CFD-RANS APPLICATIONS IN COMPLEX TERRAIN ANALYSIS. NUMERICAL VS EXPERIMENTAL RESULTS A CASE STUDY: COZZOVALLEFONDI WIND FARM IN SICILY

J.Maza (*),G.Nicoletti(**),
(*) Pisa University, Aerospace Engineering student.
Tel +39 380 717 43 03, e-mail : s186751@studenti.ing.unipi.it , giuseppe_maza@yahoo.com
(**) Enel GEM
Via A. Pisano 120, 56122 Pisa, Italy.
Tel. +39 050 6185427 , Fax +39 050 6185892, e-mail: giovanni.nicoletti@enel.it

Abstract

As stated in several studies over the last few years, CFD methods represent a powerful tool for Wind Farm planning and analysis, whose advantages with respect to linear models are evident in complex terrains. Nevertheless, to get the maximum benefit of these sophisticated tools, special care in parameters set-up is needed, in particular in the definition of the digital terrain model and the computational domain. This work makes use of different terrain representations from rough to fine and makes a comparison of numerical results versus experimental results. This work focuses on an Enel Wind Farm in Sicily with interesting terrain characteristics. This site has produced different types of experimental data. Comparison between velocity profiles, turbulence profiles, velocity and direction correlations between points has been made. The importance of some parameters such as roughness, grid conformation and spacing has been investigated . A good compromise has been found between definition and simplicity for the digital terrain of the site under consideration.

KEY WORDS: CFD-RANS, Complex terrain.

1. Introduction

As the use of CFD methods spreads worldwide in the planning phase of the Wind Energy industry, it is necessary to appreciate the sensibility of the results in variations of the setup parameters, in order to build standard analysis procedures.
With this in mind, an effective digital terrain model is necessary for the correct use of these tools. This model has to be sophisticated enough to represent the most important physical phenomenon of interest in wind farm planning but simple enough to reduce database building cost, and not least, computational costs.

With the aim to get accustomed to the use of state-of-the-art numerical tools for wind farm planning in complex terrain and to have a better understanding of constructing digital terrain models a complex terrain site with interesting characteristics has been used as a specific case study . Two parallel approaches were followed, the first regards the CFD analysis and the second regards the analysis of experimental data. A matching procedure has been done in order to make comparisons.

2. The case study: Cozzovallefondi Wind Farm in Sicily

The Cozzovallefondi Wind Farm is located in Sicily, Italy approximately 100 km south of Termini Imerese, on a hilly zone reaching 1140 m above see level. High slopes and wavy terrain makes it a good site for CFD procedures testing. The site has a ridge running at approximately west-east direction. The site presents typical Mediterranean vegetation with essentially two terrain roughness types: short grass that grows in winter and spring and fades in summer becoming yellow and “macchia” which is a evergreen group of bushes and relatively small trees.

3. CFD approach

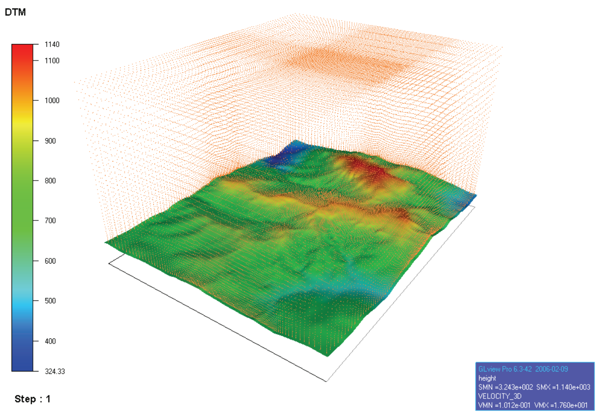
The physical phenomenon of fluid fluxes and for the present case of wind blowing through hills is translated in Mathematical form in the Navier-Stokes equations. In these equations the calculated quantities i.e. velocities, pressure , etc appear as a function of space and time. The type of flux we are interested in represent its by nature time varying (unsteady).
A CFD computer code using the so called Reynolds Averaged Navier Stokes (RANS) approach has been employed to solve the Navier Stokes equations. In this approach all of the flux unsteadiness is averaged out and all unsteadiness is regarded as part of the turbulence. On averaging, the non-linearity of the Navier-Stokes equations gives rise to terms that must be modelled because the mathematical problem is not entirely defined (closed). The CFD code models these terms using the k-ε turbulence model which introduces two new partial differential equations and is thus a second order method. One equation is for the turbulence kinetic energy k and the other for the dissipation ε . The k-ε turbulence model contains five parameters that are calibrated in order to represent the type of flux of interest. For the present work two sets of values are tested.

