

Introduction to Computational Fluid Dynamics using OpenFOAM and Octave

Lakshman Anumolu
Kumaresh Selvakumar
(August 28, 2023)

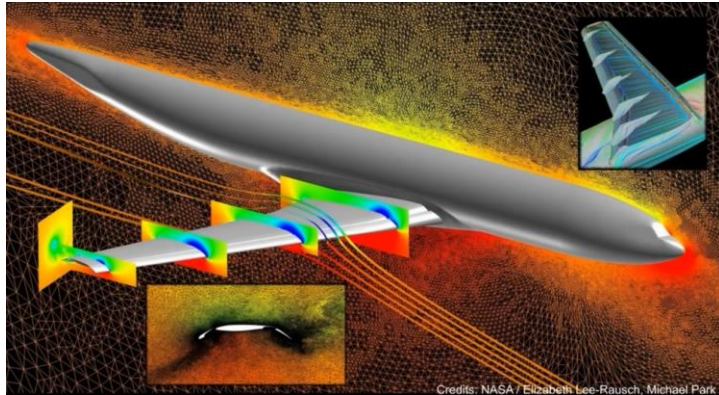
Overview

- Brief introduction
- Continuum Approximation & Governing Equations
- Installation

About this Course

- Instructor: Lakshman Anumolu
- TA: Kumaresh Selvakumar
- Course duration per session: 45-55 mins
- Requirements:
 - Virtual box and installing OS & softwares.
 - Interest to learn CFD using OpenFOAM & Octave
 - **Interest to ask questions**
 - **Work as a team**
- Exercises: 20% (equal weightage)
- Projects: 10%, 10%, 20%, 40%
 - Final project presentations & aim to use those at conferences

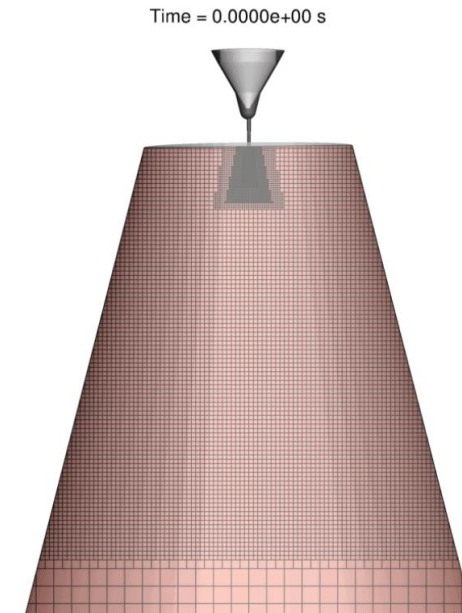
Computational Fluid Dynamics



Credit: NASA



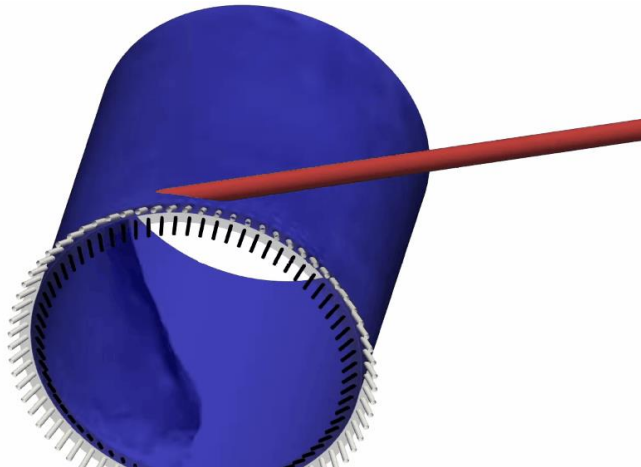
Anumolu (2019)



Anumolu, et al. (2022)

Why CFD?

- Speed of performing tests for different scenarios
- Cost
- Parametric study



Credit: CSI

Computational Fluid Dynamics (CFD)

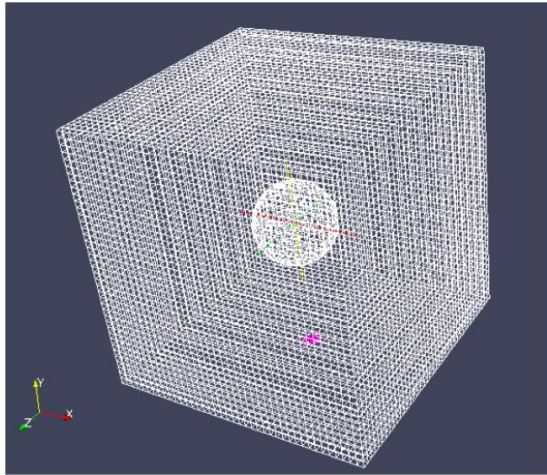
References:

- Ferziger and Peric; Computational Methods for Fluid Dynamics.
- S. Patankar; Numerical Heat Transfer and Fluid Flow.
- Tannehill et al.; Computational Fluid Mechanics and Heat Transfer.
- Versteeg, Malalasekera; An Introduction to Computational Fluid Dynamics.
- C.J. Greenshields, H.G. Weller; Notes on CFD: General Principles.

