ISSN No:-2456-2165

# Design of High Lift Low Reynolds Number Airfoil for Micro Aerial Vehicle

Shahid khan[1], Saima H Ilkal[2], Rekha R[3]
[1,2,3]Student, Acharya Institute of technology, VTU University, belagavi, Karnataka , India

**Abstract:- In this present approach using direct design method in Xflr open source software a newly designed low Reynolds number airfoil is validated. UIUC airfoil coordinates database is taken for the reference airfoil SS007 and, S1223 and E423. using Xfoil parameters, panel code the airfoil parameters like thickness, camber, camber location is optimized at different Reynolds number ranging from $3.42*10^5$ to $10.28*10^5$ at different angle of attacks . This notes derives largely from the prior publication (see refs [3]). The characteristics of new airfoil are analysed and validated from the reference airfoil SS007 which can produce a lift of 2.56 and high L/D ratio at stall angle. Application:This low Reynolds number airfoil is strongly recommended for mav design.**

## I. INTRODUCTION

### *A. Airfoil Design Methods*

The airfoil design advances from the association between geometry of the airfoil, distribution of pressure and the properties of boundary layer.Usually, airfoil is designed in such a way that it provides maximum lift with minimum drag including constraints such as thickness, pitching moment, off-design performance, or other rare constraints.There are two methods of designing an airfoil:[1]

- direct method
- inverse method

### *B. Direct Method for Airfoil Design*

This includes the specific geometry of a part and computing the pressure and performance of airfoil. Firstly, the shape is evaluated and altered so as to improve its performance . In this method the two main problems are:[1]

- To Identify the measure of performance of the airfoil
- To improve the performance by changing the shape of airfoil

These problems are fixed until there are no crucial problems in the airfoil.

### *C. Inverse Method for Airfoil Design*

In this method, the geometry is calculated for particular parameters like velocity and pressure. It involves changing the shape of airfoil so as to improve its aerodynamic performance which can be done in two ways:

- By changing the airfoil geometry
- By numerical optimization: changing the geometry of airfoil with the help of shape functions and improving the design by determining the geometry.[1]

The design of airfoil with low Reynolds number is complex as it involves the formation of separation bubble. This results in increase of drag and hence reduces lift.[2]

Using the direct design method, an effort to design an airfoil with low Reynolds number has been made to improve the aerodynamic performance for the application of micro aerial vehicles.

## II. METHODOLOGY

The main focus of this is to design an airfoil having low Reynolds number ranging from $3.42*10^5$ to $10.28*10^5$ at various angles of attack (-5 to 20 degree) to increase the aerodynamic performance in mavs and to obtain an ideal result against the existing results. This work involves the analysis and design of 2D airfoil with low Reynolds number using XFLR5 and XFOIL.The characteristics over the 2D airfoil for instance, the coefficients of lift and drag , pressure distribution are studied at different conditions of flight.[3]

As shown in fig 1 the flow chart illustrates the detailed procedure of the work.For understanding the aerodynamic characteristics the leading three airfoils i.e.SS007, S1223 and e423 are selected on the basis of the outcome of the Xfoil results.Using the initial analysis i.e., analysis of aerodynamic characteristics of almost 200 plus airfoil is done by the method of Xfoil panel code. The maximum lift coefficient is obtained by the SS007 airfoil when compared with the other two airfoils which is further used for the design of a new airfoil using XFLR5 software (Foil direct design method).Using this method,the new airfoil is generated when we modify the parameters such as the maximum thickness and camber, location of the thickness and camber.The nascent airfoil is tested for its performance against the reference airfoil i.e.SS007 .[3]

