# A STUDY ORIENTED PROJECT REPORT ON

## “Study of Fluid Structure Interaction of incompressible flow past turbine flap”

**STUDY PROJECT (ME F266)**

Submitted to

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By

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## ABSTRACT

We investigate turbine blade aerodynamics with the help of computational fluid dynamics (CFD) and finite element analysis (FEA) based fluid structure interaction study. It requires the knowledge of the concept from Fluid Structure interaction, computational solid mechanics and computational fluid dynamics. We use the open source solver called solids4foam for this purpose. Solids4foam is a toolbox based on OpenFOAM with capabilities of solving FSI problems. The motion of a small turbine blade due to the pressure and viscous forces generated by high speed incompressible flow is studied. Simulation result comprises 39 frames of data from 0 to 0.0039 sec. Fluid model is icoFluid and solid is considered to be linearly elastic. Most of the analysis is a comparison between initial condition at 0 sec and final condition at 0.0039 sec.


## TABLE OF CONTENT

## Governing equations:

For Fluid- We assume incompressible Newtonian isothermal laminar flow, where theNavier-Stokes governing equations take the form:

$$\nabla \cdot \boldsymbol{v} = 0$$

$$\frac{\partial \boldsymbol{v}}{\partial t} + \nabla \cdot (\boldsymbol{v}\boldsymbol{v}) = \nu \nabla^2 \boldsymbol{v} - \frac{1}{\rho}\nabla p + f_b$$

Solid: we assume finite strains (though a small strain assumption would be OK in this case) with the material behaviour described by the neo-Hookean hyperelastic law:

$$\rho \frac{\partial^2 \boldsymbol{u}}{\partial t^2} = \nabla \cdot \boldsymbol{\sigma} + \rho \boldsymbol{g} \qquad \boldsymbol{\sigma} = \frac{1}{J}\left[\frac{K}{2}(J^2 - 1)\mathbf{I} + \mu J^{-\frac{2}{3}} \mathrm{dev}[\boldsymbol{F} \cdot \boldsymbol{F}^T]\right]$$

$$\boldsymbol{F} = \mathbf{I} + (\nabla_0 \boldsymbol{u})^T \qquad J = \det[\boldsymbol{F}]$$

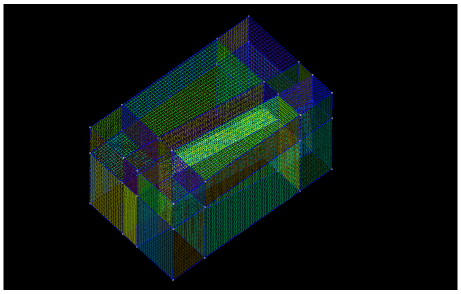
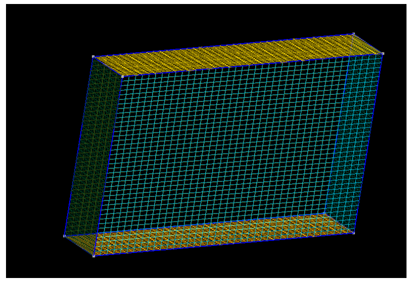
**Conditions at Fluid-Solid Interface:**

Kinematic conditions state that the velocity and displacement must be continuous across the interface:

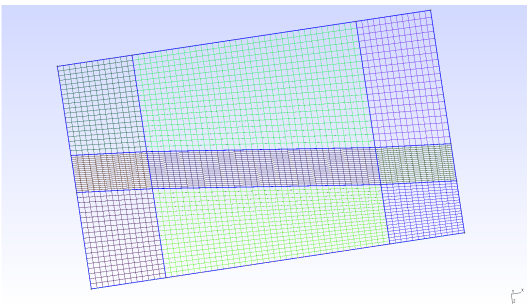
$$\boldsymbol{v}^{[i]}_{\text{fluid}} = \boldsymbol{v}^{[i]}_{\text{solid}} \qquad \boldsymbol{u}^{[i]}_{\text{fluid}} = \boldsymbol{u}^{[i]}_{\text{solid}}$$

## Geometry of turbine flap and constructing mesh:

Mesh was constructed in GMSH. We used a structured cartesian grid to match the solid and liquid interface. The fluid region has the dimension of 50×30×30 $cm^3$. Turbine flap is in a parralellopie shape with rectangular right and left face ( 30 cm base and 20 cm height), top and bottom were parallelograms with 4.86 cm height, 30 cm base and 5 cm slant side length.

