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Literature Study on Tailless UAV

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Abstract: This literature study examines tailless Unmanned Aerial Vehicles (UAVs), focusing on design, aerodynamics, control systems, materials, and applications. Tailless UAVs present advancements in maneuverability, weight reduction, and simplified design. Challenges in stability and control are addressed through aerodynamic optimization. Control systems integration enhances flight stability and autonomy. Material advancements contribute to structural integrity and weight reduction. Diverse applications include surveillance, agriculture, and environmental monitoring. This study provides insights into tailless UAV research, identifies gaps, and suggests avenues for further exploration.

Keywords: Tailless UAV, Aerodynamics, Control system, Stability.

I. INTRODUCTION

A. Unmanned Aerial Vehicle

Unmanned Aerial Vehicles (UAVs) represent a transformative advancement in aviation technology, offering a myriad of capabilities across various sectors. Also known as drones, these aircraft operate without a human pilot onboard, controlled remotely or autonomously through sophisticated systems. Initially developed for military applications, UAVs have rapidly evolved to serve commercial, scientific, and humanitarian purposes.

One of the most compelling features of UAVs is their versatility. They can be equipped with a wide range of sensors, cameras, and payloads, allowing them to perform tasks such as aerial surveillance, mapping, search and rescue operations, and environmental monitoring. Their ability to access remote or hazardous areas with ease makes them invaluable tools in disaster response efforts and scientific research.

Moreover, the miniaturization of technology and advancements in battery life has significantly expanded the operational capabilities of UAVs. From compact quad copters suitable for indoor reconnaissance to large fixed-wing aircraft capable of long-endurance missions, the UAV market offers a diverse array of platforms tailored to specific needs. As a result, UAVs have found applications across industries including agriculture, infrastructure inspection, filmmaking, and parcel delivery, revolutionizing workflows and unlocking new possibilities in sectors worldwide.

Fig. 1 General Atomics MQ-9 Reaper

B. Tailless UAV

Tailless Unmanned Aerial Vehicles (UAVs) represent a cutting-edge evolution in aerial technology, embodying a departure from conventional aircraft design paradigms. Unlike their traditional counterparts, tailless UAVs forego vertical stabilizers and horizontal tail surfaces, embracing streamlined configurations for improved aerodynamic efficiency and maneuverability. This innovative approach draws inspiration from nature's own aerial experts, such as birds and insects, to create agile and adaptable platforms capable of diverse missions.

The concept of tailless UAVs has gained traction due to their inherent advantages in mobility, agility, and energy efficiency. By eliminating tail structures, these aircraft reduce weight and complexity while enhancing their aerodynamic performance. This streamlined design not only extends flight endurance and range but also enables operations in confined spaces and challenging environments, making tailless UAVs invaluable assets across a spectrum of applications, including surveillance, reconnaissance, environmental monitoring, and disaster response.

As technological advancements continue to drive progress in aerodynamics, materials science, and flight control systems, tailless UAVs are poised to play an increasingly prominent role in the aerospace landscape. From experimental prototypes to commercial solutions, the integration of tailless design principles promises to unlock new frontiers in UAV capabilities, offering unparalleled versatility and efficiency in aerial operations.

Fig 2. Northrop Grumman Bat

Fig 3. DRDO Ghatak

C. Aerodynamics

The aerodynamics of tailless Unmanned Aerial Vehicles (UAVs) represents a fascinating intersection of advanced engineering and biomimicry. Unlike conventional aircraft designs, which rely on separate vertical and horizontal stabilizers for stability and control, tailless UAVs embrace a streamlined configuration devoid of these features. The aerodynamic principles governing the flight of tailless UAVs are intricate and multifaceted, drawing inspiration from the fluid dynamics of natural flyers such as birds and insects. Understanding these aerodynamic phenomena is crucial for optimizing the performance, maneuverability, and efficiency of tailless UAVs in various operational scenarios.

