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Wind Tunnel Modelling Of Hill And Vefetation Influence On Wind Power Availability

Task 2: Winds over Two Dimensional Hills

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1 INTRODUCTION

US Wind Power Corporation contracted Dr. Robert N. Meroney and Dr. David E. Neff of Colorado State University to forecast wind turbine power performance in forested regions. The primary focus being the potential power benefits of cutting trees near wind turbine sites located on a variety of hill shapes and slopes. This project consisted of three different studies (tasks), each being summarized in a separate report. Task 1 reviews the literature database on analytical, numerical and empirical models suitable for describing potential wind generation benefits in forested environments. Task 2, the subject the this report, uses a physical model (wind tunnel simulation) to estimate wind turbine power availability on two dimensional ridges with various forest clearings, ridge shapes and slopes. Task 3 physical models the complex topography of a potential wind turbine site area to determine the effect of forest clearing on wind turbine power availability for several hilltops within the site area.

This Task 2 report describes the experimental methodology and measurement results obtained in physical modeling a 200 foot high ridge (two dimensional) for a variety of forest clearings, tree heights, ridge shapes and slopes. A model scale of 1:1000 was chosen to be representative of the atmospheric boundary layer winds. Measurements of wind speed at several different heights above the hill crest were obtained for 96 different run conditions consisting of;

i) both triangular and sinusoidal ridge shapes,
ii) ridge slopes of 1:2, 1:3, 1:5 and 1:10,
iii) tree heights of 20, 40 and 60 feet, and
iv) forest clearings of no tree removal, highest tree top being level with hill top ground level, highest tree top being 100 feet lower than hill top ground level and all trees removed to the base of the hill.

These measured wind velocities are then normalized appropriately for comparative analysis of fractional speed ups and wind power availability.

2 EXPERIMENTAL SETUP

2.1 Model Specifications

Modeling 200 foot high ridges at a 1:1000 length scale ratio resulted in 6.1 centimeters (cm) high model ridges. Eight model ridges were constructed out of wood and plastic products, four sinusoidal and four triangular ridges at ridges slopes of 1:2, 1:3, 1:5 and 1:10 (height:half base). The full width of the 1:2, 1:3, 1:5 and 1:10 sloped ridges were 24.4, 36.6, 61.0 and 122.0 cm respectively. The wind tunnel into which these model ridges were placed limited all ridge lengths to 183 cm. The aspect ratio, i.e. ridge length to ridge full width, for each of these ridge slopes was 7.5, 5.0, 3.0 and 1.5. Figure 1 shows the cross sectional shapes of these eight model ridges.

The tree cover was simulated with an Astroturf product manufactured by Monsanto for door mats and walkways. The Astroturf, made of polyethylene, consisted of vertical bristle groups (8 bristles per group, group spacing of 1.14 cm), 1.8 cm tall, connected to flexible matting, 0.15 cm thick. At a length scale ratio of 1:1000 these 1.8 cm tall bristles are representative of the 60 foot tall trees. To simulate 40 and 20 foot tall trees sheep shears were use to cut these bristles down to 1.2 cm and 0.6 cm respectively. Figure 2 displays photographs of these three simulated forest models. Accurate multiple measurements of the three forest cover mats found that the mean tree heights were 23', 41' and 56' rather than the design heights of 20', 40' and 60'. The design heights of 20', 40' and 60' will be how these different forest covers are specified in this report.

Measurements of the percent open volume for these three forest covers were 63% for 20' trees, 82% for 40' trees and 89% for 60' trees. The bristle, which simulate the trees, on the matting were always perpendicular to the mat backing thus when the matting was stapled to the model ridge contour the simulated trees were not in a vertical position. Figure 3 shows a series of four drawings of the 60' trees on the 1:3 sloped sine ridge.

2.2 Wind Tunnel Configuration

The experiments were performed in the Meterological Wind Tunnel (MET) facility at Colorado State Unversity's Engineering Research Center. Figure 4 displays a schematic detailing the major features of this facility. This wind tunnel has a speed range of 0 to 40 m/s. The 9:1 contraction ratio upwind of the test section produces a stable, uniform flow with low turbulence (~0.1%). The test section length upwind (~20 meters) of the model site area has sufficient fetch for the natural development of simulated atmospheric boundary layer winds. The test section has a cross-sectional size of 183 cm x 183 cm. The model ridges were always 6.1 cm tall thus the wind tunnel flow blockage ratio was ~ 3.3 percent.

The MET's test section entrance did not have any turbulence conditioning spires. The initial twelve meters of the test section floor was covered with thin carpet type roughness, this was followed by six meters of Commercial Grade Astroturf with a bristle height of ~1.2 cm. These sections of ground roughness were present during all test measurements. Following these fixed ground roughness conditions, two tree height specific roughness mats of 183 cm wide by 152 cm long were placed end to end on the tunnel floor. The different model ridges were placed underneath and centered in-between these two mats. The placement of the model ridge and the downwind mat was adjusting dependent on the specific tree clearing on the ridge top being tested. Staples were used to insure that these roughness mats followed the surface contour of the different model ridges.

2.3 Velocity Profile Measurements

Pitot-static probes were used as a velocity standard during the calibration of the hot film velocity measurement system and to provide two reference velocity measurement points for each hot film measurement point within all vertical velocity profiles. The principles of operation of pitot-static probes are described in any fundamental text on fluid mechanics and will not be discussed in detail here. The operational relationship for these probes is $U = (2g_c \Delta P/\rho)^{1/2}$, where U = velocity, g_c = gravitational conversion constant, ΔP = difference between static and dynamic pressures, and ρ is the air density. The air density, ρ, is calculated from the ideal gas law and ΔP is measured using an electronic manometer.

Single-hot-film (TSI 1210 Sensor) measurements were used to document the longitudinal mean velocities and the longitudinal turbulence levels for all velocity profiles in this test program. During calibration the hot film probe voltage was recorded at several velocities covering the range of interest. These voltage-velocity (E,U) pairs are then regressed to the equation $E^2 = A + BU^c$ via a least squares approach for various assumed values of the exponent c. Convergence to the minimum residual error was accelerated by using the secant method to find the best new estimate for the exponent c.

The hot-film-probe was mounted on a vertical traverse and positioned over the desired profile location in the wind tunnel. The anemometer's output voltages was digitized and stored within an IBM AT® computer. This voltage time series was converted to a velocity time series using the

inverse of the calibration equation; $U = [(E^2 - A)/B]^{1/c}$. The velocity time series was then analyzed for pertinent statistical quantities, such as mean velocity and root-mean-square turbulent velocity fluctuations. The computer system moves the velocity probe to a vertical position, acquires and reduces the data, then moves on to the next vertical position, thus obtaining an entire vertical velocity profile automatically. Wind tunnel reference velocities, one at the top of each profile and one at an upwind location, (-200,15,6.1) cm, were obtained via a pitot-static probe for each hot film velocity measurement point. These reference velocities were used to normalize out any wind tunnel speed variations that existed between the different runs tested and during the acquisition of individual vertical profiles.

2.3.1 Error Statement

Pitot-static probe measurements have an absolute accuracy to within ±2 percent of the actual velocity. Test conditions within the wind tunnel were always maintained to within ±1.5 degrees centigrade and ±3 mmHg atmospheric pressure variation. This variation in test temperature and pressure along with analog to digital conversion errors results in a relative error in pitot probe measurements of less than ±1.0 percent.

The analytic curve fit between hot wire voltage and a velocity standard based on pitot probe measurements along with analog to digital conversion resulted in random errors of within ±1.0 percent. Testing temperature and pressure variations (similar to those stated above) on the hot wire measurement system resulted in random errors of ±2.3 percent. Thus the hot wire measurement system was accurate to within ±2.5 percent of the pitot probes reported velocity. Since all hot wire measurements are normalized by a pitot probe measurement over the same time record and the hot wire velocity was calibrated against the pitot probe, the pitot probes bias errors of ±2 percent of actual velocity does not affect the normalized velocity value.

The error introduced in a velocity measurement as the result of probe vertical positioning errors vary with the magnitude of the velocity gradient at the measurement location over the ridge. The velocity gradient is greatest at the lower measurement points thus this is where the resultant error in velocity would be the greatest. Absolute vertical positioning error was estimated to be ±1 mm. Surveying the data shows that the error in velocity due to random positioning errors of this magnitude is usually less than 1.5 percent but can be as high as 3 percent.

The total error in normalized velocity values is estimated to be less than ±2.9 percent for the majority of data values but can be as high as 3.8 percent for a few select low height values. When one cubes the velocity values to look at power changes these errors become ±8.7 and ±11.4 percent errors in power values respectively.

