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RE<C: Heliostat Flow Visualization Experiments

Overview

Heliostats depend on engineering to overcome shifting environmental factors such as wind. Aerodynamic loading and wind deflection, for example, can cause errors in lightspot positioning and, in extreme conditions, cause damage to heliostat reflectors and frames. Wind flow around multiple heliostats in a field can result in vortices and turbulence. To address these issues, we used flow visualization chambers.

Because we wanted to know how wind flows through a heliostat field and affects heliostat aiming, we used flow visualization tanks to monitor and record flow behavior. Flow visualizations provide a rapid qualitative method for gaining insight into flow patterns and the effects of obstacles. This work complements other methods we used to study wind effects, including wind tunnel measurement and surface wind data collection.

Experiment Setup

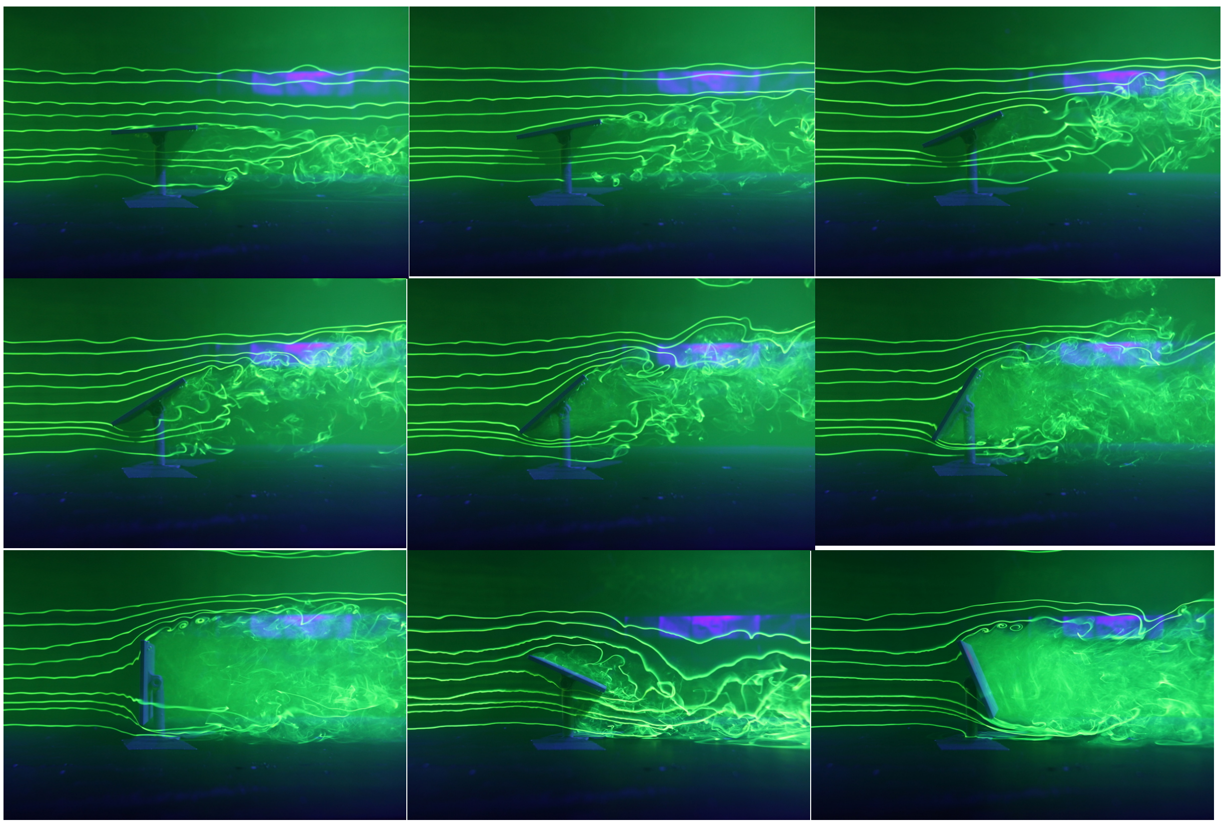
The flow visualization chamber we used at NASA Ames is a long tank filled with slow-moving (1 in/s) water with a uniform, laminar flow. Small scale models are submerged in this tank, water is allowed to recover from the disturbance, and then a UV fluorescent dye is injected in multiple locations upstream of the models.

By observing these streamlines of dye, we gained insight and knowledge into the overall flow behavior around the model. In particular, areas where the streamlines compress and move closer to each other represent areas of higher flow velocity, and flow disturbances and turbulence correlate with energy extraction by the object creating the disturbance (and thus an aerodynamic load on that object).

For our experiments, we submerged scale models (1/30th of scale) of representative heliostats in the tank and observed the flow under various conditions. In the images from the flow visualization study, the flow is moving from left to right.

