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RESEARCH ON INSECT FLIGHT MECHANISM AND ITS OPTIMIZATION IN ORNITHOPTERS USING COMPUTATIONAL FLUID DYNAMICS

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Abstract- *Ornithopters –the flapping wing unmanned aerial vehicle are developed for the stealth reconnaissance purpose. The current ornithopters uses a wing profile and wing structure of birds which does not give them an efficient lift to drag ratio and hovering capability. On other hand insects which have an interesting wing profile and uses some unique mechanism like wake capture, delayed stall which help them to have a better lift to drag ratio and hovering capability. In this paper we have tried to improve the performance of the ornithopters by implementing the insect wing profile and structure. Data relating to their flight mechanism are collected and after analyzing them it was found out that fruit fly has one of the best wing profiles. A wing based on the wing structure and wing profile of fruit fly is designed using SOLID WORKS. CFD analysis of the new wing design proposed and the current wing design of the ornithopters at different angular positions are done using Ansys Fluent software and the results are analysed. The structural analysis of the proposed wing design is also done to study their behaviour when load is applied.*

Keywords: *wing profile, lift, drag, flight mechanism, fruit fly*

1. INTRODUCTION

In this twenty first century the countries are trying to achieve supremacy over the other .Military power has become an integral part of the country's diplomacy. Thus huge amount of money are being invested for the development of the state of art technologies. Unmanned aerial vehicles have become the indispensable of any superior military force Because of its combat and reconnaissance abilities. Various type of flight mechanism currently used are –fixed wing mechanism, rotary wing mechanism and flapping wing mechanism. After detailed study it is clear that UAVs which Uses the flapping mechanism is the best option for application because of its stealth flight and good blending ability with the natural surroundings.

Flapping wing mechanism is a concept which was tried by human beings for a long time but remained unsuccessful. Moreover the success of the fixed wing mechanism rendered the further attempts in the flapping mechanism field non-existent. But the increasing importance of urban warfare has given the development of the Micro Air Vehicle (UAVs which have a maximum dimension of 15cm and a gross weight of 100g) a boost. Designing of fixed wing for the MAVs has some disadvantages. The traditional wing can suffer from viscous losses. Moreover at low Reynolds's number the ratio between the lift and drag deceases(1)(2). At low Reynolds number the wing venation also plays a Flapping wing mechanism thus provides an intriguing alternative as it is very much efficient at low Reynolds's number and provide better handling. The ornithopters which are currently used are based on the bird's flight mechanism and uses continuous drag.

The current ornithopters design uses the steady flight mechanism. The wing of these ornithopters consist of luff region and flap region for producing thrust and lift(5)

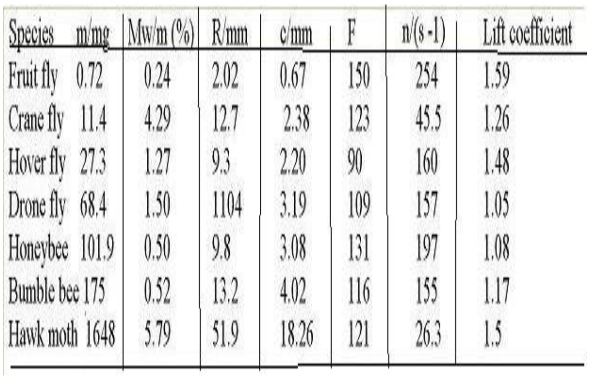
1.1 Calculation Of Lift Coefficient

The groundwork data was collected from other research papers and journals. And the following data was found about various insects. The insects size were chose from broadly three categories – small, medium and large wing spans. The initial insects selected for starting the work were honeybee, fruit-fly, dragonfly, mosquito and hawk moth. What we needed was a wing structure with high lift coefficient. Hence, the lift coefficients of all the selected insect's wing structures were calculated and analysed. As a result, the lift coefficient of fruit fly is found to be highest. A table (table: 1) of data gathered about all the insects eligible for experimenting is shown and then the model calculation for finding lift coefficient of the insect that appeared best for our experimental purposes. The data include mass of insect (m), mass of wing pair (Mw), wing length (R), frequency of flap (n) and mean chord length(c).