3 TEST PROGRAM SPECIFICATIONS

3.1 Model Validation Tests

To insure that the selected wind tunnel ridge model was accurate a series of model validation tests were performed prior to the requested model ridge measurements. Table 1 summarizes the run conditions for five different model validation and model reference test series. The A series tests the Reynolds number invariance of the wind tunnel flow field over the 60' simulated tree cover without the presence of the model ridge. The B series tests looks at the uniformity of the wind tunnel velocity profile for these same conditions in both the lateral and longitudinal directions. The C series

tests provides reference velocity profiles for the different tree heights tested (0', 20', 40' and 60') at the ridge crest location but without the model ridge present. The D series tests measure a series of velocity profiles, longitudinally down the wind tunnel, passing over a step change in roughness from simulated 60' tree cover to no tree cover conditions. The E series tests the Reynolds number invariance of the wind tunnel flow field over the 60' simulated tree cover with the 1:2 slope, triangular model ridge present.

3.2 Model Ridge Tests

Table 2 lists the run number and run conditions for the 96 requested model test conditions. These tests cover two hill shapes (triangular and sinusoidal), four hill slopes (1:2, 1:3, 1:5 and 1:10), three tree cover heights (20', 40' and 60') and four hilltop clearing configurations (all trees removed, highest tree top being 100 feet lower than hill top ground level, highest tree top being level with hill top ground level and no tree removal. Also listed in Table 2 are the distances along the ridge contour from the hill crest to the location of the simulated forest cover matting.

4 TEST PROGRAM DATA

4.1 Model Validation Velocity Profile Data (A To E Series)

Table 1 lists the specific run conditions for the velocity profiles obtained in the A through E test series. The wind speed and the profile positions, downwind and lateral, listed in this Table are in model units.

4.1.1 Approach Flow Reynolds Number Invariance Tests (A Series)

Table 3 summarizes the model velocity profiles obtained in the A test series, Runs A00 to A05. In Table 3, and subsequent tables of the similar type, the column labeled "Velocity @ 76.2 cm" is the pitot probe velocity measured 76.2 cm above ground level at the current profile position (alternatively, this column may be labeled "Velocity @ 30.5 cm" in which case the measurement height was 30.5 cm). The column labeled "Velocity @ 6.1 cm" is the pitot probe velocity measured 6.1 cm above ground level upwind ~200 cm of the location of the model ridge crest.

Table 4 displays both tabularly and graphically the comparisons of normalized velocity profiles and local turbulent intensity profiles for these six runs. The normalized height is the measurement height divided by a reference height of 30.5 cm (this is the equivalent of 305 meters in field units). The normalized velocity for this test series is defined as $(U_i/U_H)/(U_{ref1,i}/U_{ref1,H})$ where *ref1* indicates the pitot probe velocity at 76.2 cm height, *i* indicates the velocities obtain while the hot film probe was at a particular height and *H* indicates the velocities obtain while the hot film probe was at the height, $H = 30.5$ cm.

4.1.2 Wind Tunnel Flow Uniformity Tests (B Series)

4.1.2.1 Lateral Uniformity

Table 5 summarizes a series of velocity profiles obtained in the B test series, Runs B01 to B05, that were at different lateral positions in the wind tunnel. Table 6 displays both tabularly and graphically the comparisons of normalized velocity profiles and local turbulent intensity profiles for these runs. Normalized velocity for this test sequence is defined as $(U_i/U_{B03,H})/(U_{ref2,i}/U_{B03,ref2,i})$ where *B03* represents the velocity

profile obtain at tunnel centerline, *ref2* indicates the upwind pitot probe velocity at 6.1 cm height, *i* indicates the velocities obtain while the hot film probe was at a particular height and *H* indicates the velocities obtain while the hot film probe was at the height, $H = 30.5$ cm.

4.1.2.2 Longitudinal Uniformity

Table 7 summarizes a series of velocity profiles obtained in the B test series, Runs B06 to B10, that were at different longitudinal positions in the wind tunnel. Table 8 displays both tabularly and graphically the comparisons of normalized velocity profiles and local turbulent intensity profiles for these runs. Normalized velocity for this test sequence is defined as $(U_i/U_{B10,H})/(U_{ref2,i}/U_{B10,ref2,i})$ where *B10* represents the velocity profile obtain at model ridge crest position in the wind tunnel, *ref2* indicates the up-wind pitot probe velocity at 6.1 cm height, *i* indicates the velocities obtain while the hot film probe was at a particular height and *H* indicates the velocities obtain while the hot film probe was at the height, $H = 30.5$ cm. Run B06 was normalized by only its own velocity at height, *H,* since the traverse supporting the hot wire probe was up-wind of the *ref2* pitot probe, thus affecting its readings.

4.1.3 Tree Cover Reference Profile Tests (C Series)

Table 9 summarizes a series of velocity profiles obtained in the C test series, Runs C01 to C05, that document wind profiles over the different tree height simulation mats without the presents of the model ridge. Table 10 displays both tabularly and graphically the comparisons of normalized velocity profiles and local turbulent intensity profiles for these runs. Normalized velocity for this test sequence is defined as $(U_i/U_H)/(U_{ref1,i}/U_{ref1,H})$ where *ref1* indicates the pitot probe velocity at 30.5 cm height, *i* indicates the velocities obtain while the hot film probe was at a particular height and *H* indicates the velocities obtain while the hot film probe was at the height, $H = 30.5$ cm. Table 11 lists these profiles in field units scaled to a 10 m/s velocity at 305 meter height. Table 11 also shows the results of a regression analysis determining the equivalent field displacement height, *d*, roughness length, z_o, friction velocity, u_*, and power law index, *p*.

4.1.4 Tree Cover Change Reference Profiles (D Series)

Table 12 summarizes a series of velocity profiles obtained in the D test series, Runs D01 to D05, that document wind profiles over the different tree height simulation mats without the presents of the model ridge. Table 13 displays both tabularly and graphically the comparisons of normalized velocity profiles and local turbulent intensity profiles for these runs. Normalized velocity for this test sequence is defined as $(U_i/U_H)/(U_{ref1,i}/U_{ref1,H})$ where *ref1* indicates the pitot probe velocity at 76.2 cm height, *i* indicates the velocities obtain while the hot film probe was at a particular height and *H* indicates the velocities obtain while the hot film probe was at the height, $H = 30.5$ cm.

4.1.5 Model Ridge Reynolds Number Invariance Tests (E Series)

Table 14 summarizes the model velocity profiles obtained in the E test series, Runs E01 to E06. Table 15 displays both tabularly and graphically the comparisons of normalized velocity profiles and local turbulent intensity profiles for these six runs. Normalized velocity for this test series is defined as $(U_i/U_H)/(U_{ref1,i}/U_{ref1,H})$ where *ref1* indicates the pitot probe velocity at

30.5 cm height, *i* indicates the velocities obtain while the hot film probe was at a particular height and *H* indicates the velocities obtain while the hot film probe was at the height, *H* = 30.5 cm.

4.2 Model Ridge Velocity Profile Data (F To M Series)

Table 2 lists the specific run conditions for velocity profiles obtained over the 96 different model ridge setups used in the F through M test series. Included in this Table are the ground surface distances from the hill crest to the base of the nearest trees for each run condition.

4.2.1 Triangular Ridge With 1:2 Slope (F Series)

Table 16 lists the velocity profile data for the 20' high tree test cases, Runs F01 to F04. In Table 16, and subsequent tables of the similar type, the column labeled "Velocity @ 30.5 cm" is the pitot probe velocity measured 30.5 cm above ground level at the current profile position. The column labeled "Velocity @ 6.1 cm" is the pitot probe velocity measured 6.1 cm above ground level upwind ~200 cm of the location of the model ridge crest. The column labeled "Velocity Ratio" is the ratio of "Velocity @ 30.5 cm" divided by "Velocity @ 6.1 cm". Table 17 lists the velocity profile data for the 40' high tree test cases, Runs F05 to F08. Table 18 lists the velocity profile data for the 60' high tree test cases, Runs F09 to F12.

Table 19 displays both tabularly and graphically the comparisons of normalized velocity profiles for these runs. Table 20 displays both tabularly and graphically the comparisons of local turbulent intensity profiles. The normalized height is the measurement height divided by a reference height of 30.5 cm (this is the equivalent of 305 meters in field units). The normalized velocity in Table 19, and subsequent tables of the similar type in test series F through M, is defined as $(U_i/U_{ref1,i})$ where *ref1* indicates the pitot probe velocity at 30.5 cm height, *i* indicates the velocities obtain while the hot film probe was at a particular height.

