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Case Study on Investigation of Aerofoil for Flapping Wing Aircraft

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Abstract: **Flapping-wing aerodynamics recently has generated a great deal of interest and increasing research effort because of the potential application in micro-air vehicles and mainly in military applications. The aim of this project is to optimize the better and efficient aerofoil in wing design of eagle-sized flapping wing aircraft and also capable of hovering flight. Depends on viability of Ornithopters, three different characteristic aerofoils were selected. The analysis of aerofoil is carried out by using Computational Fluid Dynamics (CFD). Computations have been made adopting structural grid and k-ω turbulence model using commercial software Fluent. The results are consists of flow visualization graphs, aerodynamic drag and lift values. CFD can be used to simulate the flow over any object. We believe that the results showed in this paper will be useful for future research in development of design of flapping wing aircraft.**

Key words: Aerodynamics, Aerofoil, CFD, Drag, Flapping wings, Fluent and Lift.

I. INTRODUCTION

The human desire to duplicate bird flight has existed for hundreds of years. From Leonardo Da Vinci's drawings to Otto Lilienthal's gliders, the first five hundred years of flapping flight research focused on human transport. Today flapping flight research has shifted to a much smaller scale with the goal of an autonomous ornithopter unmanned air vehicle (UAV). Flapping wing vehicles can fill the niche left by traditional fixed and rotary wing vehicles for small, manoeuvrable and stealthy UAVs in military, civilian and research applications. Flapping wing autonomy has not yet been achieved because the kinematics, aerodynamics and the stability, guidance and navigation of birds are much more complicated than that of a fixed wing aircraft. This challenging problem has sparked a wave of research in dynamic modelling, flapping aerodynamics, structural behaviour, and control methods.

Army wants flapping wings technology to fly drones of the future that would allow drones to better navigate rugged, unpredictable environments. The logic behind the flapping wing is simple. They're more efficient and wind tolerant than inert wings, which means that drones with flapping wings could fly with more agility and even stop mid-flight to hover in the air (dynamic soaring) a serious barrier to drones offering surveillance of a given area.

A. Aerodynamics of a Flapping Wings

When flapping the wings, the air flow is highly turbulent and producing more lift compared to fixed wing flight. These effects are a consequence of the permanently changing wing position during flapping, and are connected to the Reynolds number. In this section the most important aerodynamic effects are described.

a) *Leading edge vortex:* During down stroke with a high angle of attack the flow separates from the wing and a vortex evolves along the leading edge of the wing. Due to high turbulence the flow reattaches the wing before reaching the trailing edge and stall. The vortex results in a significant, higher lift than could be observed in laminar flow.

b) *Rotational lift:* At the end of every stroke some insects and birds rotate their wings such that the angle of attack remains positive. The additional circulation around the wing results in extra lift.

Concluding it can be said that the aerodynamics of flapping wing motion are rather complex as it is unsteady and highly turbulent. The main theme of this project is to provide a predictive aerodynamic aerofoil for future autonomous ornithopter (Flapping wing) control applications. This is also accomplished by biomimetics, offers a pool of concepts that can potentially be used to enable new technologies and enhance the available capabilities. The term biomimetics represents the studies and imitation of nature's methods, mechanisms and processes. Humans have learned much from nature and the results have helped surviving generations and continue to secure a sustainable future.

II. INVESTIGATION OF AEROFOIL

For hovering flight, the flapping wings are basically described by two movements- Horizontal motion (upstroke & down stroke) and Motion around span axis. This rotation changes the angle of attack and allows the fly to generate positive lift force at up and down stroke. The most appropriate aerofoil for an ornithopter is one that is suitable for low and medium Reynolds number flight and is relatively insensitive to errors in angle of attack. In order to improve efficiency, a high lift to drag ratio is favoured. The spar is also responsible for providing the wing's required high bending stiffness. Finally, the selected aerofoil should be thick enough to accommodate torsional structural members.

