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Study of Flow Over Supercritical Airfoil and it's Comparison with NACA Airfoil

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Abstract - *During the 1960's, aerospace engineers all around the world were looking for ways to reduce the transonic drag encountered by airplanes who frequently cruised at speeds close to the edge of the sound barrier. Ever since the beginning of the jet age, more and more aircraft began encountering issues such as severe buffeting, an increase in drag etc. when approaching the sound barrier. In the United States, Dr. Richard T. Whitcomb in a bid to create something superior to the NACA 6 series airfoil currently in use as transonic airfoils, ended up creating the supercritical airfoil. This was characterized basically as an upside-down airfoil with the top surface being completely flat while the bottom surface was cambered, and it had a cusped trailing edge alongside a larger radius leading edge. Taking note of his work, wind tunnel testing soon began on the supercritical airfoil and provided fruitful results. The supercritical airfoil design was refined over time and even included increasing the aft trailing edge thickness to compensate for possible structural issues. Today, almost all aircraft operating in the transonic range are equipped with supercritical airfoils, hence proving just how important it has been and will continue to be.*

1. Supercritical Airfoil

During the 1960s, the National Advisory Committee for Aeronautics (NACA, later dissolved and integrated into NASA) was conducting various programs to help minimize transonic drag (occurring in the region between Mach 0.8 to 1.2). One of these was the invention of the supercritical airfoil by Dr. Richard Whitcomb, an engineer working at NACA. When aircraft approach the speed of sound (Mach 1.0), airflow on the upper surface of the wing moves much faster than the velocity of the aircraft resulting in premature formation of shockwaves even though the aircraft hasn't crossed Mach 1 (the aircraft is flying at the critical mach number).

The shockwave results in disturbance of the smooth airflow (boundary layer) on the upper surface to separate from the wing which in turn leads to wake turbulence. This leads to an increase in vibrations, fuel consumption and a decrease in speed. To overcome this, supercritical wings have been introduced which look like inverted normal aircraft wing. It has a flat surface on the upper portion and a curved surface on thew lower portion. This ensures the airflow on the upper surface doesn't go as fast as it would on a normal wing and in turn delays shockwave formation and drag related to the separation of the boundary layer.

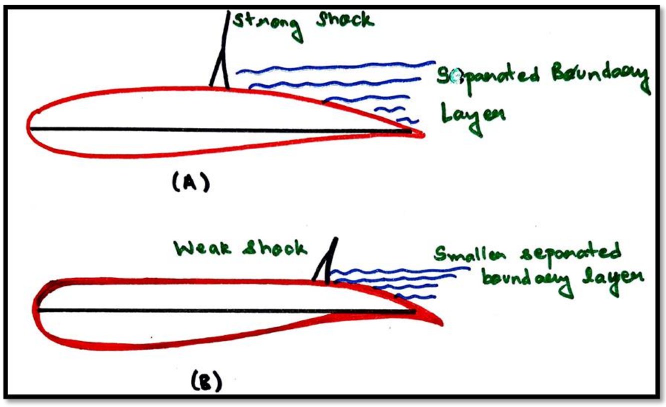


Fig 1 : Conventional vs Supercritical Airfoil

1.1 Aerodynamic Characteristics of Supercritical Airfoil

The aerodynamic characteristics and the performance advancements of the supercritical airfoil can be best analyzed by its comparison with conventional 4-series or 6-series NACA airfoil.

The primary comparison lies in the study of the shock wave formation over the suction side of the airfoil. An example of the flow comparison is done between NACA 64_2-A215 airfoil and Supercritical airfoil which is 13.5% thick.

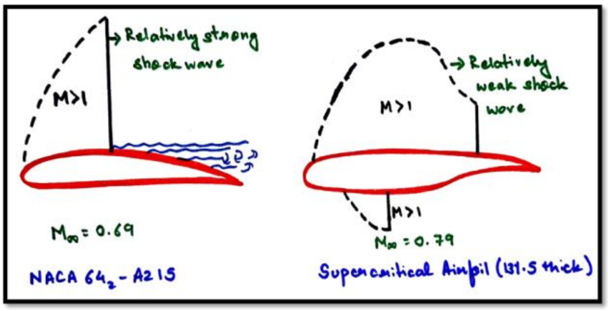


Fig 2 : Shock Wave Comparison at Cruise Life Conditions

The above figure represents that analysis was done on the NACA airfoil with a free stream mach number M_∞=0.69 and on the supercritical airfoil with higher value of free stream mach number i.e. M_∞=0.79.

Since the supercritical airfoil is designed with a relatively flat top covering around 70% of the airfoil, thus is establishes a region of the supersonic flow. However, the local values of the Mach number over the suction surface during the formation of the shock is weaker. On the other hand, it was observed that the supersonic flow generated over the NACA airfoil consisted of higher local values of the Mach number.

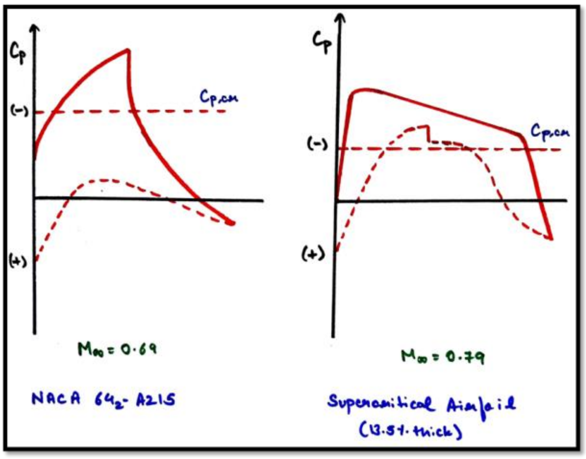


Fig 3 : "C_p" Distribution Comparison

The plot of the C_p distribution for both the NACA and the supercritical airfoil shows similar results and depicts that the supercritical airfoil is much advantageous for use.