The CFD code being used is WindSim , developed by Vector AS, Norway.

The first step in the CFD analysis is the terrain modelling. A digital terrain model sized 10x7 km covering the area around the Wind Farm has been used to represent the terrain orography. A roughness map has been constructed based on a geo referenced aerial photo. A resolution of 10x10 m is used. A domain for the CFD method is defined using the digital terrain as bottom boundary. The height of the domain is set big enough in order to avoid blocking effects and thus unphysical accelerations.

The grid conformation and spacing is varied both horizontally and vertically to test its influence in results.

Boundary Conditions of Velocity, Turbulence Kinetic energy and Dissipation are set at the inlet(s) walls of the domain. (Inlet and exit walls vary as wind direction is varied).
Due to the low speeds all over the field, the fluid (air) is considered incompressible.



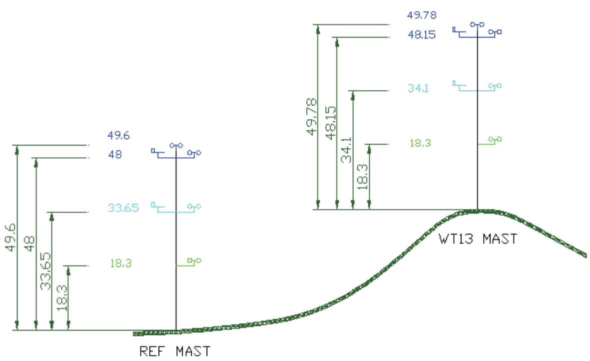
Digital Terrain and CFD domain

The Coriolis force is not included in the model. Further analysis and the introduction of the Coriolis force in the mathematical model may be desirable in order to estimate quantitatively this effect.

4. Experimental Approach

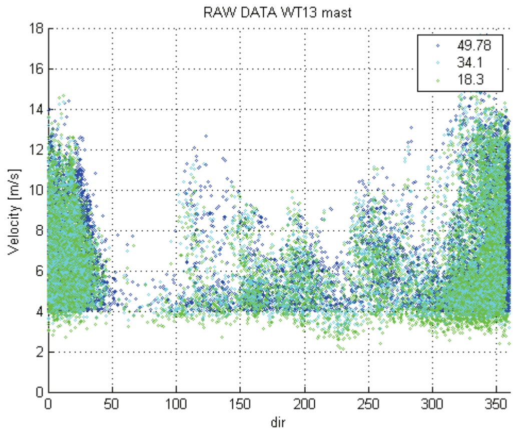
In order to check CFD results experimental results are needed.

A site assessment of the topography and obstacles characteristics was made to examine whether the test site meets the requirements of Annex A of IEC 61400-12/1998[1] concerning terrain-induced distortions to the flow. The assessment revealed major deviations from the requirements of the standard regarding topographical variations in all sectors. Thus a site calibration was considered necessary and done by CRES Institute (Greece).
In the site calibration procedure two mast with various anemometers and vanes were mounted. One on the top of the ridge in the position were the Wind Turbine is intended to be installed (the WT13 mast) and the other 168 meters away in the north-northwest direction (Reference Mast : REF).
The height difference between the two masts is 26 meters.



Mast's sketch

Site calibration raw data from CRES campaign are used to test the CFD results. Nevertheless the experimental raw data cannot be used directly. It needs to be processed.

