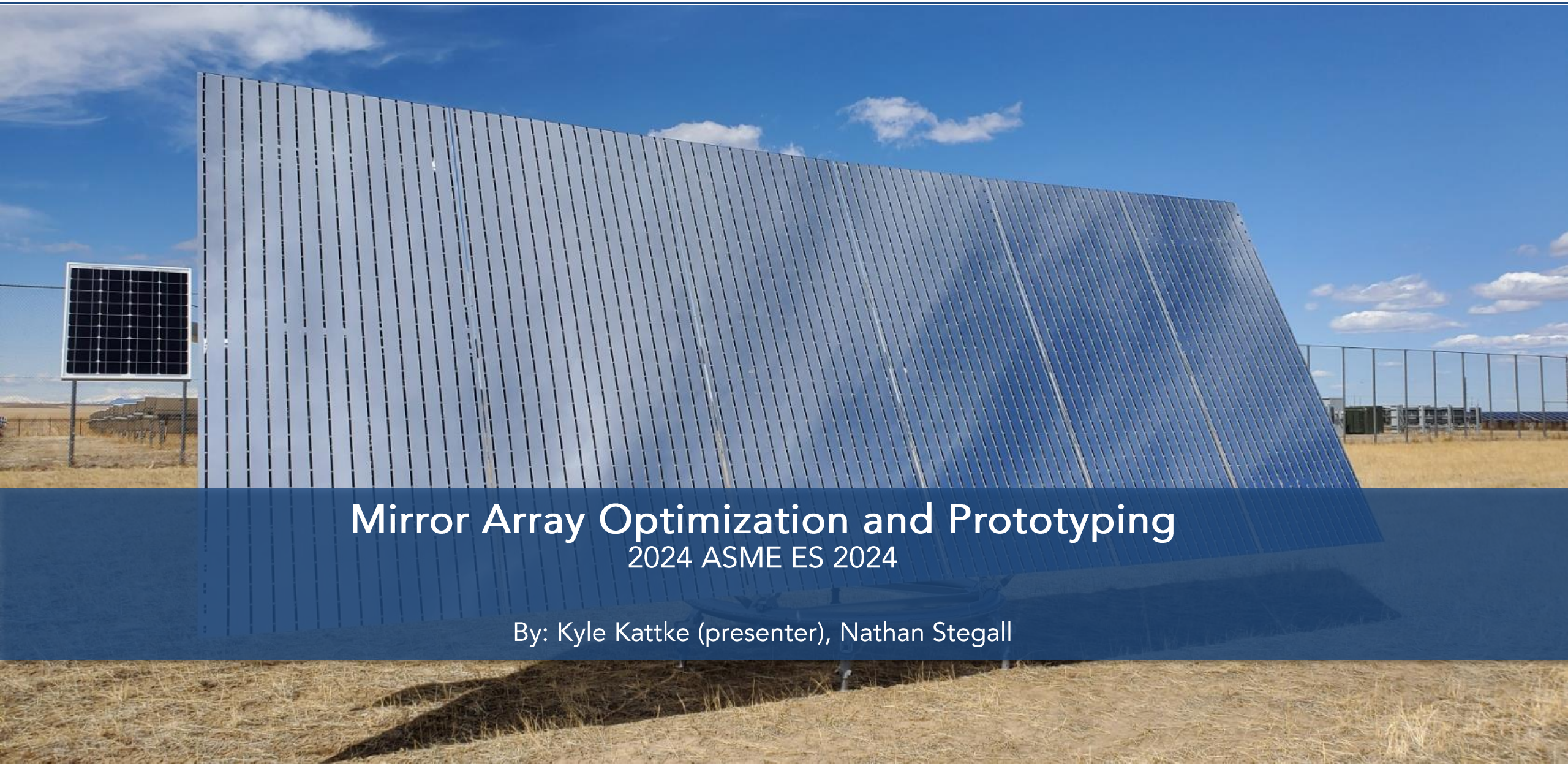


Mirror Array Optimization and Prototyping

2024 ASME ES 2024

By: Kyle Kattke (presenter), Nathan Stegall

Solar Dynamics Heliostat Development History

SolarDynamics LLC
Concentrating on a new energy future

SunRing Focus

Pedestal Heliostat Focus

Drop-C Project (4.4 years)
- Wind tunnel testing
- 3 x full-scale prototypes
- Wireless Mesh Network testing

