DESIGN CONSIDERATIONS FOR TANDEM WING CONFIGURATIONS IN SMALL UNMANNED AERIAL VECHICLES

George Răzvan BUICAN, Sebastian-Marian ZAHARIA,
Constantin-Mihaita AGAPIE

"Transilvania" University of Brașov, Romania (buican.george@unitbv.ro, zaharia_sebastian@unitbv.ro, constantin.agapie@student.unitbv.ro)

DOI: 10.19062/2247-3173.2024.25.17

Abstract: *This paper examines the design aspects of small unmanned aerial vehicles (UAVs) in tandem wing configuration. This type of wing configuration is gaining increasing attention due to its enhanced capabilities of stability, maneuverability, and efficiency. Through a detailed analysis of the main design aspects, this paper explores the integration of tandem wing configurations in small UAVs. The results and conclusions presented here aim to provide useful guidance into optimizing performance and improving operational characteristics of these aerial systems.*

Keywords: *Aerospace, Fixed-Wing UAV, Tandem Wing, Wing interference*

1. INTRODUCTION

A tandem wing configuration refers to an aircraft design in which two or more lift-generating wings are arranged sequentially along the fuselage. Unlike a biplane, which features two wings stacked vertically above one another, a tandem wing layout positions the wings longitudinally along the aircraft's body. This arrangement places the wings in separate planes both vertically and horizontally, thereby minimizing aerodynamic interference.[1]

Both wings, from a tandem wing configuration, are used to generate lift, and the rear wing also serving as a horizontal stabilizer. Tandem wings were first successfully utilized by John J. Montgomery in 1905. In 1922, Louis Peyret's glider, which won the British gliding competition, became the first fully controllable flight system.[2], [3]

In present times, tandem wing configurations have been studied and employed for their increased fuel efficiency and compact design, allowing for greater payload capacity.[1], [4], [5]

In this paper, we investigate the use of the tandem wing configuration on a small fixed-wing UAV to achieve higher power efficiency compared to traditional drones and to explore potential applications for this configuration.

To initiate analysis and testing of this design, we defined key parameters for the UAV including aircraft weight, flying altitude, maximum speed, and component weight.

The model used is a 1 kg UAV with a maximum flight speed of 25 m/s and a cruise speed of 15 m/s. It features two wings, with the front wing being slightly smaller than the rear wing for stability purposes.

Table 1. Wing parameters

Parameter name	Value	UM
Back wing area	0.056	m^2
Front wing area	0.035	m^2
Total wing area	0.091	m^2

Initial parameters were selected in accordance with the EASA Easy Access Rules for Unmanned Aircraft Systems for a Class 2 UAV, including a maximum takeoff weight of 4 kg and a maximum flying altitude of 120m [6].

The tandem wing configuration offers several advantages:

- Due to the presence of two sets of wings, the lift generated is higher compared to traditional fixed-wing UAVs.
- This increased lift capacity allows for a smaller structure that can carry more weight, which is advantageous in UAV applications.
- The configuration enables the design of a more compact structure by reducing the wingspan.

However, a significant disadvantage of the tandem wing configuration is a slight reduction in lift efficiency on the second wing due to interference caused by the first wing. This drawback can be mitigated through various strategies that will be discussed further.

2. REDUCING THE AIRFLOW TURBULENCE CREATED BY THE FRONT WING

All tests and analyses in the paper were conducted at a cruise flight speed of 15 m/s, an altitude of 80 m, and a temperature of 16 degrees Celsius. The preferred software for conducting the analysis was XFLR5, utilizing the Horseshoe Vortex analysis method [7].

The airfoil profile used for the wings is WORTMANN FX63137-il, with a chord length of 140 mm for the rear wing and 100 mm for the front wing. The wingspan of the rear wing is 400 mm, and the wingspan of the front wing is 250 mm [8].

To reduce interference between the wings, the first method employed was placing them in different Z-planes, as illustrated in Fig. 1.

