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Wing design for Jet model Dassault FALCON 7X

Jarugu Tirumala Sri Vidyananda Sagar[1] and Vignesvar Krish Subramani[2]
[1,2]PG Scholar, IPSA, ECOLE, D'INGENIURS, DE L'AIR ET DE L'ESPACE, Department, Paris, France
Email: jtsv.sagar@gmail.com
Email: tirumalasatya@gmail.com

Abstract: **Present-day wing design is more challenging in aerodynamics and there is a need for flights that consume less fuel and the necessity of self-healing for dynamic damages due to bird strikes, turbulence, etc., and aerodynamically improve the performance. Wings should be strong, stiff, durable, and lightweight to withstand aerodynamic forces. A comparative study of the use of variable geometry wings on one of the most famous business jet models, the Dassault Falcon 7X, is presented in this paper to address this problem. Here, the computational program STAR CCM+ CFD solver is used to conduct a comparative aerodynamic study of variable geometry wing advantage in the design of one of the most famous business jet modules Dassault FALCON 7X. The Falcon 7X is chosen in this work because of its structural features such as wings fitted with winglets, windshields, typical landing weight, etc., CFD study is done using self-healing material which can be auto repair under stimulus when the damage or fracture occurs in the time-of-service operation either aging or accidentally.**

Index Terms: **Swept wing, FALCON 7X, Super healing materials, CFD study.**

I. Introduction

In aeronautical engineering, variable geometry wing is a futuristic concept of wing design that helps the aircraft to morph its wing geometry while in-flight according to its different phases of flight which can enormously reduce the fuel consumption and can aerodynamically improve the performance of the aircraft. During World War II, German research came into light the concepts of the variable-sweep wing and they developed transonic flight and the Messerschmitt Me P.1101 made with a single-seat, single-jet fighter. This became the foreseen for the second generation of jet fighters for the third reach. X-plane Bell X-5[1] is a world-famous plane built based on the Me.P.1101 prototype designed after World War II with seized sheets.

There are four forces acting upon the flight during its fly, they are weight, lift, drag and thrust. The aircraft is pulled back down the earth due to weight as a force of gravity. Throughout the flight, the weight will slowly decrease as fuel is burned to power the engine. To explain the creation of lift, which is a key for the flying of an aircraft, Newton's laws of motion and Bernoulli's principle are used. The air flows smoothly around the wing making it deflect downward and causing the wing to lift. The drag limits the forward speed of an aircraft. Parasite and induced drag are the two types, parasitic drag directly proportional to the square of the speed of aircraft. For example, an aircraft traveling 120 knots will experience 4 times as much parasite drag as the same plane going 60 knots at the same altitude. In another way, the induced drag is higher at lower speeds and decreases as speed increases. This is because induced drag is worst when the airplane is flying at a high angle of attack like when we are flying slowly. The thrust and lift must be greater than the drag for an aircraft to fly. Further, there is a possibility of wing damage or ripped from the aircraft, damage may occur through the bird's strikes, or damage may occur through the severe turbulence or mechanical failure in the aircraft. The repairing of such damage is more difficult. Therefore, the design of the wing's platform, camber, aspect ratio, and the wing area is important in designing aircraft [2].

An angle of sweep is defined as the angle at which a wing is translated backward (or occasionally forward) relative to the root chord of it. An aircraft's sweep angle[3] assists when flying at supersonic or transonic speeds, resulting in the delaying of shock wave formation that results from the compression of air at high speeds.

Dassault Aviation introduced the Falcon 7x in 2001 as a new addition to the Falcon family of business jets. There is only one tri-engine business jet in service today that is as technologically advanced as the Falcon 7x. Compared with other business jets in its class, this new aviation technology consumes up to 30% less fuel, dramatically lowering operating costs and allowing multiple flights without refueling. With a Mach maximum operating speed (MMO) of 0.90, the Falcon 7X can cover 11,019 km. With a 7X, nearly 90% of its maximum takeoff weight can be landed. The landing weight of the 7X would result in an approach speed of only 104 knots (193 km/h). Upon landing and stopping, it takes just 2,070 feet (630 m). Due to this, it can reach airports that other planes cannot, such as airports with high temperatures, steep approaches, and noise restrictions. Falcon 7X's unique structural features are a longer fuselage than Falcon 900EX, winglets designed differently, and a windshield with a different structure than Falcon 900EX.

II. Wing

To withstand the aerodynamic[4] forces the wing should be strong, stiffness durable, and lightweight. Materials that are used in the early period and at the current moment are fabric material, metal alloys, and composite materials which are modern materials that are suitable for the aircraft parts but the damage that occurred through the above consequences are very severe and the repairing the damage is very difficult. The figures of the Swept wings and Dassault Falcon 7X are shown in Figure 1. and Figure 2.

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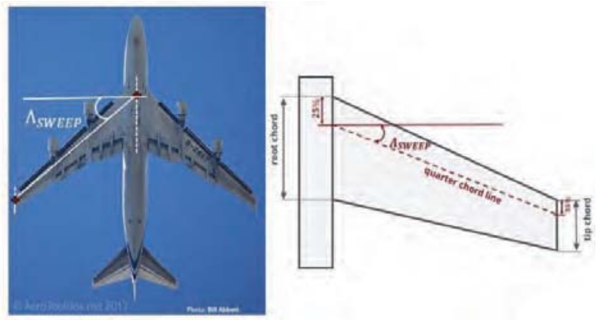

Figure 1. Swept wings

The problem of the self-healing [5-6] composite is the best source for the aircraft wing which will withstand aerodynamic forces. A pair of swept-back wing assemblies equipped with winglets are fitted to the FALCON 7X. An attachment of the type of piano is installed on each wing's lower section at the fuselage center. To attach the main landing gear to the wing, hinges are used.

Figure 2. Dassault Falcon 7X [7]

A. Fixed structure

Winglets, trailing edge, leading-edge, wing box (primary structure).

