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AERODYNAMIC PERFORMANCE COMPARISON OF AIRFOILS IN FLYING WING UAV

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Abstract

Original scientific paper

The aim of the study is to investigate how the choice of airfoil affects the aerodynamic characteristics of a flying wing UAV. For this purpose, comparative analyzes were performed for four different airfoils: MH60, TL54, Eppler 339, and TsAGI 12%. Given the maximum range performance (maximum lift /drag ratio), the best aerodynamic efficiency is given by the flying wing UAV with MH60 and TL54 airfoil. Based on their maximum lift-to-drag ratio, the flying wing UAVs made with MH60 and TL54 airfoils exhibited the best aerodynamic efficiency. Specifically, the maximum lift-to-drag ratio for the flying wing with the MH60 airfoil was 33.1, while that for the flying wing with the TL54 airfoil was 32.7. Considering the pitching moment coefficient, the flying wing made with the MH60 airfoil and TsAGI 12% exhibited a more stable characteristic than the TL54 and Eppler 339 airfoils. Based on the results of the study, it was found that the flying wing UAVs made with the TL54 and MH60 airfoils outperformed those made with the Eppler 339 and TsAGI 12% airfoils in terms of maximum range, minimum descent rate, and maximum endurance performance.

Keywords: *Flying wing, MH60, tailless aircraft, TL54, XFLR5.*

UÇAN KANAT TİPİ İHA'LARDA KULLANILAN KANAT PROFİLLERİNİN AERODİNAMİK PERFORMANSLARININ KARŞILAŞTIRILMASI

Özet

Orijinal bilimsel makale

Çalışmanın amacı, kanat profili seçiminin uçan kanat İHA'ların aerodinamik özelliklerini nasıl etkilediğini ortaya koymaktır. Bu amaçla MH60, TL54, Eppler 339 ve TsAGI %12 kanat profilleri için karşılaştırmalı analizler yapılmıştır. Maksimum menzil performansı (maksimum kaldırma / sürükleme oranı) göz önüne alındığında, en iyi aerodinamik verimi MH60 ve TL54 kanat profilinden yapılmış uçan kanatlı İHA vermektedir. MH60 kanat profili ile uçan kanatta maksimum L/D oranı 33,1'dir, bu değer TL54 kanat profili ile 32.7 uçan kanattır. Eppler 339 ile uçan kanat, TsAGI %12 ile uçan kanada kıyasla negatif hücum açılarında daha avantajlıdır. Eğim momenti katsayısı dikkate alındığında TsAGI %12 ile MH60 kanat profilinden yapılan uçan kanat TL54 ve Eppler 339'a göre daha stabil bir özellik göstermektedir. Çalışma sonucunda TL54 e MH60 airfoile sahip uçan kanat İHA, maksimum menzil, minimum iniş hızı ve maksimum dayanıklılık performansı açısından Eppler 339 ve TsAGI %12'den daha iyi performans göstermiştir.

Anahtar Kelimeler: *Kuyruksuz uçak, MH60, TL54, uçan kanat, XFLR5.*

1 Introduction

A flying wing is a type of tailless aircraft whose useful load is located in the main wing without definite fuselage. Although the flying wing has the lowest drag design configuration, it is a disadvantageous design because the wing is laterally and directionally unstable. The airfoils used in the design of flying wings are reflexed airfoils, which are also used in tailless aircraft. Reflexed airfoils are created by adding a reflex camber to an airfoil, resulting in a very small decrease in the lift coefficient and a small increase in the drag coefficient. However, this modification leads to a significant reduction in the pitching moment coefficient [1]. Hepplerle [2] proposed several airfoils (MH45, MH60, etc.) for tailless aircraft, while Eppler [3] proposed an airfoil series (E 325-E 340) for the same purpose. Alsahlani [4] claimed that the several new airfoils of varying thicknesses (ZMR-19, ZMR-26) designed for an aft-swept flying-wing UAV operating at low Reynolds number provide better aerodynamic performance. Shams et al. [5] performed wind tunnel tests to study the aerodynamic efficiency and flight stability of a flying wing micro aerial vehicle with an Eppler 387 airfoil. Mokhtar [6] conducted a parametric study of high-lift airfoils including the Eppler E423, Douglas/Liebeck LNV109A, NACA 9315 and Selig

