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Computer program for wind speeds and turbulence properties: flat or hilly sites in terrain with roughness changes

Associated software: VIEWpac E0108

ESDU DATA ITEMS

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We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item, which supersedes ESDU 92032, was monitored and guided by the Wind Engineering Panel. This Panel, which took over the work on wind engineering previously monitored by the Fluid Mechanics Steering Group, first met in 1979 and now has the following membership:

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COMPUTER PROGRAM FOR WIND SPEEDS AND TURBULENCE PROPERTIES: FLAT OR HILLY SITES IN TERRAIN WITH ROUGHNESS CHANGES

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COMPUTER PROGRAM FOR WIND SPEEDS AND TURBULENCE PROPERTIES: flat or hilly sites in terrain with roughness changes

1. NOTATION AND UNITS

		SI
d	height above ground of effective zero-plane, dependent on height and density of ground obstacles in built-up or wooded areas	m
F	value of fetch (x) for equilibrium boundary layer to have been established at site	m
f	Coriolis parameter, $f = 1.458 \times 10^{-4} \sin \Phi$	rad/s
G	distortion factor on spectral density for flow over hill; $(S_{ii})_{hill}/(S_{ii})_{flat}$, (see Section 6.7.2)	
g	gust peak factor (Section 6.2)	
H	maximum height of hill (negative if a valley)	m
h	atmospheric boundary-layer height	m
I_u, I_v, I_w	turbulence intensities of u, v, w components of turbulence respectively; $I_u = \sigma_u/V_z, I_v = \sigma_v/V_z, I_w = \sigma_w/V_z$	
K_L	speed-up factor on mean wind speed due to topography; $V_{z, hill}/V_{z, flat}$	
K_u	correction factor in evaluation of u_* (Section 6.1)	
L_{01}, L_{02}	overall length scales of topographic feature from summit to $H/2$ contour (see Sketch 4.4)	m
L	half width of hill at half height in wind direction	m
$^xL_u, ^yL_u, ^zL_u$	integral length scales of u, v and w components of turbulence along x, y and z -axes	m
$^xL_v, ^yL_v, ^zL_v$	with x -axis in wind direction and z -axis vertical	
$^xL_w, ^yL_w, ^zL_w$		
n	frequency	Hz
n_r	number of roughness changes upwind of site	
S_{ii}	spectral density of $i = u, v$ or w components of turbulence respectively at single point in space and frequency, n	m ² /s

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t	gust duration or averaging time	s
u_*	surface friction velocity in equilibrium boundary layer	m/s
u_{*0}	value of u_* within inner layer of boundary layer over site in non-uniform terrain	m/s
u, v, w	fluctuating components of wind speed along x, y and z axes respectively	m/s
V_z	hourly-mean wind speed in equilibrium boundary layer (no roughness changes upwind)	m/s
$\hat{V}_z, V_g$	gust speed averaged over t seconds	m/s
V_{ref}	reference wind speed; given wind speed (mean or gust) derived from basic wind speed maps, local met. office data or measured data at particular site, with or without terrain roughness changes upwind and/or topography effects	m/s
W_{01}, W_{02}	overall width scales of topographic feature from summit to $H/2$ contour (see Sketch 4.4)	m
$x, x_1, x_2, \dots$	lengths of terrain associated with roughnesses $z_0, z_{01}, z_{02}, \dots$	m
x_{site}, y_{site}	co-ordinates of site in relation to $0x, 0y$ axes of topographic feature (see Sketch 4.4)	m
z_{hill}	hill contour height measured from surrounding plateau level	m
z	height measured from ground	m
z_0	terrain roughness parameter (see Section 4.3)	m
z_{0eff}	effective value of z_0 for terrain patch (see Section 4.3.1)	
$z_0, z_{01}, z_{02}, \dots$	values of z_0 for lengths of uniform terrain upwind of site and upwind of first, second, ... step changes in z_0 respectively	m
$\sigma_u, \sigma_v, \sigma_w$	rms values of u, v , and w respectively	m/s
ψ	angle between mean wind direction and line normal to local ridge line passing through site (see Sketch 4.4)	degree
Φ	angle of latitude at site	degree

