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Numerical Simulation of Wind Flow over Complex Terrain of Yangon City

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ABSTRACT

To get an economical and safe design structures in design process, this study investigate how to change vertical wind profile depends on surface roughness over the terrain. Nowadays, the concern of wind engineering is increasing among Myanmar engineers because of increasing damages due to the frequent occurrence of natural disasters and construction of many tall and modernized buildings in the city centers, which are more susceptible to wind loads. Wind direction and vertical wind speed profile are sensitively influenced by local topography. These factors connect directly with wind loading and buffeting response of buildings. It is very important to find out the vertical wind speed profile and other characteristics of the wind velocity. However, predicting and properly assessing the wind flow over or around obstacles is a difficult and expensive process when using the experimental approach. In this study, the computations are performed in OpenFOAM (Open Field Operation and Manipulation) Computational Fluid Dynamics Toolbox and the turbulence is modeled by using Reynolds Averaged Navier-Stokes (RANS) models mainly k-epsilon (k- ε *) for cases.*

Key Words: *Vertical Wind Speed Profiles, Numerical Simulation, Standard K-* ε *Model, Wind Flow, OpenFOAM tools.*

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1. INTRODUCTION

CFD technique is more economical and widely available compared to wind tunnel facilities. In recent years, working industries such as aerospace and motor industries using this computational tool have been largely developed to predict the flow of air around aircraft, involving mostly attached flow over streamlined bodies with relatively small areas of separation and turbulent length scales smaller than the body under investigation. In Myanmar, there is no published paper in this field with a critical review. This research is to cover also basic knowledge of CFD simulation such as how to estimate not only wind flow over terrains but also wind flow around buildings. Specifically, this research focuses on wind flow over complex terrain, especially in Yangon City. The city is divided into four districts. The districts combined have a total of 33 townships. Most of high-rise buildings are constructed in western and southern districts (also known downtown areas) in which Ahlone, Bahan, Dagon, Kyaktada, Seikkan, Lanmadaw, Latha, Pabedan, Sanchaung, Yankin, Tamwe and Mingala Taungnyunt townships are included. Vertical wind profile conditions in these areas can be known from this paper.

2. NUMERICAL SIMULATION OF ATMOSPHERIC BOUNDARY LAYER FLOW

Nowadays, computational fluid dynamics (CFD) modeling for the atmospheric boundary layer (ABL) in complex terrain is becoming more abundant, although it is quite time demanding to perform numerical solutions of the governing fluid equations without making simplifications to the flow dynamics. Several numerical simulation techniques exist for wind flow analysis such as Reynolds Averaged Navier-Stoke (RANS), Large Eddy Simulation (LES) and Direct Numerical Simulation (DNS). The widely used numerical solvers for the wind flow over complex terrain are based on solving the incompressible Reynolds Averaged Navier-Stokes equations (RANS) linked with two equation turbulence models (typically k – ε model). RANS methods only provide information on the mean wind and turbulent kinetic energy level. Yet, they are favored due to their robustness and low computational costs. In this paper, steady state the standard k – ε model are used in simulation.

For the k – ε model, the inlet ABL boundary conditions are considered as proposed by Richards and Hoxey (1993) for this simulation [1]:

$$u_z = \frac{u^*_{ABL}}{\kappa} \ln\left[\frac{z - z_g + z_0}{z_0}\right] \quad \text{------------------------- (1)}$$

$$u^* = \kappa \frac{u_{ref}}{\ln\left(\frac{z_{ref} + z_0}{z_0}\right)} \quad \text{------------------------- (2)}$$

$$\varepsilon_z = \frac{{u^*_{ABL}}^3}{\kappa(z - z_g + z_0)} \quad \text{------------------------- (3)}$$

$$k_z = \frac{{u^*_{ABL}}^2}{\sqrt{C_\mu}} \quad \text{------------------------- (4)}$$

where

κ is the Von Karman's constant (≈0.41)

u^* is the friction velocity [m/s]

u_{ref} is reference velocity at z_{ref} [m/s]

z is the distance above the ground [m]

z_g is the minimum distance above the ground [m]

z_{ref} is the reference height [m]

z_0 is a characteristics atmospheric roughness length [m]

C_μ is a model constant of the standard k-ε model (0.09)

These profiles are used as initial inlet wind profiles for CFD simulation in this paper.