HelioCon Project A: Heliostat Refinement (24 months)
- Prototype of new mirror array and assembly jig
- Auomated assembly line design
- Heliostat cost model covering 30-year lifecycle

SBIR Project: Phase 1 (12 months)
- Improved azimuth drive design
- Proof-of-concept lifecycle testing

SBIR Project: Phase 2 (24 months)

Budget Period 1
- Refined azimuth drive thru lifecycle testing

Budget Period 2
- Heliosat prototype w/ NREL measurements of:
  - Optical performance
  - Dynamic wind loads

Oct 2017 — Feb 2022 — July 2022 — May 2023 — Aug 2023 — Oct 2024 — Aug 2025

HelioCon Project B: Wireless Demonstration (21 months)
- Demo Wireless Mesh Network in Sandia's heliostat field

Heliostat Prize (20 months)
- DFMA Redesign for Economical American Mfg

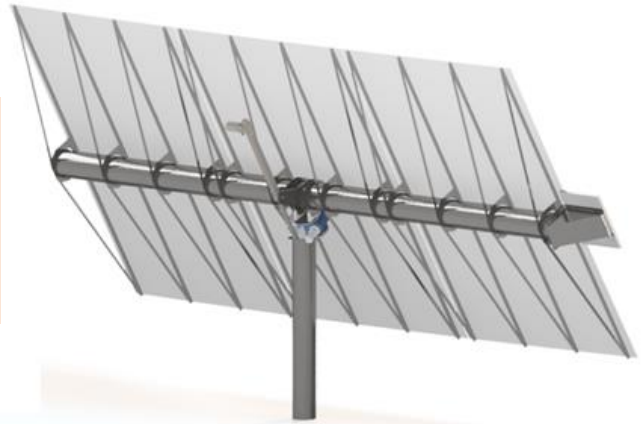
today

Design Updates

Pedestal Heliostat

Mirror Area	21.2 m^2
Optical Shape	2-D paraboloid
Facet Array	3 facets in portrait

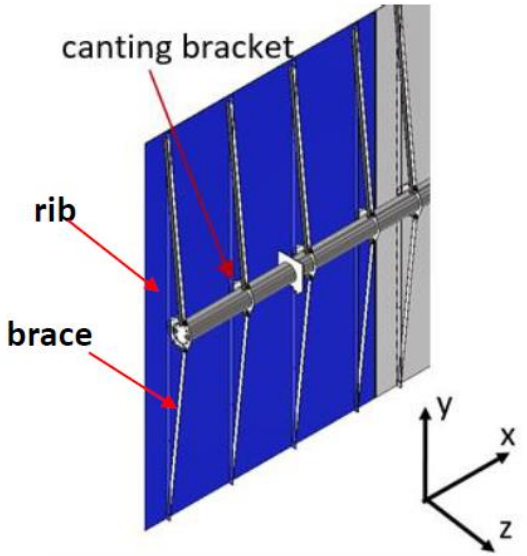
Power and Control	PV w/battery and wireless
Wind Criteria (3-sec gust)	40 mph any orientation 110 mph survival



Pedestal Heliostat

Mirror Array

- Larger format facet – maximize shipping density in standard shipping containers
  - Old: 3.21m tall x 1.4m wide
  - New: 3.21m tall x 2.2m wide
- Added 2D paraboloid curvature
  - Achieved with assembly workstation
    - Adding focused does not add material cost
    - Different focal lengths achieved based on workstation setup
- Above changes required a re-optimization of the mirror array design



Mirror Support Structure

Mirror Array Optimization

- Finite Element Analysis (FEA) model created to design mirror support structure
  - Survival wind load conditions to size members
  - Gravity load only conditions used to evaluate optical performance