4.2.2 Triangular Ridge With 1:3 Slope (G Series)

Table 21 lists the velocity profile data for the 20' high tree test cases, Runs G01 to G04. Table 22 lists the velocity profile data for the 40' high tree test cases, Runs G05 to G08. Table 23 lists the velocity profile data for the 60' high tree test cases, Runs G09 to G12. Table 24 displays both tabularly and graphically the comparisons of normalized velocity profiles for these runs. Table 25 displays both tabularly and graphically the comparisons of local turbulent intensity profiles.

4.2.3 Triangular Ridge With 1:5 Slope (H Series)

Table 26 lists the velocity profile data for the 20' high tree test cases, Runs H01 to H04. Table 27 lists the velocity profile data for the 40' high tree test cases, Runs H05 to H08. Table 28 lists the velocity profile data for the 60' high tree test cases, Runs H09 to H12. Table 29 displays both tabularly and graphically the comparisons of normalized velocity profiles for these runs. Table 30 displays both tabularly and graphically the comparisons of local turbulent intensity profiles.

4.2.4 Triangular Ridge With 1:10 Slope (I Series)

Table 31 lists the velocity profile data for the 20' high tree test cases, Runs I01 to I04. Table 32 lists the velocity profile data for the 40' high tree test cases, Runs I05 to I08. Table 33 lists the velocity profile data for the 60' high tree test cases, Runs I09 to I12. Table 34 displays both tabularly and graphically the comparisons of normalized velocity profiles for these runs. Table 35 displays both tabularly and graphically the comparisons of local turbulent intensity profiles.

4.2.5 Sinusoidal Ridge With 1:2 Slope (J Series)

Table 36 lists the velocity profile data for the 20' high tree test cases, Runs J01 to J04. Table 37 lists the velocity profile data for the 40' high tree test cases, Runs J05 to J08. Table 38 lists the velocity profile data for the 60' high tree test cases, Runs J09 to J12. Table 39 displays both tabularly and graphically the comparisons of normalized velocity profiles for these runs. Table 40 displays both tabularly and graphically the comparisons of local turbulent intensity profiles.

4.2.6 Sinusoidal Ridge With 1:3 Slope (K Series)

Table 41 lists the velocity profile data for the 20' high tree test cases, Runs K01 to K04. Table 42 lists the velocity profile data for the 40' high tree test cases, Runs K05 to K08. Table 43 lists the velocity profile data for the 60' high tree test cases, Runs K09 to K12. Table 44 displays both tabularly and graphically the comparisons of normalized velocity profiles for these runs. Table 45 displays both tabularly and graphically the comparisons of local turbulent intensity profiles.

4.2.7 Sinusoidal Ridge With 1:5 Slope (L Series)

Table 46 lists the velocity profile data for the 20' high tree test cases, Runs L01 to L04. Table 47 lists the velocity profile data for the 40' high tree test cases, Runs L05 to L08. Table 48 lists the velocity profile data for the 60' high tree test cases, Runs L09 to L12. Table 49 displays both tabularly and graphically the comparisons of normalized velocity profiles for these runs. Table 50 displays both tabularly and graphically the comparisons of local turbulent intensity profiles.

4.2.8 Sinusoidal Ridge With 1:10 Slope (M Series)

Table 51 lists the velocity profile data for the 20' high tree test cases, Runs M01 to M04. Table 52 lists the velocity profile data for the 40' high tree test cases, Runs M05 to M08. Table 53 lists the velocity profile data for the 60' high tree test cases, Runs M09 to M12. Table 54 displays both tabularly and graphically the comparisons of normalized velocity profiles for these runs. Table 55 displays both tabularly and graphically the comparisons of local turbulent intensity profiles.

5 TEST PROGRAM RESULTS

5.1 Model Validation Velocity Profile Results (A To E Series)

5.1.1 Approach Flow Reynolds Number Invariance Tests (A Series)

The graphs associated with Table 4 indicate that Reynolds number invariance in the approach flow existed for all velocities tested in this series with the possible exception of the lowest velocity test case, Run A00. It was decided that good model similarity would exist when the upwind pitot probe, at a height of 6.1 cm, registered a velocity of ~500 cm/s.

5.1.2 Wind Tunnel Flow Uniformity Tests (B Series)

5.1.2.1 Lateral Uniformity

The graphs associated with Table 6 indicate that the lateral uniformity in mean velocity profiles was ~6 percent at height, H = 30.5 cm. Since all test measurements for this entire study were to be at only one lateral position this lateral uniformity was considered acceptable. The lateral uniformity in turbulent intensity, particularly at the lower measurement heights, was good.

5.1.2.2 Longitudinal Uniformity

The graphs associated with Table 8 indicate that the longitudinal uniformity in mean velocity profiles was ~2 percent at height, H = 30.5 cm. The change in simulated forest cover matting from the fixed commercial Astroturf to the moveable 60' tree height Astroturf roughness at -152 cm is noticeable in both the mean velocity and turbulent intensity profiles at lower heights.

5.1.3 Tree Cover Reference Profile Tests (C Series)

The graphs associated with Table 10 and the values of the regression parameters in Table 11 indicate that the upwind, fixed commercial Astroturf matting was representative of ~30' high trees. The displacement heights were typically around 0.71 times the tree height. The roughness lengths vary from 0.11 m, for no trees, to 1.98 m, for 60' trees. The power law index vary from 0.19, for no trees, up to 0.32, for the 60' trees.

5.1.4 Tree Cover Change Reference Profiles (D Series)

The graphs associated with Table 13 show the progressive wind speed increase and turbulence decrease as the result of going from a simulated 60' tree cover out to a area where trees have been removed. This series of tests indicates the wind power generation benefit obtained by upwind clear cutting when located on flat terrain.

5.1.5 Model Ridge Reynolds Number Invariance Tests (E Series)

The graphs associated with Table 15 indicate that Reynolds number invariance in flow over 1:2 sloped triangular ridge existed for all velocities tested. It was decided that good model similarity would exist for all model ridges when the upwind pitot probe, at a height of 6.1 cm, registered a velocity of ~500 cm/s.

5.2 Model Ridge Velocity Profile Results (F To M Series)

5.2.1 Normalized Velocity Profile Comparisons

Table 56 presents a comparison of normalized velocity profile results for all the triangular shaped ridges. Table 57 presents a comparison of normalized velocity profile results for all the sinusoidal shaped ridges. Normalized velocity profile results for the reference profile tests (C series) are presented at the bottom of Table 57. These tables, 56 and 57, are just a representation of the velocity normalization data Tables 19, 24, 29, 34, 39, 44, 49 and 54 but the normalized height is scale to field values. This velocity normalization was defined as $(U_i/U_{ref1,i})$ where *ref1* indicates the pitot probe velocity at 30.5 cm height, *i* indicates the velocities obtain while the hot film probe was at a particular height.

5.2.2 Fractional Speed Up Factor Comparisons

Table 58 presents a comparison of percent fractional speed up factor profile results for all the triangular shaped ridges. Table 59 presents a comparison of percent fractional speed up factor profile results for all the sinusoidal shaped ridges. The percent fractional speed up factor was defined as $[\{(U_i/U_{ref2,i})/(U_{Cxx,i}/U_{Cxx,ref2,i})\}-1]*100$ where *Cxx* represents the appropriate reference profile (same tree height without the ridge present) in the C test series, *ref2* indicates the upwind pitot probe velocity at 6.1 cm height, *i* indicates the velocities obtain while the hot film probe was at a particular height.

5.2.3 Percent Power Decrease Comparisons

Table 60 presents a comparison of percent power decrease over full clear-cut option profile results for all the triangular shaped ridges. Table 61 presents a comparison of percent power decrease over full clear-cut option profile results for all the sinusoidal shaped ridges. The percent power decrease over full clear-cut option factor was defined as $[1-\{(U_i/U_{ref2,i})/(U_{Xxx,i}/U_{Xxx,ref2,i})\}^3]*100$ where *Xxx* represents the run number for the full clear-cut profile with the same ridge shape, ridge slope and tree height, *ref2* indicates the upwind pitot probe velocity at 6.1 cm height, *i* indicates the velocities obtain while the hot film probe was at a particular height.

Figures 5, 6 and 7 display bar charts of the percent power decrease results for a 40', 80' and 120' measurement heights respectively. Included in these figures are tables listing the data. The error bound for the power comparisons in these charts, as previously stated, is approximately ±10 percent. Trends seen within this error bound should only be consider lightly.

