

# Appendix: RE<C Heliostat Wind Tunnel Experiments

## Datafiles

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Single Heliostat in Uniform Flow Experiments

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Single Heliostat Comparison between Uniform Flow and Atmospheric Boundary Layer

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### Mitigations

Single Heliostat with Upstream Fence

Hemispherical Backed Heliostat Experiments

Fence Height Experiments

Fence Porosity Experiments

## Datafiles

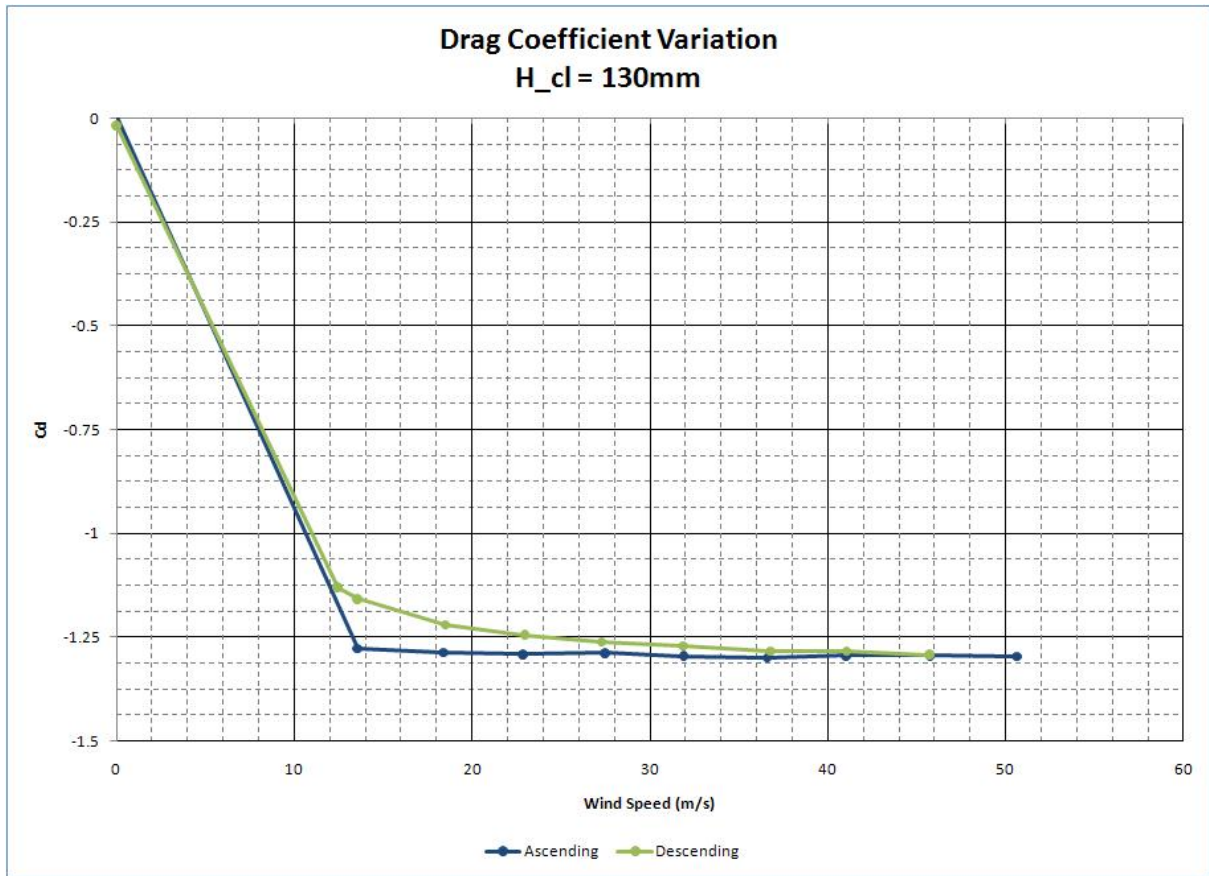
This appendix document presents a large amount of data obtained from our heliostat wind tunnel experiments. The data is divided into three sections: a single heliostat, a field of heliostats, and wind mitigations. The data files are available in the [download section of the RE<C project in code.google.com](#), the files are identified in the comments.

## Single Heliostat

The following is a set of plots relevant to the isolated heliostat tests performed in the wind tunnel.

### Wind Tunnel and Coefficient Validation

- **Heliostat Model Used:** 200mm x 200mm x 5mm reflector, HCL = 130mm
- **Test conditions were as follows:**
  - Wind Speed = 12 m/s - 50 m/s (39 ft/s - 164 ft/s)
  - Air Temperature = 23 C (74° F)
  - Air Density = 1.20 kg/m<sup>3</sup> (14.85 psia, as reported from tunnel conditions)
  - Elevation angles ( $\alpha$ ) tested: 90°
  - Wind incidence angles ( $\beta$ ) tested: 0°



### Single Heliostat in Uniform Flow Experiments

- **Heliostat Model Used:** 200mm x 200mm x 5mm reflector, HCL = 130mm
- **Test conditions were as follows:**
  - Wind Speed = 42.6 m/s (140 ft/s)
  - Air Temperature = 23 C (74° F)
  - Air Density = 1.20 kg/m<sup>3</sup> (14.85 psia, as reported from tunnel conditions)
  - Elevation angles (alpha) tested: 90, 75, 60, 45, 35, 30, 25, 15, 0 degrees
  - Azimuth angles (beta) tested: 0 - 360 deg in 5 degree increments

Figure 10 is a line graph showing the variation of the correlation coefficient  $C_{fx\_cfd}$  (Y-axis, ranging from 0 to 1.4) versus the Beta Angle (deg) (X-axis, ranging from 0 to 360). The graph displays nine curves corresponding to different elevation angles, as indicated by the legend:

- 90 deg elev (Blue line)
- 75 deg elev (Dark Red line)
- 60 deg elev (Green line)
- 45 deg elev (Light Blue line)
- 35 deg elev (Dark Green line)
- 30 deg elev (Orange line)
- 25 deg elev (Red line)
- 15 deg elev (Purple line)
- 0 deg elev (Black line)

The curves show periodic behavior, with peaks and troughs. The 90 deg elev curve has the highest peaks (around 1.2), while the 0 deg elev curve is the lowest (around 0.1). The curves for 15, 25, 30, 35, and 45 degrees show intermediate peak heights and more complex shapes with multiple local maxima and minima.

Figure 10 is a line graph showing the CFZ CFD (Y-axis, ranging from -1.5 to 1.5) versus Beta Angle (deg) (X-axis, ranging from 0 to 360). The graph displays multiple curves for different elevation angles: 90 deg elev (blue), 75 deg elev (brown), 60 deg elev (green), 45 deg elev (cyan), 35 deg elev (magenta), 30 deg elev (orange), 25 deg elev (red), 15 deg elev (purple), and 0 deg elev (black). The curves show varying trends, with some peaking around 180 degrees and others showing more complex behavior.

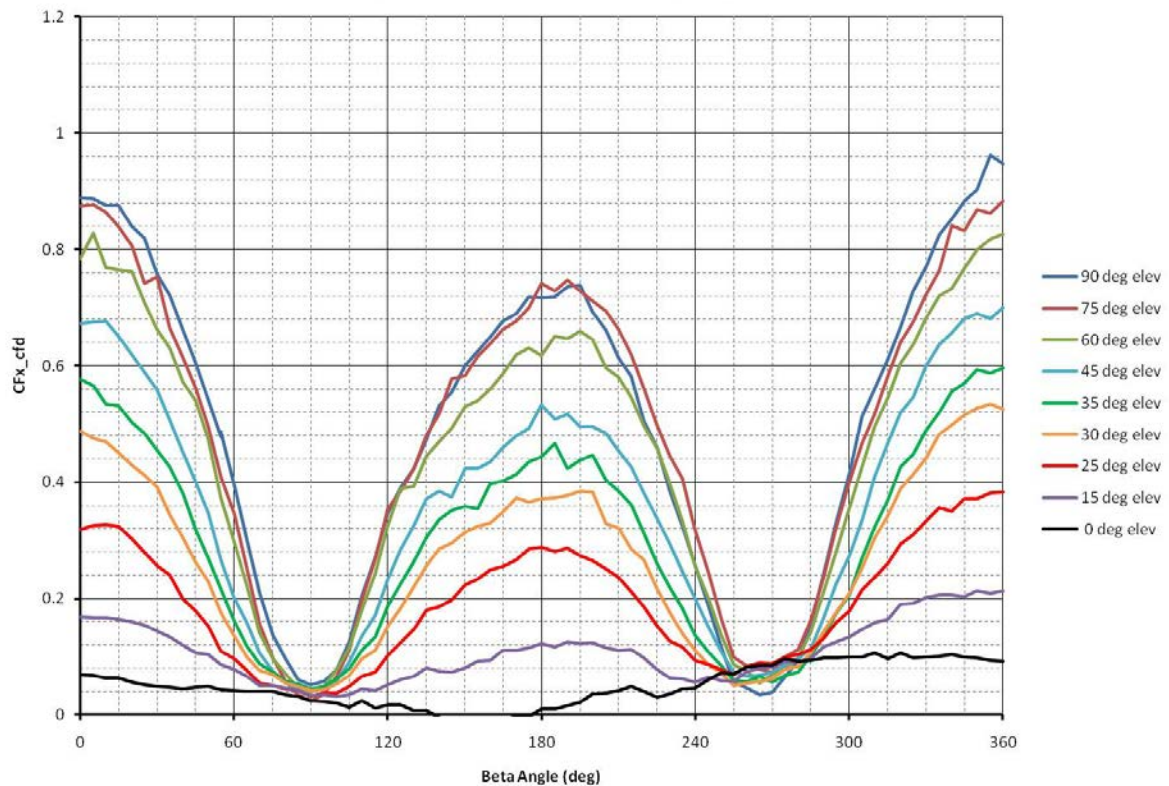




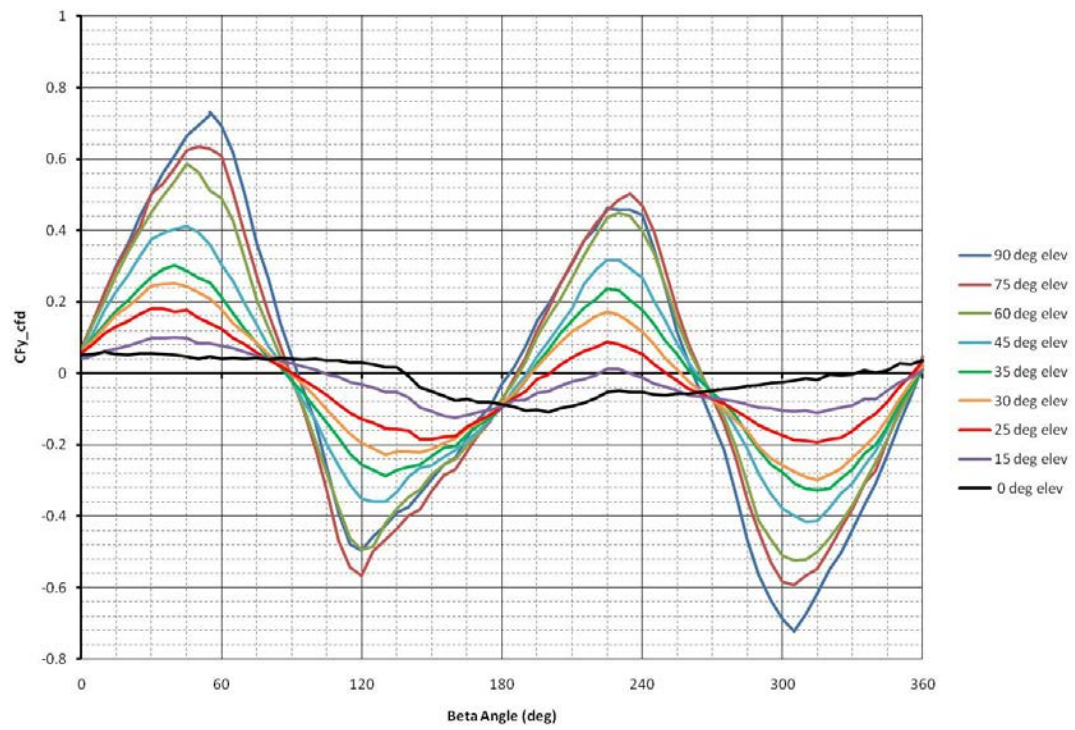
## Single Heliostat in Atmospheric Boundary Layer Experiments

- **Heliostat Model Used:** 200mm x 200mm x 5mm reflector, HCL = 130mm
- **Test conditions were as follows:**
  - Wind Speed = 18.2 m/s (60 ft/s) (41 MPH)
  - Air Temperature = 23 C (74° F)
  - Air Density = 1.20 kg/m<sup>3</sup> (14.85 psia, as reported from tunnel conditions)
  - Elevation angles ( $\alpha$ ) tested: 90, 75, 60, 45, 35, 30, 25, 15, 0 degrees
  - Wind incidence angles ( $\beta$ ) tested: 0 - 360 deg in 5 degree increments

CFx\_cfd - Phase 1 Boundary Layer Flow



CFy\_cfd - Phase 1 Boundary Layer Flow



CFz\_cfd - Phase 1 Boundary Layer Flow

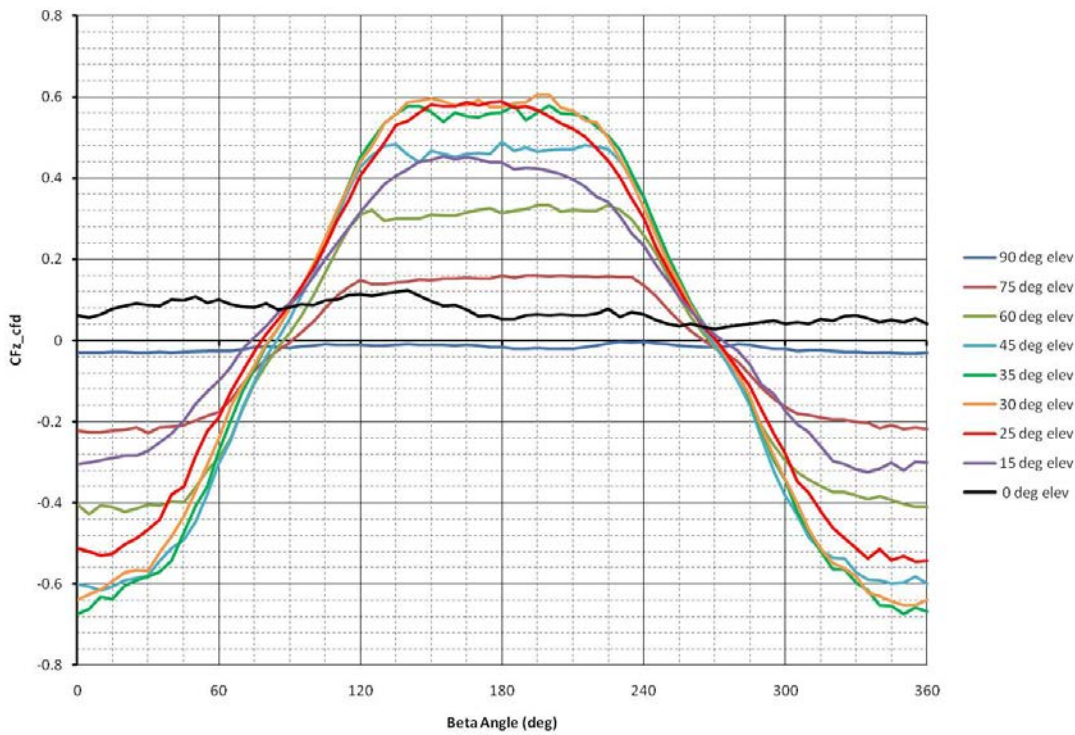
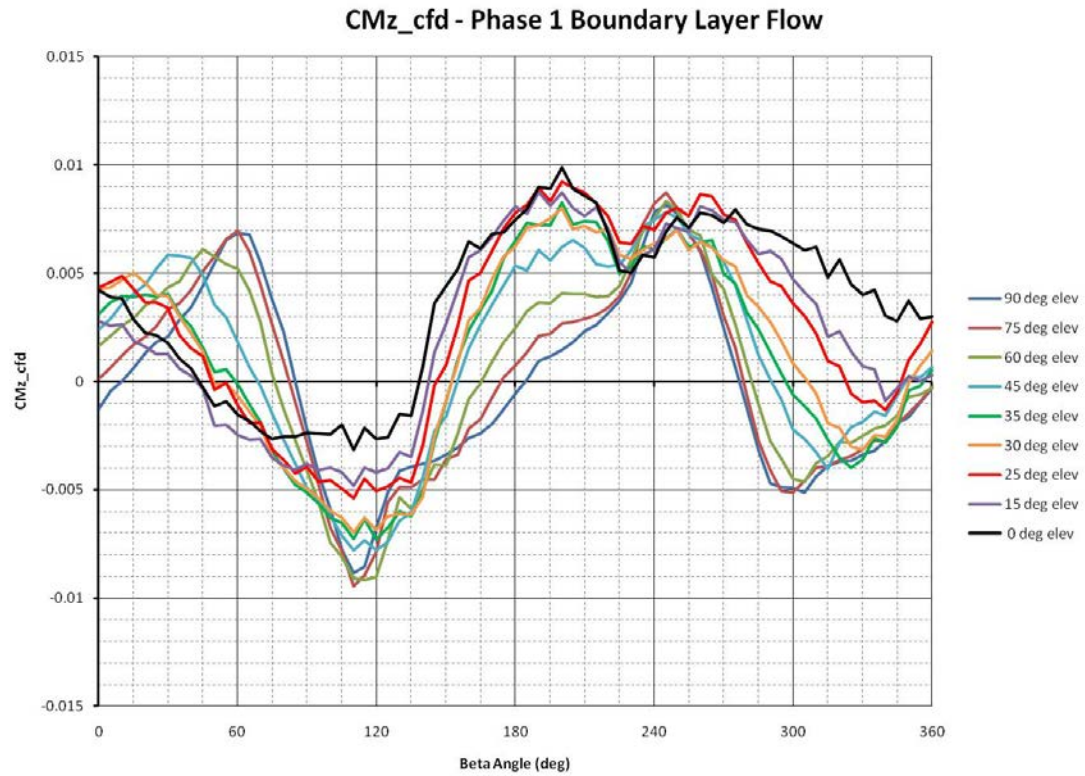