Optical Performance Weighting Factors

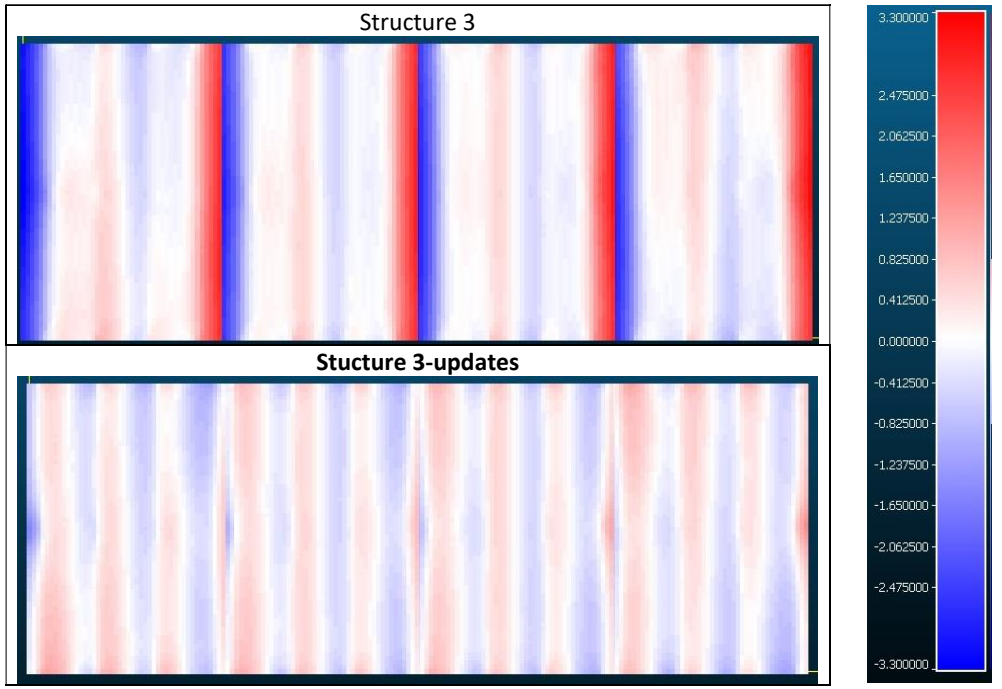
Elevation Angle [°]	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
% of Annual Energy Delivered to Receiver	1%	4%	7%	11%	18%	23%	23%	11%	1%

- Small design changes can have large optical impact
  - Moved outer ribs closer to mirror edge (220mm -> 100mm).
  - Moved holes where the braces attach closer to end of rib (51mm -> 19mm)

Slope Error Comparison on SunRing

Structure	RMS Slope Error [mrad]					
	0° Elevation Angle			60° Elevation Angle		
	σ_X	σ_Y	Total	σ_X	σ_Y	Total
3	0.38	1.24	1.29	0.73	1.11	1.33
3-updates	0.47	1.03	1.13	0.74	0.40	0.84

Contour Plot of Total Slope Error on SunRing

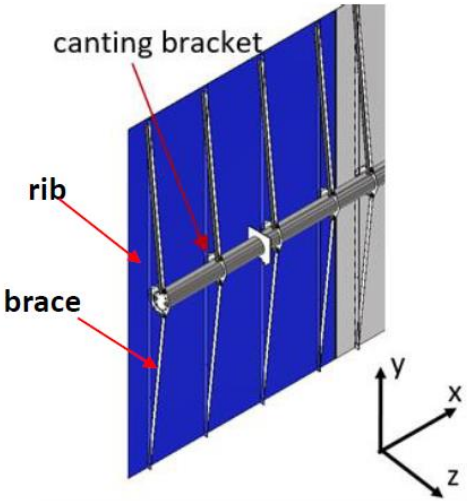


No-Cost Tuning

- Gravity load induced optical error can be minimized through no-cost tuning

- Elevation angle adjustment: compensate for overall rotation about x-axis (torque tube twist)
  - Achieved with correction factors as f(elevation angle) in heliostat's controller
  - At 60°: RMS slope error reduces from 2.1 to 0.72 mrad

- Individual facet adjustment: compensate for local x- and y-axis errors
  - Achieved by tuning mirror array assembly workstation
  - Use 60° to calculate adjustments
  - At 60°: RMS slope error reduces from 0.72 to 0.61 mrad



