — Higher power for irregular sites

17.5% N-S slope tolerance — Lower grading costs for undulating sites

Value Engineering

Powered by our SunDAT software

Higher density — Site layout optimization

Less Earth-works — Grading optimization

Cable routing — DC collections design

Lowest LCOE

201 MH/MW — **Simplicity by design** Industry leading install times

35% — Less DC cabling

99.9% — Operational availability

6.1% — Yield increase with SunPath

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Tracker Stability (and Dynamic Loads) Challenges

Dynamic Behavior Is Very Complex

- Winds have both static and dynamic content that vary greatly in character over time
- Loads vary by location both along a row and within an array
- Site conditions (terrain, layout..) impact behavior significantly
- Loads and dynamic behavior are aeroelastic (depend on position under load – negative stiffness)
- There are complex mechanical behaviors that have significant impact which can't practically be included in traditional wind tunnel scale model testing (connection play, backlash, soil resistance, load dependent structural damping…)
- Severe wind events are rare in the field making validation of models a challenge

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Design for Stability (and Other Dynamic Behavior)

FTC's Approach

- Wind tunnel testing

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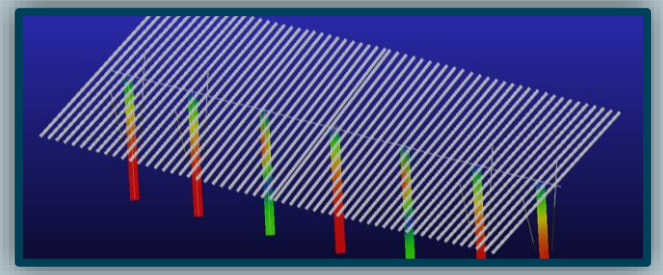

- Dynamic modeling (Adams) with wind tunnel data as input

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- A team of experts (RWDI, EPS and others) for independent review

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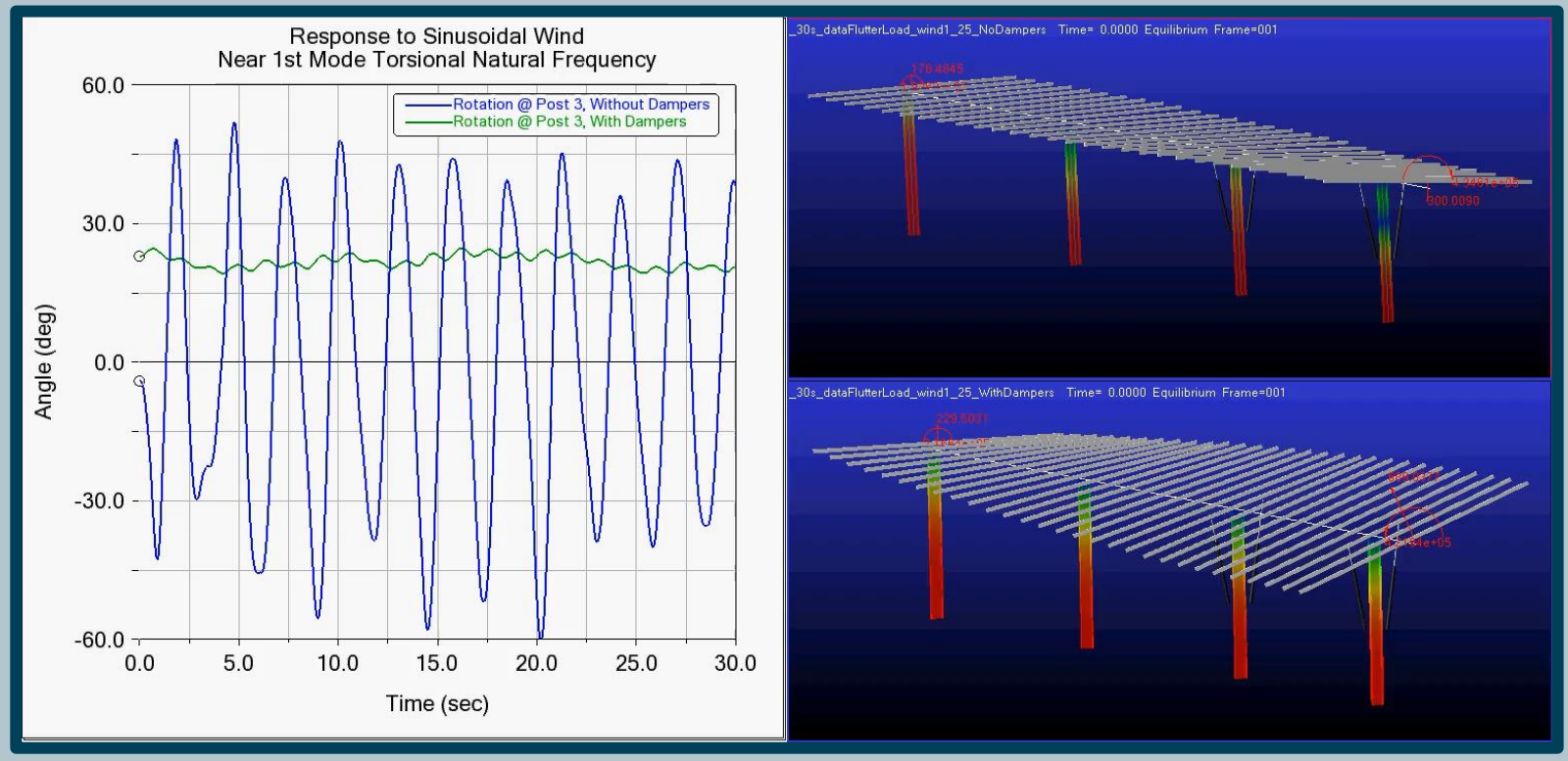
Are Stow-Flat Trackers Stable?

They Can Be If Done Right

- Adams simulation of Voyager+ tracker, under- and over-damped
- What's different from industry experience? Lots of damping, into uncharted territory…



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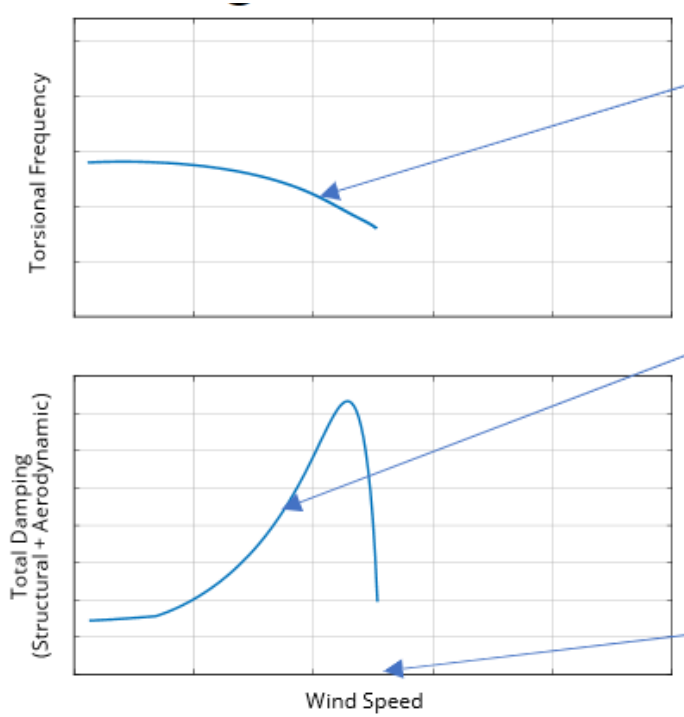
RWDI Wind Tunnel Testing