This encompasses a spectrum of challenges and considerations unique to this specialized aircraft configuration. Achieving stable flight without the presence of a traditional tail requires careful attention to factors such as wing plan form, airfoil selection, and control surface placement. Aerodynamic optimization techniques play a pivotal role in tailless UAV design, enabling engineers to minimize drag, maximize lift, and enhance overall flight performance. Moreover, the interaction between aerodynamic forces and control systems is critical for maintaining stability and maneuverability, necessitating advanced flight control algorithms and stability augmentation systems.

As the field continues to advance, researchers are exploring innovative approaches to address key challenges and unlock new capabilities. From computational fluid dynamics (CFD) simulations to wind tunnel testing and flight trials, ongoing research endeavors seek to deepen our understanding of the complex aerodynamic phenomena governing tailless UAV flight. By leveraging insights from nature and harnessing cutting-edge engineering techniques, the quest for optimized tailless UAV aerodynamics promises to yield breakthroughs in agility, endurance, and mission versatility, paving the way for the next generation of unmanned aerial systems.

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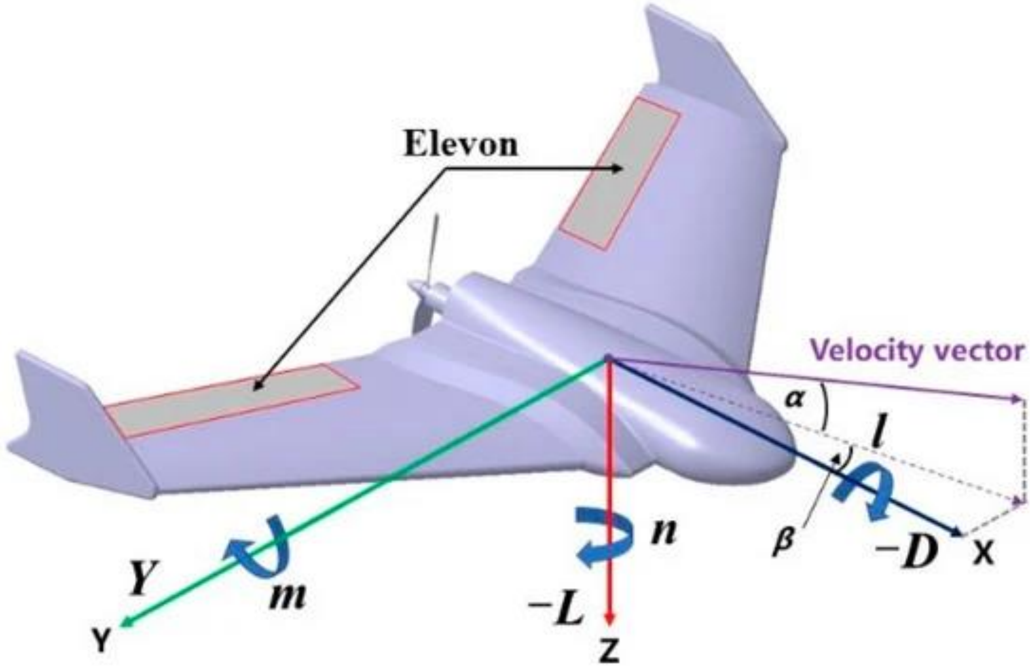

Fig 4.

Aerodynamic forces on tailless UAV

D. Design concepts for Tailless UAV

Tailless aircraft have been inspired by a variety of flying seeds and animals. From Zanonia seeds to Pterosaurs and modern birds that fly well with little or no tails, Tailless UAVs rely on a range of innovative design concepts to achieve stability, maneuverability, and efficiency. Following are few distinct design approaches commonly employed in tailless UAVs:

1. Delta Wing Configuration: Delta wing configurations are popular in tailless UAV design due to their inherent stability and simplicity. The triangular shape of the delta wing provides a large surface area for lift generation while minimizing drag. This design often integrates control surfaces like elevons or flaperons at the wingtips, enabling both pitch and roll control. Delta-winged UAVs excel in high-speed flight and agile maneuvering, making them suitable for reconnaissance missions and aerial surveillance.