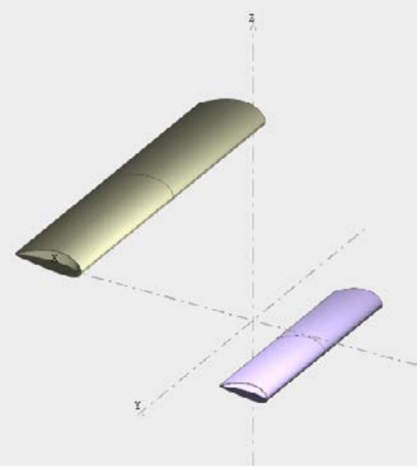
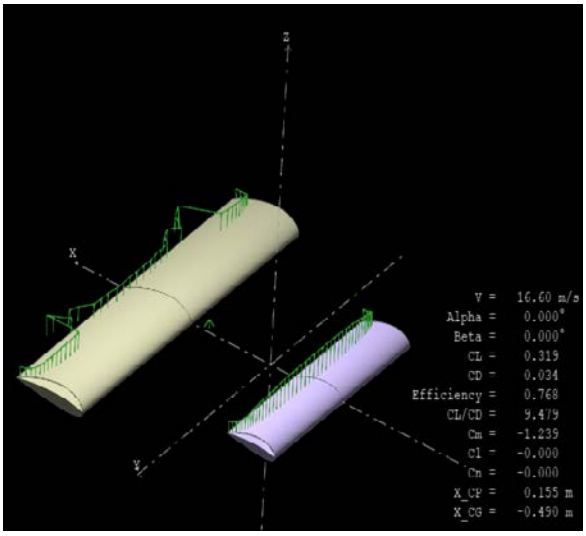


FIG. 1 Baseline wing placement

By placing the wings in separate planes from each other, we can achieve higher aerodynamic efficiency because most of the airflow interference generated by the first wing no longer affects the second wing [9].

This approach also allows for precise control over the position of the center of gravity (CG) of the UAV. By adjusting the distance between the wings, designers can effectively tailor the CG location to meet specific design parameters and optimize the overall stability and performance of the aircraft.

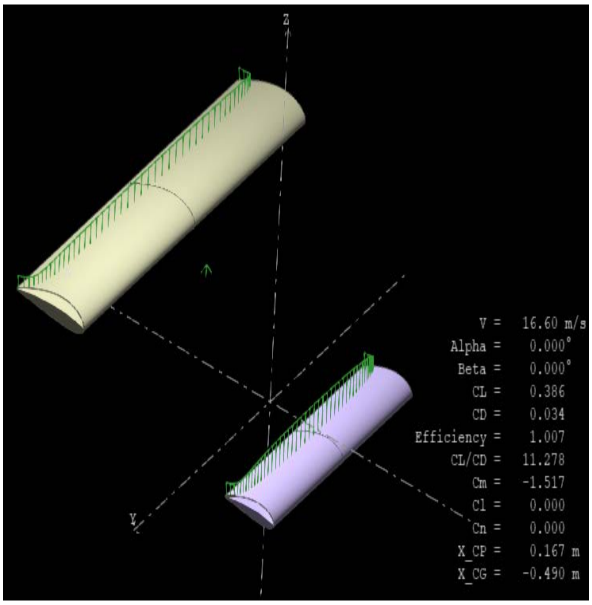
Placing the wings in different Z-planes has shown to enhance aerodynamic efficiency compared to placing them in the same plane, as demonstrated in (FIG. 2 and FIG. 3). The interference between the wings decreases with increasing distance between the Z-planes, thereby optimizing overall performance.



```
         V =   16.60 m/s
     Alpha =    0.000°
      Beta =    0.000°
        CL =    0.319
        CD =    0.034
Efficiency =    0.768
     CL/CD =    9.479
        Cm =   -1.239
        Cl =   -0.000
        Cn =   -0.000
      X_CP =    0.155 m
      X_CG =   -0.490 m
```

FIG. 2 Wings in the same Z-plane

The green lines from the two figures above represent the lift distribution across the wings, for the first wing the distribution is largely unchanged, but on the second wing we can see how much interference matters when talking about tandem wing UAVs.