Mass = 0.72 mg
Mass of Wing Pair = 0.24%
Wing Length (R) = 2.02 mm
Area of one wing (S) = 1.36 mm2
Flapping angle (Φ) =150°
Flapping frequency = 254

Mean translational Velocity $(U) = 2n\varphi R = 160$ cm/s
Reynolds Number $(Re) = cU/v = 74.83$
Kinematic viscosity of air $(v) = 0.144\ cm^2/s$
For weight balancing, Coefficient of Lift (C_l)
Fruit fly $= mg/\rho U^2 S = 0.72*981/\ (1.25*10^{-2}*160.11^2*1.36) = 1.59$ (where $\rho=1.25*10^{-2}$ g/cm, $g=981cm/s^2$)

Table 1: Gathered data for different insects



Species	m/mg	Mw/m (%)	R/mm	c/mm	F	n/(s -1)	Lift coefficient
Fruit fly	0.72	0.24	2.02	0.67	150	254	1.59
Crane fly	11.4	4.29	12.7	2.38	123	45.5	1.26
Hover fly	27.3	1.27	9.3	2.20	90	160	1.48
Drone fly	68.4	1.50	1104	3.19	109	157	1.05
Honeybee	101.9	0.50	9.8	3.08	131	197	1.08
Bumble bee	175	0.52	13.2	4.02	116	155	1.17
Hawk moth	1648	5.79	51.9	18.26	121	26.3	1.5

This led the basis to the foundation in thinking that the new wing structure needs to rely wing design of fruit fly. The housefly flap their wing in a hyperbolic form while utilizing their drag and lift from the rear of their wings. It uses the vortex generated because of the turbulence created due to the flapping in the previous stroke for the next stroke to generate lift.

3. DESIGN PARAMETERS

Current Wing design of ornithopters are based on bat wigs. And a sample of our designed wings based on the profile of fruit-fly.While current wing design in ornithopters is given on the right.

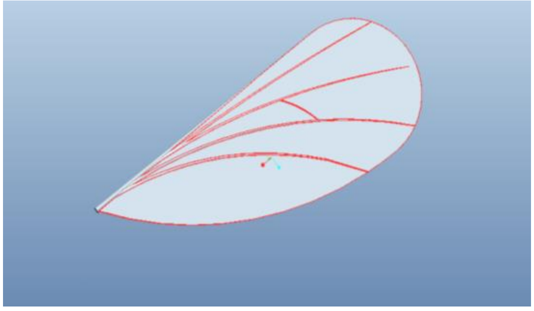


Fig.1: Proposed wing design (wing I)

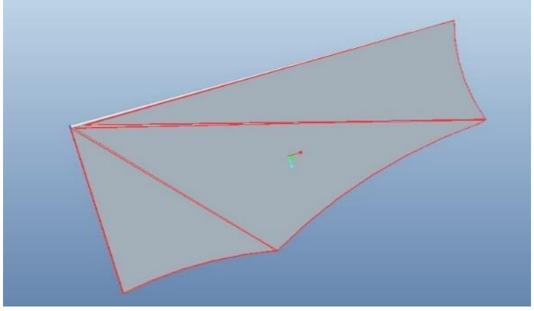


Fig.2: Current wing design(wing II)

The design mixes the features fruit fly and humming bird which is known for its stable hover. The standard wing span of humming bird 50mm. Mean chord length of humming bird ranges from (12-17mm).The wing is designed combining the geometry of humming bird and wing profile of fruit fly. The differences in the wing specification are shown in table: 2.

Table 2: Wing specification

Wing I	Wing II
Wing Span - 50mm Mean chord length – 12mm Thickness variation – 0.1mm to 0.01mm Material for analysis – Carbon fibre	Wing Span – 50mm Mean chord length – 12mm Thickness variation – 0.1mm to 0.01mm Material for analysis – Carbon fibre

3.1 Influence Of Thickness Variation

It was further noticed in our research work that the leading edge of the wing should be thicker than the trailing edge. The mean wing thickness is typically about 0.05% of the wing length ranging from 0.01 – 0.1% of the length of the wing – a general outline for the wing structure of all the insects big as well as small.

3.2 Selection Of Wing Material

For efficient flapping and to endure the acting aerodynamic forces, the wing needs to be both flexible as well as rigid and provide both lift and thrust. The wing material thus selected needs to be light weight as well as have better structural strength like that of insect wings.
Hence, wing was decided to be made up of Mylar while carbon fiber spars were used for providing strength and rigidity to the wing.

