WIND-TUNNEL STUDY OF MARWEST OFFICE BUILDING, PHOENIX

by

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LIST OF SYMBOLS

Symbol	Definition
U	Local mean velocity
D	Characteristic dimension (building height, width, etc.)
ν, ρ	Kinematic viscosity and density of approach flow
$\frac{UD}{\nu}$	Reynolds number
E	Mean voltage
A, B, n	Constants
U_{rms}	Root-mean-square of fluctuating velocity
E_{rms}	Root-mean-square of fluctuating voltage
U_∞	Reference mean velocity outside the boundary layer
Z	Height above surface
δ	Height of boundary layer
T_u	Turbulence intensity $\frac{U_{rms}}{U_\infty}$ or $\frac{U_{rms}}{U}$
$(\ )_{min}$	Minimum value during data record
$(\ )_{max}$	Maximum value during data record

1. INTRODUCTION

1.1 General

A significant characteristic of modern building design is lighter cladding and more flexible frames. These features produce an increased vulnerability of glass and cladding to wind damage and result in larger deflections of the building frame. In addition, increased use of pedestrian plazas at the base of the buildings has brought about a need to consider the effects of wind and gustiness in the design of these areas.

The building geometry itself may increase or decrease wind loading on the structure. Wind forces may be modified by nearby structures which can produce beneficial shielding or adverse increases in loading. Overestimating loads results in uneconomical design; underestimating may result in cladding or window failures. Tall structures have historically produced unpleasant wind and turbulence conditions at their bases. The intensity and frequency of objectionable winds in pedestrian areas is influenced both by the structure shape and by the shape and position of adjacent structures.

Techniques have been developed for wind tunnel modeling of proposed structures which allow the prediction of wind pressures on cladding and windows, overall structural loading, and also wind velocities and gusts in pedestrian areas adjacent to the building. Information on sidewalk-level gustiness allows plaza areas to be protected by design changes before the structure is constructed. Accurate knowledge of the intensity and distribution of the pressures on the structure permits adequate but economical selection of cladding strength to meet selected maximum design winds and overall wind loads for the design of the frame for flexural control.

Modeling of the aerodynamic loading on a structure requires special consideration of flow conditions in order to guarantee similitude between model and prototype. A detailed discussion of the similarity requirements and their wind-tunnel implementation can be found in references (1), (2), and (3). In general, the requirements are that the model and prototype be geometrically similar, that the approach mean velocity at the building site have a vertical profile shape similar to the full-scale flow, that the turbulence characteristics of the flows be similar, and that the Reynolds number for the model and prototype be equal.

These criteria are satisfied by constructing a scale model of the structure and its surroundings and performing the wind tests in a wind tunnel specifically designed to model atmospheric boundary-layer flows. Reynolds number similarity requires that the quantity UD/ν be similar for model and prototype. Since ν , the kenematic viscosity of air, is identical for both, Reynolds numbers cannot be made precisely equal with reasonable wind velocities. To accomplish this the air velocity in the wind tunnel would have to be as large as the model scale factor times the prototype wind velocity, a velocity which would introduce unacceptable compressibility effects. However, for sufficiently high Reynolds numbers ($>2x10^4$) the pressure coefficient at any location on the structure will be essentially constant for a large range of Reynolds numbers. Typical values encountered are 10^7-10^8 for the full-scale and 10^5-10^6 for the wind-tunnel model. In this range acceptable flow similarity is achieved without precise Reynolds number equality.

1.2 The Wind-Tunnel Test

The wind-engineering study is performed on a building or building group modeled at scales ranging from 1:150 to 1:400. The building model is constructed of clear plastic fastened together with screws. The structure is modeled in detail to provide accurate flow patterns in the wind passing over the building surfaces. The building under test is often located in a surrounding where nearby buildings or terrain may provide beneficial shielding or adverse wind loading. To achieve similarity in wind effects the area surrounding the test building is also modeled. A flow visualization study is first made (smoke is used to make the air currents visible) to define overall flow patterns and identify regions where local flow features might cause difficulties in building curtain-wall design or produce pedestrian discomfort.

Based on the visualization (smoke) tests and on a knowledge of heavy pedestrian use areas, a dozen or more locations may be chosen at the base of the building where wind velocities can be measured to determine the relative comfort or discomfort of pedestrians in plaza areas, near building entrances, near building corners, or on sidewalks. Usually a reference pedestrian position is also tested to determine whether the wind environment in the building area is better or worse than the environment a block or so away in an undisturbed area.

The following pages discuss in greater detail the procedures followed and the equipment and data collecting and processing methods used. In addition, the data presentation format is explained and the implications of the data are discussed.

2. EXPERIMENTAL CONFIGURATION

2.1 Wind Tunnel

Wind-engineering studies are performed in the Fluid Dynamics and Diffusion Laboratory at Colorado State University (Figure 1). Three large wind tunnels are available for wind loading studies depending on the detailed requirements of the study. The wind tunnel used for this investigation is shown in Figure 2. All tunnels have a flexible roof adjustable in height to maintain a zero pressure gradient along the test section. The mean velocity can be adjusted continuously in each tunnel to the maximum velocity available.

2.2 Model

In order to obtain an accurate assessment of local pressures using piezometer taps, models are constructed to the largest scale that does not produce significant blockage in the wind-tunnel test section. The models are constructed of 1/2 in. thick Lucite plastic and fastened together with metal screws. Significant variations in the building surface, such as mullions, are modeled. In some cases pedestrian velocity studies are performed using a model supplied by the project sponsor.

A circular area 750 to 2000 ft in radius depending on model scale and characteristics of the surrounding buildings and terrain is modeled in detail. Structures within the modeled region are made from styrofoam and cut to the individual building geometries. They are mounted on the turntable in their proper locations. Significant terrain features are included as needed. The model is mounted on a turntable (Figure 2) near the downwind end of the test section. Any buildings or terrain features which do not fit on the turntable are placed on removable pieces which are placed upwind of the turntable for appropriate wind directions. A plan view of the building and its surroundings is shown in Figure 4. The turntable is calibrated to indicate azimuthal orientation to 0.1 degree.

The region upstream from the modeled area is covered with a randomized roughness constructed using various sized cubes placed on the floor of the wind tunnel. Different roughness sizes may be used for different wind directions. Spires are installed at the test-section entrance to provide a thicker boundary layer than would otherwise be available. The thicker boundary layer permits a somewhat larger scale model than would otherwise be possible. The spires are approximately triangularly shaped pieces of 1/2 in. thick plywood 6 in. wide at the base and 1 in. wide at the top, extending from the floor to the top of the test section. They are placed so that the broad side intercepts the flow. A barrier approximately 8 in. high is placed on the test-section floor downstream of the spires to aid in development of the boundary-layer flow.

The distribution of the roughness cubes and the spires in the roughened area was designed to provide a boundary-layer thickness of approximately 4 ft, a velocity profile power-law exponent similar to that expected to occur in the region approaching the modeled area for each wind direction (a number of wind directions may have the same approach roughness). Photographs of the model in the wind-tunnel are shown in Figure 4. The wind-tunnel ceiling is adjusted after placement of the model to obtain a zero pressure gradient along the test section.

3. INSTRUMENTATION AND DATA ACQUISITION

3.1 Flow Visualization

Making the air flow visible in the vicinity of the model is helpful (a) in understanding and interpreting mean and fluctuating pressures, (b) in defining zones of separated flow and reattachment and zones of vortex formation where pressure coefficients may be expected to be high and (c) in indicating areas where pedestrian discomfort may be a problem. Titanium tetrachloride smoke is released from sources on and near the model to make the flow lines visible to the eye and to make it possible to obtain motion picture records of the tests. Conclusions obtained from these smoke studies are discussed in Sections 4.1 and 5.1.

3.2 Velocity

Mean velocity and turbulence intensity profiles are measured upstream of the model to determine that an approach boundary-layer flow appropriate to the site has been established. Tests are made at one wind velocity in the tunnel. This velocity is well above that required to produce Reynolds number similarity between the model and the prototype as discussed in Section 1.1.

In addition, mean velocity and turbulence intensity measurements are made 5 to 7 ft (prototype) above the surface at a dozen or more locations on and near the building for 16 wind directions. The measurement locations are shown on Figure 3. The surface measurements are indicative of the wind environment to which a pedestrian at the measurement location would be subjected. The locations are chosen to determine the degree of pedestrian comfort or discomfort at the building corners where relatively severe conditions frequently are found, near building entrances and on adjacent sidewalks where pedestrian traffic is heavy, and in open plaza areas. In most studies a reference pedestrian position, located about a block away, is also tested. These data are helpful in evaluating the degree of pedestrian comfort or discomfort in the proposed plaza area in terms of the undisturbed environment in the immediate vicinity.

Measurements are made with a single hot-wire anemometer mounted with its axis vertical. The instrumentation used is a Thermo Systems constant temperature anemometer (Model 1050) with a 0.001 in. diameter platinum film sensing element 0.020 in. long. Output is directed to the on-line data acquisition system for analysis.

Calibration of the hot-wire anemometer is performed by comparing output with the pitot-static tube in the wind tunnel. The calibration data are fit to a variable exponent King's Law relationship of the form

$$E^2 = A + BU^n$$

where E is the hot-wire output voltage, U the velocity and A, B, and n are coefficients selected to fit the data. The above relationship was used to determine the mean velocity at measurement points using the measured mean voltage. The fluctuating velocity in the form U_{rms} (root-mean-square velocity) was obtained from

$$U_{rms} = \frac{2\ E\ E_{rms}}{B\ n\ U^{n-1}}$$

where E_{rms} is the root-mean-square voltage output from the anemometer. For interpretation all turbulence measurements for pedestrian winds were divided by the mean velocity outside the boundary-layer U_∞. Turbulence intensity in velocity profile measurements used the local mean velocity.

