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Verification of Delayed Detached Eddy Simulation turbulence model for computational code in magnetohydrodynamics

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Abstract: *This paper focuses to verification of computational code for using for numeric simulate of magnetohydrodynamics flows. For verification of code was chosen problem of flow past a cylinder. In this benchmark the parameters of velocity field are compared with assumed experimental results. For verification of turbulence model implementation was used the basic benchmark flow of conductive fluid (melt) in square container generate by the rotating magnetic field.*

1. Introduction

The turbulence problem in computational fluid dynamics is ones of most complex problems of present mechanics. For simulation of turbulent flow can be used some approaches. First approaches is so called direct numerical simulation (DNS), there every turbulent scales must be taken by the used mesh. DNS cannot be used in case more turbulent flows, because the mesh must be very fine and cases are very demanding to time consuming and computational technology.

Second possibility is so called Reynolds averaged Navier-Stokes Approach (RANS), there the time averaged flow equations are used. This approach is successfully used for simulation of turbulent flows. But only time averaged velocity field and so-called Reynolds tensor is computed. For time depending of velocity field property can be used unsteady RANS (URANS), there same turbulence models like in case RANS are used.

Third approach is so called Large Eddy Simulation (LES). This approach simulates turbulence scales which can be taken by the used mesh and other scales are modelled.

Detached Eddy Simulation (DES) and Delayed Detached Eddy Simulation (DDES) combine URANS and LES approaches. Near wall regions and regions with high velocity gradient are computed by URANS method and free flow regions are computed by LES.

This text describes verification of DDES turbulence model by the benchmark flow past a cylinder and verification of implementation the turbulence models for code for simulation of magnetohydrodynamics flows. The problem flow of conductive fluid in square container generated by the rotating magnetic field was chosen. This benchmark can be used like basic research study for producing of high quality alloy materials.

2. Basic mathematical model

All simulations are solved as incompressible flow with constant molecular viscosity ν. The mathematics model includes Navier-Stokes equation in form (1) and continuity equation in form (2).

$$\frac{\partial u}{\partial t} + \nabla \cdot uu = -\frac{\nabla p}{\rho} + \nabla \cdot \left[(\nu_t + \nu)(\nabla u) \right] + f_L \qquad (1)$$

$$\nabla \cdot u = 0 \qquad (2)$$

Where *u* means velocity vector, *p* pressure, ρ density, *t* time, ν_t turbulence viscosity which is determined by the turbulence model and f_L is term of force field, which is used only in case of benchmark magnetically driven flow.

In case of DDES model ν_t is solved by means of Spalart-Allmaras turbulence model [1], which is determined by only one transport equation (3) with additional conditions (4, 5).

$$\frac{D\widetilde{\nu}}{Dt} = c_{b1}\widetilde{S}\,\widetilde{\nu} + \frac{1}{\sigma}\Big\{ \left[(\nu+\widetilde{\nu})\nabla\widetilde{\nu}\right] + c_{b2}(\nabla\widetilde{\nu})^2 - (c_{w1}f_w)\left(\frac{\widetilde{\nu}}{d}\right)^2 \Big\} \quad (3)$$

$$\widetilde{S} = S + \frac{\widetilde{\nu}}{\kappa^2 d^2} f_{v2} \quad (4)$$

$$\nu_t = \widetilde{\nu} \cdot f_{v1} \quad (5)$$

Where $\widetilde{\nu}$ means so called modified turbulence viscosity, *S* means size of vorticity and *d* distance of wall boundary condition. In case DDES turbulence model [2] the *d* parameter is changed for $\widetilde{d}$ which is formulated in (6).

$$\widetilde{d} = d - f_d \max\{0; d - C_{DES}\Delta\} \quad (6)$$

Function f_d is determined in (7).

$$f_d = 1 - \tanh[(8r_d)^3]$$

$$\text{and} \quad r_d = \frac{\nu + \nu_t}{\sqrt{\partial x_j u_i \partial x_i u_j}\,\kappa^2 d^2} = \frac{\widetilde{\nu}}{S\kappa^2 d^2} \quad (7)$$

The force field term is determinated as time averaged generated by the magnetic field. Basic equation is noted in (8).

$$f_L = 2 \cdot Ta \cdot \left(\vec{j} \times \vec{B}\right) \quad (8)$$

Where $\vec{B}$ means dimensionless magnetic induction and $\vec{j}$ means dimensionless electric potential. Ta is so called dimensionless magnetic Taylor number. Exact determination of a force field generated by the rotating magnetic field is better reported in [3].

The computing software is successfully validated by means of solutions laminar flow and flow generated by magnetic field [3, 4]. The computational code is based on finite element approach with explicit scheme providing further second order accuracy in time and space.

