SolarDynamics LLC *Concentrating on a new energy future*

SunLite Heliostat: Mirror Array Optical Design, Tuning, And Testing

HelioCon Seminar July 23rd 2025

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Solar Dynamics heliostat development history

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- Solar Dynamics LLC - located in Denver, CO, USA
- Small company focused on CSP collector technology, TES, O&M services, & consulting
- Low-cost heliostat development since 2017
  - Focused on US market needs, supply chain, and manufacturing (but applicable worldwide)
  - Design suitable for large and small tower receivers
  - Supported by several US Dept. of Energy R&D and Heliostat Consortium (HelioCon) projects
  - Initial design focus on carousel heliostat, recent re-focus on pedestal heliostat with novel mirror support design

SunRing™ Carousel Heliostat

SunLite™ Pedestal Heliostat

Oct 2017 | Feb 2022 | Jul 2022 | May 2023 | Aug 2023 | April 2025 | Today

SunShot Project
- Initial design & prototypes
- Wireless communication development

SBIR Phase 1
- Improved azimuth drive
- Initial lifetime testing

SBIR Phase 2
- Commercial candidate prototypes & extended testing
- 3rd party optical performance validation

HelioCon Project #1
- Advanced mirror support design
- Automated assembly

HelioCon Project #2
- Wireless communication demonstration

American Made Heliostat Prize
- Design for manufacturing & assembly

SunLite™ pedestal heliostat

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Mirror Area	21.2 m^2
Optical Shape	2-dimensional paraboloid
Mirror Array	3 facets in portrait
Power & Control	PV w/ battery wireless communication
Wind Criteria (3-sec gust)	18 m/s (40 mph) any orientation 47 m/s (105 mph) stow survival

- Key design features
  - "Lite" streamlined design
    - Roll formed parts w/ minimal processing
    - Weld-free torque tube option
    - Mechanical clinches in place of bolts / rivets
    - Designed for automated assembly
- Advantages over SunRing
  - Faster time to market
    - Using off-the-shelf azimuth slewing drive vs. custom roller pinion based azimuth drive
  - 70% fewer parts, 83% fewer fasteners
  - Lower on-site labor & equipment costs
  - Greater % automated assembly

Mirror Array Design Updates

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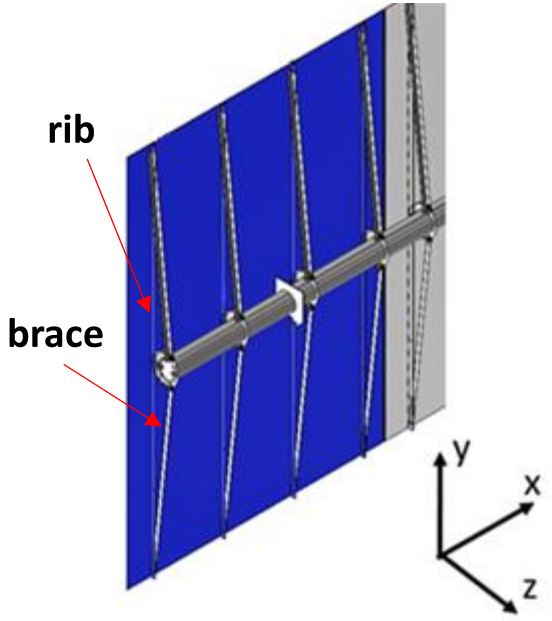
SunLite Mirror Array Design Space

Design Parameter	Design Space	Down Selected Option(s)	Previous SunRing Design
Focusing	• Flat, 1D, and 2D focusing	2D paraboloid for overall mirror array	Flat
Mirror Size	• Height: 3.21 m • Width: 2.1-2.5 m	3.21m x 2.2m	3.21 x 1.4m
Mirror Thickness	• 3 mm • 4 mm	4mm	4mm
Facet Layout	• 1 rows in portrait • 2 rows in landscape	1 row x 3 columns in portrait	1 row x 6 columns in portrait
Mirror Attachments	• Ceramic pads • Angle tabs • Ribs • Rib grid	Bonded ribs	Bonded ribs
Mirror Bracing	• None • 2 braces per rib • 4 braces per rib • Shared between facets	2 braces per rib & no-shared braces	None
Structural connections	• Bolts and rivets • Mechanical clinched	Mechanical clinched	Bolts and rivets