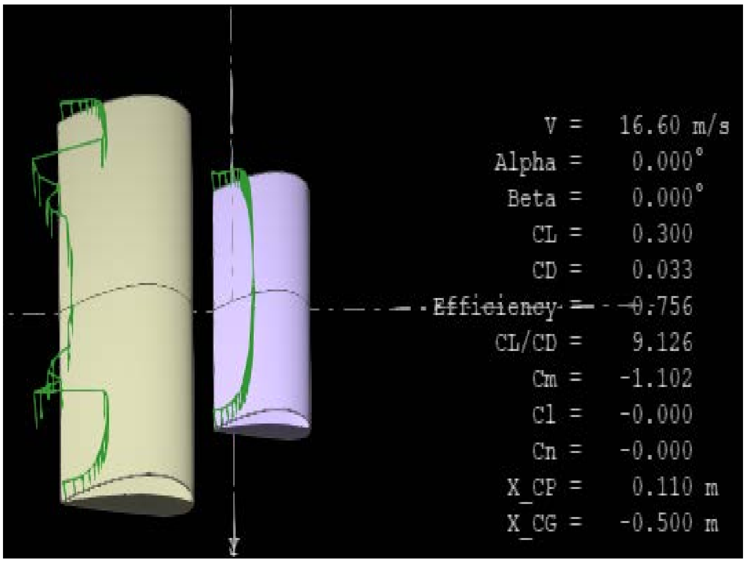


```
         V =   16.60 m/s
     Alpha =    0.000°
      Beta =    0.000°
        CL =    0.386
        CD =    0.034
Efficiency =    1.007
     CL/CD =   11.278
        Cm =   -1.517
        Cl =    0.000
        Cn =    0.000
      X_CP =    0.167 m
      X_CG =   -0.490 m
```

FIG. 3 Wings in different Z-Planes

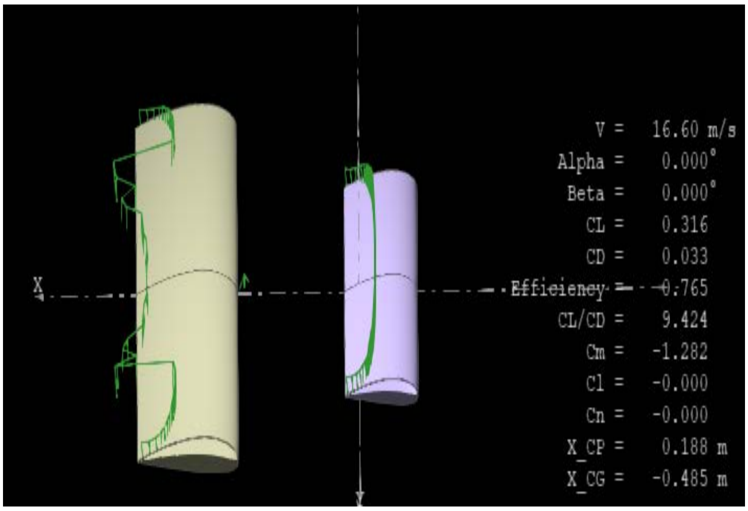
This comparison was conducted at an angle of attack of 0 degrees with the wings positioned at the same distance on the X-axis from each other. The lift coefficient for (Fig. 2) is notably lower than that for (Fig. 3) by a considerable 0.067, a difference that increases further at higher angles of attack.