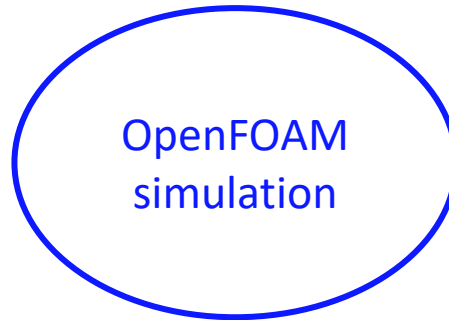
References used for this course:

- *Diversified & interdisciplinary.*

CFD - Workflow



Generate mesh



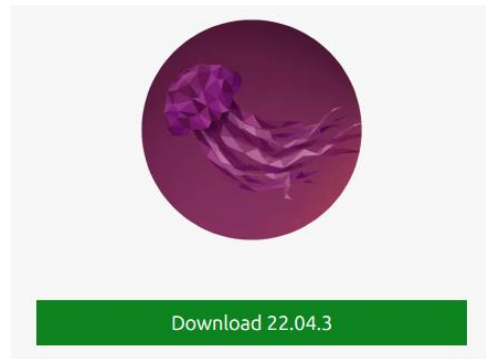
Perform simulation



Post-process results

Tools for this Course

- Operating System:
 - Ubuntu 22.04
- Softwares:
 - OpenFOAM v2306
 - Octave



Open▽FOAM®

OpenFOAM-v2306 ▾

openfoam



Exercise-1

Install required tools

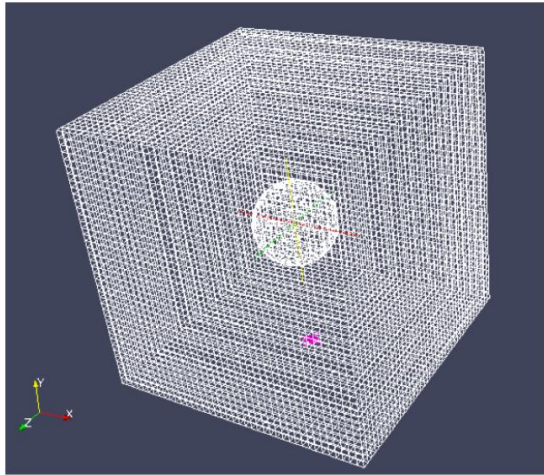
Things TODO by YOU

Exercise-1

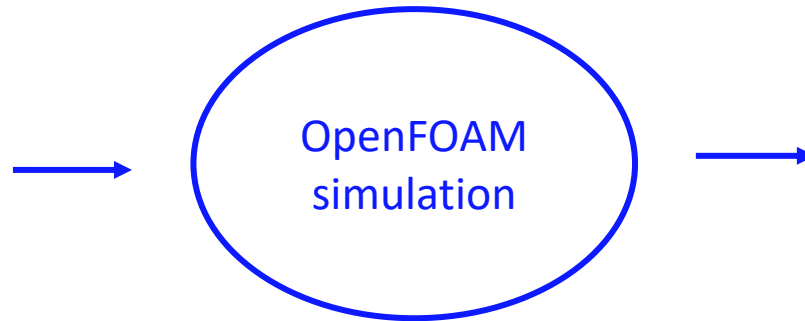
Create required accounts

- Create a github account:
 - <https://github.com>
 - Discussion forum:
 - <https://github.com/exaslate-courses/cfd-openfoam-b1/discussions>
- Part of WhatsApp group
 - <https://chat.whatsapp.com/F6Xax0plxOsJ9MgtCgTXzD>
- Queries
 - 30 mins Sunday 8AM-8:30AM IST
 - Ask in github discussion forums
 - WhatsApp for quick queries and use as a reference tool

CFD – Workflow [as an application engineer]