2. Flying Wing Design: Flying wing designs represent a radical departure from conventional aircraft configurations, eliminating the distinct fuselage and tail altogether. These UAVs feature a blended wing-body design where the entire airframe serves as a lifting surface. Flying wings leverage advanced aerodynamics to achieve stability through careful wing shaping, winglet placement, and control surface optimization. By distributing control surfaces along the wing's trailing edge, flying wings can achieve precise control over pitch, roll, and yaw, making them ideal for long-endurance missions such as aerial mapping and environmental monitoring.

3. Swept Wing Configurations: Swept-wing configurations feature wings angled backward, reducing aerodynamic drag and enhancing high-speed performance. Tailless UAVs with swept wings benefit from reduced wingtip vortices and improved lift-to-drag ratios, enabling faster speeds and increased efficiency. Swept-wing designs often incorporate leading-edge extensions (LEX) to mitigate stall tendencies and enhance low-speed handling characteristics. These UAVs are well-suited for reconnaissance, target acquisition, and tactical surveillance missions where speed and agility are paramount.

4. Variable Geometry Wings: Variable geometry wings offer the flexibility to adapt to different flight regimes, transitioning between configurations optimized for low-speed loitering and high-speed dash maneuvers. Tailless UAVs equipped with variable geometry wings can alter their wing sweep angle or aspect ratio in-flight, optimizing aerodynamic performance based on mission requirements. This versatility enables seamless transitions between endurance-focused tasks like persistent surveillance and dynamic missions requiring rapid response capabilities.

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5. Blended Body-Wing Designs: Blended body-wing designs seamlessly integrate the fuselage with the wing, creating a unified aerodynamic structure that enhances lift generation and stability. These UAVs feature a smooth transition between the body and wing, reducing drag and improving overall aerodynamic efficiency. Blended body-wing configurations often incorporate advanced control surfaces and distributed propulsion systems for precise control and enhanced maneuverability. This design concept is well-suited for multi-role UAVs capable of performing diverse missions, including intelligence gathering, communications relay, and cargo transport.

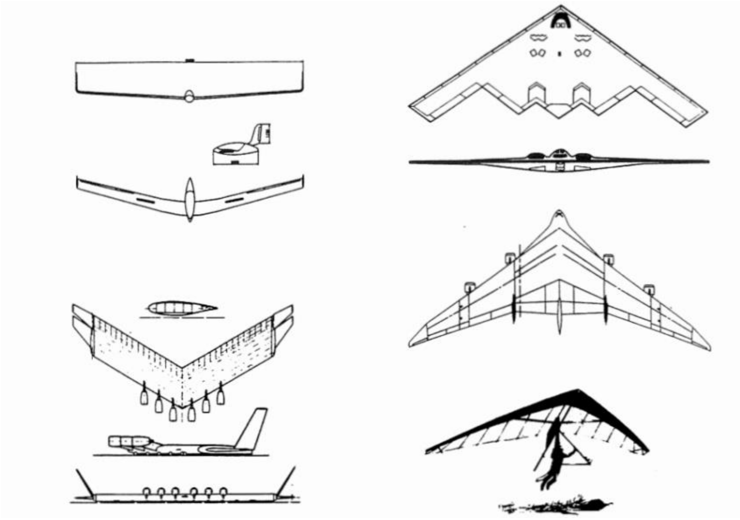

Fig 5. Design concepts for Tailless UAV

II. LITERATURE REVIEW

A. An Investigation into the aerodynamic efficiency of Tailless Aircraft by Aliya Valiyff [The university of Adelaide, Adelaide, South Australia,5005], Maziar Arjomandi [The university of Adelaide, Adelaide, South Australia,5005]

The paper discusses the aerodynamic efficiency of tailless aircraft and the use of active control systems. It highlights that the efficiency of tailless configurations is often attributed to the reduced surface area, leading to drag reductions. However, without active control, the expected aerodynamic efficiency gains may be negated by design compromises required for stability and control. The high magnitude of washout required for stability dictates the lift distribution, leading to increased induced drag. The paper proposes the use of all moving wing tips as a favorable configuration for tailless aircraft without active control. It also emphasizes the need for further theoretical and experimental investigations to optimize lift distribution and increase efficiency. The limitations of empirical methods for estimating twist angle and the effects on drag are also discussed.

