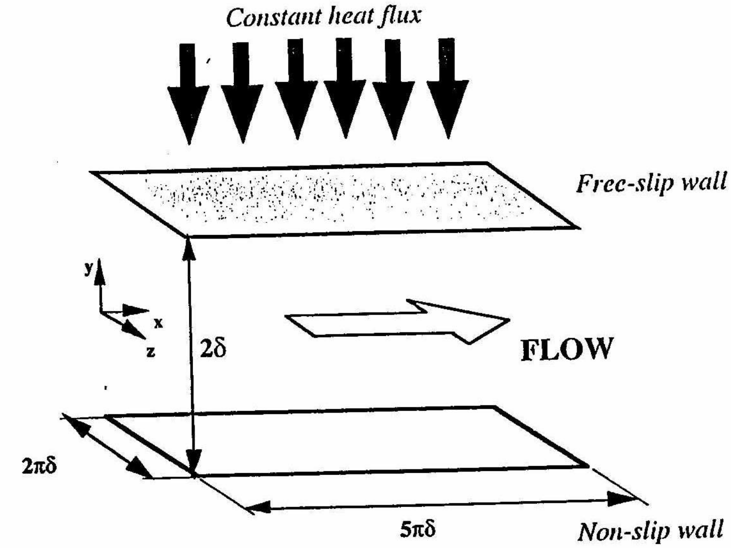


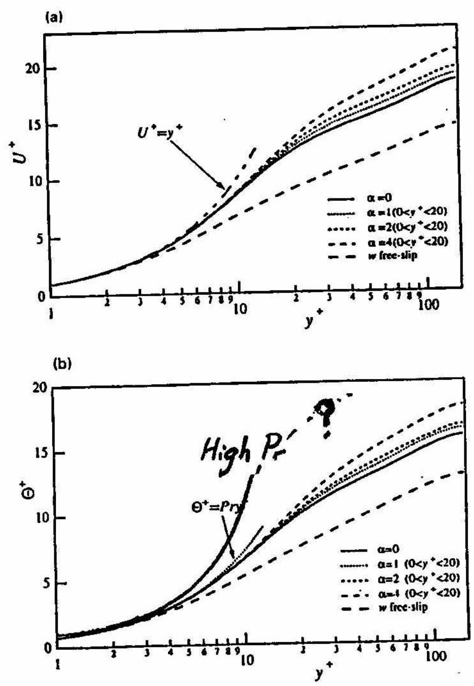


Figure 5 Near-wall mean velocity and temperature profiles: (a) velocity; (b) temperature

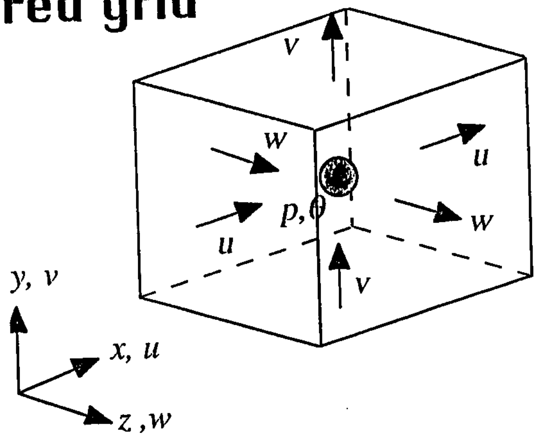
APEX/HPD Workshop, Makuhari, Chiba, Feb. 21-22, 2000

Direct Numerical Simulation of High Pr Fluid Free-Surface Flows

T. Kunugi & Y.Yamamoto, Kyoto University
Kunugi@nucleng.kyoto-u.ac.jp
S. Satake, Toyama University
ssatake@eng.toyama-u.ac.jp

