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Supercritical Airfoil Analysis for Increasing Critical Mach Number in Subsonic Flight

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Abstract:

An airfoil's aerodynamic properties are crucial for design considerations and experimental appraisal by evaluating different supercritical airfoil performance characteristics under cruising conditions, this resulted in an increase in the critical Mach Number. This project's primary goal is to investigate aerodynamic properties including the drag coefficient and critical Mach number while designing and analyzing different supercritical airfoils with the same cruising local velocity. Enhancing a subsonic aircraft's Mach number at transonic Mach speeds is the goal. The selected design profile is based on the Airbus A380-800's current airfoils.

1.Overview:

Supercritical airfoil flow differs greatly from cambered airfoil flow. The Airbus A380-800 flies at a maximum speed of 0.83 m/s, where the local velocity reaches sonic velocity somewhere over the wing and compressibility effects begin to grow up the free stream m/s. This is known as the critical m/s. An increase in the crucial Mach number is always preferable. In order to postpone the development of shockwaves, it is always preferable to raise the crucial Mach number. This can be accomplished by sweeping the wings; however, it is not advised to do so in passenger aircraft due to challenges during construction and lift loss at subsonic speeds.

2. Introduction:

2.1Mach Number

Named after the Austrian physicist Ernst Mach, a means of recording the speed of a body as a ratio of the speed of sound in the same ambient conditions. Mach Number(M) = velocity of object/speed of sound

$$M=v/a.$$

2.2 Critical Mach Number

In aerodynamics, the critical Mach number of an aircraft is the lowest Mach Number at which the air flow over some point of the aircraft reaches the speed of the sound, but does not exceed it . At the low critical number, airflow around the entire aircraft is subsonic. In other words, the free-stream Mach number at which sonic Flow is first encountered on the airfoil is known as Critical Mach number.

2.3 Drag Divergence Mach number

The drag divergence Mach number is the Mach number at which the aerodynamic drag on an airfoil or airframe begins to increase rapidly as the Mach number continues to increase .we now turns our attention to the airfoil drag coefficient CD. The figure sketches the variation of CD with M_∞. At low Mach numbers, less than $M_{cr.}$ C_D is virtually constant and is equal to its low speed value. The flow field about the airfoil for this condition.

3. Description:

3.1 Airfoil Nomenclature used in Airbus A380-800

Airfoil Name	NASA SC (2) -0610
Maximum Thickness	10% at 38% chord
Maximum Chamber	1.8% at 32% chord
Maximum	0.012
Critical Mach Number	0.83
Cruising Velocity	288.4 m/s

3.2 Airfoil nomenclature of supercritical airfoils

Airfoil Name	NACA – 2412
Maximum Thickness	12% at 30% chord
Maximum Chamber	2% at 40% chord
Maximum C_D	0.0090
Critical Mach Number	0.88