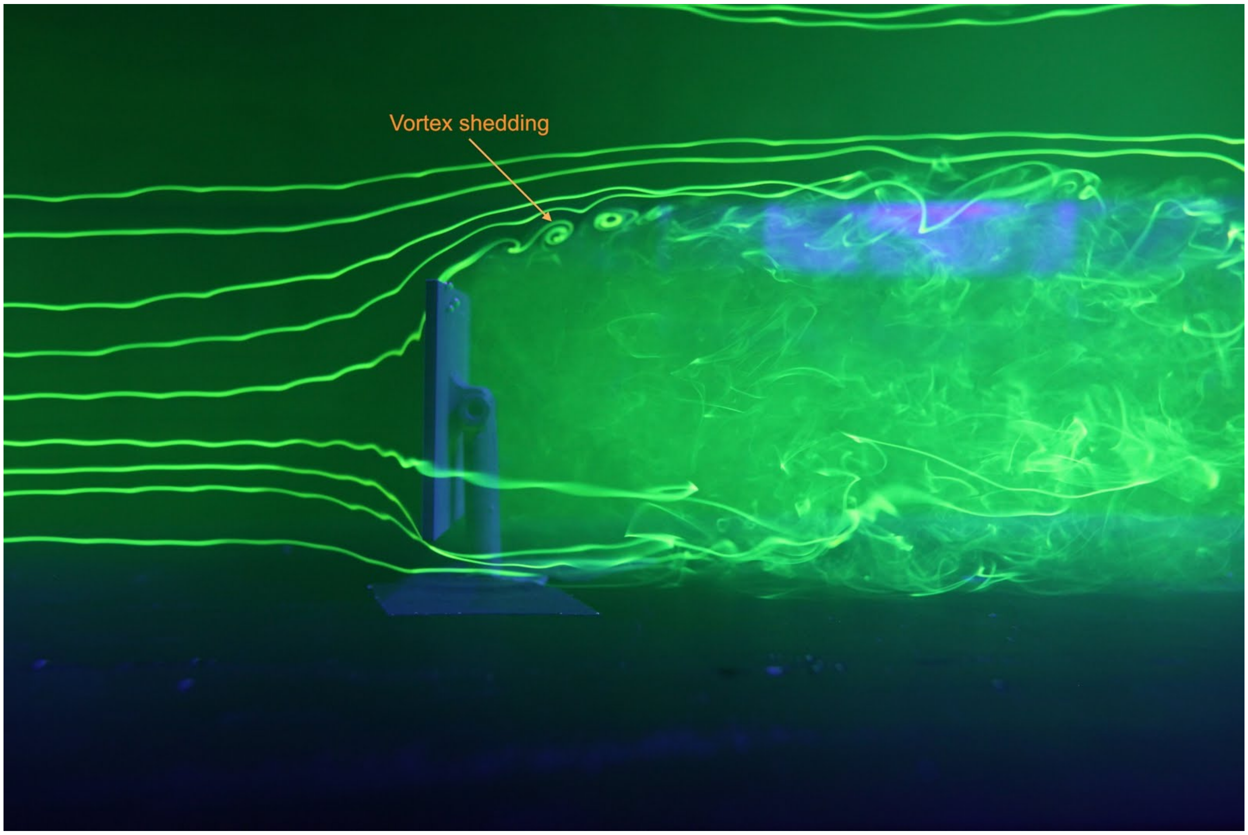
Single Heliostat

We began with flow visualization of a single, isolated heliostat. As expected, we saw significant turbulence and flow mixing (representing aerodynamic loads) for heliostats nearly perpendicular to the wind, and much less flow mixing for heliostats orientated parallel to the ground. Based on this flow model, we deduced that arranging heliostats parallel to the ground would serve as a good reflector stow position for severe weather. Because wind conditions tend to accelerate at night, parallel positioning after sunset can keep wind loading to a minimum.

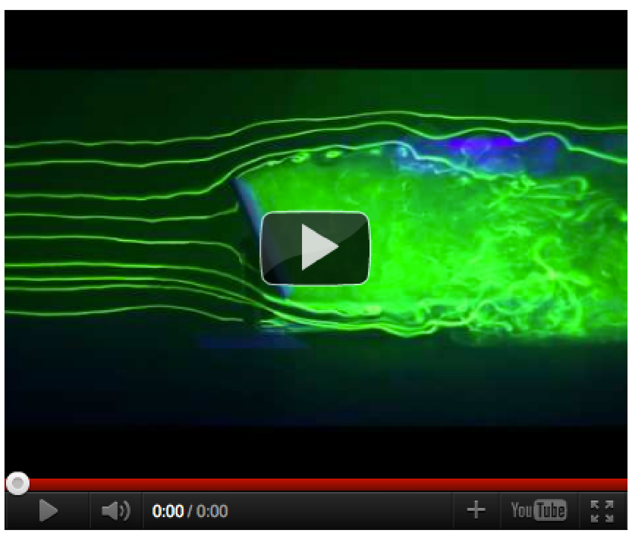


Single Heliostat in flow at various elevation angles; From top left: 0 deg; 10 deg, 20 deg, 30 deg, 45 deg, 60 deg, 90 deg, -20 deg, -80 deg (angles are approximate).

This type of flow visualization quickly illustrates what design features cause flow disturbances. This information can also guide the design of more robust components. One important example we observed in our studies was vortex shedding. Vortex shedding occurs when flow passes over a blunt object in specific flow regimes and begins to separate from the object. This separation causes alternating low pressure zones just downstream of the object, which the flow moves into, causing a vortex.



