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Innovative Morphing UAV Design and Manufacture

Sezer Çoban[1*], Tuğrul Oktay[2]

[1*]Iskenderun Technical University, Department of Airframe and Powerplant Maintenance, 31200, İskenderun, Hatay, Türkiye. (sezer.coban@iste.edu.tr)
[2]Erciyes University, Aeronautical Engineering, 38030, Kayseri, Türkiye, (tugruloktay52@gmail.com)

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Corresponding Author: *Sezer Çoban*

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Abstract

In this study, an unmanned aerial vehicle (UAV) with passive pre-flight and active in-flight morphing capability was designed and manufactured. First of all, conceptual design work was done. Wing and tail, which are the main carriers, were selected to ensure maximum liftt, minimum drag and stability of the UAV. Liquid fuel engines were preferred due to their high power and airtime. The engine, which enables the controlled and uncontrolled flight of the UAV, has been run-in to make it safer and more efficient before being used in real-time flights. Profiles were selected by analyzing the tail set consisting of the rudder and the elevator. The nose cone of the unmanned aerial vehicle was produced by improving the aerodynamic performance. In the aircraft geometry, the passive morphing mechanism, which is performed once before the flight, and the active morphing mechanism, which is performed continuously during the flight, are manufactured using servo motors. This improved the flight performance and made it possible to fly in some unfavorable conditions. The most basic superior feature of the manufactured UAV from the existing UAVs is its ability to morphing.

1.Introduction

In recent years, morphing unmanned aerial vehicles (UAVs) have received significant attention from researchers in the field of aerospace engineering. A number of studies have been conducted to investigate the design and optimization of morphing UAVs. For instance, a study by Harvey et al. (2022) presented a review of the current state of the art in morphing UAV design and control, including various morphable wing structures, actuation systems, and control strategies. Another study by Joshi et al. (2004) proposed a new morphing wing design for UAVs that can change its wing shape in flight to improve aerodynamic performance and stability. Similarly, a study by Thill et al. (2010) focused on the development of a flexible wing structure for UAVs that can change its wing shape to adjust the wing aspect ratio and improve flight efficiency. These studies demonstrate the potential of morphing UAVs to revolutionize the field of aerospace engineering and enhance the performance and versatility of UAVs.

The manufacturing of unmanned aerial vehicles (UAVs) has been the subject of numerous studies in recent years. The challenges and considerations involved in UAV manufacturing have been explored by authors such as (Konar, 2019), who conducted a study on the fabrication and assembly of UAVs. Another study by Sofla et al. (2010) investigated the use of additive manufacturing techniques for the production of lightweight UAV structures. The cost-effectiveness of different manufacturing processes for UAVs was evaluated by Vocke et al. (2011) in their study. These studies provide insight into the efforts being made to address the challenges associated with UAV manufacturing and to find the most efficient and cost-effective methods for producing UAVs.

Unmanned aerial vehicles (UAVs) have revolutionized the way we gather information and data from the air. Fixed-wing small unmanned aerial vehicles (sUAVs), in particular, have become increasingly popular due to their versatility and ease of use. With their compact size, lightweight design, and long flight times, fixed-wing sUAVs are well-suited for a variety of applications, including environmental monitoring, surveying, and aerial photography (Coban et al, 2018).

In recent years, advancements in technology have enabled the development of highly advanced fixed-wing sUAVs, equipped with a range of sensors, cameras, and other payloads. These capabilities have enabled fixed-wing sUAVs to gather critical data in a wide range of environments and conditions, from remote, inaccessible areas to urban landscapes (Oktay et al, 2017).

Despite their many advantages, there are still numerous challenges associated with the use of fixed-wing sUAVs, including safety, reliability, and regulatory compliance. As such, there is a growing need for research into the design and development of fixed-wing sUAVs, as well as their applications and limitations (Coban, 2019).