3. MODEL DESCRIPTIONS

3.1 Site characteristics

Yangon is one of the largest city in Myanmar as shown in Fig 1. It is located in lower Myanmar at the convergence of the Yangon and Bago rivers about 30 km away from the Gulf of Martaban at 16°51' North, 96°11' East (16°51' N 96°11' E), has an area of 598.75 km^2. The city experiences three season and climate falls under the tropical monsoon climate category under the Köppen climate classification system [2].

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Figure 1: Yangon City

3.2 Wind Data

To estimate the initial inlet conditions for the numerical simulation, wind data are absolutely necessary to use. In this paper, wind data at Yangon City for a period of four years (2012-2015) are used which were obtained from the Yangon International Airport Observatory. Regarding the wind data, an average mean wind speed of the Yangon is 2.18 m/s at 10 m height above ground level and southwest is the dominant wind direction as shown in Figure 2 and Figure 3.

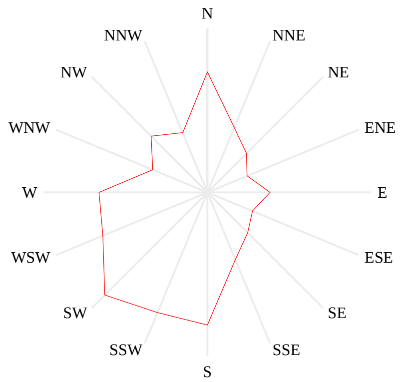

Figure 2: Wind Rose with Frequency of Occurrence

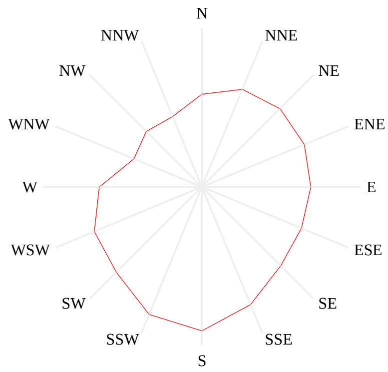

Figure 3: Wind Rose with Mean Wind Speed

3.3 Computational domain

Computational domain is defined by mesh that represents the regions of interest. For accurate flow field predictions, terrain topology should be accurately modeled with vegetation and if present, buildings. Complex landforms effect wind speed and several flow attributes relevant to wind speed significantly [3]. ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) is used for obtaining the topography for the region to be analyzed. This Digital Elevation Model (DEM) consists of the coordinates and altitude data for the region. The total size of the domain model is about 26 km x 25 km x 500 m in x-, y- and z-direction. The cell size is divided into uniform gradient size 52 m x 54 m in X and Y directions with 25 m height at Z direction. The total numbers of cells are nearly 4.5 millions.

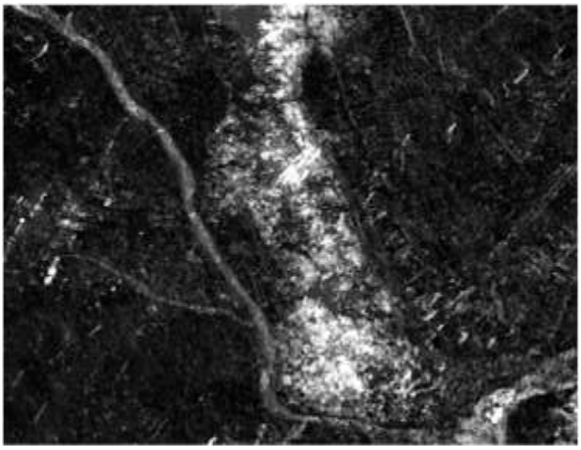

Figure 4: Digital Elevation Model of Yangon city

Figure 5: Top View of Topographic Model (StereoLithography)