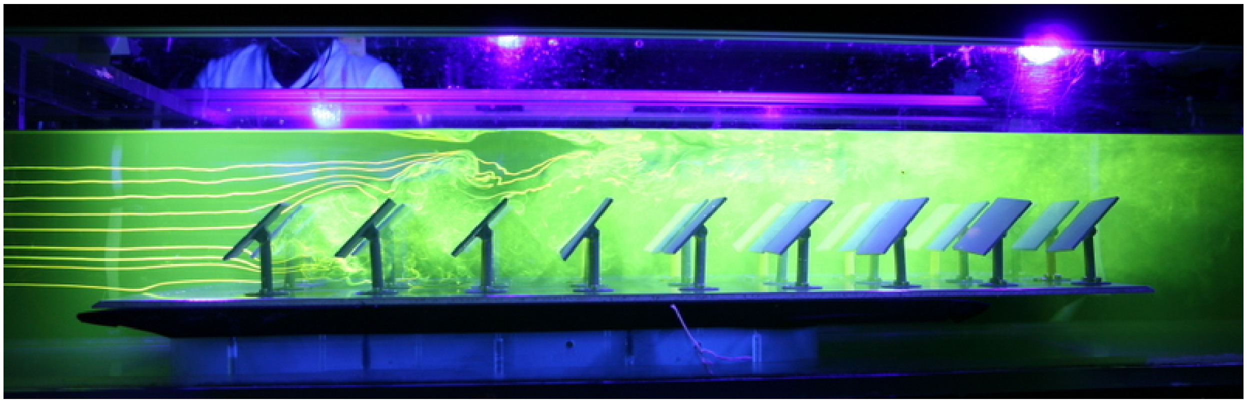
Vortex shedding observed on a heliostat perpendicular to the oncoming flow



Video: Heliostat Vortex Shedding

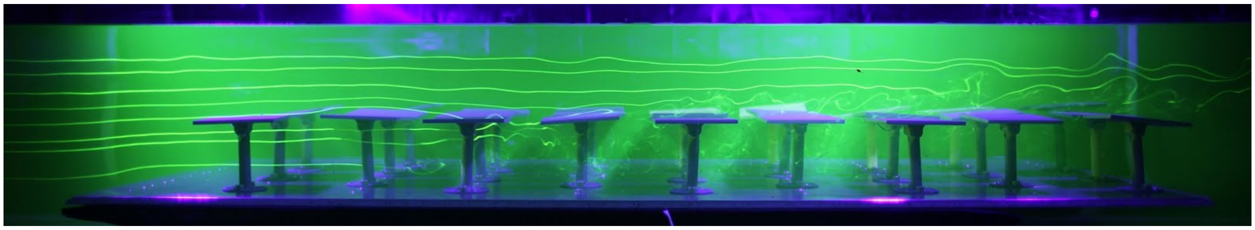
Heliostat Field

Studying a heliostat field in the flow visualization tank gave insight into how heliostats can shield each other from the wind. We found, for example, that beyond the 4th row of heliostats, the flow was thoroughly mixed and the majority of the modeled wind energy has been extracted by the first 3 rows of heliostats. This information was important in both shaping and reducing the scope of our other wind studies: we only needed to measure loads up to the 4th row of heliostats in a field, as we expect the results of loads on the 5th, 10th, or 20th row to be rather similar.



Flow propagating through a 9 heliostat deep field. Each heliostat at 45 deg elevation, 0 deg beta; No significant change in flow field beyond 4th row.

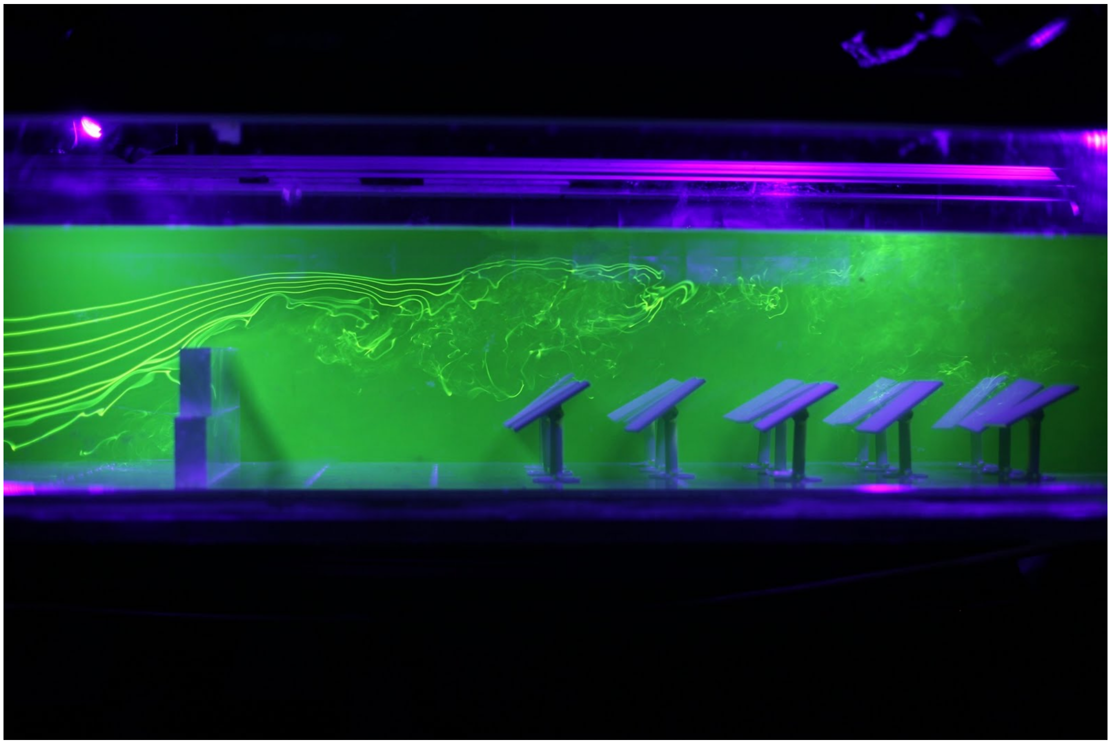
We also sought to understand what happens when heliostats are placed in a “stow,” or 0° elevation, orientation. In our flow visualization, the flow lines remain fairly smooth and evenly spaced above the heliostat field, with minimal disturbances throughout the heliostat field. This indicates that a very low amount of energy is extracted from the flow by the heliostats and that the aerodynamic loads should be reduced throughout most of the field.