A. Aerofoil Selection

Aerofoil is no doubt heart of the flying objects. It's just the magic of aerofoil that makes dead weight reach the skies. Selection of suitable and correct aerofoil is very complicated decision because of the impact it can have on the flying bird performance as well as weight and manufacturing process.

An aerofoil Selection criterion is based on the below three main criteria's

1. Max Lift Coefficient: The C_L max of an aerofoil is directly affects the stall and
   Take-off properties of the aircraft. So high value of max C_L is desired.

2. Lift to Drag Ratio: It can be termed as Aerodynamic efficiency of the aircraft. Higher the value of L/D max, the better performance is expected out of an aircraft.

3. Maximum Thickness: It doesn't only defined the stall behaviour but also adds to the weight of the wings; hence reasonably thick aerofoil has to be selected.

Basically Flapping wing aircrafts need good amount of lift at small AOA. Depends on viability of Ornithopters (i.e., flapping wing aircrafts), we selected NACA 6414, SELIG S1090 and SELIG S1091. The aerofoils co-ordinates data was taken from Internet sources like Aerofoil Investigation Data (AID) and Aerofoils Tools sites for reference purpose.

TABLE1 NACA 6414

Max C_L	1.9042
Max C_L angle	14
Max L/D	56.2
Max L/D angle	5.2
Stall angle	17°
Thickness	14%

TABLE2 Selig S1020

Max C_L	1.753
Max C_L angle	10.5
Max L/D	66.377
Max L/D angle	5.0
Stall angle	10.5°
Thickness	15.1%

TABLE3 Selig S1091

Max C_L	1.544
Max C_L angle	8.0
Max L/D	90.194
Max L/D angle	3.0
Stall angle	8.0
Thickness	5%

B. Aerodynamic Analysis

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyse problems that involve fluid flows

The analysis of NACA6414, Selig 1020 and Selig 1091 aerofoils is carried out by using ANSYS ICEM CFD and Fluent.

C. Methodology:

In all of these approaches the same basic procedure is followed. During pre-processing,

i. The geometry (physical bounds) of the problem is defined.

ii. The volume occupied by the fluid is divided into discrete cells (the mesh). The mesh may be uniform or non-uniform.

iii. The physical modelling is defined – for example, the equations of motions + enthalpy + radiation + species conservation

iv. Boundary conditions are defined. This involves specifying the fluid behaviour and properties at the boundaries of the problem. For transient problems, the initial conditions are also defined.

v. The simulation is started and the equations are solved iteratively as a steady-state or transient.

vi. Finally a postprocessor is used for the analysis and visualization of the resulting solution

The process of mesh generation on these three different aerofoils as shown in below screen shots.

Process of Mesh generation on NACA 6414:

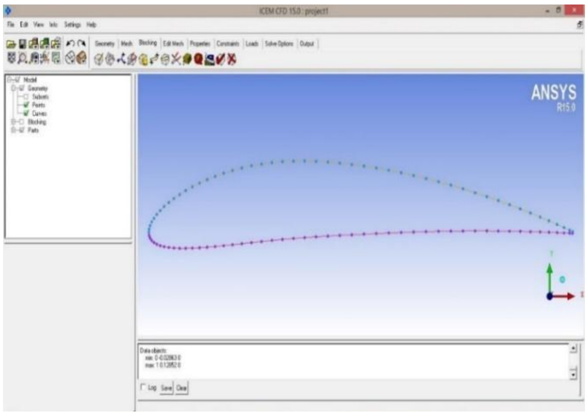

Fig. 1. Coordinates of NACA 6414

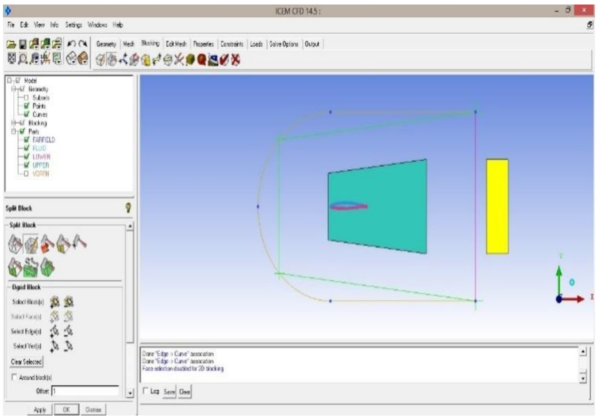

Fig. 2. O-Grid generation of NACA 6414

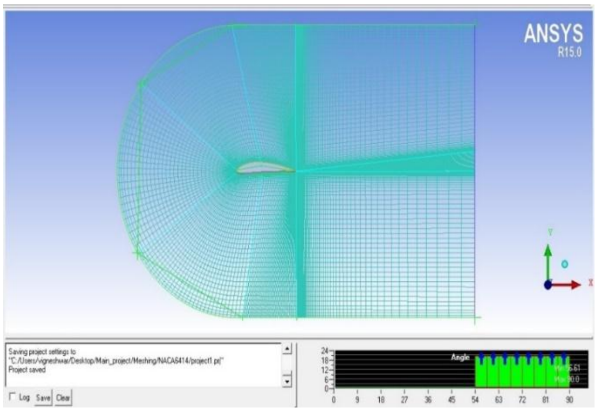

Fig. 3. Premesh quality criterion ANGLE

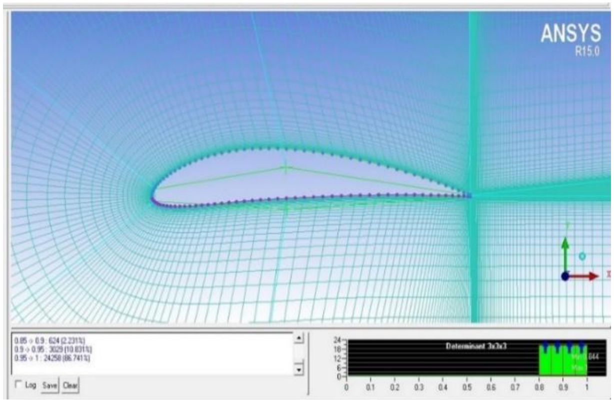

Fig. 4. Premesh quality criterion DETERMINANT

Process of Mesh generation on SELIG S1020:

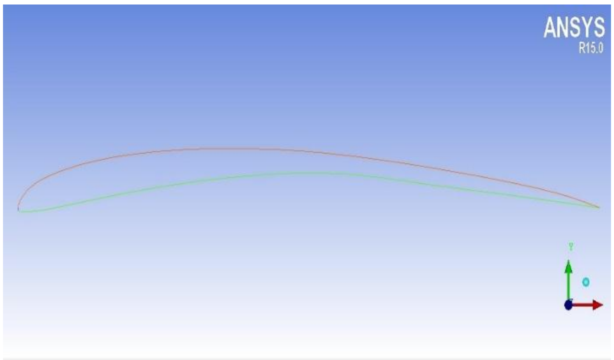

Fig.5. S1090 Aerofoil

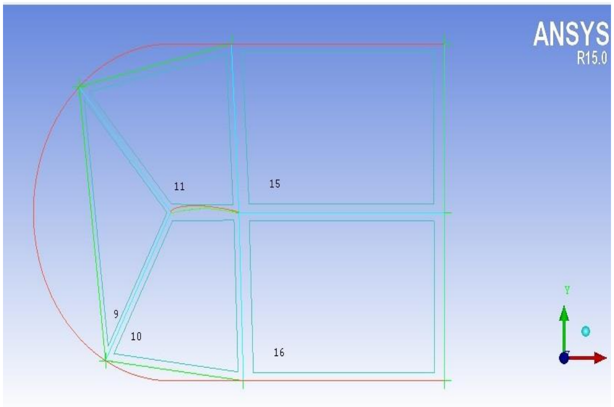

Fig. 6. Blocking of S1090

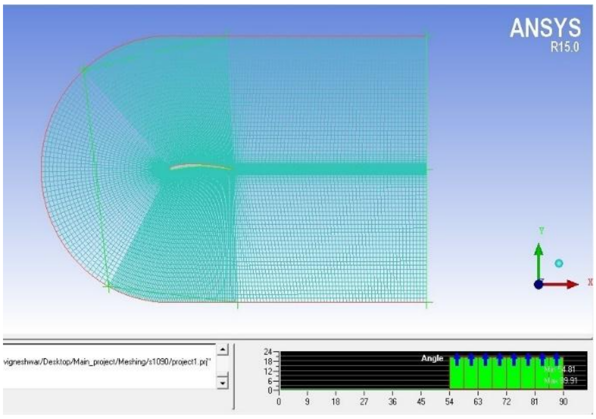

Fig. 7. Premesh Quality criterion DETERMINANT

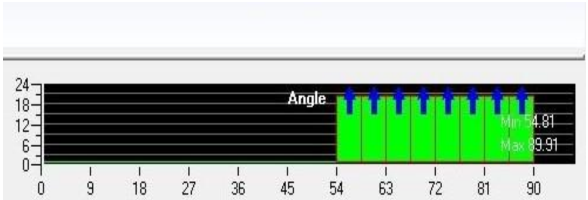

Fig. 8. Premesh Quality criterion ANGLE

Process of Mesh generation on SELIG S1091:

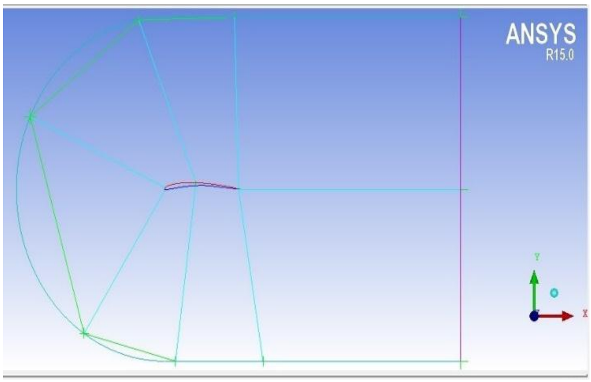

Fig. 9. Blocking of S1091

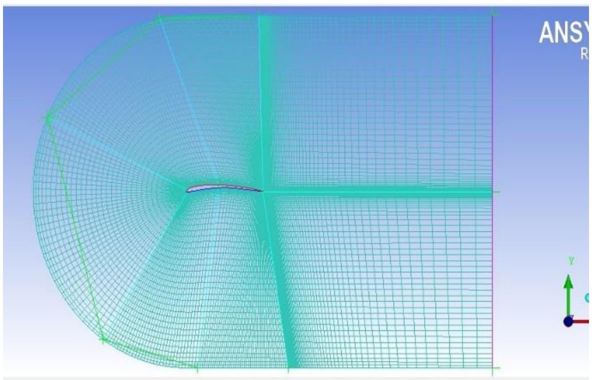

Fig. 10. Mesh generation on S1091 Aerofoil

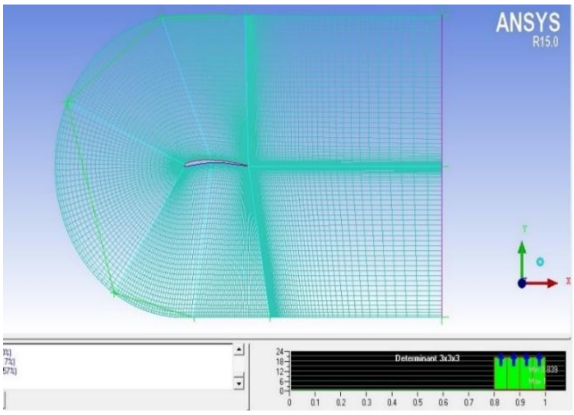

Fig. 11. Premesh Quality criterion DETERMINANT

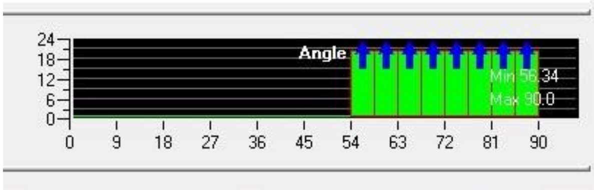

Fig. 12. Premesh Quality criterion ANGLE

III. COMPUTATIONAL RESULTS

Numerical Simulations were performed using ANSYS FLUENT, to capture the overall flow features of Aerofoil. In the present investigation, steady state axisymmetric computations have been made adopting explicit coupled solver and using "k-ω SST" turbulence model along with energy equation on. The use of this turbulence model has been arrived at, after making necessary grid sensitivity tests, convergence history and obtaining good comparison with numerical results. Structured grids were made with uniformly distributed quadrilateral cells having minimum spacing near the wall. Aerofoil simulations convergence up to 4^{th} place after point. Simulations were done at Sea level altitude data (Indian Standard Atmospheric data): Pressure = 101325 pa, Temperature = 288.15k, Density = 1.23 kg/m^3

A. CONTOURS

All simulations done at Mac = 0.2 and α=0. These are the contours resulted after completion of simulation process in ANSYS Fluent.