On comparison from the graph, it can be clearly stated that the supercritical airfoil is much more advanced in terms of the flow field characteristics and drag reduction. In this airfoil, the supersonic flow over the top surface is much closer to the airfoil surface, the local values of the Mach number are lower despite high value of free stream mach number i.e. $M_\infty=0.79$.

The supercritical airfoil is basically designed with a flat top covering around 70% airfoil which lowers the lift. However, the airfoil has been designed such that the rear section of the airfoil has an extremely positive camber which helps to compensate for the reduced lift and provides a considerable lift generating force.

Hence, the supercritical airfoil contributes in the drag reduction by increasing the value of the drag-divergence mach number discussed in plot of 'C_d vs M'. The supercritical airfoil with higher free stream mach number produces a low terminating shock wave and hence the value of drag divergence increases with the lower local mach number on the suction surface of the airfoil. The airfoil has an extremely positive camber on the rear surface thus generating a cusp-like shape at the bottom of the trailing edge.

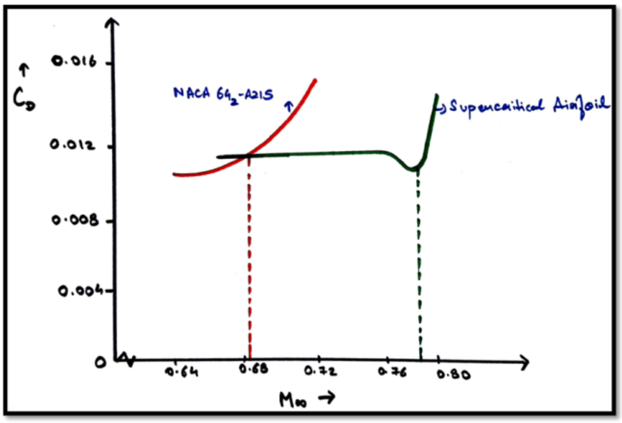


Fig 4 : Drag Divergence Properties

In totality, Supercritical airfoils have 4 main benefits:

- Higher drag divergence mach number
- Shockwaves are formed further aft
- Greatly reduce shock induced boundary layer separation
- More efficient wing design to their geometry

1.2 Stall Characteristics

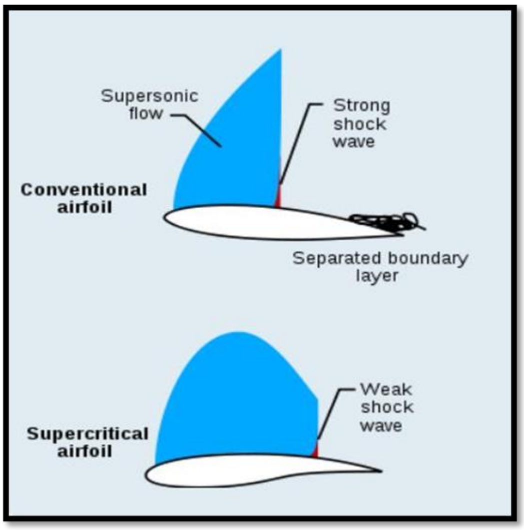


Fig 5 : Shock Formation Comparison

The stall characteristics of a supercritical profile are unlike those of conventional ones. The boundary layer along the leading edge of a supercritical wing starts off as thin and laminar at cruise angles. As the AOA increases, the laminar layer detaches in a narrow region and forms a short bubble. The airflow which is now turbulent reattaches itself once again to the surface aft of the bubble. The increase in drag, however, isn't extreme in this case. But, if the AOA keeps on increasing to the point where it reaches stall, an adverse pressure gradient builds, and a shockwave can form within the thin boundary layer ahead of the bubble even at relatively low speed. At the critical angle, the bubble rapidly expands in turn causing airflow to suddenly detach from the entire surface. This sudden loss of lift is worsened by the lack of traditional stall "warning" or buffet as a low-speed contour would provide. Due to this lack of buffet warning, aircraft using supercritical wings are regularly equipped with stick-shaker alert and stick-pusher recovery systems in order to meet certification requirements.

2. Development of Supercritical Airfoils

Richard T. Whitcomb in the early designed three different kinds of supercritical airfoils, which then resulted in the new era of the usage of high-performance airfoils in the later stages. One such example is the C-17 Globemaster which is the part of the Indian Airforce.

The developments of the airfoils were distinguished by the change in the curvature of the upper surface, substantially reduced curvature of the middle surface of the suction surface and increase in the extreme camber at the trailing edge.

2.1 Slotted Supercritical Airfoil

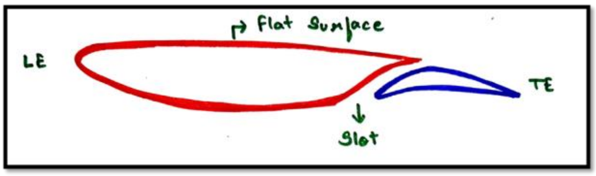


Fig 6 : Slotted Supercritical Airfoil

The slotted supercritical airfoil designed at the NASA Langley Research Centre had had a slot between the upper and lower surfaces near the three-quarter chord to energize the boundary layer. The main advantage of this supercritical airfoil was to delay the airflow separation over the suction surface of the airfoil. This particular airfoil had a negative camber ahead of the slot and positive camber at rearward of the slot.