B. Movables elements

Three anti-iced slats (slat outboard, slat middle, and inboard slat), one spoiler (primary flight control system), one aileron (primary flight control system), two flaps (inboard and outboard flap), two airbrakes (airbrake inboard and airbrake outboard), and one main landing gear door.

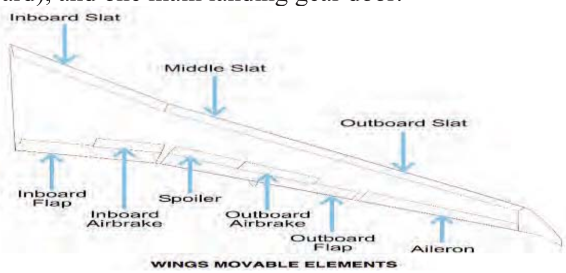

Figure 3. Falcon 7x wing

The Falcon 7x wing is shown in Figure 3. There are three major components of the wing box. They are spars, ribs, and skin panels. Wing boxes are the primary structural components of the wing, acting as both a structured box and as drag and lift resisting box. Furthermore, ground loads are applied from the main landing gear and jacking points. It is the fuselage that bears the load of the wings. There are three separate compartments in the fuel tank on the wing box. This structure is attached to the box front spar and is in front of it. Fixed trailing edge structures are attached to the wing box aft spar behind the trailing edge structures.

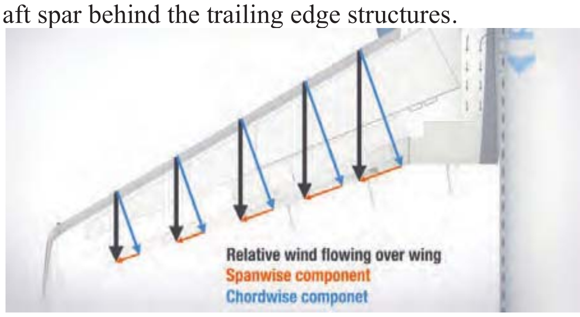

Figure 4. Swept wing spanwise flow

An airplane with a straight wing normally has airflow that runs parallel to the chord line of the aircraft. In contrast, only a small amount of air flows along the chord line of a swept wing. Another portion flows across the chord. This part is also known as spanwise flow. According to this, the airflow only accelerates in parallel to the chord line. Therefore, reducing airflow parallel to the chord line results in a reduction in lift caused by the wing. If the airspeed is high, this is not a problem since lift can be created by a small angle of attack. The issue occurs at slow speeds since lift is dependent on a high angle of attack. Although swept-wing aircraft are sometimes forced to fly at high angles of attack, even near the stalling point, most swept-wing aircraft ensure they do not do this by using advanced flap mechanisms, such as fowler flaps, and leading-edge slats.

Air has time to react at lower speeds, and spanwise pressure is practically applied to the wingtip. When the leading edge is pushed towards the wingtip, the leading edge is not the only thing pushing the airflow, the spanwise moving air beside it also pushes the airflow, so eventually, the airflow is moving toward the wingtip and not over it.

Consequently, sweeping the wings will disrupt the stall pattern. As spanwise flow approaches the wingtip, this creates a thickening of the boundary layer, resulting in a decrease in the wingtip's effective airspeed and stalling before the wing root. In this scenario, the airplane loses aileron control as soon as a stall occurs. For this reason, flow fences have been placed on the wings so that the spanwise flow is prevented from becoming too large.

III. Self-Healing Composites – Material Study

In recent developments, composite materials are used in place of metal alloys to provide lightweight and improved mechanical properties. To extend the lifetime of structures self-healing composite materials are enormously developed and used for different applications. There are two types called intrinsic healing and extrinsic healing based on the healing agent. Self-healing composite materials such as polymer matrix composite, ceramic composite (CMCs), metal matrix composite (MMCs), and cementitious composites are extensively used in various structures. This type of material is also advisable in the aerospace industry to repair the damage that may have occurred during the flight and increase the lifetime of the components including anti-corrosion and barrier coating. The approaches for this are:

1. The dispersed catalyst is combined with an encapsulated liquid agent
2. The catalyst and healing agent embedded in different capsule
3. The functionality of the matrix and healing agent both directly reacts with each other
4. The catalyst or the healing agent placed in the matrix as a separate phase under external stimulus.

Self- healing efficiency of composites are shown in table I.

TABLE I.
SELF-HEALING EFFICIENCY OF SOME COMPOSITES COMPARISON

Material	Healing approach	Loading condition	Property of interest	Efficiency
Epoxy - carbon fibres	Microcapsules	Width-tapered double - cantilever beam	Fracture toughness	80
Epoxy E-glass fibres	Epoxy E-glass fibres	Double-cantilever beam	Fracture toughness	60
Mendomer 401-carbon fibres	Reversible DA reaction	Three-point bending	Strain energy	94
2MEP4F polymer	Reversible DA reaction	Compact tension	Fracture toughness	83
Epoxy-SMA wires	Microcapsules and SMA wires	Tapered double-cantilever beam	Fracture toughness	77
Epoxy vinyl ester	Microcapsules	Tapered double cantilever beam	Fracture toughness	30
Epoxy-PCL phase	Mel table phase	Single-edge notched beam	Peak fracture load	>100
PDMS	Microcapsule	Tear test	Tear strength	>100