4. Design and Analysis:

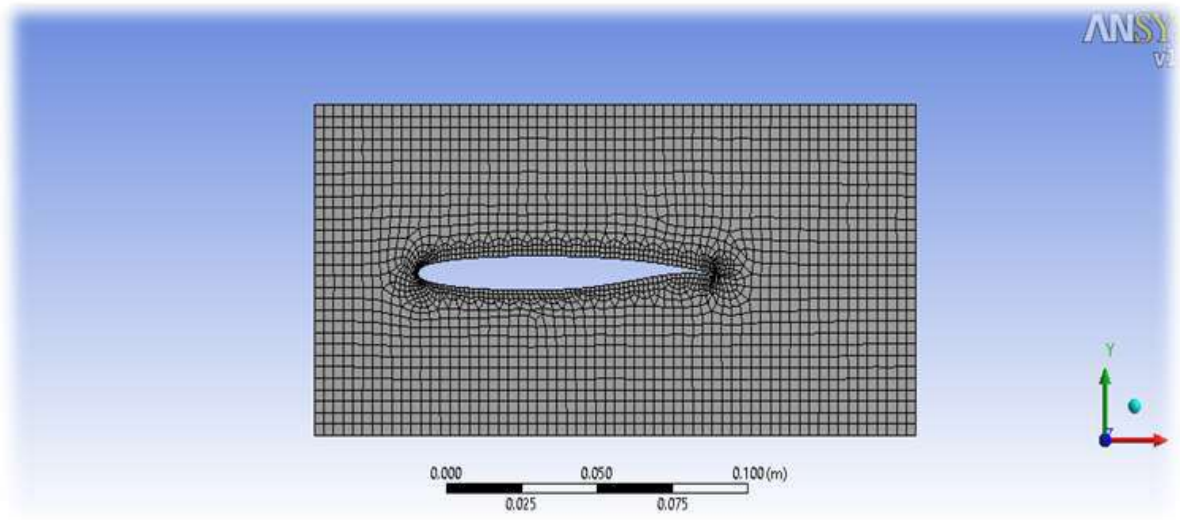

Fig.4.1 NASA SC (2) – 0610 Mesh Geometry

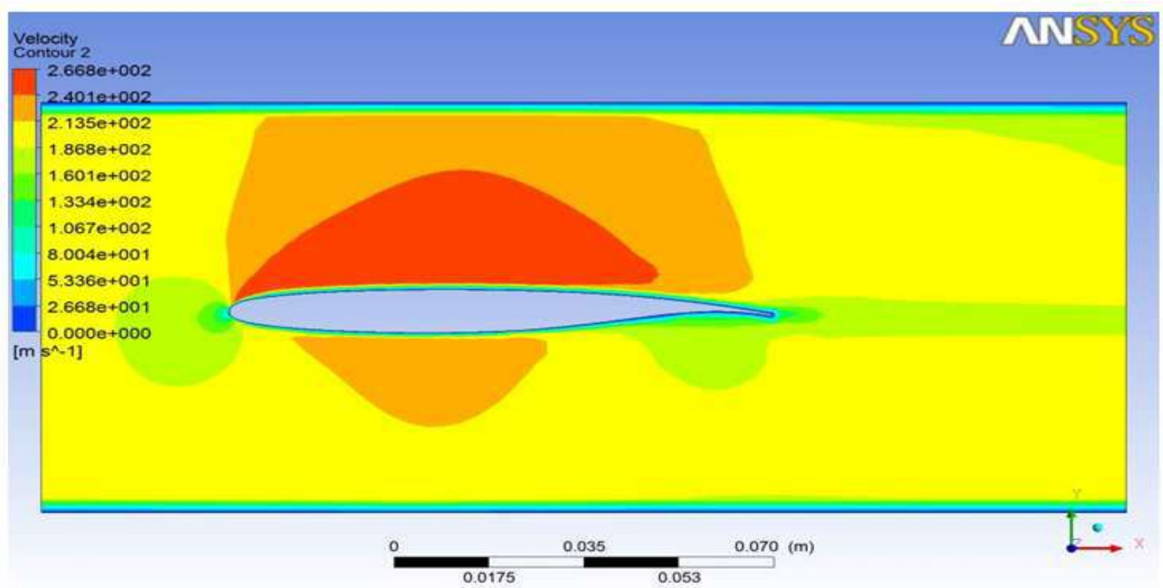

Fig.4.2NASA S-0610 Velocity Profile Diagram

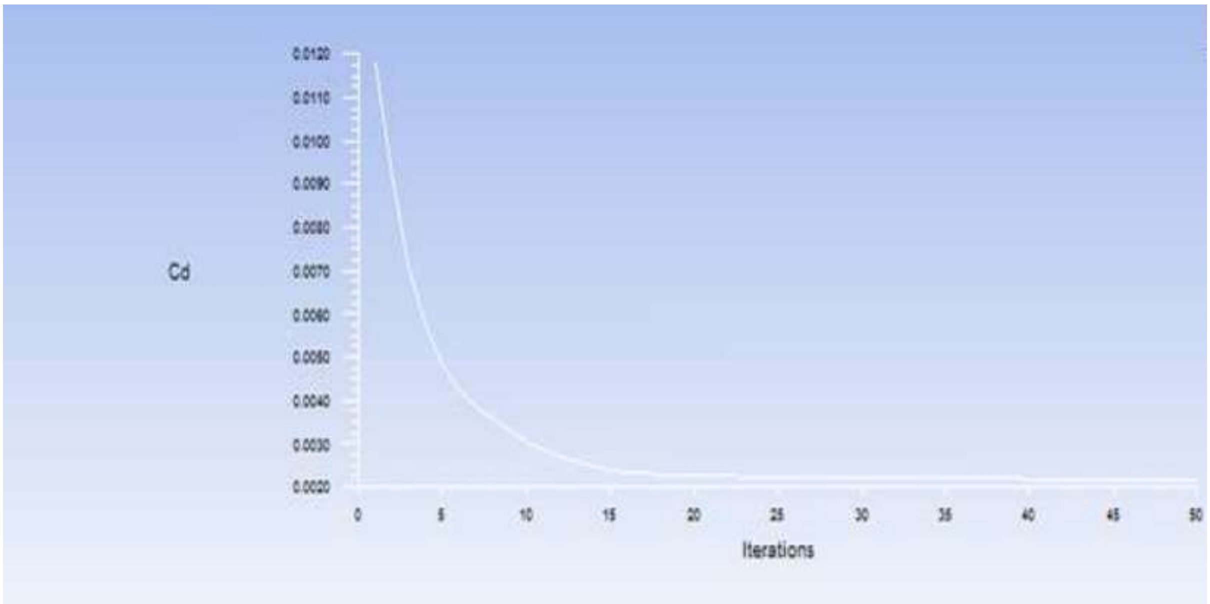

Fig.4.3 NASA S-0610 Co-efficient of Drag Diagram

4.1 Mesh Geometry Overview

- The mesh geometry demonstrates a carefully refined grid around the airfoil, enabling precise resolution of flow structures, such as boundary layers and separation zones, which are critical for accurate simulation results.

4.2 Velocity Profile Insights

- The velocity contour diagram reveals high-speed airflow above the airfoil and low-speed regions below, indicating strong lift generation characteristic of well-designed aerodynamic surfaces.
- Flow patterns show the formation of a wake behind the airfoil, consistent with expected aerodynamic behavior in practical applications.

4.3 Drag Coefficient Convergence

- The drag coefficient (Cd) graph displays rapid convergence across simulation iterations, with the value stabilizing after approximately 20 iterations, indicating that the numerical solution reached a steady state.
- Steady convergence confirms simulation reliability and validates the setup used for aerodynamic assessment.

This integrated analysis confirms that the NASA S-0610 airfoil demonstrates typical aerodynamic characteristics, and the use of a refined mesh with CFD ensures accurate prediction of velocity fields and drag forces.