2.2 Integral Supercritical Airfoil

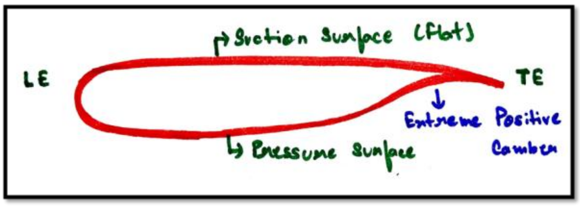


Fig 7 : Integral Supercritical Airfoil

In this airfoil, proper shaping of the pressure distributions was utilized through the design changes at the trailing edge. This was basically done to control the boundary layer effect on the airfoil and its separation rather than transfer of high-pressure air from the pressure side to the suction side using the slots. The boundary layer control is much more effective as the skin-friction losses are minimized by removing the trailing edges slots.

3. Design Generation for the NACA 0012 Airfoil

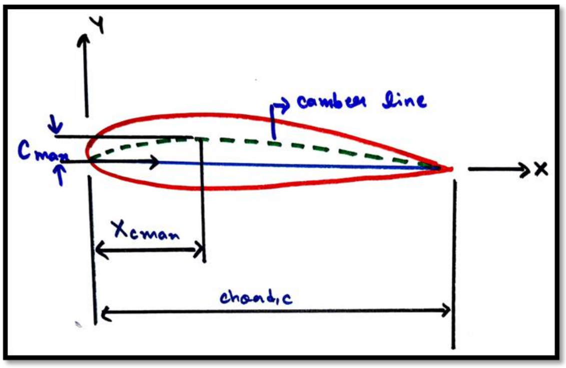
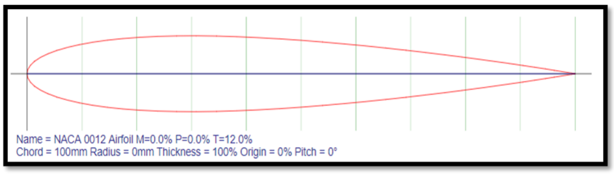


Fig 8 : Symmetrical Airfoil

The NACA 0012 symmetrical airfoil consist of the following 4 digits: -

- 0: The first digit represents the maximum camber thickness (C_{max}) in terms of percentage of the total chord.
- 0: The second digit represents the maximum camber position for the leading edge in terms of tenths of the chord length. (X_{cmax})
- 12: The last two digits represent the 't/c' ratio i.e. thickness to chord ratio of the airfoil.

The flow field pattern for the symmetrical airfoil is much simpler if compared with the cambered airfoil and the supercritical airfoil. The symmetrical airfoil has zero camber and within the framework of the Thin Airfoil Theory, the symmetrical airfoil is treated as a flat plate.



The coordinates are generated as the 'CSV file of coordinates' from the source 'Airfoil Tools for 4-Digit and 5-Digit Airfoil Plotter'.

The ANSYS Workbench R19.2 version is used for initial creation of the geometry. ANSYS is an American Public Company and was founded in 1970. It is basically a Computer Aided Engineering Software (CAE) and is used by various companies to study the real time flow filed analysis over the bodies, determination of aerodynamic forces like lift, drag, etc. It also helps to simulate the flow over the airfoils in a used defined pattern to observe the flow filed characteristics and the stress concentration region. Ansys software can provide upto 99.99% correct results as the meshing in this is exceptionally fine with the range of meshing varying from -100 to +100. The interface is very user friendly and allows the formation of 2D geometry by importing coordinates and 3D part by importing model from any CAD software.

3.1 Working Methodology in Computational Fluid Dynamics

The CFD Analysis works by performing 3 different methodologies: -

- Pre-Processor: This stage basically involves the development of the geometry, clean-up of the designed geometry and the meshing.
- Solver: This stage basically involves the implementation of the boundary conditions, domain, loads. It allows the user to specify the problem specification, addition of additional models and then the system performs the numerical computation.
- Post-Processor: It is the stages which provide the results in the form of different contours, stress distribution, deformation pattern, flow field in CFD, etc.

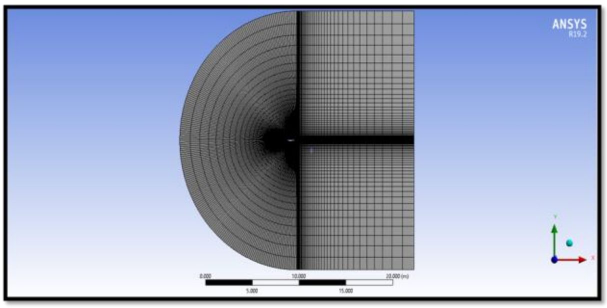


Fig 9 : CFD Solver State (Meshing and Boundary Conditions)

3.2 ANSYS Workbench for NACA 0012

ANSYS Workbench provides unique analysis systems. For the analysis of 2D flow over the symmetrical and supercritical airfoil, the primary usage is based on Fluid Flow (Fluent).

After the completion of the meshing stage, the domain is imported to ANSYS Fluent for the final analysis. The domain must set to density-based type in order to obtain the required results after running a series of iterations.

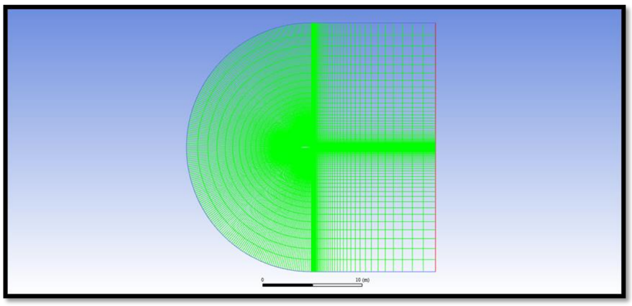


Fig 10 : Meshed Domain in ANSYS Fluent

The domain must be specified as viscous-Spalart Allmaras. The "Spalart Allmaras" is mathematical model for the 2D airfoil analysis and gives a considerable result with accuracy up to 99.99%.