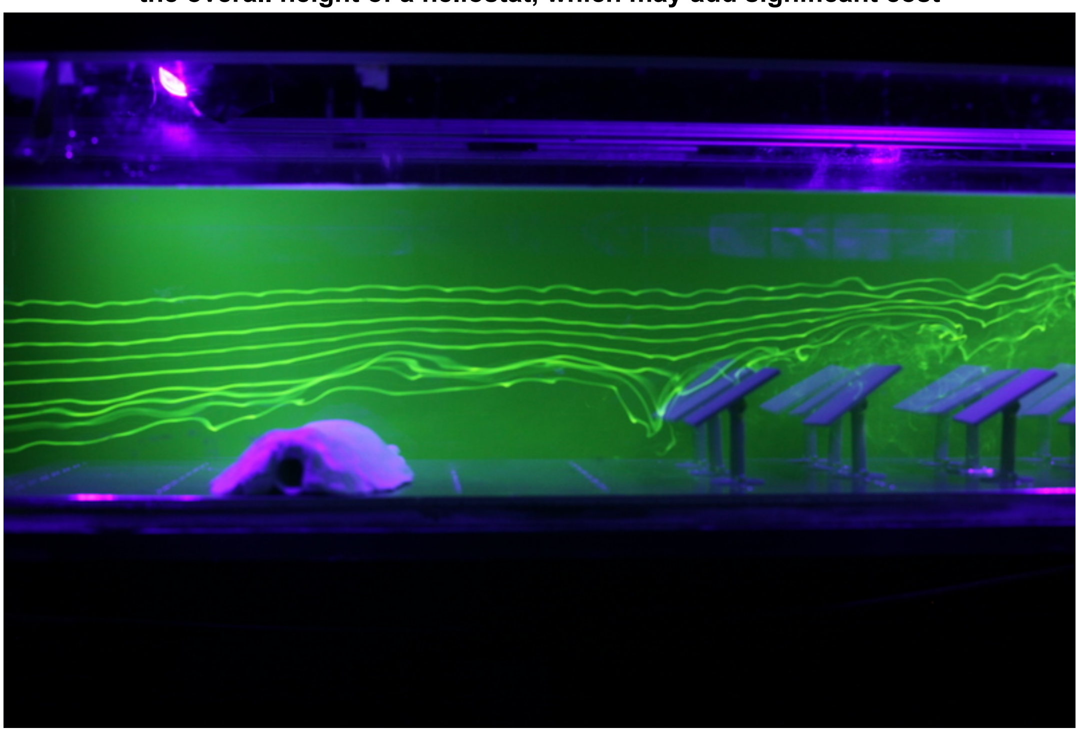
Flow propagating through heliostat field when each heliostat is at a 0° position.