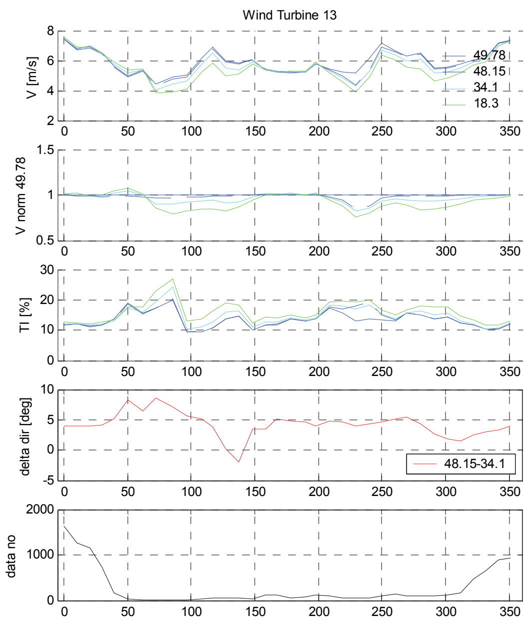


The data was processed by averaging values every 10 degrees in wind direction in two ways:

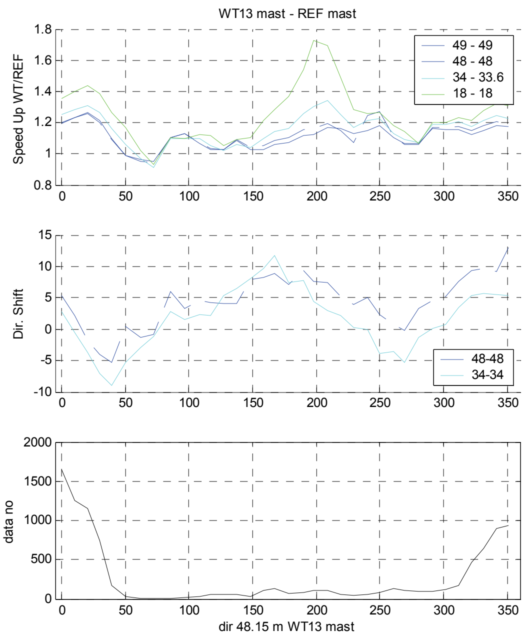
1- TOP-BOTTOM: Considering each mast alone, and thus processing velocity, turbulence intensity and directions at various heights (AGL) with direction taken at the top of the mast.

2- REF-WT mast : Considering relations between the Reference and the Wind Turbine Mast at various heights (AGL) and thus processing speed ups and direction shifts with direction taken at the top of the WT13 mast.

A special care is taken in the number of data available for each sector, as less data produces less meaningful results.



Example of TOP-BOTTOM processed data



Example REF-WT processed data

5. Matching Procedure

In the CFD code, for modelling reasons, the wind direction is set at the domain inlet (s).The experimental data is taken at the masts positions, inside the domain . Wind direction between these points varies for several reasons. Thus, in order to make comparisons of velocity and turbulence intensity profiles, speed ups and direction shifts between calculated data and experimental data we can proceed in the following two ways:

1- Ignore this change and make a comparison at same directions.
This can be a not too bad procedure for simple terrains with small obstacles.

2 - Use the direction shift calculated in the CFD code between the inlet of the domain and the measured point to establish the wind direction at the measured point and use for this direction the experimental data to make comparisons.
The idea is to make comparisons when both the calculated wind and the real wind blow in the same direction over the same reference point. For the present case the reference point is chosen at the top of the WT13 mast.
This procedure seams a better approach for complex terrains when orography and obstacles produce significant wind direction changes.

For the present work, procedure n.2 is used.

6. Projects Done

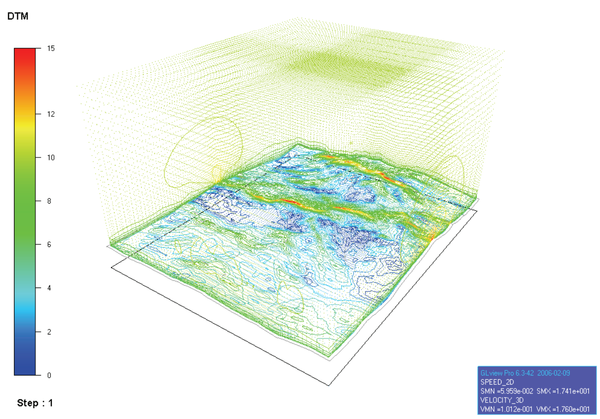
The following table resumes some of the projects done. A project is defined by the terrain model and the CFD set-up parameters used.

