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Performance analysis of high wing for a micro class unmanned aerial vehicle

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ABSTRACT

The paper deals with the design and performance analysis of high wing of a Micro Class Unmanned Aerial Vehicle. The wing design involves its initial considerations like and weight of the aircraft, planform selection, selection of airfoil, area of the wing and wing loading characteristics. The design is done based on the calculated values and performance analysis is done to show airfoil characteristics, and performance of the wing with the help of XFLR5 software. The objective of this project is to compare the results obtained for different wing planforms, different angle of attack over a range of speeds. From the results we will conclude which wing configuration meets the payload lifting goals. Selection of wing configuration is an iterative process. The iterative process allows us to accommodate other design criteria such as catering storage, systems installations (high lift devices, attachment of motors and the main undercarriage) which may or may not be directly related to the goals of the mission. The result of iterative optimization is typically a compromise in configuration which best satisfies the overall needs of the mission. The final decision upon configuration will represent a compromise based on design priorities.

Keywords— *Coefficient, Lift, Drag, lift to drag ratio, Angle of Attack, Fluid density, Fluid velocity, Characteristic length, Chord Length, Dynamic Viscosity*

1. LITERATURE REVIEW

[1] M. J. Smith, N. Komerath, R. Ames and O. Wong conducted performance analysis on wing with multiple winglets. Their effort examined the potential of multiple winglets for the reduction of induced drag without having to increase the span of wings. Wind tunnel models were built using a NACA – (National Advisory Committee for Aeronautics) 0012 airfoil section for the untwisted, rectangular wing and flat plates for the winglets. Testing of these configurations was performed over a range of Reynolds numbers from 161,000 to 300,000. Wind tunnel balances provided lift and drag measurements, and laser flow visualization obtained wingtip vortex information. A substantial increase in lift curve slope occurs with dihedral spread of winglets set at zero incidences relative to the wing. Dihedral spread also distributes the tip vortex. These observations supplement previous results on drag reduction due to lift reorientation with twisted winglets set at negative incidence.

[2] PRISACARIU Vasile conducted performance analysis on Flying Wing airfoils. He concluded that Flying wings flight performances depend directly on the 2D aerodynamic optimization (choosing aerodynamic profile). The aerodynamic profiles used in tailless aircraft have a series of specific constructive performance. His article presents a piece of analysis regarding the 2D aerodynamic profile used in the construction of a flying wing UAV type.

[3] Shamil PC, Mohammed Sanjid, Muhammed E A, Aravind Krishnan, Prof. Thomas Jacob performed CFD Analysis on wing with and without winglets. The aim of their project was computational analysis of wings without winglet and the rise in aerodynamic efficiency after installing winglets. The rise in cost of aviation fuel, operating costs and rising CO_2 in atmosphere is the reason aerospace industry started researching to get efficient aircraft designs. The aerospace industries found some design modification in wing design by adding winglets to reduce the drag and air vortex but researchers will always continue to work on better designs. In this research it was ascertained that adding winglets increase the aerodynamic efficiency in terms of C_L/C_D. Furthermore, the reduction in air vortex behind the wing, was proven in this study by the adding a winglet to the wingtip.

[4] MD Khaleel, Alka Sawale, S. Jaswanth conducted modeling and analysis of winglet of aircraft. In aerodynamic engineering, drag reduction is a big challenge. To reduce drag, a device called winglet which is placed vertically at set of angle on the end of

aircraft wing. Winglet design will lower fuel consumption by reducing drag and makes the aircraft more stable during flight; also it will give the aircraft engine longer life by reducing the load on the engine thrust. Based on the CFD results for NACA 2412 and swept back when used blended winglets they observed 4 to 10 percent reduction for Mach regime 0.5 and 0.6, however they observed the overall aerodynamic efficiency and change in lift production for both with and without winglets are minimum. However, wing configuration with winglets has less induced drag compared to wings without winglets. Further work has to be done on other winglets such as sharklets and compare those results with these and evaluate best winglets for certain configuration and flow regime. Similarly, other type of wing configurations and airfoils need to be studied.

2. WING DESIGN PARAMETERS

The design parameters like span, taper ratio, sweep, thickness, aspect ratio and dihedral are calculated and the wing is designed in Solidworks. Actual wing area can be calculated from the maximum takeoff weight and the actual Volumetric Wing cube loading (C) values.