Mitigations

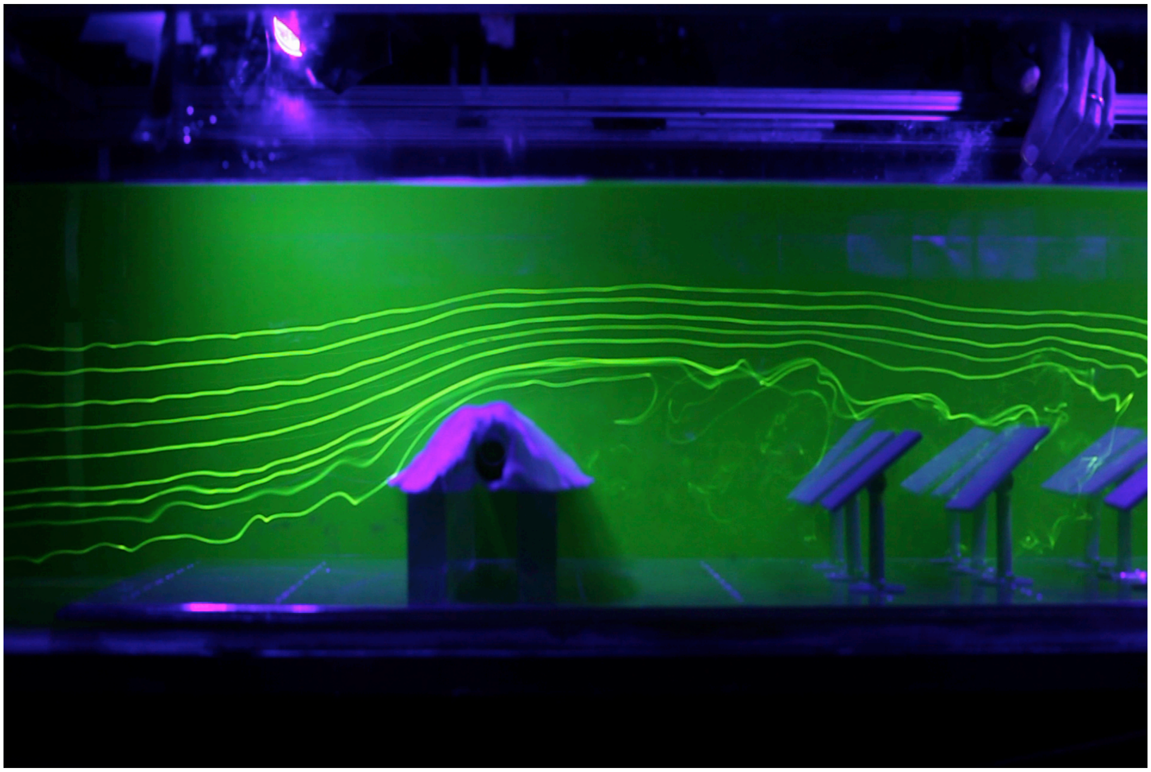
The flow visualization tank proved an excellent tool for evaluating the effects of potential wind breaks and mitigations. Different options exist for building wind breaks, including the building of wind fences or the planting of tall trees around a field of heliostats. We wanted to visualize the effect that wind mitigation would have and evaluate several different field-level mitigation strategies using solid fences, porous fences, and berms. The following set of images reflect some of the mitigation strategies we tried and the effects on the downstream flow.



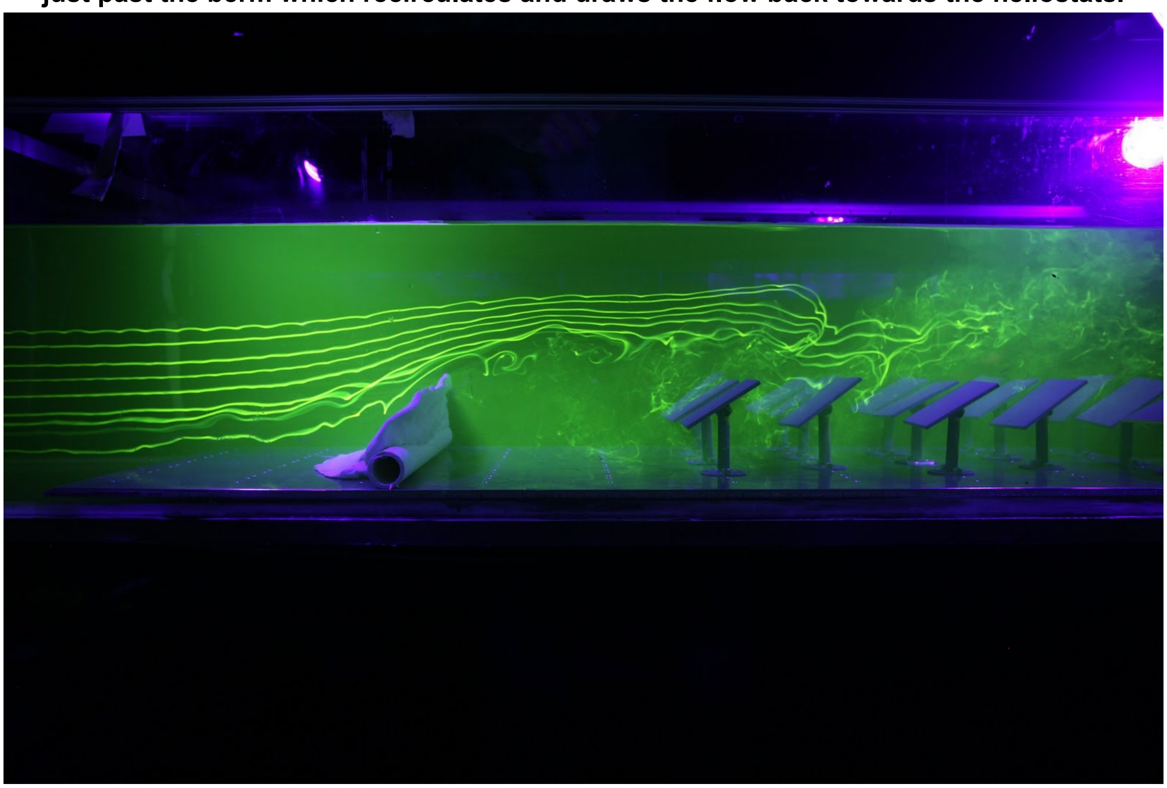
A high solid wall diverts flow above heliostat field for the most part, however the high wall is 1.5X the overall height of a heliostat, which may add significant cost



