Fluid-Structure Interaction Study of a Wing Structure

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Abstract - *Fluid-Structure Interaction is the interaction between movable or deformable part with the surrounding fluid. The surrounding fluid exerts pressure on the structure thus causing it to deform and the deformation of the structure in turn causes changes in the fluid flow. The interaction between fluid and flexible structure play a vital role in many engineering applications, due to various undesired phenomena's such as buffeting, fluttering and collapsing of bridges, fluid-excited vibration of tall building and wind turbine blades, and flutter in aircraft wings . FSI analysis is very important for the efficient and lightweight structure of various aircrafts components especially the wings. In this project we have designed a scaled down model of a wing of rectangular planform and wish to carry out the static analysis on the wing to determine the aerodynamics forces, stresses acting on it and the frequency of various modes. Following this, we have conducted the analysis in the coupled mode and compared it with the results previously obtained to observe the flow pattern and how the structure behaves when the wing is considered to be flexible.*

Key Words: **Fluid-Structure Interaction, CFD, Coupling, Wing, Flexible.**

1.INTRODUCTION

Fluid-Structure Interaction is the multi-physics coupling between the laws governing fluid dynamics and that of structural mechanics. The phenomenon of FSI is characterized by interactions between the deformable or moving body and the surrounding fluid. These interactions can be of stable or oscillatory form. When a structure is present in the fluid flow, stresses and strains are exerted by the fluid flow on the solid body these forces lead to the deformation of the structure. The deformation produced can be small or large depending on the characteristics of the flow such as pressure and velocity. The structural deformation caused in the solid due to the fluid in turn has an effect on the flow and the pressure fields of the fluid, the deformation causes a change in the flow properties and thus Fluid-Structure Interaction is the coupling between fluid dynamics and structural mechanics.

The two disciplines involved in this multi physics coupling is fluid dynamics and structural dynamics, which can be described by the relations of continuum mechanics. Therefore, FSI is a subset of multi physics applications and is defined well by Zienkiewicz and Taylor.

Coupled systems and formulations are those applicable to multiple domains and dependent variables which usually describe different physical phenomena and in which neither domain can be solved while separated from the other and neither set of dependent variables can be explicitly eliminated at the differential equation level.

When the fluid encounters a solid body it produces a deformation in the solid, if the deformation produced is small and the variation with respect to time is slow, the fluid's behaviour is not affected much by the deformation of the structure, on the other hand, if the deformation produced is large and the variation with respect to time is fast, the fluid's behaviour is highly affected by the deformation of the structure which causes the formation of pressure waves in the fluid thus affecting the pressure fields of the fluid. Therefore, it is very important to account for this factor to ensure the safety of the structure.

Fluid-Structure Interactions is very crucial and has to be taken into consideration for the design of many engineering systems such as aircrafts, spacecrafts, engines and bridges. In structures comprising of materials susceptible to fatigue, these oscillatory interactions can be very catastrophic. Fatigue can be described as a cyclic loading which leads to the development of cyclic stresses and strain in the material, under this cyclic loading at a critical stage the material fails. An aircraft wing during flight is subjected to various time dependent loads which results in deformation of the wing and oscillation in the wing which is a challenge for the design of the structure and for its safety, the loads acting on the wing can cause the formation of a crack at a region of high stress concentration which propagates till it reaches a maximum value after which the aircraft wing structure will fail due to fatigue. Thus aircraft wings are structures which are highly susceptible of fatigue and so consideration of FSI for the aircraft wing structure is of great importance. Due to various undesired phenomenon such as fluttering, buffeting in aircrafts the interaction between fluid and flexible aircraft wing have extreme importance.

The Fluid-Structure Analysis conducted would provide a deeper insight about the interaction between the solid structure and fluid when the structure is considered flexible and the results of the FSI Analysis is compared with that of static structural analysis where the aircraft wing is considered as a rigid structure and the variation in the results are observed and the results are compared.

1.1 Methodology

1. Designing the wing of the desired dimension on CATIA V5.
2. Importing the model into ANSYS to carry out analysis.
3. Perform Static Analysis to determine aerodynamic characteristics.
4. Perform Static Structural and Modal Frequency Analysis to determine the stress concentration, deformation and the natural frequency of the wing structure
5. To carry out Fluid Structure Interaction Analysis on the wing structure using ANSYS R18 and by applying different materials..
6. Comparison of the results obtained from static structural analysis to that obtained by fluid structure interaction for different materials.