These parameters will be considered for a Micro Class fixed-wing type UAV with a maximum takeoff weight of 1.75 KG, stall speed of 6 m/s and maximum cruise speed of 10 m/s.

The wing must be designed and tested to ensure it can withstand the maximum loads imposed by maneuvering, and by atmospheric gusts. To design a wing that can easily generate lift of 1.75 KG, we will consider Factor of Safety of 1.5 which means, we will design a wing for maximum lift of 2.62 Kilograms in the range of 6 m/s to 10 m/s.

3. REQUIRED LIFTING AREA AND WING PLANFORM SELECTION

To calculate the required lifting area, Volumetric Wing cube loading (C) can be considered and the formula used is:

$$\boldsymbol{C} = \frac{(\boldsymbol{Max.Takeoff\ Weight})}{(\boldsymbol{Lifting\ Area})^{1.5}} \qquad (\mathbf{1})$$

The most optimum value of Volumetric Wing cube loading (C) is selected to calculate the lifting area. After considering various values of C, ranging from C=4 to C=12, C=10 was found as the most optimum value of Volumetric Wing cube loading and the lifting area required to lift a weight of 2.62 KG was found to be 4200 cm^2. Various wing planforms were compared in order to achieve the best possible wing configuration and maximum lifting capabilities within the given dimensional constraints. There are several types of wing configurations each with its advantages and disadvantages:

- **Elliptical** Aerodynamically, the elliptical planform is the most efficient as elliptical span-wise lift distribution has the lowest possible induced drag (as given by thin airfoil theory). However, the disadvantage of elliptical wing is that its manufacturability is poor. The elliptical wing was not decided to minimize induced drag, but to house the retractable landing gear along with guns and ammunition inside a wing that had to be thin. The ellipse was simply the shape that allowed the thinnest possible wing with room inside to carry the necessary structure.
- **Rectangular** the simplest wing planform from a manufacturing point of view, the rectangular wing is a straight, un-tapered wing. The disadvantage of this wing is that it is aerodynamically inefficient.
- **Tapered Wing** is a modification of the rectangular wing where the chord is varied across the span to approximate the elliptical lift distribution. While not as efficient as the elliptical wing, it offers a compromise between manufacturability and efficiency.

The correct configuration was chosen, by performing a trade study by assigning points ranging from 1 to 10 to the topics mentioned below in table 1:

Table 1: Wing Planform comparison

Parameters	Rectangular	Tapered	Elliptical
Efficiency	8	9	10
Lift at 0° Angle of Attack	8	9	10
Construction	10	8.5	6
Stall Characteristics	10	9	9
Total	36	35.5	35

Rectangular planform is chosen by considering the total points and due to the ease of construction that it provides. Also, the performance of rectangular planform varied marginally from the tapered or elliptical wing.

4. AIRFOIL SELECTION

The choice of airfoil is important for our application which demanded a “High Lift - Low Reynolds number” airfoil. High lift airfoils at low angle of attacks demand airfoils with high degree of asymmetry. A few airfoils are extensively used in high lift applications - E423, S1210 and S1223. The properties of these airfoils were studied which is tabulated below in table 2:

Table 2: Airfoil Comparison

Parameters	S1223	S1210	E423
CL Max	2.375	2.235	2.311
Maximum L/D	125.155	109.915	67.65
Stall Angle	8	9	14.5
Thickness	12%	11.9%	12.1%

