IMPACT OF LES TURBULENCE SUBGRID MODELS IN THE JET RELEASE SIMULATION

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ABSTRACT – The right choice of sub-grid scale (SGS) models in any simulation scenario plays an important role, since it can lead to more accurate results. This paper aims to investigate SGS models in order to perform jet release simulation accurately. Fire Dynamics Simulation (FDS) code is used for this propose. Preliminary results for jet centreline velocity profile are obtained considering four different SGS models. Findings are compared with analytical model. Three of four SGS models investigated let to excellent results.

1. INTRODUCTION

Large Eddy Simulation (LES) is a technique for computation of turbulent flows where the large-scale component of the flow carrying most of the energy is resolved in the computational mesh. The LES equation is obtained after a filtering the Navier-Stokes equation. The residual part (small eddies) is modelled by sub-grid scale (SGS) models. SGS solves turbulent stresses, which is based on Boussinesq hypothesis, via eddy viscosity. The justification for LES is that the larger eddies contain most of the energy. The smaller eddies are believed to be more universal and should be easier to model (Jiang and Lai, 2009). There are a number of SGS models (Smagorinsky, 1963), (Deardorff et al, 1970), (Gemano et al., 1991), (Vreman, et al., 1995). They must be used carefully, since they present different formulation to predict the eddy viscosity. This work investigates SGS models implemented in Fire Dynamics Simulator (FDS) in order to make sure the best model for jet release investigation is considered. Preliminary results are compared with analytical formulation presented by Benintendi, 2010. Conclusions are presented pointing out the best SGS for the jet scenario investigation.

2. CFD models

2.1 Fire Dynamics Simulator code

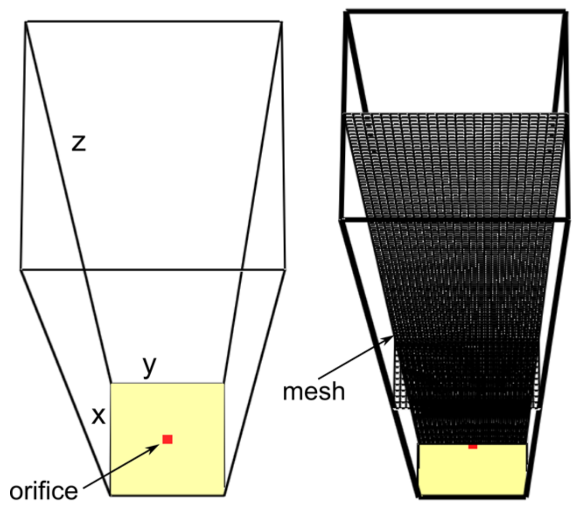
Fire Dynamics Simulation (FDS) is a Large Eddy Simulation (LES) code developed as a free and open source Computational Fluid Dynamic (CFD) program by National Institute of Standards and Technology (NIST) to deal with fire phenomenon (McGrattan, et al., 2014). The FDS code comprises the finite-difference method, with 2nd order explicit predictor-corrector time discretisation and robust techniques to space discretization, like 2nd order central difference, 2nd order upwind and Superbee (McGrattan, et al., 2014). The present application concerns sub-grid models implemented in FDS to deal with turbulent jet scenarios. The time step is determined dynamically via Courant-Freidrichs-Lewy condition

(CLF condition) during calculations. It is based on the local mesh size and local velocity to ensure numerical convergence.

2.1 Boundary conditions and analytical model

The turbulent jet has been set up in the advanced CFD code named Fire Dynamics Simulation (FDS) considering the solution of the large eddies and modelling of the small eddies by sub-grid models from the turbulent field. The jet release was simulated using the computational domain of 24 cm long, 24 cm width 200 cm height. In total 115200 (24, 24, 200) structured mesh were used. Isothermal air jet was released direct to the atmospheric ambient with exit velocity of 41.4 m/s from a square orifice of 2 cm. Figure 1 shows the computational domain used for investigation of the jet release and the its mesh.

Figura 1 – Computational domain and mesh used for investigation of the jet release.



