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Research Article

Design And CFD Analysis of Supercritical Airfoil 0714 Under Ground-Level Atmospheric Conditions

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ABSTRACT

This research focuses on analysing the fluid dynamics of flow separation over the supercritical airfoil NACA SC(2)-0714 at various angles of attack using ANSYS Fluent simulations. The performance of the airfoil is examined under subsonic conditions at a Mach number of 0.2 and a Reynolds number of 3.5×10^6, with angles of attack set at 0°, 4°, 6°, 8°, 11°, 15°, and 17°. Key aerodynamic parameters, including lift coefficient and drag coefficient, are evaluated across this range of angles.

The findings indicate that with an increase in the angle of attack, factors such as maximum pressure and maximum velocity also increase, accompanied by a rise in flow separation. The optimal aerodynamic efficiency, represented by the highest lift-to-drag ratio, is observed at an 11° angle of attack, where the airfoil achieves peak performance before significant flow separation occurs.

This study offers valuable insights into the behaviour of supercritical airfoils operating in low subsonic conditions, providing a deeper understanding of how angle of attack influences aerodynamic forces and flow separation dynamics. The results contribute to the optimization of airfoil designs for aeronautical applications, enhancing their efficiency and performance under similar operational conditions.

Keywords- ANSYS; supercritical airfoil NACA SC (2)-0714; shockwave; divergentAngle.

Introduction

Aerodynamic advancements in aviation have continually pushed the boundaries of flight efficiency and performance. Among these innovations, the development of supercritical airfoils represents a significant milestone in aerospace engineering. Supercritical airfoils are specially used to reduce wave drag and delay the onset of shock waves, particularly at transonic speeds where the airflow around an aircraft's wings approaches the speed of sound. Supercritical airfoil technology has been widely adopted in the design of commercial, military, and experimental aircraft. Its application has enabled aircraft to achieve higher cruise speeds, improved fuel efficiency, and enhanced manoeuvrability across a wider range of flight conditions. By optimizing airflow characteristics and reducing drag, supercritical airfoils have contributed to the development of faster, more efficient, and more economical aircraft.

Understanding the behaviour of supercritical airfoils at various angles of attack and Mach numbers is essential for optimizing aircraft performance, fuel efficiency, and manoeuvrability. By carefully designing the shape and contours of supercritical airfoils, engineers can achieve a delicate balance between lift generation, drag reduction, and stability throughout the aircraft's operational envelope. This optimization process is critical for modern aircraft, especially those designed for high-speed and

long-range missions where efficiency and performance are paramount. Supercritical airfoils have revolutionized aircraft design by offering improved aerodynamic efficiency, particularly at transonic speeds. These airfoils are distinguished by their flattened upper surface and curved bottom surface. The concept of supercritical airfoils emerged from the need to address the challenges posed by transonic flight, particularly the onset of wave drags as aircraft approach the speed of sound. The formation of shock waves on the wings are caused by wave drag, which can significantly increase drag and reduce efficiency. The design and optimization of airfoils are crucial for achieving efficient and high-performance aircraft. Supercritical airfoils have emerged as a significant advancement, particularly for aircraft operating in the transonic regime where aerodynamic challenges such as wave drag become prominent. The ability of supercritical airfoils to delay shock wave formation and reduce drag makes them a preferred choice for modern aircraft design, especially for high-speed flight regimes. This emphasizes their importance in enhancing fuel efficiency and overall performance.[1] Iman Jabbar Ooda conducted a detailed study on the impact of Gurney flaps (GF) on the aerodynamic performance of the supercritical airfoil RAE2822. This investigation involved a steady, two-dimensional computational analysis of the airfoil using the Spalart-Allmaras turbulence model implemented in the commercial software Fluent. The study revealed that incorporating a Gurney flap significantly enhanced the lift coefficient and delayed the onset of flow separation, thereby improving the overall aerodynamic efficiency of the airfoil. However, the research also noted that while increasing the height of the Gurney flap resulted in greater lift enhancement, it came with a trade-off in the form of increased drag, particularly when the flap height exceeded 2% of the chord length (H > 2%c). The increase in lift observed when the Gurney flap height was modified from 0% to 1% of the chord was more pronounced compared to the lift gain achieved by further increasing the height from 2% to 3% of the chord.