Morphing wing technology has been widely studied in recent years, with a focus on improving the aerodynamic performance and maneuverability of aircraft. Research in this area has explored various aspects of morphing wing design and performance, including the optimization of wing shapes, the use of computational fluid dynamics to investigate wing aerodynamics, and the integration of smart materials in wing design and control.

Studies such as Min et al. (2010) have presented research on the morphing wing design and performance optimization, while L Vasista et al. (2012) investigated the effect of wing geometry on wing performance using computational fluid dynamics. The use of smart materials in morphing wing design and control has been examined by Ameduri et al. (2020). A review of recent developments in morphing wing technology was conducted by Popov et al. (2010), highlighting the advances in this field.

The importance of wing analysis for the design and development of high-performing aircraft has been demonstrated in these studies, highlighting the potential of morphing wing technology to enhance aerodynamics and maneuverability (Gomez et al, 2011).

The morphing of the wing and tail in unmanned aerial vehicles (UAVs) can significantly affect the lift and drag forces experienced by the vehicle. By changing the shape of the wing and tail in flight, the aerodynamic performance of the UAV can be improved, resulting in improved lift and reduced drag (Gamboa et al, 2007). The morphing of the wing and tail allows the UAV to adapt to changing flight conditions and optimize its aerodynamics in real-time. For example, the wing and tail can be adjusted to increase lift during takeoff and landing, and to reduce drag during cruising flight. This results in improved efficiency, maneuverability, and stability for the UAV (Konar, 2020). Computational fluid dynamics simulations and wind tunnel experiments have been conducted to investigate the effect of wing and tail morphing on lift and drag in UAVs. The results of these studies have shown that the morphing of the wing and tail can significantly improve the aerodynamic performance of UAVs, leading to increased lift and reduced drag. (Friswell, et al, 2006).

2.Materials and Methods

2.1. Airfoil selection

Taking into account the ease of fabrication and easy access to the data, NACA 2415 series fin structures were chosen for the design and production of the wing, which is the main carrier element, and the horizontal tail, which is the stability and control surface. The variation of the lift and drag coefficients of the NACA 2415 series airfoil structures with the angle of attack (AoA) was obtained in figure 1 using the XFLR5 program. The graphic results showing the variation of pitching moment with angle of attack and the variation of lift coefficient and drag coefficient are also given in figure 3. 4^0 AoA is the angle of attack at which maximum efficiency is achieved. Analyzes were performed at a speed of 0.05 M (54 km/h = 15 m/s) at Re number 280000.