Figure 10 is a line graph showing the variation of the normalized cross-polarization ratio,  $CMW_{cfd}$ , versus the Beta Angle (deg) for different elevation angles. The x-axis ranges from 0 to 360 degrees, and the y-axis ranges from -0.2 to 0.15. The legend indicates the following elevation angles: 90 deg elev (dark blue), 75 deg elev (dark red), 60 deg elev (olive green), 45 deg elev (light blue), 35 deg elev (bright green), 30 deg elev (orange), 25 deg elev (red), 15 deg elev (purple), and 0 deg elev (black). The curves show a periodic variation with a minimum around 180 degrees and a maximum around 360 degrees. The 0 degree elevation curve is the flattest, while the 90 degree elevation curve shows the largest variation.

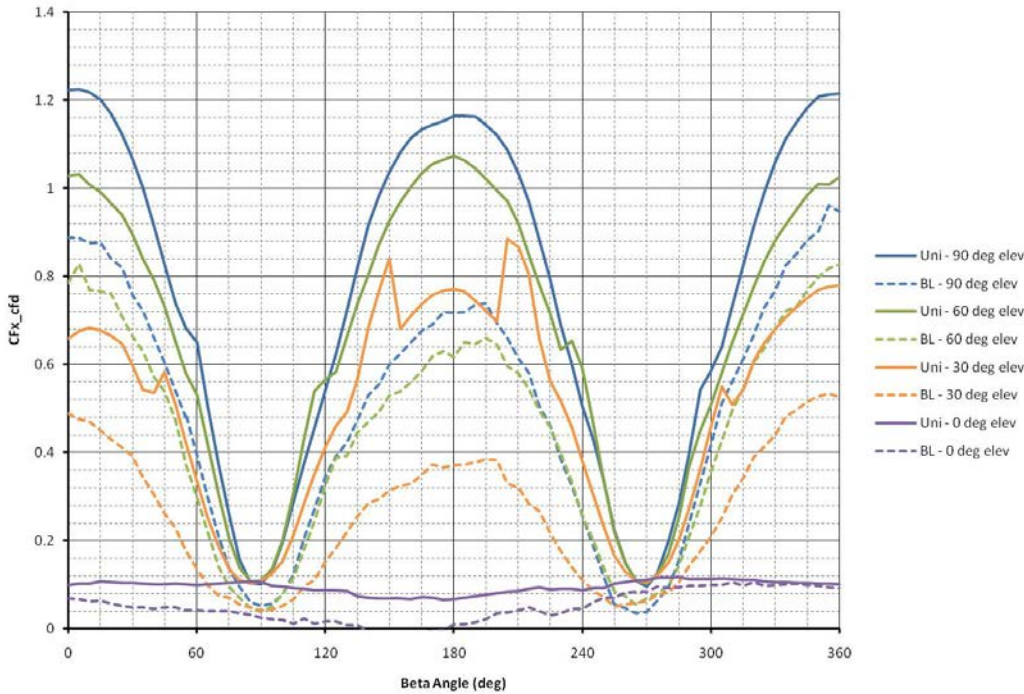




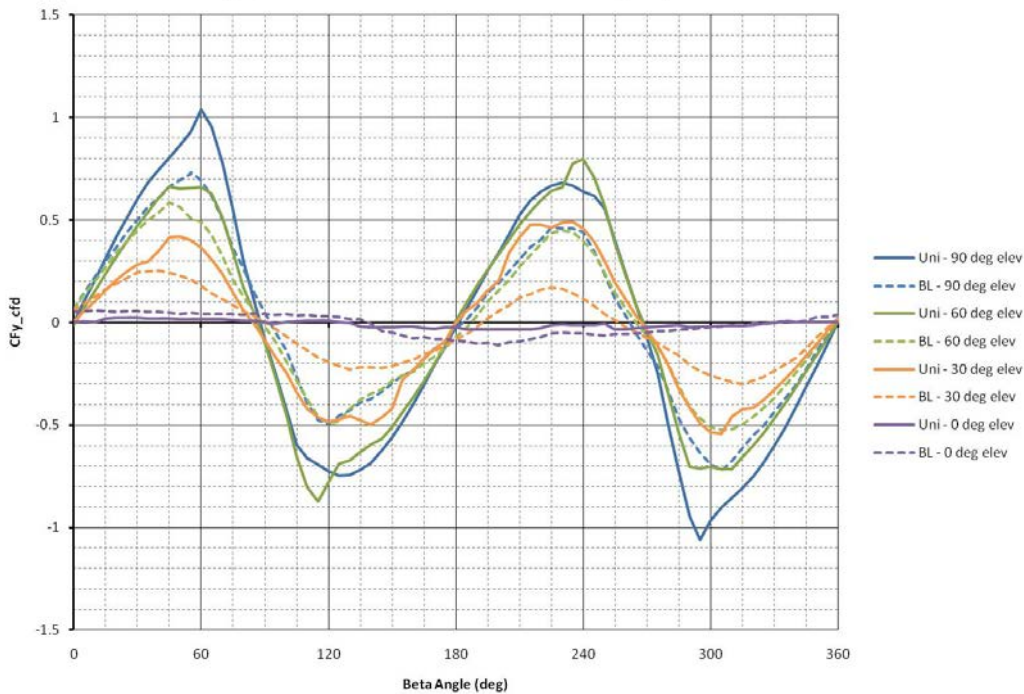
## Single Heliostat Comparison between Uniform Flow and Atmospheric Boundary Layer

- **Heliostat Model Used:** 200mm x 200mm x 5mm reflector, HCL = 130mm

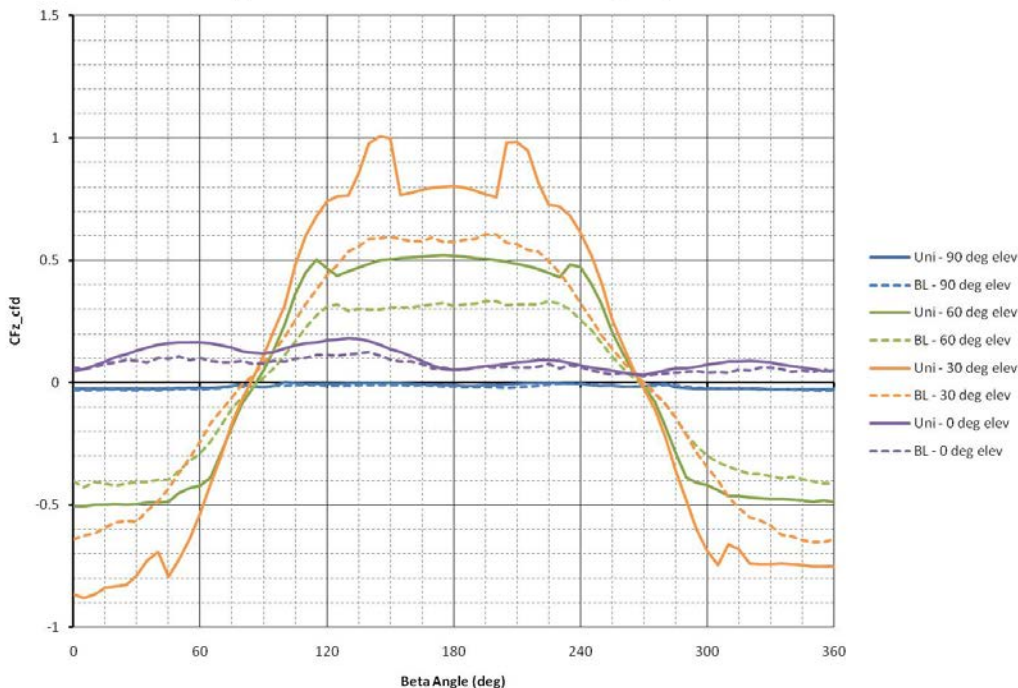
### CFx\_cfd - Uniform Flow and Boundary Layer conditions



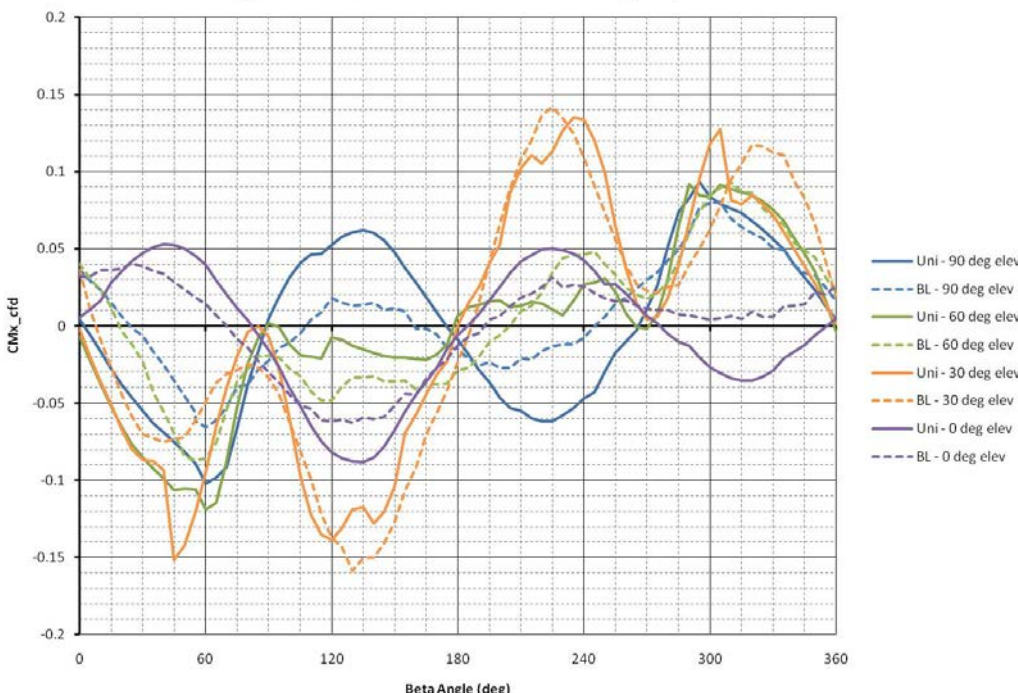
### CFy\_cfd - Uniform Flow and Boundary Layer conditions



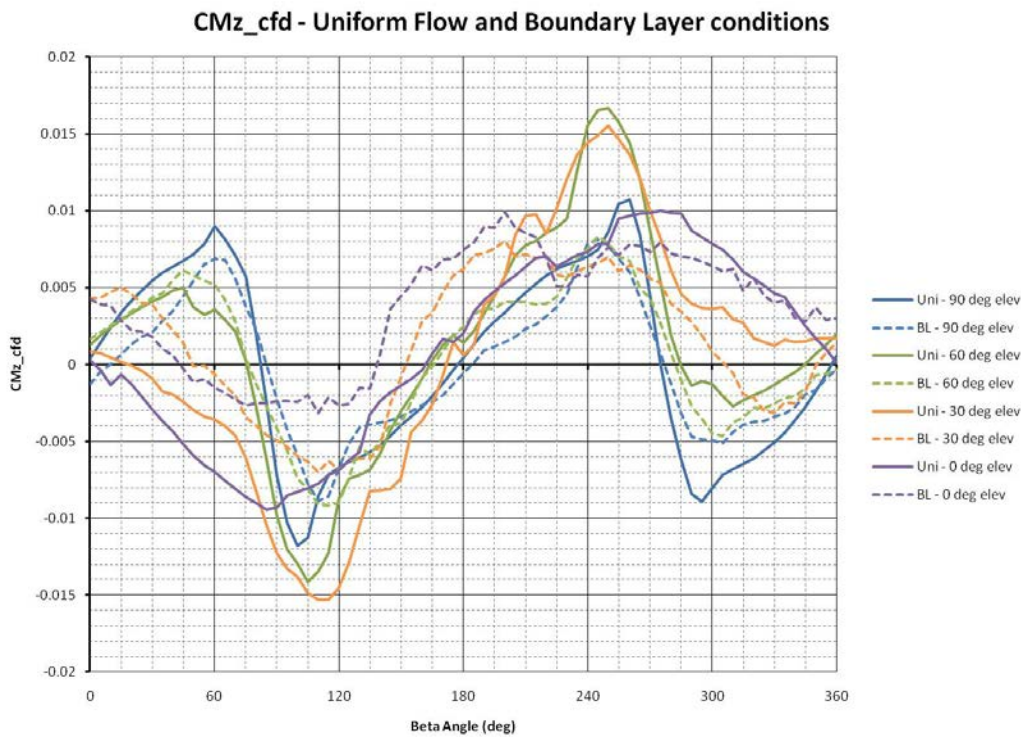
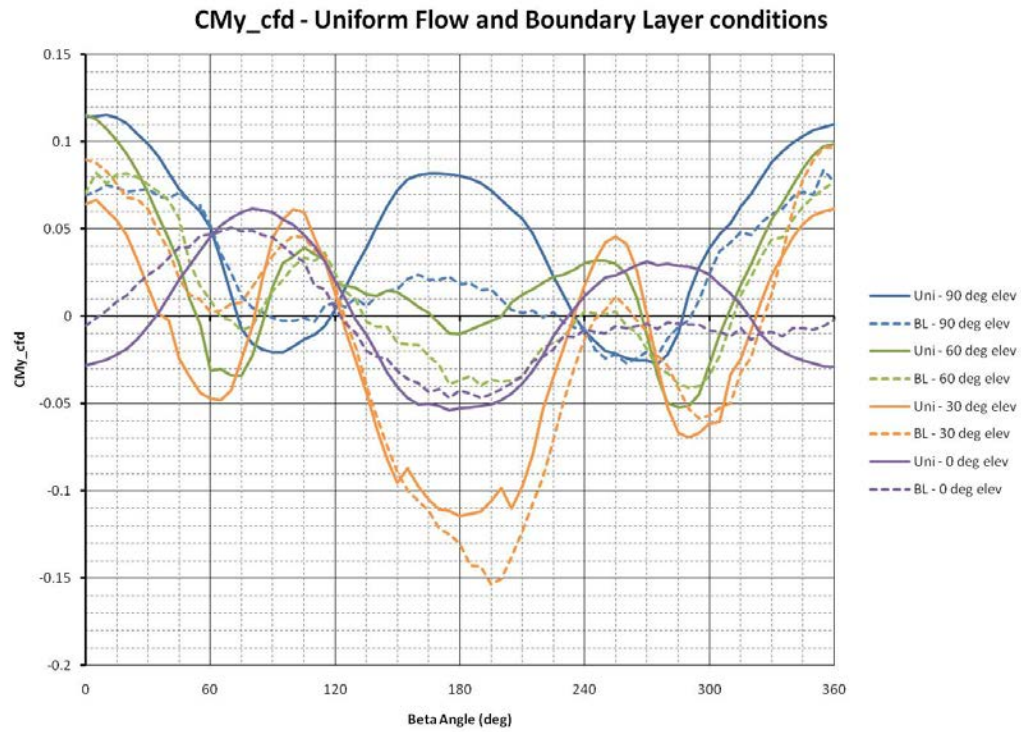
### CFz\_cfd - Uniform Flow and Boundary Layer conditions



