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OpenFOAM Case Study Project
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Performance Analysis of Novel Surveillance UAV using OpenFOAM

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Abstract

The objective of the present project is to simulate and study the flow around the UAV and also calculate the Cl and Cd. The geometry is created in Catia V5 and then saved as a .stl file, this file can then be converted and meshed using various tools built into OpenFOAM. “snappyHexMesh” is used to create the mesh for the UAV and blockMeshDict file is used to create the Domain Mesh. Also the patch conditions and other necessary changes that should be done to the case setup are going to be shown in this project. The incompressible solver “simpleFoam” is going to be used to run this simulation.

1. Introduction

The focus of this project is going to be the simulation and prediction of Cl and Cd of a novel UAV Design. The results from this simulation will help us better understand the performance characteristics of the UAV and thus will help us in optimizing and making better design in the future.

Fig 1 UAV Design [1]

2. Problem Statement

The problem considers a subsonic incompressible case at a velocity of 30 m/s. The Free Stream properties for pressure is standard Atmospheric pressure at sea level- 101325pa. For this case study we are going to be using the simpleFoam solver.

3. Governing Equations

Bernoulli's Equation that hold true for inviscid, incompressible flow is given in equation 1.

$$p_2 + \rho \frac{V_2^2}{2} = p_1 + \rho \frac{V_1^2}{2} \tag{1}$$

Where p_1 and p_2 are the pressure at point 1 and 2

V_1 and V_2 are the velocities at point 1 and 2

The momentum equation in integral form is given by the equation below

$$dp = -\rho V dV \tag{2}$$

Where ρ is pressure

ν is velocity

dV is change in velocity

From equation 3 we can calculate the Coefficient of lift, similarly we can find out Coefficient of Drag from equation 4

$$C_l = \frac{L}{q_\infty S} \tag{3}$$

Where L is the Lift

q_∞ is the dynamic Pressure

S is the Reference Area

$$C_d = \frac{D}{q_\infty S} \tag{4}$$

4. Case Setup

4.1 Geometry and Mesh

Geometry was designed in Catia V5 and was imported into OpenFOAM as a .stl file. This was then meshed using the snappyHexMesh utility provided in OpenFOAM. The Domain mesh was made using the blockMesh dict file. Dimensions for the domain are 15m for the length, 8m for the width and 4m for the breadth and the mesh is shown in Fig 2 and Fig 3.

S.I No	Model Description	Selection made
1.	Wing configuration	Low wing type
2.	Empennage assembly	V-tail
3.	Airfoil (Wing)	Selig SD-7062
4.	Airfoil (Tail)	NACA 0012
5.	Wing Span	4.2m
6.	Wing Area	1.135 m^2
7.	Aspect Ratio	6.59
8.	Taper Ratio	0.64
9.	Dihedral	1.34 degrees

Table 1 UAV Specifications [1]

