

New wall law treatment for the Large Eddy Simulation of turbulent heat transfer in a periodic channel ($Re_\tau = 180$ and $Pr = 0.025$, T0Q case)

1 Introduction

Validation made by : Pierre-Emmanuel Angeli.
Report generated 24/10/2013.

1.1 Description

- Turbulent channel flow with T0Q type conditions.
- Validated model: Robin boundary condition at walls for L.E.S. with wall function in VEF discretization.
- Validation with analytical laws (Reichardt [1]: $U^+ = R(y^+)$, and Kader [2]: $T^+ = K(y^+)$), DNS Moser-Kim-Mansour [3] and DNS Kawamura [4].

1.2 Parameters Trio_U

- Version Trio_U : 1.6.7 ;
- Version Trio_U from out: /work/trioform/PEA/Baltik_Pironneau/basic.opt (1.6.7)
- Type of problem: thermal hydraulics ;
- Discretizations: VDF and VEFPreP1B ;
- Equations: `Navier_Stokes_turbulent` and `convection_diffusion_temperature_turbulent` ;
- Turbulence model: Large Eddy Simulation ;
- Modeling of sub-filter scales: `sous_maille_WALE` (Wall-Adapting Local Eddy-viscosity [5]) ;
- Wall functions: `loi_standard_hydr` (velocity) and `loi_standard_hydr_scalaire` (temperature) ;
- Type of boundary conditions: periodicity in x and z directions, wall for top/low boundaries ;
- Time schemes: `Runge_Kutta_ordre_3` with `facsec = 1` ;
- Convection schemes: `centre` (velocity) and `QUICK` (temperature) for VDF simulations ; `EF_stab` for VEF simulations.

1.3 Test cases

- T0Q_VDF/Cas.data :
- T0Q_VEF/Cas.data : */*jdd en annexe*/*
- T0Q_VEF_Pironneau/Cas.data : */*jdd en annexe*/*
- T0Q_VEF_Pironneau_maillage_decale/Cas.data :

3 TESTS DESCRIPTION

1.4 References :

1.4 References :

- [1] J. O. Hinze, *Turbulence*, McGraw-Hill, New York, 1959.
- [2] B. A. Kader, *Temperature and concentration profiles in fully turbulent boundary layers*, International Journal of Heat and Mass Transfer, 24(9):1541-1544, 1981.
- [3] R. D. Moser, J. Kim and N. N. Mansour, <http://turbulence.ices.utexas.edu/data/MKM/chan180>.
- [4] H. Kawamura, <http://murasun.me.noda.tus.ac.jp/turbulence>.
- [5] F. Nicoud and F. Ducros, *Subgrid-scale stress modelling based on the square of the velocity gradient tensor*, Flow, Turbulence and Combustion, 62:183-200, 1999.
- [6] B. Mohammadi, O. Pironneau, P. G. Ciarlet and J.-L. Lions, *Analysis of the K-Epsilon turbulence model*, John Wiley & Sons - Masson, 1994.
- [7] R. B. Dean, *Reynolds Number Dependence of Skin Friction and Other Bulk Flow Variables in Two-Dimensional Rectangular Duct Flow*, Journal of Fluids Engineering, 100:215-223, 1978.
- [8] P.-E. Angeli, *Simulation numérique de la turbulence dans Trio-U : nouvelle méthode de prise en compte des lois de paroi via une condition aux limites de symétrie et un terme source de type Robin*, CEA Technical note, DEN-DANS-DM2S-STMF-LMSF-NT-13-011A, 2013.

2 Theoretical features

See the technical note [8] for detailed explanations.

- *Standard wall treatment approach in Trio-U:*

The wall laws for velocity and temperature used in the code can be written as $u_\tau = f(u_\tau)$ and $T_\tau = f(T_\tau)$. At each time step, a fixed point resolution of these equations gives respectively the values of u_τ and T_τ . Hence the velocity gradient and the temperature gradient at the wall are deduced. These gradients are used respectively in the momentum and energy balances for wall elements, where they replace the calculated gradients which are wrong due to the low resolution of the grid.

- *New approach validated here:*

The methodology is briefly described in [6] and is here referred to as the *Pironneau* approach. The idea is that the fixed walls are replaced by symmetries, so that the velocity and temperature gradients appearing in the momentum and energy balances are zero. Formally, the gradients calculated from the wall laws are added then to these balances, instead of replacing wrong values like in the standard approach. Let y_1 be the distance from the wall of the first calculation point. The wall law results actually in a Robin boundary condition under the form $\frac{\partial u}{\partial y}\Big|_w = f[u(y_1)]$, which is implemented by a source term in the code. The same methodology is applied for temperature. More generally, the Robin condition can be evaluated at a distance δ from the wall: $\frac{\partial u}{\partial n}(\delta) = f[u(\delta)]$. Thus the user has to choose the value of δ , such that δ is located in the logarithmic layer. Here we choose $\delta = y_1$.

3 Tests description

The present calculations are L.E.S. of turbulence and heat transport in a 3D bi-periodic channel flow with $Re_\tau = 180$ and $Pr = 0.025$. Temperature is treated like a passive scalar. Uniformly zero temperature at

3 TESTS DESCRIPTION

3.1 VDF mesh

both walls and uniform volumetric heat source $Q = 1 \text{ W} \cdot \text{m}^{-3}$ on the whole channel are applied. The dimensions of the channel are: $L_x = 6.4 \text{ m}$, $L_y = 2h = 2 \text{ m}$, $L_z = 3.2 \text{ m}$.

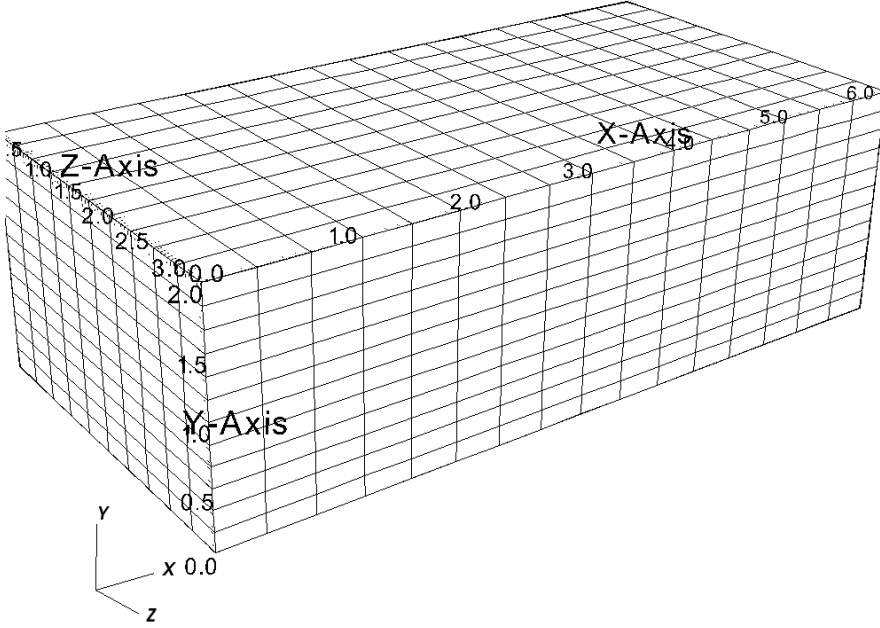
Two simulations using the standard methodology are first carried out (one using a VDF discretization and the other using a VEF discretization). Then two others simulations (in VEF) using the new approach are done. In the second one, the upper and lower walls of the channel are displaced from the distance δ toward the centerline of the channel, and a new mesh similar to the previous one is built.

3.1 VDF mesh

Number of nodes in each direction: $N_x = 17$, $N_y = 13$, $N_z = 11$.

Total number of elements: $(N_x-1)(N_y-1)(N_z-1) = 1920$.

$$dx^+ = \frac{L_x}{N_x - 1} \frac{\text{Re}_\tau}{h} = 72 ; y^+ = \frac{L_y}{2(N_y - 1)} \frac{\text{Re}_\tau}{h} = 15 ; dz^+ = \frac{L_z}{N_z - 1} \frac{\text{Re}_\tau}{h} = 58.$$



3.2 VEF mesh (entire channel)

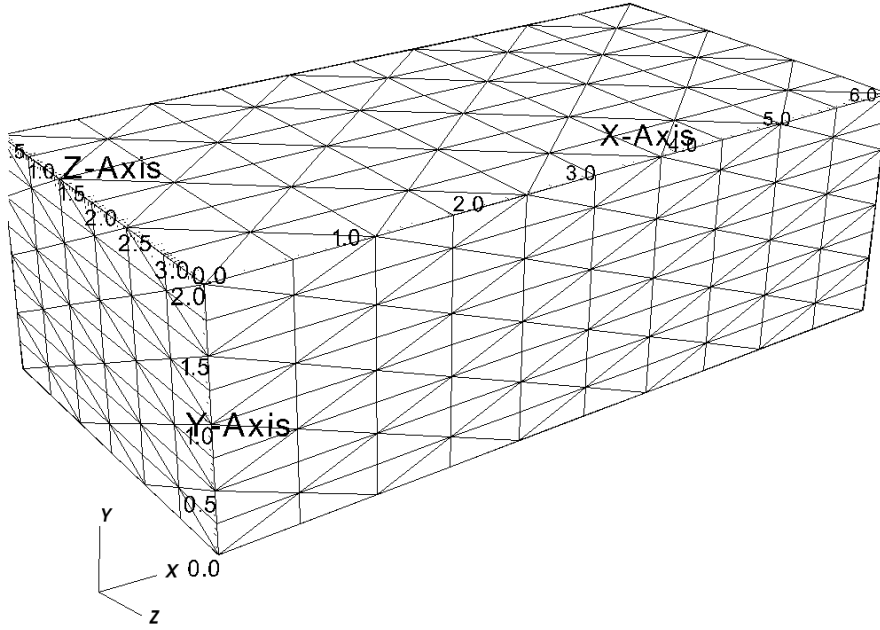
Number of nodes in each direction: $N_x = 6$, $N_y = 5$, $N_z = 4$.

