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RE<C: Heliostat Frame Design

Overview

Many existing heliostat frames and bases use large drives and actuators mounted on a poured concrete foundation. Our design focused on removing these heavy elements and creating a lightweight, easy to transport frame that could be anchored without pouring any concrete. To accomplish this goal, we needed to create heliostat structures, ground anchors, and actuators that were lightweight, inexpensive, simple to assemble and field-install.

Our design challenges were greatly assisted by having a lightweight heliostat reflector. With a lighter reflector, larger motors used to move the mirror could be replaced with lighter cable actuators; the heavy frame could be replaced with a lightweight, foldable frame; and poured concrete foundations could be replaced with simple ground anchors.

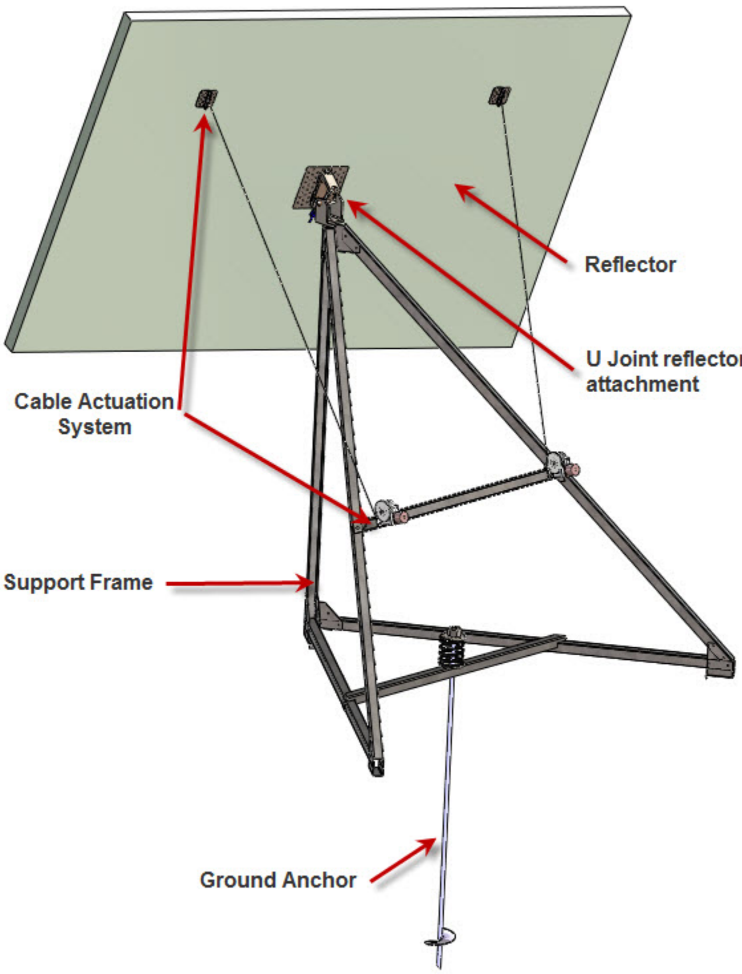
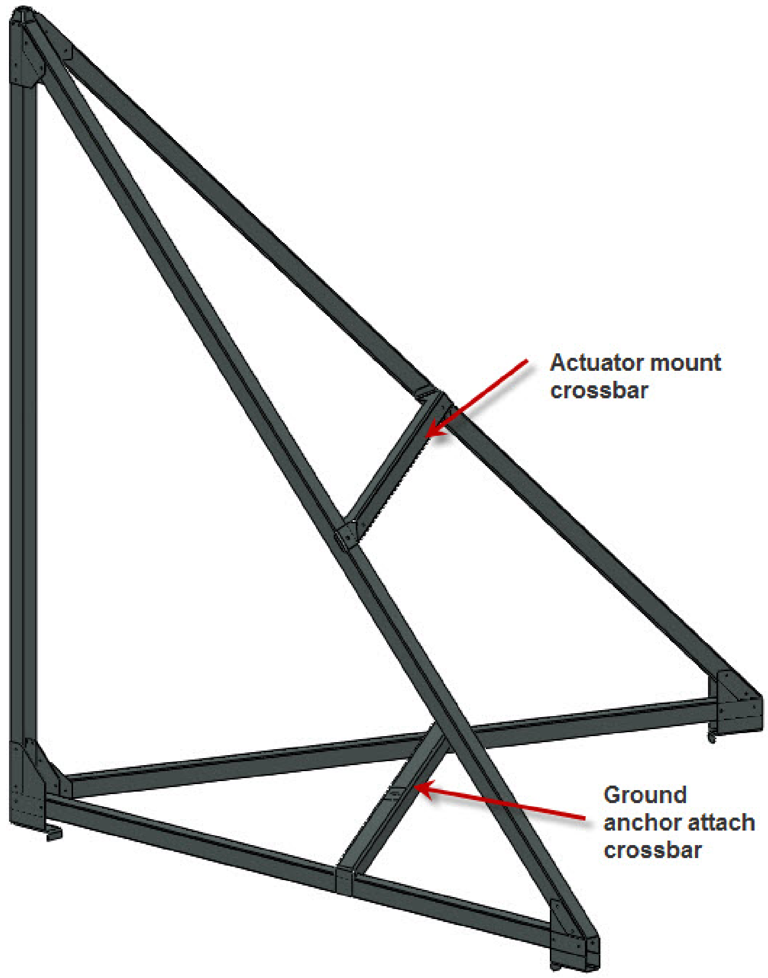