Another method to reduce interference between the wings is by making the first wing smaller than the second. This approach minimizes the airflow affecting the second wing, thereby enhancing stability and lift generation [10]. Additionally, the spacing between the wings plays a crucial role in aerodynamic performance. Greater spacing allows airflow more time to stabilize, reducing its impact on the second wing. This is demonstrated in the analysis shown in (Fig. 4 and Fig. 5), where the wings are placed in the same Z-plane but with distances of 150 mm and 296 mm between them.



```
V =       16.60 m/s
Alpha =    0.000°
Beta =     0.000°
CL =       0.300
CD =       0.033
Efficiency = 0.756
CL/CD =    9.126
Cm =      -1.102
Cl =      -0.000
Cn =      -0.000
X_CP =     0.110 m
X_CG =    -0.500 m
```

FIG. 4 Wings 150mm apart



```
V =       16.60 m/s
Alpha =    0.000°
Beta =     0.000°
CL =       0.316
CD =       0.033
Efficiency = 0.765
CL/CD =    9.424
Cm =      -1.282
Cl =      -0.000
Cn =      -0.000
X_CP =     0.188 m
X_CG =    -0.485 m
```

FIG. 5 Wings 296mm apart

While not as significant as placing the wings in different Z-planes, optimizing wing spacing remains a valuable consideration, making it feasible to position the wings as far apart as possible for optimal aircraft design.

Constructing a fuselage structure that accommodates these considerations can greatly enhance aerodynamic efficiency and result in increased lift for the same wing area, while also reducing power consumption by minimizing drag induced by turbulent airflow from the first wing [11].

For our specific aircraft design, employing a combination of these methods has proven successful in achieving both structural strength and aerodynamic efficiency, as illustrated in Fig. 6 and Fig. 7.

The wings were positioned 296 mm apart with a Z distance of 20 mm between them, and the length of the fuselage was 450 mm. This configuration proved to be the most efficient in terms of aerodynamics.

By implementing methods to reduce interference between the wings, the lift coefficient significantly increased compared to configurations that only accounted for wing spacing. Initially, the lift coefficient was approximately 0.3, considering only the distance between wings. Through optimized wing placement alone, we were able to surpass the 0.5 mark in lift coefficient.

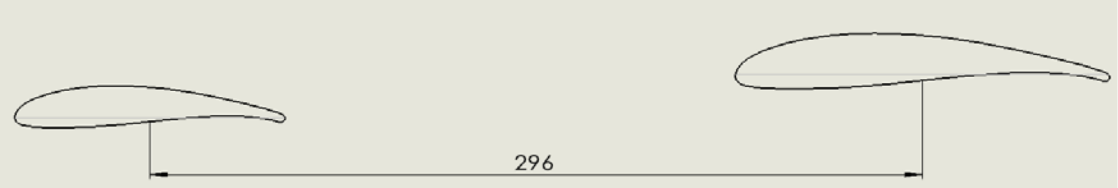


FIG. 6 Distance between wings

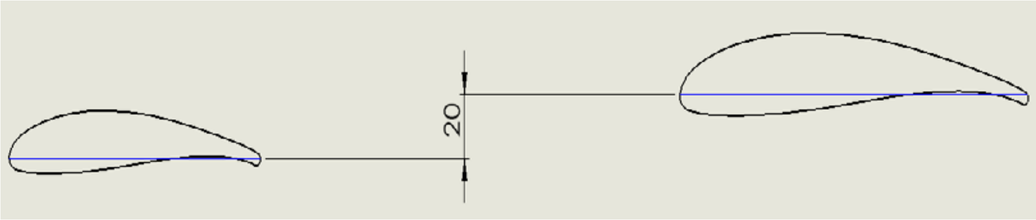
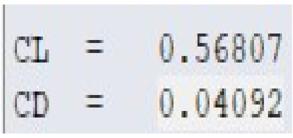


FIG. 7 Distance between wings on Z-plane



```
CL  =   0.56807
CD  =   0.04092
```

FIG. 8 Coefficient of lift and drag for the combination of methods

In tandem wing configurations, the rear wing typically serves dual roles as a stabilizer and horizontal empennage, which was similarly adopted in our design [12]. The front wing functions as an additional means to control the pitch of the aircraft, useful for emergencies and aerial maneuvers requiring enhanced maneuverability and efficiency.