To increase the efficiency of tailless aircraft, the following techniques are used:

1. Active Control Systems: Tailless aircraft rely on active control systems to achieve aerodynamic efficiency. These systems help in stabilizing the aircraft and optimizing its performance.
2. Wing Twist: Tailless aircraft use wing twist to alter the lift distribution along the span of the wing. This technique helps in achieving longitudinal stability and reducing induced drag.
3. All Moving Wing Tips: The use of all moving wing tips can optimize the lift distribution and lead to increased efficiency, especially in applications where the use of active control systems is not viable.
4. Aerodynamic Design: Tailless aircraft are designed with specific aerodynamic features such as reflex camber for low aspect ratio wings and the combined effects of sweep and twist for high aspect ratio planforms to achieve longitudinal stability and efficiency.

These techniques are aimed at addressing the challenges associated with tailless aircraft design and improving their overall aerodynamic efficiency.

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The combination of high wing loading and low power loading nature of the design required an airfoil with high lifting capacity with neutral or positive moment coefficient for stability. The reflex airfoils available could not provide the lift required and thus a slightly cambered airfoil with positive moment coefficient was used. Due to the steep lift curve slope of the aerofoil (MH78), the angle of attack of the root section of the wing was in the order of six degrees. By extending the analysis for a wide range of area ratios (wing tip and root section) and sweep angle, the optimum area ratio and sweep angle resulting in the minimum angle of attack of the wing root and tip sections, were derived. This resulted in the required twist of approximately six degrees and therefore an incidence angle of 12 degrees for the wing root.

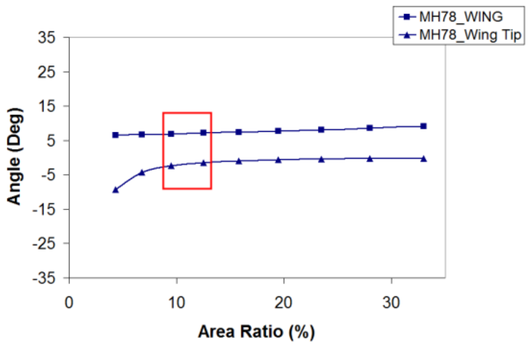

Fig 6.Incidence angle - Cruise

The aerodynamic efficiency of tailless aircraft is often claimed to be high in comparison to the conventional configuration. This belief is usually based upon the supposition that the reduced wetted surface area provided by the tailless a configuration directly leads to reductions in drag. However, without the use of active control system, the large magnitudes of twist required to stabilize the aircraft means that most of the wing section is operated at lift coefficient values above or below the desired lift coefficient, negating the affects of the above mentioned benefits.

B. Drag reduction methodology for adaptive tailless aircraft by Aaron A. Cusher [North Carolina State University, Rayleigh, North Carolina], Ashok Gopalarathnam [North Carolina State University, Rayleigh, North Carolina]

The review of “Drag Reduction Methodology for Adaptive Tailless Aircraft” discusses drag reduction schemes for cambered airfoils, focusing on the minimization of induced drag through the use of variable camber. It explores the use of multiple schemes and their impact on span efficiency, induced drag, profile drag, and total drag. The study also delves into the optimization of variable camber to achieve minimum drag. Additionally, it covers the computation of the D matrix using wing analysis methods and addresses the relative minima of multivariable functions with constraints. The findings provide valuable insights into drag reduction techniques for airfoils.

The main objective of the study presented in the document is to demonstrate drag reduction schemes for a hypothetical tailless aircraft. The study aims to optimize the flap angles of the aircraft in order to minimize total drag, with a focus on reducing induced drag and profile drag. The research also involves testing different drag reduction schemes and analyzing their effectiveness in achieving the objective of minimizing total drag while considering induced and profile drag components.

The method proposed for solving the optimal scheduling of the flaps for various flight conditions involves using multiple trailing-edge flaps to optimally distribute the lift of the wing in order to minimize drag. The approach uses superposition to construct the span wise lift distribution from basic and additional loadings, and decomposes the flap-angle distribution into mean and variation distributions. This enables the solution of the problem using semi-analytical methods that also provide insight. The study implements a numerical approach to determine the optimal lift distributions for adaptive tailless aircraft, taking into account the pitching-moment constraint to reduce both induced and profile drag.