Mirror Support Structure

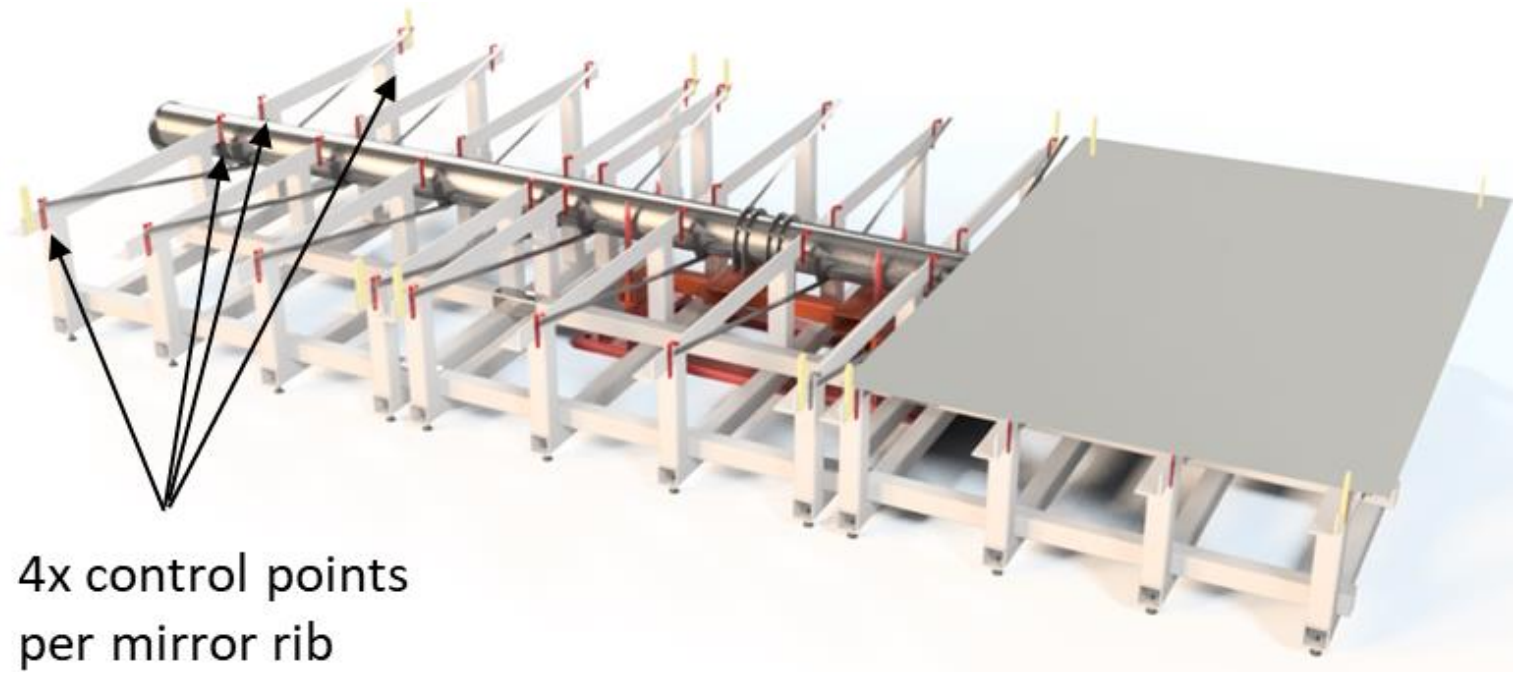
Tuned Predicted Slope Error

Elevation Angle [°]	15	30	45	60	75	Energy Weighted Average
RMS Slope Error [mrad]	1.26	1.01	0.74	0.61	0.77	0.77

Results specific to SunRing, expect similar performance from pedestal heliostat

Mirror Array Assembly Workstation - Design

- Objective: Hold mirror facets in predefined shape until mirror support structure is attached locking in shape
- Design: Mirrors face up on jig, supported by 16x control points per facet
  - Control points adjacent to attachment points between facet and support structure
  - Control points are vertically adjustable
- Application: Easily adjust heliostat's optical shape enabling:
  - Minimizing gravity induced slope errors
  - Production of multiple focal lengths
- Testing: Prototype to be built in August



Mirror Assembly Workstation: Prototype CAD Model

Mirror Array Assembly Workstation – Testing Sequence

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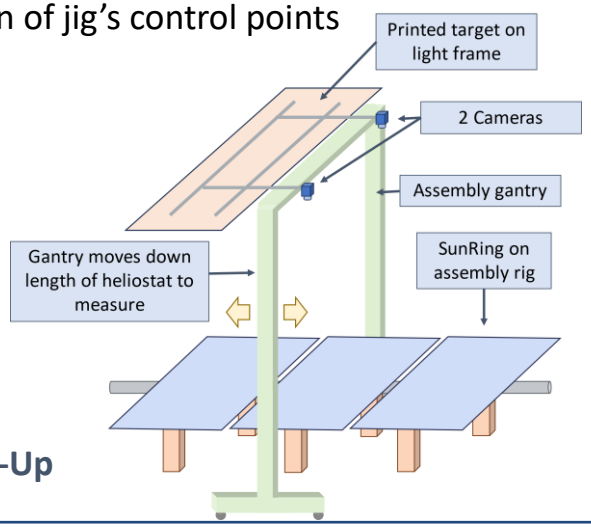
#1: Build Mirror Array on Workstation