A.Self- Healing Aircraft wing

Materials that are used in the early period and at the current moment are fabric material, metal alloys, and composite materials which are modern materials that are suitable for the aircraft parts, but the damage occurred through the reasons mentioned consequences are very severe and the repairing the damage is very difficult. To overcome this problem, the self-healing composite is the best source for the aircraft wing which will withstand aerodynamic [8-10] forces. For instance, cut the branch in the tree, automatically the tree repairs it, and the new branch will grow. In the same way, anyone cuts the finger, it will bleed, and a scab is formed, and it will protect the damaged region as soon as the wound will be repaired automatically. The same approach will use in the self-healing composite materials. In manufactured composites, liquid fills the microcapsules. When the composite materials are used to manufacture aircraft wings, the liquid leaks from cracks resulting from microcapsule ruptures caused by the damage to the composite materials. The immediate reaction will take place and the chemicals harden the materials and fill the cracks and gluing also take place similarly. This process is known as polymerization and catalysis. Because of polymerization reactions in small molecules, the wound is sealed and known as monomers and used to join in a long chain called a polymer. The monomers released from the microcapsules contain reactive chemical groups called epoxides. These groups are three-membered ring structures, they will continuously react until the polymer is created. This process is known as curing, forming the high crossed structure that is like the undamaged composite. This healing can recover up to 100 percent of the material's mechanical strength repairing the damage causes the color change. The microcapsule could be designed to leak color when ruptured, signaling the area of repair. In general, when an aircraft wing is repaired might cause panic on board of flight. Testing of the healing agent is very important because the agent must be stable enough to last the aircraft's lifetime.

IV. CFD STUDY

The wing was first designed using the computational program CATIA. The design of the wing did not take into consideration devices and details such as flaps, wingtips, or the type of surfaces. The design of the wing followed the dimensions and tolerances of a real swept wing of our jet in question, Falcon 7x. This paper introduced the conceptualization of variable wing geometry with a range of 15 degrees to 40 degrees as the maximum sweep angle. The following Figure 4 and Figure 5. represents the Swept wing spanwise flow and design of the swept wings, being the first graph the corresponding to sweep angle of 32.5º(actual wing), the second one to 15º, and the wing of the right part to 40º.

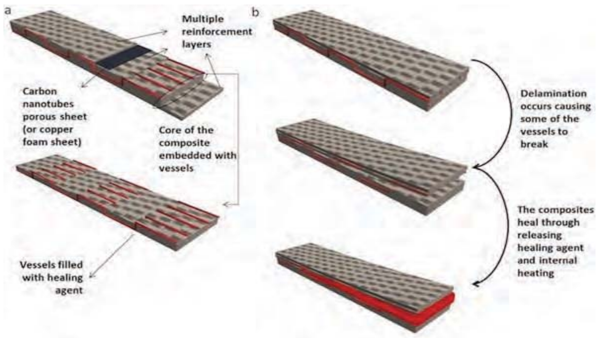

Figure 5. Self-healing process

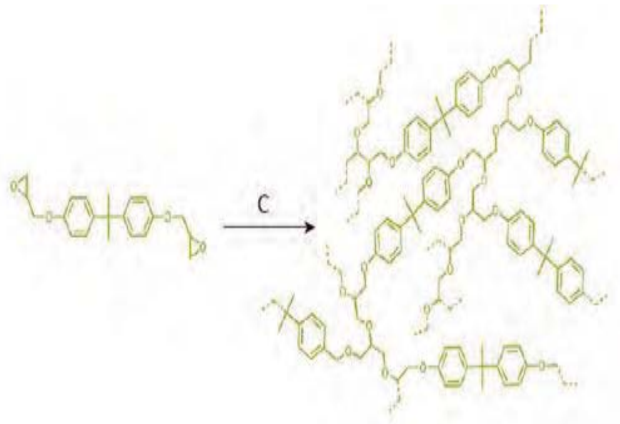

Figure 6. Colour change process

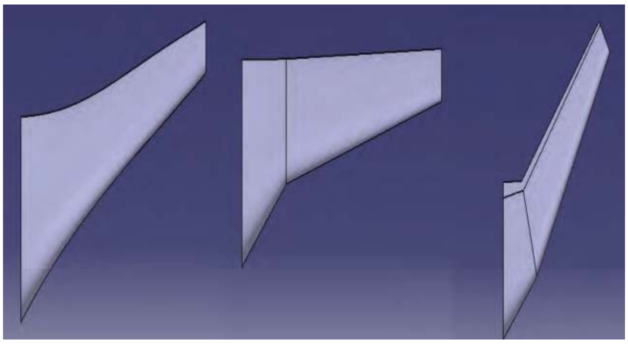

Figure 7. Swept wing designs by CATIA

The wind tunnel will be 60m x 25m x 25m in size as shown in Figure 6. The Figure 7. Shows Swept wing designs by CATIA. The wing is positioned inside the domain as a resemblance to a real wind tunnel testing. The meshing procedure was initiated after the domain was created and the wing imported in Star CCM+. The Figure 8. shows the Domain view in Star CCM+. Mesh continua parameters are shown in table II. The surface and volumetric mesh parameters were optimized in a way that would save simulation time and yield better residual convergence since a better mesh would save simulation time and yield better results. CFD analysis was implemented using assumptions for our fluid medium that were derived from the type of research. Our study is concerned with the transonic flow, which assumes that the air is a steady, compressible gas. Because our fluid the domain is a turbulent one. Choose the K-Omega's turbulent model to simulate airflow turbulent phenomena in a real environment. Consider the inlet region as a "Velocity inlet" of 0.8 Mach representing the cruise speed of the aircraft [11]. The outlet region is "Pressure outlet". The top, bottom, left and right regions of the domain region are "Symmetry plane" to simulate the atmospheric flow around the wing. The figures from Figure 9. to Figure 11. Shows the Generated volumetric mesh at different angles.

