Summer Fellowship Report

On

CFD OpenFoam

Submitted by

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Acknowledgment

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Contents

Chapter 1

Introduction

The Fossee Fellowship 2018 brings together students from every corner of the students into a classroom to harness big steps towards development of Free Open Source Software. One such Software is 'OPENFOAM', a FOSS for Computational Fluid Dynamics. The major concern on this software is the requirement of case studies on this software so as to make the learning of this software easy and viable.

OpenFOAM:

The OpenFOAM is analogous to the professional software ANSYS. The software has many applications in the field of fluid mechanics, electromagnetics, thermodynamics, heat transfer etc. The fellowship tasks are oriented in the CFD domain of the software.

The case studies preparation is the key objective in the fellowship as the base level development of the FOSS requires understanding and working on existing modules. The CFD FOSSEE aims in bringing to light, the features of OpenFOAM through the case studies and manuals to self-learn the software.

The screening tasks involved preparation of case studies on simple CFD problems. The fellowship tasks and case studies with the OpenFOAM are discussed elaborately in successive sections.

Chapter 2

Fossee Tasks

2.1 Manuals for screening tasks

2.1.1 Simulation of Water Flow Channel Experiment

- Notched/Teethed Flameholders
- **The Experiment[1]:** The model is placed in a water channel and the recirculation behind the body is observed for the mixing efficiency of the flameholders in jet engines
- **Flow Model:** Laminar,SteadyState
- **Solver:** simpleFoam [2]
- **Inference:**
  The re-entry dynamics are studied and understood from the simulation.

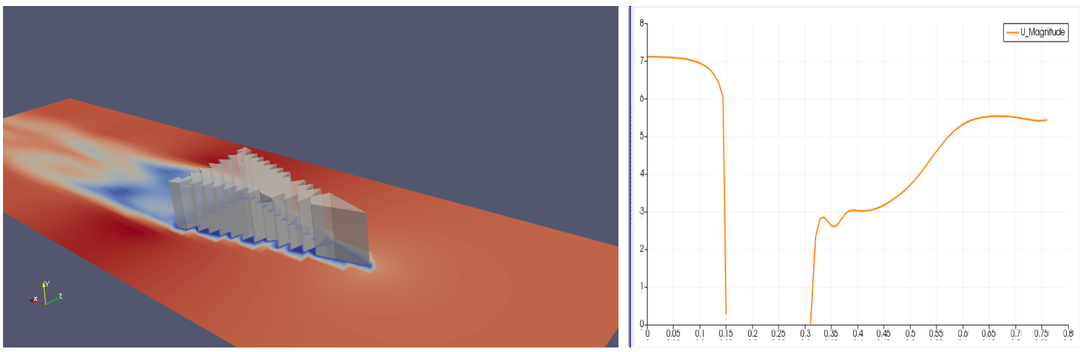
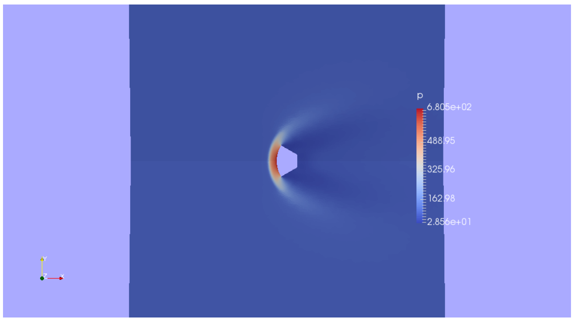
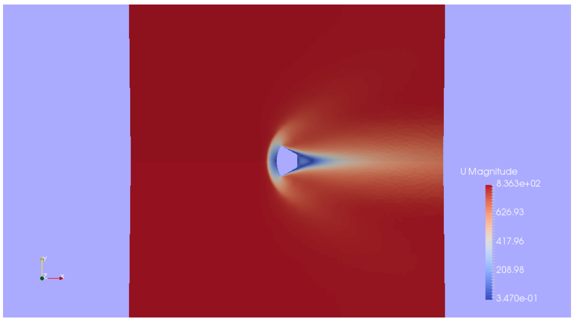


Figure 2.1: Velocity profile

2.1.2 Simulation of a re-entry vehicle

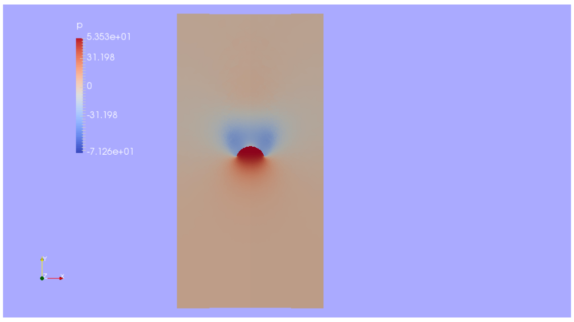
- Space X re-entry capsule
- **The Experiment:** The re-entry vehicle design of space X is obtained and simulated for inferring flight characteristics during re-entry.
- **Flow Model:** Transient State, Turbulent
- **Solver:** sonicFoam
- **Inference:**
  The re-entry is simulated and found to be efficient and safe.

