SunRing^{TM} Heliostat

Minimizing Slope Error with Smart Design and Assembly

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Kyle Kattke
kyle.kattke@solardynllc.com

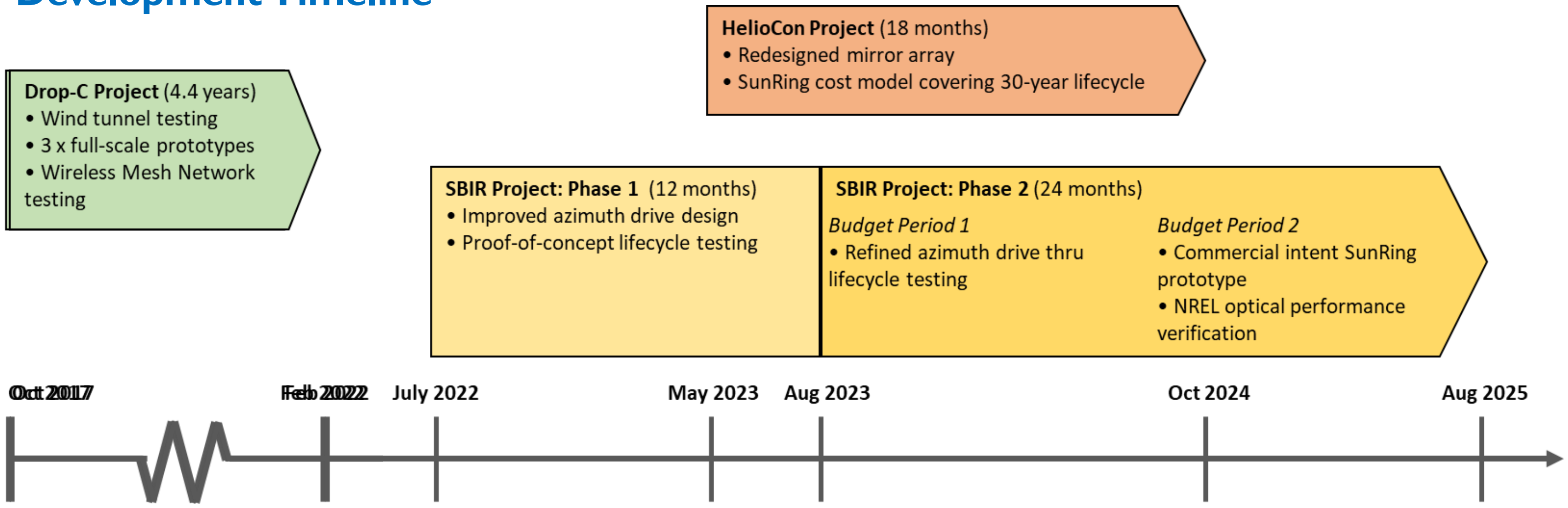
SunRing Introduction

SunRing Prototype: Rear View

Key Attributes			
Structure	Carousel space frame	Foundation	6 **(3)** x screw piles
Reflective area	27 **(28.2)** m^2	Power	PV plus battery
Mirror array	8.46 **(8.8)** m x 3.21 m 2.6 **(2.7)** aspect ratio	Control	Wireless
Stow height	1.98 m	Elevation drive	Linear actuator
Optical shape	Canted with flat facets **(2-D focused)**	Azimuth drive	Roller pinion and geared track

Black: Original Drop-C Project **Blue:** Changes in current design

Development Timeline



Performance

- Total installed cost < \$100/m_2 at commercial scale
  (10-20% additional cost savings)
- Optical error: 1.65 mrad slope error (calm conditions)
- Wind criteria: 35 mph maximum tracking / 94 mph survival in stow