These findings underscore the importance of optimizing Gurney flap dimensions to balance lift improvement with drag minimization.[2] Rama Murthy and Rambabu conducted a computational analysis to investigate flow separation over the supercritical airfoil NACA SC (2)-0714 at various angles of attack, ranging from 0° to 22.5°. Using computational fluid dynamics (CFD) simulations, the study examined key aerodynamic parameters such as pressure drag, total drag, and lift coefficient at a Mach number of 0.6. The results demonstrated that the lift coefficient (CL) of the NACA SC (2)-0714 airfoil was consistently higher than that of the NACA SC (2)-0414 airfoil across all tested Mach numbers and angles of attack. The analysis revealed that turbulence was more prominent at the trailing edge compared to the leading edge, with boundary layer separation becoming progressively significant as the Mach number and angle of attack increased for both airfoils. The comparative study emphasized the superior aerodynamic efficiency and performance of supercritical airfoils, particularly NACA SC (2)-0714 and NACA SC (2)-0414, over conventional airfoil designs. These findings highlight the critical importance of selecting suitable airfoil profiles to meet specific operational and performance requirements.

I. DESIGN CONSIDARETIONS AND OPERATING PARAMETRES

A. Design Considerations

To carry out the design of the Supercritical Airfoil NACA SC (2)-0714, some of the design aspects are considered. That design considerations are shown in Table1.

Table1: Design Consideration

Sl.No.	Design Consideration	
	Parameters	***Value***
1	Thickness	14%
2	Camber	2.5%
3	Trailing edge angle	16.7°
4	Leading edge radius	2.9%

B. Operating Parameters

When the Design of Supercritical Airfoil NACA SC (2)-0714 has done then the operating parameters are given as initial boundary conditions. That operating parameters are mentioned in the Table2.

Table2: Operating Parameters

Sl.No.	Operating Parameters		
	Parameters	***Value***	***Unit***
1	Velocity of flow	0.2	-
2	Operating temperature	300	K
3	Operating pressure	6500	Pa
4	Turbulence model transition	k-epsilon	-
5	Reynolds number	3.5×10^6	-
6	Angle of attack	0,4,6,8,11,15,17	degree

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7	Fluid	Air	-
8	Density of fluid	1.225	Kg/m^3
9	Kinematic viscosity	1.4607×10^{-5}	

II. MESHING APRROACH

Mesh generation, often referred to as "grid generation," is a crucial aspect of CFD analysis. High-quality meshing is essential for accurate simulations and realistic visualizations. Achieving a fine and effective mesh is key to reliable results. In this study, the meshing process was conducted using FEM CFD with a precision level of 0.1. A structured mesh was specifically created for the NACA SC (2)-0714 airfoil to ensure optimal accuracy.
The grid type of meshing is used. The meshing has done for the whole angle of attack such as for *0°, 4°, 6°, 8°, 11°, 15°, and 17°*. *"Figure.1"* has given about the mesh.

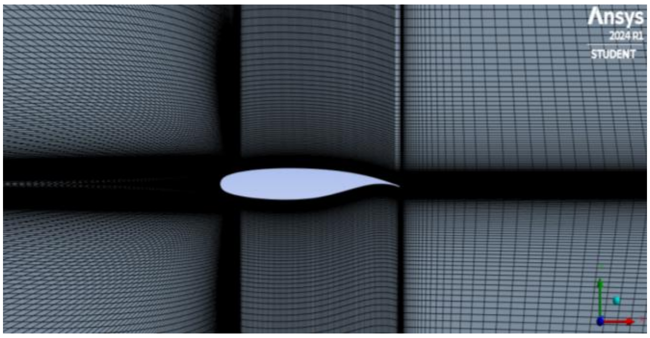

Figure 1. Mesh Generation

III. CFD POST RESULTS

We have focused mainly on lift coefficient, drag coefficient, ratio of coefficient of lift and drag at distinct angle of attack such as 0°, 4°,6°,8°,11°,15° and 17°. All Results are shown as follows with Pressure and velocity contours.

