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# Wing Design Methodology for a Hybrid Fixed Wing VTOL UAV

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**ABSTRACT:** VTOL UAVs (Vertical Take-off and Landing Unmanned Aerial Vehicles). Vertical take-off and landing is an aircraft that can take-off and land vertically. A hybrid UAV combines the capabilities of a fixed-wing for high cruising speed and a rotary-wing for vertical take-off and landing. In this paper, the methodology presented is for designing a wing for a VTOL UAV. The most difficult challenge in the aircraft/UAV design process is designing the wing. Several parameters are considered for preliminary design, including the mission requirements, which include MTOW, Take-off Weight, and endurance. An airfoil is selected based on the mission requirements and lifting surface parameters are found, which include wing aspect ratio, wing chord, thickness, area, mean camber, and lift coefficient. Later on, a CAD model is made in Autodesk Fusion 360 using the calculated wing design parameters

**KEYWORDS:** VTOL UAV, Aspect ratio, Maximum Take-off Weight (MTOW), Airfoil, Wingspan, Reynolds Number, Mach Number.

## I. INTRODUCTION

Aerial Vehicles are today widely used in Military and Civil areas for Surveillance, transport, agriculture, and other various applications. UAV's are smaller, safer, and do not need a pilot, and UAV's can fly with varying degrees of autonomy: under remote control from a human operator, or completely or intermittently autonomously by on-board computers by setting a ground control station to control them over miles. UAV's reduce the risk of human life as they are pilotless. A difficult issue with fixed-wing Unmanned Aerial Vehicles (UAV's) is that they are often not designed to operate effectively in congested airspace. This problem arises in particular in urban environments where a runway is not available and UAVs must often fly at a low speed and height. However, for countering these problems VTOL UAV's are being developed.

This paper presents the design methodology for a wing for a Fixed Wing VTOL UAV. The wing is considered the most important component of an aircraft. Since the fixed-wing aircraft cannot fly without it and the wing geometry influences other aircraft components, wing design is done first. We begin designing a wing by choosing an airfoil first. The wing's primary function is to generate enough lift force (L). The wing also produces drag force or drag (D). Since a wing designer aims to maximize lift, the drag force must be kept to a minimum. The wing is a lifting surface that generates lift by a pressure difference between the lower and upper surfaces [1]. An aerodynamically efficient wing can be designed when the suitable airfoil and planform geometry are coupled.

While designing a wing, several parameters are determined:

Aspect ratio (AR), taper ratio (l), wing area (Sw), wingspan (b), root chord (Cr), tip chord (Ct) [2]. For designing, a Wing Reference area is taken and the wingspan, along with the aspect ratio, is calculated. In this paper, several NACA airfoils are compared to determine which airfoil should be chosen and then the coefficient of lift, drag, lift to drag ratio, and angle of attack where the airfoil generates the highest lift are found using X-Foil at mean sea level. A CAD model is designed in Autodesk Fusion 360 by using the given planform parameters. Here we assume an MTOW of 30 kg.

The paper is organized as follows. Section II describes the methodology which includes mission requirements and a comparison of various configurations. Section III describes Airfoil selection criteria and it is followed by Section IV where required planform parameters are calculated. Section V presents the Final Design and Section VI is the conclusion of this paper.

II. METHODOLOGY



FIG 1: DESIGN METHODOLOGY

Figure 1 depicts the design methodology. Similar UAV systems are considered when mission and design requirements are taken into account. The take-off weight is an important parameter affecting the design, so estimating it is essential.

In this paper, we consider **mission requirements** as:

MTOW (Maximum Take-off weight) to be 30 kg and the payload weight to be 10 kg.

**Comparing various configurations:**

Sr. No.	Aircraft Model	Wing Span	MTOW	Payload weight	Cruise Speed	Service Ceiling
1	Penguin B VTOL UAV	3.9 m	30 kg	8 kg	25 m/s	4000 m
2	Switch VTOL UAV	2.6 m	12 kg	< 6.5 kg	5 m/s	4000 m
3	Stream C VTOL UAV	5 m	60 kg	10 kg	28 m/s	5000 m
5	CW-25 New VTOL UAV	4 m	29.5 kg	7 kg	27 m/s	7000 m
6	Foxtech REX 340 VTOL UAV	3.3 m	32 kg	12 kg	25 m/s	5000 m

Table 1: Various Configurations for different aircraft models

Similar UAV systems are considered when mission and design requirements are taken into account. Since the take-off weight is the most influential factor in the design, it is critical to estimate it.