Total number of elements with `tetraedriser_homogene_fin`: $48(N_x-1)(N_y-1)(N_z-1) = 2880$.

$$dx^+ = \frac{L_x}{3(N_x - 1)} \frac{\text{Re}_\tau}{h} = 77 ; y^+ = \frac{L_y}{6(N_y - 1)} \frac{\text{Re}_\tau}{h} = 15 ; dz^+ = \frac{L_z}{3(N_z - 1)} \frac{\text{Re}_\tau}{h} = 64.$$

3 TESTS DESCRIPTION

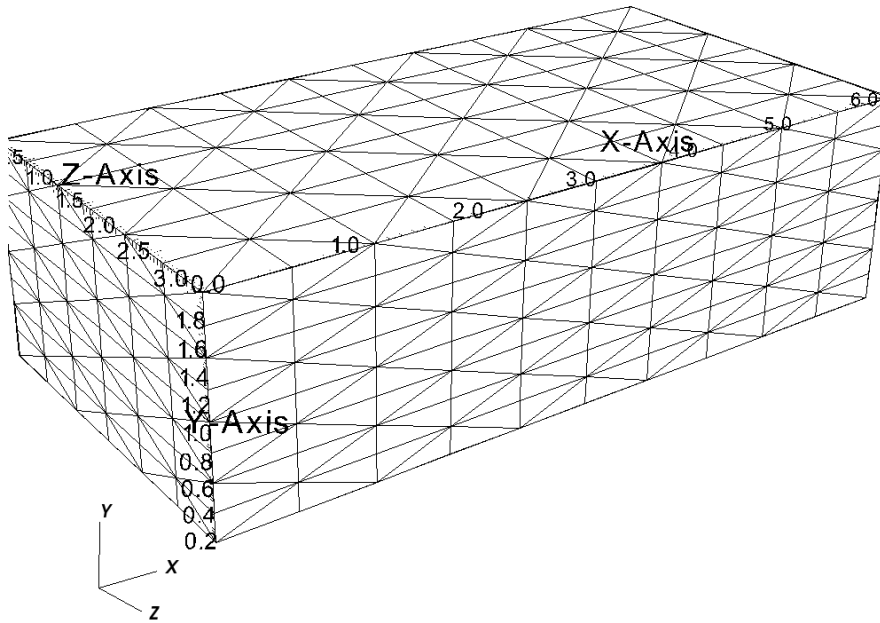
3.3 VEF mesh (truncated channel)



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Number of nodes in each direction: $N_x = 6$, $N_y = 5$, $N_z = 4$.

Total number of elements with `tetraedriser_homogene_fin`: $48(N_x-1)(N_y-1)(N_z-1) = 2880$.



3 TESTS DESCRIPTION

3.4 Physical properties and dimensionless numbers

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Physical properties:

- $\rho = 0.011928 \text{ kg} \cdot \text{m}^{-3}$
- $\mu = 2.84\text{e-}5 \text{ kg} \cdot \text{m}^{-1} \cdot \text{s}^{-1}$
- $\lambda = 5.899248 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$
- $C_p = 5193 \text{ J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$

Dimensionless numbers:

- $\text{Re}_b = \frac{\rho U_b h}{\mu} = 2770$, where $U_b = \frac{2}{3}U_c$ and $U_c = 9.8945 \text{ m} \cdot \text{s}^{-1}$ (*cf.* initial condition)
- $\text{Pr} = \frac{\mu C_p}{\lambda} = 0.025$
- $\text{Pe} = \text{Re}_b \times \text{Pr} = 1967$
- $\text{Re}_\tau = 0.175 \text{Re}_b^{7/8} = 180$ (Dean's correlation [7])

3.5 Initial and boundary conditions

Initial conditions:

- Velocity: parabolic mean profile for x-component
`Champ_init_canal_sinal 3 { Ucent 24.293 h 1 ampli_sin 0 omega 1 ampli_bruit 0.5 }`
- Temperature: $T = 0$

Hydraulic boundary conditions:

- Inlet/outlet (x-direction): periodicity
- Front/back boundaries (z-direction): periodicity
- Top/low boundaries:
 - `paroi_fixe` for the Trio_U “standard” approach
 - `paroi_decalee_Robin { _delta_value_ }` for the “Pironneau” approach^(*)

Fluid thermal boundary conditions:

- Inlet/outlet (x-direction): periodicity
- Front/back boundaries (z-direction): periodicity
- Top/low boundaries:
 - uniform temperature $T_0 = 0$ for the Trio_U “standard” approach
 - `paroi_decalee_Robin { _delta_value_ }` for the “Pironneau” approach^(*)

Source terms in the “Pironneau” approach:

- Navier-Stokes:
`source_Robin 2 Haut Bas`
- Convection diffusion:
`source_Robin_scalaire 2 Haut 0 Bas 0`

^(*) where `_delta_value_` is set according the recommandation of section 2 ($\delta = y_1$).

3.6 Numerical schemes

VDF discretization:

- Time scheme: third order Runge-Kutta method with `facsec=1`
- Convection: centered scheme for velocity and QUICK scheme for temperature

VEF discretization:

- Time scheme: third order Runge-Kutta method with `facsec=1`
- Convection schemes: `EF_stab` ($\alpha = 0.2$ for velocity and $\alpha = 1$ for temperature)

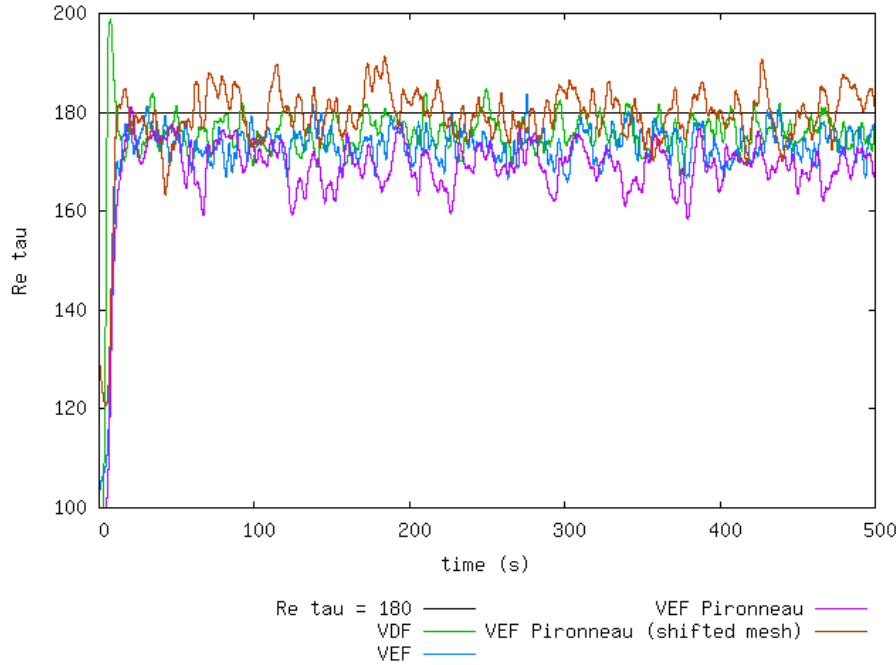
4 Friction velocity and friction Reynolds number calculated

4.1 Friction velocity u_τ

| | time (s) | u_τ (m · s ⁻¹) | Relative error (%) |
|------------------------------|----------|---------------------------------|--------------------|
| Theoretical (*) | - | 0.42857 | - |
| VDF | 1000 | 0.41879 | 2.28 |
| VEF | 1000 | 0.41341 | 3.54 |
| VEF Pironneau | 1000 | 0.4027 | 6.04 |
| VEF Pironneau (shifted mesh) | 1000 | 0.42805 | 0.12 |

(*) according to Dean's correlation [7]: $\text{Re}_\tau = 0.175\text{Re}_b^{7/8}$, and using $\text{Re}_\tau = \frac{\rho u_\tau h}{\mu}$.

4.2 Friction Reynolds Re_τ



5 Detailed results

In the next two sections, different time- and space-averaged profiles are plotted across the channel half-height: the components of velocity (u and w), the temperature (T), the components of the subscale stress tensors (T_{ij} and Q_i), the root mean square of temperature (T_{rms}), as well as the adimensional equivalent quantities.

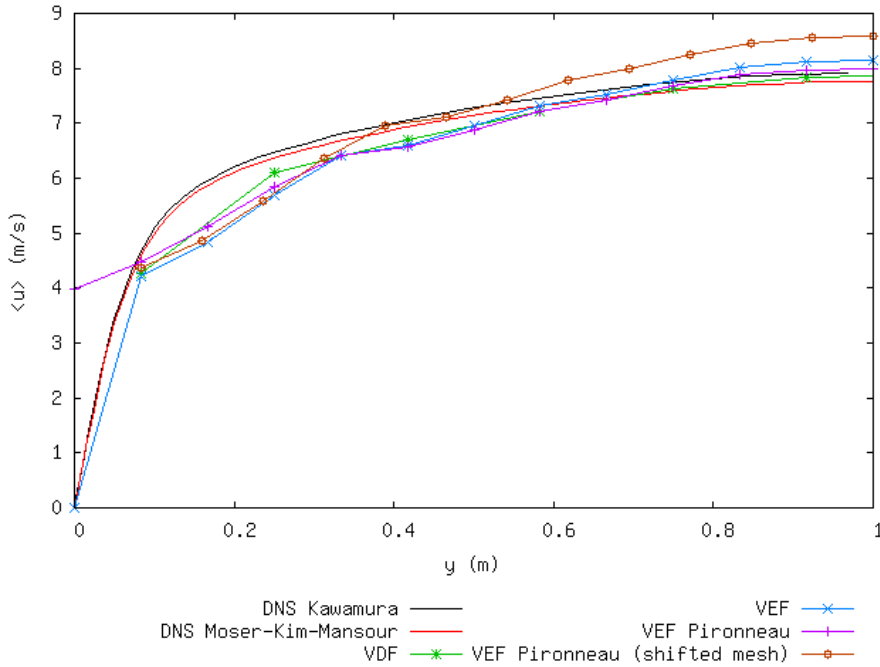
We compare the non-dimensional mean velocity profiles with the Reichardt's law [1]:

$$U^+ = \frac{1}{\kappa} \ln(1 + \kappa y^+) + A \left(1 - e^{-y^+/11} - \frac{y^+}{11} e^{-y^+/3} \right), \text{ where } \kappa = 0.415 \text{ and } A = 7.44.$$