Generate mesh

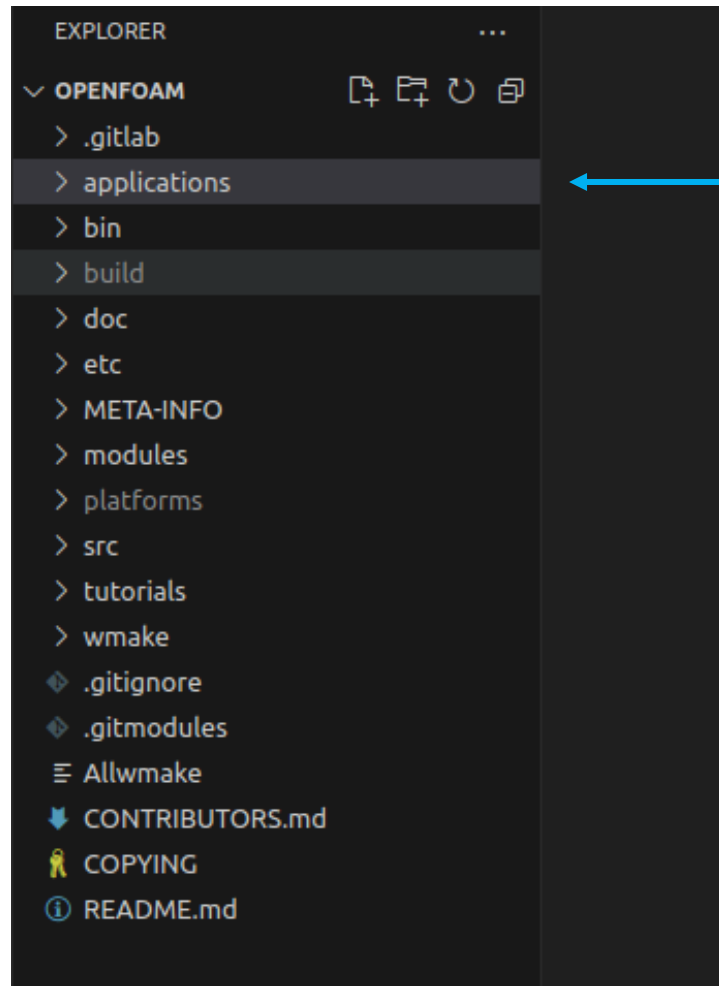


Perform simulation

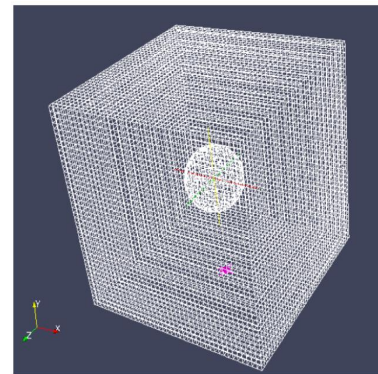


Post-process results

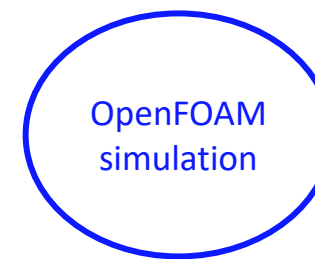
CFD – Workflow [as a developer]