### CMx cfd - Uniform Flow and Boundary Layer conditions

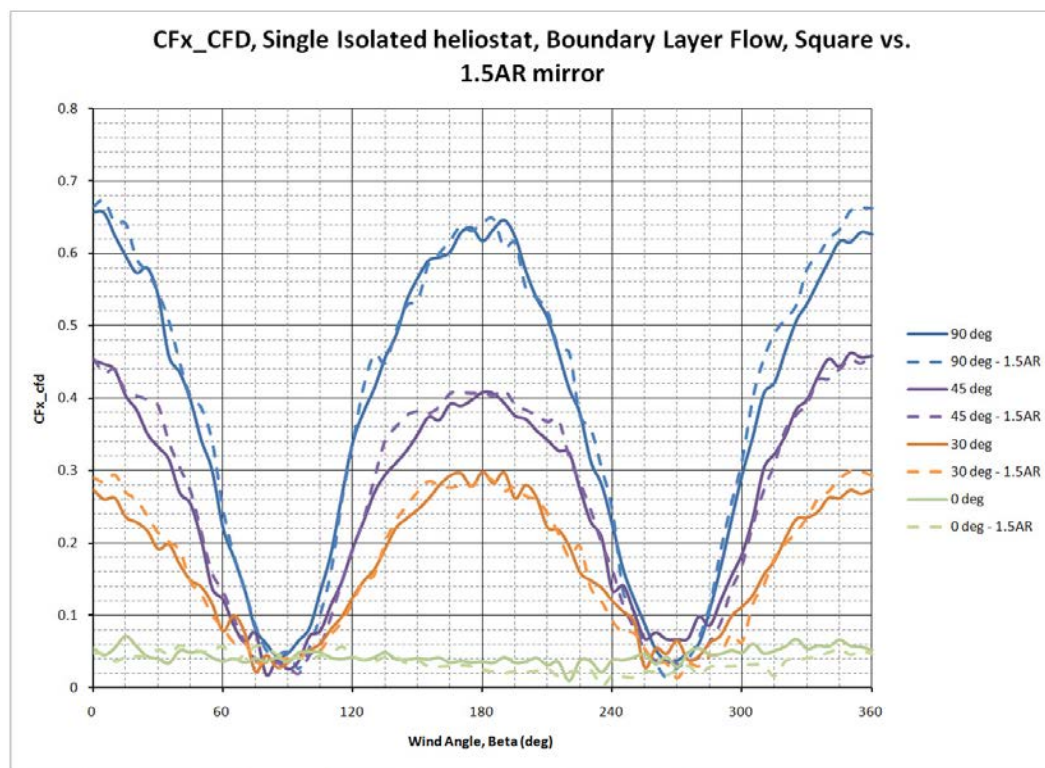




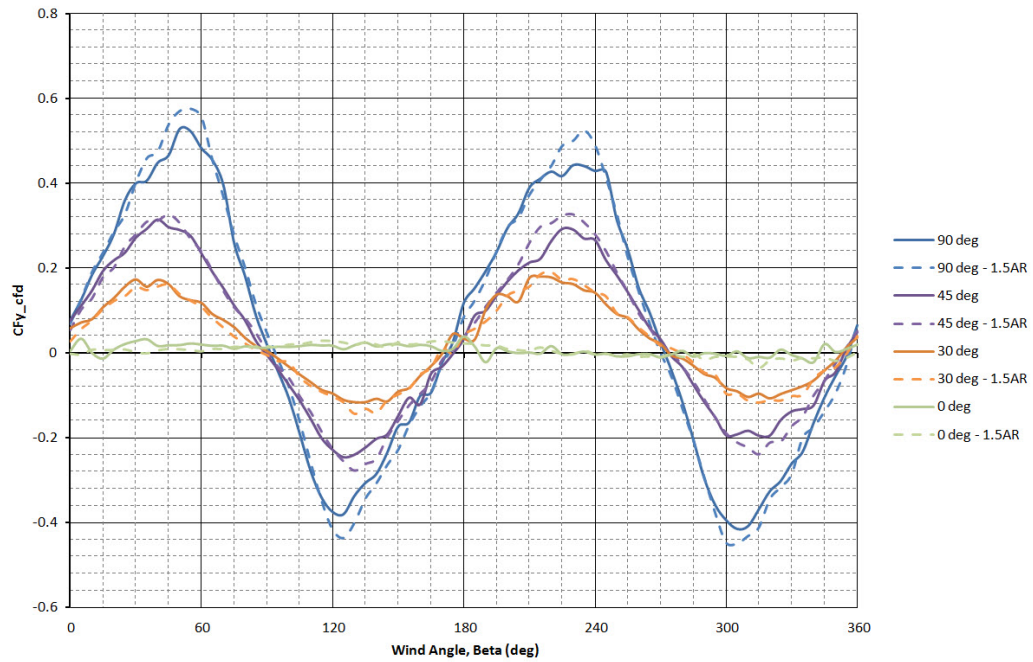


## Single Heliostat with 1.5 Aspect Ratio Reflector

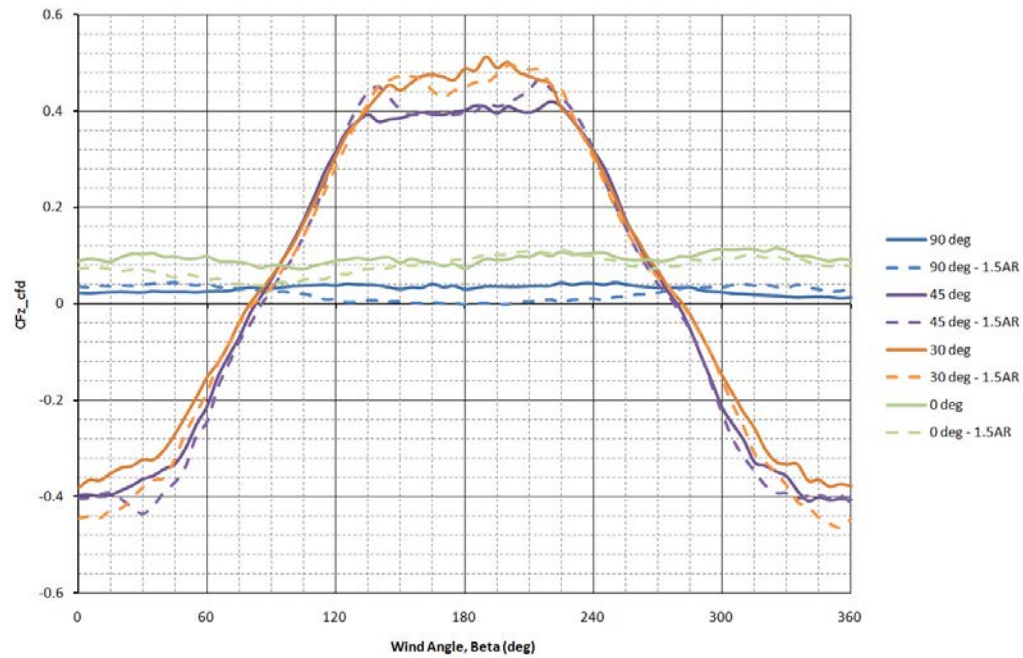
- **Heliostat Model Used:** 100mm x 100mm x 3mm reflector, HCL = 75mm
- **Test conditions were as follows (square 1.0AR reflector)**
  - $Q = 1.38$  kPa (29 psf)
  - Wind Speed = 48 m/s (158 ft/s)
  - Air Temperature = 8.3C (47° F)
  - Air Density = 1.20 kg/m<sup>3</sup> (14.85 psia, as reported from tunnel conditions)
  - Elevation angles ( $\alpha$ ) tested: 90, 45, 30, 0 degrees
  - Wind incidence angles ( $\beta$ ) tested: 0 - 360 deg in 5 degree increments
- **Heliostat Model Used:** 150mm x 100mm x 3mm reflector, HCL = 75mm
- **Test conditions were as follows (square 1.5AR reflector)**
  - $Q = 0.95$  kPa (20 psf)
  - Wind Speed = 40 m/s (131 ft/s)
  - Air Temperature = 13.9C (57° F)
  - Air Density = 1.20 kg/m<sup>3</sup> (14.85 psia, as reported from tunnel conditions)
  - Elevation angles ( $\alpha$ ) tested: 90, 45, 30, 0 degrees
  - Wind incidence angles ( $\beta$ ) tested: 0 - 360 deg in 5 degree increments



CFy\_CFD, Single Isolated heliostat, Boundary Layer Flow, Square vs.  
1.5AR mirror



CFz\_CFD, Single Isolated heliostat, Boundary Layer Flow, Square vs.  
1.5AR mirror

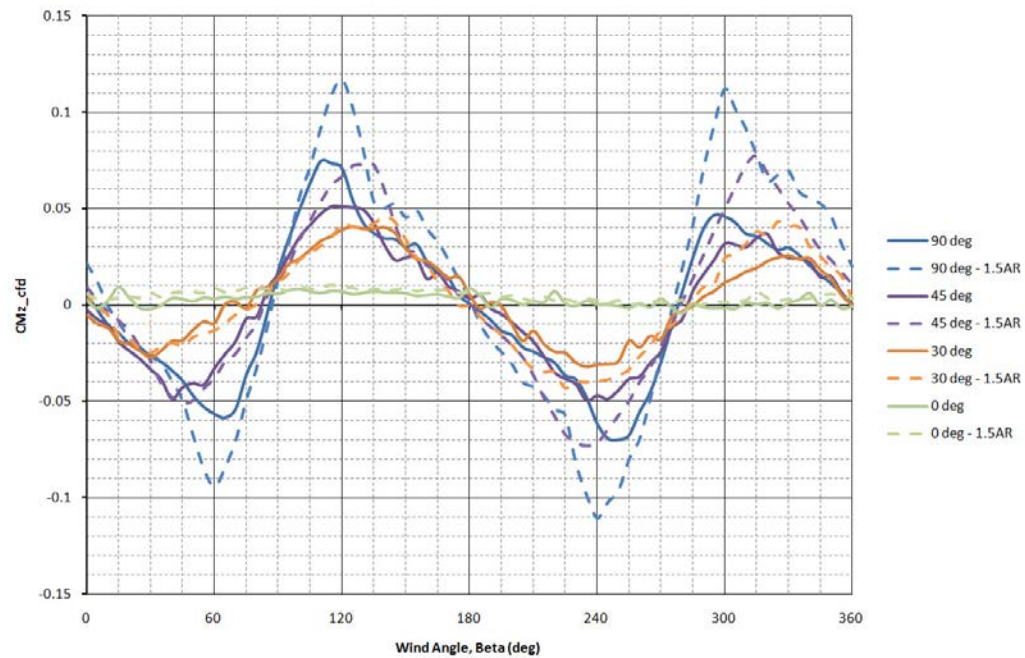




**CM<sub>y</sub>\_CFD, Single Isolated heliostat, Boundary Layer Flow, Square vs. 1.5AR mirror**



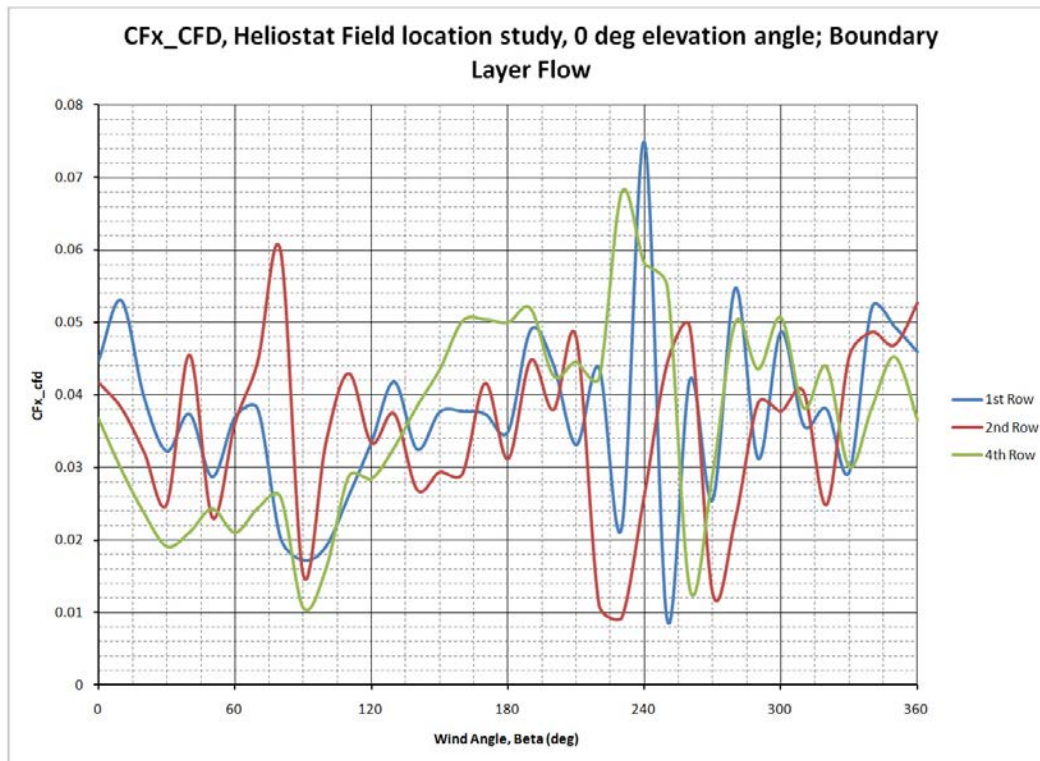
**CM<sub>z</sub>\_CFD, Single Isolated heliostat, Boundary Layer Flow, Square vs. 1.5AR mirror**



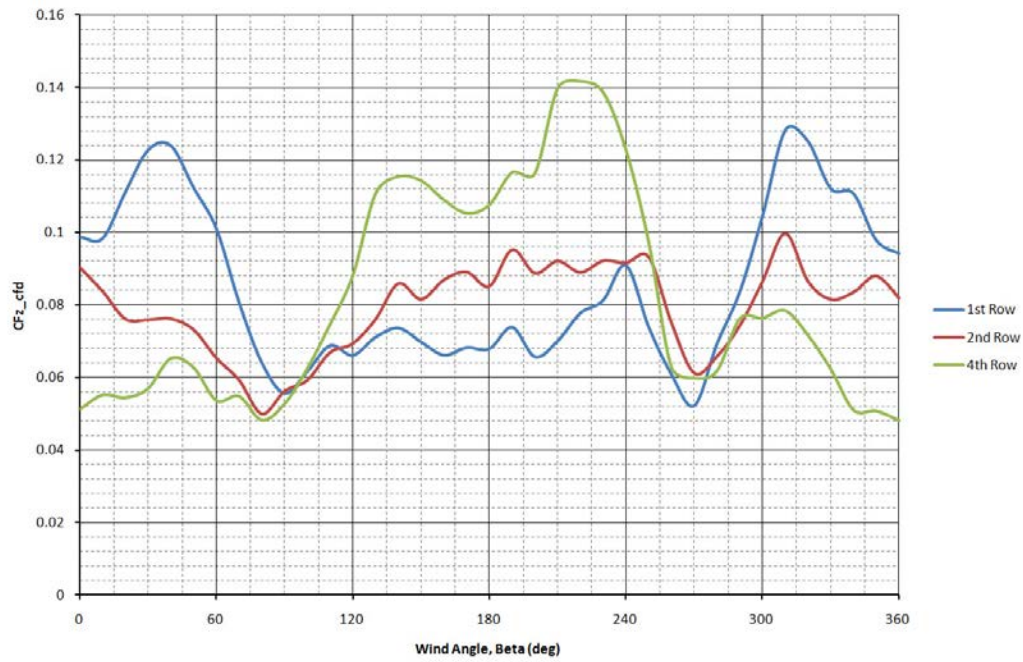
Heliostat Field

- **Heliostat Model Used:** 100mm x 100mm x 3mm reflector, HCL = 75mm
- **Test conditions were as follows:**
  - $Q = 0.95$  kPa (20psf)
  - Wind Speed = 40 m/s (132 ft/s)
  - Air Temperature = 23 C (74° F)
  - Air Density =  $1.20 \text{ kg/m}^3$  (14.85 psia, as reported from tunnel conditions)
  - Elevation angles (alpha) tested: 90, 45, 30, 3, 0 degrees
  - Azimuth angles (beta) tested: 0 - 360 deg in 5 degree increments
  - Instrumented field positions: 1st row, 2nd row, 4th row