A. Velocity contour and pressure contour of NACA SC (2)-0714 at 0°

The pressure contour and velocity contour is shown in *Figure 2. and Figure 3.* In which the angle of attack is used at 0°. It is observed that the lift coefficient is 0.292, drag coefficient is 0.0099 and lift coefficient to drag coefficient ratio is 29.4.

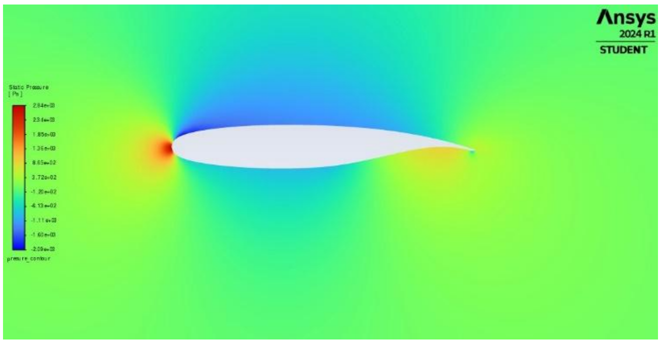

Figure 2. Pressure Contour of NACA SC (2)-0714 at 0° angle of attack

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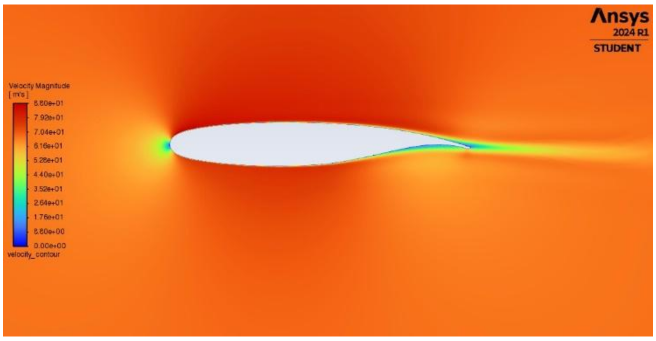

Figure 3. Velocity Contour of NACA SC (2)-0714 at 0º angle of attack

B. *Velocity contour and pressure contour of NACA SC (2)-0714 at 4º*

The pressure contour and velocity contour is shown in *Figure 4. and Figure 5.* In which the angle of attack is used at 4°. It is observed that the lift coefficient is 0.4292, drag coefficient is 0.0133 and lift coefficient to drag coefficient ratio is 36.7.

