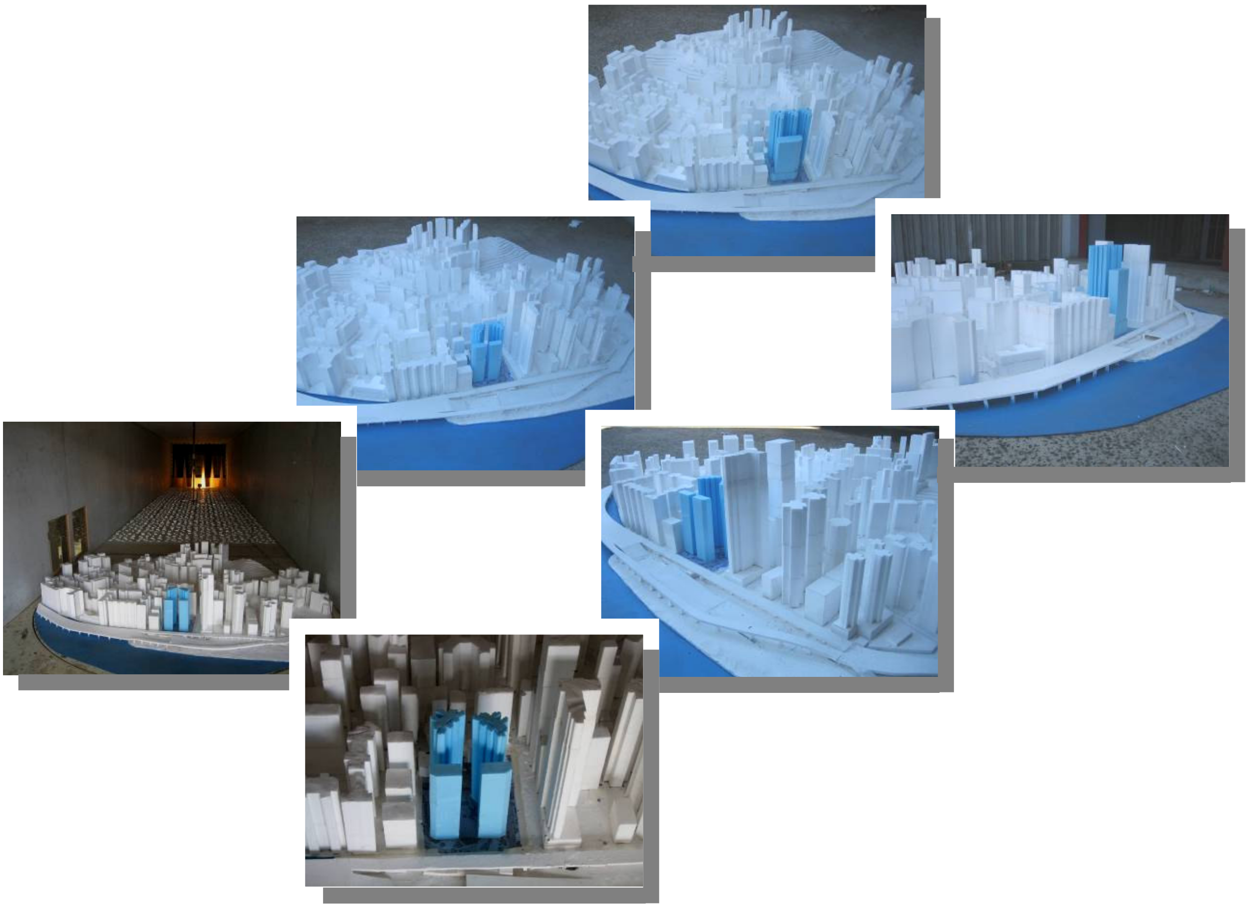
Planning Department

Air Ventilation Assessment Report
Oil Street Site
EXPERIMENTAL SITE WIND AVAILABILITY STUDY



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1. INTRODUCTION

1.1 Background of the Study

1.1.1 Planning Department has commissioned CH2M HILL Hong Kong Limited to provide term consultancy services for undertaking air ventilation assessment in September 2006. As instructed by Planning Department in November 2006, two design schemes are to be tested for the proposed development at the Oil Street Site.

1.1.2 According to the Assignment Brief of this consultancy, an Experimental Site Wind Availability Data should be conducted before commencement of the detailed study.

1.1.3 CH2M HILL Hong Kong Limited, in association with Windtech Consultants Pty Limited (Australia), has prepared this Experimental Site Wind Availability to determine the effects of local topography and the surrounding urban environment on mean wind speed and turbulence intensity profiles. A 1:4000 scale topographical model was used in the study. These wind speed profiles will be used to simulate the mean wind speed and turbulence intensity profiles accurately for the approach wind for the detailed study, which will be conducted at a scale of 1:400.

1.2 Objective of the Study

1.2.1 According to the Assignment Brief of this consultancy, the tasks of the Experimental Site Wind Availability Data should include:

- A topographical study to establish the modifying effects of the terrain surrounding the project site on the wind availability and wind boundary layer profile of the site shall be carried out by wind tunnelling;
- A topographical model of 1:4000 scale covering the surrounding area up to a distance of not less than 10km from the project site boundary showing the major topographical features and buildings of Hong Kong Island and Kowloon shall be constructed. The model shall be used to obtain precise wind availability and characteristics information in terms of wind rose (directions, magnitudes and frequencies), wind profiles and wind turbulence intensity profiles and wind turbulence intensity profiles of the site, which shall be required and suitable for use in the detailed study. Hong Kong Observatory Waglan Island wind data should be referenced to for the experimental study;
- Mean wind direction and turbulence characteristics for 16 wind directions at no less than eight heights up to an elevation of approximately 500m above the ground at each site wind position shall be measured and reported. The results shall be presented in graphical and tabulated format and shall include profiles of wind speed and turbulence intensity for each wind direction tested and windroses at a height of 500m above ground. The results shall provide the approaching wind condition for wind tunnel testing of the design schemes in the detailed study.

1.2.2 A hot-wire probe with a separate pressure-based meter measuring yaw angle was used to take measurements of mean and standard deviation of wind speed at 22.5^{o} increments for the full 360^{o} azimuth, i.e. for 16 directions, and at eight heights.

2. ASSESSMENT APPROACH

2.1 Methodology

2.1.1 The study was undertaken in accordance with the current best international practice requirements stipulated in the Australasian Wind Engineering Society Quality Assurance Manual, AWES-QAM-1-2001 (2001) and the American Society of Civil Engineers Manual, Report on Engineering Practice No. 67 for Wind Tunnel Studies of Buildings and Structures (1999) and the Technical Guide for Air Ventilation Assessment for Developments in Hong Kong (2005).

2.2 1:4000 Scale Physical Model

2.2.1 According to the Assignment Brief, a 1:4000 scale topographical model was made. The 1:4000 scale topographical study was undertaken to determine the effects of local topography and the surrounding urban environment on mean wind speed and turbulence intensity profiles above the centre of the Oil Street Site. The physical model covers the entire Hong Kong Island, the Kowloon Peninsula and mountain ranges to its north.

2.2.2 The extent of the 1:4000 scale model is shown in Figure 2-1. The landform in the model was fabricated at 40m contour intervals from information acquired from the HKSAR's Survey and Mapping Office, Lands Department. The building morphology, including existing and planned buildings and structures was constructed based on the information provided by the Planning Department. Different views of the overall model of the 20km diameter region are shown in Figure 2-2. A view of the model in the wind tunnel, including a closer view of the section of the model representing the area around the Oil Street site is shown in Figure 2-3.

2.2.3 The measurement point for the site wind availability study is located at the centre of the subject development site. During the testing, the buildings within close proximity to the site, which were included in the 1:400 scale detailed study were removed as the aim of this study is to model the approach wind to enable an appropriate simulation at 1:400 scale.

2.2.4 The topographical study results were interpreted with a statistical model of the Hong Kong wind climate, based on measurements of hourly mean wind speeds taken by Hong Kong Observatory at Waglan Island during the period of 1975 – 2001 inclusive, to arrive at the local wind roses and wind speed frequency table corresponding to annual hourly mean wind speeds at the measurement position. The Waglan Island data was analysed and corrected to a 500m reference height. The reference data for Waglan Island used in this report is given in Appendix I.

2.3 The Wind Model

2.3.1 Waglan Island, located approximately 5km southeast of Hong Kong Island, has been used by the Hong Kong Observatory (HKO) for the collection of long-term wind data since December 1952. Due to the relative lack of developments over the past 50 years and its generally uninterrupted exposure to winds, data collected at Waglan Island is considered to be representative of winds approaching Hong Kong and are of the highest quality available for wind engineering purposes. For the other inland weather stations, many developments have taken place close to them during their operational life, which make them unsuitable for wind engineering applications.

2.3.2 Correction factors for height and local terrain were applied to the Waglan Island data to determine a wind rose corresponding to annual mean wind speeds at a height equivalent to 500m above Waglan Island (refer to Appendix I). The annual wind rose for Waglan Island based on frequency data, is presented in Appendix I, indicates that prevailing and strong winds approaching Hong Kong occur mainly from the north-east quadrant and, to a lesser extent, the south-west.

2.3.3 The key parameters for modelling the wind behaviour within the atmospheric boundary layer over a particular terrain are the variation in the mean wind speed and the variation of the turbulence intensity with height. Turbulence intensity is a measure of the gustiness of wind due to eddies and vortices generated by frictional effects at surface level, the roughness of the terrain over which air is flowing and convective effects due to opposing movements of air masses of different temperature. In typical atmospheric boundary layer flow, turbulence intensity generally decreases with height. Closer to the ground, at pedestrian level for example, the magnitude of the turbulence intensity can be very large due to the effects of wind flowing around buildings and other structures.

2.3.4 Windtech's boundary layer wind tunnel test facility is shown in Figure 2-4. The test section has a 2.6m wide × 2m high working section and a maximum mean free stream wind speed of approximately 15m/s. The wind flow regime can be modified through the use of devices such as spires and fences to model different scale atmospheric boundary layer flows.

2.3.5 Appropriate combinations of roughness elements and fences were used to simulate the characteristics of winds approaching Hong Kong as represented by the mean wind speed and turbulence intensity profiles corresponding to wind flowing over open water. The mean wind speed profile of the wind flow approaching the study area has been made reference to the power law expression, defined in Equation (1), specified in Planning Department's Feasibility Study for Establishment of Air Ventilation Assessment System – Final Report (2005) as well as the corresponding profile defined in Hong Kong Code of Practice on Wind Effects (2004). This can be seen in Figure 2-5. The mean velocity profile stipulated by Feasibility Study for Establishment of AVAS (2005) is based on a 0.15 power law exponent, as defined in equation (1), below, and closely resembles the Deaves and Harris (1978) profile for boundary layer flow over open terrain;

$$\frac{\bar{u}(z)}{\bar{u}_{ref}} = \left(\frac{z}{z_{ref}}\right)^{\alpha} \qquad (1)$$

where:

$\bar{u}(z)$ = mean wind speed at a height z (m/s);

$\bar{u}_{ref}$ = mean wind speed at a suitable reference height (m/s);

z = height above zero plane displacement height (m);

z_{ref} = a suitable reference height (m);

α = the power law exponent, which is a constant commensurate with the terrain roughness, taken as approximately 0.15 for this study.

2.3.6 The turbulence intensity profile of the approaching wind flow was simulated in accordance with both the Hong Kong Code of Practice on Wind Effects (2004) and Terrain category 2 (Open) Terrain profile stipulated in Australian/New Zealand Standard AS/NZS 1170.2:2002, which corresponds to non-typhoon wind flow above rough open water surfaces. The simulated mean wind speed and turbulence intensity profiles are generally within ±10% of the target profiles defined in Equation (1), as well as in the Hong Kong Code of Practice on Wind Effects (2004) and AS/NZS 1170.2:2002 category 2 terrain and are presented in Figure 2-5. The spectrum of longitudinal turbulence of the approach flow measured at a height equivalent to 500m in prototype scale is presented in Figure 2-6 and satisfies the maximum ratio of 3 for modelling of the scaling of the length scale parameter, xLu as specified in the Engineering Science Data Unit 74031 (1974).

Title: Extent of the 1:4000 Model

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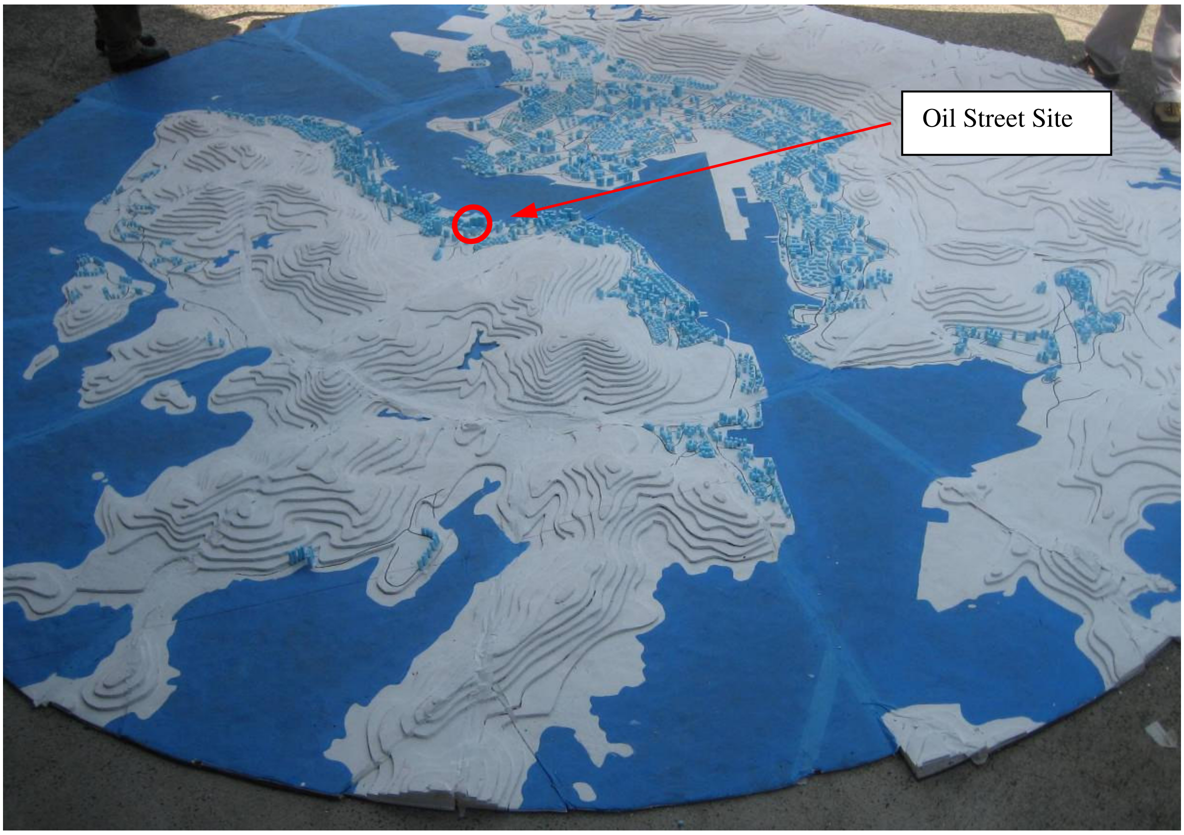
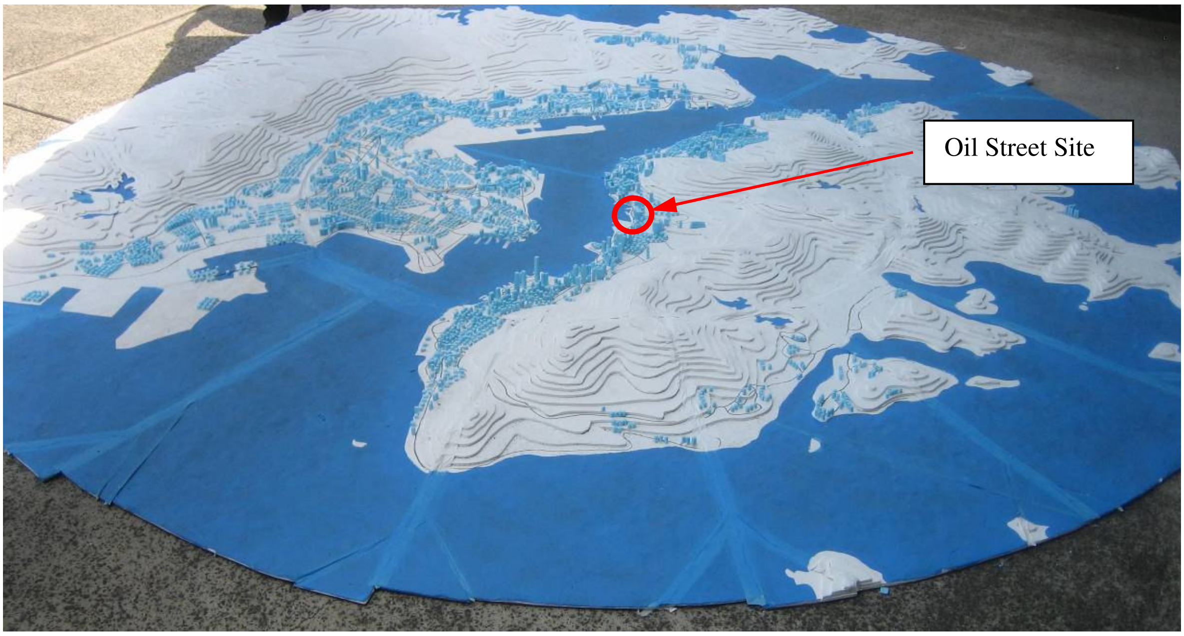
Oil Street Site - Experimental Site Wind Availability Study

Figure: 2-1

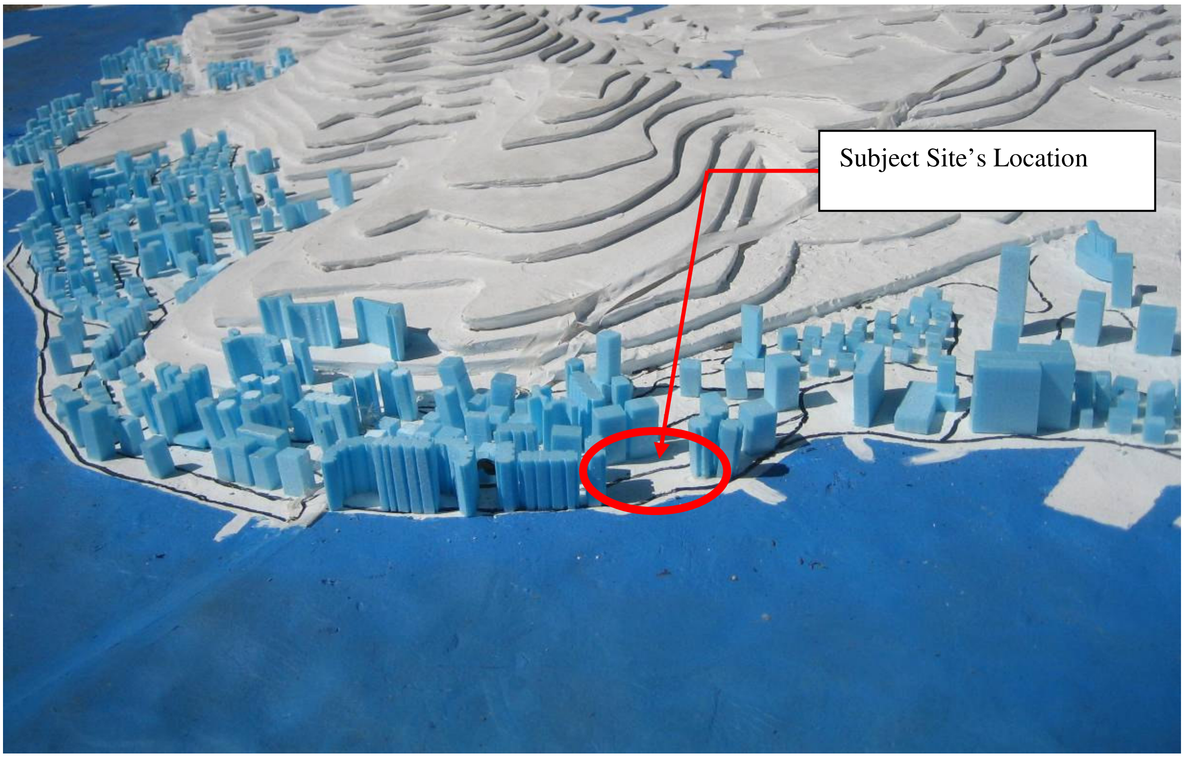


View of overall model from the South-East direction



View of overall model from the South-West direction

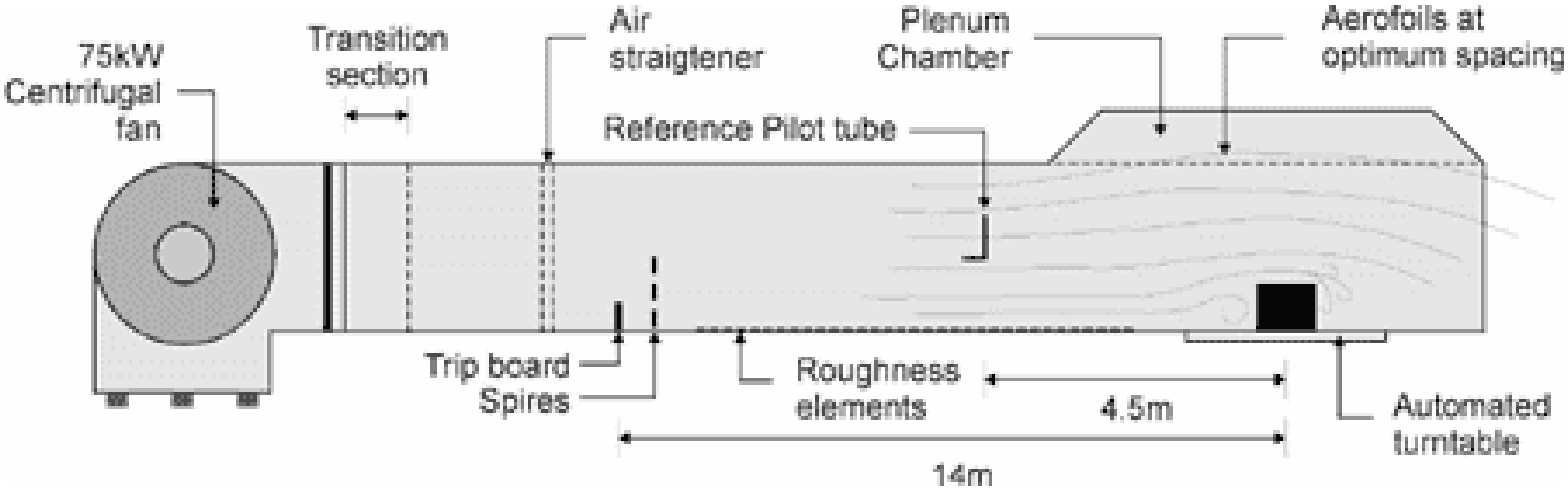
Title:	**Photographs of the 1:4000 Scale Model**	**CH2M HILL Hong Kong Limited**
Project:	**Air Ventilation Assessment** **Oil Street Site - Experimental Site Wind Availability Study**	**Figure: 2-2**



