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Impact of Airfoil Type and Placement on Aerodynamic Performance of Blended Wing Body Aircraft

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Abstract: The Blended Wing Body (BWB) design holds promise for the future by lowering total drag, emissions, fuel consumption, and noise levels. The aim of this study is to elucidate the influence of airfoil selection on the aerodynamic characteristics of the BWB, particularly focusing on the center body and outer wings. To achieve this objective, comparative analyses were conducted for four different Medium Altitude Long Endurance (MALE) Unmanned Aerial Vehicle (UAV) BWB designs, utilizing XFLR5 software and employing MH 60 and NACA 6412 airfoils. The maximum lift-drag ratio in the entire MH60 BWB design reached 26.98, while the implementation of the NACA 6412 airfoil on the outer wing led to a notable increase, resulting in a maximum lift-drag ratio of 31.83. This represents an impressive 18% enhancement in BWB's overall aerodynamic efficiency. Furthermore, the combination of a reflex airfoil on the center body, coupled with a high-lift airfoil on the outer wings, emerged as the optimal configuration, yielding the best aerodynamic performance among the tested designs. The study's findings have significant consequences for crafting future subsonic BWB aircraft with exceptional aerodynamic performance. This research adds valuable information to the ongoing development of advanced BWB designs by highlighting the importance of airfoil selection and configuration.

Key words: Blended wing body, Airfoil selection, MH60, NACA6412, MALE UAV.

Kanat Profili ve Yerleşiminin Gövde Kanat Harmanlı Uçakların Aerodinamik Performansına Etkisi

Öz: Gövde kanat harmanlı tasarım, toplam sürtünmeyi, emisyonları, yakıt tüketimini ve gürültü seviyelerini azaltarak gelecek için umut vaat etmektedir. Bu çalışmanın amacı, özellikle orta gövde ve dış kanatlara odaklanarak, kanatçık seçiminin Gövde kanat harmanlı tasarımın aerodinamik özellikleri üzerindeki etkisini aydınlatmaktır. Bu amaca ulaşmak için, XFLR5 yazılımı kullanılarak ve MH 60 ve NACA 6412 kanatçıkları kullanılarak dört farklı Orta İrtifa Uzun Dayanıklılık (MALE) İnsansız Hava Aracı (İHA) gövde kanat harmanlı tasarımı için karşılaştırmalı analizler yapılmıştır. MH60 gövde kanat harmanlı tasarımının tamamında maksimum kaldırma-sürükleme oranı 26,98'e ulaşırken, NACA 6412 kanat profilinin dış kanata uygulanması kayda değer bir artışa yol açarak maksimum kaldırma-sürükleme oranının 31,83 olmasını sağlamıştır. Bu, Gövde kanat harmanlı tasarımın genel aerodinamik verimliliğinde %18'lik etkileyici bir artışı temsil etmektedir. Ayrıca, orta gövdede kuyruksuz bir kanat profili ile dış kanatlarda yüksek kaldırma kanat profili kombinasyonu, test edilen tasarımlar arasında en iyi aerodinamik performansı sağlayan optimum konfigürasyon olarak ortaya çıkmıştır. Çalışmanın bulguları, olağanüstü aerodinamik performansa sahip gelecekteki ses altı Gövde kanat uçaklarının üretilmesi için önemli sonuçlar doğurmaktadır. Bu araştırma, kanat seçimi ve konfigürasyonunun önemini vurgulayarak gelişmiş gövde kanat harmanlı tasarımlarının devam eden gelişimine değerli bilgiler katmaktadır.

Anahtar kelimeler: Gövde kanat harmanlı tasarım, Kanat profili seçimi, MH60, NACA6412, MALE İHA.

1. Introduction

Blended Wing Body (BWB) aircraft have significant potential for the future in terms of reducing total drag, emissions, fuel consumption, and noise. For BWB optimization, Gauvrit et al. [1] proposed 5 different disciplines as geometry, propulsion, structure, aerodynamics, and task. This study primarily focusses on geometry and aerodynamics without dealing with other optimization disciplines. In this study, the performance of UAV BWBs was evaluated based on the aerodynamic twist achieved using MH60 and NACA 6412 airfoils on the central fuselage and outer wings. Aerodynamic and geometric twist are two ways of achieving washout. In geometric twist, different angles of attack are given to the same airfoil, while in aerodynamic twist a wash-out/wash-in is achieved by using different airfoils at the wing root and at wing tip [2].

