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# Very-large eddy simulation of the rotational effects on turbulent flow in a ribbed channel

**Key words:** Very-large eddy simulation (VLES); Rotation effect; Ribbed channel flow; Unsteady flow; Turbine blade

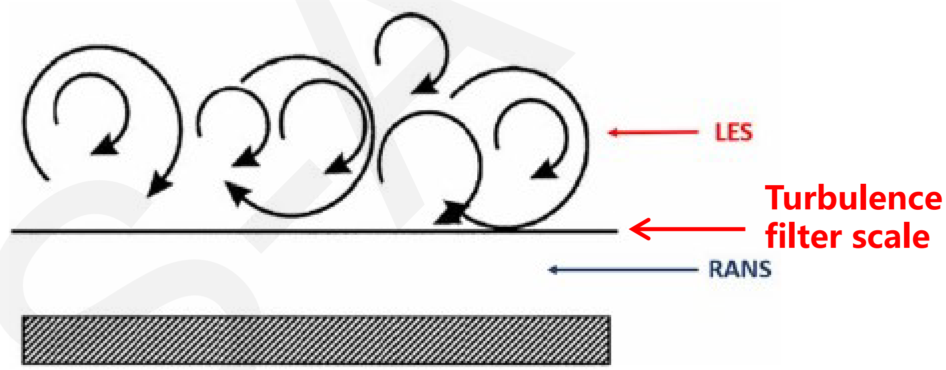
# Numerical method——Turbulence model

## Advanced self-adaptive turbulence modelling method, i.e. Very-Large Eddy Simulation (VLES) method

- **Advantages of the VLES method**

✓ **High Reynolds number flow solution with high accuracy**

✓ **Low demand for computing grid**




➢ **VLES** (Very-Large Eddy Simulation)

VLES BSL k-ω

$$\begin{cases} \dfrac{\mathrm{D}\rho k}{\mathrm{D}t} = P_k - \beta^* \rho k \omega + \dfrac{\partial}{\partial x_j}\left[\left(\mu + \sigma_{k3}\mu_{\mathrm{t}}\right)\dfrac{\partial k}{\partial x_j}\right] \\ \dfrac{\mathrm{D}\rho\omega}{\mathrm{D}t} = \dfrac{\gamma\omega}{k} P_k - \beta_3 \rho \omega^2 + \dfrac{\partial}{\partial x_j}\left[\left(\mu + \sigma_{\omega 3}\mu_{\mathrm{t}}\right)\dfrac{\partial \omega}{\partial x_j}\right] + 2(1-F_1)\rho\sigma_{\omega 2}\dfrac{1}{\omega}\dfrac{\partial k}{\partial x_j}\dfrac{\partial \omega}{\partial x_j} \end{cases}$$

$$\mu_{\mathrm{t}} = F_{\mathrm{r}} \rho \frac{k}{\omega}$$

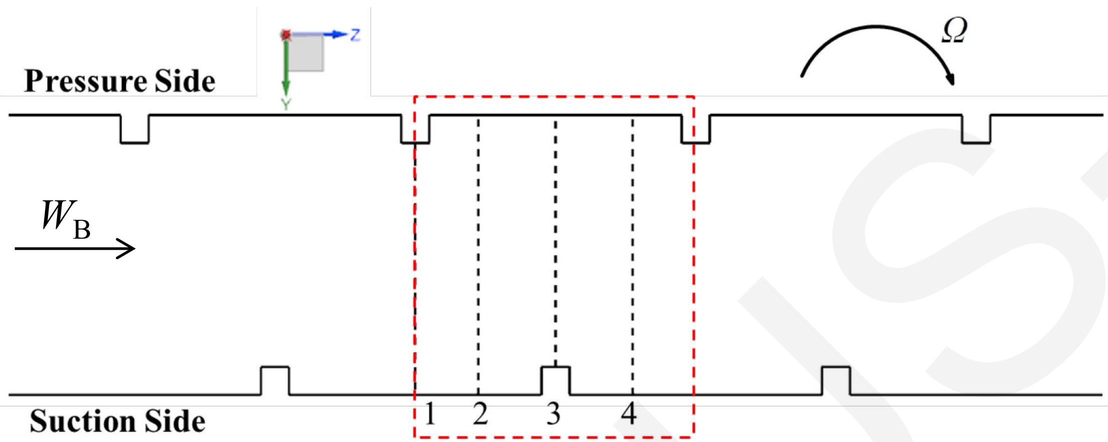
$$\boxed{F_{\mathrm{r}} = \min\left(1.0, \left[\frac{1.0 - \exp(-\beta L_c / L_k)}{1.0 - \exp(-\beta L_i / L_k)}\right]^n\right)}$$