Aerodynamic Stiffness and Damping

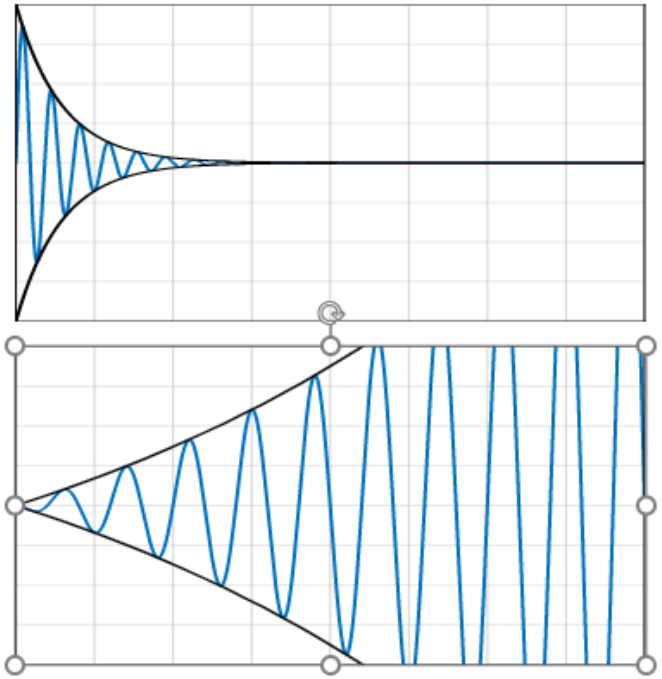
Tilt Angles Near Horizontal



Decrease in torsional frequency:
Negative Aerodynamic Stiffness

Initial increase in torsional damping:
Positive Aerodynamic Damping

Followed by rapid transition to:
Negative Aerodynamic Damping



Aerodynamic Instability

Torsional Divergence/Galloping

Negative aerodynamic stiffness overcomes structural stiffness

Observed at low tilts

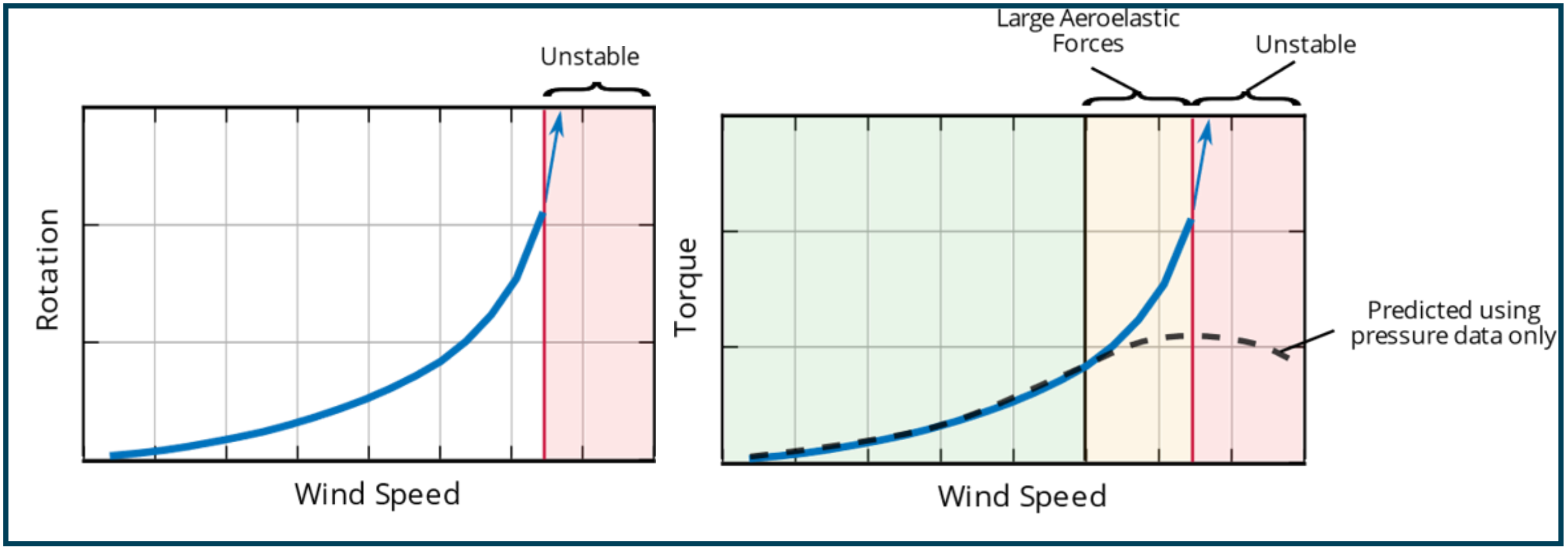
Torsional Flutter

Negative aerodynamic damping overcomes structural damping

Observed at high tilts

Wind Induced Responses

Typical Response with Wind Speed

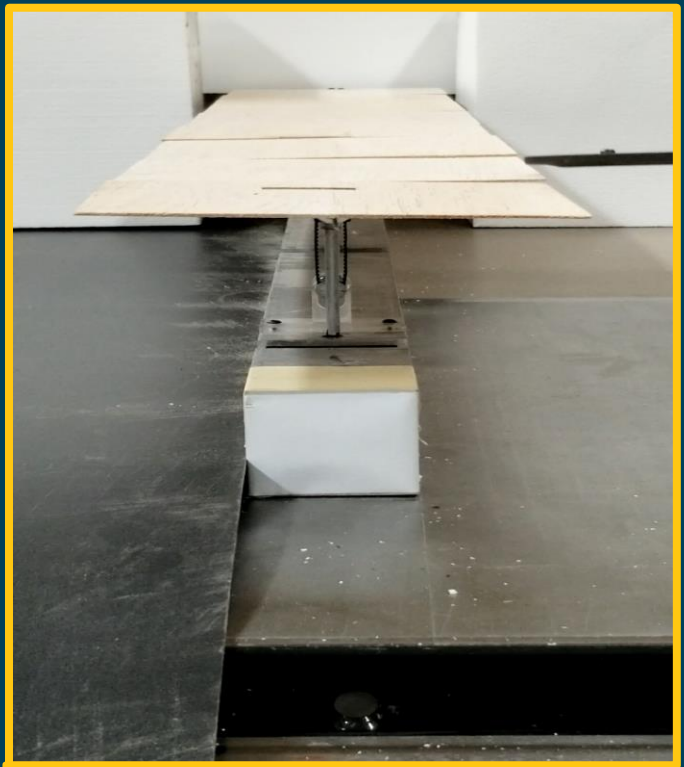


Damping

Model Scale Damper Design

- Remote control car dampers were the starting point
- Custom machined valve plates
- Variable oil weight
- Forced vibration testing to establish force-velocity curves