Diagram of prototype heliostat frame

Heliostat Support Frame

Heliostat frames currently in production require precision machining, welding, fabrication, and assembly. Each of these steps adds extra cost and assembly time to the frame.

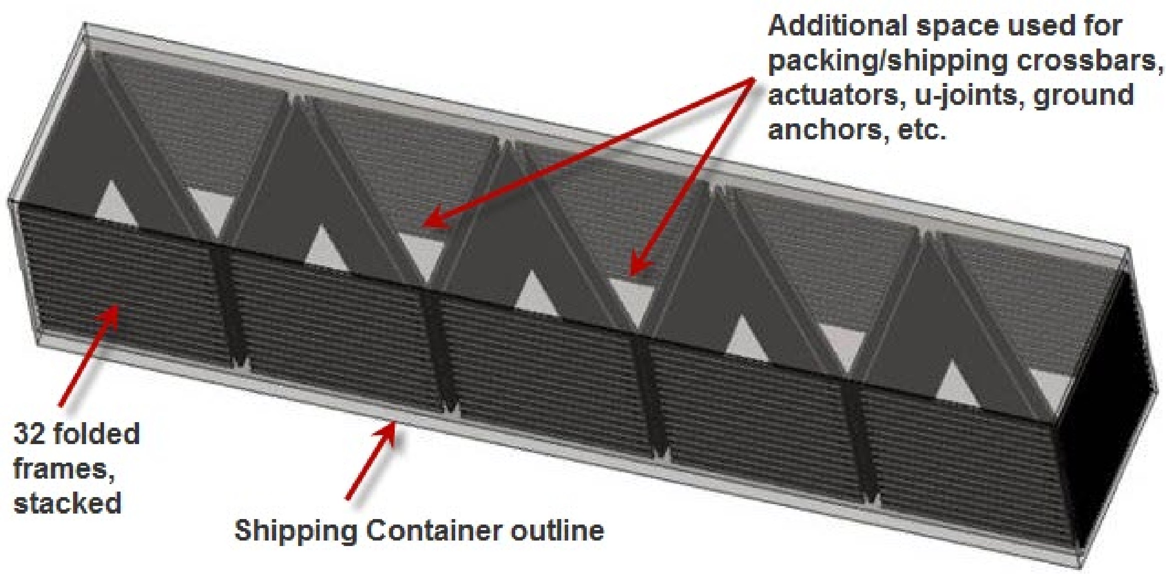
To avoid these added costs, we chose a tripod design for maximum stability with a minimum amount of material. Cross bars were used to add rigidity to the frame and as mounting points for actuators and ground anchors. The full frame weighs only 33kg (72lbs).