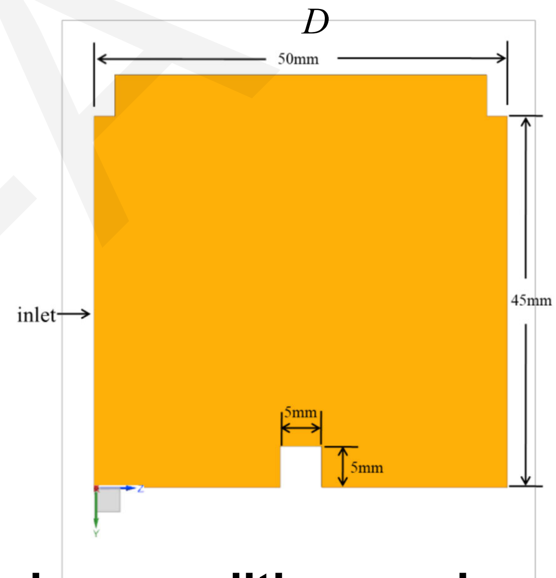
$$\begin{cases} L_i = k^{3/2} / (\beta^* k \omega) \\ L_c = C_x (\Delta_x \Delta_y \Delta_z)^{1/3}, \quad C_x = \sqrt{0.3} C_s / \beta^* \\ L_k = \nu^{3/4} / (\beta^* k \omega)^{1/4} \end{cases}$$

# Configuration

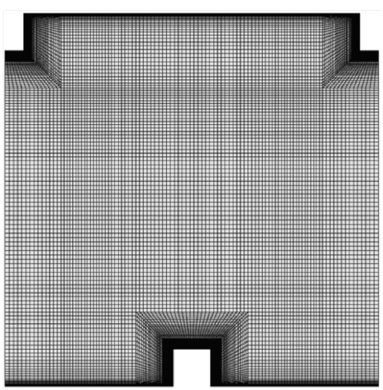
## Staggered ribbed channel

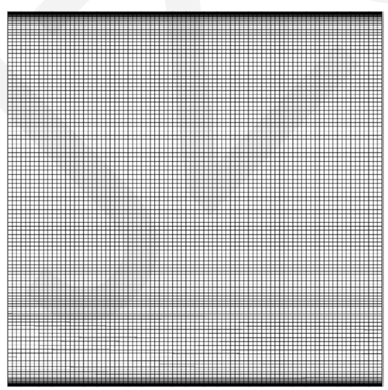
- **Channel diagram and computational domain**