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S1223, and proposed a new WM004 airfoil section. Prisacariu [7] used Easy CFD software to analyze the Phoenix, Clark YH, and MH91 airfoils for flying wings. Dinh et al. [8] concluded that the TL54 airfoil provides superior aerodynamic performance based on a collection of low-speed FW UAV airfoil series (Eppler, MH, HS series etc.). Pate ang German [9] optimized a flying wing using NACA five-series reflexed airfoils with five different reflex parameters. Reid and Kozak [1] studied the development of the reflexed airfoil for micro-UAV with Reynolds numbers ranging from 60,000 and 150,000 using Bezier curve method. Wong et al. [10] investigated the use of reflex airfoils such as MH60, MH 78, MH 82, MH 92, E186, HS 522, S 5020, and Sipkill 1,7/10B in the fabrication of VTOL UAV. Ahn and Lee [11] analyzed aerodynamic characteristics of a FW UAV with S5010 airfoils and modifications of S5010 airfoil, as well as modifications to the S5010 airfoil using Xfoil and Fluent.

Martinez et. al [12] studied the conceptual design of a 300-seat class transport flying wing with C- and U-shaped layouts. Bronz et al. [13] developed a long endurance Mini-UAV both conventional and flying wing (FW) configurations. The FW configuration tends to have better range and endurance performance due to increased wing area. Several flying wing UAVs, including the SenseFly eBee X Orbiter I, Conyca Geodrone, Eleron 10SW, Castral Atlas, and Feiyu Tech X8, are launched by catapult [14]. Pan et al. [15] investigated the effects of the airfoil selection on the lateral and directional flight quality of aircraft with a double-swept wing arrangement. Through computational fluid dynamics simulations, it was found that an increase in twist angle improved aerodynamic efficiency over a wide range of angles of attack [16]. Song et al. [17] studied the effect of dihedral angle on the lateral dynamic stability of a large aspect ratio tailless wing aircraft in three sections along spanwise sections. Xu and Zhou [18] used numerical simulations to explore the use of synthetic jet flow control for longitudinal stability improvement. Gatto et al. [19] studied the effects of articulated winglet on flying wing and suggested that articulated winglets could provide relief of gust load. Gang et al. [20] suggested that propeller thrust could stabilize the pitching moment of flying wing UAVs.

In this study, four different flying wing UAVs, each made with a different airfoil (Eppler 339, MH60, TL54, and TsAGI 12%), were analyzed using XFLR5 software. The goal was to comparatively examine which airfoil provides superior flight performance and stability.

2 Material and Method

XFLR5 is a tool based on the XFoil program that can calculate the aerodynamic properties of airfoils. In this study, four different flying wing UAVs were designed using XFLR5 software. The Eppler 339, MH60, TL54 and TsAGI 12% airfoils were used as wing profiles for the flying wing UAVs. Fig. 1 shows a schematic representation of the airfoils.

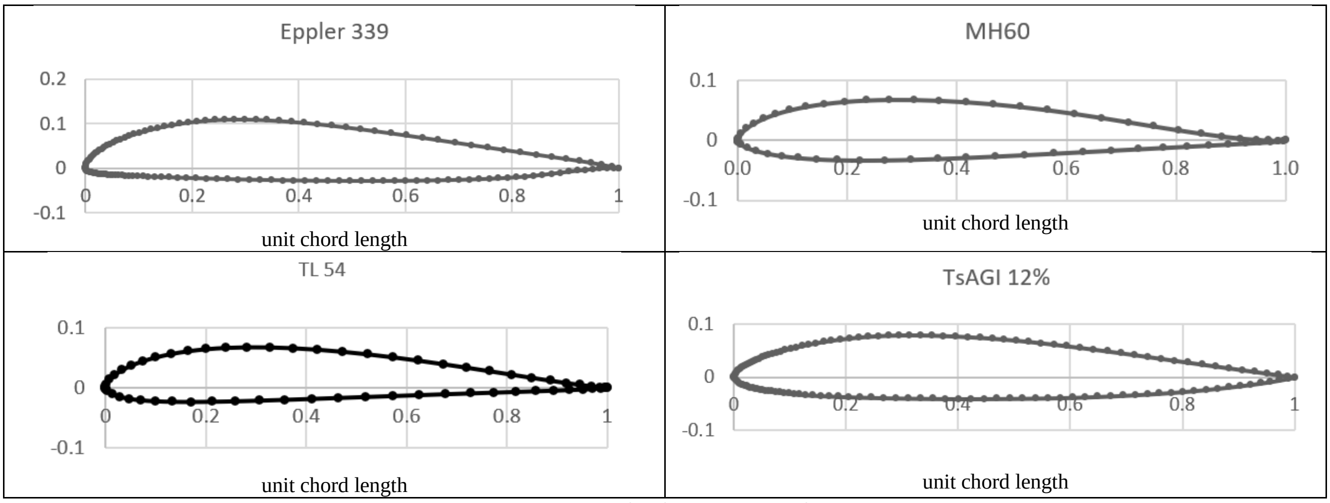
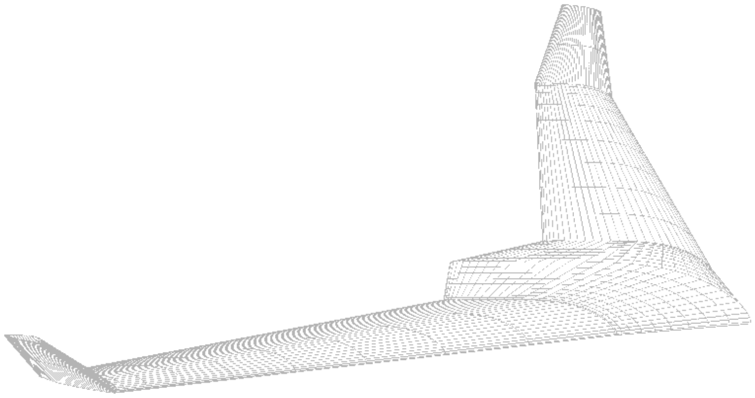