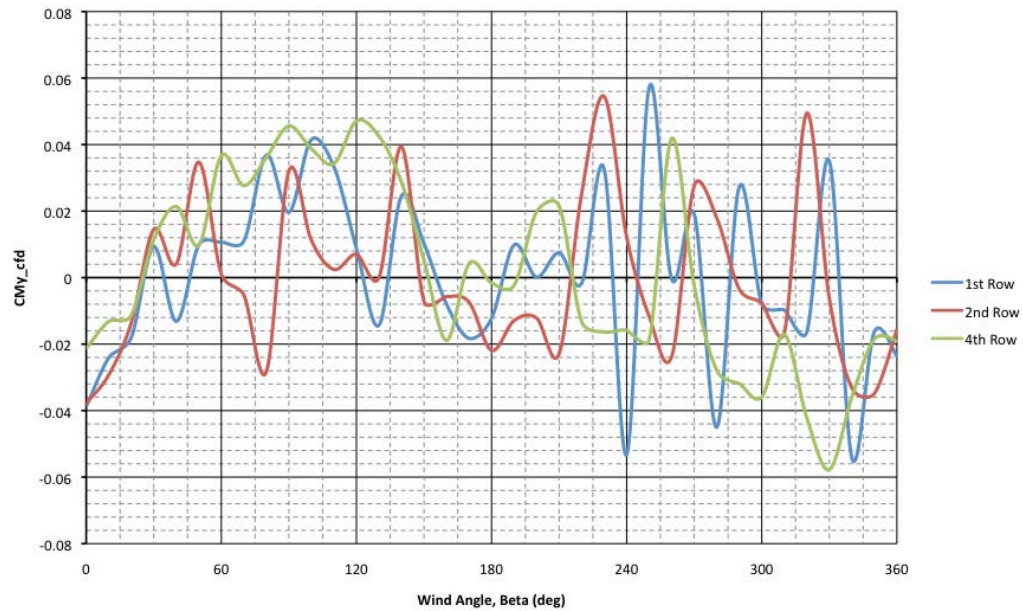
## Heliostat Field Position Experiments



CFz\_CFD, Heliostat Field location study, 0 deg elevation angle; Boundary Layer Flow

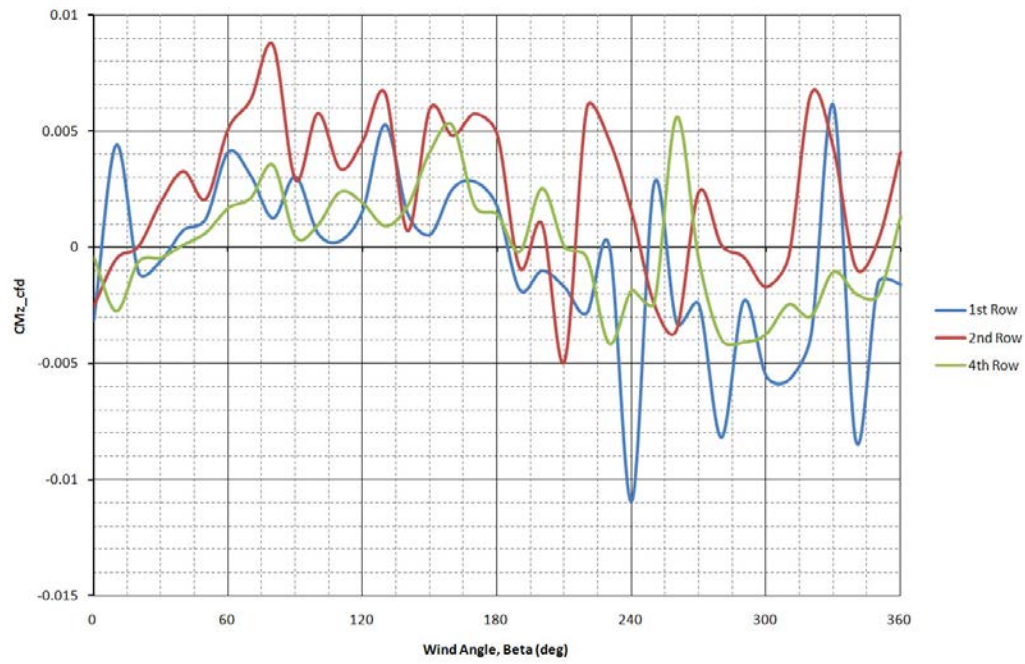


CMY\_CFD, Heliostat Field location study, 0 deg elevation angle; Boundary Layer Flow

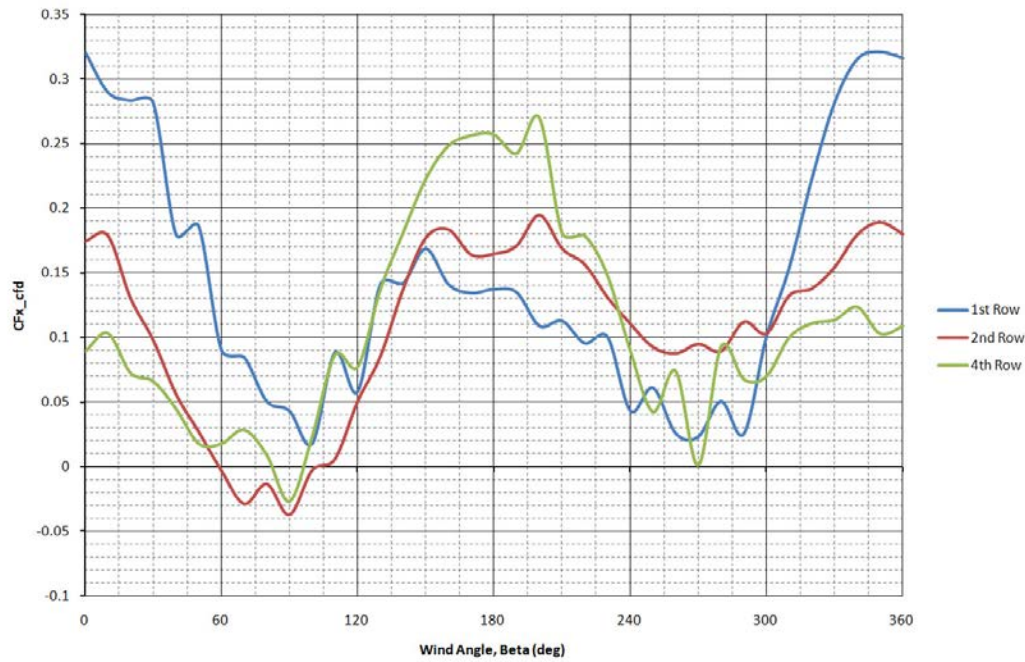




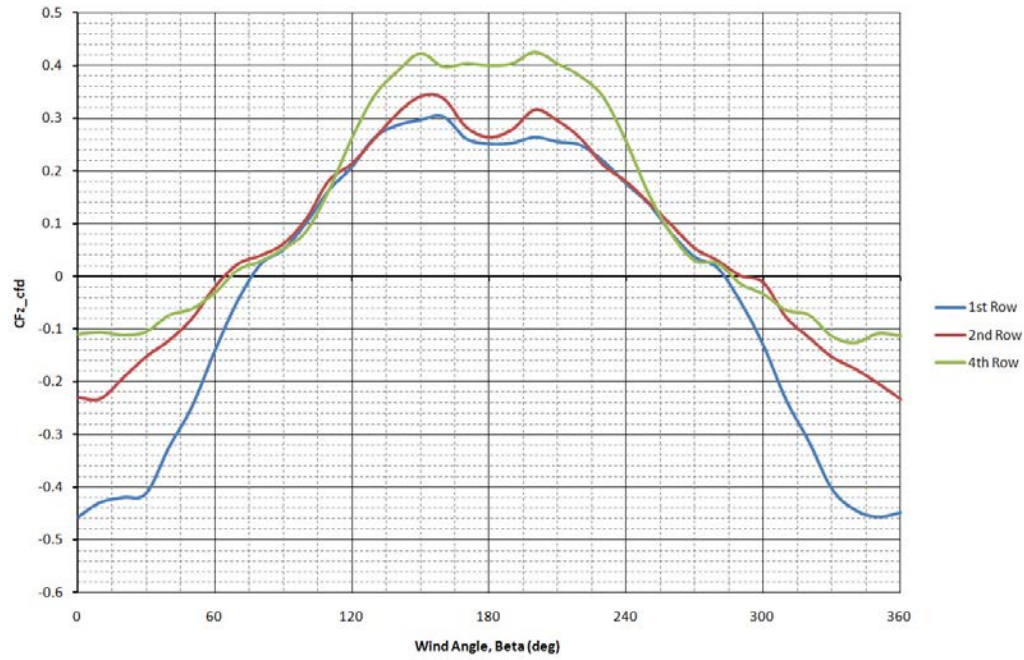
CMz\_CFD, Heliostat Field location study, 0 deg elevation angle;  
Boundary Layer Flow



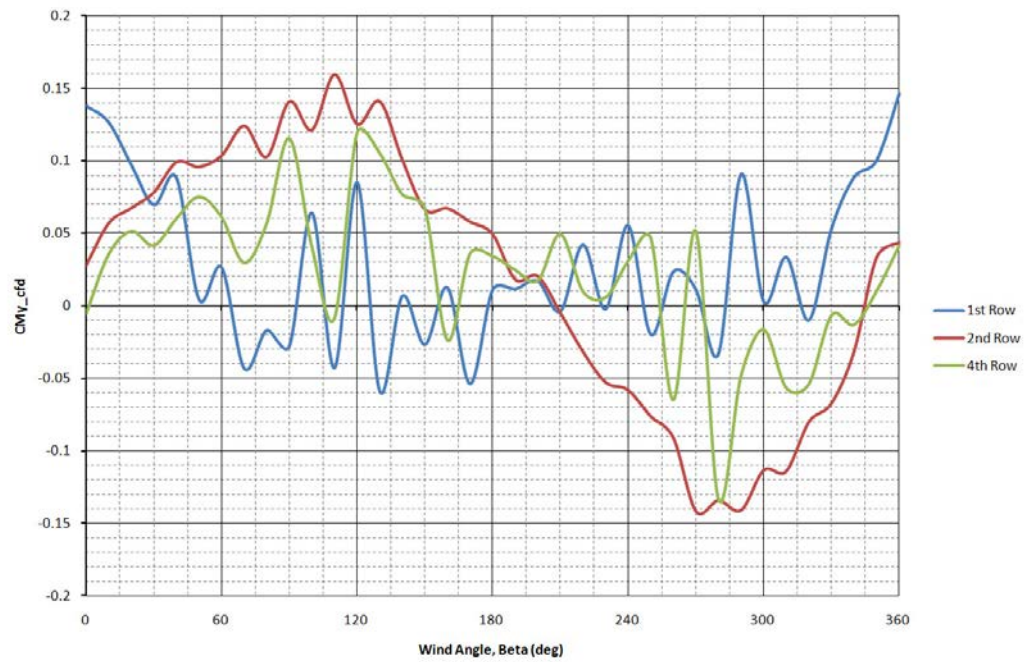
CFx\_CFD, Heliostat Field location study, 30 deg elevation angle;  
Boundary Layer Flow



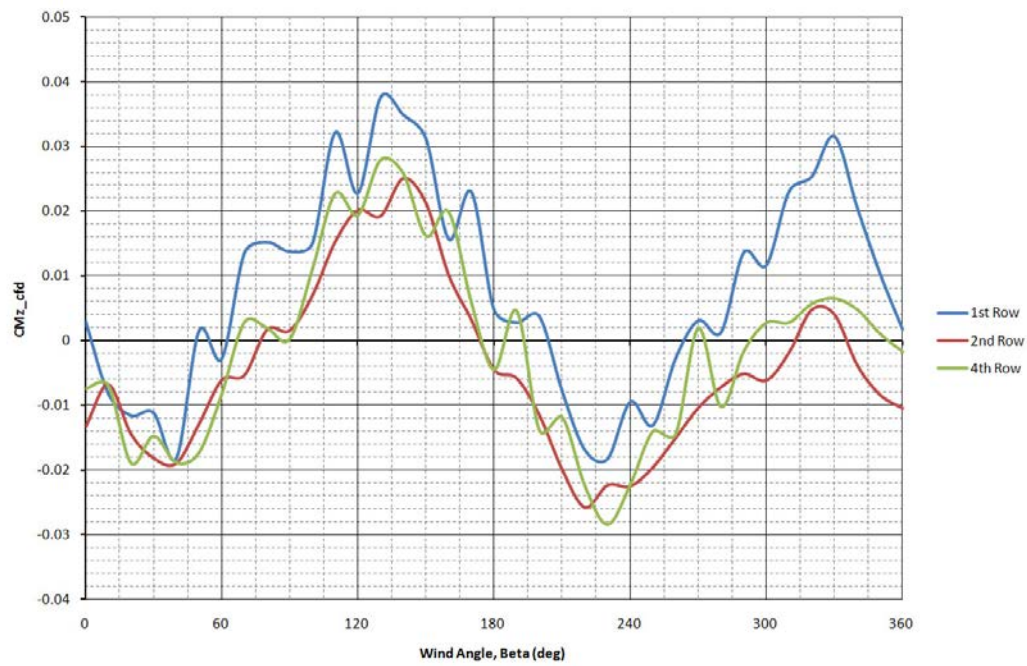
CFz\_CFD, Heliostat Field location study, 30 deg elevation angle;  
Boundary Layer Flow



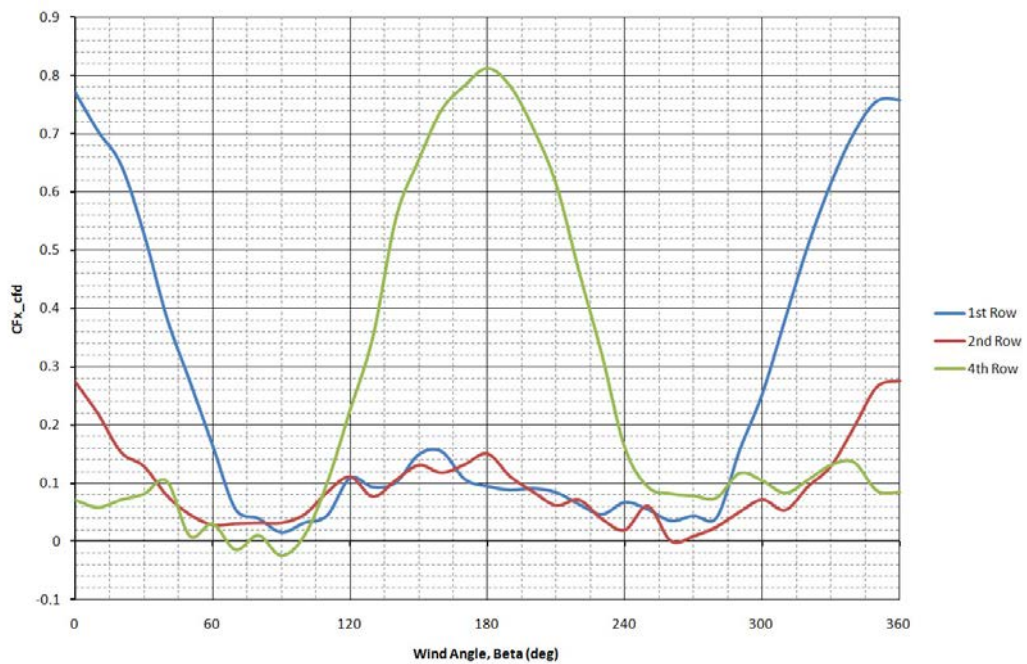
CMY\_CFD, Heliostat Field location study, 30 deg elevation angle;  
Boundary Layer Flow