This control system is facilitated by two servomotors: one for the front and rear wings to control pitch, and another dedicated to controlling roll. Given the larger size of the rear wing, it serves as the primary mechanism for both pitch and roll control. This approach not only reduces the weight of the servomotors but also minimizes their number, contributing to a streamlined and efficient control system for the UAV.

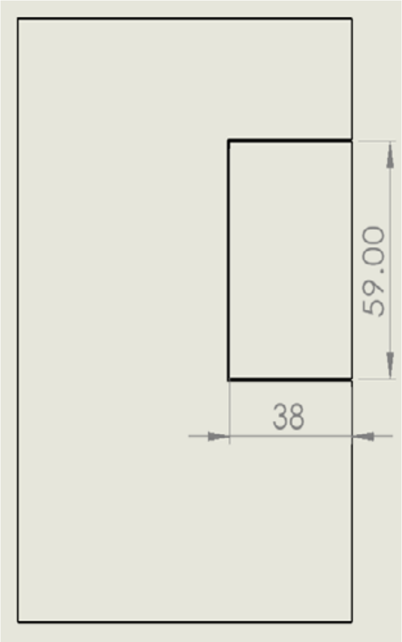


FIG. 9 Control surface for front wing

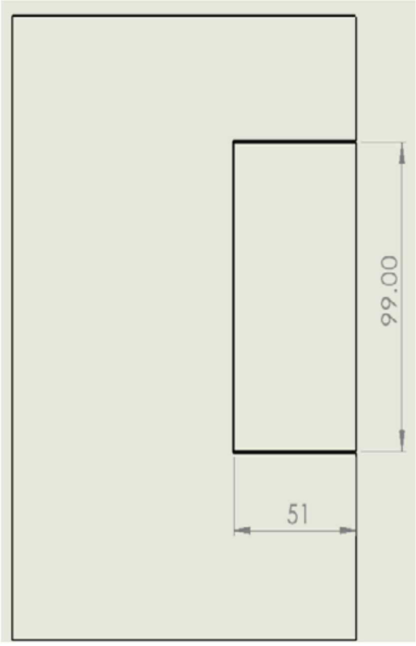


FIG. 10 Control surface for back wing

In Fig. 9 and Fig. 10, we depicted the dimensions of the control surfaces on the wings, with an additional 0.5 mm gap between the wing and the control surface.

For controlling the yaw of the UAV, we opted for a traditional vertical empennage, which has been carefully modeled to meet the specific requirements of the aircraft. This empennage provides effective yaw control, complementing the pitch and roll control provided by the tandem wings and their associated control surfaces.

3. STRUCTURAL AND POWER EFFICIENCY CONSIDERATIONS

Given the smaller wing span compared to traditional UAVs, the internal structure along the wings does not require as robust support. Utilizing generative design allows us to pinpoint precise areas needing reinforcement, enabling the creation of a modeled structure tailored to these specifications.

A 3D printed honeycomb structure is ideal for reducing weight while maintaining necessary sturdiness for the UAV. This method is particularly advantageous due to the small scale of the UAV components, making complex structures achievable through 3D printing [13]. Larger structures would pose manufacturing challenges, but the smaller components of this UAV allow for easier fabrication of intricate designs.

In addition to the honeycomb structure, we implemented a longitudinal support structure for the wings to enhance their stability. Addressing the increased stress on the main body caused by the wing weight pressing on its center, we utilized 3D printed supportive structures to bolster the main body's stress resistance.