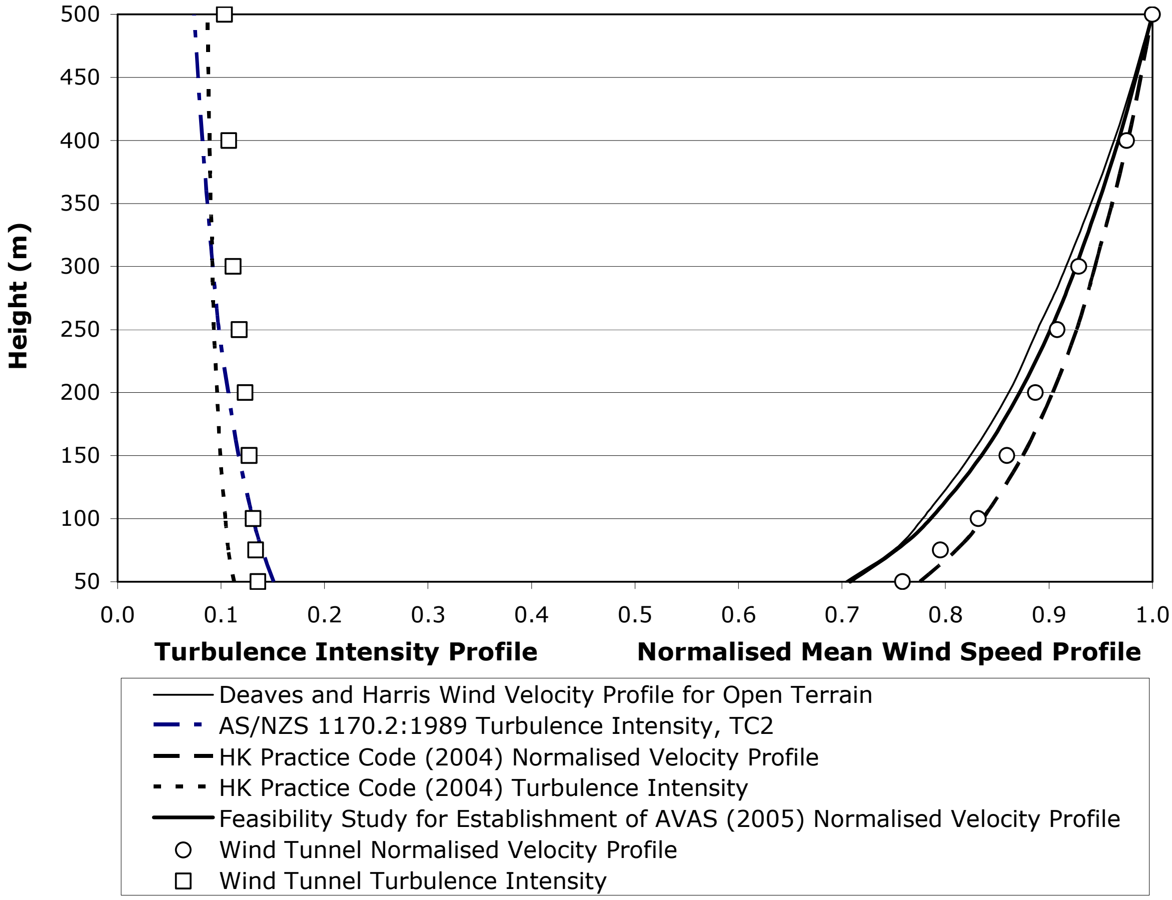
Close-up view of the 1:4000 model showing the Oil St Precinct

The 1:4000 model in the wind tunnel for wind from the North-East direction

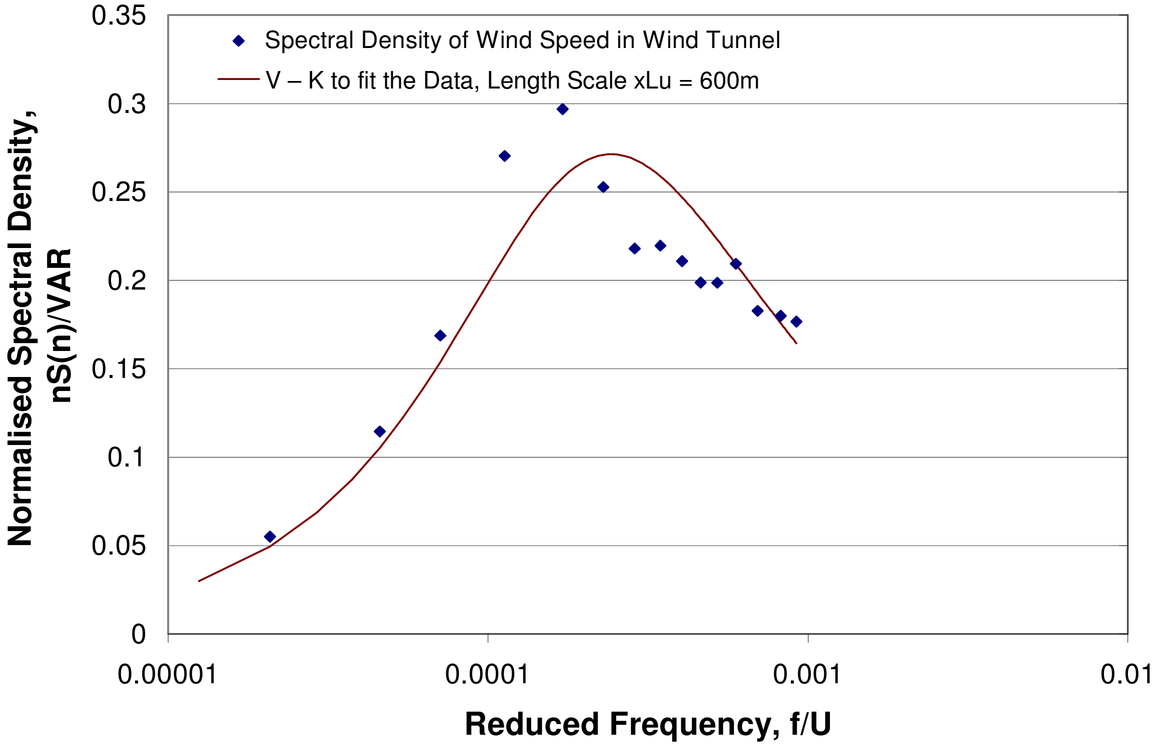
Title:	**The 1:4000 Scale Model in the Wind Tunnel**	**CH2M HILL Hong Kong Limited**
Project:	**Air Ventilation Assessment** **Oil Street Site - Experimental Site Wind Availability Study**	**Figure: 2-3**



Title:	WINDTECH's Boundary Layer Wind Tunnel Facility	CH2M HILL Hong Kong Limited
Project:	Air Ventilation Assessment Oil Street Site - Experimental Site Wind Availability Study	Figure: 2-4



Title:	**Comparsion of Standard Turbulence Intensity and Wind Speed Profiles against WINDTECH's 1:4000 Scale Wind Tunnel Velocity Profile for Hong Kong Upstream Winds beyond the 10km Radius Topography Model**	**CH2M HILL Hong Kong Limited**
Project:	**Air Ventilation Assessment** **Oil Street Site - Experimental Site Wind Availability Study**	**Figure: 2-5**



Title:	**The Spectrum of Longitudinal Turbulence Intensity at 200m for 1:4000 Scale Open Terrain Against the Von Karman Spectrum for 600m Height in Open Terrain**	**CH2M HILL Hong Kong Limited**
Project:	**Air Ventilation Assessment** **Oil Street Site - Experimental Site Wind Availability Study**	**Figure: 2-6**

3. ANALYSIS AND RESULT OF WIND DIRECTIONS AND FREQUENCY

3.1 Experimental Site Wind Measurement

3.1.1 The location of the measurement point, where the wind profiles were measured is indicated in Figure 3-1. Winds approaching the modelled region were calibrated to simulate non-typhoon winds flowing over open water and the topographical model was used to determine the effects of the surrounding complex terrain on the wind speed and turbulence intensity.

3.1.2 Wind tunnel measurements were taken at 22.5° intervals for the full 360° azimuth (i.e. 16 wind directions), where a wind direction of 0° or 360° corresponds to an incident wind approaching the study area directly from the north, 90° corresponds to an incident wind approaching the study area directly from the east, etc. For each wind direction tested, mean wind speeds and turbulence intensities were determined at eight different height levels, equivalent to 50, 100, 150, 200, 250, 300, 400 and 500m in prototype scale, above the measurement position within the study area.

3.1.3 While measurements were taken at one position, all buildings within a radius of 500m of that position were removed from the wind tunnel model for all measured wind directions. Buildings within the 500m radius will be included in the 1:400 model for the more detailed and larger scale study.

3.1.4 Wind speeds at the measurement heights were normalised by the upstream wind speed at 500m. Turbulence intensities were also obtained from the local mean and standard deviation wind speeds by the equations defined below.

$$\text{normalised wind velocity} = \frac{\overline{V}_z(\theta)}{\overline{V}_{500,\text{approach}}(\theta)} \quad (1)$$

$$\text{turbulence intensity} = \frac{\sigma_{V,z}(\theta)}{\overline{V}_z(\theta)} \quad (2)$$

In Equations (1) and (2):

$\overline{V}_z(\theta)$ = mean wind speed at a height z (z = 50, 100, 150, 200, 250, 300, 400 or 500m in prototype scale) for an approaching wind direction θ (θ = 22.5°, 45°, 67.5°, 90°, 112.5°, 135°, 157.5°, 180°, 202.5°, 225°, 247.5°, 270°, 292.5°, 315°, 337.5° or 360°);

$\overline{V}_{500,\text{approach}}(\theta)$ = mean wind speed of the approaching wind at a height equivalent to 500 m in prototype scale for an approaching wind direction θ;

$\sigma_{V,z}(\theta)$ = the standard deviation of the fluctuating wind speed V_z for an approaching wind direction θ.

3.1.5 The experimental site wind speed and turbulence intensity for each of the wind directions are presented in graphical form and are tabulated in Appendix II.

3.2 Site Wind Availability

3.2.1 Wind rose and the frequency table of the study area at an urban canopy level, i.e. 200m, were presented in Appendix III. A higher level wind rose (i.e. 500m) has been considered. It is the gradient height assumed in the Technical Guide and will not likely be affected by the ground level roughness. However, in order to better capture the "turning effects" as represented by the yaw angles (from the site wind availability testing) that resulted from the nearby topography, wind rose at 200m was chosen. This wind rose can better present the wind characteristics at the urban canopy level. Wind effects lower than this level would be presented by the built forms that existed in the model. The percentage occurrence of the prevailing winds is shown as Table 3-1.

Table 3-1 Percentage Occurrence of the Prevailing Winds at the Subject Site

Wind Angle (º)	Percentage Occurrence (%) for wind speed ranges:				
	0-3.3 m/s	3.4–7.9 m/s	8.0–13.8 m/s	>13.8 m/s	Total
22.5	3.3%	6.7%	2.1%	0.1%	12.2%
45	3.1%	5.3%	0.7%	0.0%	9.1%
67.5	5.0%	14.9%	4.9%	0.2%	24.9%
90	3.0%	8.4%	4.7%	0.4%	16.5%
112.5	2.0%	2.0%	0.4%	0.0%	4.5%
135	1.8%	1.2%	0.2%	0.0%	3.2%
157.5	2.2%	1.6%	0.2%	0.0%	4.0%
180	1.6%	1.3%	0.1%	0.0%	3.0%
202.5	2.2%	1.9%	0.1%	0.0%	4.2%
225	1.7%	2.7%	0.2%	0.0%	4.7%
247.5	1.0%	1.8%	0.3%	0.0%	3.1%
270	0.9%	0.7%	0.1%	0.0%	1.7%
292.5	0.6%	0.2%	0.0%	0.0%	0.8%
315	0.2%	0.1%	0.0%	0.0%	0.3%
337.5	0.8%	0.4%	0.1%	0.0%	1.3%
0	1.2%	3.6%	2.0%	0.2%	6.9%

3.2.2 Reference have been made to the Hong Kong Observatory wind data at North Point Pier. The position of the weather station is at 26m above mean sea level. The wind data presents the localised wind information near the location of the measurement anemometer. No wind data at the urban canopy level where most of the wind-structural interaction happens (i.e. downwash, channelling, etc.) can be revealed from this station. Therefore, the wind tunnel modelled wind rose was adopted.

3.2.3 From Table 3-1, the prevailing wind will come from the east to north-east. Over 53% of the site approaching wind at 200m above ground would come from these directions. Another 28% and 15% of the wind will come from the south-east and the south-west sectors. The remaining 4% will be south-westerly wind.

Title:	**Location of the Measurement Point**	**CH2M HILL Hong Kong Limited**
Project:	**Air Ventilation Assessment** **Oil Street Site - Experimental Site Wind Availability Study**	**Figure: 3-1**

4. CONCLUSION

4.1.1 In this study, the results indicate that for the wind directions tested, the surrounding terrain has the overall effect of reducing mean wind speeds, although the general trend of prevailing northerly and easterly winds remains.

4.1.2 For the west to north directions, there is a slight speed-up effect at 500m. For the wind from the north direction, this is possibly due to a downward trend of the winds funnelled by the upstream landform. In the case of the west to north-west directions, the slight speed-up effect could be due to the effect of the high density urban setting along the shoreline on either side of Victoria Harbour.

4.1.3 For the east to east-south-east as well as from the south to south-west directions, there are higher levels of turbulence intensity. This is probably due to a combined effect of the hills in close proximity and the high density urban setting immediately beyond the 500m radius from the centre of the site.

Appendix I

Directional Winds Result at Waglan Island

APPENDIX I
WIND SPEED FREQUENCY DATA & WIND ROSE FOR WAGLAN ISLAND

Table 1: Weibull Parameters (for Waglan Island Wind Speed Data: 1975 - 2001)

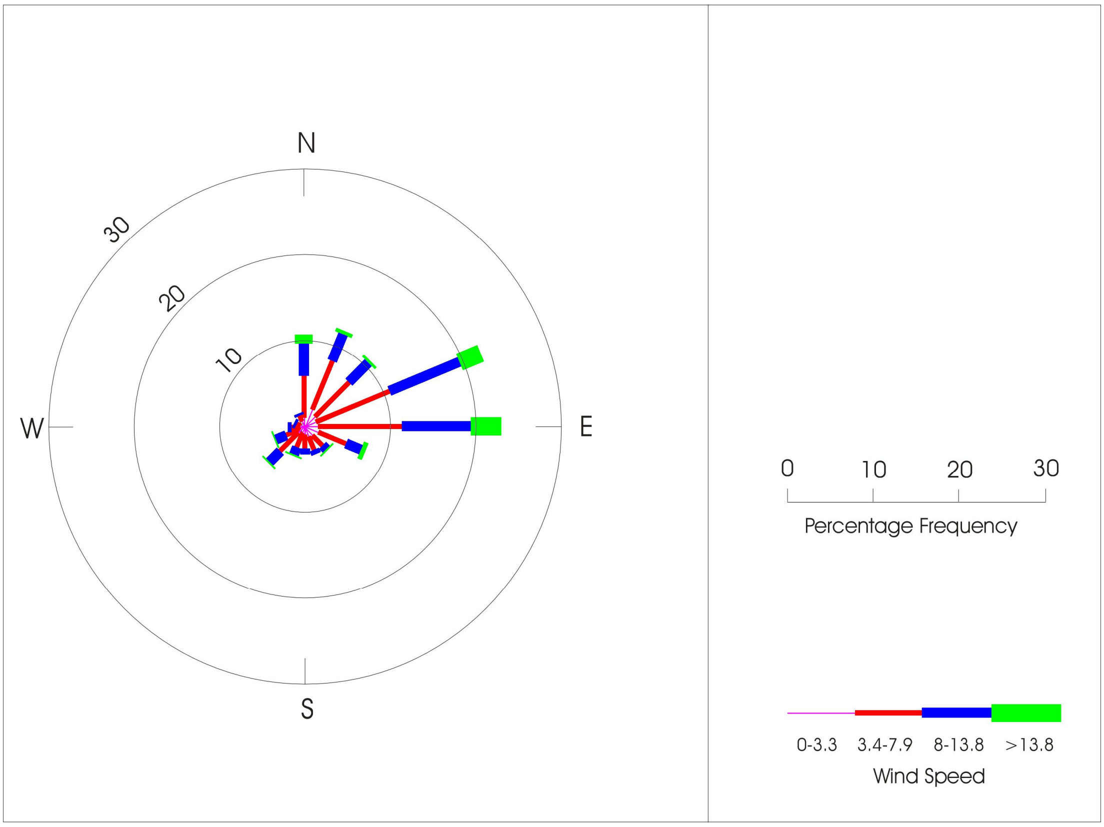
Wind direction (degrees)	A	k	C			
			Waglan Island	500m above Waglan Is.	Site/Waglan (at 500m)*	500m above site
22.5	**0.1087**	**1.94**	6.60	**7.46**	0.98	**7.31**
45	**0.1002**	**2.15**	6.37	**7.50**	0.87	**6.53**
67.5	**0.1822**	**2.39**	8.76	**10.36**	0.80	**8.29**
90	**0.1834**	**2.16**	8.90	**10.72**	0.83	**8.90**
112.5	**0.0655**	**1.55**	6.09	**7.50**	0.87	**6.53**
135	**0.0345**	**1.42**	5.00	**5.75**	0.79	**4.54**
157.5	**0.0305**	**1.57**	4.85	**5.37**	0.92	**4.94**
180	**0.0289**	**1.73**	5.72	**6.19**	0.87	**5.39**
202.5	**0.0329**	**1.87**	6.23	**6.78**	0.85	**5.76**
225	**0.0530**	**2.13**	6.60	**7.51**	0.96	**7.21**
247.5	**0.0333**	**2.24**	6.96	**8.00**	0.93	**7.44**
270	**0.0183**	**1.74**	5.52	**6.26**	1.01	**6.32**
292.5	**0.0115**	**1.39**	4.70	**5.48**	1.08	**5.92**
315	**0.0064**	**1.11**	3.20	**3.78**	1.06	**4.01**
337.5	**0.0138**	**1.10**	4.14	**4.96**	0.95	**4.71**
360	**0.0899**	**2.09**	8.35	**9.41**	1.07	**10.07**

* This is obtained from wind speed profile data – see Appendix II

Table 2: Percentage occurrence of directional winds at 500m

Wind Angle (º)	Percentage Occurrence (%) for wind speed ranges:				
	0-3.3 m/s	3.4–7.9 m/s	8.0–13.8 m/s	>13.8 m/s	Total
0	1.0%	4.5%	3.5%	1.0%	10.0%
22.5	2.0%	5.7%	3.2%	0.4%	11.3%
45	1.6%	5.4%	3.0%	0.2%	10.3%
67.5	1.1%	8.8%	8.3%	2.5%	20.7%
90	1.4%	9.3%	7.7%	3.3%	21.6%
112.5	1.6%	3.2%	1.7%	0.5%	7.0%
135	1.3%	1.6%	0.6%	0.1%	3.6%
157.5	1.1%	1.5%	0.5%	0.0%	3.1%
180	0.8%	1.5%	0.6%	0.1%	2.9%
202.5	0.8%	1.7%	0.8%	0.1%	3.4%
225	0.8%	2.9%	1.6%	0.1%	5.4%
247.5	0.4%	1.8%	1.1%	0.1%	3.4%
270	0.5%	0.9%	0.4%	0.0%	1.9%
292.5	0.4%	0.5%	0.2%	0.0%	1.2%
315	0.4%	0.2%	0.1%	0.0%	0.6%
337.5	0.7%	0.5%	0.2%	0.1%	1.4%

Corresponding wind rose below.