Solvers



Generate mesh

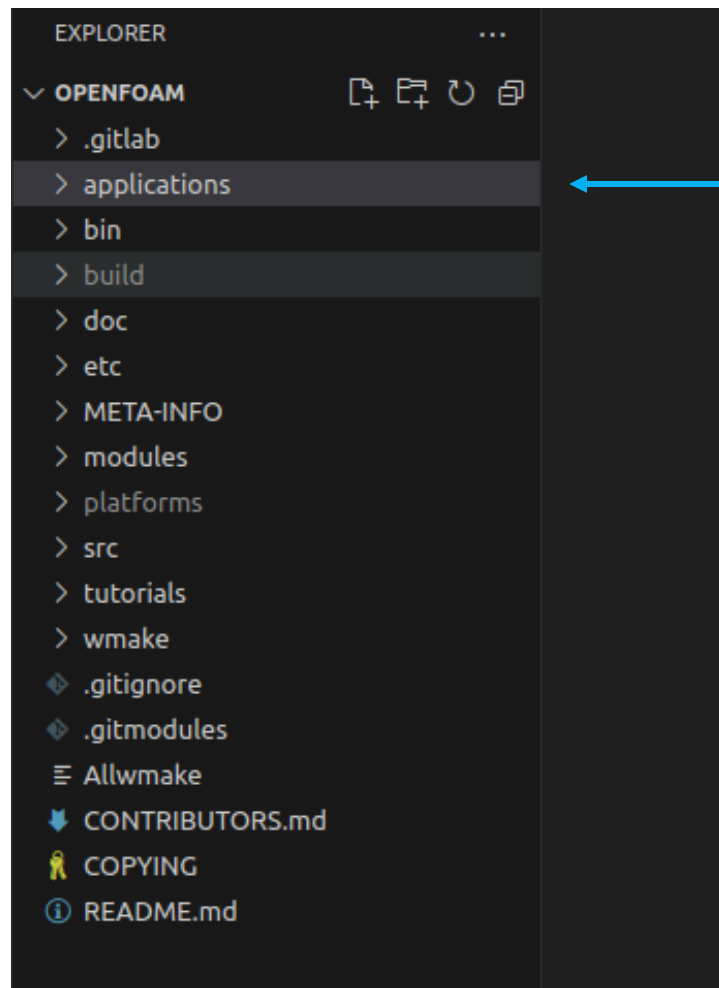


Perform simulation

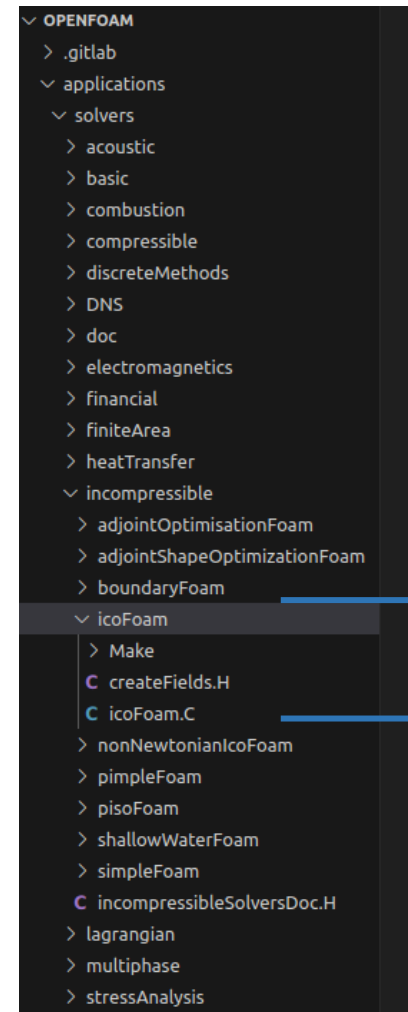


Post-process results

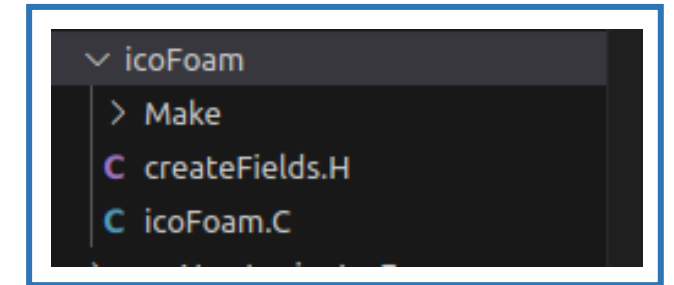
CFD – Workflow [as a developer]



Solvers



Transient,
incompressible solver.