- Place torque tube into mirror array jig
- Place facets onto mirror array jig
- Connect facets to mirror support structure
  - Simulate clinched joints with clamps

Mirror Assembly Workstation

- Use NREL's ReTNA to measure slope error while on jig
- Coarse calibration of jig's control points

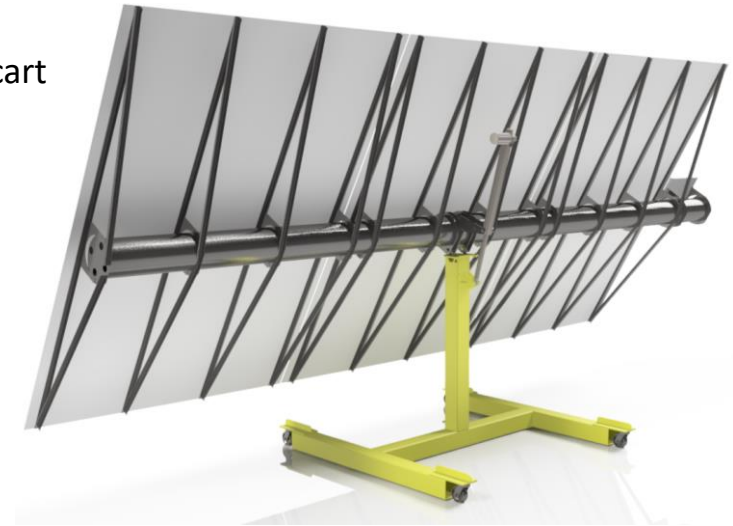


ReTNA Set-Up

Iterate on height of control points until SOFAST measured slope error is minimized

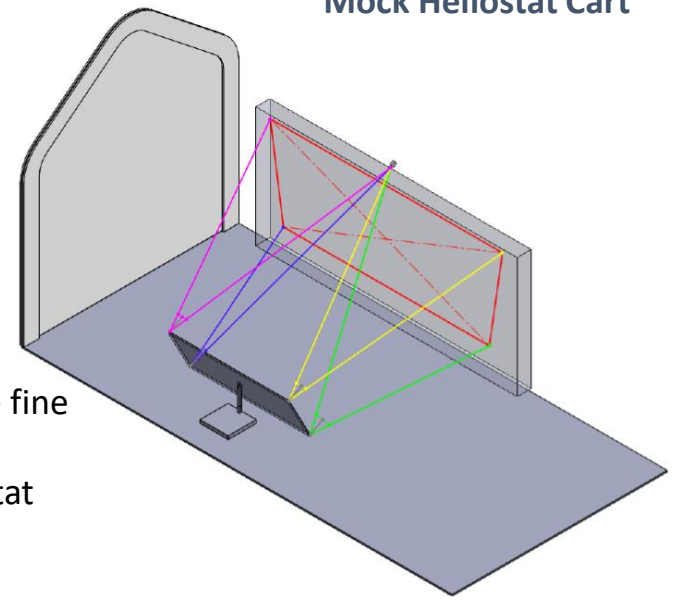
#2: Mock Heliostat Cart and SOFAST

- Place mirror array onto heliostat cart
- Attach linear actuator
- Move cart to SOFAST testing area



Mock Heliostat Cart

- Use Sandia's SOFAST to measure fine resolution slope error
- Performed at ~60° where heliostat performance is optimized



SOFAST

Summary

- Solar Dynamics has changed focus from the SunRing to a pedestal style heliostat
- Mirror array updates include larger facet and adding 2D focusing
- Mirror array assembly imparts optical shape and compensates for gravity induced error
- Prototyping with SOFAST metrology to start in August

Acknowledgements

This project was made possible with funding from the US Department of Energy's Solar Energy Technology Office under HelioCon award SUB-2023-10314.

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