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Experimental analysis to assess the aerodynamic characteristics of the newly designed airfoil

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ABSTRACT: *The aerodynamic efficiency of an airfoil plays a crucial role in the performance, stability, and maneuverability of radio-controlled (RC) aircraft and unmanned aerial vehicles (UAVs). This study focuses on the design, development, and performance evaluation of a newly engineered airfoil tailored for low-speed, high-lift applications. The research involves computational and experimental analysis to assess the aerodynamic characteristics of the newly designed airfoil. Computational Fluid Dynamics (CFD) simulations are conducted to evaluate lift, drag, pressure distribution, and flow separation at various angles of attack (AOA) and Reynolds numbers. Additionally, wind tunnel testing is performed to validate the numerical results and analyze real-world flight behavior. The performance of the new airfoil is compared with existing airfoil designs commonly used in RC aircraft and UAVs. The results indicate a significant improvement in lift-to-drag ratio, stall characteristics, and overall aerodynamic efficiency, making it suitable for enhanced endurance, payload capacity, and energy-efficient flight. This study contributes to the advancement of lightweight, high-performance UAVs and RC aircraft, offering potential applications in reconnaissance, surveillance, and commercial drone operations.*

Keywords: A*irfoil, RC aircrafts, UAVs*

I. INRODUCTION AND BACKGROUND

The growing interest in research of UAVs and RC planes, equipped with increased payloads, shortened take-off and landing distances and lower stall speed, has created a need for new airfoils with high lift and increased performance in low Reynold's number conditions. Apart from armies of various countries, some private companies are also working on design of UAVs, capable of performing recon missions, rescue missions and fire-fighting applications. An optimized and high performing airfoil enables heightened maneuverability as well as stability and thus has earned an enormous importance in modern day Aeronautical Engineering. The results of this research will be useful in such aircraft and will pave the way for further development in this field.

II. LITERATURE REVIEW

A study on pressure coefficients and lift generation in airfoils has shown that the upper surface has lower negative coefficient of pressure at higher angles of attack and lower surface has lower negative coefficient of pressure at lower angles of attack. The difference in pressures between the lower surface of airfoil and the incoming flow stream is significant to push the airfoil upward, normal to flow direction. [Sagat et al. (2012)]. A comparative study between existing high lift airfoils by Reza et al. (2016) showed the best airfoils currently in use. These were; Selig 1223, Eppler 420, Eppler 423, Wortmann FX, and CH-10. This study also gave the max coefficient of lift, moment, stall angle, and coefficient of drag values. Karna et al. (2014) have reported their studies on NACA airfoils at different angles of attack and given the CFD analysis results with air flow and pressure contours. These indicate that the nose of the airfoil plays an important role in separating the air flow and that increment in angle of attack results in increase in lift as well as drag before stall. Benavent et al. (2013), in their studies, have given comparative studies between different NACA airfoils with different wing loading, speeds, length attributes, angles of attack, wing twist and dihedral angles. These give the optimum angles of attack with corresponding lift for different modes of flight like cruise, glide, land, take-off etc.

Primary areas where we needed to do research was regarding the software we were about to use i.e. XFLR and ANSYS. The software and their uses were studied and then we came to know about how we could efficiently use them for our research purposes many journals and conference notes were particularly helpful to us on this account.

While browsing through the literature our key words had been -

1. High lift, low Reynolds number airfoil,
2. XFLR analysis of above mentioned airfoil
3. ANSYS flow analysis of a 2-D airfoil

III. OBJECTIVES OF THE WORK

The objectives of the work are the following-

1. Understanding key features of airfoils and study of the equations and mathematicalmodels used to determine their characteristics.
2. Development of a new airfoil
3. Testing of airfoil in multiple software
4. Ensuring that its feature is better than the pre-existing models
5. Fixing parameters keeping in mind the economic constraints
6. Learning the proper use of the software and the nature and effect of changes of shapeof an airfoil on lift and other defining parameters
7. Publish the work in a good journal or conference.