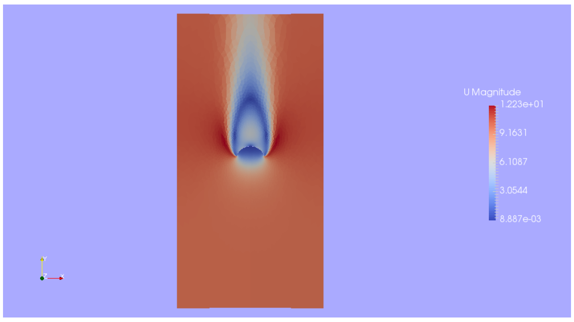




2.1.3 Simulation of a Parachute deployment

- **The Experiment:** The re-entry vehicle is tested for parachute aided landing as it enters viable atmosphere for the parachute to deploy.
- **Flow Model:** Steady State, Turbulent
- **Solver:** simpleFoam
- **Inference:**
  The idea is innovation to the development of the re-entry vehicle experiment.

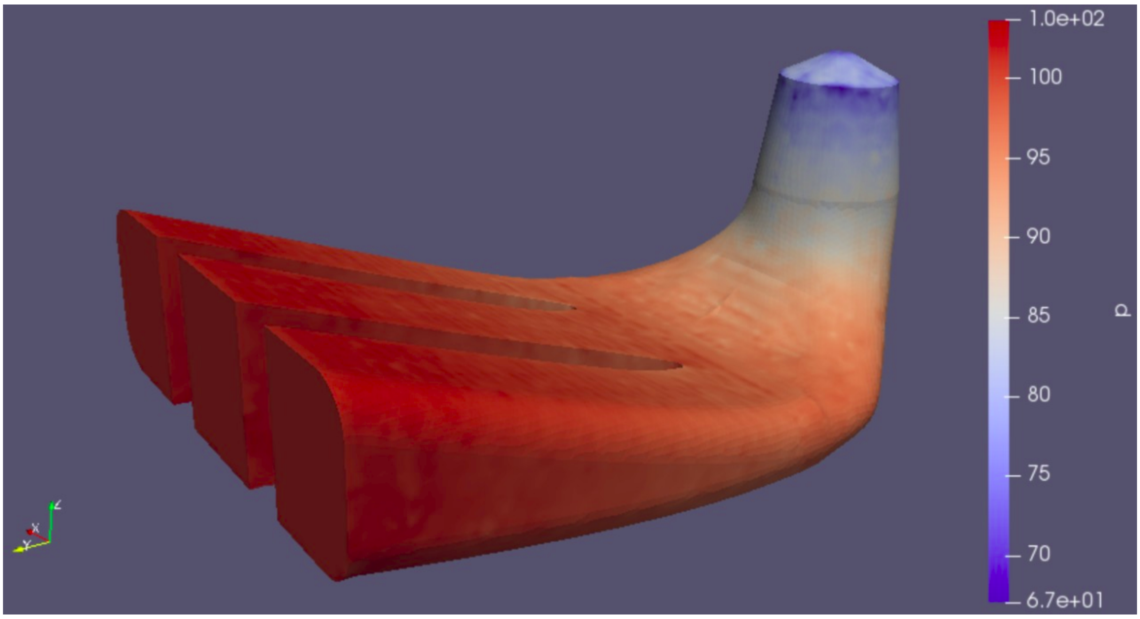




2.2 Follow up of incomplete screening tasks

The fellow participants of Fossee Fellowship Screening who were halfway through the completion of tasks were contacted and motivated to complete the case studies. The following case studies were obtained on curating the participants.

Flow in a Draft tube of Francis Turbine - simpleFoam, Arpit Jain



The simulation encountered error with improper boundary condition which was guided and rectified to get the case study complete. The study is also proposed for an upgradation from the participant.

The other case studies include:

Simulation of 2D Shocktube - rhoCentralFoam, Rohan Hari

Laminar Vortex Shedding - icoFoam, Nishant Kumar

The case directories of the above mentioned cases along with the report of each study has been obtained and added to the repository.

Chapter 3

Core Task: Simulation of Fighter Aircraft

3.1 Objective

To obtain the CAD Model of the fighter aircraft Sukhoi Su 30MKI [3] and to mesh it in any of the OpenFOAM Mesh utilities and to solve it in appropriate solver for obtaining contours of pressure over the fighter aircraft

Methdology

- Literature Review
- Obtaining Geometry in .stl file [4]
- Setting up the domain and boundary condition
- Meshing with snappyHexMesh utility
- Setting up flow model and solver
- Solution and postprocessing
- Documentation

3.2 Meshing

The case directories [5] 0, constant, system are created with appropriate sub-directories (triSurface in constant directory) and dictionaries (blockMeshDict, snappyHexMeshDict and surfaceFeatureExtractDict in system directory) .

3.2.1 Geometry

The CAD model of the fighter aircraft is obtained and is stored in the triSurface directory. General specifications of the model is listed below:

Sukhoi Su 30 MKI[2] Length: 22 m Wingspan: 15 m Hieght: 6 m

The model is scaled at 1:10 ratio to obtain the model at 1.5 m * 0.5 m * 2. 2 m

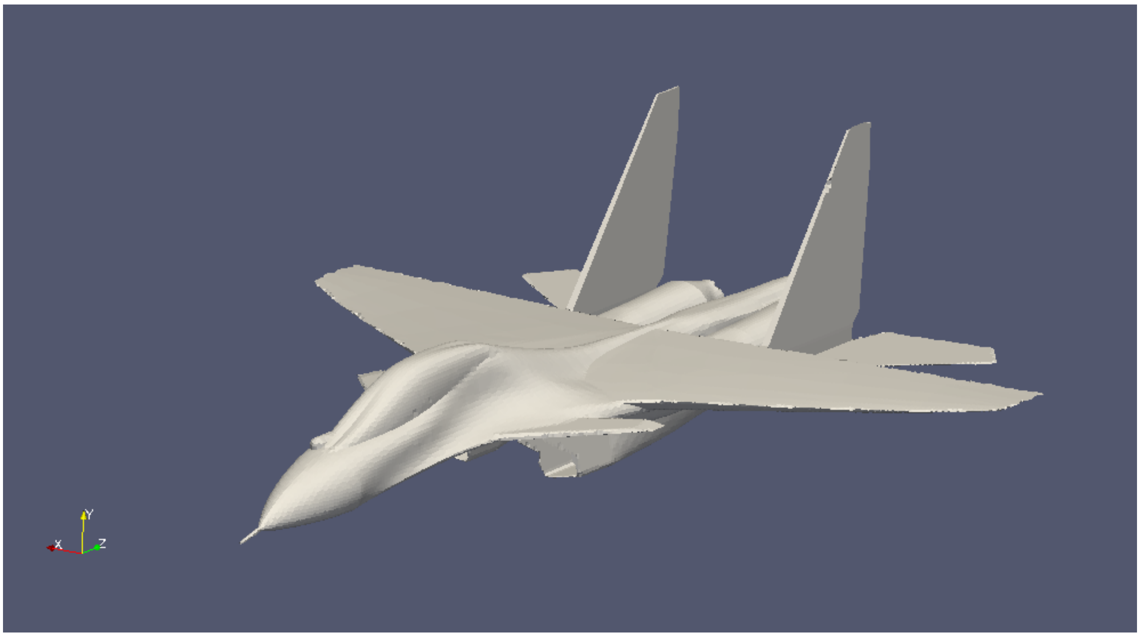


Figure 3.1: Mesh of Sukhoi

3.2.2 blockMesh

Domain Specifications:
A domain size of 5 m * 5 m * 12.5 m is designed around the model as a single block. The domain is designed with the convention[6] of 10x * 10x *(5x+15x), where x is the minimum dimension in the windward side.
Grading and refinement:
The domain is graded so as to have fine mesh around the model with AR$\bar{1}$ and courser mesh near the periphery of the domain. The grading[7] and division are done with care on smooth transitions all over the domain.

Code:

```
vertices
( ( -2.5 -2.5 -5.0) ( 2.5 -2.5 -5.0) ( 2.5 2.5 -5.0) ( -2.5 2.5 -5.0) ( -2.5 -2.5 7.5) ( 2.5
-2.5 7.5) ( 2.5 2.5 7.5) ( -2.5 2.5 7.5) );
blocks
( hex ( 0 1 2 3 4 5 6 7) ( 50 50 125)
simpleGrading            ( ((0.3 0.5 0.5)(0.4 2 1)(0.3 0.5 2))
                         ((0.4 0.75 0.5)(0.2 1 1)(0.4 0.75 2))
                         ((0.2 0.5 0.5)(0.25 1 1)(0.55 0.7 3)) ) );
```

Patches and Boundaries:

The sides, top and bottom are modelled as symmetryPlane while the inlet and outlet faces are modelled as patch.

The complete code can be viewed in the blockMeshDict in system directory.