DNS codes

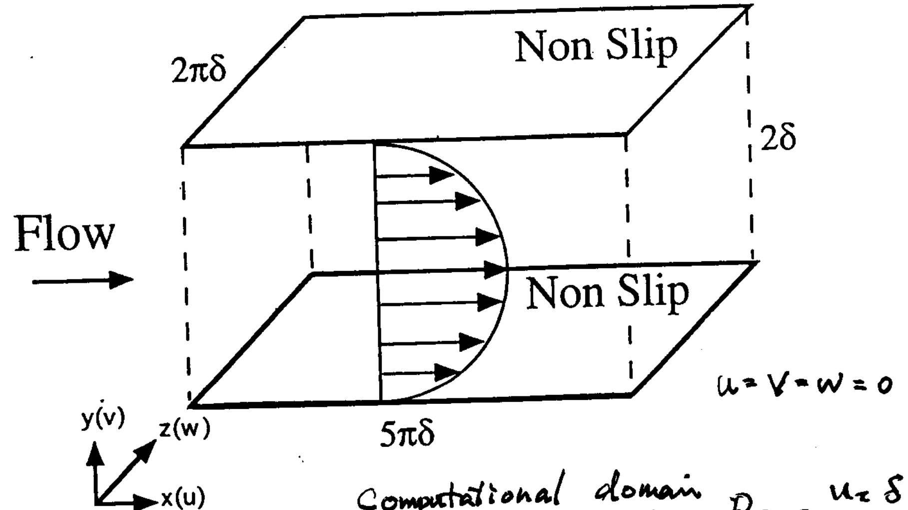
- Control volume method
- Staggered grid



- 3rd-order Runge-Kutta method for Nonlinear terms
  Crank-Nicolson method for Viscous terms.

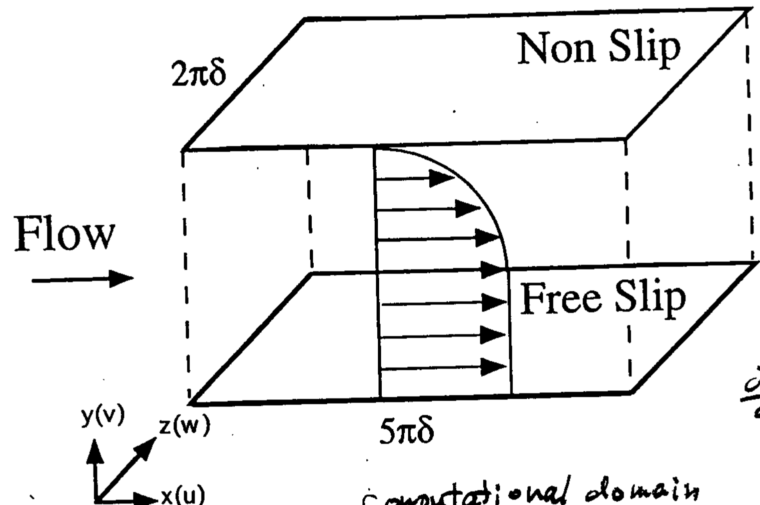
- Fractional step method

- Pressure poisson eq.
  FFT based method for x-z direction.
  TDMA for normal direction



Computational domain
図1.1 計算領域（Non-Slip）

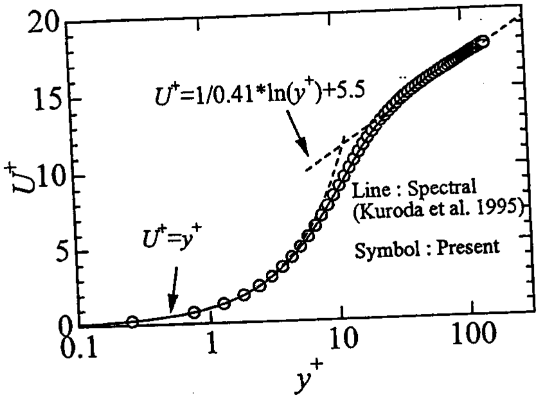
$Re_\tau = \frac{u_\tau \delta}{\nu} = 150$



$Re_\tau = \frac{u_\tau \delta}{\nu} = 150$

$\frac{\partial u}{\partial y} = v = \frac{\partial w}{\partial y} = 0$

Computational domain
図1.2 計算領域（Free-Slip）



Mean velocity profile
(Open-channel flow R_τ=150)