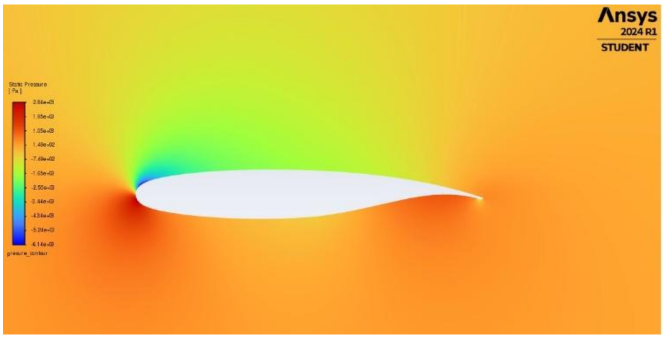

Figure 4. Pressure Contour of NACA SC (2)-0714 at 4º angle of attack

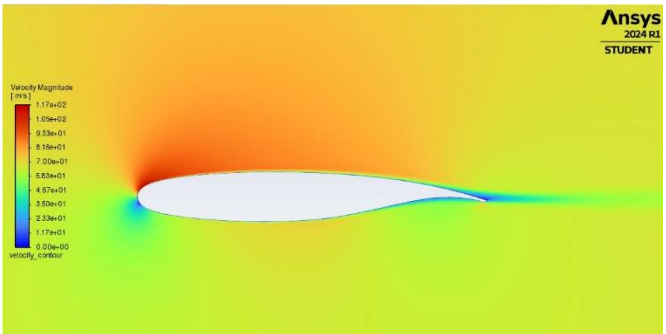

Figure 5. Velocity Contour of NACA SC (2)-0714 at 4º angle of attack

C. *Velocity contour and pressure contour of NACA SC (2)-0714 at 6º*

The pressure contour and velocity contour is shown in *Figure 6. and Figure 7.* In which the angle of attack is used at 6°. It is observed that the lift coefficient is 0.6292, drag coefficient is 0.0157 and lift coefficient to drag coefficient ratio is 40.1.

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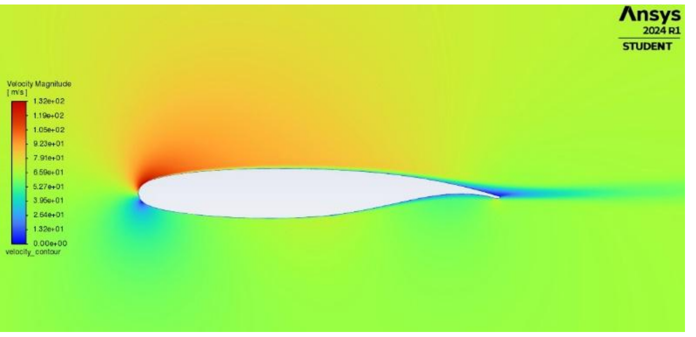

Figure 6. Pressure Contour of NACA SC (2)-0714 at 6° angle of attack

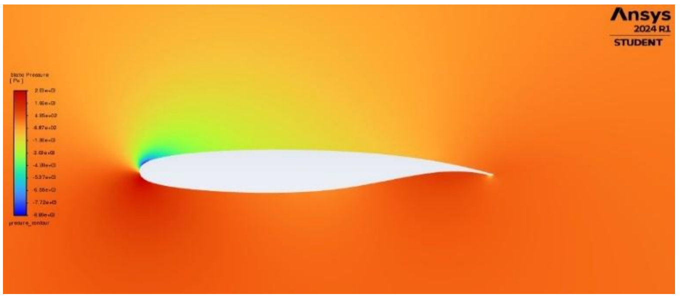

Figure 7. Velocity Contour of NACA SC (2)-0714 at 6° angle of attack

D. *Velocity contour and pressure contour of NACA SC (2)-0714 at 8°*

The pressure contour and velocity contour is shown in *Figure 8. and Figure 9.* In which the angle of attack is used at 8°. It is observed that the lift coefficient is 0.8292, drag coefficient is 0.0196 and lift coefficient to drag coefficient ratio is 42.3.

