DNS OF TURBULENT CHANNEL FLOW AT HIGH REYNOLDS NUMBER UNDER A UNIFORM MAGNETIC FIELD

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Introduction. A direct numerical simulation (DNS) of turbulent channel flow with high Reynolds number has been carried out to understand the effects of magnetic field. In this paper, we applied uniform magnetic fields to our channel DNS database (Satake *et al.* (2003)) at high Reynolds number. The objectives of this study are to understand the turbulence suppression the turbulent channel flow in a transverse magnetic field and to reveal the mechanism of disappearance of large scale turbulence structures. In this study, the Reynolds number for channel flow based on a friction velocity and channel half width was set to be constant; $\mathrm{Re}_\tau = 1194$. The flow filed is under a uniform magnetic filed. The Hartman number is 65. The number of computational grids used in this study was $1024 \times 1024 \times 768$ in the x-, y- and z-directions, respectively. The turbulent quantities such as the mean flow, turbulent stresses and the turbulent statistics were obtained via present DNS.

1. Computational conditions. Our DNS code is hybrid spectral finite difference methods (Satake and Kunugi (2003) and Satake *et al.* (2003)). The number of grid points, the Reynolds number and grid resolutions summarized in Table 1. Our computation is adopted for 224GB main memory as 32 PEs on a vector-parallel computer Fujitsu VPP 5000 at JAERI. The periodic boundary conditions are applied to the streamwise (x) and the spanwise (z) directions. As for the wall normal direction (y), non-uniform mesh spacing specified by a hyperbolic tangent function is employed. The all velocity components imposed the non-slip condition at the wall. The non-slip condition is used at the wall. A uniform magnetic field $\mathbf{B}_0$ defines that the y-axis lies along the axis of the streamwise direction in Fig. 1. The Neumann condition for the electrical potential is adopted at the wall: Insulation wall assumption. The Hartmann numbers $\left(\mathrm{Ha} = B_0 2\delta(\sigma/\rho\nu)^{1/2}\right)$

Fig. 1. Computational domain.

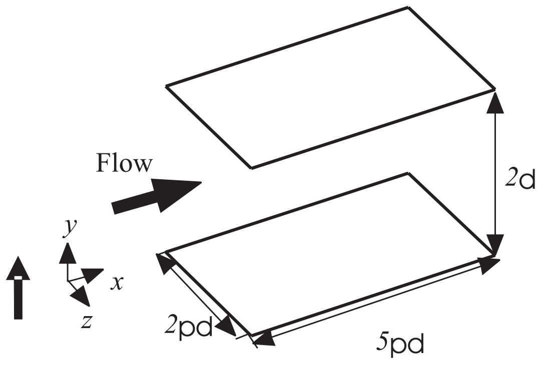

Table 1. The number of grid points, the Reynolds number and grid resolutions.

Rn_τ	Ha	Region	Grid number	Δx^+	Δy^+	Δz^+
1100	0	$5\pi\delta \times 2\delta \times 2\pi\delta$	$1024 \times 1024 \times 768$	16.8	0.16–4.18	8.9
1194	65	$5\pi\delta \times 2\delta \times 2\pi\delta$	$1024 \times 1024 \times 768$	18.8	0.17–4.54	9.6

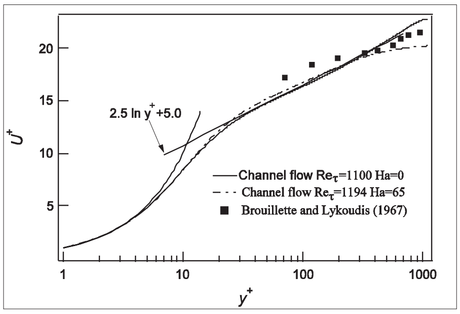

Fig. 2. Mean velocity profiles.

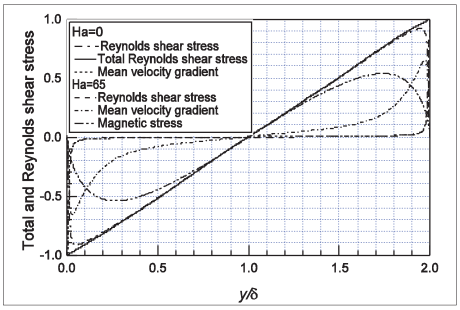

Fig. 3. Total and Reynolds shear stresses.

based on the magnetic field $\mathbf{B}_0$, the kinematic viscosity ν, the electrical conductivity σ and the channel width 2δ are set to 65.