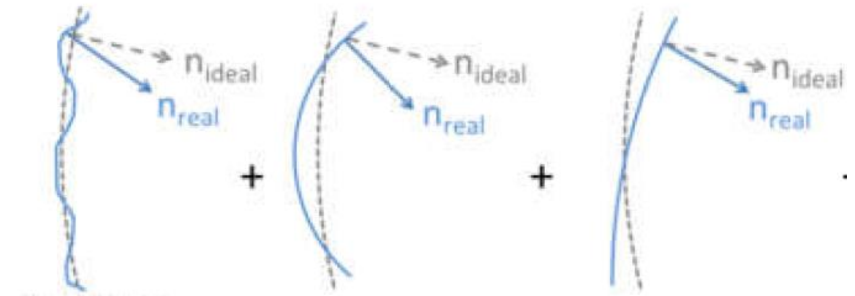
Optical Error Introduction

- Total optical error comprised of Slope Error and Tracking Error
  - Slope error is the focus in this presentation
- Slope error is deviation between actual mirror surface's normal vector and ideal optical shape's normal vector
- SunRing ideal optical shape = 2-D focused paraboloid
  - Focal length dependent on distance to tower

- Slope error is not constant, dependent on:
  - Heliostat orientation (i.e. time of year and location in solar field)
    - Errors due to gravity load
  - Wind speed and direction
    - Errors due to wind load
  - Temperature of the heliostat
    - Errors due to differential thermal expansion

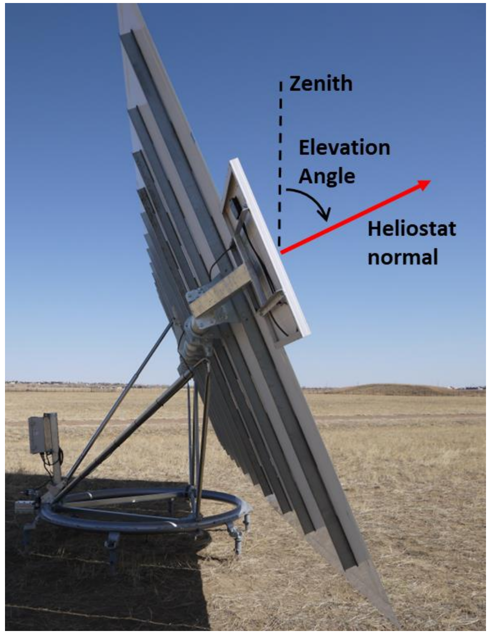
Focus of this presentation: minimize slope error due to gravity loads

Slope Error Schematic[1]



Local Waviness — Global Shape — Alignment Error (i.e. canting error)

SunRing Elevation Angle Definition



[1] Röger, Marc. SolarPACES Guideline for Heliostat Performance Testing, Draft Version 0.991.

Impact of Orientation on Gravity Induced Slope Error

- Elevation angle has a large influence on slope error
- Use annual energy delivered to receiver as weighting factor
  - Approx 1.1M m^2 field with MS receiver in Arizona, USA

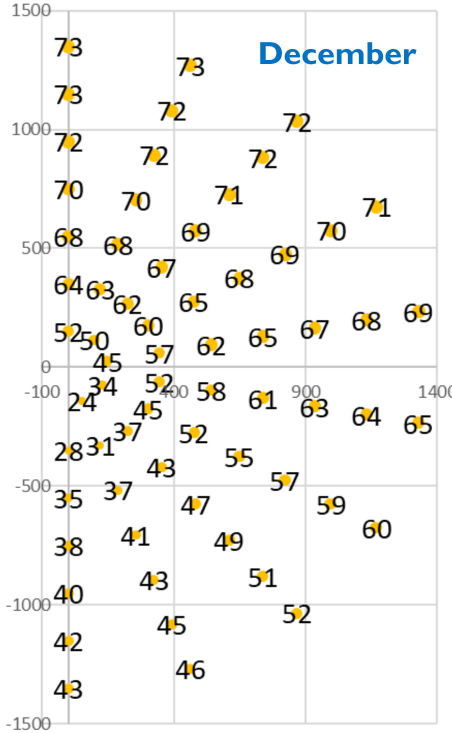
FEA Predicted RMS Slope Error from 2nd Generation Prototype