Material Selected for Flow: Air with seal level density of 1.225 kg/m3.

Boundary Conditions for Flow Field

1. Inlet Velocity: 20 m/s, specified with horizontal and vertical velocity components.
2. Angle of Attack: For a particular case, the angle of attack was initially set to 6 degrees and the analysis is performed for the determination of C_l, C_d, pressure distribution, pressure and velocity contours, etc.

he results obtained on performing analysis on NACA 0012 symmetrical airfoil are explained below as follows: -

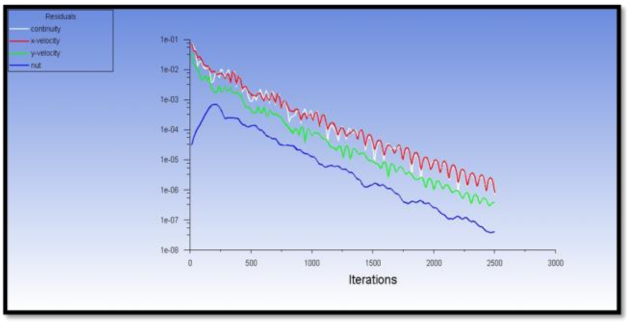


Fig 11 : Scaled Residuals

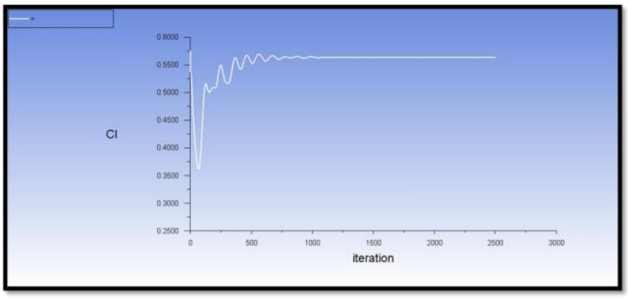


Fig 12 : Coefficient of Lift Plot

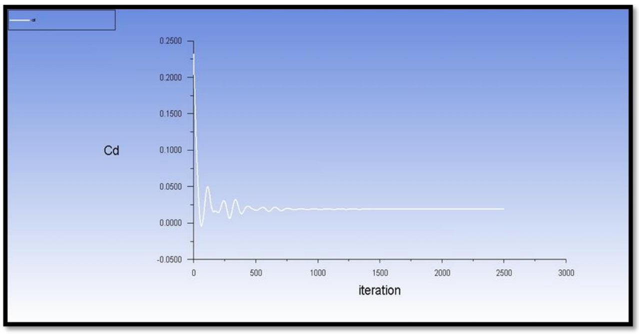


Fig 13 : Coefficient of Drag Plot

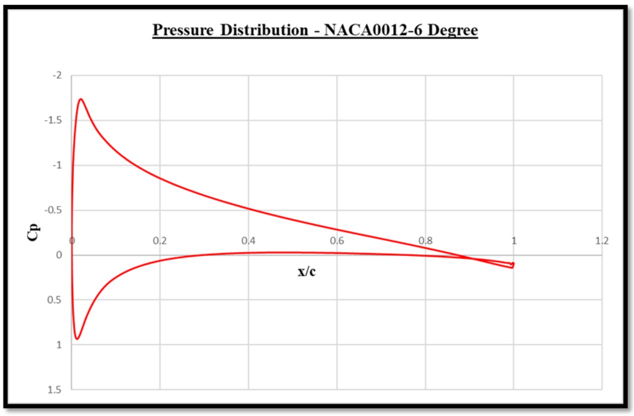


Fig 14 : Pressure Distribution Plot

3.3 Results and Discussions

On performing analysis on NACA 0012 symmetrical airfoil, at inlet velocity of 20 m/s and angle of attack of 6 degree, the following results were obtained: -

1. Coefficient of Lift (C_l): 0.56406
2. Coefficient of Drag (C_d): 0.019440
3. Highest Velocity Magnitude: 30.5 m/s
4. Value of Pressure Coefficient on Lower Surface (C_p)= 0.934
5. Value of Pressure Coefficient on Upper Surface (C_p)= -1.73

The plots were generated for pressure coefficient, velocity magnitude, velocity vectors, plots of coefficient of lifts and drags and the convergence criteria plot of the scaled residuals.

The results obtained at a 6-degree angle of attack with inlet velocity of 20 m/s show that the NACA 0012 airfoil has a symmetrical lift distribution with a maximum lift coefficient of 1. The pressure distribution plots show the lift generated by the area of the contour. The larger the area of the plot, the higher is the lift coefficient. Hence, the angle of attack increases with the increase in angle of attack before it reaches its critical value where stall occurs.

The CFD analysis was then performed on several angles of attacks ranging from 3 degree to 12 degree where stall occurrence was observed at 20m/s inlet velocity.

4. ANSYS Workbench for Supercritical Airfoil

The geometry generation of the supercritical airfoil has been discussed in the following section of the report. The supercritical airfoil is a highly designed airfoil with 70 percent flat surface on the suction surface and extreme positive camber at the rearward 30 percent of the airfoil. This design change has led to an increase in the angle of attack when compared with the conventional NACA airfoils and shows much more desirable flow field characteristics with low value of drag.