Predicted Optical Performance

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- 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

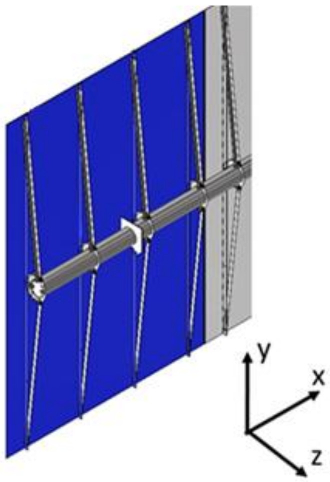
Elevation Angle [°]	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
% of Annual Energy Delivered to Receiver	1%	11%	23%	23%	18%	11%	7%	4%	1%

- Minimizing gravity induced error through <u>no-cost tuning</u>
  - Elevation angle adjustment: compensate for overall rotation about x-axis
    - — Achieved with correction factors as f(elevation angle) in heliostat's controller
  - Individual facet adjustment: compensate for local x- and y-axis errors
    - — Achieved by tuning assembly jig for a *single elevation angle*
      - → 30° is commercial target, used 90° for prototype

Slope Error as f(elevation angle) with Jig Tuned for 30° Elevation Angle

Elevation Angle [°]		15	30	45	60	75	Energy Weighted Average
RMS Slope Error [mrad]	SunLite – 75m FL	1.05	0.76	0.76	0.93	1.1	0.85

Mirror support structure



Mirror Array Assembly Jig

- Facets supported by 48 control points with vertical adjustability
  - Control points are adjacent to the 48 clinched connections between the mirror facets and mirror support structure
    - the mirror array is supported with similar boundary conditions on the workstation as on the heliostat

- **Optical Tuning Goal** – adjust height of control points such that these points when superimposed on mirror surface (mirror points) lie on the 2D paraboloid surface with a 75m focal length and compensate for gravity deformation at 90° elevation angle