IV. METHODOLOGY

The Project Planning is carried out keeping in mind the effectiveness of the end produce/product which will be used for further applications like in the field of medicine, recon missions etc. On a whole the project is aimed at manufacturing a suitable airfoil for construction of light UAVs. For instance in the case of a reconnaissance, a light weight UAV would be the most preferred in terms of low manufacturing cost but with an efficient set of performance characteristics for example in monitoring an enemy region, scanning of a location or primarily and more feasibly in that of the case of disaster management and medical aid package delivery etc. Hence the velocity of the given aircraft will be of a lower magnitude since overall costly in these cases. Moreover the important thing to remember is that all the other parameters except that relating to the airfoil are assumed to remain constant

i.e. only the airfoil parameters are being compared and contrasted here. XFLR 5 and ANSYS analysis was done using airfoils like Selig 1223, Eppler 423, Ch10, Wortman FX to find out the best airfoil so that we could perform modifications on it. The procedure to use these software was studied online. The parameters being C_L (Coefficient of lift), C_D (Coefficient of drag) and their relationship with α (Angle of attack).

a. EQUATIONS NEEDED

Reynolds number formula

$Re = \rho\, v\, l / \mu = v\, l / \vartheta$

v=velocity of fluid

l=the characteristic length or chord of the airfoilρ=the density of the fluid

μ=the dynamic viscosity of the fluidϑ=the kinematic viscosity

v=15m/sl=15 cm

μ=1.4X10^ (-5)

ρ=1.224 kg/m^3

Therefore Reynolds number for our aircrafts we are concentrating 150,000-300,000 rangeand we are working in this range.

V. ANALYSIS WORK

a. BASE AIRFOIL SELECTION AND ANALYSIS

After the literature review we decided upon 4 airfoils for base consideration. These are as follows:

Figure 1 Selig1223

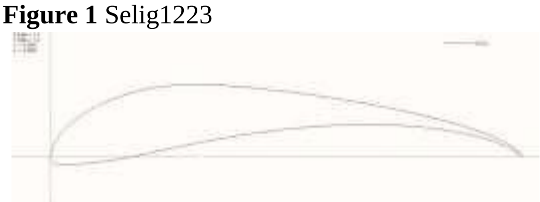


Figure 3 Eppler423

Figure 2 CH10

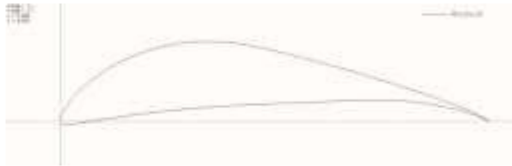


Figure 4 Wortmann FX

These airfoils were loaded onto XFLR5 software and analyzed for their Cl vs alpha and Cl/Cd vs alpha characteristics. The Reynolds number used was 150,000.