Project	no. Cell.	roughness	Turbulence model	no. Sect	Vtop
Mont1	345k	cost 0.1	k-ε	12	10
Mont2	345k	cost 0.1	k-ε mod	12	10
Mont3	594k	cost 0.1	k-ε	12	10
Mont4	594k	var. 0.06-0.2	k-ε	12	10
Mont5	594k	var. 0.06-0.2	k-ε	12	6

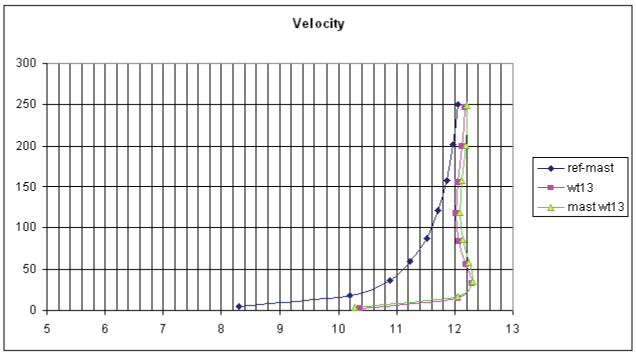
Some of these parameters are the number of domain discretization cells and thus terrain modelling (the terrain is the bottom of the computational domain) , the roughness map, the turbulence model used and the velocity at the top of the inlet boundary layer. Other set up parameters include area extension, horizontal and vertical grid conformation and spacing, height of vertical domain and height of inlet boundary layer.

7. Results and Comparisons

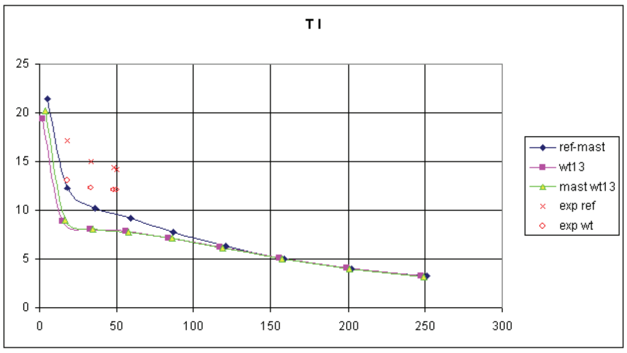
The following Plots show some typical CFD results and Comparisons with experimental values.



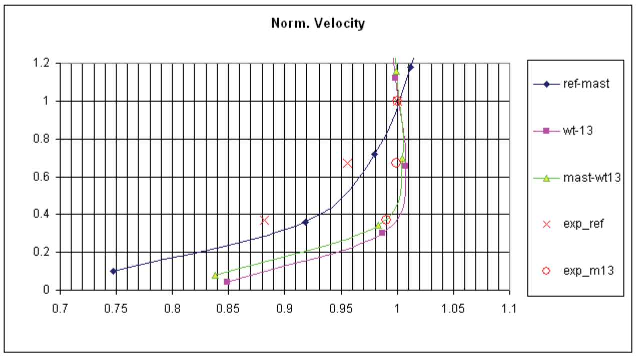
Velocity Distribution



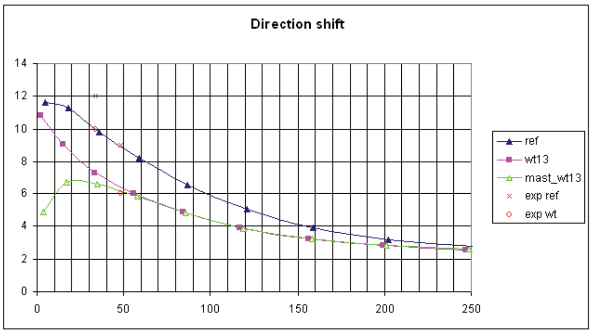
CFD Velocity Profiles, Speed up effect is evident