**CMz\_CFD, Heliostat Field location study, 30 deg elevation angle;  
Boundary Layer Flow**

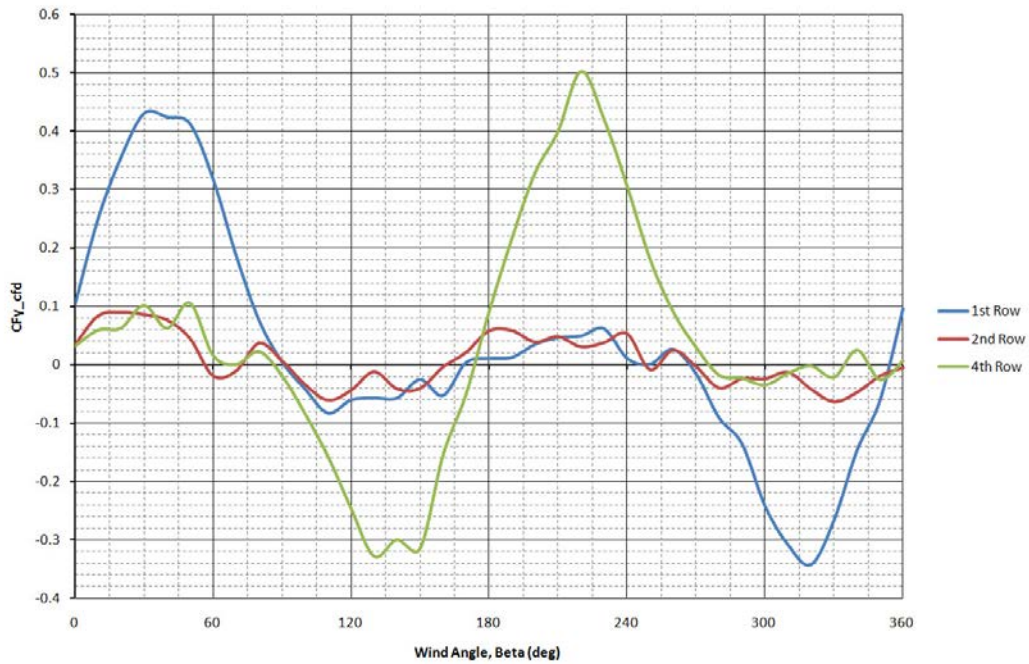


**CFx\_CFD, Heliostat Field location study, 90 deg elevation angle;  
Boundary Layer Flow**

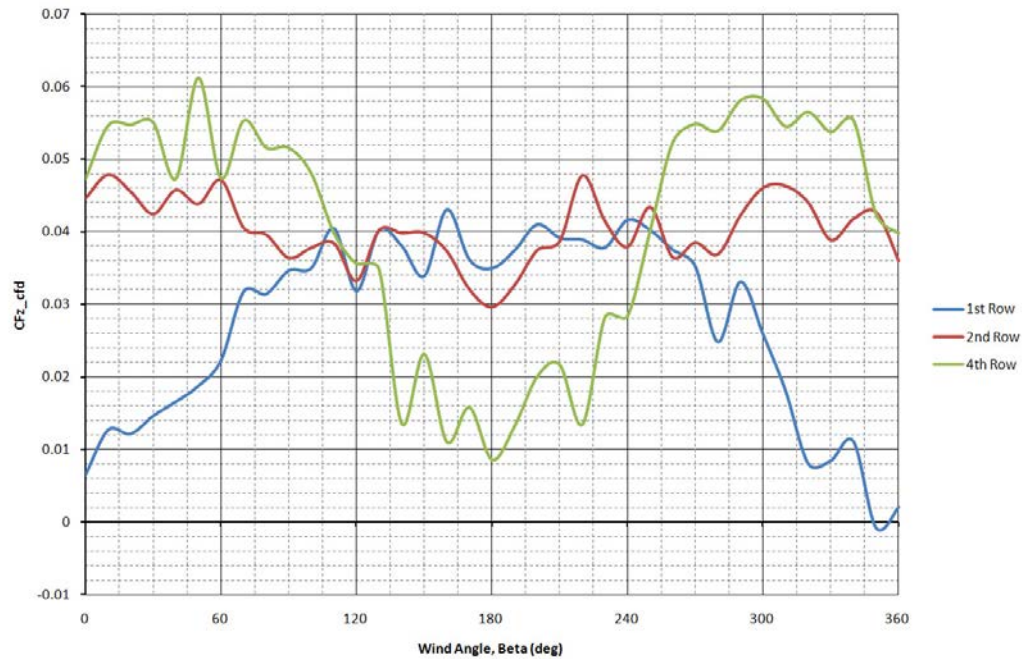


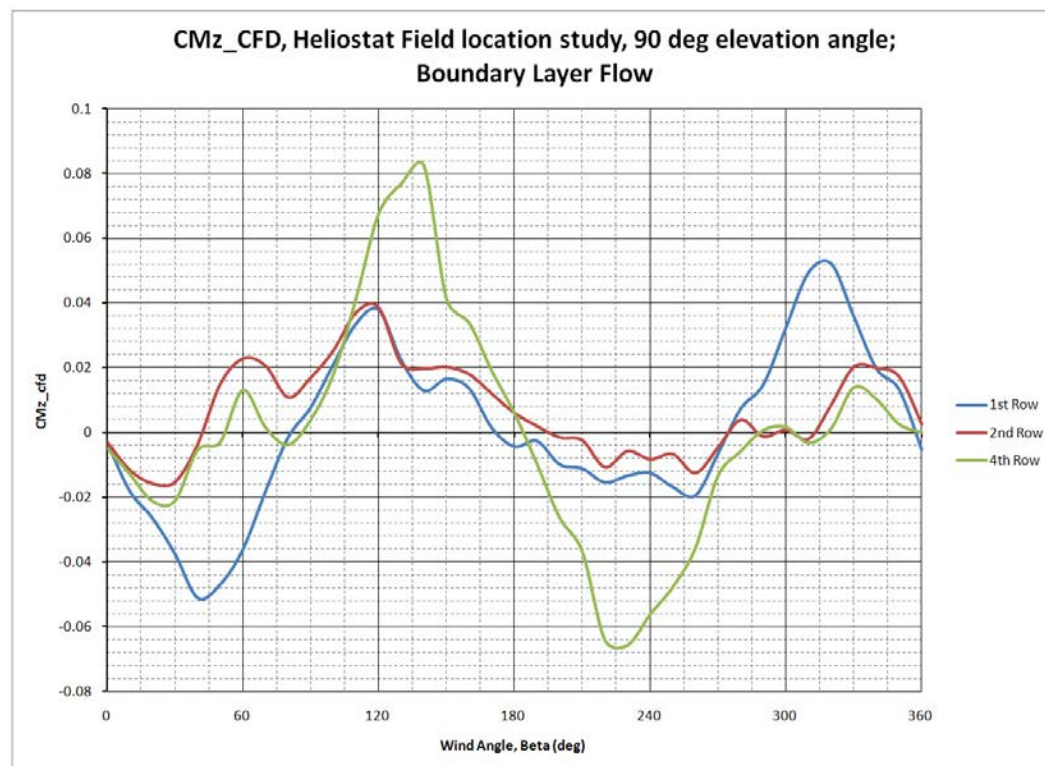
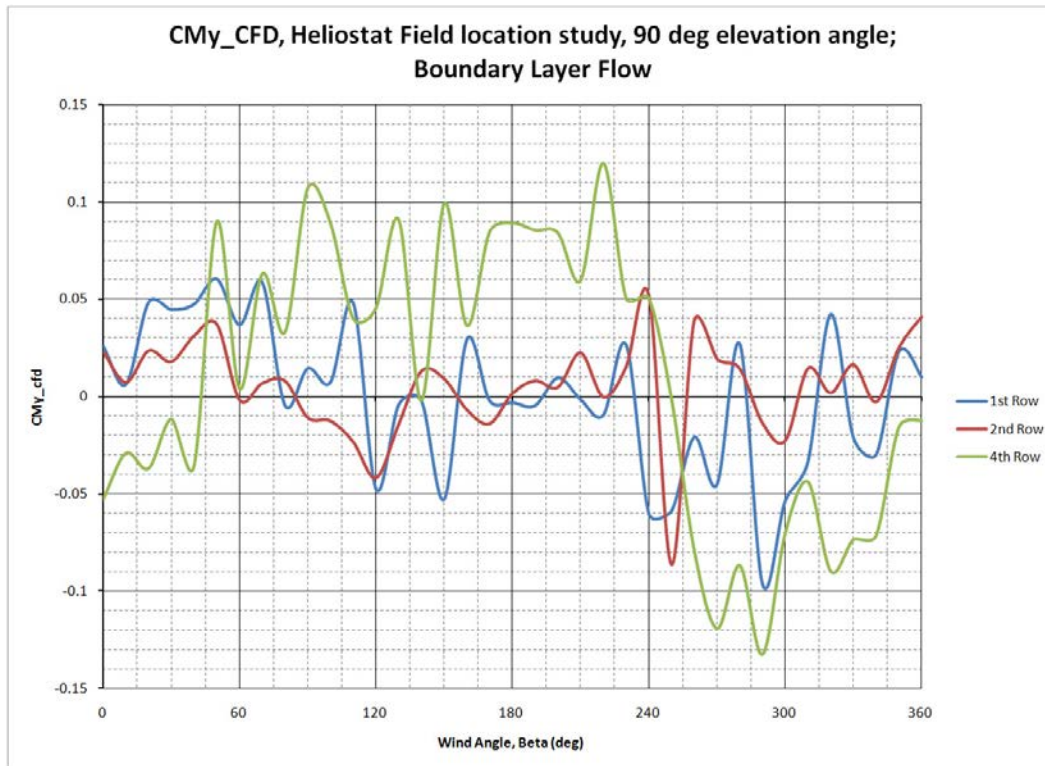


**CFy\_CFD, Heliostat Field location study, 90 deg elevation angle,  
Boundary Layer Flow**



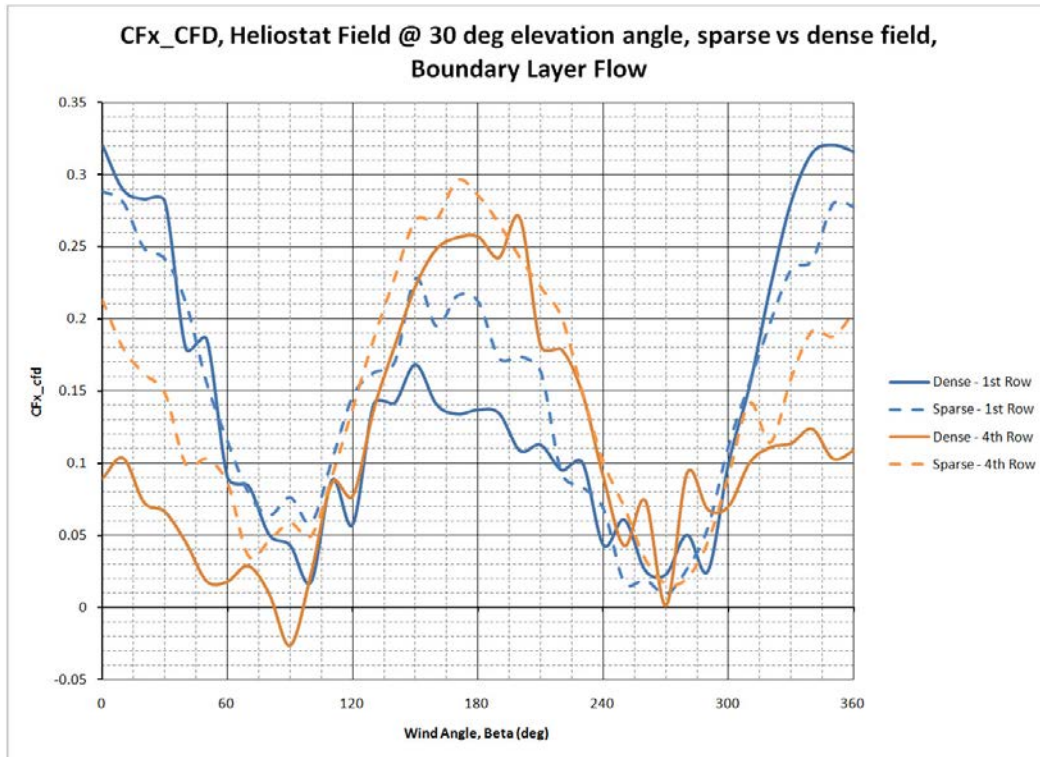
**CFz\_CFD, Heliostat Field location study, 90 deg elevation angle;  
Boundary Layer Flow**





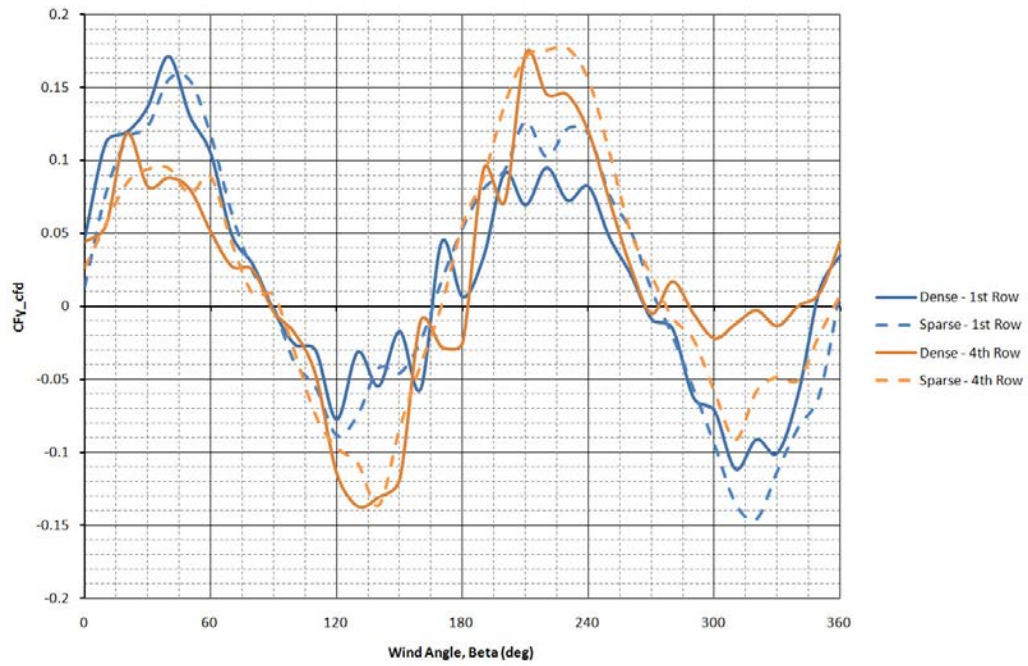
Heliostat Field Packing Density (25% vs 50%)

- **Heliostat Model Used:** 100mm x 100mm x 3mm reflector, HCL = 75mm
- **Test conditions were as follows:**
  - $Q = 0.95$  kPa (20psf)
  - Wind Speed = 40 m/s (132 ft/s)
  - Air Temperature = 23 C (74° F)
  - Air Density =  $1.20 \text{ kg/m}^3$  (14.85 psia, as reported from tunnel conditions)
  - Elevation angles (alpha) tested: 90, 30, 0 degrees
  - Azimuth angles (beta) tested: 0 - 360 deg in 5 degree increments
  - Instrumented field positions: 1st row, 4th row

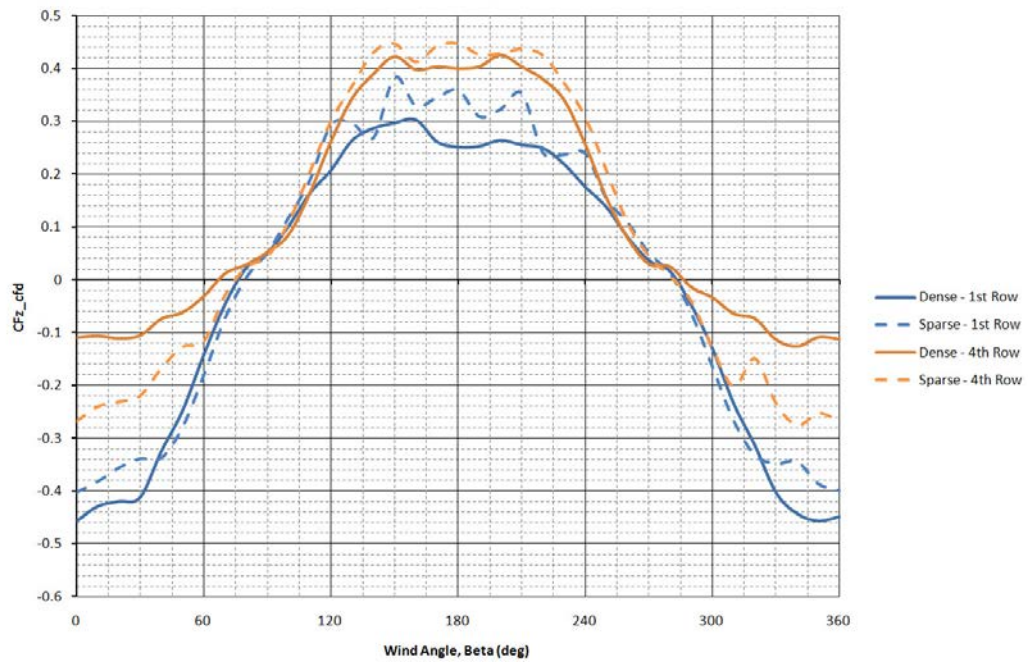




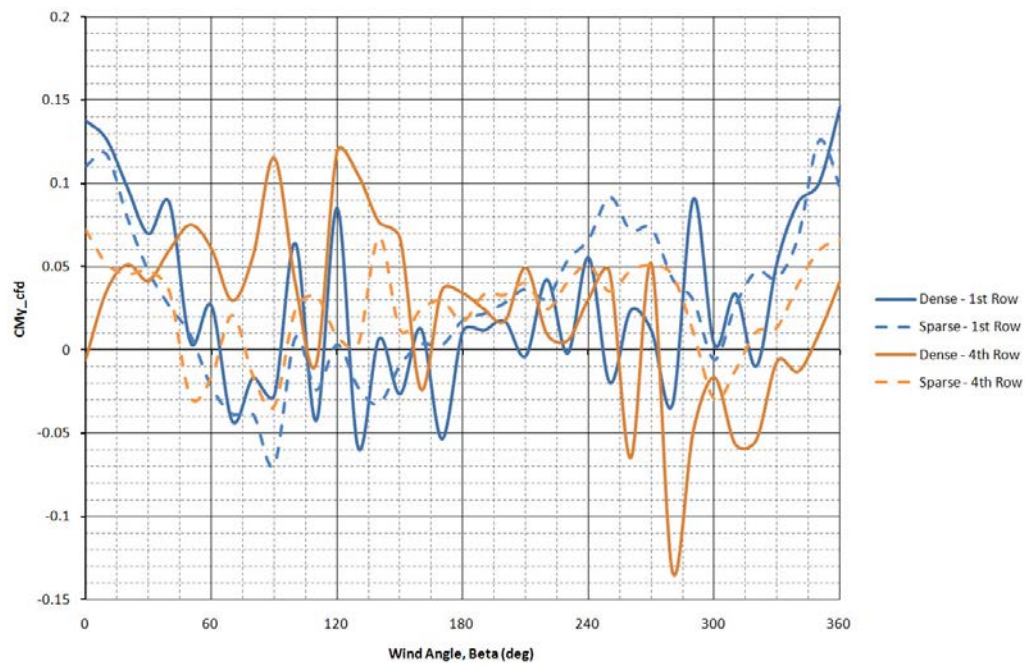
CFy\_CFD, Heliostat Field @ 30 deg elevation angle, sparse vs dense field,  
Boundary Layer Flow



