Study of flow around a Re-entry Space Capsule and a parachute using OpenFOAM

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Abstract — This report aims to describe the flow simulation around a re-entry space capsule entering the Earth's atmosphere at a speed of 825 m/sec and the flow simulation around a parachute which is deployed at 10m/sec. The geometry taken for both the cases is axi-symmetrical in a wedge domain.

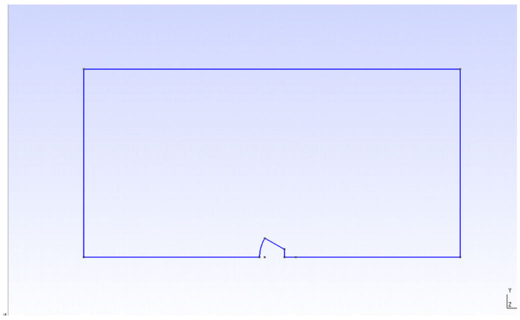
SIMULATION OF A RE-ENTRY SPACE CAPSULE

INTRODUCTION

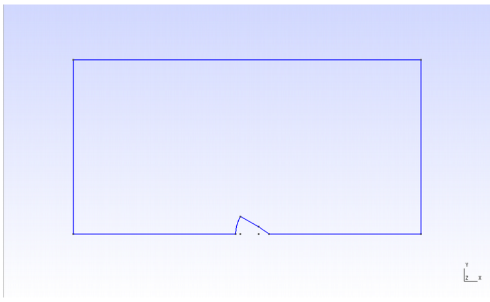
A space capsule contains cargo varying from humans of Earth to utilities for the International Space Station. A study of the flow around the space capsule is necessary to understand and compare different designs in terms of drag force and coefficient of drag.

Geometry

Two geometries are created using Gmsh(2.10.1). The total length of the geometry(1) is 0.13 m and that of geometry(2) is 0.19m. Both have a shield radius of 0.19 m.



Geometry(1)

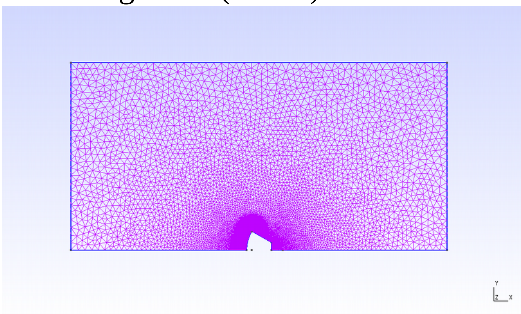


Geometry(2)

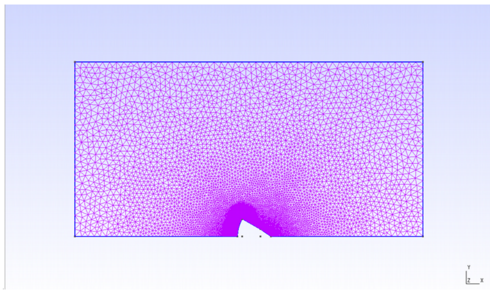
The geometries have been made in an axi-symmetrical manner (wedge domain) for fater computation.

Mesh

An unstructured 1D, 2D, 3D mesh was created using Gmsh(2.10.1).



Mesh of Geometry(1)



Mesh of Geometry(2)

Boundary Conditions

The following boundary conditions are used

1. Inlet (Supersonic Inlet)
2. Outlet
3. Vehicle (Wall)
4. Wedge 1 and Wedge 0
5. Tunnel (Slip)

The inlet velocity is 825 m/sec (Mach 2.5) in the X-dir with a pressure of 70 Pascals and a temperature of 270K.
These values were taken considering the atmosphere at around 60-80 km above sea level.

Turbulence

K-ε turbulence model has been used. K and ε have been calulated using the formula below:

$$k = \frac{3}{2}(I \times U)^2$$

$$\varepsilon = \frac{0.09^{075} \times k^{1.5}}{L}$$

where I -Turbulent Intensity
U – Mean Flow Velocity
L – Reference Length Scale

$$\varepsilon = 35000 \frac{m^2}{sec^3}$$

$$k = 1000 \frac{m^2}{sec^2}$$

Solver

Since the case is in supersonic conditions with high turbulence and speed, sonicFoam of OpenFOAM is used.

