A review of passive control flow past UAV wings

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Abstract— *In this paper a number of control surfaces method for UAV performance optimization was objected. An unmanned aerial vehicle is a type of aircraft that operates without any human intervention. Unmanned aerial vehicles are used in many industries and applications, including communications, GIS, border surveillance, research and rescue, scientific and environmental studies, agriculture, as well as the military industries. The advantages of using drones include high efficiency, access to difficult and dangerous zones, cost reduction and human hoarding. However, the use of UAVs also comes with challenges and problems. One of the most important problems is the risk of losing control and running out of fuel and aerodynamic problems at different angles of attack or flow condition around the UAVs that change the performance and stability of UAVs. In this research, the samples are examined, Geometries and shapes changes created on the UAV's wing to improve the aerodynamic coefficients in the low and high angle of attack, flight range and etc. in other words, this current research is to enhance the manoeuvrability of a UAV, performance and stability parameter and aerodynamics behaviour of UAV, a number passive flow control method was employed and studied.*

Keywords— *UAV, Dog tooth, Fence, winglet, Leading edge droop, Sinusoidal leading edge*

I. INTRODUCTION

UAVs[1] or in other words, drones, are a type of aircraft that can fly without the need for human pilots. The drones are capable of autonomous navigation and carrying out specific missions in the air by utilizing intelligent processors, sensors, and accessing GPS information and weather data [1]. Unmanned aircraft are considered a significant innovation in the aerospace and aviation industry from a technological standpoint. These technological marvels provide capabilities for guidance, data collection, mapping, enhancing security, and conducting scientific research in various fields [2]. One of the best advantages of unmanned aircraft is their high performance and accuracy. This allows them to efficiently and effectively carry out various tasks [3]. In addition, due to the lack of need for a pilot, the use of unmanned aircraft significantly reduces maintenance and operational costs [4]. Some of the major applications of unmanned aircraft include:

1- Environmental protection: Unmanned aircraft can help in environmental monitoring and surveillance missions by detecting air and water pollution, identifying fires, observing natural changes, and identifying animals and plants in difficult areas.

2- Border security and military systems: These aircraft are used alongside soldiers and security forces for border control, intelligent detection of suspicious boats and aircraft, monitoring natural resources, and identifying restricted areas.

3- Smart agriculture: Unmanned aircraft have numerous applications in smart agriculture. By analysing aerial images and using intelligent algorithms, they can identify irrigation needs, types and quantities of nutrients in the soil, and propose optimal plans for efficient agricultural production.

In general, unmanned aircraft, with the use of artificial intelligence and technology employed in digital industries, are considered a necessity in the field of aviation and aerospace industry according to various demands and needs [6,7]. Predicting and accurately assessing the aerodynamic characteristics of an aircraft is vital during the initial design process. Additionally, defining the aerodynamic properties of existing aircraft is also important. In both cases, obtaining aerodynamic coefficients, such as lift, drag, and moment curves, is necessary to determine the stability and performance of the aircraft [8]. With the advancement of aerodynamics, various methods are employed to improve the control performance of aircraft. In the early 1990s, the United States launched the Innovative Control Effectors Program, aimed at developing and researching control systems for unmanned aircraft. This program was divided into two phases. In this study, analytical and conceptual investigations were carried out on control effectors, including conventional ones such as flaps, ailerons, leading-edge flaps, and some other effectors like split drag rudder flaps and all moving wing tips were examined [9]. There are multiple methods to mitigate the issues caused by flow separation and vortices on control surfaces. Generally, aerodynamic devices that induce changes in wing vortices include sinusoidal leading-edge flaps, winglets, Dogtooth flaps, vortex generators, fences, etc. [10]. One of the major

[1] Unmanned Aerial Vehicle

challenges in unmanned and all aircraft is the risk of losing control, fuel depletion, and aerodynamic issues at different angles of attack. In this study, we investigate examples, tools, and shape modifications made to aircraft wings to improve aerodynamic coefficients at low and high angles of attack, flight range, and fuel consumption. One of the aerodynamics problems that happen for UAVS is Dynamic stall that occurs when UAV's wing is in unsteady motion. In a dynamic stall, lift and pitching moment of UAV will fluctuate in a wide range, and the performance of UAV will face a serious problem. The advantage of using the variable droop leading-edge (VDLE), is decreasing the overall angle of attack to gets too large, also the adverse pressure gradient reduced [11]. Another way for this serious problem, there are various techniques for predict and solving these problems are usually classified as either active or passive control methods. One of the passive control methods for stall problem is using sinusoidal leading edges [12]. Another passive control method that also changes the geometry of the wing is the slot, the slot is an extension tool of the leading edge of the wing. This modification in wing geometry, produces not only a change in lift, but also an increase in drag that have advantages in low-speed flight condition and disadvantages in high-speed flight condition [13]. The purpose of this paper is to review of selected control surfaces and control methods for UAVs aerodynamics performance and stability improves.