4. RESULTS

4.1 Flow Visualization

A film is included as part of this report showing the characteristics of flow about the structure using smoke to make the flow visible. A listing of the contents of the film is shown in Table 1. Several features can be noted from the visualization. As with all large structures, wind approaching the building is deflected down to the plaza level, up over the structure and around the sides. A description of the smoke test results emphasizing flow patterns of concern relative to possible high-wind load areas and pedestrian comfort is given in Section 5.1.

4.2 Velocity

Velocity and turbulence profiles are shown in Figure 5. Profiles were taken upstream from the model which are characteristic of the boundary layer approaching the model and sometimes at the building site with building removed. The boundary-layer thickness, δ, is shown in Figure 5. The corresponding prototype value of δ for this study is also shown in the figure. This value was established as a reasonable height for this study. The mean velocity profile approaching the modeled area has the form

$$\frac{U}{U_\infty} = \left(\frac{z}{\delta}\right)^n .$$

The exponent n for the approach flow established for this study is shown in Figure 5.

Profiles of longitudinal turbulence intensity in the flow approaching the modeled area are shown in Figure 5. The turbulence intensities are approprite for the approach mean velocity profile selected. For the velocity profiles, turbulence intensity is defined as the root-mean-square about the mean of the longitudinal velocity fluctuations divided by the local mean velocity U,

$$Tu = \frac{U_{rms}}{U} .$$

Velocity data obtained at each of the pedestrian measurement locations shown in Figure 3 are listed in Table 2 as mean velocity U/U_∞, turbulence intensity U_{rms}/U_∞, and largest effective gust

$$U_{pk} = \frac{U + 3U_{rms}}{U_\infty} .$$

These data are plotted in polar form in Figure 6. Measurements were taken 5 to 7 ft above the ground surface. A site map is superimposed on the polar plots to aid in visualization of the effects of the nearby structures on the velocity and turbulence magnitudes. An analysis of these wind data is given in Section 5.2.

To enable a quantitative assessment of the wind environment, the wind-tunnel data were combined with wind frequency and direction information obtained at the local airport. Table 3 shows wind frequency by direction and magnitude obtained from summaries published by the National Weather Service. These data, usually obtained at an elevation of about 30-40 ft, were converted to velocities at the reference velocity height for the wind-tunnel measurements and combined with the wind-tunnel data to obtain cumulative probability distributions (percent time a given velocity is exceeded) for wind velocity at each measuring location. The percentage times were summed by wind direction to obtain a percent time exceeded at each measuring position independent of wind direction (but accounting for the fact that the wind blows from different directions with varying frequency). These results are plotted in Figure 7.

Interpretation of Figure 7 is aided by a description of the effects of wind of various magnitudes on people. The earliest quantitative description of wind effects was established by Sir Francis Beaufort in 1806 for use at sea and is still in use today. Several recent investigators have added to the knowledge of wind effects of pedestrians. These investigations along with suggested criteria for acceptance have been summarized by Penwarden and Wise (4) and Melbourne (5). The Beaufort scale (from ref. 4), based on mean velocity only, is reproduced as Table 4 including qualitative descriptions of wind effects. Table 4 suggests that mean wind speeds below 12 mph are of minor concern and that mean speeds above 24 mph are definitely inconvenient. Quantitative criteria for acceptance from reference 5 are superimposed as dashed lines on Figure 7. The peak gust curves shown in Figure 7 are the percent of time during which a short gust of the stated magnitude could occur (say about one of these gusts per hour). Implications of the data plotted in Figure 7 are presented in Section 5.2.

Because some pedestrian wind measuring positions are purposely chosen at sites where the smoke tests showed large velocities of small spacial extent, the general wind environment about the structure may be less severe than one might infer from a strict analysis of Table 2 and Figure 7.

5. DISCUSSION

5.1 Flow Visualization

Flow patterns identified with smoke showed that the highest pedestrian winds would occur near the front corners of the structure. Velocity magnitudes in these locations did not appear to be exceptionally strong. Wind speeds in the plaza area between the two towers were quite low. The low connector between the towers appeared to be active in protecting the plaza area from higher wind speeds. Wind speeds on the top deck of the parking garage appeared stronger than in undisturbed winds away from the building, but not as large as at the building front corners.

Wind patterns over the structure itself did not indicate any areas where local cladding loads would be expected to be larger than normal due to positioning or shape of the towers.

5.2 Pedestrian Winds

Figure 3 shows the 8 locations selected for investigation of pedestrian wind comfort. Location 1 was atop the parking structure; locations 2, 3, 7 and 8 were on the walk along Central Avenue; and locations 4, 5 and 6 were in the plaza. Table 2 and Figure 6 show that the largest values of mean velocity were measured at locations 2 and 8 with values of 50 to 65 percent of the velocity U_∞ at the boundary-layer height measured for 5 wind directions at location 2 and 3 wind directions at location 8. Location 7 also showed a high value at 135° azimuth. The values are not overly large compared to an expected value of about 45 percent in an open-country environment.

The largest values of fluctuating velocity, U_{rms}, were between 17 and 20 percent of U_∞ measured for 2 wind directions each at locations

1 and 7. Comparatively, a maximum value of 10 to 12 percent is typical of an open-country environment. The largest values of peak gust, represented by the mean plus 3 rms as discussed in Section 4.2, were obtained at locations 1 and 7 with values of 102 and 107 percent of U_∞. These values are not large compared to the 80 to 90 percent expected in an open-country environment.

Velocity data of Table 2 integrated with local wind data of Table 3 are shown in Figure 7. Based on the data of this figure, the windiest locations will be locations 2 and 8 where comfort criteria for walking will be exceeded 10 to 30 percent of the time for mean winds. Locations not on the walk along Central Avenue did not exceed the comfort criteria for long exposure for a significant percentage of time.

The pedestrian wind analysis showed that all measured areas had acceptable wind environments and would not likely be considered as uncomfortable due to winds. It is anticipated that no corrective action be required.

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FIGURES

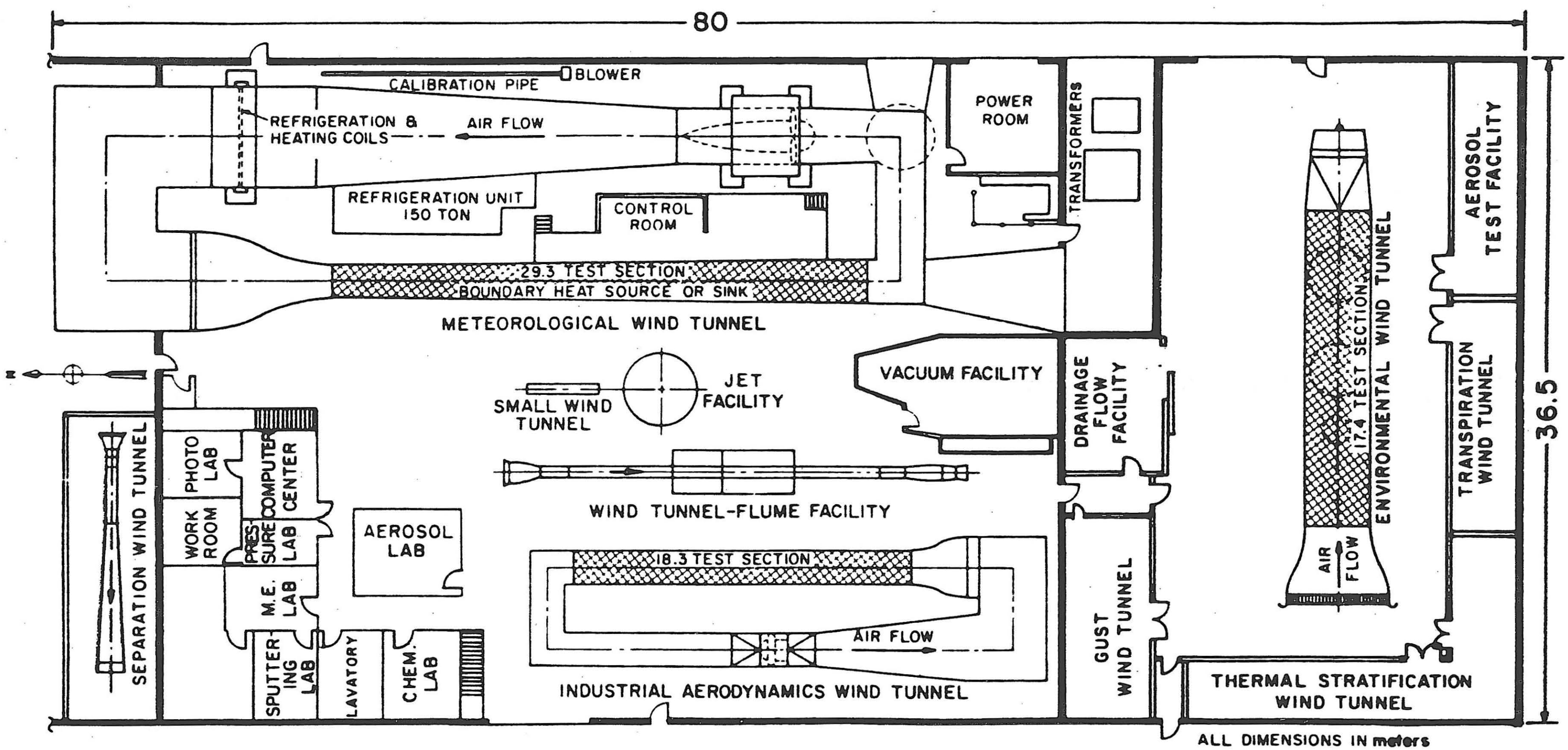
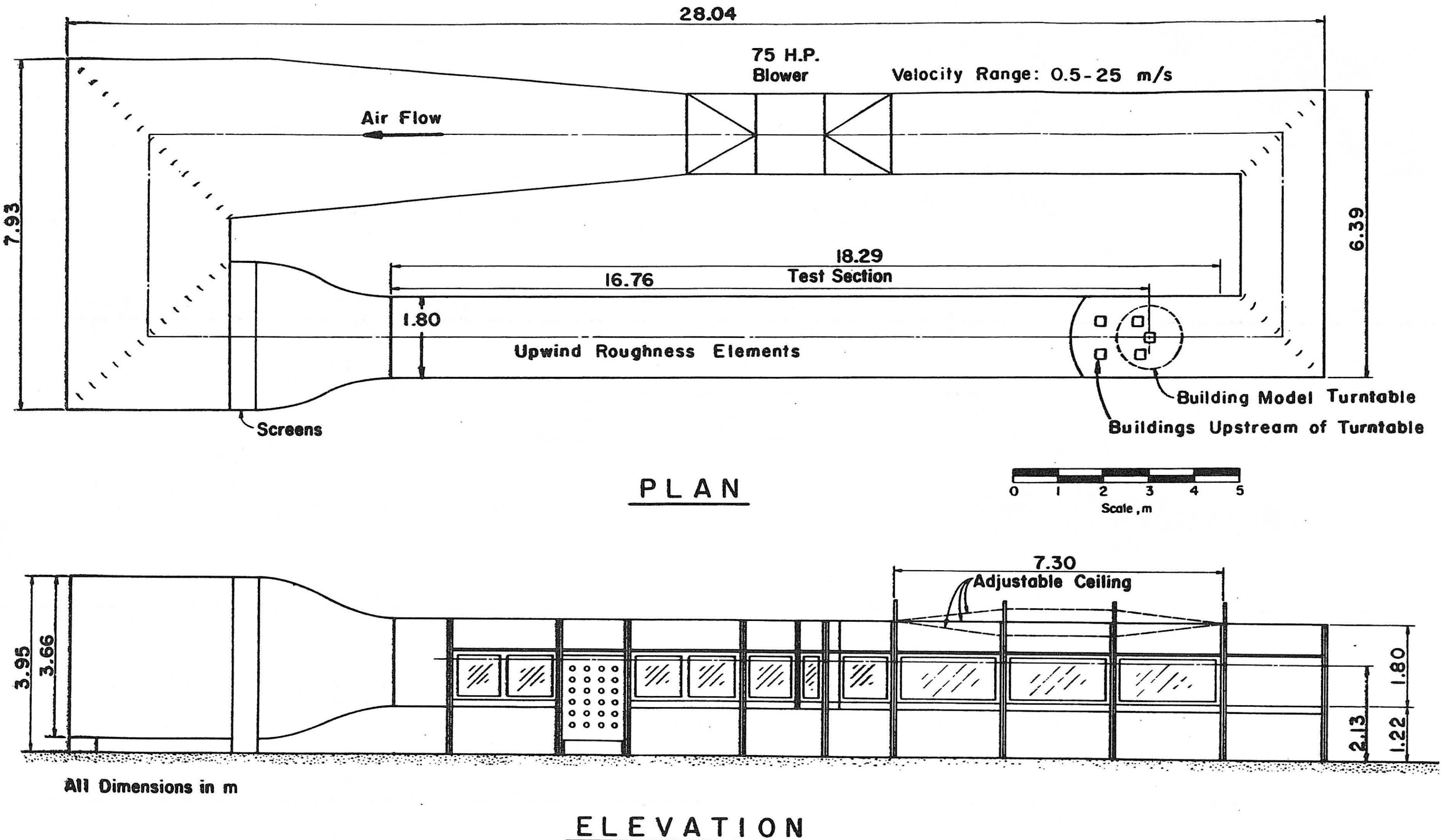