- **Meshing ($y^+$<1)**





- **Boundary conditions and characteristic parameters**

Boundary conditions：

Import and export periodicity

Non-slip solid wall

Clockwise rotation

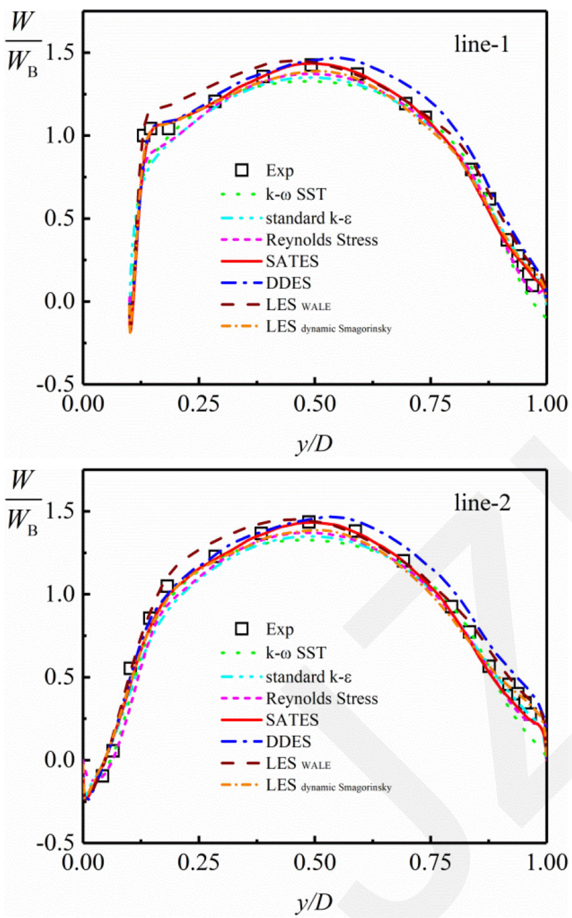
Characteristic parameters ：

**Re**= $W_B D/\nu$ **= 100000**

**Ro**=$\Omega D/W_B$ **= 0.2**

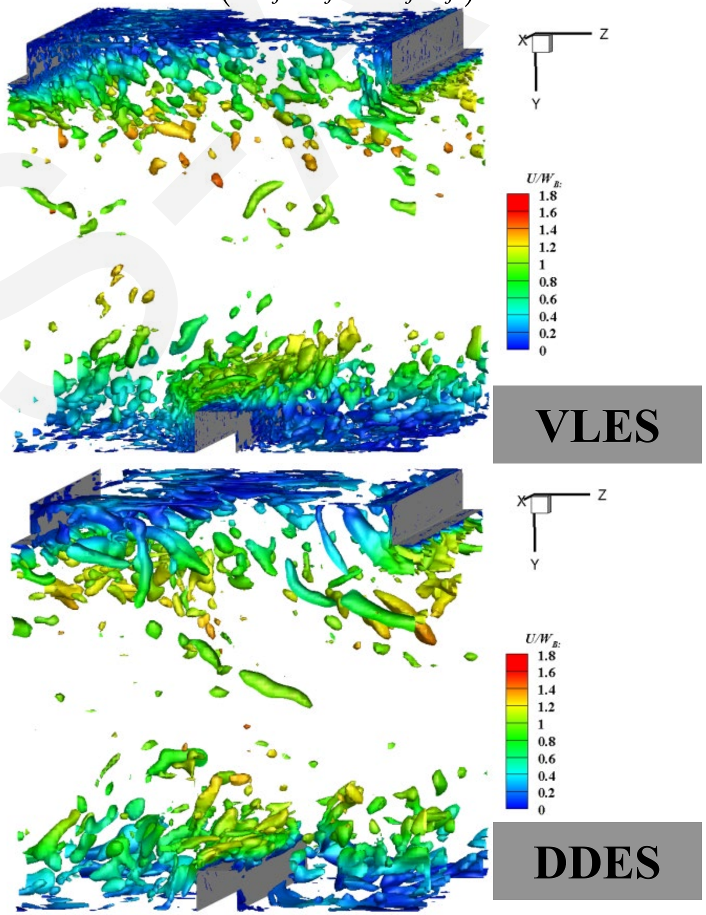
# Flow characteristics in the stationary state

- Time-averaged velocity distribution at different positions




- Turbulent flow structure in the channel (Q criterion)

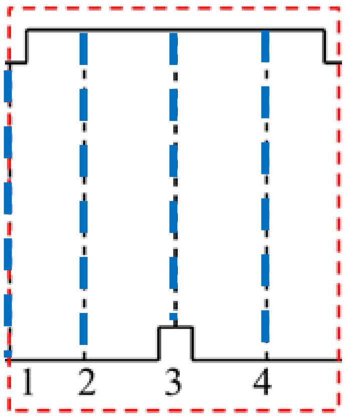
$$Q = 0.5\left(\Omega_{ij}\Omega_{ij} - S_{ij}S_{ij}\right) = 2\times10^{5}\,\mathrm{s}^{-2}$$