Figure 1. Schematics of airfoils used in the flying wing UAV.

Panel method is a numerical technique used in aerodynamics to calculate the flow field around a given airfoil. The method divides the surface into several flat segments. Each panel is treated as a source or sink of fluid, and the flow field is represented by a set of equations that describe the velocity potential and the stream function. Aerodynamic analysis was performed using a total of 1300 panels. The wingspan of all flying wing designs is 2.36 meters, which includes the winglet. The root chord is 0.7 meters, and the taper ratio is 0.129. The mean aerodynamic chord (MAC) is often used in aerodynamics to describe a characteristic length of a wing. MAC is a reference point that represents the average location of the aerodynamic forces acting on the wing. Fig. 2 shows the mass and size characteristics of the flying wing, including the surface panels. The vortex lattice method (VLM) is a numerical technique used to calculate the aerodynamic forces. The VLM method models the airflow around the object as a grid of interconnected vortex filaments, which represent the circulation of air around the object. Analysis results were obtained for the ranges of changes in angles of attack from -2 to 10 degrees. The results of the analysis were obtained using the vortex lattice method for a fixed cruise speed (108 km/h) under viscous flow conditions.



Wingspan (m)	2.360
Wing Area (m^2)	0.733
Aircraft Mass (kg)	5.0
Wing Load (kg/m^2)	6.96
Root Chord (m)	0.7
MAC (m)	0.371
Aspect Ratio	7.603
Taper Ratio	0.129

Figure 2. Aerodynamic, mass, and size properties of flying wing UAV with panels.

3 Results

The lift and drag characteristics of flying wing UAV with Eppler 339, MH60, TL54 and TsAGI 12% airfoils are presented comparatively. To compare the aerodynamic characteristics of four different flying wing UAVs, the change of lift coefficient (C_L), drag coefficient (C_D), lift to drag ratio (C_L /C_D ratio), the endurance curve ($\sqrt{{C_L}^3/{C_D}^2}$), and pitching moment coefficient (C_M) while varying the angle of attack was shown. C_D vs angle of attack curve is shown in Fig. 3.

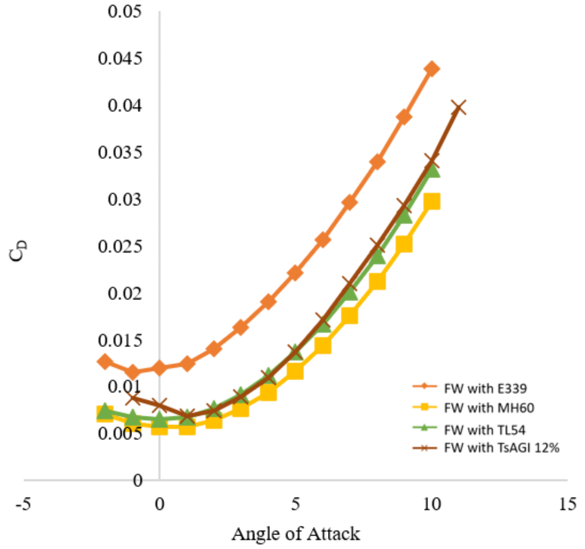


Figure 3. Change of the drag coefficient (CD) with varying the angle of attack

An airfoil with high aerodynamic efficiency can generate the desired amount of lift with minimal drag. The flying wing UAV designed with the TL54 and MH60 for low angles of attack gives the lowest drag coefficients, while the flying wing UAV designed with the MH60 airfoil for high angles of attack exhibits higher aerodynamic efficiency. The flying wing UAV with Eppler 339 has a significantly higher drag coefficient compared to other designs.