Figure 1. FLUID DYNAMICS AND DIFFUSION LABORATORY
COLORADO STATE UNIVERSITY



INDUSTRIAL AERODYNAMICS WIND TUNNEL

Figure 2. Wind-Tunnel Configuration

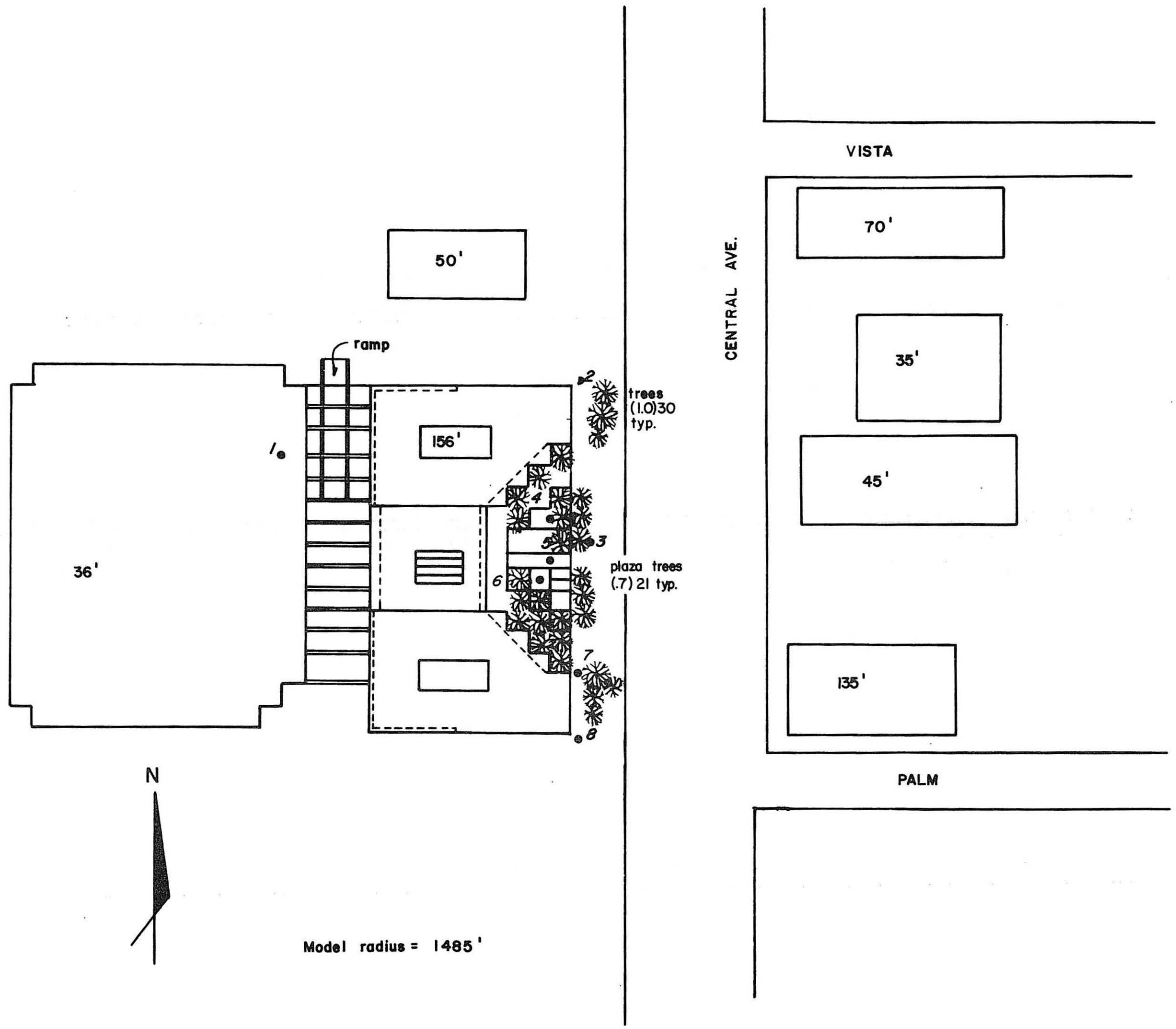


Figure 3. Pressure Tap Locations

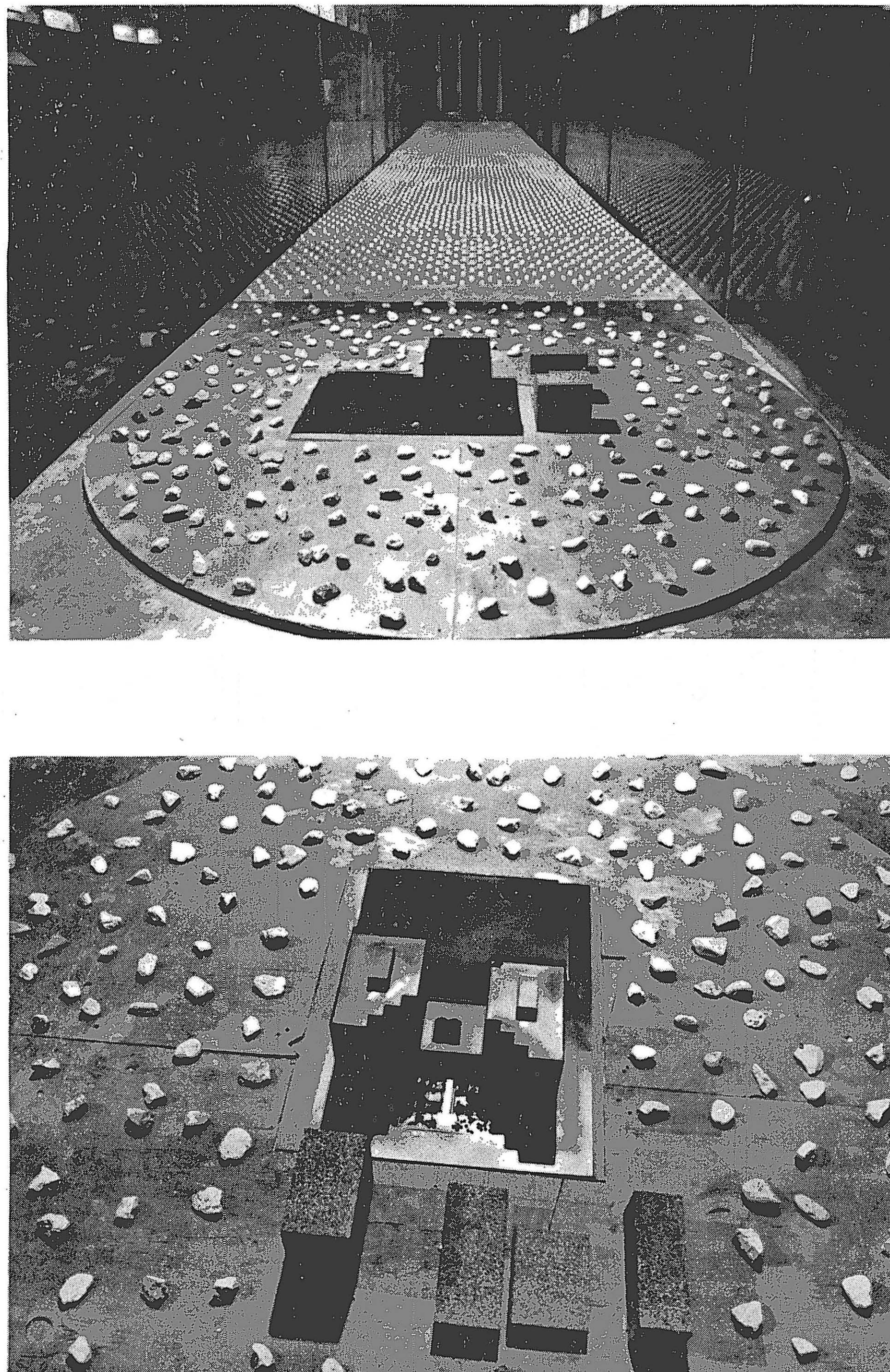
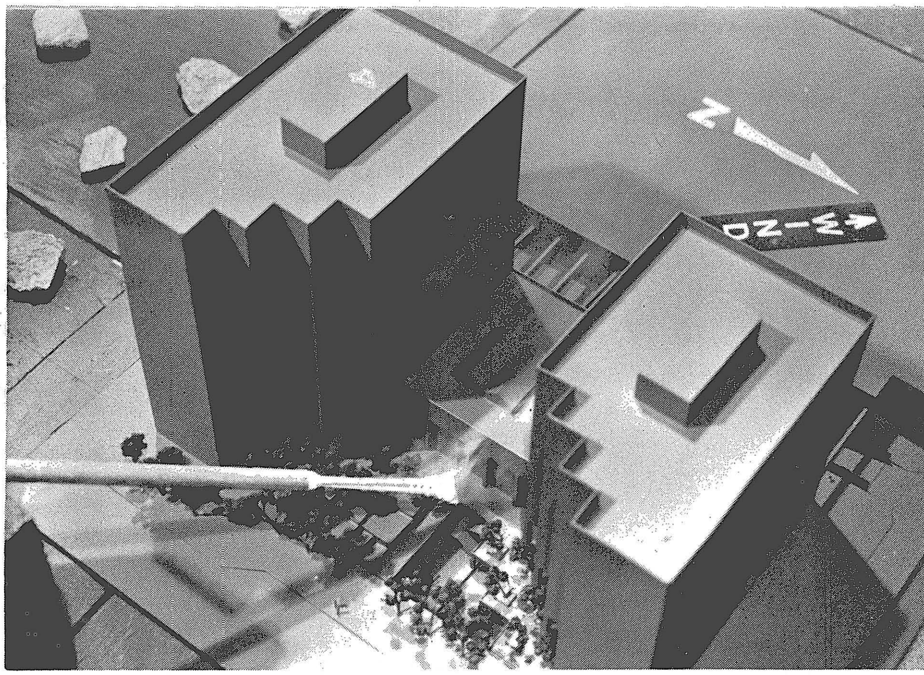