Prototype frame model

The frame is built using stamped galvanized steel and riveted together before shipping. Galvanized steel was chosen for its resistance to rust, sand, and sunlight. The metal struts on the frame were designed with C-shaped cross sections for simplicity and strength. This design is lighter and cheaper than using sealed metal tubing and is easier to fabricate in most sheet metal shops.

In addition to its lightweight and durable design, the frame folds flat and stacks for easy transport. When folded, 32 frames can fit on a pallet and 5 pallets will fit in a standard 40 foot shipping container. With these dimensions, the frames can be fabricated, inspected and packed in a single factory with minimal additional labor.



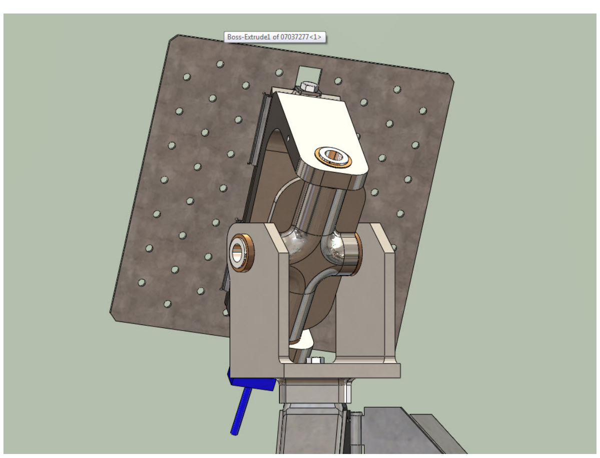
Standard 40 ft shipping container with 160 folded heliostat frames

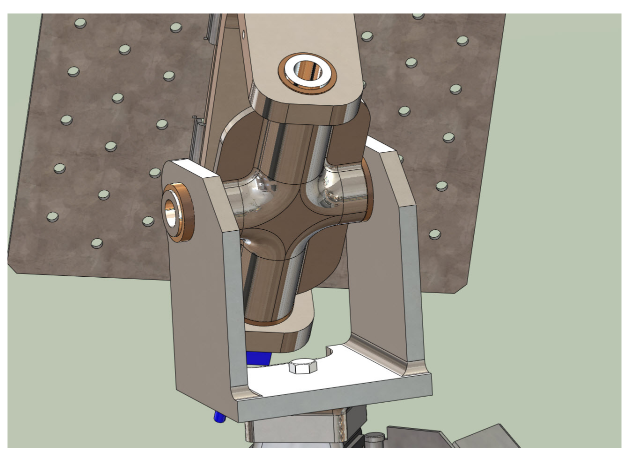
Each frame costs approximately $70 to produce. In the heliostat community, costs are quoted as $/m², so our frame design combined with our 6 m² mirror implies the frame contributes $11.70 to the dollars/meter sq of the heliostat.

Reflector Mount Universal Joint

The heliostat reflector is mounted to the frame using a universal joint, or u-joint. The u-joint provides 2 degrees of freedom to the reflector, allowing it to pitch and roll about the heliostat frame. The u-joint itself is not motorized and does not directly control the reflector. Instead, it acts as the the reflector's pivot point and structural support point.

The u-joint is similar in construction to u-joints used in automotive drivetrains. It is low-cost and durable with self-lubricating bushings. The U-Joint operates in compression throughout its range of motion so manufacturing tolerances don't have to be very tight.

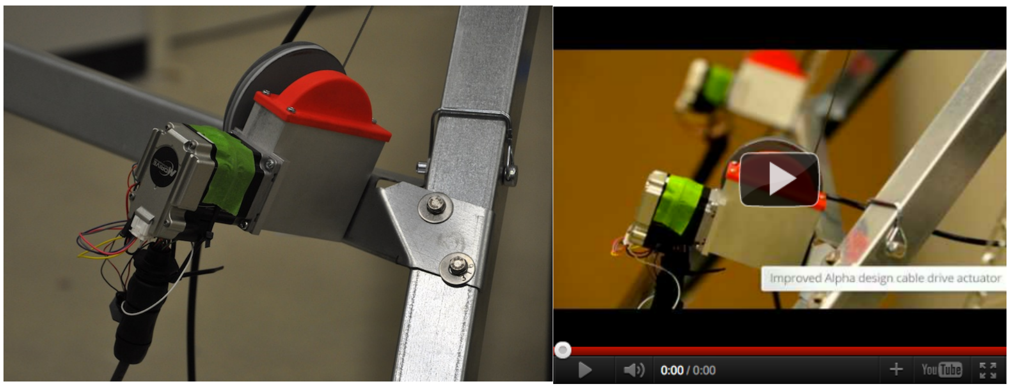




Mirror Mounting U-Joint (shown as CNC machined, but would be a casting in production)