Damping



Under Damped

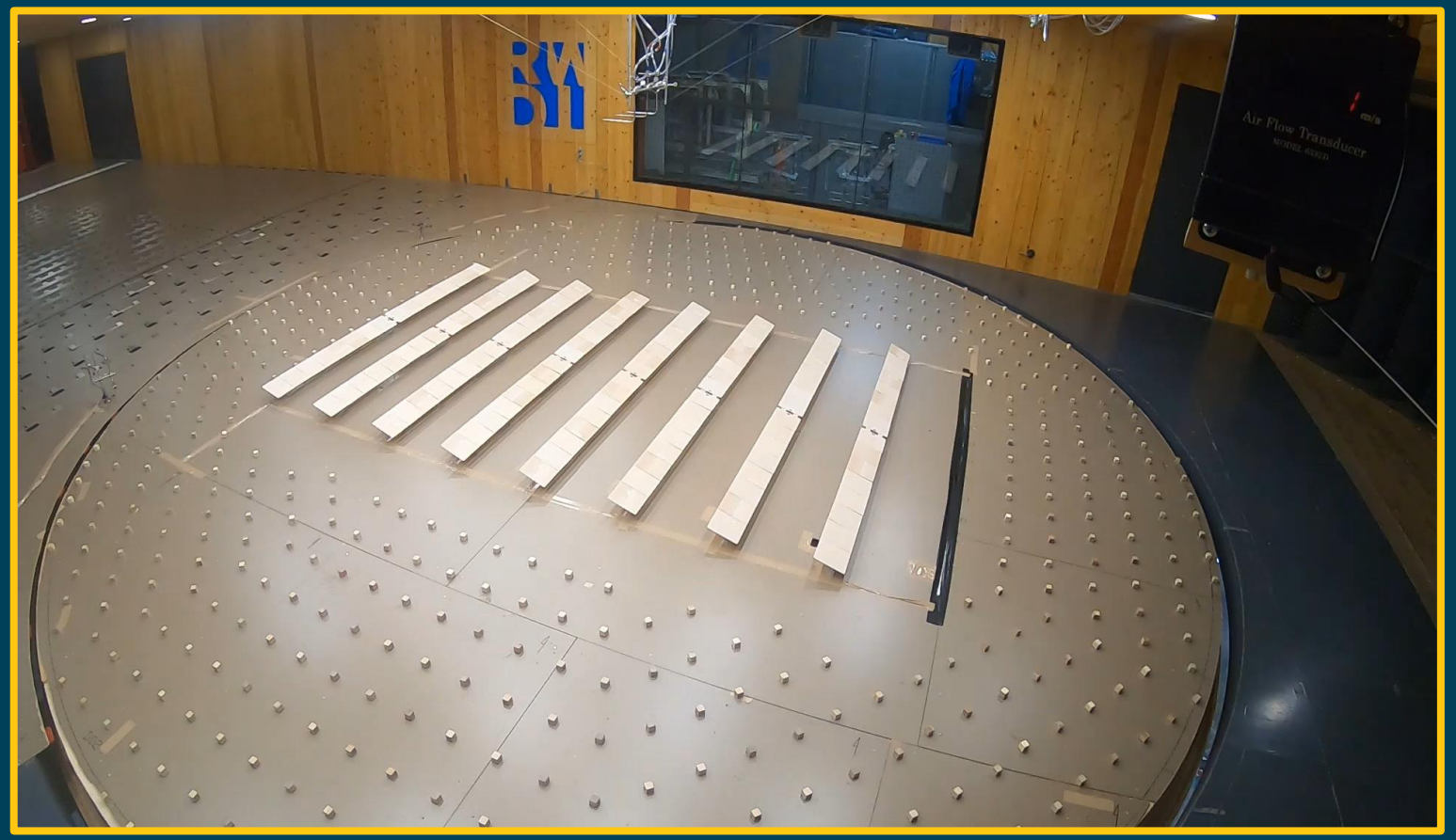
- Inherent and/or supplemental damping
- Effectiveness depends on tilt angle

Over Damped

- Customized damping devices
- Strongly non-linear

Underdamped Performance

Response typical of torsional divergence/galloping



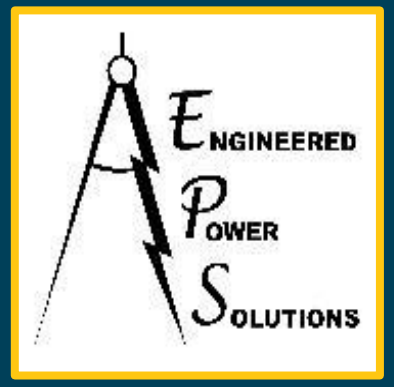
Overdamped Performance

Dynamic motion is suppressed with a heavily overdamped system

Summary

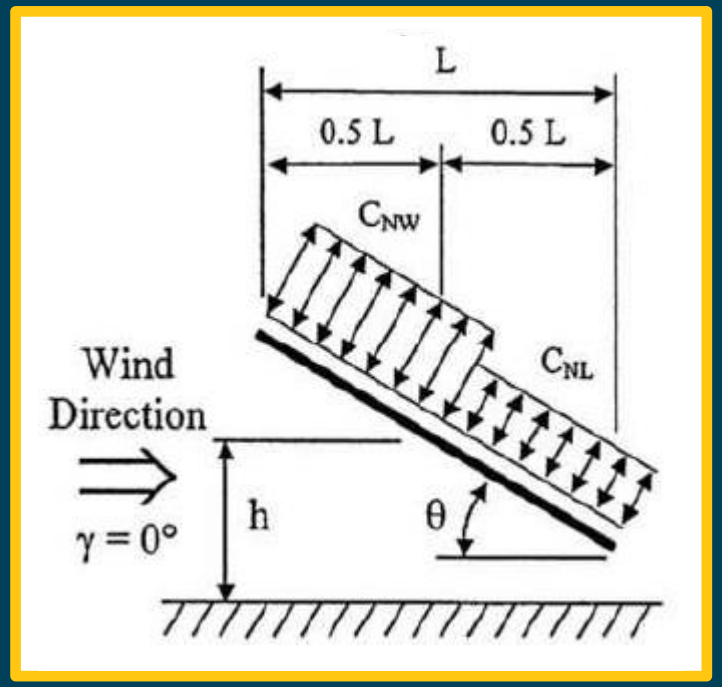
- Wind-induced vibrations are a serious design concern for single-axis solar trackers
- Stowing near horizontal typically requires significant stiffness to suppress aerodynamic instabilities
- Wind tunnel testing has been performed on FTC's system w/ and w/out external dampers
- A heavily overdamped system is shown to suppress dynamic motion