Appendix II

Result of Site Wind Speed and Turbulence Intensity Profiles

APPENDIX II

PLOTS AND TABULATED RESULTS OF THE SITE WIND SPEED AND TURBULENCE INTENSITY PROFILES AND YAW ANGLE PROFILES

Table 1: Wind Characteristics at 22.5^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.98	0.145
400	0.89	0.151
300	0.81	0.160
250	0.81	0.174
200	0.75	0.172
150	0.61	0.180
100	0.57	0.184
50	0.45	0.207

Table 2: Wind Characteristics at 45^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.87	0.137
400	0.82	0.150
300	0.75	0.166
250	0.64	0.210
200	0.63	0.216
150	0.52	0.237
100	0.46	0.255
50	0.40	0.320

Table 3: Wind Characteristics at 67.5^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.80	0.124
400	0.76	0.132
300	0.68	0.135
250	0.67	0.143
200	0.62	0.137
150	0.54	0.163
100	0.51	0.167
50	0.49	0.175

Table 4: Wind Characteristics at 90^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.83	0.139
400	0.80	0.145
300	0.76	0.155
250	0.75	0.157
200	0.72	0.176
150	0.57	0.221
100	0.41	0.274
50	0.27	0.393

Table 5: Wind Characteristics at 112.5^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.87	0.128
400	0.78	0.145
300	0.70	0.167
250	0.66	0.207
200	0.62	0.233
150	0.52	0.271
100	0.46	0.286
50	0.31	0.299

Table 6: Wind Characteristics at 135^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.79	0.132
400	0.77	0.133
300	0.70	0.152
250	0.68	0.164
200	0.64	0.180
150	0.58	0.209
100	0.46	0.245
50	0.39	0.265

Table 7: Wind Characteristics at 157.5^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.92	0.171
400	0.89	0.177
300	0.80	0.193
250	0.73	0.192
200	0.69	0.191
150	0.63	0.213
100	0.56	0.248
50	0.47	0.280

Table 8: Wind Characteristics at 180^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.87	0.121
400	0.82	0.134
300	0.76	0.155
250	0.73	0.163
200	0.68	0.179
150	0.61	0.200
100	0.39	0.307
50	0.35	0.342

Table 9: Wind Characteristics at 202.5^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.85	0.141
400	0.75	0.187
300	0.62	0.229
250	0.55	0.287
200	0.49	0.326
150	0.37	0.377
100	0.30	0.370
50	0.23	0.372

Table 10: Wind Characteristics at 225^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.96	0.181
400	0.85	0.219
300	0.70	0.289
250	0.62	0.295
200	0.61	0.298
150	0.42	0.368
100	0.35	0.366
50	0.33	0.358

Table 11: Wind Characteristics at 247.5^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.93	0.197
400	0.83	0.208
300	0.75	0.230
250	0.73	0.229
200	0.67	0.236
150	0.63	0.236
100	0.63	0.237
50	0.39	0.479

Table 12: Wind Characteristics at 270^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	1.01	0.127
400	0.89	0.152
300	0.81	0.173
250	0.73	0.179
200	0.71	0.184
150	0.65	0.202
100	0.62	0.203
50	0.55	0.223

Table 13: Wind Characteristics at 292.5^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	1.08	0.107
400	0.95	0.137
300	0.83	0.165
250	0.73	0.178
200	0.66	0.194
150	0.57	0.231
100	0.54	0.212
50	0.45	0.228

Table 14: Wind Characteristics at 315^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	1.06	0.171
400	0.90	0.201
300	0.79	0.218
250	0.72	0.230
200	0.63	0.246
150	0.56	0.246
100	0.53	0.255
50	0.47	0.261

Table 15: Wind Characteristics at 337.5^0

Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	0.95	0.139
400	0.87	0.148
300	0.81	0.167
250	0.75	0.169
200	0.69	0.177
150	0.64	0.201
100	0.53	0.206
50	0.48	0.241

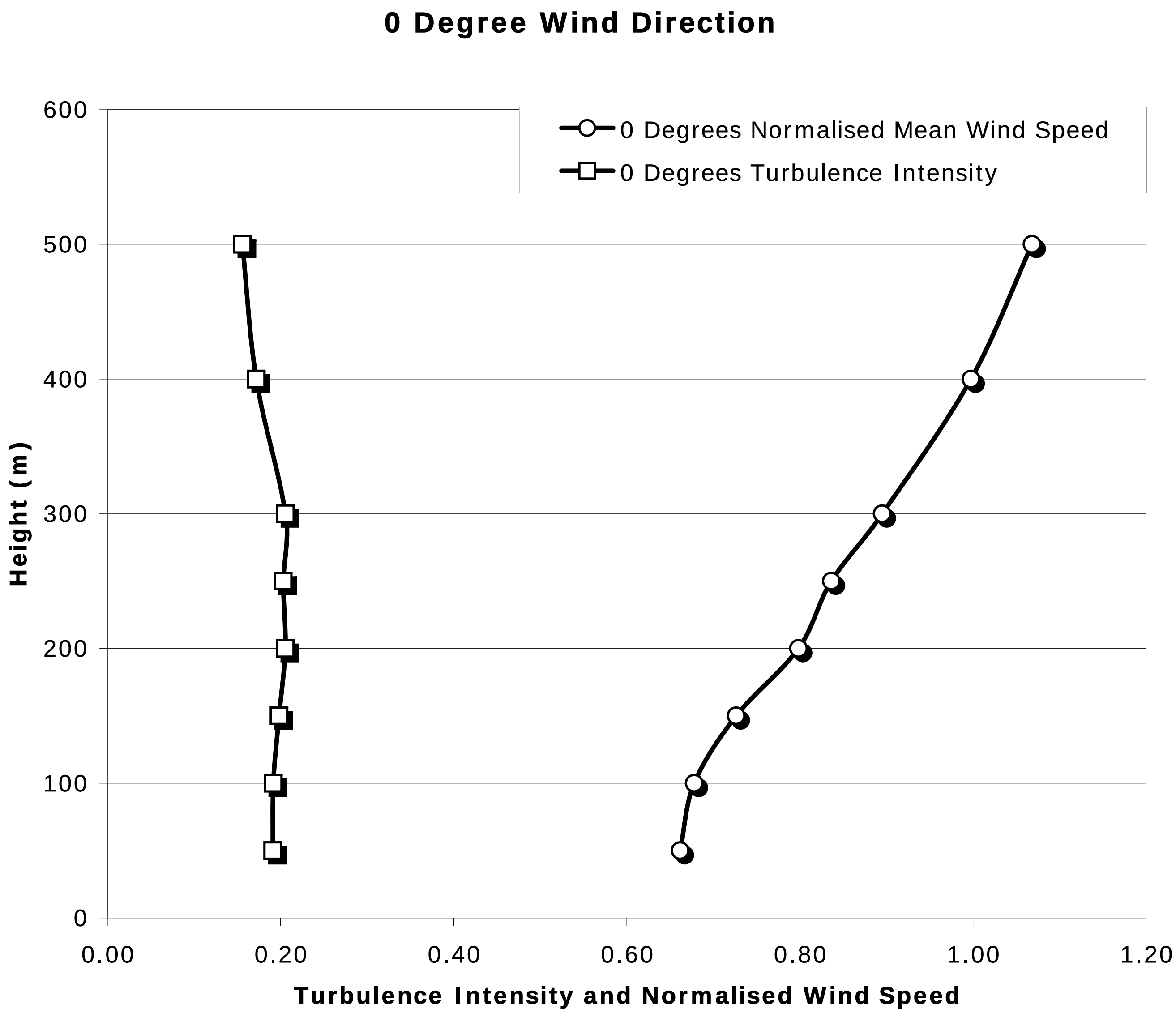
Table 16: Wind Characteristics at 360^0

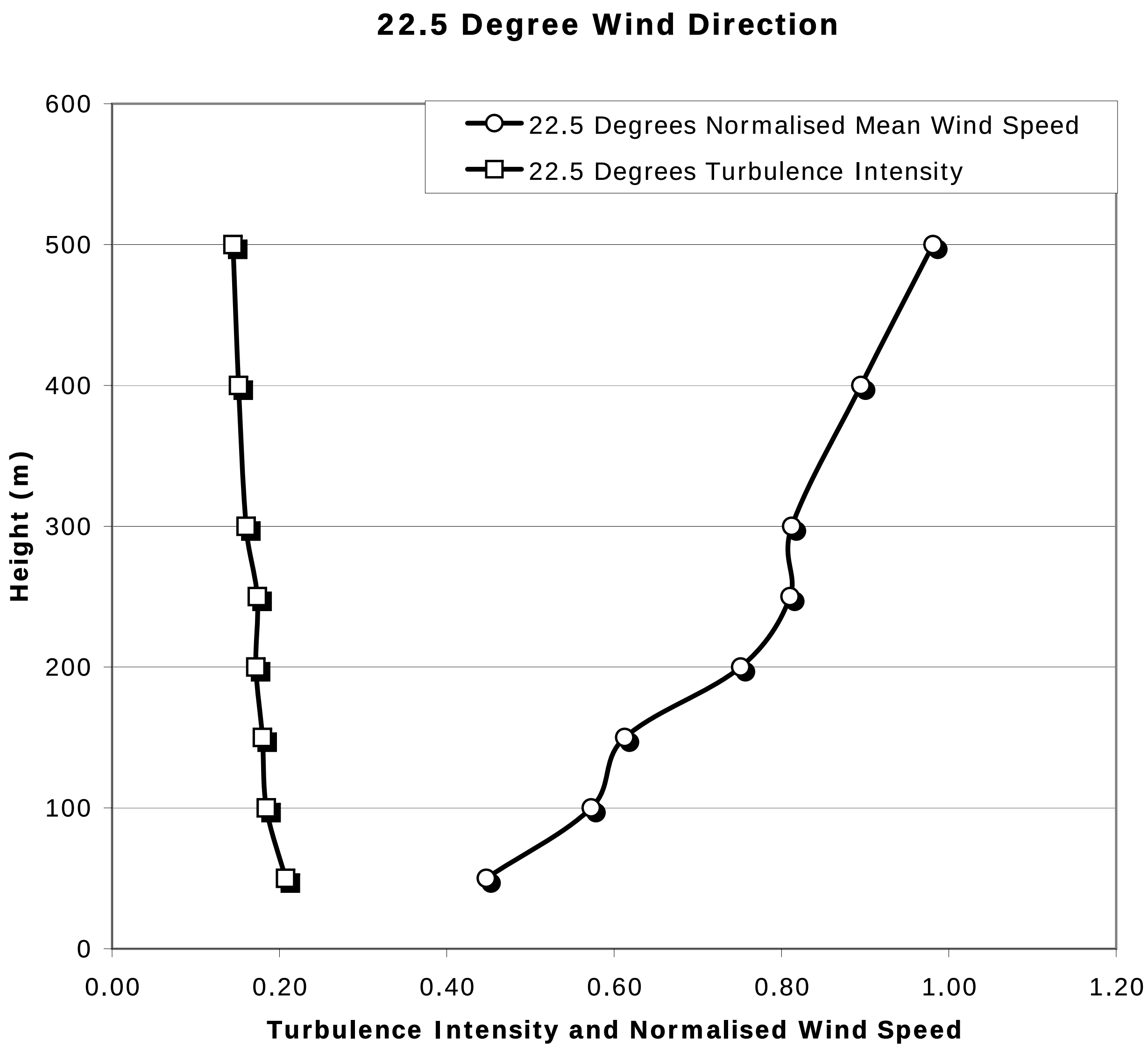
Prototype scale height (m)	Normalised mean wind speed	Turbulence Intensity
500	1.07	0.156
400	1.00	0.172
300	0.90	0.206
250	0.84	0.203
200	0.80	0.206
150	0.73	0.198
100	0.68	0.192
50	0.66	0.191

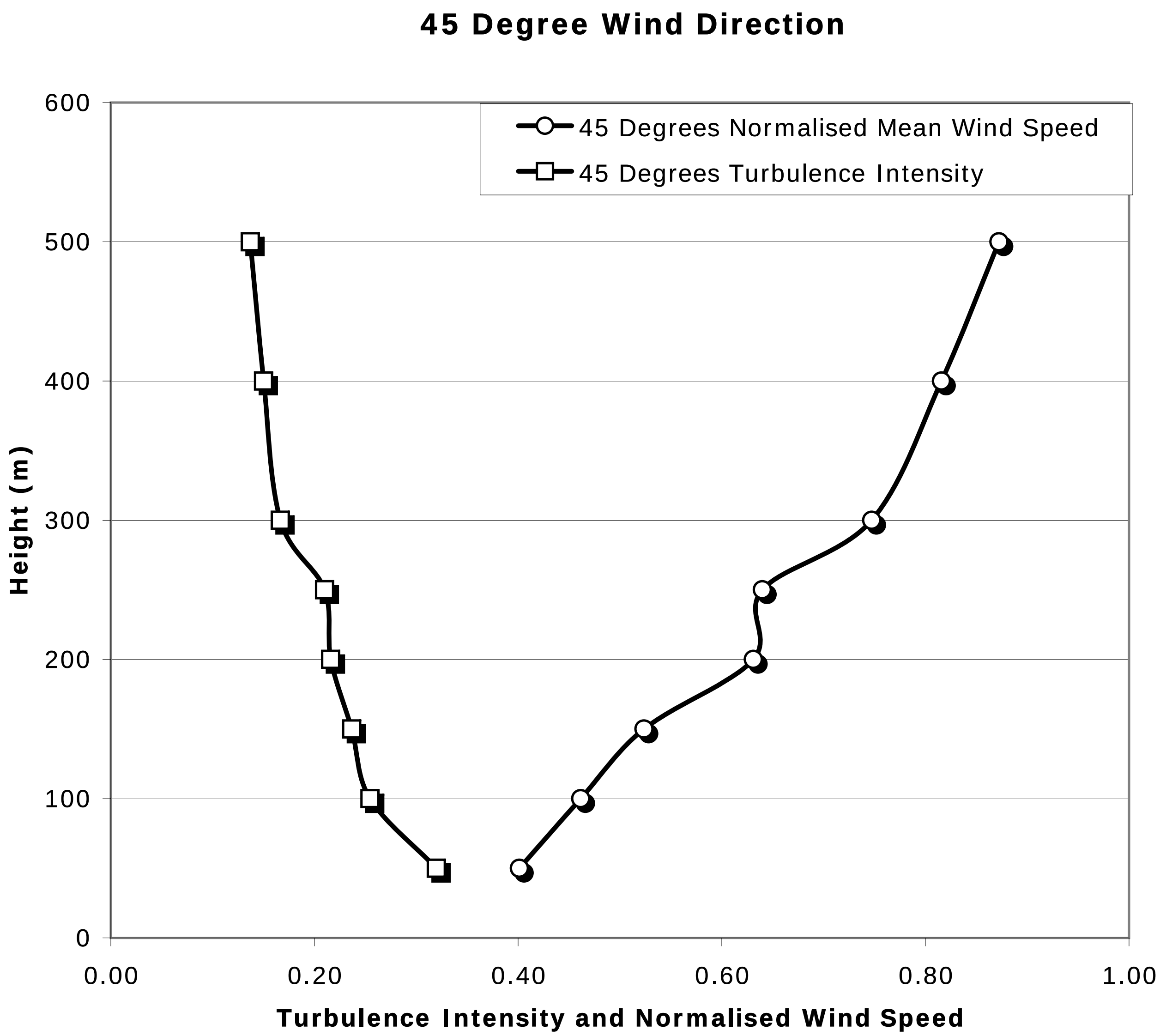
Table 17: YAW ANGLE PROFILES

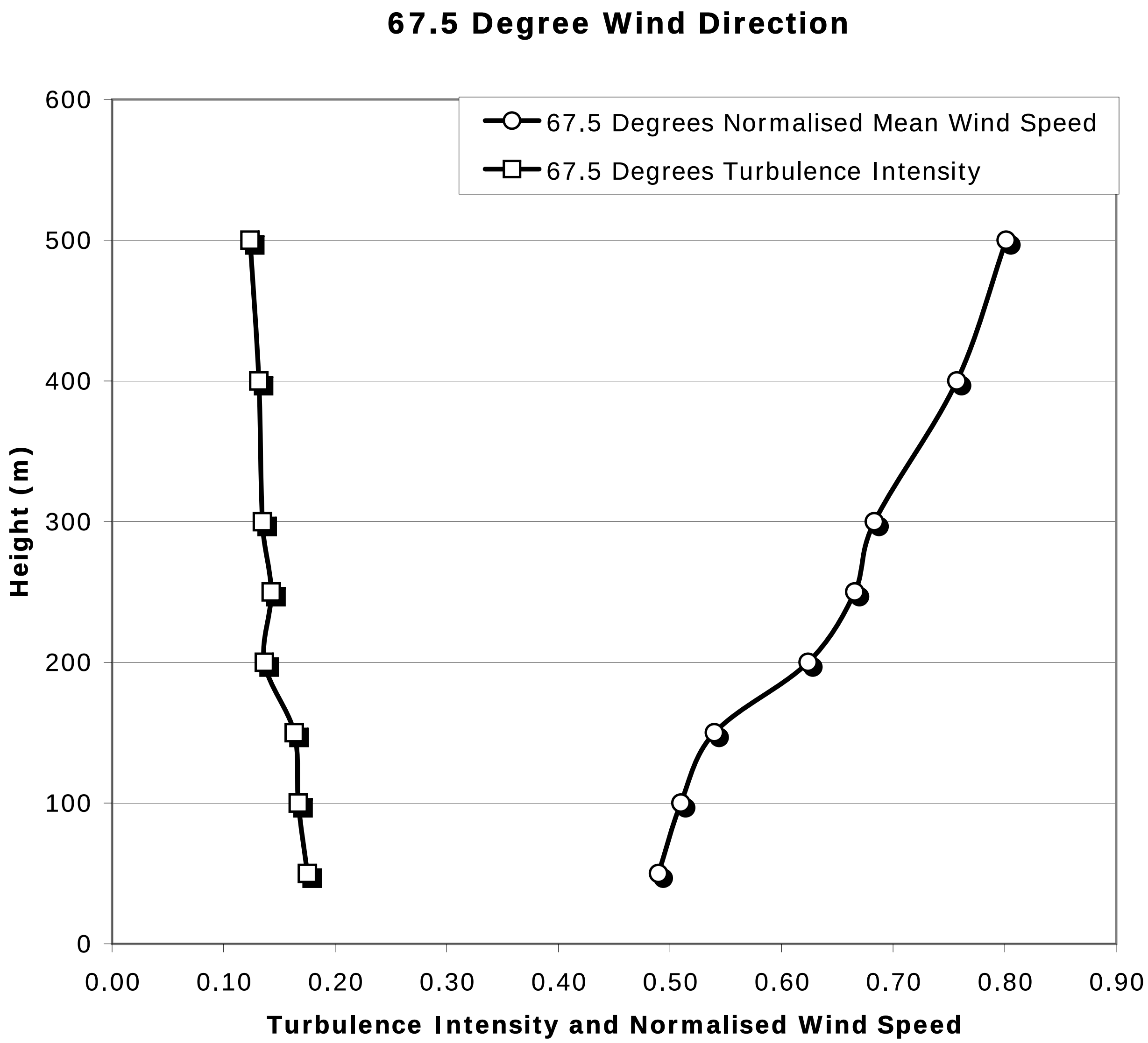
Wind Direction	Height Above Ground (m)							
	50	100	150	200	250	300	400	500
0.0	12.2	1.9	5.4	6.0	-1.0	-6.7	-3.4	3.0
22.5	10.8	0.2	3.9	2.5	-5.8	-12.3	-9.4	1.0
45.0	7.7	0.4	3.9	6.9	-1.3	-9.4	-1.7	1.7
67.5	-3.4	-11.1	-3.0	-1.1	-8.7	-15.8	-9.9	-0.6
90.0	-31.8	-26.1	-18.3	-5.3	-13.3	-19.7	-12.9	-2.3
112.5	17.7	-11.1	-5.2	-7.2	-10.2	-23.9	-9.4	-2.4
135.0	5.0	5.3	4.9	1.7	-14.8	-21.4	-16.8	-0.3
157.5	28.0	9.3	7.1	1.4	10.6	-12.9	-6.0	4.9
180.0	8.0	-0.3	4.8	-6.7	-11.8	-10.3	-5.8	-4.3
202.5	-13.1	-2.5	-0.5	-5.3	-14.1	-13.2	-5.0	-0.2
225.0	-0.4	-7.2	-3.7	-7.2	-14.8	-14.4	-6.3	-0.8
247.5	-27.1	-7.0	-4.1	-7.5	-14.7	-15.1	-5.0	0.2
270.0	-39.0	-10.8	-6.9	-10.5	-18.7	-18.5	-8.0	-2.2
292.5	-43.4	-15.0	-10.8	-14.0	-21.1	-20.3	-9.4	-3.6
315.0	-36.5	-16.6	-11.3	-13.7	-19.3	-16.9	-7.1	-1.7
337.5	6.9	-3.7	3.0	2.3	-7.9	-16.2	-10.1	0.1

Note: Yaw angle is positive if the change in wind direction is in the clockwise direction.

