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Flow Investigation over Oblique Wing Configuration

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Abstract- This paper discusses the aerodynamic performance of oblique wing configuration in transonic and supersonic flight regimes. By using CFD tools within the ANSYS, the research has explored the function of oblique wing towards wave drag reduction and efficiency enhancement. Pivot angle variations of 0°, 30°, 45°, and 60° were used in asymmetrically designed wing and analysed at Mach 0.9 and 1.2. Some critical parameters include CL, CD, and pressure distribution, through which the design attains optimum operating characteristics. Some results reveal wave drag at specific pivot angles with the oblique wing. As the wave drags show least values for specific pivot angles (30°: Mach 0.9; 45°: Mach 1.2), these result in great applicability in improved aerodynamic efficiency and adaptability in varied conditions of flight towards the further developments of high-speed aircraft technology.

Index Terms- Oblique wing, Elliptical wing, CFD analysis, Transonic and supersonic regimes

I. INTRODUCTION

Oblique wing configurations were first proposed by R.T. Jones in 1958 and have since attracted attention for the possibility of improving aerodynamic efficiency at transonic and low supersonic speeds. In contrast to the traditional wing design, oblique wings pivot asymmetrically, with one wing swept forward and the other swept backward. This reduces wave drag, a primary source of aerodynamic inefficiency at higher speeds, and enhances performance across varied flight conditions. The regime of transonic speeds,

Mach 0.8 to 1.2, is complicated by shock waves and boundary layer interactions that dramatically affect lift, drag, and stability. Traditional wing geometries often suffer from higher drag and reduced efficiency at transonic speeds. The oblique wing has addressed these problems by optimizing the sweep angle, thereby reducing the intensity of shock waves and improving lift-to-drag ratios. The current study is about the aerodynamic performance of oblique wings by using computational tools. The current work aims to explore the advantages of this new wing configuration based on various parameters, such as pivot angles, angle of attack, and Mach numbers. With the integration of modern computational methods, such as ANSYS Fluent, detailed flow behaviour simulations are possible, including lift, drag, and pressure distribution. These analyses suggest the possibility of oblique wing designs for future high-speed aircraft, offering a promise of efficiency, performance, and sustainability. As the field of aviation advances, so too does the quest for the discovery of more advanced wing geometries, including oblique wings. The design offers an optimal opportunity for achieving the performance characteristics required at transonic and supersonic speeds to provide a route toward efficient, versatile, and sustainable aircraft technologies.

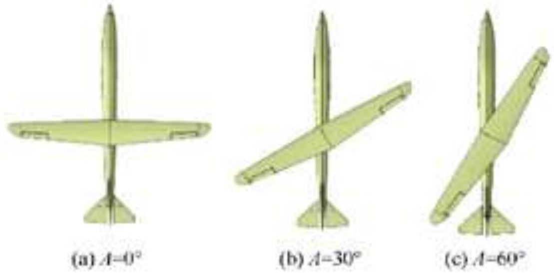
(a) Λ=0° (b) Λ=30° (c) Λ=60°

Figure.1 Oblique wing research aircraft. [5]

The experiments conducted by Robert T. Jones at Ames Research center, NASA. at transonic speeds a conventional "subsonic" wing turned at an oblique angle to the flow has demonstrated lift-drag ratios higher than conventional swept-back or delta wings. When returned to its straight position, perpendicular to the flow, such a wing would minimize the display of energy and noise in the airport environment. Following a brief review of theoretical and experimental results, the paper discusses various characteristics of the oblique wing as they relate to aircraft design. Topics covered are lift-drag ratio, flight control and trim and aeroelastic stability The possibility of an all-wing aircraft for flight at Mach 2 is suggested [1].

A comprehensive study was conducted Musdhfiqul Alam and Kashyapa Narenathreyas their result shows that oblique wing concept with elliptical wing platform offers a significant reduction in drag at transonic and supersonic speeds and approximately twice the lift distribution compared to conventional operating aircrafts. The paper also presents a preliminary conceptual aircraft sizing which can be used for further experimental analysis [2].