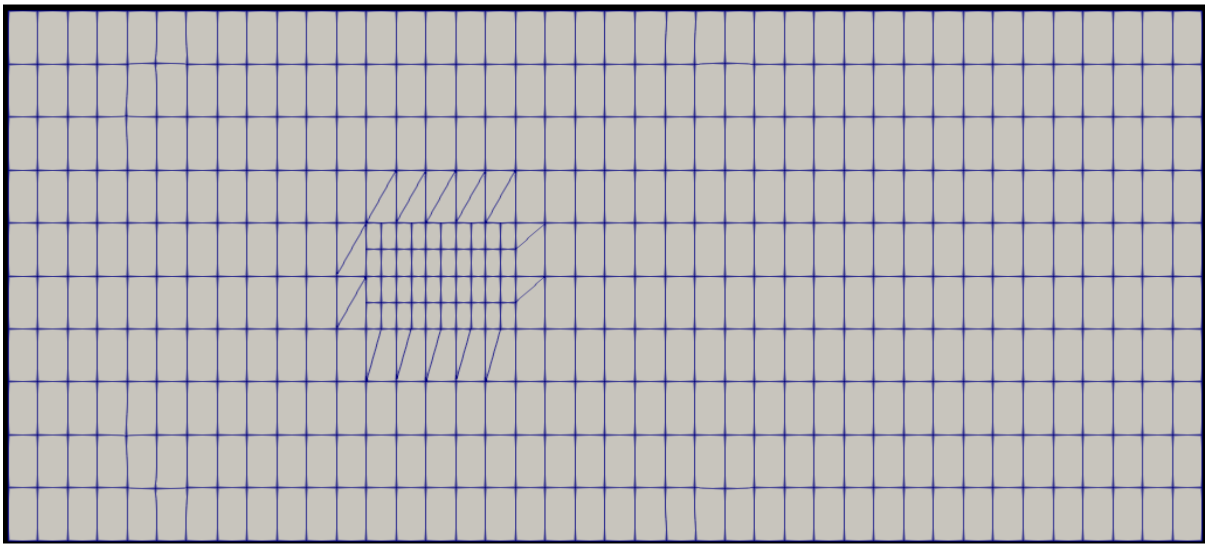

Fig 2 Domain Mesh

The mesh generated using the snappyhexMesh code takes up a lot of time to do auto-refinement and should be used with care as using refinement requires very high Memory usage and if the system is not capable, it would lead to system lock up. This can be changed in the snappyHexMesh dict by adjusting the maxIteration, nLayerIteration and MaxGlobalCells according to your system capability. However this would reduce the mesh refinement and would hence directly reduce the accuracy of the solution. This should be set according to what level of complexity and accuracy you want the solution to be solved.

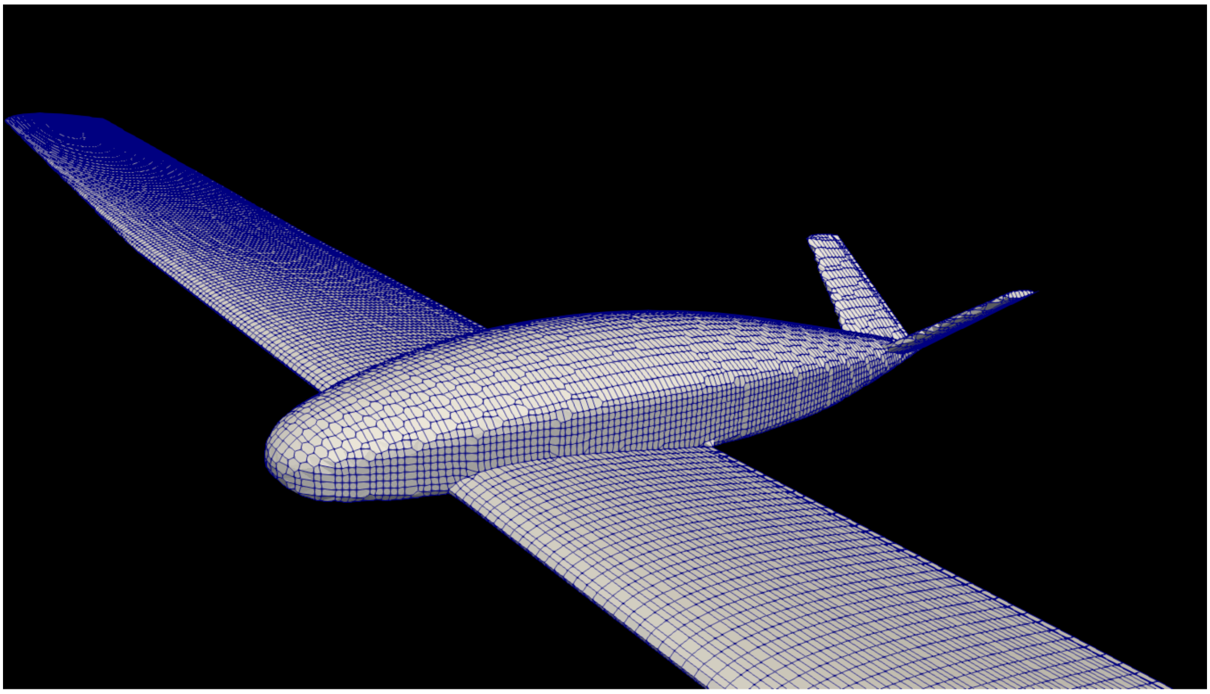

Fig 3 UAV surface Mesh

4.2 Boundary Conditions

The boundary conditions used for the patches are as shown below in Table 2.The Pressure is 101325 Pa (standard Atmospheric pressure at sea level) and the Velocity is set to 30 m/s.