Mirror array workstation – without facets

Mirror array workstation – with facets

Optical Tuning: Physical Results

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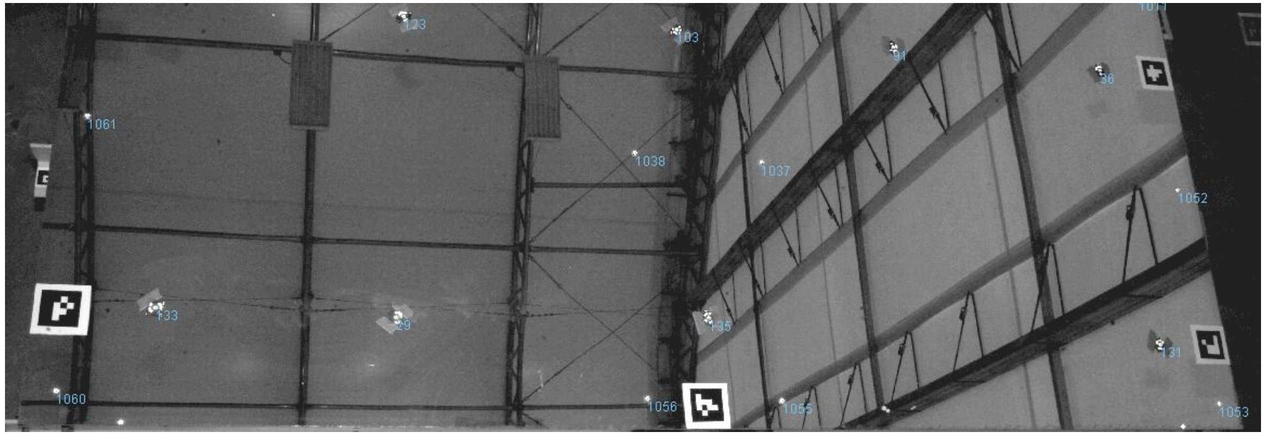
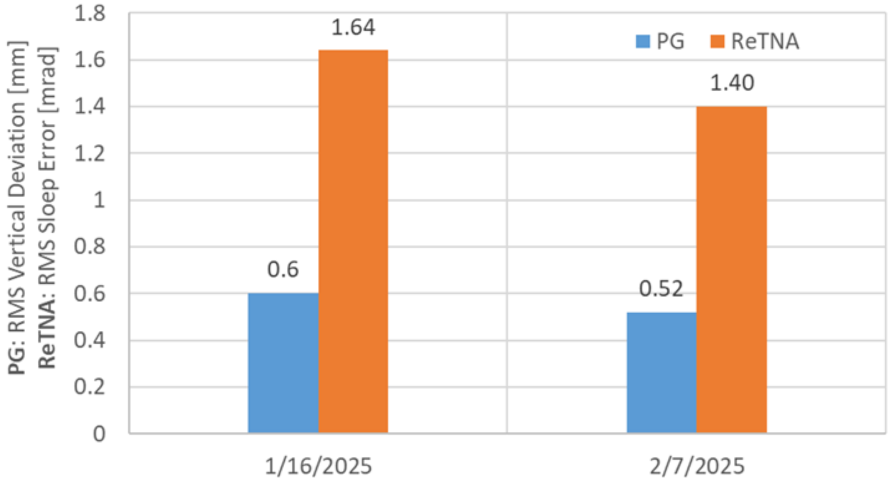
- Used Photogrammetry (PG) to measure the spatial position of the mirror points with mirror array <u>lifted off jig and supported similar as when installed on the heliostat</u>
  - Mirror points under gravity loading at 90° elevation angle
- Compared PG point cloud to ideal 75m FL paraboloid
  - Spatial difference became vertical corrections for each control point.
  - FEA showed that minimizing control point deviations also minimizes RMS slope error
    - — Supported by ReTNA results

PG Identified Mirror Points on Portion of Mirror Array



Error Progression in Final 2 Round of Jig Tuning

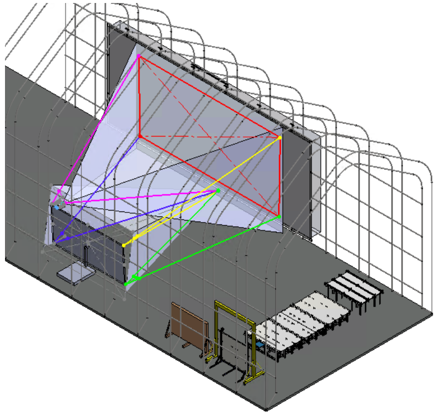


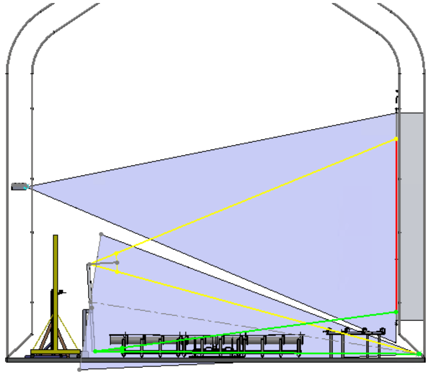
- Slope error would decrease further with subsequent jig tuning
  - FEA predicts an ideally tuned jig <u>with actual prototype mirror</u> facets yields 1.16 mrad RMS slope error
  - 21% higher than ideal FEA prediction with perfect mirror facets is within expectations
- Jig tuning stopped after 2/7 due to scheduling constraints, but will continue under SBIR project in Fall 2025