Figure 4. Completed Model in Wind Tunnel



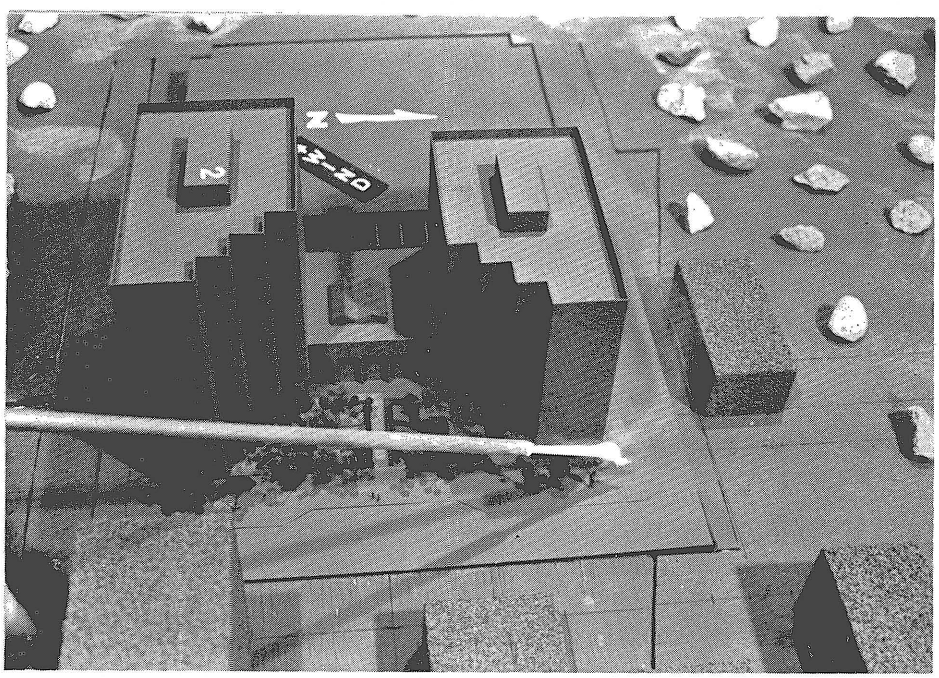


Figure 4. Completed Model in Wind Tunnel

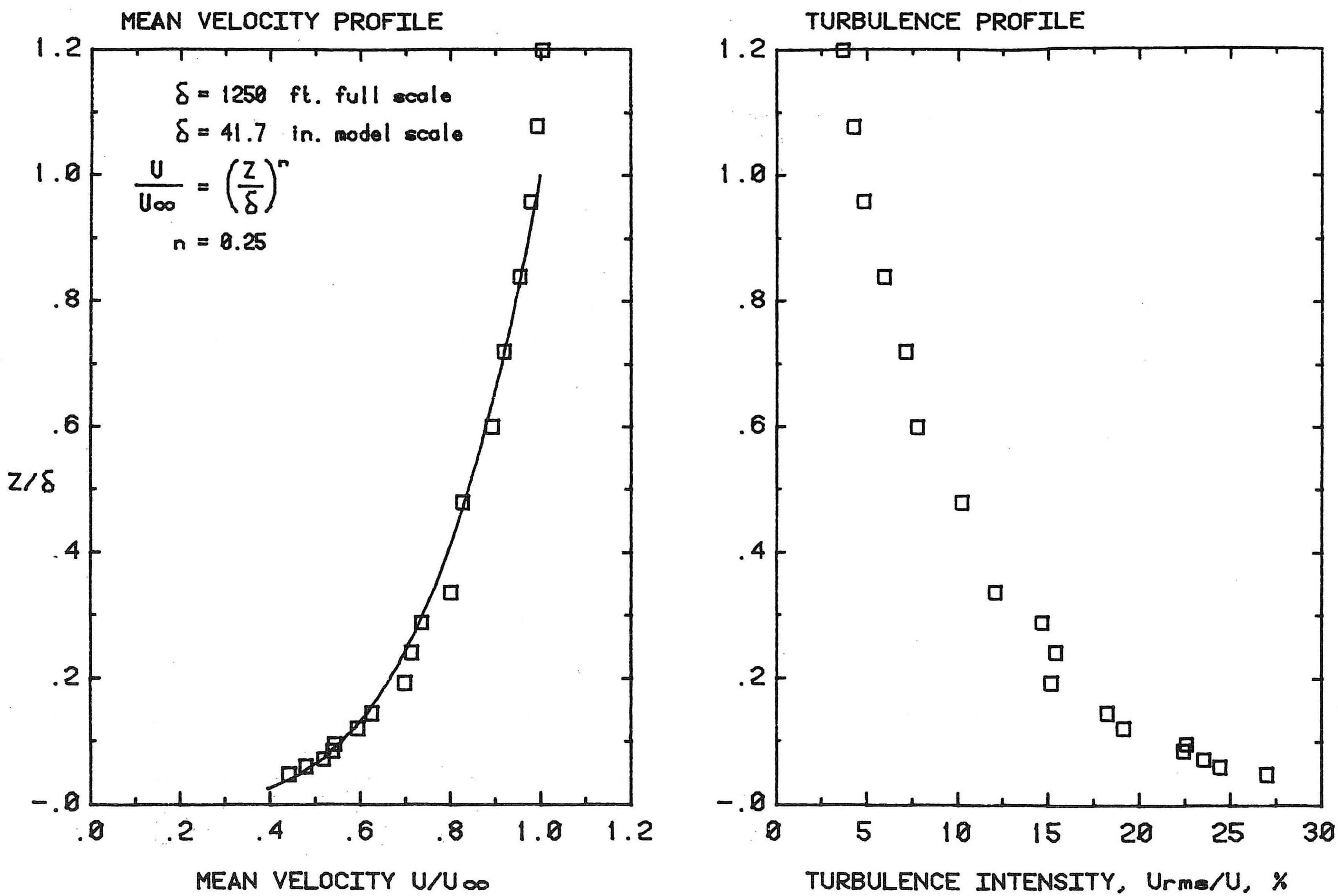


Figure 5. Mean Velocity and Turbulence Profiles Approaching the Model

