

# Wing Design for Jet Model Dassault FALCON 7X

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**Abstract**—In this paper a comparative aerodynamic study on the usage of variable geometry wing and designed for one of the most famous business jet model Dassault FALCON 7X is presented using the computational program STAR CCM+ CFD solver.

**Index Terms**— Swift Wing, FALCON 7X, CFD Study and Residual Graphs.

## I. INTRODUCTION

In aeronautical engineering, a variable geometry wing is a futuristic concept of wing design which helps the aircraft to morph its wing geometry while in-flight according to its different phases of flight which can enormously reduce fuel consumption and also can aerodynamically improve the performance of the aircraft.

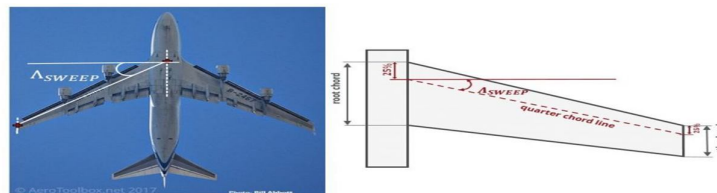


Figure 1: Swept wings

The sweep angle of a wing is the angle at which the wing is translated backward (or occasionally forwards) relative to the root chord of the wing. The sweep angle for an aircraft aids in flying at supersonic or transonic speeds which affects in the delaying of shock waves formation caused by the compressibility of air at high speeds. [2] Dassault Aviation presented a new addition the Falcon family of business jets, a Falcon 7x long-range jet in 2001. It is a technologically advanced business jet in the world and has a tri-engine. It is the new generation of business aircraft with fuel consumption 15-30% lower than other jets in its class, it dramatically lowers operating costs and allows multiple short and long flights without having to refuel. The Falcon 7X is designed to fly 11,019 km with a 0.90 Mach Maximum Operating Speed (MMO). The 7X can land at almost 90 percent of its maximum takeoff weight. A typical landing weight, the approach speed of the 7X is only 104 knots (193 km/h). It can land and stop in just 2,070 feet (630 m). As a result, it can access hundreds of airports other jets cannot, including those with hot and high conditions, steep approaches, and stringent noise restrictions. The particular structural features of Falcon 7X compared with the other aircraft in the Falcon family are: A fuselage longer than the falcon 900EX but with a similar diameter, new design of wings fitted with winglets, and the structure of windshields.

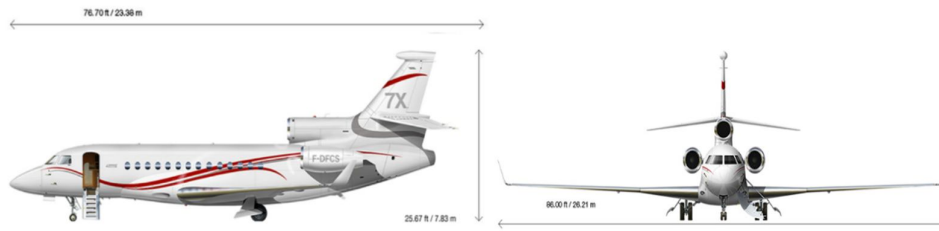


Figure 2: Dassault Falcon 7X

## II. WING

To withstand the aerodynamic forces the wing should be strong, stiffness durable, and lightweight. Materials that are used the early period and at the current moment are fabric material, metal alloys, and composite materials that are modern materials which are suitable for the aircraft parts but the damage occurred through the above consequences are very severe and repairing the damage is very difficult. To over the solution for the problem the self-healing composite the best source for the aircraft wing which will withstand aerodynamic forces. The FALCON 7X has two swept-back wing assemblies fitted with winglets. Each wing is connected to the fuselage center lower section by a piano-type attachment. The main landing gear is hinged and locked onto the wing. Each wing is composed of:

**Fixed structure:** Wing box (primary structure), leading-edge, trailing edge, winglets.

**Movables elements:** 3 anti-iced slats (slat inboard, slat middle, and slat outboard), 1 aileron (primary flight control system), 1 spoiler (primary flight control system), 2 airbrakes (airbrake inboard and airbrake outboard), 2 flaps (inboard and outboard flap) and 1 main landing gear door.