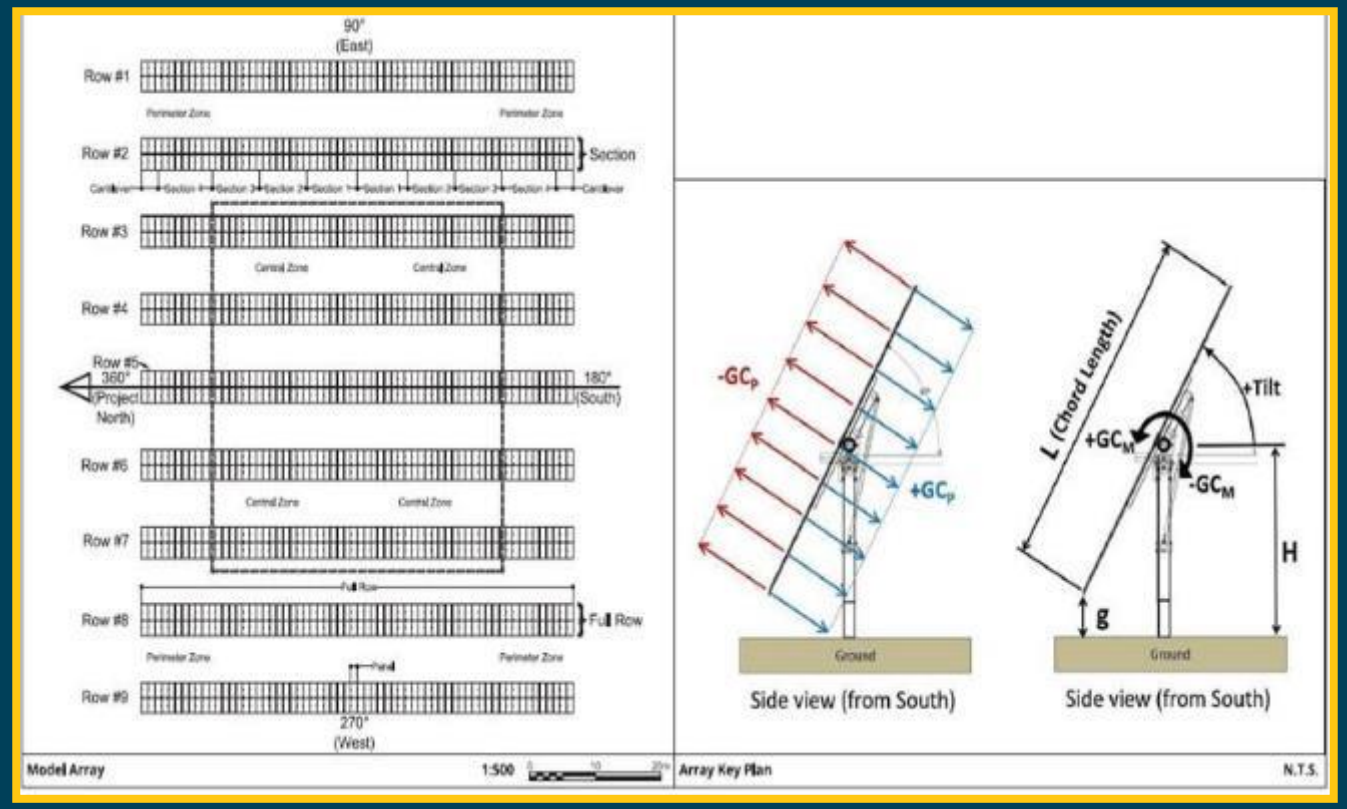
Applying RWDI Validation to Voyager+



Wind Dynamics

- Shielding effects
- Effective wind area
- Corner and edge vortices vs central zones
- Dynamic and aeroelastic wind effects

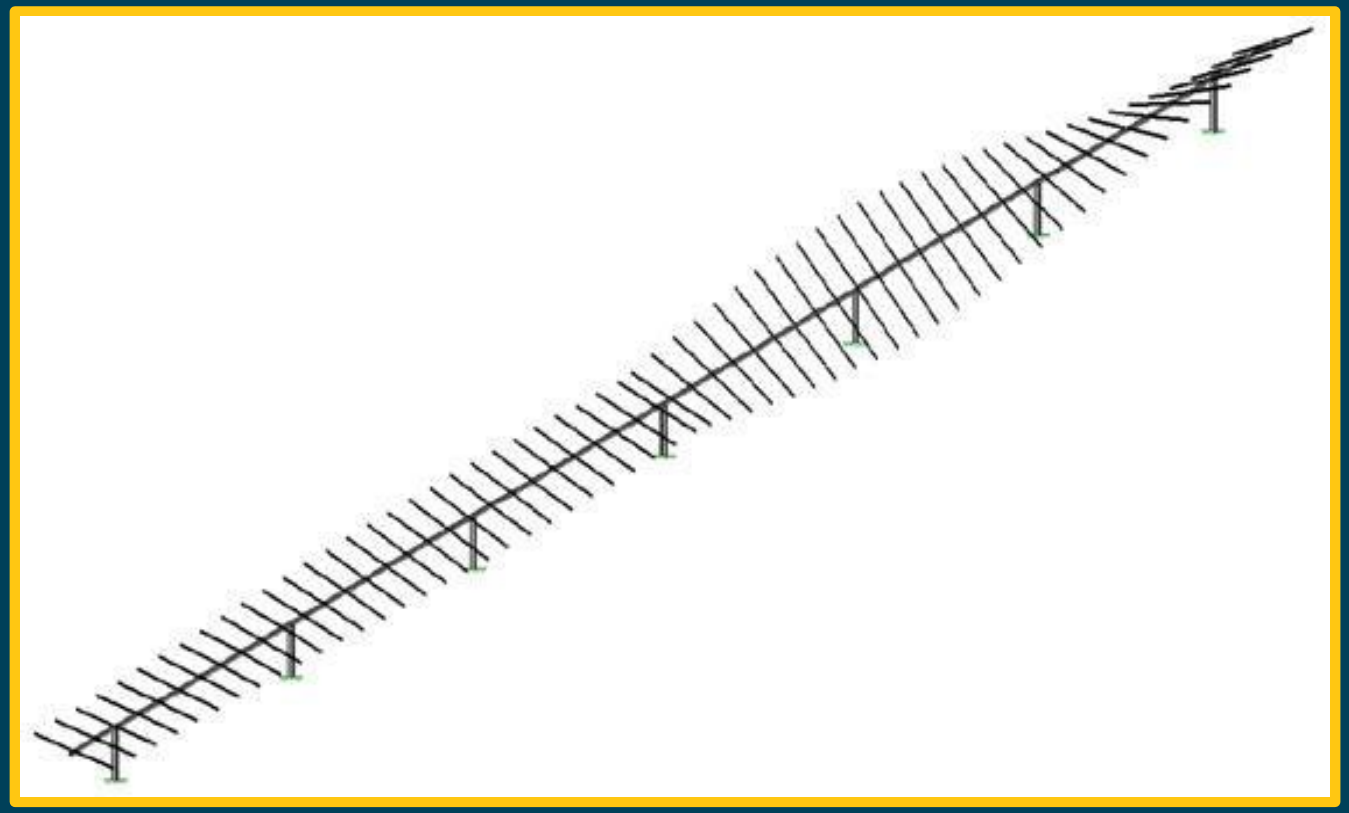


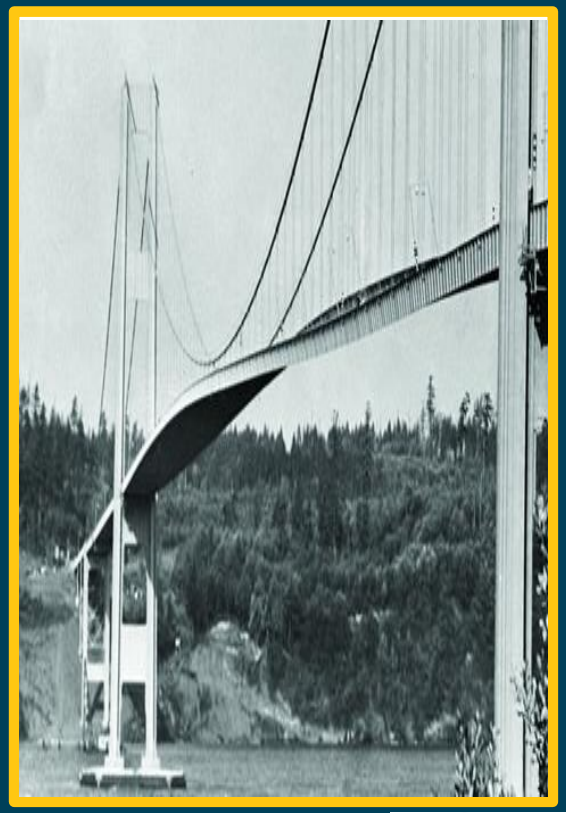


Engineered Power Solutions

Wind Instability

- Trackers susceptible to wind dynamics
- Wind dynamics may govern over static loads
- Both static and dynamic wind loads should be considered

