Concentrating Sunlight to Make Clean Fuels

Design and operation of Heliostats with Shape-adjustable mirrors

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INTRODUCTION: Range of required shapes

Goals:

- Bring sunlight to a focus on target receiver
- Maintain focus as the solar AOI changes throughout the day
- Achieve concentrations > 3000 suns

With the motivation of achieving high reactor temperatures for generating clean fuels, we characterize the performance of target-axis mounted, shape-adjustable heliostats [1] and their ability to maintain a focused image of the sun on a receiver throughout the day as the angle of incidence (AOI) changes . Each AOI requires the heliostat reflector to be deformed into a unique concave toroidal shape to keep the solar image focused on the target [2].

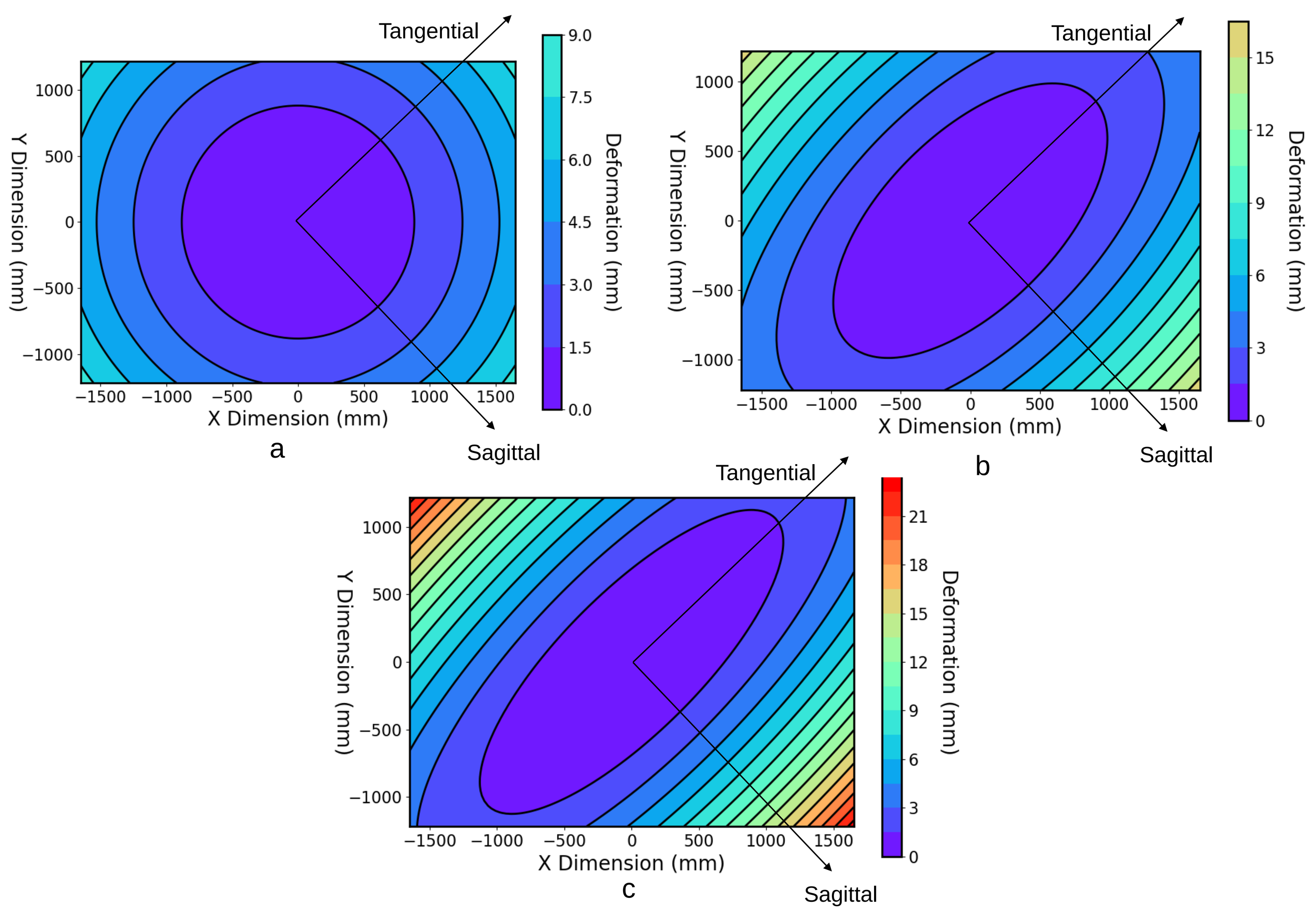

Fig. 1 Required toroidal figures at 0 degrees AOI (a), 60 degrees AOI (b), and 70 degrees AOI (c)

The reflector is a single 2.4m x 3.3m flat rectangular sheet of silvered glass mounted to a flat steel frame. The glass shape is initially set by adjusting the height of the mounting points to the toroidal shape required at 60 degrees AOI. Shapes for the other AOIs are obtained by twisting the frame from its four corners. This twisting is achieved by adjusting the heights of the two pairs of back struts connecting the corners of the frame with the central mast.