The simulation runs for a time of 0.003 seconds with a DeltaT of 3e-07.

To calculate the coefficient of drag and lift, the follwing codes were added to the controlDict file of the case :

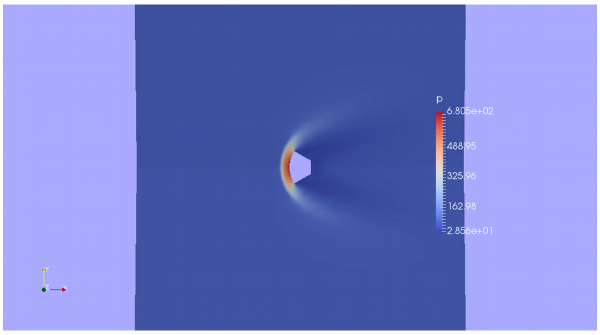
```
functions
{
        forceCoeffs1
        {
                type            forceCoeffs;
                libs            ("libforces.so");
                writeControl    timeStep;
                writeInterval   10;
                log             true;
                patches         (vehicle);
                rhoName         rhoInf;
                rhoInf          9.77e-4;
                liftDir  (0 1 0);
                dragDir         (1 0 0);
                CofR            (0 0 0);
                pitchAxis       (0 0 1);
                magUInf         825;
                lRef            0.19;
                Aref            0.5;
        }
}
```

ANALYSIS

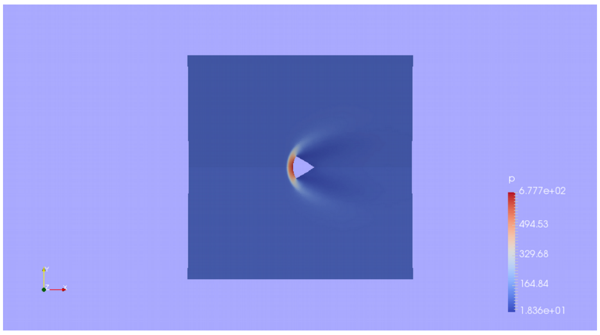
The Coefficient of lift, drag and moment are the important characteristics to study.

For Gemetry 1 -
Coefficient of Lift : -0.627911
Coefficient of Drag : 1.33293
Coefficient of Moment : -0.534953

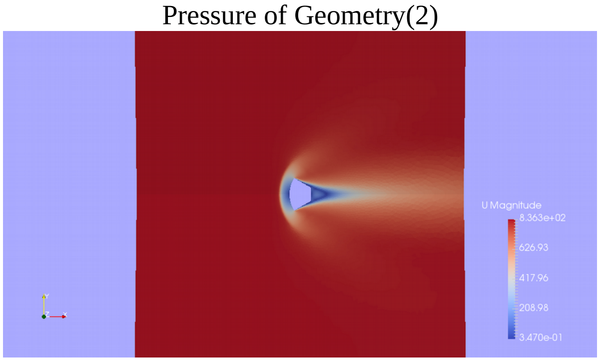
For Gemetry 2 -
Coefficient of Lift : -0.65399
Coefficient of Drag : 1.33002
Coefficient of Moment : -0.556915



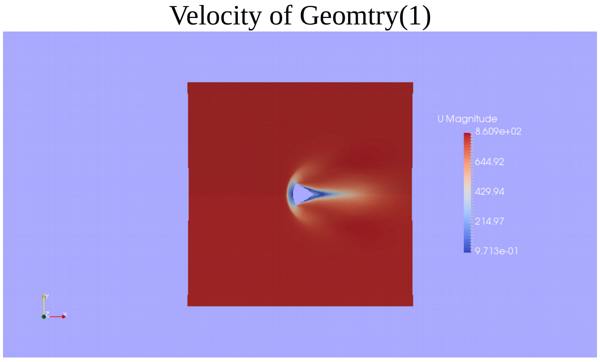
Pressure of Geometry(1)



