WIND FLOW MODELIG IN URBAN

COST ACTION TU1304

WINERCOST

STSM Final Report

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BACKGROUND

1.1 Members of Short Term Scientific Mission (STSM)

The participant of this STSM was:

- **Vaidotas Zimnickas**, PhD student
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  Laboratory for Renewable Energy and Energy Efficiency,
  Kaunas technology university, Kaunas, Lithuania

1.2 Host and Hosting Institute

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  The Center of Computational Engineering and Integrated Design (CEID),
  Lappeenranta University of Technology, Lamppeeranta, Finland

1.3 Goal of the STSM

The first goal at this STSM was to improve my CFD modelling knowledge which is related to geometry and grid generation. To achieve this goal I have determined the following objectives:

1. To learn how to deal with LIDAR (*Light Imaging, Detection, And Ranging*) data.
2. To get a better understanding about high quality mesh generation and it' importance to final solution.

The second goal was find out more about different mathematical methods which are suitable for solving turbulence wind flow problems: Large Eddy Simulation (LES) and Reynolds Averaged Navier – Stokes (RANS). To achieve this goal I have determined the following objectives:

1. To learn more about near – wall modelling and suitable methods for solving this problem.
2. To get a better understanding about which mathematical methods would be most suitable for city modelling.

The third goal was to develop a better understanding about most common errors and uncertainties of DNS, LES and RANS mathematical methods: reasons why they occur; ways to avoid or remove them. To achieve this goal I have determined the following objectives:

1. To get a better understanding about errors that occur the most and how to detect and remove them.
2. To learn more about numerical coding and user errors.
3. To get a better understanding about errors that occur the most and how to detect and remove them.

1.4 Period of STSM

This mission started on the 20th of March 2017 and lasted until the 24nd March 2015.

THEORY

2.1 The Advantages and disadvantages of RANS and LES

Reynolds-averaged Navier–Stokes (RANS) and Large Eddy Simulation (LES) are two the most common methods used for turbulent flow modelling. In RANS case we get only mean value for velocity field. Velocity field in this method is averaged over a time period, which is considerably higher than time constant of velocity fluctuations. Therefor within the period of time there is only a constant mean velocity and could not monitor its time-dependent variations.

The fundamental idea of LES is that large eddies of the flow which are most energetic and dependent on the geometry are resolved directly in computational grid in LES. While eddies are smaller than grid size, they are assumed to be more isotopic and modelled using subgrid-scale model (SGS model). Filtered governing equations for incompressible flow can be written as:

$$\frac{\partial \overline{u_i}}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(\widetilde{u_i}) + \frac{\partial}{\partial x_j}(\widetilde{u_i}\widetilde{u_j}) = \nu \frac{\partial}{\partial x_j}\left(\frac{\partial \widetilde{u_i}}{\partial x_j}\right) - \frac{1}{\rho}\frac{\partial \tilde{p}}{\partial x_i} - \frac{\partial \tau_{ij}}{\partial x_j} \tag{2}$$

Here $\tilde{u}_i$ and $\tilde{p}$ are grid filtered values of velocity and pressure; ν is kinematic velocity, ρ - fluid density and τ_{ij} sub-grid scale stress [1].

There could be identified several advantages of LES method: LES is able to reproduce turbulence with a much higher accuracy. Also LES by using it is possible to predict the vortex shedding and flow recirculation accurately. However LES require much more computing time compared with RANS.

2.2 Wall functions

Fluid flow in near-wall regions are different compared to flow in whole volume. For this reason the near wall region should be taken into the account while modelling the near-wall regions. The boundary layer region can be divided into three different regions:

- viscous sub-layer
- buffer layer
- inertial sub-layer

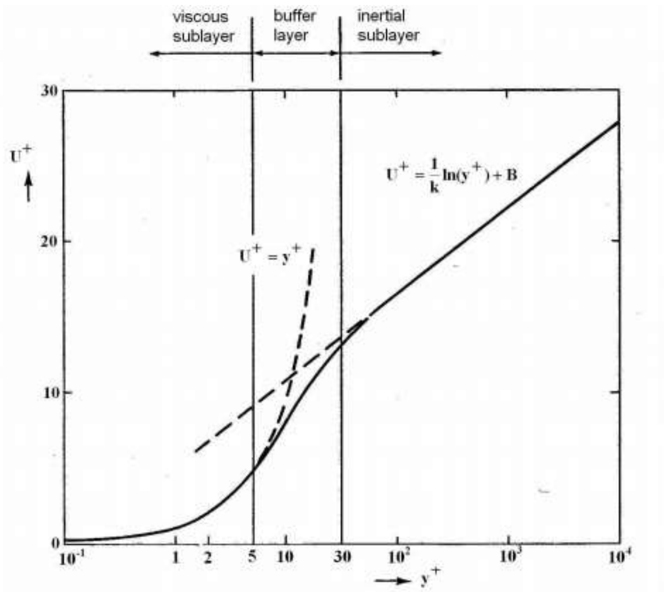

Fig. 1 The law of the wall [2]

Near-wall approach gives opportunity to use coarse mesh and is suitable for high Re numbers flows [2].