Subscripts or postscripts

<i>flat</i>	relates to value for flat terrain
<i>hill</i>	relates to value for hill (or valley)
<i>ref</i>	relates to values at reference site (where wind conditions are known)
<i>site</i>	relates to value at target site (where wind conditions are to be calculated)
<i>x</i>	relates to local value at site in non-equilibrium boundary layer (with roughness changes upwind)
<i>z</i>	relates to value at height <i>z</i>

2. PURPOSE AND SCOPE

For strong winds (neutral atmosphere), estimation methods are provided in ESDU 82026⁶, 83045⁷, 85020¹² and 86010¹³ giving the variation of hourly-mean wind speed, gusts, intensities of turbulence and integral length scales and spectral densities of turbulence with height over terrain with roughness changes. For convenience, tables of wind speed factors and properties of the u -component of turbulence based on these methods are presented in ESDU 84011⁹, 84030¹⁰ and 86035¹⁴ for various combinations of ground roughness at the site and upwind.

The computer program used to generate the data for these simple look-up tables has been extensively modified for more general use and expanded to include topographic effects. A number of features have been added to the program to assist practical application. In particular, the program has now been converted to Visual Basic and is run as a module in Microsoft Excel 97 (or later) using a spreadsheet format for entering data and printing the resultant output.

A major modification to the previous version (A9232) is that topographic effects are now computed via a program based on the theoretical model of Deaves³ rather than on a simplified model which could only be applied conveniently to isolated hills. The program can be used to calculate wind speeds over hilly terrain which may consist of several peaks and troughs. It has also been adapted to provide estimates for steep terrain where flow separation effects occur. Also included is a simplified method for the distortion effect of topography on turbulence.

The user is recommended to use Tables 3.1 and 3.2 which provide a summary and guidance for the input data required. The rest of this document supplies more detailed information concerning the input data (cross-referenced in Tables 3.1 and 3.2), the use of the program, an example and the basis of the methods used.

The main features of the program are listed in Section 2.1 and the installation and setting up of the program is described in Section 3. A description of the input and output data formats is given in Sections 4 and 5 and a summary of the basis of the methods used is described in Section 6. Examples of the use of the program are given in Section 7 and comparisons with two sets of full-scale measurements on hills are given in Section 9.

Other programs which perform some of the same tasks as the program given in this Item have been included previously in ESDU 84011⁹ and 85003¹¹. These programs will give values of wind speed and turbulence intensity (I_u) to within a few percent (typically less than 5%) of the values given by the present program for a single roughness change. However, the present program has a more definitive source (see Section 6) and is likely to be more reliable in general application. It is also more comprehensive and has a research and application role in providing a means of correcting measured data to specified standard conditions.

The application of the neutral atmosphere model to tropical storms such as hurricanes and typhoons is discussed in ESDU 87034. It is reasonable to expect that over land the program can be used for such storms at heights below 200 m.

2.1 Features of the Program

The program can be used in the following ways.

- (a) To calculate for a given site (and wind direction) the properties listed in (i) to (v) below for a specified reference wind speed condition (see Section 4.1.1).
- (b) To investigate the effect on selected wind properties of changing some of the input variables (such

as reference wind speed, ground roughness or gust averaging time). The spreadsheet presentation facilitates repeat runs with changes to the input.

- (c) To reduce or correct measured wind properties (such as those from a local met. station) to values corresponding to standard conditions such as flat, uniform open country terrain, or to obtain corresponding values for some other specified terrain.

The program will calculate the following wind properties as a function of height over the site.

- (i) Hourly-mean wind speed.
- (ii) Maximum gust speed or 'fastest mile of wind' averaged over t seconds where $0.3 \leq t \leq 3600$ s.
- (iii) Properties of the longitudinal (u) component of turbulence (intensity I_u and integral length scales $^xL_u, ^yL_u, ^zL_u$) and spectral density, nS_{uu}/σ_u^2 .
- (iv) Properties of the lateral (v) component of turbulence (intensity I_v and integral length scales $^xL_v, ^yL_v, ^zL_v$) and spectral density, nS_{vv}/σ_v^2 .
- (v) Properties of the vertical (w) component of turbulence (intensity I_w and integral length scales $^xL_w, ^yL_w, ^zL_w$) and spectral density, nS_{ww}/σ_w^2 .

The program takes into account the following local conditions.

