HELIOSTAT FIELD-ARRAY WIND-TUNNEL TEST

by

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ACKNOWLEDGMENTS

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LIST OF SYMBOLS

A_{ref} = constant area, 0.852 ft^2 model

C_{F_x}, C_{F_y} = nondimensional force coefficients in x and y directions, respectively

$C_{m_z}, C_{m_x}, C_{m_y}$ = nondimensional moment coefficients about the base z, x, y axes, respectively

C_{mh_x}, C_{mh_y} = nondimensional moment coefficients about hinge x and y axes, respectively

C_{mu_x}, C_{mu_y} = nondimensional moment coefficient about upper point x and y axes, respectively

$C_{P_{mean}}$ = mean pressure coefficient $\dfrac{(P-P_\infty)_{mean}}{(\frac{1}{2}\rho U_R^2)}$

D = characteristic length (structure height, width, etc.)

F = force along chosen axis

F_x, F_y = measured force along x and y axes, respectively

H = fence height, 0.8 ft model

L_{ref} = reference length, 0.968 ft model

M = moment about chosen axis

M_z, M_x, M_y = measured moment about z, x, and y axes, respectively

M_{h_x}, M_{h_y} = measured hinge moment about x and y axes, respectively

M_{u_x}, M_{u_y} = measured upper-point moment about x and y axes, respectively

P = instantaneous fluctuating pressure at tap

P_{mean} = $(P-P_\infty)_{mean}$, mean pressure at tap location

P_∞ = instantaneous static pressure in wind tunnel above model

U = local mean velocity

U_R = reference mean velocity at 1.20 feet model

U_∞ = reference free stream mean velocity at 4.12 feet model

x,y = mutually perpendicular horizontal coordinates

X = upstream distance of the fence from the cluster configuration

z = vertical coordinate

α = tilt angle of heliostat reflector plates

β = incident wind direction

ν = kinematic viscosity of air

ρ = density of air

$\frac{UD}{\nu}$ = Reynolds number

$\frac{\rho U_R^2}{2}$ = reference dynamic pressure

INTRODUCTION

The purpose of this study is to investigate the characteristics of the wind loads produced by airflow patterns in and around certain configurations of heliostat clusters. Although the last decade has seen the emergence of a better understanding of wind loading on structures, the complexity of the interrelationships between the wind velocity field and heliostats in a cluster makes the use of analytical techniques for determining wind loading difficult, if not impossible. Fortunately, techniques have been developed for the small-scale modeling of wind loading on structures in boundary-layer wind tunnels and the subsequent prediction of full-scale wind loading.

The primary consideration in modeling wind forces on structures in a wind tunnel is that the wind characteristics in the tunnel simulate natural boundary-layer winds at the actual site. In general, this requires that the vertical distribution of mean velocity and turbulence in the wind tunnel boundary layer match those at the site and that the Reynolds numbers of the model and the prototype be equal. In addition, the small-scale structure must be geometrically similar to its prototype. A detailed discussion of these requirements and their implementation in the wind tunnel environment can be found in references 1, 2, and 3.

The construction of a 1:22 scale model of the prototype structure and its immediate surroundings (in this case, a flat, open area), submerged in a turbulent boundary layer of the meteorological wind tunnel shown in Figure 1, satisfies all the above criteria except that of equal Reynolds numbers. In the Reynolds number $\frac{UD}{\nu}$, ν is the same for both the tunnel and the full-scale structure. Because of this, the wind tunnel air speed, ν, would have to be 22 times the full-scale value if the model and prototype Reynolds numbers are to be equal. Testing at such high wind speeds is not possible. However, for Reynolds numbers larger than 2×10^4, there is no significant change in the values of aerodynamic coefficients as the Reynolds number increases. Since typical Reynolds number values are 10^7-10^8 for full-scale flow and 10^5-10^6 for wind tunnel flow, acceptable flow similarity is achieved without equality of the Reynolds numbers.

THE MODELS

The full-scale structure to be modeled is a field array of heliostat mirrors. Clusters from the field array were chosen so that representative wind flow patterns within typical arrays could be simulated. There were five basic cluster configurations--two compact clusters designated as configurations 1 and 2, and three extended clusters designated as configurations Linear A, Linear B and Linear C. In addition, some of the cluster configurations were modified by placing a fence upwind of the models (see Figure 2 for photographs of a single model and a typical configuration in the wind tunnel; refer to Figure 3 for the cluster configurations).

Configuration 1 was a hexagon-shaped cluster with six heliostat models surrounding an instrumented model in their center. When configuration 1 was run with the fence upstream of the cluster, the instrumented model was moved to the position closest to the fence. Configuration 2 was a diamond-shaped cluster with eight heliostat models surrounding a central instrumented model. This configuration was not run with the fence upstream (see Figures 3a and 3b for these configurations).

The first of the extended clusters, configuration Linear A, consisted of eleven heliostat models upstream of the twelfth instrumented model. This configuration was not run with the fence modification. Configuration Linear B was somewhat similar to configuration Linear A (see Figure 3c) and was run with two fence modifications. The first modification placed the fence parallel to the leading two heliostat models in the cluster, with the instrumented model in the third position. The second modification placed the fence at a 45° angle with respect to the first modification, with one leading heliostat model removed (see Figure 3d). Configuration Linear C was the only cluster tested solely with the fence in place parallel to the two leading heliostats. Eight heliostat models were placed upstream of the instrumented model in this configuration (see Figure 3e).

The incident wind direction was designated as β for this test with $\beta = 0$ fixed along the long axis of each configuration (see Figure 3). For those configurations tested with the fence, the fence was placed at four different distances from a line drawn through the two leading heliostats of the cluster. These distances were 1H, 1.5H, 2H and 2.5H, where H was the height of the fence. The variable X was used to designate the distance of the fence from the cluster. The fence itself was constructed of sheet metal perforated with uniformly spaced 3/8 in. diameter holes, to simulate a fence with a model height of 0.8 feet and approximately 33 percent porosity.

The model heliostats were constructed of plexiglass to a scale of 1:22. The two reflector plates of the models were separated by a gap which could be partially or completely closed by a plexiglass insert. The reflector plates could also be tilted about their common centerline, with the tilt angle being designated as α and measured in degrees of declination from the horizontal plane (i.e., $\alpha = 90°$ indicated the plates were perpendicular to the floor, $\alpha = 180°$ indicated stowed position; see Figure 4).

One model was specially constructed to be used with a force balance for the measurement of forces and moments, and another was instrumented with 42 pressure taps for the measurement of wind pressures. Details of the model which was mounted on the force balance are shown in Figure 5.

The heliostats used in the arrays surrounding this model were slightly simplified at the hinge. The pressure tap locations on the model used for pressure measurements are given in Figure 6. The support column for this heliostat was increased in diameter and the hinge details were simplified to accommodate the pressure tubes.

The approach azimuth β was defined with respect to each heliostat as well as with respect to each array configuration. The angle β was defined as an angle in the horizontal plane as shown in Figure 7. The coordinate system used for the force and moment measurements is given in Figures 4 and 7.

TEST PROCEDURES

The study was performed in the meteorological wind tunnel of the Fluid Dynamics and Diffusion Laboratory at Colorado State University. The tunnel is a closed-circuit facility with a test section 1.8 meters (6 ft) square and 26.8 meters (88 ft) long. It is driven by a 400 hp variable-pitch propeller and can maintain velocities varying continuously from 0.61 meters per second to 36.6 meters per second (2 ft per second to 120 ft per second) (see Figure 1).

The heliostat field-array wind tunnel test was divided into six sections, as given in Table 1. In the first section, a single heliostat mounted on a balance to measure forces and moments, with an angle of tilt of $\alpha = 30°$, was rotated through five wind directions. The second phase, runs 6-40, was the tilt angle study, in which the tilt angle of the heliostat panels was varied. A single heliostat model was rotated through five wind directions for each of seven tilt angles to obtain the forces and moments acting on the model. The third part of the test, runs 41-50 and 141-150, measured the effect of closing the slot between the heliostat reflector panels. An insert was placed between the panels, first to close the top half of the slot and then to close both the top and bottom halves. Forces and moments were measured for the single heliostat model at five wind directions for each of two tilt angles.

The next section of the test was the cluster study, runs 51-94. With each heliostat model in the cluster set to the same tilt angle, configurations 1, 2 and Linear A were tested for four values of α and four wind directions per tilt angle. The instrumented model in each configuration was then used to obtain forces and moments. The fifth part, runs 95-108A, measured the distribution of mean pressures on the instrumented model in each cluster. Six values of β were tested for a single heliostat model and for configurations 1 and 2, while three wind directions were tested for configuration Linear A.

The final section of the field-array test, runs 110-137, measured the effects of an upwind fence on the heliostat models. Configurations 1, Linear B and Linear C were tested for two wind directions and four distances from the cluster for each direction. Configuration Linear B was also run at a second fence orientation. The instrumented model in each configuration was used to obtain forces and moments on the model.

INSTRUMENTATION AND DATA ACQUISITION

Forces and Moments

Forces and moments on the instrumented model were measured using an Inca six-component strain-gauge balance, in an x, y, z coordinate system fixed to the model according to Figures 4 and 7. Three forces and two moments were measured on the model. Each strain-gauge bridge of the balance was monitored by a Honeywell Accudata 118 Gauge Control/ Amplifier unit which supplied excitation of the bridge and amplified the bridge output. These units are characterized by a very stable excitation voltage and amplifier gain. Each channel signal was further reduced on line by digital integrating voltmeters for mean values and processed on the Colorado State University Control Data Corporation 6400 computer system.

Calibration of the balance was performed in a test rig in which known forces and moments could be applied to the balance. A calibration matrix was then developed for reducing the mean output of the strain gauges. The load and strain relationship was strictly linear for the range of loads applied in these tests. In addition, the force balance and electronic system are supported by their manufactured specifications to be accurate to within 0.1 percent of full-scale. This would indicate a possible error of 2.5 percent in the force and moment measurements.

Pressures

Mean fluctuating pressures were obtained at each of the 42 pressure taps on the surface of the instrumented model. Forty-two pieces of 1/32 in. I.D. plastic tubing were used to connect the pressure taps to an 80 tap pressure switch mounted below and beside the tunnel floor. The switch was designed and fabricated by the Fluid Dynamics and

Diffusion Laboratory. Each of the measurement ports was directed in turn by the switch to one of the four pressure transducers mounted close to the switch. The switch was operated manually and locked into place by a built-in mechanical indexing feature. Four of the unused pressure ports were connected to a common tube leading outside the tunnel. This arrangement allowed for in-place calibration of the transducers and, by connecting the tube to a pitot tube mounted inside the wind tunnel, automatic monitoring of the tunnel speed.

The pressure transducers used were Statham Model PM 283TC differential strain-gauge transducers with a 0.15 psid range. These were selected because of their stability, their linearity in the required working range, and because their resonant frequency of approximately 2000 cycles per second allows resonance effects on the measured pressures to be ignored. Reference pressures were obtained by connecting the reference sides of the four transducers to a pitot tube mounted inside the tunnel. Since the pitot tube was mounted in the wind flow above the heliostat models, the transducer measured the instantaneous pressure difference between the surface of the instrumented model and the static pressure in the free stream above the models.

Each pressure transducer contains an electrical bridge which was monitored by a Honeywell Accudata 118 Gauge Control/Amplifier unit to provide excitation and amplify the bridge output. The output was then sent via analog lines specially designed to minimize distortion to a Preston Model GMAD-4 Analogy-to-Digital Converter. The A/D converter data was then fed to a Hewlett-Packard System 1000 minicomputer where it was processed and analyzed under program control.

All four transducers were recorded simultaneously for 16 seconds at 250 samples per second. The 16-second time period was chosen as the result of an experiment to determine the length of record necessary to obtain stable mean pressures. Experience with a large number of pressure taps has shown that the overall accuracy for a 16-second sampling period is three percent of the dynamic pressure of the approach wind at the edge of the boundary layer for the mean pressure coefficient.

Velocity Profiles

Mean velocity and turbulence profiles were measured in the wind tunnel for the wind flow approaching the cluster configurations. These were obtained with a Thermosystems Model 1050 constant temperature anemometer with a 0.001 inch diameter platinum film sensing element 0.02 inches long attached to a vertical traverse. These profiles are given in Figure 8.

Flow Visualization

To visually determine the airflow patterns around and within the heliostat configurations, titanium tetrachloride smoke was released in the tunnel near the models. A 484 foot, 18-scene motion picture was made of various configurations, tilt angle and wind direction combinations. A listing of the contents of the film is given in Table 2.

TEST RESULTS

Forces and Moments

The forces and moments measured on the heliostat model are expressed, respectively, in terms of the nondimensional coefficients C_F, C_m, C_{mh} and C_{mu}. They are defined as follows:

force coefficient along the x-axis

$$C_{F_x} = \frac{F_x}{\left(\frac{\rho U_R^2}{2}\right)(A_{ref})} ,$$

force coefficient along the y-axis

$$C_{F_y} = \frac{F_y}{\left(\frac{\rho U_R^2}{2}\right)(A_{ref})} ,$$

moment coefficient about the z-axis

$$C_{m_z} = \frac{M_z}{\left(\frac{\rho U_R^2}{2}\right)(A_{ref})(L_{ref})} ,$$

moment coefficient about the x-axis at the base of the model (see Figure 4)

$$C_{m_x} = \frac{M_x}{\left(\frac{\rho U_R^2}{2}\right)(A_{ref})(L_{ref})} ,$$

moment coefficient about the y-axis at the base of the model (see Figure 4)

$$C_{m_y} = \frac{M_y}{\left(\frac{\rho U_R^2}{2}\right)(A_{ref})(L_{ref})} ,$$

moment coefficient about the x-axis at the hinge (see Figure 4)

$$C_{mh_x} = \frac{M_{h_x}}{\left(\frac{\rho U_R^{\,2}}{2}\right)(A_{ref})(L_{ref})} ,$$

moment coefficient about the y-axis at the hinge (see Figure 4)

$$C_{mh_y} = \frac{M_{h_y}}{\left(\frac{\rho U_R^{\,2}}{2}\right)(A_{ref})(L_{ref})} ,$$

moment coefficient about the x-axis at the upper point (see Figure 4)

$$C_{mu_x} = \frac{M_{u_x}}{\left(\frac{\rho U_R^{\,2}}{2}\right)(A_{ref})(L_{ref})} ,$$

moment coefficient about the y-axis at the upper point (see Figure 4)

$$C_{mu_y} = \frac{M_{u_y}}{\left(\frac{\rho U_R^{\,2}}{2}\right)(A_{ref})(L_{ref})} ,$$

where

U_R = reference free stream mean velocity at 1.2 feet model,

ρ = density of air,

$A_{(ref)}$ = reference area (0.852 ft^2 model),

$L_{(ref)}$ = reference length (0.968 ft model),

F_x, F_y, F_z = measured force along axis,

M_z, M_x, M_y = measured moment about axis

M_{h_x}, M_{h_y} = measured hinge moment about axis, and

M_{u_x}, M_{u_y} = measured upper-point moment about axis.