Research conducted by A.V.Panina, A.D. Kosinov, N.V. Semionov and Yu.G. Yermolaev Presented herein are the results of an experimental study of the controlled pulsations development in the spanwise modulated boundary layer of a swept wing. The experiments were done at Mach 2 and unit Reynolds number Re1 = 6×106 m−1. Square stickers were used to induce the mean flow to spanwise modulation in the boundary layer. It was found that the presence of roughness leads to a reduction of the source efficiency of the disturbance at the subharmonic and fundamental frequency, while the oblique breakdown mechanism begins to appear at smaller values of the longitudinal coordinate x in comparison with the smooth wing case [3].

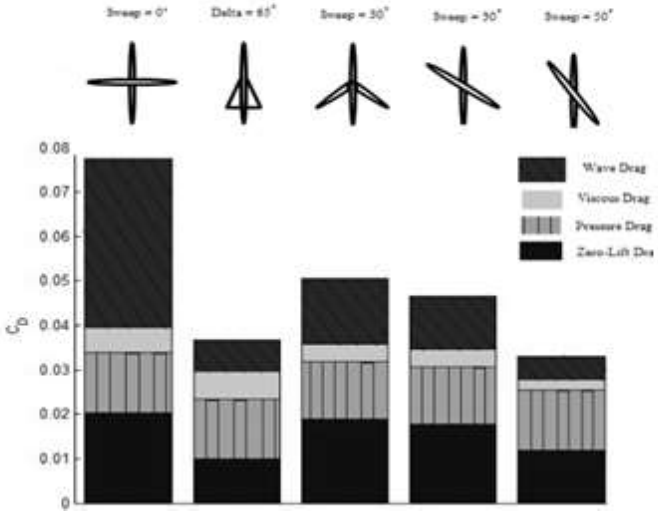

Figure.2 Drag coefficient at Mach 0.9 for different wing-body combination. [2]

Dr.Vinayaka, Akshaya, Raveena, Praveen Kumar and Marulasiddeshi conducted an comprehensive study on the formation of shock wave and its studies is a research field for many aerodynamicists. This work of research linchpins on effect of turbulence intensity on airfoil in transonic regime at various angle of attacks (AoA).

A supercritical airfoil is computationally tested at 2% and 10% turbulence intensity levels, Mach0.8 and Mach 0.9 at 00 and 50 AoA. Computational Fluid Dynamics method is Airfoil coordinates were imported from airfoil tools. The built airfoil inside a control volume is discretized (meshed) using CFD. A consistent structured mesh is built around the airfoil. Simulation of model is carried out using Ansys Fluent solver. Simulations were done at specific boundary conditions till the solutions were converged. The research revealed that, increment in turbulence intensity leads to the decrement of coefficient of lift (CL). As the Mach number is increased to 0.9, CL decreases.

The position of shock wave moves away from the LE as the turbulence intensity increases. Flow separation is found to occur at 50 AoA at Mach 0.8. There is no occurrence of flow separation at Mach 0.9. The variation in turbulence intensity effected the position of shock wave [4].

This study investigates the flow over oblique wing at transonic regimes using CFD stimulation to analyse the lift-coefficient (CL), drag- coefficient (CD) and lift to drag ratio (CL/CD) at various angles of attack (00, 30,60,90) and various pivot angles (00,300,450,600) to analyse the performance and aerodynamic behaviour of the oblique wing at transonic and low supersonic speeds.

II. METHODOLOGY

CATIA V5, developed by Dassault Systems, is a leading 3D computer aided design (CAD) software, extensively utilized across industries such as aerospace, automotive, and industrial machinery. The oblique wing has been designed using CATIA V5 software with the following specifications.

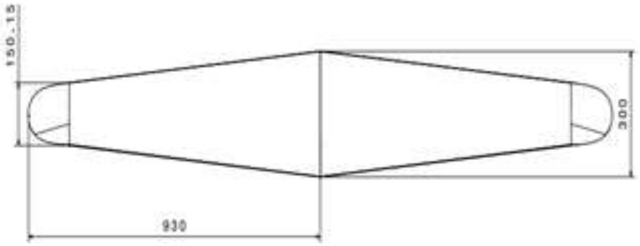

Figure.3 Dimensions of wing

1. Design

The wing has designed with span of 0.930m, root chord of the wing with 0.3m and tip chord of 0.15m. The has total surface area of 0.4376m2 with an aspect ratio of 3.94. The super critical airfoil SC (2) 0406 has used as the root chord of the wing and NACA 0012 a symmetrical airfoil as used as the tip chord of 0.15m.

