Modifications to RANS Turbulence Model for Use in Urban Wind Resource Assessment

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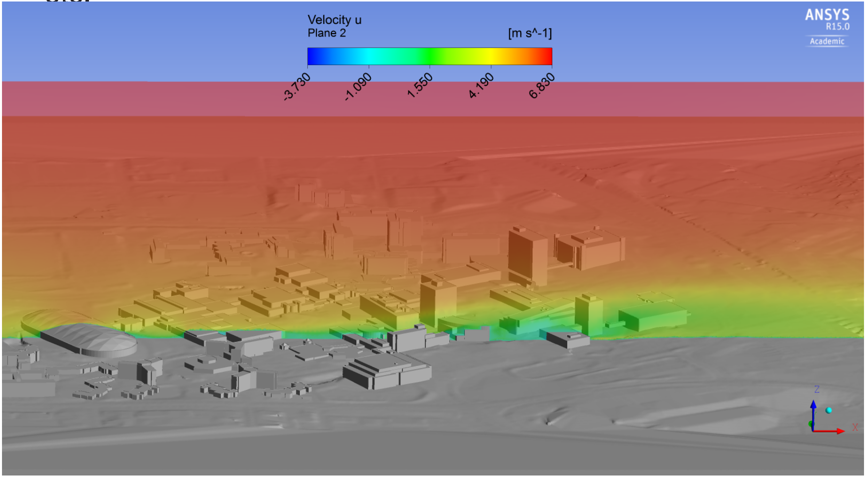
- CFD seen as a pecuniary palliative for wind resource assessment.
- Why the $k - \epsilon$? Tabrizi et al. (2013) Van Hoof and Blocken (2010), etc.



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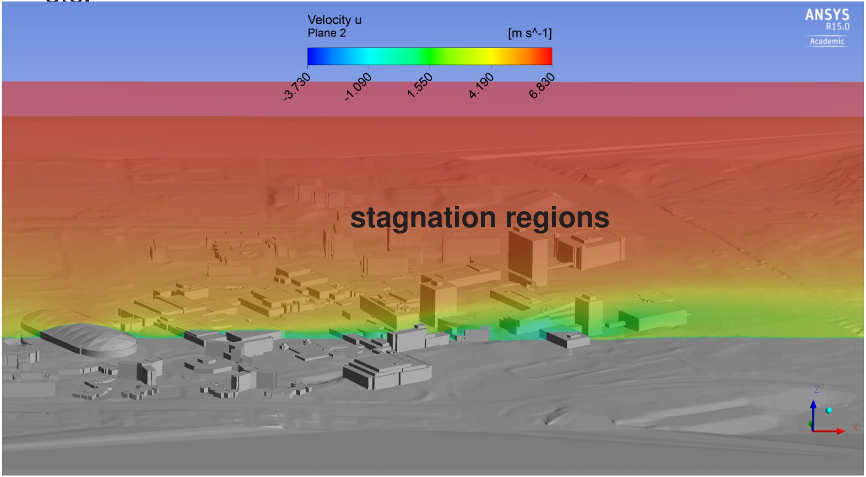

The people's choice: The $k - \epsilon$ model

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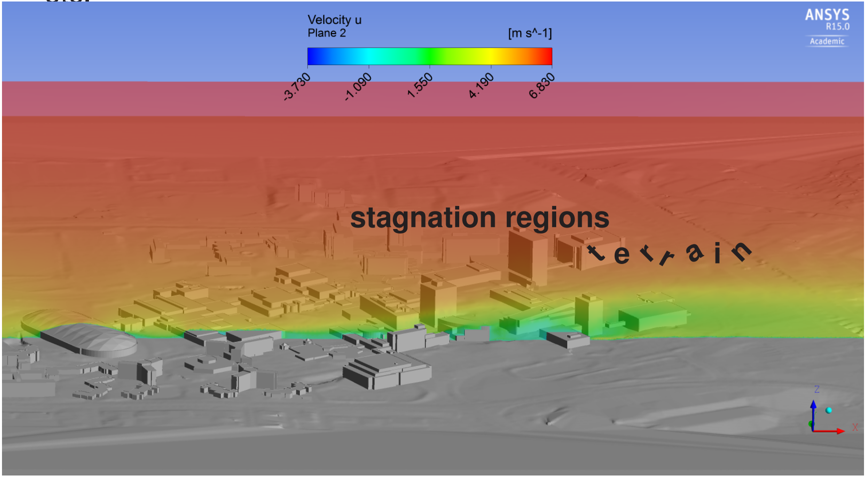