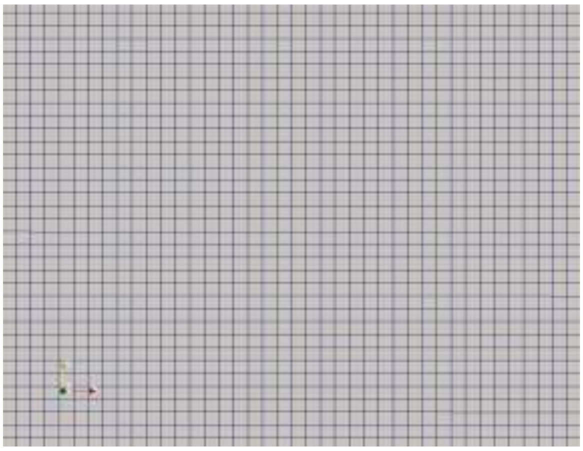

Figure 6: Computational Domain Mesh

3.4 Boundary conditions

Before going to start the simulation, the first step is to state precisely the location of boundaries such as inlet, outlet, wall, and symmetry and also supplying the suitable boundary conditions for the specific boundaries in the computational domain. Boundary conditions can be easily seen in sample model geometry in Fig 7. In this paper, the boundary conditions are considered as follows:

1) *Inlet boundary:* Using openFOAM libraires atmBoundaryLayerInletVelocity, atmBoundaryLayer-InletEpsilon and atmBoundaryLayerInletK for U, k and ε are used based on RH93. For pressure, zero gradient condition is assumed.

2) *Outlet boundary:* Applying zero gradient condition for all variables except for pressure. For pressure, a uniform fixed value is set (p = 0).

3) *Top boundary:* All variables are considered as slip conditions.

4) *Sides:* All variables are considered as slip conditions.

5) *Ground:* For k, ε and turbulent viscosity ν is used as standard wall function because of the variables close to the viscous layer are modeled as via wall function.

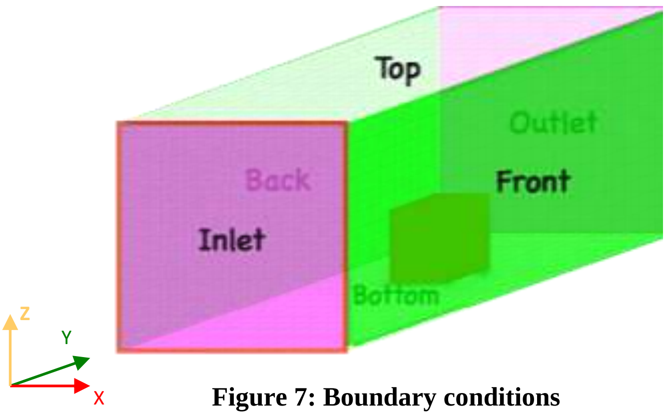

Figure 7: Boundary conditions

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4. METHODOLOGY

To simulate ABL with OpenFOAM CFD code, three main steps are needed. Each step would be described as following.

4.1 Pre-processing

In this paper, topographical digital elevation model is obtained from ASTER DGEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) as shown in Figure 4. Such digital elevation model (DEM) format must be converted into stereolithography (STL) format needed by the OpenFOAM tool. Firstly, surface data extracted from DEM via ArcGIS, and then a third party tool call MeshLab is used to reconstruct the geometry. After that, the surface geometry converted into STL format that is used in OpenFOAM tool as shown in Figure 5. The next step is to generate a mesh block, covering the terrain and including surrounding features, that consists solely of hexahedral cells as shown in Figure 6. This block mesh represents the extent of the computational domain within which the flow will be resolved. In order to mesh the volume around the terrain, the OpenFOAM utility snappyHexMesh was used. The snappyHexMesh utility was then employed to snap the hexahedral mesh onto the surface of the terrain, resulting in the surface mesh shown in Figure 8. Separate meshes were created for each of the four wind flow directions considered by rotating the terrain to the appropriate angle of incidence and re-meshing [4].