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Bolsunovsky et al. [3] studied a TsAGI with a capacity of 750 passengers, and Liebeck [4] conducted the conceptual design of a BWB with a capacity of 800 passengers, which was the first study on passenger transport BWB in the literature. Other notable conceptual studies on passenger aircraft BWBs include Scholz's [5] Very Efficient Large Aircraft (VELA), Hilemann et al.'s [6] Sax-40 BWB, NASA's Environmentally Friendly Aviation (ERA) BWB Project [7], Boeing's Subsonic Ultra Green Aircraft Research (SUGAR) BWB design [8], Nickol's [9] HWB 216, HWB 301, HWB 400 designs, Mohr's [10] active control for flexible aircraft (ACFA) design, Gern's [11] Open Rotor Engine Integration On a BWB (OREIO), Dehpenaj and Nejat's [12] aerodynamic research on passenger plane (AEROPP) design, Prakasha et al.'s [13] A Aircraft 3rd Generation MDO for Innovative Collaboration of Heterogeneous Teams of Experts AGILE EU BWB, and Larrimer's [14] BWB MD-11 are some other conceptual studies in the literature for a passenger aircraft BWB. Blended Wing Body (BWB) aircraft designs have shown promising aerodynamic performance improvements over conventional aircraft. Studies have demonstrated that BWB configurations can achieve higher lift-to-drag (L/D) ratios, with improvements ranging from 9.4% to 21% compared to conventional designs [15-17]. These enhancements are primarily attributed to drag reduction, particularly at medium subsonic speeds [15]. The aerodynamic benefits of BWB designs vary depending on aircraft size, with wide-body BWBs showing greater potential for drag reduction compared to regional-class BWBs [16]. Additionally, distributed propulsion systems integrated into BWB designs can further improve aerodynamic performance, with one study reporting a cruise L/D ratio of 24.0 and enhanced low-speed lift characteristics [17].

The literature includes numerous studies on the BWB UAV concept [18-20]. Baig et al. [21] designed a small scale BWB with a center body with NACA 25111 and outer wing with MH78 airfoil. Hoe and Mohd [22] conducted a CFD study of conventional aircraft configuration versus BWB, and results showed that the BWB configuration showed a decrease in the total drag and an increase in lift to drag ratio. Chung [23] studied manufacturing and flight tests of an electrically powered flying-wing UAV. Communier et al. [24] verified that the XFLR5 analyses for an aircraft wing were consistent with the experimental wind tunnel results. Khushbash et al. [25], with the help of XLFR5 and CFD, performed analyzes of a micro flying wing and concluded that underpredicts the drag coefficient compared to CFD analysis, while XFLR overestimates the lift coefficient. Kaya et al. [26] studied the conceptual design of the VTOL-BWB using the XFLR5 tool and the Improved Blade Element and Momentum Theory (IBEMT). Siouris and Qin [27] studied the effect of wing sweep on BWB and concluded that the maximum lift to drag ratio was found, with an outer wing sweep angle of 45°. Hepplerle [28] studied the airfoils (MH45, MH60, etc.) used in tailless airplanes. Eppler [29] developed an airfoil series (E 325-E 340) for tailless aircraft. Liebeck [30] designed LNV109A to maximize the lift coefficient for BWB.

In this study, four different BWB UAVs created with NACA 6412 and MH 60 airfoil combinations on the central fuselage and outer wing in XFLR5 software were analyzed. Blended Wing Body (BWB) aircraft design studies have concentrated on optimizing both the body and wing profiles to achieve superior performance. Body profile studies emphasize improved internal volume for payload, fuel, and passenger accommodation, along with reduced structural weight compared to traditional tube-and-wing designs. The integrated body-wing geometry also enhances aerodynamic efficiency. Wing profile studies focus on minimizing wing tip vortices and induced drag, achieving improved lift distribution across the aircraft, ensuring more uniform pressure distribution compared to conventional wings, and enhancing the potential for laminar flow control. The original contribution of this study lies in its innovative configuration, which combines a reflex airfoil in the fuselage center with a high-lift airfoil on the outer wings. Additionally, it proposes a method to maximize aerodynamic performance through strategic airfoil selection. The basic problem addressed in this new design is improving the aerodynamic efficiency of Blended Wing Body (BWB) aircraft and overcoming the traditional limitations associated with wing and body profile aerodynamics. Current research suggests a unique airfoil combination that has not been previously explored in BWB studies. This combination optimizes lift distribution, reduces drag, and employs a systematic configuration design to achieve holistic aerodynamic performance improvements.

2. Material and Methods

The XFLR5 software, an advanced computational tool, employs the XFoil program to meticulously analyze airfoil performance by calculating crucial parameters such as pressure distribution, lift, and drag characteristics. Leveraging the capabilities of XFLR5, his study undertakes the design and evaluation of four distinct Blended Wing Body (BWB) configurations. When performing wing analysis in XFLR5, several typical assumptions are made to simplify complex aerodynamic interactions for computational analysis. These include steady-state flow conditions, incompressible airflow, and inviscid flow near the wing surface. The analysis also assumes the application of linear aerodynamic theory, small angle of attack approximations, and the extension of two-dimensional airfoil characteristics to three-dimensional wing analysis. Furthermore, the wing structure is considered rigid without deformation, boundary layer and viscous effects are neglected, and uniform atmospheric conditions are assumed. Compressibility effects are also disregarded at low Mach numbers, allowing for a more straightforward evaluation of wing performance and characteristics.