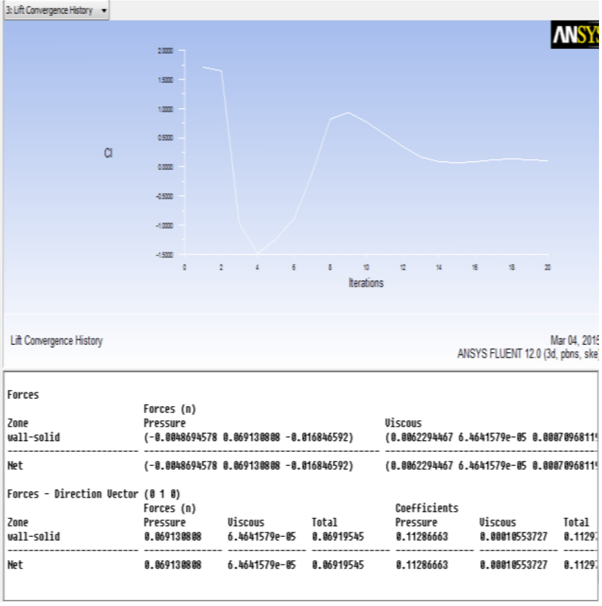
3.3 Wing Venation And Flexural Structural patterns.

Venation is kept generally denser near the wing base and leading edge and vein diameter and cuticular thickness taper from base to top. This provides additional strength where bending stresses are highest. Wing venation actually contributes to localization of pressure in a uniformly distributed way along the whole wing structure while as mentioned providing additional strength to the wings. Thus, it is an extremely important part of wing structure.

4. CFD PARAMETERS

As a means of initial validation of the CFD model, the lift acting on the ornithopter wing plan form operating in a highly-separated flow regime with an angular position of 90 ◦and a free stream velocity of 0.001 m/s was measured (Velocity close to zero is used to study hovering characteristics). The wing was 50mm in span and 12 mm in chord and had a thickness varying from 0.1mm to 0.01mm from the leading end to the trailing end of the wing respectively. The computational domain consisted of a large box 500mm in height, 500mm in the span wise direction, and 500mm in the chord wise direction. These dimensions were chosen to match the dimensions of a standard wind tunnel. The number of cells ranged from 97,000 to 530,000. For the Computational Fluid Dynamics study, the pressure-based coupled solver is used, the QUICK scheme is used for spatial discretization, Green-Gauss Node Based gradient interpolation is used, and standard pressure interpolation is used. The flow is assumed to be viscous and laminar, which for small flapping wings is an assumption well supported in the literature. The solid material used was carbon fiber and the fluid medium – air. The boundary conditions at inlet was fixed, inlet velocity – 0.025m/s as velocity of flow should be close to 0 for hovering conditions. The gauge pressure at outlet was fixed to be zero. FLUENT is shown to be able to predict the lift on stationary wings at high angles of attack. Though only a single wing is analysed in CFD, the resulting forces are doubled in the figure to account for symmetry in the problem.

4.1 Lift And Drag Comparison In The Normal Position Of The Wing



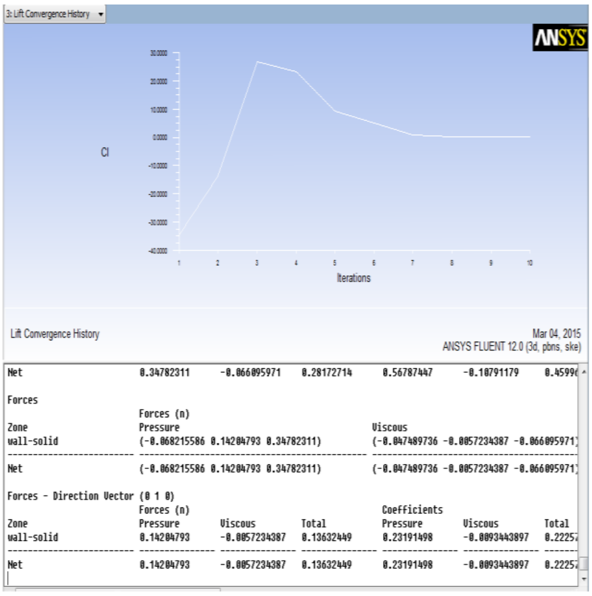
```
Forces
                         Forces (n)
Zone                     Pressure                                  Viscous
wall-solid               (-0.0048694578 0.069130808 -0.016846592)  (0.0062294467 6.4641579e-05 0.0007096811
------------------------ ----------------------------------------- ------------------------------------------
Net                      (-0.0048694578 0.069130808 -0.016846592)  (0.0062294467 6.4641579e-05 0.0007096811

Forces - Direction Vector (0 1 0)
                         Forces (n)                                  Coefficients
Zone                     Pressure       Viscous        Total          Pressure       Viscous        Total
wall-solid               0.069130808    6.4641579e-05  0.06919545     0.11286663     0.00010553727  0.1129
------------------------ -------------- -------------- -------------- -------------- -------------- -------
Net                      0.069130808    6.4641579e-05  0.06919545     0.11286663     0.00010553727  0.1129
```