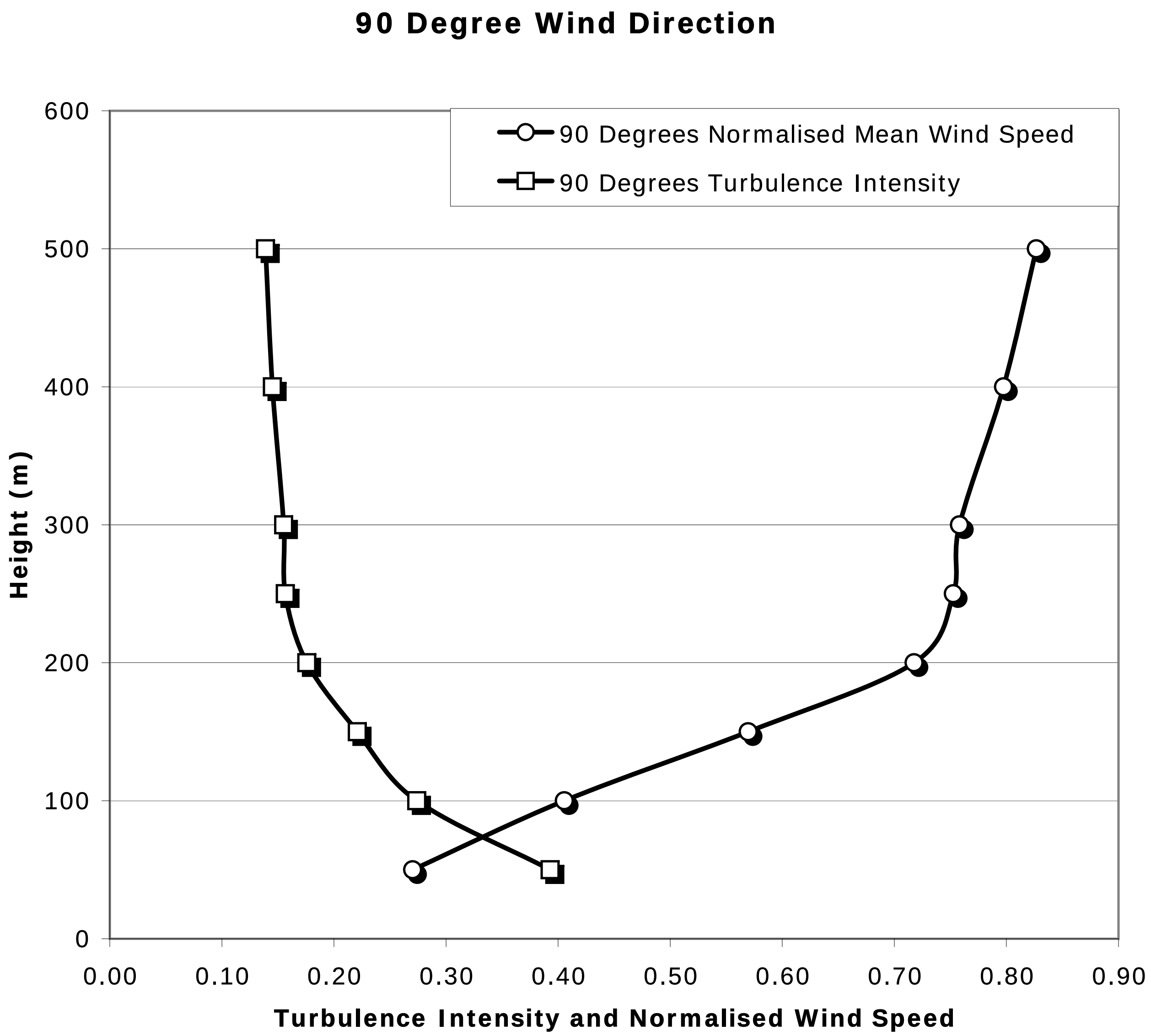

0 Degree Wind Direction
0 Degrees Normalised Mean Wind Speed
0 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Turbulence Intensity and Normalised Wind Speed

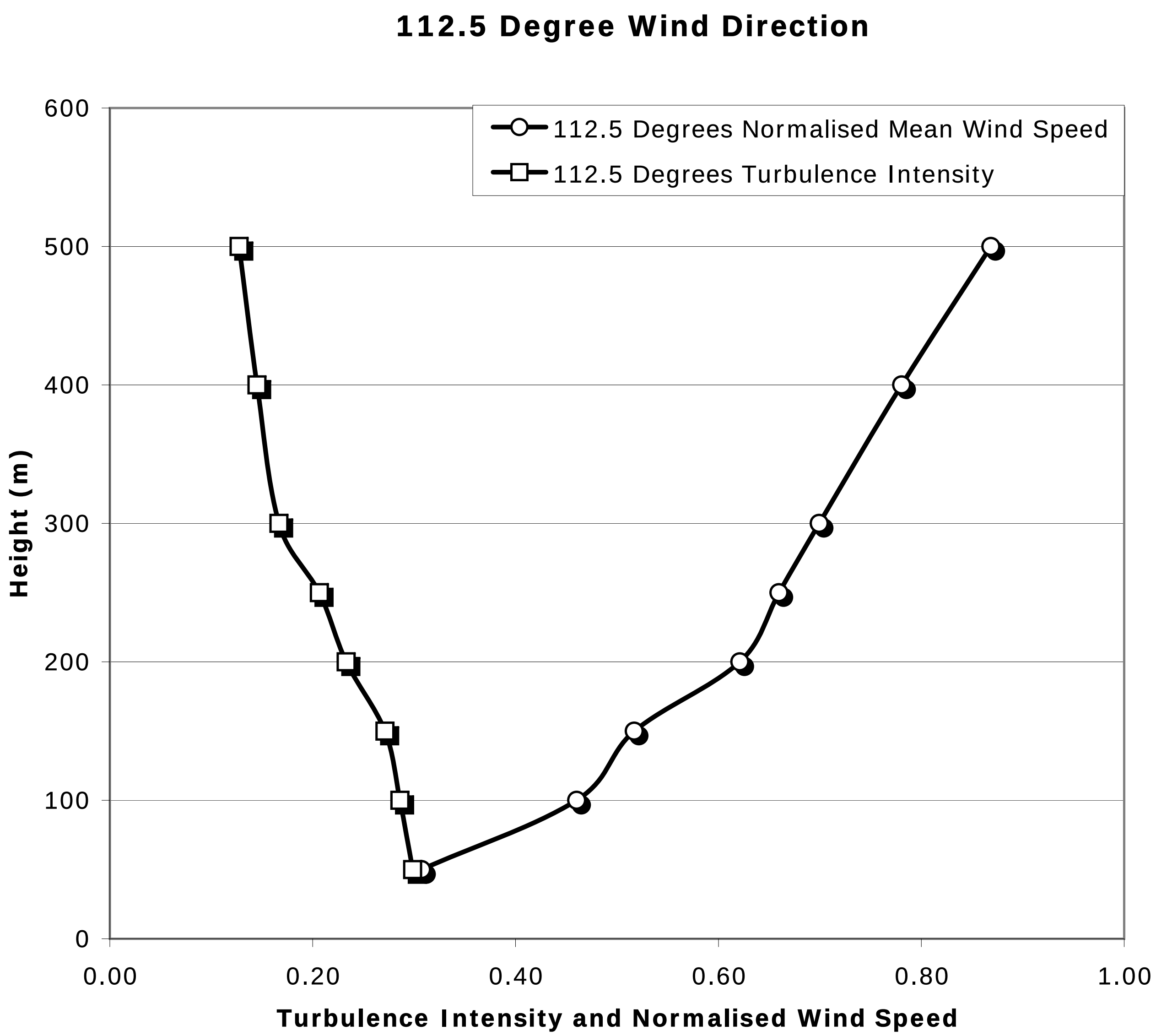

22.5 Degree Wind Direction
22.5 Degrees Normalised Mean Wind Speed
22.5 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Turbulence Intensity and Normalised Wind Speed

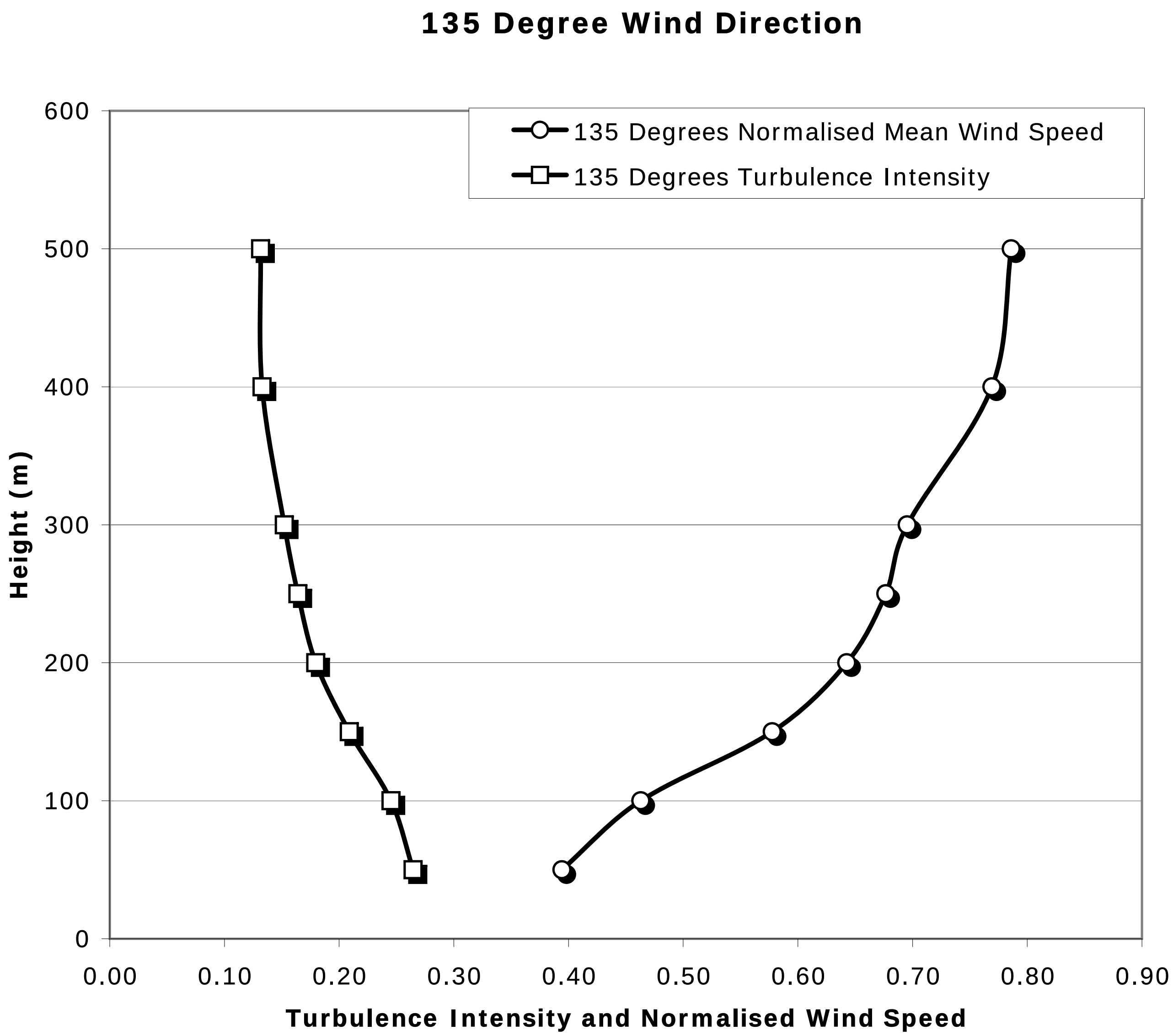

45 Degree Wind Direction
45 Degrees Normalised Mean Wind Speed
45 Degrees Turbulence Intensity
Height (m)
Turbulence Intensity and Normalised Wind Speed
0
100
200
300
400
500
600
0.00
0.20
0.40
0.60
0.80
1.00

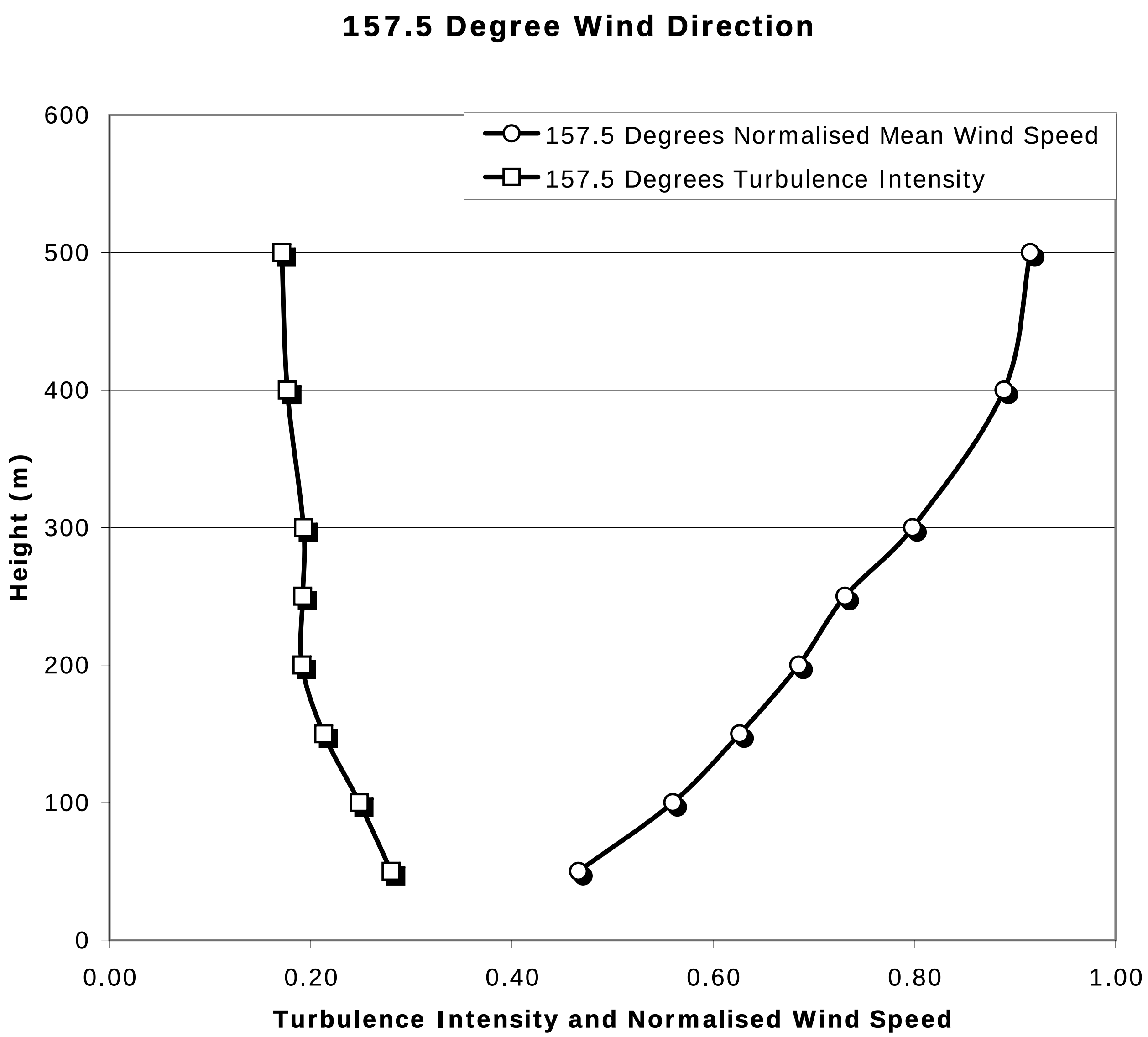


67.5 Degree Wind Direction
67.5 Degrees Normalised Mean Wind Speed
67.5 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
Turbulence Intensity and Normalised Wind Speed

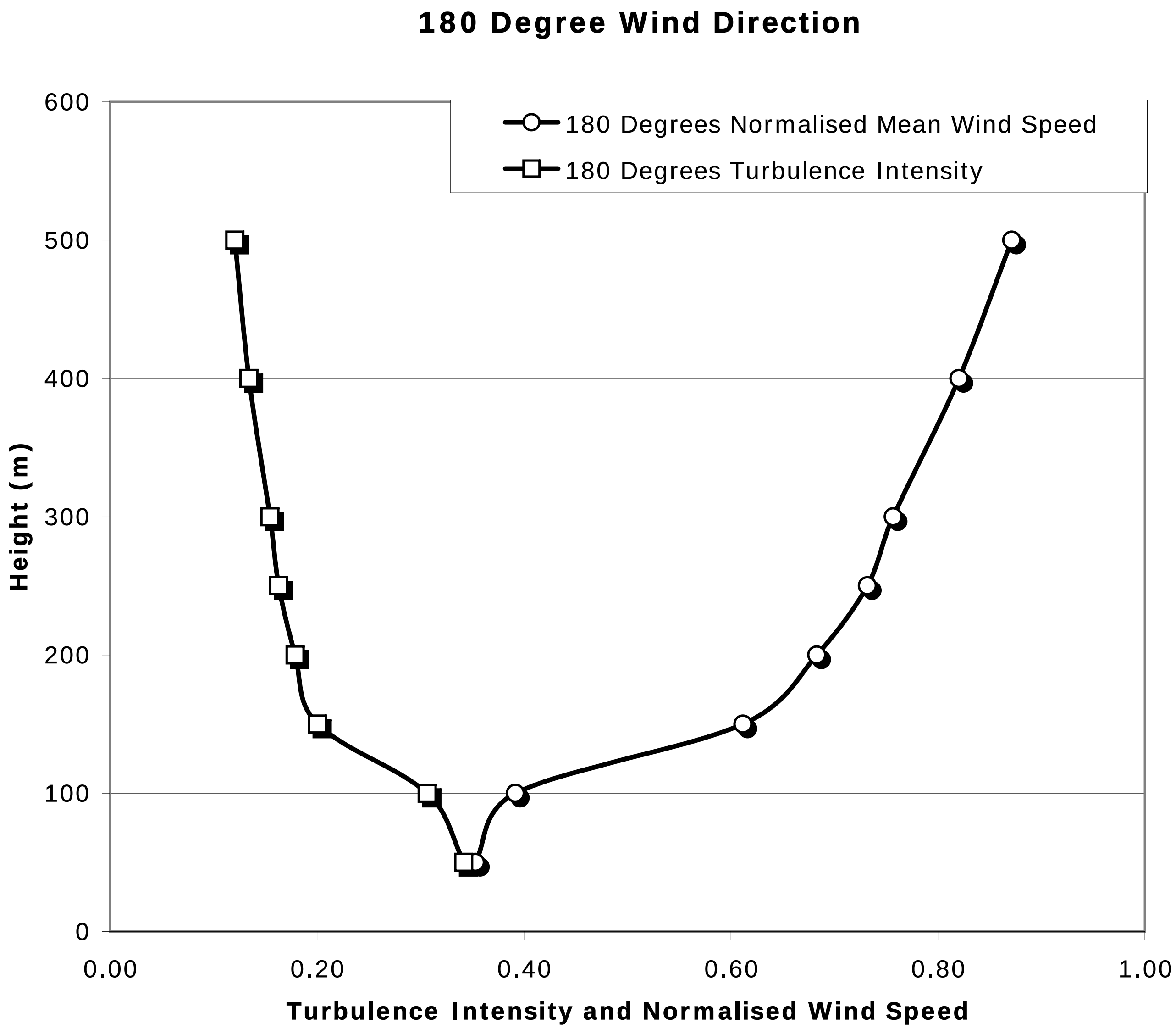

90 Degree Wind Direction
90 Degrees Normalised Mean Wind Speed
90 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
Turbulence Intensity and Normalised Wind Speed

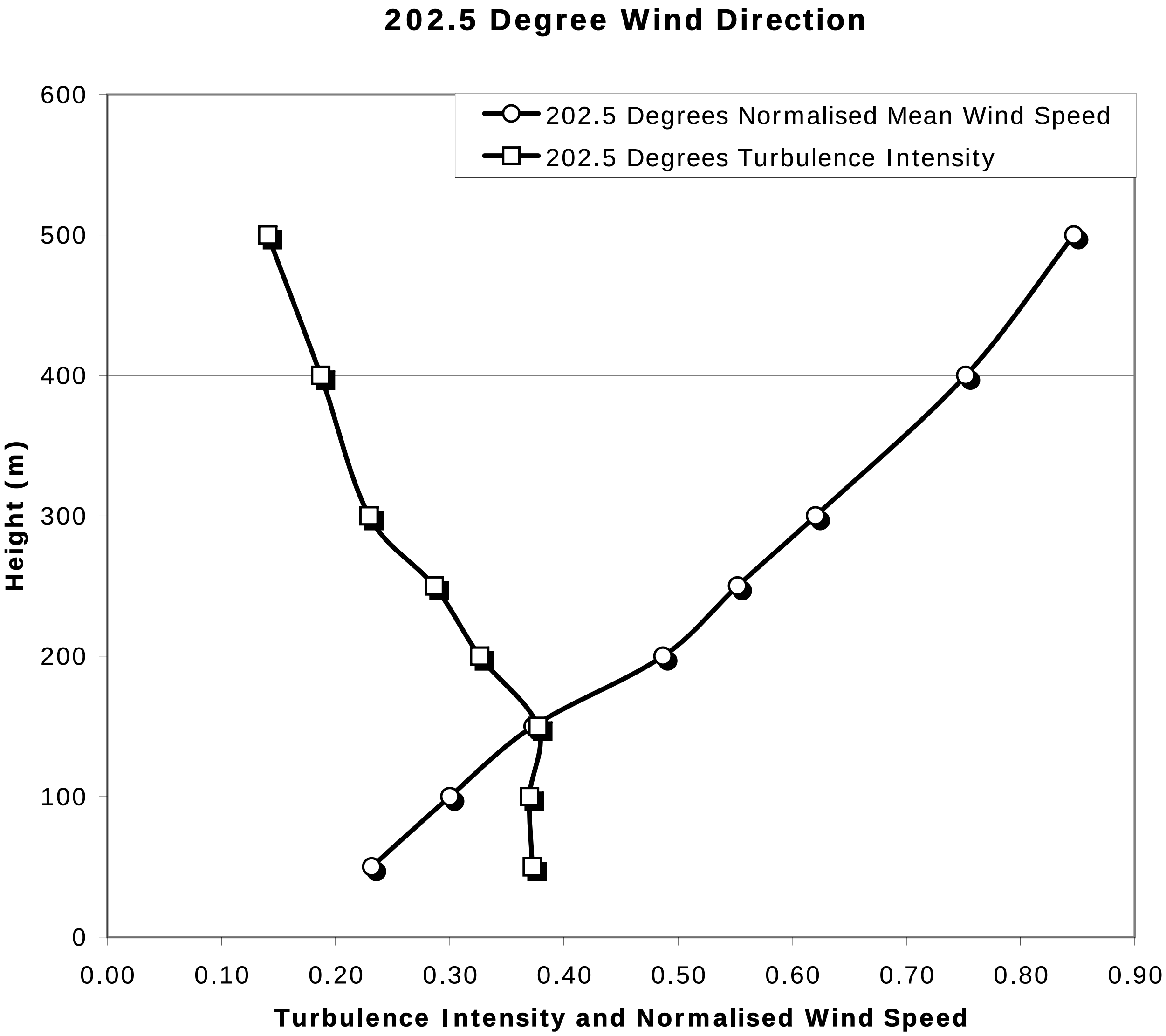

112.5 Degree Wind Direction
112.5 Degrees Normalised Mean Wind Speed
112.5 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.20
0.40
0.60
0.80
1.00
Turbulence Intensity and Normalised Wind Speed