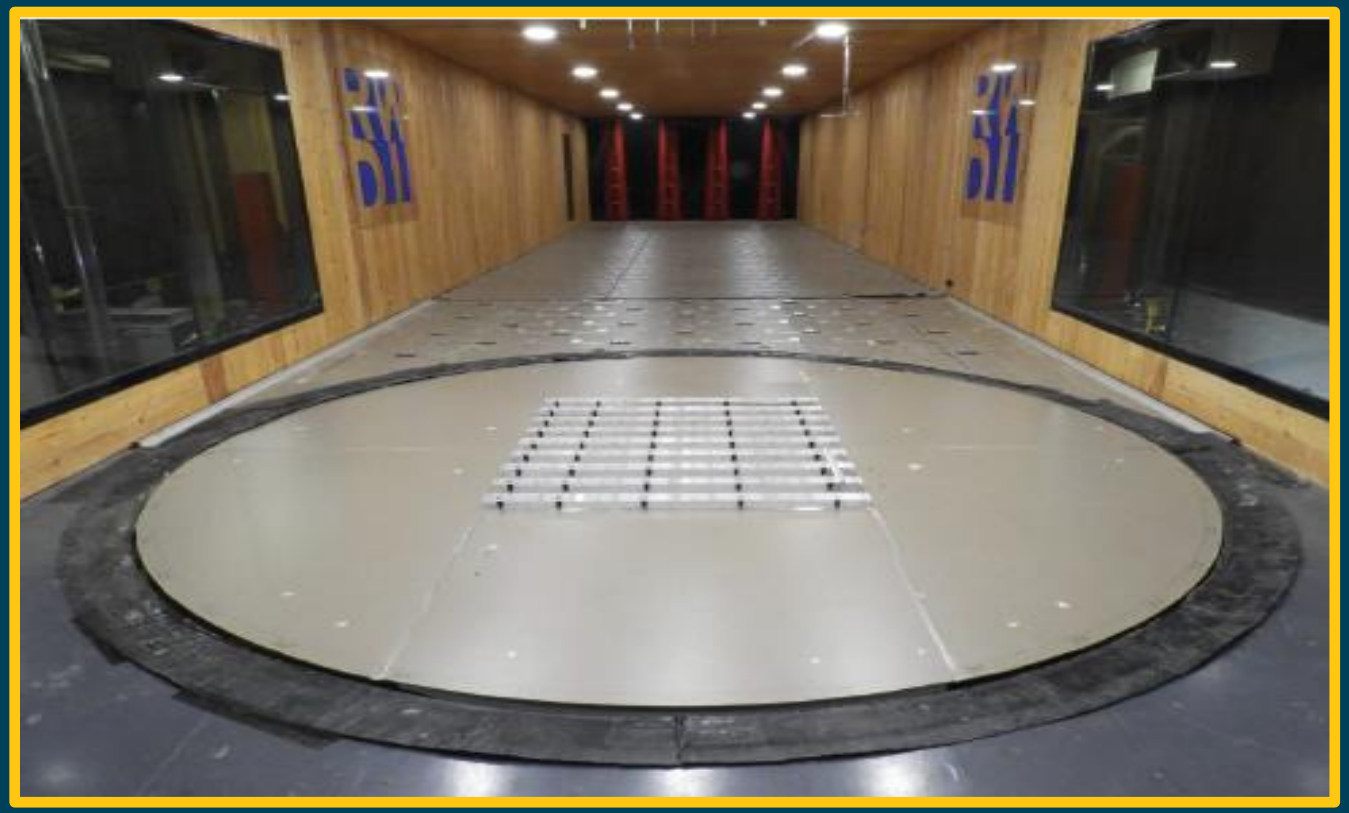


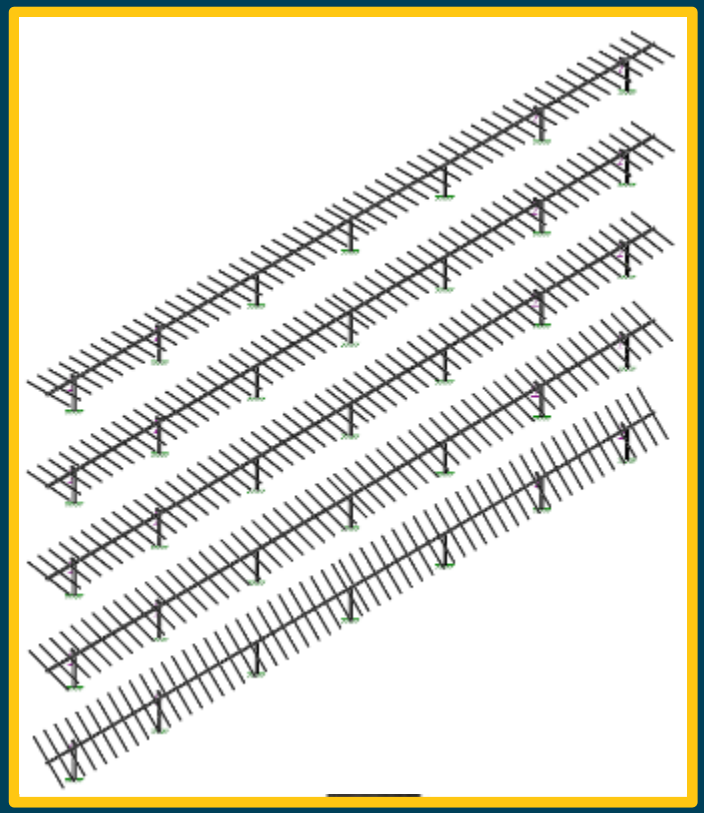


Engineered Power Solutions

Aeroelastic Strategy

- Increased stiffness (more steel)
- Stowing at a higher angle
- Dampers
- More points of fixity (motors, locking dampers, etc.)