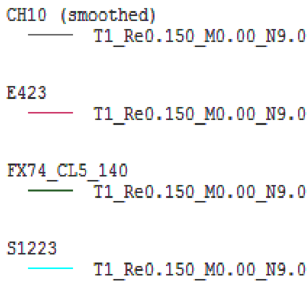


Figure 5 Legend for base airfoil comparisons

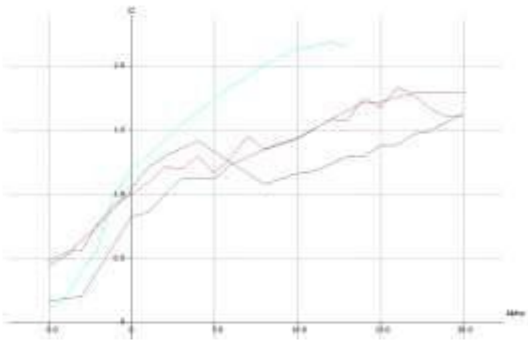


Figure 6 Coefficient of Lift Vs Angle of Attack

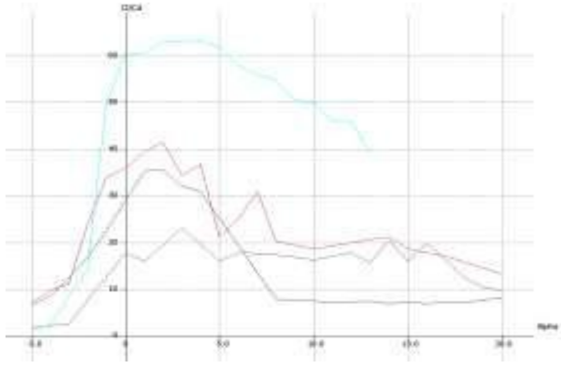


Figure 7 Ratio of Coefficient of Lift by Coefficient of drag Vs Angle of attack of base airfoils

In the above graphs we see that the coefficient of lift as well as C_L/C_D for Selig1223 is the highest among the four base airfoils. This suggests that Selig1223 airfoil is suitable for base airfoil considerations.

After Selig1223, Wortmann FX has the second highest C_L. Thus, it was also selected as a base airfoil on which modifications were to be made. Thus all modifications were to be made using this as a standard.