We compare the non-dimensional mean temperature profiles with the Kader's law [2]:

$$T^+ = \text{Pr} y^+ e^{-\Gamma} + [2.12 \ln(1 + y^+) + \beta] e^{-1/\Gamma}, \text{ where } \beta = \left(3.85 \text{Pr}^{1/3} - 1.3 \right)^2 + 2.12 \ln(\text{Pr}) \text{ and } \Gamma = \frac{0.01(y^+ \text{Pr})^4}{1 + 5y^+ \text{Pr}^3}.$$

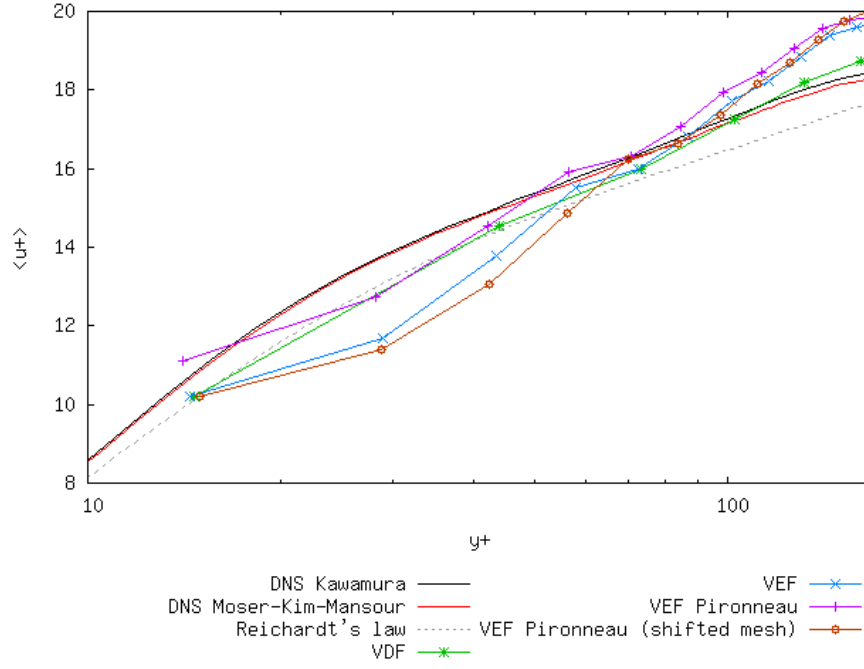
5.1 Mean x -velocity profile $\langle u \rangle$



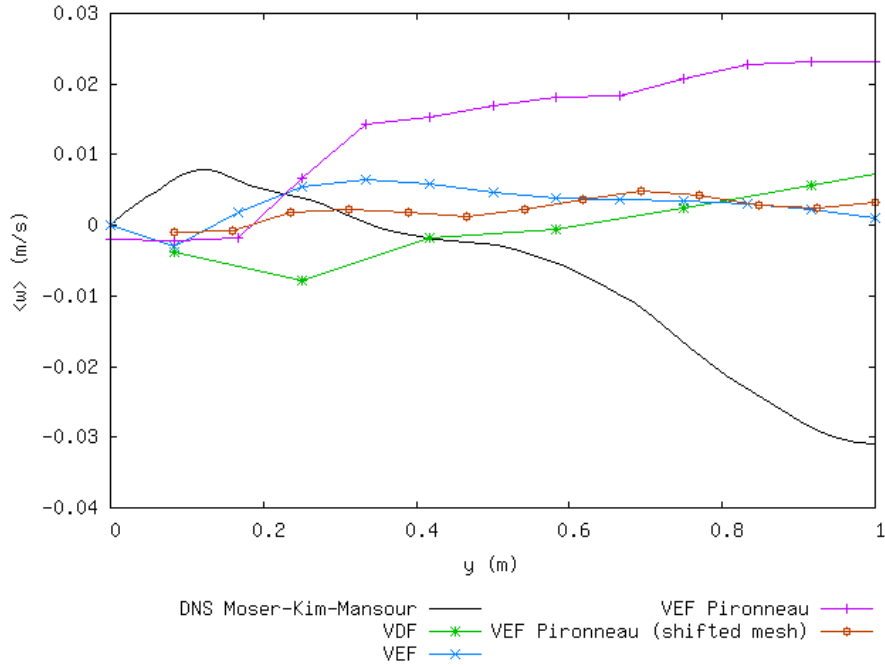
5 DETAILED RESULTS

5.2 Non-dimensional mean x -velocity profile $\langle u^+ \rangle$

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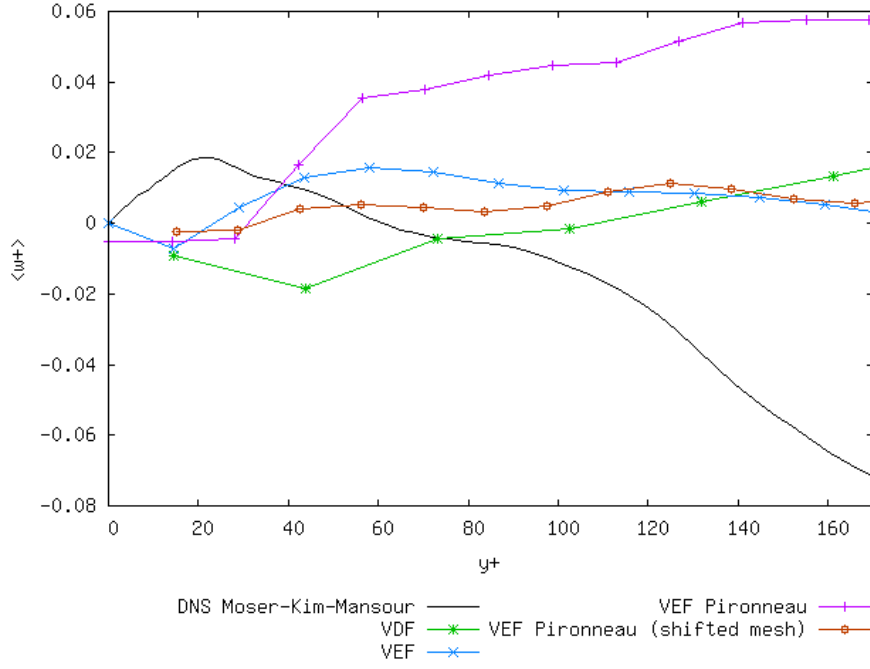
5.3 Mean z -velocity profile $\langle w \rangle$



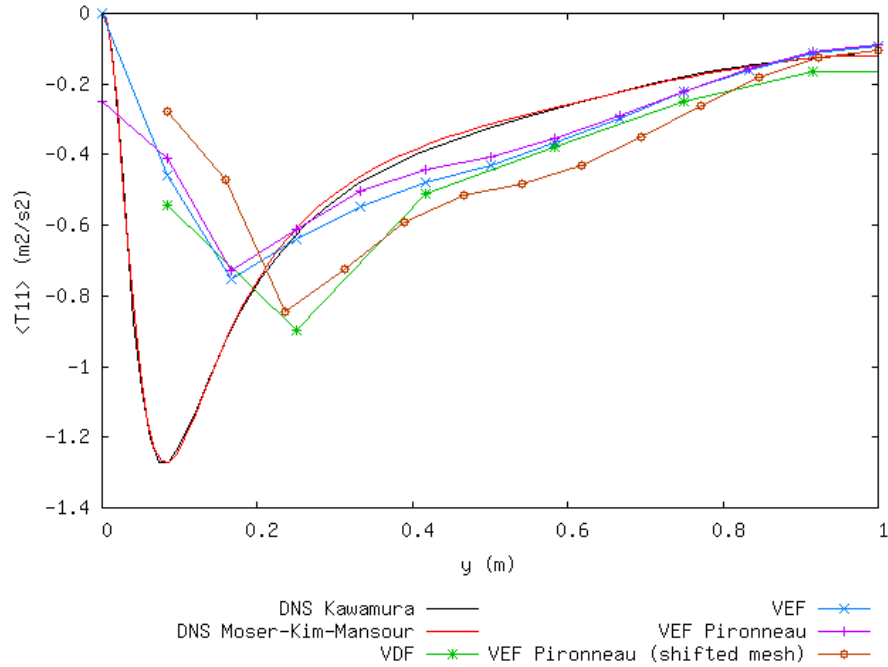
5 DETAILED RESULTS

5.4 Non-dimensional mean z -velocity profile $\langle w^+ \rangle$

5.4 Non-dimensional mean z -velocity profile $\langle w^+ \rangle$



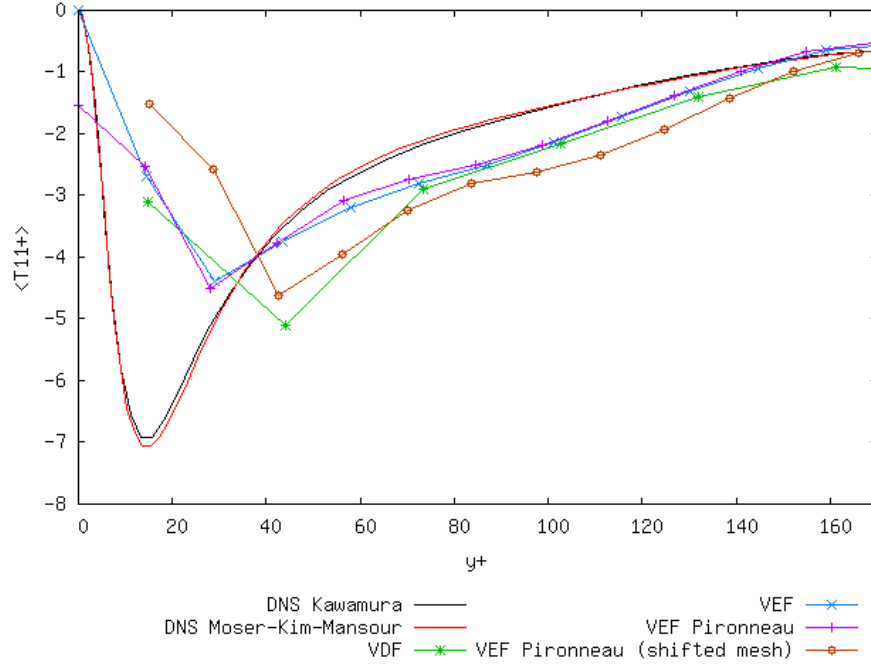
5.5 Mean xx -component of subgrid scale tensor $\langle T_{11} \rangle$