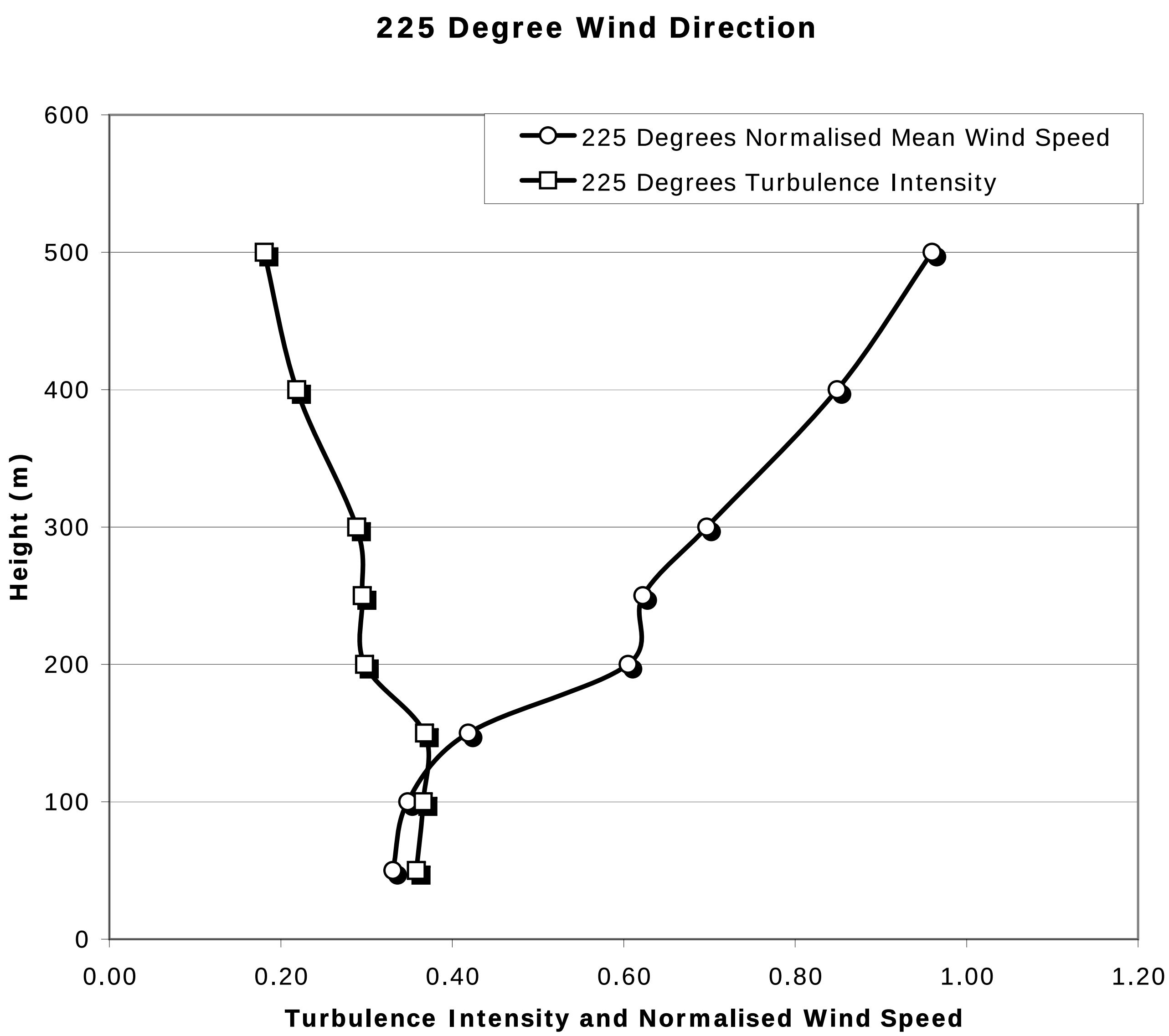

135 Degree Wind Direction
135 Degrees Normalised Mean Wind Speed
135 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
Turbulence Intensity and Normalised Wind Speed

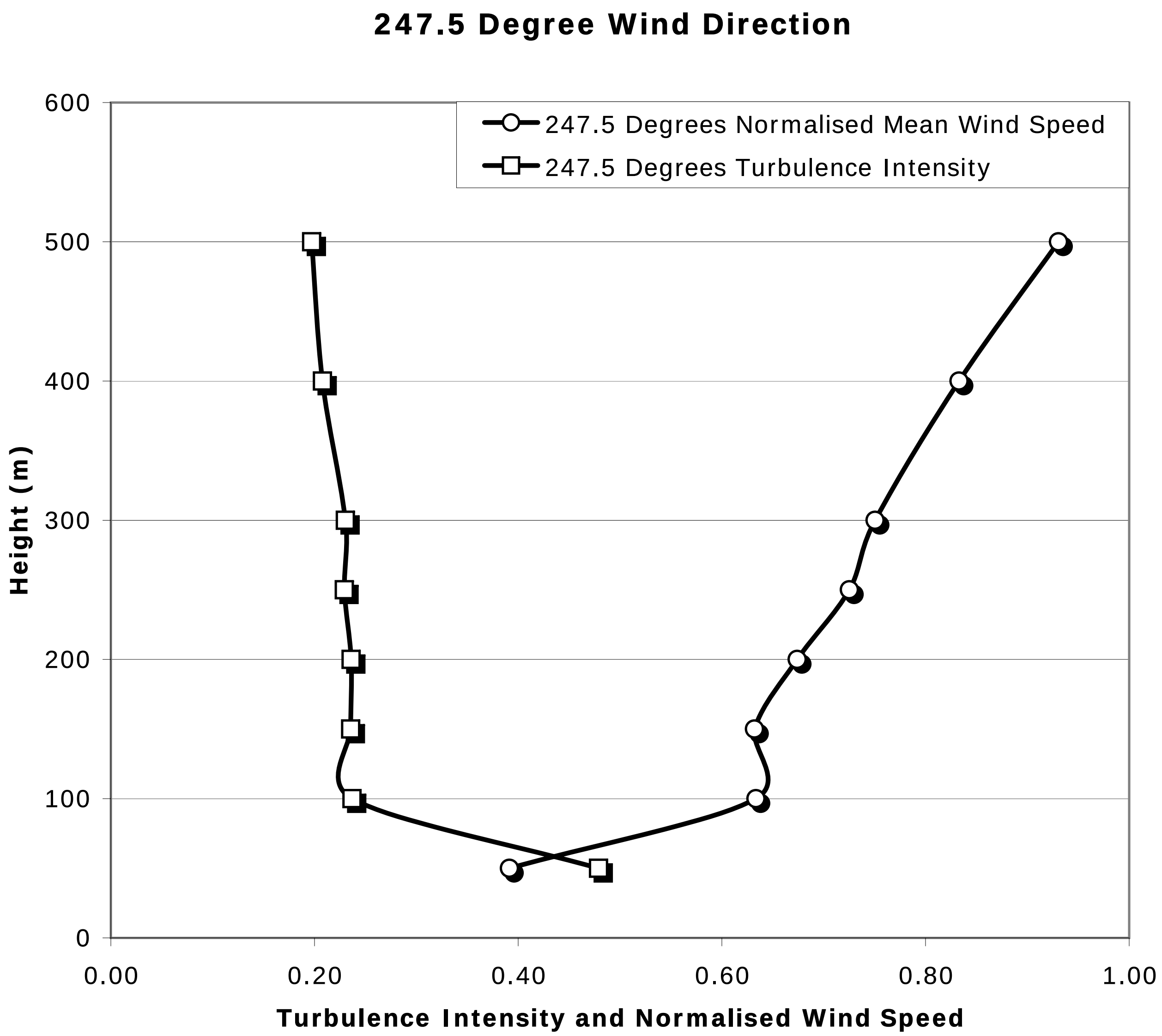


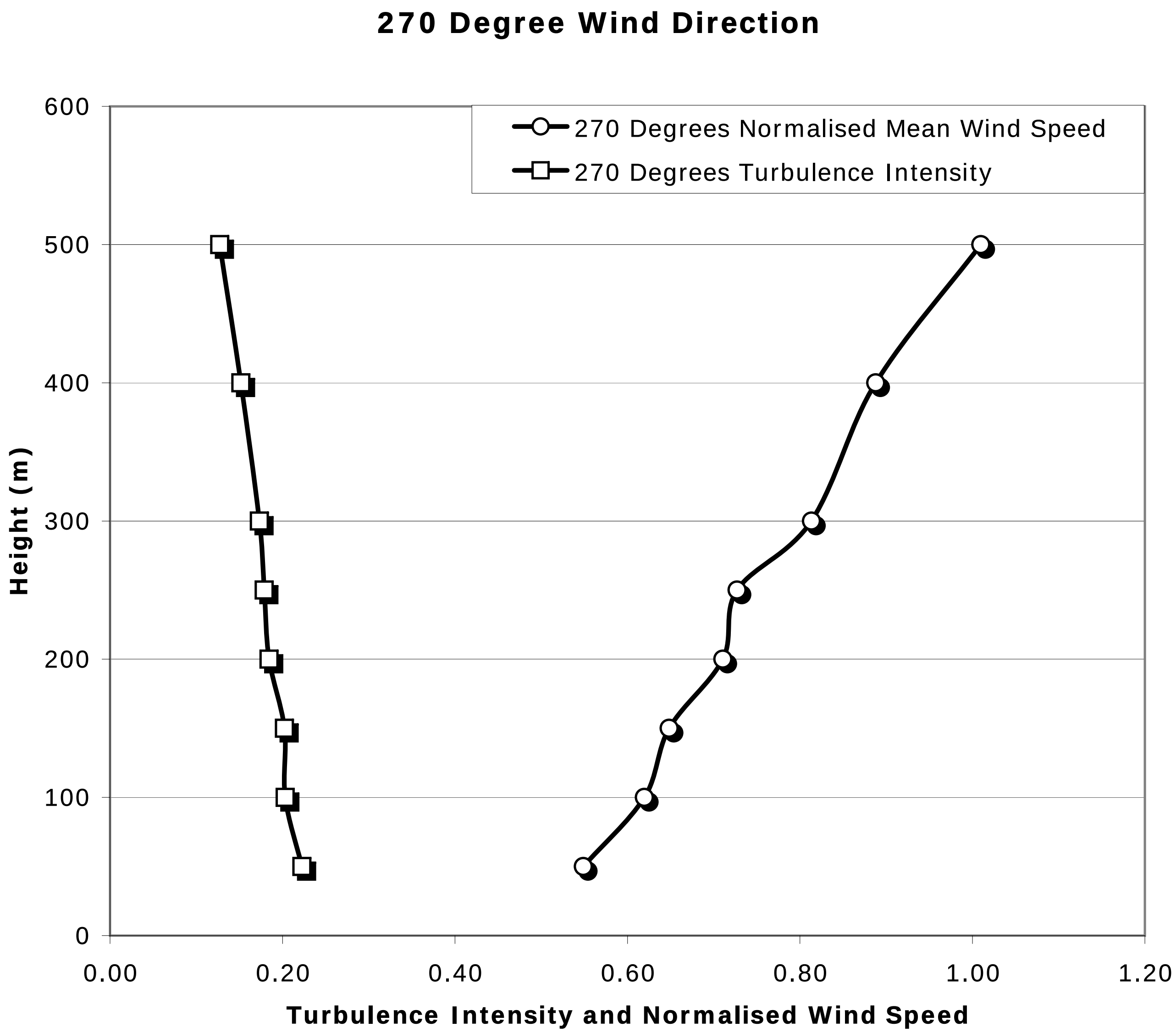
157.5 Degree Wind Direction
157.5 Degrees Normalised Mean Wind Speed
157.5 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.20
0.40
0.60
0.80
1.00
Turbulence Intensity and Normalised Wind Speed


180 Degree Wind Direction
180 Degrees Normalised Mean Wind Speed
180 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.20
0.40
0.60
0.80
1.00
Turbulence Intensity and Normalised Wind Speed

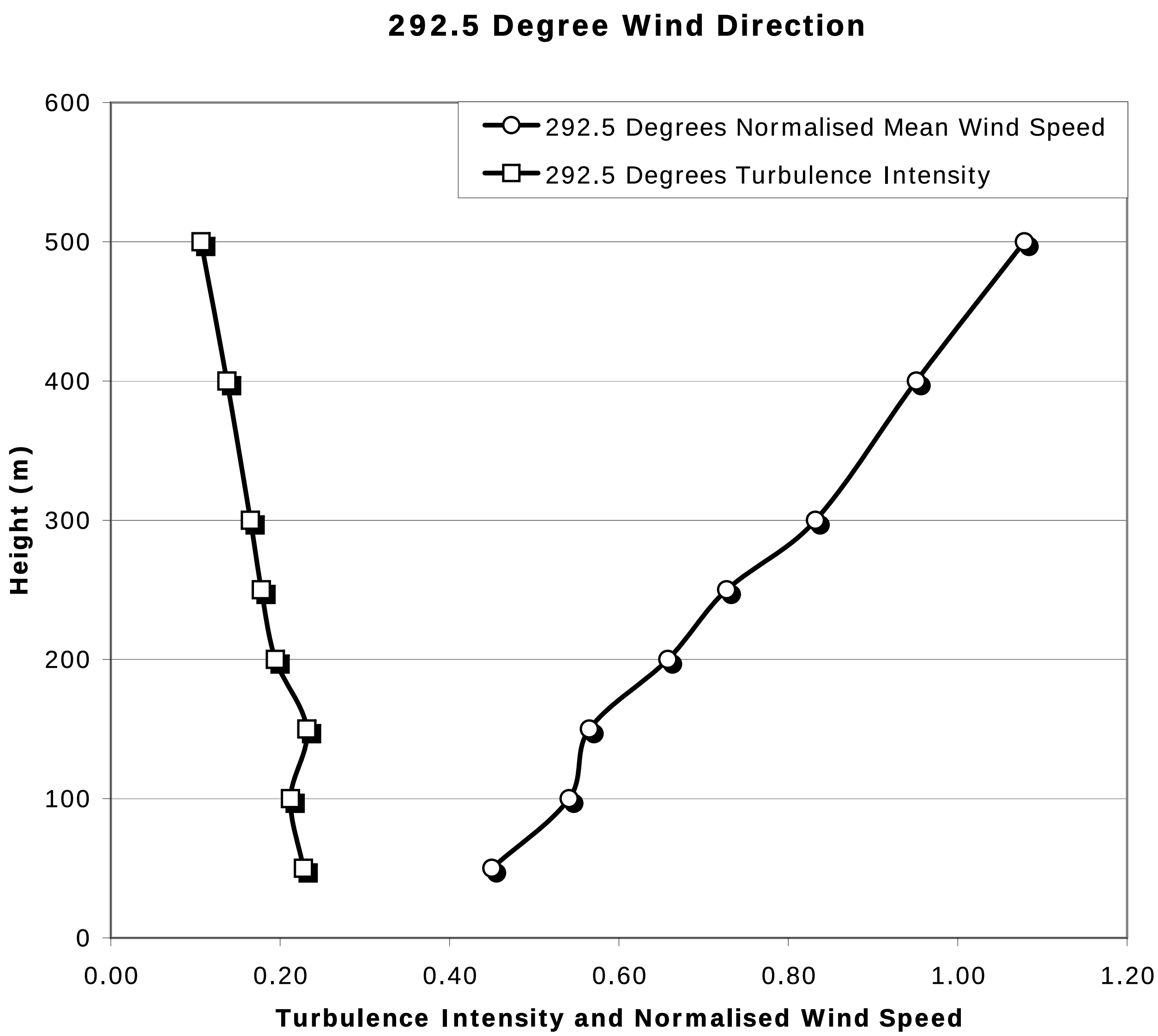

202.5 Degree Wind Direction
202.5 Degrees Normalised Mean Wind Speed
202.5 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
Turbulence Intensity and Normalised Wind Speed


225 Degree Wind Direction
225 Degrees Normalised Mean Wind Speed
225 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Turbulence Intensity and Normalised Wind Speed

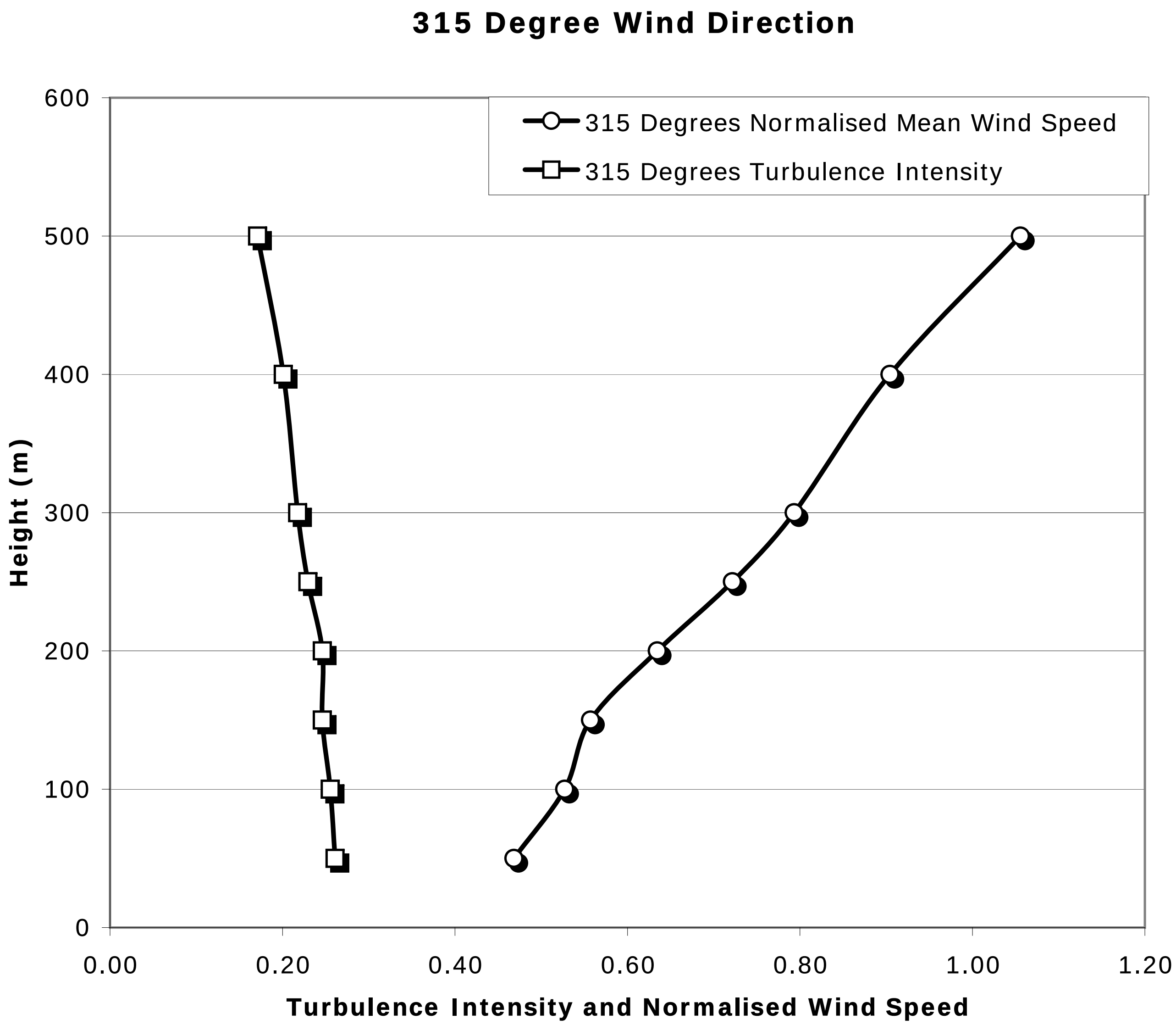

247.5 Degree Wind Direction
247.5 Degrees Normalised Mean Wind Speed
247.5 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.20
0.40
0.60
0.80
1.00
Turbulence Intensity and Normalised Wind Speed