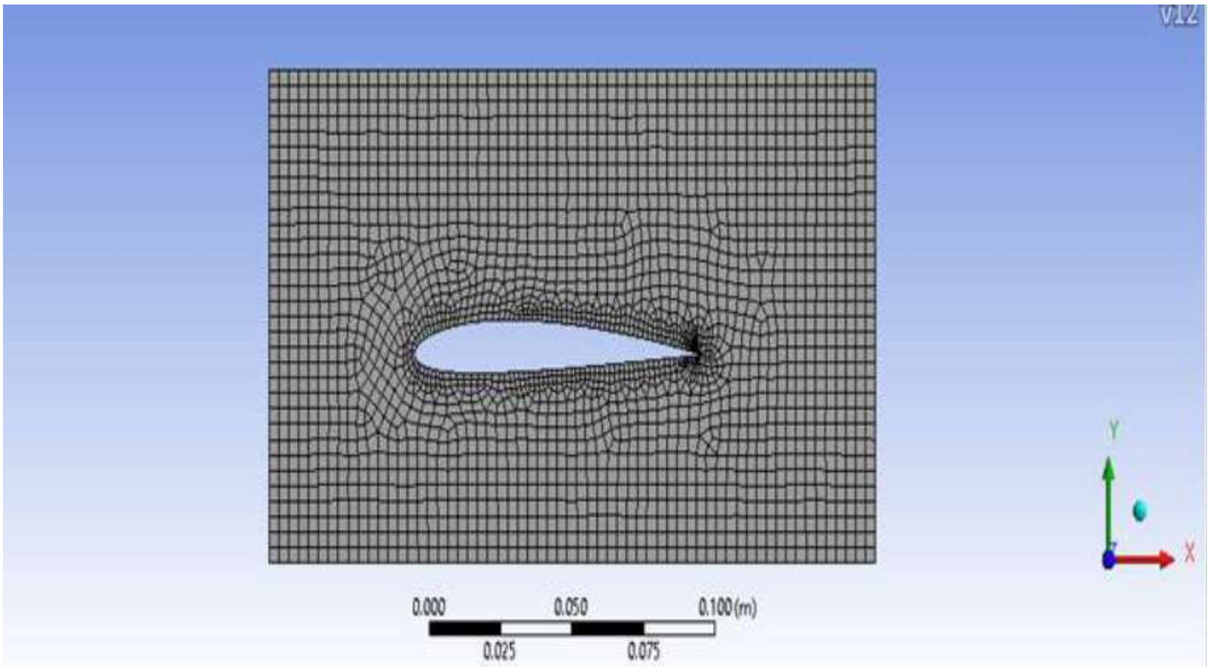

Fig.4.4 NACA2412 Mesh Geometry

4.4 Mesh Geometry

- The mesh shows a structured grid with refined elements around the airfoil, providing higher resolution where flow gradients are strongest.
- Local refinement ensures precise capture of boundary layer and wake effects around the airfoil.

4.5 Velocity Profile

- The velocity contour reveals higher airflow velocities above the airfoil and lower velocities below, consistent with lift generation on a typical airfoil.
- Flow separation and wake formation are visible in the profile, essential for understanding aerodynamic efficiency.