Optical Testing - SOFAST

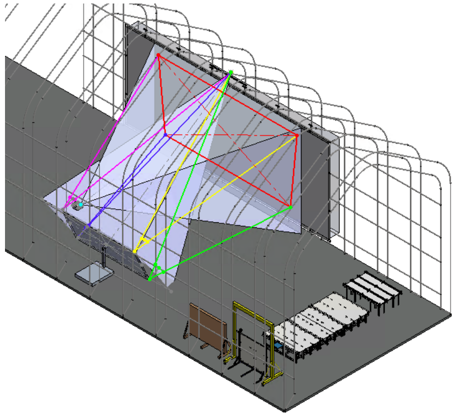
- Sandia designed SOFAST for SolarTAC test facility to:
  - Image complete mirror array
  - Capability of measuring at multiple elevation angles

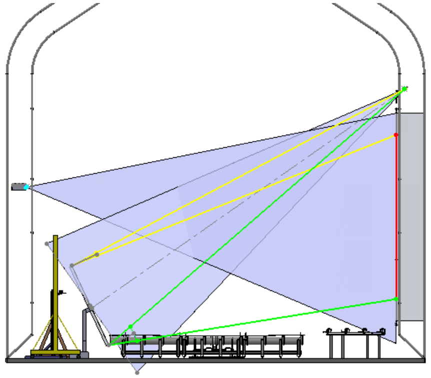
Camera Position A: Measure at 3.5° Elevation





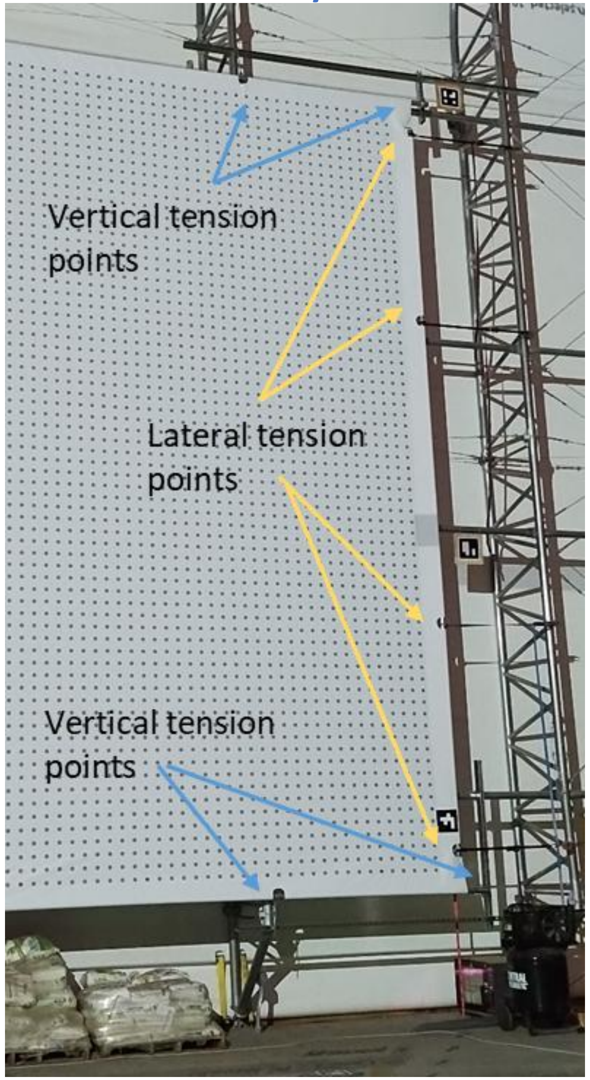
Camera Position B: Measure at 25° Elevation





- SD designed and deployed 1st of a kind stretched screen
  - 60.75 ft wide x 25 ft tall
  - Vinyl screen with pockets on 4 sides
  - Piping in pockets provide attachment points to pull tension
  - Testing limited to calm wind periods to minimize screen movement