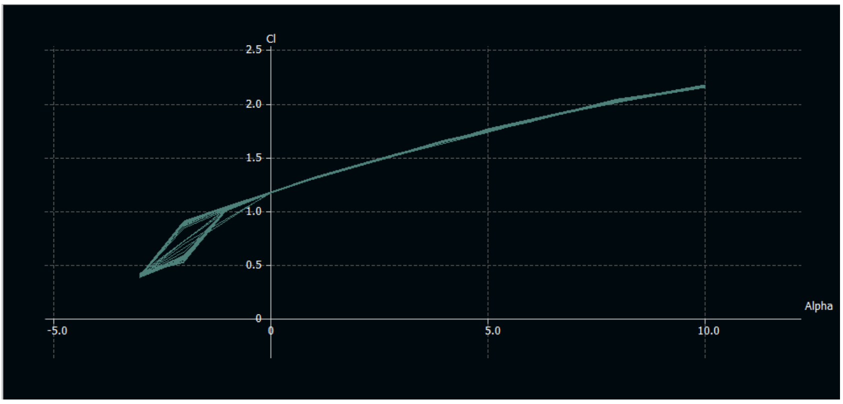

Fig. 1: CL v/s Alpha for S1223

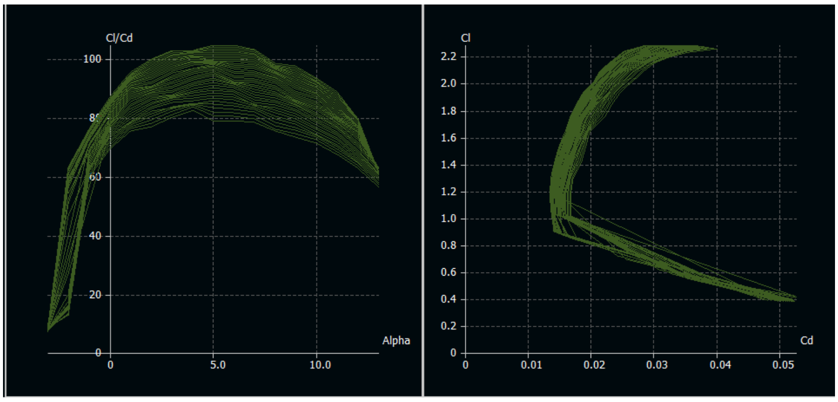

Fig. 2: CL/CD v/s Alpha and CL v/s CD for S1223

5. ASPECT RATIO

The selection of the Aspect Ratio was made through an iterative process, starting with a literature research in which High and Low Aspect Ratios were compared. It was then decided to use a moderate Aspect Ratio wing due its efficiency. Aspect Ratios of 4.5, 4.85 and 5 were compared between their C_{Lmax} and C_L/C_D. The AR of 5 resulted in higher efficiency and lift but increased wing deflection so was discarded. After detailed analysis in the given range, Aspect Ratio of 4.85 was selected. After selecting this aspect ratio, and detailed simulation of the wing planform, a Chord of 30 cm and Wingspan of 148 cm was determined.

6. SELECTION OF ANGLE OF ATTACK

Takeoff distance for Micro Class UAV should be in the range of 8-12 ft. In order to generate more lift during takeoff and reduce the overall takeoff distance, initial angle of attack is provided to the wing. Angle of Attack ranging from $\alpha = 0$ to $\alpha = 2.5$ was simulated on XFLR5 Software. It was found that $\alpha = 2^{o}$ is the most optimum angle of attack. Though S1223 has comparatively low efficiency, total useful lift produced by S1223 is greater comparative to other airfoils at every angle of attack. Design approach is to design a higher payload lifting aircraft.

7. FULL WING PERFORMANCE ANALYSIS

Full wing performance analysis was conducted on XFLR5 Software for flat rectangular planform with aspect ratio of 4.85 and 4200 cm^2 of lifting area at 12 m/s which is the maximum cruise speed of this aircraft. The Reynolds Number (R_e) was found using the given formula:

$$R_e = \frac{DVL}{\mu} \tag{2}$$

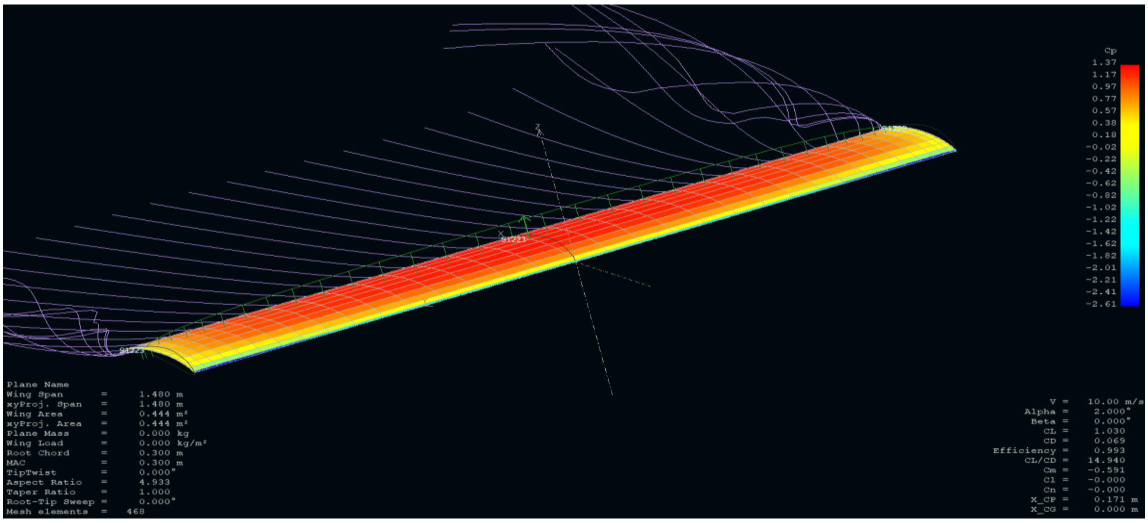

Fig. 3: Rectangular Configuration

8. OPTIMIZATION AND RESULTS

Simple rectangular configuration offered high lift and moderate coefficient of drag. To optimize performance of this wing keeping speed and dimensions constant, dihedral angle and tip dihedral configurations were also considered and the results were studied.