The upper-point moments are calculated for a point on the upper surface of the heliostat reflector plates 6.72 in. from the tunnel floor for the model. The hinge moments are calculated at the heliostat hinge, 6,066 in. from the tunnel floor for the model. And the remaining moments are calculated at the base of the heliostat

The force and moment coefficients are given in Table 3.

Pressures

The mean pressures on the instrumented heliostat model are given in terms of the nondimensional pressure coefficient $C_{p_{mean}}$. (No attempt was made to obtain peak pressure coefficients because the small size of the plastic tubing--1/32 in. I.D.--necessary for the model prohibited adequate frequency response.) This mean pressure coefficient relates the mean pressure difference between the model surface and the ambient static pressure measured at each tap on the heliostat model to the mean dynamic pressure in the wind tunnel approach flow. The tunnel mean pressure is measured by a pitot tube suspended in an undisturbed flow area upstream of the models (49.5 in. from the floor for the model). The coefficients were related to the dynamic pressure at 1.20 ft ($1/2\ \rho U_R^{2}$) using the velocity profile of Figure 8.

The mean pressure coefficient is defined as follows:

$$C_{p_{mean}} = \frac{(p-p_\infty)_{mean}}{\left(\frac{\rho U_R^{2}}{2}\right)} \quad ;$$

where

p = instantaneous fluctuating pressure at tap,

p_∞ = instantaneous static pressure in wind tunnel above model,

$\frac{\rho U_R^{2}}{2}$ = dynamic pressure above model at 1.2 ft model.

This coefficient indicates that the mean pressure difference $(p-p_\infty)_{mean}$ at a given point on the model is some fraction greater or less than the dynamic mean pressure in the tunnel.

The mean pressure coefficients are given in Table 4.

Conclusions

Measurements of force and moment coefficients were taken with the fence in four different positions. Table 3 gives a comparison of data for all configurations with and without the fence. An examination specifically of runs 118, 120, 122, 124 and 126 for configuration Linear B indicates (see Figure 9) that the coefficients C_{m_x} and C_{m_y} undergo a substantial reduction with fence protection. Similar conclusions may be drawn by comparing runs 128, 130, 132, 134 and 136 for configuration Linear C (as also shown in Figure 9).

In configurations 1 and 2, the instrumented model was located in the center of a surrounding cluster of seven and nine heliostats, respectively. Table 3 gives a comparison of data for both configurations with varying tilt and wind angles. Runs 59, 60, 61 and 62 indicate that all coefficients were substantially reduced from the case where no heliostats surrounded the model (run 16). They also show that wind direction $\beta = 0°$ is not necessarily the direction that causes the highest loading coefficients; C_{m_x} was maximum for a wind of $\beta = 45°$ from the x-axis and C_{m_y} was maximum for $\beta = 180°$ from the x-axis.

A comparison of runs 16, 128 and 130 shows an influence of upwind heliostats and a fence addition. Run 16 is a single, unprotected, unfenced, and instrumented heliostat. Run 128 has the instrumented model downstream of eight heliostats, and run 130 is the same as run 128 with the addition of an upstream fence. The data show that the upwind heliostats alone offer no protection in a configuration where channeling between heliostats can be significant. Run 130, however, shows that significant reductions in the wind load are achieved by the addition of a fence at the upwind extent of the linear array.

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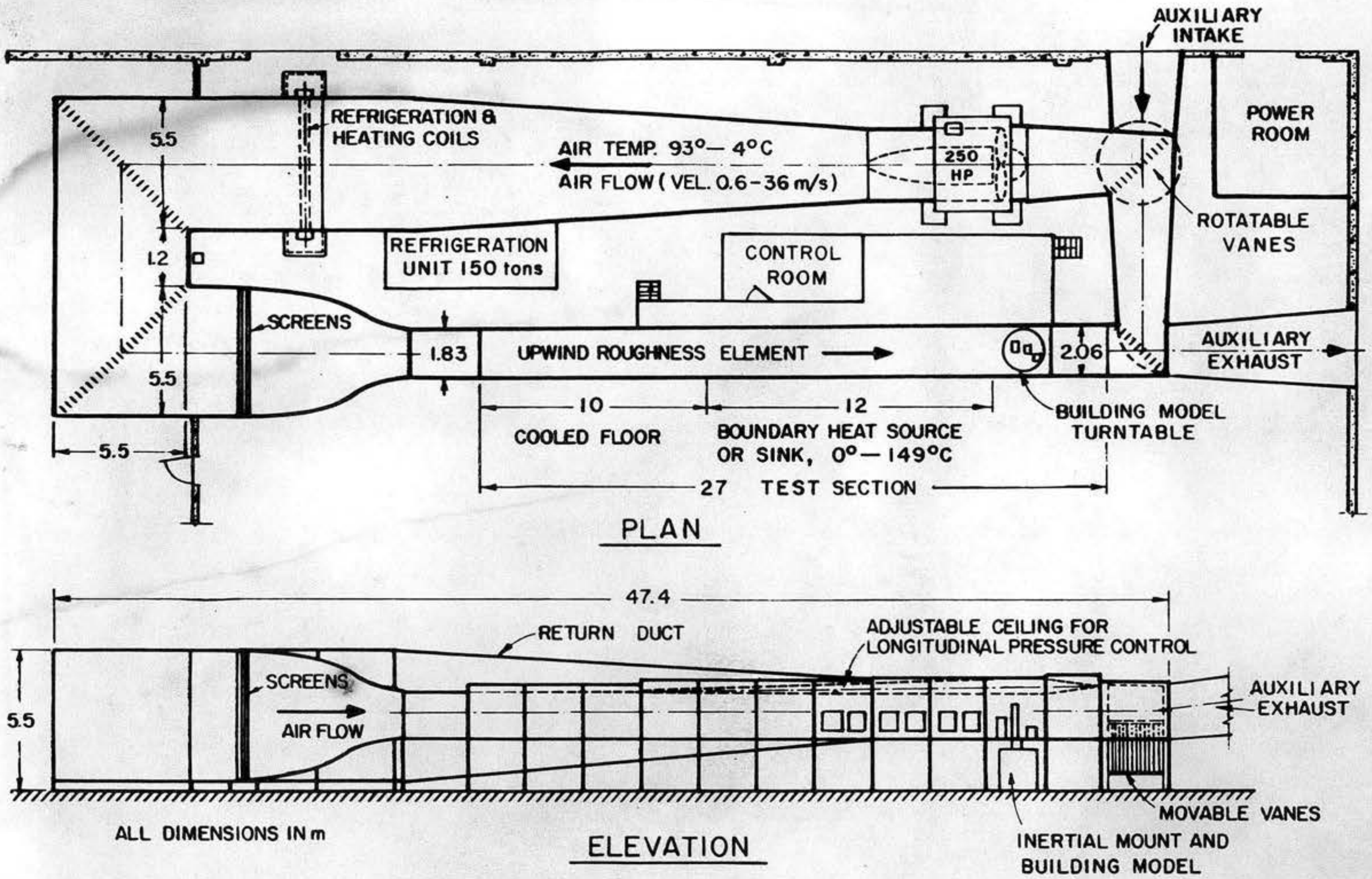
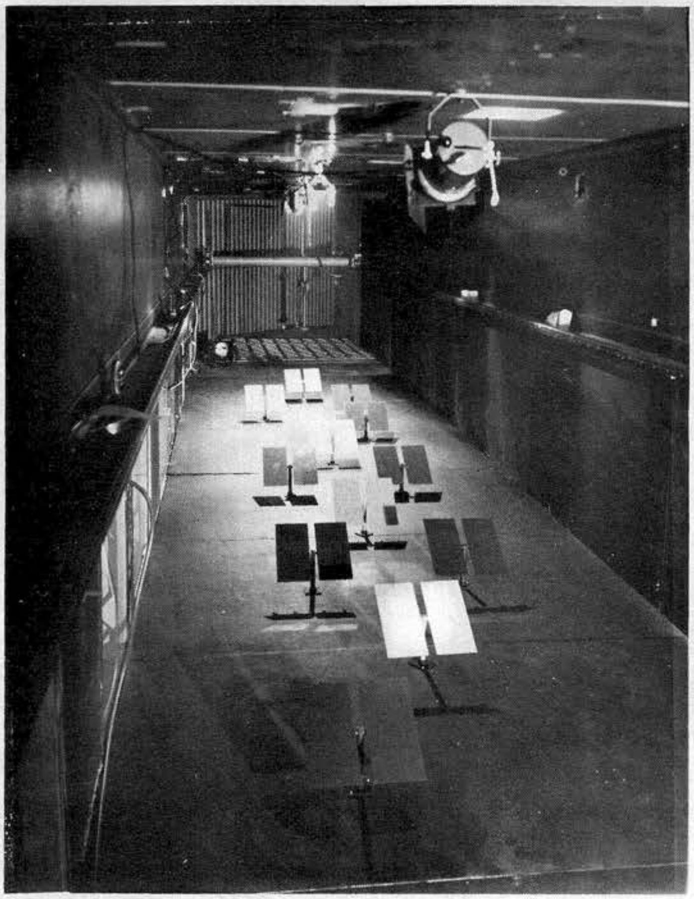
FIGURES



METEOROLOGICAL WIND TUNNEL (Completed in 1963)
FLUID DYNAMICS & DIFFUSION LABORATORY
COLORADO STATE UNIVERSITY

Figure 1. Meteorological wind tunnel.



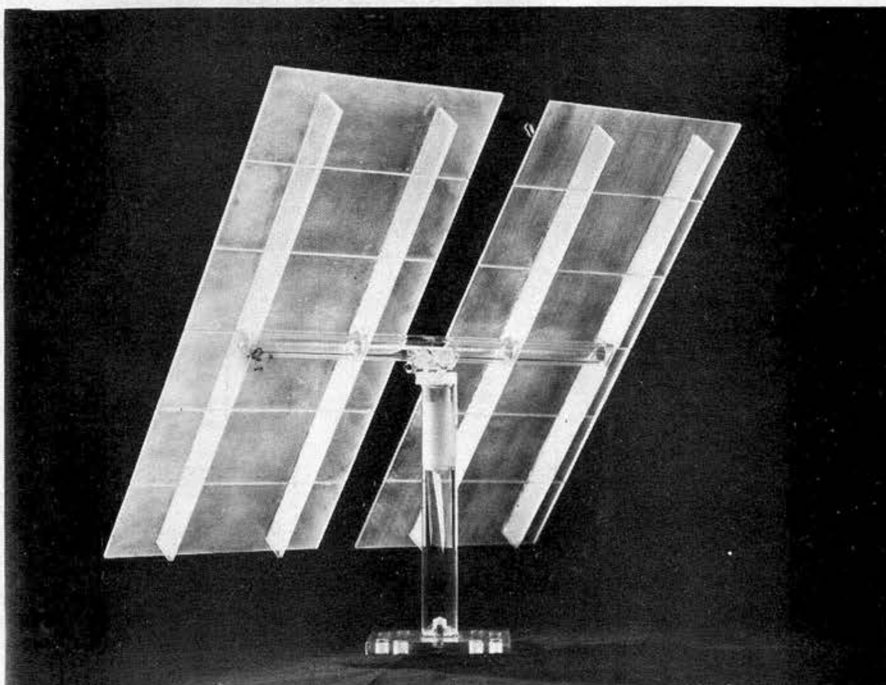


Figure 2. Photographs of single heliostat model and typical cluster configuration in the wind tunnel.