Heliostat Cable Drive Actuation

To rotate our heliostat reflector, we needed motors that could pivot the reflector around the frame's u-joint. We re-thought the motor actuation architecture to reduce size, cost, and power demand, and designed a custom low-power electric cable drive. A full description of the heliostat cable actuation system is available in the RE<C: Heliostat Cable Actuation System Design document.

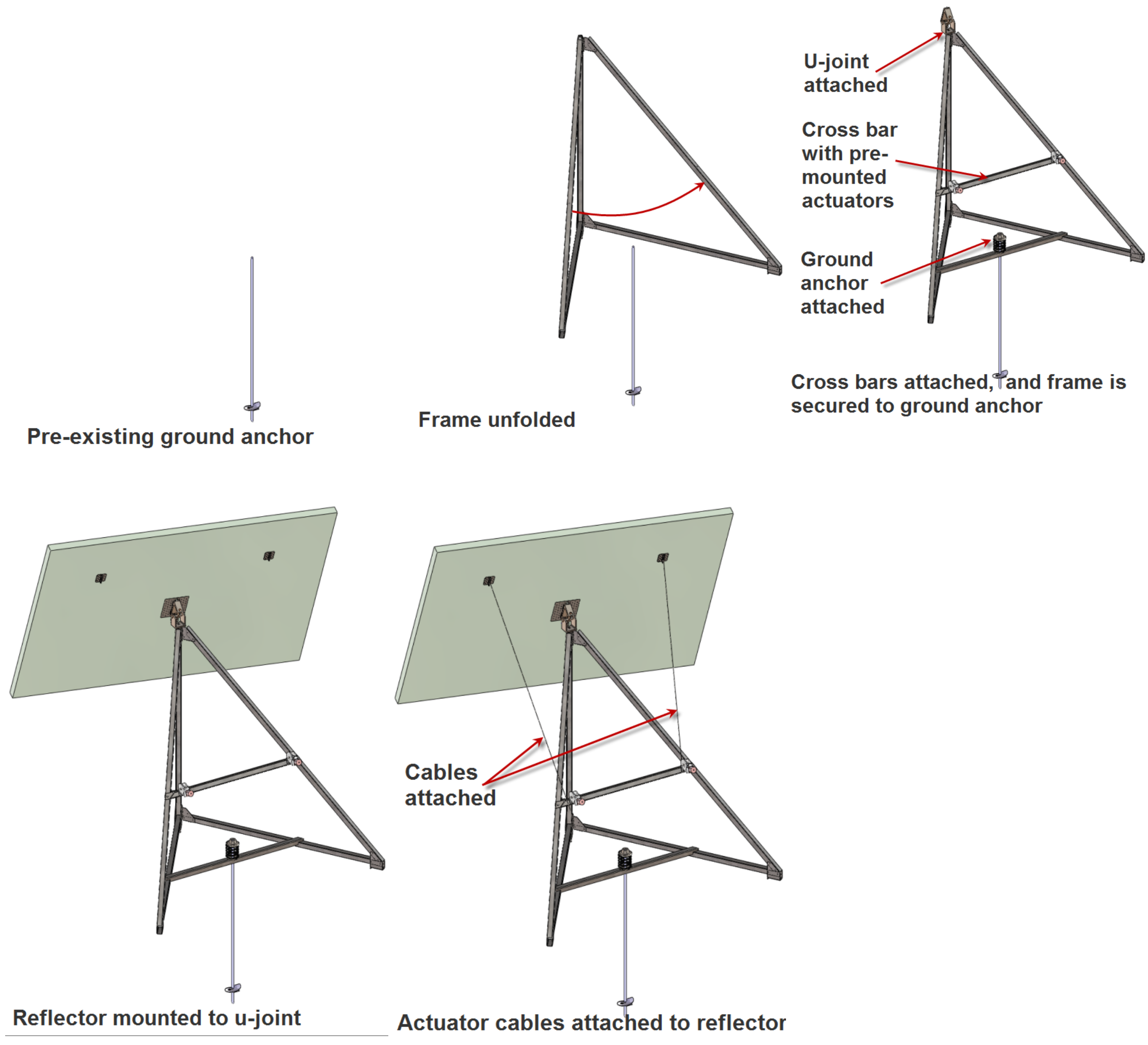