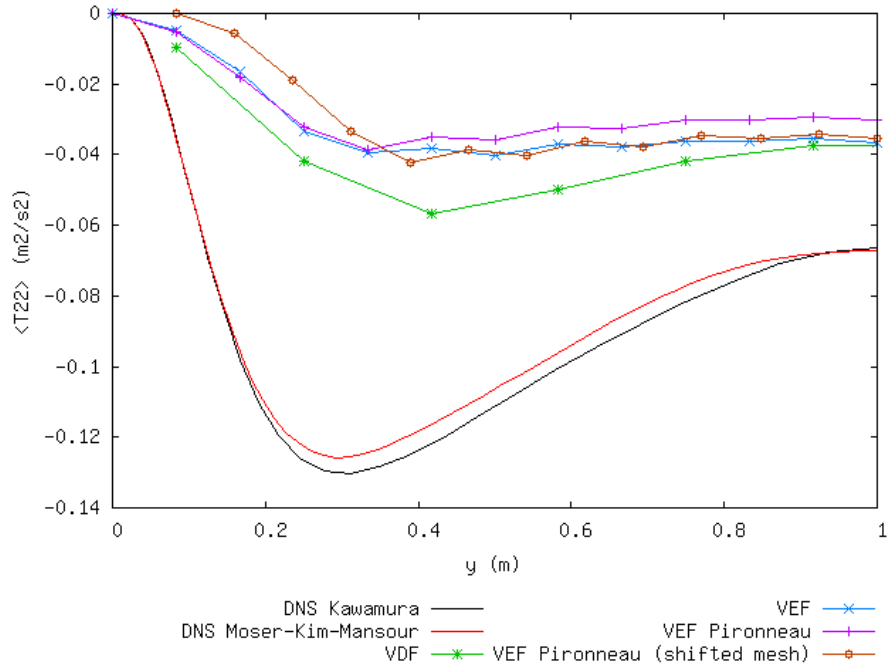
5 DETAILED RESULTS

5.6 Non-dimensional mean xx -component of subgrid scale tensor $\langle T_{11}^+ \rangle$

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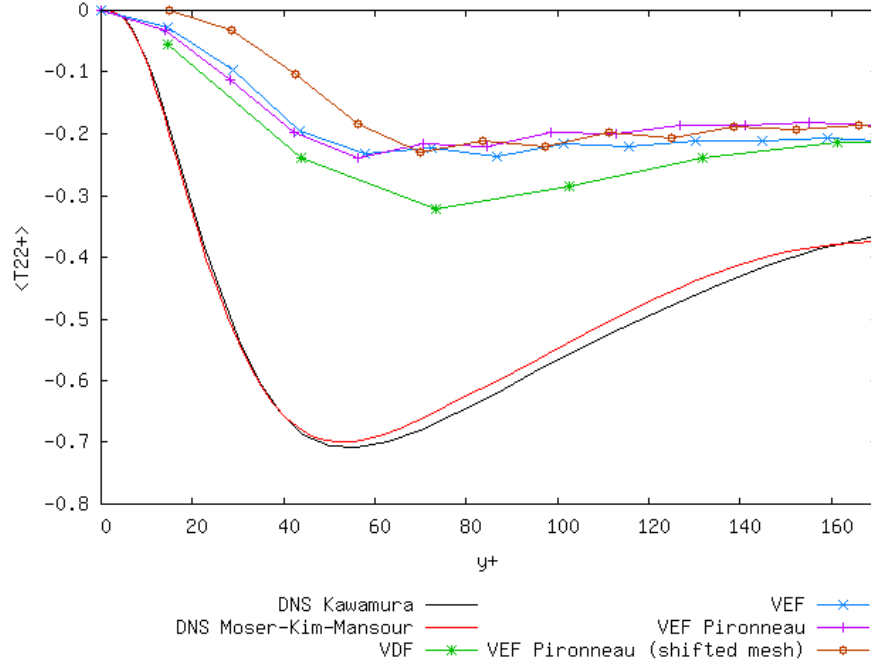
5.7 Mean yy -component of subgrid scale tensor $\langle T_{22} \rangle$



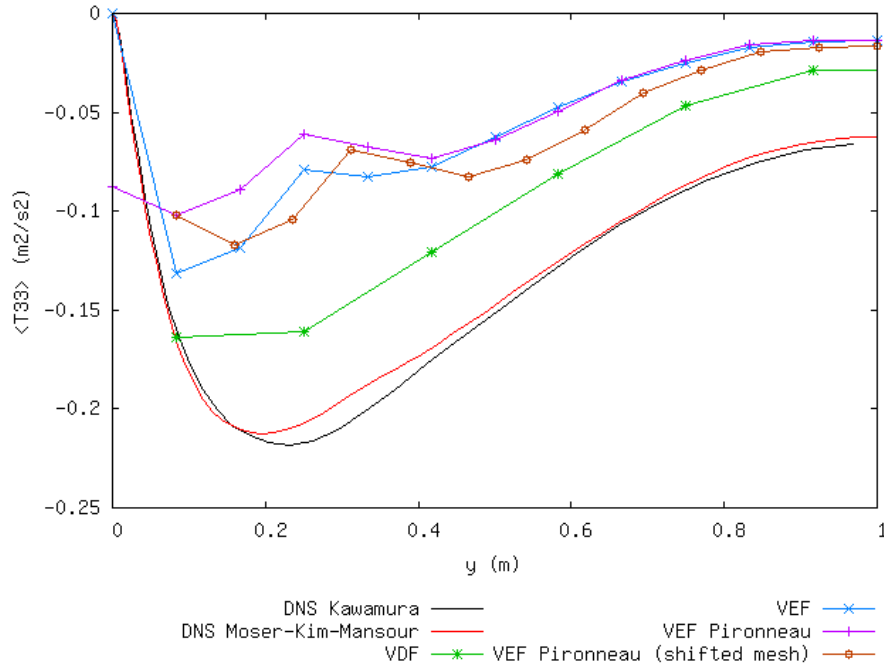
5 DETAILED RESULTS

5.8 Non-dimensional mean yy -component of subgrid scale tensor $\langle T_{22}^+ \rangle$

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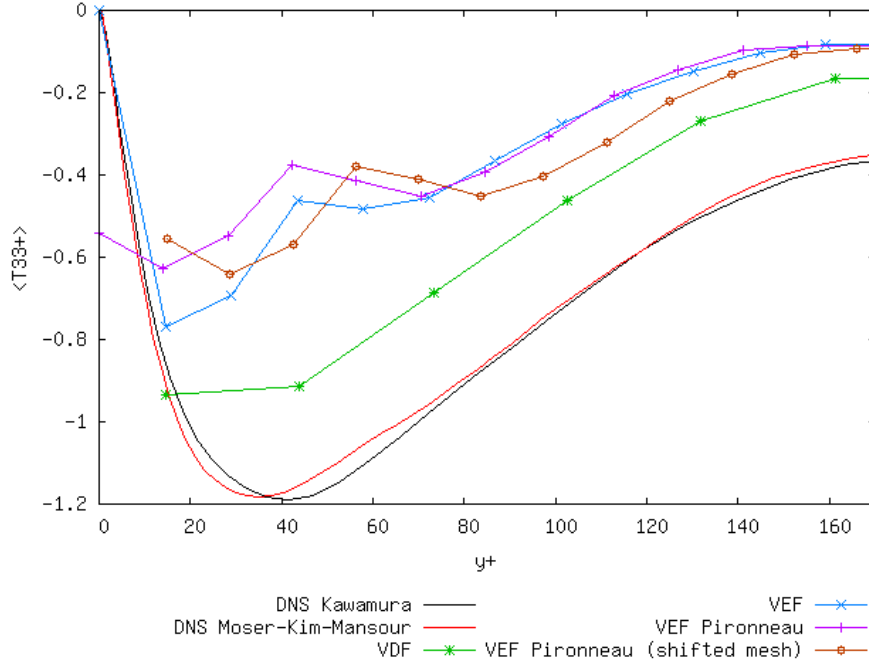
5.9 Mean zz -component of subgrid scale tensor $\langle T_{33} \rangle$