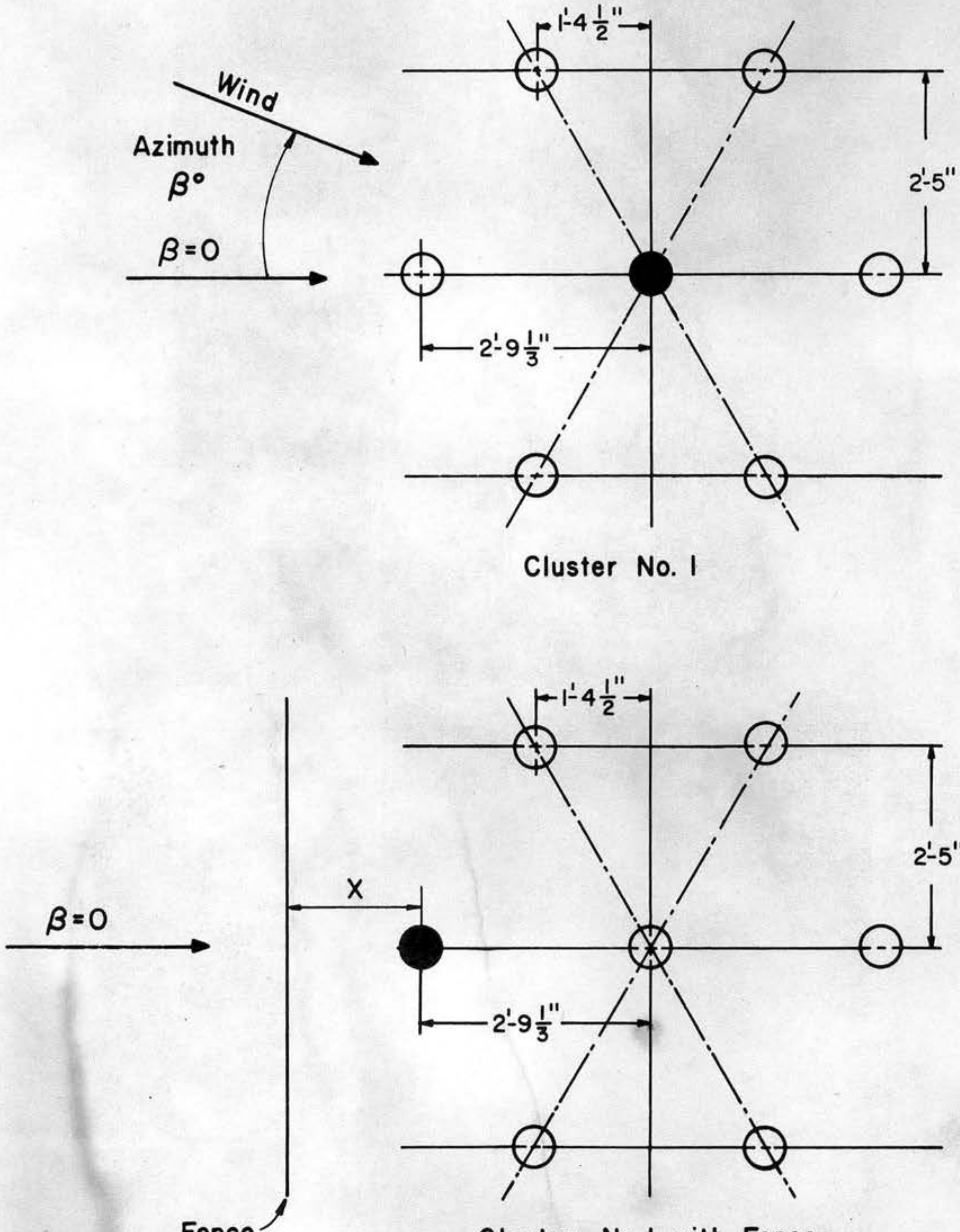
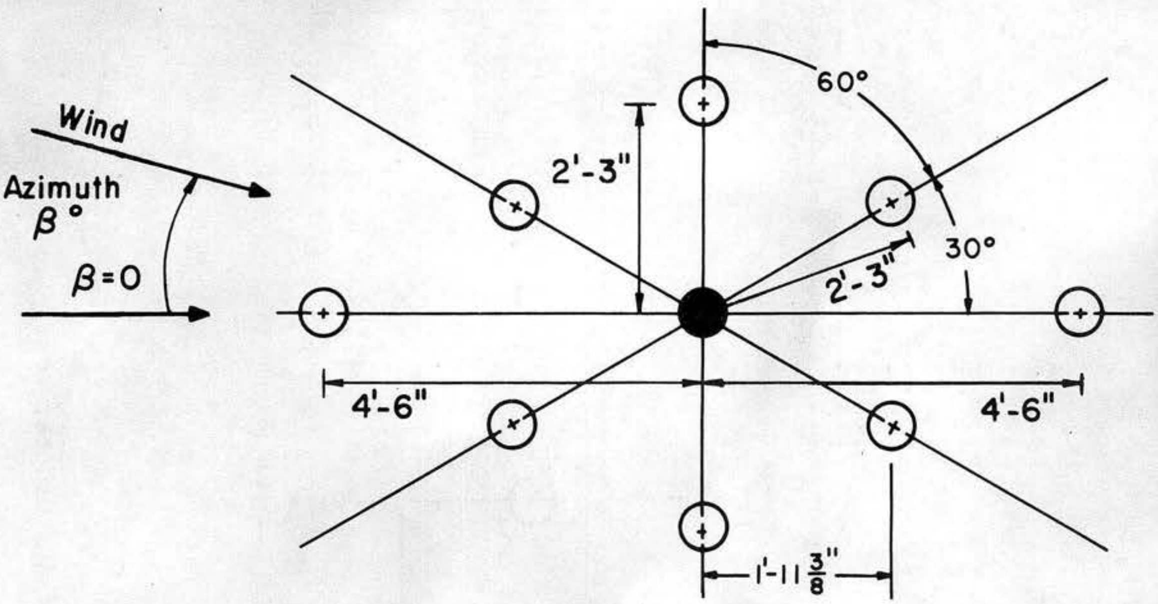
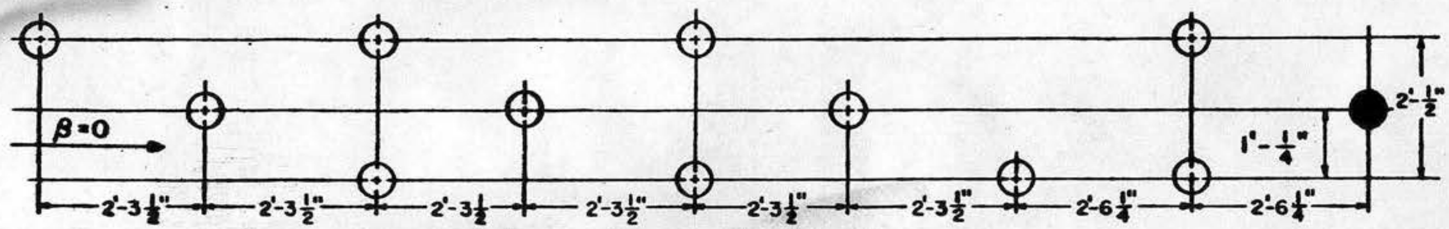


Figure 3a. Cluster configurations.

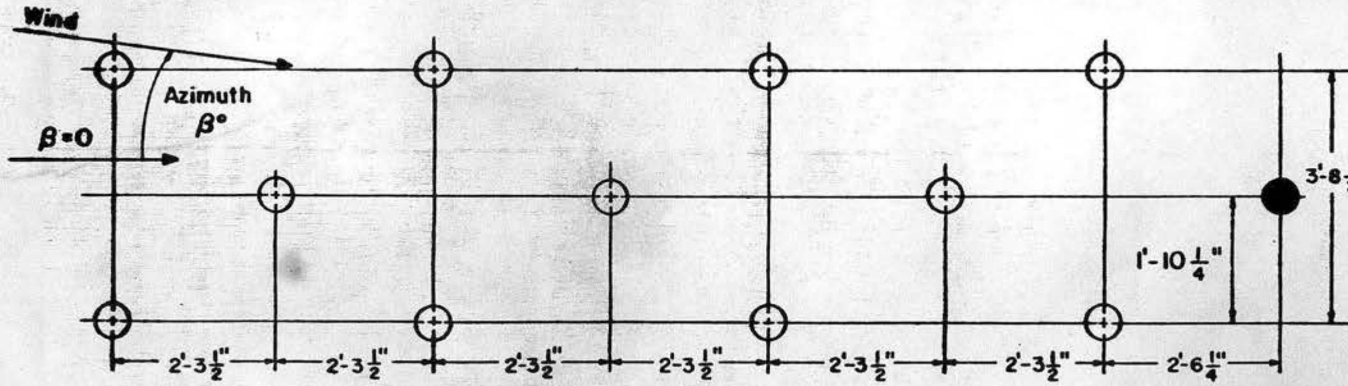


Cluster No. 2

Figure 3b, Cluster configurations.

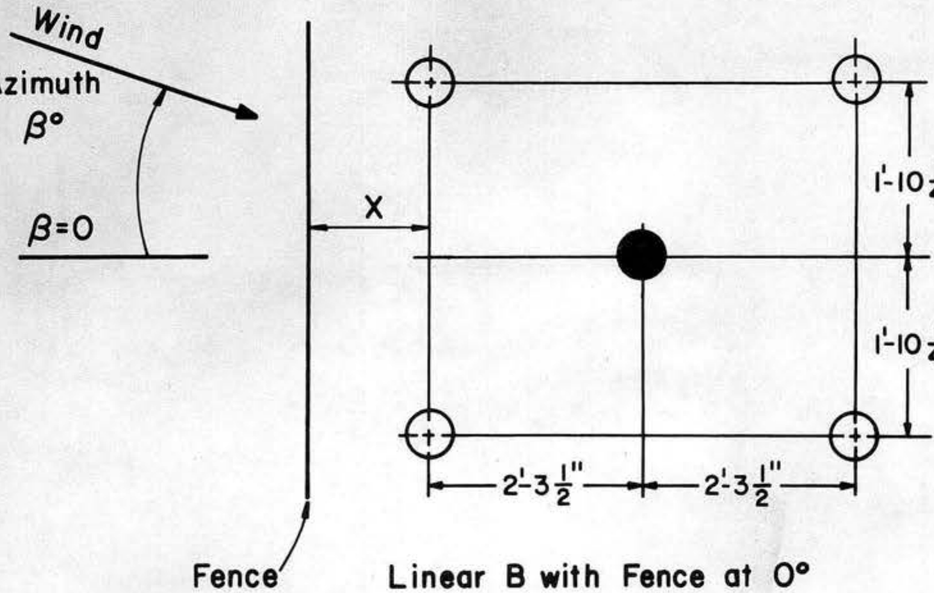


Linear A

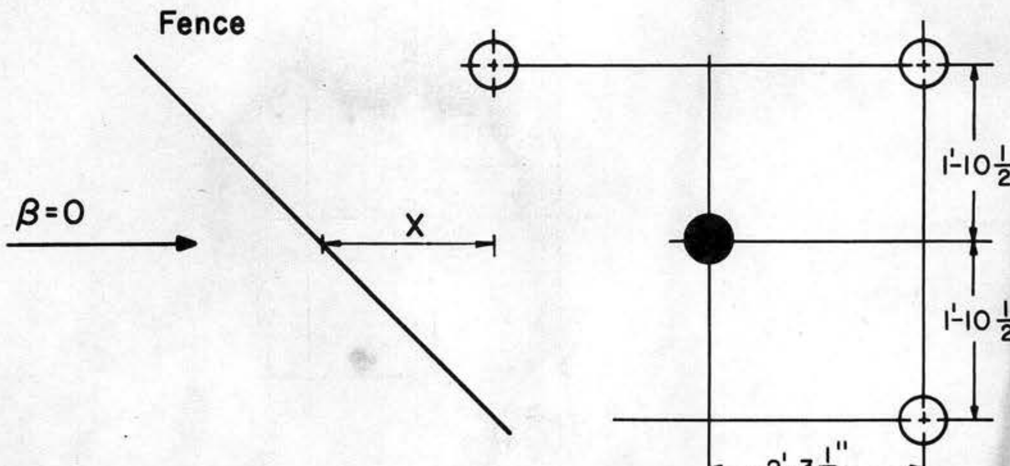


Linear B

Figure 3c. Cluster configurations.

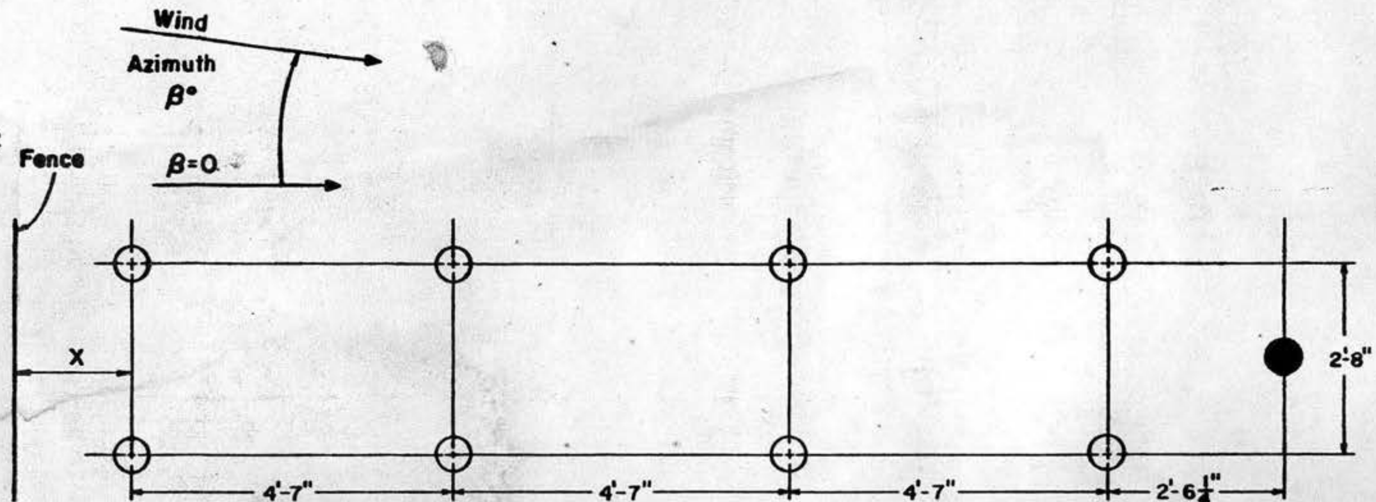


Linear B with Fence at 0°



Linear B with Fence at 45°

Figure 3d. Cluster configurations.



Linear C with Fence

Figure 3e. Cluster configurations.