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- Production of k

$$\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial x_j} = 2\nu_t S_{ij} S_{ij} + \frac{\partial}{\partial x_j}\left((\nu + \nu_t) \frac{\partial k}{\partial x_j} \right) + \epsilon$$

Go to Strain Rate

$$\nu_t = C_\mu \frac{k^2}{\epsilon}$$

The modeled terms in $k - \epsilon$ model

- Production of k

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- Turbulent diffusion

▸ Go to Strain Rate

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- Turbulent diffusion
- Dissipation rate of k

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Deficiency 1 of $k - \epsilon$ model

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- Is the dissipation rate of k unable to catch up with the production of k?
- Is the production of k not modeled correctly?
- Is the gradient diffusion model not valid?

Meanwhile, at the inlet ...

- Production of k is balanced by its dissipation rate.
- When and to what extent is this valid?
- What about buoyancy?

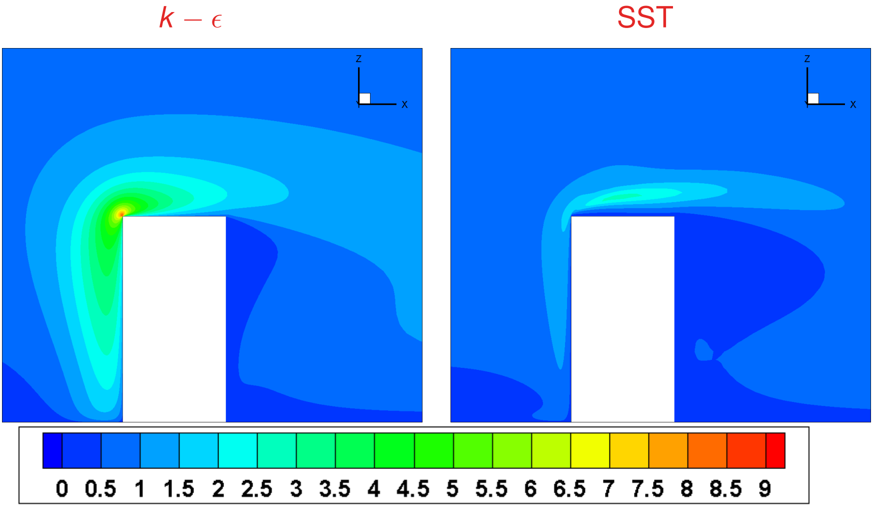
Neutrally-Stratified Atmosphere

$$U = \frac{u_\tau}{\kappa} ln\left(\frac{z - y_0}{z_0}\right), \tag{1}$$

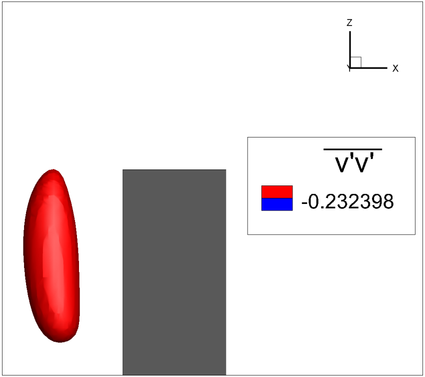
$$k = \frac{u_\tau^2}{\sqrt{C_\mu}} \tag{2}$$

$$\epsilon = \frac{u_\tau^3}{\kappa z} \tag{3}$$

- Over-prediction of k in stagnation regions. $\Rightarrow$ Buildings.