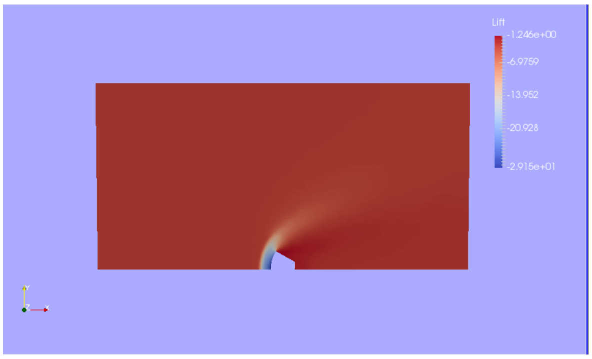
Pressure of Geometry(2)



Velocity of Geomtry(1)



Velocity of Geometry(2)



Lift

RESULT

The flow analysis around the space capsule was studied for two different geometries, and the coesfficient of lift, drag, and moment were compared between the two designs.

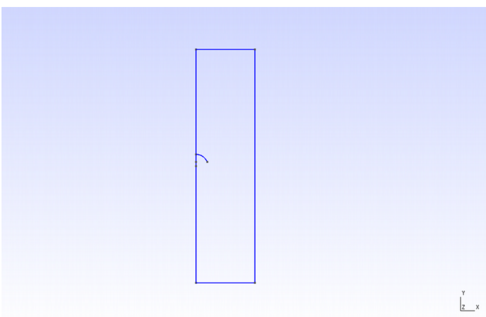
SIMULATION OF A PARACHUTE

INTRODUCTION

“All things that go up will evantually come down.” Since highly sensitive equipments are coming from space back to the Earth at supersonic speeds, it is required to deploy a parachute for the free-falling object to slow down and land safely. Hence a study of the parachute in determining the drag and the time taken for the object to fall on the surface is required, and this can be achieved through the flow analysis.

Geometry

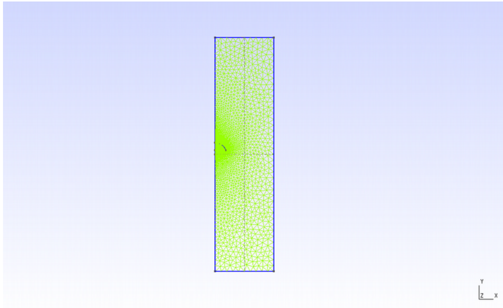
The geometry was created using Gmsh. The total diameter of the parachute is 2 m. The geometry has been made in an axi-symmetrical way (wedge domain) for faster computation.



Geometry

Mesh

An unstructured 1D, 2D, 3D mesh was created using Gmsh.



Mesh

Boundary Conditions

The wedge domain has the following boundaries:

1. Inlet
2. Outlet
3. Parachute
4. Wedge 1 and Wedge 0
5. Tunnel

The inlet velocity is 10 m/sec in the Y-dir.

Turbulence

K-ε turbulence model has been used. K and ε have been calulated using the formula below:

$$k = \frac{3}{2}(I \times U)^2$$

$$\varepsilon = \frac{0.09^{075} \times k^{1.5}}{L}$$

where I -Turbulent Intensity
U – Mean Flow Velocity
L – Reference Length Scale

$$\varepsilon = 0.000765 \frac{m^2}{sec^3}$$

$$k = 0.00325 \frac{m^2}{sec^2}$$

Solver

The flow is subsonic and the air is incompressible, hence simpleFOAM of the OpenFOAM solver has been used.

The study is of the simulation of the parachute with the space capsule for a time of 3000 seconds and a deltaT of 1.