Prototype heliostat cable drive actuator (left) with video (right)

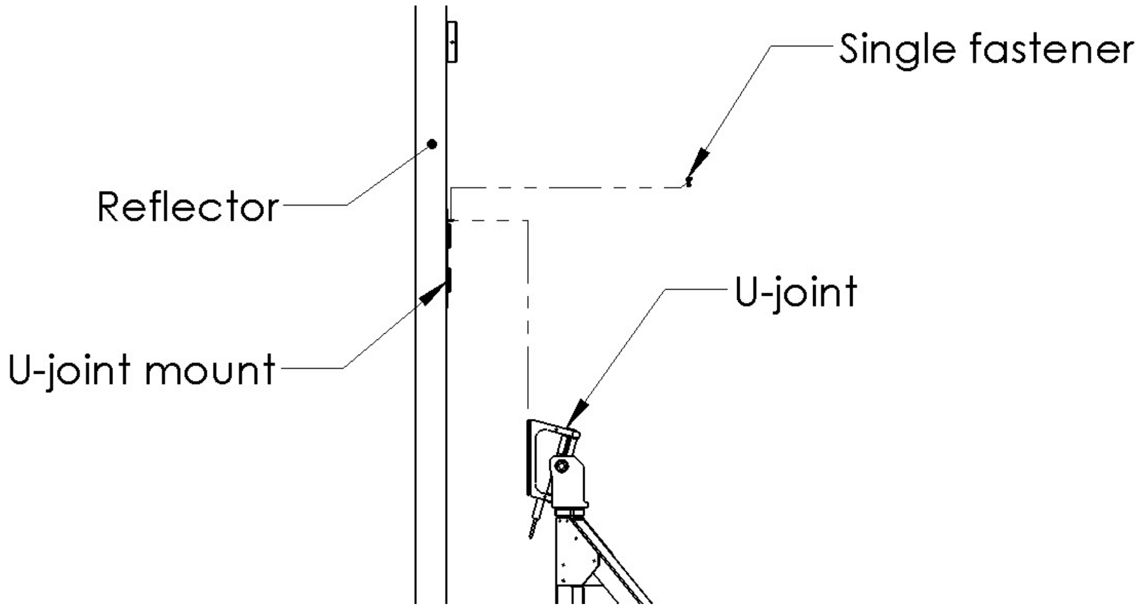
Final Heliostat Assembly

The heliostat is designed to be rapidly assembled with no fine tuning or adjustments needed at the time of installation. Field installation involves unloading frames from their packaging, unfolding them, securing them with cross bars, and attaching them to ground anchors. The entire process can be accomplished in a few minutes by two people using only a few wrenches.