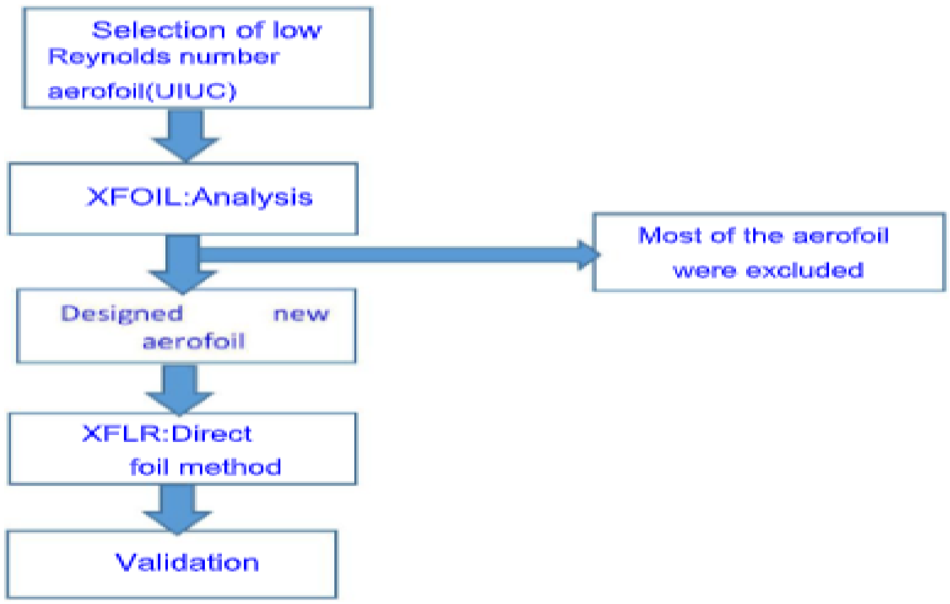


Fig 1:- Methodology [3]

## III. FOIL ANALYSIS AND DESIGN MODES

### A. *Xfoil*

For 2D airfoil, the aerodynamic characteristics are attained from the Xfoil. The airfoil coordinates are enlisted to obtain the geometry. Further, the Reynolds number and the AOA sequence is entered from -5 to 20 degrees and the generated aerodynamic characteristics are drag,lift, pressure coefficient and moment coefficients.

Re= · *Vc* · ·

Where · =1.78 X 10-5 N-s/m2, V = 5, 10, 15 m/s, chord (c) = 1 m, · =1.22 kg/m3

- *Case-1: V = 5 m/s; Re = 342697*
- *Case-2: V = 10 m/s; Re = 685393*
- *Case-3: V= 15 m/s; Re = 1028090*

The parameters of the airfoil selected are:

| Airfoil parameters | SS007 | E423 | S1223 |
|---|---|---|---|
| Thickness(%) | 12.18 | 12.52 | 12.13 |
| Max thickness position(%) | 20.20 | 24.24 | 20.21 |
| Max camber(%) | 10.56 | 10.03 | 8.67 |
| Max camber position(%) | 49.50 | 44.45 | 49.50 |
| Number of panels | 200 | 72 | 81 |

Table 1

### B. *XFLR5*

By using direct foil design method , altering the airfoil parameters such as maximum camber and thickness, location of thickness and camber, the nascent airfoil is generated.

The parameters below are modified and analysed for the conditions given.[3]

- *Condition-*

- 1% increment in the camber
- 2% increment in the camber
- 3% increment in the camber
- 1% increment in the camber condition
- 2% Increment in thickness Condition
- 1% Decrement in camber Condition
- 1% Decrement in thickness Condition
- 1% Increment camber & thickness Condition
- 1% Increment thickness & increment 10% location Condition
- 1% Increment thickness & decrement 10% location Condition
- 1% Increment thickness & increment 5% location [3]

ISSN No:-2456-2165

## IV. RESULT AND DISCUSSIONS

### *A. Xfoil*

Here, 3 aerofoils have been selected namely SS007, e423, S1223 and it is been tested at different conditions of 5m/s, 10m/s and 15m/s respectively. The maximum lift coefficient obtained based on the above selected aerofoil is taken as the reference aerofoil for the design of new aerofoil.