RESULTS

3.1 Geometry creation

To create an accurate 3D city map which later could be used for CFD simulation it is necessary to use some LIDAR (*Light Imaging, Detection, And Ranging*) data. This data usually is in coordinate format like .xyz. It might be difficult to import this type of files (.xyz) into commercial CFD programs. For this reason, I was offered to start working with open source code program. Open source programs like OpenFOAM® has few advantages. Firstly the utilization of CFD simulation is free of license. Secondly, capability of parallel computation and flexibility of high level code which gives opportunity to implement new flow solvers using existing OpenFOAM® libraries [2].

The first goal of my STSM was to get 3D geometry creation from LIDAR data. As learning material I used Taurage city LIDAR data. At first step .xyz file was changed into 3D surface file format .stl. This type of file can be imported easily into OpenFoam open source code program. For 3D surface formation data processing program Matlab was used. The surface which was created is shown in Fig.1. Fig.1 illustrates a 1km^2 part of Taurage city. However results appeared to be not as expected. The shapes of buildings and relief are quite good, but some black dots were clearly visible at Fig.1 It was a result of bad data. Data analysis revealed that the distances between the vectors are not the same. The average spacing between points are 0.75m for *x* direction and 2.53m for *y* direction. Results showed that data is unstructured.

Fig.2. 3D surface of Taurage city

3.2 Mesh generation

OpenFoam® mesh solver SnappyHexmesh was used for mesh generation. This solver generates mesh in 3 steps:

- Block mesh generation
- Cutting
- Removal of unused cells

Before meshing procedure begins it should defend the volume of studied area. This might be done by defining coordinates of two parallel plains. Also it is necessary to define refinement regions. There are 4 levels of refinements (Fig. 3).

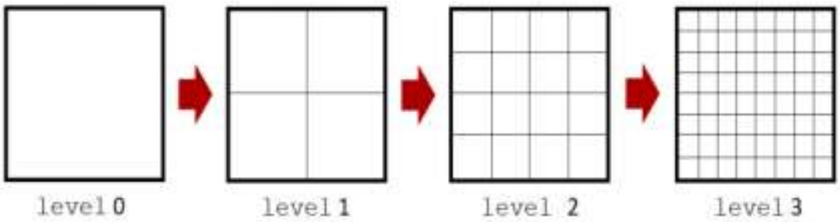

Fig. 3 Refinement levels [3]

Before SnappyHexMesh is executed the background mesh of hexahedral cells that fills the entire region, must be created. This can be accomplished by simply using blockMesh. The following criteria must be observed when creating the background mesh:

- the mesh must consist purely of hexes;
- the cell aspect ratio should be approximately 1, at least near surfaces where subsequent snapping procedure is applied. Otherwise the convergence of the snapping procedure is slow, possibly to the point of failure;
- there must be at least one intersection of a cell edge with the STL surface, i.e. a mesh of one cell will not work [3].

Second step is cutting 3D surface from volume which was defined. Cell removal requires one or more regions enclosed entirely by a bounding surface within the domain. Cells are retained if, approximately 50% or more of their volume lies within the region. Results of this process are illustrated in Fig. 4 Those cells that lie within one or more specified volume regions will be refined. And then second step will be repeated.

The last stage of meshing process involves moving cell vertex points onto surface geometry to remove the jagged castellated surface from the mesh. Stages of this process:

- displace the vertices in the castellated boundary onto the STL surface;
- solve for relaxation of the internal mesh with the latest displaced boundary vertices;
- find the vertices that cause mesh quality parameters to be violated;

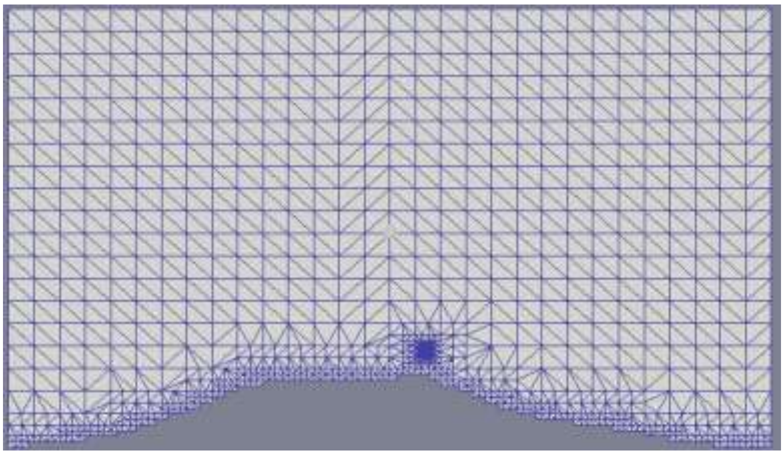

Fig. 4 Cells cutting

CONCLUSIONS

For solving wind flows in urban areas it is necessary to use high quality Lidar data. Distance between points should be the same. Solving method should be chosen very carefully, RANS is faster but it gives only average values of velocity field. However LES is more accurately for vortex shedding and flow recirculation predictions. OpenFOAM® is a powerful tool that gives an opportunity to solve turbulence problems easily for parallel. Also using OpenFOAM® is an opportunity to use rough wall function, which is not possible in most commercial codes.

Reference

1. A. Chaudhari, V. Vourinen, J. Hämäläinen, A., Hellsten, Large-eddy simulations for hill terrains: validation with tunnel and field measurements“, *Computational and Applied Mathematics*, Vol. 36, 2017, p. 1-22
2. H.Tennekes, J.L.Lumley, A First Course in Turbulence, The Massachusetts Institute of Technology, 1972.
3. The OpenFOAM Foundation, “OpenFOAM User Guide version 4.0”, 24th June 2016