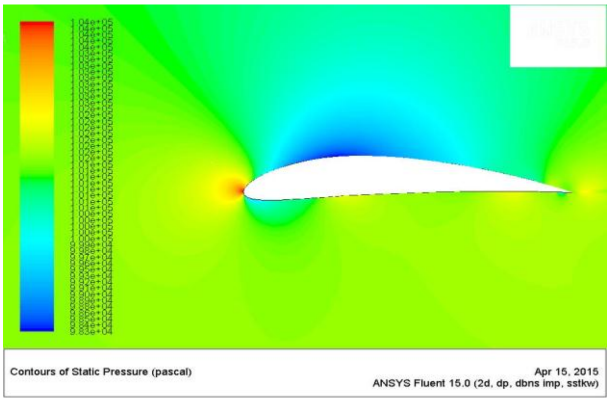

Fig. 13. Static pressure contour of NACA6414

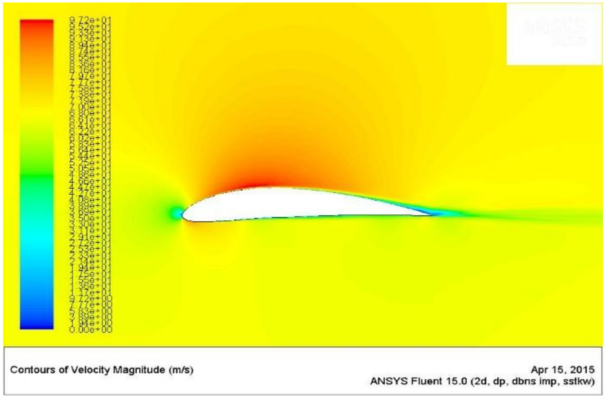

Fig. 14. Velocity Magnitude contour of NACA6414

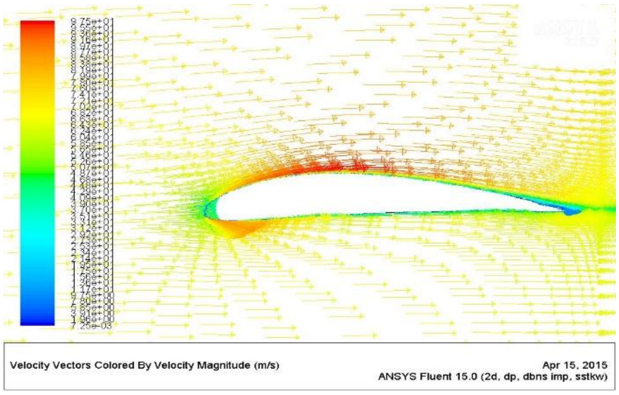

Fig. 15. Velocity Vector Contour of NACA 6414

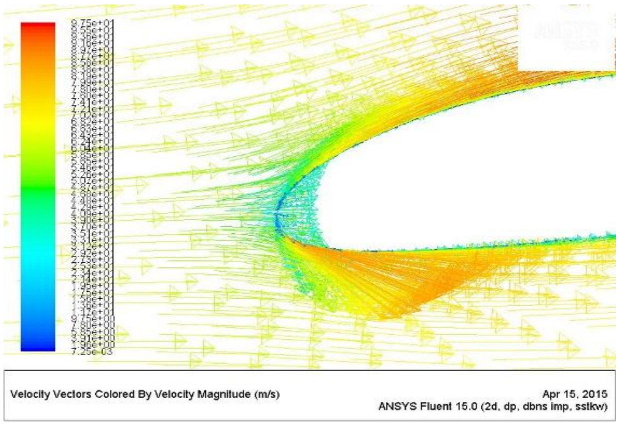

Fig. 16. Zoomed view at L.E of Velocity vector

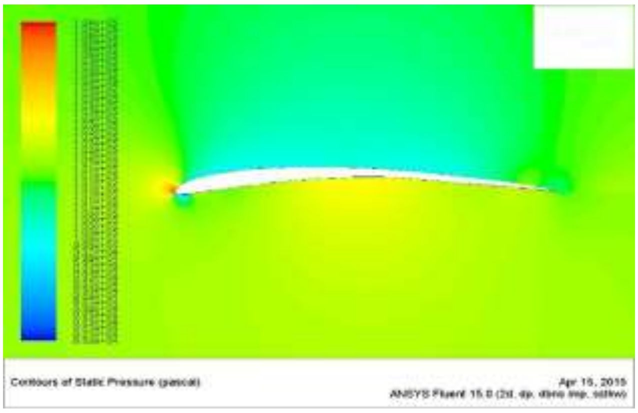

Fig. 17. Static pressure contour of S1020 Aerofoil

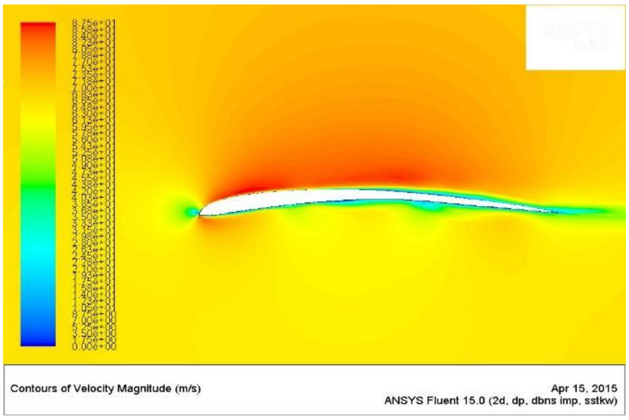

Fig. 18.Velocity Magnitude Contour of S1020 Aerofoil

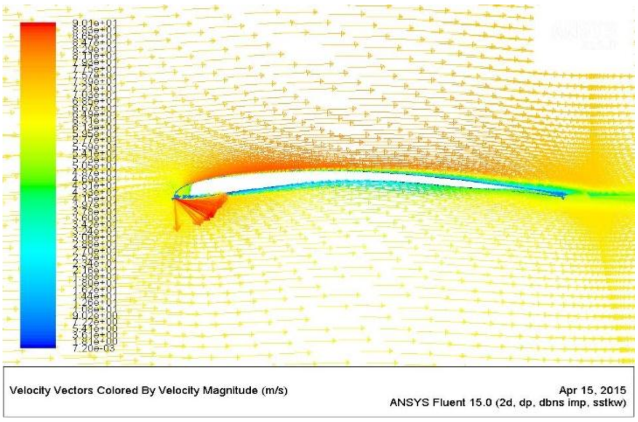

Fig. 19. Velocity Vector Contour of S1020

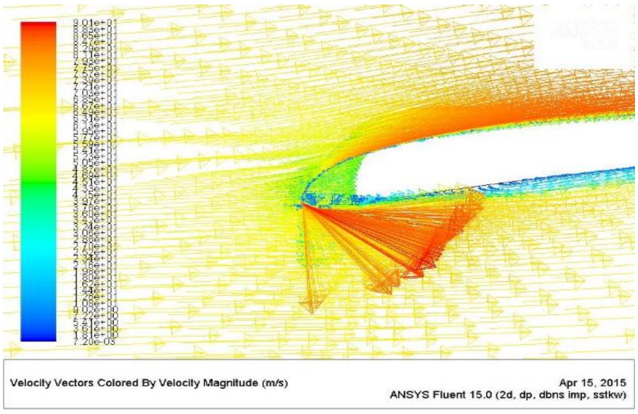

Fig. 20. Zoomed view at L.E. Velocity Vector

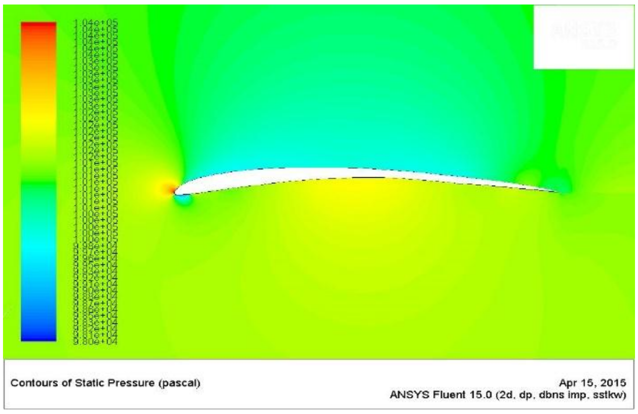

Fig. 21. Static pressure contour of S1091

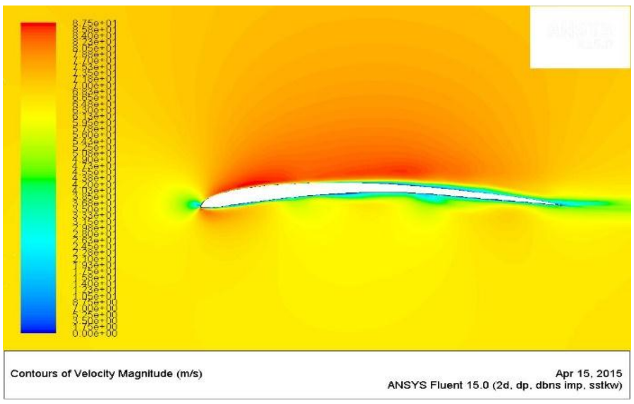

Fig. 22. Velocity Magnitude contour of S1091

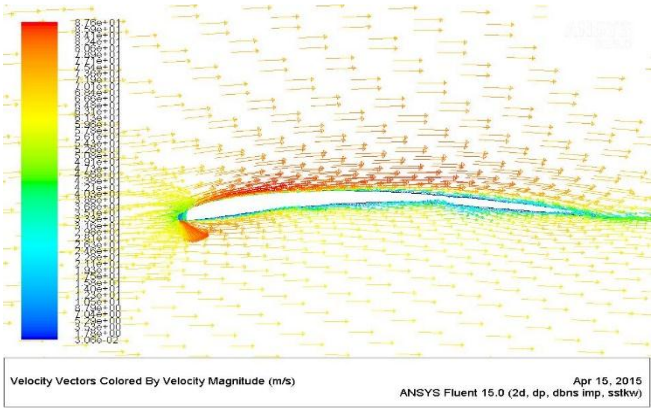

Fig. 23. Velocity Vector Contour of S1091

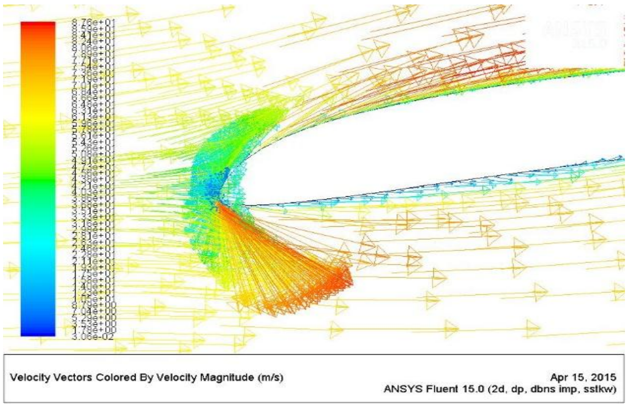

Fig. 24. Velocity vector at L.E. of S1091

IV. CALCULATIONS

The Axial and Normal Forces and its coefficients are obtained from the simulation results through force report files. These force values are subjected to calculate the lift and drag generated due to the subsonic flow over the aerofoils. The comparison is made between these aerofoils among the flow properties i.e. the aerodynamic loads.

