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TECHNICAL PAPER

CFD modeling of dust dispersion through Najaf historic city centre

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Abstract

The aim of this project is to study the influences of the wind flow and dust particles dispersion through Najaf historic city centre. Two phase Computational Fluid Dynamics (CFD) model using a Reynolds Average Navier Stokes (RANS) equations has been used to simulate the wind flow and the transport and dispersion of the dust particles through the historic city centre. This work may provide useful insight to urban designers and planners interested in examining the variation of city breathability as a local dynamic morphological parameter with the local building packing density.

Keywords: Dust dispersion, Particle transport, CFD, Airflow through a city, Najaf historic city centre.

1. Introduction

The fluid dynamics of airflow through a city controls the transport and dispersion of airborne contaminants. It also controls environmental air quality, wind forces on buildings, and the ambient noise level due to the winds. These are urban aerodynamics problems primarily, not meteorology. The space scales are short, a few meters to at most a few kilometers. The average airflow, the dynamic fluctuations, and the building-scale turbulence are all closely coupled to the complicated geometry. Buildings create large “rooster-tail” wakes; they shed vortices dynamically and support complex recirculation zones; there are systematic fountain flows up the backs of tall buildings; and dust in the wind can move perpendicular to or even against the locally prevailing wind direction. In principle, meteorology provides the aerodynamic boundary conditions for an urban region and influences the airflow in a city but the weather can be treated as known over times of a few minutes to a fraction of an hour. Urban aerodynamics is driven by a deep, stratified urban boundary layer with significant wind fluctuations. We require time-dependent, Computational Fluid Dynamics (CFD) to predict accurately these unsteady, obstructed, buoyant flows and the dynamic contaminant plumes that they drive. In typical urban scenarios most particulate and gaseous contaminants behave similarly with respect to the overall transport and dispersion but the full physics of multi-group particle and droplet distributions are required for some problems [1].

2. Description of the study area

Najaf is one of the sacred cities of Iraq. The Najaf area is located 30 km south of the ancient city of Babylon and 400 km north of the ancient Biblical city of Ur. It is located on the edge of western plateau of Iraq, at southwest of Baghdad the capital city of Iraq, with 160 km far from the capital. It is raised upon sea level with almost 70 meters, and is situated on the longitude of 19 degree and 44 minutes, as well as on the latitude of 31 degree and 59 minutes [2].

3. CFD modeling

The wind environment over Najaf historic city centre is governed by the conservation laws of mass and momentum. The flow is assumed to be incompressible Newtonian fluid with constant density. Based on the above assumptions, the Reynolds average Navier–Stokes (RANS) equations are as [3, 4];

$$\rho\frac{\partial \mathbf{U}}{\partial t}+\rho\mathbf{U}.\nabla\mathbf{U}+\nabla.\overline{(\rho\mathbf{u'}\otimes\mathbf{u'})}=-\nabla P+\nabla.\mu(\nabla\mathbf{U}+(\nabla\mathbf{U})^{T})+\mathbf{F} \tag{1}$$

$$\rho\nabla.\mathbf{U}=0 \tag{2}$$

where **U** is the averaged velocity field and ⊗ is the outer vector product.

The turbulent viscosity is modeled using k-ε model as;

$$\mu_T=\rho C_\mu\frac{k^2}{\varepsilon} \tag{3}$$

where C_μ is a model constant, k is the turbulent kinetic energy, and ε is the turbulent dissipation rate.

The transport equation for k is;

$$\rho\frac{\partial k}{\partial t}+\rho\mathbf{u}.\nabla.\left(\left(\mu+\frac{\mu_T}{\sigma_k}\right)\nabla k\right)+P_k-\rho\varepsilon \tag{4}$$

where the production term is;

$$P_k=\mu_T\left(\nabla\mathbf{u}:(\nabla\mathbf{u}+(\nabla\mathbf{u})^T)-\frac{2}{3}(\nabla.\mathbf{u})^2\right)-\frac{2}{3}\rho k\nabla.\mathbf{u} \tag{5}$$

The transport equation for ε is;

$$\rho\frac{\partial\varepsilon}{\partial t}+\rho\mathbf{u}.\nabla\varepsilon=\nabla.\left(\left(\mu+\frac{\mu_T}{\sigma_\varepsilon}\right)\nabla\varepsilon\right)+C_{\varepsilon1}\frac{\varepsilon}{k}P_k-C_{\varepsilon2}\rho\frac{\varepsilon^2}{k} \tag{6}$$

where $C_{\varepsilon1}$, $C_{\varepsilon2}$, σ_ε, σ_k are model constant.

The particle momentum comes from Newton's second law;

$$\frac{d}{dt}(m_p\mathbf{V})=\mathbf{F}_{\boldsymbol{D}}+\mathbf{F}_{\boldsymbol{g}}+\mathbf{F}_{\boldsymbol{ext}} \tag{7}$$

where m_p is the particle mass [kg], **v** is the velocity of particle [m/s], $\mathbf{F}_{\boldsymbol{D}}$ is the drag force [N], $\mathbf{F}_{\boldsymbol{g}}$ is the gravitational force vector [N], $\mathbf{F}_{\boldsymbol{ext}}$ is any other external force [N].