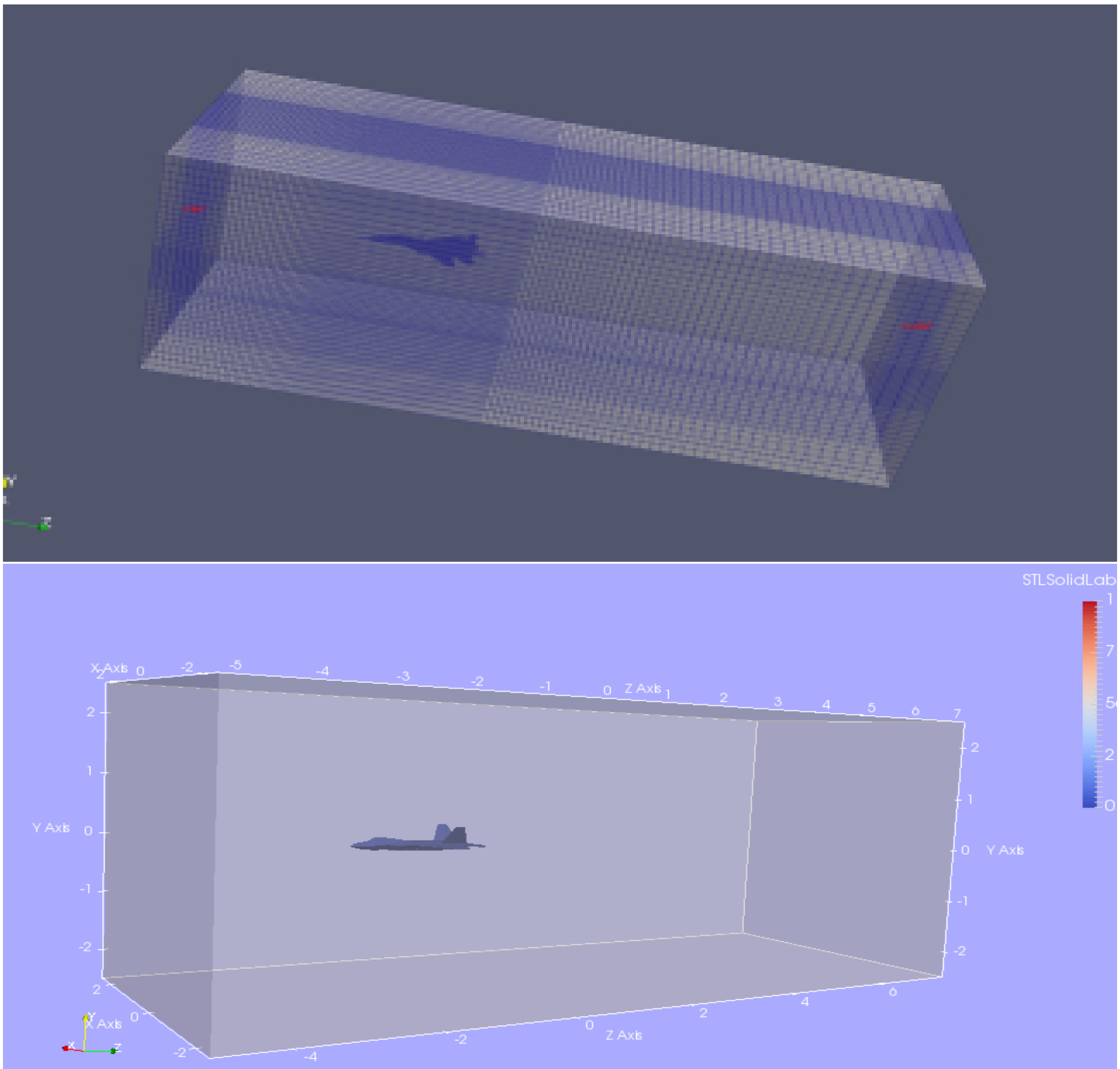


Figure 3.2: Block and Grading

3.2.3 surfaceFeatureExtract

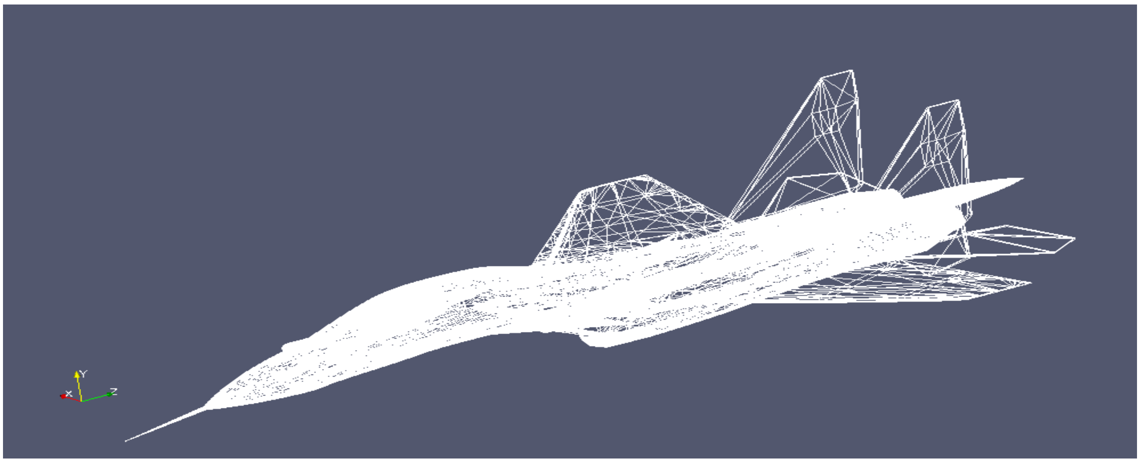


Figure 3.3: Edge Mesh

Process of sFE

This feature projects the stl file onto the domain before snappyHexMesh.
The surfaceFeatureExtractDict is set to extract all edges so as to mesh complex contours.

```
*******************************************************
extractFromSurfaceCoeffs
{
includedAngle 180; /*- 0 : selects no edges, - 180: selects all edges */
}
*******************************************************
```

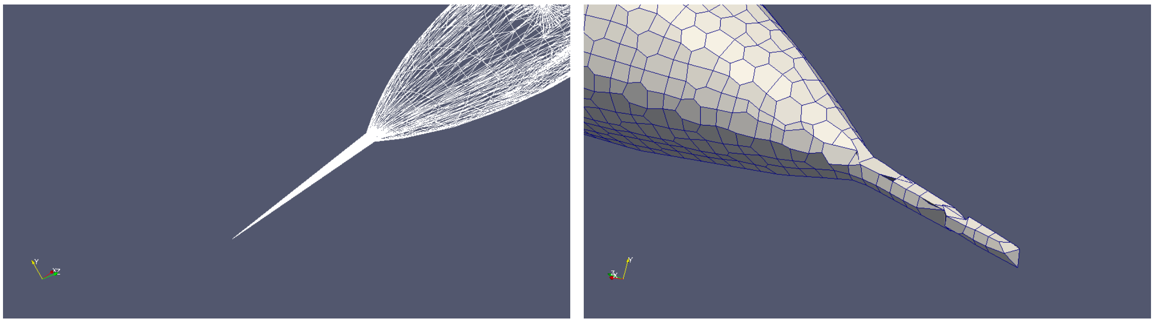


Figure 3.4: Meshing of Sukhoi Antenna

3.2.4 snappyHexMesh

The sHM utility uses the geometry file, base mesh (**blockMesh**) and the **surfaceFeatureExtract(sFE)** utility to mesh the complex contour of the fighter aircraft. The snappyHexMesh is used with the surfaceFeatureExtract utility to mesh the underlying model by following operations:

- The edges are extracted from the .stl file through the surfaceExtractFeature and is stored as sukhoi.eMesh in the triSurface directory. To run the feature, the surfaceFeatureExtractDict[5] is specified with the .stl file to operate and the settings are tuned to extracct all the edges in the .stl file i.e., the model.
- The domain detects the model and uses castelled Mesh to coarsely remove the blocks that are contained within the models outline. This is further refined upto the level specified. The refinement surfaces is set to the eMesh generated, to detect the edges, through which the castelled mesh is generated upon.
- The sHM is carried out in steps of castelledMesh, snap and addLayers so as to check compatibility of mesh.
- The sHM dictionary is set with refinements of level 4 to obtain intricate contours of aircraft.

```
castellatedMeshControls
{
    features
    (
            {
            file "sukhoi.eMesh";
            level 4;
            }
    );
    refinementSurfaces
    {
        sukhoi
        {
            level ( 3 4 );
            patchInfo
            {
            type wall;
            inGroups (sukhoi);
            }
        }
```

The **Mesh statistics** are obtained from the checkMesh utility as follows:

```
Mesh stats
    points:           601756
    faces:            1572033
    internal faces:   1449903
    cells:            485280
    faces per cell:   6.227200791
    boundary patches: 7
    point zones:      0
    face zones:       0
    cell zones:       0

Overall number of cells of each type:
    hexahedra:     450168
    prisms:        0
    wedges:        0
    pyramids:      0
    tet wedges:    0
    tetrahedra:    0
    polyhedra:     35112
    Breakdown of polyhedra by number of faces:
        faces   number of cells
            6   8084
            9   19414
           12   5673
           15   1790
           18   133
           21   18

Checking topology...
    Boundary definition OK.
    Cell to face addressing OK.
    Point usage OK.
    Upper triangular ordering OK.
    Face vertices OK.
    Number of regions: 1 (OK).
```

```
Checking topology...
    Boundary definition OK.
    Cell to face addressing OK.
    Point usage OK.
    Upper triangular ordering OK.
    Face vertices OK.
    Number of regions: 1 (OK).

Checking patch topology for multiply connected surfaces...
                   Patch    Faces   Points                  Surface topology
                   inlet     2500     2601  ok (non-closed singly connected)
                  outlet     2500     2601  ok (non-closed singly connected)
                  bottom     6250     6426  ok (non-closed singly connected)
                     top     6250     6426  ok (non-closed singly connected)
                    port     6250     6426  ok (non-closed singly connected)
               starboard     6250     6426  ok (non-closed singly connected)
            sukhoi_solid0   92130    92293  multiply connected (shared edge)
  <<Writing 2 conflicting points to set nonManifoldPoints

Checking geometry...
    Overall domain bounding box (-2.5 -2.5 -5) (2.5 2.5 7.5)
    Mesh (non-empty, non-wedge) directions (1 1 1)
    Mesh (non-empty) directions (1 1 1)
    Boundary openness (-3.794617074e-18 -1.086483404e-17 -4.336733923e-18) OK.
    Max cell openness = 2.602085214e-16 OK.
    Max aspect ratio = 1 OK.
    Minimum face area = 3.90625e-05. Maximum face area = 0.01.  Face area magnit
udes OK.
    Min volume = 2.44140625e-07. Max volume = 0.001.  Total volume = 312.4484551
.  Cell volumes OK.
    Mesh non-orthogonality Max: 25.23940182 average: 7.973579209
    Non-orthogonality check OK.
    Face pyramids OK.
    Max skewness = 1 OK.
    Coupled point location match (average 0) OK.

Mesh OK.

End
```

Figure 3.5: Mesh Check

3.3 Governing Equations

- It is intended to solve the standard governing fluid equations in an Eulerian frame of reference:
- Mass consrevation

$$\frac{\delta \rho}{\delta t} + \Delta.(\rho U) = 0$$

- Conservation of momentum (neglecting body forces)

$$\frac{\delta \rho U}{\delta t} + \Delta.(\rho U U) = \Delta p + \Delta.\tau$$

where ρ is the mass density, U the fluid velocity, p the pressure and τ is the viscous stress tensor. Following the assumption proposed by Boussinesq the stress tensor can be represented by:

$$\tau = 2\mu dev(D)$$

μ is the dynamic viscosity, D = $\frac{1}{2}[\Delta U + (\Delta U)^T]$ is the deformation gradient tensor and dev(D) = D $\frac{1}{3}$ tr(D)I is its deviator component. I is the unit tensor.

3.4 The Solver

- The Mesh for Sukhoi Su 30 MKI is generated.The mesh is set to be solved with sonicFoam as it is suitable for compressible supersonic flow simulations.
- **sonicFoam :** a transient solver for trans-sonic/supersonic, turbulent flow of a compressible gas.
- Verification of the solver :To check if the solver chosen and conditions fed are compatible for the simulation, the case of a cylinder at Mach 2 is simulated and validated.
- Both the cases of the Cylinder and the Sukhoi are discussed.