The geometry coordinates of the supercritical airfoil are generated from NASA Airfoils Tool Plotter where various researchers have already worked on the airfoil sections. In the ANSYS Workbench, the coordinates files are imported and converted into a 2D section. The coordinates must be designed such that the curve should be closed from the leading edge and the trailing edge, with a cusp formation at the aft section of the airfoil.

Following considerations must be taken into account while dealing with geometry generation:

1. 2-D Surface Generation
2. C-Domain generation around the supercritical airfoil
3. Projection of horizontal and the vertical lines
4. Dividing the entire domain into 4 quadrant surfaces.

A properly generated domain will give good meshing pattern around the airfoil which will further enhance the result determination while performing CFD analysis.

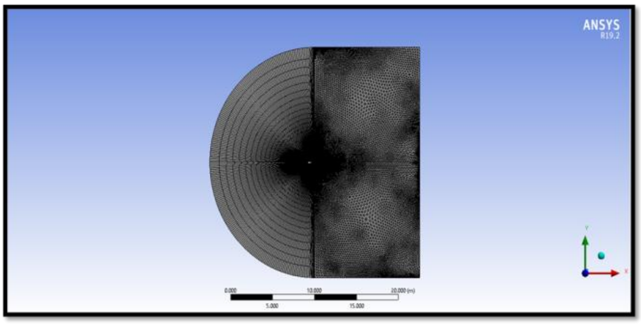


Fig 15 : Fine Meshing on Domain

4.1 ANSYS of SC (2)-0714 Supercritical Airfoil

The fine meshing of the domain in case of supercritical airfoil is especially important in the critical regions like the rearward cusp. Since the flat surface of the airfoil in addition with the extreme positive camber at the aft 30 percent of the airfoil provides aerodynamic advantages over conventional NACA airfoils.

As the meshing is completed, the domain is then imported to ANSYS Fluent Workbench so that the model can be prepared for the final analysis. The domain must be specified with Viscous (Spalart-Allmaras (1 eqn)) model. Spalart-Allmaras is a mathematical model which provides accurate results for the airfoils.

While proceeding with the analysis part, certain parameters and boundary conditions must be implemented on the software with the same values as those implemented for the conventional NACA0012 airfoil to obtain good comparable results.

Material Selected for Flow: Air (Density =1.225 kg/m3)

Boundary Conditions for Flow Field

1. Inlet Velocity: The inlet velocity must be specified as 20m/s with horizontal component as V_h=20.cos (α) and vertical component of velocity as V_v=20.sin (α).

The experiment is performed at 20m/s for the scope of future study and verification of results with the actual wind tunnel testing. The maximum velocity of the wind tunnel ranges up to 26m/s and gives comparable results when compared with the CFD results performed using the CFD software.

2. Angle of Attack (AOA): The analysis over the supercritical airfoil is carried out on several angles of attack (α) ranging from 2 degree to 15 degree. This is done to observe the change in the lift and drag coefficient with the change in angle of attack.

The results are calculated for 3000 iterations to achieve a constant value of C_l and C_d. Once the iterations are over, various results and plots can be determined like velocity contours, pressure contours, velocity vectors, pressure distribution plot, lift curve slope, etc.