Fig3: Lift produced by the proposed wing design (wing I)

The results show a value of 0.069N lift force being generated by wing I and 0.142N lift force being generated by wing II under same conditions. Here lift force of wing II is higher.

While the lift results were significantly high in the wing II at similar conditions as of our designed wings, the drag results shown below indicate that current wing experience higher drag results as well.The results show 0.016N drag force being experienced by wing I whereas 0.34N of drag force is experienced by wing II which is much greater and is undesirable for hovering flight.

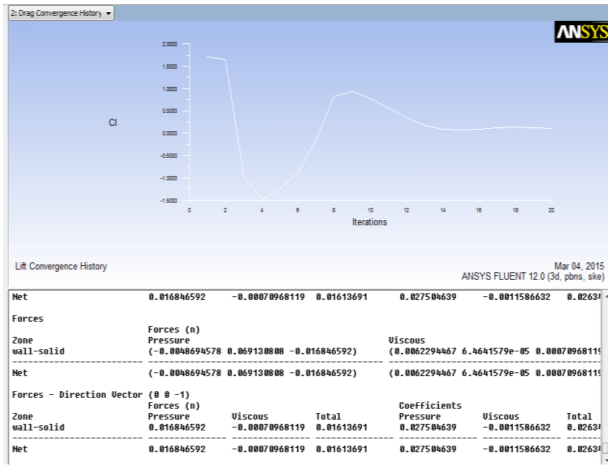


```
Net                      0.34782311     -0.066095971   0.28172714     0.56787447     -0.10791179    0.4599

Forces
                         Forces (n)
Zone                     Pressure                                  Viscous
wall-solid               (-0.068215586 0.14204793 0.34782311)      (-0.047489736 -0.0057234387 -0.066095971)
------------------------ ----------------------------------------- ------------------------------------------
Net                      (-0.068215586 0.14204793 0.34782311)      (-0.047489736 -0.0057234387 -0.066095971)

Forces - Direction Vector (0 1 0)
                         Forces (n)                                  Coefficients
Zone                     Pressure       Viscous        Total          Pressure       Viscous        Total
wall-solid               0.14204793     -0.0057234387  0.13632449     0.23191498     -0.0093443897  0.2225
------------------------ -------------- -------------- -------------- -------------- -------------- -------
Net                      0.14204793     -0.0057234387  0.13632449     0.23191498     -0.0093443897  0.2225
```