3. Benchmark flow past a cylinder

Basic geometry of the benchmark domain is shown in figure 1.
Boundary conditions are defined bellow

Inlet: $u_x = \frac{Re \cdot \nu}{D}$, $u_y = 0$, $u_z = 0$, $\widetilde{\nu} = 0$

Where *Re* means Reynolds number.

Wall of cylinder: $u_x = 0$, $u_y = 0$, $u_z = 0$, $\widetilde{\nu} = 0$

Top and low wall: $u_y = 0$

Outflow: $\vec{n} \cdot \left[p + \nu \cdot \nabla \cdot \vec{u}\right] = 0$, where $\vec{n}$ is normal vector to plane, in this case $\vec{n} = [1,0,0]$

Pressure is solved like pressure potential.

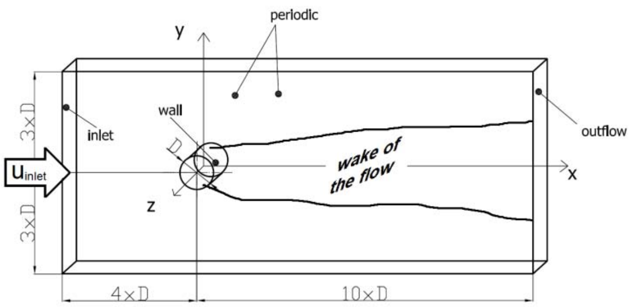

Figure 1: Domain of benchmark flow past a cylinder

The simulations were performed with two grids which are different by area of domain in z direction. Basic properties of these simulations and theirs marks are listed in table 1.

Table 1: Marks of simulations

	Number of elements	
Re	2524325	1256539
3900	LRE-32	LRE-16
140000	HRE-32	HRE-16

Main parameters which were evaluated are velocity profiles and profiles of Reynolds stress term in lines past a cylinder. These results are compared with assumed experimental results [5, 6, 7]. These parameters are shown in figures 2, 3 and 4. Case LRE-32 provides best results in comparison with assumed experiment.

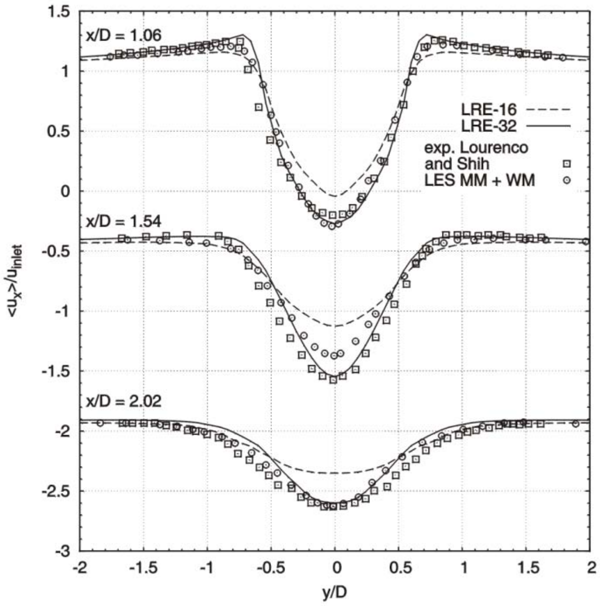

Figure 2: Time averaged x-component of velocity vector, Re=3900, (Lorenco and Shih [5], LES MM + WM [6])

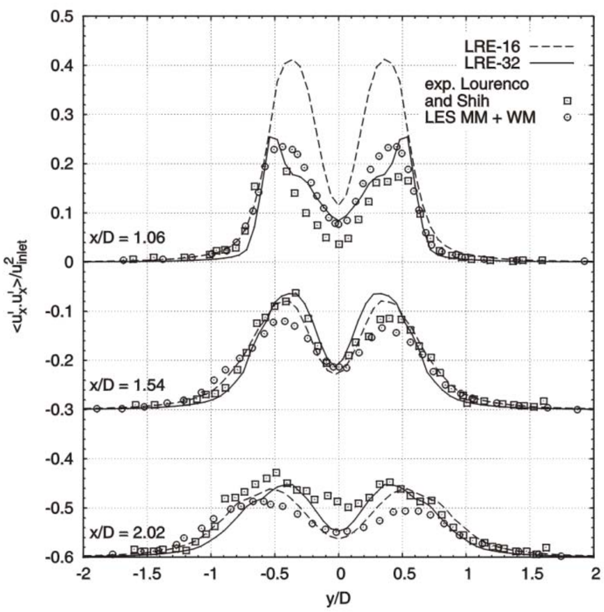

Figure 3: Reynolds stress $<u'_x.u'_x>$, Re=3900, (Lorenco and Shih [5], LES MM + WM [6])