Boundary Name	U	nut	omega	P
Inlet	fixedValue	fixedValue	fixedValue	zeroGradient
outlet	inletOutlet	inletOutlet	inletOutlet	fixedValue
topWall	slip	slip	slip	slip
lowerWall	fixedValue	inletOutlet	omegaWall function	zeroGradient
uav_Modelgroup	noSlip	zeroGradient	omegaWall function	zeroGradient

Table 2 Boundary Conditions For simpleFoam

4.3 Solver and Simulation Controls

“simpleFoam” is used for this simulation with the turbulence model set to KOmegaSST. The time step is set to 1 second and the simulation is run for 500 seconds.

S.I No	Description	Data
1.	Turbulence Model	kOmegaSST
2.	Boundary conditions	Velocity inlet – 30 m/sec
3.	Number of iterations set	500

Table 3 Solver Settings

5. Result and Analysis

5.1 Pressure Contours

In Fig 4 we can see the pressure contour at Final time step. The change in pressure is clearly visible on the UAV.The Blue over the wing shows that there is a low pressure region being formed. This results in a pressure differential between the upper and lower region of the airfoil and thus lift is generated.

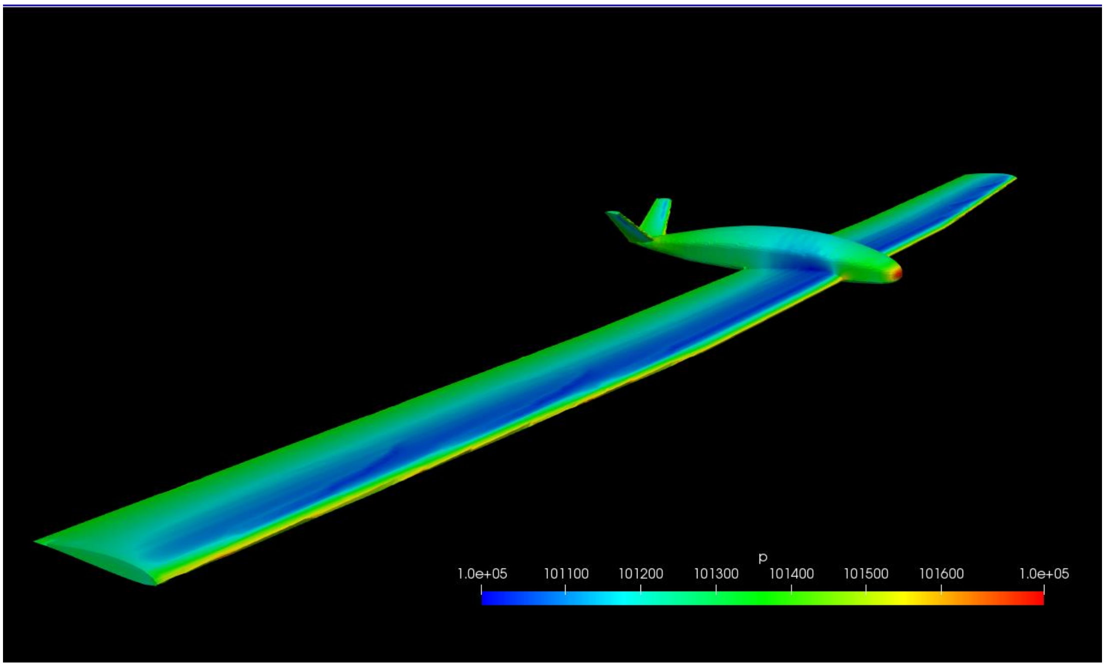

Fig 4 Pressure Contour

5.2 Velocity Contours

In Fig 5 we can see the pressure contour at final time step. We can see the high velocity region over the upper surface of the wing, this is represented by the red color in the contour below.