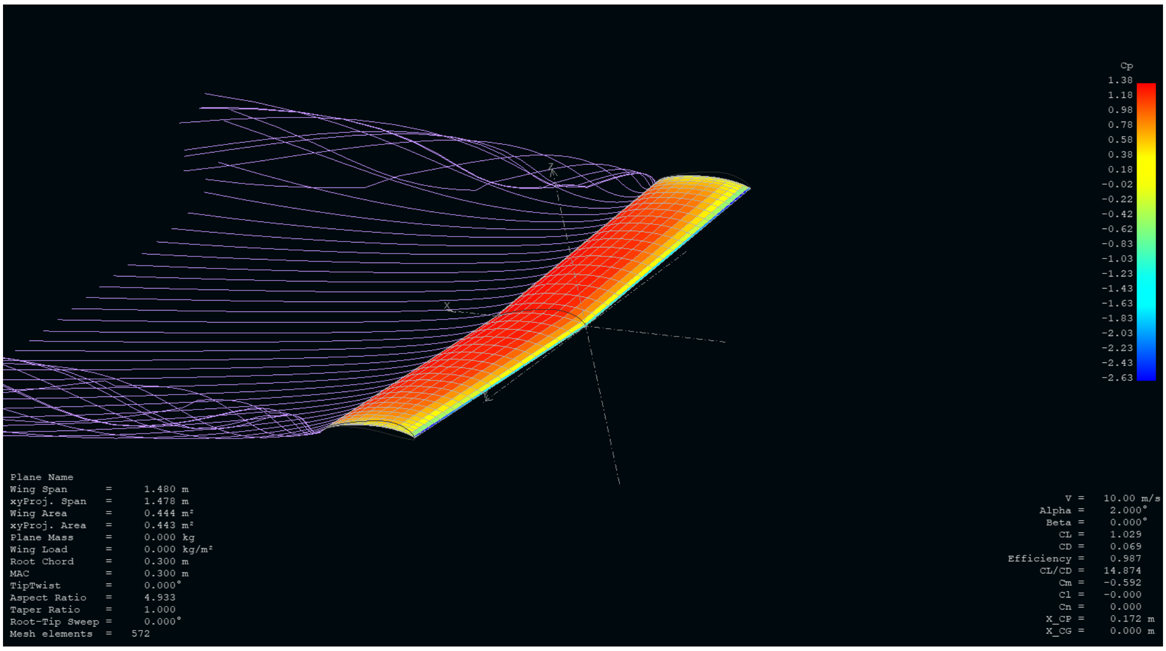

Fig. 4: Dihedral Configuration

Fig. 5: Manufactured Dihedral Wing

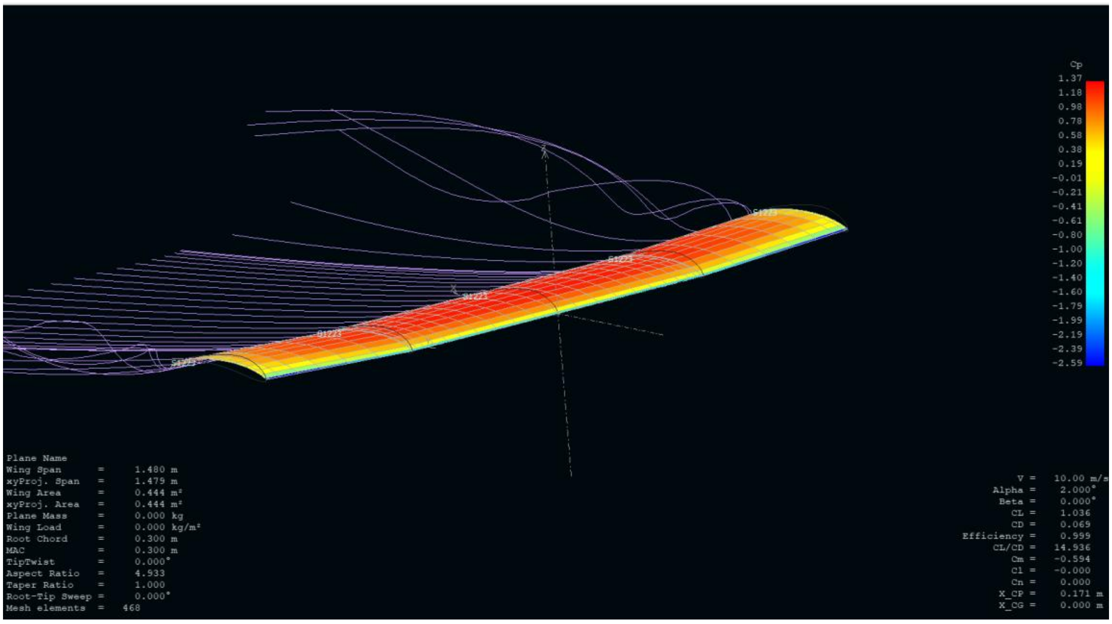

Fig. 6: Tip Dihedral Configuration

Fig. 7: Manufactured Tip Dihedral Wing

Table 3: Performance Comparison

Configuration	**C_L**	**C_D**	**C_L/C_D**	**Efficiency**
Simple Rectangular	1.030	0.069	14.940	0.993
Dihedral	1.029	0.069	14.874	0.987
Tip Dihedral	1.036	0.069	14.936	0.999

Results for all three configurations were studied in table 3 and it was found that Tip Dihedral configuration was the most suitable amongst the three configurations as it offered the most optimum efficiency while offering 10% higher coefficient of lift than simple rectangular configuration. Though it offered marginally higher drag coefficient, our design approach is to design a high payload lifting aircraft. Therefore, Tip Dihedral configuration was selected.

9. CONCLUSION

Based on the performance analysis for three wing configurations with Selig 1223 airfoil we observed 6 to 10 percent increase in generated lift, however we observed the difference in overall aerodynamic efficiency and increase in drag for all three configurations are marginal. We observed rise in induced drag by 8 to 11%. However, tip dihedral wing configuration offers higher roll stability and thus it is the most suitable configuration for a micro class UAV.

10. FUTURE SCOPE

Further work has to be done on wings with sweep, taper along with dihedral and tip dihedral configurations and compare those results with these results. The above-mentioned wing is designed for moderate speed micro class UAV. Similarly, other type of wing configurations and airfoil need to be studied and understood for high speed and low speed micro class UAVs. Future work includes structural design and analysis for a wing along with calculation of total drag and lift produced by the wing using advanced tools like Computational Fluid Dynamics.

11. REFERENCES

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APPENDIX

Symbols

C_L - Coefficient of Lift
C_{Lmax} - Maximum Coefficient of Lift
C_D - Coefficient of Drag
C_l/C_D – lift to drag ratio
α - Angle of Attack
D – Fluid density
V – Fluid velocity
L – Characteristic length or Chord Length
μ - Fluid Dynamic Viscosity