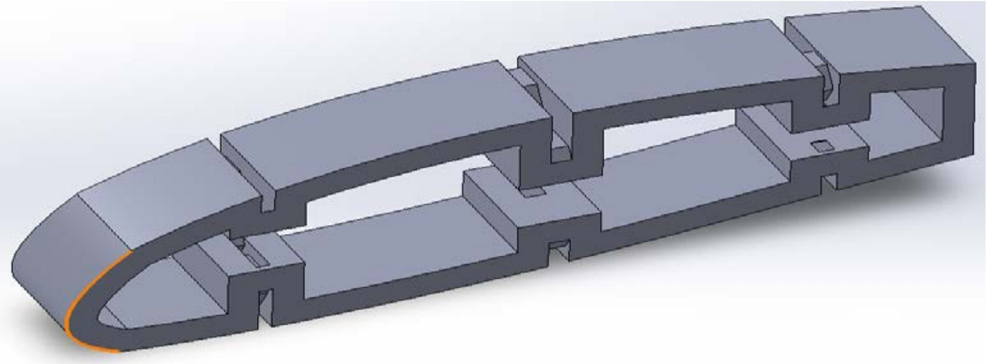


FIG. 11 Longitudinal wing support

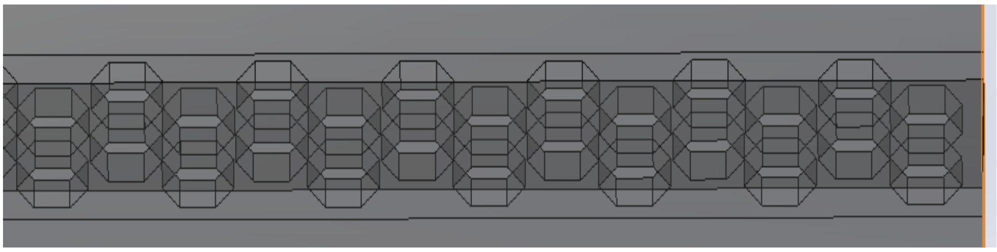


FIG. 12 Transversal wing support

To calculate the power efficiency and flight time of the UAV, the following data has been used:

- Engine Specifications: 900 Kv, 50A, 11.4V
- Battery Capacity: 2 Ah
- Traction generated by engine at full power: 20 N

These parameters were essential for conducting an analysis to determine the operational characteristics and performance metrics of the UAV.

Table 2. Data for calculating power efficiency

Parameter name	**Value**	**UM**
Z-axis force generated by engine at 15 degrees alfa	5.176	N
Takeoff alfa	15	grade
Engine consumption on 100%	38.6	A
	428	W
Engine consumption on 10%	4.7	A
Battery discharge safety	10	%

And the results obtained are as follows:

Table 3. Calculated UAV endurance

Parameter name	**Value**	**UM**
Endurance (Engine at 100%)	0.048	h
Endurance (Engine at 20%)	0.406	h
Range	22.579	km

After testing the wing model and analyzing its performance at a cruise speed of 15 m/s, we observed that the wings generate approximately 15 N of lift.

Considering the total weight of the UAV, including all components, is about 1 kg, we can conclude that the aircraft can take off and fly safely under these conditions.

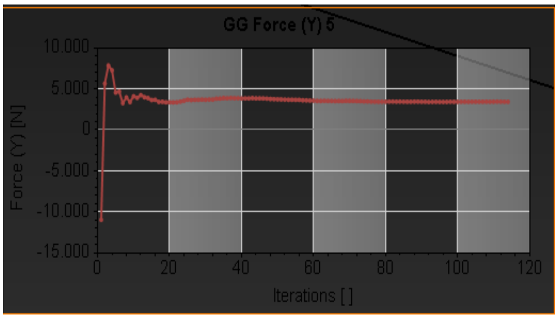


FIG. 13 Generated lift

Take-off speed	2.337	m/s
Lift generated by engine at 15 degrees	5.176	N
Weight lifted by engine at 15 degrees	0.528	kg

FIG. 14 Lift generated by engine and take-off speed of the UAV

In this study, we have also accounted for the force generated by the engine, which is significant during takeoff, especially at a high angle of attack (15 degrees).