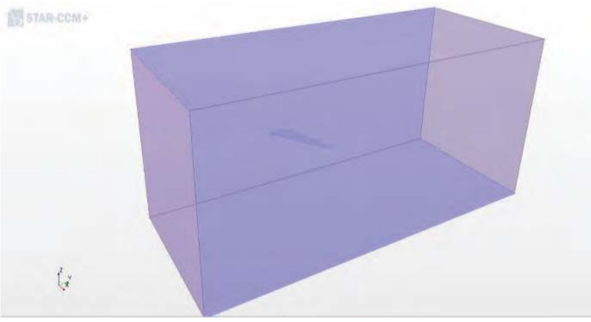

Figure 8. Domain view in Star CCM+

TABLE II.
MESH PARAMETERS

Mesh type	Polyhedral Mesher Surface Re mesher
Base size	5.0 m
Surface Size (Relative Minimum Size)	0.5
Surface Size (Relative Target Size)	50
Tet/Poly Density	0.5
Volumetric Controls – Block	Relative Size – 5%

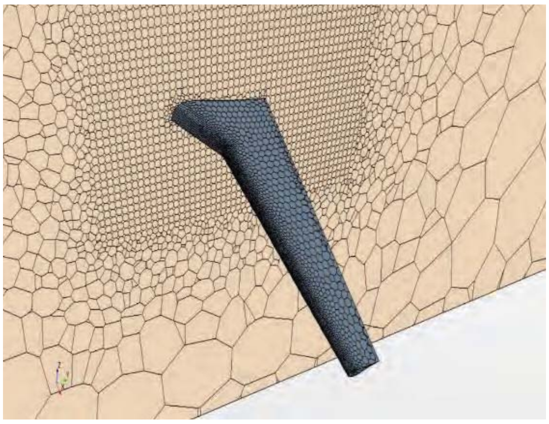

Figure 9. Generated volumetric mesh (sweep angle 15º)

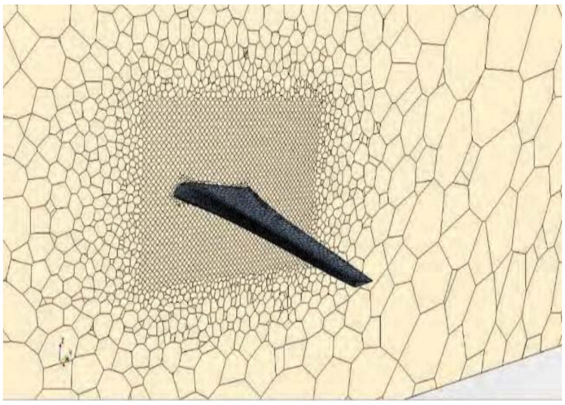

Figure 10. Generated volumetric mesh (sweep angle 32,5º)

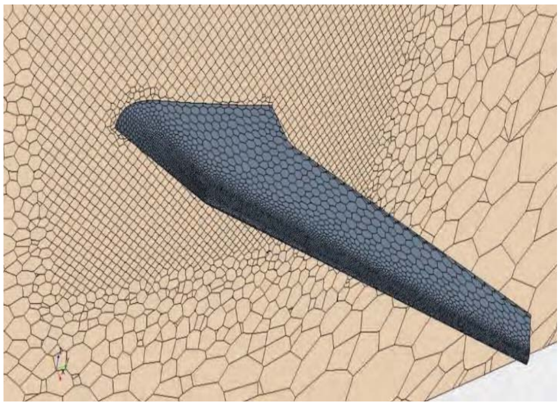

Figure 11. Generated volumetric mesh (sweep angle 40º)

A. Models chosen

- All y+ Wall Treatment
- Exact Wall Distance
- Fluid Film
- Coupled Energy
- Coupled Flow
- Gas
- Gradients
- K-Omega Turbulence
- Reynolds-Averaged Navier-Stokes
- SST (Menter) K-Omega

- Ideal Gas
- Steady
- Three Dimensional
- Turbulent

The boundary conditions of Wing are shown below in table III.

TABLE III.
BOUNDARY CONDITIONS

Boundary	Type
Top,Bottom, Left,Right	Symmetry plane
Outlet	Pressure outlet
Inlet	Velocity inlet

B. Initial conditions

Consider the cruise phase of the Falcon 7x to understand the transonic aerodynamics [8-10] of the aircraft. At a cruise altitude of 41000 ft and with a Mach number 0.8, the air standard properties at the cruise phase are the following. Table IV sows the Air standard properties at cruise altitude.

TABLE IV.
AIR STANDARD PROPERTIES

Cruise altitude	41000 ft
Cruise Mach	0.8 (274.399 m/sec)
Temperature	216.649 K
Pressure	17874.5 N/m^2
Speed of Sound	295.0728

V. RESULTS AND DISCUSSION

The Analysis is carried out in terms of pressure coefficient, lift coefficient, drag coefficient.

A. Pressure Contours

The airflow does not remain supersonic forever due to its speed exceeding Mach 1 and reversing back to capillary flow. At Mach numbers that are slightly above the critical value, shock waves begin to form on the wing.

Subsonic flight's pressure waves converge at this point, and they begin to affect the wing significantly. Essentially, this means that when pressure waves converge, the air in front of wings gets compressed. These can be visually observed on the pressure contour graphs, where the leading edge of the wing is where the pressure is greatest, then the bottom. Pressure waves are produced by the air as it passes along the wing at the speed of sound. The pressure waves cannot move forward in the supersonic flow of air, which means they are stationary. As a result, massive pressure is created. These large pressure changes also result in large forces and moments being transmitted to the wing as well. The plots above show that all three types of swept wings had negative lift coefficients. It is related to the previously discussed phenomena which happen at transonic and supersonic speeds. Figure 12. Shows the formation of shock waves. Different Pressure coefficients at different angles are shown in Figure 13 to Figure 15. Different Lift coefficients at different angles are shown in Figure 16 to Figure 18.