**Airfoil Selection:**

Selecting an airfoil is a very important part of wing design. The designer also has to take into account different airfoils for supersonic and subsonic flight requirements. For UAV's, the flight is subsonic most of the time. If you do not want to design your airfoil, you should pick one from the previously designed and published airfoil sections. NACA and Eppler are two reliable airfoil resources [3]. Proper airfoil selection leads to the calculation of planform parameters and then wing design. If we consider that the UAV is unlikely to fly at very high speeds, then we should not adopt a very thin wing section. Wing design and selection of airfoil are done in accordance to minimize induced drag. A moderate to high aspect ratio should be used. To reduce the pitch down moment by an aft wing configuration, aerofoils with high lift and low moment coefficients are selected [4].

**Calculating Planform parameters:**

Planform parameters include inboard sweep angle, outboard sweep angle, aspect ratio, and taper ratio, wingspan, wing area, chord, thickness, etc. Drag Estimation for the wing can be found out by using simulation software. The lift will also be found, giving us a lift-to-drag ratio for the wing. Drag should be kept to a minimum for any surface in a UAV and lift should be at a maximum [6]. For calculating planform parameters, as we have the airfoil finalized first, the chord of the airfoil should be known, which can be calculated by aspect ratio and wingspan. Maximum thickness, Maximum camber are also found out by using these given parameters. The methodology for planform parameters after the selection of airfoil is for the tapered wing. Taper ratio, Root mean chord, and tip chord are found in later phases of designing a wing for our mission requirement.

**Final Design:**

After calculating all required planform parameters, a wing using the finalized airfoil is made in CAD Software (Autodesk Fusion 360).

**III. AIRFOIL SELECTION**

Airfoil: Any section of the wing cut by a plane parallel to the aircraft X-Z plane is called an airfoil. It is a solid body moving through a fluid that produces an aerodynamic force.

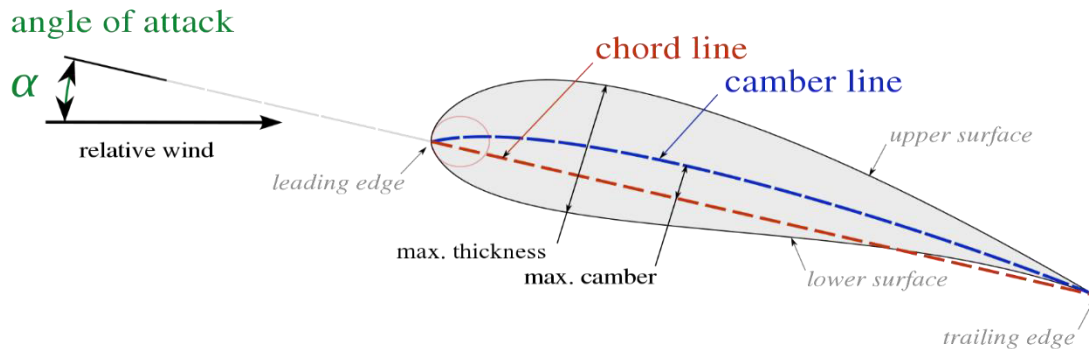


Fig 2: Airfoil Nomenclature

The following are the criteria to select an airfoil for a wing with a collection of design requirements [5]:

1. The airfoil with the highest maximum lift coefficient (max Cl).
2. The airfoil with the proper ideal or design lift coefficient(Cli).
3. The airfoil with the lowest minimum drag coefficient(Cdmin).
4. The airfoil with the highest lift-to-drag ratio ((Cl/Cd) max).
5. The airfoil with the lowest pitching moment coefficient (Cmo).

For the selected Airfoils for comparison, these parameters are used to find out which Airfoil would give the Highest Lift Coefficient, Lift-to-Drag ratio, and lowest Drag Coefficient [4].

There are various types of Airfoil shapes, in this paper, we compare various NACA 4,5, and 6 digit airfoils to find out which should be used for our assumed MTOW of 30 kg.

Sr.No.	Airfoil Section	Clmaxat Rn=3x10^6	αs (deg)	(Cl/Cd)max	Cli	Cdmin	(t/c)max	Cmo
1	0009	1.25	13	39	0	0.053	9%	0
2	4412	1.54	13	71	0.4	0.006	12%	-0.09
3	2415	1.4	14	86	0.3	0.0065	15%	-0.05
4	23012	1.6	16	60	0.3	0.006	12%	-0.013
5	23015	1.5	15	52	0.1	0.0063	15%	-0.008
6	632-015	1.4	14	61	0	0.005	15%	0
7	632-618	1.3	14	52	0.5	0.0052	18%	-0.1
8	64-210	1.4	12	57	0.2	0.004	10%	-0.042
9	654-221	1.1	16	46	0.1	0.0048	21%	-0.025

Table 2: Comparison of several NACA Airfoil sections

In this table, Reynolds Number is considered as 300000, and αs is the highest angle of attack, after αs the aircraft begins to stall. The results we get from this table are that NACA 4412 Airfoil is the most suitable as it satisfies all the design requirements.