Table 1 Specifications of wing

Specification	Value
S	0.43765m^2
AR	3.94
ROOT CHORD	0.3m
SPAN	1.86m

Figure.4 oblique wing changing its pivot angles (top view)

2. Boundary Conditions

In order to insert boundary condition first select domain for options select insert and boundary and enter the following conditions. The images below show the setup of the computational domain for the analysis of airflow over an oblique wing in ANSYS. The domain is bounded by defined inlet, outlet, and far-field boundaries. The inlet boundary (Figures 5 and 6) shows airflow entering the domain, with the oblique wing centrally positioned to interact with the flow. The far-field boundary (Figure 7) encompasses the domain, representing the infinite space around the wing. It is depicted as a big, arc-shaped surface which would ensure proper flow simulation without any boundary reflections. It focuses on critical aerodynamic phenomena like shock waves and pressure distribution for the transonic analysis.

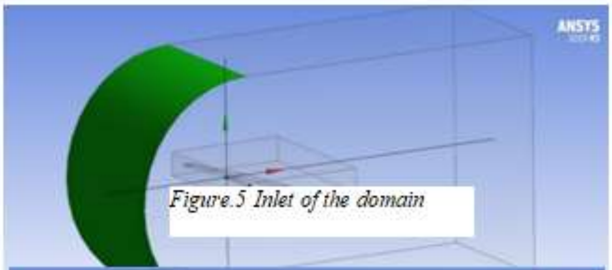

Figure.5 Inlet of the domain

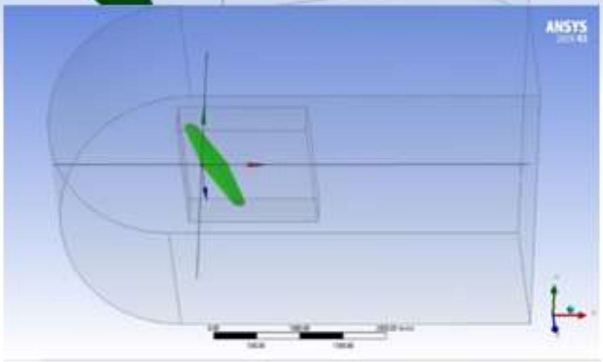

Figure.6 wing in the domain

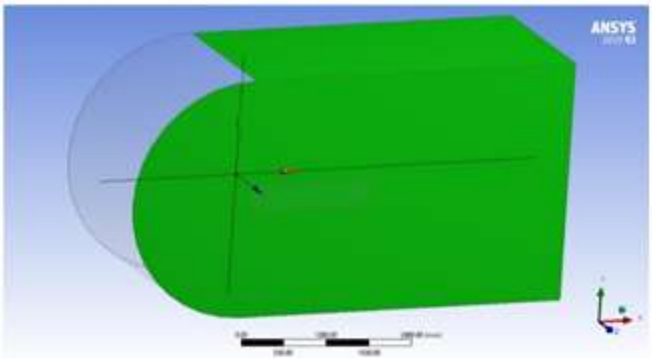

Figure.7 Far field of the domain

Discretization

Discretizing control volumes in CFD is a crucial step in converting the continuous governing equations of fluid flow into a solvable system of algebraic equations. This procedure involves splitting the computational domain into smaller, finite volumes or parts, allowing numerical solutions to the equations that govern fluid dynamics. Mesh quality plays a critical role in CFD analysis and represents an important area for the determination of accurate simulation results. This is because mesh quality affects numerical methods capabilities to accurately represent the physics of fluid flow.