2. Results and Discussion. Mean velocity profiles are shown in Fig. 2. Satake & Kunugi (2003) and Satake *et al.* (2003) found that the logarithmic profile exits and elongated to the channel center. The logarithmic profile at Ha = 65 shifted to the channel center, and wake region disappears clearly. The profile is good agreement with the experimental profile by Brouillette & Lykoudis (1967). Fig. 3 shows the total and Reynolds shear stress. At Ha = 65, Magnetic stress appears and it is very large. Reynolds shear stress is decrease at Ha = 65 and the peak value is decreased. The velocity fluctuations are shown by Fig. 4. It is interesting that all components are decreased at the channel center. The streamwise component is remained near wall region. Figs. 5*a*–*c* show streamwise wavelength of the peak of the pre-multiplied power spectrum at a different height from the wall. The values at a different height from the wall can understand the dominant turbulent scales. The dominant scale of structure at the near wall region is larger than that at the channel center owing to applied magnetic field. Thus, the structure at the near wall region is elongated to the streamwise direction. Figs. 6*a*–*c* show spanwise wavelength of the peak of the pre-multiplied power spectrum at a different height from the wall. The dominant scale of structure at the near wall region is almost same, even if it is applied a magnetic field. However, the scale at the channel center is decreased.

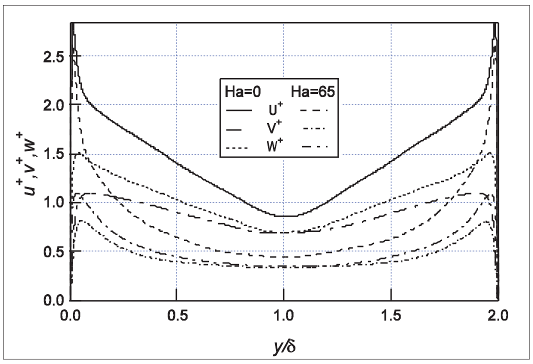

Fig. 4. Turbulent intensities.

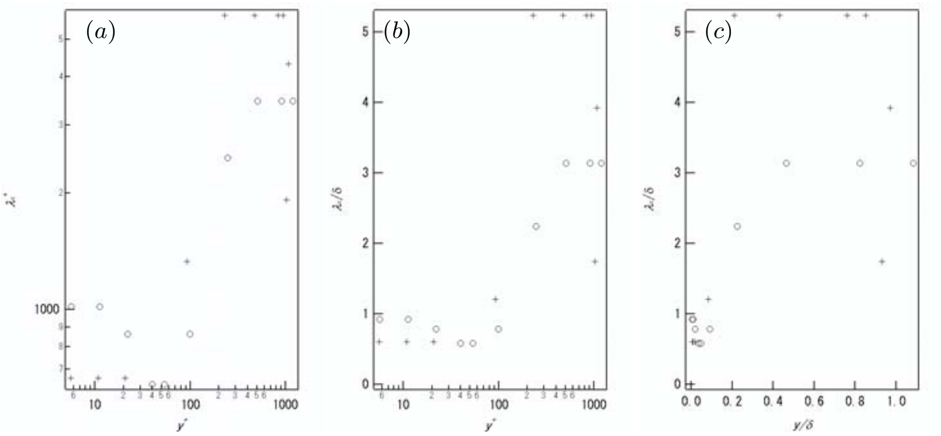

Fig. 5. Streamwise wavelength of the peak of the pre-multiplied power spectrum at a different height from the wall. $\circ$: Ha = 65, $+$: $Ha = 0$, (a) inner-inner scaling (b) outer-inner scaling (c) outer-outer scalings.

