Study on consistency of "mean wind speed" in wind environment analyses

1 Research Objectives

- There is inconformity in the definitions of “Mean Speed” of none-directional anemometers and RANS (Reynolds-averaged Navier–Stokes equations) .
  - none-directional anemometers： mean value of instantaneous scalar velocities
  - RANS：scalar speed from the mean velocity vectors
- Research objectives
  - Part 1： mathematical analysis of the Relationship among the various mean wind speed
  - Part 2： Large-eddy simulation (LES) simulation of the wind field around a building, and a quantitative valuation of the degree of inconsistency among various mean speeds

2 Definition of “Mean Speed”

Table 1 Definition equations of “Mean Speed”

mean-vector speed V_{mv}	$\boldsymbol{V}_{\mathrm{mv}} \equiv \|\langle \mathbf{u} \rangle\| = \left(\langle \mathbf{u} \rangle^{\mathrm{T}} \langle \mathbf{u} \rangle\right)^{0.5} = (2K)^{0.5}$
mean speed V_{ms}	$\boldsymbol{V}_{\mathrm{ms}} \equiv \langle \|\mathbf{u}\| \rangle = \langle s \rangle$
effective speed V_{es}	$\boldsymbol{V}_{\mathrm{es}} \equiv \langle \|\mathbf{u}\|^2 \rangle^{0.5} = \langle s^2 \rangle^{0.5} = (2K + 2k)^{0.5}$

Table 2 Simulation methods and available mean speeds

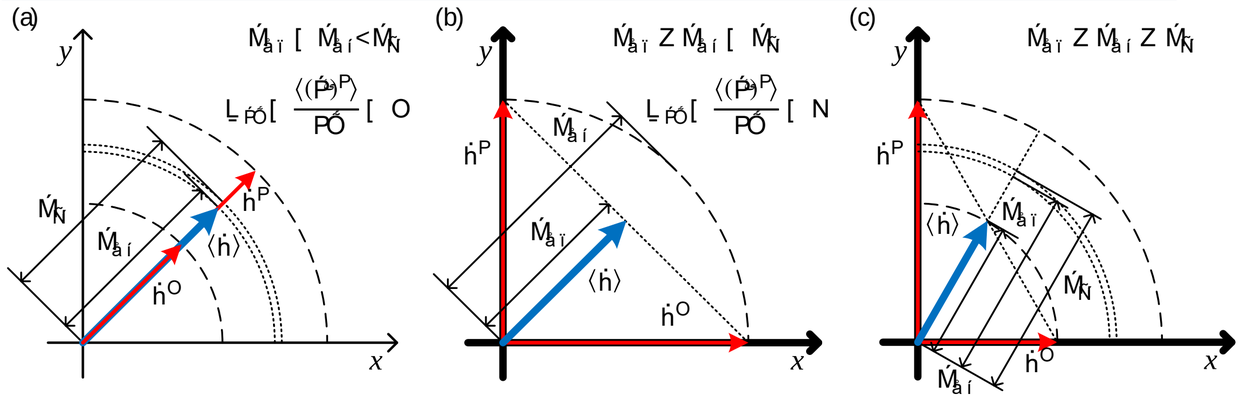
	V_{mv}	V_{ms}	V_{es}
Wind tunnel experiment*		○	
CFD (RANS)	○		○
CFD (LES)	○	○	○**

*Wind tunnel experiments by using none-directional anemometers;
**Approximated value due to the spatial filtering of small-scale turbulence in LES

3 Mathematical Relationship Among Mean Speeds

- The relationship showed below is existed among various mean speeds.
  - $\boldsymbol{V}_{ms}^2 - \boldsymbol{V}_{mv}^2 = \langle s \rangle^2 - 2K = 2k - \langle (s')^2 \rangle$, $\quad \langle (s')^2 \rangle \geq 0$
  - $\boldsymbol{V}_{ms} = (\boldsymbol{V}_{mv}^2 + 2k - \langle (s')^2 \rangle)^{0.5} \leq (\boldsymbol{V}_{mv}^2 + 2k)^{0.5} = \boldsymbol{V}_{es}$
  - $\boldsymbol{V}_{ms} - \boldsymbol{V}_{mv} = \langle \|\boldsymbol{u}\| \rangle - \|\langle \boldsymbol{u} \rangle\| \geq 0$
  - $\boldsymbol{V}_{mv} \leq \boldsymbol{V}_{ms} \leq \boldsymbol{V}_{es}$ or $2K \leq \langle s \rangle^2 \leq 2K + 2k = \langle s^2 \rangle$
- V_{ms} locates between V_{mv} and V_{es}, different from either of them.
  If $R_{sk} \equiv \langle (s')^2 \rangle / 2k$ is defined, the relationship showed below is tenable.
  - $0 \leq R_{sk} \leq 1$