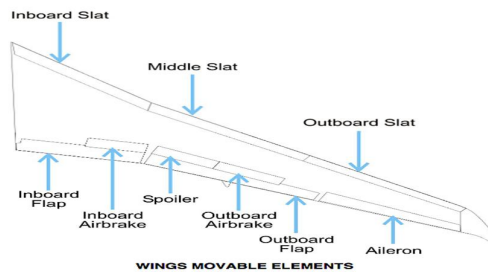


Figure 3: Falcon 7x wing

The wing box is consisting of spars, ribs and skin panels. The wing box is the primary structure of the wing and acts first as a structure box, withstanding inertia loads and aerodynamic drag and lift. The ground loads coming from the main landing gear and jacking points are received by this wing box. Wing loading is transmitted to the fuselage. A fuel tank which is a large section in wing box and divided into three compartments. The fixed trailing edge structure is located behind the wing box, is called the aft spar. The fixed leading-edge structure is located in front of the box called forward spar.



Figure 4: Swept wing spanwise flow

Normally, what happens on a straight wing airplane is that all of the airflows over the wing travels parallel to the aircraft's chord line. However, on a swept wing, only some of the air flows parallel to the chord line. The other part flows perpendicular to the chord and this is also called spanwise flow (Figure 4). It means, that only the component of airflow flowing parallel to the chord line accelerates. As a consequence, we have that by reducing

the amount of airflow flowing parallel to the chord line, we reduce the amount of lift the wing creates. At high speed, this is not a problem because the high airspeed requires a small angle of attack to create lift. The problem comes up at slow speeds since it is needed a high angle of attack to create lift. Although with this problem encountered when sweeping back, the wing can even force a very high angle of attack close to the stalling angle of attack, the swept wing aircraft usually counter this using extensive flap systems such as fowler flaps, and leading-edge slats. At lower speeds, the air has time to react and is practically pushed spanwise towards the wingtip. There is a noticeable effect at the wing root, the airflow is moving along the wing instead of over it because the airflow pushed not only by the leading edge, but also the spanwise moving air beside it. For that reason, sweeping the wings could affect the stall pattern. The amount of spanwise flow compounds as it approaches the wingtip, decreasing the wingtip's effective airspeed and thickening the boundary layer, that in turn, can cause the wingtip to stall before the wing root. This process means the airplane loses aileron control at the onset of the stall. However, to counter this, there are placed flow fences on the wing to stop the spanwise flow from building up.

### III. 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 nor 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. We introduced our conceptualization of variable wing geometry with a range of 15 degrees to 40 degrees as a maximum sweep angle. The following (Figure 5) represents the design of the swept wings, being the first graph the corresponding to sweep angle of  $32.5^\circ$  (actual wing), the second one to  $15^\circ$  and the wing of the right part to  $40^\circ$ . We have chosen a domain (Figure 6) visualized to be a wind tunnel of  $60\text{m} \times 25\text{m} \times 25\text{m}$  dimensions. The wing is positioned inside the domain as a resemblance to a real wind tunnel testing. Once created the domain in Star CCM+ and imported the wing, we proceeded with the meshing procedures. Mesh continua parameters are shown in table:2 We chose to minimize our surface and volumetric mesh parameters in a way to optimize the whole meshing procedure since an optimized mesh would save our simulation time and also yield better convergence of residuals. For our implementation of the CFD study, we ensured to make assumptions for our fluid medium depending upon the nature of the study we indulge in. The air fluid is assumed to be a steady, compressible gas of coupled flow since we are dealing with the transonic study. The K-Omega model of turbulent mode is chosen for our fluid domain since we need to analyses the real-world turbulent phenomenon of the airflow. Consider the inlet region as a “Velocity inlet” of 0.8 Mach representing the cruise speed of the aircraft. The outlet region is considered to be “Pressure outlet”. The top, bottom, left and right regions of the domain region are considered to be “Symmetry plane” so as to simulate the atmospheric flow around the wing.