Stretched Vinyl SOFAST Screen



Optical Testing - SOFAST

- Sandia commissioned SOFAST at SolarTAC on in Oct 2024
  - Performed on 1st article mirror array (<u>before optical tuning iterations</u>)
  - Both SOFAST-fixed and SOFAST-fringe calibration and measurement photos taken
- Processed results from Sandia
  - <u>Showed great agreement between SOFAST Fixed and Fringe</u>

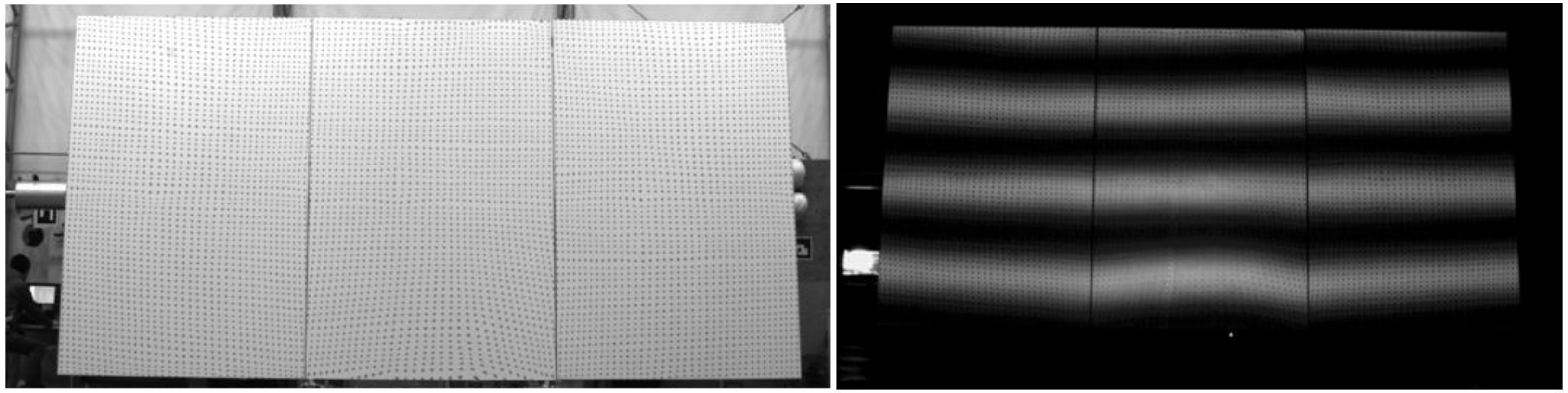
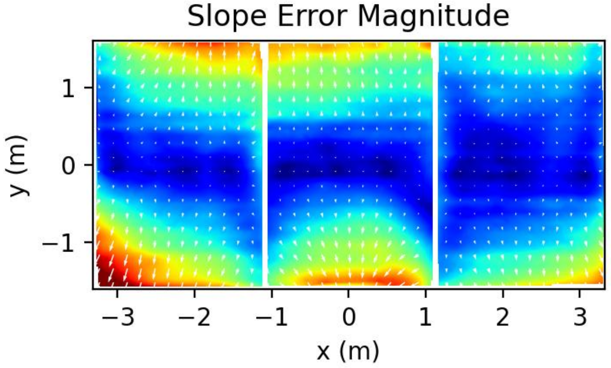
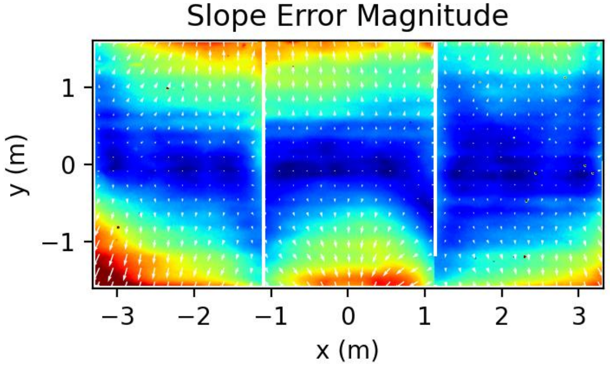