The table given below indicates the maximum lift coefficient of all the cases:

| Airfoil | Re=342697 | | Re=685393 | | Re=1028090 | |
|---|---|---|---|---|---|---|
| | · stall | Clmax | · stall | Clmax | · stall | Clmax |
| S1223 | 11 | 2.2733 | 13 | 2.2767 | 13 | 2.2849 |
| e423 | 13 | 2.0065 | 13 | 2.0481 | 13 | 2.0604 |
| SS007 | 15 | 2.4693 | 15 | 2.5162 | 15 | 2.5252 |

Table 2:- Xfoil results

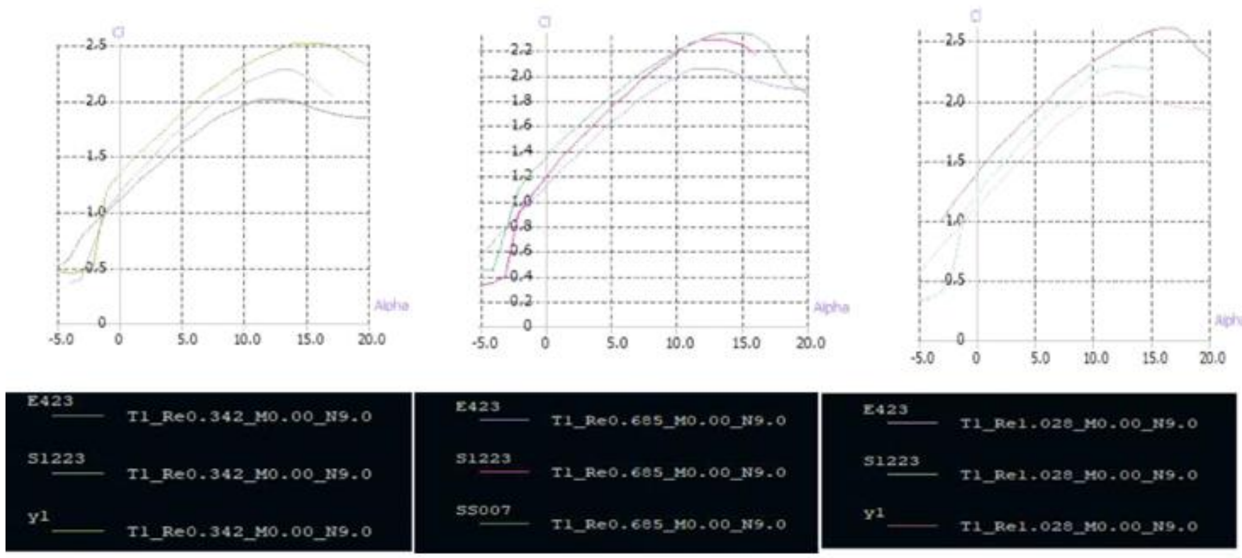


Fig 2:- Lift coefficient versus angle of attack

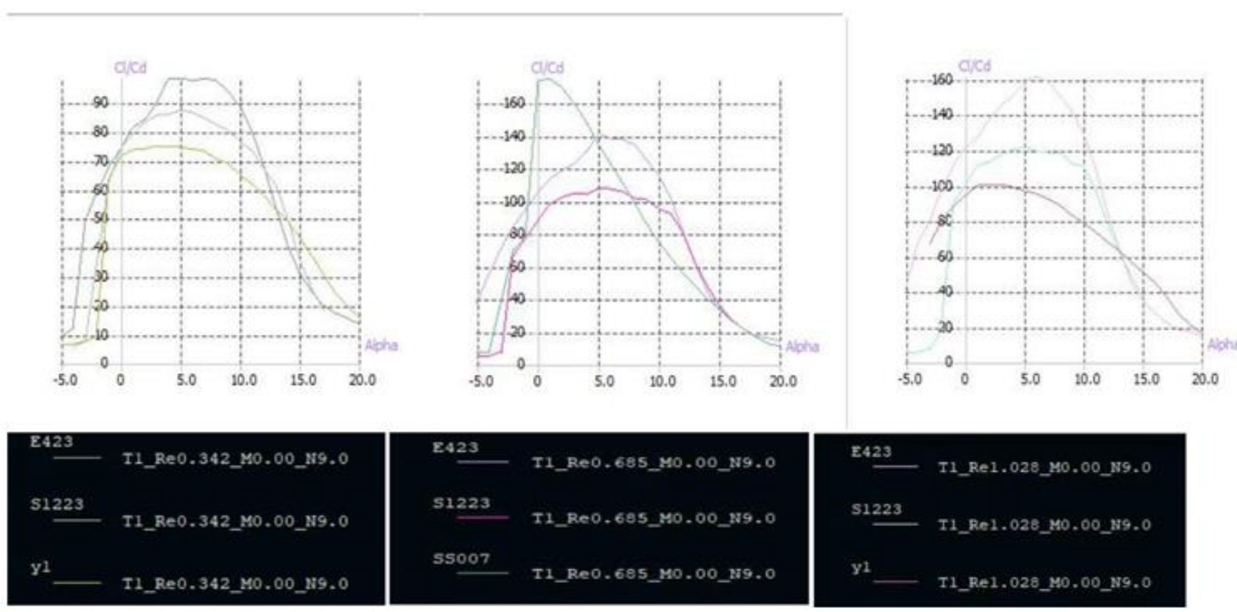


Fig 3:- Lift/drag coefficient ratio versus angle of attack

| Airfoil | | Re 342697 | Re 685393 | Re 1028090 |
|---|---|---|---|---|
| Parameters | | Clmax | Clmax | Clmax |
| Camber | 1%increment | 2.3806 | 2.4421 | 2.3461 |
| | 3%increment | 2.4817 | 2.5144 | 2.5655 |
| | 1%decrement | 2.2001 | 2.2532 | 2.2921 |
| Thickness | 1%increment | 2.3531 | 2.3851 | 2.4231 |
| | 2%increment | 2.3431 | 2.4213 | 2.4521 |
| | 3%increment | 2.3653 | 2.4341 | 2.4839 |
| | 1%decrement | 2.1321 | 2.3162 | 2.3432 |
| 1% Increases camber & thickness | | 2.4123 | 2.4821 | 2.5143 |
| 1% Increased thickness & increased 10% location | | 2.1821 | 2.2001 | 2.1521 |
| 1% Increased thickness & decreased 10% location | | 2.2621 | 2.2921 | 2.3621 |
| 1% Increased thickness & increased 5% location | | 2.2823 | 2.2642 | 2.2958 |
| SS007 (Reference Airfoil) | | 2.4693 | 2.5162 | 2.5252 |

Table 3:- The maximum lift coefficient at different conditions and the second condition i.e; 3% increase in the camber gives the maximum Cl compared to other conditions.

The table here gives the newly developed SR007 low Reynolds number aerofoil with maximum lift and the aerofoil parameters are defined below:

| Airfoil Parameters | SR007 |
|---|---|
| Thickness (%) | 13.50 |
| Max. Thickness Position (%) | 22.23 |
| Max Camber (%) | 11.47 |
| Max. Camber Position (%) | 50.51 |
| Number of Panels | 200 |