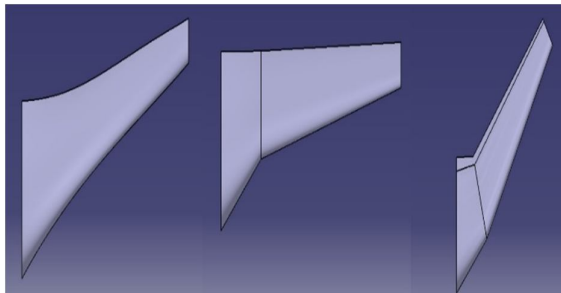


Figure 5: Swept wing designs by CATIA

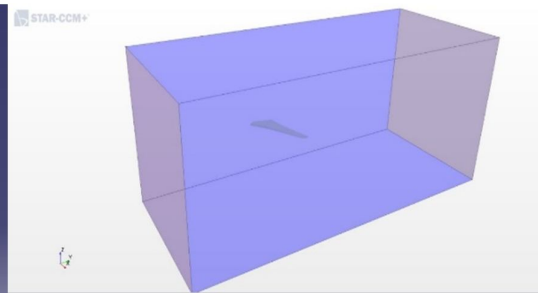


Figure 6: Domain view in Star CCM+

TABLE I. MESH PARAMETERS

|                                      |                                       |
|--------------------------------------|---------------------------------------|
| Mesh type                            | Polyhedral Mesher<br>Surface Remesher |
| 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%                    |

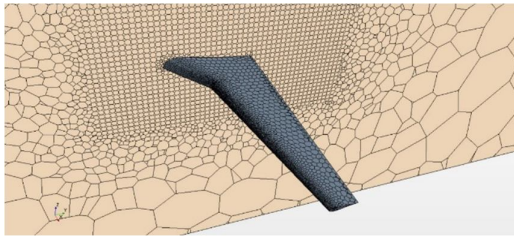


Figure 7: Generated volumetric mesh (sweep angle 15°)

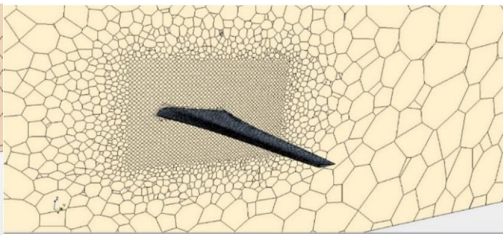


Figure 8: Generated volumetric mesh (sweep angle 32,5°)

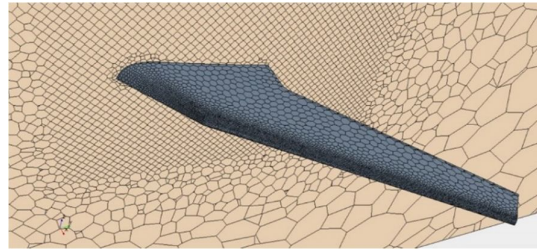


Figure 9: Generated volumetric mesh (sweep angle 40°)

*Models chosen:*

|                         |                                        |                         |                                      |
|-------------------------|----------------------------------------|-------------------------|--------------------------------------|
| • All y+ Wall Treatment | • Coupled Energy                       | • Ideal Gas             | • Coupled Energy                     |
| • Fluid Film            | • Coupled Flow                         | • Gradients             | • Gas                                |
| • Three Dimensional     | • SST (Menter)<br>K-Omega<br>Ideal Gas | • K-Omega<br>Turbulence | • Reynolds-Averaged<br>Navier-Stokes |
| • Exact Wall Distances  | • Steady                               | • Ideal Gas             | • Turbulent                          |

TABLE III. BOUNDARY CONDITIONS

| Boundary                       | Type            |
|--------------------------------|-----------------|
| Inlet                          | Velocity inlet  |
| Outlet                         | Pressure outlet |
| Top<br>Bottom<br>Left<br>Right | Symmetry plane  |