II. EXAMPLES OF CONNECTIONS TO THE WING AND CREATING VARIOUS WING MODIFICATIONS

1. Dog tooth

A "dog tooth" in the context of UAV (unmanned aerial vehicles) refers to a specific design feature found in some aircraft wings. It describes a stepped or jagged leading edge of the wing, resembling the shape of a dog's tooth. The purpose of incorporating a dog tooth into the wing design is primarily to improve the aircraft's aerodynamic performance. This feature helps to reduce drag and enhance lift, resulting in better overall flight characteristics.
Here are some explanations regarding the benefits of a dog tooth design in a UAV:

1- Drag reduction: The jagged leading edge disrupts the airflow over the wing surface. This turbulent flow separates the boundary layer from the wing surface, reducing the drag caused by the interaction between the air and the wing.
2- Delay of stall: The dog tooth design creates vortices or small swirls of air over the wing. These vortices help delay the stall, which is a situation where the wing loses lift and the aircraft's control becomes difficult. By delaying the stall, the aircraft stays controllable at higher angles of attack (the angle between the wing chord line and the oncoming airflow) and slower speeds.
3- Improved lift distribution: The uneven shape of the leading edge causes a variation in lift distribution along the wing span. This results in a more efficient lift distribution, reducing the chances of wings tip stall and improving low-speed handling.
4- Reduced wingtip vortices: Wingtip vortices are swirls of air generated at the end of the wing, which cause induced drag. The presence of a dog tooth disturbs the formation of these vortices, effectively reducing the drag produced by them.
5- Stability at high angles of attack: The dog tooth design provides additional stability to the UAV when it operates at high angles of attack, allowing for more precise control during maneuvers, takeoff, and landing.

It's important to note that not all UAVs incorporate a dog tooth design in their wings. The use of a dog tooth depends on the specific requirements of the UAV's intended mission, and other factors such as weight, size, and overall design considerations [14,15,16].
Rao et al. examined a UAV sample by applying canine teeth on its wings. According to their results, the aerodynamic characteristics and the discussion of control and flight at low speed have been improved [17].
An example of creating a dogtooth on the wing of an unmanned aircraft can be seen in Fig1.

Fig.1. A dog's tooth on the wing of an unmanned aircraft

2. Sinus leading edge

A sinus leading edge wing, also known as a sinusoidal wing or a wavy wing, is a type of wing design used in unmanned aerial vehicles (UAVs) and other aircraft. It is characterized by a series of sinusoidal or wave-like curves along the leading edge of the wing. The main purpose of using a sinus leading edge wing in UAVs is to improve aerodynamic efficiency and enhance flight performance. The sinusoidal shape creates a continuous variation in the wing's angle of attack, allowing for smoother airflow over the wing surface. This reduction in aerodynamic disturbances such as turbulence and drag minimizes energy losses and increases the overall lift-to-drag ratio. The primary advantage of the sinus leading edge wing is its ability to delay the onset of stall at higher angles of attack. As the wings encounter higher angles of attack, the sinusoidal shape redistributes the air pressure across the wing surface, maintaining lift generation even at steeper angles. This improves the aircraft's maneuverability, stability, and control in various flight conditions, making it particularly suited for UAVs that need to operate in challenging environments or perform advanced aerial maneuvers. Another benefit of the sinusoidal wing design is its ability to reduce structural weight. The wavy shape allows for a thinner yet still rigid wing structure, which in turn reduces the weight of the overall aircraft. This weight reduction translates into improved fuel efficiency and extended flight endurance, enabling longer missions or increased payload capacity. Furthermore, the sinus leading edge wing also contributes to noise reduction. The smooth airflow over the wing surface helps minimize aerodynamic noise, leading to a quieter UAV operation. This can be important in applications where stealth or low detectability is desired, such as surveillance or military operations. It is worth noting that while the sinus leading edge wing offers several advantages, it also introduces additional design complexity and manufacturing challenges. Creating and maintaining the precise sinusoidal shape requires specialized manufacturing techniques and materials. However, with advancements in computer-aided design and additive manufacturing technologies, these challenges are becoming more manageable, and the use of sinus leading edge wings in UAVs is expected to become more widespread in the future [18,19,20,21].