Table 4:- SR007 Airfoil Parameters


Fig 4:- SR007Airfoil Geometry

ISSN No:-2456-2165

| X(mm) | Y(mm) | X(mm) | Y(mm) | X(mm) | Y(mm) | X(mm) | Y(mm) |
|---|---|---|---|---|---|---|---|
| 99.67 | 0.357 | 74.865 | 11.324 | 37.124 | 16.7 | 8.648 | 10.333 |
| 99.201 | 0.931 | 73.403 | 11.637 | 35.719 | 16.74 | 7.823 | 9.828 |
| 98.746 | 1.487 | 71.932 | 12.004 | 34.331 | 16.76 | 7.046 | 9.322 |
| 98.284 | 1.996 | 70.454 | 12.325 | 32.961 | 16.76 | 6.319 | 8.818 |
| 97.797 | 2.457 | 68.97 | 12.635 | 31.616 | 16.738 | 5.642 | 8.317 |
| 97.267 | 2.889 | 67.479 | 12.933 | 30.311 | 16.692 | 5.015 | 7.823 |
| 96.683 | 3.307 | 65.979 | 13.219 | 29.055 | 16.619 | 4.436 | 7.337 |
| 96.041 | 3.722 | 64.469 | 13.496 | 27.843 | 16.517 | 3.905 | 6.862 |
| 95.335 | 4.14 | 62.95 | 13.763 | 26.66 | 16.387 | 3.422 | 6.401 |
| 94.562 | 4.565 | 61.424 | 14.02 | 25.496 | 16.229 | 2.987 | 5.956 |
| 93.716 | 4.999 | 59.894 | 14.266 | 24.343 | 16.043 | 2.595 | 5.526 |
| 92.795 | 5.443 | 58.358 | 14.504 | 23.197 | 15.828 | 2.245 | 5.109 |
| 91.8 | 5.896 | 56.816 | 14.732 | 22.06 | 15.586 | 1.931 | 4.704 |
| 90.742 | 6.351 | 55.268 | 14.951 | 20.932 | 15.317 | 1.65 | 4.312 |
| 89.627 | 6.805 | 53.715 | 15.162 | 19.814 | 15.021 | 1.4 | 3.931 |
| 88.456 | 7.256 | 52.159 | 15.364 | 18.705 | 14.696 | 1.178 | 3.559 |
| 87.232 | 7.703 | 50.604 | 15.557 | 17.603 | 14.344 | 0.98 | 3.201 |
| 85.958 | 8.146 | 49.053 | 15.74 | 16.512 | 13.968 | 0.804 | 2.85 |
| 84.647 | 8.584 | 47.509 | 15.912 | 15.435 | 13.57 | 0.649 | 2.519 |
| 83.309 | 9.011 | 45.974 | 16.072 | 14.379 | 13.153 | 0.513 | 2.2 |
| 81.95 | 9.426 | 44.453 | 16.218 | 13.345 | 12.717 | 0.394 | 1.889 |
| 80.569 | 9.829 | 42.948 | 16.35 | 12.337 | 12.266 | 0.292 | 1.595 |
| 79.169 | 10.219 | 41.462 | 16.465 | 11.362 | 11.801 | 0.206 | 1.319 |
| 77.75 | 10.599 | 39.996 | 16.563 | 10.421 | 11.323 | 0.137 | 1.059 |
| 76.315 | 10.967 | 38.55 | 16.641 | 9.515 | 10.833 | 0.082 | 0.792 |
| 0.043 | 0.552 | 6.317 | -0.885 | 41.726 | 6.09 | 77.801 | 7.828 |
| 0.017 | 0.282 | 7.197 | -0.753 | 43.225 | 6.336 | 79.245 | 7.664 |
| 0.004 | -0.032 | 8.201 | -0.596 | 44.723 | 6.571 | 80.575 | 7.48 |
| 0.005 | -0.057 | 9.332 | -0.414 | 46.219 | 6.793 | 81.886 | 7.275 |
| 0.02 | -0.38 | 10.575 | -0.208 | 47.712 | 7.004 | 83.173 | 7.051 |
| 0.048 | -0.596 | 11.896 | 0.014 | 49.2 | 7.202 | 84.434 | 6.808 |
| 0.092 | -0.798 | 13.248 | 0.248 | 50.685 | 7.386 | 85.667 | 6.545 |
| 0.159 | -1 | 14.607 | 0.495 | 52.167 | 7.556 | 86.877 | 6.26 |
| 0.258 | -1.166 | 15.983 | 0.759 | 53.648 | 7.713 | 88.061 | 5.955 |
| 0.395 | -1.289 | 17.392 | 1.048 | 55.126 | 7.854 | 89.211 | 5.632 |
| 0.567 | -1.363 | 18.854 | 1.364 | 56.601 | 7.981 | 90.318 | 5.295 |
| 0.764 | -1.414 | 20.372 | 1.704 | 58.07 | 8.093 | 91.373 | 4.948 |
| 0.973 | -1.442 | 21.928 | 2.057 | 59.533 | 8.189 | 92.375 | 4.588 |
| 1.194 | -1.453 | 23.49 | 2.41 | 60.991 | 8.268 | 93.323 | 4.218 |
| 1.429 | -1.446 | 25.044 | 2.758 | 62.442 | 8.331 | 94.218 | 3.838 |
| 1.682 | -1.428 | 26.589 | 3.1 | 63.888 | 8.378 | 95.055 | 3.45 |
| 1.958 | -1.404 | 28.125 | 3.435 | 65.328 | 8.406 | 95.835 | 3.056 |
| 2.259 | -1.379 | 29.651 | 3.762 | 66.762 | 8.417 | 96.56 | 2.651 |
| 2.588 | -1.352 | 31.168 | 4.082 | 68.189 | 8.41 | 97.238 | 2.231 |
| 2.95 | -1.321 | 32.679 | 4.396 | 69.608 | 8.385 | 97.877 | 1.794 |
| 3.351 | -1.282 | 34.19 | 4.702 | 71.017 | 8.341 | 98.483 | 1.332 |
| 3.797 | -1.231 | 35.703 | 5 | 72.415 | 8.279 | 99.065 | 0.841 |
| 4.303 | -1.168 | 37.215 | 5.288 | 73.803 | 8.196 | 99.628 | 0.332 |
| 4.882 | -1.09 | 38.723 | 5.566 | 75.18 | 8.094 | 100 | -0.019 |
| 5.549 | -0.996 | 40.227 | 5.834 | 76.546 | 7.971 | 0 | 0 |