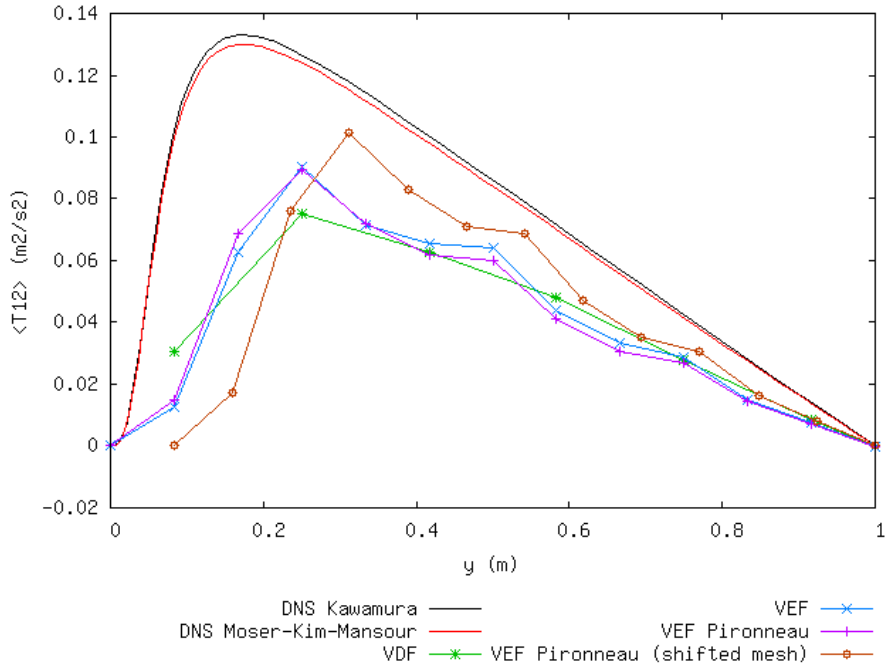
5 DETAILED RESULTS

5.10 Non-dimensional mean zz -component of subgrid scale tensor $\langle T_{33}^+ \rangle$

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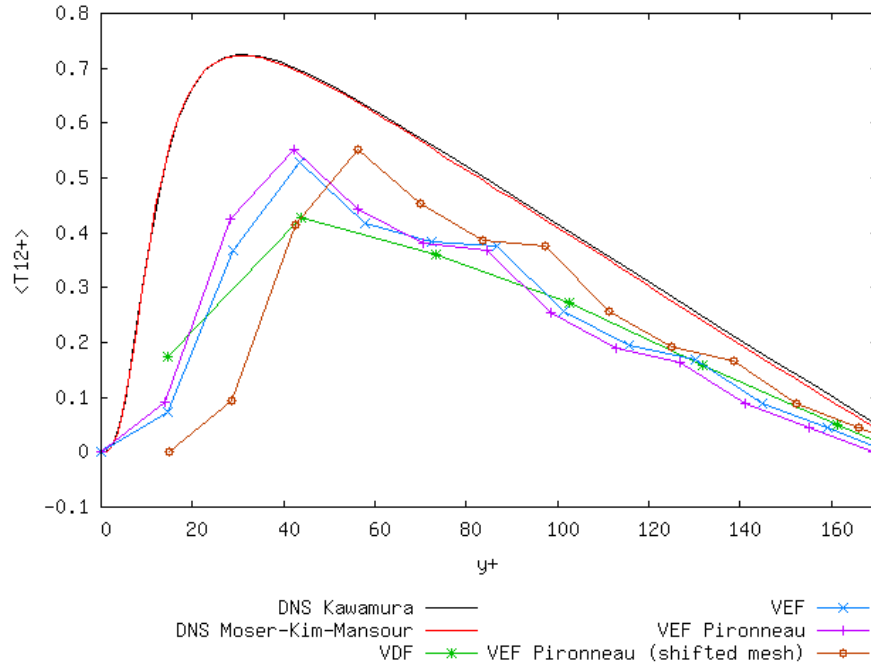
5.11 Mean xy -component of subgrid scale tensor $\langle T_{12} \rangle$



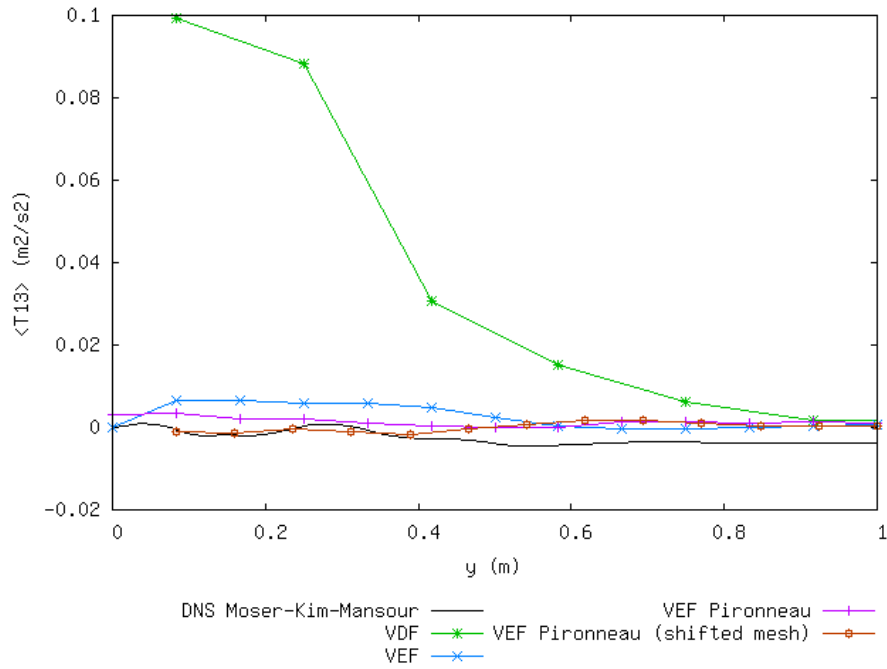
5 DETAILED RESULTS

5.12 Non-dimensional mean xy -component of subgrid scale tensor $\langle T_{12}^+ \rangle$

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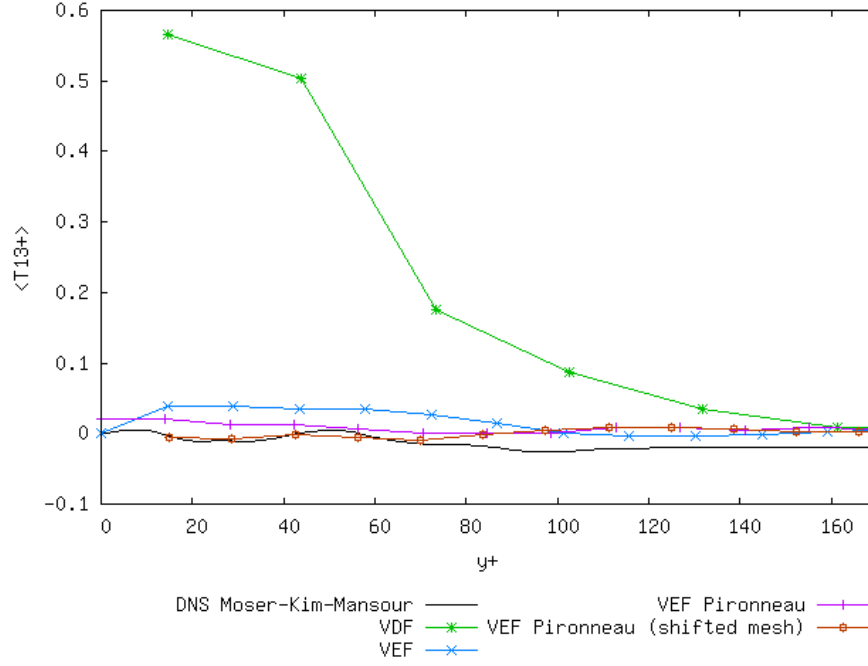
5.13 Mean xz -component of subgrid scale tensor $\langle T_{13} \rangle$



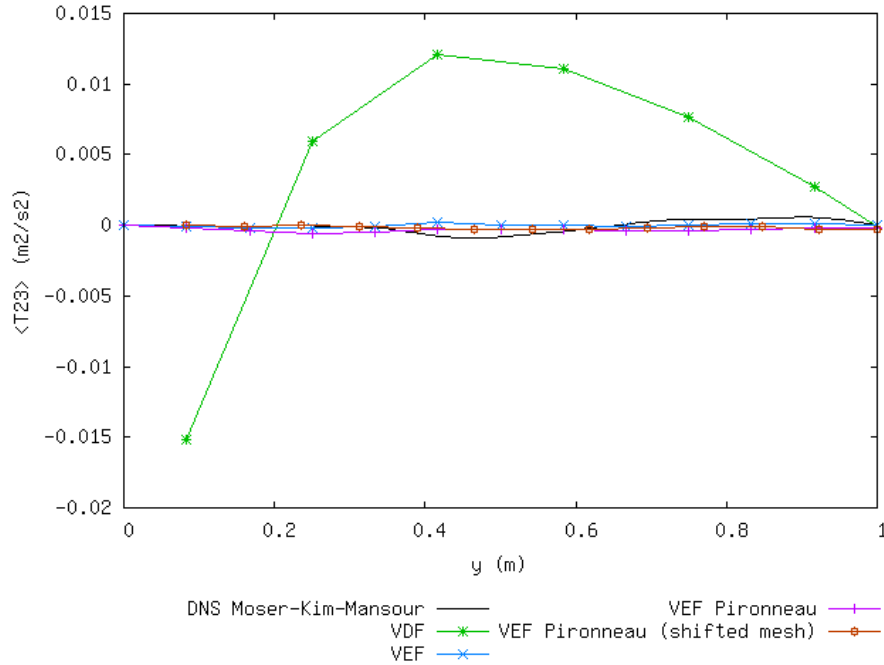
5 DETAILED RESULTS

5.14 Non-dimensional mean xz -component of subgrid scale tensor $\langle T_{13}^+ \rangle$

5.14 Non-dimensional mean xz -component of subgrid scale tensor $\langle T_{13}^+ \rangle$



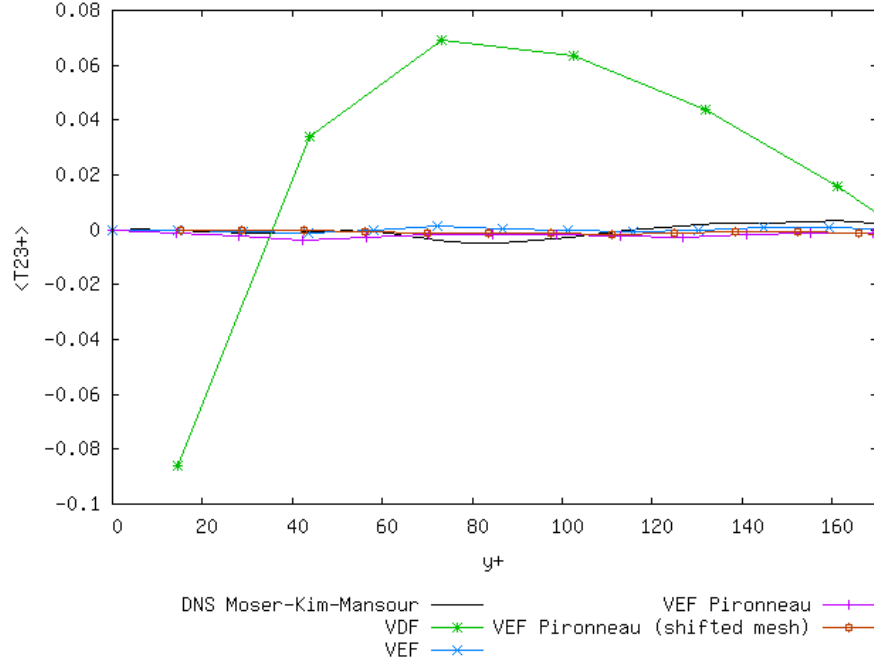
5.15 Mean yz -component of subgrid scale tensor $\langle T_{23} \rangle$