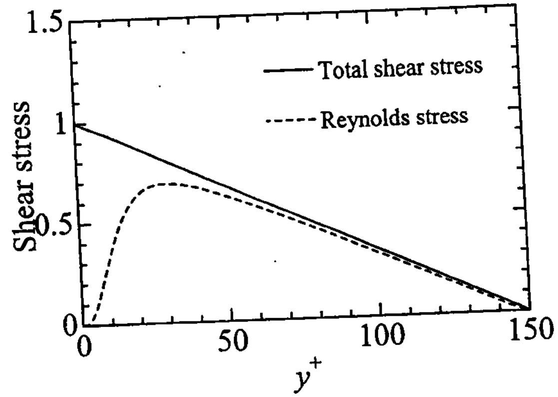
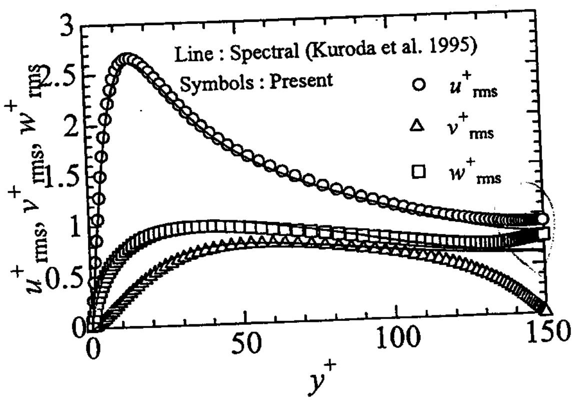


図4.3 Shear stress
(Open-channel flow R_τ=150)



Turbulent intensity
(Open-channle flow R_τ=150)

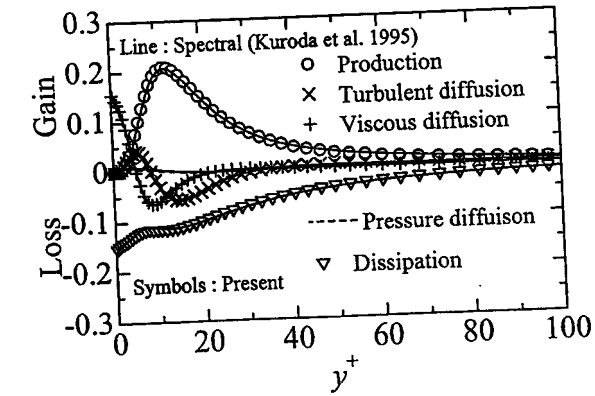


図4.4 Budget of turbulent kinetic energy k
(Open-channel flow R_τ=150)

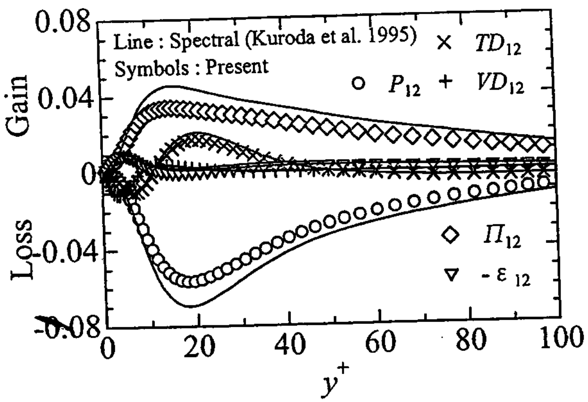


図4.5 Budget of $\overline{u\,v}$
(Open-channel flow R_τ=150)

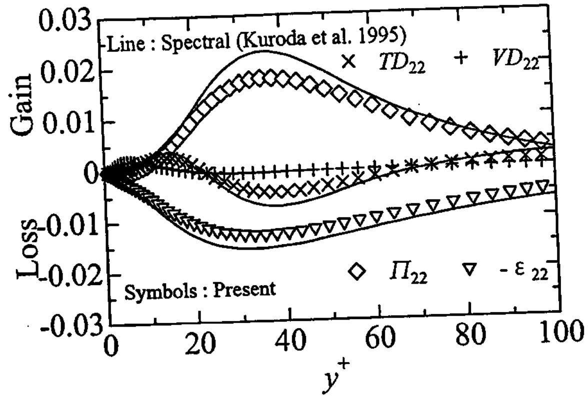


図4.7 Budget of $\overline{vv}$
(Open-channel flow R_τ=150)