TABLES

USWP Task 2 Test Program

USW2_PRO.WK3 Sheet A: 02/18/93

Tunnel Boundary Layer Reynolds Number Invariance Tests

Run Number	Wind Speed @ 6.1 cm (cm/s)	Downwind Position (cm)	Lateral Position (cm)	Hill Shape	Hill Slope	Tree Height (ft)	Tree Cover
A00	231	0	0	No Hill	-	60	all trees
A01	311	0	0	No Hill	-	60	all trees
A02	413	0	0	No Hill	-	60	all trees
A03	533	0	0	No Hill	-	60	all trees
A04	626	0	0	No Hill	-	60	all trees
A05	728	0	0	No Hill	-	60	all trees

Tunnel Boundary Layer Uniformity Tests

Run Number	Wind Speed @ 6.1 cm (cm/s)	Downwind Position (cm)	Lateral Position (cm)	Hill Shape	Hill Slope	Tree Height (ft)	Tree Cover
B01	511	0	-30	No Hill	-	60	all trees
B02	506	0	-15	No Hill	-	60	all trees
B03	510	0	0	No Hill	-	60	all trees
B04	504	0	15	No Hill	-	60	all trees
B05	507	0	30	No Hill	-	60	all trees
B06	~491	-300	0	No Hill	-	60	all trees
B07	500	-200	0	No Hill	-	60	all trees
B08	503	-100	0	No Hill	-	60	all trees
B09	503	100	0	No Hill	-	60	all trees
B10	502	0	0	No Hill	-	60	all trees

Reference Profile Comparison Tests

Run Number	Wind Speed @ 6.1 cm (cm/s)	Downwind Position (cm)	Lateral Position (cm)	Hill Shape	Hill Slope	Tree Height (ft)	Tree Cover
C01	530	-200	0	No Hill	-	0	all trees
C02	521	0	0	No Hill	-	0	all trees
C03	510	0	0	No Hill	-	20	all trees
C04	498	0	0	No Hill	-	40	all trees
C05	518	0	0	No Hill	-	60	all trees

Step Roughness Change Tests

Run Number	Wind Speed @ 6.1 cm (cm/s)	Downwind Position (cm)	Lateral Position (cm)	Hill Shape	Hill Slope	Tree Height (ft)	Tree Cover
D01	491	-10	0	No Hill	-	60	all trees
D02	490	0	0	No Hill	-	60	all trees
D03	487	10	0	No Hill	-	60	all trees
D04	487	20	0	No Hill	-	60	all trees
D05	492	40	0	No Hill	-	60	all trees
D06	490	60	0	No Hill	-	60	all trees

Prototype Hill Reynolds Number Invariance Tests

Run Number	Wind Speed @ 6.1 cm (cm/s)	Downwind Position (cm)	Lateral Position (cm)	Hill Shape	Hill Slope	Tree Height (ft)	Tree Cover
E01	409	0	0	Triangular	1:2	0	no trees
E02	512	0	0	Triangular	1:2	0	no trees
E03	618	0	0	Triangular	1:2	0	no trees
E04	410	0	0	Triangular	1:2	60	all trees
E05	505	0	0	Triangular	1:2	60	all trees
E06	592	0	0	Triangular	1:2	60	all trees

TABLE 1 Model Validation Test Specifications

USWP Task 2 Test Program

USW2_PRO.WK3 Sheet B: 02/18/93

Run No.	Hill Shape	Hill Slope	Tree Height (ft)	Clear Cut Option	Cut Dist. (ft)
F01	Triangle	1:2	20	all cut	448
F02	Triangle	1:2	20	-100' cut	302
F03	Triangle	1:2	20	hilltop cut	72
F04	Triangle	1:2	20	no cut	0
F05	Triangle	1:2	40	all cut	448
F06	Triangle	1:2	40	-100' cut	344
F07	Triangle	1:2	40	hilltop cut	118
F08	Triangle	1:2	40	no cut	0
F09	Triangle	1:2	60	all cut	448
F10	Triangle	1:2	60	-100' cut	371
F11	Triangle	1:2	60	hilltop cut	128
F12	Triangle	1:2	60	no cut	0
G01	Triangle	1:3	20	all cut	633
G02	Triangle	1:3	20	-100' cut	433
G03	Triangle	1:3	20	hilltop cut	112
G04	Triangle	1:3	20	no cut	0
G05	Triangle	1:3	40	all cut	633
G06	Triangle	1:3	40	-100' cut	476
G07	Triangle	1:3	40	hilltop cut	148
G08	Triangle	1:3	40	no cut	0
G09	Triangle	1:3	60	all cut	633
G10	Triangle	1:3	60	-100' cut	512
G11	Triangle	1:3	60	hilltop cut	187
G12	Triangle	1:3	60	no cut	0
H01	Triangle	1:5	20	all cut	1020
H02	Triangle	1:5	20	-100' cut	738
H03	Triangle	1:5	20	hilltop cut	213
H04	Triangle	1:5	20	no cut	0
H05	Triangle	1:5	40	all cut	1020
H06	Triangle	1:5	40	-100' cut	797
H07	Triangle	1:5	40	hilltop cut	282
H08	Triangle	1:5	40	no cut	0
H09	Triangle	1:5	60	all cut	1020
H10	Triangle	1:5	60	-100' cut	843
H11	Triangle	1:5	60	hilltop cut	305
H12	Triangle	1:5	60	no cut	0
I01	Triangle	1:10	20	all cut	2011
I02	Triangle	1:10	20	-100' cut	1499
I03	Triangle	1:10	20	hilltop cut	384
I04	Triangle	1:10	20	no cut	0
I05	Triangle	1:10	40	all cut	2011
I06	Triangle	1:10	40	-100' cut	1539
I07	Triangle	1:10	40	hilltop cut	509
I08	Triangle	1:10	40	no cut	0
I09	Triangle	1:10	60	all cut	2011
I10	Triangle	1:10	60	-100' cut	1575
I11	Triangle	1:10	60	hilltop cut	627
I12	Triangle	1:10	60	no cut	0

Run No.	Hill Shape	Hill Slope	Tree Height (ft)	Clear Cut Option	Cut Dist. (ft)
J01	Sine	1:2	20	all cut	453
J02	Sine	1:2	20	-100' cut	292
J03	Sine	1:2	20	hilltop cut	128
J04	Sine	1:2	20	no cut	0
J05	Sine	1:2	40	all cut	453
J06	Sine	1:2	40	-100' cut	305
J07	Sine	1:2	40	hilltop cut	135
J08	Sine	1:2	40	no cut	0
J09	Sine	1:2	60	all cut	453
J10	Sine	1:2	60	-100' cut	338
J11	Sine	1:2	60	hilltop cut	154
J12	Sine	1:2	60	no cut	0
K01	Sine	1:3	20	all cut	640
K02	Sine	1:3	20	-100' cut	381
K03	Sine	1:3	20	hilltop cut	171
K04	Sine	1:3	20	no cut	0
K05	Sine	1:3	40	all cut	640
K06	Sine	1:3	40	-100' cut	440
K07	Sine	1:3	40	hilltop cut	217
K08	Sine	1:3	40	no cut	0
K09	Sine	1:3	60	all cut	640
K10	Sine	1:3	60	-100' cut	459
K11	Sine	1:3	60	hilltop cut	233
K12	Sine	1:3	60	no cut	0
L01	Sine	1:5	20	all cut	1026
L02	Sine	1:5	20	-100' cut	614
L03	Sine	1:5	20	hilltop cut	305
L04	Sine	1:5	20	no cut	0
L05	Sine	1:5	40	all cut	1026
L06	Sine	1:5	40	-100' cut	646
L07	Sine	1:5	40	hilltop cut	331
L08	Sine	1:5	40	no cut	0
L09	Sine	1:5	60	all cut	1026
L10	Sine	1:5	60	-100' cut	728
L11	Sine	1:5	60	hilltop cut	374
L12	Sine	1:5	60	no cut	0
M01	Sine	1:10	20	all cut	2011
M02	Sine	1:10	20	-100' cut	1247
M03	Sine	1:10	20	hilltop cut	646
M04	Sine	1:10	20	no cut	0
M05	Sine	1:10	40	all cut	2011
M06	Sine	1:10	40	-100' cut	1404
M07	Sine	1:10	40	hilltop cut	682
M08	Sine	1:10	40	no cut	0
M09	Sine	1:10	60	all cut	2011
M10	Sine	1:10	60	-100' cut	1476
M11	Sine	1:10	60	hilltop cut	791
M12	Sine	1:10	60	no cut	0

Notes: 1) Wind direction is always perpendicular to the 2D hill
2) Vertical profile location is always at hill crest, centertunnel
3) Vertical profile measurement heights are up to 30 cm

TABLE 2 Test Program Specifications

USWP Task 2 Test Results A Series Tests

USW_VELA.WK3 Sheet A: 02/18/93

Velocity Profile Data
Run A00 No Hill; 60' Trees: B.L. Re# Tests

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	138	32.1	418	230
3.7	186	25.1	418	221
4.9	199	24.2	418	233
6.1	215	22.5	421	236
9.1	261	18.2	420	230
12.9	291	14.0	421	233
18.3	314	11.9	421	229
24.4	346	10.1	420	234
30.5	367	8.2	420	230
Average =			420	231