4. CONCLUSIONS

The study conducted in this paper on tandem wing configurations for UAVs yielded positive results across several aspects.:

This configuration enabled the modeling of a UAV weighing 1 kg, significantly enhancing lift compared to other alternatives. Moreover, the UAV can lift an additional half kilogram, which in this case represents half of its own weight, making it potentially advantageous for transport applications.

Achieving nearly half an hour of flight time with such a small battery capacity is a notable achievement for UAVs, considering many drones struggle to surpass 20 minutes. Further improvements in flight duration can be explored by incorporating larger batteries, underscoring the focus on power efficiency with the tandem wing configuration.

The design's ability to utilize smaller wing spans and inherently resilient wings reduces reliance on the main body or fuselage, allowing for safer component placement. This approach enhances overall safety and structural integrity.

Capable of covering approximately 22 km in flight, the UAV is well-suited for reconnaissance missions or monitoring agricultural crops. Its cost-effectiveness, attributed to minimal electrical components and the feasibility of 3D printing the structure, enhances its utility as a powerful and economical tool for area analysis.

Equipped with a robust receiver/transmitter, the UAV facilitates efficient oversight missions.

Through the methods employed, interferences between the wings were minimized, significantly improving aerodynamic efficiency in the process.

REFERENCES

[1] J. W. Bottomley, *The tandem-wing concept applied to modern transports*, The Aeronautical Journal, vol. 78, no. 767, pp. 523–524, Nov. 1974, doi: 10.1017/S0001924000037568;

[2] Montgomery Glider, Accessed: Jun. 14, 2024. [Online]. Available: https://www.asme.org/About-ASME/Engineering-History/Landmarks/189-Montgomery-Glider;

[3] P. Louis, Le Concours de Vol A Voile D'itford Maneyrol gagne le prix du Daily Mail sur appareil L. Peyret, L'Aérophile, vol. 1922, no. Novembre, pp. 322–325, 1922;

[4] D. W. Fanjoy, *Numerical Simulations of Tandem-Airfoil Aerodynamics*, presented at the Aerospace Atlantic Conference & Exposition, SAE International, May 1996. doi: 10.4271/961295;

[5] D. F. Scharpf and T. J. Mueller, *Experimental study of a low Reynolds number tandem airfoil configuration*, Journal of Aircraft, vol. 29, no. 2, pp. 231–236, Mar. 1992, doi: 10.2514/3.46149;

[6] European Aviation Safety Agencyl Easy Access Rules for UAS, September 2022. Available at www.easa.eu.int, accessed on 13 February. 2024;

[7] A. Deperrois, *Illustration of the use of Control Polars in XFLR5*, Presentation document, July 2008. Available at http://xflr5.sourceforge.net/docs/Control analysis.pdf;

[8] I. K. Wiratama , I. M. Suartika, I. W. Joniarta, I. M. Mara, I. M. Nuarsa, Muammil Ansori, *Analysis Aerodynamic Performance Airfoil WORTMANN FX63-137 in Different Reynolds Number,* University of Matamaran, Matamaran, Indonesia;

[9] J. W. Bottomley, (1977), *Tandem-Wing Aircraft*, Aerospace, vol. 4, October 1977. pp. 12–20.2;

[10] The Distribution of Loads Between the Wings of a Biplane Having Decalage, NACA technical report No.269, p.18, November 1927;

[11]Kuethe, Arnold M. and Chow, Chuen-Yen, *Foundations of Aerodynamics: Basis of Aerodynamic Design*, John Wiley & Sons, 1976;

[12]Somnay, Rajesh J., *Design of Dual Wing Structures*, UMR Thesis, Rolla, Mo.,1983;

[13]D. Bhatti, J. Bhalbar, S. Chaurasiya, K. Mannikeri & R. Iyer, (2018, May), Clairvoyant Raven. In 2018 2nd International Conference on Electronics, Materials Engineering & Nano-Technology (IEMENTech) (pp. 1-5). IEEE.