Fig 4: Lift produced by the current wing design (wing II)



```
Net                      0.016846592    -0.00070968119 0.01613691     0.027504639    -0.0011586632  0.0263

Forces
                         Forces (n)
Zone                     Pressure                                  Viscous
wall-solid               (-0.0048694578 0.069130808 -0.016846592)  (0.0062294467 6.4641579e-05 0.0007096811
------------------------ ----------------------------------------- ------------------------------------------
Net                      (-0.0048694578 0.069130808 -0.016846592)  (0.0062294467 6.4641579e-05 0.0007096811

Forces - Direction Vector (0 0 -1)
                         Forces (n)                                  Coefficients
Zone                     Pressure       Viscous        Total          Pressure       Viscous        Total
wall-solid               0.016846592    -0.00070968119 0.01613691     0.027504639    -0.0011586632  0.0263
------------------------ -------------- -------------- -------------- -------------- -------------- -------
Net                      0.016846592    -0.00070968119 0.01613691     0.027504639    -0.0011586632  0.0263
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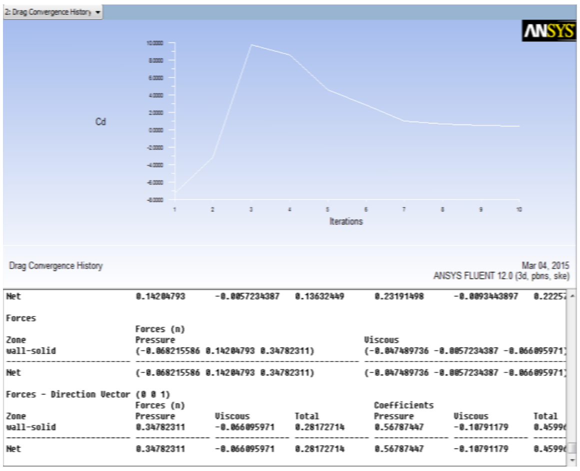
Fig 5: Drag produced by the proposed wing design (wing I)



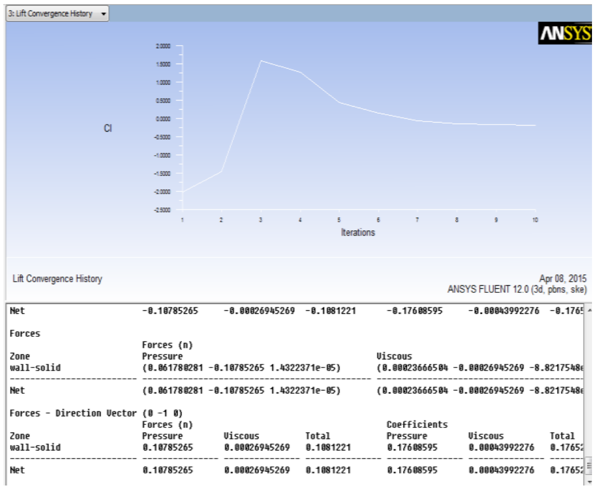
```
Net                      0.14204793     -0.0057234387  0.13632449     0.23191498     -0.0093443897  0.2225

Forces
                         Forces (n)
Zone                     Pressure                                  Viscous
wall-solid               (-0.068215586 0.14204793 0.34782311)      (-0.047489736 -0.0057234387 -0.066095971)
------------------------ ----------------------------------------- ------------------------------------------
Net                      (-0.068215586 0.14204793 0.34782311)      (-0.047489736 -0.0057234387 -0.066095971)

Forces - Direction Vector (0 0 1)
                         Forces (n)                                  Coefficients
Zone                     Pressure       Viscous        Total          Pressure       Viscous        Total
wall-solid               0.34782311     -0.066095971   0.28172714     0.56787447     -0.10791179    0.4599
------------------------ -------------- -------------- -------------- -------------- -------------- -------
Net                      0.34782311     -0.066095971   0.28172714     0.56787447     -0.10791179    0.4599
```

Fig 6: Drag produced by the current wing design(wing II)

4.2 Lift And Drag Comparison Of The Wing At An Angular Position Of 60◦

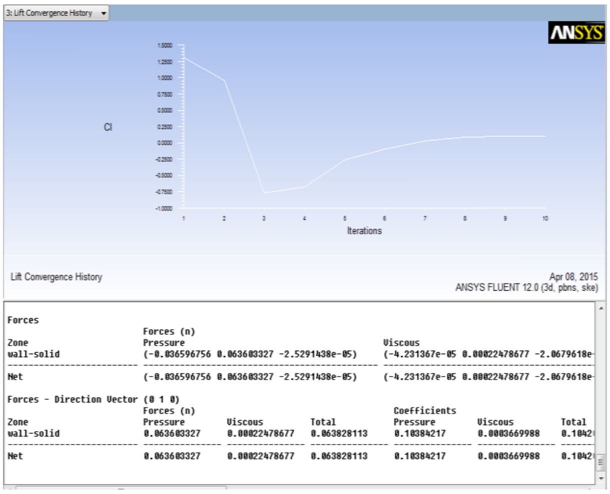


```
Net                       -0.10785265     -0.00026945269  -0.1081221      -0.17608595     -0.00043992276  -0.1765

Forces
                          Forces (n)
Zone                      Pressure                                        Viscous
wall-solid                (0.061780281 -0.10785265 1.4322371e-05)         (0.00023666504 -0.00026945269 -8.8217548e
------------------------- ---------------------------------------------  -----------------------------------------
Net                       (0.061780281 -0.10785265 1.4322371e-05)         (0.00023666504 -0.00026945269 -8.8217548e