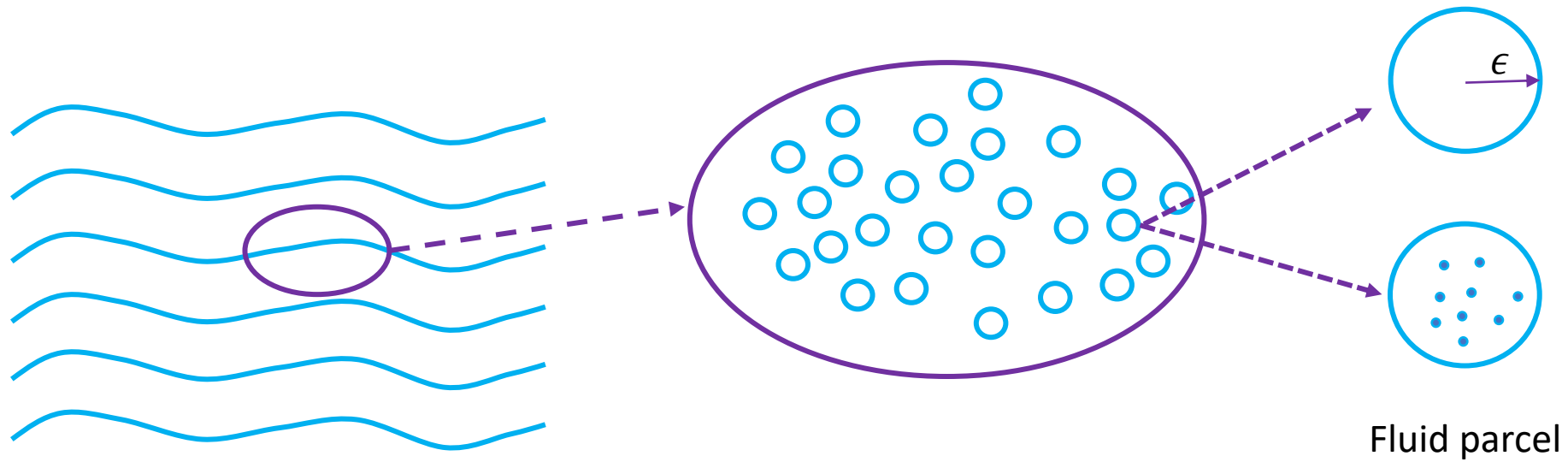
Takeaway Points

- OS and tools to install
 - Ubuntu, OpenFOAM, Octave
- Create github accounts and use github discussions as forums
- Steps as a CFD engineer
- OpenFOAM code structure

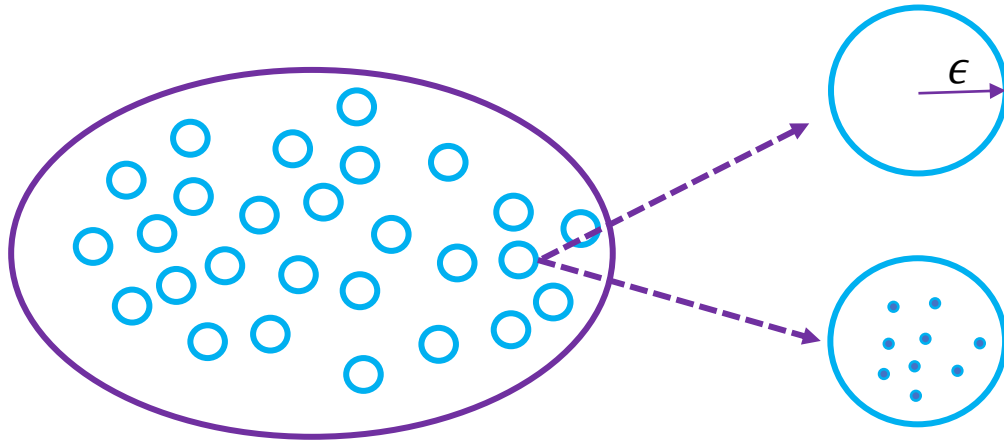
CFD Fundamentals & Governing Equations

Fluid

- A substance whose molecular structure offers no resistance to external forces
- Ferziger, Peric

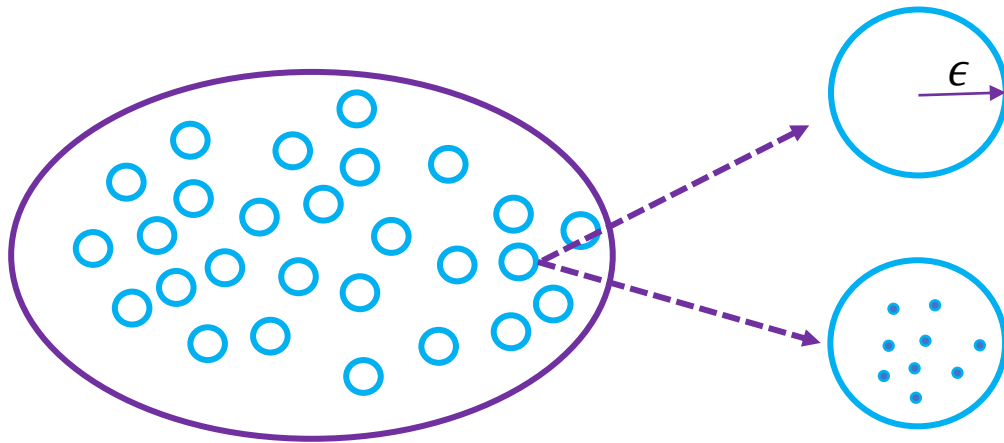


Fluid (Continuum)