In research, Miklosik et al evaluated the performance of a wing with a sinusoidal leading edge and a simple wing with the same conditions in the wind tunnel. They concluded that creating a sinusoidal leading edge in a wing can increase the stall angle by about 40%. to give [22].

In a research, Ney et al. numerically investigated the creation of twist in the wing and its effect on aerodynamic performance. They came to the conclusion that twisting has caused delay and retardation and, in this way, it has prevented the decrease of the coefficient of friction [20]. Shoorbaghi et al. experimentally investigated the aerodynamic performance of a simple wing with a sinusoidal wing by placing the wing in a wind tunnel. In this study, it was observed that the creation of a sinus decreased the drag coefficient by 28% and increased the drag coefficient by 48%.[23].

A noticeable example of a sinus leading edge can be seen in Fig.2

Fig 2. Sinus leading Edge in the Wing

3. Fence

The fence on the UAV wing is a structural element that is typically located near the leading edge of the wing. It is a small, vertical barrier that extends upwards from the wing surface. The primary function of a fence is to control the airflow over the wing, particularly at high angles of attack. When an aircraft is operating at a high angle of attack, there is a tendency for the airflow to separate from the wing surface, leading to a loss of lift and potential aerodynamic instability. The fence helps to prevent this by impeding the spanwise flow of air, thus maintaining a smooth and attached airflow over the wing. By reducing the airflow separation, the fence helps to improve the aircraft's stall characteristics, increase control authority, and enhance overall aerodynamic performance. It also aids in reducing undesirable effects such as wingtip vortices and wingtip stalls. Moreover, the fence on a UAV wing can also play a role in enhancing the overall stability and maneuverability of the aircraft. It can act as a reference point for pilots or autopilot systems, helping to maintain a desired flight path and prevent excessive roll or yaw. Overall, the fence on a UAV wing serves to optimize the aerodynamic performance and stability of the aircraft, enabling safer and more efficient flight operations. Winglets are small protrusions or extensions on the wingtips of an aircraft, typically vertical in shape. Their purpose is to improve the aircraft's aerodynamic efficiency by reducing drag and increasing fuel efficiency [24,25,26].

Williams et al. investigated an example of a wing-body unmanned aerial vehicle with fans applied to the wings. According to their results, the lift and drag coefficient did not change much until the attack angle of 8 degrees. But from 8 degrees and above, the lift coefficient has shown a better performance [27]. Moghimi and Javareshkian reduced the rolling moment coefficient of an airplane model by using a fence, and by using optimization, they reached the best place for the fence to reduce the rolling moment at a high angle of attack. [28]. Papadopoulos et al. investigated an example of a single-body wing drone with fenders on the wings. According to their results, the lift and drag coefficient did not change much until the attack angle of 8 degrees. But it has shown a better performance from 8 degrees and above [29]. In figure 3, a fence is created on the aircraft's wing that is visible.

Fig 3. Fence on the wing of airplane

4. Winglets

When applied to Unmanned Aerial Vehicles (UAVs), winglets serve the same purpose. They are added to the wingtips of the UAV to enhance its overall performance and effectiveness. Here are some key reasons why winglets are used on UAVs:

1. Drag reduction: Winglets help to reduce the drag created by vortices that form at the wingtips of an aircraft when it generates lift. By reducing these vortices, winglets effectively decrease the overall drag, leading to improved fuel efficiency and increased range.
2. Increased lift-to-drag ratio: By reducing drag, winglets enable an aircraft to maintain a higher lift-to-drag ratio. This means that the aircraft can generate more lift while experiencing less drag, allowing for better overall performance and maneuverability.

3. Improved stability: Winglets contribute to the stability and control of an aircraft, as they help to counteract yawing movements caused by various factors such as crosswinds. By reducing the side force and creating a more streamlined airflow, winglets contribute to a more stable flight experience for the UAV.
4. Enhanced endurance and range: With reduced drag and increased lift-to-drag ratio, UAVs equipped with winglets can experience improved endurance and range capabilities. This is particularly important for long-duration missions or when operating in challenging environments.
5. Safety and maneuverability: Winglets can improve the safety and maneuverability of UAVs, especially during critical flight phases such as takeoff and landing. By reducing drag and enhancing stability, winglets allow for smoother and more controlled flight operations in various flight conditions and environments.