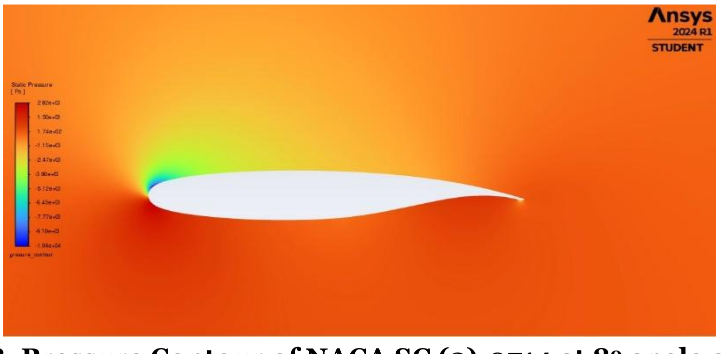

Figure 8. Pressure Contour of NACA SC (2)-0714 at 8° angle of attack

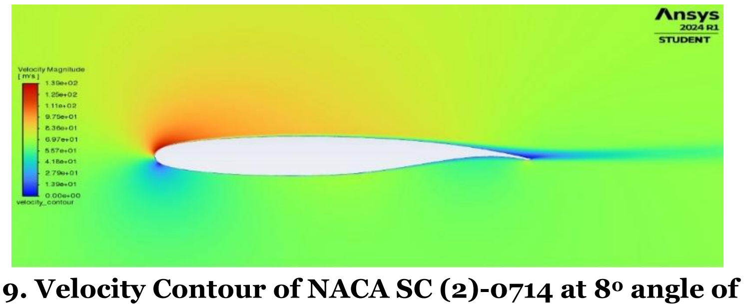

Figure 9. Velocity Contour of NACA SC (2)-0714 at 8° angle of attack

Velocity contour and pressure contour of NACA SC (2)-0714 at 11°

The pressure contour and velocity contour is shown in *Figure 10. and Figure 11.* In which the angle of attack is used at 11°. It is observed that the lift coefficient is 1.33, drag coefficient is 0.0264 and lift coefficient to drag coefficient ratio is 50.378.

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Figure 10. Pressure Contour of NACA SC (2)-0714 at 11° angle of attack

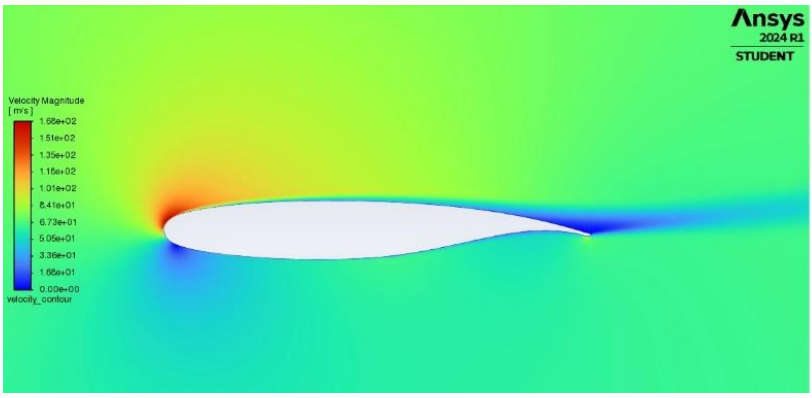

Figure 11. Velocity Contour of NACA SC (2)-0714 at 11° angle of attack

E. Velocity contour and pressure contour of NACA SC (2)-0714 at 15°

The pressure contour and velocity contour is shown in *Figure 12. and Figure 13.* In which the angle of attack is used at 15°. It is observed that the lift coefficient is 1.5196, drag coefficient is 0.0609 and lift coefficient to drag coefficient ratio is 24.95.

Figure 12. Pressure Contour of NACA SC (2)-0714 at 15° angle of attack

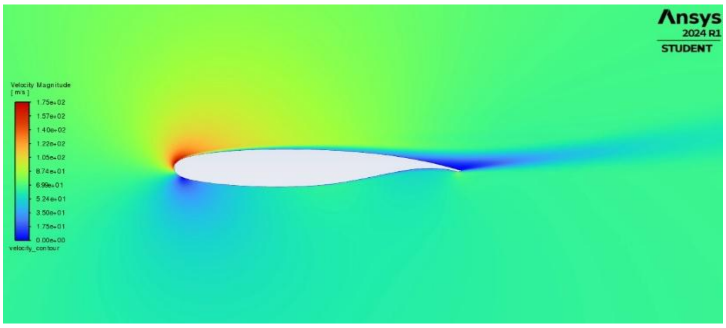

Figure 13. Velocity Contour of NACA SC (2)-0714 at 15° angle of attack

F. Velocity contour and pressure contour of NACA SC (2)-0714 at 17°

The pressure contour and velocity contour is shown in *Figure 14. and Figure 15.* In which the angle of attack is used at

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17°. It is observed that the lift coefficient is 1.434, drag coefficient is 0.0933 and lift coefficient to drag coefficient ratio is 15.36.

