Turbulence Modeling using OpenFOAM
(Introduction to Turbulence - ENGR5005G)

Arup Jyoti Chutia , Brayden York and Marcus Ebert

Mechanical Engineering
Ontario Tech University

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Outline

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- OpenFOAM solvers
- Geometry and problem parameters
- Mesh and boundary conditions
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Introduction

Turbulent flow

- Chaotic changes in field values :
  - velocity
  - pressure
- High Reynolds number flow :
  - low momentum diffusion (μ)
  - high momentum convection

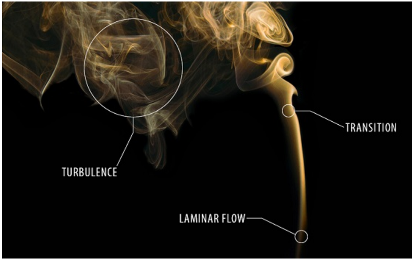

Figure: 1. Flow visualisation (source: www.bronkhorst.com).

Introduction (contd...)

Why turbulence modeling?

- No general analytical theory
- Chaotic flow
- Closure Problem
- Mathematical models.

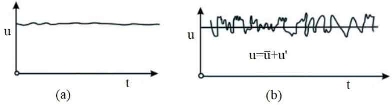

Figure: 2.(a)Laminar and (b) turbulent velocity (source: https://nptel.ac.in).

Objectives

- Understanding turbulence models in CFD (OpenFOAM).
- Simulations for transient and steady state conditions.
- Selecting turbulence model.

Governing equations (Mean flow)[1]

RANS *equations for incompressible flow*:
Continuity equation

$$\frac{\partial \overline{u_i}}{\partial x_i} = 0 \tag{1}$$

Momentum equations

$$\frac{\partial \overline{u_i}}{\partial t} + \overline{u_j}\frac{\partial \overline{u_i}}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{P}}{\partial x_i} + \nu \frac{\partial^2 \overline{u_i}}{\partial x_j \partial x_j} - \frac{\partial \overline{u_i' u_j'}}{\partial x_j} + \overline{g_i} \tag{2}$$

Scaler equation

$$\frac{\partial \overline{\phi}}{\partial t} + \overline{u_i}\frac{\partial \overline{\phi}}{\partial x_i} = \frac{\partial}{\partial x_i}(D\frac{\partial \overline{\phi}}{\partial x_i}) - \frac{\partial (\overline{u_i' \phi'})}{\partial x_i} \tag{3}$$

[1] Dipal Patel. *Lecture 3 - Governing Equations - I*. Lecture Notes. 2019.

Standard k-ϵ model[2]

$\nu_{eff} = \nu + \nu_t, \ \nu_t = ?$

- k-turbulent kinetic energy

$$k = \frac{1}{2}(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}) \tag{4}$$

- ϵ -turbulent dissipation
  - rate of dissipation of k.
- Turbulent viscosity
  - $\nu_t = 0.09\frac{k^2}{\epsilon}$
- Transport equations for k and ϵ

[2] Henk Kaarle Versteeg and Weeratunge Malalasekera. *An introduction to computational fluid dynamics: the finite volume method*. Pearson education, 2007.

OpenFOAM solvers

OpenFOAM solvers used in this project

- **simpleFoam**[3]: for steady state simulation.
  - RAS models: *kEpsilon*, *kOmega* and *LRR*.
- **pisoFoam**[4]: transient simulation for incompressible flow.
  - LES models : *Smagorinsky*, *kEqn*.
  - RAS model: *kEpsilon*

[3] Bahram Haddadi. *Tutorial 6, Turbulence, Steady State*. 5th edition, Sept. 2019 (accessed November 7, 2019).

[4] Bahram Haddadi. *Tutorial 7, Turbulence, Transient*. 5th edition, Sept. 2019 (accessed November 7, 2019).

Geometry and problem parameters

Figure: 3.Schematic of geometry used for simulations (source: http://training.uhem.itu.edu.tr).

Mesh and boundary conditions

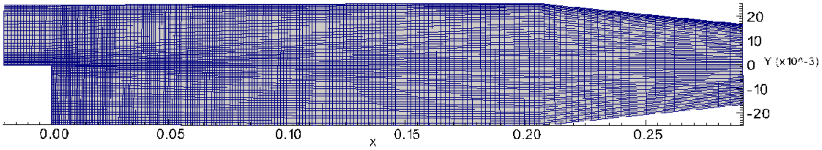

Figure: 4.Hexahedral mesh (source:www.cfdsupport.com).

Velocity boundary conditions

- *Inlet*: Dirichlet condition.
- *Outlet*: Zero-gradient condition.
- *Upper Wall*: No slip .
- *Bottom Wall*: No slip.

Turbulence – Steady State: Results

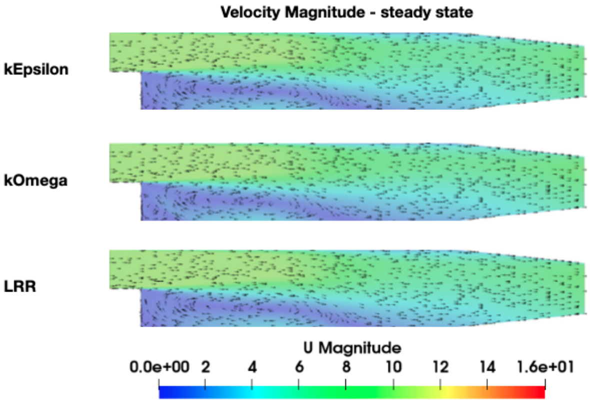

Figure: 5.Velocity magnitude for *kEpsilon*, *kOmega* and LRR models.