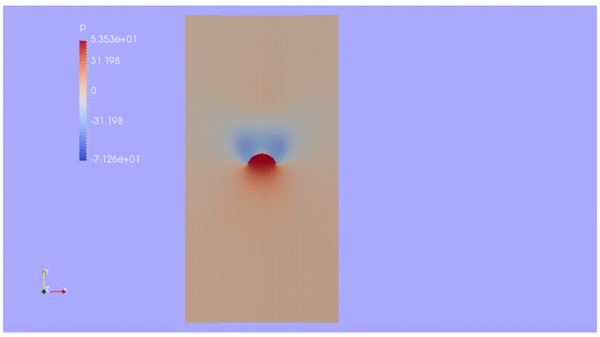
For calulating the coefficients of drag, lift and moment, the following codes wereadded to the ControlDict file of the case:

```
functions
{
   forceCoeffs1
   {
      type          forceCoeffs;
      libs          ("libforces.so");
      writeControl    timeStep;
      writeInterval   10;
      log           true;
      patches         (parachute);
      rho           rhoInf;
      rhoInf          1.18;
      liftDir         (1 0 0);
      dragDir           (0 1 0);
      CofR            (0 0 0);
      pitchAxis         (0 0 1);
      magUInf           10;
      lRef          1.0;
      Aref          0.0436;
   }
}
```

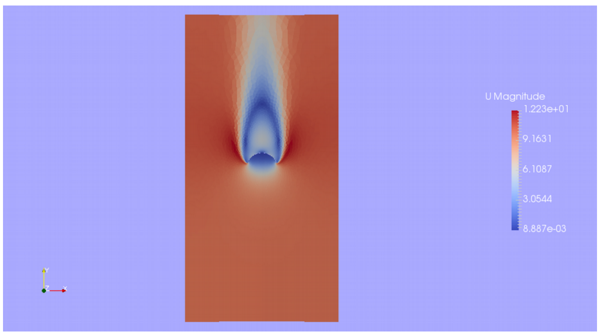
ANALYSIS

The Coefficient of lift, drag and moment are the important characteristics to study.

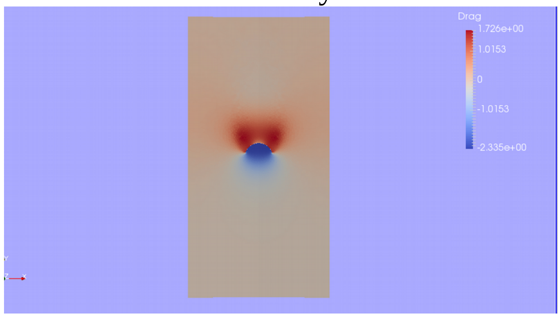
The following contours were observed through Paraview :



Pressure



Velocity



Drag

Drag Force : 1.6837 N

Coefficient of Drag : 1.4541193285

Hence the pressure, velocity, drag around the parachute were observed and studied thorugh OpenFOAM.

Verification

According to ‘Parachute Recovery Systems Design Manual’ by the ‘Naval Weapons Center, China Lake, California’, the estimated drag coefficient range of the given parachute of constant diameter lies between 1.3 to 1.7.
Since the coefficient of drag through the flow analysis done by OpenFOAM is coming out to be 1.4541193285. We can conclude the results are correct.

In real time scenario, after the deployment of the parachute the area keeps on changing depending on the velocity and the elasticity of the material.
The formula for calculating the drag in drag-area model is:

$$Cd(s)=\left(\eta+(1-\eta)\left(\frac{t}{t(max)^{h}}\right)\right)*C$$

$$\eta=\frac{Cd(a)}{Cd(s)}$$

where,
Cd(a) : drag area at the beginning of the disreefing
C : drag area at the end of the disreefing
t(max) : direefing time
h: elasticity of the material

CONCLUSION

The flow simulation around a re-entry space capsule and a parachute were studied thorugh OpenFOAM and paraview using sonicFoam and simpleFoam respectively.
The coefficient of drag, lift, moment were calculated through iterative processes.

Further optimzations in the designs were done in the Reentry Space Capsule and the coefficient of the forces were compared.
The drag coefficient of the parachute was verified through parachute manuals used by the Navy.

REFERENCES

1. Viraj Belakr, Airflow Simulation over Ahmed Body.

2. Karl-Friedrich Doherr, Parachute Flight Dynamics and Trajectory Simulation

3. Theo W. Knacke, Parachute Recovery Systems Design Manual