Table 5:- SR007 Airfoil Coordinates

*B. XFLR5*

Here, the non dimensional force Cl and Cd ( Aerodynamical forces ) has been tabulated below at different angles of attack att different conditions of 5m/s, 10m/s and 15m/s respectively

| SR007 Airfoil | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| AOA | Re = 342697 | | | Re = 685393 | | | Re = 1028090 | | |
| | Cl | Cd | Cl/Cd | Cl | Cd | Cl/Cd | Cl | Cd | Cl/Cd |
| -5 | 0.4138 | 0.07710 | 5.367 | 0.4578 | 0.07315 | 6.26 | 0.4438 | 0.07346 | 6.042 |
| -3 | 0.4527 | 0.06504 | 6.960 | 0.4825 | 0.05679 | 8.51 | 0.4433 | 0.06329 | 7.001 |
| -1 | 0.6583 | 0.04501 | 14.62 | 0.7035 | 0.04023 | 17.47 | 0.5094 | 0.05304 | 9.604 |
| 1 | 1.5088 | 0.02217 | 68.05 | 1.5270 | 0.01987 | 76.85 | 1.5621 | 0.01806 | 86.51 |
| 3 | 1.7359 | 0.02449 | 70.88 | 1.7356 | 0.02227 | 77.93 | 1.7715 | 0.02005 | 88.35 |
| 5 | 1.9411 | 0.02711 | 71.60 | 1.9150 | 0.02511 | 76.26 | 1.9468 | 0.02281 | 85.35 |
| 7 | 2.1289 | 0.02973 | 71.61 | 2.0849 | 0.02831 | 73.64 | 2.1082 | 0.02623 | 80.41 |
| 9 | 2.3018 | 0.03330 | 69.12 | 2.2358 | 0.03186 | 70.16 | 2.2593 | 0.02987 | 75.63 |
| 11 | 2.4112 | 0.03842 | 62.75 | 2.3588 | 0.03722 | 63.37 | 2.3871 | 0.03504 | 68.12 |
| 13 | 2.4672 | 0.04611 | 53.35 | 2.4525 | 0.04494 | 54.58 | 2.5027 | 0.04130 | 60.60 |
| 15 | 2.4817 | 0.05897 | 42.08 | 2.5144 | 0.05651 | 44.51 | 2.5655 | 0.05247 | 48.91 |

Table 6:- summary of the results

Figure 5 gives the overview of complete study carried out in this present work at different angle of attack -5$^{o}$ to 20$^{o}$ and different Reynolds number 3.28*10$^{5}$ to 10.28*10$^{5}$