Image of mirror array at ~87° from SOFAST camera
Fixed mode (left) & fringe mode (right)

<u>Fixed</u>



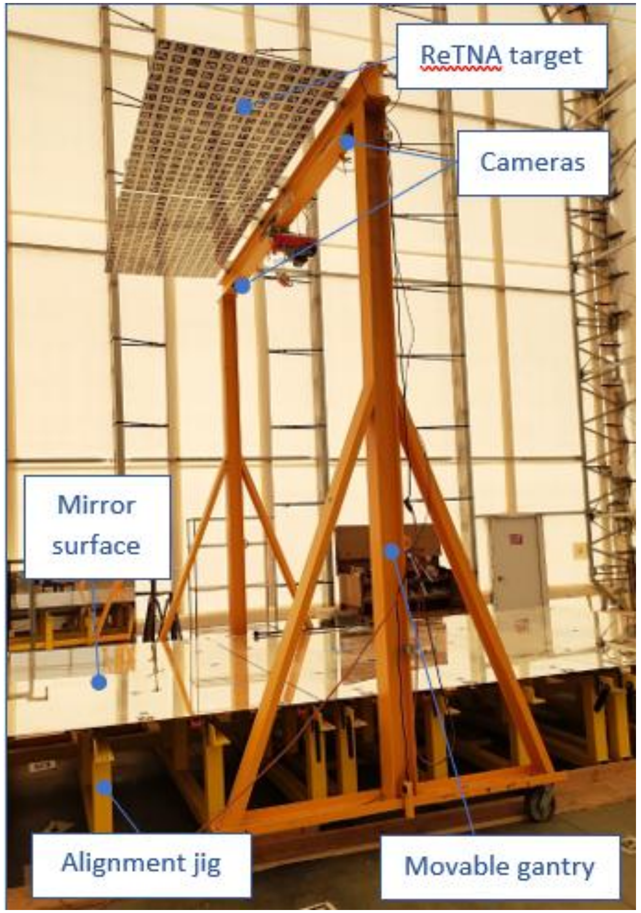
<u>Fringe</u>



- Due to delay in SOFAST processing and difficulty moving mirror array on/off jig and onto cart, <u>ReTNA was used as optical feedback for jig tuning</u>

Optical Testing - ReTNA

- ReTNA used to measure surface slope error with mirror array at 90° elevation angle
  - ReTNA target and cameras positioned above mirror array on gantry crane
  - Sequential pictures of target reflection gathered as gantry crane moved across mirror array
  - Images stitched together to represent the full mirror array