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Voyager Addresses Aeroelastic Concerns

- Increased damper strength
- Matching deflection results of wind tunnel testing physical models with computer models
- Determination of torsional rotation and corresponding loads

Engineered Power Solutions

Design for Stability (and Other Dynamic Behavior)

FTC's Digital Tracker


Validation Testing at R&D Facility

- Wind tunnel testing is the best first step
  - Wind field and loads on tracker
  - Static and dynamic motion
  - Full character of dynamic behavior partly obscured by data reduction and instrumentation limits
  - Limited by what can be included in the scale model
- Dynamic modeling (Adams and similar)
  - Needs wind fields and loads as inputs
  - Requires correlation with wind tunnel and field measurements
  - Can include very complex and non-linear behavior (eg a damper or bearing with play)
  - No instrumentation limits – everything can be "seen"
- A team of experts (RWDI, EPS and others) for independent review
- Combining the three gives a complete and accurate picture of tracker behavior

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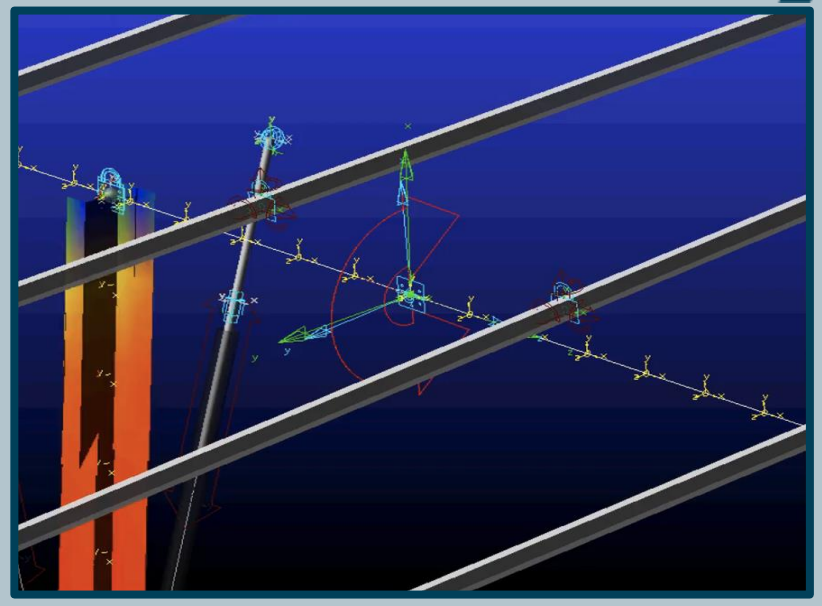
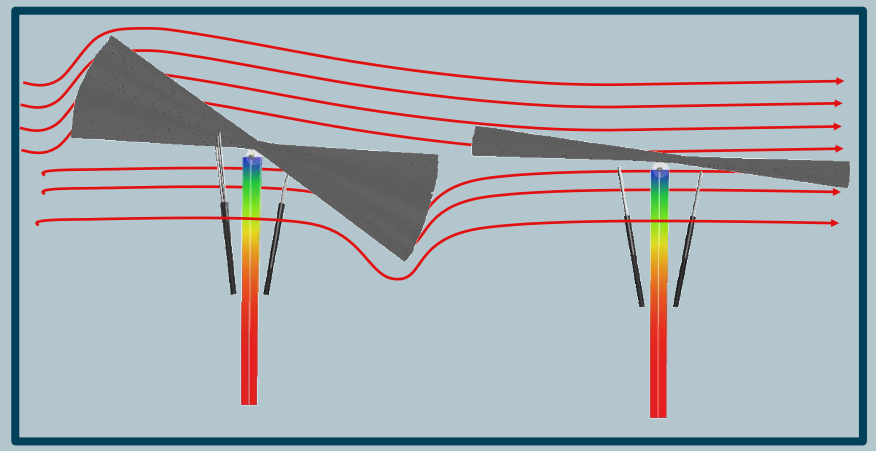
Adams Model

Things That Can Be Included With Adams

- Dampers with play
- Bearings with friction and play
- Structural damping with load dependence
- Slew drive with equation-based motion profile
- Flexible torque tubes with play in couplers
- Flexible rails and modules
- Flexible piles and soil resistance above point of fixity
- 14 wind splines distributed along the length of a row
- Moments and forces on each rail that vary with rail angle
- Wind and loads adjusted for different row types
- …





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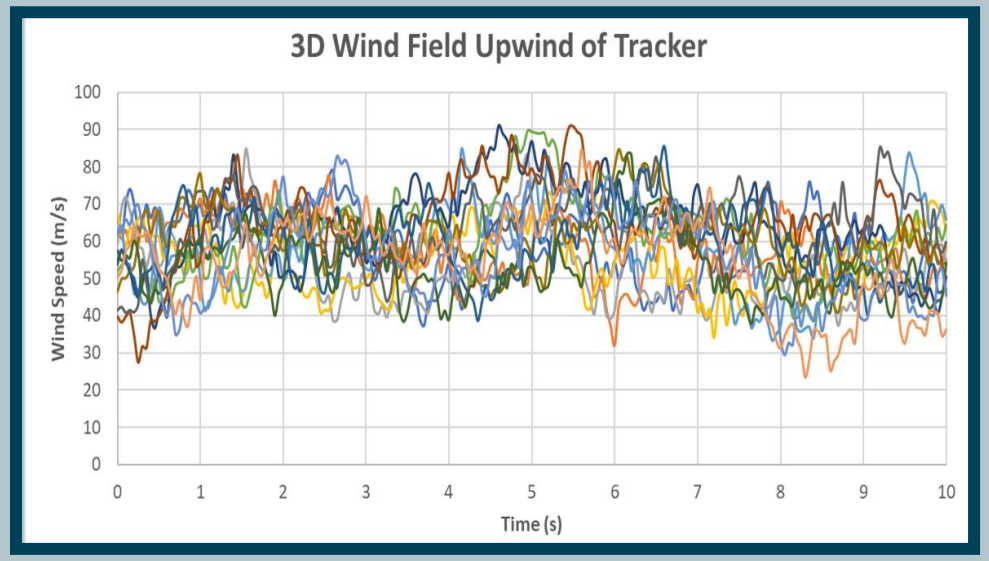
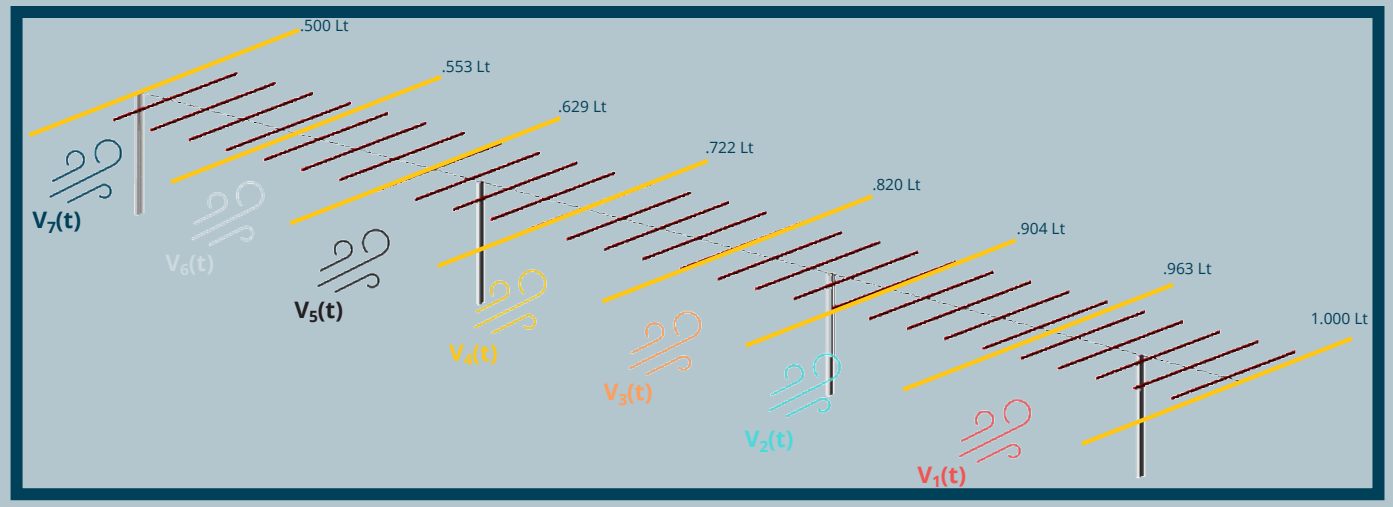
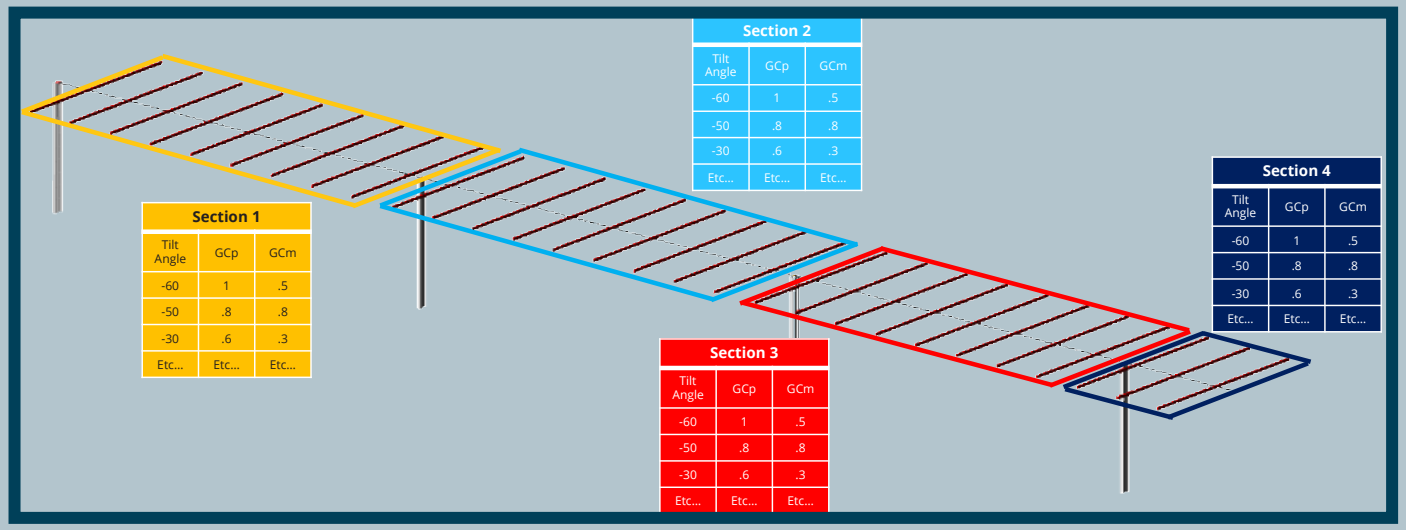
Adams Model