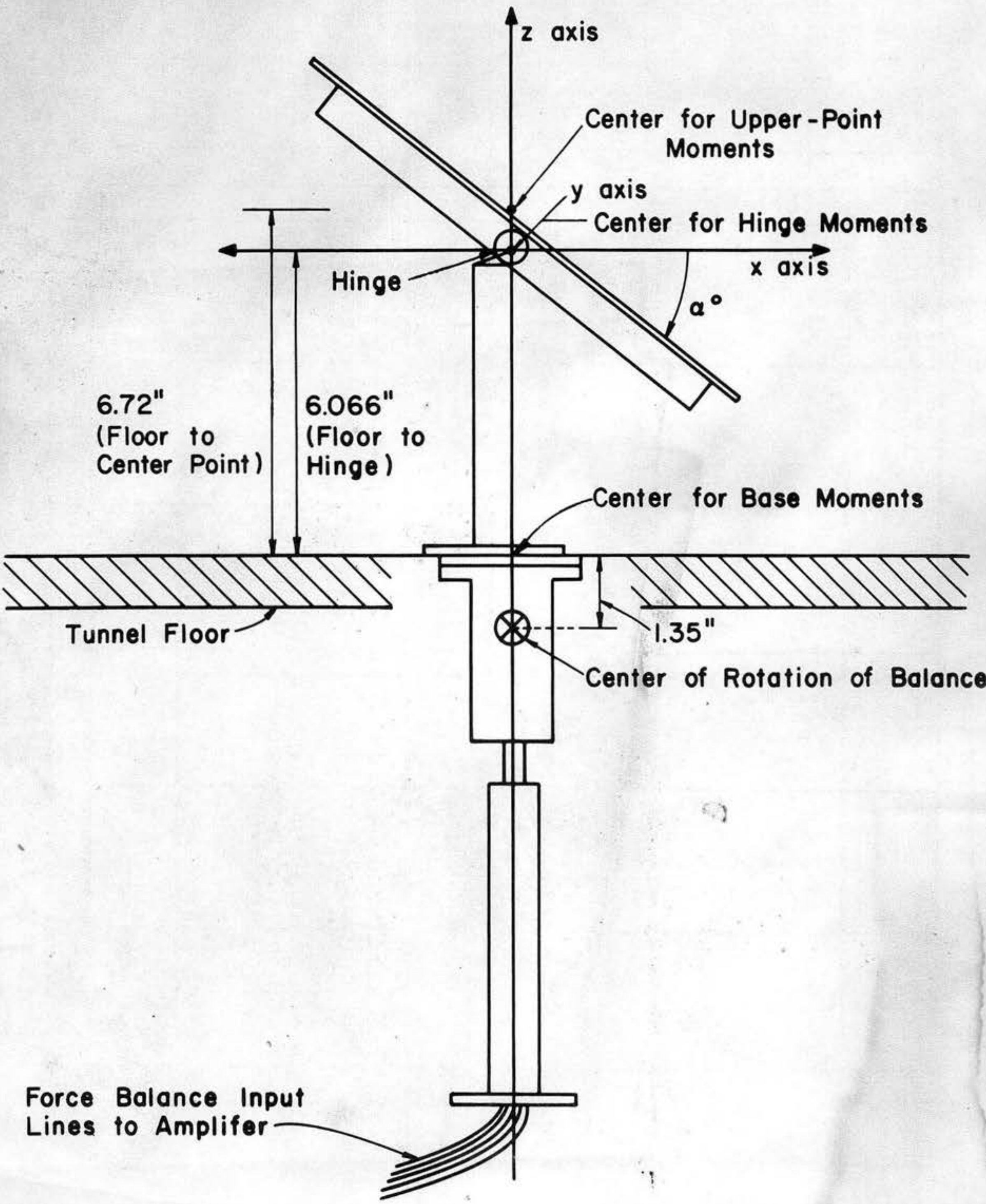


Figure 4. Definition of angle α and force balance assembly.

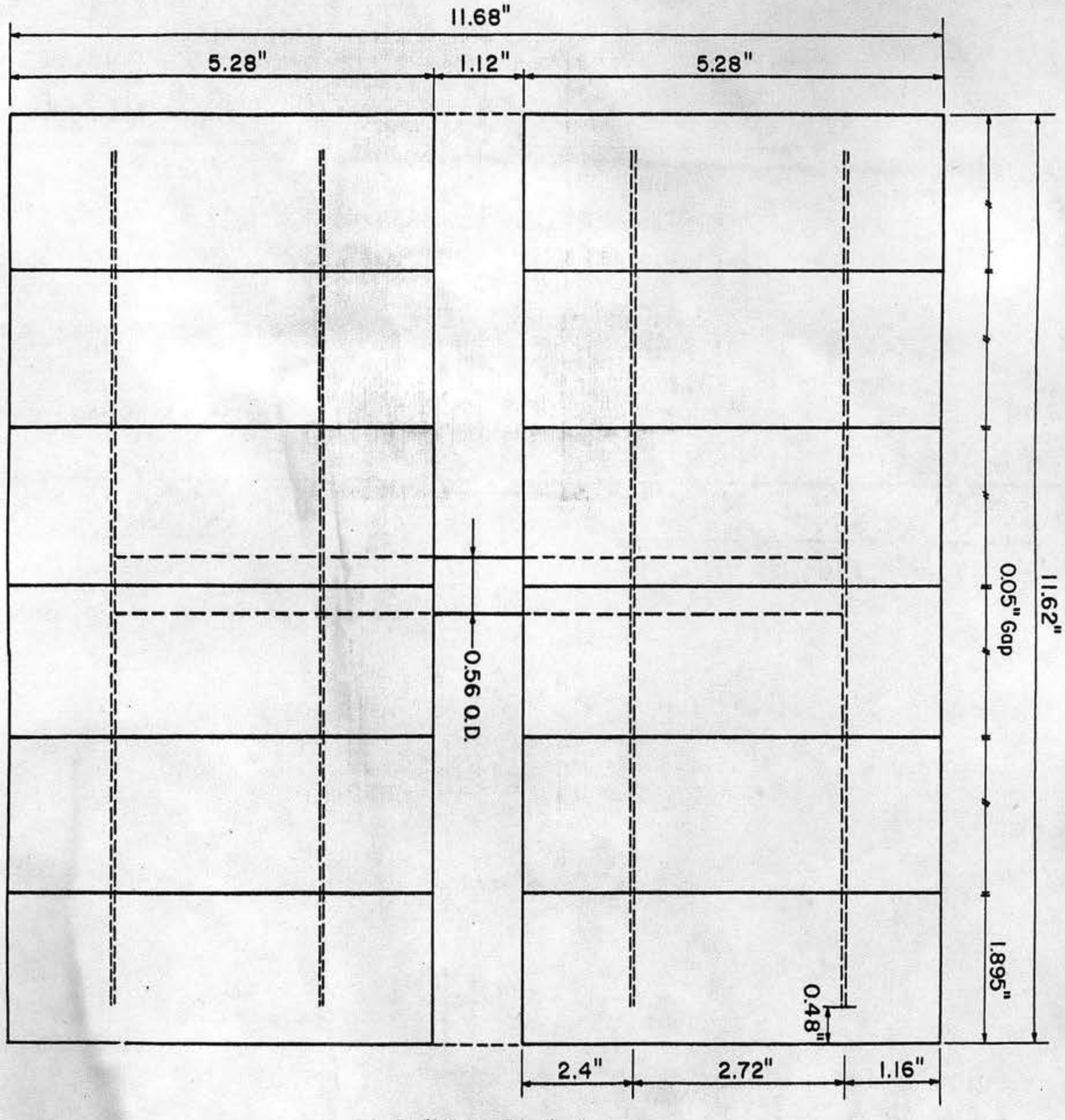
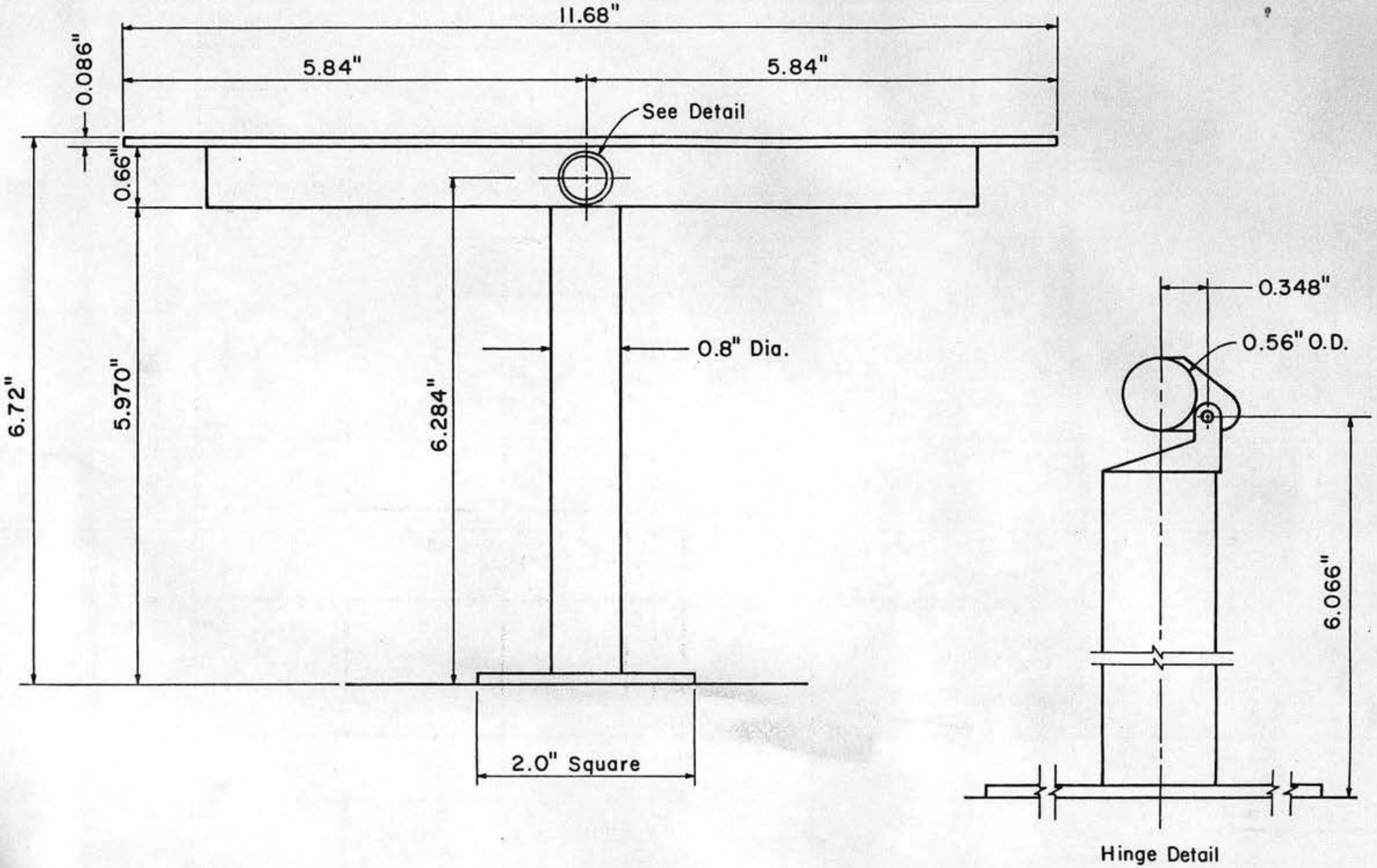


Figure 5a. Heliostat test model dimensions.



Heliostat
(Not to Scale)

Figure 5b. Heliostat test model dimensions.

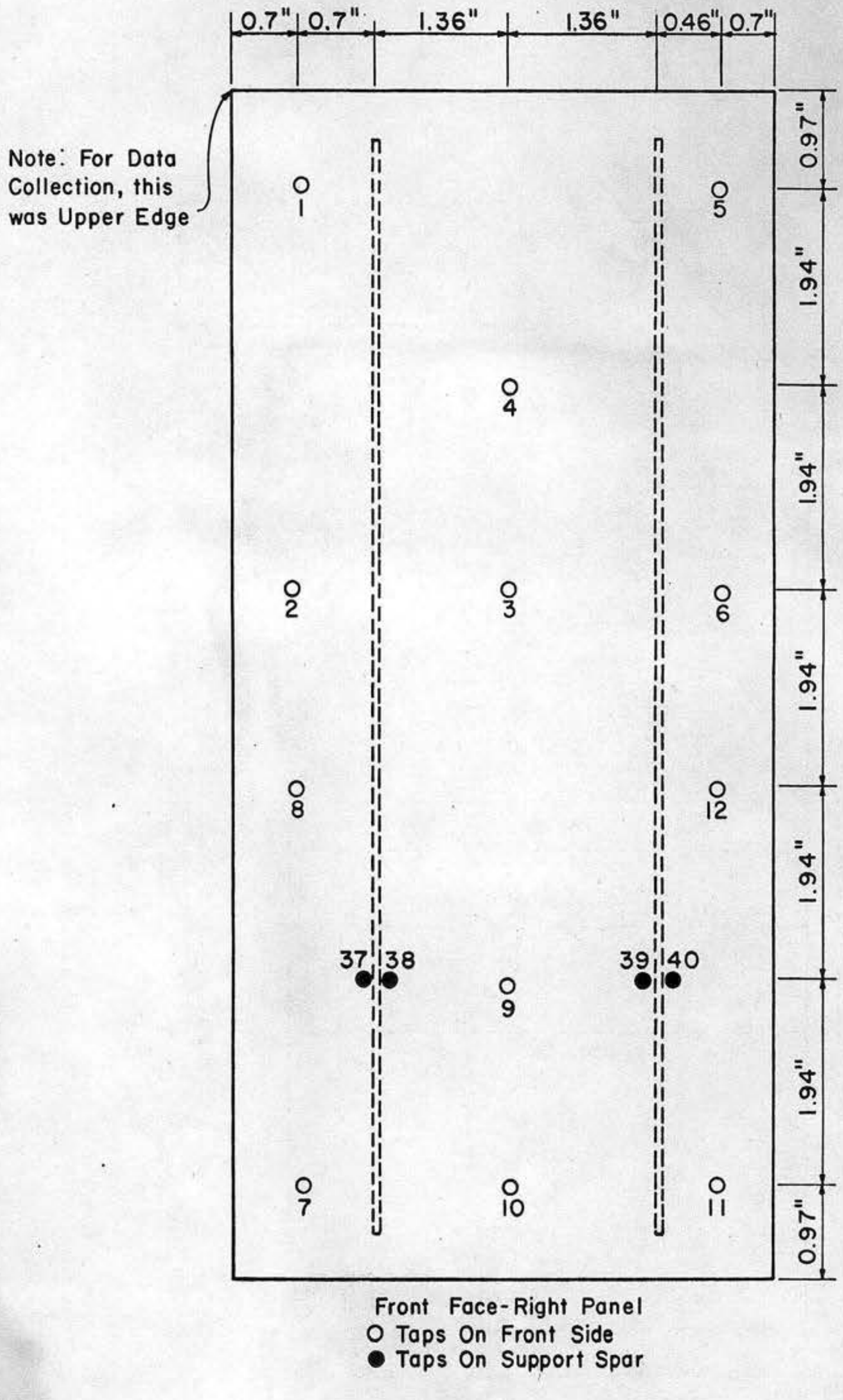


Figure 6a. Pressure tap locations..