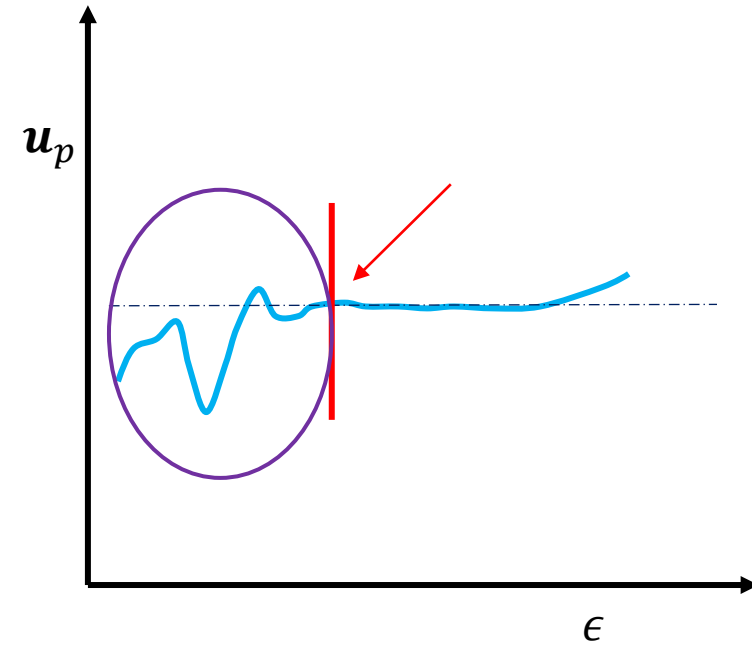


$$\mathbf{u}_p = \frac{\sum_{i=1}^{N_{mol}} \mathbf{u}_{mol}}{N_{mol}}$$

Fluid (Continuum)




Continuum approximation




Fluid velocity: $u(x, t)$

Governing Equations

- Conservation of mass

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} = 0 \quad 3D: \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$


- Conservation of momentum

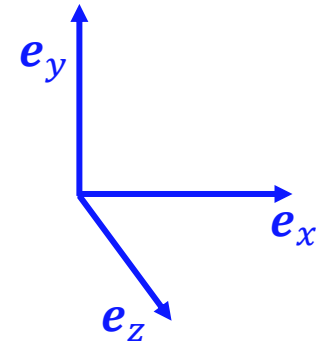
$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u} \mathbf{u}) = -\nabla p + \nabla \cdot \boldsymbol{\sigma} + F_b$$


Mathematical Operations

- Gradient

$$\nabla \rho = \left(\frac{\partial}{\partial x} \mathbf{e}_x + \frac{\partial}{\partial y} \mathbf{e}_y + \frac{\partial}{\partial z} \mathbf{e}_z \right) \rho = \left(\frac{\partial \rho}{\partial x} \mathbf{e}_x + \frac{\partial \rho}{\partial y} \mathbf{e}_y + \frac{\partial \rho}{\partial z} \mathbf{e}_z \right)$$

$$\nabla \mathbf{u} = \begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial v}{\partial x} & \frac{\partial w}{\partial x} \\ \frac{\partial u}{\partial y} & \frac{\partial v}{\partial y} & \frac{\partial w}{\partial y} \\ \frac{\partial u}{\partial z} & \frac{\partial v}{\partial z} & \frac{\partial w}{\partial z} \end{bmatrix}$$