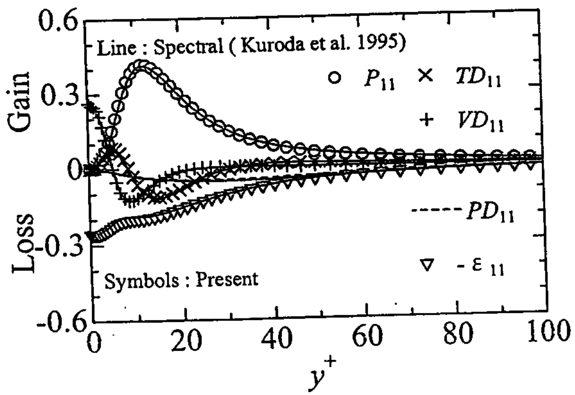


図4.6 Budget of $\overline{u\,u}$
(Open-channel flow R_τ=150)

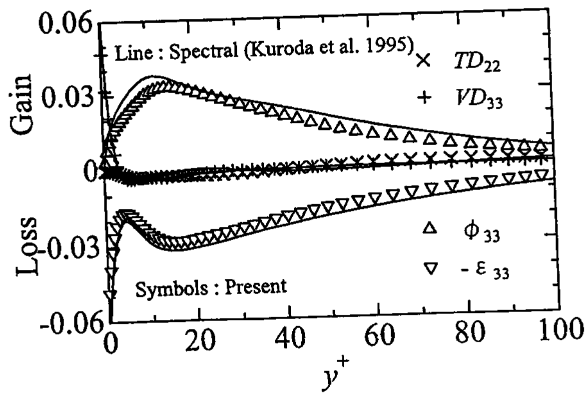


図4.8 Budget of $\overline{ww}$
(Open-channel flow R_τ=150)