b. FINAL CUSTOM AIRFOILS

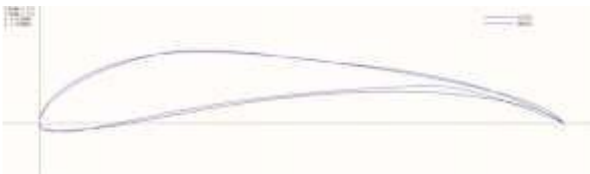


Figure 8 SMOD1

Figure 9 SMOD2

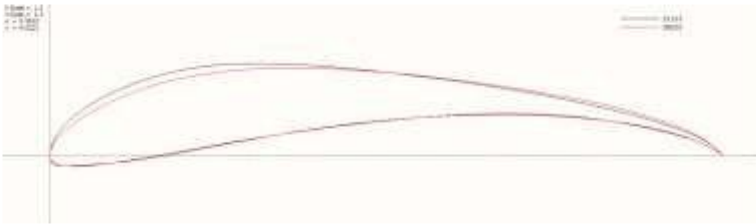


Figure 10 SMOD3

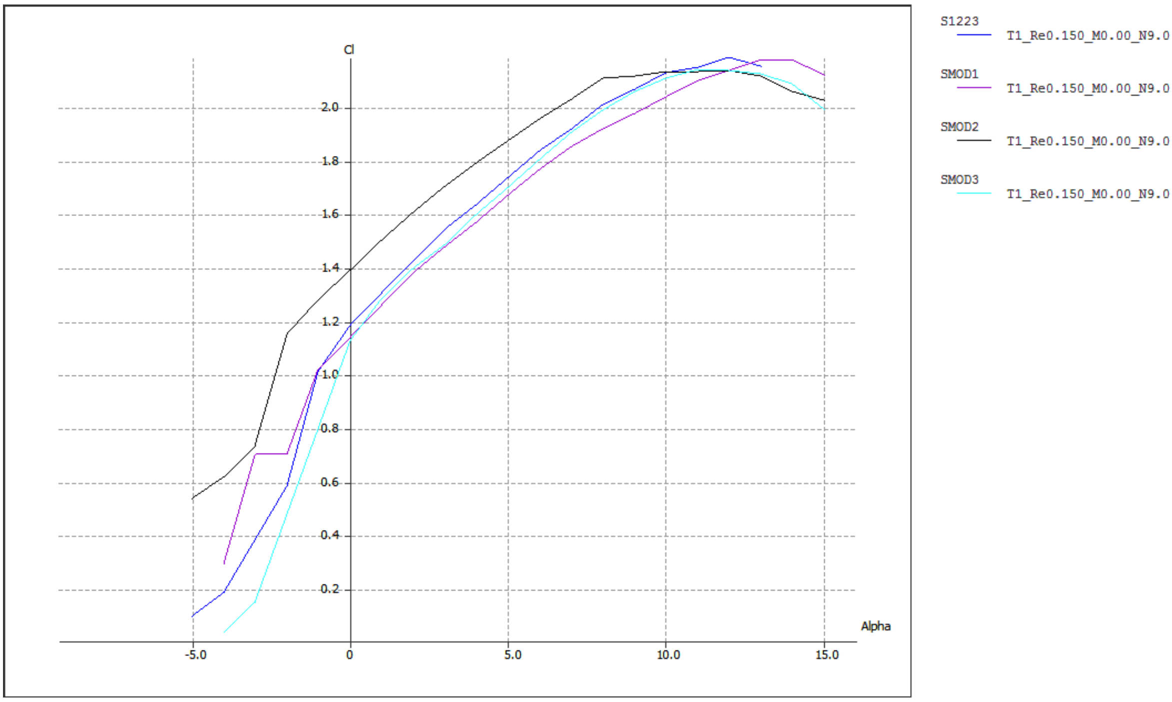


Figure 11 C_L Vs α graph for above airfoils

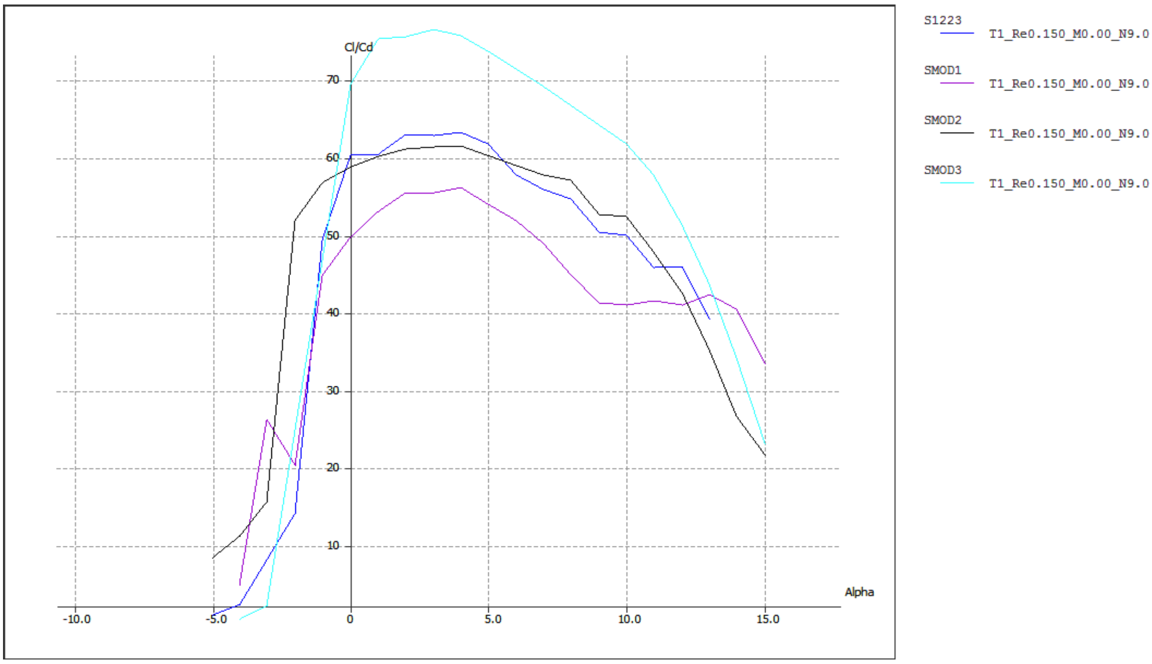


Figure 12 C_L/C_D Vs α graph for above airfoils

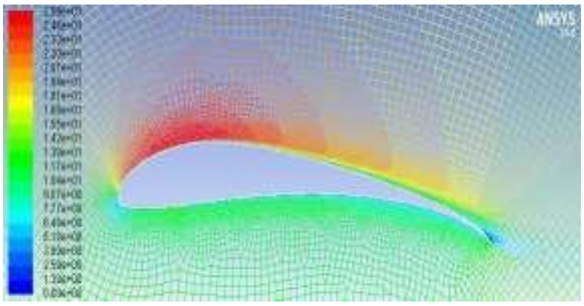
The analysis gave us the required results and as you can see from graphs above are a proofthat the airfoils we designed are better and have superior lift qualities while are not compromising on the drag features of the airfoil.