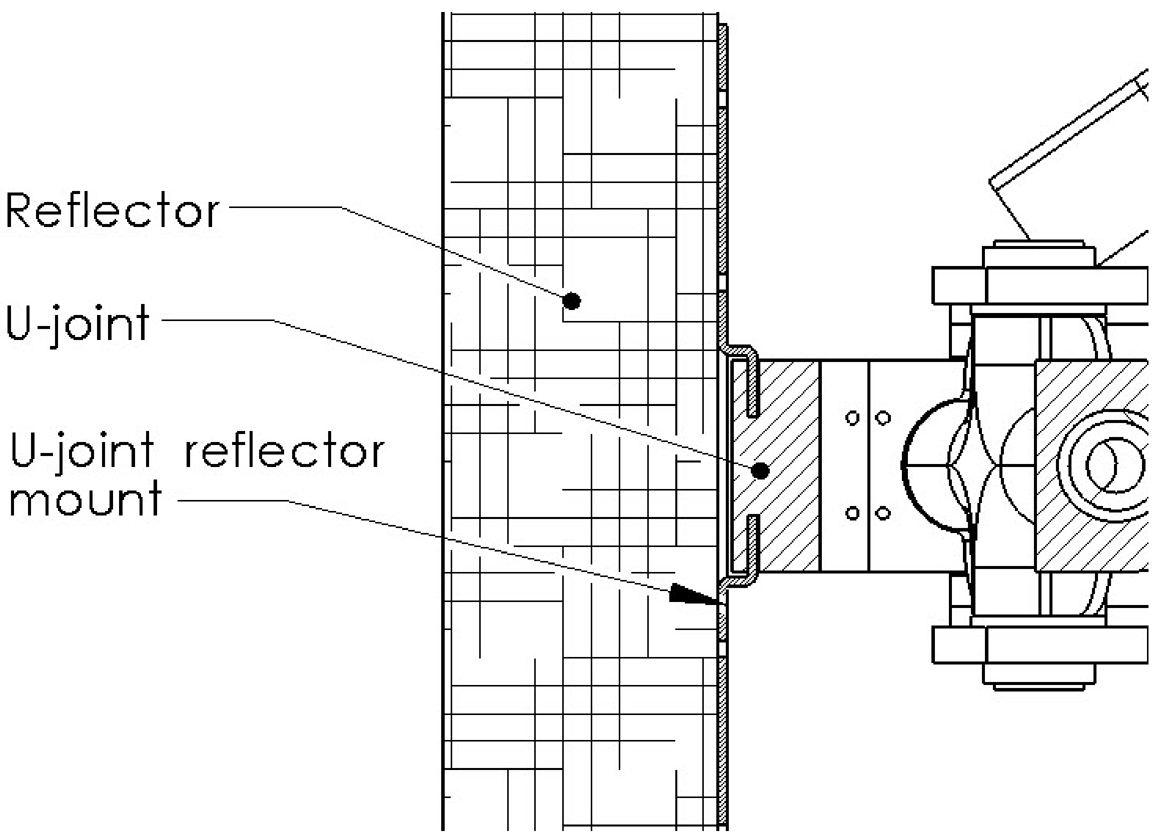
Once the frame is secured, the mirror attaches to the u-joint and is secured by an integrated dovetail mount and a single fastener. Cables from the actuators (pre-mounted on the heliostat cross bar at the factory) are attached to the mount points on the reflector. Then, prebuilt wire harnesses for the actuators and controller are connected, completing the assembly.