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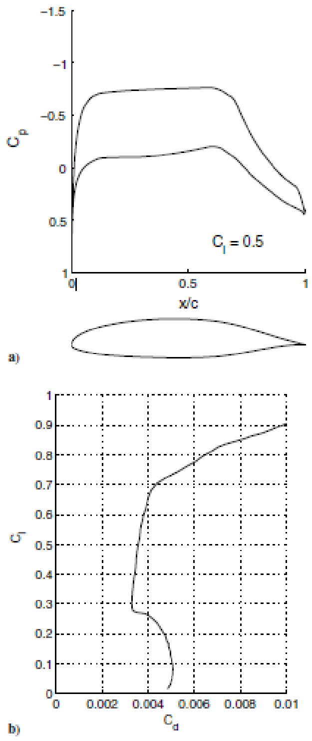

Fig 7. Airfoil A (cambered):
a) geometry and C_p distribution
b) drag polar at Re= $3x10^6$

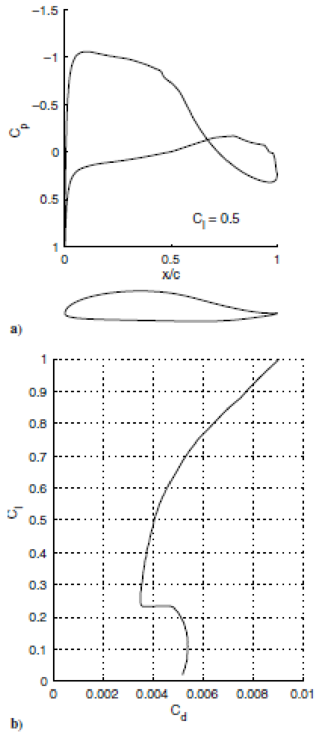

Fig 8. Airfoil B (reflexed):
a) geometry and C_p distribution
b) drag polar at Re = $3x10^6$

In this study two types of airfoils were tested: a cambered NLF airfoil (Airfoil A) and a reflexed NLF airfoil (Airfoil B). Airfoil A has a zero-lift pitching-moment coefficient Cm0 of -0.0802, while Airfoil B has a positive Cm0 value of 0.0562. Both airfoils were created using the multipoint inverse airfoil design method PROFOIL.
The results of the study included the properties of these airfoils as predicted by XFOIL, calculated at a Reynolds number of three million, as well as their corresponding geometries. The study also presented the total drag predictions for each drag reduction scheme along with their induced and profile components for a range of CL values for the cambered airfoil case.

The final results of the study indicated that the drag reduction schemes had varying impacts on induced and profile drag. Scheme A focused on reducing induced drag and was successful in doing so, achieving a span efficiency of 1. However, it incurred penalties in profile drag. Scheme B, on the other hand, successfully reduced profile drag but suffered in terms of induced drag. Scheme C optimized the flap angles to achieve a balance between the drag components, resulting in total drag reduction. The study provided insights into the trade-offs between induced and profile drag reduction, highlighting the need to find a balance between the two for overall drag reduction.

C. Integrated Aerodynamics and Control System Design for Tailless Aircraft by S J Morris [Stanford University, Stanford, CA]

The paper presents a numerical method for the simultaneous design of an aircraft and its feedback control system to minimize drag while maintaining a fixed level of handling qualities. The approach uses nonlinear optimization to optimize both the aircraft configuration and the control gains to minimize a composite performance index consisting of trimmed drag and handling qualities measure. The study focuses on tailless aircraft and considers designs with and without stability augmentation to assess the impact of active control on reduced trimmed drag. The results show that designs with stability augmentation demonstrate a significant reduction in drag over unaugmented designs, with the optimal configuration utilizing generous wing sweep and low taper ratio to achieve low trimmed drag.