Turbine flap is kept 10 cm from inlet as shown in figure below. Fluid region was divided into 8 volumes excluding the cavity for turbine flap.



## Properties of Fluid and turbine flap

Linear elastic model is used for solid turbine flap. A linear elastic material can be seen as the generalisation of Hooke's law for a spring. Young's modulus of material is $10^4\ N/m^2$ .Density of material is 1000 $kg/m^3$ . Poisson's ratio of material is 0.4. Kinematic viscosity of fluid is $10^{-3}m^2/s$, and density of fluid is 1000 $kg/m^3$. Initial velocity of fluid at inlet is 2 m/s. Flow is considered to be laminar and incompressible, we are using icoFluid model for fluid. Bottom of the solid part (flap) is considered to be fixed.

## Variation of Pressure

Initially Pressure is considered to have fixed value i.e 0, everywhere. Fig 1 shows the variation of pressure at a horizontal plane which cuts through the centre of the turbine flap at 0.0001 sec. At 0.018 m from inlet we got the highest pressure of 70.92 Pa. Fig 2 shows variation of pressure at a horizontal plane which cuts through the centre of the turbine flap at 0.0039 sec, we can see that pressure is oscillating from the graph, it gets damped as we go further from inlet, it takes the highest value of 12.17 Pa at 0.0178 m from the inlet.

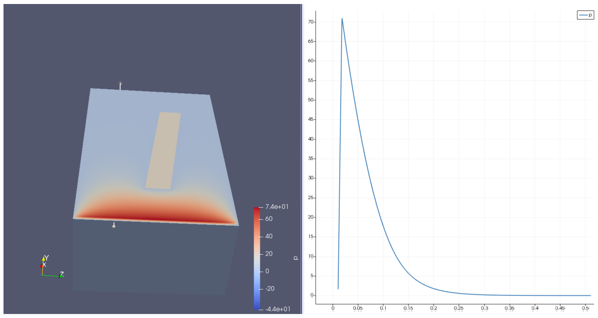


Fig 1

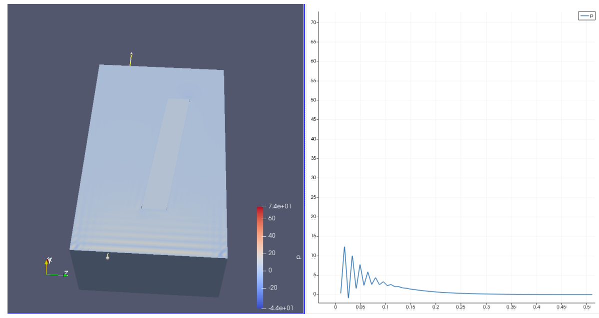


Fig 2

Fig 3 shows the variation of pressure at 0.0001 sec on a vertical plane parallel to the inlet wall and at 0.1 m from it (same position at which flap it kept from the inlet wall). The orange line in the graph shows the variation of pressure. We get maximum pressure of 12.88 Pa at 0.064 m from the left wall, the same behaviour is seen on the other side of the flap.

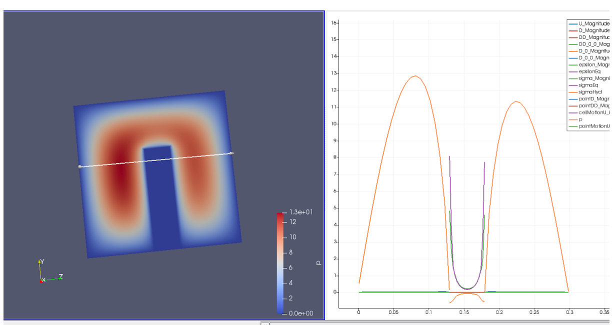


Fig 3

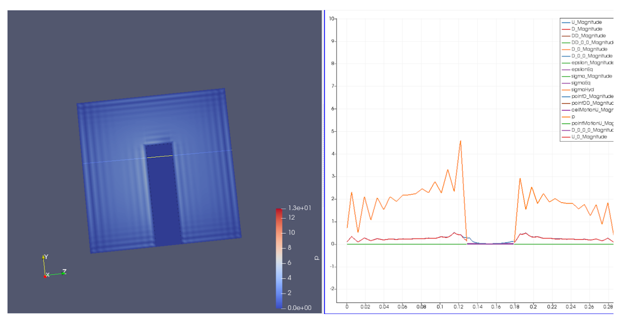


Fig 4

Fig 4 shows the variation of pressure at 0.0039 sec. We see oscillating behaviour of pressure with its amplitude increasing as we go outward and inward from a particular set of points which have steady pressure. These points can be seen at 0.064 m from the left wall and 0.061 m from the right wall.