Velocity Profile Data
Run A01 No Hill; 60' Trees: B.L. Re# Tests

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	189	35.8	612	307
3.7	249	28.5	610	318
4.9	281	24.1	610	309
6.1	318	23.5	611	315
9.1	361	17.1	610	308
12.9	392	14.9	611	319
18.3	437	12.5	611	309
24.4	475	11.0	610	306
30.5	506	10.2	610	312
Average =			610	311

Velocity Profile Data
Run A02 No Hill; 60' Trees: B.L. Re# Tests

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	251	35.5	805	405
3.7	321	29.3	804	409
4.9	371	24.0	805	416
6.1	402	23.2	804	414
9.1	477	18.1	804	409
12.9	517	16.2	804	410
18.3	570	13.4	804	422
24.4	617	12.4	804	422
30.5	659	10.8	804	412
Average =			804	413

Velocity Profile Data
Run A03 No Hill; 60' Trees: B.L. Re# Tests

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	319	36.4	1032	541
3.7	415	29.2	1030	539
4.9	477	25.8	1029	523
6.1	505	24.1	1030	544
9.1	584	19.8	1030	533
12.9	648	16.3	1029	522
18.3	724	13.3	1029	529
24.4	789	11.6	1029	530
30.5	845	10.2	1029	537
Average =			1030	533

Velocity Profile Data
Run A04 No Hill; 60' Trees: B.L. Re# Tests

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	380	36.0	1222	625
3.7	486	28.8	1222	625
4.9	552	25.6	1221	632
6.1	628	22.6	1221	621
9.1	721	18.5	1220	617
12.9	795	15.5	1219	632
18.3	864	13.2	1218	615
24.4	948	11.3	1218	636
30.5	1011	9.5	1217	632
Average =			1220	626

Velocity Profile Data
Run A05 No Hill; 60' Trees: B.L. Re# Tests

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	429	36.4	1415	746
3.7	570	29.4	1415	746
4.9	651	25.4	1414	715
6.1	715	22.0	1413	720
9.1	823	20.2	1414	719
12.9	914	15.4	1413	715
18.3	1018	13.3	1415	727
24.4	1093	11.7	1411	728
30.5	1161	9.8	1411	734
Average =			1413	728

TABLE 3 Approach Flow Reynolds Number Invariance Test Data

USWP Task 2 Test Results A Series Tests

USW_VELA.WK3 Sheet B: 02/18/93

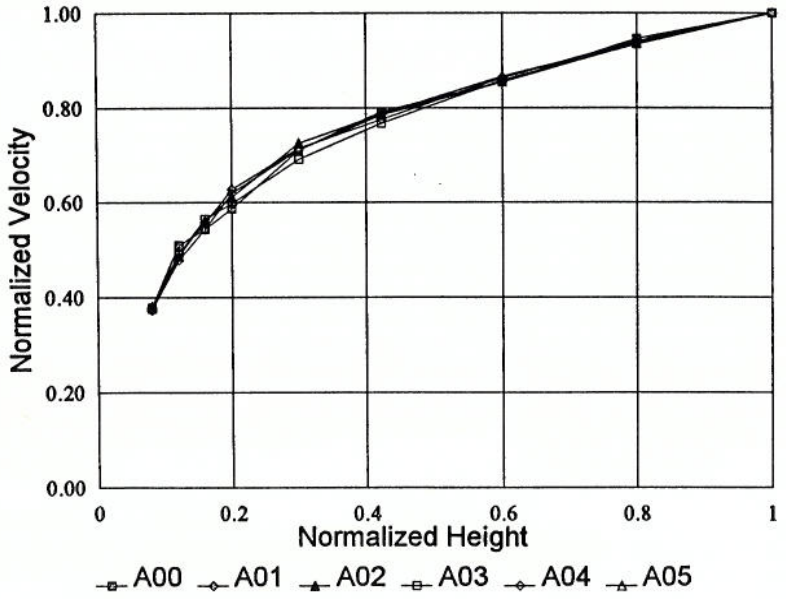
Velocity Profile Comparisons
No Hill; 60' Trees; B.L. Re# Tests

Height Norm.	Velocity Norm. A00	Velocity Norm. A01	Velocity Norm. A02	Velocity Norm. A03	Velocity Norm. A04	Velocity Norm. A05
0.08	0.38	0.37	0.38	0.38	0.37	0.37
0.12	0.51	0.49	0.49	0.49	0.48	0.49
0.16	0.54	0.56	0.56	0.57	0.54	0.56
0.20	0.59	0.63	0.61	0.60	0.62	0.62
0.30	0.71	0.71	0.72	0.69	0.71	0.71
0.42	0.79	0.77	0.79	0.77	0.78	0.79
0.60	0.85	0.86	0.87	0.86	0.85	0.87
0.80	0.94	0.94	0.94	0.93	0.94	0.94
1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ur@76.2cm =	420	610	804	1030	1220	1413
Ur@6.1cm =	231	311	413	533	626	728
Href (cm) =	30.5	30.5	30.5	30.5	30.5	30.5

Turbulent Intensity Profile Comparisons
No Hill; 60' Trees; B.L. Re# Tests

Height Norm.	Turb.Int. (%) A00	Turb.Int. (%) A01	Turb.Int. (%) A02	Turb.Int. (%) A03	Turb.Int. (%) A04	Turb.Int. (%) A05
0.08	32.1	35.8	35.5	36.4	36.0	36.4
0.12	25.1	28.5	29.3	29.2	28.8	29.4
0.16	24.2	24.1	24.0	25.8	25.6	25.4
0.20	22.5	23.5	23.2	24.1	22.6	22.0
0.30	18.2	17.1	18.1	19.8	18.5	20.2
0.42	14.0	14.9	16.2	16.3	15.5	15.4
0.60	11.9	12.5	13.4	13.3	13.2	13.3
0.80	10.1	11.0	12.4	11.6	11.3	11.7
1.00	8.2	10.2	10.8	10.2	9.5	9.8
Ur@76.2cm =	420	610	804	1030	1220	1413
Ur@6.1cm =	231	311	413	533	626	728
Href (cm) =	30.5	30.5	30.5	30.5	30.5	30.5

B.L. Reynolds Number Invariance Tests
A Series Tests



B.L. Reynolds Number Invariance Tests
A Series Tests

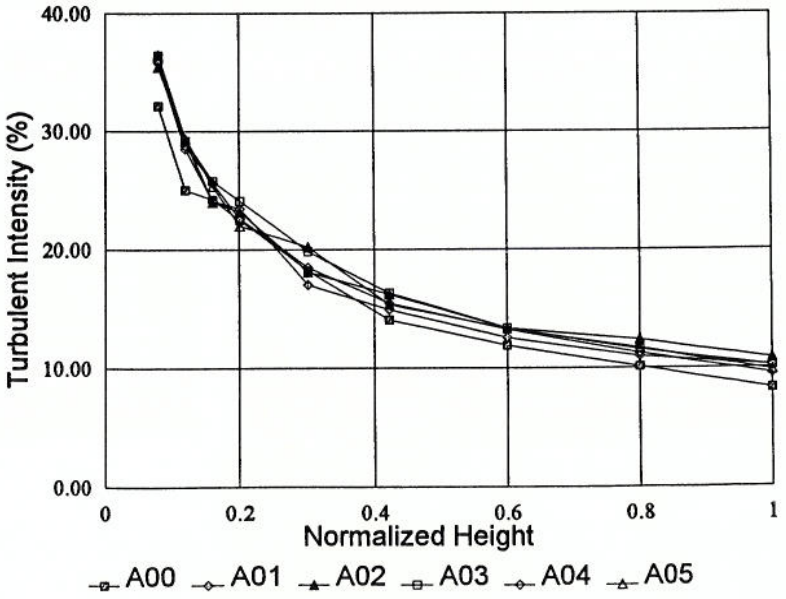


TABLE 4 Approach Flow Reynolds Number Invariance Test Results

USWP Task 2 Test Results B Series Tests

USW_VELB.WK3 Sheet A: 02/18/93

Velocity Profile Data
Run B01 No Hill; 60' Trees; Lateral Uniformity Test

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	294	38.1	916	512
3.7	396	29.7	915	515
4.9	475	26.1	916	512
6.1	527	23.7	916	518
9.1	616	18.6	915	511
12.9	690	14.7	914	505
18.3	762	12.0	916	511
24.4	822	10.2	914	511
30.5	873	8.0	915	506
Average =			915	511