TABLE IV. AIR STANDARD PROPERTIES AT CRUISE ALTITUDE

|                 |                          |
|-----------------|--------------------------|
| Cruise altitude | 41000 ft                 |
| Cruise Mach     | 0.8 (274.399 m/sec)      |
| Temperature     | 216.649 K                |
| Pressure        | 17874.5 N/m <sup>2</sup> |
| Speed of Sound  | 295.0728                 |

*Initial Conditions*

We considered the cruise phase of the Falcon 7x to understand the transonic aerodynamics of the aircraft. At the cruise altitude of 41000 ft and with a Mach number 0.8, the air standard properties at cruise phase are the following.

IV. RESULTS AND DISCUSSION

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

### Pressure Countours

The airflow does not stay supersonic forever, due it speeds up and exceeds Mach 1, and then slows back down to a subsonic speed. The formation of shock waves comes up on the wing at a Mach number slightly in excess of the critical value. At this moment, the pressure waves associated with subsonic flight converge and begin to affect considerably the wing.

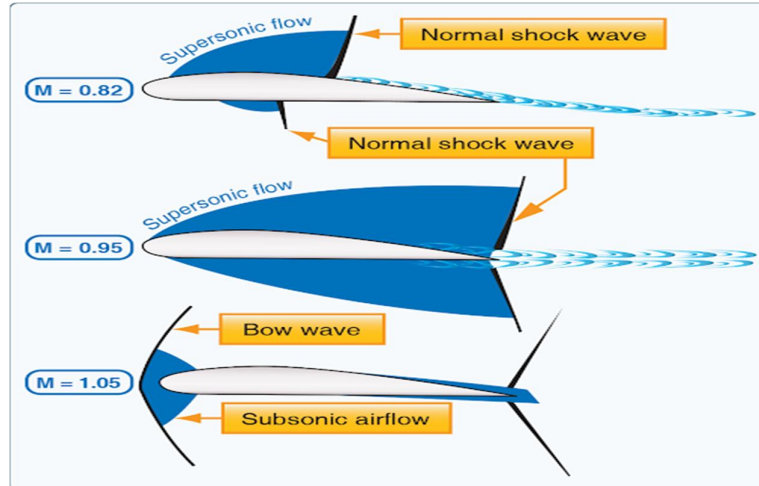


Figure 10: Formation of shock waves

This means that as the pressure waves converge, the air in front of the wing begins to compress. We can note this through the graphs of pressure contours where the leading edge of the wing has the maximum values of pressure, followed by the bottom part. The Pressure waves move with the speed of sound sends out when the air flows along the wing. That means the pressure waves cannot move forward through the supersonic airflow. Instead, they build up into massive pressure. This in general, cause not only large changes in the pressures on the wing but also in the forces and moments.

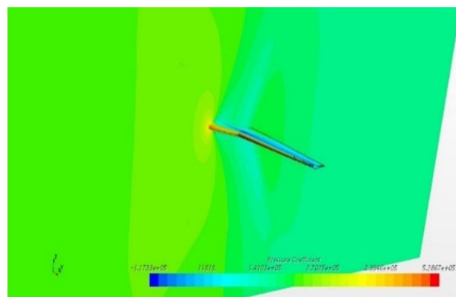


Figure 11: Pressure coefficient (sweep angle 15°)

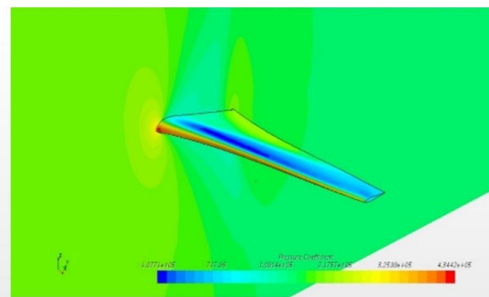


Figure 12: Pressure coefficient (sweep angle 32.5°)