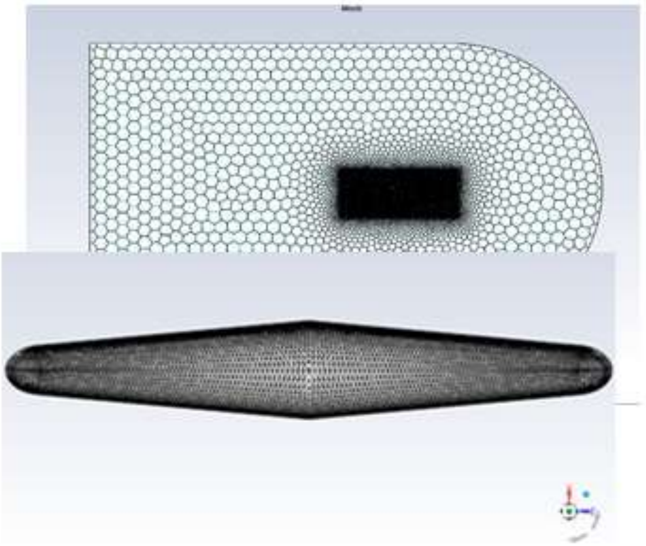

Figure.8 The fluid C-domains with poly hexacore

Analysis Method

In order to analyse the program ANSYS CFD is used. Firstly, Mesh has to be imported from CFD which has been saved earlier to do so select file then new case, general, mesh and last select import mesh (CFD). Once the program has been imported stimulation has to be done to do so select flow analysis, insert, domain and lastly Domain j. the program has to undergo some basic setting such as:

- Location: - Wing

- Fluid: - Air
- Turbulence: K-Omega-SST
- Mach- 0.9 and 1.2

III. RESULTS

The oblique wing has been examined in transonic regimes where CL and CD values are obtained, at Mach 0.9 and 1.2 at angles of attack 0o, 3o, 6o, and 9o. These values provide insights into the aerodynamic performance of the oblique wing, highlighting the variations in lift and drag coefficients as the angle of attack increases within these Mach numbers. Further analysis of these results can inform design improvements for high-speed aircraft operating in similar conditions. Additionally, understanding the behaviour of the oblique wing in transonic flow can aid in optimizing configurations that maximize efficiency and stability. By correlating these aerodynamic characteristics with real-world flight data, engineers can develop more effective flight control systems tailored for high-performance aircraft.

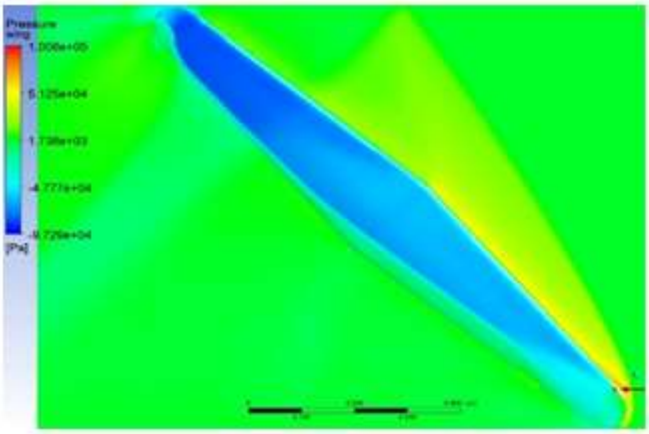

Figure.9 Mesh on the wing

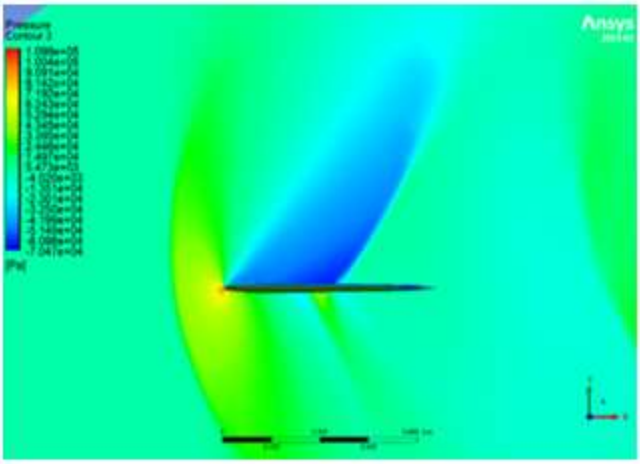

Figure 10 pressure contour at Mach 1.2, AoA 9o and pivot 30o

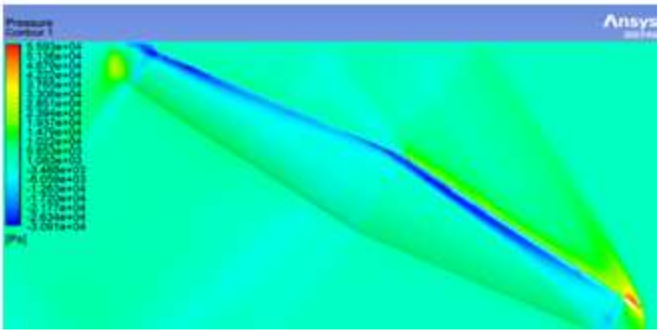

Figure 11` Pressure contour over the wing at Mach 1.2, pivot 45o and AoA 9o (top view)