2. SELECTION OF AIRFOIL

Eppler 421, Eppler 423, FX 74, NACA 2415 and Selig 1223 met the required criteria. The airfoil polars are plotted using XFLR5 at a Reynolds Number of 250000 which corresponds to a velocity of 15m/s. Upon comparison between the five airfoils Eppler 423 and Selig 1223 were shortlisted since they had the best aerodynamic characteristics. In order to select between the airfoils Eppler 423 and Selig 1223 a pugh matrix is employed where fabrication, C_{lmax}, C_l/C_d are the parameters chosen for the selection.

The airfoils are rated on a scale of 1 to 5 based on their compatibility to the requirements, where 5 indicates the highest rating and 1 indicates the lowest rating respectively. Fabrication and C_l/C_d are considered to be the most important parameters hence they are given a rating of 5 followed by C_{lmax} which is rated at 4. Taking the ratings into considerations, Eppler 423 and Selig 1223 are rated after carefully evaluating the polars and their ease of fabrication. It is also noticed that it is easier to fabricate Eppler 423 due to its relatively thick trailing edge when compared to Selig 1223. The Pugh matrix is shown in the Table 1 below:

Table -1: Airfoil Selection Pugh Matrix

Parameters	Weight	Airfoil	
		Eppler 423	Selig 1223
Fabrication	5	5	4
Cl max	4	3	4
Cl/Cd	5	5	4
Total	-	62	56

Eppler 423 is the finalised airfoil since it has a higher total score of 62 compared to that of Selig 1223 which has a total score of 56. Eppler 423 is given the highest rating for fabrication since it has a thicker trailing edge in comparison to S1223. It also has the highest lift to drag ratio. Hence E423 is chosen.

The aerodynamic characteristics of E423 obtained from XFLR5 airfoil polars is specified in Table 2 below:

