Study on turbulence structure over a wavy wall using wavelet analysis of time-series PIV data

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The purpose of this study is to propose a new approach to extract meaningful information from time-series PIV data. Recently, using a high speed camera, laser illumination and a particle image velocimetry (PIV) technique, we can measure 2-dimensional vector maps with a high frame rate. A tremendous amount of information about flow field will be obtained. We need some kind of filter to find what we want from vast quantities of information effectively.

We adopt a wavelet analysis of time-series velocity fluctuation at a spatial point. From this analysis we can obtain spectral information at the spatial point with time. Moreover we apply the wavelet analysis to every spatial point of PIV measurement. This process produces 4-dimensional (2-dimension in space, 1-dimension in time, and 1-dimension in frequency) information concerning coherent structures of flow. Utilizing an information visualization technique will enable the direct observation of a coherent structure in time and space.

We applied the above mentioned analysis and visualization to turbulent flow over a wavy surface. Turbulent flow over a wavy surface relates to various natural phenomena and technical applications, such as winds over the ocean and sand dune surfaces and gas-liquid flow in a pipeline. Turbulent flow over a wavy surface involves successive separations and reattachments. The intermittent appearance of large scale coherent structure is observed in the flow.

Experimental apparatus and procedure

A wavy wall is placed on the bottom of a test section. The height, width, and length of the test section are 34.5 mm, 300 mm, and 1000 mm, respectively. The wavelength $\lambda$ and amplitude $a$ of the wave are 32 mm and 4.5 mm. The amplitude to wavelength ratio of the wavy wall, $a/\lambda$, is 0.14.

Experiments have been conducted for the Reynolds number $Re$ of 550, 1100 and 3300. Air flow was seeded with Ethylene glycol droplets as tracers. The position of visualization was 688 mm from the inlet of the test section and the center of breadth. The visualized flow was recorded using the high-speed video camera with the frame rate of 1500 to 6000 per seconds.

Wavelet analysis is used to divide a continuous-time signal into different scale components with time resolution. In this study, wavelet analysis is applied to the time series of the wall-normal velocity component. A one-dimensional Gabor function is used as a mother wavelet.

Applying wavelet analysis to one measurement point of vector map produces a result as 2-dimensional contour plot. With the time-series PIV measurement, we obtain velocity vector at hundreds of spatial positions. As a result, hundreds of counters are produced.

We used an open-source visualization software, ParaView, to visualize results effectively. Four-dimensional data (2-dimension in space, 1-dimension in time, and 1-dimension in frequency) is stored in the Visualization ToolKit format. Three-dimensional coordinate (2-dimension in space and 1-dimension in frequency) is used and the change in time is represented as animation.

Results and Discussions

Figure 1 shows an example of wavelet analysis result. Wavelet modulus at fixed frequency of 33Hz is shown at successive moments. From this figure the spatial size of coherent structure having a predominant frequency and its transition is clarified.

Coherent structure detected in figure 1 corresponds to flow shown in figure 2. Low momentum fluid in the trough rushes into mainstream periodically, and vice versa.

Using the visualized results, we can easily detect the feature of flow field from the viewpoints of space, time, and frequency.