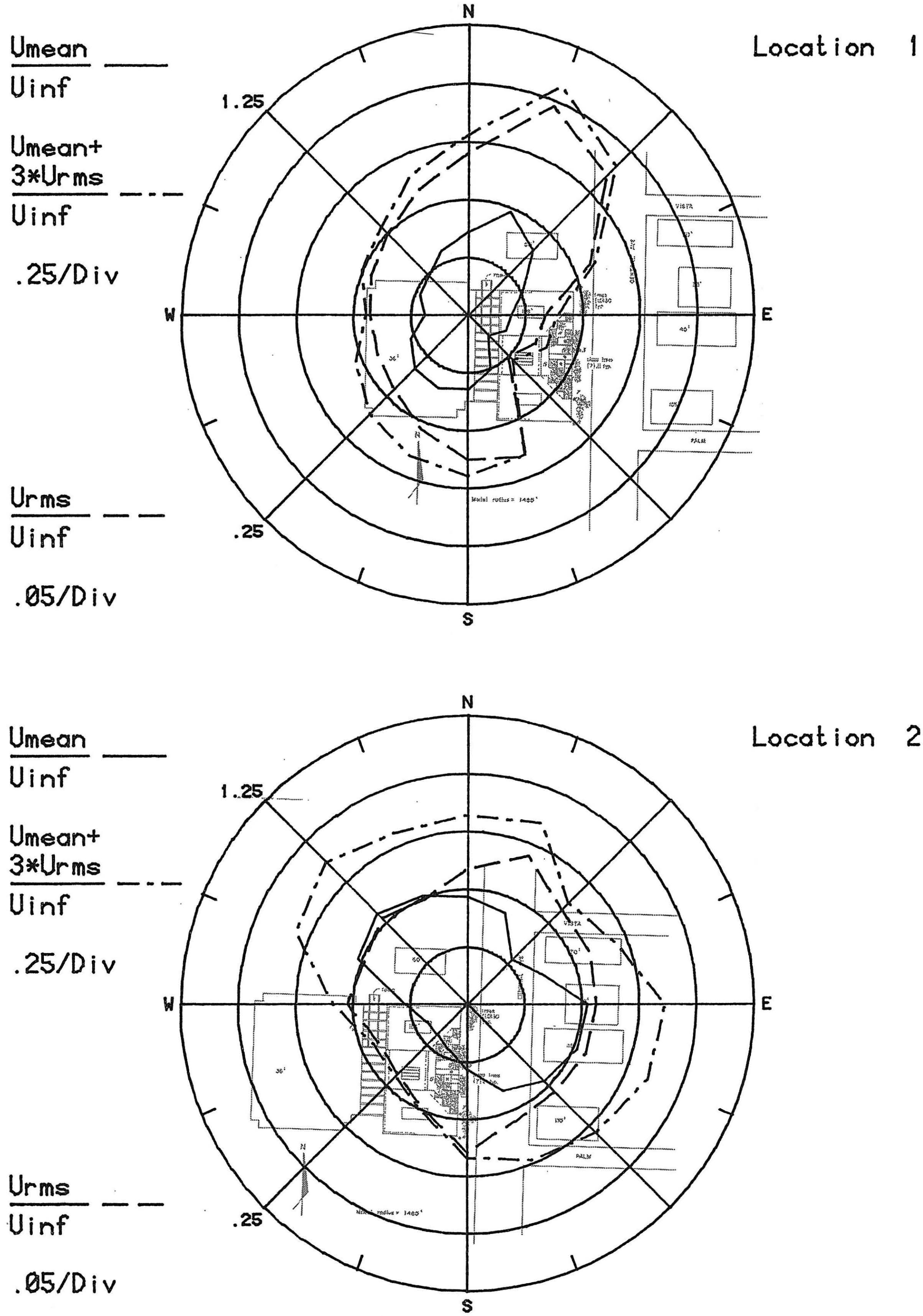
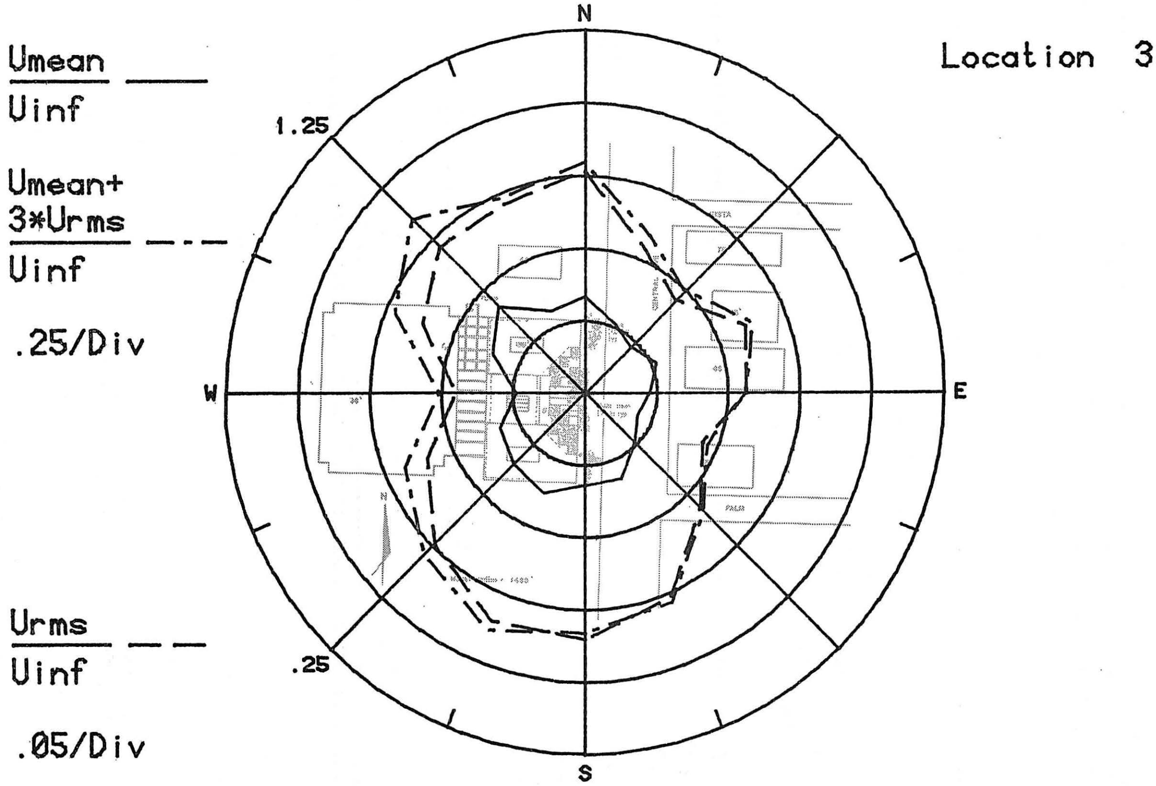


Figure 6a. Mean Velocities and Turbulence Intensities at Pedestrian Locations 1 and 2



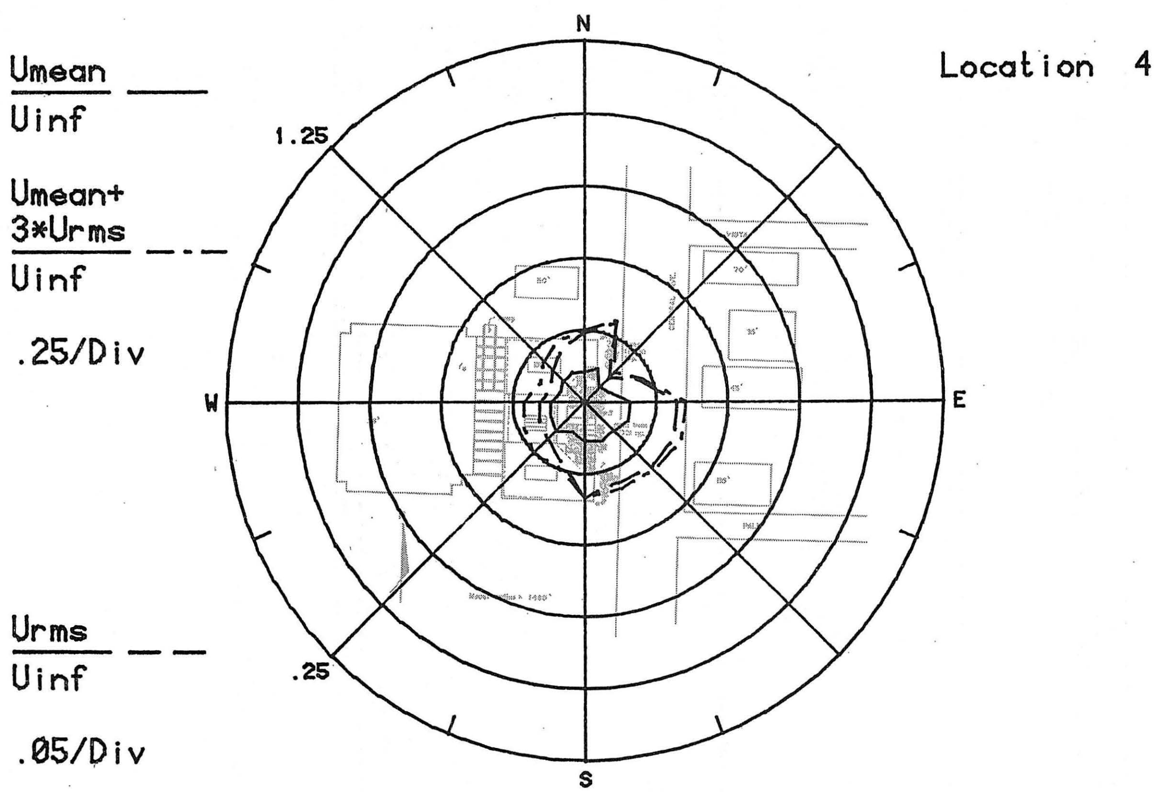
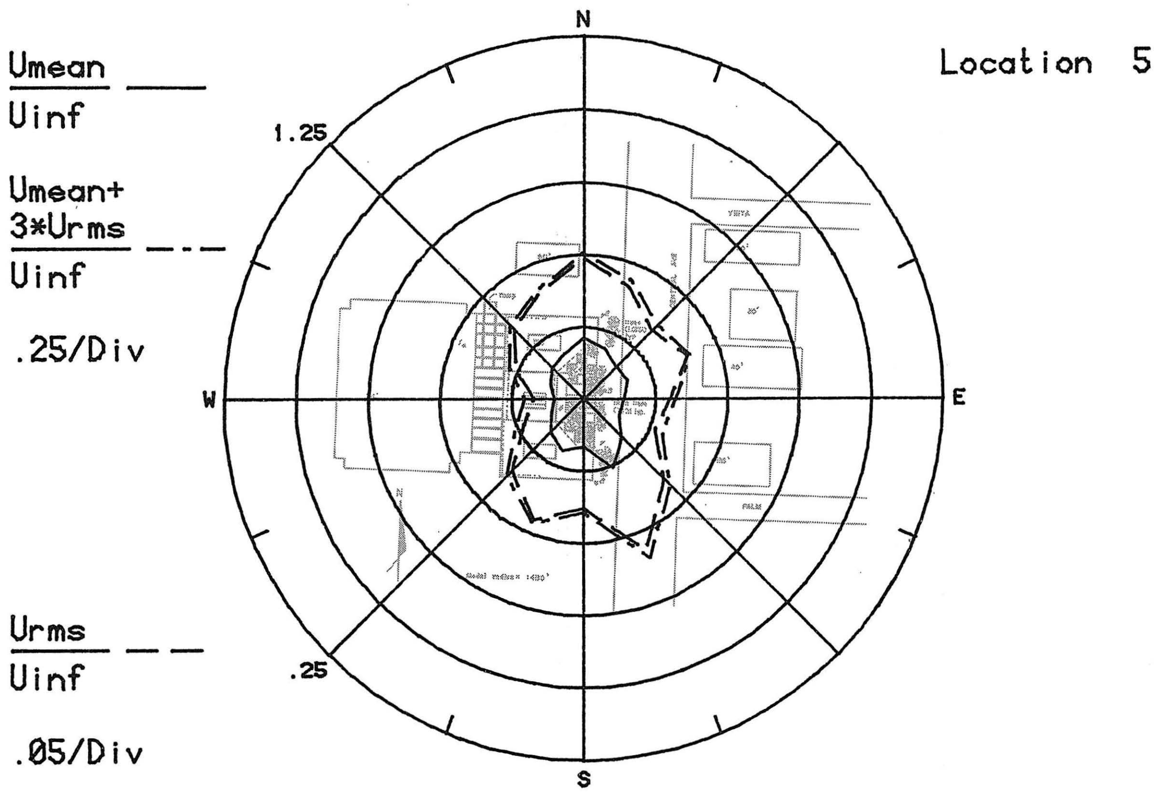


