Hierarchy of coherent vortices and energy cascade in turbulence behind a cylinder

Yutaro Motoori*, Jun Fujino* and Susumu Goto*

By conducting a direct numerical simulation (DNS) of turbulence behind a cylinder, we investigate the generation mechanism of coherent vortices with various sizes. The Reynolds number is $Re_D = 5000$ (which is defined by the inflow velocity and the cylinder diameter D). At this Re_D, a hierarchy of vortices appears, which implies a sufficiently large scale-separation in the turbulence. We show in Fig. 1 these vortices, which are identified by positive isosurfaces of the second invariant $\widetilde{Q}^{(\ell)}$ of the velocity gradient tensor at three different scales ℓ. Here, we evaluate $\widetilde{Q}^{(\ell)}$ from ℓ-scale velocity $\widetilde{u}^{(\ell)}$ obtained by applying the band-pass filter[1] with three different filter widths ℓ. The scale of grey vortices is approximately equal to the cylinder diameter ($\ell \approx D$), corresponding to the roller vortices shedding from the cylinder. Blue and yellow ones are $\ell \approx D/4$ and $D/16$, respectively, and black ones are identified by Q without the filtering. We see in Fig. 1(a) that blue vortices tend to align in the direction perpendicular to larger grey ones. Figure 1(b) is the magnification of a subdomain of (a). We also see that yellow vortices are perpendicular to the blue ones. These observations imply that smaller vortices are stretched and amplified in the strain-rate fields around four-times-larger ones. Moreover, we also show the relevance of the vortex stretching to the energy cascade by quantifying the kinetic energy transfer due to vortex stretching and compression. Our DNS shows that small vortices receive the energy of larger vortices due to vortex stretching; and, at the same time, they compress their parent vortices, reducing the energy of the larger-scale kinetic energy[2]. In the conference, we will show the detailed evidence of this scale-local inter-scale energy transfer due to vortex stretching and compression.

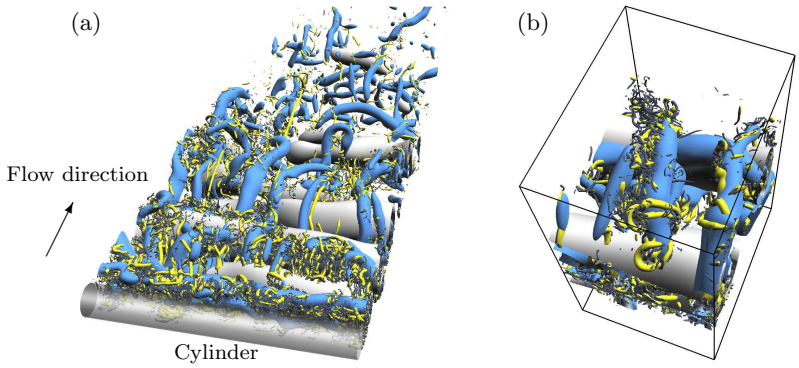

Figure 1: (a) Hierarchy of coherent vortices in turbulent wake behind a cylinder. (b) Magnification of subdomain of (a). Smaller yellow/blue vortices are stretched and amplified around larger blue/grey ones; and at the same time, they compress their parent vortices.

*Graduate School of Engineering Science, Osaka University, 1-3 Machikaneyama, Toyonaka, Osaka, 560-8531, Japan

[1]Motoori and Goto, *J. Fluid Mech.* **911**, A27 (2021).

[2]Fujino, Motoori and Goto, *Submitted to J. Fluid Mech.*