In these BWB designs, both the MH 60 and NACA 6412 airfoils are strategically deployed across various sections, including the center body, blending area, and outer wing, of the Medium Altitude Long Endurance (MALE) BWB Unmanned Aerial Vehicle (UAV). The NACA 6412 and MH 60 airfoils were selected for this analysis due to their distinct and representative characteristics in aerodynamic design. The NACA 6412 is a typical high-lift airfoil, characterized by its cambered profile that provides excellent lift generation at lower speeds, making it particularly suitable for applications requiring enhanced lifting performance. In contrast, the MH 60 airfoil is a classic example of a reflex airfoil design. Reflex airfoils are distinguished by their unique upper surface profile, which curves upward near the trailing edge, creating a distinctive geometric characteristic that influences its aerodynamic behavior. The MH 60 airfoil, known for its superior aerodynamic properties, was selected for its suitability in enhancing lift capabilities, while the NACA 6412 airfoil, renowned for its versatility and stability, was chosen to optimize performance across the BWB's different sections. To visualize the configuration of these airfoils, refer to Figure 1, which schematically displays the distinctive profiles of the NACA 6412 (Fig. 1(a)) and MH 60 (Fig. 1(b)) airfoils. This illustration provides a clear depiction of the geometric characteristics and relative placements of the selected airfoils within the BWB design.

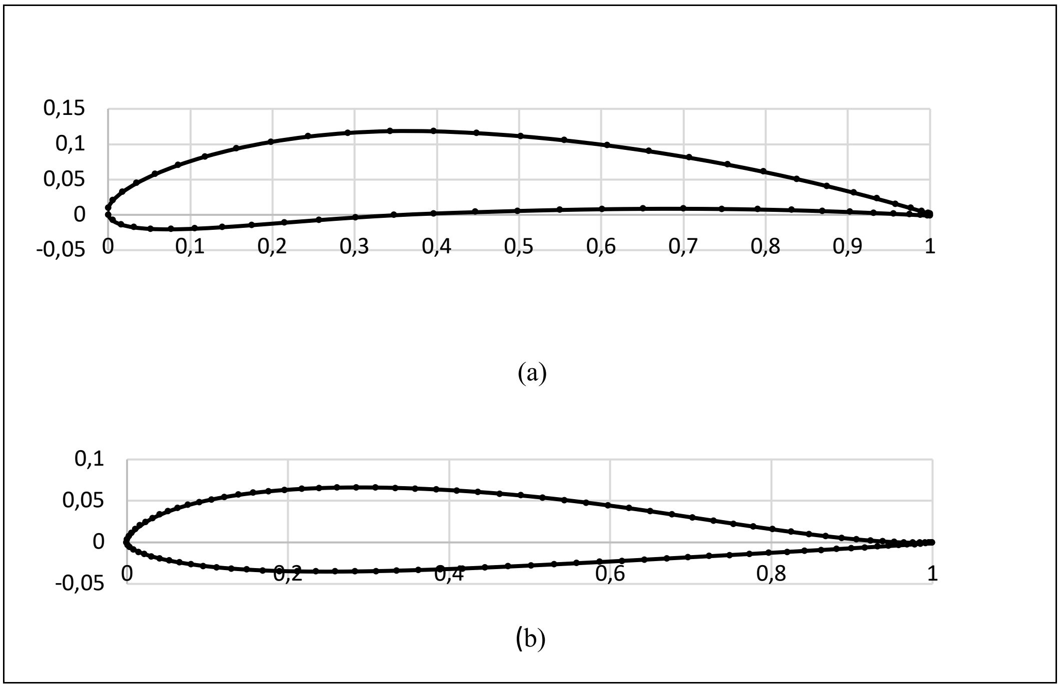

Figure 1. Schematic display of (a) the NACA 6412 airfoil and (b) the MH 60 airfoil.

The analysis was meticulously conducted using a comprehensive framework comprising a total of 1,880 panels within the XFLR5 software environment. This computational setup facilitated a detailed examination of the Medium Altitude Long Endurance (MALE) Blended Wing Body (BWB) design. The MALE BWB, characterized by a wingspan spanning 7.2 meters, features a root chord measuring 3 meters and a taper ratio of 0.067. These dimensional specifications play a pivotal role in determining the aerodynamic performance and structural integrity of the BWB UAV. For a comprehensive understanding of the mass distribution and size characteristics of the MALE BWB, refer to Fig. 2. This schematic depiction provides valuable insights into the surface panel configuration, enabling a visual representation of the aircraft's structural layout and design parameters. Equations related to aerodynamic wings are given in Eq. 1.-Eq.3. The aspect ratio of a wing is calculated as:

$$Aspect\ ratio\ (AR) = \frac{b^2}{S} \tag{1}$$

where b is the wingspan and S is the wing area. The taper ratio of a wing is calculated as:

$$Taper\ ratio\ (\lambda) = \frac{c_t}{c_r} \tag{2}$$

where c_t is the chord length at the wingtip, and c_r is the chord length at the wing root. The mean aerodynamic chord (MAC) of a wing is calculated as:

$$Mean\ aerodynamic\ chord\ (MAC) = \frac{2}{S}\int_{y_1}^{y_2} c^2(y)dy \tag{3}$$

where S is the total wing area, c(y) is the local chord length at spanwise position y; y_1 and y_2 are the spanwise limits of the wing.