Velocity Profile Data
Run B02 No Hill; 60' Trees; Lateral Uniformity Test

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	314	35.3	981	502
3.7	396	29.0	981	505
4.9	462	25.8	981	505
6.1	504	23.1	981	507
9.1	582	19.0	982	507
12.9	648	15.9	980	503
18.3	713	13.2	980	511
24.4	781	10.8	980	507
30.5	835	9.0	982	510
Average =			981	506

Velocity Profile Data
Run B03 No Hill; 60' Trees; Lateral Uniformity Test

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	305	35.9	988	526
3.7	394	29.1	987	504
4.9	456	25.4	987	511
6.1	491	23.9	987	504
9.1	565	19.6	985	507
12.9	625	15.9	984	507
18.3	693	13.7	988	513
24.4	756	11.5	987	512
30.5	802	10.4	985	502
Average =			986	510

Velocity Profile Data
Run B04 No Hill; 60' Trees; Lateral Uniformity Test

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	269	36.3	918	504
3.7	361	29.3	921	504
4.9	421	25.9	921	506
6.1	452	23.5	916	500
9.1	522	20.8	915	500
12.9	594	16.6	915	512
18.3	645	13.8	917	496
24.4	716	12.1	916	511
30.5	770	10.9	915	501
Average =			917	504

Velocity Profile Data
Run B05 No Hill; 60' Trees; Lateral Uniformity Test

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	285	37.1	905	517
3.7	390	29.6	904	501
4.9	463	25.1	903	499
6.1	514	23.6	904	507
9.1	593	19.0	904	501
12.9	660	16.3	904	501
18.3	725	12.4	903	508
24.4	776	11.1	904	514
30.5	820	9.6	903	507
Average =			904	506

TABLE 5 Wind Tunnel Lateral Uniformity Test Data

USWP Task 2 Test Results B Series Tests

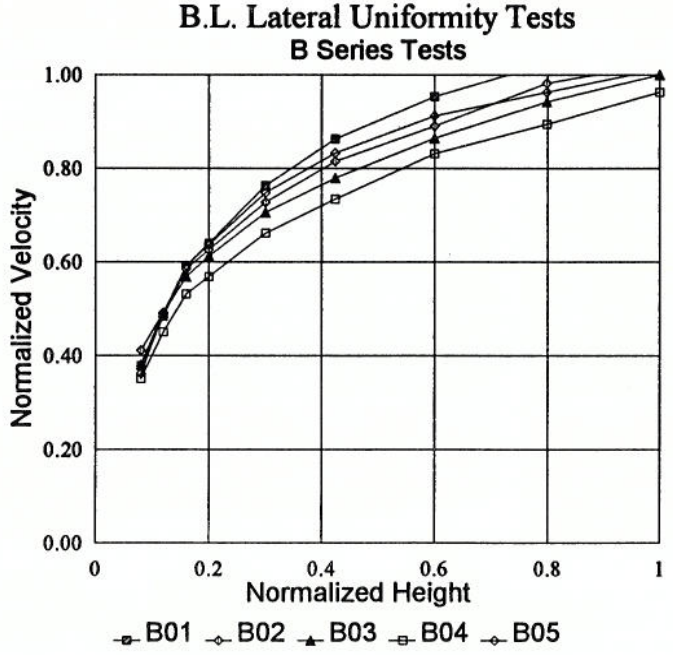
USW_VELB.WK3 Sheet B: 02/18/93

Velocity Profile Comparisons
No Hill; 60' Trees; Lateral Uniformity Test

Height Norm.	Velocity Norm. B01	Velocity Norm. B02	Velocity Norm. B03	Velocity Norm. B04	Velocity Norm. B05
0.08	0.38	0.41	0.38	0.35	0.36
0.12	0.48	0.49	0.49	0.45	0.49
0.16	0.59	0.58	0.57	0.53	0.59
0.20	0.64	0.63	0.61	0.57	0.64
0.30	0.76	0.73	0.70	0.66	0.75
0.42	0.86	0.81	0.78	0.73	0.83
0.60	0.95	0.89	0.86	0.83	0.91
0.80	1.02	0.98	0.94	0.89	0.96
1.00	1.08	1.03	1.00	0.96	1.01
Ur@76.2cm =	915	981	986	917	904
Ur@6.1cm =	511	506	510	504	506
Href (cm) =	30.5	30.5	30.5	30.5	30.5

Turbulent Intensity Profile Comparisons
No Hill; 60' Trees; Lateral Uniformity Test

Height Norm.	Turb.Int. (%) B01	Turb.Int. (%) B02	Turb.Int. (%) B03	Turb.Int. (%) B04	Turb.Int. (%) B05
0.08	38.1	35.3	35.9	36.3	37.1
0.12	29.7	29.0	29.1	29.3	29.6
0.16	26.1	25.8	25.4	25.9	25.1
0.20	23.7	23.1	23.9	23.5	23.6
0.30	18.6	19.0	19.6	20.8	19.0
0.42	14.7	15.9	15.9	16.6	16.3
0.60	12.0	13.2	13.7	13.8	12.4
0.80	10.2	10.8	11.5	12.1	11.1
1.00	8.0	9.0	10.4	10.9	9.6
Ur@76.2cm =	915	981	986	917	904
Ur@6.1cm =	511	506	510	504	506
Href (cm) =	30.5	30.5	30.5	30.5	30.5



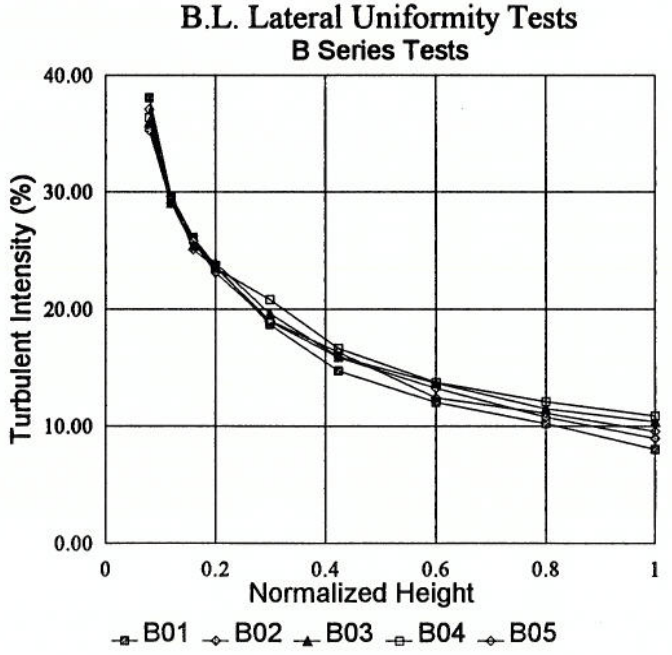


TABLE 6 Wind Tunnel Lateral Uniformity Test Results

USWP Task 2 Test Results B Series Tests

USW_VELB.WK3 Sheet A: 02/18/93

Velocity Profile Data
Run B06 No Hill; 60' Trees; Longitudinal Uniformity Test

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	314	31.9	960	~491
3.7	393	26.3	960	~491
4.9	460	22.3	960	~491
6.1	487	21.5	959	~491
9.1	558	18.2	958	~491
12.9	614	15.5	959	~491
18.3	682	13.6	958	~491
24.4	742	11.3	960	~491
30.5	799	9.4	958	~491
Average =			959	~491

Velocity Profile Data
Run B07 No Hill; 60' Trees; Longitudinal Uniformity Test

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	338	28.2	992	493
3.7	412	23.6	991	494
4.9	477	22.5	992	497
6.1	513	19.7	991	504
9.1	570	18.0	990	504
12.9	635	15.0	992	491
18.3	693	13.3	992	512
24.4	750	11.9	992	502
30.5	812	9.7	991	500
Average =			991	500

Velocity Profile Data
Run B08 No Hill; 60' Trees; Longitudinal Uniformity Test

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	289	37.4	983	510
3.7	388	28.3	983	501
4.9	454	23.0	983	504
6.1	493	21.2	982	506
9.1	573	17.6	981	501
12.9	629	15.4	981	510
18.3	695	13.5	983	497
24.4	751	11.5	980	505
30.5	800	10.0	978	494
Average =			982	503

Velocity Profile Data
Run B09 No Hill; 60' Trees; Longitudinal Uniformity Test

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	290	35.8	983	498
3.7	372	29.1	984	497
4.9	437	25.7	983	502
6.1	467	23.7	984	512
9.1	546	19.6	983	500
12.9	606	17.1	983	505
18.3	670	14.9	982	509
24.4	737	12.1	982	504
30.5	786	10.9	982	502
Average =			983	503

