Vortex Structure Analysis Method for Separated Shear Flow

Takuto Ogawa*, Tomoaki Tatsukawa* and Fujii Kozo*
Corresponding author: 4418701@ed.tus.ac.jp

* Tokyo University of Science, Japan.

Abstract: We propose a new technique to precisely identify vortex filaments from separated shear flow and quantitatively evaluate the characteristics of the vortex structures. To confirm the effectiveness of the proposed method, it was applied to actual LES data that is a separated shear flow around an NACA0015 airfoil. As a result, the vortex filaments were successfully identified, and the strength, size and trajectory each of the vortex structure were quantitatively evaluated.

Keywords: Vortex Structure, Vortex Filament, Separated Flow, Shear Layer, Computational Fluid Dynamics.

1 Introduction

Vortex is one of the most important elements for analyzing the fluid flow phenomena. In the engineering field, the characteristics of the vortex structure are analyzed to evaluate the performance and safety of machinery. In many cases, the second invariant of the velocity gradient tensor (Q^*) is used to identify the vortex structure from numerical data. Besides that, the identified vortex structure is often visualized and qualitatively evaluated. However, in the unsteady or complicated turbulent flow condition, it is difficult to evaluate the influence of the vortex structure on the flow and the machinery only by using the visualization analysis method. Therefore, to accurately analyze unsteady or complex turbulent flow, quantitatively evaluation of their characteristics are required. Wang et al. [1] studied the location and characteristics of coherent fine vortices in the turbulent flow. They proposed the identification method for vortex filament [2] of coherent fine vortices from the turbulent flow and evaluated the distribution and direction of vortices against the free-stream. This method is required to be applied to the flow at low Reynolds numbers, and uses the vorticity vector to identify the vortex filaments. Therefore, it is difficult to identify the vortex filaments by applying this method to the case of separated shear flow at high Reynolds numbers. In this study, we propose an analysis method that identifies the vortex filaments from the separated shear flow and quantitatively evaluates the characteristics of vortex structures. The proposed method is applied to the actual LES data. The vortex filaments are identified, and the strength, size and trajectory each of the vortex structure were quantitatively evaluated.

2 Vortex Structure Analysis Method

Figure shows the process for identifying the vortex filaments from the numerical data. First, the regions where the rotational motion exceeds the deformation motion ($Q^* > 0$) are identified as the vortex structures. Second, the magnitude relationships of Q^* between adjacent points are evaluated. An arbitrary reference point is selected as P_A in this paper. Among all points that are adjacent to P_A, the point where Q^* is the highest and higher than Q^* at the P_A is selected as the P_B. An edge between P_A and P_B is created. Tree structures for Q^* are constructed by performing this process on every point. Finally, the path integrals of Q^* on every path are compared to estimate the path of the vortex filament. This method can be applied not only to two-dimensional data but also to multi-dimensional data such as three-dimensional data and four-dimensional data with a time axis because this method is based on the very general idea of referencing and merging adjacent points.

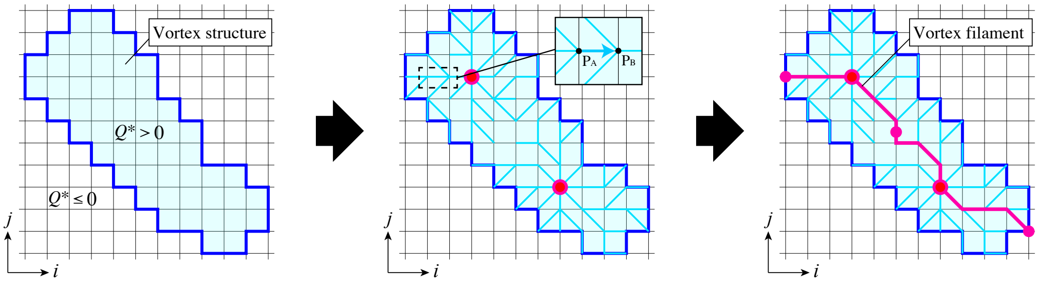
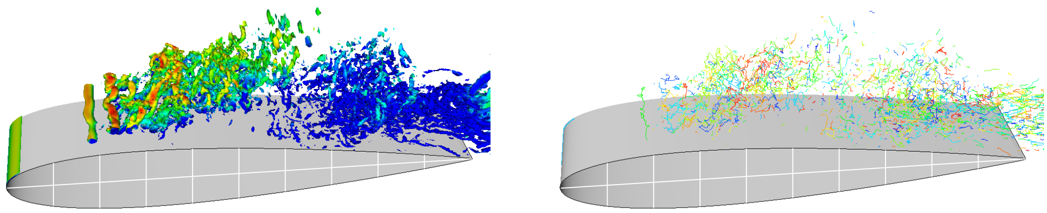


Figure 1 The process for identifying the vortex filaments from the numerical data.

To confirm the effectiveness of the proposed method, it was applied to actual LES data that is a separated shear flow around an NACA0015 airfoil, as shown in Fig. 2(a). Figure 2(b) shows the result of the identification of vortex filaments. The vortex filaments are distributed corresponding to the distribution of the vortex structures. Therefore, the effectiveness of the proposed method is confirmed.



(a) Vortex structures that are visualized by Q^*.

(b) Identified vortex filaments.

Figure 2 Vortex structures and filaments in the separated shear flow around the NACA15 airfoil.

3 Conclusion

We proposed the analysis method that identifies the vortex filaments from the separated shear flow and quantitatively evaluates the characteristics of vortex structures. The proposed method is applied to the actual LES data, and its effectiveness was confirmed.

References

[1] Wang T, Tanahashi M and Miyauchi T, "Coherent fine scale eddies in turbulence transition of spatially-developing mixing layer," International Journal of Heat and Fluid Flow, 28(6), pp. 1280-1290, 2007.

[2] Jiménez J and Wray A. A, "On the characteristics of vortex filaments in isotropic turbulence," Journal of Fluid Mechanics, 25(373), pp. 255-285, 1998.