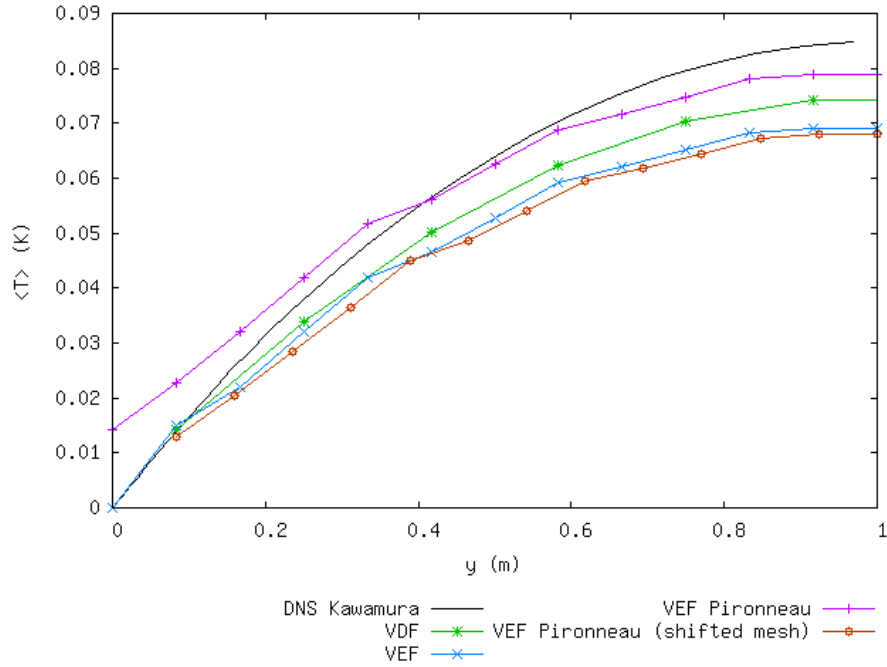
5 DETAILED RESULTS

5.16 Non-dimensional mean yz -component of subgrid scale tensor $\langle T_{23}^+ \rangle$

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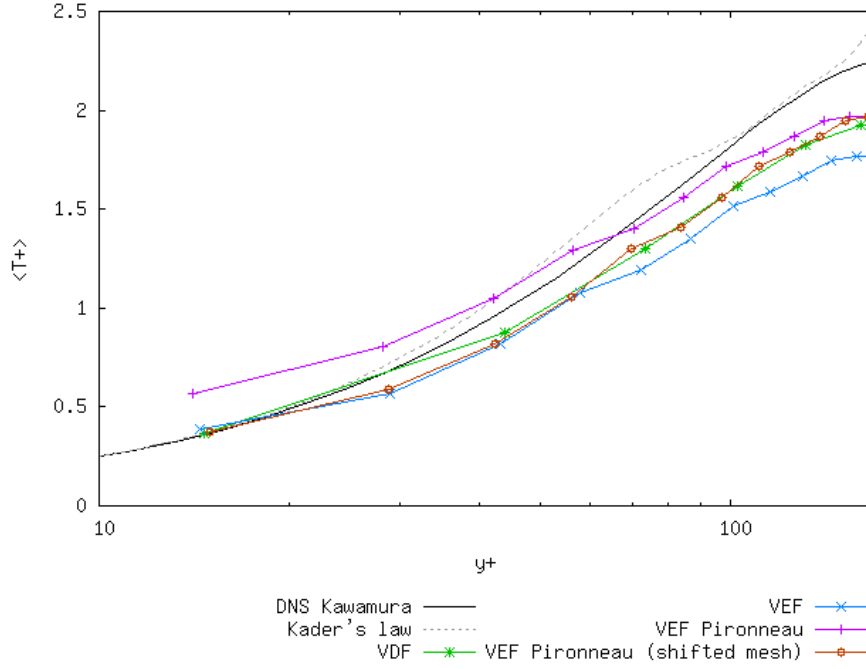
5.17 Mean temperature profile $\langle T \rangle$



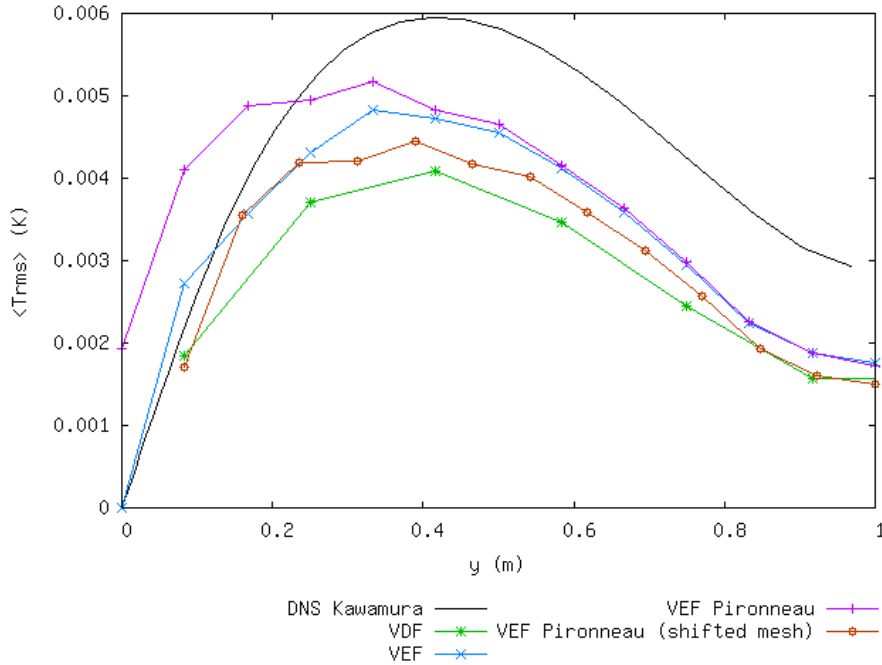
5 DETAILED RESULTS

5.18 Non-dimensional mean temperature profile $\langle T^+ \rangle$

5.18 Non-dimensional mean temperature profile $\langle T^+ \rangle$



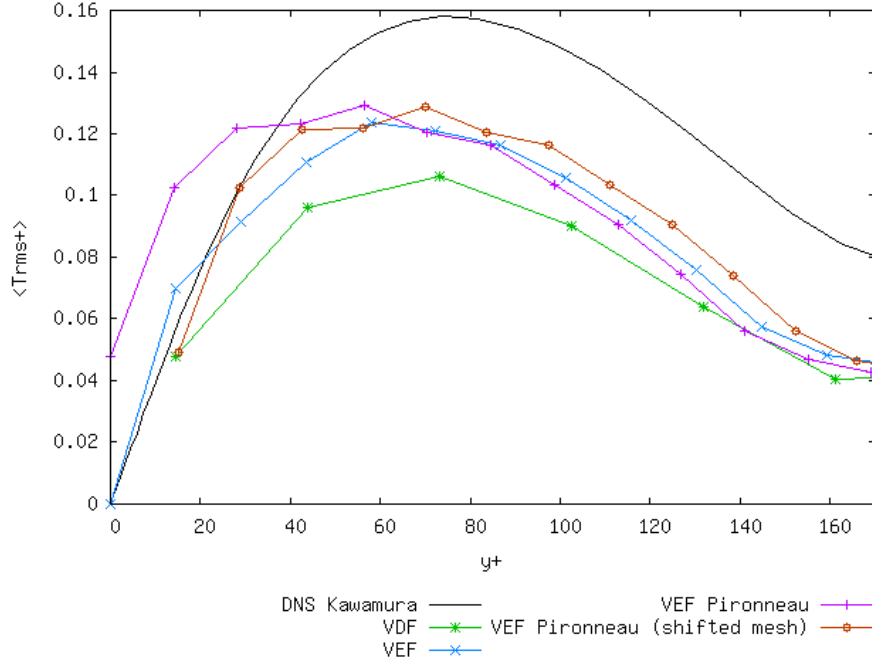
5.19 Quadratic mean of temperature $\langle T_{rms} \rangle$