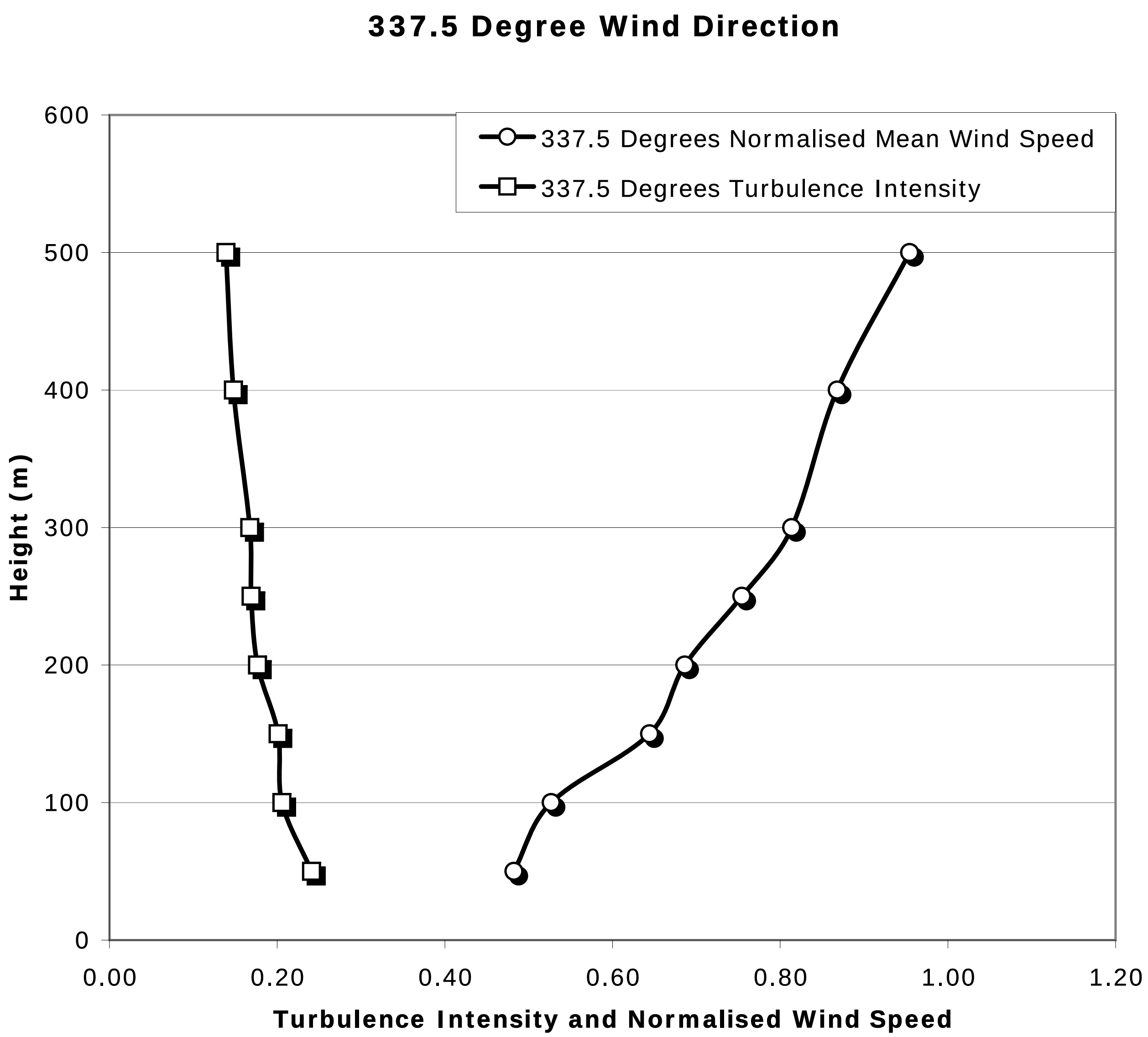
270 Degree Wind Direction
270 Degrees Normalised Mean Wind Speed
270 Degrees Turbulence Intensity
Height (m)
0
100
200
300
400
500
600
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Turbulence Intensity and Normalised Wind Speed



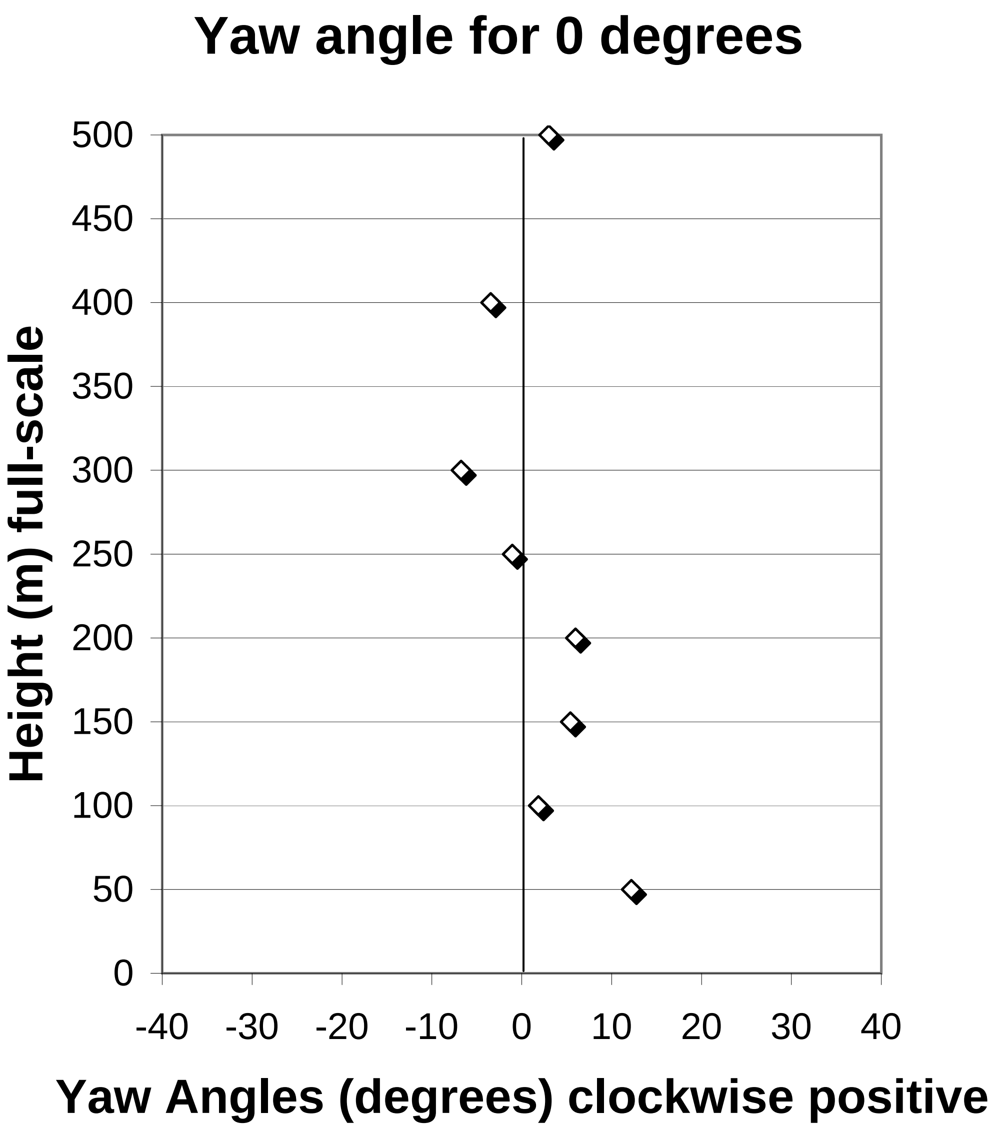
292.5 Degree Wind Direction
292.5 Degrees Normalised Mean Wind Speed
292.5 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Turbulence Intensity and Normalised Wind Speed



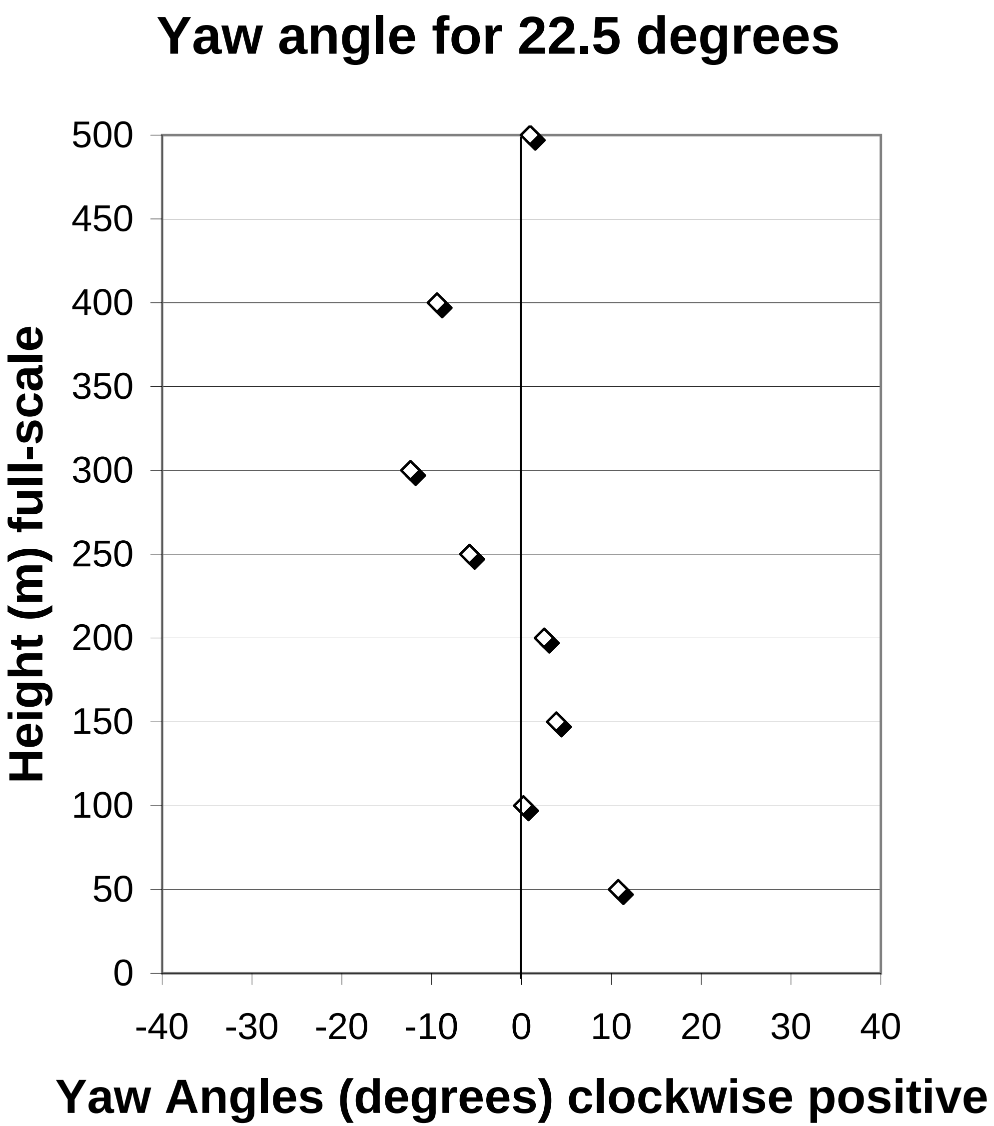
315 Degree Wind Direction
315 Degrees Normalised Mean Wind Speed
315 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Turbulence Intensity and Normalised Wind Speed



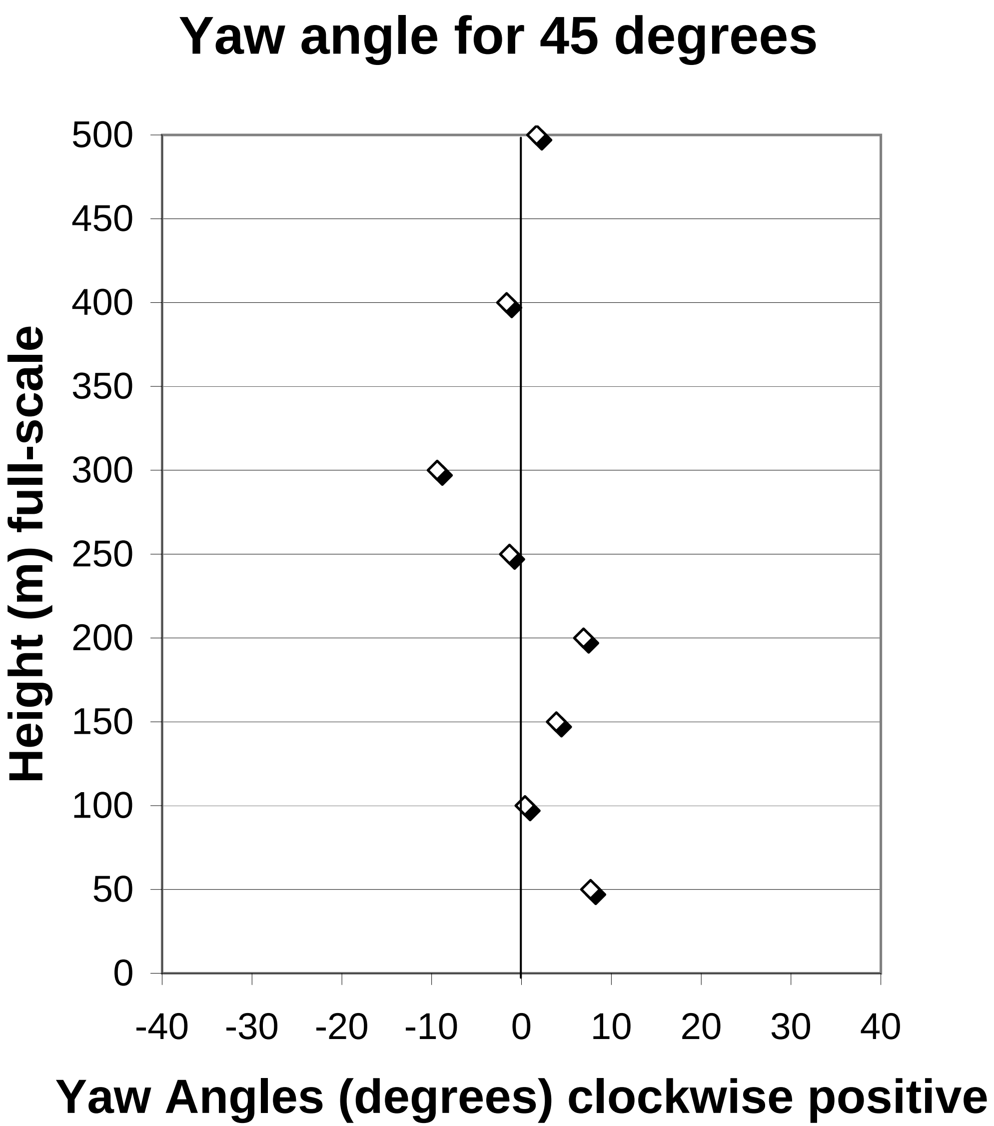
337.5 Degree Wind Direction
337.5 Degrees Normalised Mean Wind Speed
337.5 Degrees Turbulence Intensity
Height (m)
600
500
400
300
200
100
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Turbulence Intensity and Normalised Wind Speed



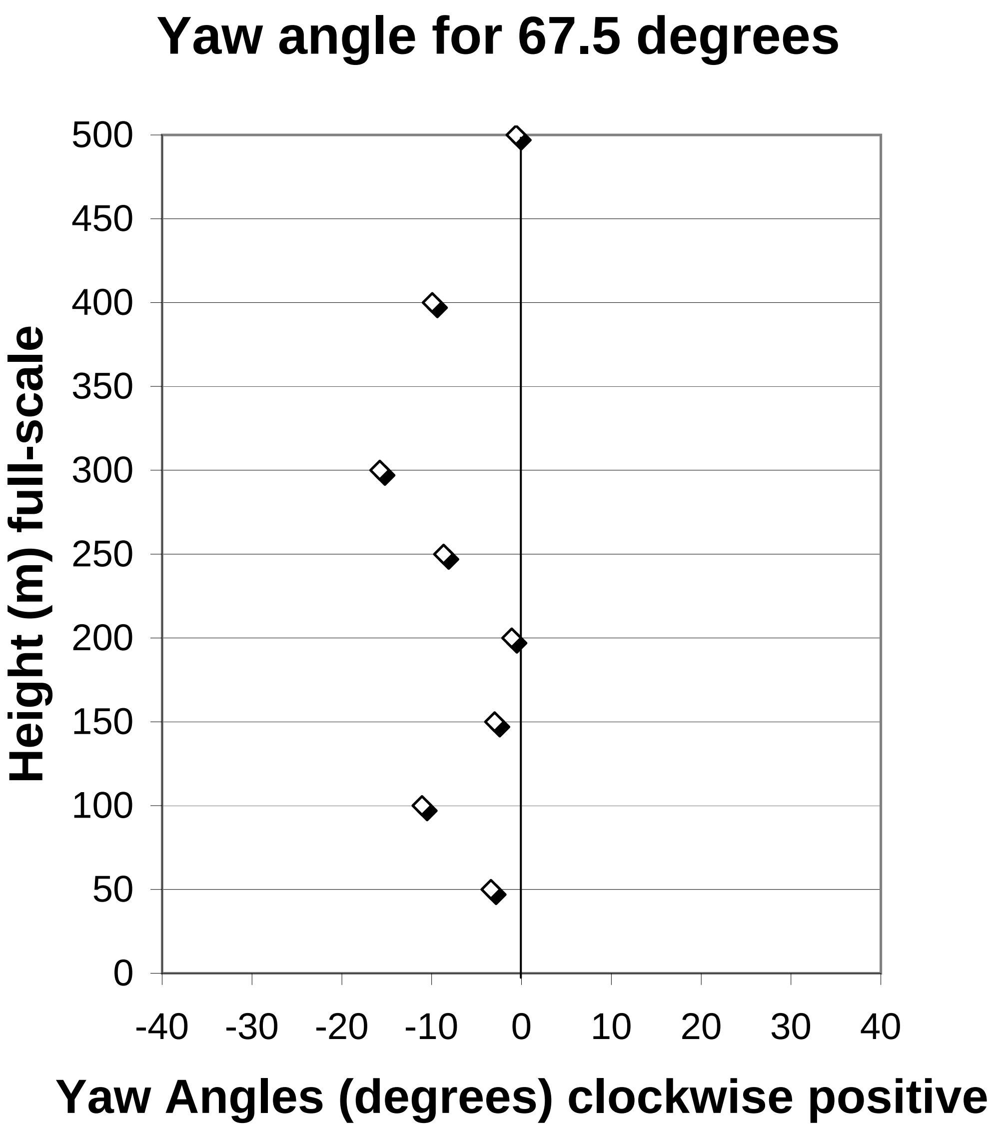
Yaw angle for 0 degrees
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Height (m) full-scale
Yaw Angles (degrees) clockwise positive



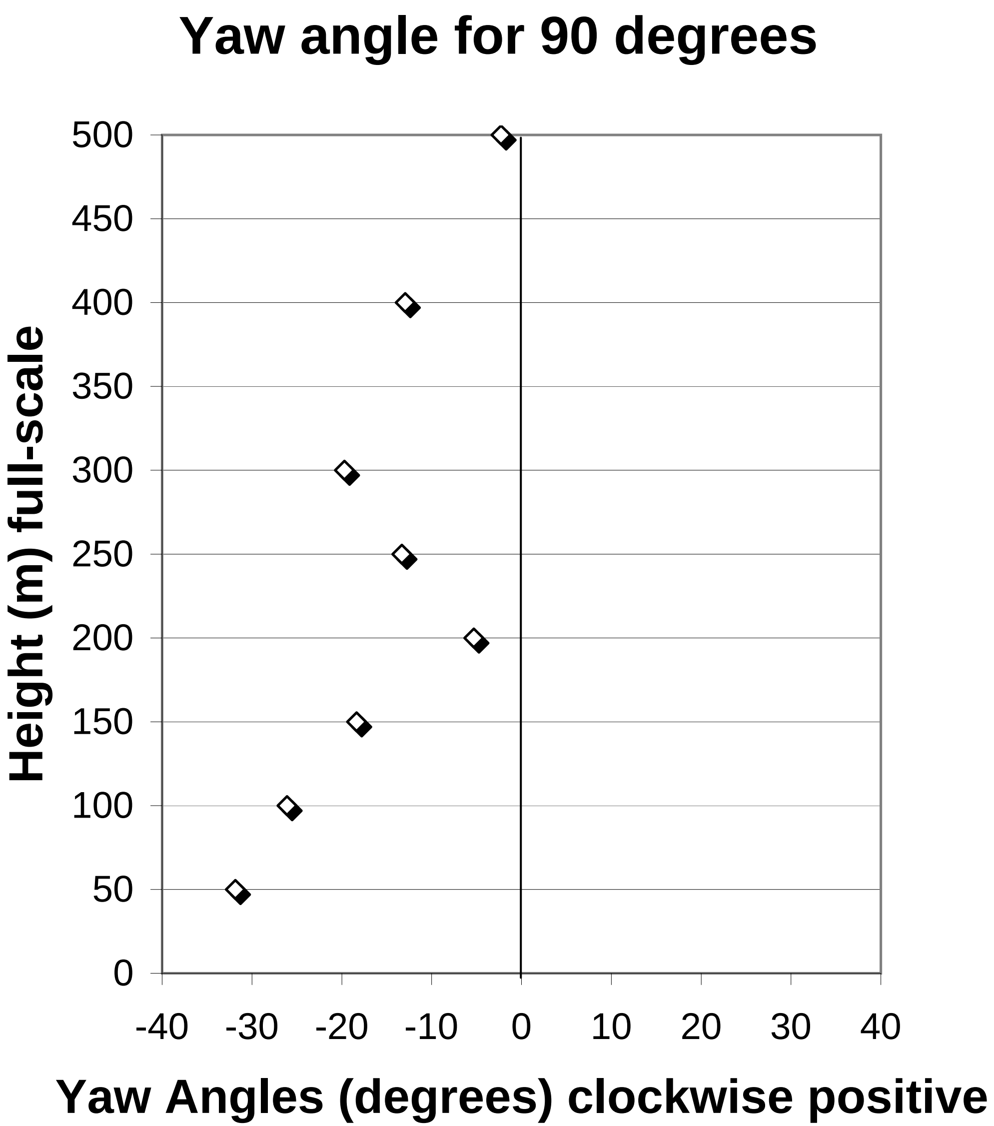
Yaw angle for 22.5 degrees
Height (m) full-scale
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Yaw Angles (degrees) clockwise positive