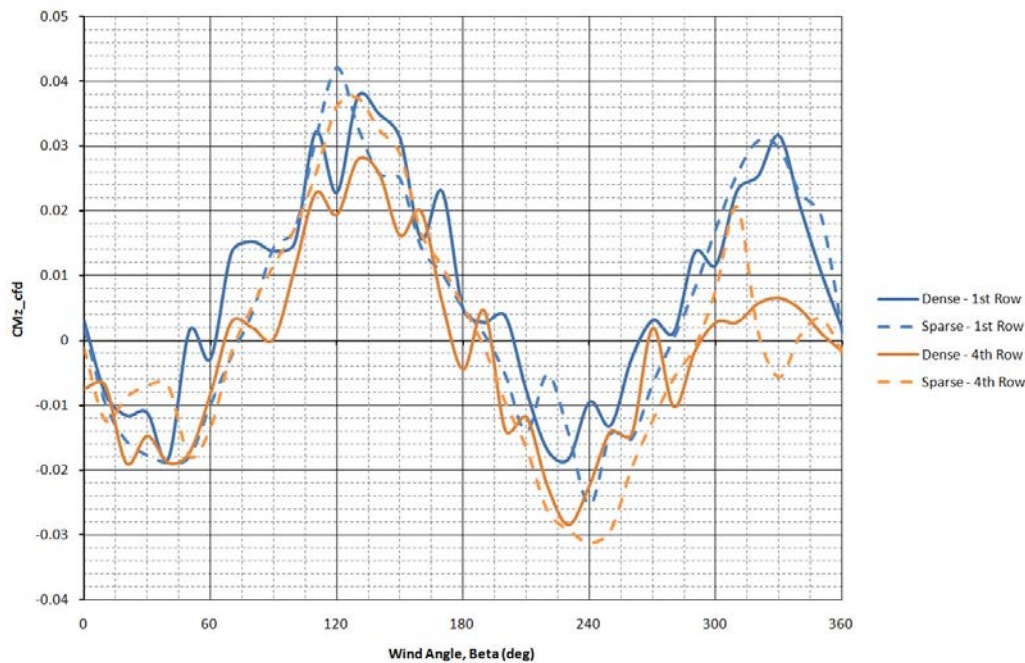
CFz\_CFD, Heliostat Field @ 30 deg elevation angle, sparse vs dense field,  
Boundary Layer Flow



**CM<sub>y</sub>\_CFD, Heliostat Field @ 30 deg elevation angle, sparse vs dense field, Boundary Layer Flow**



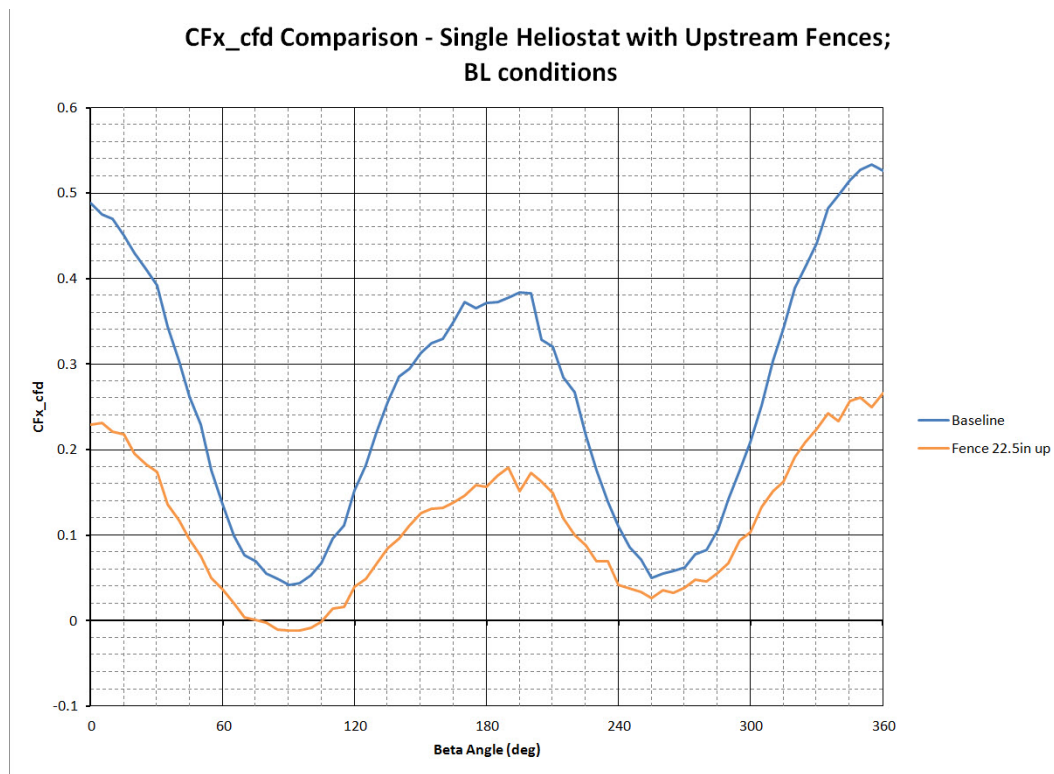
**CM<sub>z</sub>\_CFD, Heliostat Field @ 30 deg elevation angle, sparse vs dense field, Boundary Layer Flow**



## Mitigations

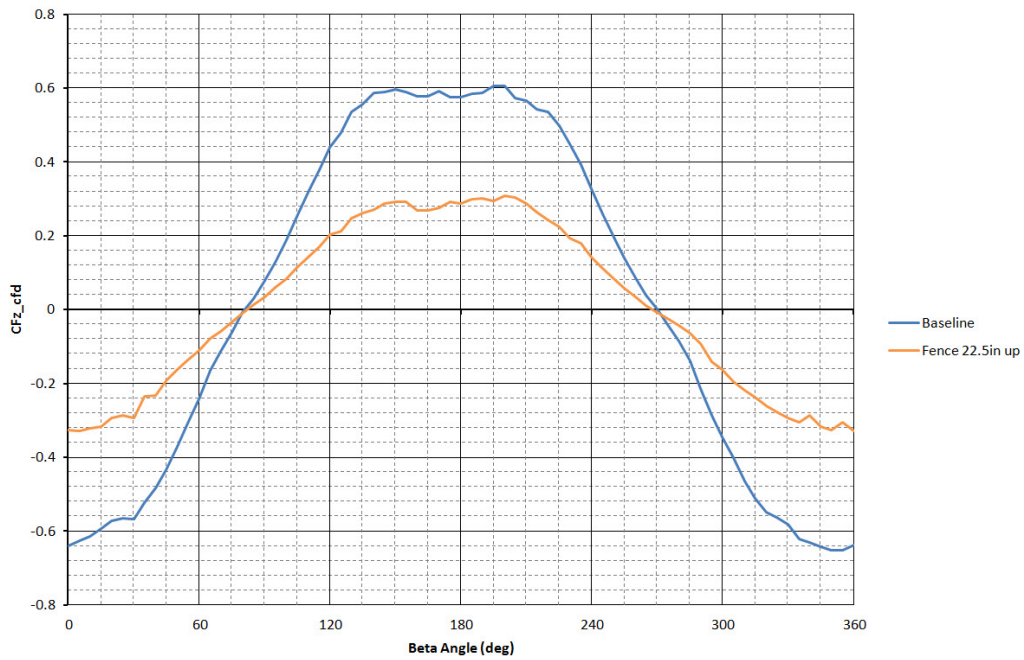
### Single Heliostat with Upstream Fence

- **Heliostat Model Used:** 200mm x 200mm x 5mm reflector, HCL = 130mm
- **Fence model used:** 114mm tall, 47% open area, installed 571mm (2.85\*H) upstream of the heliostat model
- **Test conditions were as follows:**
  - Wind Speed = 18.2 m/s (60 ft/s) (41 MPH)
  - Air Temperature = 23 C (74° F)
  - Air Density = 1.20 kg/m<sup>3</sup> (14.85 psia, as reported from tunnel conditions)
  - Elevation angles ( $\alpha$ ) tested: 30degrees
  - Wind incidence angles ( $\beta$ ) tested: 0 - 360 deg in 5 degree increments

