Modelling turbulent flows through Large Eddy Simulation in SPH

10th May 2006 – 1st SPHERIC workshop, Rome

Réza ISSA – Bendiks Jan BOERSMA – Damien VIOLEAU – Dominique LAURENCE

EDF – TU Delft – EDF – Univ. Manch. / EDF
Modelling turbulent flows through Large Eddy Simulation in SPH

1. Introduction to turbulence modelling
2. Large Eddy Simulation in SPH
3. Applications
Introduction to turbulence modelling
Characteristics of turbulent flows (1)

Unsteady and unpredictable

Tong et al, 1995

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Characteristics of turbulent flows (2)

Wide range of eddies

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Direct Numerical Simulation (DNS)

ALL turbulence scales are SIMULATED

Reference method, but:

- Very fine grid is required
- Very small time step
- Restricted to low Reynolds number flows

Impossible in practice with SPH

Le and Moin, Stanford Uni.
**Statistical modelling (RANS)**

ALL turbulence scales are MODELLED

![Image](Luo et al, 1996)

Only averaged values are considered

Widespread in industrial codes
Large Eddy Simulation (LES)

Large scales are simulated ~ DNS

The influence of small scales is modelled ~ RANS

• Velocity fluctuations are known
• Enables high Reynolds number flow simulation

More and more used in industry
Filtered field computation

Definition of filtered fields that only contain the large scale contribution

Spatial filter function characterized by a width $\Delta$:

- Gaussian
- Box function
- Computation grid

$$\tilde{u}_i(x) = \int u_i(x') G(x, x') dx'$$

$$A(r) = \int_{\Omega} A(r') w_h \left(|r - r'|\right) dr'$$

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Filtered Navier-Stokes equations in SPH formalism

Filtered momentum equation

\[
\frac{D\tilde{u}_a}{Dt} = -\sum_b m_b \left( \tilde{p}_a + \tilde{p}_b - \frac{8}{\tilde{\rho}_a + \tilde{\rho}_b} \tilde{u}_{ab} \cdot \tilde{r}_{ab} \right) \tilde{\omega}_h \left( r_{ab} \right) \frac{r_{ab}}{r_{ab}} + F^e_a
\]

Filtered continuity equation

\[
\frac{D\tilde{\rho}_a}{Dt} = \sum_b m_b \tilde{u}_{ab} \tilde{\omega}_h \left( r_{ab} \right) \frac{r_{ab}}{r_{ab}}
\]

Filtered state equation

\[
\tilde{p}_a = \frac{\rho_0 c_0^2}{\gamma} \left[ \left( \frac{\tilde{\rho}_a}{\rho_0} \right)^\gamma - 1 \right]
\]

Smagorinsky model

\[
\nu_{T,a} = (C_S h)^2 \sqrt{2\tilde{S}_{ij,a} \tilde{S}_{ij,a}}
\]
3D turbulent free surface channel
3D turbulent free surface channel

Free surface

$H = 0.4 \text{ m}$

$U = 1.35 \text{ m.s}^{-1}$

$Re = 538,000$

$F$

$g$

$l = 0.2 \text{ m}$

$L = 1.2 \text{ m}$

105,000 particles

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Instantaneous axial velocity field

$T = 0.000000000000000000000000000$ s

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Interpolated instantaneous axial velocity field
Instantaneous axial velocity slices
Instantaneous axial velocity profiles

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Averaged axial velocity profile

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3D dam breaking
### System modelling

**Dimensions in m**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_w$</td>
<td>0.9</td>
</tr>
<tr>
<td>$H_f$</td>
<td>0.3</td>
</tr>
<tr>
<td>$L_w$</td>
<td>0.9</td>
</tr>
<tr>
<td>$L_f$</td>
<td>0.3</td>
</tr>
<tr>
<td>$l_w$</td>
<td>0.6</td>
</tr>
<tr>
<td>$l_f$</td>
<td>0.6</td>
</tr>
</tbody>
</table>

120 000 particles

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Experiment visualization

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Comparison with SPH

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Conclusions and future work

• First results relative to LES in SPH

• Development of a fully incompressible algorithm
  (E.S Lee, Univ. Man)

• Expensive computational coast  Parallelization
  (J.C Marongiu, ECL)

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Thank you for your attention…
Intensité turbulente

$u_{rms}/u$ by Spartacus-3D
$u_{rms}/u$ experimental
$v_{rms}/u$ by Spartacus-3D
$v_{rms}/u$ experimental

$z/H$

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Profils de pression instantanée
Friction velocity estimation

\[
<u>_M = \sum_b \frac{m_b}{\rho_b} u_b w_h \left( |r_{Mb}| \right)
\]

\[
<u>_M = \frac{1}{\kappa} \ln \left( \frac{(\Delta + \delta)u_\tau}{\nu} \right) + C
\]

\[u_\tau\text{ obtained by iteration}\]

\[
<u_{\text{edge}}>_M = \frac{1}{\kappa} \ln \left( \frac{\delta u_\tau}{\nu} \right) + C
\]

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Boundary and initial conditions

Free surface

Turbulent boundary layer

\[ \langle u \_ edge \rangle = \frac{1}{\kappa} \ln \left( \frac{\delta u_\tau}{v} \right) + C \]

• Initial conditions
  Averaged velocity profile without perturbation