- Divergence

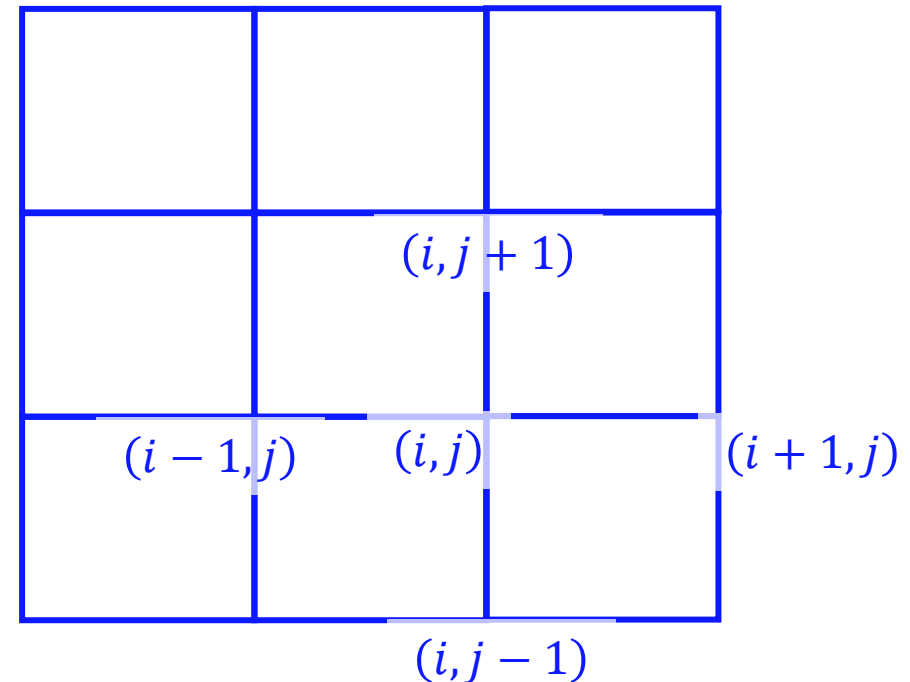
$$\nabla \cdot \mathbf{u} = \left(\frac{\partial}{\partial x} \mathbf{e}_x + \frac{\partial}{\partial y} \mathbf{e}_y + \frac{\partial}{\partial z} \mathbf{e}_z \right) (u \mathbf{e}_x + v \mathbf{e}_y + w \mathbf{e}_z) = \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right)$$

Discrete Operations

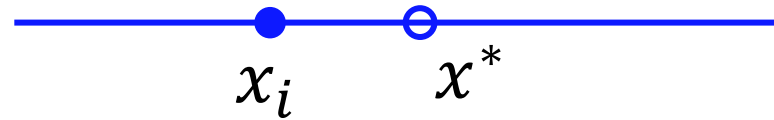
- Finite difference

$$\nabla \rho = \left(\frac{\partial}{\partial x} \mathbf{e}_x + \frac{\partial}{\partial y} \mathbf{e}_y + \frac{\partial}{\partial z} \mathbf{e}_z \right) \rho = \left(\frac{\partial \rho}{\partial x} \mathbf{e}_x + \frac{\partial \rho}{\partial y} \mathbf{e}_y + \frac{\partial \rho}{\partial z} \mathbf{e}_z \right)$$

$$\left(\frac{\partial \rho}{\partial x} \right)_{i,j} = \frac{\rho_{i+1,j} - \rho_{i-1,j}}{2\Delta x}$$



Taylor Series: Discrete Operations



$$\rho(x^*) = \rho(x_i) + (x^* - x_i) \left(\frac{\partial \rho}{\partial x} \right)_i + (x^* - x_i)^2 \left(\frac{\partial^2 \rho}{\partial x^2} \right)_i + (x^* - x_i)^3 \left(\frac{\partial^3 \rho}{\partial x^3} \right)_i + \dots$$

Taylor Series: Discrete Operations



$$\rho(x_{i+1}) = \rho(x_i) + (x_{i+1} - x_i) \left(\frac{\partial \rho}{\partial x} \right)_i + (x_{i+1} - x_i)^2 \left(\frac{\partial^2 \rho}{\partial x^2} \right)_i + (x_{i+1} - x_i)^3 \left(\frac{\partial^3 \rho}{\partial x^3} \right)_i + \dots$$

$$\rho(x_{i+1}) = \rho(x_i) + (x_{i+1} - x_i) \left(\frac{\partial \rho}{\partial x} \right)_i + O(\Delta x_i^2); \quad \Delta x_i = (x_{i+1} - x_i)$$

$$\rho(x_{i+1}) = \rho(x_i) + \Delta x_i \left(\frac{\partial \rho}{\partial x} \right)_i + O(\Delta x_i^2)$$

Taylor Series: Discrete Operations

$$\rho(x_{i+1}) = \rho(x_i) + \Delta x_i \left(\frac{\partial \rho}{\partial x} \right)_i + O(\Delta x_i^2)$$

$$\left(\frac{\partial \rho}{\partial x} \right)_i = \frac{\rho(x_{i+1}) - \rho(x_i)}{\Delta x_i} + \frac{1}{\Delta x_i} O(\Delta x_i^2)$$

$$\left(\frac{\partial \rho}{\partial x} \right)_i = \frac{\rho(x_{i+1}) - \rho(x_i)}{\Delta x_i} + O(\Delta x_i)$$

$$\left(\frac{\partial \rho}{\partial x} \right)_i \approx \frac{\rho(x_{i+1}) - \rho(x_i)}{\Delta x_i}$$