Wingspan (m)	7.2
Wing Area (m^2)	6.24
Aircraft Mass (kg)	200.0
Wing Load (kg/m^2)	32.051
Root Chord (m)	3.0
MAC (m)	1.651
Aspect Ratio	8.308
Taper Ratio	0.067

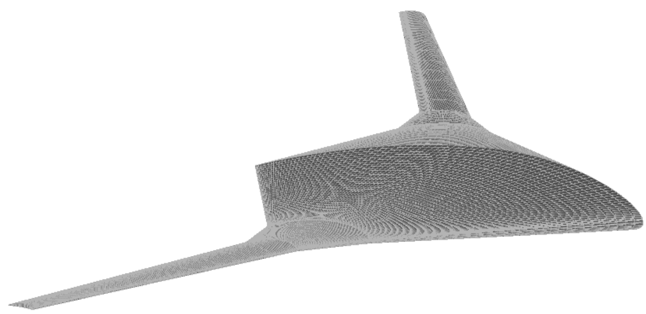

Figure 2. BWB design: size metrics and aerodynamic panel visualization.

Fig. 3 provides a visual representation of four distinct Blended Wing Body (BWB) designs, each tailored with unique airfoil configurations to explore their respective aerodynamic characteristics. The first BWB iteration [Fig. 3 (a)] utilizes the MH60 airfoil across its entirety, emphasizing the aerodynamic properties inherent to this specific profile. Conversely, the second BWB variant [Fig. 3 (b)] adopts the NACA 6412 airfoil exclusively, showcasing a different approach to aerodynamic optimization. In the third BWB design (Fig. 3 (c)), a hybrid configuration is employed, with the NACA 6412 airfoil strategically integrated into the center body while the MH60 airfoil is implemented in the outer wing region. This combination aims to leverage the strengths of each airfoil type for enhanced performance. Similarly, the fourth BWB iteration (Fig. 3 (b)) adopts a reverse hybrid configuration, with the MH60 airfoil deployed in the center body and the NACA 6412 airfoil employed in the outer wing section. This design approach seeks to capitalize on the unique aerodynamic characteristics offered by each airfoil profile. To facilitate a comprehensive understanding of the aerodynamic performance associated with these diverse airfoil combinations, the results section presents detailed comparisons among the BWBs designed with different airfoil configurations. Through these analyses, valuable insights into the impact of airfoil selection on BWB aerodynamic performance are elucidated.

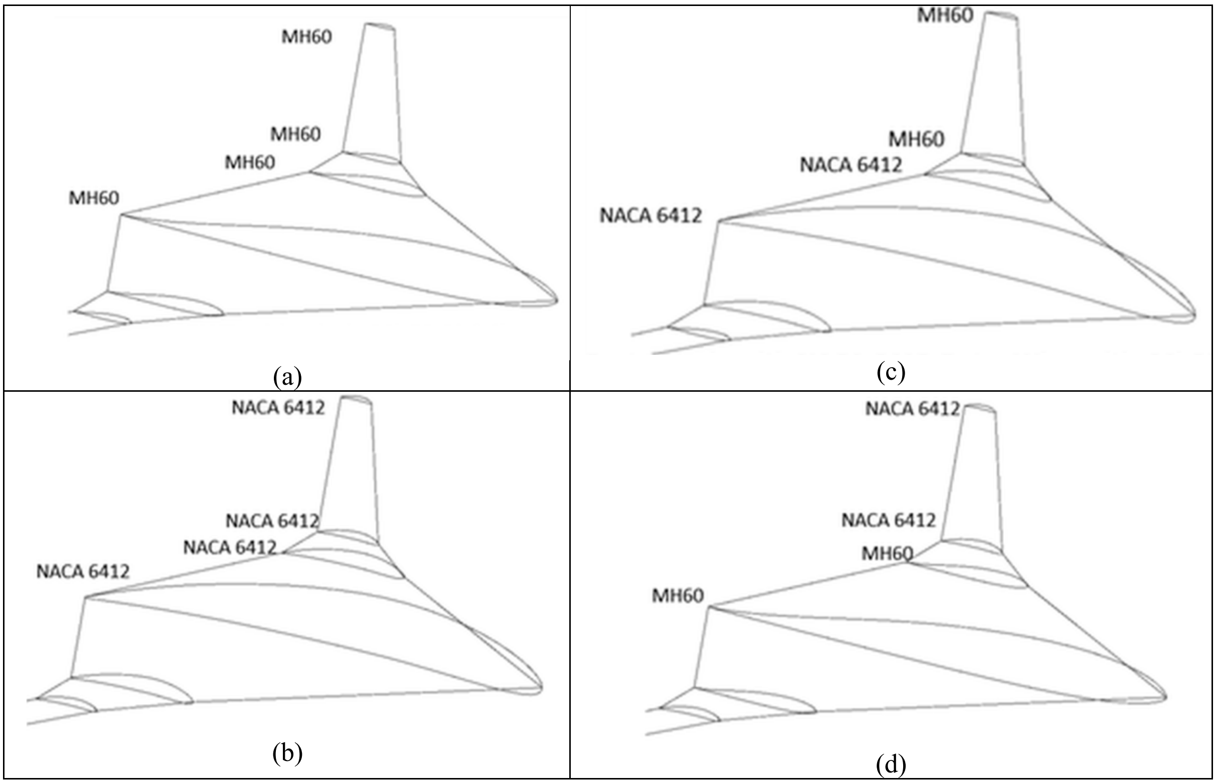

Figure 3. Airfoil Variations in Center Body and Outer Wings Across BWB Designs: (a) BWB with the whole MH60 airfoil, (b) BWB with the whole NACA 6412 airfoil, (c) BWB with a center body using NACA 6412 and an outer wing using MH 60, and (d) BWB with a center body using MH 60 and an outer wing using NACA 6412.