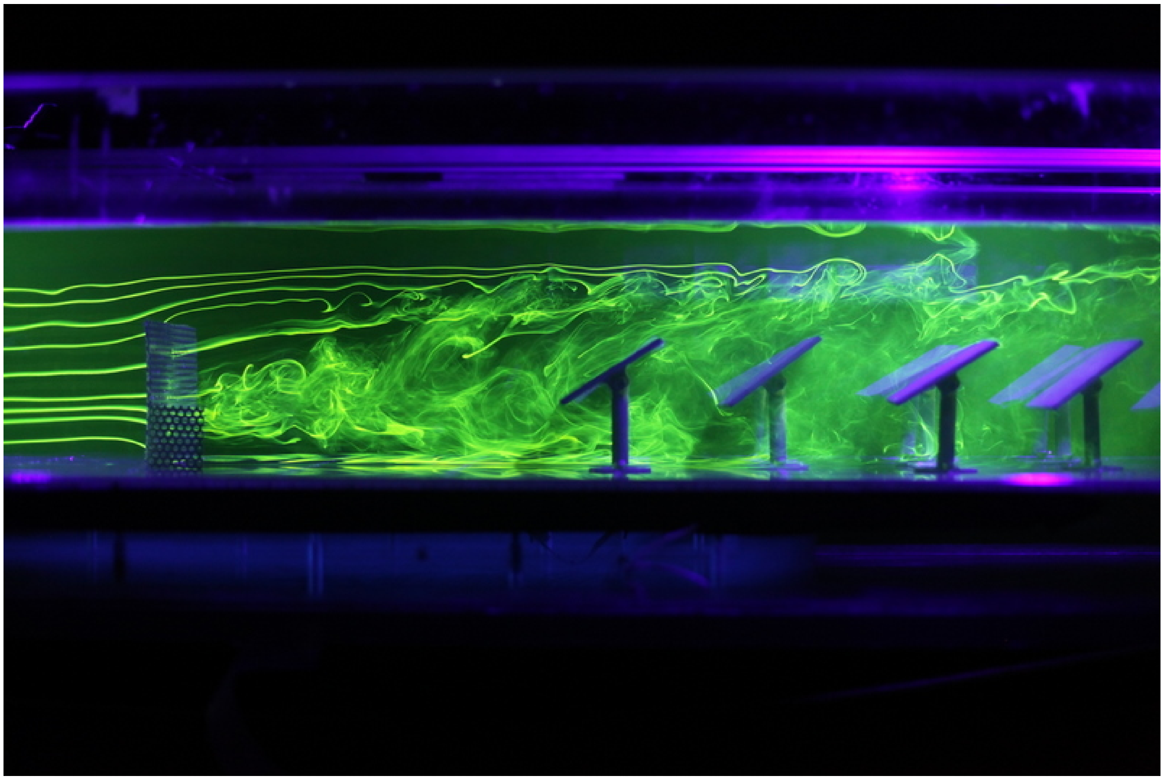
Low upstream berm (simulating a mound of earth) compresses flow and actually accelerates flow into the heliostat field, which will increase loads on the heliostats



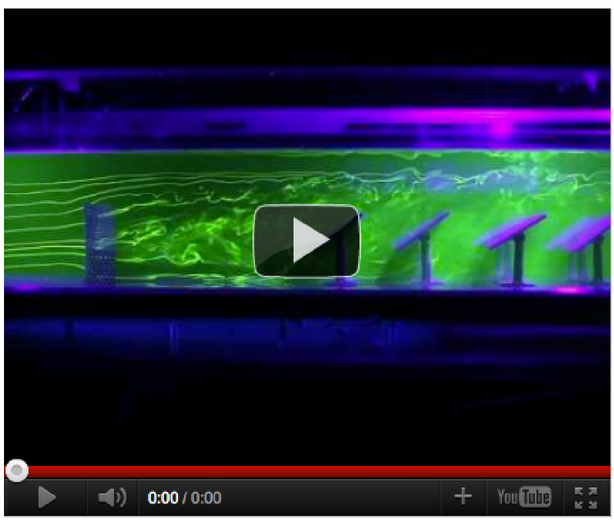
A high berm accelerated the flow above the heliostat field, however it also created a dead zone just past the berm which recirculates and draws the flow back towards the heliostats.