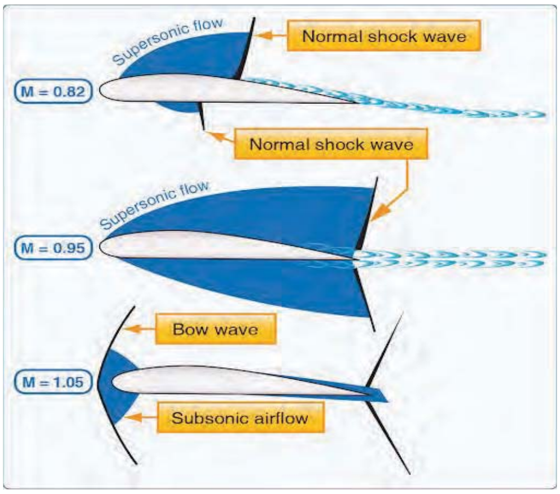

Figure 12. Formation of shock waves

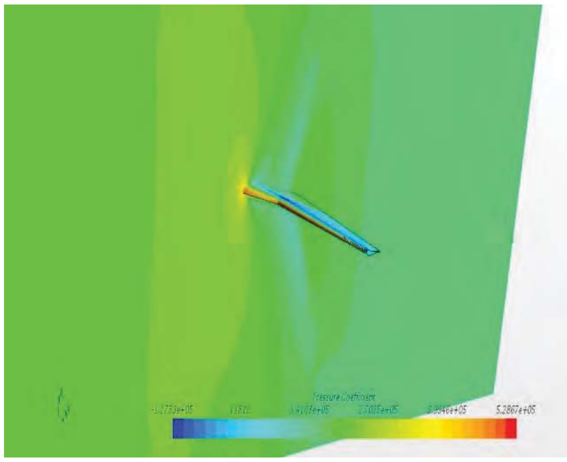

Figure 13. Pressure coefficient (sweep angle 15º)

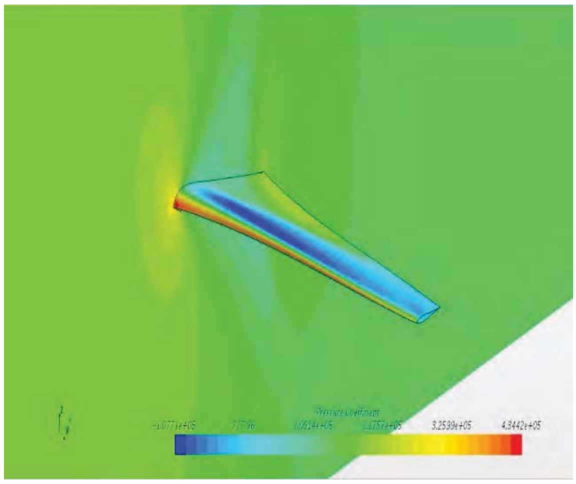

Figure 14. Pressure coefficient (sweep angle 32.5º)

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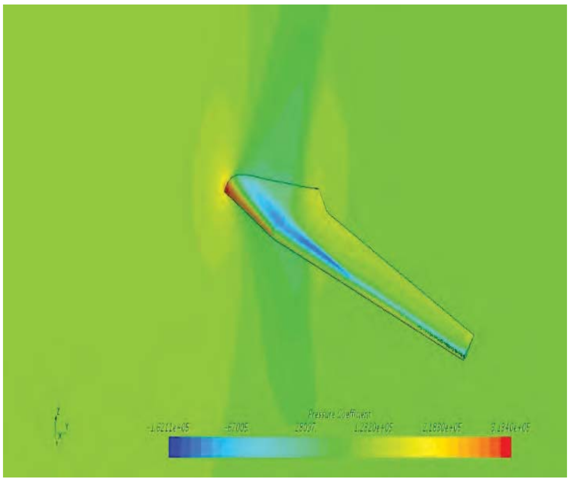

Figure 15. Pressure coefficient (sweep angle 40º)

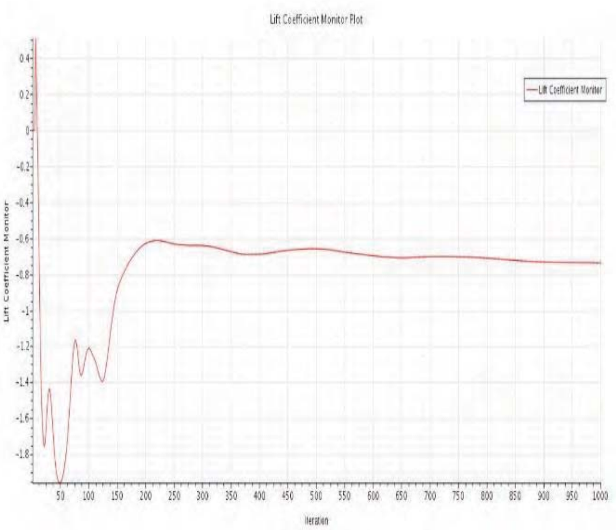

Figure 16. Lift coefficient (sweep angle 15º)

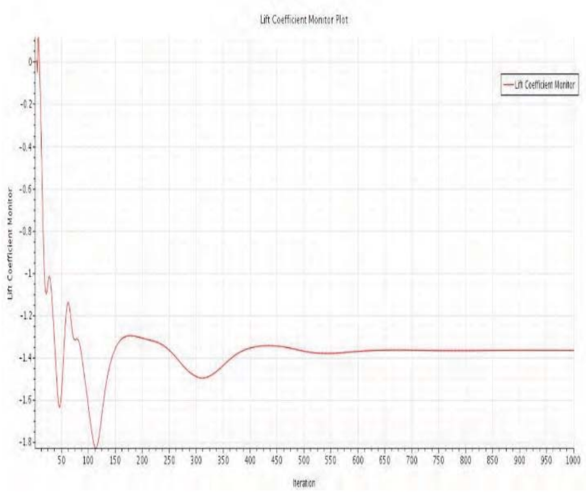

Figure 17. Lift coefficient (sweep angle 32.5º)

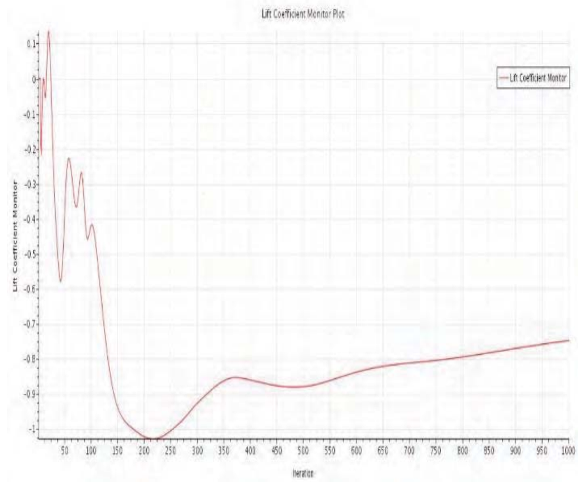

Figure 18. Lift coefficient (sweep angle 40º)

It is related to the previously discussed phenomena which happen at transonic and supersonic speeds. Upon reaching its critical Mach number, air passing over the wing surfaces forms a shock, which results in flow separation. As a result, the trailed edge of the wing experiences a high-pressure field, which negatively influences the lift coefficient.