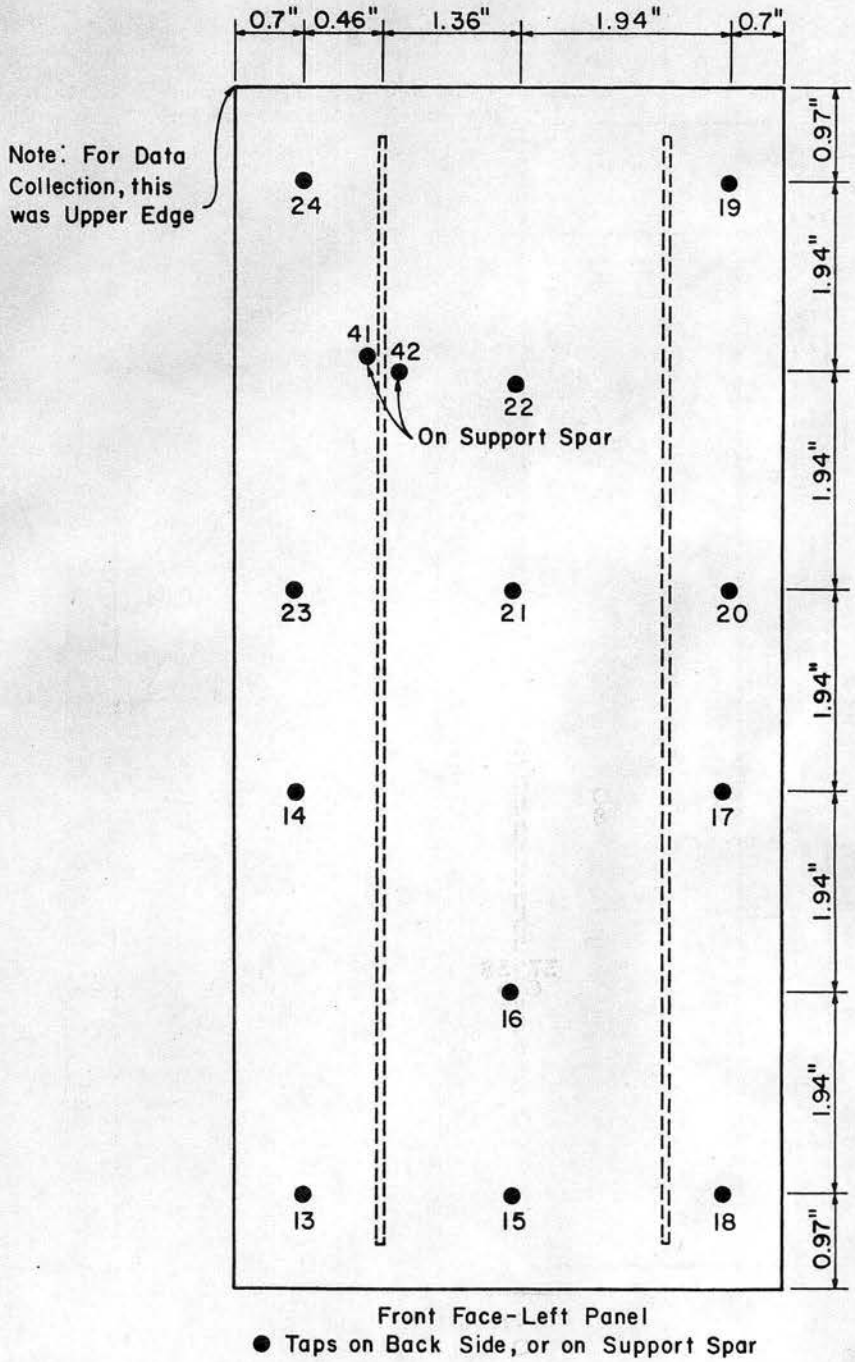


Figure 6b. Pressure tap locations.

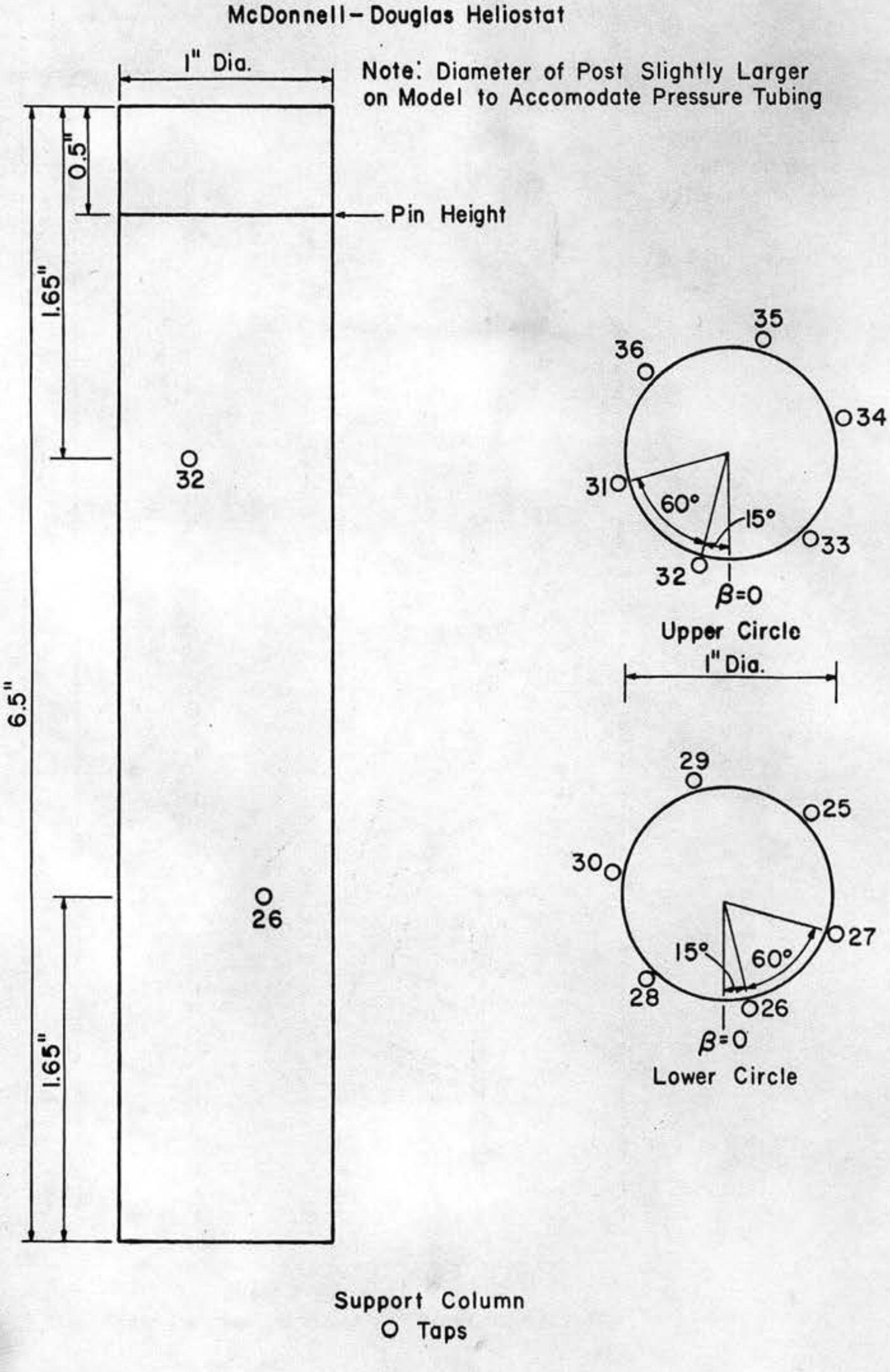


Figure 6c. Pressure tap locations.

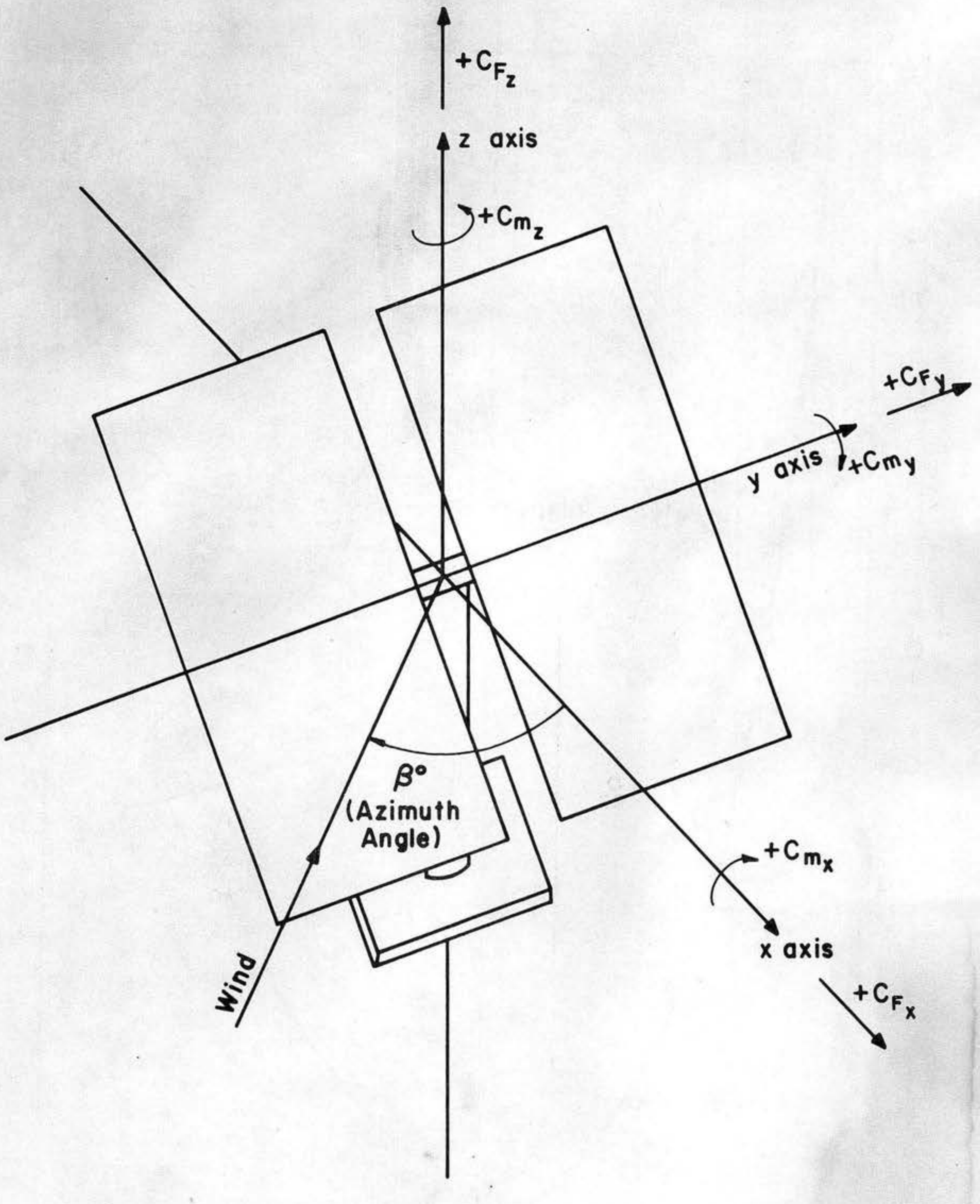


Figure 7. Definition of angle β and coordinate system for force and moment coefficients.

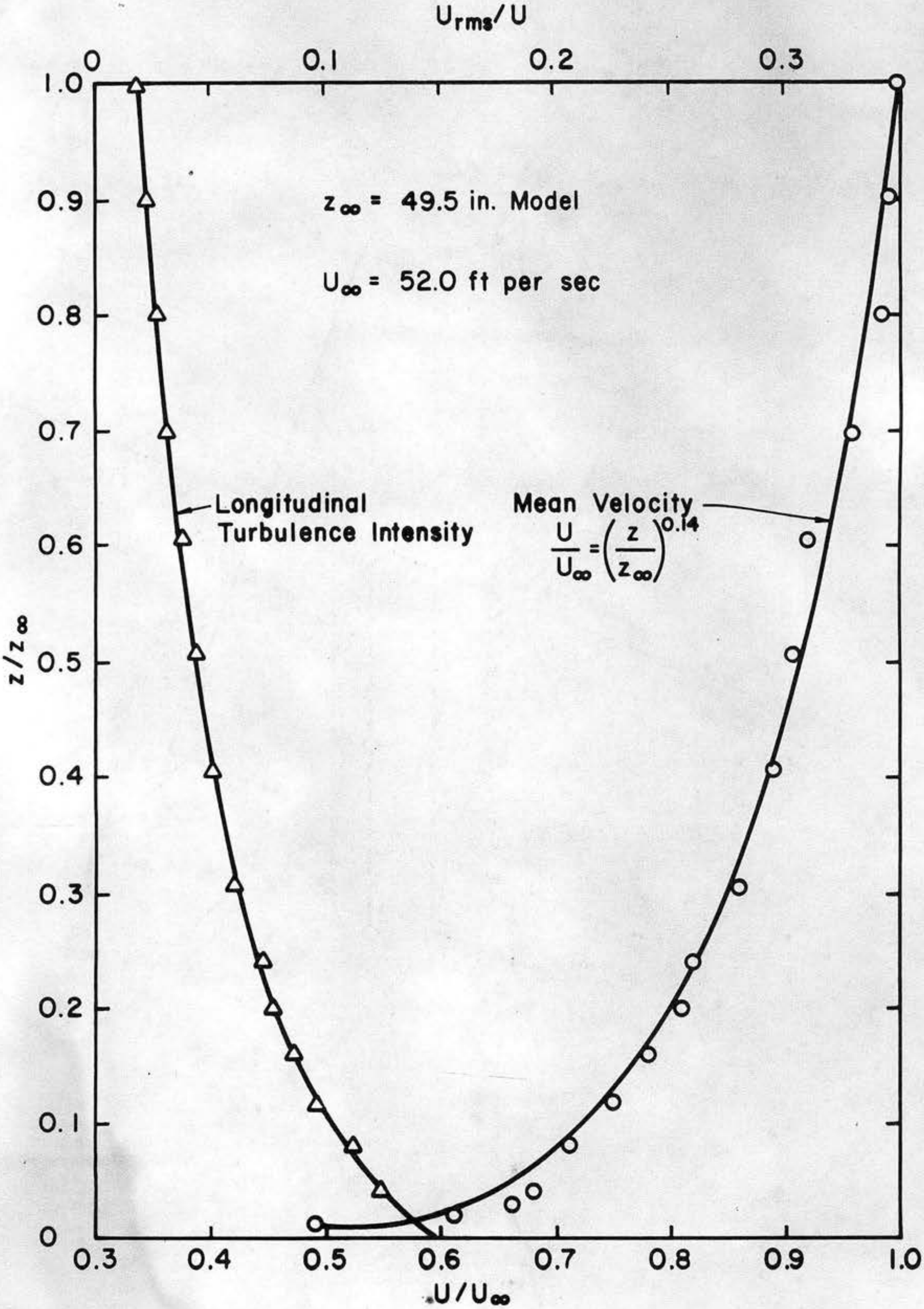


Figure 8. Wind tunnel velocity and turbulence profile for wind flow approaching model configurations.