Figure 6b. Mean Velocities and Turbulence Intensities at Pedestrian Locations 3 and 4



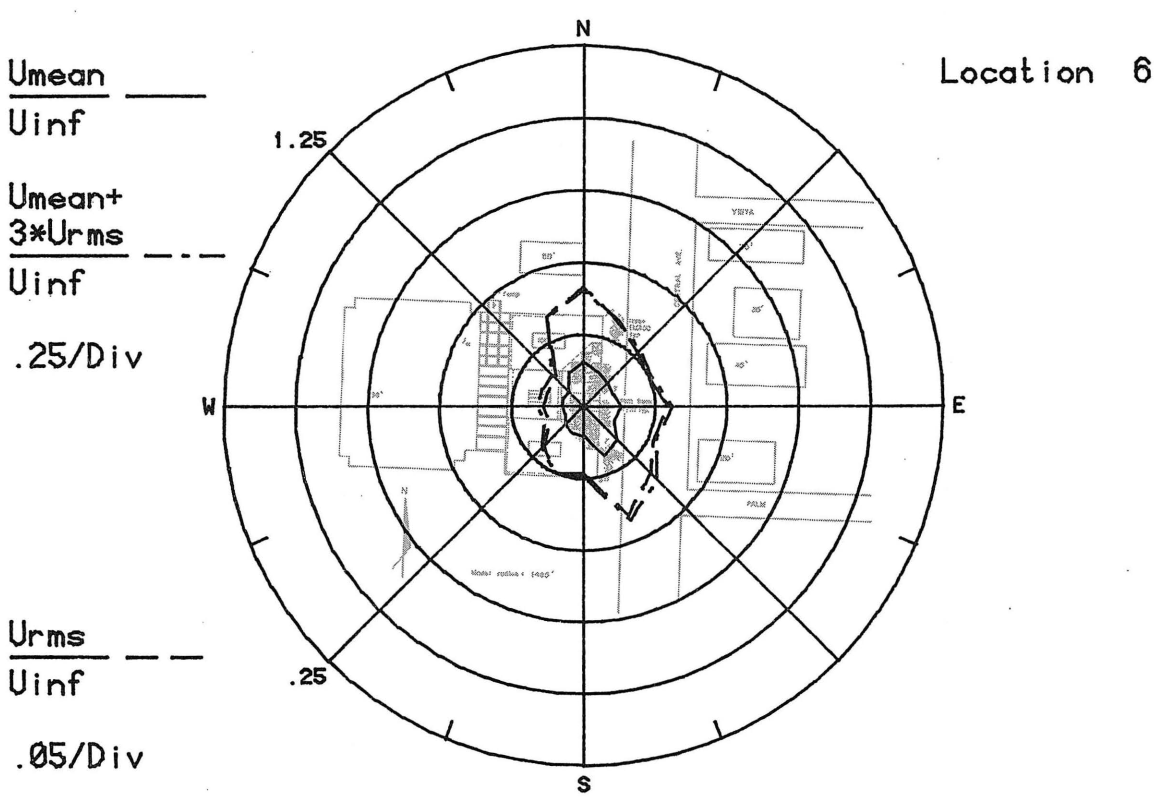


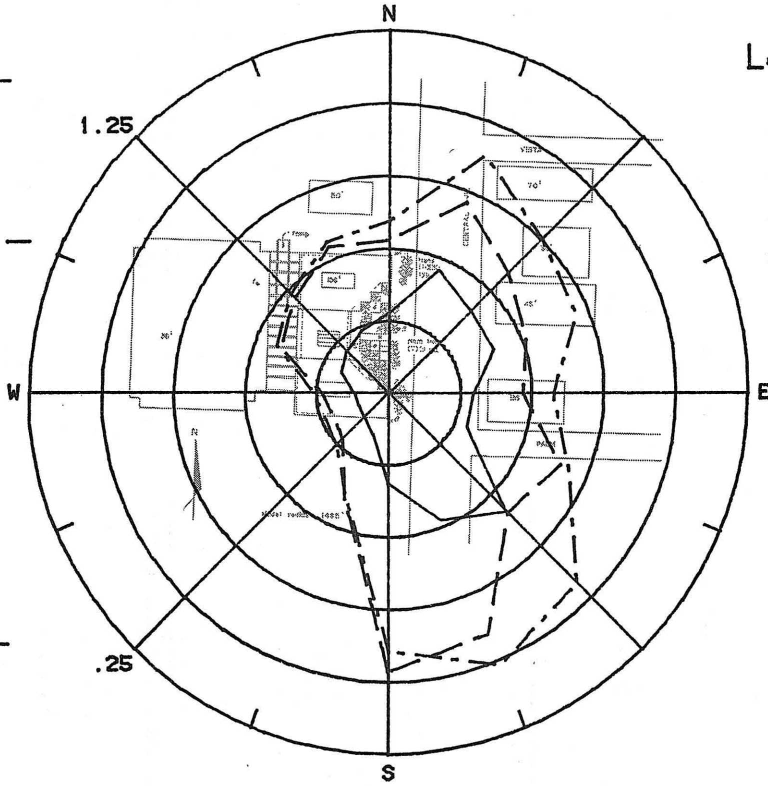
Figure 6c. Mean Velocities and Turbulence Intensities at Pedestrian Locations 5 and 6

Location 7

Umean
Uinf

Umean+
3*Urms
Uinf

.25/Div



Urms
Uinf

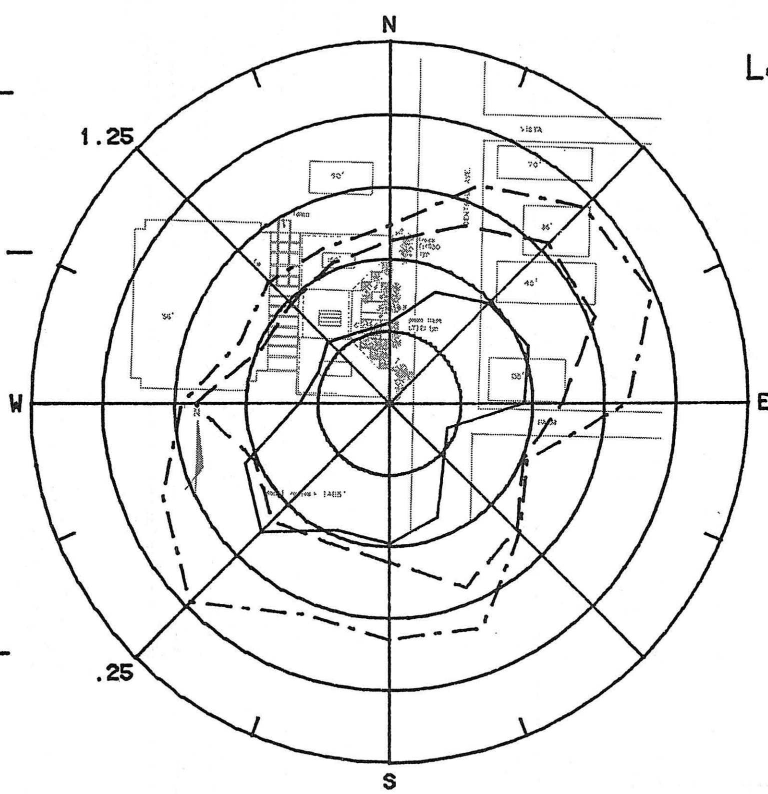
.05/Div

Location 8

Umean
Uinf

Umean+
3*Urms
Uinf

.25/Div



Urms
Uinf

.05/Div

Figure 6d. Mean Velocities and Turbulence Intensities at Pedestrian Locations 7 and 8