For the sweep angle 15º, the lift coefficient has a value of 0.76 while for the actual wing it changes to 1.37. For the 40º swept wing, it does not show a proper convergence as for the previous ones, and the reasons why will be analyzed further through the residuals of the simulations. For this last wing, the lift tends to have a close value of 0.75 similar to the 15º swept wing. This drop-in lift can be explained by the theory of swept wings [12].

According to the graphs of the drag coefficient obtained, the drag coefficient value tends to decrease as the sweep angle increases, so they are inversely proportional. For example, for the 10º swept wing its corresponding drag coefficient value is equal to 2.3, and it is much bigger than the obtained one for the actual wing 32.5º which is about 1.64. For the last case, it was obtained a value of 0.37 represents a dramatic drop compared to the previous two cases.

The swept-wing thickness ratio and the airfoil thickness ratio are crucial factors in determining transonic drag levels. When the sweep angle is increased for a wing of a given thickness ratio, the drag level at higher speeds is also decreased significantly. It is essential to note that an aircraft designed to penetrate the low-supersonic speed range should have thin wings with swept tails. The advantage of this type of wing over a straight wing is that a swept-wing offers improved cruising Mach numbers while enabling robust aspect ratios to make maximum lift-drag values possible. There is a complex series of trade-off studies that must be carried out to arrive at the optimal sweep angle, aspect ratio, airfoil thickness ratio, and wing weight for adequate wing strength and stiffness.

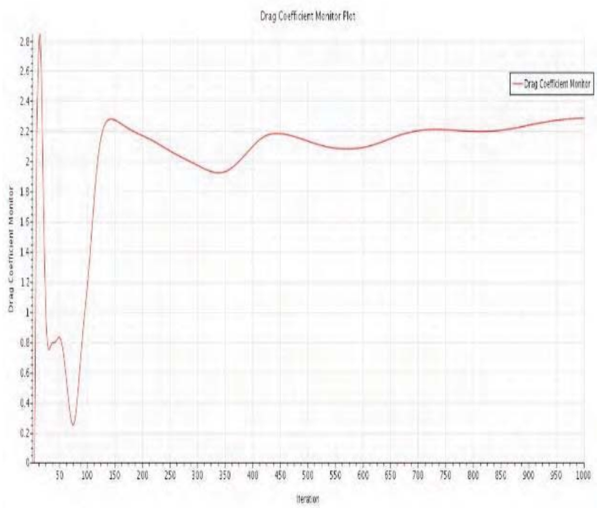

Figure 19. Drag coefficient (sweep angle 15º)

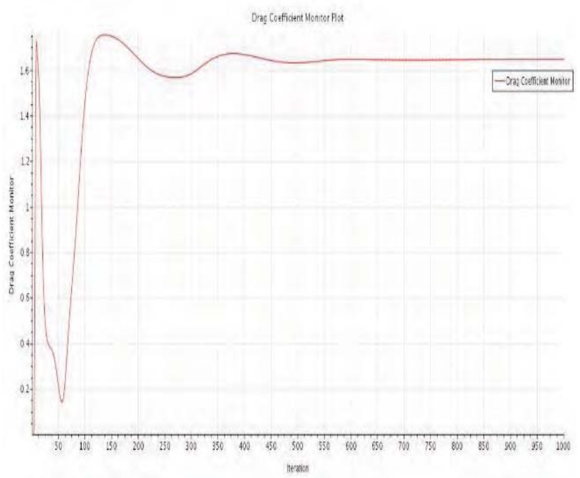

Figure 20. Drag coefficient (sweep angle 32.5º)

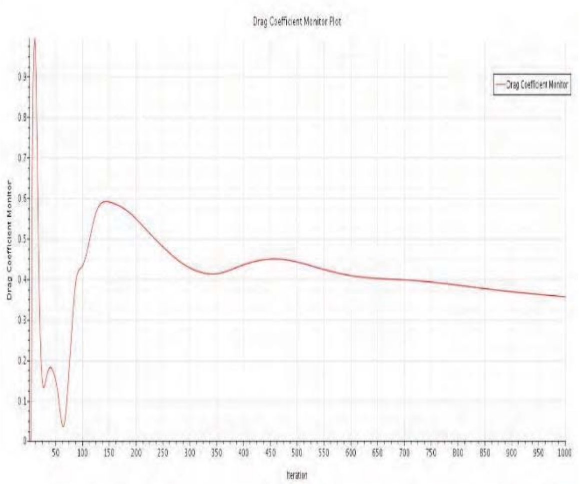

Figure 21. Drag coefficient (sweep angle 40º)

The figures from Figure 19. to Figure 21. Shows the drag coefficients at different angles.

A. Span Wise Pressure Distribution

The below plots illustrate pressure contours on three parts of the wingspan with an offset of 7m between each pressure contour plane. The Pressure coefficients along with wingspan at different angles are shown in Figure22 to Figure 24. The Residual graphs at different angles are shown from Figure 25. to Figure 27.