- Negative normal stresses. $\Rightarrow$ Realizability.



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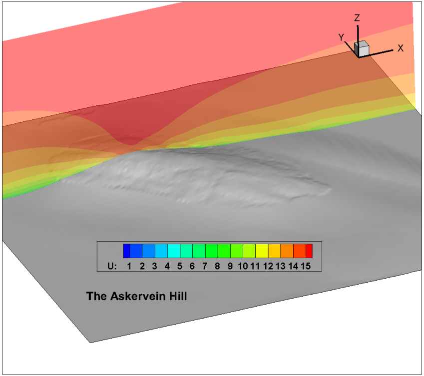
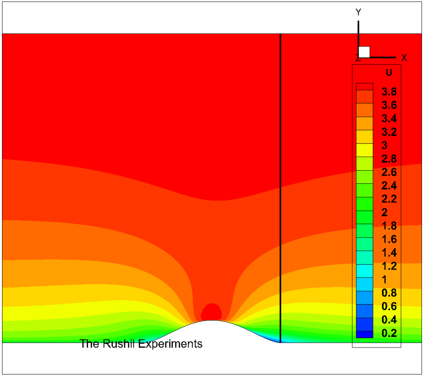
- Over-prediction of *k* and under-prediction of recirculation region at the lee of hills . $\Rightarrow$ Terrain.





Durbin's Model

$$\nu_t = \min\left(C_\mu \frac{k^2}{\epsilon}, \frac{k}{\sqrt{6}S}\right). \quad (4)$$

Yaps's Model

$$S_\epsilon = 0.83\frac{\epsilon^2}{k}\left(\frac{k^{1.5}}{\epsilon l_e} - 1\right)\left(\frac{k^{1.5}}{\epsilon l_e}\right)^2 \quad (5)$$

where l_e is $C_\mu^{-0.75}\kappa y_n$ with y_n being the normal distance to the nearest wall and κ is the Karman constant in the logarithmic law for the mean velocity.

Strain rate immediately upstream of a building.

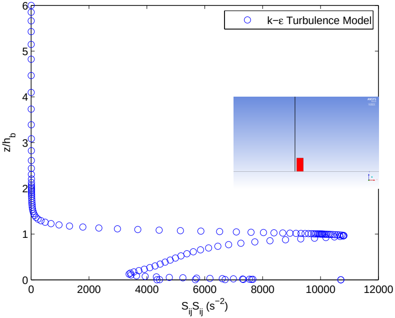


Figure: The computed $S_{ij}S_{ij}$ at x/b=-0.75 using the $k-\epsilon$ turbulence model.

Go to Production of k

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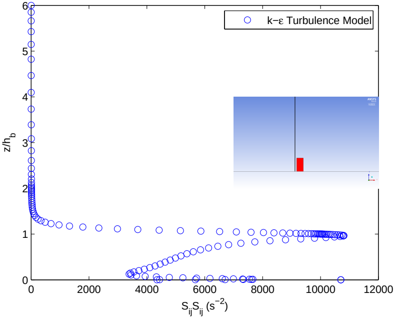

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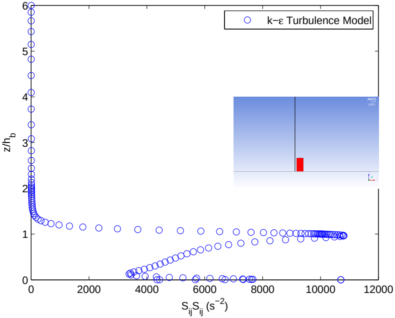
Go to Production of k

$$\nu_t = C_\mu \frac{k}{S_{ij}S_{ij}} |\sum S_{ij}|, \quad G_k = 2C_\mu k |\sum S_{ij}| \tag{6}$$



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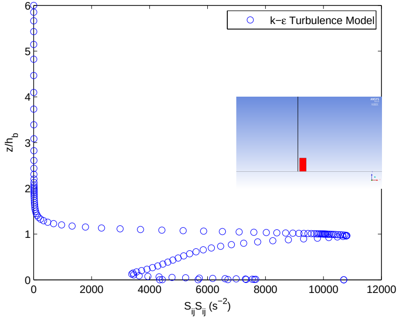
The birth of the MW turbulence model!