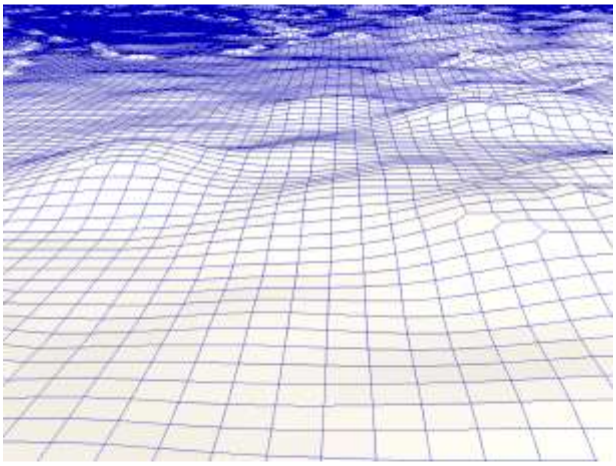

Figure 8: SnappyHexMesh on Terrain

After mesh generation is done, boundary conditions types for each of the domain surfaces is to be defined. Based on the Richards and Hoxay (1993) formulas the inlet boundary conditions for ABL are calculated. In this paper, the average mean wind velocity (u) is 2.18 m/s at the reference height (z) 10 m and roughness height (z_0) is assumed 0.03 for open terrain condition. Hence, the friction velocity u^* is 0.15 m/s calculated from equation (2). After calculation of u*, energy dissipation rate ε and turbulent kinetic energy k values are calculated by equation (3) and (4).

4.2. Solving

The numerical simulations were performed using the OpenFOAM CFD code (v 3.0.0). The 3D steady state RANS equations are solved in combination with the standard k-ε turbulence model. Pressure-velocity coupling is taken care of by the SIMPLE algorithm, pressure interpolation is standard and second order discretization schemes are used for both the convection terms and the viscous terms of the governing equations.

4.3 Post-processing

After solving the case, the results should be checked for convergence. For the complete computations, the iterations are made to run until all the residuals are converged.

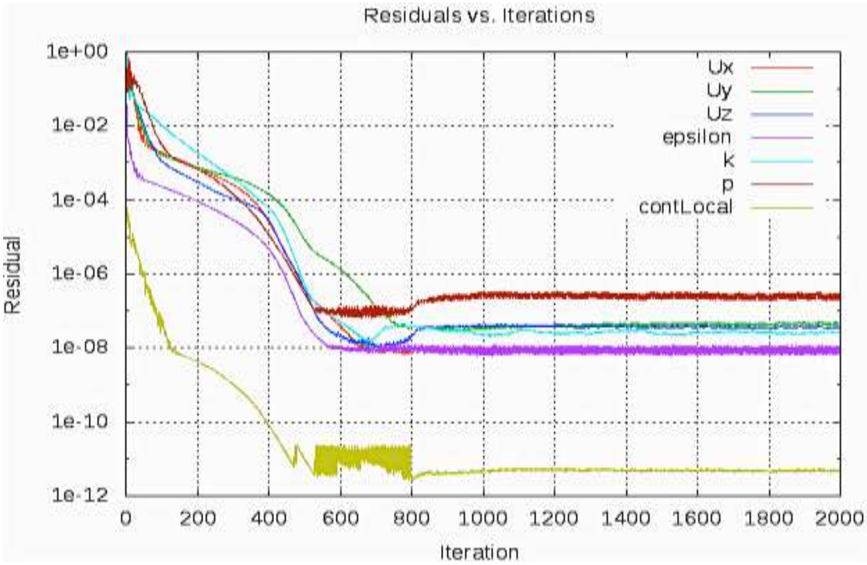

Figure 9: Initial Residuals

From the above Figure 9, all initial residuals and local continuity error have small values, which confirm that the results are converged.

5. SIMULATION RESULTS AND DISCUSSIONS

Figure 10 shows velocity magnitude contours at 90 m height above the ground level. In this paper, the calculation results are considered under the condition of four wind directions. The Figure 10 shows the calculation results under the condition of four types of inflow such as north, east, south and west wind.