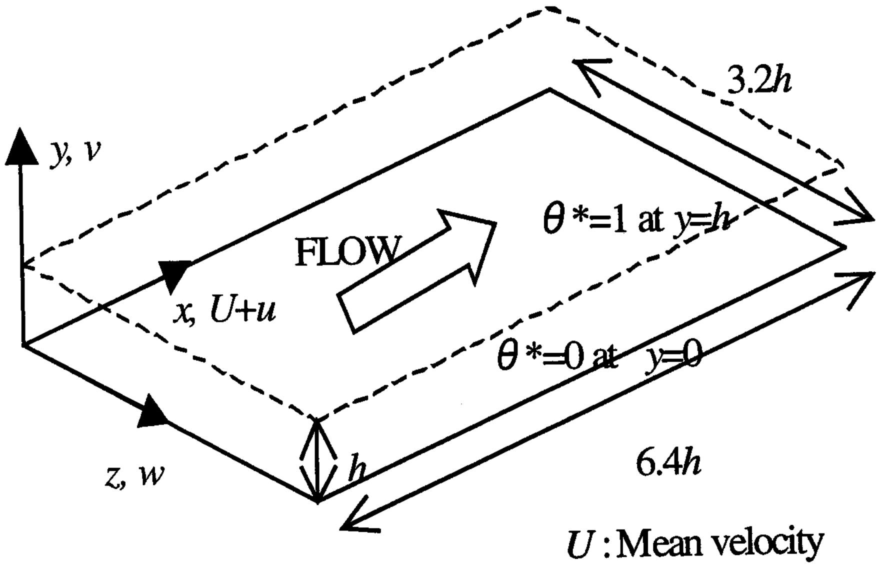


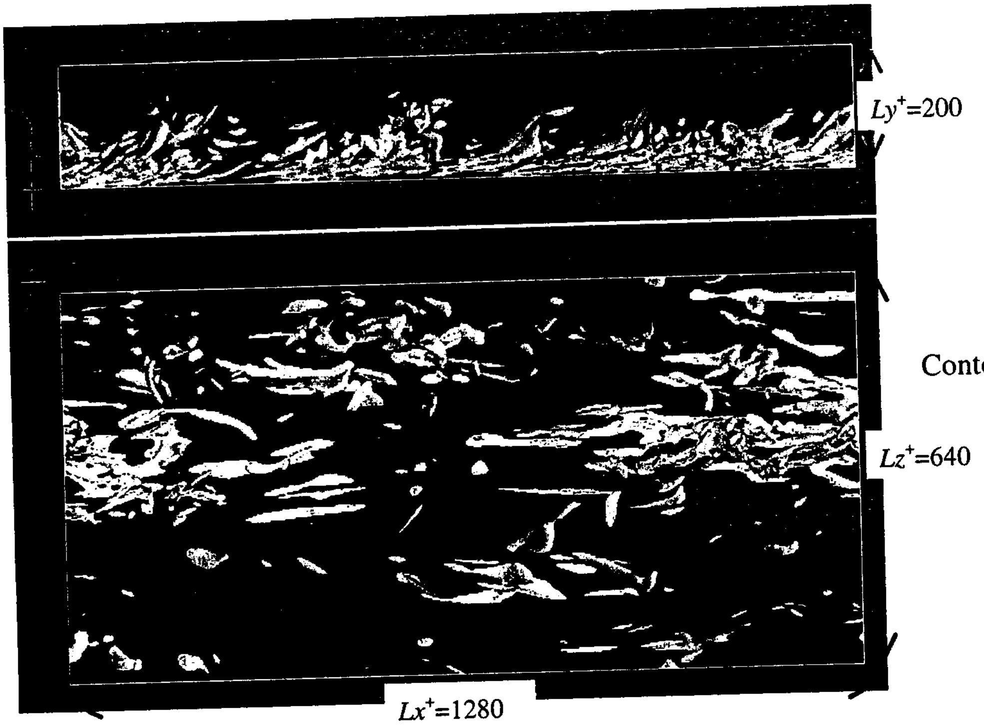
Fig.1 Computational domain and coordinate system

Identification of Coherent Structure of Turbulence based on Second Invariant

- Velocity gradient tensor: $W_{ij} = \frac{\partial u_i}{\partial x_j}$
- Rotation: $\Omega_{ij} = \frac{1}{2}(W_{ij} - W_{ji})$ Shearing: $S_{ij} = \frac{1}{2}(W_{ij} + W_{ji})$
- Second Invariant: $Q = \frac{1}{2}(W_{ij}W_{ij} - S_{ij}S_{ij}) = \Delta\left(\frac{P}{\rho}\right)$