c. ANSYS ANALYSIS

The shortlisted modified Selig airfoils namely Smod1, Smod2 and Smod3 are further analyzed through ANSYS along with the original Selig S1223. The analysis for AOA(Angle of attack= 0° did not yield optimum results since the angle of attack of an wing is generally 5° this angle of attack was selected and analysis was performed. From this analysis SMOD 2 gave superior results as compared to the already pre-existing S1223 airfoil which was the superior low Reynolds no. high lift airfoil as can be seen below.

ANSYS Results and Discussions for AOA = 5°:

Selig S1223 (pre-existing airfoil):



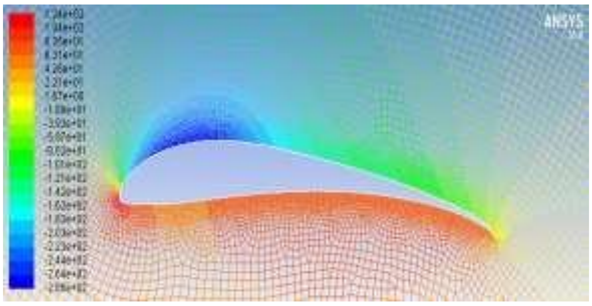


Figure 13 Contours of Velocity Magnitude (m/s) **Figure 14** Contours of Static Pressure (pascal)

LIFT FORCE:

Forces - Direction Vector (0 1 0)

Zone	Forces (n) Pressure	Viscous	Total
part1	162.60381	0.034949437	162.63875
part2	73.129059	-0.014164452	73.114894
Net	235.73286	0.020784985	235.75365

COEFFICIENT OF LIFT (C_L):

Coefficients

Pressure	Viscous	Total
265.4756	0.057060305	265.53266
119.39438	-0.023125635	119.37126
384.86998	0.03393467	384.90392

DRAG FORCE:

Forces - Direction Vector (1 0 0)

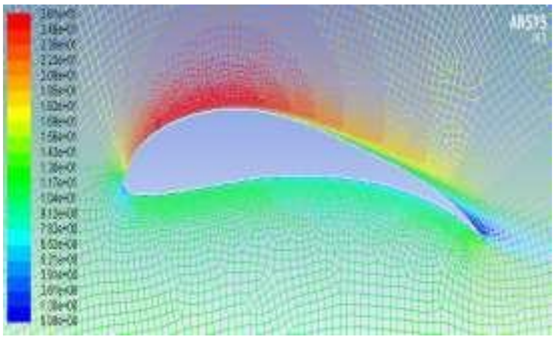
Zone	Forces (n) Pressure	Viscous	Total
part1	-2.2200947	1.0531032	-1.1669915
part2	7.535296	0.30543575	7.8407317
Net	5.3152013	1.358539	6.6737402

COEFFICIENT OF DRAG (C_D):

Coefficients

Pressure	Viscous	Total
-3.6246444	1.7193522	-1.9052922
12.302524	0.49867061	12.801195
---------------	---------------	----------
8.6778796	2.2180228	10.895902

Smod2:



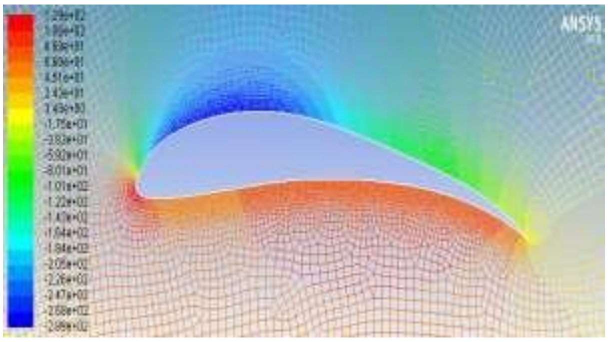


Figure 15 Contours of Velocity Magnitude (m/s) **Figure 47** Contours of Static Pressure (pascal)

LIFT FORCE:

Forces - Direction Vector (0 1 0)

	Forces (n)		
Zone	Pressure	Viscous	Total
part1	173.96589	0.066195858	174.03208
part2	72.766817	-0.016716269	72.7501
-------------------------	---------------	---------------	----------
Net	246.7327	0.04947959	246.78218

COEFFICIENT OF LIFT (C_L):

Coefficients

Pressure	Viscous	Total
284.02594	0.10807487	284.13401
118.80297	-0.027291867	118.77567
---------------	---------------	----------
402.8289	0.080783003	402.90968

DRAG FORCE:

Forces - Direction Vector (1 0 0)

	Forces (n)		
Zone	Pressure	Viscous	Total
part1	-3.3567234	1.0692597	-2.2874637
part2	8.4350279	0.30808724	8.7431152
-------------------------	---------------	---------------	----------
Net	5.0783045	1.3773469	6.4556515

COEFFICIENT OF DRAG (C_D):

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Coefficients
Pressure        Viscous         Total
-5.4803647      1.7457301       -3.7346346
13.771474       0.50299957      14.274474
--------------- --------------- -----------
8.2911095       2.2487297       10.539839
```

d. Conclusions and Discussion:

i. The results obtained show that Smod2 gives excellent and much better flightperformance characteristics than the base airfoil Selig S1223.

ii. The Lift Force and Lift Coefficient is significantly higher for Smod2 than S1223.

iii. C_L/ C_D ratio is quite high for Smod2 than S1223.

Thus it can be concluded that the shortlisted Smod2 airfoil has shown much better and higher Lift Performance Characteristics than the base airfoil S1223 through XFLR and ANSYS analysis.

Also after the XFLR analysis following can be concluded

iv. Bigger crown give more C_L than smaller crown

v. Shifting crown backwards gives more C_L

vi. Shifting the tail down gives more C_L than shifting it up

vii. Making the airfoil thinner from bottom edge gives higher C_L

viii. Wortmann FX based airfoils are not optimum

ix. Thicker airfoils give higher C_L/C_D

x. Nose rounding optimization is essential for flow separation and thus higher C_L/C_D

VI. FINAL CONCLUSION

The obvious conclusions that can be drawn is that by changing the airfoil shape i.e. by curving it on the front and making its ends more curved and thinning its ends you get better results and that of the airfoils Selig 1223 is the best when modified and it will be the solefocus core of our project.

- ANSYS analysis done on the SELIG modified done proves that thinned and curved airfoils were better and give better lift and lower drag
- The ends of SELIG Modified 3 are lower than (0,0) and it gives a higher lift and good drag and higher stall angle.
- SELIG MODIFIED 2(SMOD2) IS THE BEST AIRFOIL AMONGST THE ALL OF THEM CL/CD (Coefficient of lift CD-Coefficient of drag) best
- CL Quite high
- Higher stall angle than Selig
- The potential for future work can be said to include U.A.V and R.C aircrafts which when made will use this airfoil as their working airfoil and will find that their performance has increased and the efficiency has also increased.
- Novelty work on low Reynolds no. airfoils has been done which has not been done otherwise the Reynolds no. range is very low and such low Reynolds no airfoil characteristics have not been explored anywhere else.
- Over and all it is a project which although may be published in a good journal will take a long time for practical implementation.
- In future more curvature, shifting the tail downwards and bigger crown airfoils can give more lift and this can be used to make better airfoils than the previously existing ones.

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