- (1) Ground roughness at the site (z_0).
- (2) Variations in ground roughness upwind of the site (z_{01}, z_{02} , etc., see Section 4.4).
- (3) The variation of sea-surface roughness with wind speed.
- (4) Height above the ground.
- (5) Topographic effects on wind speed due to the location of the site in a hilly region, including ridges, embankments, escarpments or cliffs, or in a valley; also, topographic effects on turbulence properties for flow over hills with no flow separation.
- (6) Variation of wind properties and turbulence with wind speed (for a neutral atmosphere).

3. RUNNING THE PROGRAM

The program E0108, which supersedes program A9232 previously available, is written in Visual Basic and runs as a module in Microsoft Excel 97. The code that runs the Excel module is hidden to ensure that only authorised changes can be made.

The input data required for the program may be considerable, particularly if the terrain is hilly. To assist in achieving a complete and correct set of input data, each Worksheet contains notes and sketches to provide guidance and copious error traps are built into the program to catch input errors. Additionally, Tables 3.1 and 3.2 provide a summary of the required input data on each Worksheet together with cross references to Sections in this Data Item where further guidance or explanation can be found.

TABLE 3.1 Summary of Input Data for Worksheets “Reference site” and “Target site”

Reference site Worksheet Cell/Row No.	Input entry	Target site Worksheet Cell/Row No.	For further guidance see:
Cell F3	Enter location name or source reference.	Cell F3	
Row 5	Case number refers to a particular calculation case.	Row 8	
Row 6	Wind direction for Case (degrees from North). Direction from which the wind is blowing.	Row 9	
–	On Target site Worksheet, enter start Case number and end Case number for calculation run.	Cells D10, F10	
Row 8	Latitude of Reference site in degrees.	-	
Row 9	Reference wind speed from basic wind speed map or other source, or measured data (may include terrain changes and hill effects).	-	ESDU 82026 ⁶
Row 10	Gust averaging time, t . For fastest mile of wind, $t = 1609 / V_{ref}$ where V_{ref} is the fastest mile of wind in m/s.	Row 11	
Row 11	Height above ground (not zero plane).	Cell A11, A12, etc.	
Row 12	Height of zero plane above ground (accounts for upward displacement of wind profile due to ground obstructions). Typically, $d \approx 0.8 \times$ general level of obstructions for town centres and wooded terrain. See ESDU 82026 for more information.	Row 12	Sections 6.5
Row 13	If Reference site and/or Target site is on hilly terrain, check box (tick will appear) on relevant sheet.	Row 13	
Row 19	n_{ref} and n . Number of terrain roughness changes upwind of Reference site and Target site respectively.	Row 21	Section 4.3
Row 20	Terrain roughness (z_0 in metres) in 1st patch of terrain (x) between site and 1st roughness change upwind.	Row 22	Section 4.3
Row 21	Length of 1st patch (x) in metres.	Row 23	
Row 22	Terrain roughness (z_{01} in metres) in 2nd patch (x_1) between 1st and 2nd roughness changes upwind of site.	Row 24	
Row 23	Length of 2nd patch (x_1) in metres.	Row 25	
Row (20+2 n_{ref})	Terrain roughness in final patch where equilibrium conditions assumed.	Row (22+2 n)	Section 4.3
Row (21+2 n_{ref})	Leave blank.	Row (23+2 n)	
–	Calculation options are on Worksheet Target site. In column over Cells B1 to B7, choose one or more options by checking relevant boxes. To delete previous output, check last box; in this case, copy old results to separate Worksheet if so required.	Cells B1 to B7	
–	On completion of all input data, the Cases chosen are run by clicking the ‘Run cases’ button on Worksheet Target site.	Run button	

TABLE 3.2 Summary of Topography Input Data

This Table relates to input data for the Worksheets ‘**Reference site topography**’ and ‘**Target site topography**’.