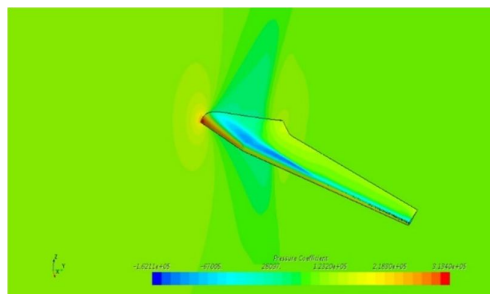


Figure 13: Pressure coefficient (sweep angle 40°)

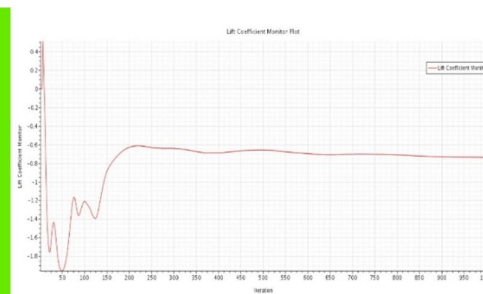


Figure 14: Lift coefficient (sweep angle 15°)

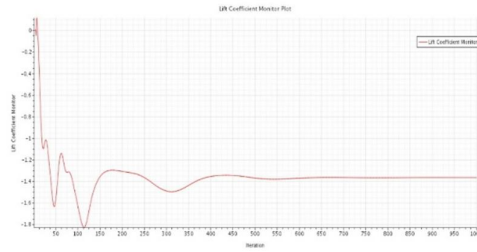


Figure 15: Lift coefficient (sweep angle 32.5°)

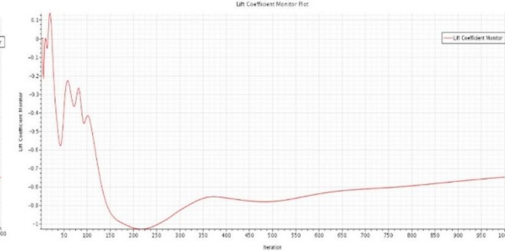


Figure 16: Lift coefficient (sweep angle 40°)

From the above plots of lift coefficients, we can see that all the three types of swept wings showed negative lift coefficient values. It is related to the previously discussed phenomena which happen at transonic and supersonic speeds. As the air passing over the upper surface of the wing reaches its critical Mach number, a shock is formed which leads to flow separation. This flow separation leads to high pressure field at the trailed edge of the wing which influences the negative value of the lift coefficient. For the sweep angle 15°, the lift coefficient has a value of 0.76 while for the actual wing it changes to 1.37. For the 40° 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 15° swept wing. For explaining this drop in a lift, we need to resort to the theory of swept wings. Analyzing the graphs of the drag coefficient obtained, we can note how the drag coefficient value tends to decrease as the sweep angle increases, thus, being inversely proportional. For example, for the 10° 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 32.5° which is about 1.64. For the last case, it was obtained a value of 0.37 which represents a dramatic drop compared to the previous two cases. The swept wing and airfoil thickness ratio play a key role in establishing the drag level at transonic speeds. For a given thickness ratio, if the sweep angle for a wing increases, it reduces drag level at speeds above Mach 1.0 significantly. It is important to remark that the wings of an aircraft designed to penetrate into the low-supersonic speed range should be thin and swept. If one compares this type of wing to a straight wing, the swept wing offers significant increases in cruising Mach number and at the same time, allows high enough aspect ratios with the use of wings of sufficient thickness for good values of the maximum lift-drag ratio. The sweep angle, aspect ratio, airfoil thickness ratio, and wing weight necessary for adequate wing strength and stiffness are all related and require a complex series of trade-off studies to arrive at an optimum design for a given set of requirements.