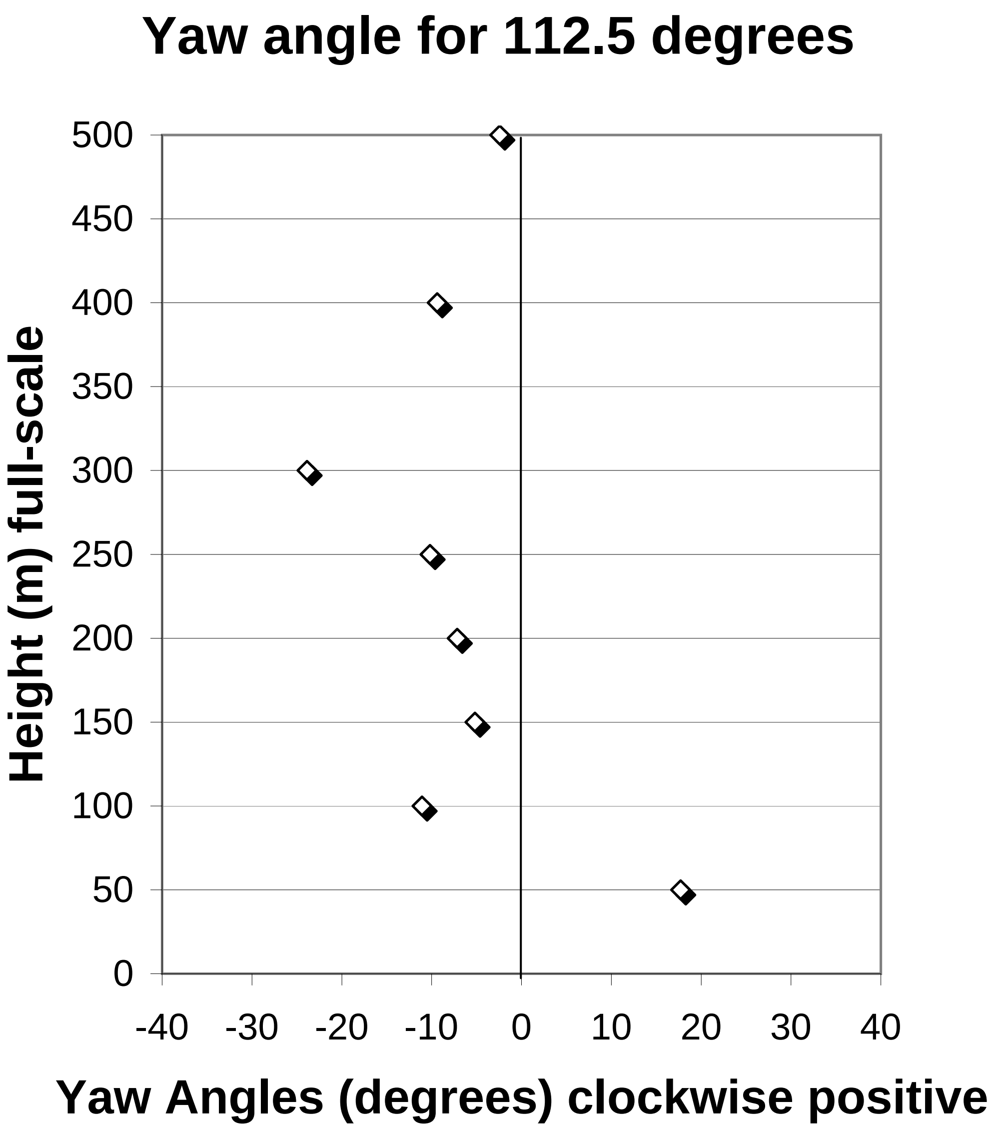


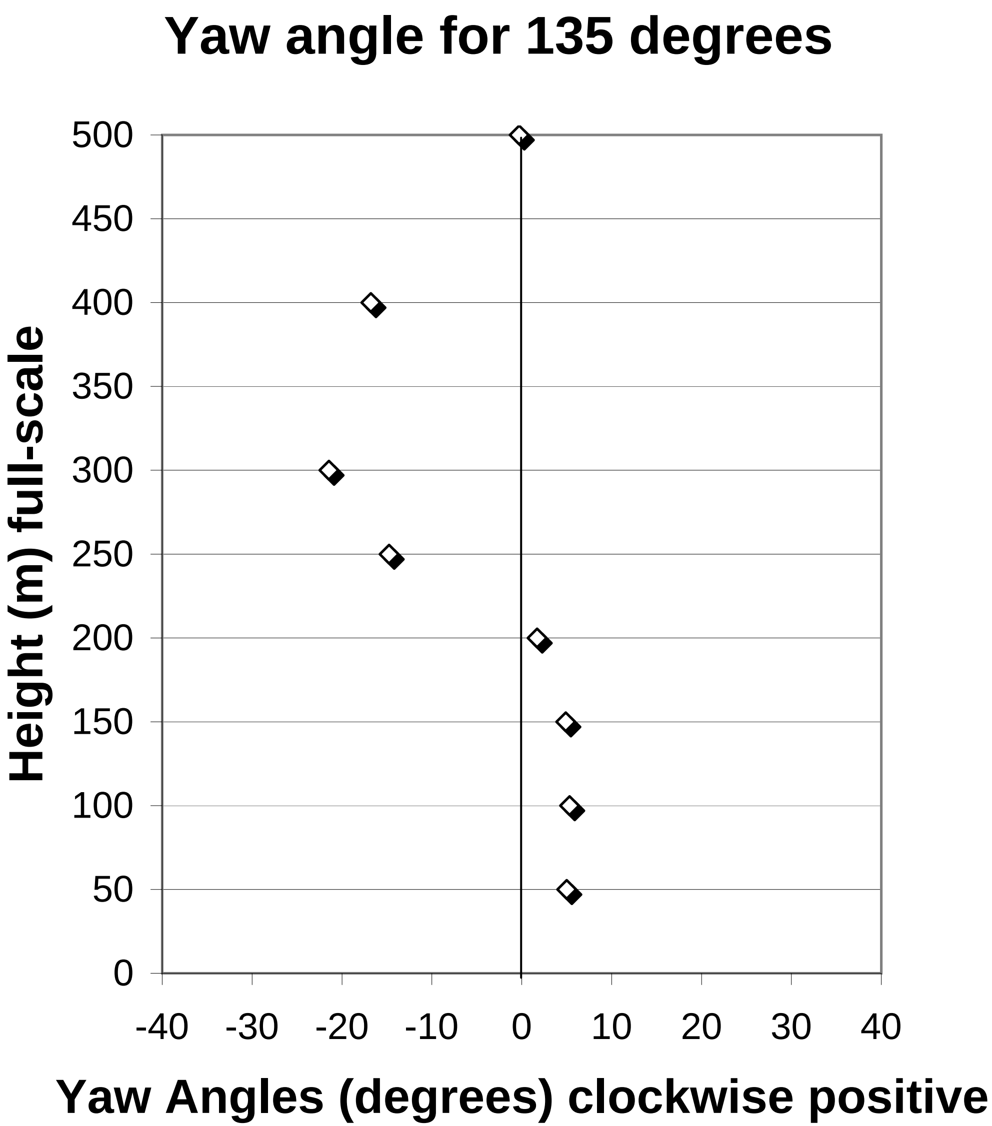
Yaw angle for 45 degrees
Height (m) full-scale
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Yaw Angles (degrees) clockwise positive



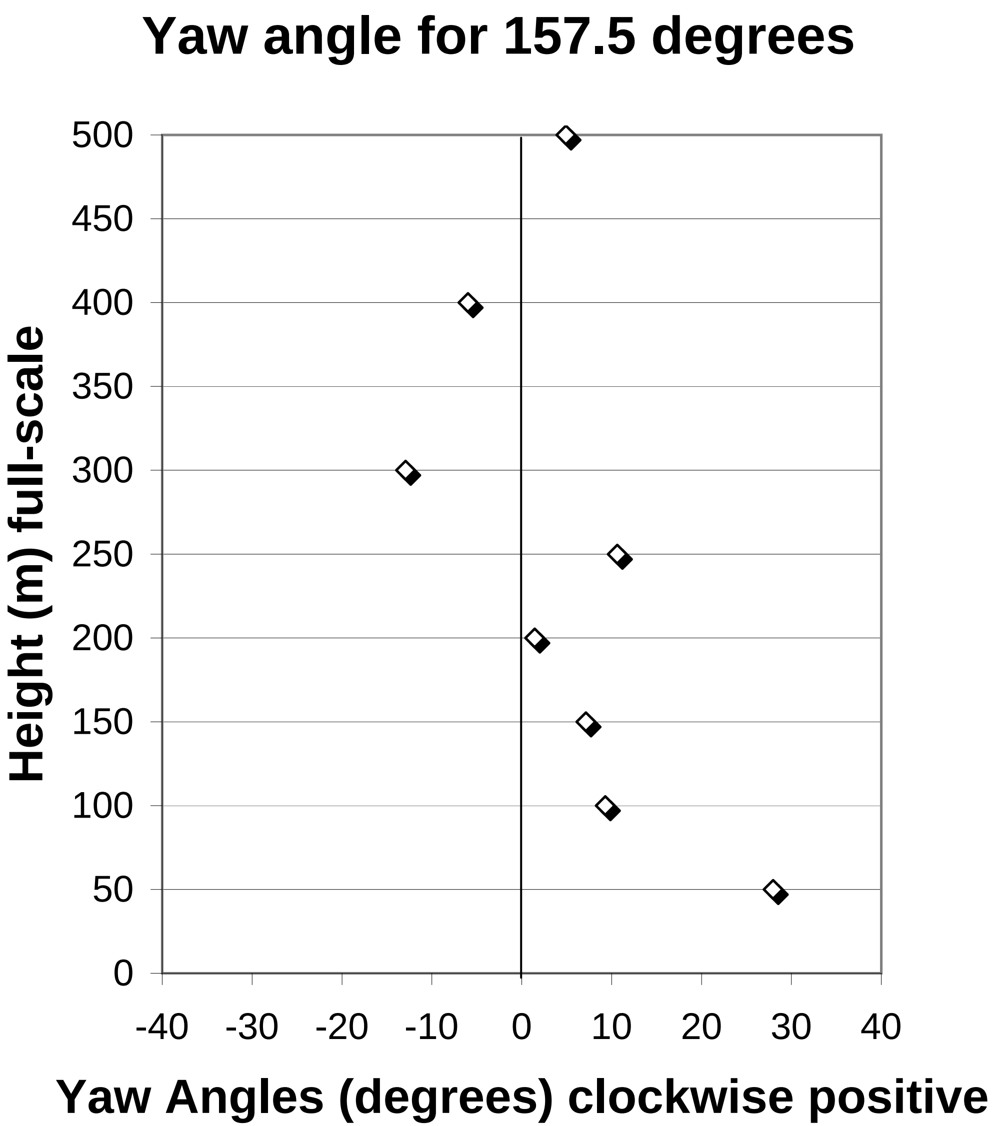
Yaw angle for 67.5 degrees
Height (m) full-scale
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Yaw Angles (degrees) clockwise positive

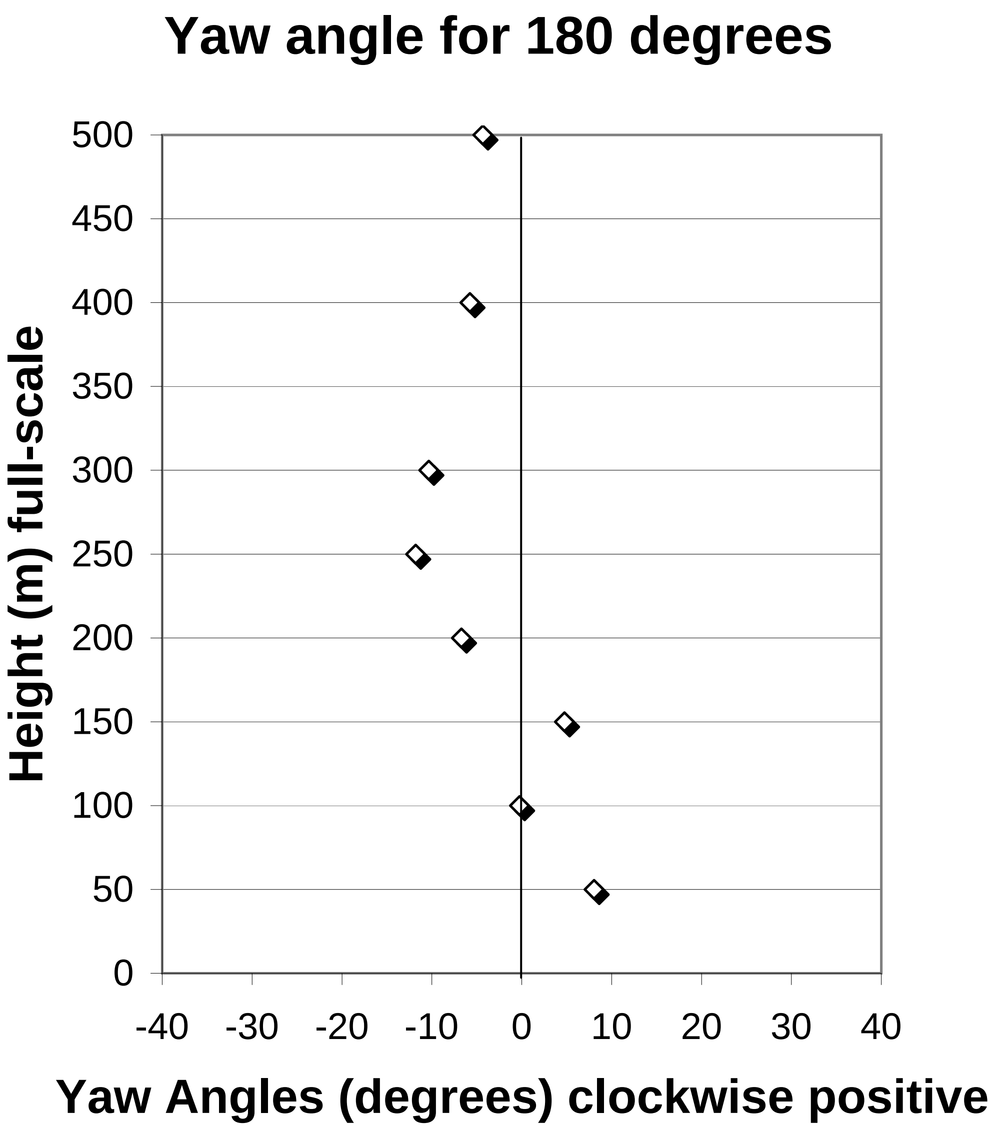

Yaw angle for 90 degrees
Height (m) full-scale
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Yaw Angles (degrees) clockwise positive


Yaw angle for 112.5 degrees
500
450
400
350
300
250
200
150
100
50
0
Height (m) full-scale
-40
-30
-20
-10
0
10
20
30
40
Yaw Angles (degrees) clockwise positive



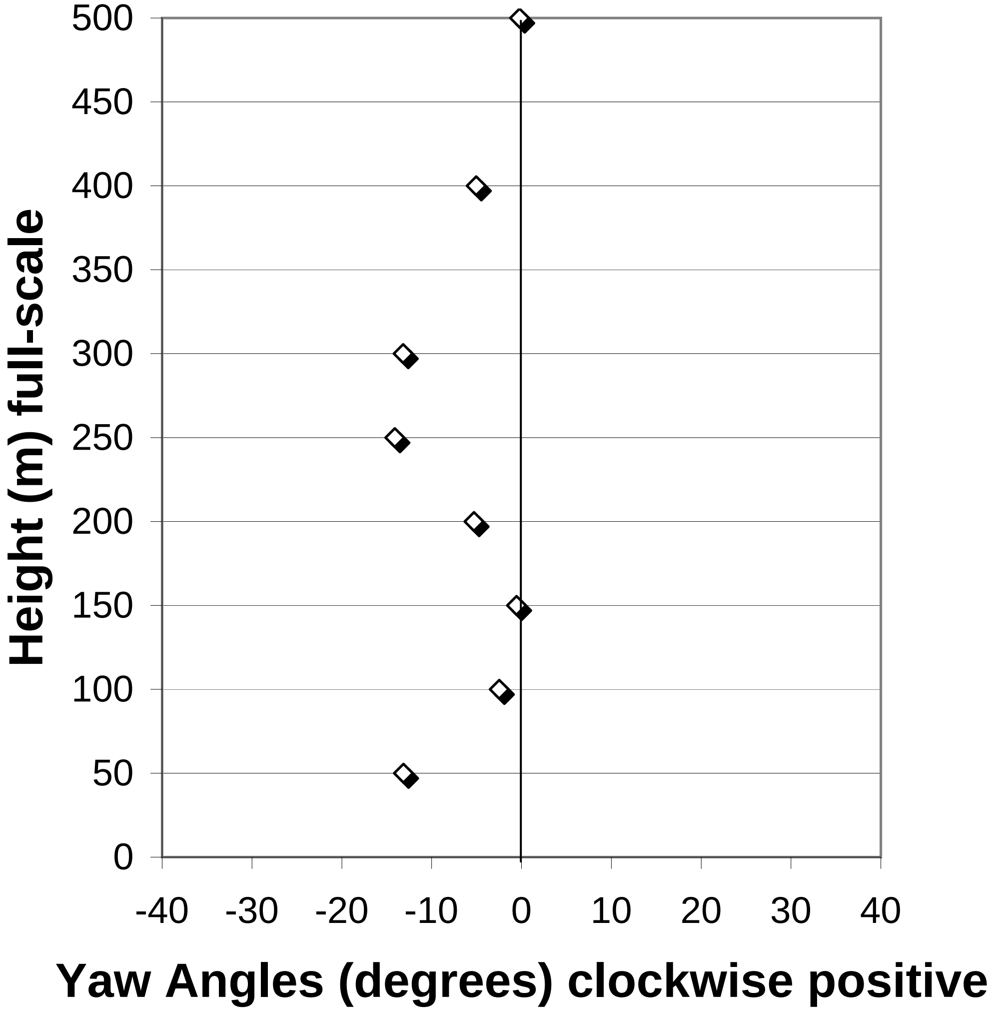
Yaw angle for 135 degrees
Height (m) full-scale
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Yaw Angles (degrees) clockwise positive

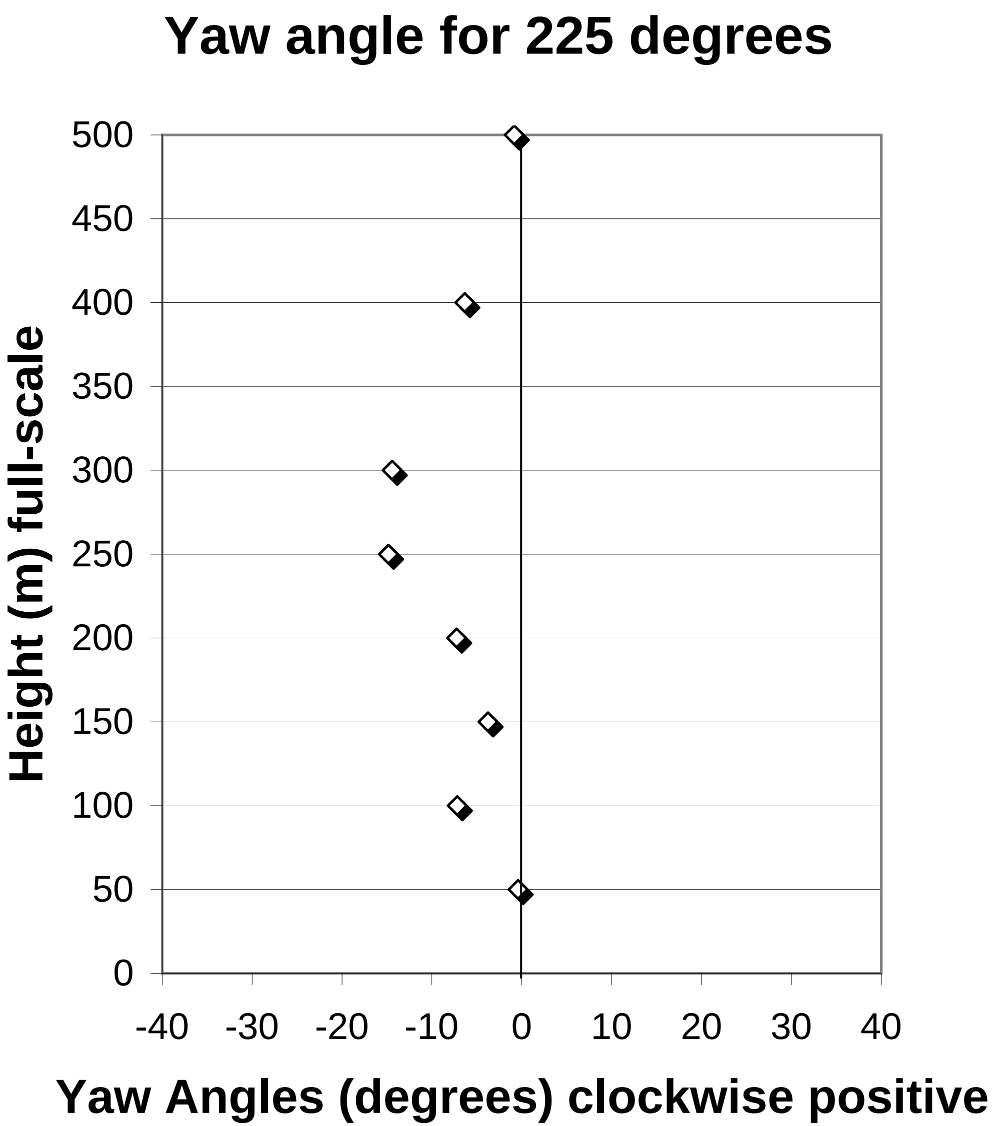

Yaw angle for 157.5 degrees
500
450
400
350
300
250
200
150
100
50
0
Height (m) full-scale
-40
-30
-20
-10
0
10
20
30
40
Yaw Angles (degrees) clockwise positive