The curve showing the relationship between C_L and angle of attack for the four different flying wing UAVs is given in Fig. 4. The flying wing UAV with Eppler 339 airfoil exhibits the highest lift coefficient, followed by flying wing UAV with TL54 airfoil. The flying wing UAV with MH60 and TsAGI 12% airfoil exhibits a similar trend and lower lift coefficient.

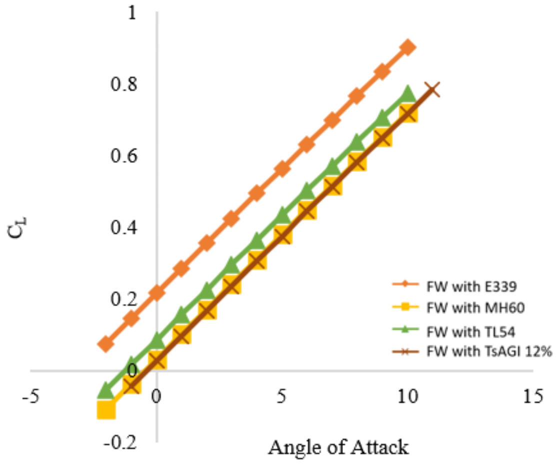


Figure 4. Change of the lift coefficient (C_L) with varying the angle of attack

The C_L/C_D ratio is a measurement of aerodynamic efficiency, maximum range, and best glide ratio performance. The curve showing the relationship between C_L/C_D ratio and angle of attack is shown in Fig. 5.

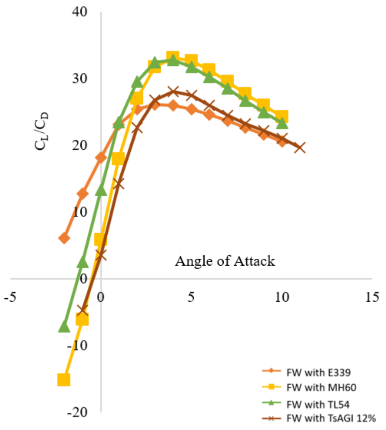


Figure 5. Change of the lift to drag ratio with varying the angle of attack.

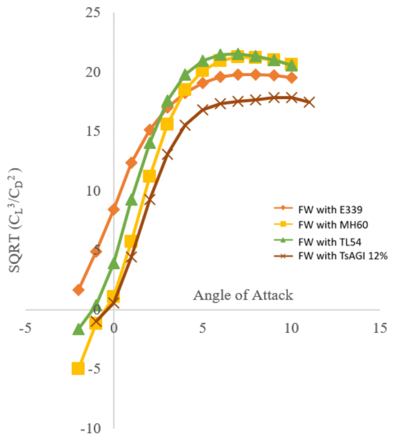


Figure 6. Change of the minimum descent rate factor $(\sqrt{{C_L}^3/{C_D}^2})$ with varying the angle of attack.

Considering the C_L/C_D ratio, the highest aerodynamic efficiency is provided by the flying wing UAV with MH60 and TL54 airfoil at angle of attack 3-5 degrees. The maximum lift to drag ratio in flying wing UAV with MH60 airfoil is 32.7 at the 5-degree angle of attack, while it is 33.1 flying wing UAV with TL54 airfoil. Flying wing UAV with the Eppler 339 airfoil, which gives the highest lift/drag ratio at negative attack angles, loses this advantage at high attack angles. The flying wing UAV with the TL54 and TsAGI 12% airfoils shows a similar drag curve trend, while the flying wing with UAV TL54 has a higher lift coefficient compared to TsAGI 12%, which resulting in a more aerodynamically efficient design. Beyond 3-degree angle of attack, the MH60 and TL54 airfoil exhibits better performance than the FW with MH60 airfoil, after which the MH60 and TL54 exhibit similar trends, and the MH60 performed better, although the difference was small.

The parameter of endurance $(\sqrt{{C_L}^3/{C_D}^2})$ indicates the maximum endurance and minimum descent rate. Fig. 6 shows the endurance curve $(\sqrt{{C_L}^3/{C_D}^2})$ vs angle of attack of four different flying wing UAVs. In terms of maximum endurance and minimum descent rate, flying wing UAV with MH60 and TL54 is more aerodynamically efficient. The flying wing UAV with Eppler 339 exhibits better aerodynamic performance than TsAGI 12%. The flying wing UAV with TsAGI 12% exhibits the lowest aerodynamic efficiency at positive angle of attack.