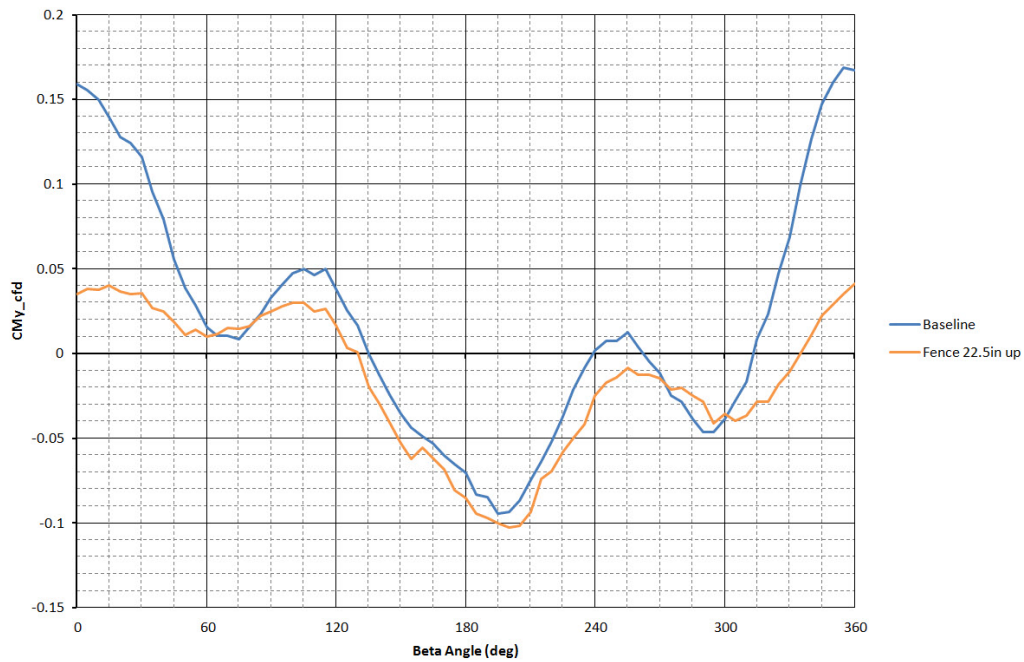




**CFz\_cfd Comparison - Single Heliostat with Upstream Fences;  
BL conditions**

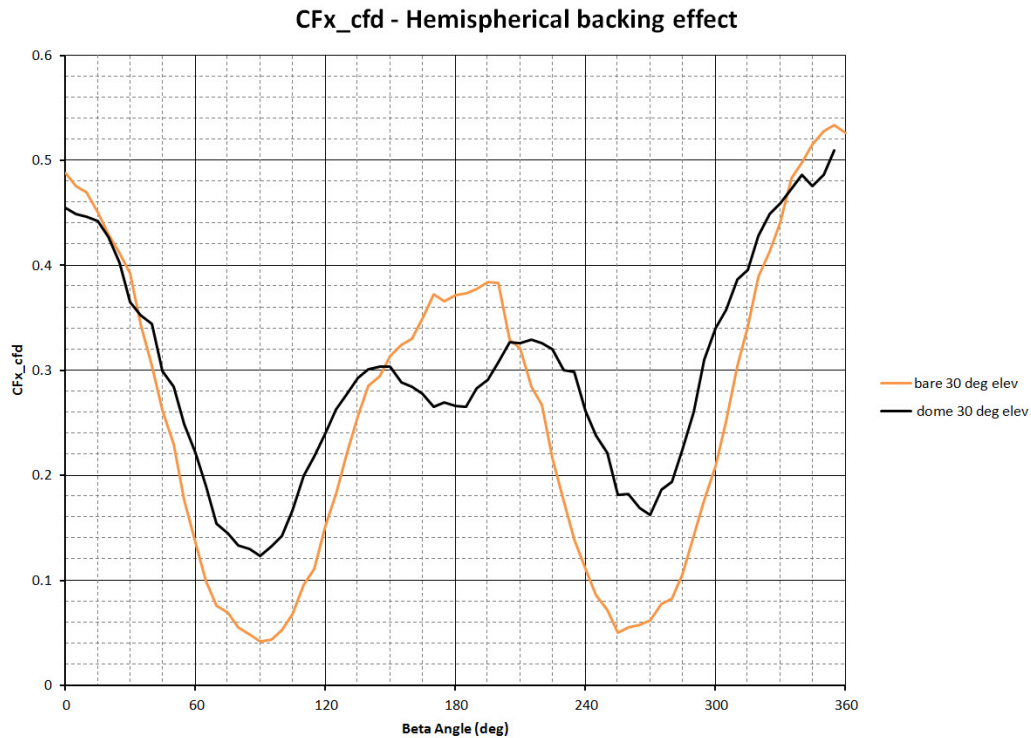


**CMY\_cfd Comparison - Single Heliostat with Upstream Fences;  
BL conditions**

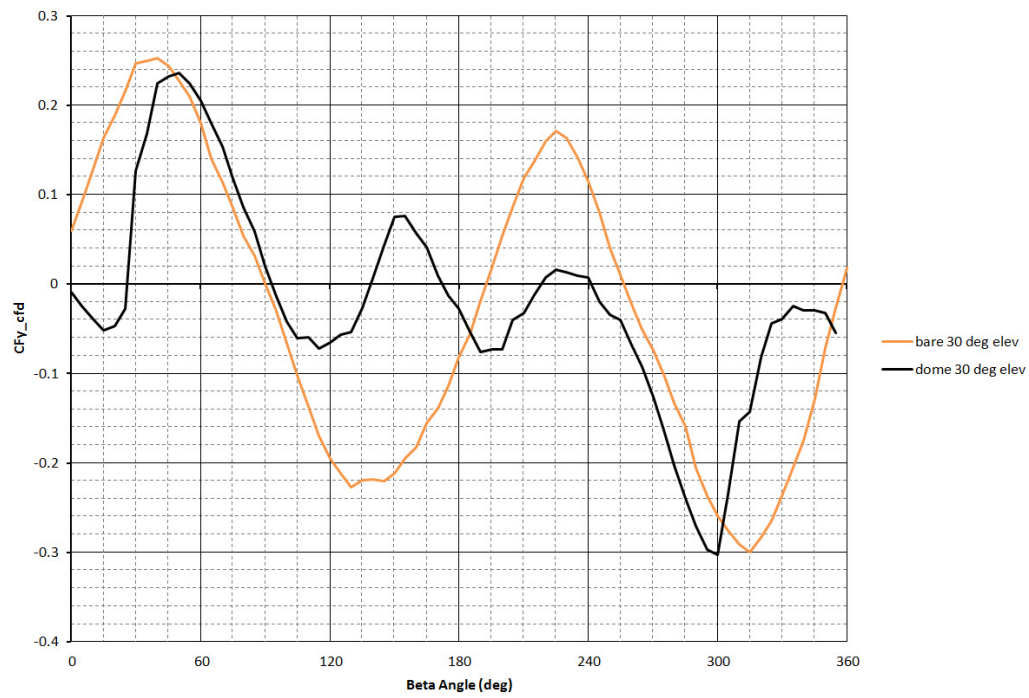


Hemispherical Backed Heliostat Experiments

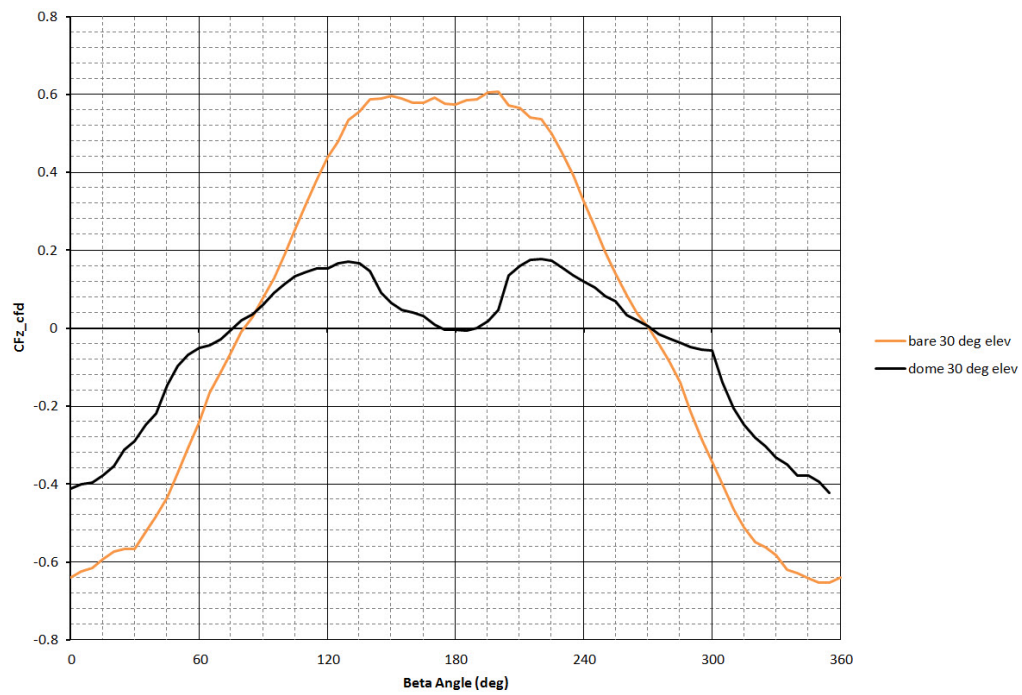
- **Heliostat Model Used:** 200mm x 200mm x 5mm reflector, HCL = 130mm
- **Hemispherical backing used:** 100mm peak height
- **Test conditions were as follows:**
  - Wind Speed = 18.2 m/s (60 ft/s) (41 MPH)
  - Air Temperature = 23 C (74° F)
  - Air Density = 1.20 kg/m<sup>3</sup> (14.85 psia, as reported from tunnel conditions)
  - Elevation angles ( $\alpha$ ) tested: 30degrees
  - Wind incidence angles ( $\beta$ ) tested: 0 - 360 deg in 5 degree increments



CFy\_cfd - Hemispherical backing effect

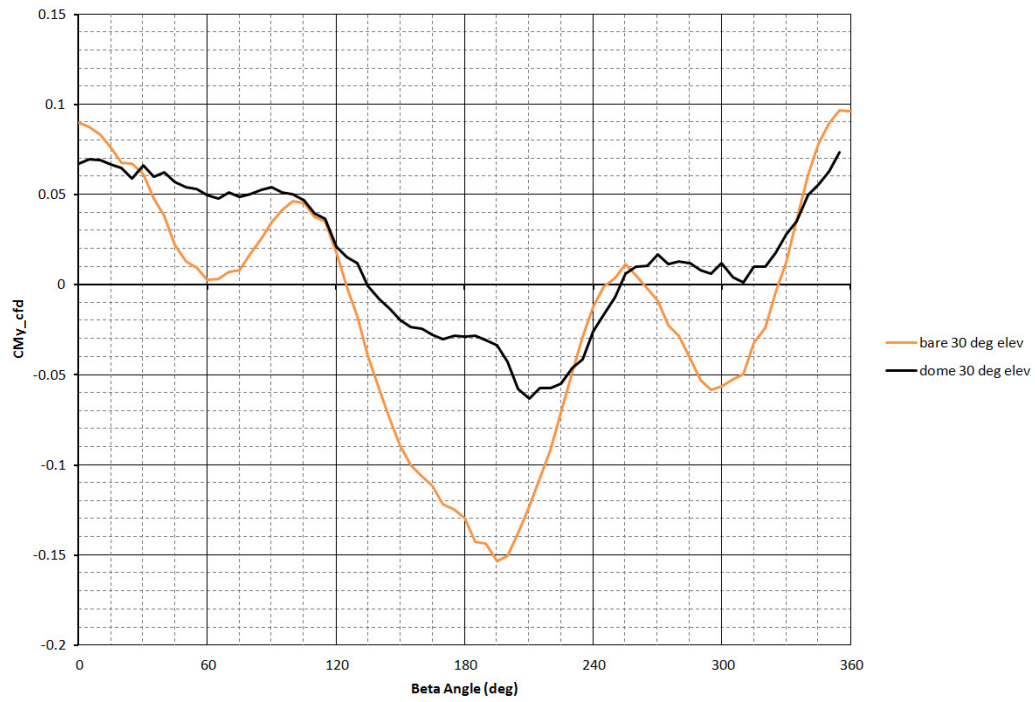


CFz\_cfd - Hemispherical backing effect

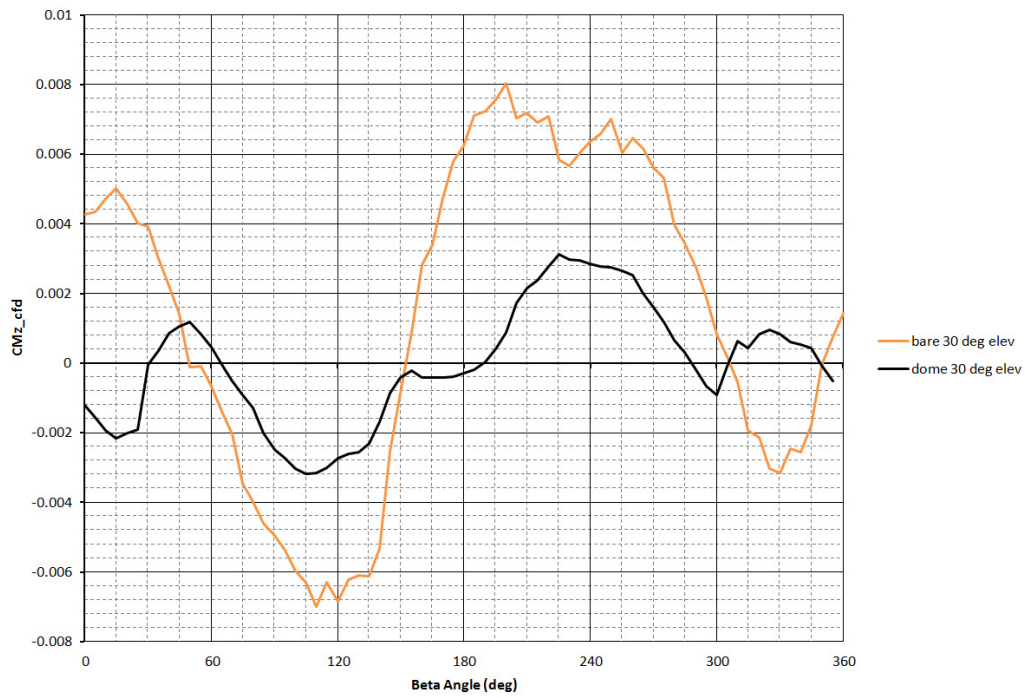




CM<sub>y\_cfd</sub> - Hemispherical backing effect

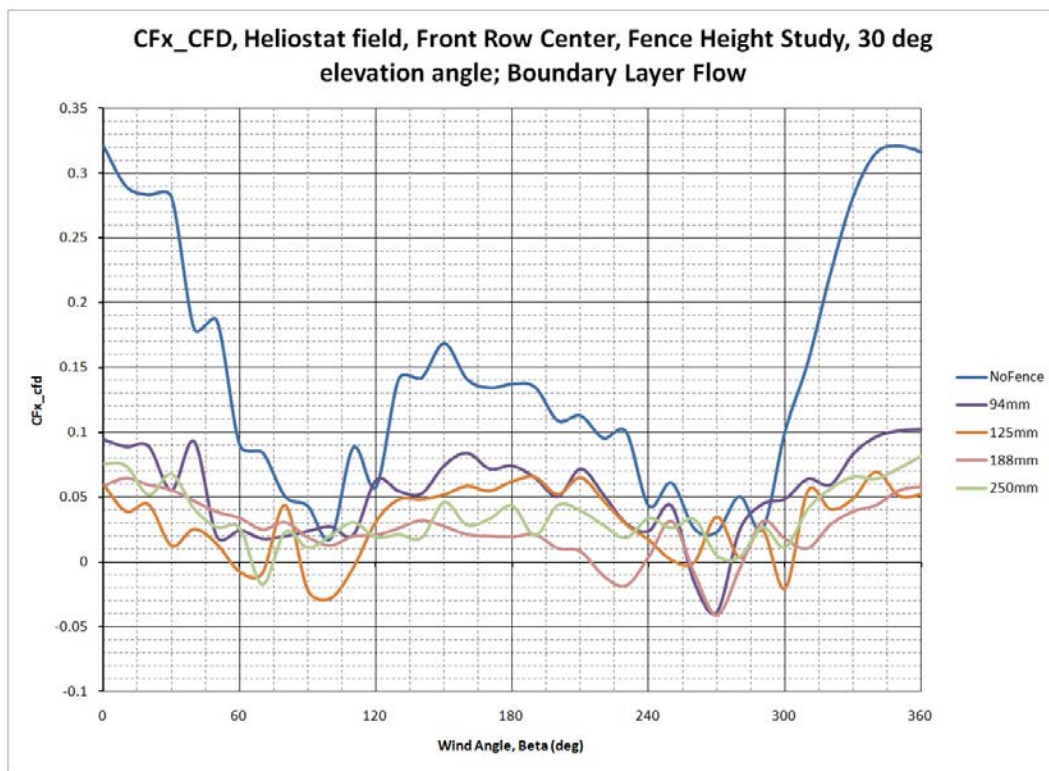


CM<sub>z\_cfd</sub> - Hemispherical backing effect

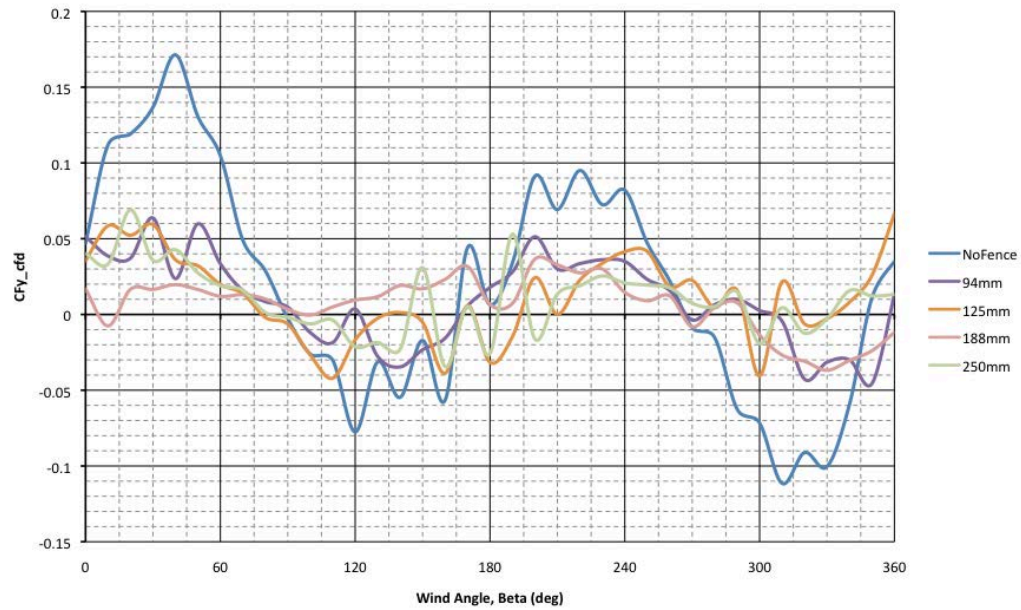


## Fence Height Experiments

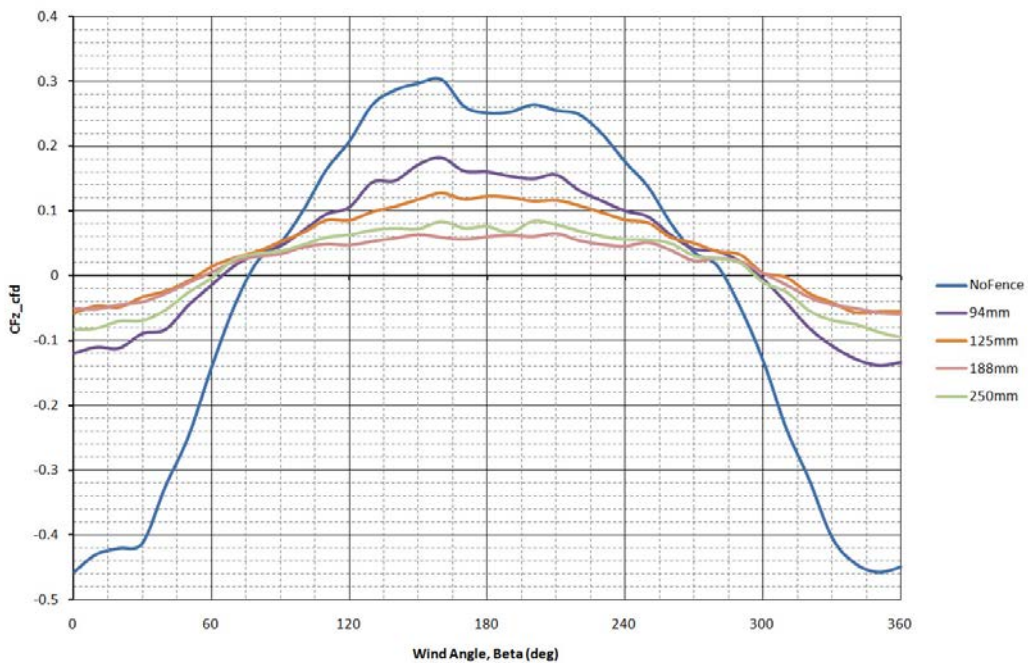
- **Heliostat Model Used:** 100mm x 100mm x 3mm reflector, HCL = 75mm
- **Fence Model Used:** 94mm, 125mm, 188mm, 250mm tall, 46% OA
- **Test conditions were as follows:**
  - $Q = 0.95$  kPa (20psf)
  - Wind Speed = 40 m/s (132 ft/s)
  - Air Temperature = 23 C (74° F)
  - Air Density =  $1.20 \text{ kg/m}^3$  (14.85 psia, as reported from tunnel conditions)
  - Elevation angles (alpha) tested: 30, 0 degrees
  - Azimuth angles (beta) tested: 0 - 360 deg in 5 degree increments
  - Instrumented field positions: 1st row, 4th row