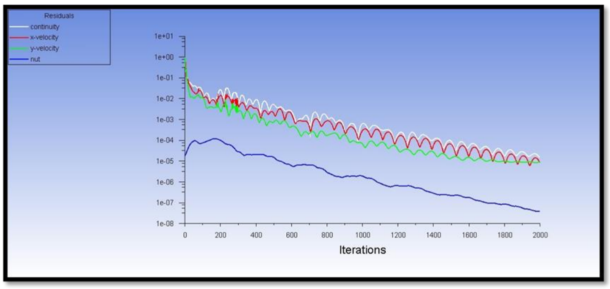


Fig 16 : Scaled Residuals

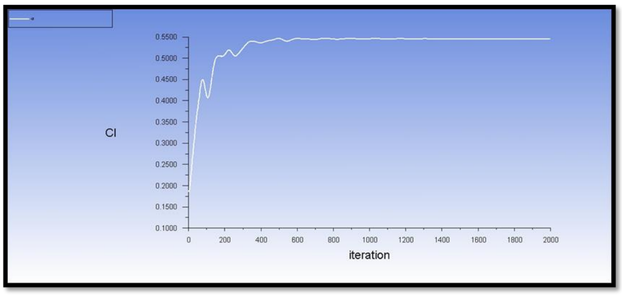


Fig 17 : Coefficient of Lift

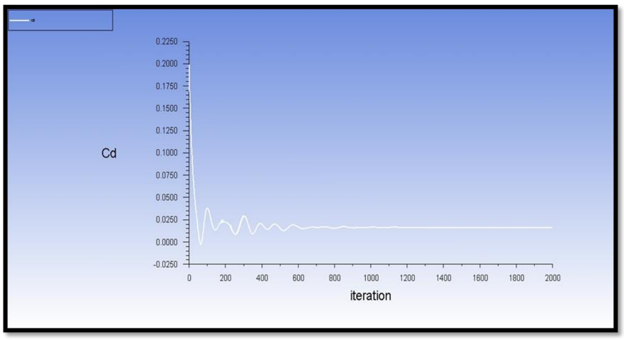


Fig 18 : Coefficient of Drag

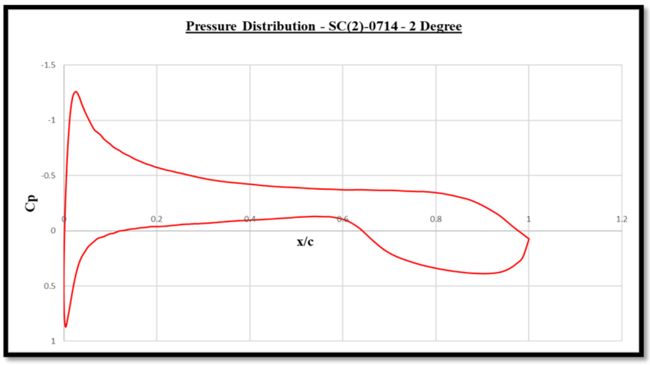


Fig 19 : Pressure Distribution Plot

4.2 Results and Discussions

On performing the CFD analysis on the SC (2)-0714 supercritical airfoil, it was observed that the coefficient of lift was increased at low angles of attack when compared to the conventional NACA0012 airfoil. The pressure distribution over the suction surface of the airfoil was also constant because of the flat design of the upper surface. Moreover, at the minimal drag value, there was a significant increase in the lift as the angle of attack increases. This clearly depicts high performance and increases the maneuverability aspects even at low angles of attack. The following values of lift and drag coefficient were observed during the analysis at 20m/s: -

AOA (α)	Coefficient of Lift (C_l)	Coefficient of Drag (C_d)
2 degree	0.54653	0.016727
4 degree	0.74225	0.021349
6 degree	0.91126	0.028530
8 degree	1.0295	0.041222
10 degree	0.91179	0.094479
12 degree	0.86905	0.13187
13 degree	0.87277	0.14808
14 degree	0.88469	0.16456

A significant change in the lift coefficient is clearly observed starting from 2 degrees. It can also be observed that the change in the coefficient of lift was small with the increase in angle of attack hence providing an aerodynamic advantage over the conventional NACA airfoil.

The ratio of lift and drag i.e. C_l/C_d also gives a good approximation to the fact that the supercritical airfoil is more advantageous in the subsonic and transonic regime. In the further part of the report, discussions are based on the comparison of L/D ratio and the Lift Curve Slope i.e. 'Cl vs α'.

5. Comparison between NACA 0012 and SC (2)-0714 Supercritical Airfoil

5.1 NACA 0012 Symmetrical Airfoil

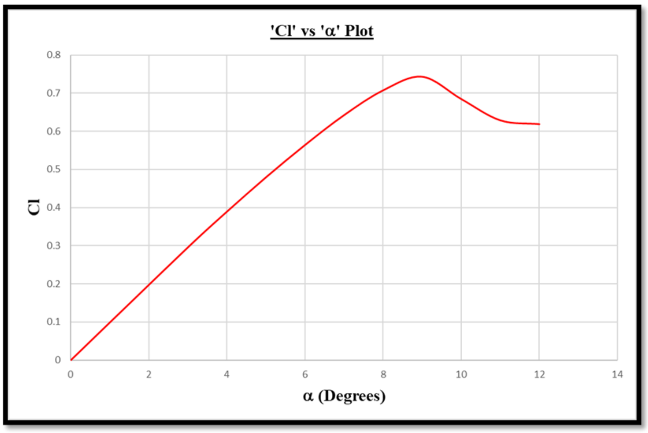


Fig 20 : Lift Curve Slope

The analysis was performed on the conventional NACA 0012 airfoil at 20m/s at various angles of attack i.e. 0-degree, 2-degree, 4-degree, 8-degree, 10-degree, 12-degree. The model used in the analysis was Viscous Laminar. It was observed that a linear plot was observed till 9-degree angle of attack. It was analyzed that the lift coefficient increased by a little amount on increasing the angle of attack due to the symmetrical flow field distribution.

The other observation is on the stall occurrence of NACA 0012. The CFD analysis showed that NACA 0012 symmetrical airfoil stalled at an angle of attack of 9 degrees after which there is a sudden reduction in the lift. Moreover, from the pressure distribution plots, the pressure does not remain constant over the suction surface of the airfoil, and flow separation occurs at early stages and shock waves generated at much stronger. Hence, NACA 0012 is not suitable for aircraft as it does not provide major aerodynamic advantages.

5.2 SC (2)-0714 Supercritical Airfoil

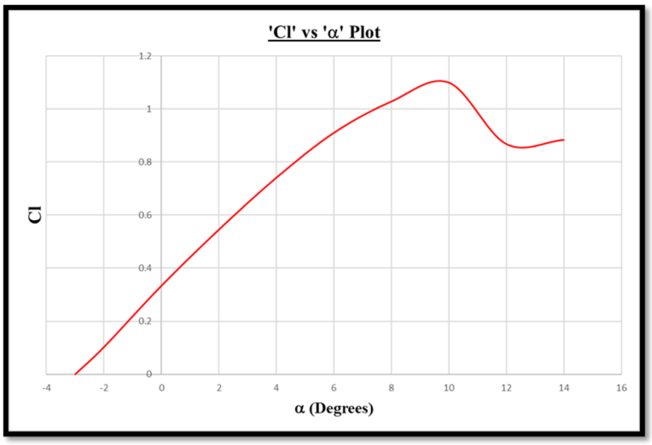
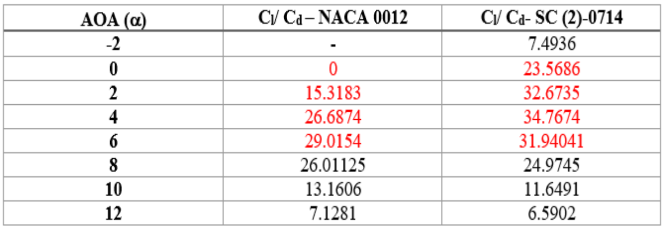


Fig 21 : Lift Curve Slope

The analysis was performed on the conventional SC(2)-0714 airfoil at 20m/s at various angles of attack i.e. -2-Degree, 0-degree, 2-degree, 4-degree, 8-degree, 10-degree, 12-degree. The model used in the analysis was Viscous Laminar. It was observed that a linear plot was observed till 10-degree angle of attack. It was analyzed that there was a significant increase in the lift coefficient of the supercritical airfoil from 2-degree onwards. This is due to the flat upper surface of the airfoil covering 70 percent of the airfoil section and the aft extreme positive camber at the rearward 30 percent of the airfoil generates a significant amount of lift.