## Variation of velocity

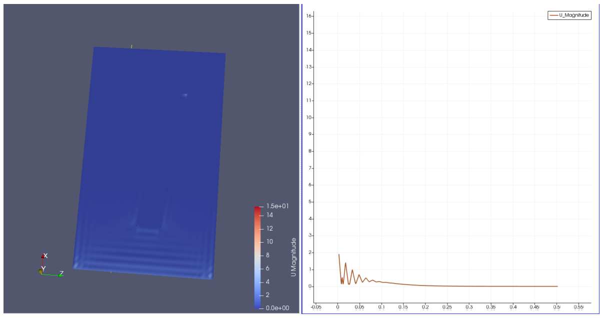


Fig 5

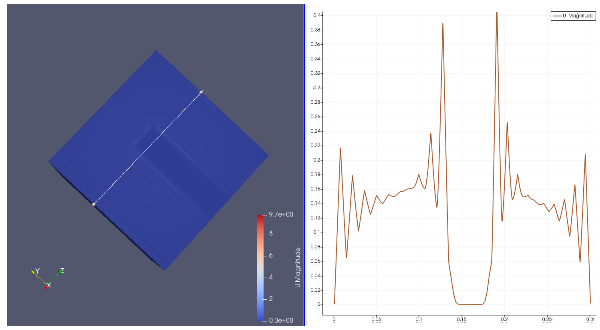


Fig 6

Fig 5 shows variation of velocity at a horizontal plane which cuts through the centre of the turbine flap at 0.0039 sec. We can see that the value of velocity is oscillating, its amplitude gets damped as we go away from the inlet wall. Maximum value is 2 m/s at inlet. We also get oscillating values of Velocity as we go from right to left wall as shown in the graph below.

Fig 6 shows variation of velocity along the line on the vertical plane which is used in Fig 4 at 0.0039 sec. Velocity also shows similar variation as pressure shown in Fig 4. 0.392 m/s is the peak velocity amplitude of fluid left of turbine flap, and 0.44 m/s is the peak velocity amplitude of fluid right of turbine flap.

## Deformation in turbine flap

From the figure we can find that flap edges of face facing fluid flow, have suffered the most deformation. The value of deformation is Oscillating as we go from base to top of the front face.

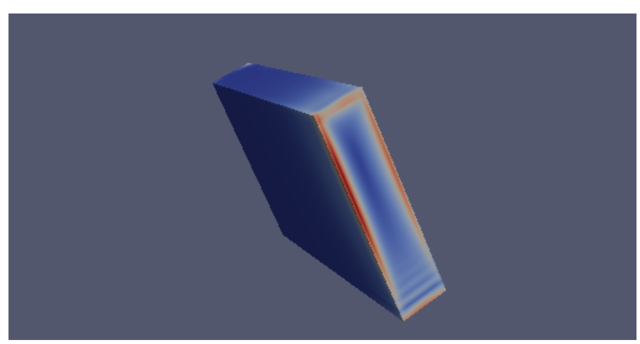


Fig 7 shows the variation of displacement on the left edge of the face facing towards fluid flow. Initially at bottom of the edge, displacement values are oscillating, as we can see from the graph, then the value starts to increase, the maximum displacement is 0.000558 m at 0.1483 m from the bottom of the flap, then value starts to decrease and towards the top of flap we get a local maximum and minimum.

Beside from the edges of the front face of the flap, we also get deformation at the right edge of the face of the turbine which is facing the outlet wall in Fig 8 at 0.0039 sec. Value Deformation gradually starts to increase and hits the maximum of 0.000296 m at 0.0063 m from the bottom. Then we get a local minimum at 0.1 m from bottom of edge, followed by a local maximum of 0.000357m at 0.1259m from bottom of edge. Top part of the edge suffers maximum deformation of 0.000612m. After analysing all the values of deformation in flap, we can conclude that 0.000612 m is the maximum deformation suffered by flap.