**CFy\_CFD, Heliostat field, Front Row Center, Fence Height Study, 30 deg elevation angle; Boundary Layer Flow**

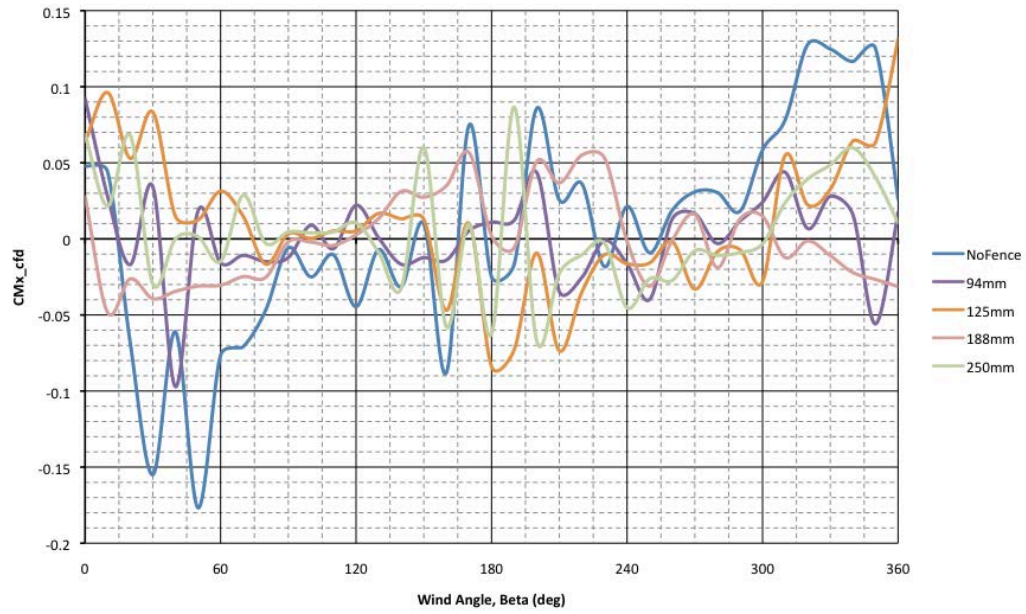


**CFz\_CFD, Heliostat field, Front Row Center, Fence Height Study, 30 deg elevation angle; Boundary Layer Flow**

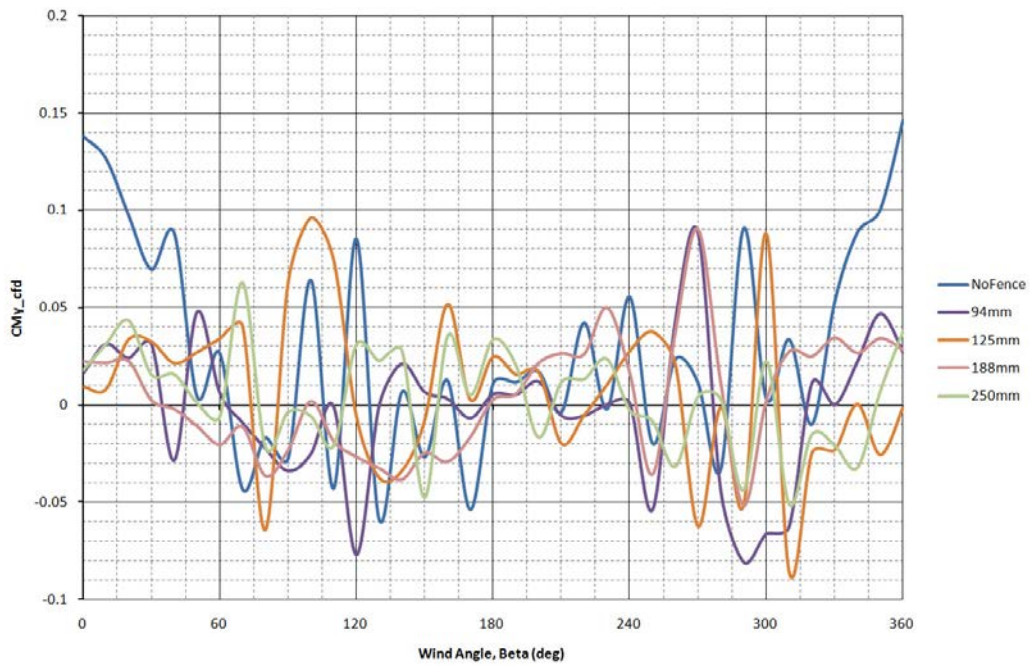


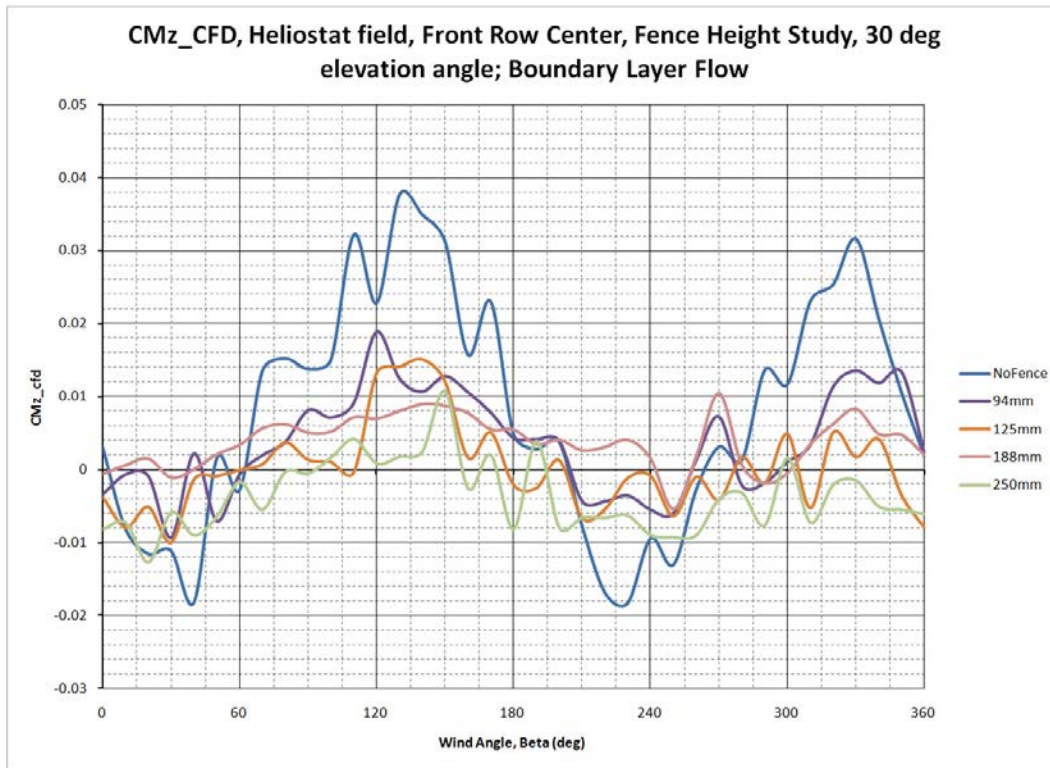


**CMx\_CFD, Heliostat field, Front Row Center, Fence Height Study, 30 deg elevation angle; Boundary Layer Flow**



**CMy\_CFD, Heliostat field, Front Row Center, Fence Height Study, 30 deg elevation angle; Boundary Layer Flow**

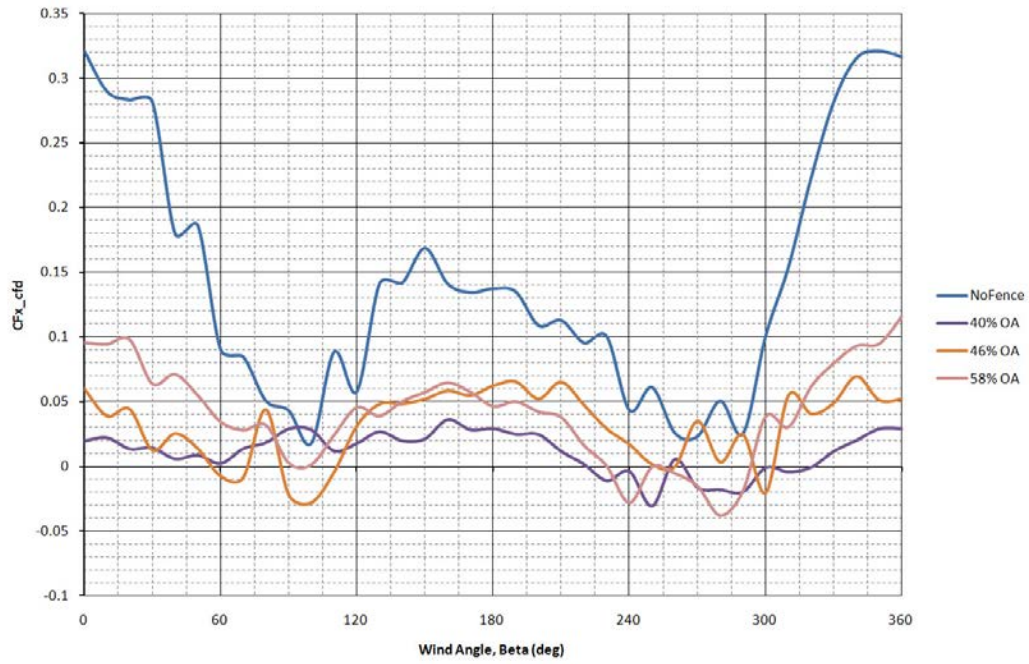




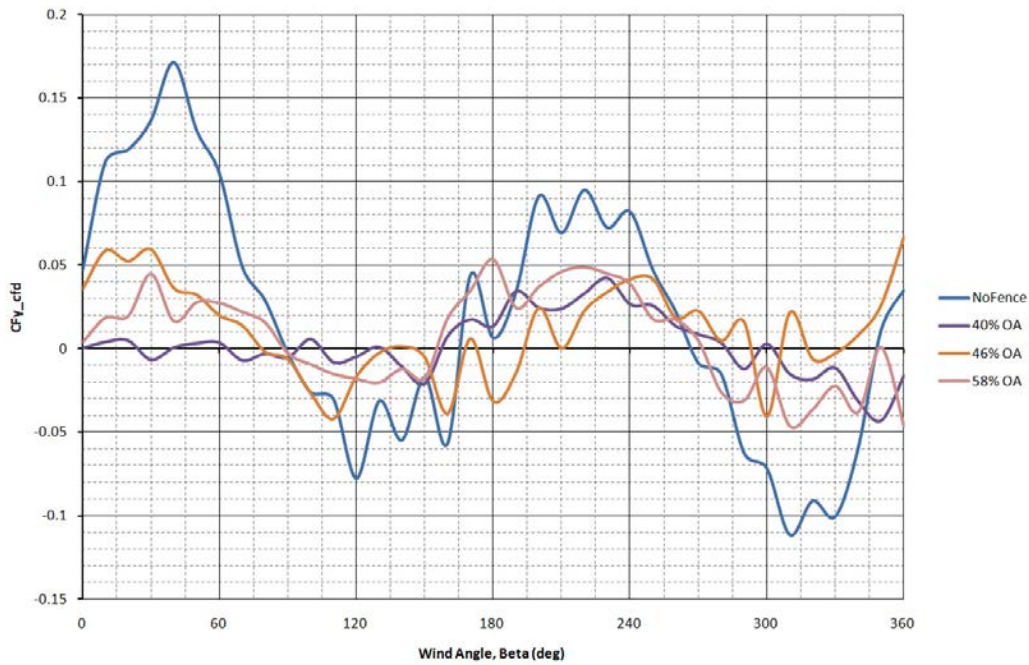
## Fence Porosity Experiments

- **Heliostat Model Used:** 100mm x 100mm x 3mm reflector, HCL = 75mm
- **Fence Model Used:** 125mm tall, 40%OA, 46% OA, 58%OA
- **Test conditions were as follows:**
  - $Q = 0.95$  kPa (20psf)
  - Wind Speed = 40 m/s (132 ft/s)
  - Air Temperature = 23 C (74° F)
  - Air Density =  $1.20 \text{ kg/m}^3$  (14.85 psia, as reported from tunnel conditions)
  - Elevation angles ( $\alpha$ ) tested: 30 degrees
  - Azimuth angles ( $\beta$ ) tested: 0 - 360 deg in 5 degree increments
  - Instrumented field positions: 1st row

CFx\_CFD, Heliostat field, Front Row Center, Fence Porosity Study, 30 deg elevation angle; Boundary Layer Flow

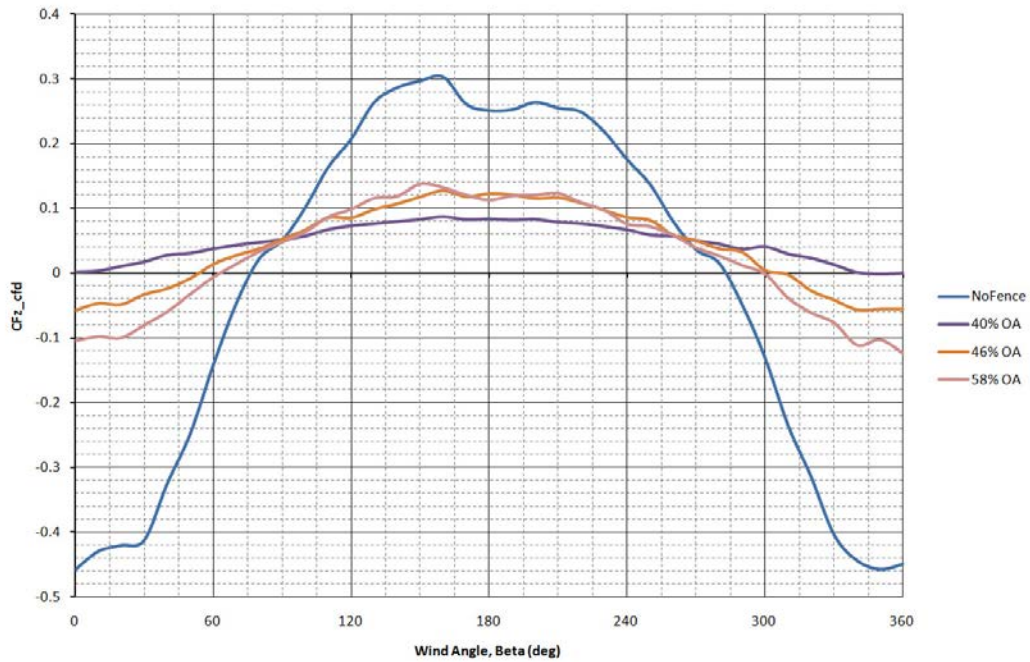


CFy\_CFD, Heliostat field, Front Row Center, Fence Porosity Study, 30 deg elevation angle; Boundary Layer Flow

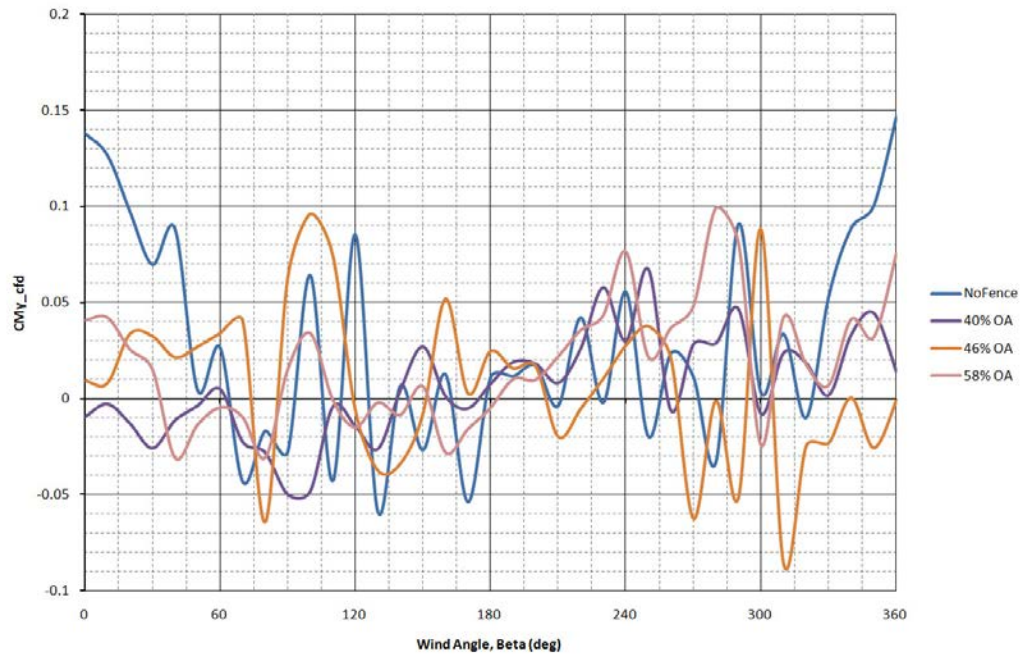




CFz\_CFD, Heliostat field, Front Row Center, Fence Porosity Study, 30 deg elevation angle; Boundary Layer Flow



CMy\_CFD, Heliostat field, Front Row Center, Fence Porosity Study, 30 deg elevation angle; Boundary Layer Flow



CMz\_CFD, Heliostat field, Front Row Center, Fence Porosity Study, 30 deg elevation angle; Boundary Layer Flow