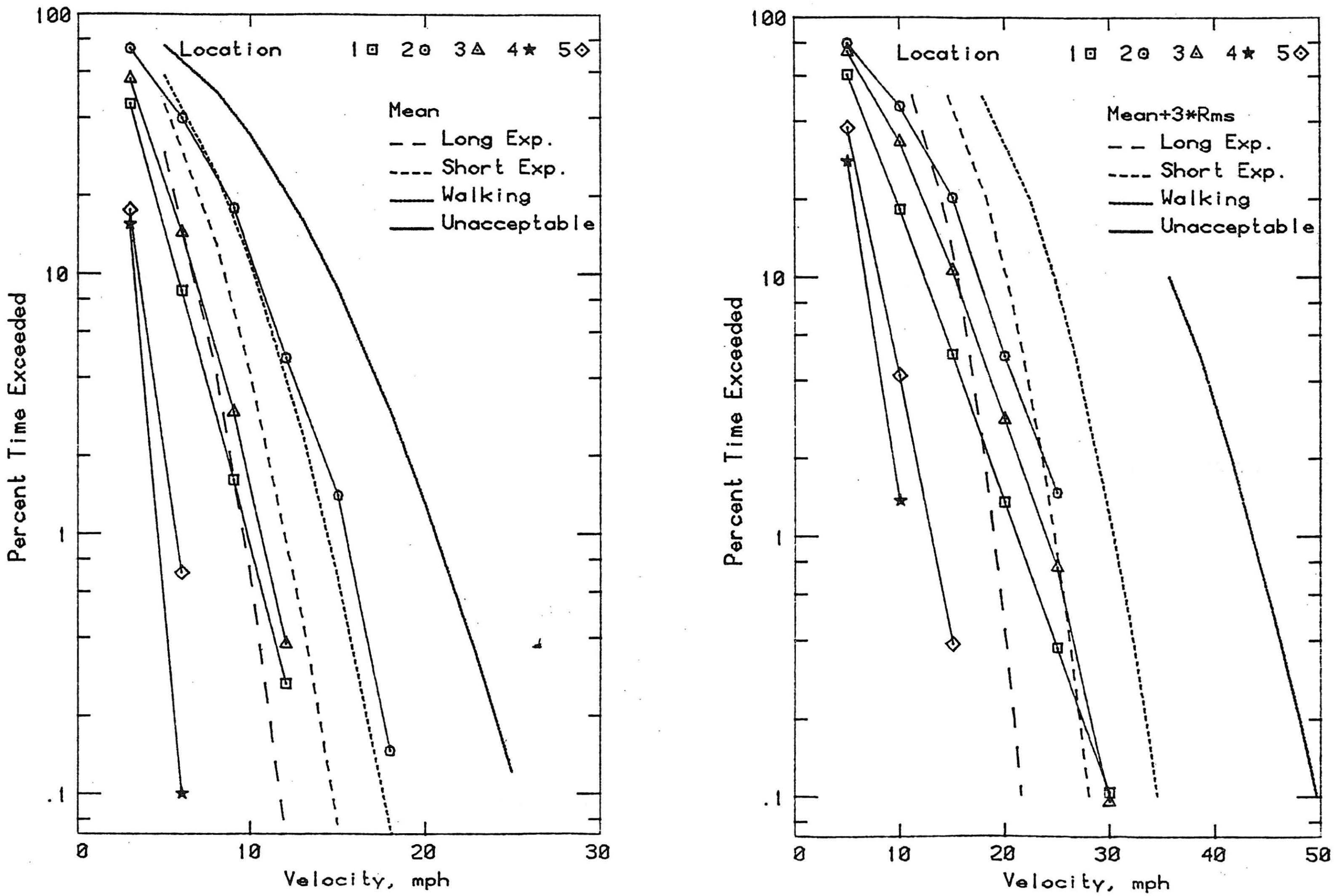


Figure 7a. Wind Velocity Probabilities for Pedestrian Locations

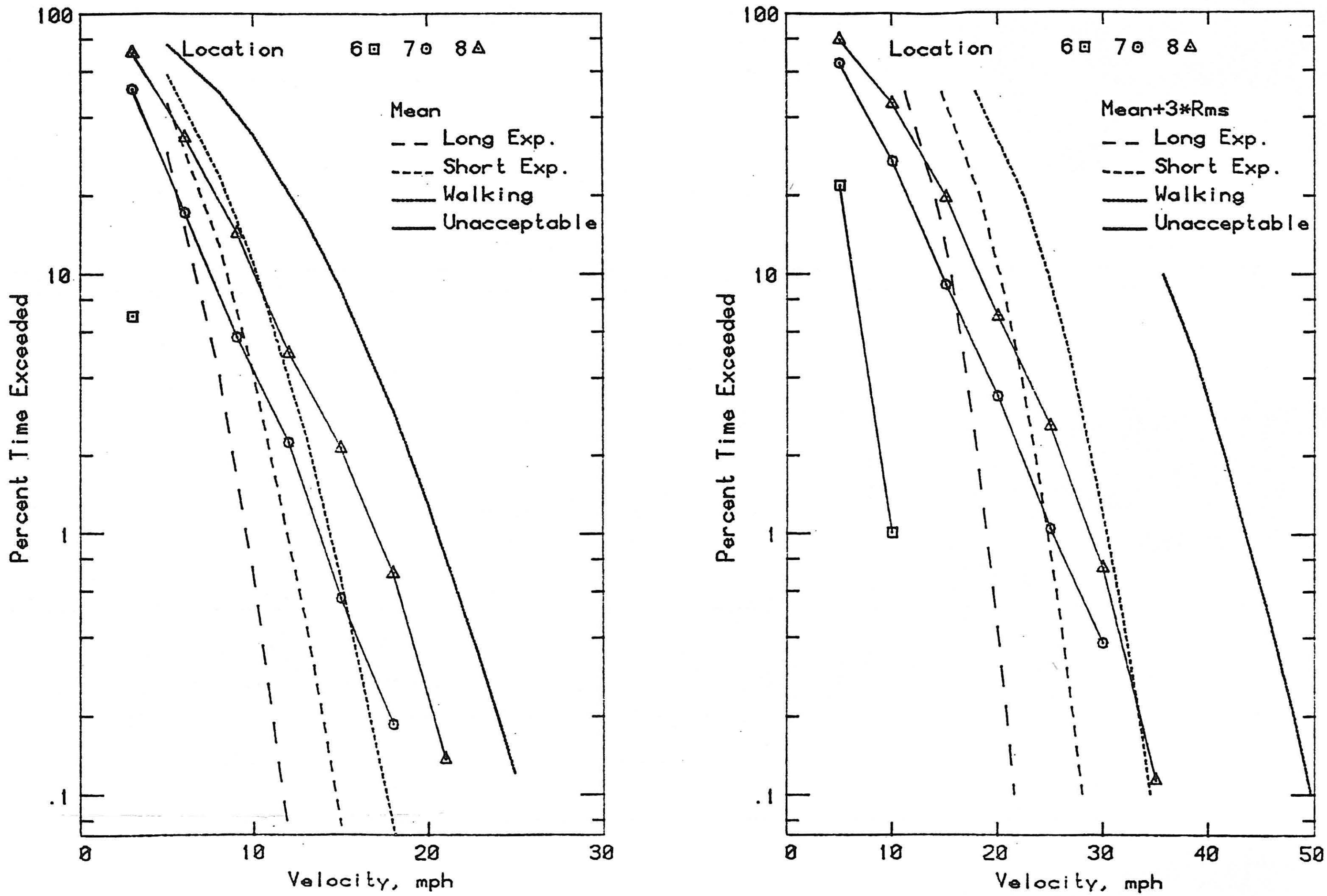


Figure 7b. Wind Velocity Probabilities for Pedestrian Locations

TABLES

TABLE 1

FLOW VISUALIZATION GUIDE

PHOENIX-MARWEST OFFICE BUILDING

Run	Azimuth, °
1	00
2	45
3	90
4	135
5	180
6	225
7	270
8	315

TABLE 2--PEDESTRIAN WIND VELOCITIES AND TURBULENCE INTENSITIES

PHOENIX/MARWEST OFFICE BUILDING

LOCATION 1

WIND AZIMUTH	UMEAN/UINF (PERCENT)	URMS/UINF (PERCENT)	UMEAN+3*URMS/UINF (PERCENT)
0.00	35.8	14.0	77.7
22.50	48.3	19.5	106.9
45.00	39.9	17.1	91.2
67.50	25.4	11.4	59.7
90.00	18.6	6.7	38.8
112.50	17.7	6.4	36.7
135.00	12.4	5.0	27.5
157.50	25.4	13.3	65.4
180.00	32.1	12.5	69.6
202.50	33.9	10.7	65.9
225.00	33.0	9.1	60.4
247.50	27.2	8.6	53.0
270.00	18.8	8.5	44.4
292.50	22.9	9.1	50.3
315.00	24.1	9.9	53.9
337.50	30.5	11.7	65.4

LOCATION 2

WIND AZIMUTH	UMEAN/UINF (PERCENT)	URMS/UINF (PERCENT)	UMEAN+3*URMS/UINF (PERCENT)
0.00	46.7	11.7	81.9
22.50	43.0	13.9	84.8
45.00	27.5	11.6	62.4
67.50	35.0	11.7	70.0
90.00	52.5	11.3	86.3
112.50	51.4	11.1	84.8
135.00	47.0	10.7	79.2
157.50	40.5	11.0	73.4
180.00	28.2	12.9	66.8
202.50	21.3	9.9	51.0
225.00	18.6	8.6	44.4
247.50	19.3	8.4	44.7
270.00	27.1	10.5	58.6
292.50	51.9	9.7	81.0
315.00	55.6	10.5	87.2
337.50	51.1	9.8	80.6