The formulae used for the calculations as follows.

$$Lift\ (L) = N * Cos(\propto) - A * Sin(\propto) \quad (1)$$

$$Drag\ (D) = N * \mathrm{Cos}(\propto) + A * Sin(\propto) \quad (2)$$

Where, N= normal force

A= axial force

α= angle of attack

TABLE4 Calculations of Lift and Drag at α=0°

Type of Aerofoil	NACA 6414	SELIG S1020	SELIG S1091
Axial Force	26.884556	16.357446	51.088784
Normal Force	1502.486	1537.2025	1475.793
Lift	1502.486	1537.2025	1475.793
C_L	0.52996	0.5422	0.5205
Drag	26.884556	16.357	51.088784
C_D	0.0094828	0.00576	0.01802
L/D ratio	55.88658	93.978266	28.886829

V. CONCLUSION

Computations have been made to obtain the flow field on a NACA 6414, S1020 and S1091 aerofoils at a subsonic flow i.e. Mach number of 0.2. However our final calculations showed that for an angle of attack of 0 degrees, the Selig S1020 has a maximum lift coefficient of 0.542 and a drag coefficient of 0.005 is good enough, aerodynamically speaking, for low speed long range operational flapping aircraft [TABLE4]. By comparison, S1020 has good L/D ratio, this enables S1020 aerofoil is much efficient and predictive aerofoil for this flapping wing aircraft. The above results are all compared. Computations results indicate more details of flow field and effect of Mac number. The flow around and behind simple fixed wings at low Reynolds numbers similar to bird flight is not necessarily simple itself, and the wakes of flying birds are not significantly more complex than that. This observation suggests that simple aerodynamic models might help to understand many features of bird flight, as complex kinematics and geometry are reduced to simple principles. In other side, our computational analysis will be useful for future research in development of design of flapping wing aircraft.

The gained knowledge can be used for further improvements and opens the way toward an autonomous flapping wing aircraft for military operations.

VI. FUTURE SCOPE OF WORK

Security staff can use it to watch events or beaches. Anti-poaching: Evidence can be filmed by our birds, allowing for poachers arrest. The army may want to check out a zone before entering. A local bird is the best possible way to approach without being noticed. The police may want to watch a crowd without expressing aggressive means. A Bird Spy is just perfect, flying and filming peacefully above people. Custom patrols may fly along the border, and equip the RC Gull with specific cameras (IR, etc…).

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