The drag force ($\mathbf{F}_{\boldsymbol{D}}$) is defined as;

$$\mathbf{F}_{\boldsymbol{D}}=\left(\frac{1}{\tau_p}\right)m_p(\mathbf{u}-\mathbf{v}) \tag{8}$$

where τ_p is the particle velocity response time [sec], **u** is the fluid velocity [m/s]

The fluid velocity used in the drag force in turbulent dispersion becomes;

$$\mathbf{u}=\mathbf{U}+\mathbf{u'} \tag{9}$$

where **U** is the mean velocity and **u'** is a turbulent fluctuation defined as;

$$\mathbf{u}'=\varphi\sqrt{\frac{2k}{3}} \tag{10}$$

where **k** is the turbulent kinetic energy, and φ is a normally distributed random number with zero mean and unit standard deviation.

The gravity force is given by;

$$\mathbf{F}_{\boldsymbol{g}}=m_p\mathbf{g}\frac{(\rho_p-\rho)}{\rho_p} \tag{11}$$

Where ρ_a is the particle density [kg/m^3], ρ is the density of the surrounding fluid [kg/m^3], and **g** is the gravity vector.

4. Results

The resolved built area and the area of interest are depicted in Figure 1. Najaf historic city centre building geometry used in CFD model is shown in Figure 2. Figure 3. shows the flow direction and wind speeds in the historic city centre. Figure 4. Shows dust particles dispersion in the historic city centre. Finally, Figure 5. Shows the dust particles in the wind over the city. The source was an instantaneous release of a neutrally buoyant tracer dust particles at ground level in the historic city centre. The frames show relative tracer concentrations at 2, 3, 4, 5, 6 and 8 minutes after release.

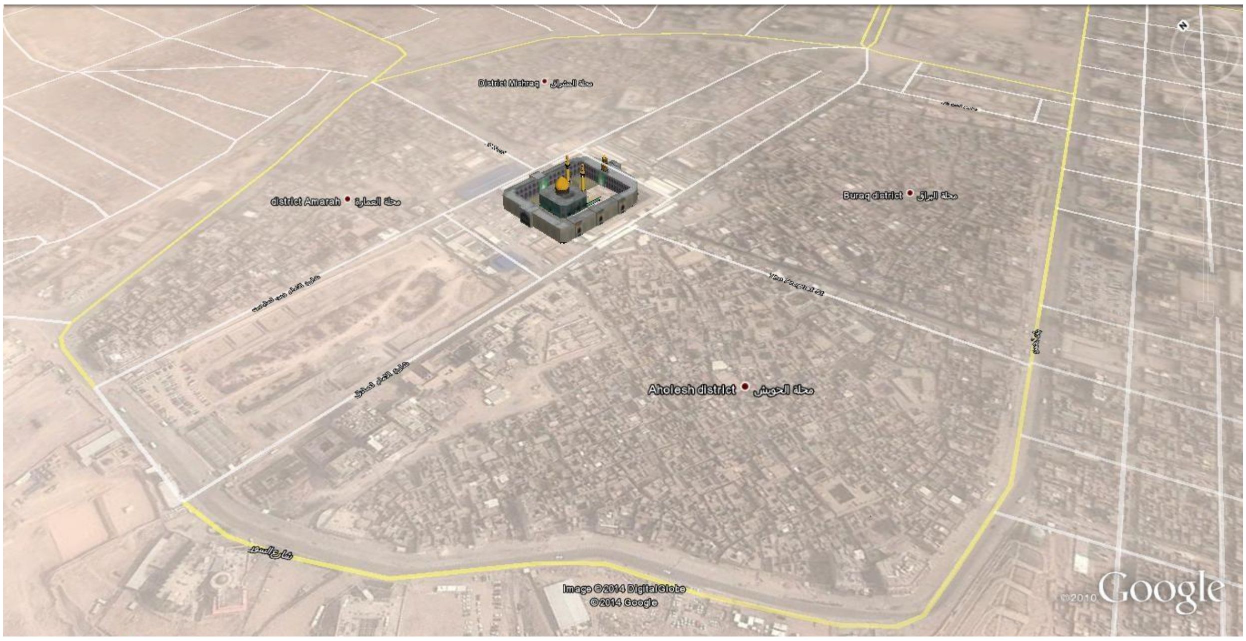


Figure 1. Satellite image of Najaf historic city centre [Google earth, 2014].