$Q > 0$:Rotation Dominant

$Q < 0$:Dissipation Dominant

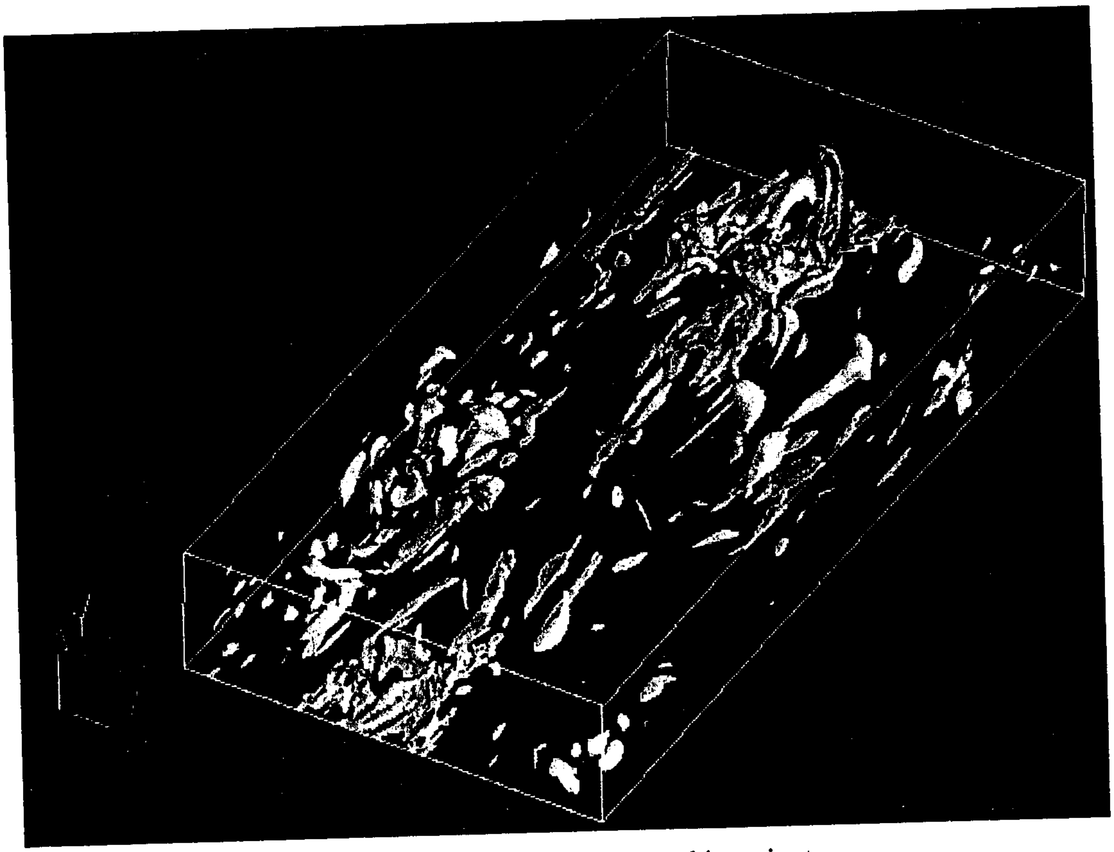


Contour of surfaces of second invariant velocity gradient tensor

Grid numbers : $512 \times 131 \times 256$ $(x \times y \times z)$

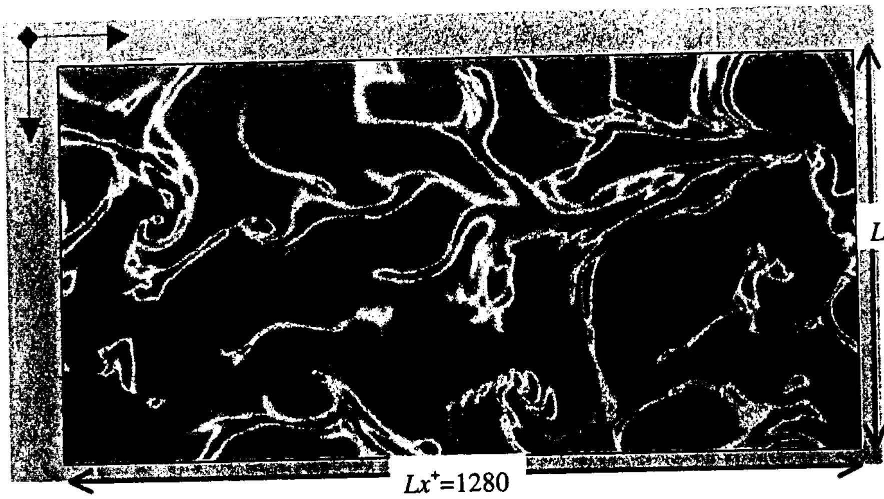
$(\Delta x^+ = 2.5, \Delta y^+ = 0.25 - 2, \Delta z^+ = 2.5)$

3



Contour of surfaces of second invariant velocity gradient tensor (Bird view)

(1)



(1) Turbulent temperature field
(Pr=5.0)
Near free-surface

Grid numbers : 512×131×256
(x×y×z)

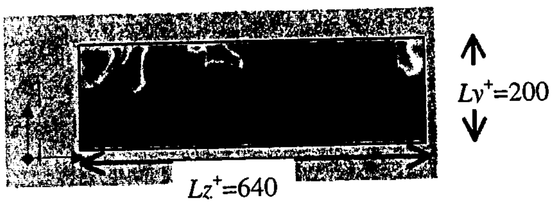
($\Delta x^+ = 2.5, \Delta y^+ = 0.25 - 2, \Delta z^+ = 2.5$)

