CFD using OpenFOAM
Lecture 7: Essential Flow Governing Laws & OpenFOAM Implementation

Part III : OpenFOAM Implementation and Illustration

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Co-ordinator : Prof. Janani S Murallidharan
Indian Institute of Technology, Bombay

Outline

Recap of Part I and II

Incompressible Flow Solvers in OpenFOAM

OpenFOAM Implementation

OpenFOAM Illustration

- Mass Conservation (2D):

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$$y\text{-Momentum:} \quad \rho\frac{\partial v}{\partial t} + \rho u\frac{\partial v}{\partial x} + \rho v\frac{\partial v}{\partial y} = \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{\partial p}{\partial y}$$

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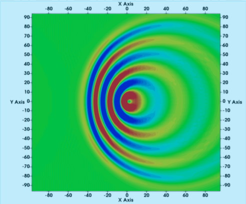
- Finite Volume Discretisation
- Challenges Faced & Solution Methodology

Division of contents for CFD & OpenFOAM Implementation

Part I : Governing Laws and PDE Format → $$\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0$$

Part II : Discretisation & Solution Methodology → $$\frac{U_{i,j+1} - U_{i,j-1}}{\Delta x} = 0$$

Part III : OpenFOAM Implementation & Illustration →



Vector format of Navier Stokes Equation

- Since algorithms are implemented from vector notation-based equations, the N-S can be written as:

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where, $\overrightarrow{m}$ & $\overrightarrow{u}$ represents mass-flux and velocity vector respectively
∇ is the divergence vector, given by

$$\nabla = \frac{\partial}{\partial x}\hat{i} + \frac{\partial}{\partial y}\hat{j} + \frac{\partial}{\partial z}\hat{k}$$

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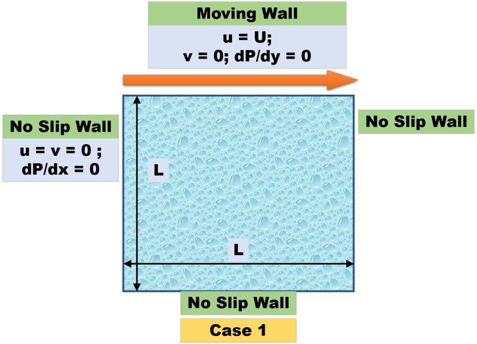
and Δ is the Laplacian, given by

$$\Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

- Before solving a problem, it is important to understand flow behavior so that correct algorithm is selected :
- Consider 2 variations for a lid-driven-cavity problem as given below



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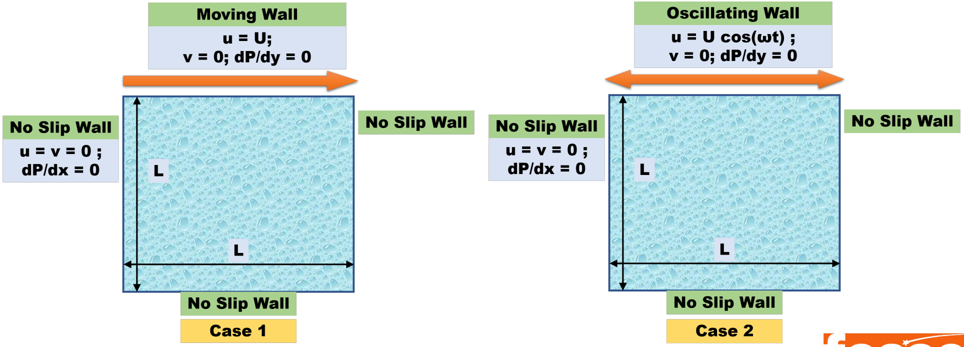
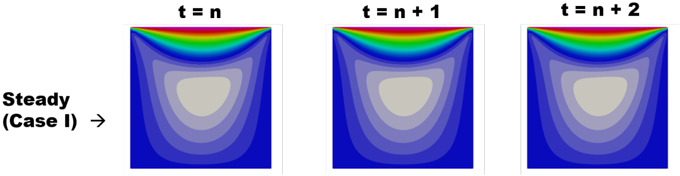


Differences in various flow conditions

- Let us see differences in the flow behavior in 2 cases presented previously:



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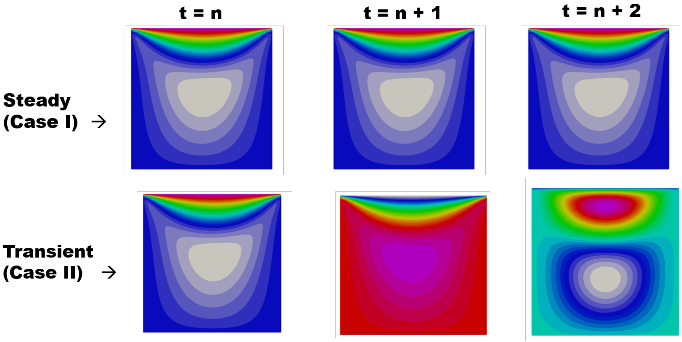
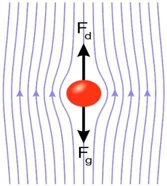