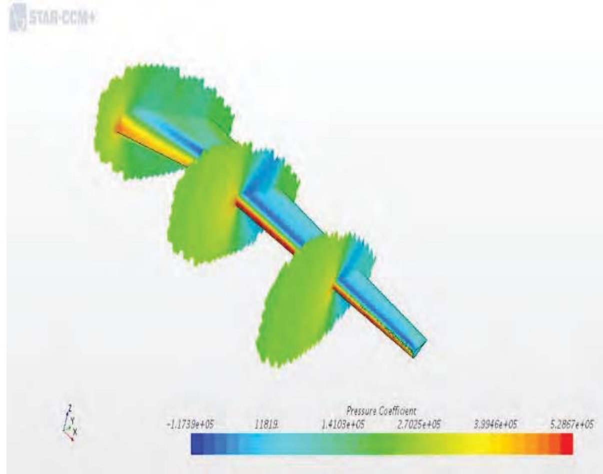

Figure 22. Pressure Coefficient along the wingspan (sweep angle 15º)

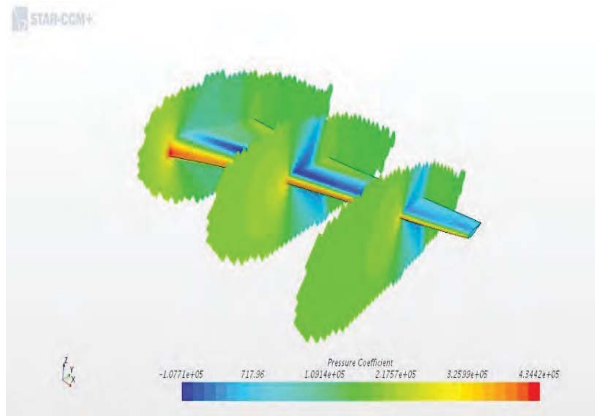

Figure 23. Pressure Coefficient along the wingspan (sweep angle 32,5º)

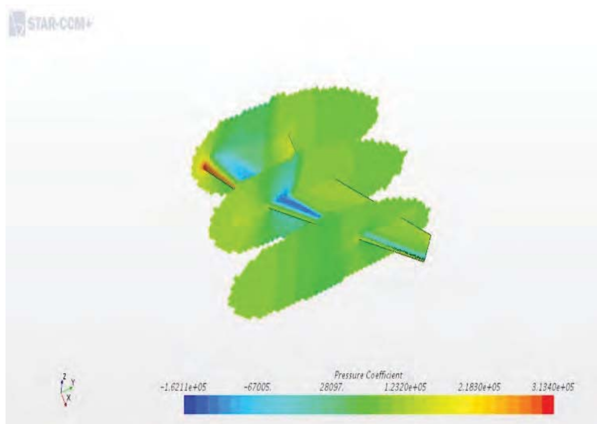

Figure 24. Pressure Coefficient along the wingspan (sweep angle 40º)

The contours images clearly show that as the sweep angle increases, the pressure coefficient decreases at the leading edge of the wings. This again confirms the fact that at transonic speeds, the increasing sweep angle decreases the form drag as the airflow passes comparatively easier than that of the less swept wings (15º here).

B. Residuals Graphs

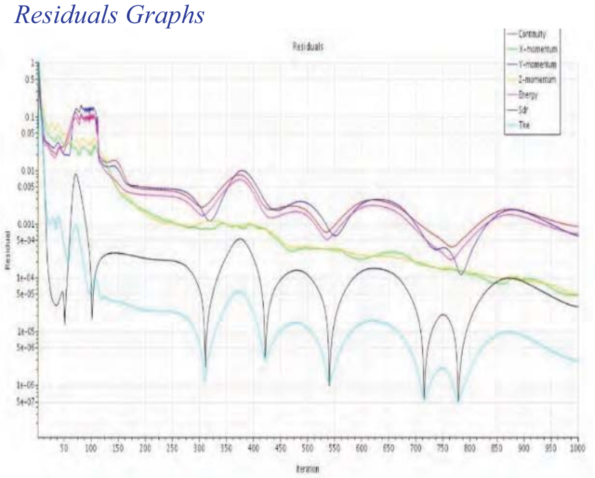

Figure 25. Residuals (sweep angle 15º)

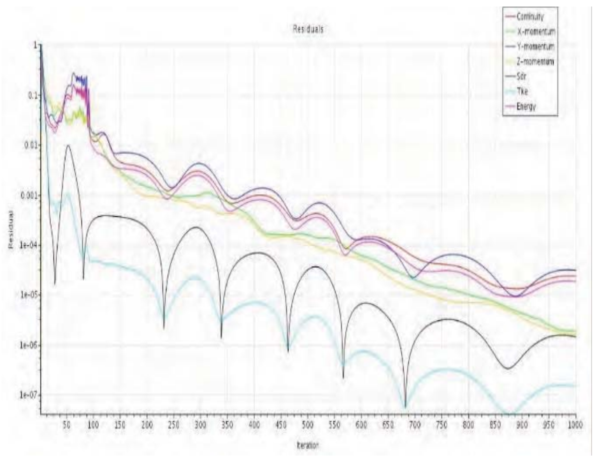

Figure 26. Residuals (sweep angle 32.5º)

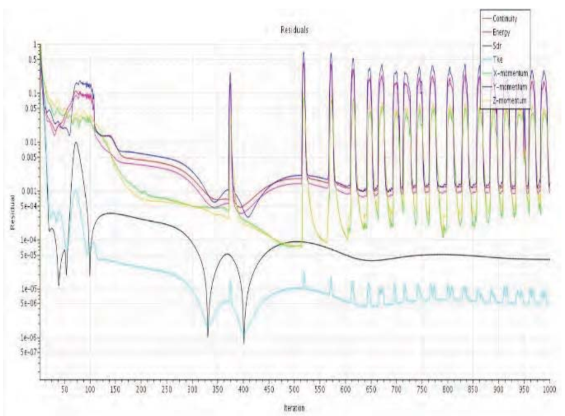

Figure 27. Residuals (sweep angle 40º)

An analysis of the drag and lift coefficients revealed that the convergence rates between the three cases were different. For the sweep angle 40º, the drag and lift coefficient tend to converge, but the behavior is not the same as in the other wings. Observed from the residual graph of a 40º swept wing, there are some unwanted perturbations after 500 iterations.