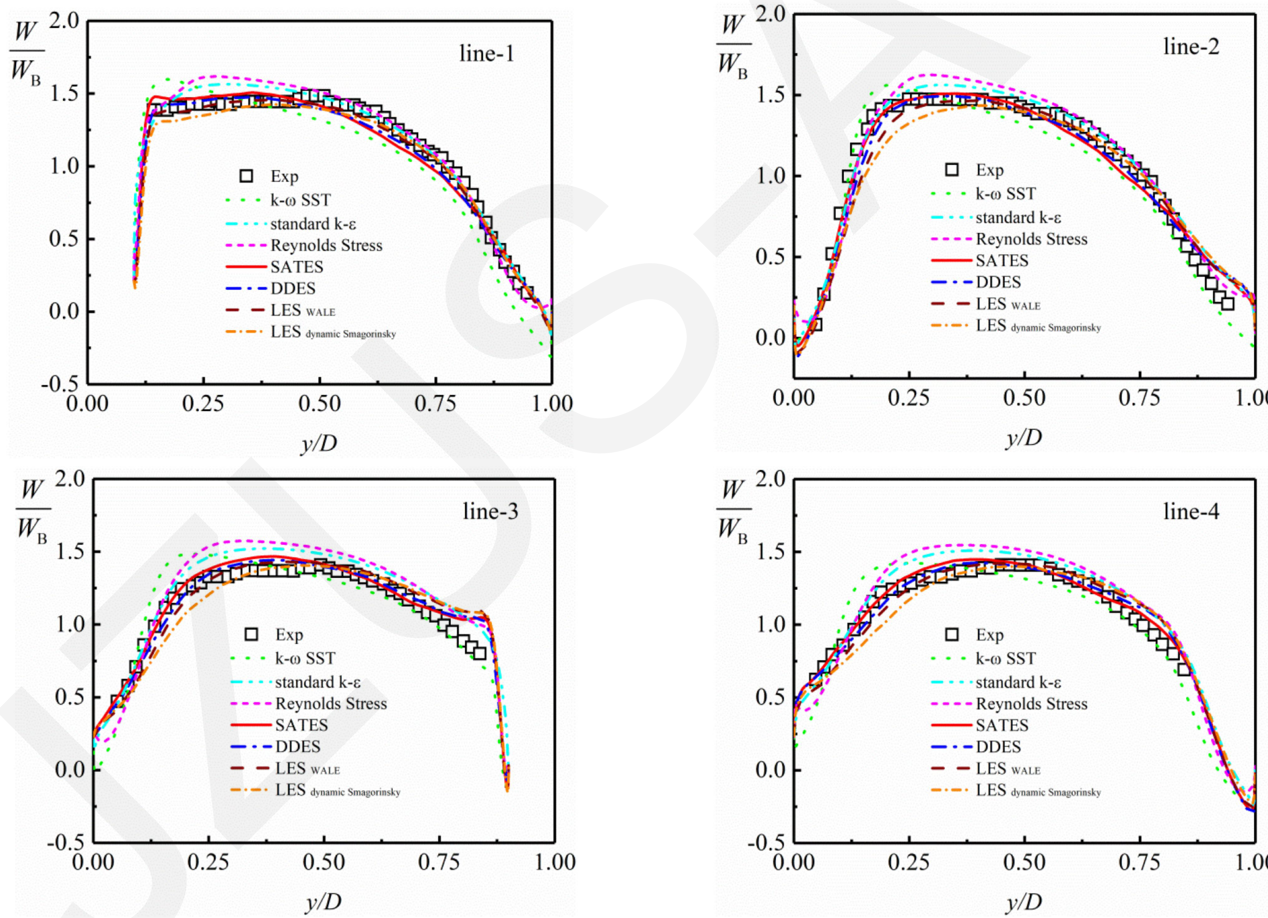



**With the same mesh, the velocity distribution obtained by the VLES method in a static state has higher accuracy, and it captures more wall turbulence structures**