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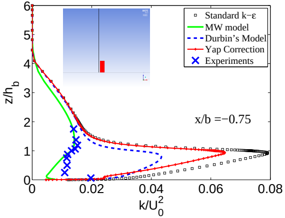
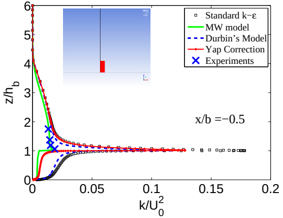
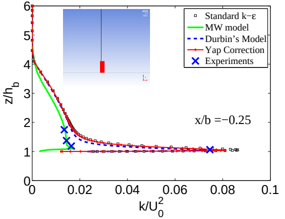


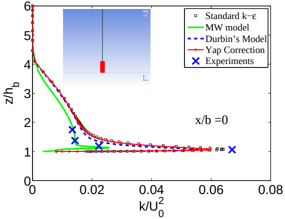
(a) *k* profile at position $x/b = -0.75$



(b) *k* profile at position $x/b = -0.5$



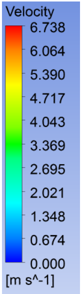
(c) *k* profile at position $x/b = -0.25$



(d) *k* profile at position $x/b = -0.25$

Hills

- Will the MW work in the lee of a hill?
- Re-circulation region.
- Production of k smears out the steep velocity profile resulting in a shorter attachment length.



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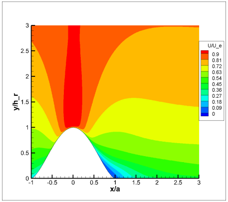
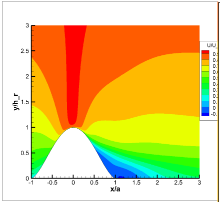
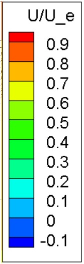
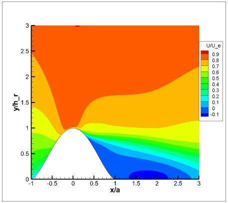


(a) Original $k-\epsilon$.

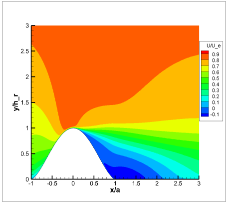


(b) Modified $k-\epsilon$.





(c) MW.



(d) SST.

Re-attachment point

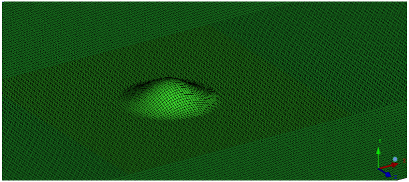
Measured:
x/a=2.2

Standard $k-\epsilon$:
x/a=1.09

Modified $k-\epsilon$:
x/a=1.58

MW:
x/a=2.58

SST $k-\omega$:
x/a=2.18



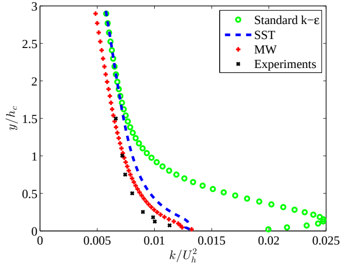


Figure: Profile of k at the crest.

Conclusions

- Development of a RANS turbulence model to reduce *k* in stagnation region.
- Re-formulation of the eddy viscosity.
- Tested on an isolated building and achieved good results relative to other conventional models
- Model applied to complex topography. Extended re-circulation region compared to the $k-\epsilon$.
- Computationally less expensive than the SST.

Thank you. спасибо.

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Questions?