Forces - Direction Vector (0 -1 0)
                          Forces (n)                                      Coefficients
Zone                      Pressure        Viscous         Total           Pressure        Viscous         Total
wall-solid                0.10785265      0.00026945269   0.1081221       0.17608595      0.00043992276   0.17652
------------------------- --------------- --------------- --------------- --------------- --------------- -------
Net                       0.10785265      0.00026945269   0.1081221       0.17608595      0.00043992276   0.17652
```

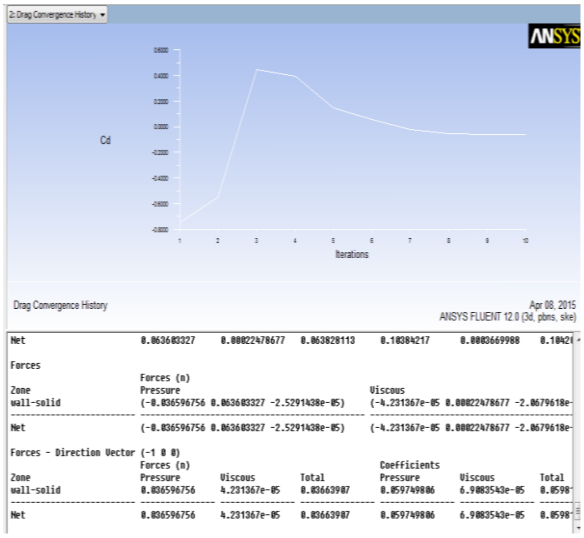
Fig .7: Lift produced by the proposed wing design(wing I)



```
Forces
                          Forces (n)
Zone                      Pressure                                        Viscous
wall-solid                (-0.036596756 0.063603327 -2.5291438e-05)       (-4.231367e-05 0.00022478677 -2.0679618e-
------------------------- ---------------------------------------------  -----------------------------------------
Net                       (-0.036596756 0.063603327 -2.5291438e-05)       (-4.231367e-05 0.00022478677 -2.0679618e-

Forces - Direction Vector (0 1 0)
                          Forces (n)                                      Coefficients
Zone                      Pressure        Viscous         Total           Pressure        Viscous         Total
wall-solid                0.063603327     0.00022478677   0.063828113     0.10384217      0.0003669988    0.1042
------------------------- --------------- --------------- --------------- --------------- --------------- -------
Net                       0.063603327     0.00022478677   0.063828113     0.10384217      0.0003669988    0.1042
```

Fig. 8: Lift produced by the current wing design (wing II)



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Net                       0.063603327     0.00022478677   0.063828113     0.10384217      0.0003669988    0.1042

Forces
                          Forces (n)
Zone                      Pressure                                        Viscous
wall-solid                (-0.036596756 0.063603327 -2.5291438e-05)       (-4.231367e-05 0.00022478677 -2.0679618e-
------------------------- ---------------------------------------------  -----------------------------------------
Net                       (-0.036596756 0.063603327 -2.5291438e-05)       (-4.231367e-05 0.00022478677 -2.0679618e-

Forces - Direction Vector (-1 0 0)
                          Forces (n)                                      Coefficients
Zone                      Pressure        Viscous         Total           Pressure        Viscous         Total
wall-solid                0.036596756     4.231367e-05    0.03663907      0.059749806     6.9083543e-05   0.0598
------------------------- --------------- --------------- --------------- --------------- --------------- -------
Net                       0.036596756     4.231367e-05    0.03663907      0.059749806     6.9083543e-05   0.0598
```
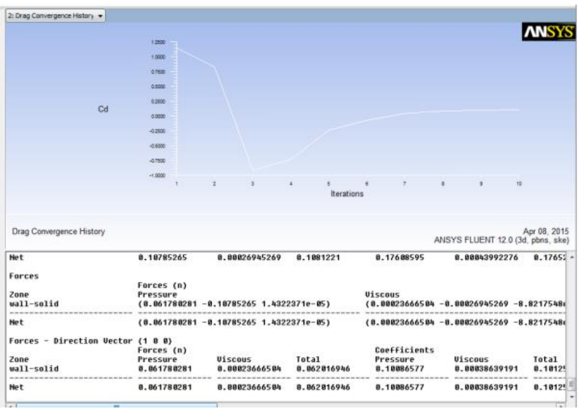