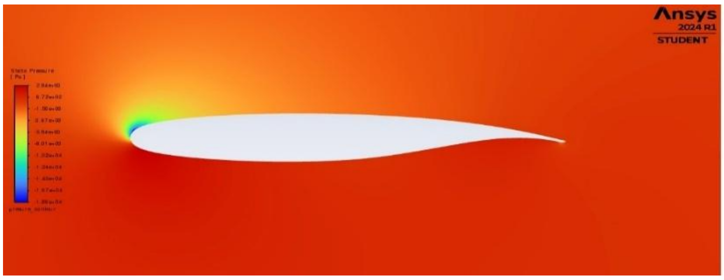


Figure 14. Pressure Contour of NACA SC (2)-0714 at 17° angle of attack

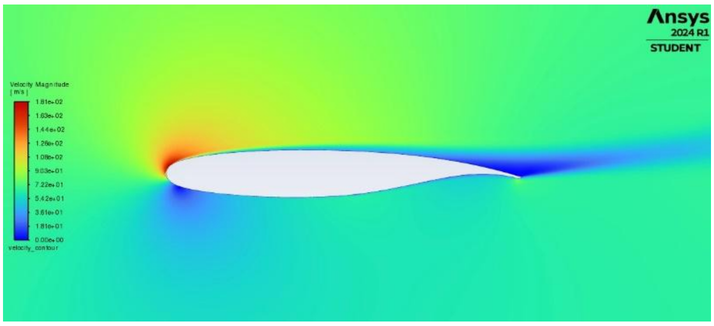


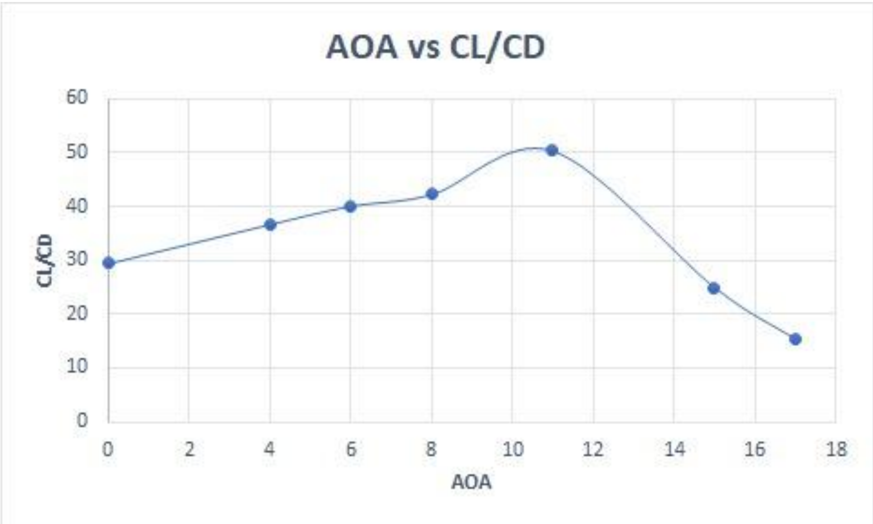
Figure 15. Velocity Contour of NACA SC (2)-0714 at 17° angle of attack

H. NACA SC(2)-0714 values

Table2: NACA SC (2)-0714 Values

Angle of attack	0°	4°	6°	8°	11°	15°	17°
Lift coefficient (C_L)	0.292	0.429	0.629	0.829	1.33	1.519	1.434
Drag coefficient (C_D)	0.0099	0.0133	0.0157	0.0196	0.0264	0.0609	0.0933
C_L/C_D	29.4	36.7	40.1	42.3	50.37	24.95	15.36

Graph 1: NACA SC (2)-0714 Angle of attack vs C_L/C_D



Conclusion

The results demonstrate that aerodynamic efficiency improves with increasing angle of attack, reaching its maximum at 11º, where the lift-to-drag ratio (C_L/C_D) achieves its highest value. Beyond this angle, significant flow separation occurs, leading to a noticeable decrease in the C_L/C_D ratio. This trend, as depicted in the C_L/C_D versus angle of attack graph, marks the critical angle for the NACA SC (2)-0714 airfoil. At angles beyond this point, aerodynamic performance declines due to elevated drag and the onset of unstable airflow.

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