Those perturbations are due to the existence of a vortex shedding of the flow. This vortex shedding phenomenon happens when the attached flow over a body gets separated and therefore altering its dynamics. A wing's leading-edge vortices [13-15] have an important impact on its pressure distribution and, therefore, its aerodynamic performance, stability characteristics, and structural design loads.

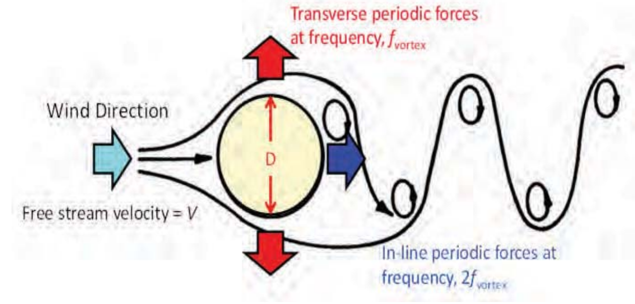

Figure 28. Vortex shedding phenomenon

Figure 28. shows the Vortex shedding phenomenon waveform. A very high negative pressure develops due to the expansion of the flow around the leading-edge pressure gradient. The boundary layer can easily separate due to this. A wing that is breaking up along its leading edge creates a region of concentrated vorticity in the lower surface of the boundary layer. As the vorticity opens, the upper side of the wing produces an intense side wash that travels towards the leading edge. A minimum of pressure results under these vortices, increasing lift in the form of a vortex on the upper surface of the wing. This could increase lift, generate forces and moments for flight control, and reduce drag by reducing the vortex effects. There are several ways to control the flow, including the control of flow separation, shear layer separation, and vortex formation. These phenomena are also dependent on the wing sweep angle, as well as their relative importance.

C. Boundry Layer

For that reason, as the sweep angle increases, the vortex starts to appear on the wing. As a result, sweeping wings with 40o swept are more likely to exhibit those kinds of perturbations than wings with 32.5º or 15º swept. Figure 29. to Figure 30. Shows Y+ distance or Boundary layer at different sweep angles. This line represents the distance between boundary layer walls, and the value gets larger at the trailing edge of the wing. Consequently, there is flow separation on the upper surface of the wing due to the supersonic flow. The supersonic flow is caused by the air traveling on the wing having an increase in velocity near the sound speed on both its upper and lower surfaces.

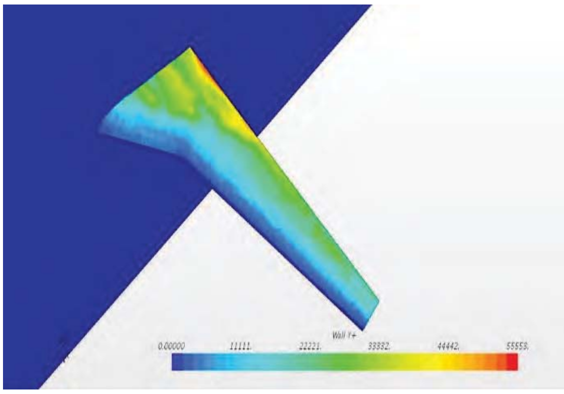

Figure 29. Y+ distance or Boundary layer (Sweep angle 15º)

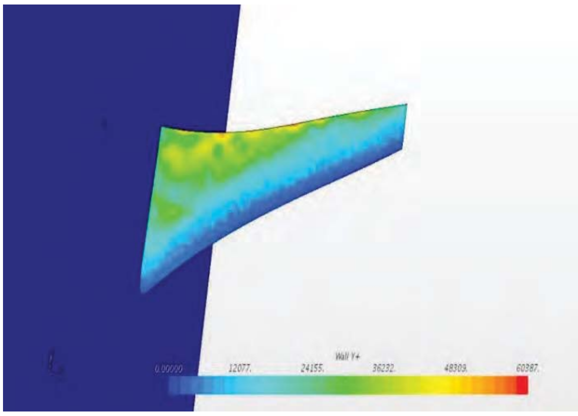

Figure 30. Y+ distance or Boundary layer (Sweep angle 32,5º)

This again confirms the presence of flow separation at the trailing edge of the 15-degree sweep angle wing which will lead to an unstable moment on the wing because of the stalling region formed by the flow separation regions. The stalling region reduces as it sweeps angle increases from 15 degrees to 40 degrees. Therefore, high-speed fighter jets like F-14 Tomcat and Mikoyan MiG-27 uses high swept wings for supersonic maneuvers and low swept wings for subsonic flight phases like takeoff, landing, and cruise.

VI. Conclusions

The CSV files exported from the STAR CCM+ CFD solver show that the Drag coefficients are significantly lower for the maximum swept wing at transonic speeds, but the Lift coefficients are better for the minimum swept wing. As a result, the undertaken concept of wing design will prove to be efficient for subsonic flight phases such as takeoff, landing, and climbing if we can employ a low sweep configuration. At transonic speeds, the maximum swept-wing configuration will improve its aerodynamic performance to a greater extent. To reduce the acceleration, the amount of air flowing parallel to the chord line must be reduced, by delaying the critical Mach number. This allows the aircraft to fly at higher Mach numbers before facing waves of drag. Therefore, sweeping the wing-back delays the supersonic flow from occurring over the wing by lessening the amount of acceleration over the wing. It is however important to consider the fact that a swept-wing always has more drag at slower speeds since low-speed drag is determined by the aspect ratio and by the span compared to chord, which in this case is shorter from tip to tip than a swept wing. Many airlines and commercial aircraft manufacturers hesitate to choose the morphing wings or the simple variable wings concept for its complex mechanical system which can lead to further increase in the MTOW (Maximum Take-off Weight) causing more demanding engine requirements and more fuel consumption. The recent research in the aerospace field under the fields of Flapping wings, Morphing airfoils, control surfaces, etc., which are highly futuristic and encourage aspiring students and engineers in exploring the underlying possibilities for a top-notch efficient future commercial aircraft

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