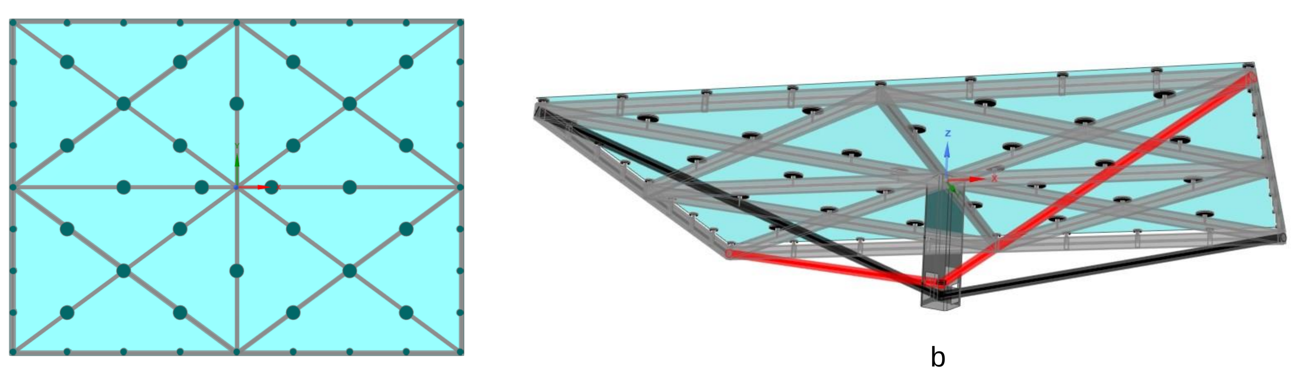

Fig. 2 Heliostat reflector and frame design top-down view (a) and side view showing the two pairs of back struts (b)

MODEL: 8 m^2 mirror with support and array configuration

Analysis objectives:

- Determine spillage losses from heliostat figure and pointing errors.
- Calculate encircled energy over receiver diameter.
- Determine geometric throughput losses from cosine factor, blocking, and shadowing.
- Calculate total geometric throughput.

A finite element model was used to evaluate the reflector shapes created by the twisting mechanism. The deformation of the glass reflector was also modeled under gravity and the average expected wind load at 60 degrees elevation. Slope error maps were computed and used to calculate the encircled energy over the receiver diameter. (see 3rd column

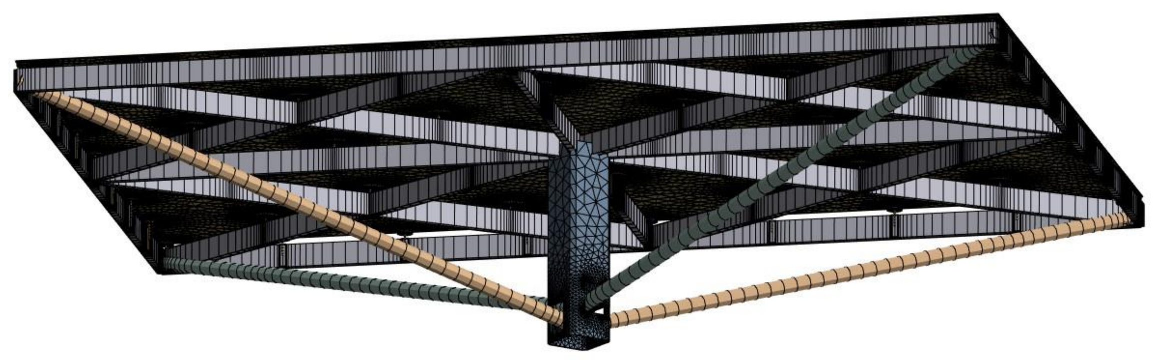

Fig. 3 Finite element model of heliostat frame

A heliostat field was designed to focus sunlight into compound paraboloidal concentrators (CPCs). The field consists of 5 groups of 89 heliostats ranging from 70-110 m focal lengths, each focusing light into a conical CPC with a 1 m diameter entrance pupil. Geometric throughput losses, including cosine loss, blocking, and shadowing were calculated for various solar positions.