# Flow characteristics in rotating state

- Time-averaged velocity distribution at different positions

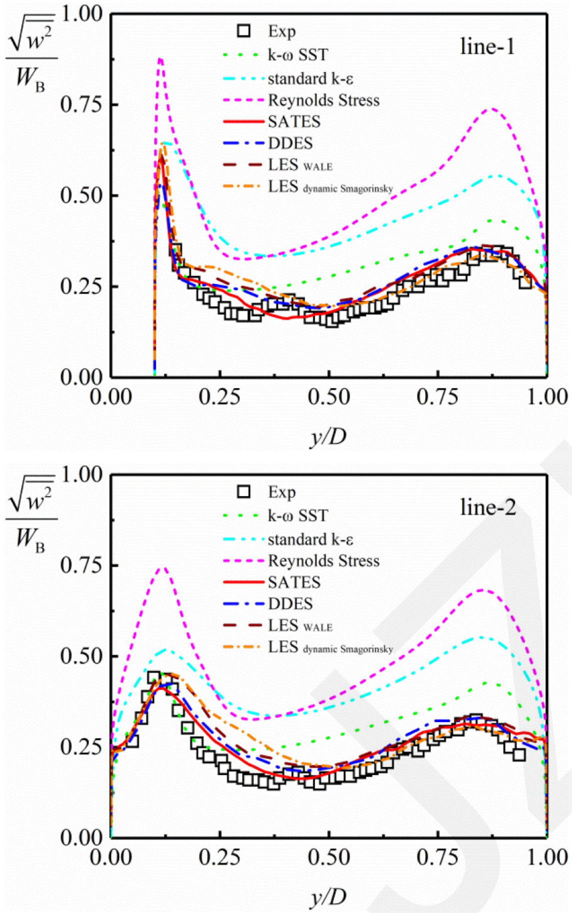


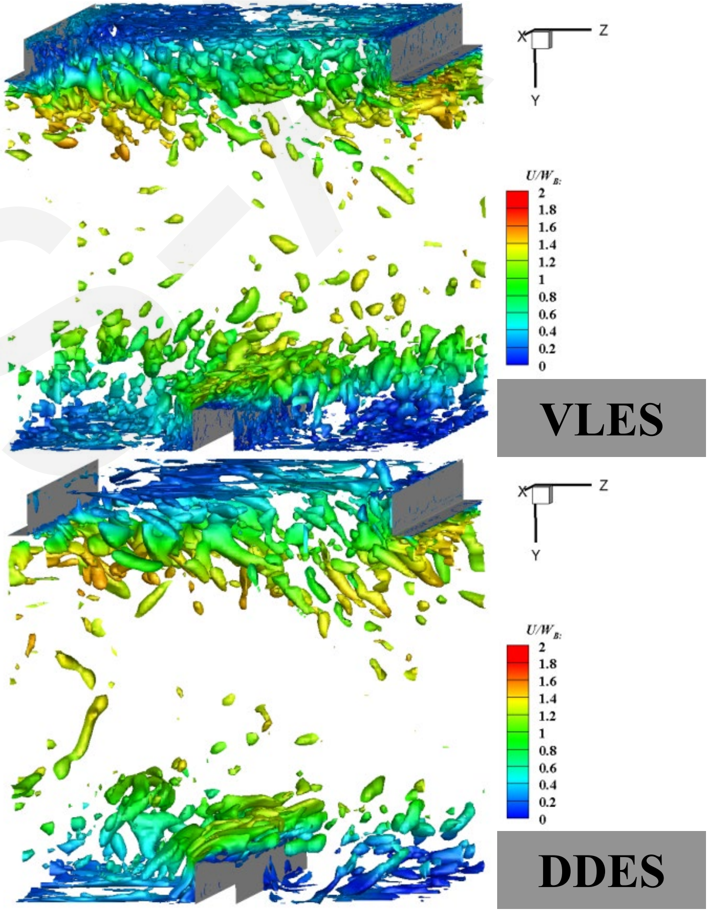

**With the same grid, compared with the simulation results of other methods, the VLES method is closer to the experimental data.**

# Flow characteristics in rotating state

- Fluctuating velocity distribution at different positions




- Turbulent flow structure in the channel （$Q=2\times10^5$）




**With the same mesh, the time-averaged velocity and the fluctuating velocity in the rotating state obtained by the VLES method are better predicted.**

# Conclusions

- For the ribbed channel flow at high Reynolds number of $Re=10^5$ under both the stationary state and the rotating state, the mean and fluctuation velocity results at different locations calculated by the present VLES method agree well with the experimental data, indicating that the VLES method has high accuracy and reliability in the flow analysis of ribbed channels under high Reynolds number and rotating state. As a comparison, the DDES and RANS method have insufficient prediction of flow characteristics in a certain aspect.

- The Coriolis force has significant effects on the flow structure in the ribbed channel. The mainstream region is shifted toward the pressure side and mixed with the pressure side shear layer. It produces strong momentum exchange. The Coriolis force also significantly changes the position and length of the recirculation bubble behind the ribs. The rotation also partly offsets the disturbance caused by the ribs. In addition, the secondary flow caused by the rotation causes a significant counter-rotating vortex structure inside the channel.

- With increasing rotation number, the rotational effect is continually enhanced. The mainstream velocity generally increases. The separation region on the suction side is increased significantly.