RWDI Synthesis







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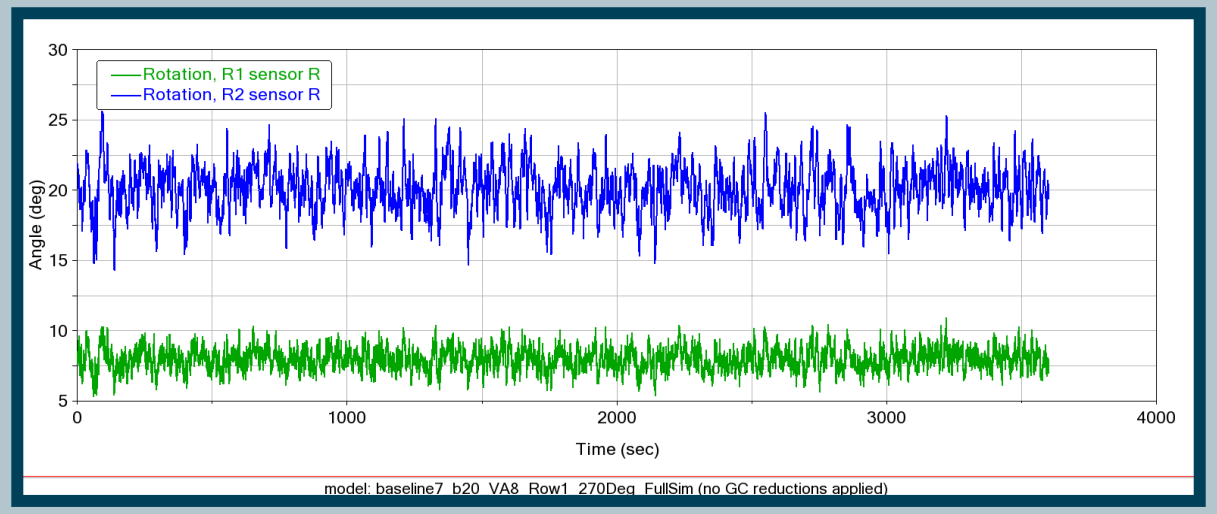
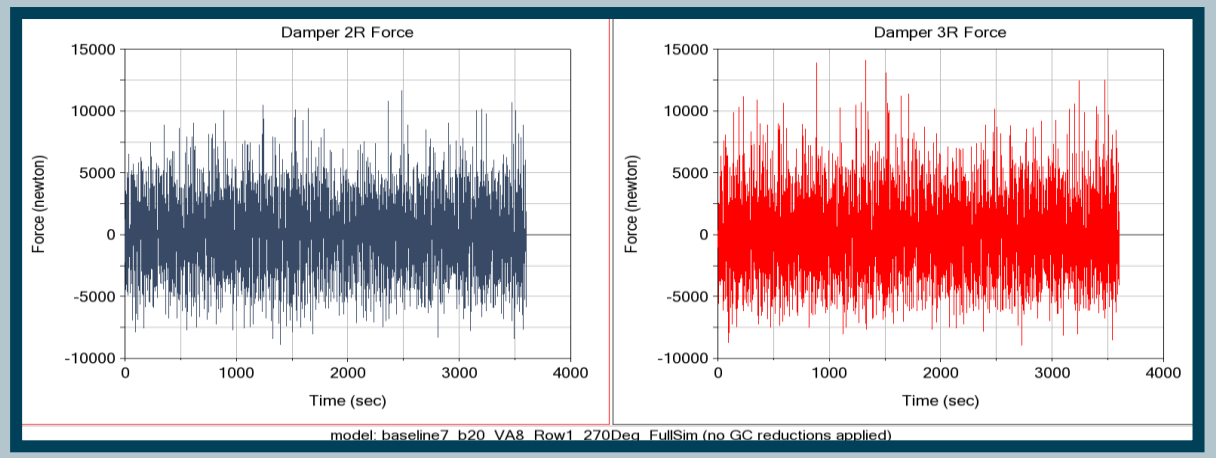
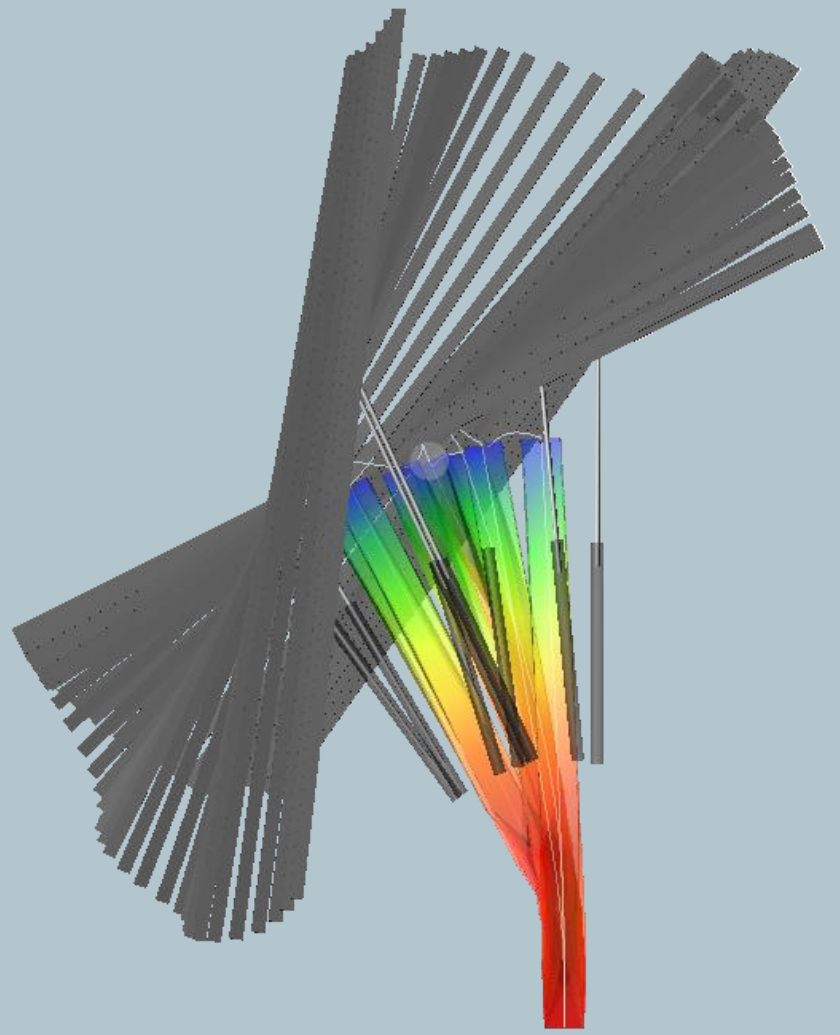
Adams Model