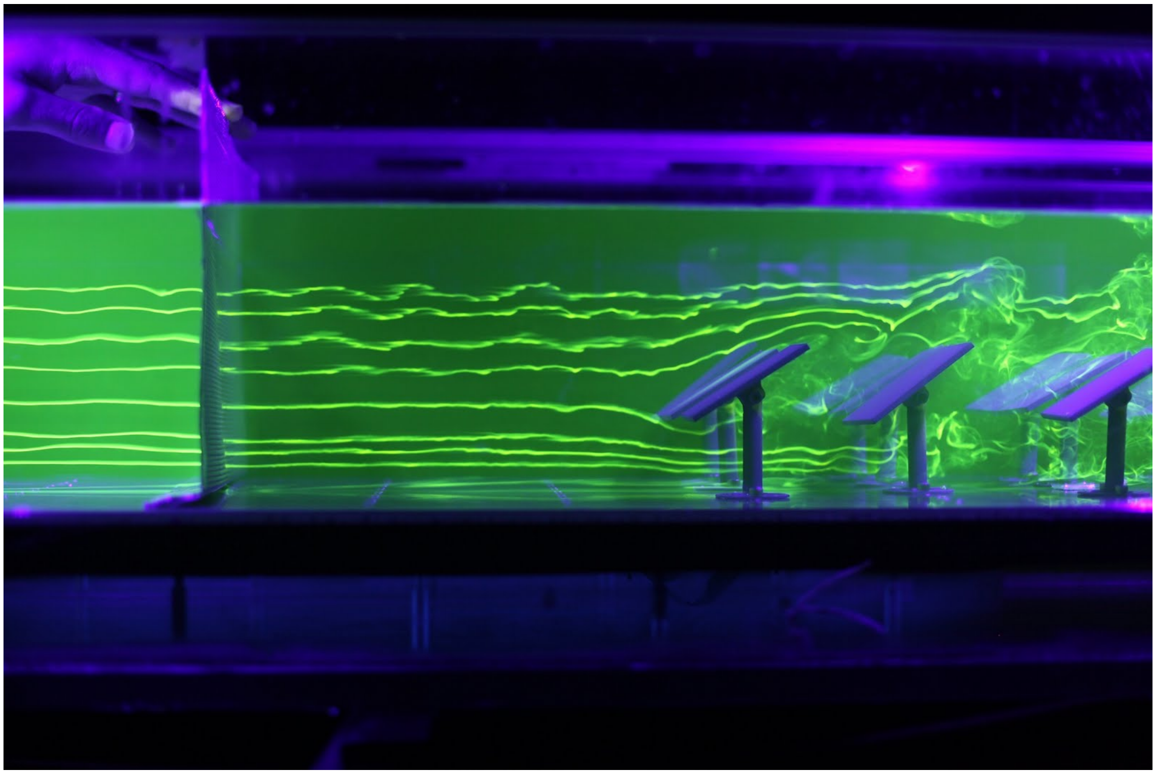
A ramp style berm acted similar to a high berm and accelerated the flow above the heliostat field



An upstream fence (50% open area,), as tall as heliostat overall height, creates disruptive flow immediately, lowering the flow velocity for all heliostats in the field.

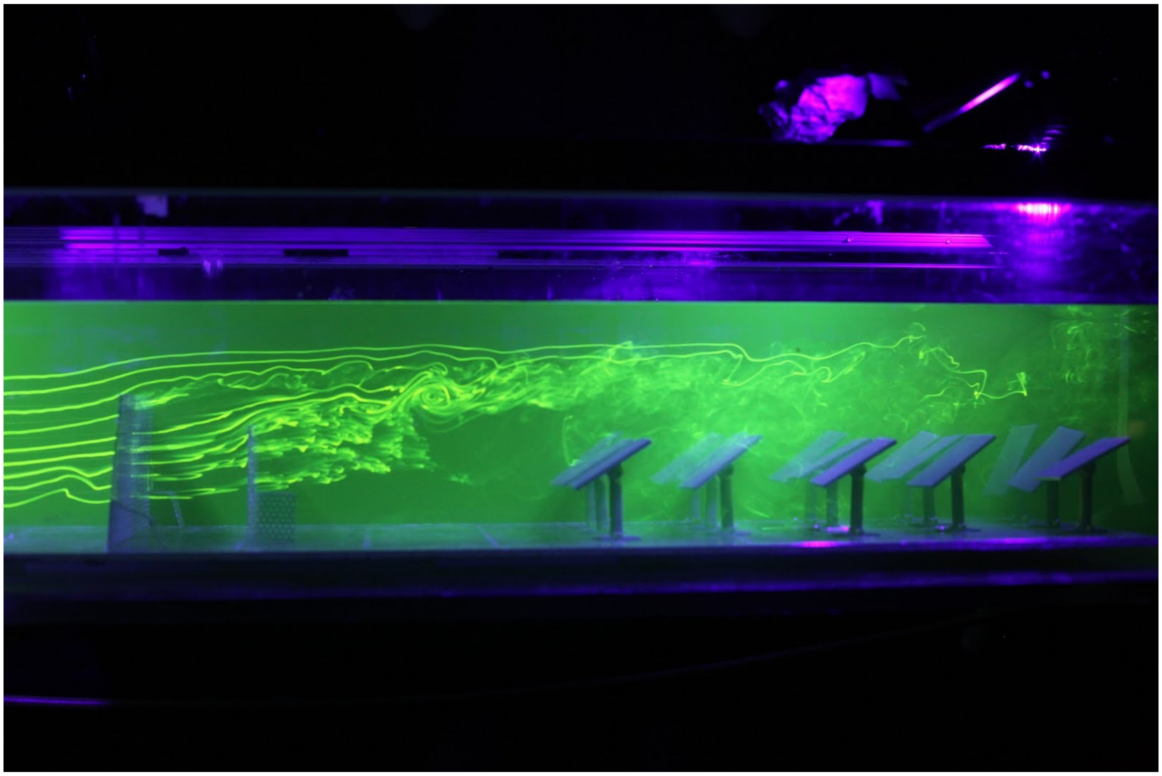


[Video: Fence protection of heliostat field]