Velocity Profile Data
Run B10 No Hill; 60' Trees; Longitudinal Uniformity Test

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	264	40.9	983	507
3.7	366	31.7	981	504
4.9	418	27.5	982	499
6.1	484	23.6	983	496
9.1	544	20.1	983	498
12.9	636	16.5	982	500
18.3	694	13.7	983	505
24.4	753	11.7	982	510
30.5	800	10.8	982	498
Average =			982	502

TABLE 7 Wind Tunnel Longitudinal Uniformity Test Data

USWP Task 2 Test Results B Series Tests

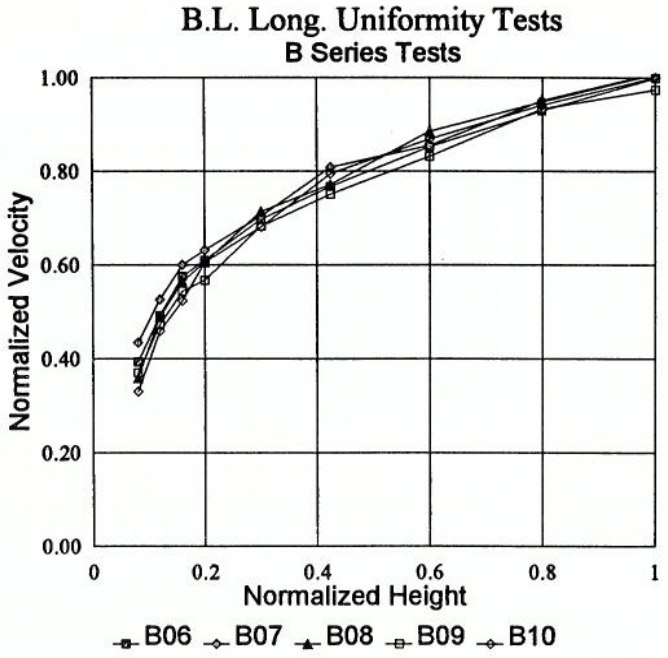
USW_VELB.WK3 Sheet B: 02/18/93

Velocity Profile Comparisons
No Hill; 60' Trees; Longitudinal Uniformity Test

Height Norm.	Velocity Norm. B06	Velocity Norm. B07	Velocity Norm. B08	Velocity Norm. B09	Velocity Norm. B10
0.08	0.39	0.43	0.36	0.37	0.33
0.12	0.49	0.53	0.49	0.47	0.46
0.16	0.57	0.60	0.56	0.54	0.52
0.20	0.61	0.63	0.60	0.57	0.61
0.30	0.70	0.70	0.71	0.68	0.68
0.42	0.77	0.81	0.77	0.75	0.79
0.60	0.85	0.85	0.88	0.83	0.87
0.80	0.93	0.95	0.95	0.93	0.94
1.00	1.00	1.01	1.01	0.97	1.00
Ur@76.2cm =	959	991	982	983	982
Ur@6.1cm =	~491	500	503	503	502
Href (cm) =	30.5	30.5	30.5	30.5	30.5

Turbulent Intensity Profile Comparisons
No Hill; 60' Trees; Longitudinal Uniformity Test

Height Norm.	Turb.Int. (%) B06	Turb.Int. (%) B07	Turb.Int. (%) B08	Turb.Int. (%) B09	Turb.Int. (%) B10
0.08	31.9	28.2	37.4	35.8	40.9
0.12	26.3	23.6	28.3	29.1	31.7
0.16	22.3	22.5	23.0	25.7	27.5
0.20	21.5	19.7	21.2	23.7	23.6
0.30	18.2	18.0	17.6	19.6	20.1
0.42	15.5	15.0	15.4	17.1	16.5
0.60	13.6	13.3	13.5	14.9	13.7
0.80	11.3	11.9	11.5	12.1	11.7
1.00	9.4	9.7	10.0	10.9	10.8
Ur@76.2cm =	959	991	982	983	982
Ur@6.1cm =	~491	500	503	503	502
Href (cm) =	30.5	30.5	30.5	30.5	30.5



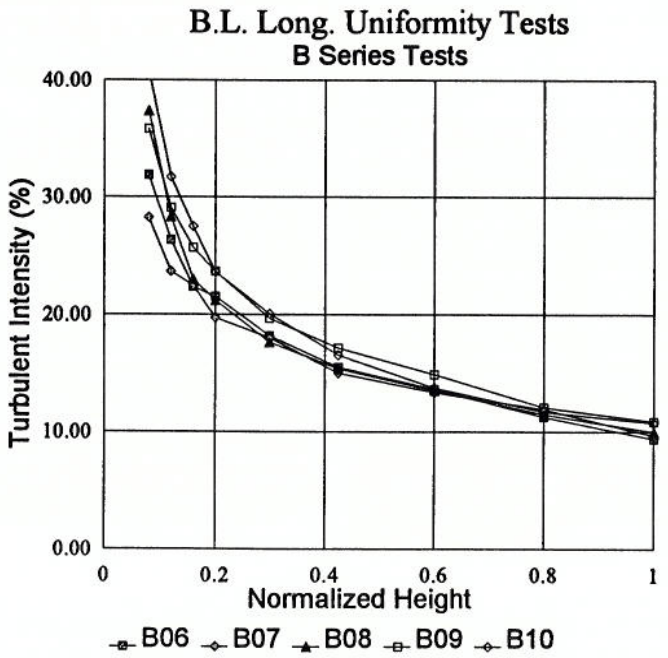


TABLE 8 Wind Tunnel Longitudinal Uniformity Test Results

USWP Task 2 Test Results C Series Tests

USW_VELC.WK3 Sheet A: 02/18/93

Velocity Profile Data
Run C01 No Hill; No Trees; Upwind Position

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @30.5cm (cm/s)	Velocity @6.1cm (cm/s)
1.2				
2.4	380	25.9	824	532
3.7	452	22.8	830	536
4.9	513	19.8	825	521
6.1	535	17.6	825	524
9.1	600	15.9	830	534
12.9	660	13.7	828	526
18.3	721	11.9	825	539
24.4	779	10.0	828	525
30.5	829	8.5	832	534
Average =			827	530

Velocity Profile Data
Run C02 No Hill; No Trees; Hill Center Position

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @30.5cm (cm/s)	Velocity @6.1cm (cm/s)
1.2	463	19.3	819	520
2.4	514	16.9	821	511
3.7	540	16.0	817	521
4.9	564	16.7	820	517
6.1	586	15.6	820	522
9.1	629	14.3	816	525
12.9	669	13.3	822	517
18.3	719	12.3	813	526
24.4	769	10.4	813	523
30.5	828	8.5	826	528
Average =			819	521

Velocity Profile Data
Run C03 No Hill; 20' Trees; Hill Center Position

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @30.5cm (cm/s)	Velocity @6.1cm (cm/s)
1.2	278	33.2	806	519
2.4	413	24.8	805	507
3.7	477	21.5	808	501
4.9	519	19.4	804	510
6.1	546	18.3	804	521
9.1	600	16.1	806	510
12.9	654	13.9	808	500
18.3	710	11.6	808	509
24.4	763	10.7	805	512
30.5	813	9.1	810	513
Average =			806	510

Velocity Profile Data
Run C04 No Hill; 40' Trees; Hill Center Position

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @30.5cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	320	31.8	791	506
3.7	416	25.9	793	500
4.9	467	22.3	796	501
6.1	507	20.8	788	505
9.1	576	17.2	789	500
12.9	638	14.3	798	483
18.3	693	12.3	798	495
24.4	749	10.5	791	497
30.5	794	9.0	799	498
Average =			794	498

Velocity Profile Data
Run C05 No Hill; 60' Trees; Hill Center Position

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @30.5cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	283	36.1	822	526
3.7	387	28.8	823	515
4.9	465	24.5	823	518
6.1	507	21.7	822	524
9.1	583	19.2	824	516
12.9	650	15.6	821	512
18.3	721	12.2	822	508
24.4	775	10.5	821	524
30.5	831	9.2	824	516
Average =			822	518