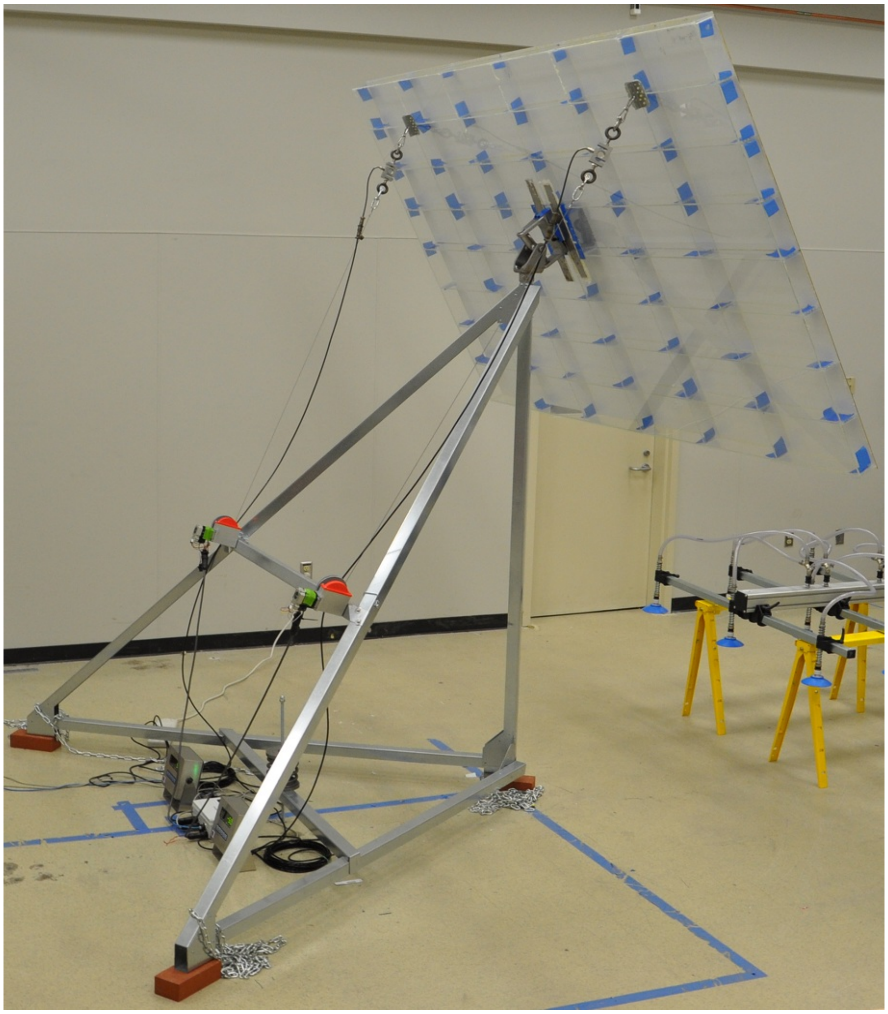
Heliostat Assembly Process (From top left)



Reflector Mounting Process for Heliostat Frame



Cross Section of Reflector Dovetail Attachment



Fully assembled prototype heliostat

Foundation, or Lack Thereof

Most heliostat designs are installed on prepared land that may require grading, compacting, and leveling. These heliostats have robust foundations of reinforced concrete that require a significant amount of labor to construct. Our design requires minimal site preparation and no traditional foundation construction before installing the heliostat, since our control software compensates for variations in heliostat installation (for example, a slightly tilted frame due to uneven ground).

For a ground anchor, we designed a simple ground screw similar to those used in the utility pole industry. The anchor screws into the ground in minutes using automated machinery and can provide a holding force in excess of 13 kN, which is about 3 times greater than our design requirements. The flexibility of this anchoring system makes it adaptable to various types of soil and environmental conditions. An additional benefit is that it’s minimally invasive to the terrain and completely removable.

Field installing a field of ground anchors and heliostat frames is designed to be fast and simple.

First, ground anchors are driven into the ground at predetermined locations. The tripod frame is then set over it. The anchor attaches to a crossbar on the bottom of the tripod frame and uses a coil spring to apply constant downward pressure. This clamps the frame firmly against the ground, accommodating any ground settling or shifting that may occur. As part of the annual heliostat field maintenance, the spring tension is inspected and adjusted if necessary.

Ground anchor installation

Once the spring is set, pointed sheet metal 'feet' on the heliostat frame pierce the soil, and prevent frame rotation due to wind.

Conclusions

Designing holistically with the goal of reducing the cost of electricity from a CSP plant led us to think differently about the costs and reasons behind site preparation, site logistics, shipping, assembly, and installation.

The heliostat support structure we designed, developed, and prototyped looks very different from many existing heliostats but it maintains the necessary functionality. Our heliostat frame is lightweight, easy to bulk ship, and quick to assemble. The combination of ground anchors and control system capabilities allows the heliostat to operate with very little site preparation prior to installation.

Future Research

Areas for future work:

- Test anchors in a wide variety of soil conditions, and through seasonal weather cycles since soil conditions vary significantly across potential solar sites.
- Develop automated field installation equipment to speed up and further reduce the cost of installing heliostats in the field.
- Refine and improve shipping methods for manufacturing, packing and shipping frames.
- C-channel construction has lower torsional stiffness than tubular. We believe from modeling and initial testing that this is within acceptable limits, but further testing is required.