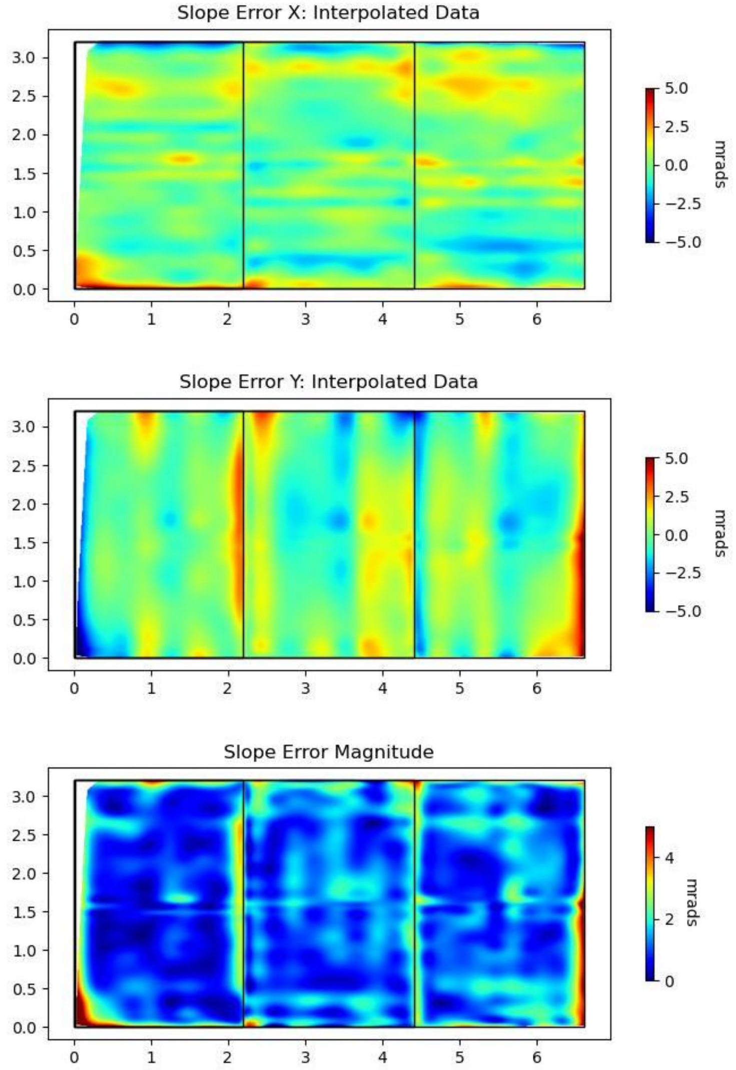
ReTNA Set-Up During Measurement

ReTNA Final Measurement

Slope Error x-axis: 0.9 mrad RMS

Slope error y-axis: 1.1 mrad RMS

Slope error total: 1.4 mrad RMS



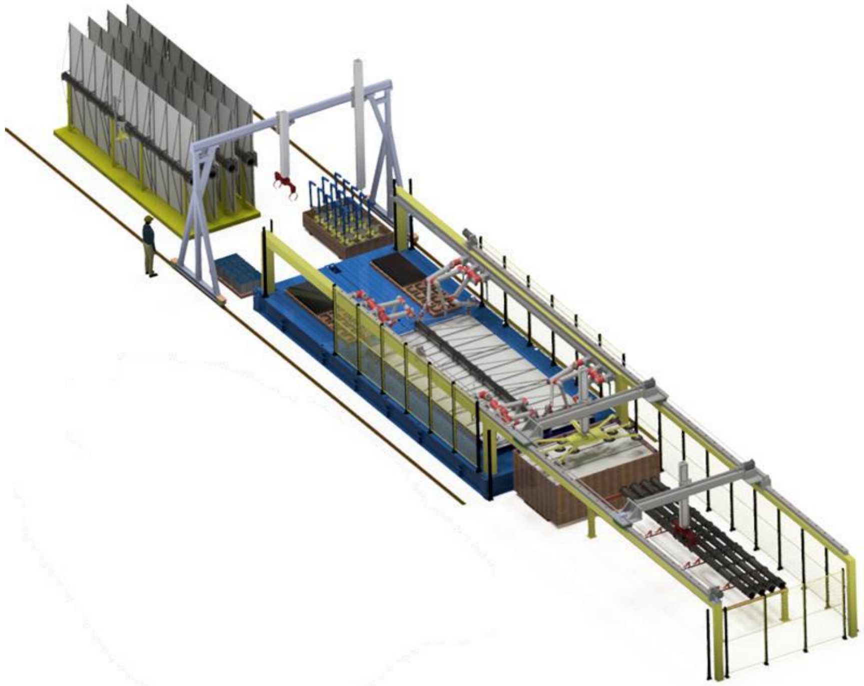
Next steps

- Continue testing under SBIR funded project
  - Confirm tracking accuracy (0.5 mrad measured to date)
  - Perform additional optical tuning of mirror array jig to achieve commercial slope error performance
    - Jig tuned to commercial 30° elevation angle
    - Build up to 2 more SunLite's

1st SunLite Prototype – with mirror array from HelioCon project

- Prototype automated assembly system
  - Awaiting decision on DOE FOA proposal

Commercial Automated Assembly Line Design



Thank you!

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