TABLE 9 Tree Cover Reference Profile Test Data

USWP Task 2 Test Results C Series Tests

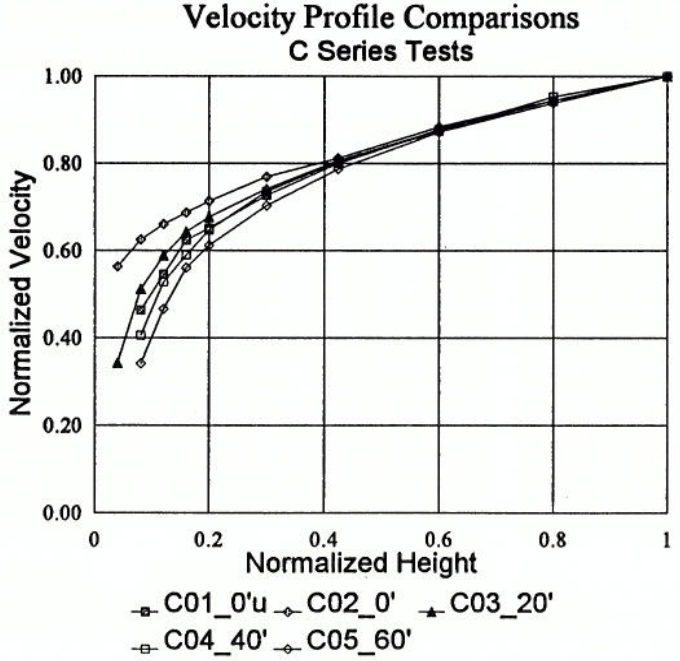
USW_VELC.WK3 Sheet B: 02/18/93

Velocity Profile Comparisons
No Hill; Reference Profile Tests

Height Norm.	Velocity Norm. C01_0'u	Velocity Norm. C02_0'	Velocity Norm. C03_20'	Velocity Norm. C04_40'	Velocity Norm. C05_60'
0.04		0.56	0.34		
0.08	0.46	0.63	0.51	0.41	0.34
0.12	0.55	0.66	0.59	0.53	0.47
0.16	0.62	0.69	0.64	0.59	0.56
0.20	0.65	0.71	0.68	0.65	0.61
0.30	0.73	0.77	0.74	0.73	0.70
0.42	0.80	0.81	0.81	0.80	0.79
0.60	0.88	0.88	0.88	0.87	0.87
0.80	0.94	0.94	0.94	0.95	0.94
1.00	1.00	1.00	1.00	1.00	1.00
Ur@30.5cm =	827	819	806	794	822
Ur@6.1cm =	530	521	510	498	518
Href (cm) =	30.5	30.5	30.5	30.5	30.5

Turbulent Intensity Profile Comparisons
No Hill; Reference Profile Tests

Height Norm.	Turb.Int. (%) C01_0'u	Turb.Int. (%) C02_0'	Turb.Int. (%) C03_20'	Turb.Int. (%) C04_40'	Turb.Int. (%) C05_60'
0.04		19.3	33.2		
0.08	25.9	16.9	24.8	31.8	36.1
0.12	22.8	16.0	21.5	25.9	28.8
0.16	19.8	16.7	19.4	22.3	24.5
0.20	17.6	15.6	18.3	20.8	21.7
0.30	15.9	14.3	16.1	17.2	19.2
0.42	13.7	13.3	13.9	14.3	15.6
0.60	11.9	12.3	11.6	12.3	12.2
0.80	10.0	10.4	10.7	10.5	10.5
1.00	8.5	8.5	9.1	9.0	9.2
Ur@30.5cm =	827	819	806	794	822
Ur@6.1cm =	530	521	510	498	518
Href (cm) =	30.5	30.5	30.5	30.5	30.5



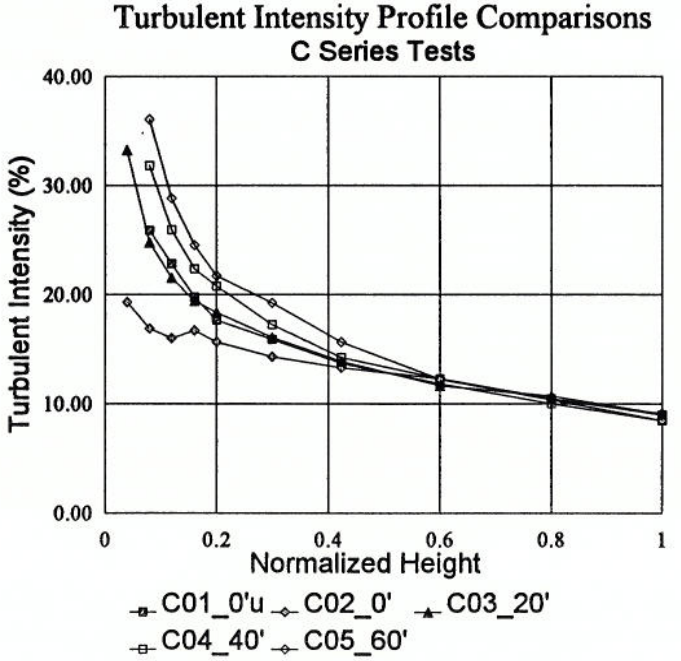


TABLE 10 Tree Cover Reference Profile Test Results

USWP Task 2 Test Results — C Series Tests

USW_VELC.WK3 Sheet C: 02/18/93

Reference Velocity Profile Comparisons

Height (m)	Velocity (m/s) C01 0'u	Velocity (m/s) C02 0'	Velocity (m/s) C03 20'	Velocity (m/s) C04 40'	Velocity (m/s) C05 60'
24.4	4.6	6.3	5.1	4.1	3.4
36.6	5.5	6.6	5.9	5.3	4.7
48.8	6.2	6.9	6.4	5.9	5.6
61.0	6.5	7.1	6.8	6.5	6.1
91.4	7.3	7.7	7.4	7.3	7.0
129.0	8.0	8.1	8.1	8.0	7.9
182.9	8.8	8.8	8.8	8.7	8.7
243.8	9.4	9.4	9.4	9.5	9.4
304.8	10.0	10.0	10.0	10.0	10.0
d (m) =	8.0	0.2	4.3	8.7	13.0
U* (m/s) =	0.67	0.45	0.64	0.78	0.77
Zo (m) =	1.04	0.11	0.80	1.90	1.98
p =	0.26	0.19	0.24	0.29	0.32

Model Conditions		Field Conditions	
Href (cm) =	30.48	Href (m) =	305
Uref (cm/s) =	800.0	Uref (m/s) =	10.0
Length Scale =	1000.0	Length Scale =	1.0

TABLE 11 Reference Profile Regression Analysis

USWP Task 2 Test Results D Series Tests

USW_VELD.WK3 Sheet A: 02/18/93

Velocity Profile Data
Run D01 No Hill; 60' Trees; -10cm step position

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	320	34.1	800	496
3.7	429	27.2	804	496
4.9	488	23.2	796	486
6.1	543	20.8	797	490
9.1	614	17.7	800	493
12.9	665	15.4	806	496
18.3	736	12.3	806	485
24.4	793	10.5	798	486
30.5	833	9.2	799	493
Average =			801	491

Velocity Profile Data
Run D02 No Hill; 60' Trees; 10cm step position

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	363	31.0	802	488
3.7	447	25.7	800	488
4.9	494	22.1	804	494
6.1	545	20.3	803	493
9.1	607	17.4	800	491
12.9	680	14.0	801	492
18.3	738	12.1	797	491
24.4	792	10.7	800	488
30.5	832	9.6	799	485
Average =			801	490

Velocity Profile Data
Run D03 No Hill; 60' Trees; 40cm step position

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	351	33.3	796	494
3.7	435	26.4	795	478
4.9	477	24.7	793	484
6.1	520	21.7	792	494
9.1	607	17.6	796	492
12.9	661	14.8	794	481
18.3	715	13.0	782	488
24.4	779	11.1	793	486
30.5	818	9.6	785	487
Average =			792	487

Velocity Profile Data
Run D04 No Hill; 60' Trees; 0cm step position

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	383	29.8	802	489
3.7	436	27.0	793	481
4.9	491	23.5	797	490
6.1	532	21.5	792	488
9.1	604	17.8	788	474
12.9	663	15.6	794	498
18.3	736	11.9	805	486
24.4	788	11.0	798	495
30.5	834	9.4	799	485
Average =			796	487

Velocity Profile Data
Run D05 No Hill; 60' Trees; 20cm step position

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	432	23.2	797	493
3.7	465	23.6	799	497
4.9	499	22.5	790	499
6.1	542	20.6	797	483
9.1	606	17.9	793	495
12.9	654	15.2	794	493
18.3	728	12.4	794	483
24.4	786	10.5	795	486
30.5	832	9.7	797	496
Average =			795	492

Velocity Profile Data
Run D06 No Hill; 60' Trees; 60cm step position

Height (cm)	Velocity HW (cm/s)	Turbulent Intensity (%)	Velocity @76.2cm (cm/s)	Velocity @6.1cm (cm/s)
2.4	457	21.4	798	489
3.7	485	20.6	796	492
4.9	523	21.7	795	495
6.1	539	20.2	797	494
9.1	593	18.4	792	491
12.9	669	14.6	792	489
18.3	725	13.1	798	493
24.4	786	10.5	800	490
30.5	836	9.4	801	478
Average =			797	490

TABLE 12 Tree Cover Step Roughness Change Test Data