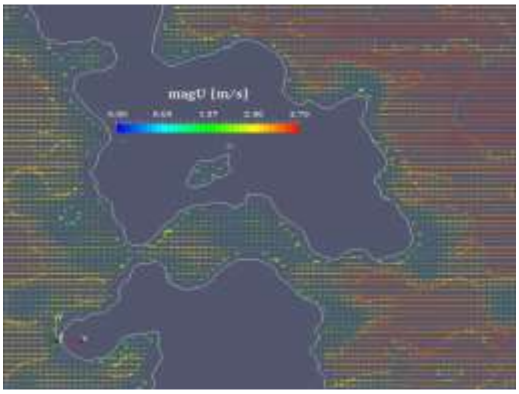

Figure 10 (a): Simulation of East Wind at Z = 90 m

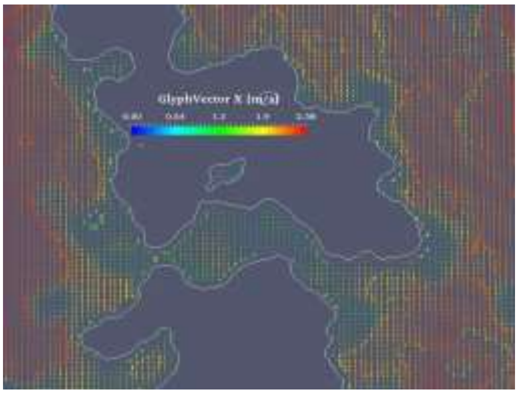

Figure 10 (b): Simulation of North Wind at Z = 90 m

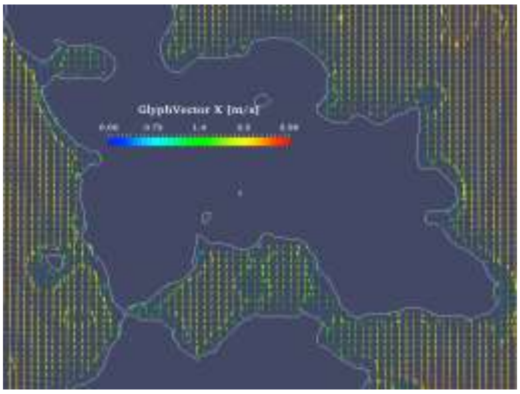

Figure 10 (c): Simulation of South Wind at Z = 90

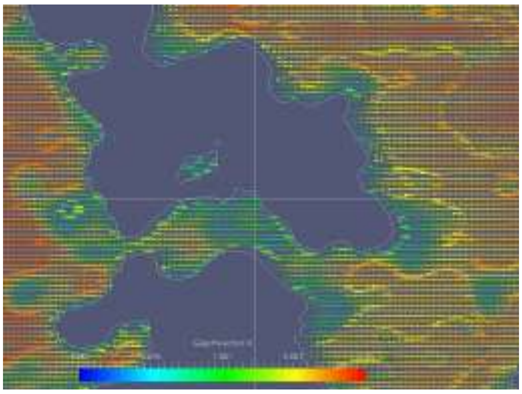

Figure 10 (d): Simulation of West Wind at Z = 90 m

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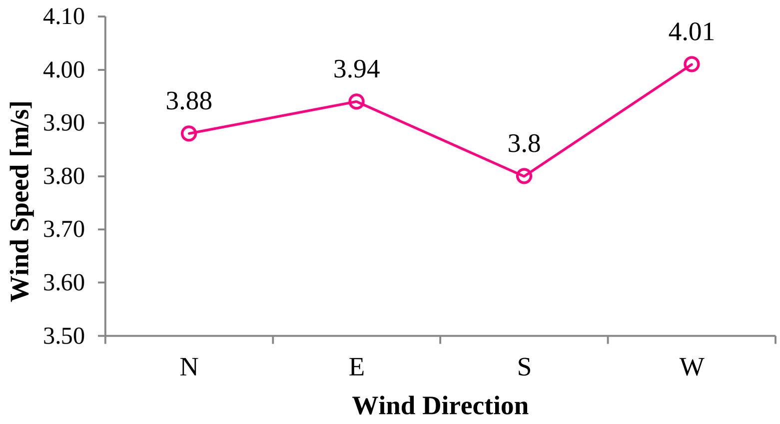