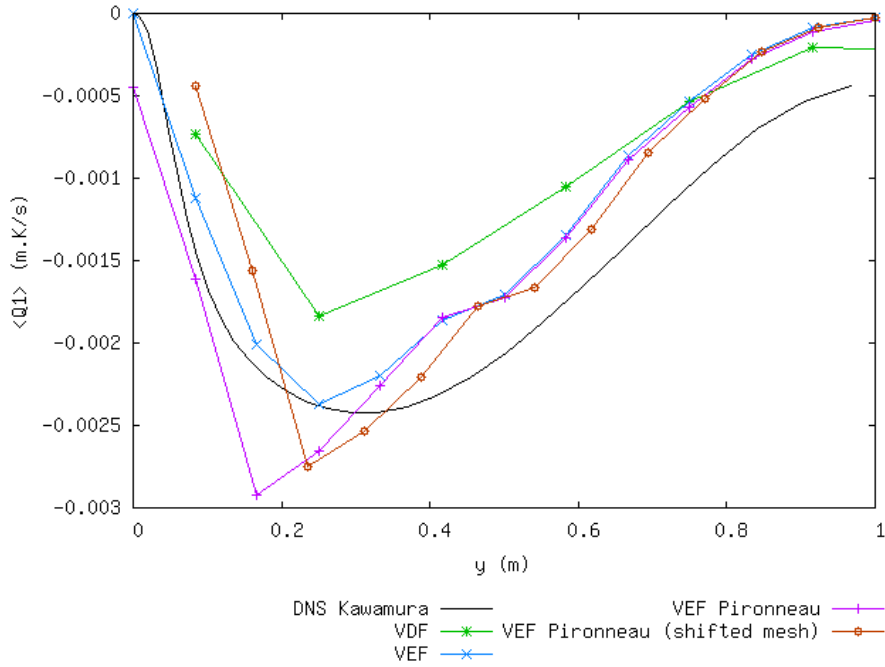
5 DETAILED RESULTS

5.20 Non-dimensional quadratic mean of temperature $\langle T_{rms}^+ \rangle$

5.20 Non-dimensional quadratic mean of temperature $\langle T_{rms}^+ \rangle$



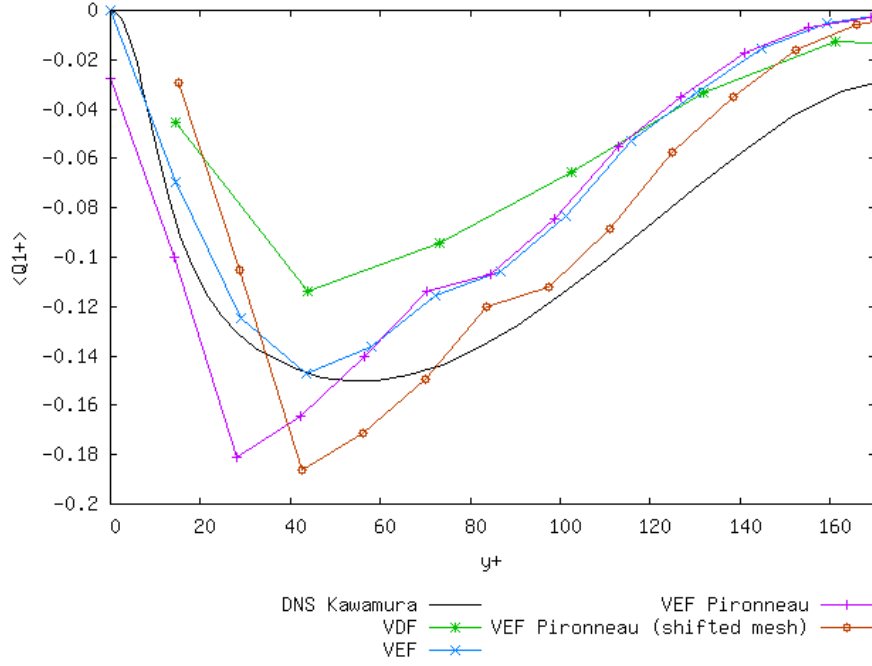
5.21 Streamwise turbulent heat flux $\langle Q_1 \rangle$



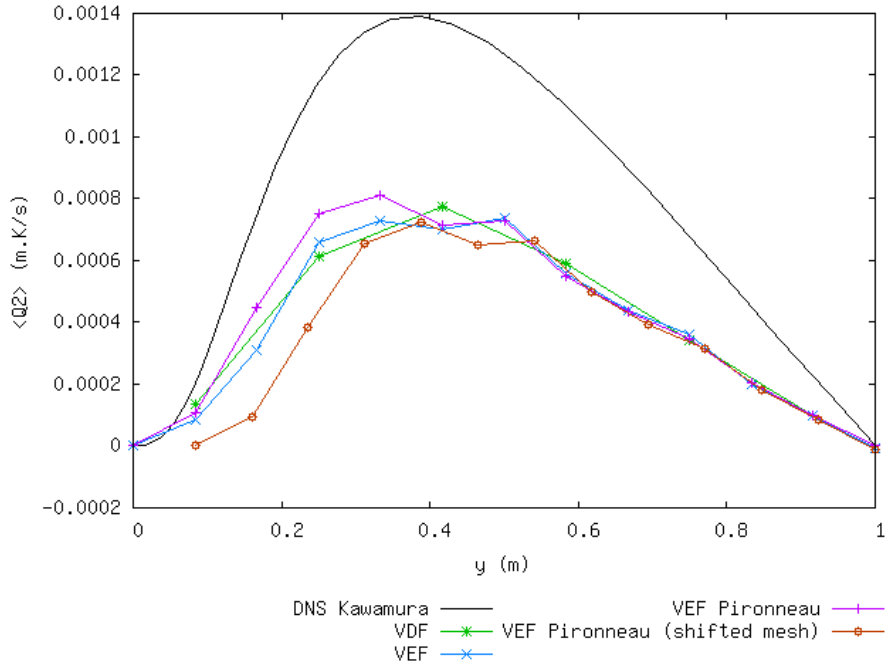
5 DETAILED RESULTS

5.22 Non-dimensional streamwise turbulent heat flux $\langle Q_1^+ \rangle$

5.22 Non-dimensional streamwise turbulent heat flux $\langle Q_1^+ \rangle$



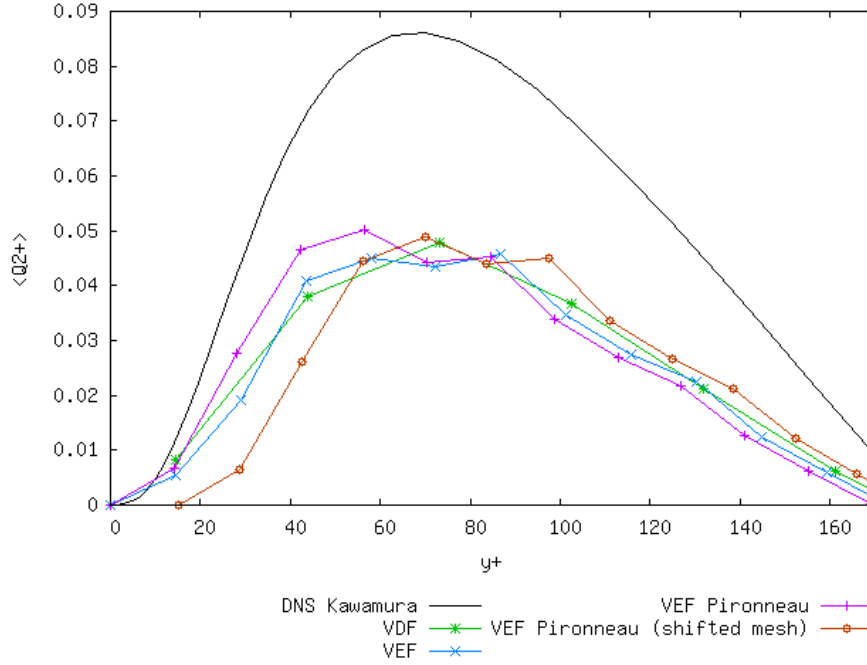
5.23 Wall-normal turbulent heat flux $\langle Q_2 \rangle$



6 ANALYSIS OF THE RESULTS

5.24 Non-dimensional wall-normal turbulent heat flux $\langle Q_2^+ \rangle$

5.24 Non-dimensional wall-normal turbulent heat flux $\langle Q_2^+ \rangle$



6 Analysis of the results

- On the whole, all the simulations provide an analogous and good quality of results. None of them is found to be much better than the others.
- Friction velocity: the best friction velocity in the comparison with the theoretical value is obtained with the VEF simulation and the truncated channel, which yields a very accurate result (0.2% relative error). The other Pironneau simulation gives an almost as good relative error as the standard approach (3.36% vs. 5.31%)
- Velocity: for the non-dimensional mean x -velocity profile $\langle u \rangle$, the first calculation points for all simulations are located on the Reichardt's law as expected, except for the VEF Pironneau. In this case, the real first point is not represented on the logarithmic graph because it corresponds to $y = 0$. Thus the first represented point of the VEF Pironneau profile (in fact the second calculated point) has no reason to satisfy the Reichardt's law.
- Temperature: the analysis is the same as for velocity.
- Subscale stress tensor components $\langle T_{ij} \rangle$: the tendencies are in correct agreement with the DNS results of Kawamura and Moser-Kim-Mansour, except the VDF simulation which gives bad results on particular components.
- Subscale stress tensor components $\langle Q_i \rangle$: all the simulations are in relatively good agreement with the DNS results of Kawamura.

7 Computer performance

| | host | system | Total CPU Time | CPU time/step | number of cell |
|---------------------------------------|--------|--------|----------------|---------------|----------------|
| T0Q_VDF/Cas | vannes | Linux | 551.411 | 0.0133056 | 1920 |
| T0Q_VEF/Cas | vannes | Linux | 14942.3 | 0.0630126 | 2880 |
| T0Q_VEF_Pironneau/Cas | vannes | Linux | 13837.2 | 0.0596934 | 2880 |
| T0Q_VEF_Pironneau_maillage_decale/Cas | vannes | Linux | 19319.7 | 0.0730521 | 2880 |
| Total | | | 48650.6 | | |

8 Data Files

8.1 Cas

```

Dimension 3
Pb_Thermohydraulique_Turbulent pb
Domaine dom
Mailler dom
{
  Pave Cavite
  {
    Origine 0 0 0
    Nombre_de_Noeuds 6 5 4
    Longueurs 6.4 2 3.2
    Facteurs 1 1 1
  }
  {
    Bord PerioX X = 0    0 <= Y <= 2 0 <= Z <= 3.2
    Bord PerioX X = 6.4  0 <= Y <= 2 0 <= Z <= 3.2
    Bord PerioZ Z = 0    0 <= X <= 6.4    0 <= Y <= 2
    Bord PerioZ Z = 3.2  0 <= X <= 6.4    0 <= Y <= 2
    Bord Bas   Y = 0 0 <= X <= 6.4    0 <= Z <= 3.2
    Bord Haut Y = 2 0 <= X <= 6.4    0 <= Z <= 3.2
  }
}
Tetraedriser_homogene_fin dom
Reordonner_faces_periodiques dom PerioX
Reordonner_faces_periodiques dom PerioZ
VEFFPreP1b dis
Runge_Kutta_ordre_3 sch_RK3
Lire sch_RK3
{
  tinit 0
  tmax 1000
  dt_start dt_calc
  dt_min 1e-7
  dt_max 1
  dt_impr 5
  dt_sauv 500
  seuil_statio 1e-15
  facsec 1
  no_check_disk_space
  periode_sauvegarde_securite_en_heures 11
}
Fluide_incompressible air
Lire air
{
  mu champ_uniforme 1 2.84e-5
  rho champ_uniforme 1 0.011928
  lambda champ_uniforme 1 5.899248
  Cp champ_uniforme 1 5193
  beta_th champ_uniforme 1 1.9954e-3
}
Champ_uniforme gravite