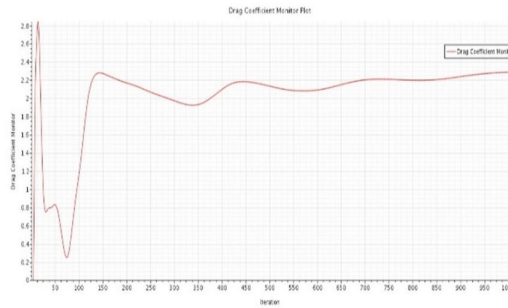


Figure 17: Drag coefficient (sweep angle 15°)

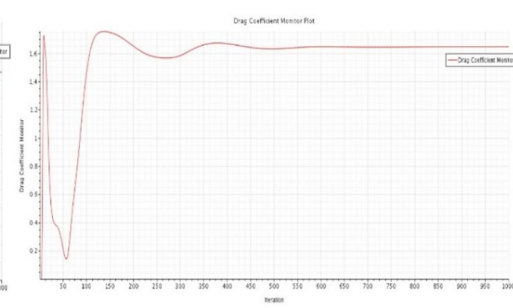


Figure 18: Drag coefficient (sweep angle 32.5°)

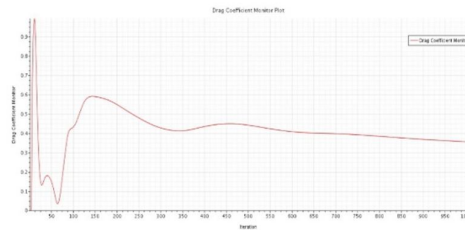


Figure 19: Drag coefficient (sweep angle 40°)

### Span Wise Pressure Distribution

From the below plots we can see the pressure contours at three parts of the wing span with an offset of 7m between each pressure contour planes.

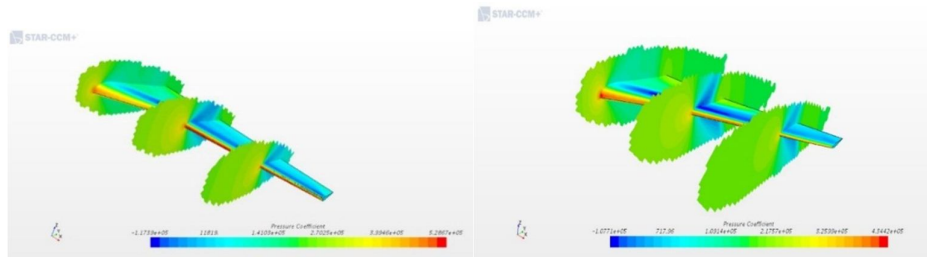


Figure 20: Pressure Coefficient along the wingspan (sweep angle 15°)

Figure 21: Pressure Coefficient along the wingspan (sweep angle 32,5°)

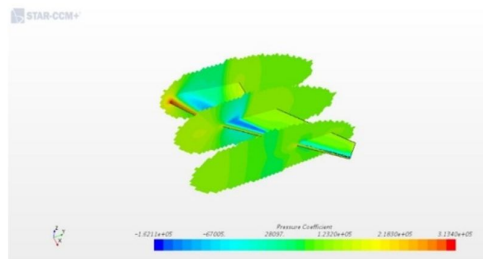


Figure 22: Pressure Coefficient along the wingspan (sweep angle 40°)

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 air flow passes comparatively easier than that of the less swept wings (15° here).

### Residuals Graps

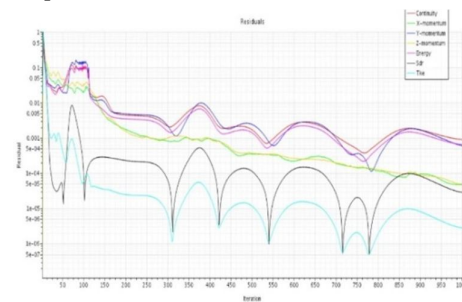


Figure 21: Residuals (sweep angle 15°)

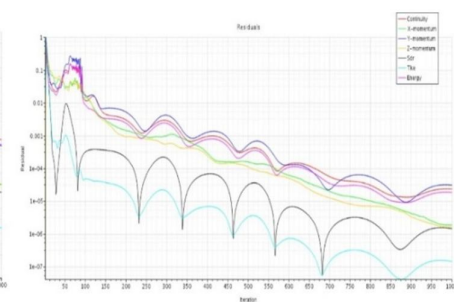


Figure 24: Residuals (sweep angle 32.5°)