NACA 4412:

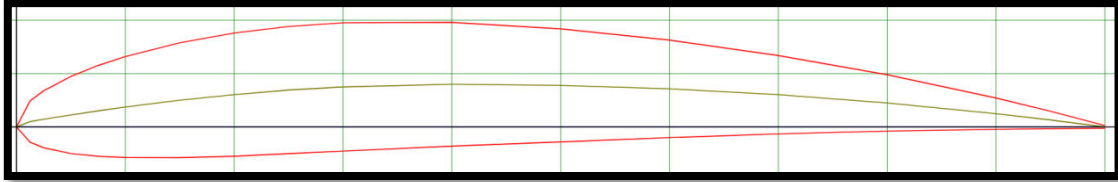


Fig 3: NACA 4412 Airfoil

#### IV. PLANFORM PARAMETERS CALCULATION

Wing sizing is done according to the requirements of the MTOW (Maximum Take-off Weight), Endurance, Altitude. For the first preliminary Sizing MTOW should be known or should be defined Earlier.

Aspect Ratio: Aspect ratio (AR) is defined as the ratio between the square of wingspan(b) to the wing area(S)

- Aspect Ratio =  $b^2/S$ .

For High lift requirements, a high aspect ratio is used. The higher the aspect ratio, the bigger the maximum lift coefficient due to the portion of wing area that is not affected by tip vortices. The aspect ratio of the VTOL-FW UAV is selected as big as possible to get rid of the vorticity near the tip of the wing [5]. We take the Aspect ratio as 15 (For High lift devices Aspect ratio is taken between 12-20).

From the market study, it was shown that the higher the cruise speed, the higher the market share. Therefore, the optimum design should be designed to cruise at high subsonic speeds. To achieve the most fuel-efficient design, the vehicle is required to have a high lift and low drag (i.e. a high lift-to-drag ratio). As the vehicle will spend most of its time on the cruise the high lift-to-drag ratio required means that the wing should have a medium to high aspect ratio (AR). The higher lift and lower drag characteristics of a Blended Wing Body (BWB) design, offers another option for maximizing the lift-to-drag ratio[1].

Airfoil Root Chord can be calculated by using the Aspect ratio and wingspan.

- Aspect ratio = Wing Span / Root chord
- So, Root Chord = Wing span / Aspect ratio.

From table 1, For 30 kg MTOW, we get that the wingspan is between 3 and 4 m and the aspect ratio we are considering is high. The reference value here for wingspan taken is 3.9 m. So we get the Root chord as 0.261 m.

For NACA 4-Digit Airfoil (NACA 4412):

- From First Digit
  - Maximum camber =  $(x/100) * C$ , where  $x$ =First digit = 4 and  $C$ = Root chord = 0.261 m

Therefore, we get maximum camber as = 0.0104 m

- From Second Digit:
  - Location of maximum camber =  $(x/10) * C$ , where  $x$ =Second digit = 4.

Therefore, the location of maximum camber is = 0.104 m

- From Third and Fourth Digit:
  - Maximum Thickness =  $(x/100) * C$ , where third and fourth digit = 12

Therefore, maximum Thickness = 0.03 m

**Taper ratio:** The taper ratio ( $\lambda$ ) is defined as the ratio between the tip chord ( $C_t$ ) and the root chord ( $C_r$ ) Historically, most straight-wing airplanes incorporate taper ratios on the order of 0.4 to 0.6[7]. The taper ratio is taken 0.5. Now for designing a tapered wing in CAD, the Root mean chord is also required. Root mean chord (C) is the mean chord of the wing which lies at the middle of the wingspan [8]. Root mean chord can be calculated by

$$\bar{C} = \frac{2}{3} C_r \left( \frac{1 + \lambda + \lambda^2}{1 + \lambda} \right)$$

Fig 4: Formula for Calculating Root mean chord [3]



By using this formula, we get Root mean chord as 203 mm.

Now at mean sea level, using the Xfoil Coefficient of lift, the Coefficient of drag, L/D ratio is calculated for the NACA 4412 airfoil in subsonic conditions.