To investigate this phenomenon for the change of the dominant scales, the streaky structures are visualized in Figs. 7 and 8. It is normalized by ν and $u\tau$. The volume visualized obtained as full volume ($L_x^+ = 17278$, $L_y^+ = 2200$, $L_z^+ = 6911$). The many small streaky structures exist in large streaky structures. The width of the large streaky structures are larger than 1000, located at away from the wall. A few merged large streaks elongated to the channel center away from the wall in Fig. 7. A characteristic size of the large streaky structures to the streamwise direction is even larger than the half of the channel width. Almost large structures located in $y^+ > 200$, correspond to the wake region in the mean velocity profile. On the other hand, the large scale motion at the channel center disappeared in Fig. 8. It is evident as the reason that the turbulent intensities in Fig. 4 are decrease at the channel center owing to the applied magnetic field. Moreover, the streaky structures are elongated to the streamwise direction. The phenomena are coincident to the turbulent scale decreased in Figs. 5.

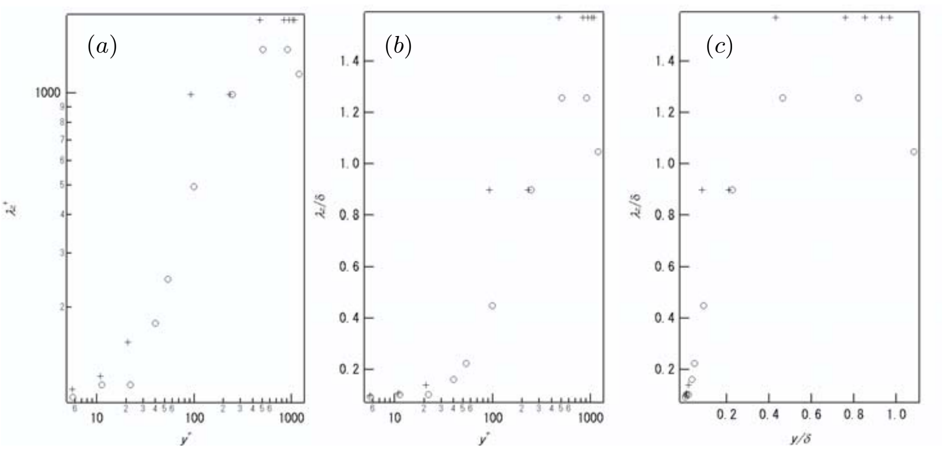

Fig. 6. Spanwise wavelength of the peak of the pre-multiplied power spectrum at a different height from the wall. $\circ$: Ha = 65, $+$: $Ha = 0$, (a) inner-inner scaling (b) outer-inner scaling (c) outer-outer scalings.

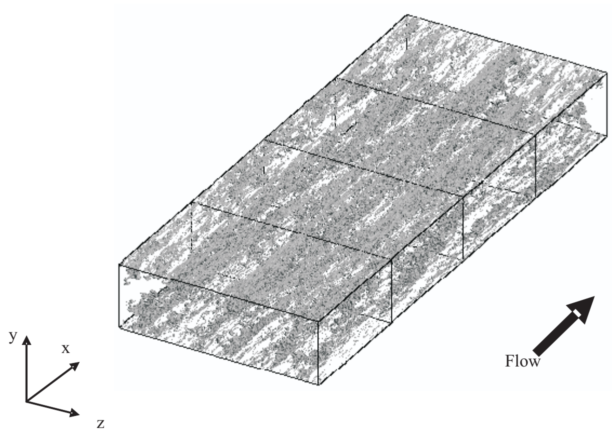

Fig. 7. The contour of streaky structure; $u^+ < -3$: Ha $= 0$.

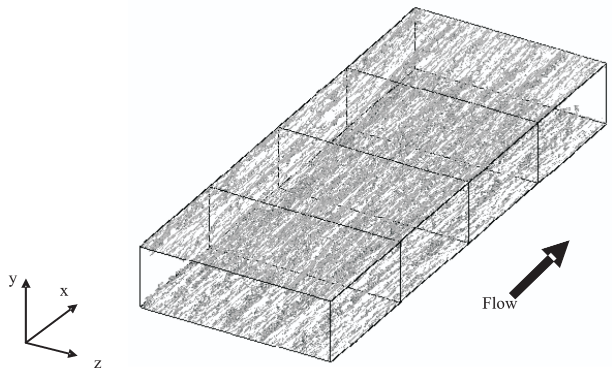

Fig. 8. The contour of streaky structure; $u^+ < -3$: Ha $= 65$.

3. Summary A The DNS for the channel flow at High Reynolds number was carried out under a uniform magnetic field. The result is compared with previous DNS data for Non-MHD. Turbulent intensities and large scale turbulent strictures are decreased at the channel center.

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