Differences in various flow conditions

Laminar →



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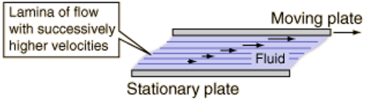

By R NaveGeorgia State University - HyperPhysicshhttp://hyperphysics.phy-astr.gsu.edu/hbase/pfric.html

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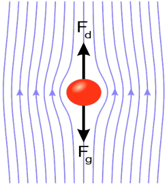

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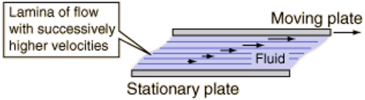

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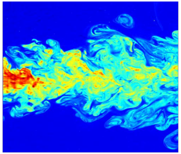
Turbulent →



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- Let us look at important Incompressible flow solvers in OpenFOAM and their capabilities :

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- What if problem is Laminar, Steady State ?
- 2 options : (1) modify simpleFoam for Laminar flow (2) run icoFoam only (for longer time)

- Location of the solver to check implementation :
  /opt/openfoam7/applications/solvers/incompressible/icoFoam

icoFoam Implementation

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$$\boldsymbol{UEqn} = \frac{\partial \boldsymbol{U}}{\partial \boldsymbol{t}} + \boldsymbol{\nabla} \cdot \left(\vec{\boldsymbol{U}}\vec{\boldsymbol{U}}\right) - \boldsymbol{\nu}\boldsymbol{\nabla}^2\vec{\boldsymbol{U}}$$

```
fvVectorMatrix UEqn
(
    fvm::ddt(U)
  + fvm::div(phi, U)
  - fvm::laplacian(nu, U)
);
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$$\boldsymbol{UEqn = -\nabla p}$$

(Obtain U) →

```
if (piso.momentumPredictor())
{
    solve(UEqn == -fvc::grad(p));
}
```

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$$\nabla^2 p^{n+1} = \frac{\rho}{\Delta t} \nabla \cdot \mathbf{u}^*$$

```
fvScalarMatrix pEqn
(
    fvm::laplacian(rAU, p) == fvc::div(phiHbyA)
);
```

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$$\boldsymbol{UEqn} : \boldsymbol{\nabla} \cdot \left(\overrightarrow{\boldsymbol{U}}\overrightarrow{\boldsymbol{U}}\right) + \boldsymbol{MRF} + \boldsymbol{u'u'} - \boldsymbol{\nu}\boldsymbol{\nabla}^2\overrightarrow{\boldsymbol{U}} = \boldsymbol{S}$$

```
tmp<fvVectorMatrix> tUEqn
(
    fvm::div(phi, U)
  + MRF.DDt(U)
  + turbulence->divDevReff(U)
 ==
    fvOptions(U)
);
fvVectorMatrix& UEqn = tUEqn.ref();
```

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$$UEqn = -\nabla p$$

(Obtain U)

$\Rightarrow$

```
if (simple.momentumPredictor())
{
    solve(UEqn == -fvc::grad(p));

    fvOptions.correct(U);
}
```

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simpleFoam Implementation

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- To modify a solver : (1) make a copy of existing solver (2) change code (UEqn mostly) (3) compile using ‘wmake’ command

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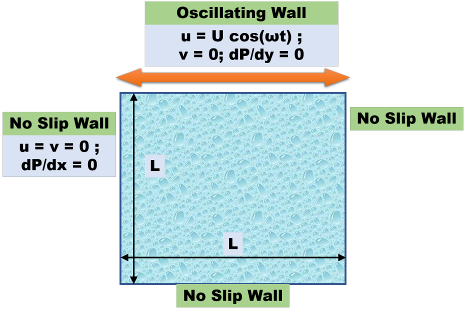
- The domain consists of oscillating wall at the top of fluid-filled cavity as shown in Figure.



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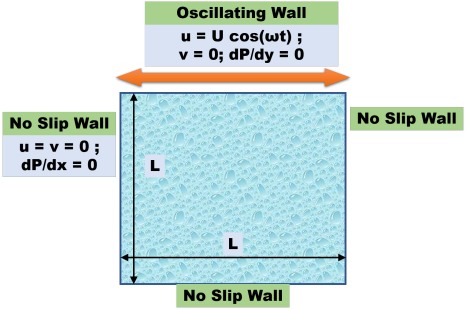

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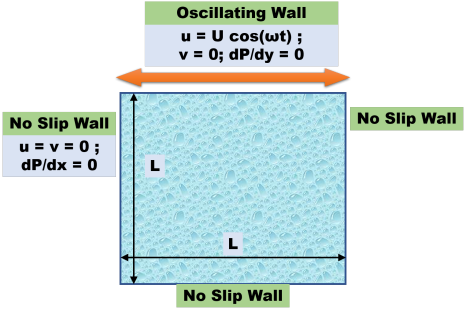

- Since the flow is periodic, icoFoam solver is used.
- Domain Size $(L) = 1$
- Frequency $(\omega) = 2\pi/6$
- Maximum Velocity $(U) = 1$
- Grid Size : 100×100
- $Re = \frac{UL}{\nu} = 100$

Steps to Execute the Solver

- Go to the Folder: /opt/openfoam7/tutorials/incompressible/icoFoam/cavity

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```
movingWall
{
    type            codedFixedValue;
    value           uniform (1.0 0 0);

    name    parabolicVelocity;
    code
    #{
            const vectorField& Cf = patch().Cf();
            const scalar t = this->db().time().value();

            vectorField& field = *this;
            const scalar Umax = 1.0;

            forAll(Cf, faceI)
            {
                    field[faceI] = vector( Umax*cos(2.0*3.142*t/6.0) , 0, 0);
            }
    #};
}
```