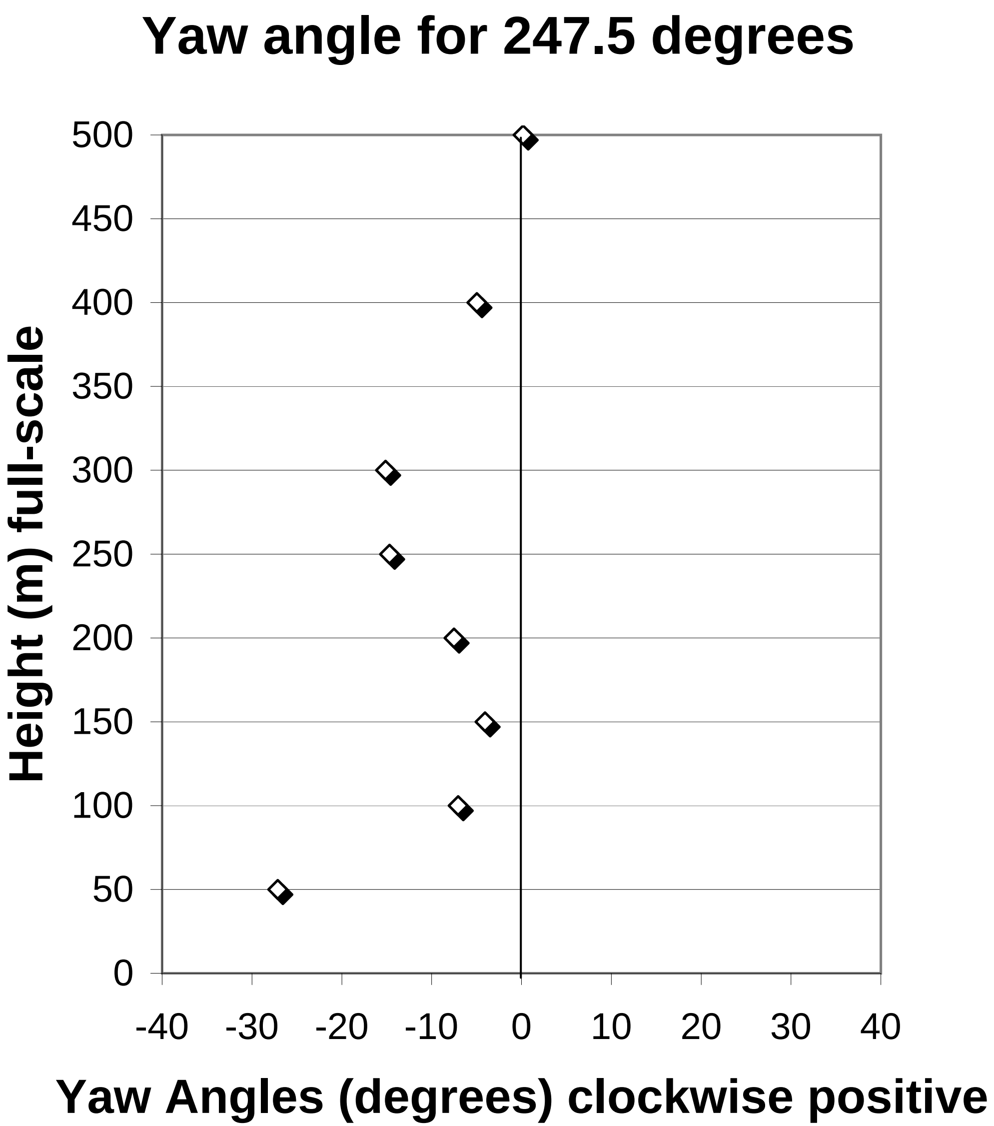
Yaw angle for 180 degrees
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Height (m) full-scale
Yaw Angles (degrees) clockwise positive

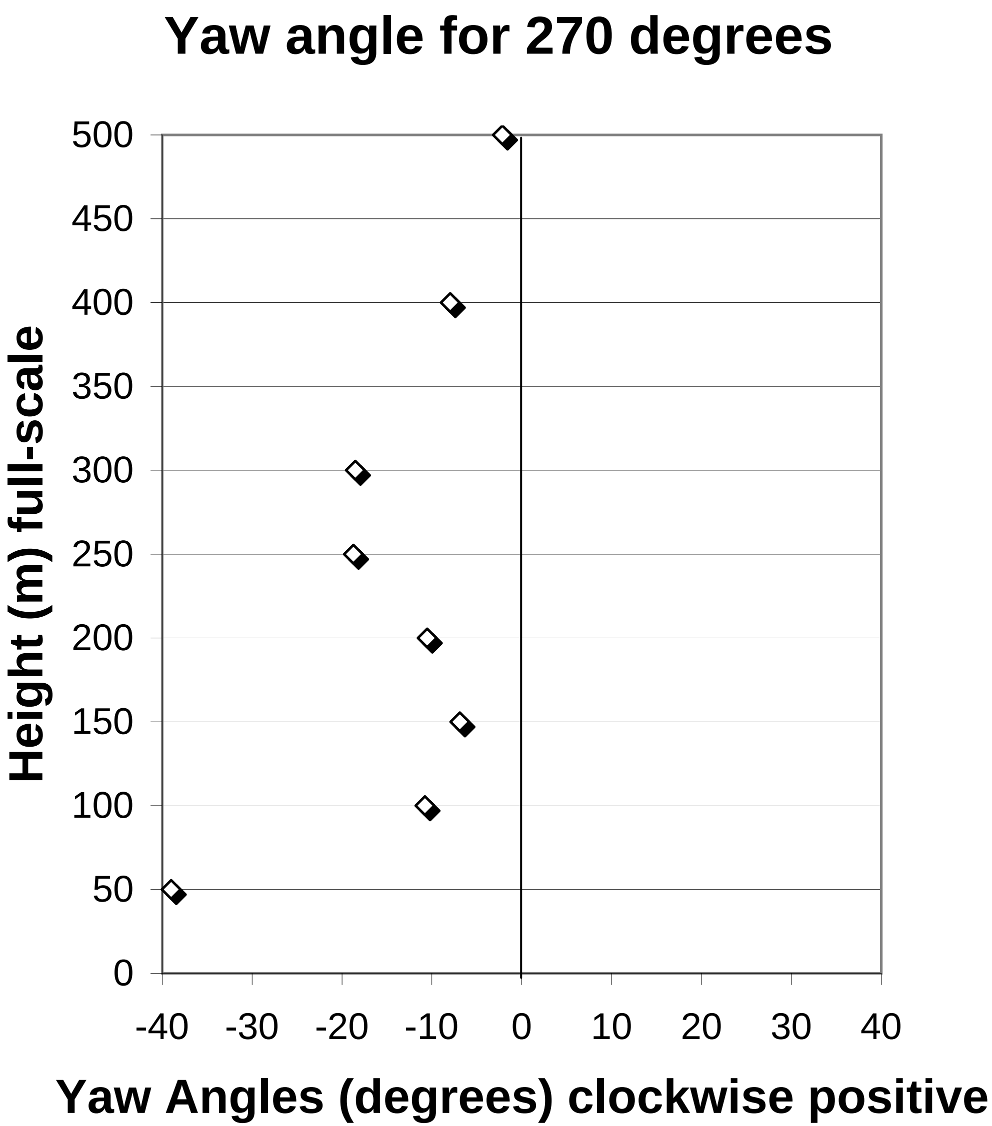
Yaw angle for 202.5 degrees



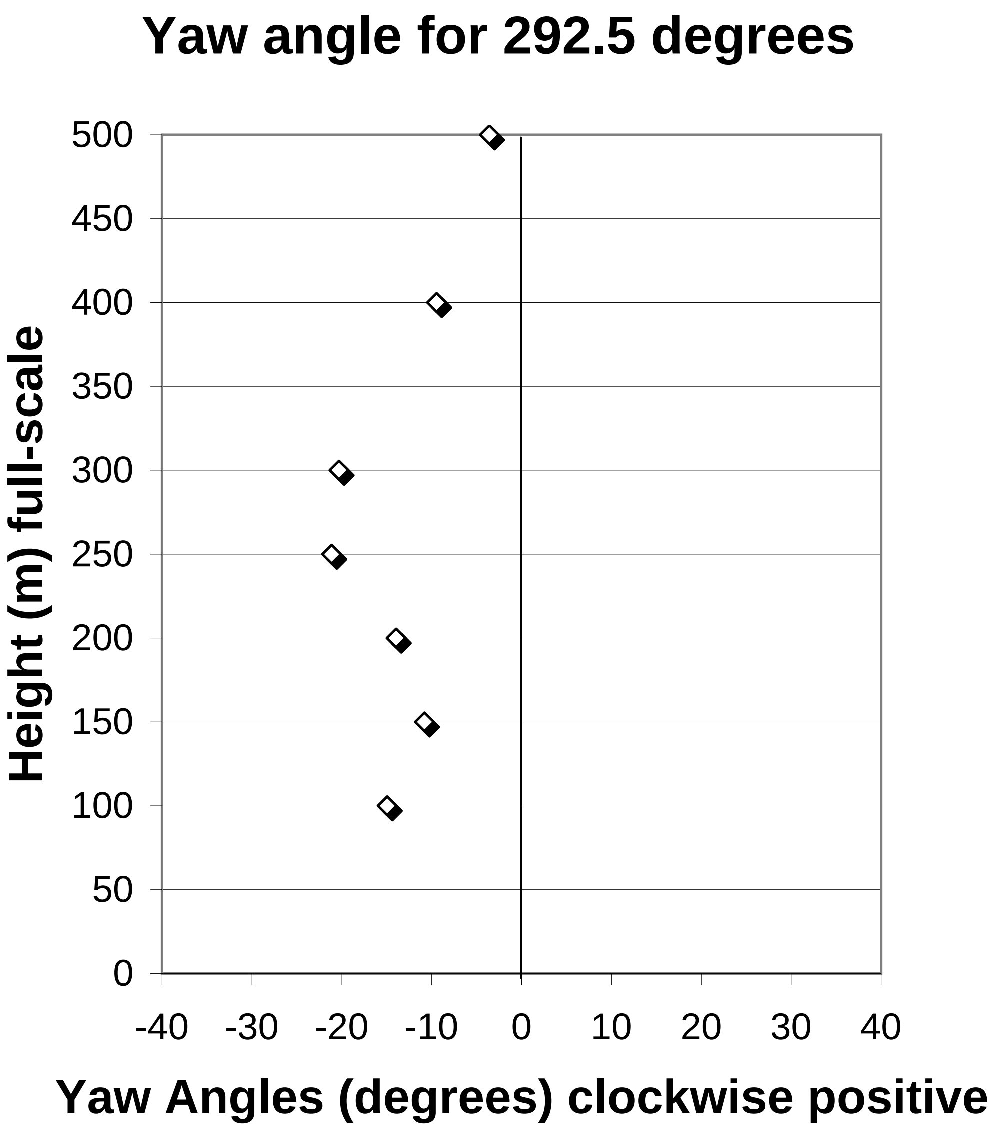


Yaw angle for 225 degrees
Height (m) full-scale
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Yaw Angles (degrees) clockwise positive

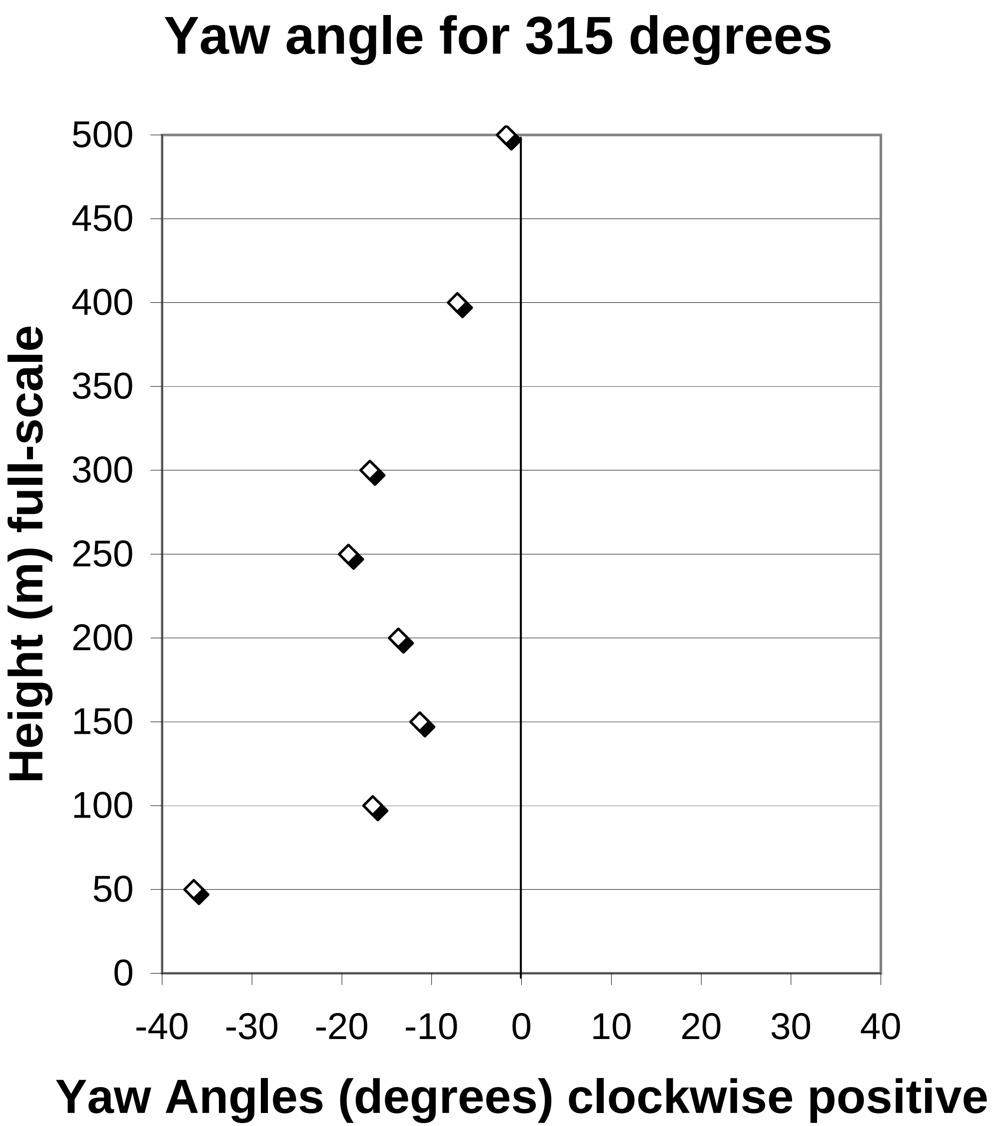

Yaw angle for 247.5 degrees
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Height (m) full-scale
Yaw Angles (degrees) clockwise positive

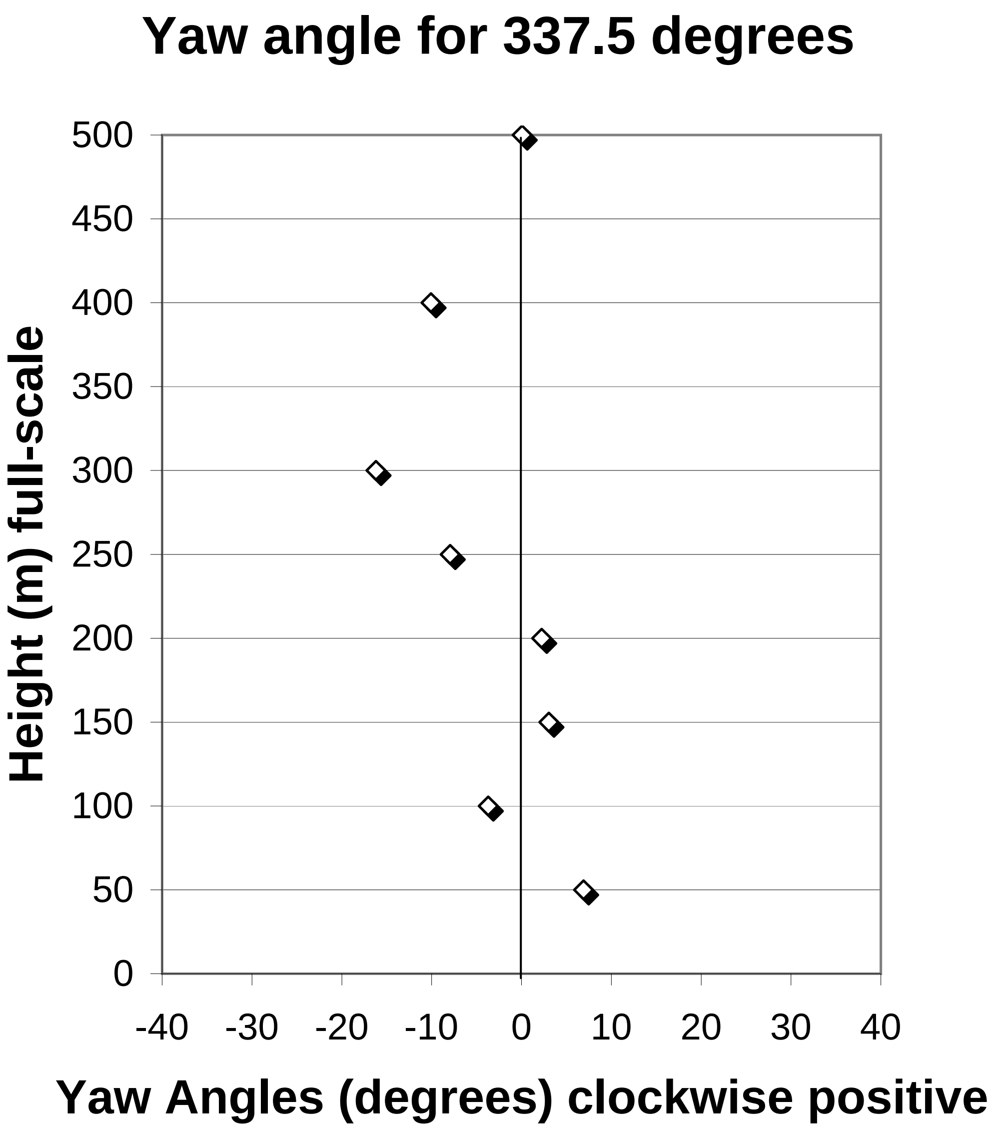


Yaw angle for 270 degrees
Height (m) full-scale
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Yaw Angles (degrees) clockwise positive



Yaw angle for 292.5 degrees
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Height (m) full-scale
Yaw Angles (degrees) clockwise positive


Yaw angle for 315 degrees
Height (m) full-scale
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Yaw Angles (degrees) clockwise positive



Yaw angle for 337.5 degrees
Height (m) full-scale
500
450
400
350
300
250
200
150
100
50
0
-40
-30
-20
-10
0
10
20
30
40
Yaw Angles (degrees) clockwise positive

Appendix III

Result of Frequency of Winds for the Oil Street Site

APPENDIX III
WIND SPEED FREQUENCY TABLES & WIND ROSE FOR OIL STREET SITE

Table 1: Percentage occurrence of directional winds at 200m (with the effect of Yaw Angle)

Wind Angle (°)	Percentage Occurrence (%) for wind speed ranges:				
	0-3.3 m/s	3.4-7.9 m/s	8.0-13.8 m/s	>13.8 m/s	Total
0	1.2%	3.6%	2.0%	0.2%	6.9%
22.5	3.3%	6.7%	2.1%	0.1%	12.2%
45	3.1%	5.3%	0.7%	0.0%	9.1%
67.5	5.0%	14.9%	4.9%	0.2%	24.9%
90	3.0%	8.4%	4.7%	0.4%	16.5%
112.5	2.0%	2.0%	0.4%	0.0%	4.5%
135	1.8%	1.2%	0.2%	0.0%	3.2%
157.5	2.2%	1.6%	0.2%	0.0%	4.0%
180	1.6%	1.3%	0.1%	0.0%	3.0%
202.5	2.2%	1.9%	0.1%	0.0%	4.2%
225	1.7%	2.7%	0.3%	0.0%	4.7%
247.5	1.0%	1.8%	0.3%	0.0%	3.1%
270	0.9%	0.7%	0.1%	0.0%	1.7%
292.5	0.6%	0.2%	0.0%	0.0%	0.8%
315	0.2%	0.1%	0.0%	0.0%	0.3%
337.5	0.8%	0.4%	0.1%	0.0%	1.3%

Corresponding wind rose (with the effect of Yaw Angle).