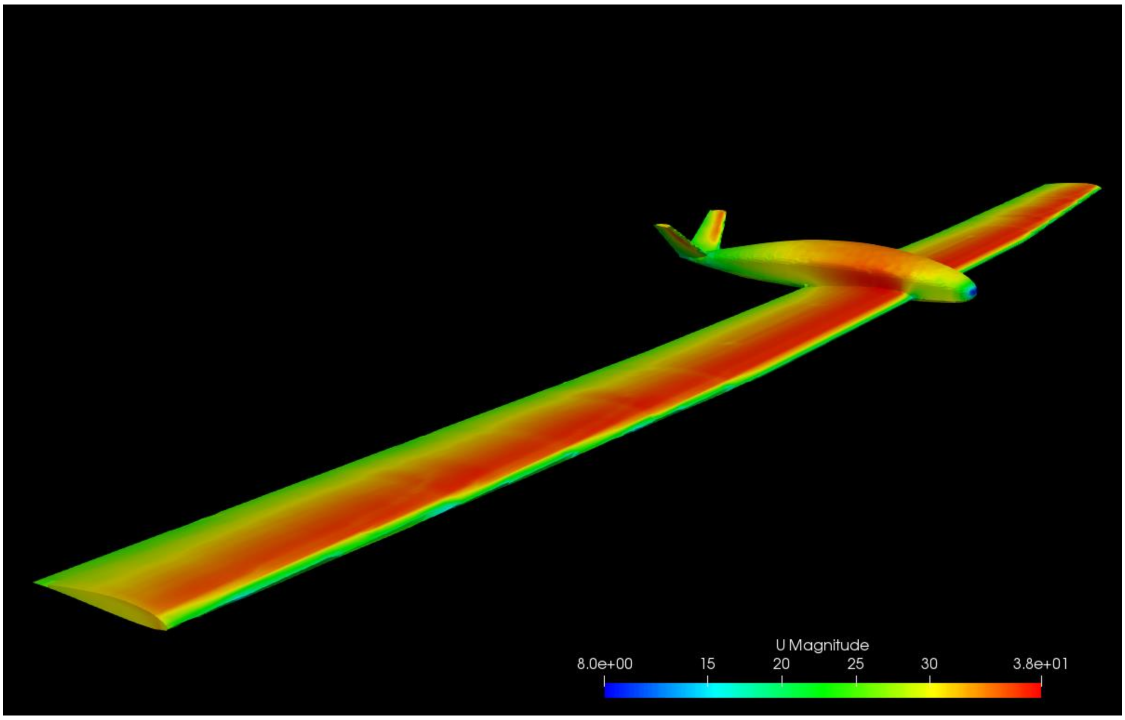

Fig 5 velocity Contour

5.3 Cl and Cd values

The Cl and Cd values have been calculated using the forceCoeffs function that can found at the bottom of the control dict file and the forceCoeffs dict in the system folder. To Calculate the Cl and Cd we need to provide the Reference Area and the directions in which the forces are acting.

Coefficient of Lift (Cl)	0.242523
Coefficient of Drag (Cd)	0.015457

Table 4 lift and Drag Coefficients

6. Conclusion

This case study has resulted in a better understanding of the flow around the UAV, performance characteristics and also locations where improvements can be made. This study also shows that open source software can be a very powerful tool if you can set it up correctly, with very broad industry uses. Some areas where the UAV design can be improved for performance are adding winglets to increase wing area and also reduce drag caused by wing tip vortex.

References

1. Sahil Kukian, Karan Kotian, Manoj Vijay (2018), "Design and Performance Analysis of a Solar Powered UAV", Final Year project Thesis.

2. Anderson, J.D, Introduction to Flight, McGraw Hill Inc., New York, 1989.

3. OpenFOAM Official User guide