```

8 DATA FILES

8.1 Cas

```
Lire gravite 3 0 0 0
Associer air gravite
Associer pb dom
Associer pb sch_RK3
Associer pb air
Discretiser pb dis
Lire pb
{
  Navier_Stokes_turbulent
  {
    Solveur_pression  petsc Cholesky { }
    Convection        { EF_stab { volumes_etendus alpha 0.2 } }
    Diffusion          { }
    Conditions_initiales { vitesse champ_init_canal_sinal 3 { Ucent 9.8945 h 1 ampli_sin 0 om
    Conditions_limites {
      PerioX  periodique
      PerioZ  periodique
      Haut    paroi_fixe
      Bas     paroi_fixe
    }
    Modele_turbulence sous_maille_WALE
    {
      turbulence_paroι loi_standard_hydr
      dt_impr_ustar 20
    }
    Traitement_particulier {
      canal {
        dt_impr_moy_spat 200
        dt_impr_moy_temp 200
        debut_stat 600
      }
    }
    Sources { canal_perio { direction_ecoulement 0 } }
  }
  Convection_diffusion_temperature_turbulent
  {
    Convection        { EF_stab { volumes_etendus alpha 1 } }
    Diffusion          { }
    Conditions_initiales { temperature champ_fonc_xyz dom 1 0 }
    Conditions_limites {
      PerioX  periodique
      PerioZ  periodique
      Haut    paroi_temperature_imposee champ_front_uniforme 1 0
      Bas     paroi_temperature_imposee champ_front_uniforme 1 0
    }
    Modele_turbulence Prandtl
    {
      turbulence_paroι loi_standard_hydr_scalaire
      dt_impr_nusselt 20
    }
    Sources { puissance_thermique champ_uniforme 1 1 }
  }
Postraitement
{
```

8 DATA FILES

8.2 Cas

```
Definition_champs {
    moyenne_vitesse    Moyenne { t_deb 600 t_fin 1000 source refChamp { Pb_champ pb vitesse
    moyenne_temperature Moyenne { t_deb 600 t_fin 1000 source refChamp { Pb_champ pb temperature
    ecart_type_vitesse  Ecart_type { t_deb 600 t_fin 1000 source refChamp { Pb_champ pb vitesse
    ecart_type_temperature Ecart_type { t_deb 600 t_fin 1000 source refChamp { Pb_champ pb temperature
    min_temperature     Reduction_0D { methode min source refChamp { Pb_champ pb temperature
    max_temperature     Reduction_0D { methode max source refChamp { Pb_champ pb temperature
}
Sondes {
    sonde_vitesse      nodes vitesse      periode 0.5 points 1 3.2 1 1.6
    sonde_temperature  nodes temperature  periode 0.5 points 1 3.2 1 1.6
    sonde_moyenne_vitesse nodes moyenne_vitesse periode 0.5 points 1 3.2 1 1.6
    sonde_moyenne_temperature nodes moyenne_temperature periode 0.5 points 1 3.2 1 1.6
    sonde_ecart_type_vitesse nodes ecart_type_vitesse periode 0.5 points 1 3.2 1 1.6
    sonde_ecart_type_temperature nodes ecart_type_temperature periode 0.5 points 1 3.2 1 1.6
    coupe_vitesse      nodes vitesse      periode 5 segment 9 0.213333 0 0.177778 0.213333
    coupe_temperature  nodes temperature  periode 5 segment 9 0.213333 0 0.177778 0.213333
    coupe_moyenne_vitesse nodes moyenne_vitesse periode 5 segment 9 0.213333 0 0.177778 0.213333
    coupe_moyenne_temperature nodes moyenne_temperature periode 5 segment 9 0.213333 0 0.177778 0.213333
    coupe_ecart_type_vitesse nodes ecart_type_vitesse periode 5 segment 9 0.213333 0 0.177778 0.213333
    coupe_ecart_type_temperature nodes ecart_type_temperature periode 5 segment 9 0.213333 0 0.177778 0.213333
}
Format lata_v2
Champs dt_post 200 {
    vitesse som
    temperature som
    min_temperature som
    max_temperature som
}
Statistiques dt_post 200
{
    t_deb 600 t_fin 1000
    moyenne vitesse
    moyenne temperature
    ecart_type vitesse
    ecart_type temperature
}
}
sauvegarde formatte pb.sauv
}
Resoudre pb
Fin
```

8.2 Cas

Dimension 3

Pb_Thermohydraulique_Turbulent pb

Domaine dom

Mailler dom

{

 Pave Cavite

 {

 Origine 0 0 0

 Nombre_de_Noeuds 6 5 4

8 DATA FILES

8.2 Cas

```
Longueurs 6.4 2 3.2
Facteurs 1 1 1
}
{
  Bord PerioX X = 0    0 <= Y <= 2 0 <= Z <= 3.2
  Bord PerioX X = 6.4  0 <= Y <= 2 0 <= Z <= 3.2
  Bord PerioZ Z = 0    0 <= X <= 6.4    0 <= Y <= 2
  Bord PerioZ Z = 3.2  0 <= X <= 6.4    0 <= Y <= 2
  Bord Bas   Y = 0 0 <= X <= 6.4    0 <= Z <= 3.2
  Bord Haut  Y = 2 0 <= X <= 6.4    0 <= Z <= 3.2
}
}
Tetraedriser_homogene_fin dom
Reordonner_faces_periodiques dom PerioX
Reordonner_faces_periodiques dom PerioZ
VEFPreP1b dis
Runge_Kutta_ordre_3 sch_RK3
Lire sch_RK3
{
  tinit 0
  tmax 1000
  dt_start dt_calc
  dt_min 1e-7
  dt_max 1
  dt_impr 5
  dt_sauv 500
  seuil_statio 1e-15
  facsec 1
  no_check_disk_space
  periode_sauvegarde_securite_en_heures 11
}
Fluide_incompressible air
Lire air
{
  mu champ_uniforme 1 2.84e-5
  rho champ_uniforme 1 0.011928
  lambda champ_uniforme 1 5.899248
  Cp champ_uniforme 1 5193
  beta_th champ_uniforme 1 1.9954e-3
}
Champ_uniforme gravite
Lire gravite 3 0 0 0
Associer air gravite
Associer pb dom
Associer pb sch_RK3
Associer pb air
Discretiser pb dis
Lire pb
{
  Navier_Stokes_turbulent
  {
    Solveur_pression petsc Cholesky { }
    Convection { EF_stab { volumes_etendus alpha 0.2 } }
    Diffusion { }
  }
}
```


8 DATA FILES

8.2 Cas

```
Conditions_initiales { vitesse champ_init_canal_sinal 3 { Ucent 9.8945 h 1 ampli_sin 0 om
Conditions_limites {
    PerioX periodique
    PerioZ periodique
    Haut paroi_decalee_Robin { delta 0.083333 }
    Bas paroi_decalee_Robin { delta 0.083333 }
}
Modele_turbulence sous_maille_WALE
{
    turbulence_parois loi_standard_hydr
    dt_impr_ustar 20
}
Traitement_particulier {
    canal {
        dt_impr_moy_spat 200
        dt_impr_moy_temp 200
        debut_stat 600
    }
}
Sources { canal_perio { direction_ecoulement 0 } }
Sources { source_Robin 2 Haut Bas 0.005 }
}
Convection_diffusion_temperature_turbulent
{
    Convection { EF_stab { volumes_etendus alpha 1 } }
    Diffusion { }
    Conditions_initiales { temperature champ_fonc_xyz dom 1 0 }
    Conditions_limites {
        PerioX periodique
        PerioZ periodique
        Haut paroi_decalee_Robin { delta 0.083333 }
        Bas paroi_decalee_Robin { delta 0.083333 }
    }
    Modele_turbulence Prandtl
    {
        turbulence_parois loi_standard_hydr_scalaire
        dt_impr_nusselt 20
    }
    Sources { puissance_thermique champ_uniforme 1 1 }
    Sources { source_Robin_scalaire 2 Haut 0 Bas 0 0.005 }
}
Postraitement
{
    Definition_champs {
        moyenne_vitesse Moyenne { t_deb 600 t_fin 1000 source refChamp { Pb_champ pb vitess
        moyenne_temperature Moyenne { t_deb 600 t_fin 1000 source refChamp { Pb_champ pb temp
        ecart_type_vitesse Ecart_type { t_deb 600 t_fin 1000 source refChamp { Pb_champ pb v
        ecart_type_temperature Ecart_type { t_deb 600 t_fin 1000 source refChamp { Pb_champ
        min_temperature Reduction_0D { methode min source refChamp { Pb_champ pb temperatur
        max_temperature Reduction_0D { methode max source refChamp { Pb_champ pb temperatur
    }
    Sondes {
        sonde_vitesse nodes vitesse periode 0.5 points 1 3.2 1 1.6
        sonde_temperature nodes temperature periode 0.5 points 1 3.2 1 1.6
```

8 DATA FILES

8.2 Cas

```
sonde_moyenne_vitesse  nodes moyenne_vitesse  periode 0.5 points 1 3.2 1 1.6
sonde_moyenne_temperature nodes moyenne_temperature periode 0.5 points 1 3.2 1 1.6
sonde_ecart_type_vitesse  nodes ecart_type_vitesse  periode 0.5 points 1 3.2 1 1.6
sonde_ecart_type_temperature nodes ecart_type_temperature periode 0.5 points 1 3.2
coupe_vitesse          nodes vitesse          periode 5 segment 9 0.213333 0 0.177778 0.213333
coupe_temperature      nodes temperature      periode 5 segment 9 0.213333 0 0.177778 0.213
coupe_moyenne_vitesse  nodes moyenne_vitesse  periode 5 segment 9 0.213333 0 0.1777
coupe_moyenne_temperature nodes moyenne_temperature periode 5 segment 9 0.213333 0 0.
coupe_ecart_type_vitesse  nodes ecart_type_vitesse  periode 5 segment 9 0.213333 0 0.
coupe_ecart_type_temperature nodes ecart_type_temperature periode 5 segment 9 0.213
}
Format lata_v2
Champs dt_post 200 {
    vitesse som
    temperature som
    min_temperature som
    max_temperature som
}
Statistiques dt_post 200
{
    t_deb 600 t_fin 1000
    moyenne vitesse
    moyenne temperature
    ecart_type vitesse
    ecart_type temperature
}
}
sauvegarde formatte pb.sauv
}
Resoudre pb
Fin
```