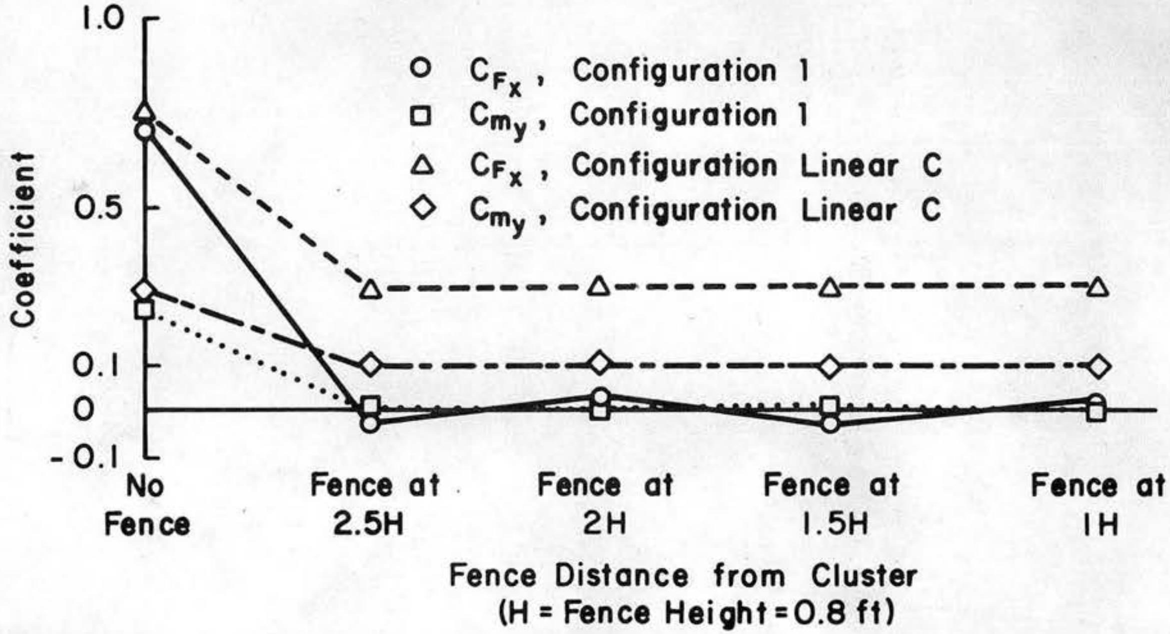


Figure 9. Plot of force and moment coefficient reduction with varying fence distance.

TABLES

Table 1. Heliostat Field-Array Wind Tunnel Study Test Runs

Velocity Study

Run Number	Configu-ration	Tilt α°	Wind β°	Slot
1	Single	30	0	Open
2	Single	30	45	Open
3	Single	30	90	Open
4	Single	30	135	Open
5	Single	30	180	Open

Tilt Angle Study

Run Number	Configu-ration	Tilt α°	Wind β°	Slot
6	Single	-10	0	Open
7	Single	-10	45	Open
8	Single	-10	90	Open
9	Single	-10	135	Open
10	Single	-10	180	Open
11	Single	10	0	Open
12	Single	10	45	Open
13	Single	10	90	Open
14	Single	10	135	Open
15	Single	10	180	Open
16	Single	30	0	Open
17	Single	30	45	Open
18	Single	30	90	Open
19	Single	30	135	Open
20	Single	30	180	Open
21	Single	45	0	Open
22	Single	45	45	Open
23	Single	45	90	Open
24	Single	45	135	Open
25	Single	45	180	Open
26	Single	60	0	Open
27	Single	60	45	Open
28	Single	60	90	Open
29	Single	60	135	Open
30	Single	60	180	Open
31	Single	90	0	Open
32	Single	90	45	Open
33	Single	90	90	Open
34	Single	90	135	Open

Run Number	Configu-ration	Tilt α°	Wind β°	Slot
35	Single	90	180	Open
36	Single	170	0	Open
37	Single	170	45	Open
38	Single	170	90	Open
39	Single	170	135	Open
40	Single	170	180	Open

Slot Study

Run Number	Configu-ation	Tilt α°	Wind β°	Slot
41	Single	45	0	Top half closed
42	Single	45	45	Top half closed
43	Single	45	90	Top half closed
44	Single	45	135	Top half closed
45	Single	45	180	Top half closed
46	Single	45	0	Both halves closed
47	Single	45	45	Both halves closed
48	Single	45	90	Both halves closed
49	Single	45	135	Both halves closed
50	Single	45	180	Both halves closed
141	Single	30	0	Top half closed
142	Single	30	45	Top half closed
143	Single	30	90	Top half closed
144	Single	30	135	Top half closed
145	Single	30	180	Top half closed
146	Single	30	0	Both halves closed
147	Single	30	45	Both halves closed
148	Single	30	90	Both halves closed
149	Single	30	135	Both halves closed
150	Single	30	180	Both halves closed

Table 1. Heliostat Field-Array Wind Tunnel Study Test Runs

Cluster Study

Run Number	Configuration	Tilt α°	Wind β°	Slot
51	1	-10	0	Open
52	1	-10	45	Open
53	1	-10	90	Open
54	1	-10	180	Open
55	1	10	0	Open
56	1	10	45	Open
57	1	10	90	Open
58	1	10	180	Open
59	1	30	0	Open
60	1	30	45	Open
61	1	30	90	Open
62	1	30	180	Open
63	1	90	0	Open
64	1	90	45	Open
65	1	90	90	Open
66	1	90	180	Open
67	2	-10	0	Open
68	2	-10	45	Open
69	2	-10	90	Open
70	2	-10	180	Open
71	2	10	0	Open
72	2	10	45	Open
73	2	10	90	Open
74	2	10	180	Open
75	2	30	0	Open
76	2	30	45	Open
77	2	30	90	Open
78	2	30	180	Open
79	2	90	0	Open
80	2	90	45	Open
81	2	90	90	Open
82	2	90	180	Open
83	Linear A	-10	0	Open
84	Linear A	-10	8	Open
85	omitted			
86	Linear A	10	0	Open
87	Linear A	10	8	Open
88	omitted			
89	Linear A	30	0	Open
90	Linear A	30	8	Open
91	omitted			
92	Linear A	90	0	Open
93	Linear A	90	8	Open
94	omitted			

Pressure Distribution Study

Run Number	Configuration	Tilt α°	Wind β°	Slot
95	1	30	0	Open
96	1	30	45	Open
96A	1	30	-45	Open
97	1	30	90	Open
97A	1	30	-90	Open
98	1	30	180	Open
99	2	30	0	Open
100	2	30	45	Open
100A	2	30	-45	Open
101	2	30	90	Open
101A	2	30	-90	Open
102	2	30	180	Open
103	Single	30	0	Open
104	Single	30	45	Open
104A	Single	30	-45	Open
105	Single	30	90	Open
105A	Single	30	-90	Open
106	Single	30	180	Open
107	Linear A	30	0	Open
108	Linear A	30	8	Open
108A	Linear A	30	-8	Open

Table 1. Heliostat Field-Array Wind Tunnel Study Test Runs

Fence Study

Run Number	Configu-ation	Tilt $\alpha°$	Wind $\beta°$	Slot	Fence Orientation	Fence Distance[1]
110	1	30	0	Open	0	1H
111	1	30	30	Open	0	1H
112	1	30	0	Open	0	1.5H
113	1	30	30	Open	0	1.5H
114	1	30	0	Open	0	2H
115	1	30	30	Open	0	2H
116	1	30	0	Open	0	2.5H
117	1	30	30	Open	0	2.5H
117A[2]	1	30	30	Open	0	2.5H
118	Linear B	30	0	Open	No Fence	No Fence
119	Linear B	30	30	Open	No Fence	No Fence
120	Linear B	30	0	Open	0	1H
120A	Linear B	30	0	Open	45	1H
121	Linear B	30	30	Open	0	1H
121A	Linear B	30	30	Open	45	1H
122	Linear B	30	0	Open	0	1.5H
122A	Linear B	30	0	Open	45	1.5H
123	Linear B	30	30	Open	0	1.5H
123A	Linear B	30	30	Open	45	1.5H
124	Linear	30	0	Open	0	2H
124A	Linear B	30	0	Open	45	2H
125	Linear B	30	30	Open	0	2H
125A	Linear B	30	30	Open	45	2H
126	Linear B	30	0	Open	0	2.5H
126A	Linear B	30	0	Open	45	2.5H
127	Linear B	30	30	Open	0	2.5H
127A	Linear B	30	30	Open	45	2.5H
128	Linear C	30	0	Open	No Fence	No Fence
129	Linear C	30	30	Open	No Fence	No Fence
130	Linear C	30	0	Open	0	1H
131	Linear C	30	30	Open	0	1H
132	Linear C	30	0	Open	0	1.5H
133	Linear C	30	30	Open	0	1.5H
134	Linear C	30	0	Open	0	2H
135	Linear C	30	30	Open	0	2H
136	Linear C	30	0	Open	0	2.5H
137	Linear C	30	30	Open	0	2.5H

[1] H = fence model height = 0.8 ft.

[2] Configuration 117A has the instrumental heliostat in the center of the cluster.

Table 2. Motion Picture Scene Guide

Scene	Configuration	Tilt α°	Wind β°	Run Number
1	Single	10	0	6
2	Single	30	0	16
3	Single	90	0	31
4	Single	90	45	32
5	Single	90	90	33
6	1	-10	0	51
7	1	30	0	59
8	1	90	0	63
9	1	90	45	64
10	1	90	90	65
11	2	-10	0	67
12	2	30	0	75
13	2	90	0	79
14	2	90	45	80
15	2	90	90	81
16	Linear A	-10	0	83
17	Linear A	30	0	89
18	Linear A	90	0	92

Model wind velocity: 10 fps
Movie Length: 484 ft.
Movie speed: 24 frames per second
Running time: 13 min. 20 sec.

Table 3. Force and Moment Coefficients

Velocity Study

Configuration: Single

Run Number	Tilt $\alpha°$	Wind $\beta°$	Slot	C_{F_x}	C_{F_y}	C_{m_z}	C_{m_y}	C_{m_x}	C_{mh_y}	C_{mh_x}	C_{mu_y}	C_{mu_x}
1	30	0	Open	-1.129	.033	-.002	-.595	.022	.000	.004	.064	.002
2	30	45	Open	-1.068	.017	-.091	-.583	-.043	-.019	-.052	.041	-.053
3	30	90	Open	.031	.091	.045	.009	.088	-.008	.040	-.010	.035
4	30	135	Open	.796	.161	.103	.485	.158	.064	.073	.019	.063
5	30	180	Open	1.504	-.070	.003	.661	-.013	.104	.024	.045	.028

Slot Study

Configuration: Single

Run Number	Tilt $\alpha°$	Wind $\beta°$	Slot	C_{F_x}	C_{F_y}	C_{m_z}	C_{m_y}	C_{m_x}	C_{mh_y}	C_{mh_x}	C_{mu_y}	C_{mu_x}
41	45	0	Top Half Closed	-.856	.019	.000	-.446	.006	.005	-.005	.053	-.006
42	45	45	Top Half Closed	-.839	.035	-.079	-.422	-.069	.020	-.087	.067	-.089
43	45	90	Top Half Closed	.019	.137	.032	-.003	.093	-.013	.021	-.015	.013
44	45	135	Top Half Closed	.676	.174	.074	.467	.170	.109	.077	.071	.068
45	45	180	Top Half Closed	.852	-.002	.006	.602	-.002	.152	-.001	.104	-.001
46	45	0	Both Halves Closed	-.935	-.016	-.000	-.466	.002	.027	.010	.080	.011
47	45	45	Both Halves Closed	-.885	.009	-.086	-.441	-.076	.025	-.080	.075	-.081
48	45	90	Both Halves Closed	.029	.133	.038	.007	.104	-.008	.034	-.010	.026
49	45	135	Both Halves Closed	.724	.172	.071	.470	.176	.087	.085	.047	.075
50	45	180	Both Halves Closed	.948	-.024	.005	.640	-.005	.139	.008	.086	.009
141	30	0	Top Half Closed	-.642	-.011	.003	-.267	.007	.071	.013	.107	.013
142	30	45	Top Half Closed	-.544	.040	-.036	-.224	-.037	.062	-.058	.093	-.060
143	30	90	Top Half Closed	.013	.122	.025	.002	.127	-.005	.062	-.006	.055
144	30	135	Top Half Closed	.523	.156	.064	.458	.224	.180	.141	.151	.132
145	30	180	Top Half Closed	.623	-.042	.004	.516	-.004	.186	.018	.151	.021
146	30	0	Both Halves Closed	-.706	.010	.001	-.266	.002	.105	-.004	.145	-.005
147	30	45	Both Halves Closed	-.535	.066	-.041	-.224	-.046	.058	-.080	.088	-.083
148	30	90	Both Halves Closed	.002	.128	.027	.011	.131	.010	.063	.010	.055
149	30	135	Both Halves Closed	.564	.152	.071	.480	.237	.181	.156	.149	.147
150	30	180	Both Halves Closed	.735	-.025	.002	.576	-.010	.187	.003	.145	.005