The CL value of the oblique wing has a graph as plotted and compared to the traditional configurations. This comparison highlights the aerodynamic advantages and performance enhancements offered by the oblique wing design, particularly in terms of lift and drag characteristics during various flight conditions. This comparison concludes that CL graph at pivot 30o have high CL values compared to pivot 0o and 60o. Lift to drag ratio of the oblique wing at the pivot 30o is high when compared to other pivot angles.

A critical performance comparison from the curves of CL versus angle of attack (α) and the ratios CL/CD of the oblique wing for pivot angles 0∘, 30∘, 45∘, and 60∘ at Mach 0.9 and Mach 1.2 is evident. At Mach 0.9, it is observed that with an increase in angle of attack, lift coefficient CL increases across all pivot angles. However, theslope of CL is maximum at 30∘ and 45∘, indicating that lift generation is maximum in these configurations. On the other hand, the CL at 60∘ has a decreased rate of increase, indicating that aerodynamic efficiency degrades at higher pivot angles. This trend is consistent with the CL/CD ratios, which peak significantly at 45∘ and 30∘, with values reaching 140.05 and 58.63, respectively, at 9∘ angle of attack. However, the CL/CD decreases precipitously to 60∘ and shows major drag penalties.

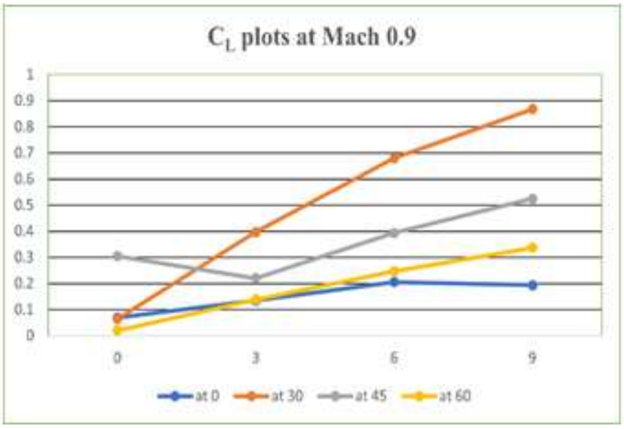

Figure.12 Comparison of CL Vs α curves at Mach 0.9

At Mach 1.2, a crossing of the compressibility drag curve has taken place. Though CL still increases with αα, the magnitude is much smaller than for the subsonic conditions; this only reflects the influence of compressibility and shock waves at supersonic velocities. The trends are otherwise consistent, but the values of CL/CD at Mach 1.2 are much smaller than those at Mach 0.9 for any pivot angle. The pivot angle of 45∘ achieves the highest CL/CD ratio (8.298 at 9∘), demonstrating superior aerodynamic performance in balancing lift and drag at supersonic speeds.

In summary, the oblique wing presents an optimal aerodynamic performance at pivot angles of 30∘ and 45∘. Mach 0.9 conditions are more favorable to higher lift-to-drag efficiency. These results give a great insight into the design and operating envelope of oblique wings in transonic and supersonic applications, where pivot angle is of utmost importance for determining aerodynamic performance.

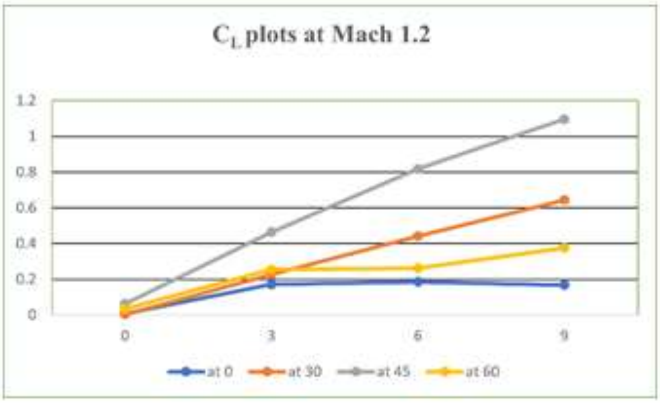

Figure.13 Pressure contour over the wing at Mach 1.2, pivot 60o and AoA 3o (top view)