The study reveals that tailless designs without stability augmentation favor small amounts of static pitch instability and unstable spiral mode to improve pilot-in-the-loop phugoid damping and roll rate. On the other hand, designs with

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stability augmentation exhibit improved roll performance and phugoid damping due to the presence of active control. The proposed approach offers a general method for considering arbitrary configurations and has the potential for extension to synthesize various aircraft types, such as aft tail, canard, etc. The study identifies the challenges and trade-offs involved in achieving good handling qualities while minimizing trimmed drag, providing insights into the integrated design technique for tailless aircraft.

The proposed method for simultaneously synthesizing an aircraft and its control system for minimum trimmed drag with a fixed level of handling qualities utilizes a numerical optimization approach. It involves reconfiguring the aircraft and selecting control gains to minimize a composite performance index consisting of trimmed drag and a handling qualities measure, evaluated at various flight conditions. The method employs a nonlinear optimization scheme to determine the aircraft configuration variables and control gains that minimize a weighted composite performance index, which includes dynamic performance, trimmed drag, and penalty functions.

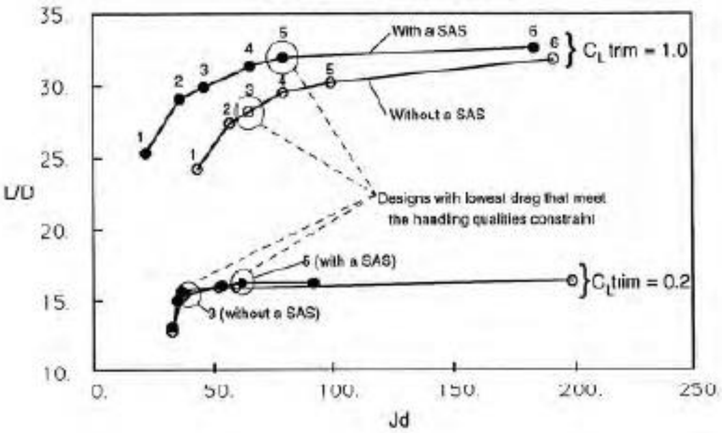

Fig 9. Trade-off between trimmed drag and handling qualities for the optimized tailless aircraft

The dynamic performance is based on a model-following error, and the trimmed drag is a weighted sum of the aircraft's drag coefficient at the specified flight conditions. Penalty functions are used to enforce constraints on the size of design variables, dynamic stability, and aircraft trim at specified flight conditions. The approach allows for the consideration of cases with and without feedback control systems, enabling the assessment of the impact of active control on reduced trimmed drag. The method also includes detailed drag estimation and the possibility of linear feedback control systems of arbitrary architecture.

The results obtained from the study indicate that tailless aircraft designs with stability augmentation systems (SAS) demonstrate a significant reduction in drag compared to unaugmented designs. The optimal configuration for reduced trimmed drag involves generous wing sweep and low taper ratio.

D. An Aerodynamic Design Method to Improve the High Speed Performance of a Low Aspect Ratio Tailless Aircraft by Zhongyuan Liu [School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China], Binqian Zhang [School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China], Lie Luo [The First Aircraft Institute of AVIC, Xi'an 710089, China]

The paper discusses an aerodynamic design method to enhance the high-speed performance of a low-aspect-ratio tailless aircraft. It emphasizes the importance of improving the aerodynamic and longitudinal moment characteristics of the aircraft. The study analyzes the effects of twisting the wing and designing key section airfoils on the aerodynamic performance. It is found that these design modifications can improve the longitudinal moment characteristics, with aft-reflexing being more efficient than fore-loading at tip and kink airfoils. The study also addresses the constraints and requirements for the aerodynamic design of the low-aspect-ratio tailless configuration, considering factors such as lift-to-drag ratio, zero-lift pitching moment, and cruising design lift coefficient.

Twisting the wing, fore-loading, and aft-reflexing key section airfoils have a significant impact on the high-speed aerodynamic performance of the configuration. Twisting the wing clockwise can improve the stall characteristics of the aircraft, but the twist angle should not be too large to avoid increasing structural and manufacturing difficulties. Fore-loading and aft-reflexing the key section airfoils can improve the longitudinal moment characteristics of the aircraft. Aft-reflexing is found to be more efficient than fore-loading at the tip and kink airfoils. However, twisting the

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wing clockwise has an adverse influence on the lift-to-drag ratio.