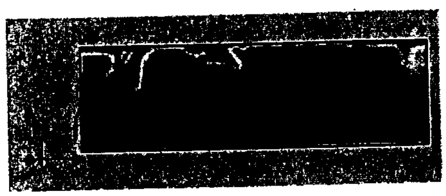
(2)

(2) Instantaneous temperature field
(Pr=5.0)
Near free-surface

Grid numbers : 512×131×256

($\Delta x^+ = 2.5, \Delta y^+ = 0.25 - 2, \Delta z^+ = 2.5$)

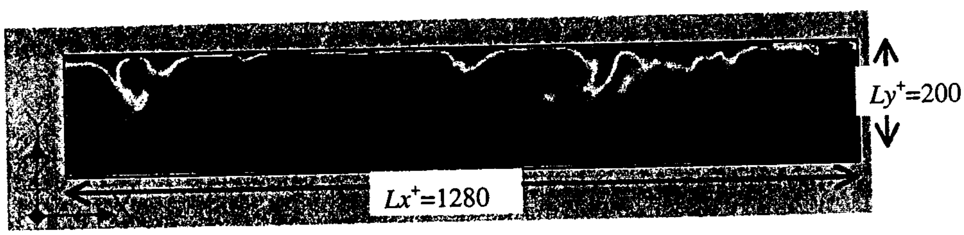




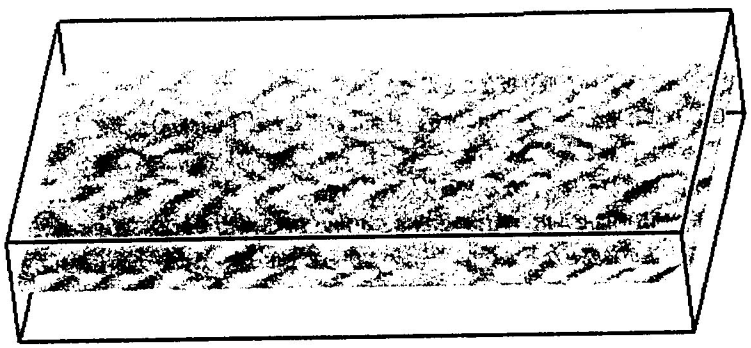
(1) Turbulent temperature field

(2) Instantaneous temperature field

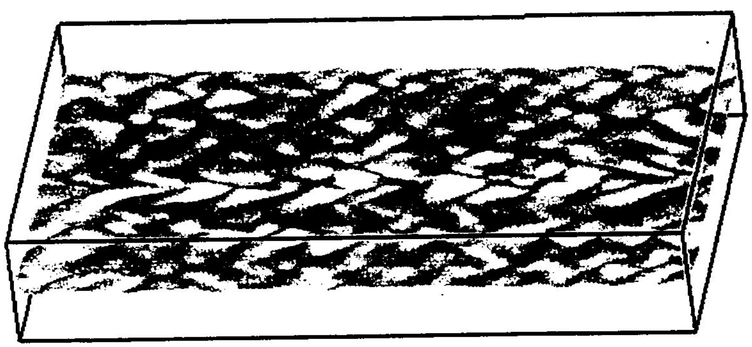
(Pr=5.0)



(3) Instantaneous temperature field (Side view)
(Pr=5.0)
Grid numbers : 512×131×256
(x×y×z)
($\Delta x^+ = 2.5, \Delta y^+ = 0.25 - 2, \Delta z^+ = 2.5$)



Re=2736



Re=5472

Snapshots of free surface shape

Conclusion

- DNS has been carried out for turbulent free-surface flows of High Prandtl number fluid.
- Thermal mixing decreases with increase of Prandtl number of fluid.
- However, thermal mixing could be enhanced by turbulent coherent structure near the wall.
- Further investigation will be necessary to be clear the role of free-surface deformation via experiments and numerical simulations.