LOCATION 3

WIND AZIMUTH	UMEAN/UINF (PERCENT)	URMS/UINF (PERCENT)	UMEAN+3*URMS/UINF (PERCENT)
0.00	33.4	15.3	79.4
22.50	26.3	10.8	58.8
45.00	22.6	9.0	49.7
67.50	26.9	12.1	63.2
90.00	22.1	11.3	55.9
112.50	19.4	8.9	46.1
135.00	24.1	11.3	58.0
157.50	32.1	15.4	78.2
180.00	31.8	17.0	82.9
202.50	37.4	17.0	88.6
225.00	34.8	14.8	79.2
247.50	32.1	11.9	67.8
270.00	23.8	9.0	50.8
292.50	34.7	12.3	71.5
315.00	42.1	14.3	84.9
337.50	30.5	14.2	73.0

LOCATION 4

WIND AZIMUTH	UMEAN/UINF (PERCENT)	URMS/UINF (PERCENT)	UMEAN+3*URMS/UINF (PERCENT)
0.00	10.5	4.8	24.8
22.50	12.6	5.9	30.2
45.00	7.3	2.4	14.5
67.50	9.0	4.0	21.1
90.00	15.9	6.5	35.4
112.50	16.4	6.7	36.5
135.00	14.1	6.5	33.6
157.50	14.5	6.1	32.8
180.00	13.4	6.7	33.4
202.50	11.1	4.4	24.4
225.00	14.1	3.7	25.1
247.50	12.8	3.4	23.0
270.00	11.8	3.1	21.1
292.50	9.2	2.5	16.6
315.00	10.5	3.1	19.9
337.50	11.0	4.0	23.0

TABLE 2--PEDESTRIAN WIND VELOCITIES AND TURBULENCE INTENSITIES

PHOENIX/MARWEST OFFICE BUILDING

LOCATION 5

WIND AZIMUTH	UMEAN/UINF (PERCENT)	URMS/UINF (PERCENT)	UMEAN+3*URMS/UINF (PERCENT)
0.00	21.0	9.7	50.3
22.50	19.0	8.3	44.0
45.00	16.0	6.7	36.1
67.50	16.6	7.8	40.0
90.00	13.9	6.0	31.8
112.50	13.3	5.4	29.4
135.00	18.8	7.9	42.5
157.50	25.6	11.3	59.5
180.00	16.6	7.6	39.4
202.50	19.4	9.1	46.6
225.00	16.4	7.1	37.7
247.50	11.9	4.5	25.4
270.00	10.1	3.5	20.5
292.50	12.6	5.1	27.9
315.00	15.5	6.9	36.1
337.50	17.2	8.0	41.0

LOCATION 6

WIND AZIMUTH	UMEAN/UINF (PERCENT)	URMS/UINF (PERCENT)	UMEAN+3*URMS/UINF (PERCENT)
0.00	15.5	8.3	40.3
22.50	13.0	6.4	32.1
45.00	11.7	5.4	27.8
67.50	11.2	5.0	26.0
90.00	13.2	5.9	31.0
112.50	11.5	5.3	27.5
135.00	16.5	6.6	36.3
157.50	18.2	8.1	42.6
180.00	10.3	4.6	24.2
202.50	10.1	5.0	25.1
225.00	8.8	3.9	20.5
247.50	7.0	2.5	14.5
270.00	7.5	2.8	16.0
292.50	7.5	2.7	15.5
315.00	7.3	2.6	15.1
337.50	13.0	6.7	33.2

LOCATION 7

WIND AZIMUTH	UMEAN/UINF (PERCENT)	URMS/UINF (PERCENT)	UMEAN+3*URMS/UINF (PERCENT)
0.00	27.6	10.6	59.3
22.50	45.8	14.2	88.5
45.00	40.2	11.8	75.6
67.50	39.6	10.4	70.7
90.00	29.3	9.4	57.4
112.50	29.1	13.0	68.1
135.00	58.1	11.7	93.2
157.50	47.5	18.0	101.7
180.00	31.3	19.3	89.2
202.50	15.1	7.9	38.8
225.00	11.9	4.5	25.3
247.50	11.2	4.1	23.7
270.00	12.0	4.7	26.0
292.50	17.8	8.1	42.2
315.00	20.5	9.2	48.2
337.50	23.6	10.9	56.3

LOCATION 8

WIND AZIMUTH	UMEAN/UINF (PERCENT)	URMS/UINF (PERCENT)	UMEAN+3*URMS/UINF (PERCENT)
0.00	27.8	11.2	61.4
22.50	41.7	13.3	81.6
45.00	48.8	15.7	95.8
67.50	52.6	15.5	99.1
90.00	46.9	12.0	82.9
112.50	21.7	10.1	51.9
135.00	26.6	12.5	64.2
157.50	43.1	13.9	84.7
180.00	48.9	11.1	82.2
202.50	47.7	10.6	79.4
225.00	63.3	11.6	98.1
247.50	54.7	10.2	85.4
270.00	31.5	13.6	72.2
292.50	27.1	9.7	56.2
315.00	30.3	9.7	59.5
337.50	26.8	10.5	58.3

TABLE 2--PEDESTRIAN WIND VELOCITIES AND TURBULENCE INTENSITIES

PHOENIX/MARWEST OFFICE BUILDING

* * GREATEST VALUES * *

UMEAN/UINF (PERCENT)

LOC	AZ	MEAN	RMS	M+3RMS
8	225.0	63.3	11.6	98.1
7	135.0	58.1	11.7	93.2
2	315.0	55.6	10.5	87.2
8	247.5	54.7	10.2	85.4
8	67.5	52.6	15.5	99.1
2	90.0	52.5	11.3	86.3
2	292 5	51.9	9.7	81.0
2	112.5	51.4	11.1	84.8
2	337.5	51.1	9.8	80.6
8	180.0	48.9	11.1	82.2

URMS/UINF (PERCENT)

LOC	AZ	MEAN	RMS	M+3RMS
1	22.5	48.3	19.5	106.9
7	180.0	31.3	19.3	89.2
7	157.5	47.5	18.0	101.7
1	45.0	39.9	17.1	91.2
3	202.5	37.4	17.0	88.6
3	180.0	31.8	17.0	82.9
8	45.0	48.8	15.7	95.8
8	67.5	52.6	15.5	99.1
3	157.5	32.1	15.4	78.2
3	0.0	33.4	15.3	79.4

UMEAN+3*RMS/UINF (PERCENT)

LOC	AZ	MEAN	RMS	M+3RMS
1	22.5	48.3	19.5	106.9
7	157.5	47.5	18.0	101.7
8	67.5	52.6	15.5	99.1
8	225.0	63.3	11.6	98.1
8	45.0	48.8	15.7	95.8
7	135.0	58.1	11.7	93.2
1	45.0	39.9	17.1	91.2
7	180.0	31.3	19.3	89.2
3	202.5	37.4	17.0	88.6
7	22.5	45.8	14.2	88.5

TABLE 3

PERCENTAGE FREQUENCY OF WIND DIRECTION AND SPEED

SKY HARBOR INTERNATIONAL AIRPORT, PHOENIX (1965-1974)

SEASON : ANNUAL NO. OF OBS.= 29215 HT. OF MEAS.= 18. FT.

VELOCITY LEVELS IN MPH

DIRECTION	0- 3	4- 7	8-12	13-18	19-24	25 +	TOTAL
N	.70	1.30	.50	.10	0.00	0.00	2.60
NNE	.30	.70	.20	.10	0.00	0.00	1.40
NE	.70	1.40	.50	.20	0.00	0.00	2.90
ENE	.80	2.20	1.00	.60	.10	0.00	4.70
E	1.70	8.00	6.30	.70	0.00	0.00	16.80
ESE	1.40	7.10	5.50	.50	0.00	0.00	14.50
SE	1.40	4.60	2.60	.50	0.00	0.00	9.10
SSE	.70	1.50	.80	.20	0.00	0.00	3.30
S	.80	1.70	.70	.30	.10	0.00	3.50
SSW	.40	1.10	.40	.10	0.00	0.00	2.00
SW	.60	2.00	1.10	.30	0.00	0.00	4.00
WSW	.60	2.30	2.40	1.00	.10	0.00	6.40
W	.90	4.30	5.30	2.20	.10	0.00	12.90
WNW	.60	2.00	2.00	.50	0.00	0.00	5.10
NW	.60	1.70	1.10	.30	0.00	0.00	3.80
NNW	.40	1.30	.50	.10	0.00	0.00	2.30
CALM	4.80	0.00	0.00	0.00	0.00	0.00	4.80
TOT	17.30	43.00	31.20	7.70	.70	.10	100.00

TABLE 4

SUMMARY OF WIND EFFECTS ON PEOPLE

	Beaufort number	Speed (mph)	Effects
Calm, light air	0, 1	0- 3	Calm, no noticeable wind
Light breeze	2	4- 7	Wind felt on face
Gentle breeze	3	8-12	Wind extends light flag Hair is disturbed Clothing flaps
Moderate breeze	4	13-18	Raises dust, dry soil and loose paper Hair disarranged
Fresh breeze	5	19-24	Force of wind felt on body Drifting snow becomes airborne Limit of agreeable wind on land
Strong breeze	6	25-31	Umbrellas used with difficulty Hair blown straight Difficult to walk steadily Wind noise on ears unpleasant Windborne snow above head height (blizzard)
Near gale	7	32-38	Inconvenience felt when walking
Gale	8	39-46	Generally impedes progress Great difficulty with balance in gusts
Strong gale	9	47-54	People blown over by gusts

Note: Table from Reference 4, p. 40.