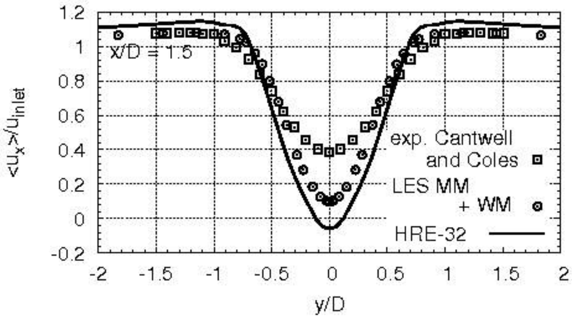

Figure 4: Time averaged x-component of velocity vector, Re=140000, (LES MM + WM [6], Cantwell and Coles [7]

4. Benchmark flow in square container generated by the rotating magnetic field

Basic geometry of the benchmark domain is shown in figure 5. Every boundary conditions are defined like static wall.

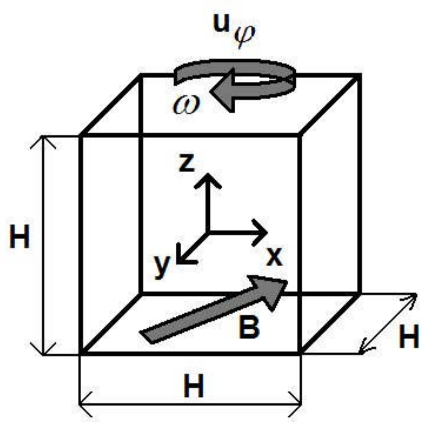

Figure 5: Basic geometry of benchmark flow in square cylinder driven by rotating magnetic field

This benchmark was simulated for five cases of magnetic Taylor number Ta = 10^6, 5.10^6, 10^7, 5.10^7 and 10^8.

Figure 6 shows time averaged radial component of velocity vector in case benchmark magnetically driven flow in square container. Lines of velocity profile are placed on horizontal central plane of container. Left part of diagram shows data on axis line and right part shows data on diagonal line.

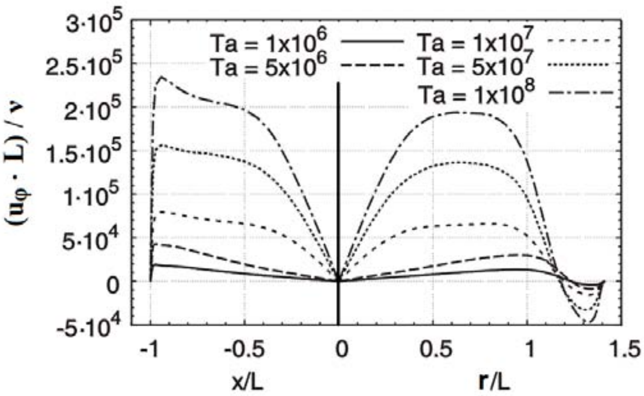

Figure 6: Magnetically driven flow in square container – time averaged radial component of velocity vector

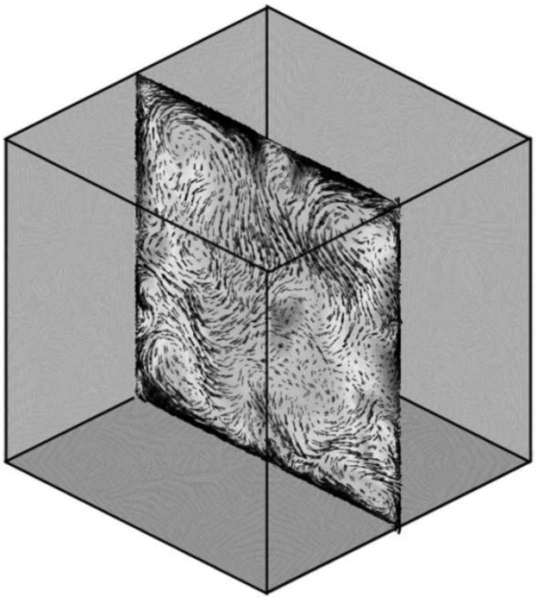

Figure 7: Magnetically driven flow in square container – time shot of velocity field of case $Ta=10^6$

5. Conclusion

In case of benchmark flow past a cylinder result of time averaged velocity and Reynolds stress are shown. The results are less accurate for greater Reynolds number. This is normal for used turbulence model. In case of benchmark flow in square container time averaged radial component of velocity was shown as well. There results don't compare with experimental data. In this case obtaining of experimental data is practically impossible in light of present technology. This result may be used for determination of velocity dependency of magnetic Taylor number.

6. Acknowledgements

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