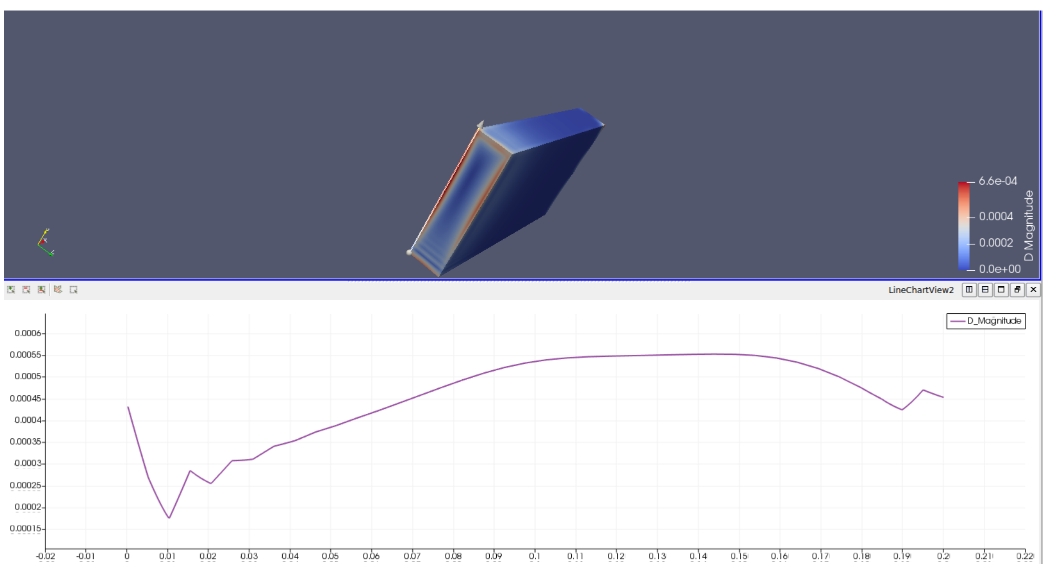


Fig 7

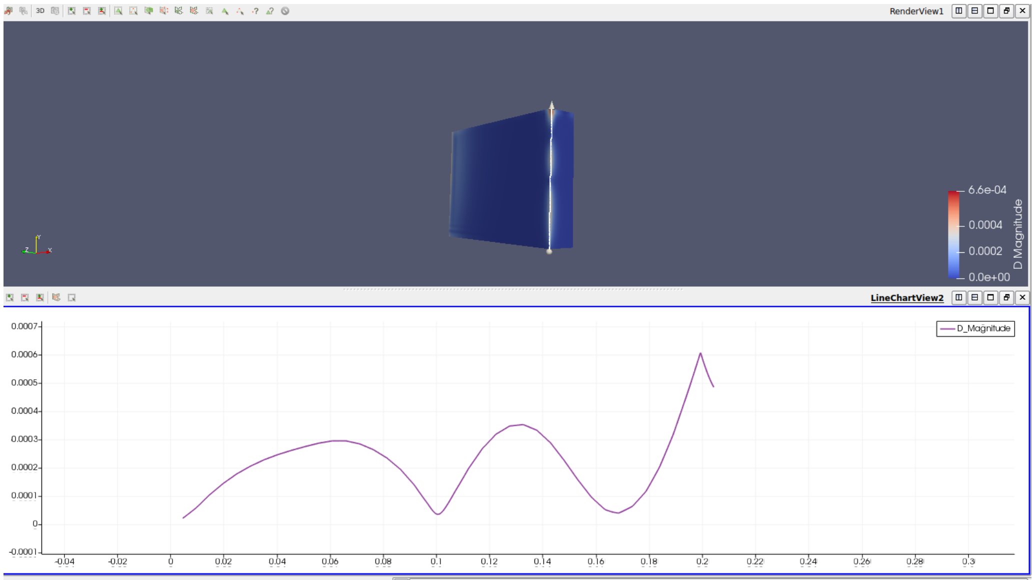


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Fig 8