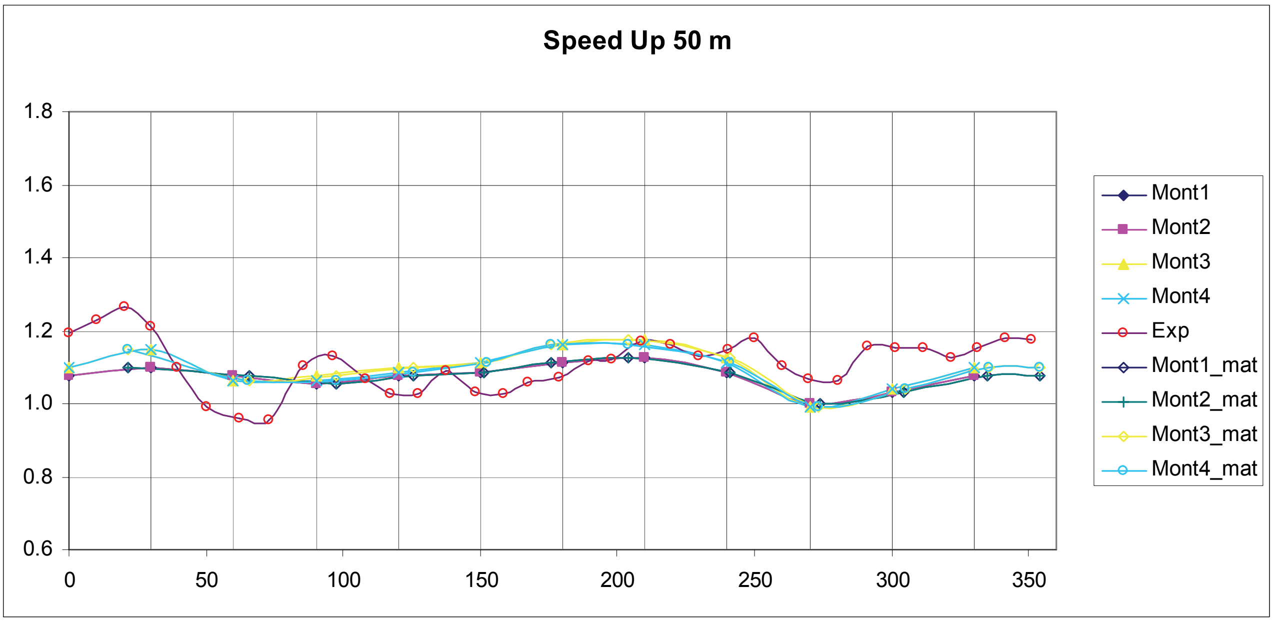
Comparison: Turbulence Intensity Profiles



Comparison: Normalized Velocity



Comparison: Direction Shift



Comparison: Speed Ups

8. Conclusions

Many terrain models from rough to detailed have been tested. Set up parameters have been varied in order to test their influence.
The importance of some modelling parameters has been investigated.

Finer discretizations in both grid an directions improve the CFD results, but need a lot of experimental data for appropriate matching.
Computing times rise drastically with finer models. A good compromise between definition and simplicity has been found for the site under consideration. These results can be the basis for standard analysis procedures in similar sites.

References

1.Tritton DJ, Physical Fluid Dynamics, Clarendon Press, Oxford 1988.
2-Ferziger JH, Perić M. , Computational Methods for Fluid Dynamics 3rd ed. , Springer, 2002.
3- CFD code Website : www.windsim.com

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J. Maza, Pisa University, Aerospace Engineering student, Italy.
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SITE DESCRIPTION

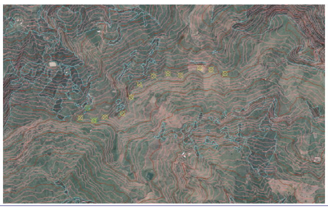
Typical Orography

Masts Positions (East view)

Different Roughness levels

North View

CFD APPROACH

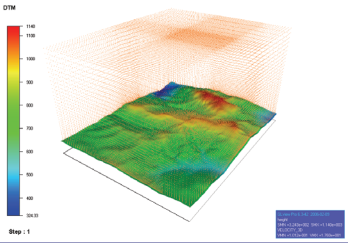


TERRAIN MODELING

Digital Orography

Roughness map from Geo referenced aerial photo

Masts and Turbines positions



Preprocessing and CFD set up

Numerical approach (CFD-RANS)

Domain Definition : horizontal and vertical extension, grid configuration and spacing.