The design and collocation methods of key section airfoils for the low-aspect-ratio tailless configuration can be obtained based on the study, considering the constraints of geometry. The aft-reflexing design of the airfoil has a significant influence on the longitudinal moment of the aircraft, providing an optimal nose-up moment while having a negligible influence on the lift-to-drag ratio. Additionally, fore-loading and aft-reflexing airfoils at the kink section can increase the nose-up moment and improve the longitudinal performance.

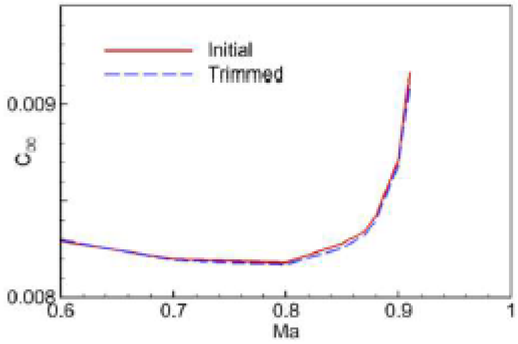

Fig 10. The drag divergence characteristics of the initial and final trimmed configuration

The final results obtained from the study include the aerodynamic performance analysis of the initial configuration, the grid convergence study, and the assessment of the trimmed configuration. The aerodynamic performance analysis of the initial configuration revealed poor longitudinal pitching characteristics, necessitating aerodynamic design with the constraint of longitudinal trim. The study also verified the trimmed configuration through wind tunnel experiments and numerical simulations, showing that the trimmed configuration achieved lower zero-lift pitching moment, higher available lift-to-drag ratio, and better drags divergence characteristics.

E. Lateral Stability and Control of Tailless Aircraft by Gloria Stenfelt [Royal Institute of Technology, Stockholm, Sweden], Ulf Ringertz [Royal Institute of Technology, Stockholm, Sweden]

The paper investigates the lateral stability and control of a tailless aircraft configuration, with a focus on reducing radar signature in military aircraft. The study uses low-speed wind tunnel testing to examine the aerodynamics of a specific aircraft configuration known as Swing. The configuration features two trailing-edge flaps on each wing that are used for control around all three stability axes: pitch, roll, and yaw.

The results of the study confirm that controlling a reduced radar signature aircraft, such as the one tested, can be quite challenging. The focus of the study is on yaw control using differential flaps, but it is noted that the four flaps on the aircraft are also needed for pitch and roll control. The paper highlights the difficulties associated with low-speed flight, particularly during approach and takeoff, where control surface authority is limited. Additionally, the aircraft's sensitivity to gusts and crosswind during takeoff and landing is discussed.

The study also delves into the modeling of lateral aerodynamics, noting that a linear model is adequate for modeling the effect of sideslip on yaw moment, roll moment, and side force. However, a nonlinear model is required for the influence of a split flap command on the yaw moment. The paper concludes by emphasizing the challenges in control system design for such aircraft configurations, particularly in low-speed flight conditions.

The results obtained from the low-speed wind tunnel testing of the Swing aircraft configuration in relation to lateral stability and control indicated that control of a reduced radar signature aircraft may be quite challenging. The focus was on yaw control using differential flaps, and it was found that there are two very different flap settings that give the same yaw moment, one better at low angle of attack and the other better at high angle of attack.

III. CONCLUSION

Tailless UAVs illuminates a dynamic landscape of innovation, where engineering ingenuity and aerodynamic principles converge to redefine the possibilities of unmanned aerial technology. Through a synthesis of diverse design concepts, ranging from swept wings and control surfaces to advanced propulsion systems and autonomous flight control, researchers and engineers continue to push the boundaries of performance, efficiency, and mission adaptability in tailless UAV development. The exploration of tailless UAV design concepts underscores the interdisciplinary nature of this field, where aerodynamics, structural engineering, materials science, and robotics intersect to address the unique challenges posed by the absence of a traditional tail section. From blended wing-body

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configurations to wing morphing technologies, each design concept offers distinct advantages in terms of aerodynamic efficiency, stability, and maneuverability, catering to a diverse array of mission requirements and operational environments.

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