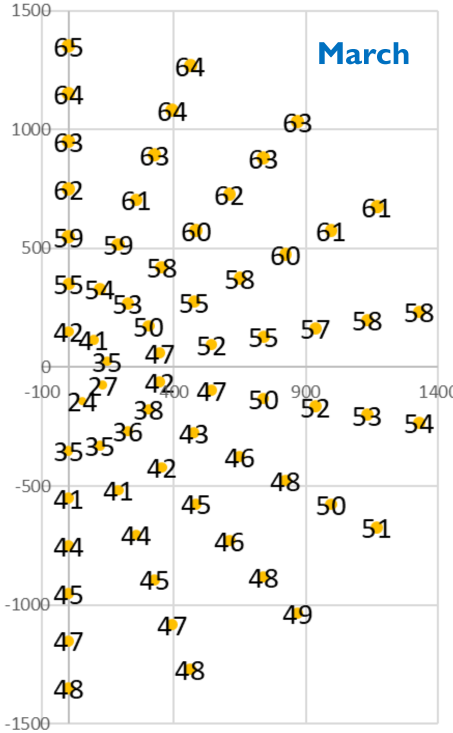
Elevation Angle [°]	30°	45°	60°	75°	Annual Avg.
Slope Error [mrad]	2.1	1.6	1.2	0.9	1.38

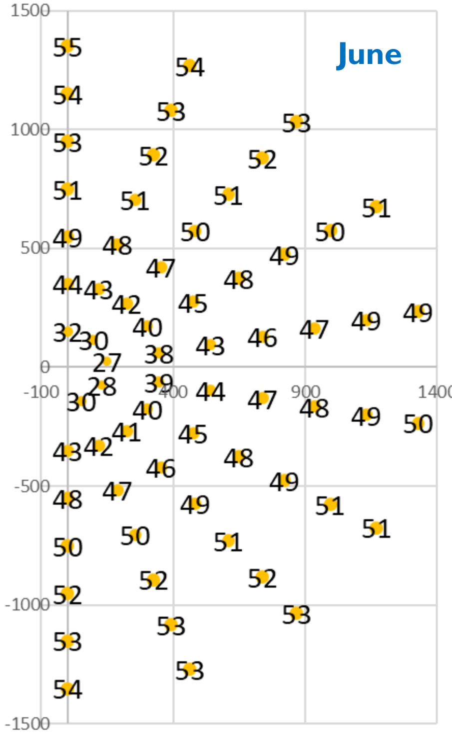
Elevation Angle [°]	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
% of Annual Energy Delivered to Receiver	1%	4%	7%	11%	18%	23%	23%	11%	1%

- Potential to tune heliostat for field location and/or time of year

Energy Weighted Elevation Angle at
- Specific Field Locations
- Specific Month







Smart Assembly to Minimize Slope Error

- Gravity loads cause rotation of each facet's overall normal vector, i.e. "canting or facet rotation error"
  - Primary cause is torque tube bending and twisting
  - Magnitude of rotation is f(elevation angle)
- Facet rotation error calculated from Photogrammetry and FEA point clouds

Slope Error due to Facet Rotation from 2nd Generation Prototype

Elevation Angle [°]		0	30	60	75	90	Annual Weighted Average
Rotation Error [mrad]	Predicted	1.29	0.84	0.33	0.44	0.75	0.47
	Measured	1.31	0.86	0.68	0.77	1.07	0.74
	Smart Assembly	0.83	0.38	0.2	0.29	0.59	0.26