Turbulence Model: k-ε

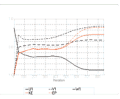
Boundary conditions:

Velocity

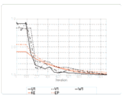
Turbulence Kinetic energy

Dissipation

Number of sectors



Variables Monitor

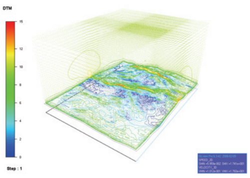


Residuals Monitor

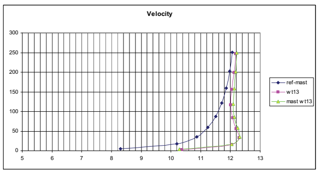
Processing

Convergence monitoring

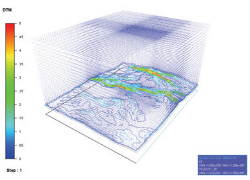
Post Processing and data analysis



Velocity Distribution

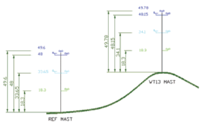


Velocity Profiles



Turbulence Kinetic Energy Distribution

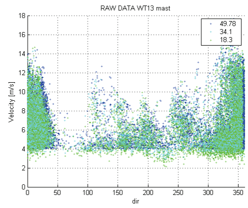
EXPERIMENTAL APPROACH

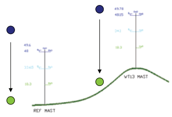


DATA AQUISITION

Site calibration data from CRES campaign are used.

Raw data presents large dispersion. Need to be processed





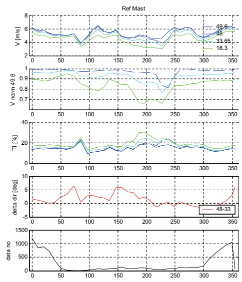
Processed data
TOP - BOTTOM

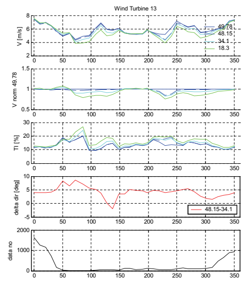
Velocity

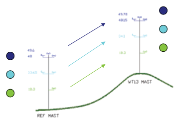
Normalized Velocity

Turbulence Intensity

Direction shift



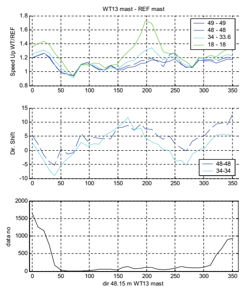




Processed data
REF - WT masts

Speed Up

Direction Shift



REF mast and WT13 during power curve measuring campaign

(North-east view, summer)

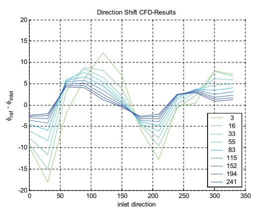
COMPARISON

MATCHING PROCEDURE

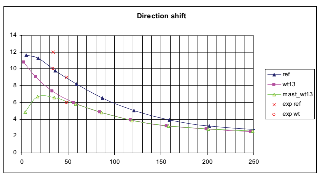
CFD wind direction is assigned as boundary condition at the domain inlet (s) .

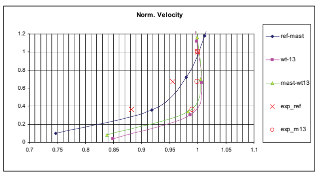
Local wind direction is measured on reference points (masts).

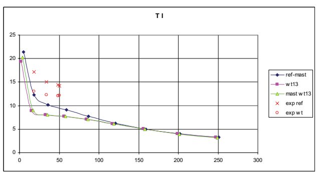
CFD solutions are used to determine direction shifts between inlet and reference points in order to make comparisons.

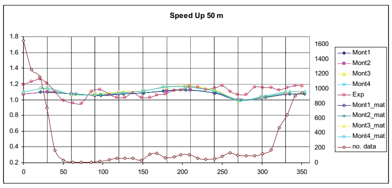


SOME EXAMPLES









CONCLUSIONS

Many terrain models from rough to detailed have been made.

Set up parameters are varied in order to test their influence:

Terrain Roughness, Grid Conformation, Turbulence Model settings, Inlet Velocity.

Several computations have been made.

The importance of some modeling parameters has been investigated.

Finer discretizations in both grid and directions improve the CFD results but need a lot of experimental data for appropriate matching.

Computing times rise drastically with finer models

A good compromise between definition and simplicity has been found for the site under consideration.

These results can be the basis for standard analysis procedures in similar sites.

(*) **CFD—RANS** : Computational Fluid Dynamics , Reynolds Averaged Navier Stokes

CFD code used: **WindSim**, developed by Vector AS, Norway