Turbulence – Steady State: Results(contd...)

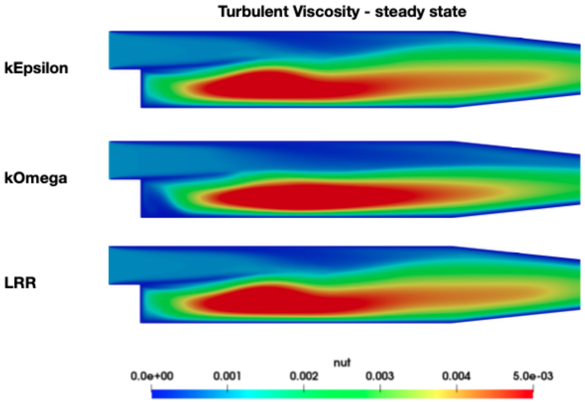

Figure: 6.Turbulent viscosity for *kEpsilon*, *kOmega* and LRR models.

Turbulence - Transient : Results (Smargorinsky model)

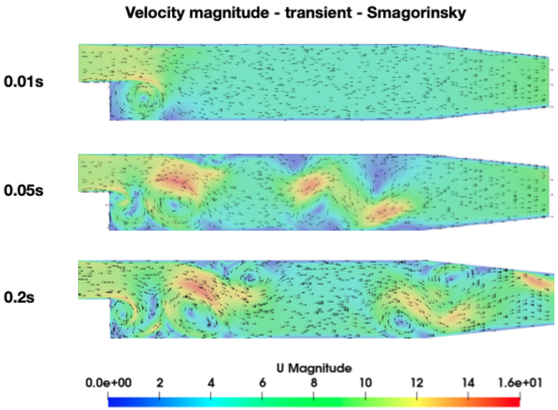

Figure: 7.Smargorinsky velocity magnitude at different time steps.

Turbulence - Transient : Results (Smargorinsky model)

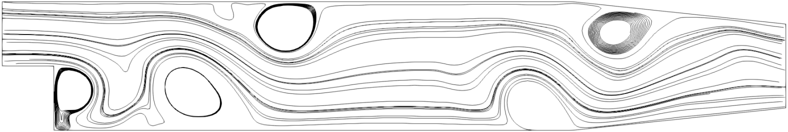

Figure: 8.Streamlines at 0.2s for Smargorinsky model.

Turbulence - Transient : Results (kEpsilon)

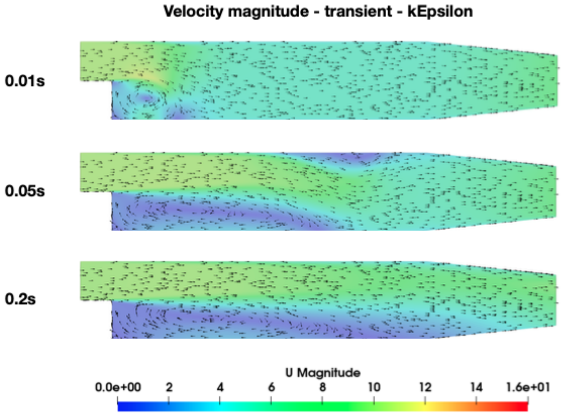

Figure: 9.*kEpsilon* model - Velocity magnitude at different time steps .

Turbulence - Transient : Results (contd...)

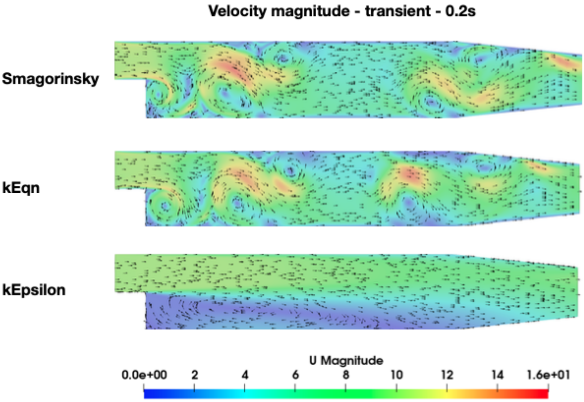

Figure: 10.Velocity vectors for different turbulence models - at 0.2s

Turbulence - Transient : Results (contd...)

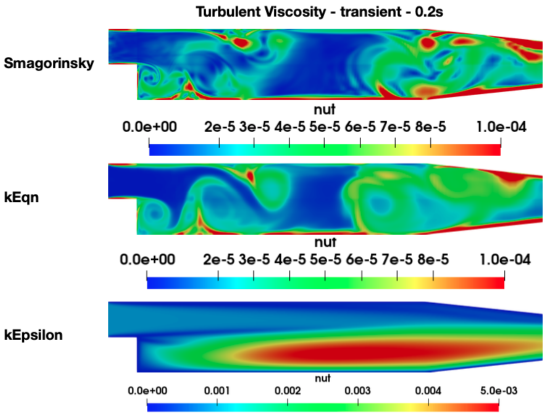

Figure: 11.Turbulent viscosity for different turbulence models - at 0.2s

Conclusions and Recommendations

Steady State Simulations

- Similar results for *kEpsilon*, *kOmega* and *LRR*.

Transient Simulations

- LES -(*Smagorinsky, kEqn)* detail, fluctuation based.
- RAS -(*kEpsilon*), averaging nature.

References

Haddadi, Bahram. *Tutorial 6, Turbulence, Steady State*. 5th edition, Sept. 2019 (accessed November 7, 2019).

– .*Tutorial 7, Turbulence, Transient*. 5th edition, Sept. 2019 (accessed November 7, 2019).

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