3.5 Simulation of the cylinder

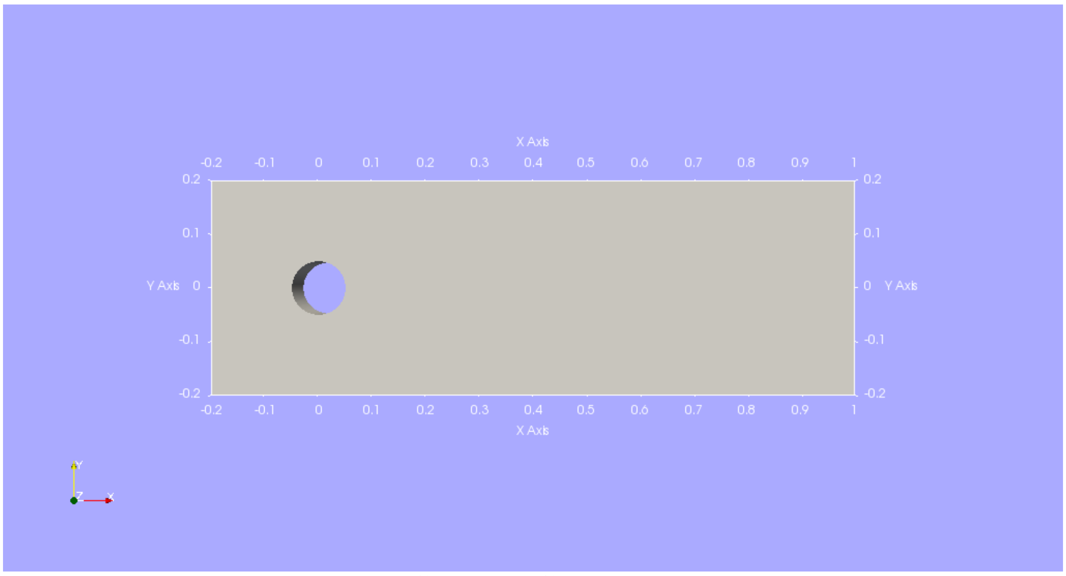


Figure 3.6: Cylinder:Computaion Domain

Domain size : 1.2 m * 0.4 m * 0.05 m.
The diameter of the cylinder is 0.1 m. The length aft the cylinder is 10d, and the length before the cylinder is 2d.

Mesh Quality -

Cells : 42400

Maximum Aspect Ratio : 7.9

Maximum Skewness : 0.577 The cylinder is set in compressible flow conditions at

Mach 2. The simulation is carried out in sonicFOAM and the vortex shedding characteristics are observed. The simulation corresponds with the actual case and hence the solver chosen is deemed accurate for the simulation of Sukhoi. The simulation is discussed as follows.