Table 3. Force and Moment Coefficients

Tilt Angle Study

Configuration: Single

Run Number	Tilt $\alpha°$	Wind $\beta°$	Slot	C_{F_X}	C_{F_y}	C_{m_z}	C_{m_y}	C_{m_x}	C_{mh_y}	C_{mh_x}	C_{mu_y}	C_{mu_x}
6	-10	0	Open	-.153	.025	.003	-.189	-.004	-.107	-.017	-.098	-.018
7	-10	45	Open	-.118	.177	-.004	-.126	.148	-.063	.054	-.057	.044
8	-10	90	Open	.006	.149	-.016	-.002	.116	-.005	.038	-.006	.029
9	-10	135	Open	.114	.150	-.021	.025	.062	-.035	-.017	-.041	-.025
10	-10	180	Open	.152	.010	.002	.026	-.010	-.054	-.014	-.062	-.015
11	10	0	Open	-.128	.020	.001	-.046	-.003	.022	-.013	.029	-.015
12	10	45	Open	-.102	.150	.014	-.042	.073	.012	-.006	.017	-.015
13	10	90	Open	.008	.129	.005	-.004	.115	-.008	.047	-.009	.039
14	10	135	Open	.139	.155	-.008	.128	.146	.054	.063	.047	.055
15	10	180	Open	.146	.012	.001	.195	-.007	.117	-.014	.108	-.014
16	30	0	Open	-.626	.004	.003	-.214	.001	.115	-.001	.150	-.001
17	30	45	Open	-.538	.031	-.032	-.219	-.049	.064	-.065	.094	-.067
18	30	90	Open	.014	.114	.024	.007	.111	-.000	.051	-.001	.044
19	30	135	Open	.176	.151	.045	.085	.182	-.008	.102	-.018	.093
20	30	180	Open	.619	-.020	.004	.524	-.009	.196	.002	.161	.003
21	45	0	Open	-.892	.017	-.001	-.449	.006	.021	-.004	.071	-.005
22	45	45	Open	-.783	.034	-.066	-.410	-.064	.003	-.081	.047	-.083
23	45	90	Open	.036	.123	.035	-.001	.101	-.020	.036	-.022	.029
24	45	135	Open	.625	.210	.067	.404	.183	.073	.071	.038	.059
25	45	180	Open	.866	-.008	.004	.574	-.006	.117	-.002	.068	-.002
26	60	0	Open	-1.115	-.004	-.000	-.588	.006	.000	.008	.063	.008
27	60	45	Open	-1.085	-.026	-.091	-.584	-.057	-.012	-.043	.049	-.041
28	60	90	Open	.029	.118	.046	.007	.090	-.008	.028	-.010	.021
29	60	135	Open	.748	.200	.100	.479	.166	.084	.060	.042	.049
30	60	180	Open	1.046	-.023	.000	.667	-.006	.114	.006	.055	.007
31	90	0	Open	-1.318	.022	.001	-.741	.007	-.046	-.005	.028	-.006
32	90	45	Open	-1.155	.019	-.083	-.657	.003	-.047	-.006	.018	-.007
33	90	90	Open	.011	.126	.047	-.000	.056	-.006	-.010	-.007	-.018
34	90	135	Open	.883	.204	.110	.502	.103	.036	-.004	-.014	-.016
35	90	180	Open	1.190	-.007	-.005	.706	.000	.078	.004	.011	.004
36	170	0	Open	-.137	-.006	-.000	-.131	.000	-.058	.003	-.050	.003
37	170	45	Open	-.109	.112	.016	-.109	.082	-.051	.023	-.045	.016
38	170	90	Open	-.012	.122	.009	-.007	.033	-.001	-.030	-.000	-.037
39	170	135	Open	.088	.155	-.006	.016	.023	-.030	-.058	-.035	-.067
40	170	180	Open	.115	-.019	.002	-.006	-.001	-.066	.009	-.072	.011

Table 3. Force and Moment Coefficients

Cluster Study

Configuration: 1

Run Number	Tilt α°	Wind β°	Slot	C_{F_x}	C_{F_y}	C_{m_z}	C_{m_y}	C_{m_x}	C_{mh_y}	C_{mh_x}	C_{mu_y}	C_{mu_x}
51	-10	0	Open	-.129	-.011	.001	-.116	.003	-.048	.009	-.040	.009
52	-10	45	Open	-.118	.120	.000	-.136	.154	-.073	.090	-.067	.083
53	-10	90	Open	.006	.096	-.016	-.003	.138	-.006	.087	-.007	.081
54	-10	180	Open	.096	-.021	.002	.042	.001	-.008	.013	-.014	.014
55	10	0	Open	-.081	.025	-.000	-.047	-.002	-.004	-.015	.001	-.017
56	10	45	Open	-.097	.165	.014	-.023	.091	.028	.004	.034	-.006
57	10	90	Open	.017	.145	.004	.006	.130	-.003	.053	-.004	.045
58	10	180	Open	.127	-.006	.001	.115	-.005	.047	-.002	.040	-.002
59	30	0	Open	-.389	.015	.003	-.109	.008	.095	-.000	.117	-.001
60	30	45	Open	-.484	.041	-.021	-.174	-.007	.080	-.029	.108	-.031
61	30	90	Open	-.003	.133	.026	.009	.125	.010	.054	.010	.047
62	30	180	Open	.459	-.045	.008	.452	-.011	.208	.013	.182	.015
63	90	0	Open	-.892	.039	-.000	-.507	.018	-.036	-.002	.014	-.005
64	90	45	Open	-1.164	-.001	-.062	-.657	.001	-.042	.002	.023	.002
65	90	90	Open	-.021	.116	.045	-.014	.065	-.003	.003	-.002	-.003
66 .	90	180	Open	.769	-.020	.004	.437	-.009	.031	.002	-.012	.003

Cluster Study

Configuration: 2

Run Number	Tilt α°	Wind β°	Slot	C_{F_x}	C_{F_y}	C_{m_z}	C_{m_y}	C_{m_x}	C_{mh_y}	C_{mh_x}	C_{mu_y}	C_{mu_x}
67	-10	0	Open	-.153	.011	.001	-.167	.007	-.086	.001	-.077	.001
68	-10	45	Open	-.094	.135	-.004	-.077	.155	-.027	.083	-.021	.075
69	-10	90	Open	.035	.089	-.010	-.004	.085	-.022	.037	-.023	.032
70	-10	180	Open	.207	-.014	.002	.007	-.006	-.101	.001	-.112	.002
71	10	0	Open	-.126	.013	.004	-.032	.008	.034	.001	.041	.000
72	10	45	Open	-.087	.136	.009	-.052	.046	-.006	-.026	-.001	-.034
73	10	90	Open	.043	.103	.004	-.001	.088	-.023	.034	-.026	.028
74	10	180	Open	.133	.000	.003	.227	-.007	.155	-.007	.147	-.007
75	30	0	Open	-.446	.005	.007	-.155	.011	.079	.008	.104	.008
76	30	45	Open	-.446	.070	-.036	-.223	-.049	.012	-.085	.037	-.089
77	30	90	Open	.016	.075	.014	.005	.084	-.004	.045	-.005	.040
78	30	180	Open	.457	-.018	.003	.369	.001	.127	.011	.101	.012
79	90	0	Open	-.738	-.003	-.002	-.413	.003	-.024	.004	.018	.005
80	90	45	Open	-1.153	-.019	-.118	-.668	.003	-.060	.013	.005	.014
81	90	90	Open	0.025	.082	.025	-.026	.053	-.013	.010	-.011	.005
82	90	180	Open	.766	-.013	.004	.434	.000	.030	.007	-.013	.008

Table 3. Force and Moment Coefficients

Cluster Study

Configuration: Linear A

Run Number	Tilt $\alpha°$	Wind $\beta°$	Slot	C_{F_X}	C_{F_y}	C_{m_z}	C_{m_y}	C_{m_x}	C_{mh_y}	C_{mh_x}	C_{mu_y}	C_{mu_x}
83	-10	0	Open	-.128	-.048	.001	-.159	.008	-.090	.033	-.083	.035
84	-10	8	Open	-.152	.016	.001	-.167	.022	-.086	.014	-.077	.013
85	Omitted											
86	10	0	Open	-.090	-.074	.002	-.029	.009	.018	.048	.023	.052
87	10	8	Open	-.132	.028	.008	-.034	.031	.035	.016	.042	.015
88	Omitted											
89	30	0	Open	-.290	-.071	.004	-.079	.014	.073	.051	.089	.055
90	30	8	Open	-.361	-.003	.004	-.148	.003	.042	.005	.062	.005
91	Omitted											
92	90	0	Open	-.751	-.061	.006	-.422	.014	-.025	.046	.017	.049
93	90	8	Open	-.638	-.014	.015	-.374	.008	-.037	.016	-.001	.016
94	Omitted											

Fence Study

Configuration: 1 with Fence

Run No.	Tilt $\alpha°$	Wind $\beta°$	Slot	Fence Distance[1]	C_{F_X}	C_{F_y}	C_{m_z}	C_{m_y}	C_{m_x}	C_{mh_y}	C_{mh_x}	C_{mu_y}	C_{mu_x}
110	30	0	Open	1H	-.036	.002	-.000	-.007	-.002	.012	-.003	.014	-.003
111	30	30	Open	1H	-.039	-.004	.001	-.008	.000	.012	.002	.015	.002
112	30	0	Open	1.5H	-.036	-.010	.002	-.006	-.008	-.013	-.003	.015	-.002
113	30	30	Open	1.5H	-.025	-.002	.001	-.007	-.000	-.006	.001	.007	.001
114	30	0	Open	2H	-.023	-.017	.003	.002	-.009	.014	.000	.015	.001
115	30	30	Open	2H	-.017	-.021	.001	-.007	-.001	.002	.010	.003	.011
116	30	0	Open	2.5H	.001	-.011	.002	-.005	-.004	-.006	.002	-.006	.002
117	30	30	Open	2.5H	-.001	-.015	.002	-.007	.000	-.006	.008	-.006	.009
117A[2]	30	30	Open	2.5H	-.004	-.006	-.000	-.002	-.002	.001	.002	.001	.002

[1] H = fence model height = 0.8 ft.

[2] Configuration 117A has the instrumented heliostat in the center of the cluster.

Table 3. Force and Momentum Coefficients

Fence Study

Configuration: Linear B with fence at 0°

Run No.	Tilt α°	Wind β°	Slot	Fence Distance[1]	C_{F_X}	C_{F_y}	C_{m_z}	C_{m_y}	C_{m_x}	C_{mh_y}	C_{mh_x}	C_{mu_y}	C_{mu_x}
118	30	0	Open	No fence	-.735	.022	.004	-.255	.015	.131	.003	.172	.002
119	30	30	Open	No fence	-.416	.027	.016	-.135	.043	.083	.028	.107	.027
120	30	0	Open	1H	-.013	-.027	.002	.000	.006	.007	.020	.008	.022
121	30	30	Open	1H	-.021	-.006	.002	-.002	.001	.009	.004	.011	.005
122	30	0	Open	1.5H	.011	-.004	.002	-.005	.001	-.011	.003	-.012	.003
123	30	30	Open	1.5H	-.010	.002	.001	-.003	-.001	.002	-.003	.003	-.003
124	30	0	Open	2H	-.026	-.004	.001	-.011	-.005	.003	-.003	.004	-.003
125	30	30	Open	2H	-.046	-.006	.001	-.002	-.006	.022	-.003	.025	-.003
126	30	0	Open	2.5H	.004	-.009	.001	-.015	-.002	-.017	.003	-.017	.003
127	30	30	Open	2.5H	-.029	.004	.001	-.008	-.007	.007	-.009	.009	-.010

[1] H = fence model height = 0.8 ft.

Fence Study

Configuration: Linear B with Fence at 45°

Run No.	Tilt α°	Wind β°	Slot	Fence Distance[1]	C_{F_X}	C_{F_y}	C_{m_z}	C_{m_y}	C_{m_x}	C_{mh_y}	C_{mh_x}	C_{mu_y}	C_{mu_x}
120A	30	0	Open	1H	-.114	.012	-.007	-.051	-.021	.009	-.028	.015	-.028
121A	30	30	Open	1H	-.146	.119	.006	-.104	.031	-.027	-.032	-.019	-.039
122A	30	0	Open	1.5H	-.191	-.001	-.014	-.084	-.035	.016	-.034	.027	-.034
123A	30	30	Open	1.5H	-.147	.117	.001	-.107	.008	-.029	-.053	-.021	-.060
124A	30	0	Open	2H	-.296	.006	-.030	-.123	-.067	.033	-.070	.049	-.070
125A	30	30	Open	2H	-.177	.109	-.006	-.127	-.010	-.033	-.067	-.023	-.074
126A	30	0	Open	2.5H	-.339	-.021	-.034	-.140	-.076	.039	-.064	.058	-.063
127A	30	30	Open	2.5H	-.202	.091	-.010	-.128	-.018	-.021	-.065	-.010	-.071

[1] H = fence model height = 0.8 ft.

Table 3. Force and Moment Coefficients

Fence Study

Configuration: Linear C

Run No.	Tilt $\alpha°$	Wind $\beta°$	Slot	Fence Distance[1]	C_{F_X}	C_{F_y}	C_{m_z}	C_{m_y}	C_{m_x}	C_{mh_y}	C_{mh_x}	C_{mu_y}	C_{mu_x}
128	30	0	Open	No Fence	-.797	.009	.004	-.301	.014	.118	.009	.162	.009
129	30	30	Open	No Fence	-.469	.013	.010	-.140	.020	.106	.013	.133	.012
130	30	0	Open	1H	-.315	.004	.000	-.114	.007	.051	.005	.069	.004
131	30	30	Open	1H	-.297	.010	.007	-.114	.012	.043	.007	.059	.006
132	30	0	Open	1.5H	-.317	.008	.001	-.118	.010	.049	.006	.066	.006
133	30	30	Open	1.5H	-.274	.008	.007	-.104	.009	.040	.005	.055	.005
134	30	0	Open	2H	-.312	.000	.002	-.121	.008	.043	.008	.061	.008
135	30	30	Open	2H	-.270	.012	.007	-.105	.009	.038	.003	.056	.002
136	30	0	Open	2.5H	-.308	-.002	.002	-.124	.007	.038	.008	.055	.008
137	30	30	Open	2.5H	-.289	.020	.007	-.112	.009	.040	-.002	.057	-.003
138	Omitted												
139	Omitted												
140	Omitted												

[1] H = fence model height = 0.8 ft.