The analysis encompassed a comprehensive range of angles of attack, spanning from -6 to 8 degrees, to thoroughly evaluate the aerodynamic behavior of the Blended Wing Body (BWB) designs. These analyses were conducted under International Standard Atmosphere (ISA) sea level conditions, ensuring consistency in air characteristics across the evaluations. To facilitate detailed aerodynamic assessments, additional panels were strategically incorporated into the BWB designs. This augmentation allowed for a thorough analysis leveraging the vortex lattice method (VLM2) under fixed cruise speed conditions, even viscous flow complexities. Limitations of the XFLR5 software include computational constraints, in that the software exhibits limited accuracy when analyzing complex 3D geometries and is less sensitive for transonic and supersonic flow conditions. Additionally, XFLR5's analysis capabilities are limited and are primarily suitable for low-speed aerodynamic analysis. It cannot directly simulate compressibility effects and has limited turbulence modeling capabilities, further limiting its application in advanced aerodynamic studies. Since the current study focuses on steady flow conditions at low speeds, the absence of CFD does not introduce significant negative effects, as the scenarios analyzed fall within the capabilities of alternative methods like XFLR5.

3. Results

The analysis encompassed a comprehensive range of angles of attack, spanning from -6 to 8 degrees, to thoroughly evaluate the aerodynamic behavior of the Blended Wing Body (BWB) designs. These analyses were conducted under International Standard Atmosphere (ISA) sea level conditions, ensuring consistency in air characteristics across the evaluations. To facilitate detailed aerodynamic assessments, additional panels were strategically incorporated into the BWB designs. This augmentation allowed for a thorough analysis leveraging the vortex lattice method (VLM2) under fixed cruise speed conditions, even viscous flow complexities.

To understand the influence of airfoil selection across all BWB designs, lift and drag coefficients at various angles of attack were obtained and comparatively analyzed. Several aerodynamic characteristics of the four different BWBs were assessed, including CL vs. angle of attack curve, polar drag curve (C_L vs C_D,), C_L /C_D, vs angle of attack, and $\sqrt{{C_L}^3/{C_D}^2}$ vs angle of attack curve. The comparison of lift curves for all cases is depicted in Fig. 4. Figure 4 compares the lift curves for various airfoil designs, including the whole MH60 and NACA6412 airfoils as well as their fuselage and outer wing components. The plot shows the lift coefficient (Cl) across a range of angles of attack, providing insights into the aerodynamic performance of these airfoil configurations. As anticipated, the BWB design utilizing exclusively NACA6412 airfoils exhibited the highest lift coefficient, while the BWB design employing solely MH60 airfoils demonstrated the lowest. Notably, the BWB design featuring a center body with NACA 6412 airfoil and outer wing with MH60 airfoil exhibited a higher lift coefficient compared to the configuration with a center body employing MH60 airfoil and outer wing employing NACA 6412 airfoil.

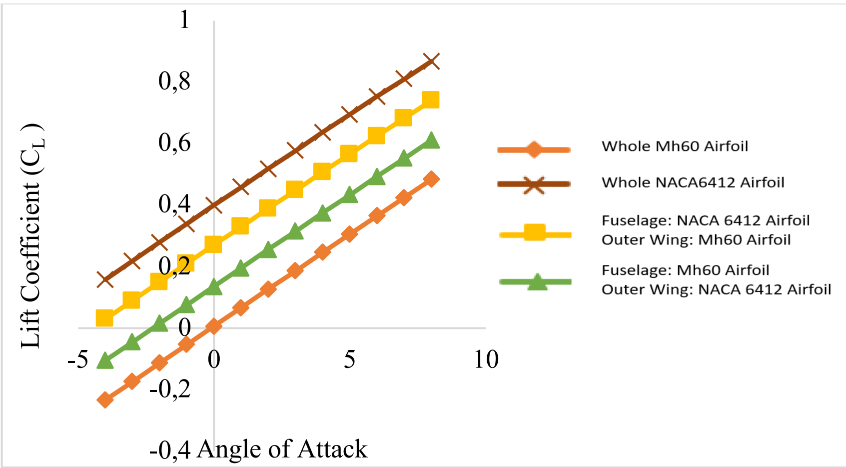

Figure 4. Lift curve comparison for various BWB designs.