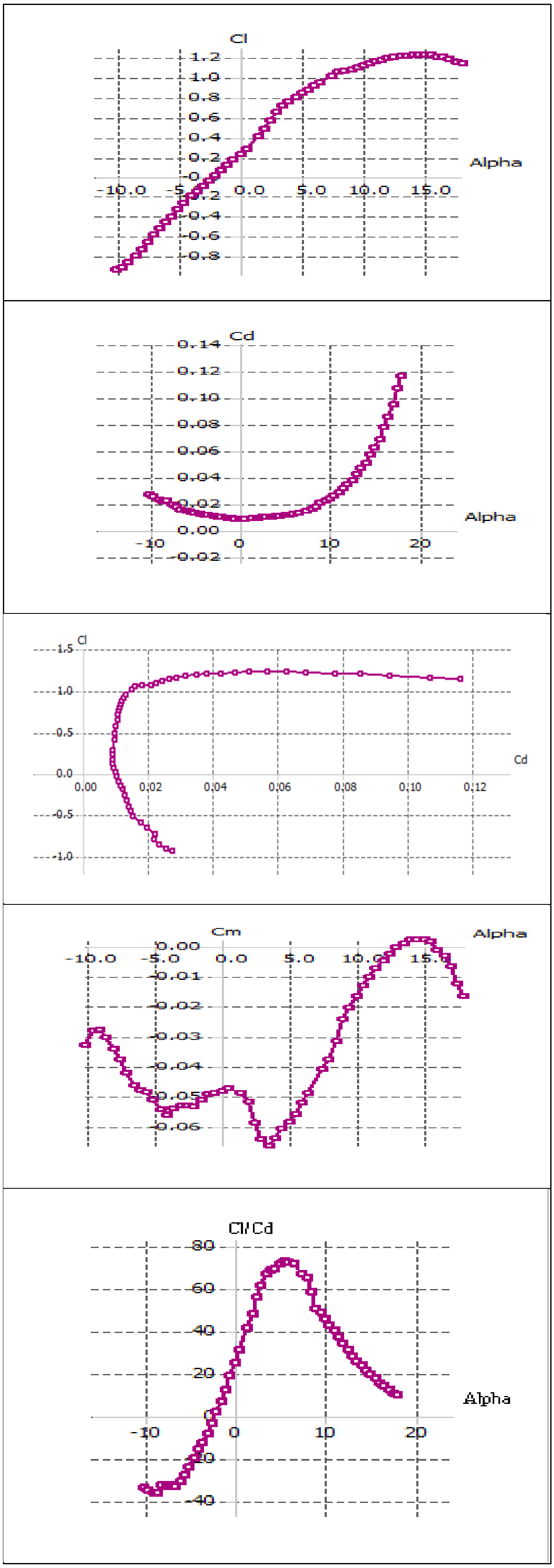

Figure 1. The variation of the lift and drag coefficients of the NACA 2415 series airfoil structures with the AoA

2.2. Airfoil Analysis

The wingspan of the UAV is 4000 mm. Rectangular blade structure has been chosen for easy production and the blade cord length is 400 mm. The wing can morph up to 10%.The solid model of the selected airfoil NACA 2415 is given in figure 2.

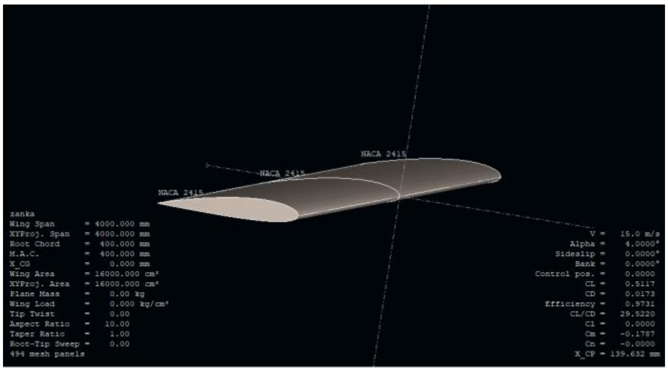

Figure 2. Solid model of wing profil

The force analysis results of the selected airfoil are given in figure 3.

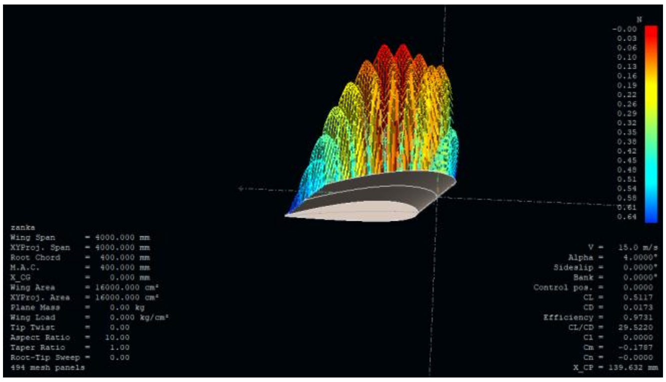

Figure 3. Wing force analysis

2.3. UAV Passive and Active Morphing Mechanism Manufacture Stages

Necessary wing section drawing was made. The necessary production drawing for the forward-backward (passive) morphing of the wing was made. A profile drawing was made for the active morphing of the extended wing. As a result of the drawings, the wing section was cut on the balsa with laser cutting. The production drawing required for the back and forth morphing of the wing was cut on the control plate with laser cutting. The metamorphosed wing was constructed from styrofoam material using hot wire. The necessary mechanical equipment was installed to attach the wing back and forth morphing to the fuselage. The alternating elongated wing was covered with composite. The necessary movement mechanism for the alternating elongated wing was installed. The necessary electronics for the metamorphosed elongated wing were installed. The battery system required for the electronics of the metamorphosed elongated wing was installed.