The stall occurrence took place on the SC (2)-0714 after 10 degrees. However, there was great increase in the lift coefficient which was much greater than those compared to conventional NACA airfoil. The pressure distribution plots show that uniform pressure exists on the suction surface of airfoil due to flat surface. Hence, the shock wave formed is weaker and the flow separation is delayed with this design change. It can be concluded that the supercritical airfoil is best suited for use in aircraft as it provides significant increase in lift with low drag value and the weaker shock wave formation, and even help to improve maneuverability and safes fuel for during flights operations.

5.3 Comparison of C_l/ C_d Ratio of NACA 0012 and Supercritical Airfoil



AOA (α)	C_l/ C_d – NACA 0012	C_l/ C_d- SC (2)-0714
-2	-	7.4936
0	0	23.5686
2	15.3183	32.6735
4	26.6874	34.7674
6	29.0154	31.94041
8	26.01125	24.9745
10	13.1606	11.6491
12	7.1281	6.5902

The comparative study of the ratio of lift to drag coefficient represents that the C_l/ C_d of the SC (2)-0714 supercritical is extremely high as compared to the conventional NACA 0012 airfoil.

It is known that for the commercial/ passenger aircraft, the normal range of cruising angle of attack is between 1 to 3 degrees, and during the complete flight operation from take-off, cursing and landing, cruising part covers almost 80% of the flight operation. This means that the aircraft's efficiency needs to be more in this flight regime.

The value of Cl/ Cd ratio of SC (2)-0714 Supercritical Airfoil is more for the angle of attack between 0-degree to 6-degree which lies in the aircraft's cruising regime.

6. Impact of Supercritical Airfoil on Civil Aviation

During the 60's and 70's, as aircraft manufactures were busy trying to build aircraft that could go faster, cover longer distances and cut down on overall travel time, the ongoing supercritical airfoil projected by NASA thanks to the esteemed Dr Richard Whitcomb attracted the interest of aircraft manufacturers all over the world at the time including the likes of Boeing, Airbus, McDonnell Douglas, Lockheed, Martin, Northrop, Grumman, Dassault, Sud, Vought, Republic etc. Data obtained from tests on modified F-8 and T-2 aircraft showed extensive benefits as compared to conventional wings. The characteristics of the supercritical airfoil proved 3 potential benefits regarding applications on civil aircraft.

- For aircraft designed to operate in the regime of Mach 0.7 to Mach 0.9, weight reductions allow for an increase in payload or fuel volume which helps to not only increase range, but to compensate for weight added to reduce engine noise and pollutant emissions thus improving aerodynamic performance through increased aspect ratio.
- Allows for cruising at high subsonic speeds by delaying the transonic drag rise. This is especially beneficial not just for business jets, but also for commercial and military aircraft by cutting down on significant amount of time needed to complete long-range journeys by avoiding the need to have a stopover in between for refueling which incurs extra costs for the operator. Several wind tunnel tests carried out have proven that by combining supercritical airfoil with wing sweep and configuration area ruling, it is possible to achieve efficient cruise speeds near the speed of sound.
- Supercritical airfoil has benefits with regards to both buffeting and maneuverability. Proper integration of supercritical airfoil into aircraft layouts significantly delays the Mach number for buffet onset at a given lift coefficient and increases the maximum lift coefficient for buffet onset at a given Mach number.

If the supercritical airfoil is drafted in to increase structure efficiency by increasing the thickness of the wing, it will have no effect on the aircraft's cruise mach number. Shaking of the wings due to buffeting accelerates increases the rate of fatigue and in turn makes passengers feel uncomfortable. The supercritical wing has significantly better buffet characteristics than a conventional wing throughout the operational flight envelope. It improves the maneuvering g-margin, the altitude increments between the design cruise altitude and the buffet boundary at a constant Mach number. It also improves the low-speed cruise margin, the Mach number increment between the design cruise mach number and low-speed buffet boundary at a constant altitude but, it slightly reduces the overspeed buffet margin, the Mach number increment between the design cruise Mach number and the high-speed buffet boundary at constant altitude. A similar increase in thickness for a conventional wing would reduce the high-speed boundary much more via the reduction in drag-rise Mach number. Another advantage of the thick supercritical wing at low speeds is that, due to the much larger leading-edge radius of the thick supercritical wing, the modified wing of the T-2C testbed aircraft proved to be able to provide a higher maximum lift without flaps than the original wing with flaps down.

Fig 22 : Airbus A330, one of the most used Commercial Aircraft which uses Supercritical Airfoil

Supercritical airfoils, when used for increasing wing thickness rather than speed, allow for new approaches to achieve high lift. The wing can enclose internal ducting for limited propulsive lift or permit more complex vane and slat arrangements. When the wing thickness is brought to that of conventional airfoils, the new shape of the supercritical sections introduces new limitations and opportunities in the design of flaps and controls.