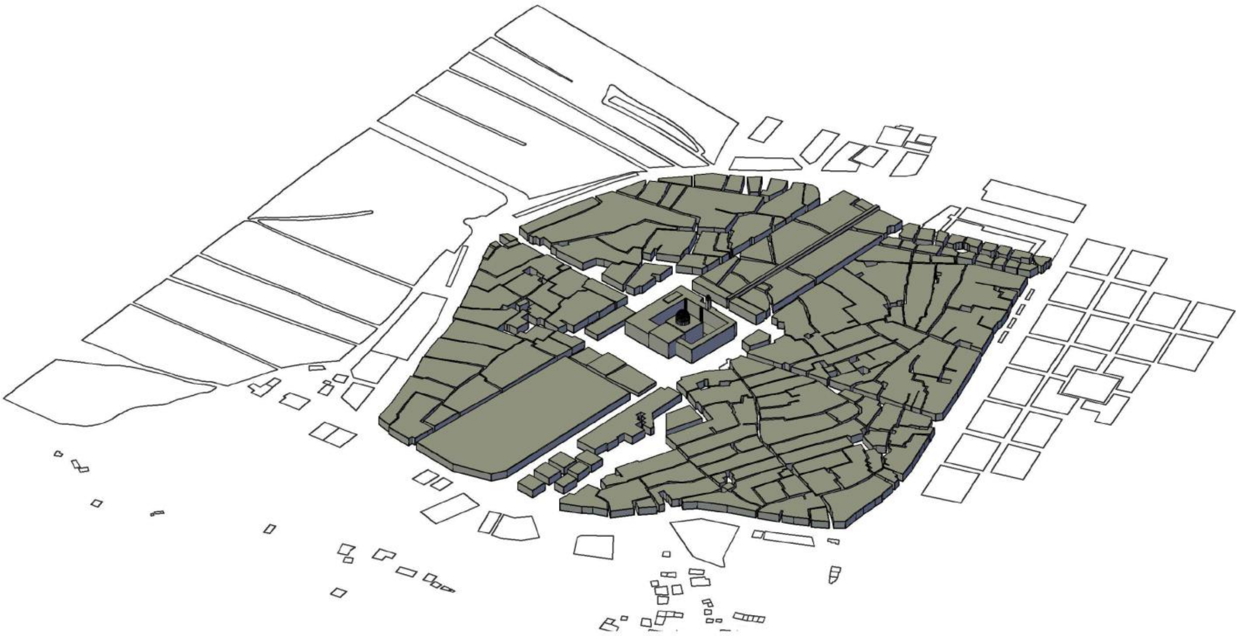


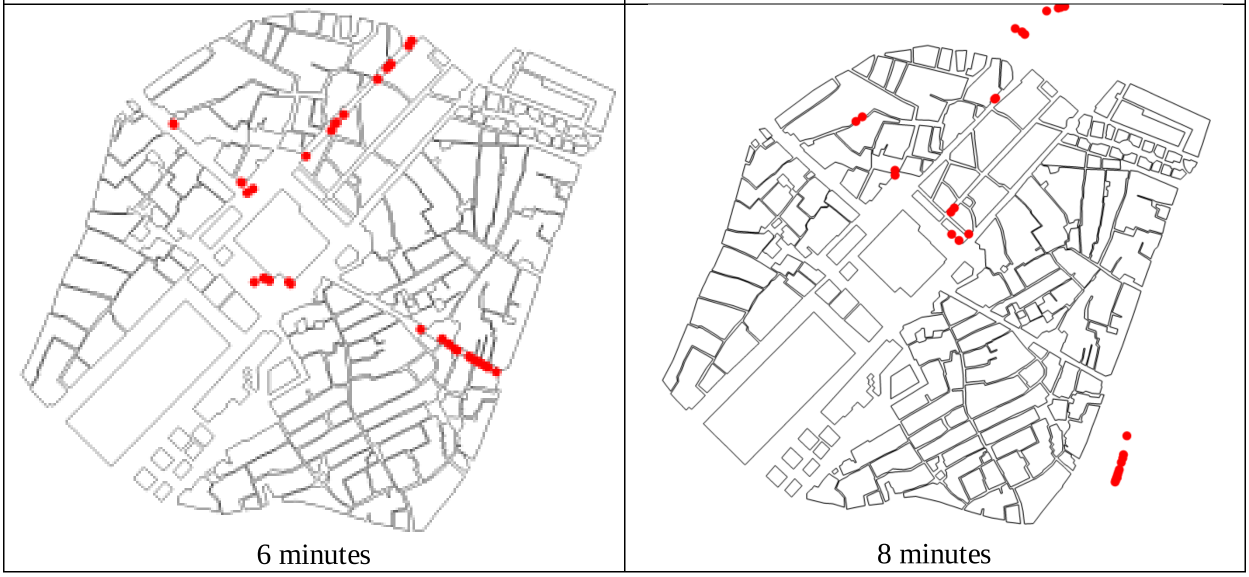
Figure 2. CAD model for a wind flow analysis of Najaf historic city centre.

Figure 3. Plan view of streamlines showing flow direction and wind speeds in the historic city centre.

Figure 4. Dust particles dispersion through the historic city centre.

2 minutes 3 minutes

4 minutes 5 minutes



6 minutes 8 minutes

Figure 5. Visualizations of the dust particles in the wind through the city. The source was an instantaneous release of a neutrally buoyant tracer dust particles at ground level in the historic city centre. The frames show relative tracer concentrations at 2, 3, 4, 5, 6 and 8 minutes after release.

5. Conclusion

In conclusion, CFD benefits this project by cutting down the time and costs spent in parametric, case and design exploration studies. The wind flow and dust particles dispersion through a realistic complex urban geometry were examined using numerical results from a CFD simulation.

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