The comparison of drag polar curves (C_L vs C_D curves) for all BWB designs is visually depicted in Figure 5. The drag polar comparison highlights the distinct aerodynamic characteristics of the NACA 6412 and MH60 airfoils for various BWB designs. The NACA 6412 exhibits higher lift at lower drag coefficients, indicating its suitability for high-lift applications. Conversely, the MH60 airfoil maintains more gradual lift increases with increasing drag, suggesting better stability. A notable observation from these curves is the distinct trends arising from the contrasting drag characteristics between the center body and the outer wings. This disparity led to the emergence of two separate polar curve trends. Interestingly, the BWB design featuring exclusively NACA6412 airfoils exhibited the highest coefficient of drag across all angles of attack. This phenomenon underscores the nuanced interplay between airfoil selection and aerodynamic performance. Remarkably, this design concept managed to achieve a balance between minimizing drag coefficient, similar to the performance of the entire MH60 design, while simultaneously attaining a higher lift coefficient, particularly evident at positive angles of attack. This achievement was made possible by strategically integrating NACA 6412 airfoils on the outer wings, thereby optimizing lift generation while mitigating drag.

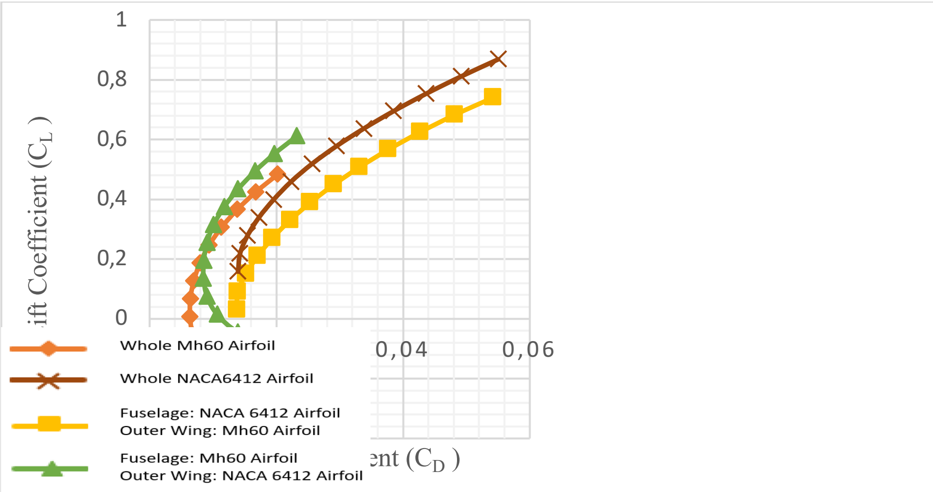

Figure 5. Drag polar curve comparison for various BWB designs.

The C_L/C_D ratios presented in Fig. 6 serve to simultaneously evaluate the drag and lift characteristics for aerodynamic efficiency comparison. The NACA 6412 airfoil exhibits a higher peak lift-to-drag ratio, indicating superior aerodynamic efficiency at certain angles of attack. In contrast, the MH60 airfoil maintains a more gradual lift-to-drag profile, suggesting better stall characteristics and overall stability. Among the analyzed configurations, the BWB design featuring an MH60 center-body with NACA 6412 outer wing demonstrates the highest aerodynamic efficiency based on the lift-to-drag ratio. Closely following is the entire MH60 BWB design, ranking second in terms of lift to drag ratio. For the entire MH60 BWB design, the maximum lift-drag ratio is recorded at 26.98, occurring at a 5-degree angle of attack. Conversely, the MH60 center-body with NACA 6412 outer wing BWB design achieves a superior lift-drag ratio of 31.83, observed at a 4-degree angle of attack. This configuration's use of the NACA 6412 airfoil on the outer wing yields an impressive 18% enhancement in aerodynamic performance (lift-to-drag ratio). While the BWB design featuring solely NACA 6412 airfoils exhibits superior performance at negative angles of attack, the MH60 configuration excels at positive angles of attack. Consequently, the synergistic combination of a reflex airfoil (MH60) on the center body and a high-lift airfoil (NACA 6412) on the outer wings emerges as the optimal configuration, yielding the best overall aerodynamic performance.

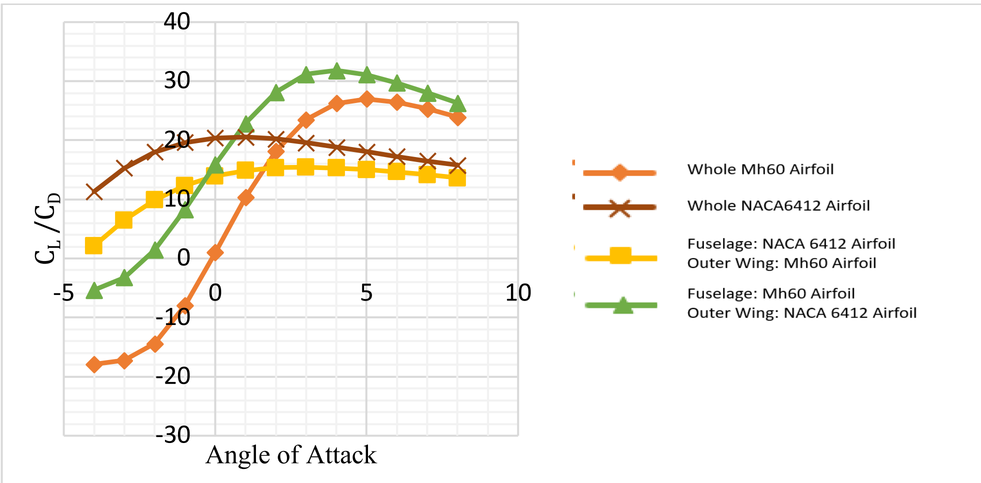

Figure 6. Lift to drag ratio (aerodynamic efficiency) curve comparison for various BWB designs.