2.4. UAV Power Group Preference

Liquid fuel engine was preferred due to its high power and airtime. Plastic and wooden propellers were preferred considering the factors of being widespread and easy to obtain. Propellers suitable for the engine were preferred. An external receiver battery was preferred to feed the control receiver. Due to the high current and charging time, the lipo battery was preferred. For the control of UAV and morphing system, a fourteen-channel model controller was preferred. High speed and torque digital servo was preferred. The ignition system suitable for the engine was preferred. High power power box was preferred for power group control. Fuel system suitable for engine and fuel was preferred.

2.3. UAV Manufacturing Stages

The profiles that formed the structure of the wing of the unmanned aerial vehicle were drawn using the CAD program. The wing profiles created with the help of CAD program were transferred to program to be cut on the CNC machine. First of all, styrofoam in suitable sizes was adjusted for the wing cutting of the UAV. Styrofoam was meticulously placed under the hot wire of the cutting table. After that, the wing profiles drawn in Auto CAD were cut with a CNC machine ,as shown in Figure 4.

Figure 4. Obtaining the wing of the UAV from the CNC machine

After the profiles of UAV were cut on the CNC machine, the profiles cut on the cutting machine were freed from unnecessary parts. Border drawings were made in accordance with the lateral surface dimensions of the profiles. The drawings were cut on plywood with laser cutting. Plywood cut borders were glued to the side surfaces of the cut profiles with the help of epoxy. In order to ensure the smoothness of the new piece, the outer surfaces were carefully sanded and made ready for placement on carbon pipes.

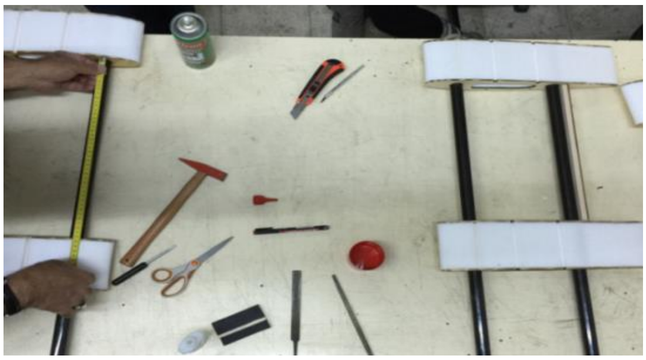

Figure 5. Threading the profiles of UAV into carbon pipes

The measurements of the gaps on the leading edge of the wing were taken. In the light of these dimensions, a leading edge drawing was made to complete the profile. Appropriately sized styrofoams were selected. The parts drawn in the computer program were cut on the selected styrofoam. Sanding was done to ensure the smoothness of the cut parts.

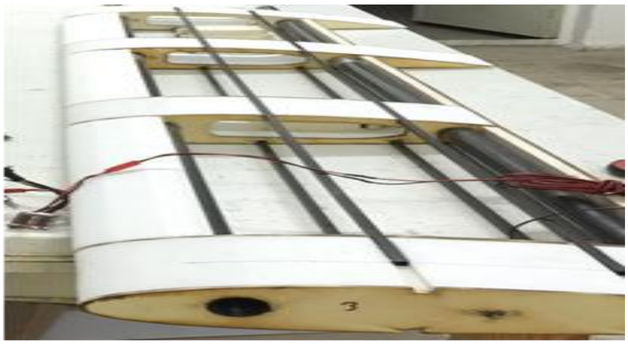

Figure 6. Conformity check and fixation

The nerves of the moving part of the morphing mechanism at the wing tip were aligned with the help of carbon pipes. Aligned nerves were glued with epoxy. Then the carbon pipes were fixed with epoxy. As in figure 7, suitable points were selected and holes were drilled for the mounting of the moving parts of the morphing mechanism to the wing profile. Movement mechanism parts that could move freely in the drilled holes were mounted. A healthy and continuous course of movement was observed.