- Reynolds Number = 7,34,589
- Mach number = 0.104
- Density = 1.225 kg/m<sup>3</sup>
- Root chord = 0.261 m

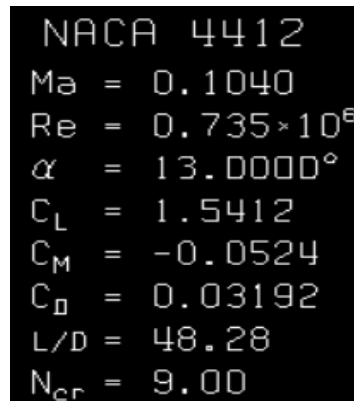


Fig 5: X-foil analysis results for NACA 4412

#### V. FINAL DESIGN



Fig 6: Final Wing Design

This is the Final Design, designed on CAD (Autodesk Fusion 360) by using the above planform parameter

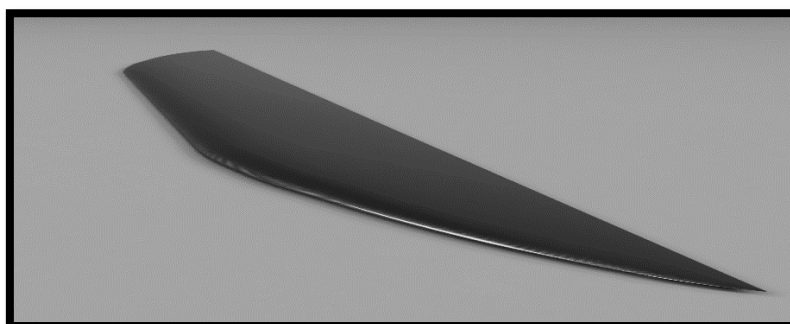


Fig 7

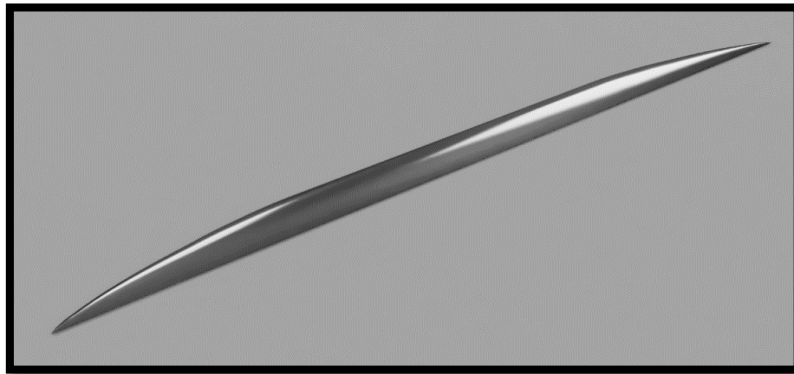


Fig 8

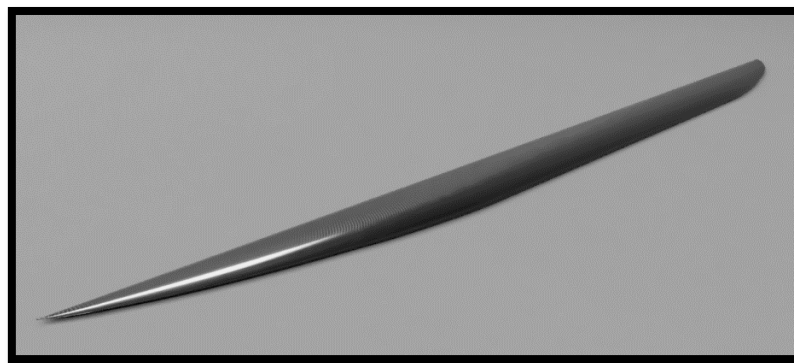


Fig 9

## VI. CONCLUSION

In this paper, with the aim to design a high lift generating wing for Fixed-Wing Hybrid VTOL UAV, a design methodology is presented. For design, we first need mission requirements, then similar systems or wings are compared and analyzed to know what planform parameters they have used for the same MTOW. Airfoil selection is a very important part and the parameters for selecting an airfoil are also given. Planform parameters required for the design of the tapered ratio are calculated. In the latter part, endurance calculations for the calculated chord for the selected NACA 4412 airfoil are done. Endurance calculations help us to find out the coefficient of lift, drag and lift to drag ratio. and the final wing is designed in Autodesk Fusion 360. Future work could be to do an aerodynamic analysis of the wing to find out the lift, drag, and lift-to-drag ratio generated.

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