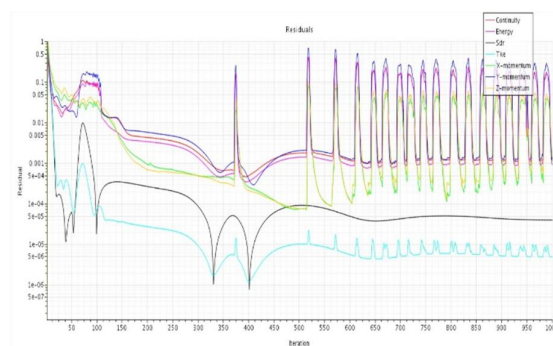


Figure 24: Residuals (sweep angle 40°)

During the analysis of the drag and lift coefficient, we identified a difference in the convergence between the three cases. For the sweep angle  $40^\circ$ , the drag and lift coefficient tend to convergence but the behavior is not the same as in the other wings. It is observed that from the residual graph for the  $40^\circ$  swept wing, we find some perturbations after the 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. These leading-edge vortices have a considerable influence on the wing pressure distribution and, hence, on the aerodynamic performance, stability characteristics, and structural design loads.

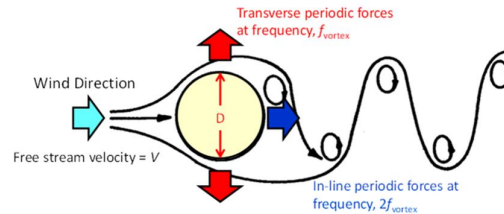


Figure 25: Vortex shedding phenomenon

The expansion of the flow going around the pressure gradient of leading-edge results in a very high negative pressure. This can cause easily a boundary layer separation. When this occurs, the lower surface of the boundary layer leaves the wing along the leading edge and rolls up into a region of concentrated vorticity. Strong vorticity draws air above the wing into the spiral sheets and induces a strong side wash on the upper surface of the wing that is directed toward the leading edge. As a consequence, there is a minimum pressure under the leading-edge vortices on an upper surface of the wing, and an increase in a lift that it is also called vortex lift. In that way, controlling the vortex phenomenon may have benefits, such as enhancement of lift force, generation of forces and moments for flight control, and reduction of drag. Control methods include manipulation of flow separation from the wing, separated shear layer, vortex formation. In addition, the occurrence and relative importance of these phenomena strongly depend on the wing sweep angle.

#### Boundary Layer

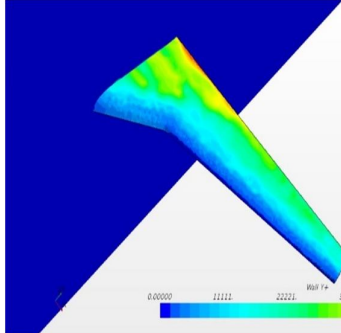


Figure 26: Y+ distance or Boundary layer (Sweep angle  $15^\circ$ )

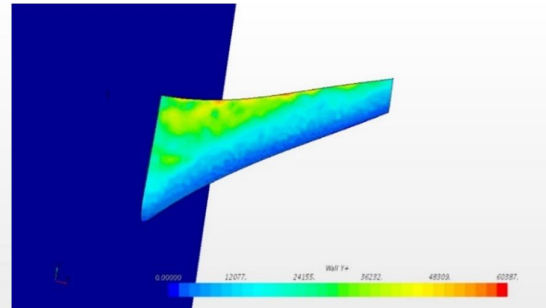


Figure 27: Y+ distance or Boundary layer (Sweep angle  $32.5^\circ$ )