It is important to note that while winglets offer significant benefits to UAVs, their design and integration need to be carefully considered. Factors such as wing shape, size, aspect ratio, and aircraft mission requirements play key roles in determining the optimal winglet design for a specific UAV. Overall, winglets are a valuable addition to UAVs that contributes to their overall performance, endurance, and efficiency [30,31]. John and Naryan investigated the effect of adding a specific type of winglet to a wing with the NACA 2412 airfoil in the initial phase of their research. Their simulation results showed that at a 4-degree angle of attack, the aerodynamic efficiency of the winglet was 14.81% compared to 3.54% without the winglet [32].

III. Conclusion

In this research, selected elements of airplane wing design were investigated. These elements are mechanical systems that change the shape of the wing, allowing for significant improvements in stability and flight safety during takeoff and landing by increasing the wing area and changing the wing.

References

[1] Koparan, C., Koc, A.B., Privette, C.V. and Sawyer, C.B., 2019. Autonomous in situ measurements of noncontaminant water quality indicators and sample collection with a UAV. Water, 11(3), p.604. DOI:10.3390/w11030604

[2] Koparan, C., Koc, A.B., Privette, C.V. and Sawyer, C.B., 2018. In situ water quality measurements using an unmanned aerial vehicle (UAV) system. Water, 10(3), p.264. DOI:10.3390/w10030264

[3] Brett, J. and Ooi, A., 2014. Effect of sweep angle on the vortical flow over delta wings at an angle of attack of 10. Journal of Engineering Science and Technology, 9(6), pp.768-781.

[4] Navy, R.A., 2001. UNMANNED AERIAL VEHICLES AND THE FUTURE NAVY.

[5] Abu-Jassar, et al,. (Accepted/In press). Access control to robotic systems based on biometric: the generalized model and its practical implementation. International Journal of Intelligent Engineering and Systems, 16(5), 313-328. https://doi.org/10.22266/ijies2023.1031.27

[6] Sobhani, M.K., Dehghani Manshadi, M., Bazzazzadeh, M. and Ilbeygi, M., 2015. Experimental Investigation of The Flow Field Over a Non-Slender lambda Shaped Wing by Pressure Measurement. Journal of Aeronautical Engineering, 17(1), pp.10-21.

[7] Guerrero, J.E., Maestro, D. and Bottaro, A., 2012. Biomimetic spiroid winglets for lift and drag control. Comptes Rendus Mecanique, 340(1-2), pp.67-80. https://doi.org/10.1016/j.crme.2011.11.007

[8] Adams, S.M. and Friedland, C.J., 2011, September. A survey of unmanned aerial vehicle (UAV) usage for imagery collection in disaster research and management. In 9th international workshop on remote sensing for disaster response (Vol. 8, pp. 1-8).

[9] Li, Z.J. and Ma, D.L., 2014. Control characteristics analysis of split-drag-rudder. Applied Mechanics and Materials, 472, pp.185-190.

[10] Bevan, R.L.T., Poole, D.J., Allen, C.B. and Rendall, T.C.S., 2017. Adaptive surrogate-based optimization of vortex generators for tiltrotor geometry. Journal of Aircraft, 54(3), pp.1011-1024. https://doi.org/10.2514/1.C033838

[11] Niu, J., Lei, J. and Lu, T., 2018. Numerical research on the effect of variable droop leading-edge on oscillating NACA 0012 airfoil dynamic stall. Aerospace Science and Technology, 72, pp.476-485.

[12] Esmaeili, A. and Sousa, J.M.M., 2014, September. Influence of wing aspect ratio on passive stall control at low Reynolds number using sinusoidal leading edges. In 29th Conference of the International Council of the Aeronautical Sciences, St Petersburg, Russia (pp. 7-12).

[13] Granizo, J.F., Gudmundsson, S. and Engblom, W.A., 2017. Effect of the Slot Span on the Wing Performance. In 35th AIAA Applied Aerodynamics Conference (p. 3578).