Table 4. Pressure Coefficients
Pressure Study

Run 95		β = 0°		Run 96		β = 45°	
Configuration 1		α = 30°		Configuration 1		α = 30°	
Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$
1	- .134	22	- .658	1	.017	22	- .661
2	- .127	23	- .720	2	.174	23	- .699
3	- .105	24	- .552	3	.068	24	- .354
4	- .130	25	- .680	4	.020	25	- .939
5	- .202	26	.363	5	- .105	26	- .862
6	- .153	27	- .809	6	- .083	27	- .964
7	.172	28	- .500	7	.501	28	.730
8	- .018	29	- .669	8	.233	29	- .948
9	.045	30	- .703	9	.185	30	-1.178
10	.286	31	- .995	10	.279	31	.056
11	.290	32	.101	11	- .056	32	- .573
12	- .080	33	- .760	12	- .086	33	-1.138
13	-1.390	34	- .881	13	-1.308	34	-1.217
14	- .666	35	- .718	14	- .793	35	-1.154
15	- .763	36	- .774	15	- .988	36	-1.200
16	- .638	37	- .465	16	- .703	37	- .856
17	- .203	38	- .820	17	- .410	38	- .706
18	- .945	39	- .857	18	- .823	39	- .643
19	- .314	40	- .651	19	- .358	40	- .713
20	- .701	41	- .613	20	- .472	41	- .255
21	- .277	42	- .370	21	- .562	42	- .496

Table 4. Pressure Coefficients
Pressure Study

Run 96A		β = - 45°		Run 97		β = 90°	
Configuration 1		α = 30°		Configuration 1		α = 30°	
Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$
1	- .077	22	- .573	1	- .149	22	- .527
2	.105	23	- .435	2	- .137	23	.771
3	.264	24	- .395	3	- .108	24	.672
4	.155	25	- .960	4	- .102	25	- .490
5	.022	26	.453	5	- .114	26	- .502
6	.377	27	- .522	6	- .140	27	- .502
7	.217	28	-1.082	7	- .183	28	- .344
8	.229	29	-1.046	8	- .139	29	- .569
9	.413	30	-1.095	9	- .102	30	.570
10	.499	31	-1.282	10	- .113	31	.334
11	.694	32	-1.254	11	- .121	32	-1.062
12	.482	33	.236	12	- .136	33	- .959
13	- .656	34	-1.095	13	.597	34	- .756
14	- .518	35	-1.130	14	.757	35	- .596
15	- .843	36	-1.143	15	- .619	36	- .088
16	- .814	37	- .793	16	- .509	37	.168
17	- .041	38	- .665	17	- .200	38	- .332
18	- .893	39	-1.235	18	- .187	39	- .127
19	- .517	40	-1.356	19	- .273	40	- .286
20	- .662	41	- .372	20	- .238	41	.838
21	- .455	42	- .229	21	- .511	42	- .413

Table 4. Pressure Coefficients
Pressure Study

Run 97 A		β = -90°		Run 98		β = 180°	
Configuration 1		α = 30°		Configuration 1		α = 30°	
Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$
1	- .111	22	- .203	1	-1.325	22	.856
2	- .108	23	- .250	2	- .608	23	-1.117
3	- .094	24	- .365	3	- .236	24	.185
4	- .104	25	- .327	4	- .783	25	- .175
5	- .445	26	- .590	5	-1.576	26	- .273
6	- .500	27	.537	6	-1.074	27	- .309
7	- .054	28	- .517	7	- .098	28	- .315
8	- .095	29	- .486	8	- .387	29	.656
9	- .073	30	- .506	9	- .279	30	- .408
10	- .088	31	- .735	10	- .266	31	- .384
11	- .562	32	- .843	11	- .547	32	- .393
12	- .492	33	- .578	12	- .905	33	- .368
13	- .341	34	.429	13	- .284	34	- .499
14	- .241	35	- .670	14	- .401	35	.624
15	- .463	36	- .644	15	.039	36	- .093
16	- .381	37	- .269	16	- .170	37	- .000
17	- .014	38	- .517	17	- .382	38	- .139
18	.360	39	- .471	18	.043	39	.014
19	.045	40	.634	19	.383	40	- .463
20	- .051	41	- .260	20	.615	41	- .036
21	- .224	42	- .010	21	.300	42	.171

Table 4. Pressure Coefficients
Pressure Study

Run 99		β = 0°		Run 100		β = 45°	
Configuration 2		α = 30°		Configuration 2		α = 30°	
Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$
1	- .047	22	- .630	1	.150	22	- .851
2	.122	23	- .622	2	.090	23	- .898
3	.149	24	- .434	3	- .008	24	- .852
4	.077	25	- .762	4	.022	25	- .964
5	- .062	26	.457	5	- .086	26	-1.204
6	.012	27	- .804	6	- .178	27	- .976
7	.423	28	- .597	7	.268	28	.681
8	.223	29	- .734	8	- .015	29	- .961
9	.244	30	- .804	9	- .025	30	-1.047
10	.372	31	- .709	10	.021	31	.194
11	.085	32	- .140	11	- .216	32	- .325
12	.019	33	- .803	12	- .188	33	- .939
13	-1.178	34	- .699	13	- .210	34	-1.016
14	- .716	35	- .590	14	- .881	35	- .956
15	- .882	36	- .651	15	-1.067	36	-1.052
16	- .894	37	- .805	16	- .769	37	- .010
17	- .686	38	- .970	17	- .462	38	- .832
18	-1.194	39	- .914	18	- .983	39	- .394
19	- .460	40	- .941	19	- .584	40	- .665
20	- .618	41	- .494	20	- .844	41	- .874
21	- .424	42	- .326	21	- .754	42	- .658

Table 4. Pressure Coefficients
Pressure Study

Run 100A				Run 101			
Configuration 2		$\beta = -45°$ $\alpha = 30°$		Configuration 2		$\beta = 90°$ $\alpha = 30°$	
Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$
1	- .155	22	- .600	1	- .150	22	- .454
2	.051	23	- .374	2	- .158	23	.454
3	.314	24	- .287	3	- .089	24	.471
4	.252	25	-1.059	4	- .106	25	- .366
5	.281	26	- .183	5	- .108	26	- .393
6	.549	27	.156	6	- .134	27	- .365
7	.032	28	-1.009	7	- .134	28	- .274
8	.185	29	-1.063	8	- .143	29	- .454
9	.295	30	-1.064	9	- .098	30	.355
10	.304	31	- .981	10	- .115	31	.144
11	.613	32	-1.143	11	- .104	32	- .684
12	.607	33	.389	12	- .126	33	- .632
13	- .781	34	- .976	13	.491	34	- .428
14	- .503	35	- .954	14	.426	35	- .361
15	- .803	36	-1.001	15	- .483	36	- .108
16	- .848	37	- .748	16	- .419	37	.119
17	.314	38	- .070	17	- .104	38	- .276
18	- .925	39	-1.130	18	- .165	39	- .117
19	- .628	40	-1.305	19	- .172	40	- .239
20	- .732	41	- .329	20	- .164	41	.598
21	- .554	42	- .284	21	- .384	42	- .266

Table 4. Pressure Coefficients
Pressure Study

Run 101A		β = -90°		Run 102		β = 180°	
Configuration 2		α = 30°		Configuration 2		α = 30°	
Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$
1	- .087	22	- .201	1	-1.027	22	.626
2	- .091	23	- .187	2	- .659	23	- .178
3	- .067	24	- .295	3	- .427	24	.204
4	- .080	25	- .203	4	- .754	25	- .084
5	- .267	26	- .490	5	-1.114	26	- .233
6	- .188	27	.366	6	- .595	27	- .221
7	- .037	28	- .425	7	- .224	28	- .247
8	- .062	29	- .412	8	- .445	29	.595
9	- .100	30	- .415	9	- .251	30	- .351
10	- .103	31	- .518	10	- .254	31	- .323
11	- .355	32	- .637	11	- .262	32	- .320
12	- .186	33	- .442	12	- .442	33	- .330
13	- .283	34	.333	13	.006	34	- .416
14	- .212	35	- .446	14	- .193	35	.435
15	- .347	36	- .414	15	.104	36	.009
16	- .293	37	- .176	16	.152	37	.113
17	- .002	38	- .367	17	- .097	38	.078
18	.226	39	- .304	18	.067	39	.225
19	.179	40	.449	19	.465	40	- .203
20	.036	41	- .234	20	.484	41	- .163
21	- .241	42	.033	21	.412	42	.415

Table 4. Pressure Coefficients
Pressure Study

Run 103		$\beta = 0°$		Run 104		$\beta = 45°$	
Configuration Single		$\alpha = 30°$		Configuration Single		$\alpha = 30°$	
Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$
1	.004	22	- .811	1	.056	22	- .883
2	.258	23	-1.016	2	.208	23	- .916
3	.286	24	- .657	3	.108	24	- .832
4	.186	25	- .842	4	.045	25	- .915
5	- .044	26	.551	5	- .112	26	- .876
6	.164	27	- .876	6	- .075	27	- .905
7	.617	28	- .653	7	.554	28	.586
8	.403	29	- .858	8	.234	29	- .967
9	.502	30	- .879	9	.196	30	-1.159
10	.696	31	- .944	10	.304	31	.125
11	.423	32	- .012	11	- .010	32	- .313
12	.239	33	-1.195	12	- .059	33	- .928
13	-1.533	34	- .985	13	-1.068	34	- .986
14	-1.033	35	- .788	14	- .939	35	- .895
15	-1.054	36	- .865	15	-1.279	36	- .938
16	-1.098	37	-1.055	16	- .457	37	- .508
17	- .763	38	-1.220	17	- .389	38	- .808
18	-1.404	39	-1.218	18	- .985	39	- .608
19	- .622	40	-1.370	19	- .496	40	- .721
20	- .794	41	- .892	20	- .799	41	- .884
21	- .538	42	- .401	21	.759	42	- .669

Table 4. Pressure Coefficients
Pressure Study

Run 104 A $\beta = -45^\circ$ Configuration Single $\alpha = 30^\circ$

Run 105 $\beta = 90^\circ$ Configuration Single $\alpha = 30^\circ$

Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$
1	- .151	22	- .604	1	- .136	22	- .537
2	.065	23	- .369	2	- .130	23	.771
3	.268	24	- .276	3	- .085	24	.667
4	.196	25	- .971	4	- .096	25	- .502
5	.240	26	.201	5	- .124	26	- .507
6	.483	27	- .207	6	- .143	27	- .490
7	.183	28	- .991	7	- .150	28	- .307
8	.227	29	- .992	8	- .120	29	- .573
9	.370	30	-1.014	9	- .107	30	.542
10	.439	31	- .954	10	- .117	31	.245
11	.616	32	-1.096	11	- .109	32	-1.024
12	.535	33	.413	12	- .134	33	- .946
13	- .666	34	- .994	13	.597	34	- .707
14	- .484	35	- .924	14	.731	35	- .521
15	- .825	36	- .968	15	- .606	36	- .077
16	- .826	37	- .692	16	- .520	37	.154
17	.085	38	- .061	17	- .195	38	- .342
18	- .908	39	-1.154	18	- .197	39	- .118
19	- .564	40	-1.141	19	- .259	40	- .293
20	- .772	41	- .316	20	- .239	41	.830
21	- .526	42	- .273	21	- .511	42	- .379

Table 4. Pressure Coefficients
Pressure Study

Run 105A		β = -90°		Run 106		β = 180°	
Configuration Single		α = 30°		Configuration Single		α = 30°	
Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$
1	- .112	22	- .215	1	-1.176	22	.923
2	- .108	23	- .246	2	-1.087	23	- .161
3	- .089	24	- .410	3	- .682	24	.516
4	- .100	25	- .295	4	-1.251	25	- .090
5	- .560	26	- .618	5	-1.184	26	- .264
6	- .610	27	.580	6	-1.032	27	- .227
7	- .037	28	- .542	7	- .372	28	- .264
8	- .085	29	- .506	8	- .797	29	.639
9	- .099	30	- .523	9	- .442	30	- .379
10	- .103	31	- .773	10	- .354	31	- .410
11	- .659	32	- .902	11	- .488	32	- .436
12	- .598	33	- .728	12	- .841	33	- .436
13	- .344	34	.634	13	- .011	34	- .598
14	- .264	35	- .729	14	- .308	35	.708
15	- .435	36	- .725	15	.135	36	.067
16	- .381	37	- .259	16	.221	37	.192
17	.005	38	- .538	17	- .242	38	.177
18	.366	39	- .428	18	.156	39	.370
19	.189	40	.684	19	.733	40	- .374
20	.002	41	- .281	20	.670	41	- .070
21	- .274	42	- .008	21	.623	42	.591

Table 4. Pressure Coefficients
Pressure Study

Run 107		$\beta = 0°$		Run 108		$\beta = 8°$	
Configuration Linear A		$\alpha = 30°$		Configuration Linear A		$\alpha = 30°$	
Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$
1	-.070	22	-.445	1	-.016	22	-.636
2	.011	23	-.493	2	.075	23	-.684
3	.036	24	-.346	3	.111	24	-.495
4	-.013	25	-.530	4	.066	25	-.813
5	-.134	26	.289	5	-.070	26	.334
6	-.047	27	-.538	6	-.006	27	-.902
7	.254	28	-.309	7	.206	28	-.492
8	.090	29	-.516	8	.141	29	-.738
9	.133	30	-.543	9	.182	30	-.857
10	.261	31	-.575	10	.258	31	-.657
11	.127	32	.025	11	.132	32	-.718
12	.000	33	-.628	12	.023	33	-.692
13	-.773	34	-.580	13	-.581	34	-.792
14	-.446	35	-.468	14	-.545	35	-.614
15	-.574	36	-.591	15	-.826	36	-.700
16	-.488	37	-.525	16	-.480	37	-.657
17	-.362	38	-.656	17	-.428	38	-.729
18	-.774	39	-.669	18	-.863	39	-.664
19	-.247	40	-.580	19	-.331	40	-.701
20	-.435	41	-.457	20	-.542	41	-.586
21	-.237	41	-.217	21	-.338	42	-.380

Table 4. Pressure Coefficients
Pressure Study

Run 108 A $\beta = -8°$

Configuration Linear A $\alpha = 30°$

Tap	$C_{p_{mean}}$	Tap	$C_{p_{mean}}$
1	- .097	22	- .442
2	- .053	23	- .441
3	- .029	24	- .257
4	- .080	25	- .595
5	- .193	26	.395
6	- .076	27	- .699
7	.179	28	- .505
8	.024	29	- .566
9	.076	30	- .612
10	.185	31	- .614
11	.148	32	- .020
12	- .022	33	- .506
13	-1.005	34	- .696
14	- .503	35	- .566
15	- .707	36	- .569
16	- .648	37	- .487
17	- .427	38	- .581
18	- .921	39	- .610
19	- .340	40	- .343
20	- .504	41	- .364
21	- .293	42	- .204