Figure 7. Installation of the morphing mechanism on the UAV

The morphing mechanism profile was placed on the tested mechanism, as in Figure 8. The movement of the profile was carried out on the assembly. A healthy opening and closing movement was observed.

Figure 8. Installation of morphing mechanism on UAV

The profile with the trailing edge banded was coated as in figure 9 and made ready to form a fiber mold. In this way, the adhesion of the fiber fabric, which was adhered with epoxy, to the profile surface was prevented. The coated profile was re-coated with a separate coating that is more resistant to epoxy. An appropriate amount of fiber fabric was cut for the profile prepared for the fiber coating.

Figure 9. Coating

Appropriately sized slots were made on the wing to place the servos as in figure 10. The locations of the screws required to fix the servos on the blade were determined and marked. Holes were drilled in the marked areas with the help of a drill. Appropriate sized screws were inserted into the drilled holes. Thanks to these screws, the servos placed in the slots were fixed on the wing.

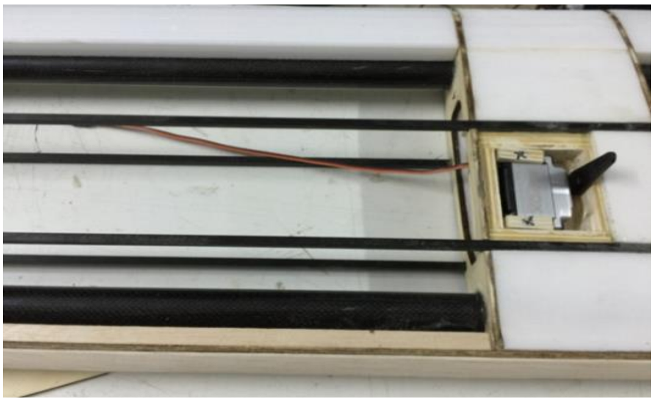

Figure 10. Adding servo motor to the wing

The drawings of the skeleton parts that formed the fuselage were made in a computer program. The parts whose drawings were made were cut with laser cutting. By gluing the appropriate parts together, the fuselage skeleton began to be formed as in figure 11. The epoxy applied parts were compressed with hinges to ensure the strength of the bonding. While the glued parts were left to dry, the nose and tail of the fuselage were glued separately. After the tail part was combined, it was glued to the fuselage skeleton. After the tail part was glued, the nose part was glued to complete the fuselage skeleton and left to dry.

Figure 11. Fuselage Manufacturing

The fuselage size was taken for the foam coating that formed the outer surface of the fuselage. Drawings were made in a computer program in line with these dimensions. The drawing was made concrete by cutting it on the CNC machine. The cut parts were tried on the fuselage. Inappropriate areas were sanded to ensure full compliance. The same process was applied for all foam parts, and they were made ready to be glued as in figure 12. After ensuring the integrity of the parts, they were glued and fixed on the fuselage. The open areas on the upper surface were covered with plywood cut in accordance with.

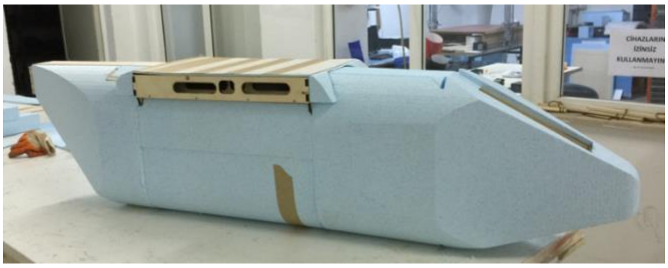

Figure 12. Covering the fuselage with foam

Balsas of suitable sizes were cut for the coating of the airfoil skeleton, the internal structure of which was completed. The cut pieces were glued onto the wing profile skeleton and covered. The newly created surface was sanded and smoothed. After the wing skeleton was covered with balsa, the fiber piece completing the morphing mechanism, which was cut in appropriate sizes, was mounted on the balsa at the tip with small screws, as in figure 13. It was observed that the moving part, which went in and out of its interior, worked easily after this region was mounted. After the necessary joints were made, the wing was remounted on the fuselage.