Lift Coefficient (CL) Behavior at Mach 0.9:

Trend Across Pivot Angles

- At 0° pivot angle, CL values are consistently low at all angles of attack, showing that lift generation is minimal as the aerodynamic advantage is limited.
- At 30° pivot angle, there is a tremendous increase in CL, and the rise steepens with the angle of attack, showing efficient lift production.
- CL at 45° pivot angle: moderate, positive and linear with α angle
- The balanced performance of CL values indicates balanced performance at the angle of attack.
- Lift generation at 60° pivot angle is weaker compared to 30° but is higher than at 0°. Aerodynamic efficiency has degraded because drag penalties are more considerable.

Influence of Angle of Attack

- For all pivot angles, the CL increases with the angle of attack, showing a direct relationship between lift and angle of attack at subsonic speeds (Mach 0.9).
- Maximum lift is realized at 30° pivot angle and higher angles of attack, aligning the wing's aerodynamic profile for optimal lift

Table.5 CL to CD ratio at pivot 60o

Angles of attack	Mach 0.9				Mach 1.2			
	0°	3°	6°	9°	0°	3°	6°	9°
C_L/C_D	3.19	4.54	5.34	8.29	0.01	2.22	4.33	2.53

Angles of attack	Mach 0.9				Mach 1.2			
	0°	3°	6°	9°	0°	3°	6°	9°
C_L/C_D	1.69	31.53	44.19	58.63	0.06	3.47	6.88	10.49

Angles of attack	Mach 0.9				Mach 1.2			
	0°	3°	6°	9°	0°	3°	6°	9°
C_L/C_D	2.458	27.26	117.7	140.05	3.192	4.548	5.317	8.298

Angles of attack	Mach 0.9				Mach 1.2			
	0°	3°	6°	9°	0°	3°	6°	9°
C_L/C_D	2.45	25.94	-485.06	-197.12	2.08	21.35	87.08	143.91

Lift Coefficient (CL) Behavior at Mach 1.2:

Trend Across Pivot Angles

- At 0° pivot angle, the lift is still relatively low, much like in the Mach 0.9 case, since the oblique wing contribution is still relatively low at this configuration.
- At 30° pivot angle, the CL is improved substantially but less than that of Mach 0.9. This would indicate lower aerodynamic efficiency at higher speeds.
- At 45° pivot angle, the CL values are the highest of all the pivot angles. This configuration is optimized for high-speed conditions to allow maximum lift production at higher angles of attack.

- At 60° pivot angle, the CL values have a steady increase, showing good performance in supersonic conditions

Angle of Attack Influence
Like Mach 0.9, the CL increases with the angle of attack for all pivot angles, but for higher pivot angles and especially at 45° there is steeper growth to their peak, which illustrates its efficiency especially at Mach 1.2

IV. CONCLUSION

A comprehensive analysis was performed to study the behavior of flow over the oblique wing with different pivot angle in the transonic regime. Computational Fluid Dynamics Simulations were performed at various boundary conditions to anticipate oblique wing and shock wave behavior. The conclusions derived from the a forementioned case Studies are provided below. The oblique wing configuration demonstrates excellent adaptability to different flight regimes.

For Subsonic Speeds (Mach 0.9)
The optimal pivot angle is 30°, which provides the highest lift for increasing angles of attack. Higher pivot angles (e.g., 60°) are less efficient, likely due to drag penalties outweighing lift benefits at lower speeds.

For Supersonic Speeds (Mach 1.2)
The optimal pivot angle shifts to 45°, where lift generation is maximized, showing the wing's ability to adapt to high-speed conditions. Lower pivot angles (e.g., 30°) remain effective but less optimal compared to the high pivot angle.

Overall Aerodynamic Efficiency
The oblique wing design allows for dynamic adjustment of pivot angles to optimize aerodynamic performance across a wide range of speeds and angles of attack. The shift in optimal performance from 30° at subsonic speeds to 45° at supersonic speeds highlights the versatility and efficiency of this wing design in different flight regimes.

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