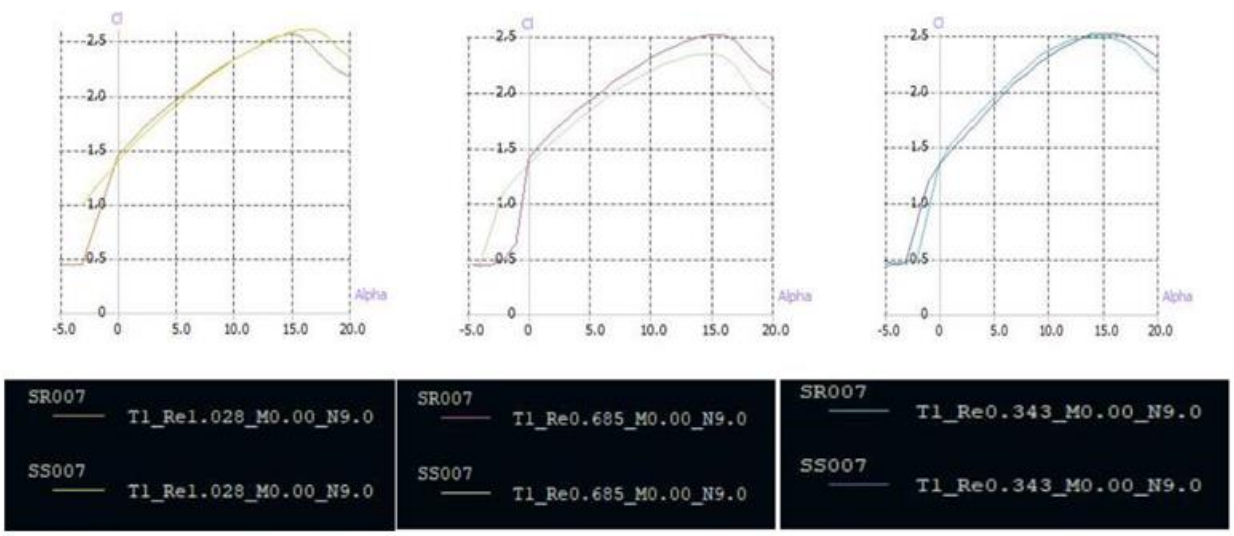


Fig 5:- Lift coefficient versus angle of attack

From the above figure 5 the comparison is made between SS007(Reference aerofoil) and SR007 at different angle of attack ranging from -5o to 20o with different Reynolds number condition ranging from 3.42*105 to 10.28*105 is been plotted which produces a maximum lift of 2.56 at Reynolds number 10.28*105 and the reference aerofoil produces 2.53 maximum lift at 10.28*105 Reynolds number respectively.

## V. CONCLUSIONS

As a result of this present work using xflr5 open source software allows Reynolds number aerofoil with maximum lift co-efficient at stall angle with maximum Cl/Cd ratio can be designed using this xfoil panel method which produces more lift than the reference aerofoil SS007. SS007 produces 10.96% more lift from the S1223 aerofoil and SR007 produces 12.12% more lift compared to S1223 aerofoil. The maximum lift is 2.56 from the 3.42*105 to 10.28*105 Reynolds number range. It is proved that newly developed

SR007 2D aerofoil gives the better aerodynamic performance than the reference aerofoil, this can be strongly recommended to be used in the construction of MAV.

## REFERENCES

[1]. XFLR5, 2009, Analysis of foils and wings operating at low Reynolds numbers, Guidelines for QFLR5 v0.03.
[2]. Somashekar V, 2014, "A Computational Investigation of Unsteady Aerodynamics of InsectInspired Fixed Wing Micro Aerial Vehicle's 2D Airfoil", Hindawi Publishing Corporation, Volume 2014, Article ID 504049, 7 pages.
[3]. Design of low Reynolds number airfoil for micro aerial vehicle.
[4]. Michael S. Selig, Christopher A. Lyon, Philippe Giguere, Cameron P. Ninham. James J. Guglielmo, 1996, "Summary of Low-Speed Airfoil Data", SoarTech Publications, Virginia Beach, Virginia.
[5]. Ali Doosttalab, Mohammad Mohammadi, Mehdi Doosttalab, Ali Ashrafizadeh, 2012, "Numerical Investigation of Aerodynamical Performance of Damaged Low-Reynolds Airfoils for UAV Application", TFAWS 2012.
[6]. Mostafa Hassanalian, Hamed Khaki and Mehrdad Khosrawi, 2014, "A new method for design of fixed wing micro air vehicle" Journal of Aerospace Engineering 2014.