- In the 'system/blockMeshDict' file, change number of grid points as follows:

```
blocks
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    hex (0 1 2 3 4 5 6 7) (60 60 1) simpleGrading (1 1 1)
);
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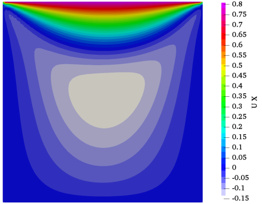
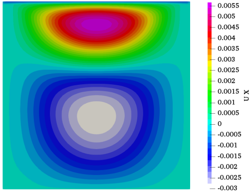
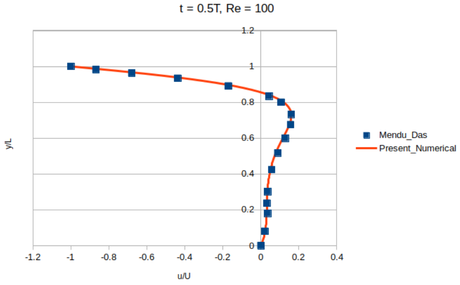
- The contours at t/T = 0.1, 0.25 look as follows :

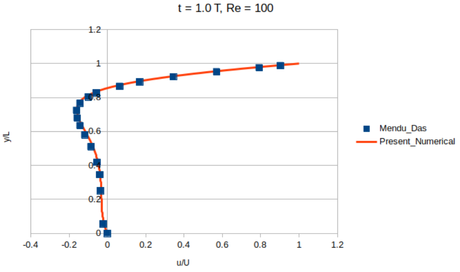




Validation of Results

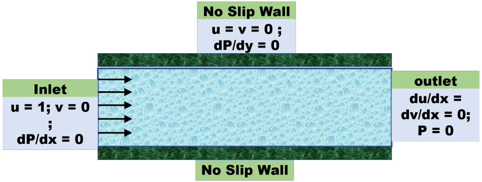
- In order to check whether correct results are obtained or not, X-velocity along vertical centerline at X = 0.5 is compared with literature [2] at different time-instants.





Problems to Try Out ... !

- To understand the implementation of grid generation and boundary conditions, following examples can be tried out:
- Flow inside a Channel:



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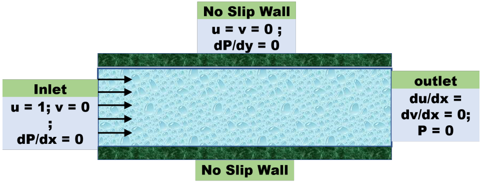
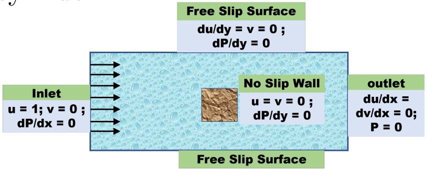


- Flow across square cylinder:



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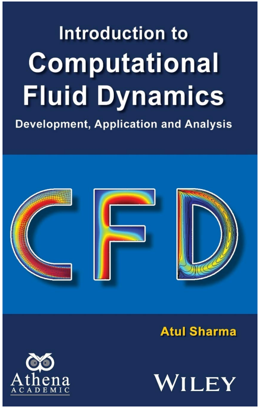
In the next lecture, we shall look into the problems involving complex geometry.

References

1. Sharma, A. (2016). Introduction to computational fluid dynamics: development, application and analysis. John Wiley & Sons.
2. Mendu, S. S., & Das, P. K. (2013). Fluid flow in a cavity driven by an oscillating lid—A simulation by lattice Boltzmann method. European Journal of Mechanics-B/Fluids, 39, 59-70.
3. https://www.openfoam.com/



Thank you for listening!

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