Concerning analytical centreline velocity profile $V(0,z)$, the following hyperbolic decay law may be assumed (Benintendi, 2010).

$$V(0,z) = 6 \cdot \frac{Deq \cdot Ve}{z} \quad (1)$$

$$Deq = De \cdot \sqrt{\frac{Pe}{Pa}} \quad (2)$$

In equation 1, Deq is the equivalent diameter, Ve stands for the exit jet velocity and z means the downstream distance in the centreline of the jet. In equation 2, De is the orifice, Pe stands for exit pressure and Pa means atmospheric pressure. Details of these equation are present in Benintendi, 2010.

2. RESULTS AND DISCUSSIONS

Figure 2, Figure 3, Figure 4 and Figure 5 show the velocity profile of the turbulent jet investigated using constant Smagorinsky, dynamic Smagorinsky, Deadorff and Vreman sub-grid models, respectively. The screenshots of the each jet profile simulated in FDS are shown in Figures with subscript (a). Figures with subscript (b) show the comparison among the jet profiles achieved using sub-grid models with analytical jet model. It is observed that downstream the jet exit, Constant Smagorinsky sub-grid model has very poor prediction. This sub-grid model estimates the eddy viscosity considering an experimental constant, which used the value of 0.2 (default FDS value).

Dynamic Smagorinsky, Deardorff and Vreman sub-grid models reached excellent approximation with analytical model. In Dynamic Smagorinsky the experimental constant considered by constant Smagorinsky is no longer taken as a constant, but rather computed based on local flow conditions as a function of both space and time. Deardorff and Vreman models also consider an experimental constant (0.1 and 0.5, respectively) in their models, however, Deardorff worries to capture information in the middle of each cells, and Vreman expand the velocity field in a Taylor series to model accurately the eddy viscosity.

Figura 2 –Velocity profile of the turbulent jet. (a) Screenshot of a jet release. (b) Normalized jet velocity decay versus centreline distance predicted by constant Smagorinsky sub-grid model.

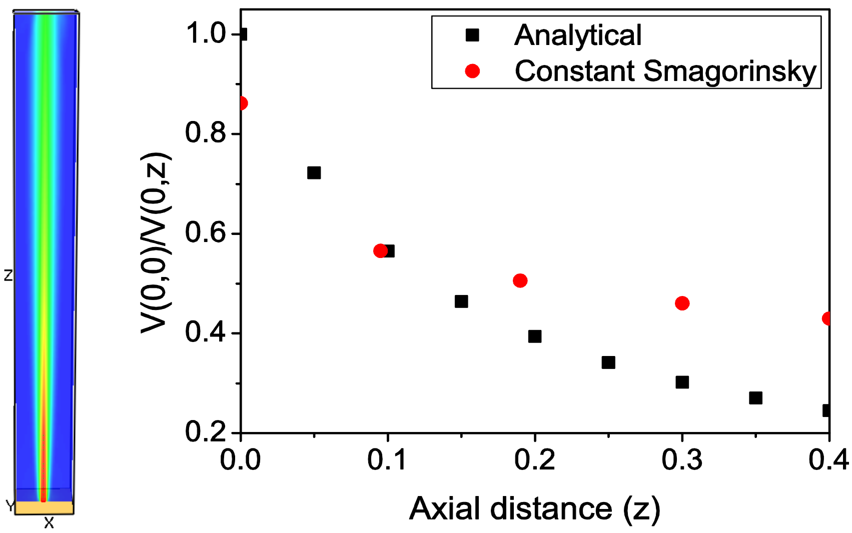


Figura 3 – Velocity profile of a turbulent jet. (a) Screenshot of a jet release. (b) Normalized jet velocity decay versus centreline distance predicted by dynamic Smagorinsky sub-grid model.