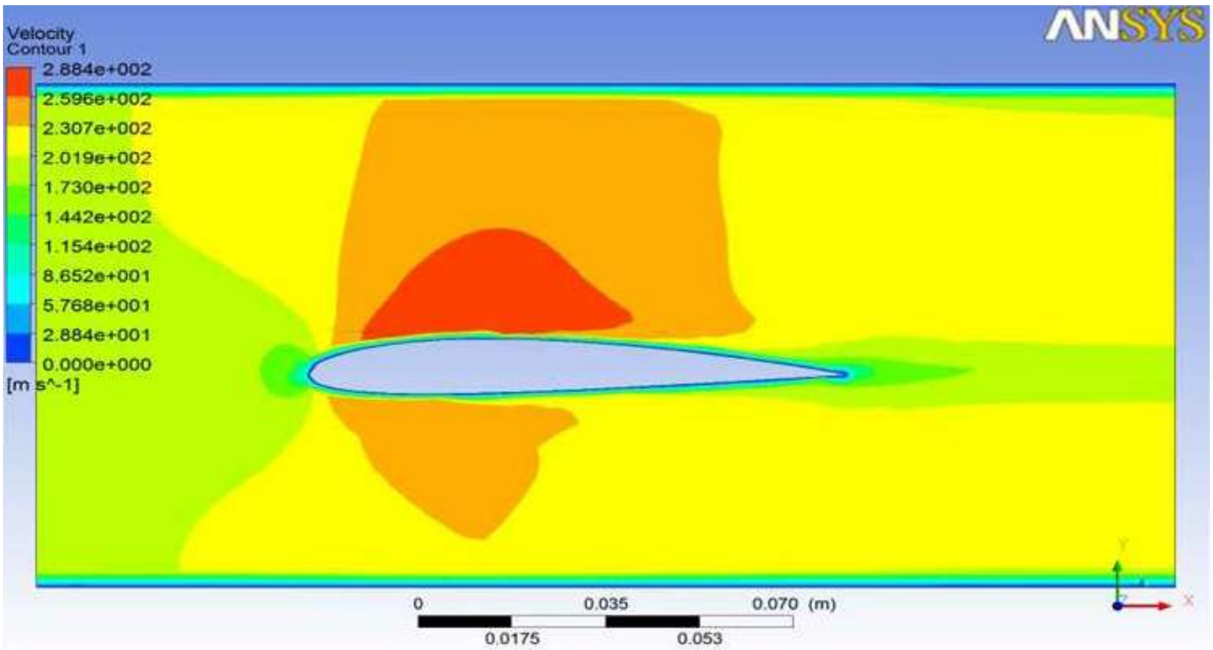

Fig.4.5 NACA-2412 velocity profile

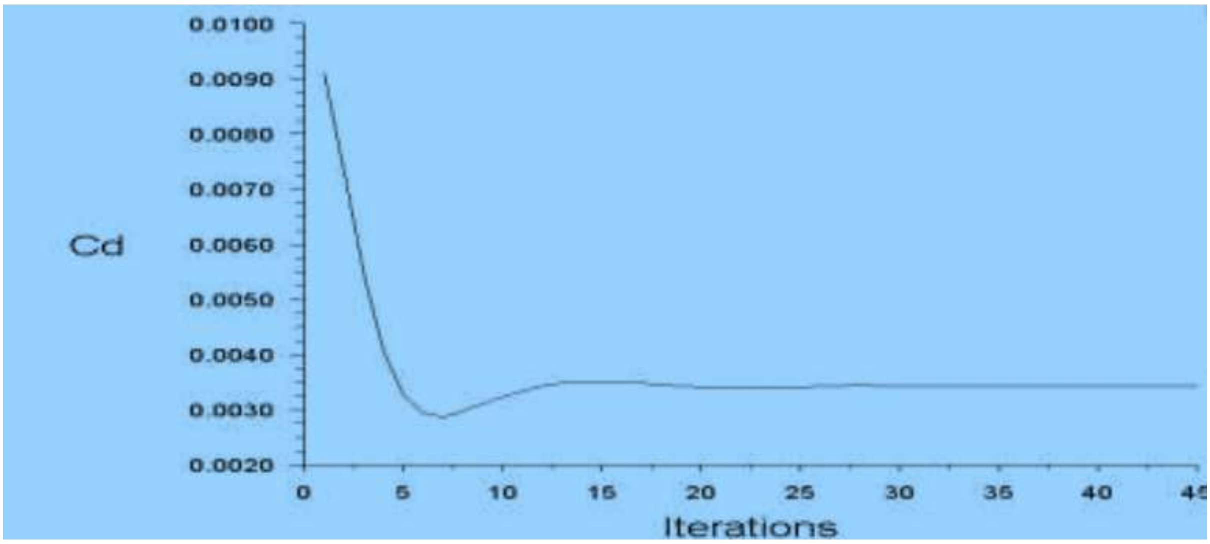

Fig4.6 NACA – 2412 Coefficient of Drag Diagram

4.6 Drag Coefficient Convergence

- The drag coefficient (Cd) rapidly decreases and then stabilizes after about 10 iterations, showing solution convergence.
- The final stable drag value indicates numerical reliability of the simulation results.

5. Summary:

Analytical studies have been conducted to evaluate the performance of the different supercritical airfoils to enhance the speed during subsonic flight. Merging the outcomes from the computational Analysis with the current airfoil. NACA-2412 generated a maximum cruising speed of 288.4 m/s and the highest design The drag coefficients measure 0.009. From the NACA – 2412 supercritical airfoil, we determine it generates optimal cruising speed and reduced drag coefficient in relation to other supercritical airfoils

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