- Finite difference

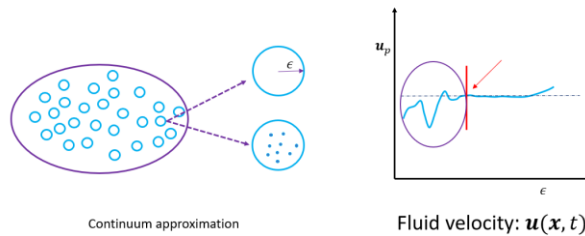
$$\nabla \rho = \left(\frac{\partial}{\partial x} \mathbf{e}_x + \frac{\partial}{\partial y} \mathbf{e}_y + \frac{\partial}{\partial z} \mathbf{e}_z \right) \rho = \left(\frac{\partial \rho}{\partial x} \mathbf{e}_x + \frac{\partial \rho}{\partial y} \mathbf{e}_y + \frac{\partial \rho}{\partial z} \mathbf{e}_z \right)$$

$$\left(\frac{\partial \rho}{\partial x} \right)_{i,j} = \frac{\rho_{i+1,j} - \rho_{i-1,j}}{2\Delta x}$$

What Did We Discuss?

- Continuum approximation

Fluid (Continuum)



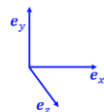
- Mathematical Operations

Mathematical Operations

- Gradient

$$\nabla \rho = \left(\frac{\partial}{\partial x} \mathbf{e}_x + \frac{\partial}{\partial y} \mathbf{e}_y + \frac{\partial}{\partial z} \mathbf{e}_z \right) \rho = \left(\frac{\partial \rho}{\partial x} \mathbf{e}_x + \frac{\partial \rho}{\partial y} \mathbf{e}_y + \frac{\partial \rho}{\partial z} \mathbf{e}_z \right)$$

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- Divergence

$$\nabla \cdot \mathbf{u} = \left(\frac{\partial}{\partial x} \mathbf{e}_x + \frac{\partial}{\partial y} \mathbf{e}_y + \frac{\partial}{\partial z} \mathbf{e}_z \right) (u \mathbf{e}_x + v \mathbf{e}_y + w \mathbf{e}_z) = \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right)$$

- Discrete approximations

Taylor Series: Discrete Operations

$$\rho(x_{i+1}) = \rho(x_i) + \Delta x_i \left(\frac{\partial \rho}{\partial x} \right)_i + O(\Delta x_i^2)$$

$$\left(\frac{\partial \rho}{\partial x} \right)_i = \frac{\rho(x_{i+1}) - \rho(x_i)}{\Delta x_i} + \frac{1}{\Delta x_i} O(\Delta x_i^2)$$

$$\left(\frac{\partial \rho}{\partial x} \right)_i = \frac{\rho(x_{i+1}) - \rho(x_i)}{\Delta x_i} + O(\Delta x_i)$$

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- Finite difference

$$\nabla \rho = \left(\frac{\partial}{\partial x} \mathbf{e}_x + \frac{\partial}{\partial y} \mathbf{e}_y + \frac{\partial}{\partial z} \mathbf{e}_z \right) \rho = \left(\frac{\partial \rho}{\partial x} \mathbf{e}_x + \frac{\partial \rho}{\partial y} \mathbf{e}_y + \frac{\partial \rho}{\partial z} \mathbf{e}_z \right)$$

$$\left(\frac{\partial \rho}{\partial x} \right)_{i,j} = \frac{\rho_{i+1,j} - \rho_{i-1,j}}{2\Delta x}$$

Next Session

- Illustration of fluid behavior
 - Deformation, Rotation, ...
- Lagrangian & Eulerian Frameworks
- Conservation Laws

Installations

Required Applications

- Preconfiguration packages:
 - <https://1drv.ms/f/s!AqT2YEB97-1RgP8MtsMPqoOGsq4ddg?e=locXv0>
- List
 - Virtual Box [to create virtual machines]
 - Ubuntu 22.04 [OS to install OpenFOAM & Octave]
 - AnyDesk [For remote access]

Exercises

Exercise-1 [Due August 30, 2023]

- Operating System:

- Ubuntu 22.04

- Softwares:

- OpenFOAM v2306



- Octave



- Create a github account:

- <https://github.com>
- Discussion forum:
 - <https://github.com/exaslate-courses/cfd-openfoam-b1/discussions>

- Part of WhatsApp group

- <https://chat.whatsapp.com/F6Xax0plxOsJ9MgtCgTXzD>

- Queries

- 30 mins Sunday 8AM-8:30AM IST
- Ask in github discussion forums
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