4 Geometrical Relationship Among Mean Speeds



- It’s universal to use none-directional anemometers in wind tunnel experiments or RANS type CFD during wind environment evaluation. However, the mean wind speeds’ definitions are distinctive on the basis of methods.
- The relationship $V_{\mathrm{mv}} \leq V_{\mathrm{ms}} \leq V_{\mathrm{es}}$ has been shown by analysis of the various mean wind speeds based on different definitions.

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Study on consistency of "mean wind speed" in wind environment analyses Part 2

Comparison of mean wind speeds in flow around single building model

5 Model & Boundary of Simulation

Table 1　Simulation Boundary

Model	LES, Smagorinsky model(C_s=0.12)
Wind Field	10.75 H (x)×6.875 H (y)×5.625 H (z)
Mesh	Minimum：1/64 H, Quantity：3.8 million
Time step･marching	0.001 s, PISO
Time discretization	Euler-implicit
Space discretization	2nd-order central difference
Inflow B.C.	Inflow turbulence data obtained from an additional LES which simulated urban boundary layer flow in a wind tunnel
Outflow B.C.	Gradient-zero
Wall B.C.	Wall function(Spalding's law)

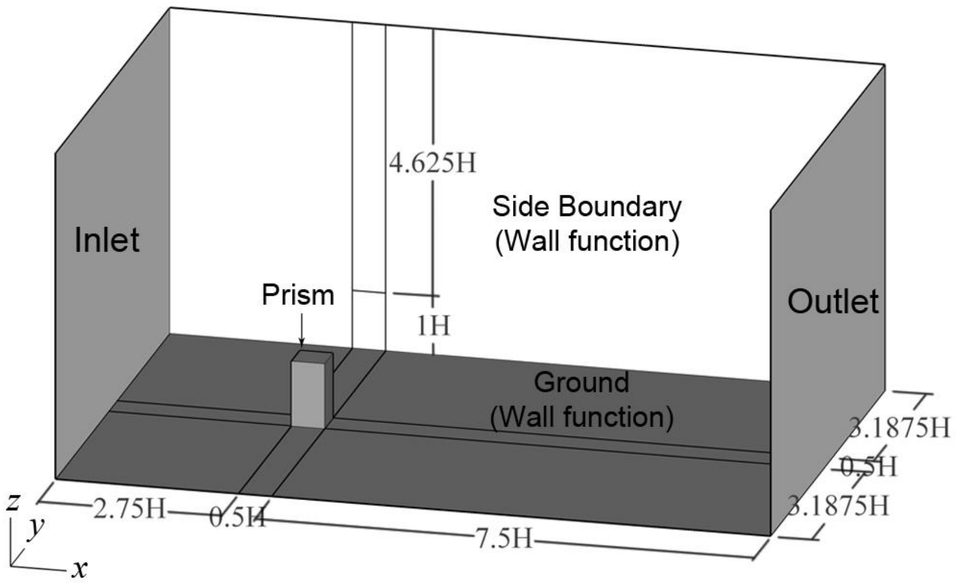

Fig. 1　Analysis domain of LES

6 Comparison among Various Mean Speeds

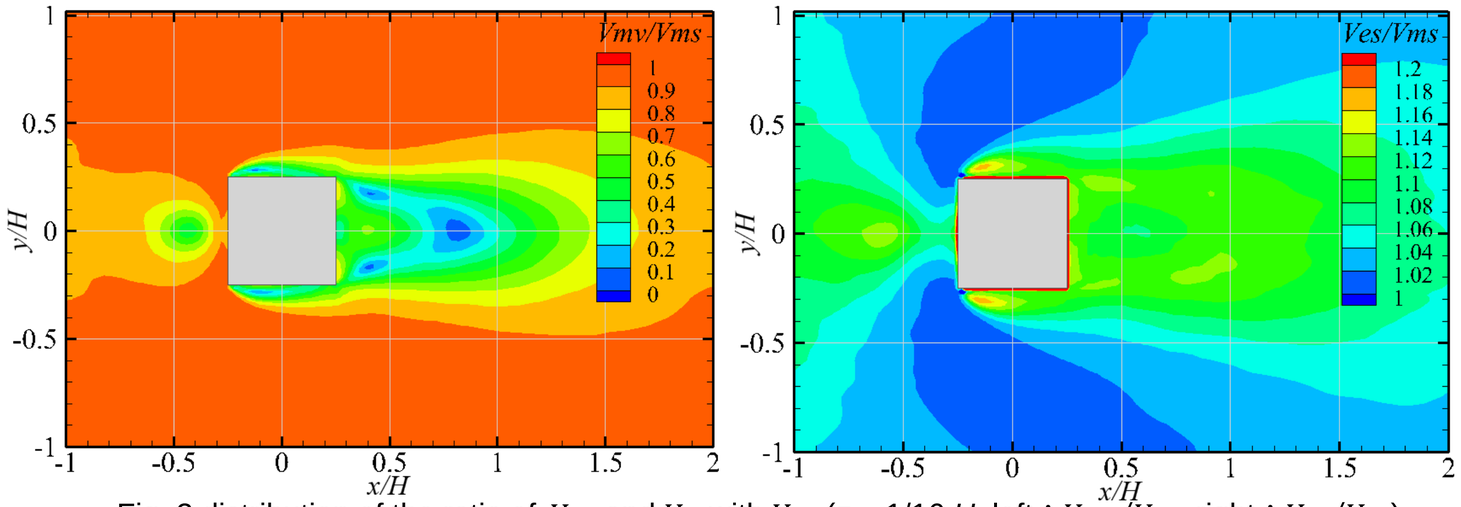

Fig. 2 distribution of the ratio of V_{mv} and V_{es} with V_{ms} (z = 1/16 H, left：V_{mv} /V_{ms}, right：V_{es} /V_{ms})

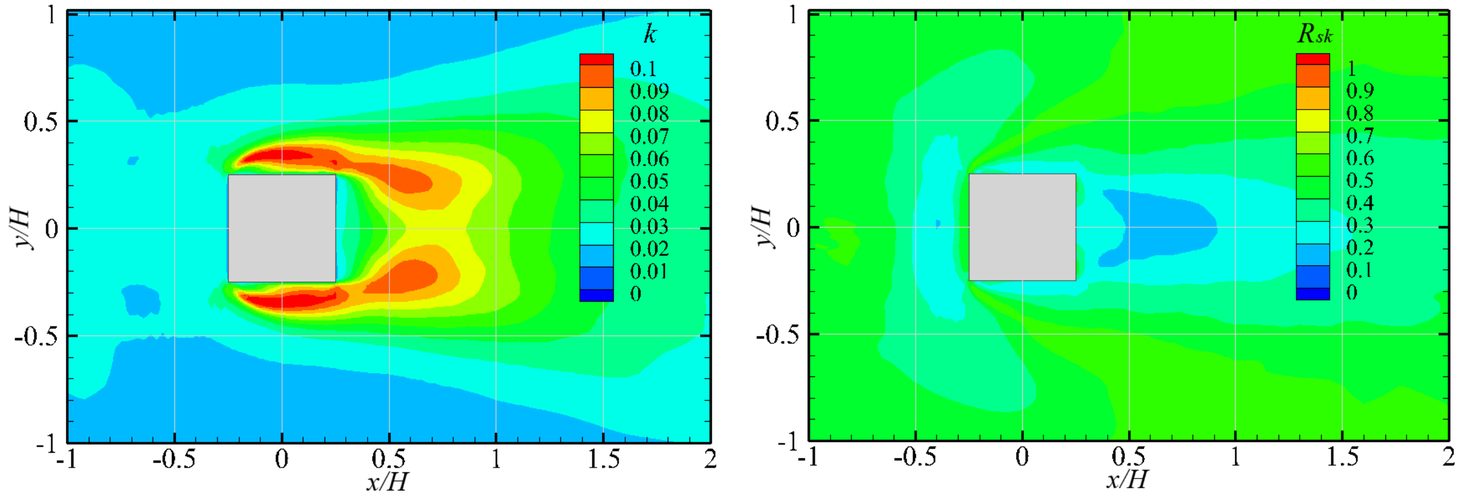

Fig. 3　horizontal distribution of k and R_{sk} (z = 1/16 H, left：k, right：R_{sk})

- The discrepancies between the three mean wind speeds were quantitatively analyzed by LES of flow around a building in an urban boundary layer. In the vicinity of the ground surface, the difference between the mean wind speeds became larger in the recirculation flow near the building's windward corners and in the wake of the building.

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