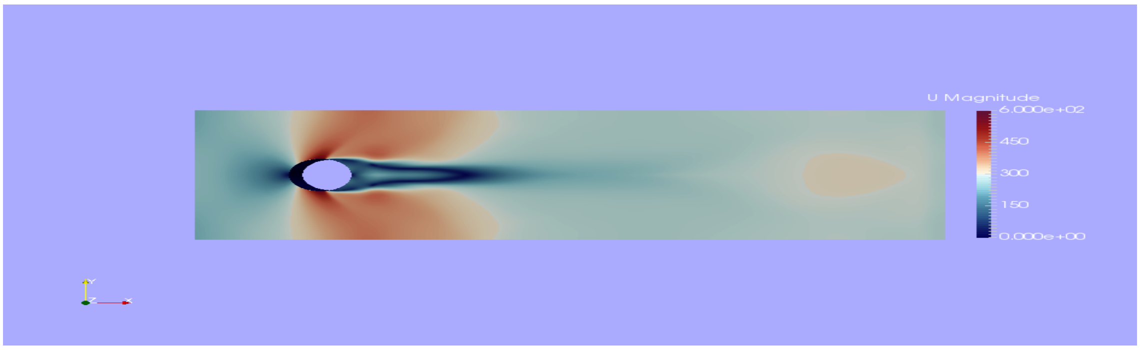


Figure 3.7: t = 0.002

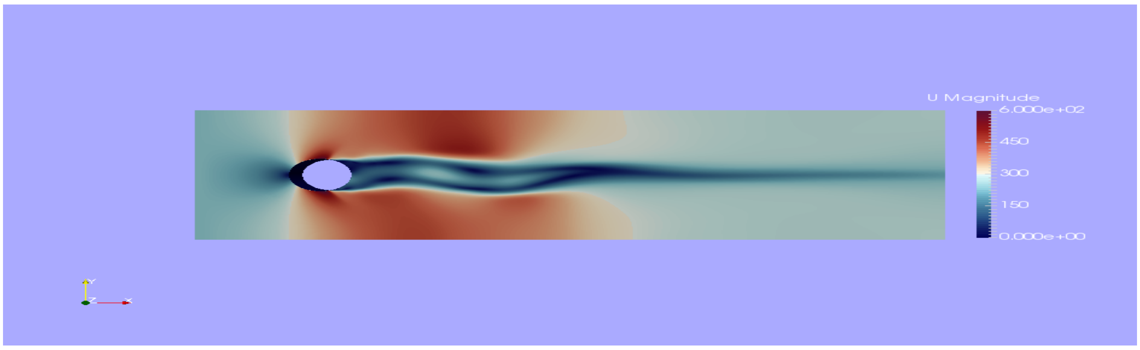


Figure 3.8: t = 0.005

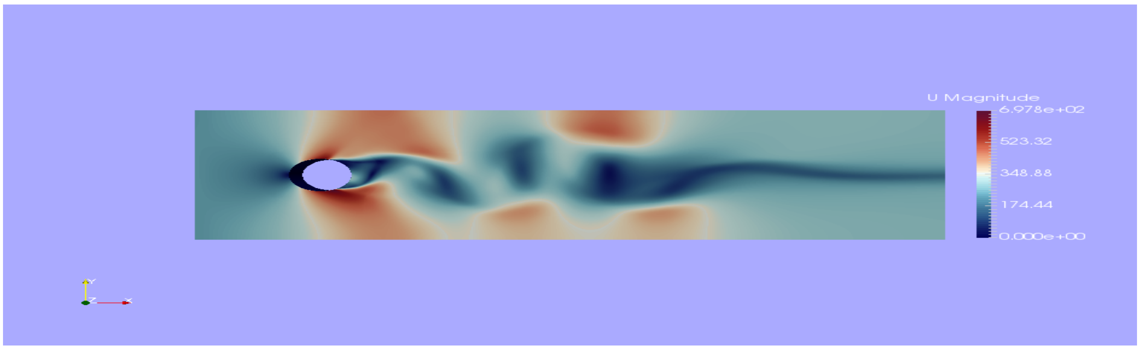
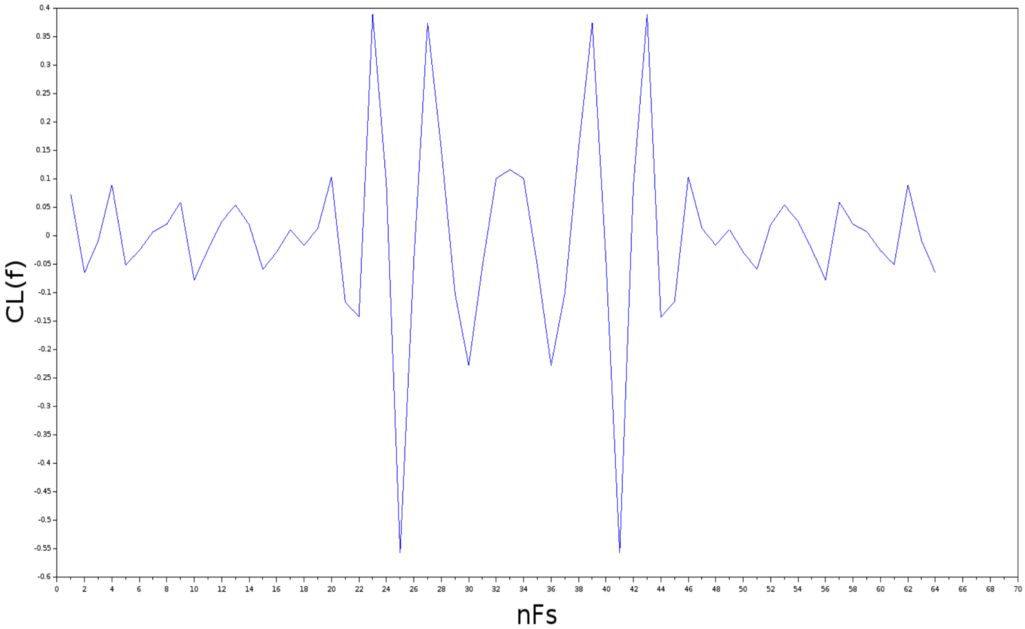
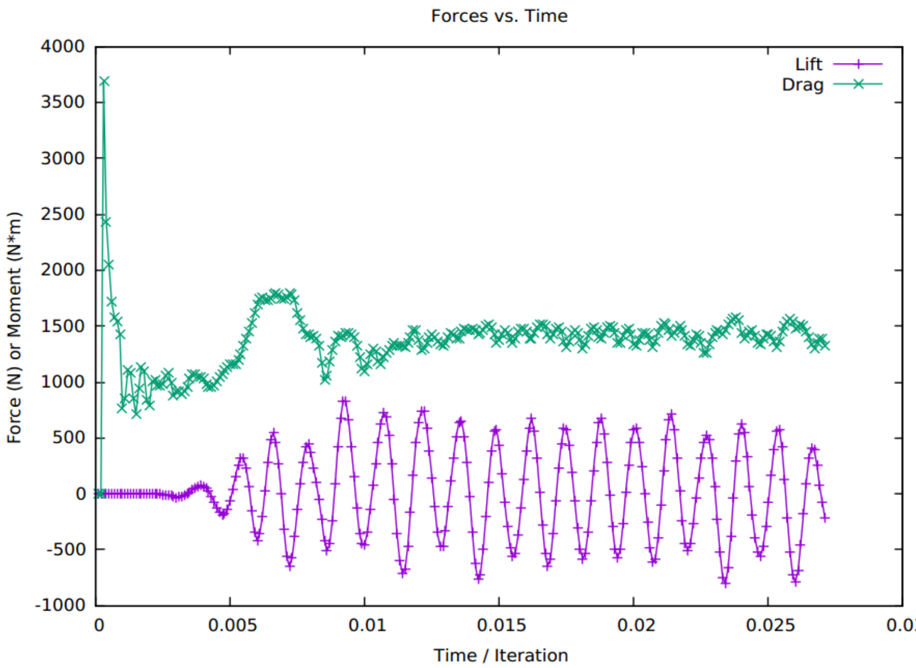


Figure 3.9: t = 0.006

Figure 3.10: Simulation of vortex shedding in cylinder : compressible flow





The above images correspond to the vortex shedding frequency and strouhal number calculations which are evidently validating the cylinder case.

3.6 Solving for Sukhoi

The system folder is updated with the fvSchemes and fvSolution files from sonicFoam cylinder reference case and controlDict is written with time step 1e-6 and force coefficient functions. The transport properties and turbulence Properties are also updated in constant folder with nu 1e-5 and laminar simulation respectively.

