Introduction

The purpose of this part of the software is to calculate simple wind-wave interactions by take into account the effect of the waves on the wind speed.

The vertical profile of wind speed with height in neutral stability condition is given by:

$$U_z = \frac{u_*}{\kappa} \ln\left(\frac{Z}{Z_o}\right) \qquad (1)$$

Where U_z is the horizontal wind speed at the height Z above the ocean surface; u_* is the friction velocity; κ is the von Kármán constant, and Z_o is aerodynamic roughness length.

The effects of the wave field on the wind vertical profile are represented by the lumped constant Z_o. Usually this constant is calculated by using Charnock expression for the aerodynamic roughness height [1]:

$$Z_o = \alpha \frac{u_*^2}{g} \qquad (2)$$

Where g is the acceleration of gravity, and α is known as Charnock constant which is given the value of 0.012 by Charnock. The Charnock expression doesn't include the effect of the wave characteristics such as wave speed.

Stewart [2] suggested a modification for Charnock expression by relating the aerodynamics roughness height to the wave age as following:

$$Z_o = \frac{u_*^2}{g} A \left(\frac{C_p}{u_*}\right)^B \qquad (3)$$

Where C_p is the peak phase speed of the ocean wave, and $\left(\frac{C_p}{u_*}\right)$ is the wave age.

The A and B coefficients in Stewart expression are given different values in different studies.

The engineering toolkit code calculates the aerodynamics roughness height by using both the Charnock expression and the one suggested by Stewart and compared between them. The coefficients, A and B are given different values [3] depending on five different references as in table 1

Reference	A	B
Toba et al.	0.020	0.5
Sugimori et al.	0.020	0.7
Smith et al.	0.48	-1.0
Johanson et al.	1.89	-1.59
Drennan et al.	1.7	-1.7

The calculated aerodynamic roughness is then used in equation (1) to calculate the velocity at the turbine hub height, which is needed to estimate the power output from the turbine.

The turbine power output is calculated as following:

$$P = 0.5 \times Air\ density \times Energy\ pattern\ factor \times Efficiency\ \times Swept\ area \times Windspeed^3 \quad (4)$$

Where the air density is taken to be 1.225, the energy pattern 1.91 (Rayleigh distribution), and the swept area is calculated depending on the turbine diameter.

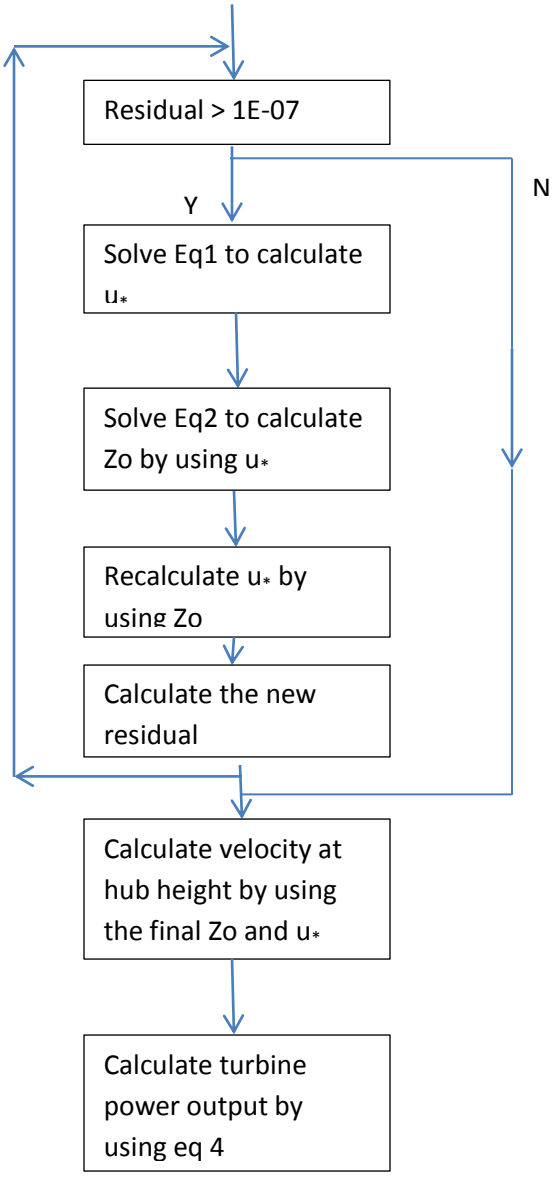
The Code

The code starts by asking the user to inter some input:

- ***Enter Wind Speed*** Wind speed measured at a known height (m/s) U_g.
- ***Enter Reference Height*** The height at which the wind velocity is measured (m) Z_g.
- ***Enter Turbine Hub Height*** Turbine hub height (m) Z_{hub} .
- ***Enter Turbine Diameter*** Turbine diameter (m) T_d .
- ***Enter Turbine Efficiency*** Turbine efficiency (%) E_f .
- ***Enter Wave Speed*** Wave speed (m/s) C_w .

Then a loop is made to calculate the friction velocity and aerodynamic roughness as following:

Initial value for Zo (=2E-04) and residual (=1)



By using the seam method as above, the aerodynamic roughness and the friction velocity is calculated by using equation (3) instead of equation (2). The constants in table 1 are used in equation (3).

The aerodynamic roughness, friction velocity, and hub height velocity are compared. The estimated turbine power outputs are also compared by using the power output calculated by Charnock, which is the stander equation to estimate the aerodynamic roughness in wind turbine industries, as a reference value:

Power differences (%) = Absolute [(Power calculated by taken into account the wave speed) – (power calculated by Charnock, no wave age effect)] / (power calculated by Charnock, no wave age effect)

Example:

Input:-

- Ref Velocity 7 m/s
- Ref height 20 m
- Turbine hub height 100 m
- Turbine Diameter 100 m
- Turbine efficiency 35%
- Wave velocity 2 m/s

Output:

Method	Friction velocity m/s	Roughness height m	Hub height velocity m/s	Output power MW	Power differences %
Charnock	0.21994	5.92e-05	7.88495	1.57868	**0**
Toba	0.25734	3.76e-04	8.03542	1.67079	**5.8**
Sugimori	0.26888	6.00e-04	8.08187	1.69994	**7.7**
smith	0.26073	4.34e0-4	8.04907	1.67932	**6.4**
Johnson	0.26706	5.59e-04	8.07455	1.69532	**7.4**
Drennan	0.25491	3.39e-04	8.02567	1.66472	**5.4**

References

[1] Charnock H. 1955. Wind stress on a water surface. Quart J Roy Meteorology Soc, 81:639-640

[2] Stewart RW. 1974. The air-sea momentum exchange. Bound. Layer Meteor., 16, 151-167

[3] Shi Jian et al. 2011 Dependence of sea surface drag coefficient on wind-wave parameters