Typical Results







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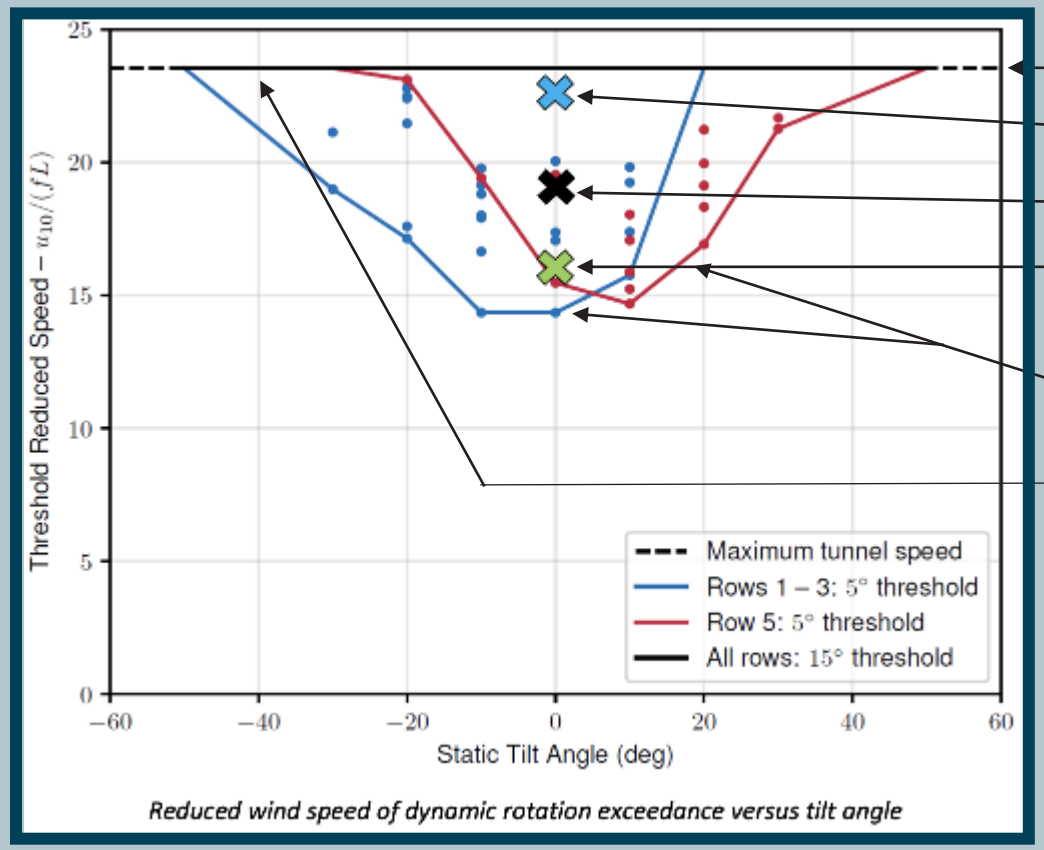
Stability Conclusions

RWDI + Adams



Reduced wind speed of dynamic rotation exceedance versus tilt angle

- **Wind tunnel tests show Voyager+ is very stable for all practical designs**
- **Adams extends for elements not included in the wind tunnel scale model**

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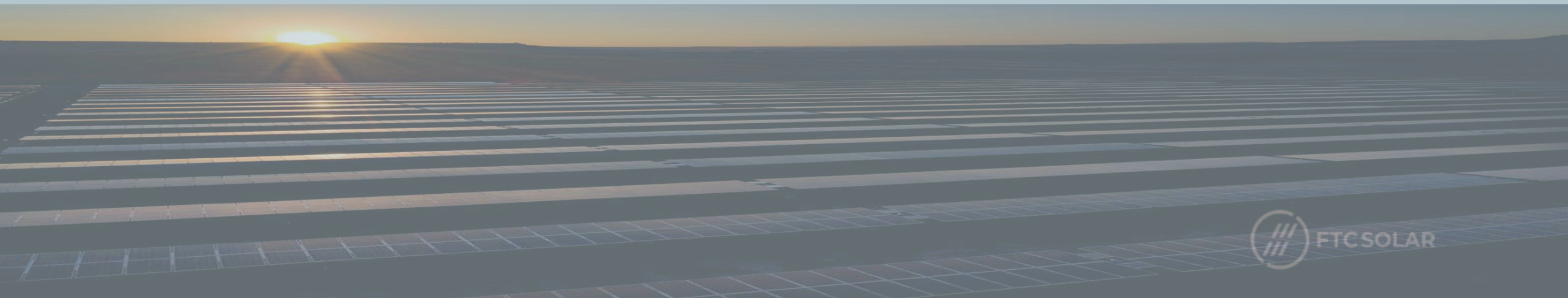
Conclusion

- Damping is not new, but very large amounts were uncharted territory
- The Voyager stow-flat tracker is highly stable with very large amounts of damping
- This directly contradicts the current industry consensus about stow-flat trackers
- These conclusions are backed up with comprehensive wind tunnel and field testing plus state-of-the-art dynamic modeling



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Download our wind mitigation white paper!

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Questions?

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FTC Solar integrates industry-leading engineering, software, and lean construction to lower the total cost of ownership and deploy reliable solar tracking solutions.

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1/6/2022