Fig. 9: Drag produced by the proposed wing design (wing I)



```
Net                       0.10785265      0.00026945269   0.1081221       0.17608595      0.00043992276   0.17652

Forces
                          Forces (n)
Zone                      Pressure                                        Viscous
wall-solid                (0.061780281 -0.10785265 1.4322371e-05)         (0.00023666504 -0.00026945269 -8.8217548e
------------------------- ---------------------------------------------  -----------------------------------------
Net                       (0.061780281 -0.10785265 1.4322371e-05)         (0.00023666504 -0.00026945269 -8.8217548e

Forces - Direction Vector (1 0 0)
                          Forces (n)                                      Coefficients
Zone                      Pressure        Viscous         Total           Pressure        Viscous         Total
wall-solid                0.061780281     0.00023666504   0.062016946     0.10086577      0.00038639191   0.10125
------------------------- --------------- --------------- --------------- --------------- --------------- -------
Net                       0.061780281     0.00023666504   0.062016946     0.10086577      0.00038639191   0.10125
```

Fig. 10: Drag produced by the current wing design(wing II)

The lift force generated by wing I and wing II are 0.060N and 0.112N respectively. The drag force generated by wing I and wing II are 0.034N and 0.193N respectively. Here also wing I proves to be better because of better lift to drag ratio.

4. STRUCTURAL ANALYSIS

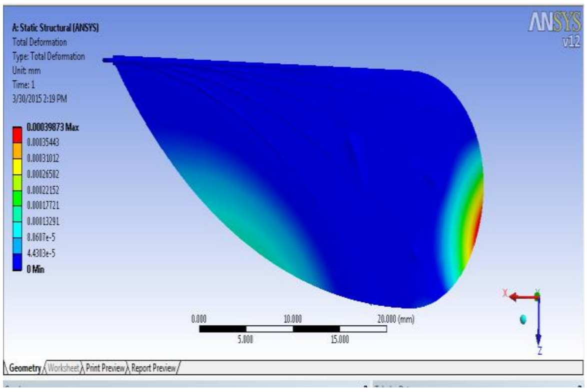


Fig .11: Total deformation

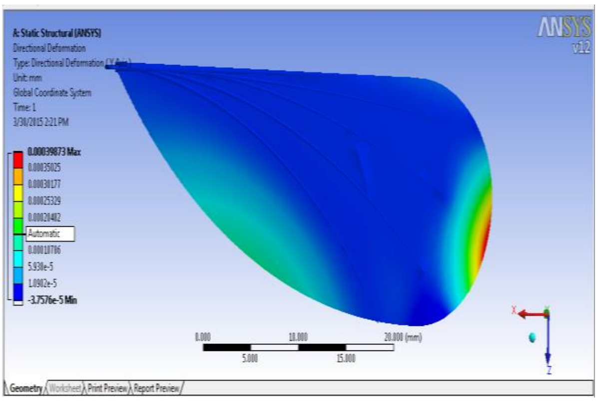


Fig. 12: Directional deformation

Structural analysis was carried out in addition to the computational fluid dynamic analysis. The analysis was done on ANYSYS workbench platform, the material chosen was carbon fiber. The lift and drag forces obtained after the CFD analysis were then used as the force acting on the wings for the analysis. The wings were medium meshed. Following figures show the results obtained from the analysis. The total deformation is found to be 0.0003983mm.

5. CONCLUSION

After comparing the lift and drag ratio the two wings at the different angular position it can be inferred that the wing based on the profile of fruit fly is better than the wing based on the bat because of the better lift to drag ratio.

Moreover hovering requires drag as minimum as possible while lift needs to be higher and stable throughout the flapping cycle. Structural analysis is also done on the proposed wing design to study its behaviour when the lift force is applied. Our suggestion hence positively favors the implementation of wing designed with a hybrid wing profile inspired by fruitful while having geometry of humming bird wing in ornithopters

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8. NOMENCLATURE

Symbol	Meaning	Unit
Cl	Coefficient of lift	Dimensionless
Cd	Coefficient of drag	Dimensionless
C	Mean chord length	Mm
R	Wing length	Mm
Φ	Flapping angle	Degree
N	Flapping frequency	n/s^{-1}
M	Mass	mg
Mw	Mass of wing	Mg