The pitching moment coefficient vs angle of attack of four different flying wing UAVs, which provides an indication of the flying wing's stability are given in Fig. 7. As can be seen from the chart, the FW with the MH60 airfoil with TsAGI 12% exhibits a more stable behavior than TL54 and Eppler 339.

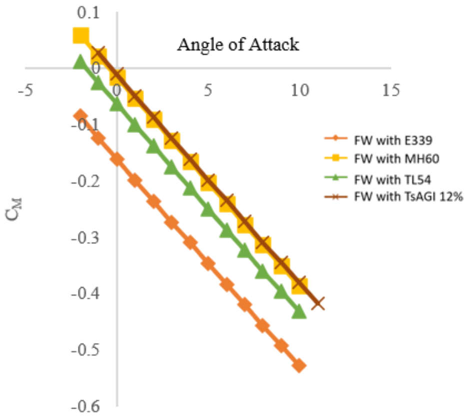


Figure 7. Change of the pitching moment coefficient (C_M) with varying the angle of attack

Fig. 8 shows the pressure coefficient contours and airflow of FW with TL54 airfoil. With the exception of the nose of the flying wing UAV, positive pressure coefficient ($+C_P$) values occurred at leading edge and negative pressure coefficient ($-C_P$) values occurred at trailing edge of flying wing UAV.

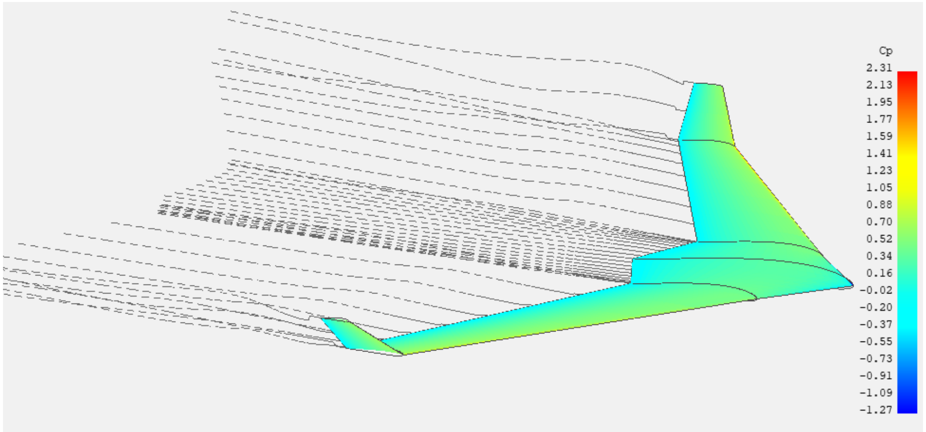


Figure 8. Display of pressure coefficient (C_P) with airflow at 3-degree angle of attack of FW design with TL54.

As a result of the study, it was revealed that the use of flying wing UAV with the TL54 airfoil and the MH60 airfoil exhibited better performance than flying wing UAV with Eppler 339 and TsAGI 12% in terms of aerodynamic efficiency, maximum range, minimum descent rate, and maximum endurance performance.

4 Conclusion

The study focused on airfoil selection in flying wing UAVs, and thus, the lift, drag, and pitching moment characteristics of flying wing UAVs with MH60, TL54, Eppler 339, and TsAGI 12% airfoils are presented comparatively. Considering the lift to drag ratio, the best aerodynamic efficiency was exhibited by the flying wing UAV with MH60 and TL54 airfoil at angle of attack 3-5 degrees. While the maximum lift-drag ratio in flying wing UAV with MH60 airfoil is 32.7 at the 5-degree angle of attack, while the flying wing UAV with TL54 airfoil exhibits 33.1. Up to a 3-degree angle of attack, flying wing UAV with TL54 airfoil exhibited better performance than the FW with MH60 airfoil, after which the MH60 and TL54 exhibited similar trends, and the MH60 exhibited slightly better performance. The flying wing UAV with the Eppler 339 airfoil exhibited better performance than the flying wing UAV with the TsAGI 12% airfoil. Considering the pitching moment coefficient, the flying wing UAV with the MH60 airfoil with TsAGI 12% exhibited a more stable characteristic than TL54 and Eppler 339. As a result of the study, it was revealed that the use of flying wing UAV with TL54 airfoil and MH60 airfoils exhibited better performance than Eppler 339 and TsAGI 12% in terms of highest range, maximum glide performance, as minimum descent rate, and maximum endurance performance.

Declaration

Ethics committee approval is not required.

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