3.6.1 Boundary Conditions

Boundary	Pressure	Velocity
• Inlet	Total Pressure	zeroGradient
• Outlet	zeroGradient	zeroGradient
• Top, Bottom, Sides	symmetryPlane	symmetryPlane
• Sukhoi	zeroGradient	noSlip

3.6.2 Flow Conditions

Mach Number	1.5
Fluid	Air at STP
Model	Laminar, Incompressible, Transient

3.7 Postprocessing

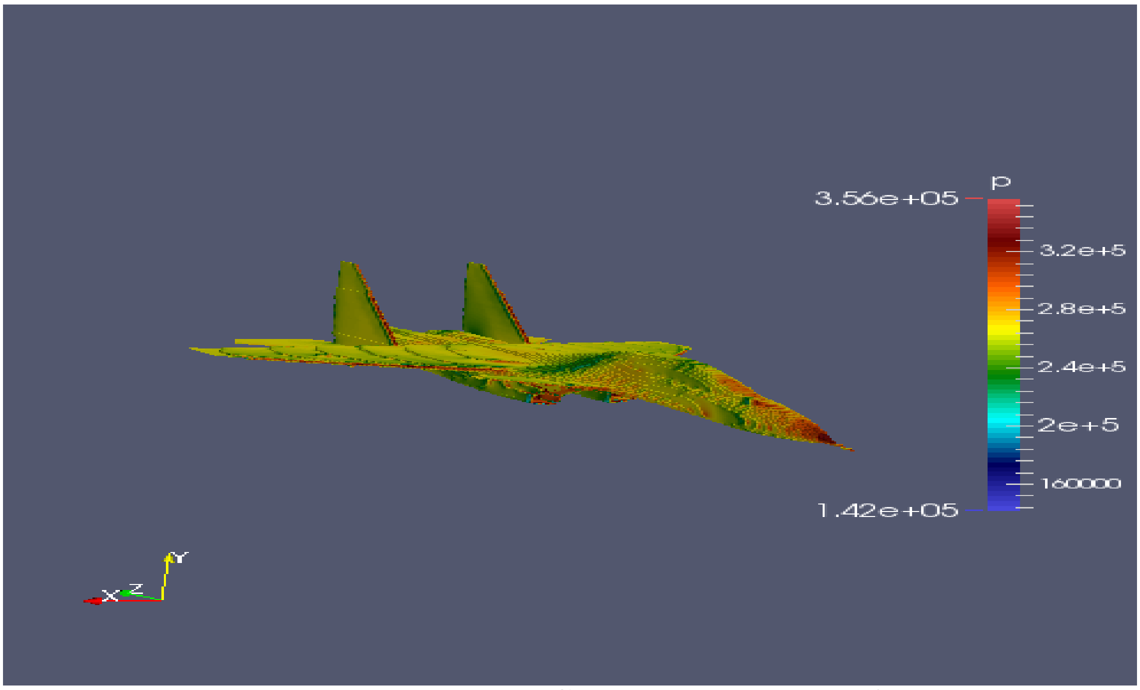


Figure 3.11: Pressure Contour over the aircraft

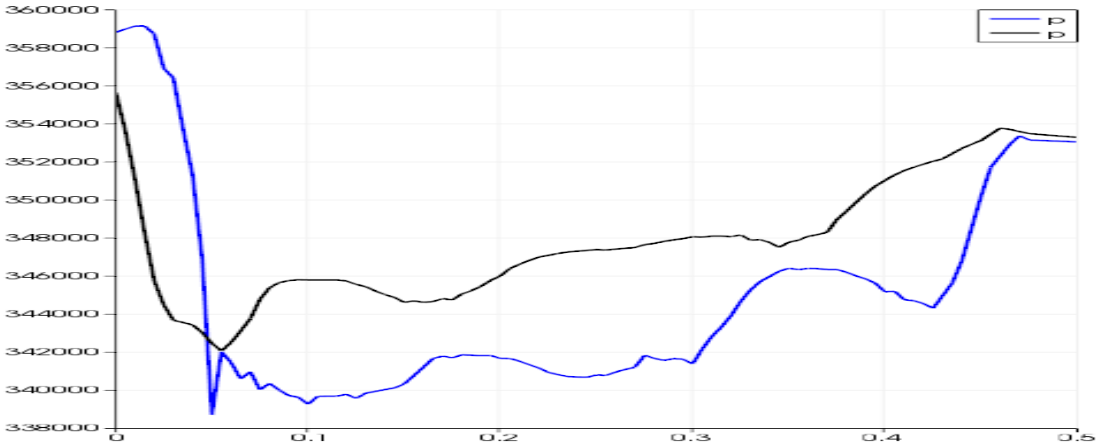


Figure 3.12: Pressure plot over the wing

The plots indicate that the simulation is in coherence with the general aspects of flight. The simulation is to be updated for further studies on compressible aerodynamics of the fighter aircraft.

3.8 Results

- The simulation is not complete. The case being a 3D Supersonic Case, the computation time is long.
- After the completion of updated simulation, plots on drag forces shall be obtained and validated.
- The case can also be developed to compare with a similar simulation of other fighter aircraft and efficiency of one over other can be studied.

Chapter 4

Summary

- The Manuals prepared shall be used by students to experiment real time and innovative cases in OpenFOAM
- The follow up on fellow participants have been so welcoming and was profitable in gaining knowledge from both ends. The participants were motivated for submission of more case studies.
- The Simulation of Fighter Aircraft helped in getting immense insight on the OpenFOAM skeleton- complex mesh, supersonic flow simulation.
- Future Works
  - Documenting the core task
  - Comparison of the Sukhoi aircraft simulation with Lockheed F22 aircraft
  - Working on implementing case specific solvers and generaing new CFD Modules in OpenFOAM

Reference

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