The parameter $\sqrt{{C_L}^3/{C_D}^2}$ offers insight into both the minimum descent rate and the maximum endurance factor, providing valuable information regarding the overall performance of the aircraft. Figure 7 illustrates the variation of $\sqrt{{C_L}^3/{C_D}^2}$ with the angle of attack, depicting distinct curves for negative and positive angles of attack. The endurance curve comparison highlights key differences in the lift-to-drag ratios of the NACA 6412 and MH60 airfoils. The NACA 6412 exhibits higher peak lift-to-drag performance, indicating superior aerodynamic efficiency at certain angles of attack. Meanwhile, the MH60 maintains a more gradual endurance curve, suggesting better stall characteristics and overall stability. Notably, the airfoils exhibit different performance characteristics at varying angles of attack. At negative angles of attack, the NACA 6412 airfoil demonstrates favorable performance, while the MH-60 airfoil proves advantageous at positive angles of attack. This distinction is reflected in the formation of seperate curves for each airfoil type. For the BWB design with an MH60 center body and NACA 6412 outer wings, optimal performance in terms of both minimum descent rate and maximum endurance factor is achieved. Once again, the synergistic combination of the reflex MH60 airfoil on the center body and the high-lift NACA 6412 airfoil on the outer wings emerges as the configuration offering the minimum rate of descent, underscoring its efficiency in flight operations requiring prolonged endurance.

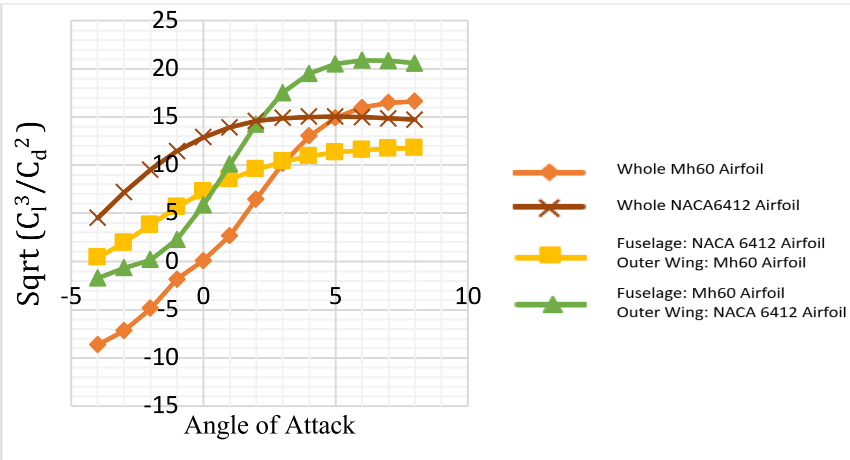

Figure 7. Endurance curve comparison for various BWB designs.

C_m vs. α (moment coefficient vs. angle of attack) curve is essential for understanding the stability and control characteristics of a BWB. Fig. 8 illustrates the variation of moment coefficient with the angle of attack. The moment coefficient curves reveal the different pitching moment characteristics of the NACA 6412 and MH60 airfoil configurations. The NACA 6412 exhibits a more linear moment coefficient trend, while the MH60 demonstrates a more pronounced reflex shape. This reflects the improved stability of the MH60 design, particularly at higher angles of attack. All configurations show negative slopes in the C_m vs. α curves, indicating that all designs are statically stable. The C_m starts positive and becomes negative as the angle of attack increases, passing through zero at a positive angle of attack for BWB with whole Mh60 airfoil. This suggests a stable design with a neutral point at a positive angle of attack, meaning it tends to pitch down as the angle of attack increases beyond this point. The curve of BWB with whole NACA 6412 airfoil shows a similar pattern to the Whole Mh60 Airfoil but with a steeper negative slope. The moment coefficient starts positive but decreases more rapidly, suggesting it reaches a neutral point at a lower angle of attack compared to the Whole Mh60 Airfoil. This design is more dynamically responsive to changes in angle of attack.

The moment coefficient of BWB made of fuselage with NACA 6412 airfoil and outer wing with Mh60 airfoil starts positive and transitions to negative, with a neutral point at a moderate angle of attack. The mix of airfoils provides a balanced characteristic between the Whole Mh60 and Whole NACA6412 airfoils, offering stability with moderate sensitivity to angle of attack changes. The moment coefficient of BWB made of fuselage with Mh60 airfoil and outer wing with NACA 6412 airfoil starts positive and gradually becomes negative, with the neutral point occurring at a higher angle of attack compared to the other configurations. This suggests a stable design with a tendency to pitch down at higher angles of attack, providing a delayed but stable response to increasing angles of attack. Therefore, BWB made of whole NACA6412 airfoil offers greater dynamic response and sensitivity. BWB made of whole Mh60 airfoil provides stable and less sensitive characteristics. The mixed airfoil configurations have neutral points at intermediate angles of attack, with the NACA 6412 fuselage/Mh60 wing combination being more responsive. Mixed configurations provide a more gradual change in the moment's coefficient.