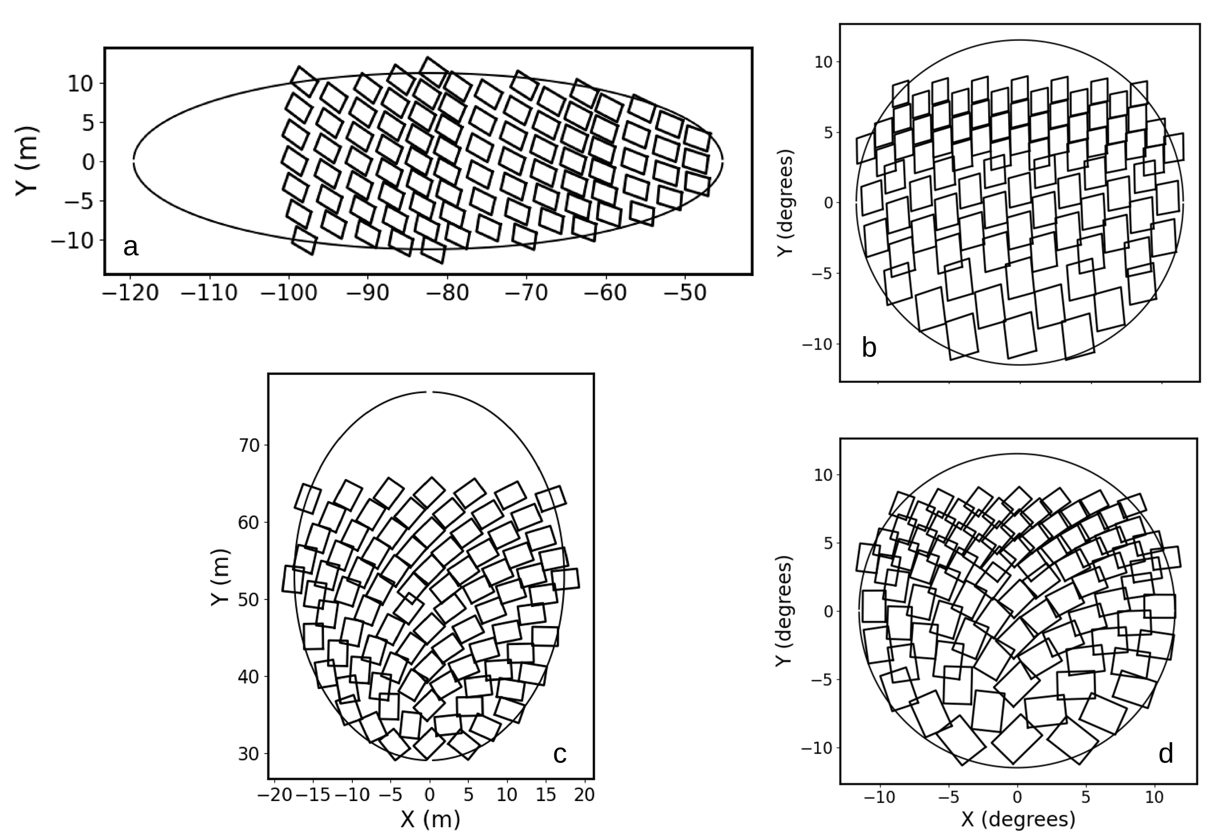

Fig. 4 Field of 89 heliostats as viewed from the sun (a) (c) and from the receiver (b) (d) for a solar elevation of 40 degrees. Solar azimuth positions are 90 degrees (a) (b) and 0 degrees (c) (d).

RESULTS: Encircled energy and solar concentration

The RMS slope error is less than 0.7 mrad for the average wind condition. Encircled energy is greater than 85%.

