Modification of Near-Wall Turbulence by Stable Stratification

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ABSTRACT

Stably stratified flows are frequently observed in geophysical flows as well as in many engineering flows. Therefore the study of stably stratified turbulent flow has been of interest both for physical understanding and engineering applications. However previous studies have been focused on the modification of turbulence in the outer layer. Moreover most experiments and numerical simulations were performed for weakly stably stratified flow.

In this study, we investigated detailed characteristics of stably stratified turbulent flow using direct numerical simulation and large-eddy simulation. Some statistics obtained from high Richardson number flows were analyzed too. Here the Richardson number is defined by $Ri = \beta \Delta T g \delta / u_\tau^2$ (Garg, et al., 2000). Where each parameter means thermal expansion coefficient, temperature different between walls, gravity acceleration, channel half width and friction velocity, respectively. Large-eddy simulation was performed to obtain statistics of high Richardson and Reynolds number flows. To do this we used dynamic subgrid-scale model (Germano, et al, 1991 ; Cabot & Moin, 1993) for momentum equation and heat equation.

Numerical simulations were performed for two Reynolds numbers and several Richardson numbers. Table 1 shows flow parameters used in DNS and LES. Figure 1 shows that mean velocities are increasing in the channel center region as Richardson number is increasing. As shown in figure 2, the slope of the mean velocity profile at the wall is invariant owing to the constant pressure gradient.

Figure 2 shows that velocity rms normalized by wall-shear velocity is decreased in near-wall region but increased in the outer region for *Re*=180 case. When *Ri* is very high, rms profile has dual peaks and the peak moves into the outer region. Furthermore velocity profile is starting to

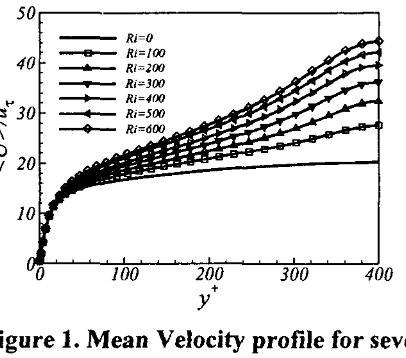

Figure 1. Mean Velocity profile for several levels of stratification for *Re*=400 obtained by LES

Table 1: Flow parameters of DNS and LES

	Re	Pr	Nx*Ny*Nz	Ri
DNS	180	0.71	128*129*128	0~120
LES	180	0.71	32*65*32	0~450
LES	400	0.71	64*129*96	0~600

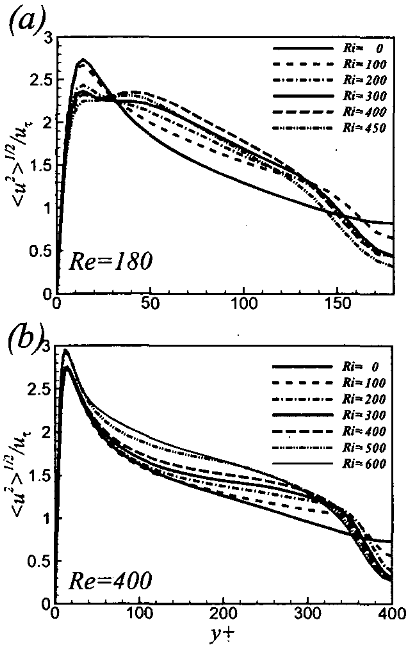

Figure 2. Velocity fluctuations normalized by wall unit: (a) Re=180, (b) Re=400. LES results.

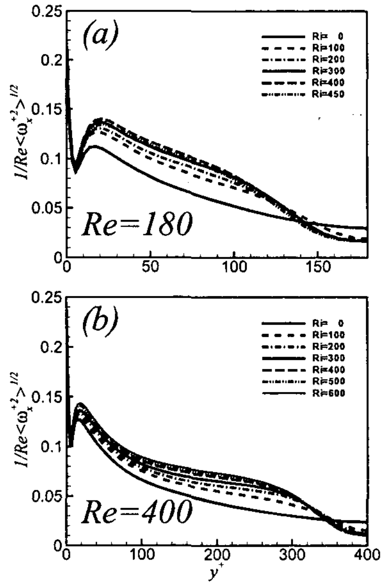

Figure 3. Vorticity fluctuations normalized by wall unit: (a) Re=180, (b) Re=400. LES results.

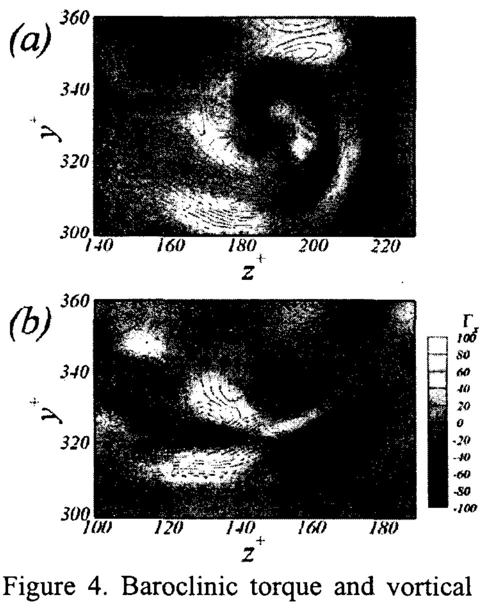

Figure 4. Baroclinic torque and vortical structures: (a) Re=180, Ri=0, (b) Re=180, Ri=120. Flooding contours denote streamwise component of baroclinic torque, $\Gamma = \nabla T \times (-\nabla p)$. Solid and dashed lines are positive and negative streamwise vorticities, respectively. DNS results.

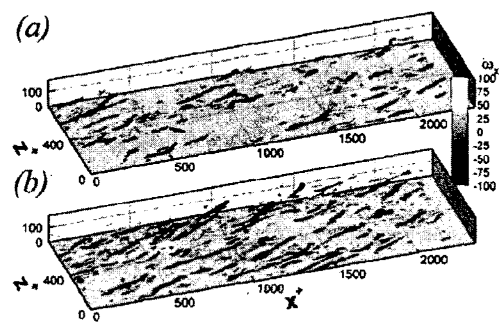

Figure 5. Coherent vortical structures. Contours on surfaces denote streamwise vorticity, ω_x . DNS results.

decreases in all region when Richardson number is greater than 450. In the case of *Re*=400, peaks do not change so much but continuously increase in the outer region. Vorticity *rms*'s increase in all region and for all Reynolds number except in the case of *Ri* greater than 450 when *Re*=180.

The role of the baroclinic torque, $\Gamma = \nabla T \times (-\nabla p)$, is investigated. In the figure 4(a) the size of non-zero torque regions is smaller than pre-existing neighboring vortical structures. These sources or sinks tend to generate new vortical structures and distort the vertical structures. Similar pattern is observed in *Ri*=120 case. However, it is not clear how vortical structures get elongated in the streamwise direction as shown in figures 5 (a) and 5(b). It may be speculated that suppressed vertical motion causes the streamwise vortices less inclined with the wall, resulting in elongation in the streamwise direction. Detailed statistics will be presented in the meeting.

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