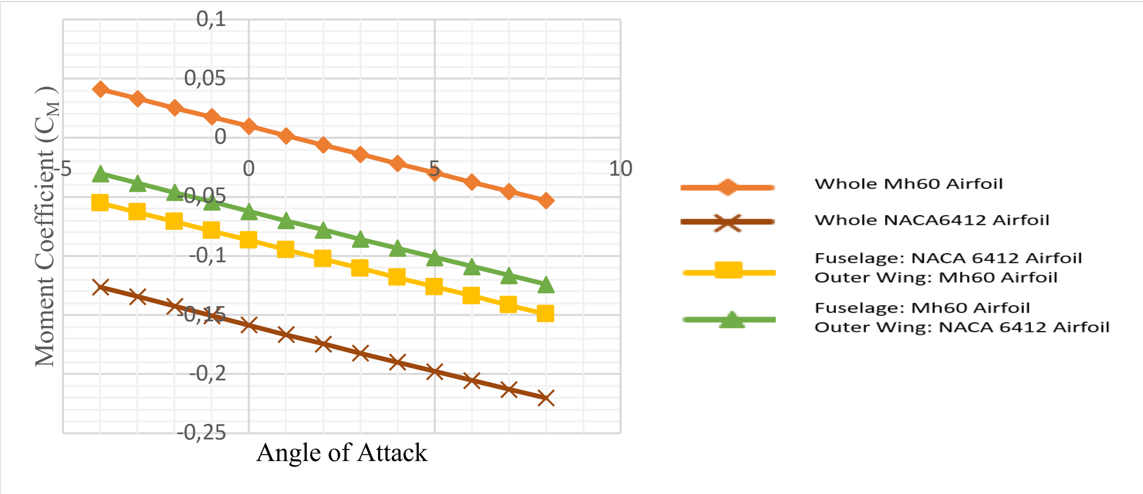

Figure 8. Moment coefficient curve comparison for various BWB designs.

The findings of the study underscore the advantages of employing the MH60 airfoil on the center body and the NACA 6412 airfoil on the outer wing. This configuration not only enhances aerodynamic efficiency, as evidenced by the superior lift-to-drag ratio, but also contributes to minimizing the descent rate and maximizing the endurance factor. The lower pressure coefficient observed across the center body in the MH60-NACA 6412 design indicates reduced drag and improved overall aerodynamic performance. These results confirm the effectiveness of reflex airfoils such as the MH60 in combination with high-lift airfoils like the NACA 6412, highlighting their synergistic impact on the BWB's aerodynamic characteristics.

In terms of accuracy, XFLR5 is based on linear potential flow methods, while CFD includes advanced turbulence and compressibility modeling. In terms of flow condition representation, XFLR5 is limited in handling complex or nonlinear flow scenarios, whereas CFD is excellent at capturing complex aerodynamic interactions and provides higher accuracy in transient and turbulent flow conditions. CFD provides more precise analysis of flow fields and pressure distributions using detailed mesh resolution and boundary layer modeling. The generalizability and validity of XFLR5 analyses are subject to several limitations and constraints. The generalizability of the software is limited by its dependence on linear aerodynamic methods, its limited ability to handle complex geometries, and its inadequate representation of real-world flow conditions. Experimental validation is essential to ensure the accuracy and reliability of computational predictions. This includes wind tunnel testing, full-scale prototype measurements, and experimental data collection under various flight conditions. Such comprehensive validation efforts are crucial to closing the gap between computational predictions and real-world aerodynamic performance.

4.Conclusion

The study focused on the selection of airfoils for the center body and outer wing of the blended wing body (BWB). A medium-altitude, long-endurance (MALE) UAV BWB was designed using the MH60 airfoil with sufficient number of panels in XFLR5 software. Based on considerations of lift-to-drag ratio, minimum rate of descent, and optimal endurance factors, the most efficient aerodynamic configuration was identified as the BWB design featuring an MH60 center body and NACA 6412 outer wing. In the BWB design with the MH60 center body and NACA 6412 outer wing, the maximum lift-drag ratio was recorded at 31.83, achieved at a 4-degree angle of attack, representing an 18% improvement in aerodynamic performance compared to the whole MH60 BWB design. This configuration, utilizing the NACA 6412 airfoil on the outer wing, demonstrated enhanced aerodynamic efficiency. The utilization of a reflex airfoil on the center body combined with a high-lift airfoil on the outer wings emerged as the optimal choice for maximizing aerodynamic performance. The findings of this study hold significant potential to influence the widespread adoption of high-lift wing profiles for the outer wing and low-drag profiles for the main body of BWBs, thereby advancing the field of aerodynamic design in aerospace engineering. In the future, the performance of different airfoil studies will be investigated, which will be verified by CFD and wind tunnel tests. Advanced computational fluid dynamics (CFD) simulations with higher-resolution mesh and more sophisticated turbulence models to capture intricate flow characteristics. Experimental investigations using advanced measurement techniques like particle image velocimetry (PIV) to validate computational predictions. Comparative studies exploring the aerodynamic performance of hybrid airfoil designs that combine characteristics of high-lift and reflex configurations.

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