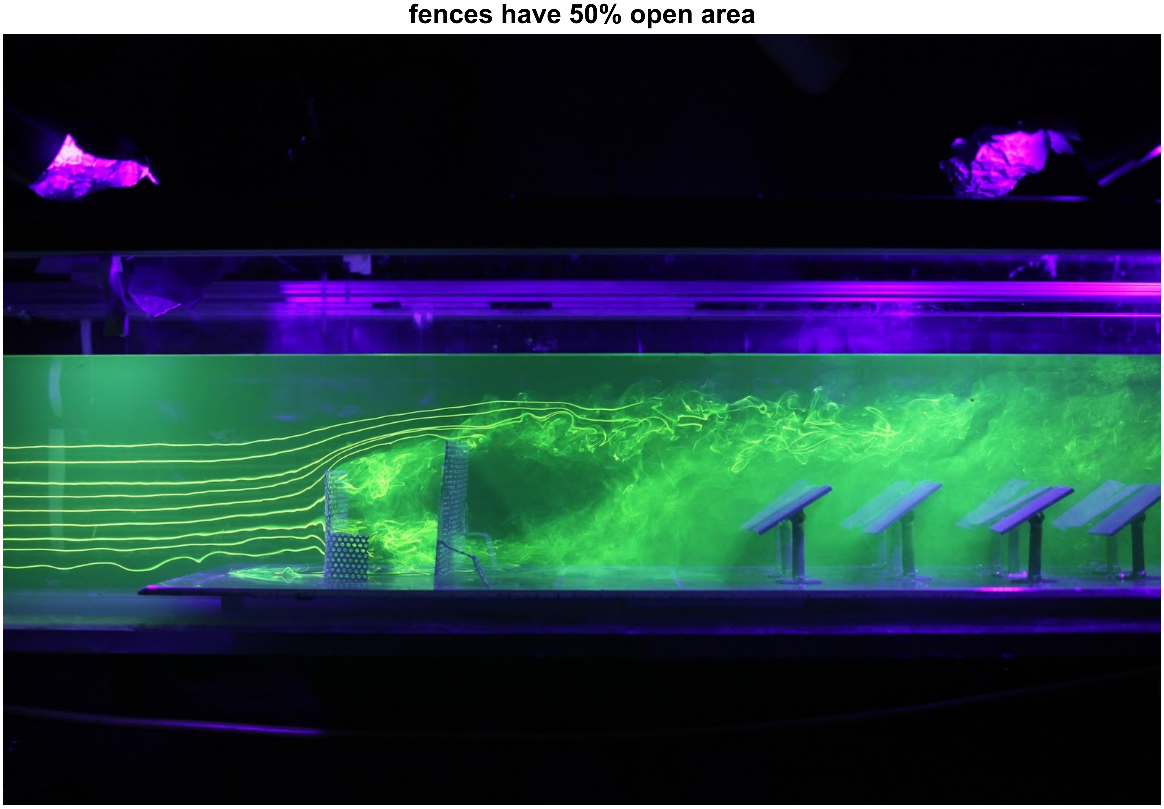


An upstream fence (~80% open area) has very little effect on reducing flow velocity or extracting energy from the flow stream (i.e. steady and smooth flow lines remain)

With the knowledge gained from the flow visualization chamber, we tried various fence combinations, since the upstream fence seemed to be the best mitigation approach. We noticed that multiple upstream fences appeared to have a qualitative effect in reducing local flow velocity in the heliostat field above that of a single upstream fence. This was verified in our wind tunnel experiments by comparing the observed loads on a heliostat with no upstream fence, with a single upstream fence, and with multiple upstream fences.



Multiple upstream fences, with shorter fence (1x heliostat height) nearer the heliostat field. Both fences have 50% open area



Multiple upstream fences, with taller fence (1.5x heliostat height) nearer the heliostat field. Both fences have 50% open area

Conclusions

Flow visualization helped us in modeling airflow and understanding how turbulence affects heliostats in the field. We were able to draw the following qualitative conclusions:

- Heliostats at the outer edge of a heliostat field encounter the highest wind loads, but they shield the remainder of the heliostat field and provide a level of protection by disrupting the airflow and scattering wind energy.
- Semi-porous fences have a significant impact on reducing local flow velocity through the heliostat field.
- Installing multiple upstream fences, while costly, may reduce wind loads on heliostats enough to allow weaker and lower cost structural components
- Heliostats in a horizontal position disturb the flow less and are subject to lower loads, so this is a good "stowing" position for high wind conditions.