[14] E. Lakzian, S. Yazdani, R. Mobini, M. H. M.-E. Abadi, A. Ramezani, M. Yahyazadeh, et al., "Investigation of the effect of water droplet injection on condensation flow of different nozzles geometry," *The European Physical Journal Plus,* vol. 137, no. 5, p. 613, 2022

[15] V. Singh, S. K. Sharma, and S. Vaibhav, "Transport aircraft conceptual design optimization using real coded genetic algorithm," *International Journal of Aerospace Engineering,* vol. 2016, 2016.

[16] M. H. Moghimi Esfandabadi and M. H. Djavareshkian, "Design and optimization of the wing fence of a lambda-shaped aircraft model to reduce the rolling moment coefficient," *Technology in Aerospace Engineering,* 2023.

[17] M. K. Moghimi and F. Mohanna, "A joint adaptive evolutionary model towards optical image contrast enhancement and geometrical reconstruction approach in underwater remote sensing," *SN Applied Sciences,* vol. 1, no. 10, p. 1242, 2019.

[18] F. Aghaei, H. B. Eldeeb, and M. Uysal, "A Comparative Evaluation of Propagation Characteristics of Vehicular VLC and MMW Channels," *IEEE Transactions on Vehicular Technology,* 2023.

[19] M. K. Moghimi and H. Pourghassem, "Shadow detection based on combinations of hessenberg decomposition and principal component analysis in surveillance applications," *IETE Journal of Research,* vol. 61, no. 3, pp. 269-284, 2015.

[20] M. K. Moghimi and F. Mohanna, "Reliable object recognition using deep transfer learning for marine transportation systems with underwater surveillance," *IEEE Transactions on Intelligent Transportation Systems,* vol. 24, no. 2, pp. 2515-2524, 2023.

[21] A. Madani, M. Moghimi Esfandabadi, and M. Javarshekian, "Numerical simulation of the placement of the split drag rudder system along the wing of a flying wing UAV," 2023.

[22] Jr. W. A. Newsom, D. R. Satran, and Jr. J. L. Johnson, "Effects of wing-leading-edge modifications on a full-scale, low-wing general aviation airplane: Wind-tunnel investigation of high-angle-of-attack aerodynamic characteristics," No. L-15101, June 1983.

[23] J. K. Dickson, and F. B. Sutton, "The Effect of Wing Height on the Longitudinal Characteristics at High Subsonic Speeds of a Wing-fuselage-tail Combination Having a Wing with 40 Degrees of Sweepback and NACA Four-digit Thickness Distribution," No. NACA-RM-A55C30, May 1995.

[24] F. Neitzel, and J. Klonowski, "Mobile 3D mapping with a low-cost UAV system," Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci, vol. 38, p.C22, September 2011.

[25] W. A. Newsom Jr, D. R. Satran, and J. L. Johnson Jr, "Effects of wing-leading-edge modifications on a full-scale, low-wing general aviation airplane: Wind-tunnel investigation of high-angle-of-attack aerodynamic characteristics," 1982.

[26] M. H. Moghimi Esfandabadi and M. H. Djavareshkian, "Design and optimization of the wing fence of a lambda-shaped aircraft model to reduce the rolling moment coefficient," Technology in Aerospace Engineering, 2023.

[27] M. h. MoghimiEsfandabadi and M. H. Djavareshkian, "Maintenance grouping optimization with air systems to improve risk management," *International Journal of Reliability, Risk and Safety: Theory and Application,* pp. -, 2023, doi: 10.22034/ijrrs.2023.421330.1143.

[28] M. H. Moghimi EsfandAbadi, A. Mohammadi, and M. H. Djavareshkian, "Design and Analysis of Supersonic Inlet for Ramjet Engines: Aerodynamic Considerations and Performance Optimization," *Journal of Aerospace Science and Technology,* 2023.

[29] Y. Oda, K. Rinoie, and T. Yuhara, "Studies on wingtip geometries by optimum spanwise lift distribution design method," in 55th AIAA Aerospace Sciences Meeting, p. 1657, 2017.

[30] A. Beechook and J. Wang, "Aerodynamic analysis of variable cant angle winglets for improved aircraft performance," in 2013 19th International Conference on Automation and Computing, IEEE, pp. 1-6, 2013.

[31] M. H. MoghimiEsfandabadi, M. H. Djavareshkian, and S. Abedi, "The significance of aviation safety, its evaluation, and ways to strengthen security."

[32] M. H. Moghimi Esfandabadi and M. H. Djavareshkian, "Investigating selected methods to improve aerodynamic coefficients and better performance of UAV," *Technology in Aerospace Engineering,* pp. 1-15, 2023.