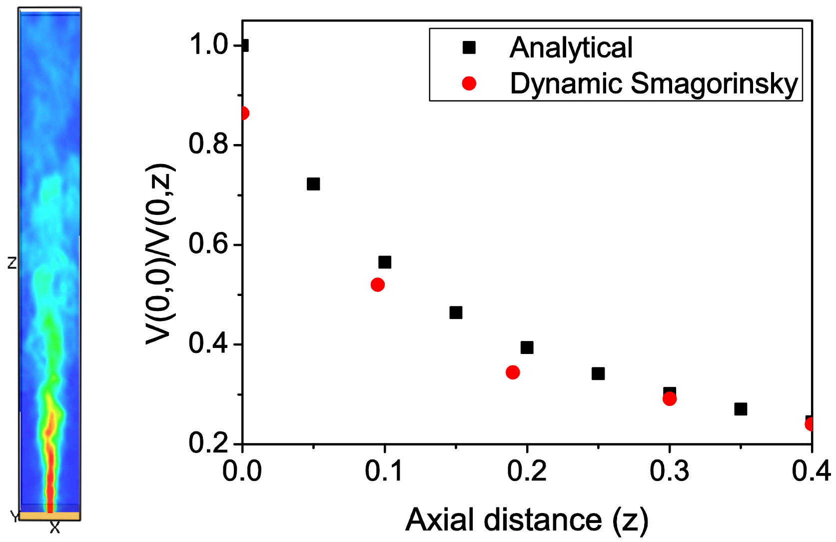


Figura 4 – Velocity profile of a turbulent jet. (a) Screenshot of a jet release. (b) Normalized jet velocity decay versus centreline distance predicted by Deardorff sub-grid model.

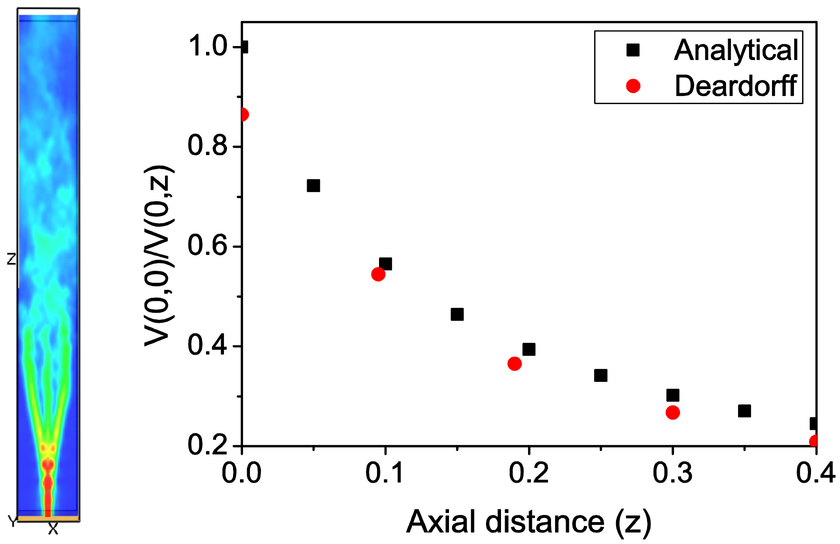
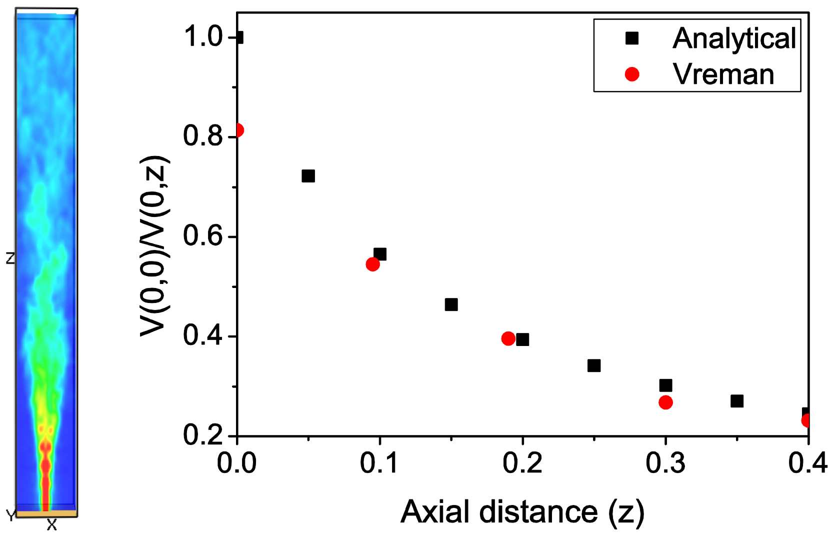


Figura 5 – Velocity profile of a turbulent jet. (a) Screenshot of a jet release. (b) Normalized jet velocity decay versus centreline distance predicted by Vreman sub-grid model.



4. CONCLUSIONS

This work has been performed in order to investigate SGS models in jet scenarios. Analysis of the sub-grid scale models has shown that the dynamic Smagorinsky, Deardorff and Vreman give excellent results downstream the jet exit. On the other hand, constant Smagorinsky model reached the poorest agreement with the analytical model.

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