The above advantages as have been explained above led to the Airbus A300 being the first commercial aircraft to make use of supercritical airfoil technology and every single Airbus aircraft that has followed through since such as the 310, 320, 330, 340, 350, 380 etc. incorporate it as well. With regards to Boeing, the 757 and 767 were the first to incorporate supercritical airfoils and it was later adapted onto next generation 737 and 747 variants as well alongside the 777 and 787.

7. Materials Used in the Manufacturing of Supercritical Airfoils

The Boeing 787, also known as the Dreamliner, is a wide body airliner manufactured by the Boeing aircraft company in the US. Often considered a revolution in the way that airliners have progressed ever since the Boeing 707, it incorporates many brand-new technologies that have made it a worldwide success with orders for 3000 and increasing. Besides innovations such as being made up mostly of composites (the only aircraft in the world where composites account for more than 50% of its total weight), one-piece barrel section, electric systems (replacing the conventional hydraulic ones of the past), chevrons to reduce noise levels emitted by the engine etc., one of the most important is its supercritical wing.

Being made up of mostly Carbon Laminates, Carbon Sandwiches, and other Composites, it's extremely light and has far more strength when compared to wings used on previous airliners made of conventional materials.

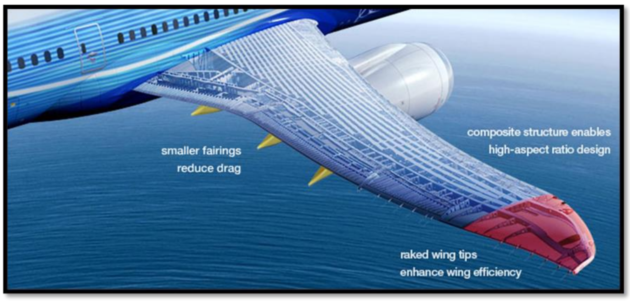


Fig 23 : Wing of the Boeing 787

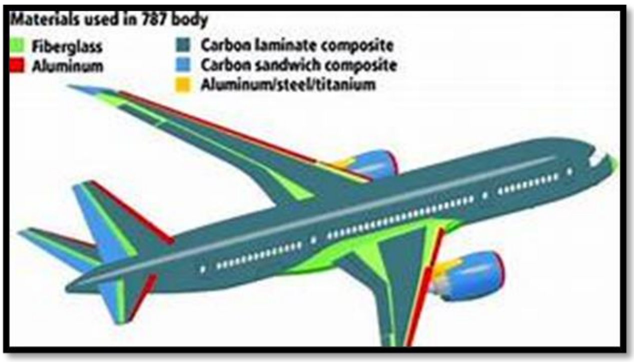


Fig 24 : Composites used in Aircraft

Fibreglass is a common type of fibre-reinforced plastic using glass fibre. The fibres may be randomly arranged, flattened into a sheet (called a chopped strand mat), or woven into a fabric. The plastic matrix may be a thermoset polymer matrix—most often based on thermosetting polymers such as epoxy, polyester resin, or vinyl ester—or a thermoplastic.

Cheaper and more flexible than carbon fibre, it is stronger than many metals by weight, is non-magnetic, non-conductive, transparent to electromagnetic radiation, can be molded into complex shapes, and is chemically inert under many circumstances. Applications include aircraft, boats, automobiles, bathtubs and enclosures, swimming pools, hot tubs, septic tanks, water tanks, roofing, pipes, cladding, orthopedic casts, surfboards, and external door skins.

Aluminium alloys

- The Aluminum-lithium alloys have been made for the aerospace industry to decrease the aircraft weight and thus enhance the performance of the aircraft.
- Al-Lithium alloys are advanced materials due to their high specific modulus, low density, and excellent fatigue and cryogenic toughness properties.
- Alloy 2091, 8090 sheet and Al-Mg-Si alloy 6013-T6 sheet have been evaluated for fuselage skin materials.

- GLARE, a structural laminate of glass fibers and aluminum alloy sheet, are all being evaluated for fuselage skin materials.

8. CONCLUSIONS

In this report, analysis was performed for both NACA 0012 and Supercritical airfoil at conventional AOA (between 2 and 6 degrees) at which normal commercial jetliners fly but keeping the density that of sea level and velocity 20 m/s which is the speed of our wind tunnel. We know that for commercial airplane having jet engines, the endurance is directly proportional to cl/cd and range is proportional to cl ^ (1/2)/cd from Breguet's formula for endurance and range respectively. Now, we can see that from 2-degree angle of attack to 6-degree angle of attack which has been considered as the normal allowance for nose up and nose down for commercial airplane only. In the climb regime considering the angle of climb to be between 2 to 6, the cl/cd of supercritical airfoil is dominating. Also, if we operate in steady level flight, the cl/cd value of supercritical airfoil is far much better than the NACA 0012. So, from 2-degree angle of attack to 6-degree angle of attack, the range and endurance of commercial aircraft having supercritical airfoil is much better than in the case of commercial airplane having NACA 0012. Since, the supercritical airfoil has higher Mach drag divergence number, so it can be used to achieve the higher cruise speed.

With this, we have proven that the supercritical airfoil indeed is much more efficient than the conventional NACA 0012 airfoil and is widely in use today in most commercial aircraft. Since, the range and endurance are more so this airfoil has been used for long distance flights. It will also have lower fuel consumption per unit time due to higher value of endurance. Comparing the data, we have acquired the values of Cl, Cd and obtaining the contours of velocity and total pressure magnitudes alongside vector velocities With this, we have proven that the supercritical airfoil indeed is much more efficient than the conventional NACA 0012 airfoil and is widely in use today in most commercial aircraft. The advantages provided by supercritical airfoil include :

- Less drag
- Higher cruise speed
- Lower fuel consumption
- Increase in range
- Increase in endurance

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