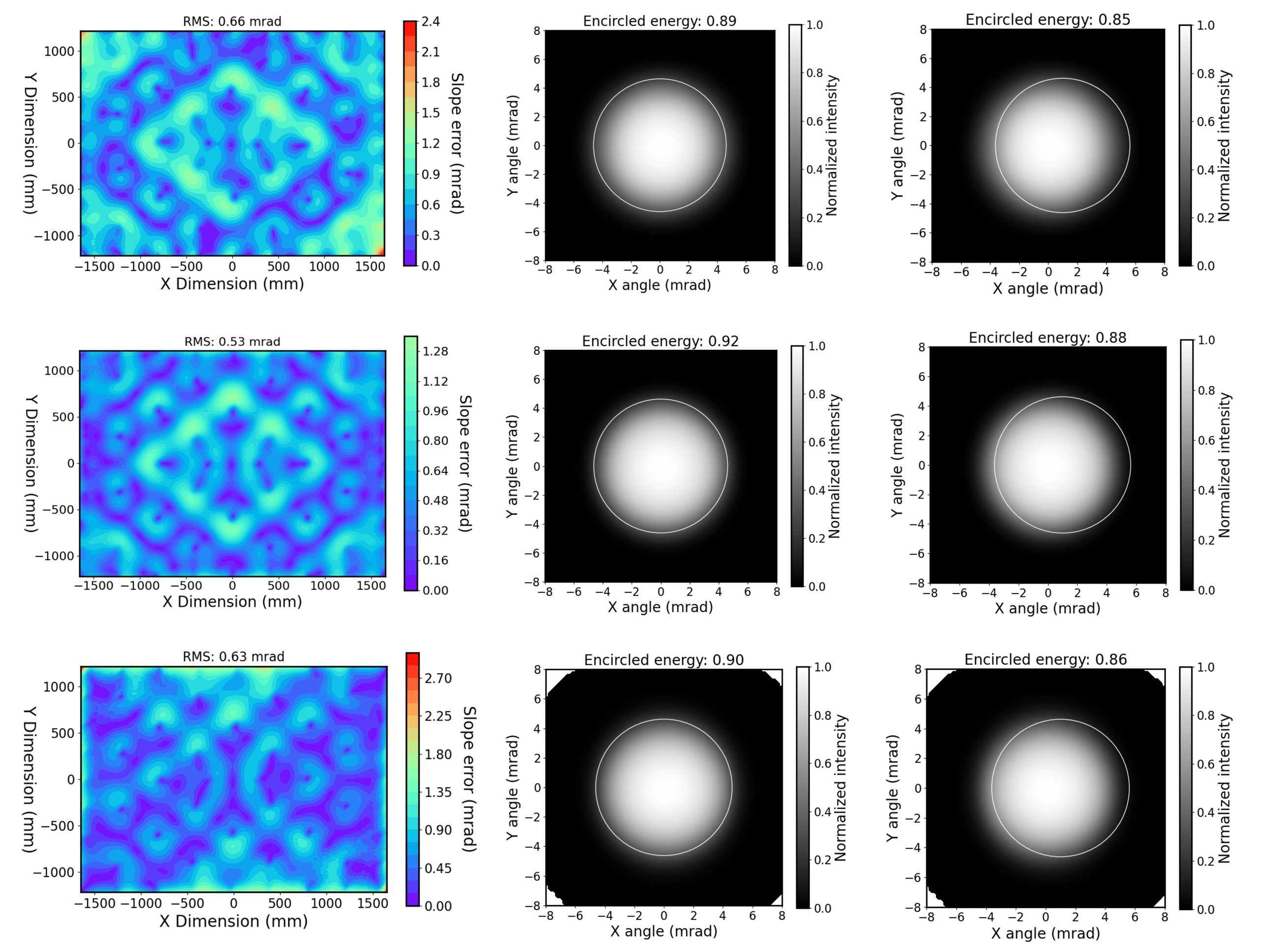

Fig. 5 Slope error maps (left) and encircled energy with perfect pointing (middle) and 0.5 mrad pointing error (right) for AOIs of 0 degrees (top), 60 degrees (middle) and 70 degrees (bottom).

Throughput source	Fraction
Encircled energy	0.85
Geometric throughput	0.73
Heliostat reflectivity	0.9
CPC reflectivity	0.9
CPC window transmission	0.9
Solar concentration calculation	
Total throughput (fraction of total heliostat area)	0.45
Total heliostat area	3560 m^2
Effective area of sunlight	1602 m^2
CPC pupil area	3.93 m^2
CPC concentration	10x
Total solar concentration	**4076x**

CONCLUSIONS

- **Encircled energy > 85% for individual heliostats**
- **Geometric throughput > 70% for heliostat groups**
- **Solar concentration of > 4000 suns for whole heliostat field**

REFERENCES

1. R. Angel, M. Rademacher, N. Didato, *Adjustable shape heliostats in fields for concentration > 3000 at power > 1 MW,* SPIE invited paper (2023)

2. R. Angel, R. Eads, N. Didato, N. Emerson, C. Davila, *Actively Shaped Focusing Heliostat,* AIP Conference Proceedings Vol. 2445 (2022)

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