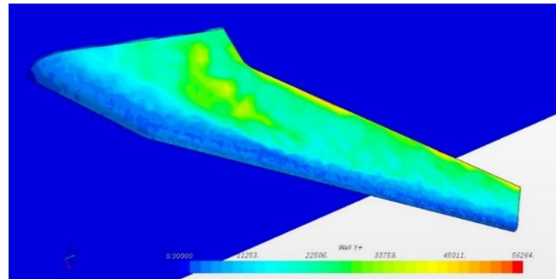


Figure 28: Y+ distance or Boundary layer (Sweep angle  $40^\circ$ )

For that reason, as we increase the sweep angle, the vortex starts to appear on the wing, thus, for  $40^\circ$  swept wing we find those kinds of perturbations more noticeable than for the  $32.5^\circ$  and  $15^\circ$  swept wing. The contours show

the boundary layer wall distance and the value gets more at the trailing edge of the wing. This explains the flow separation because of the supersonic flow on the upper surface of the wing. This supersonic flow is the air traveling on the wing which has had an increase in velocity to the speed of sound on the upper and lower surface of the wing. From all the three figures: 26,27,28 we can clearly see that the Wall Y+ value decreases at the trailing edge of the wing with increasing sweep angles. 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 t sweep angle increases from 15 degrees to 40 degree. This is why 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.

## V. CONCLUSIONS

By plotting the CSV (Comma Separated Values) files exported from the STAR CCM+ CFD solver, we can clearly see that the Drag coefficients significantly reduce for the maximum swept wing at transonic speeds and also the Lift coefficients show better results for the wing with the minimum swept wing. Hence, we can say the undertaken concept of wing design prove to be really efficient if we can use low sweep configuration for demanding subsonic flight phases like takeoff, landing, and climbing. While at transonic speeds, maximum swept wing configuration will improve its aerodynamic performance to a greater extent. When the amount of airflow flowing parallel to the chord line is reduced, it is possible to reduce the amount of acceleration and delay the critical Mach number. As a result, an airplane is able to fly at a higher Mach number before it starts to create a wave drag. This means that sweeping the wing back helps delay the supersonic flow by reducing the amount of acceleration over the wing. Nevertheless, it is important to note that a swept wing always has more drag at lower speeds, since low speed drag is correlated with the aspect ratio and the span compared to a chord that in this case, it is shorter from tip-to-tip than the same wing that is not swept. Many airliners and commercial aircraft manufactures hesitate to choose the morphing wings or the simple variable wings concept for its complex mechanism system which can lead to further increase in the MTOW (Maximum Take-off Weight) causing more demanding engine requirements and more fuel consumption. But the recent researches in the aerospace field under the fields of Flapping wings, Morphing airfoils and 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.

## REFERENCES

- [1] R. Das,C. Melchior, K.M.Karumbaiah “Self-healing composites for aerospace applications”,. University of Auckland, Auckland, New Zealand; 2National Polytechnic Institute of Chemical Engineering and Technology (INP-ENSIACET), Toulouse, France.
- [2] Self-healing aircraft wings: a dream or a possibility? <https://www.scienceinschool.org/content/self-healing-aircraft-wings-dream-or-possibility>
- [3] Nirmal Prabhakar, Embry-Riddle, “Design and Dynamic Analysis of a Variable-Sweep, Variable-Span Morphing UAV” Aeronautical University - Daytona Beach
- [4] Ajoy Kumar Kundu, “Aircraft Design “,. Cambridge Aerospace Series,. Cambridge University Press, 2010.
- [5] Mark Drela, “Flight Vehicles Aerodynamics”, Massachusetts Institute of Technology, 2014.
- [6] Dietrich Kuchemann, “The Aerodynamic Design Of Aircraft “,.American Institute of Aeronautics and Astronautics, Inc. 2012.
- [7] Bertin, John J Cummings, Russell M., “Aerodynamics for Engineers “, Pearson Education Limited, 2014.
- [8] ” Business And Commercial Aviation, Pilot report Dassault Falcon 7x “,.The MacGraw Hill Companies, 2006 .
- [9] Charles J. Donlan and Joseph Weil Langley,“Characteristics Of Swept Wings At High Speeds”, Naca National Advisory Committee For Aeronautics. Aeronautical Laboratory Langley Field.