Figure 13. Wing - Body Assembly

In order not to disturb the aerodynamics of the engine of the UAV, it was deemed appropriate to place it behind the fuselage.

Figure 14. UAV engine mount

The final version of the UAV with nose wheel landing gear is shown in Figure 15 after production.

Figure 15. The final version of the UAV

3. Results and Discussion

Wingtip morphing, that is, passive morphing, enables UAVs to have higher maneuverability. The movement of the wingtip control surfaces makes it easier to perform maneuvers such as quick turns, tight bends and more precise flight controls. Wingtip morphing reduces wingtip drag and improves aerodynamic efficiency. Control surfaces reduce the effects of wingtip vortices in flight and help the wings produce lift more effectively. Wing tip morphing increases the flight stability of UAVs. Thanks to the movement of the control surfaces, the imbalances that may occur during the flight can be corrected and stability can be achieved. This provides a more controlled and safe flying experience. Wingtip morphing can improve the performance of UAVs in high speed flight. The movement of the control surfaces can reduce the overloads that can occur at high speeds and help the blades direct the airflow more effectively. Increasing the wing's area provides the possibility to produce greater lift and have greater load carrying capacity. The large wing area allows the UAV to carry heavier loads and fly more stably over long distances. Reducing the area of the wing allows the UAV to experience less resistance at high speeds. The small wing area reduces air resistance and allows the UAV to reach higher speeds. This allows the UAV to operate more effectively and efficiently in missions that require speed.

The wing's reciprocating motion, or active morphing, provides speed and lift control during flight. The wing's backward movement reduces lift with increasing speed, while its forward movement produces additional lift when speed decreases. In this way, the UAV can provide an optimized lift at different speeds and flight situations. The wing's ability to move back and forth enables the UAV to be effective over a wider speed range. You can fly at higher speeds with forward motion, while better control can be achieved at lower speeds with reverse motion. This allows the UAV to gain flexibility in various missions and adapt to different speed requirements. The wings that can move back and forth increase the maneuverability of the UAV. Especially during turns and bends, faster and sharper maneuvers can be made by changing the position of the wing. This ensures that the UAV can be controlled more precisely and display more dynamic flight performance. The back and forth movement of the wing increases the flight stability of the UAV. The backward movement of the wing increases stability, helping the UAV to fly smoothly and controllably. It also provides stable flight by changing the position of the control surfaces and corrects any instability that may occur during flight.

4. Conclusion

Passive morphing can be briefly defined as minor physical changes in aircraft geometry, performed once prior to flight, aimed at optimizing flight performance. Why do we change the location of the component with a certain position only once before the flight? If the wing and tail were fixed in the longitudinal axis and other axes, after the payload is placed, due to the change in the center of gravity, more or less ballast load must be added depending on the situation. This will cause an increase in the total weight and will affect performance parameters such as energy consumption, maximum range, airtime, maximum ceiling, maximum speed more or less negatively. Placing the aerodynamic center of the wing slightly in front of the aircraft's center of gravity instead of using the ballast load easily eliminates the negative situation that the ballast load will create.

Active morphing can be briefly defined as small physical changes in aircraft geometry that are continuously made during flight, aimed at optimizing flight performance. Instead of adding such a complex mechanism, why not fly an aircraft with a long wing and horizontal tail? First of all, it should be known that active morphing is a very good backup system in unexpected situations. It is a known situation that there are limits on the wing length as well. As an example, the width of the runway may not allow it in some cases, as well as for other reasons such as increase in drag force, negative impact on aerodynamic fines, increase in fuel consumption, decrease in airtime.

Ethical approval

Not applicable.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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