Figure 11: Comparison of Wind Speed

Figure 11 shows the average wind speed at the height of 500 m from the ground in simulation is then compared to the wind speed at inlet. From the above Figure 11, it can clearly see that wind speed variation for each cases of the wind directions. The calculation shows that the direction of west becomes quite difference would cause by the terrain gradient and others are nearly equal. In this paper, it is tried to achieve a balance between the mesh size and expected computational time due to limitation of the memory of the hard disk that simulation executed on it, as the more mesh quality, the more computational time needed.

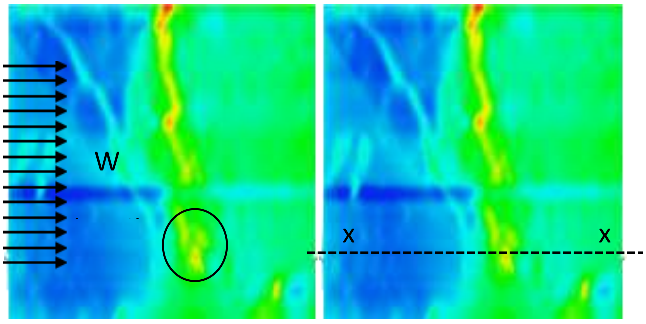

Figure 12: Simulation of West Wind

In Figure 12 results of the simulation of west wind condition is shown. It shows the average velocity contours at a height of 500 m. The red color areas show a region where the wind speed is high. The other three wind directions also show a high wind speed between in black circle region. This area is the downtown district in Yangon city so surface roughness is high. In Figure 13 shows the vertical wind speed profile at Yangon International Airport location. To test the accuracy of the predictions, CFD simulations need to be validated against field measurements. Therefore, the comparison between measured and simulated velocity at airport location is described in Table 1. Form Table 1, simulated results are very similar with field measurement data. So, this numerical modeling and solution is good to predict wind field.

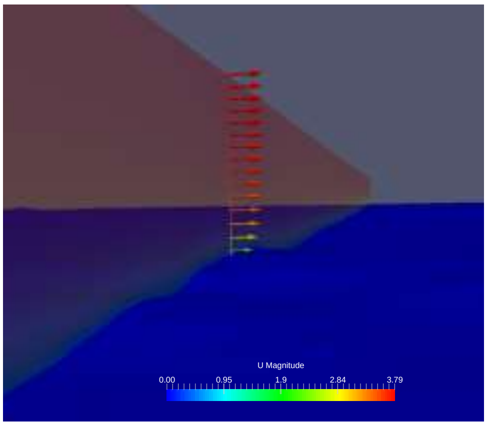

Figure 13: Vertical Wind Speed Profile

Table 1. Comparison between measured and simulated data at Yangon International Airport

Wind Direction (°)	Measured Wind Speed at 10m (m/s)	Simulated Wind Speed at 10m (m/s)	Speed-up Factor
East	2.07	2.01	-2.90 %
West	1.95	2.06	5.64 %
North	1.80	1.92	6.67 %
South	2.73	2.40	12.09 %

6. CONCLUSION

A three-dimensional flow simulation is performed to investigate the wind flow over complex terrain. In this paper, numerical simulations of ABL flows over a real terrain in Yangon city were carried out using CFD code OpenFOAM implemented with standard k-epsilon model. The flow field due to the terrain is calculated with RANS. The mean velocity of west direction at the top of terrain is larger than that in other three directions. Therefore, it is clear that the Yangon topography has an influence on the west wind direction. Hence, the design of the structures orientation on that direction must be considered carefully. But, considering of four wind directions in simulation are not captured the whole area of the terrain. Furthermore, by increasing the numbers of wind direction sectors in the simulation would be considered that might improve the vertical wind profile predictions.

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