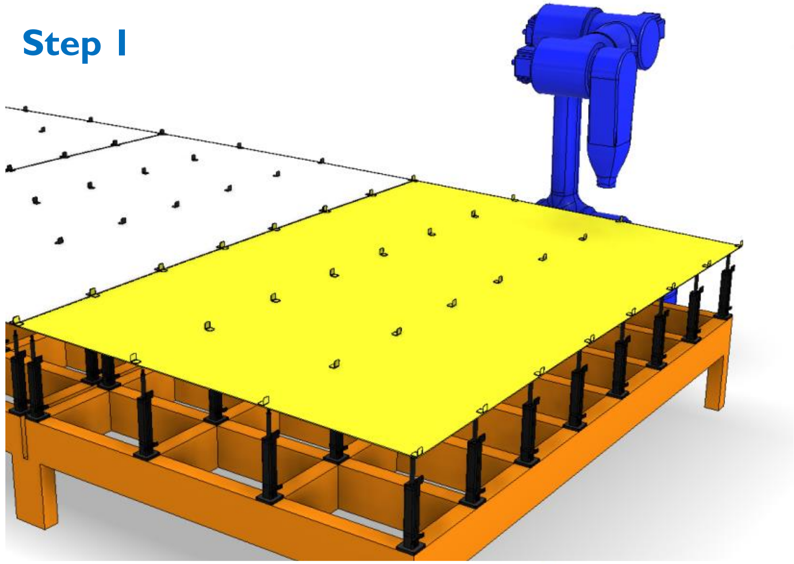
- Assembly jig can tune out facet rotation error
  - Choose 1 elevation angle for tuning (use energy delivered to receiver as basis)
  - Tune at 60° minimizes annual slope error
    - Remove most error at 60°, other orientations maintain change in error compared to the 60° case

Mirror Array Workstation

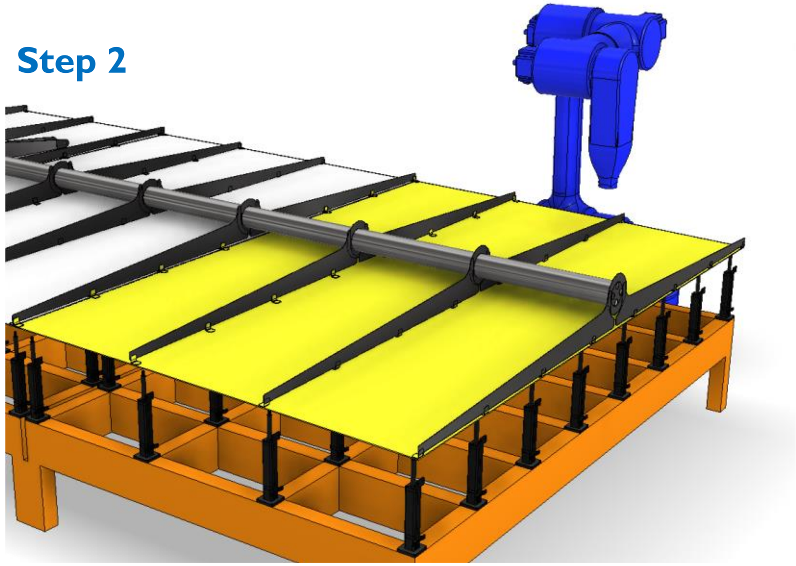
SolarDynamics LLC
Concentrating on a new energy future

- Mirror array workstation enables precision alignment of mirror facets
  - Being developed and prototyped in Q4 2023 through HelioCon project
- 2 step assembly process
  1. Place blank mirror facets onto workstation
     — Mirrors are supported at each point where they will be attached to the heliostat's mirror support structure
       → Supported with adjustable height tooling
     — Mirror supports adjust their height to realize goal mirror array optical shape
     — Canting angle offset added to compensate for gravity induced facet rotation error
  2. Attach mirror support structure
     — Locks in optical shape set by workstation
- Application: easily adjust heliostat's optical shape accounting for
  - Different focal lengths
  - Different canting angle offsets based on field location

Step 1



Step 2



Conclusion

- An annual average slope error metric is useful for design trade-off studies and for annual performance modeling
  - Energy weighted elevation angle factors incorporate the heliostat orientation’s impact on annual slope error
- Smart assembly of the mirror array enables minimizing impact of gravity loads on facet rotation error
  - Annual slope error reductions of 0.5 mrad possible on SunRing
  - Enabled by precision control over mirror shape during assembly of mirror array
  - Opens possibility for less stiff structures that are tuned for their respective highest energy ranking elevation angle

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HelioCon
Heliostat Consortium for Concentrating Solar-Thermal Power

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