Cell /Row no.	Input entry	For further guidance see:
C4	Number of horizontal grid nodes; the default is 40.	Section 4.4.3
Row 22	Wind direction; degrees from North. Direction from which the wind is blowing.	
Row 23	Angle $N0y$; angle between North and the (minor) $0y$ hill axis.	Section 4.4.1(iii)
Row 24	Remaining input. If input data from Row 25 onwards is the same as another Case already input, that Case no. can be entered into Cell F24, J24, <i>etc.</i> , as appropriate. This avoids re-entering the same input data (but see Section 4.4.1).	Section 4.4.1
Rows 25, 26	L_{01} , L_{02} , W_{01} , W_{02} . Enter half-height length scales in grey Cells C25 to D26 for Case 1, G25 to H26 for Case 2, <i>etc.</i> If these cells are left blank, the program will evaluate default values.	Section 4.4.1(iv) Section 4.4.2.1
Row 26	x_{peak} , y_{peak} . Enter coordinates of the local peak on which site is located into blue Cells E26, F26 for Case 1, Cells I26, J26 for Case 2, <i>etc.</i> The local peak is not necessarily the highest peak where terrain with several peaks is under consideration.	
Row 27	H_{peak} . Enter height of the local peak on which the site is located in Cell F27 for Case 1, J27 for Case2, <i>etc.</i>	
Row 27	x_{site} , y_{site} . Enter coordinates of the site in green Cells C27, D27 for Case 1, G27, H27 for Case 2, <i>etc.</i>	Sketch 4.4
Row 29 onwards	y_{AB} , z_{AB} ; x_{CD} , z_{CD} . Enter coordinates of the hill profile along sections AB and CD respectively where A, B, C, D are the start and end points where the section profile meets the surrounding plateau levels. Start and end plateau levels need not be the same.	Section 4.4.1(vi) and Worksheet
Row 74	Wind direction components and hill profile plots are provided automatically for verification purposes. If separated flow is predicted to occur, the modification to the hill profile for computation purposes is shown on the profile plots subsequent to running the Case(s).	Section 5
	All length measurements are in metres. All heights here are relative to a common level defined by the user.	

4. INPUT DATA

The input data required relate to the Reference Site and to the Target Site. The Reference Site represents the conditions of the site for which a known reference wind speed applies (see Section 4.1). This may include topographic effects and/or several changes in terrain roughness upwind of the site.

The Target Site represents the site for which wind speeds and/or turbulence data are required to be calculated. These are determined from the given wind speed at the Reference Site taking into account changes in terrain roughness, topography, gust averaging time, *etc.* (see Section 4.2).

4.1 Terrain Input Data for Reference Site

Select the Worksheet “Reference site”. The spreadsheet is mostly self explanatory through the sketches displayed and the Notes which appear when the cursor is placed on a cell containing a red marker in the top right-hand corner.

A range of **Cases** may be dealt with in any one run but note that the Reference Site data for Case 1 corresponds to that required for Case 1 at the Target Site, *etc.*

The value of ‘**Wind direction**’ entered in Row 6 is not used by the program, it is used here simply as a description of the ‘Case’. Wind direction becomes important when entering topographic data.

Details of the **Reference wind speed** are entered into rows 9 to 12. Further description of this data is given in Section 4.1.1.

If the Reference Site is situated in hilly terrain then the relevant box must be checked in row 13 by clicking into the relevant cell. Details of the topography must then be entered into the “Ref. site topography” Worksheet (see Section 4.4).

Details of the terrain at, and upwind of, the Reference Site are entered into rows 19 onwards for each Case. Firstly, the number of roughness changes must be entered into row 19, and this must be compatible with the following entries giving details of the terrain changes. If incompatibility is found by the program, an error message is displayed; this is done to avoid misinterpretation of the input data by the user.

Values of the terrain roughness parameter (z_0 , z_{01} , *etc.*) and their respective terrain patch lengths (x , x_1 , *etc.*) are required corresponding to the types of terrain upwind. Sudden (step) changes in terrain roughness are assumed to occur. Guidance in choosing values of z_0 for various terrains is given in the Worksheet “Terrain roughness”. Section 4.3 provides more detailed guidance, particularly for cases where there is a significant variation in terrain roughness across a patch normal to the wind direction.

If the Reference Site is on a hill or in a valley the consequent topographic effect (speed-up factor) is taken into account by the program to produce an equivalent reference wind speed for flat terrain. The relevant box must be checked in Row 13 by clicking onto the appropriate cell. Select the “Ref. site topography” Worksheet tab and input the relevant data for the reference site topography. Again, the sketches and Notes attached to various cells will assist in understanding the input data required. Further description of the topography input data parameters is given in Section 4.4.

4.1.1 Reference wind speed

The Reference wind speed can be either a basic design wind speed for standard conditions or, for example, a measured wind speed for specified (non-standard) conditions.