Table-2: Eppler 423 Characteristics

C_{lmax}	C_{lmin}	C_{l0}	C_{dmin}	Stall Angle
2.0035	0.0419	1.1905	0.0192	12.25°

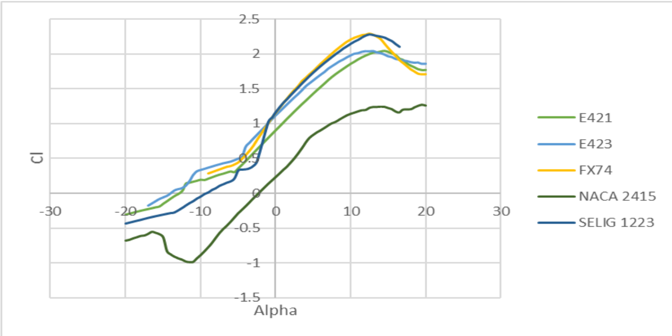

Fig-1 : C_l Vs Alpha

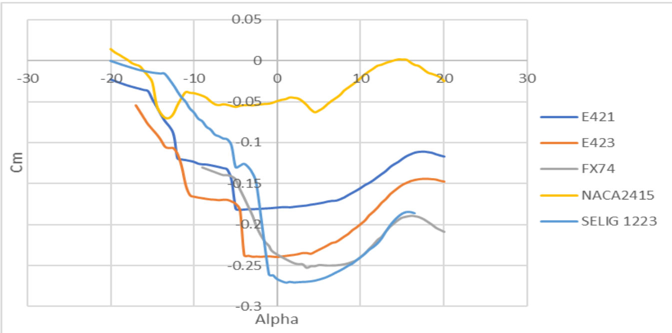

Fig-2 : C_m Vs Alpha

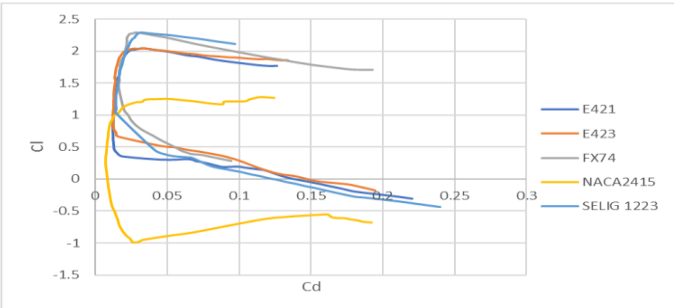

Fig-3 : C_l Vs C_d

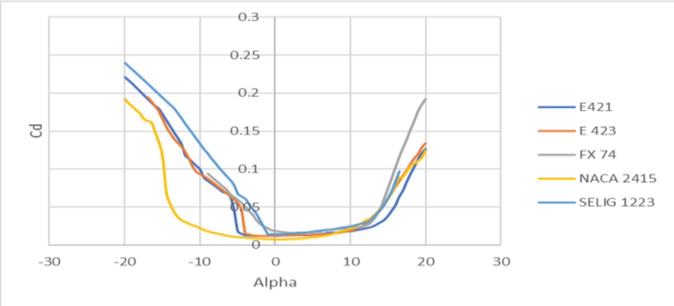

Fig-4 : C_d Vs Alpha

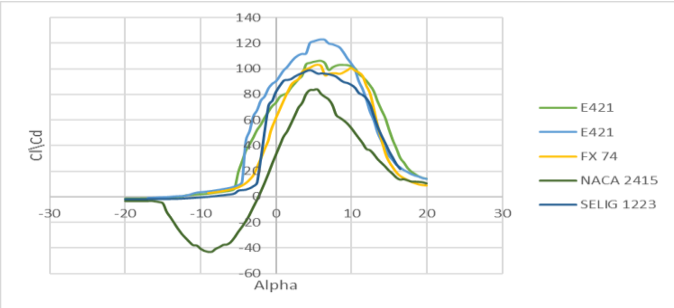

Fig-5 : C_l/C_d Vs Alpha

3. WING CONFIGURATION

The airfoil coordinates are imported onto CATIA V5. The wing is of rectangular plan form and has 7 ribs, 10 stringers of circular cross section and 2 spars of I cross-section . The wing is of a span of 1.52 m, the wing span is the distance measured from one wingtip to the other wingtip. The chord is 0.254m, the chord of the wing is the distance measured from the leading edge to the trailing edge of the wing. The aspect ratio is 6, the aspect ratio is the ratio of the span of the wing to its mean chord. The dimensions of the wing are specified in Table 3 below:

Table-3 : Wing Dimensions

Planform	Span	Chord	Aspect Ratio
Rectangular	1.52m	0.254m	6

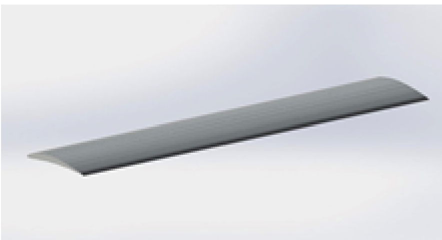

Fig-6 : Wing Structure with Skin

Fig-7 : Wing Structure without Skin

4. MATERIAL SELECTION

The materials to be applied for the wing was selected such that there was one alloy, one composite and one fibre used so as to compare the behavior of different material under similar loadings. The materials used in this project, their composition and their physical properties are specified in the Table 4 below:

Table-4 : Material Selection

Material	Composition	Density	Tensile Ultimate Strength	Poisson Ratio
Glass Fibre Reinforced Polymer (GFRP)	Reinforcement- E-glass fiber 200 GSM, Matrix- Epoxy: Araldite LY556, Hardener– HY951	2630 kg/m^3	2080 MPa	0.28
Aluminium Metal Matrix Composite (AMC)	Continuous fibre reinforced- AMC	3400 kg/m^3	1230 MPa	0.32

5. BOUNDARY CONDITIONS

5.1 Static Structural Analysis

The weight of a conventional two-seater aircraft is taken into consideration for this present work. In order to decrease the computation time the weight is scaled down in a ratio of 10:1. One end of the wing is considered fixed and the wing is considered as a cantilever beam. Wings are the important structures in an aircraft and carry 80% of the total load of the aircraft. The following calculations are carried out to determine the loading:

Two seater aircraft's average weight = 937 kg

Scaled down weight, w = 93.7 kg

Force acting on aircraft = w x g

= 937 N

Load that acts on the wings = 80% of the total load

= 750 N

Therefore, a uniformly distributed load of 750 N is applied on the spars of the aircraft.

This force is defined as a vector which is directed in the downward direction. This is shown in figure 8 below:

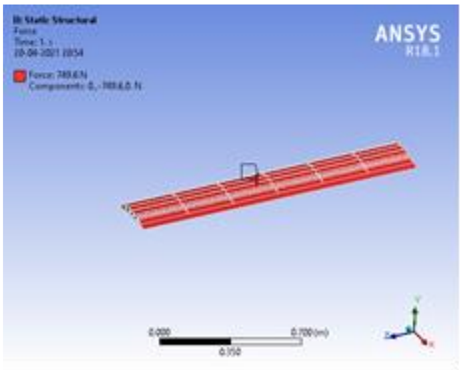

Fig-8 : Load acting on the structure

5.2 CFD Analysis

1. Viscous Model: There are various viscous models which can be chosen to carry out the CFD analysis.
2. Materials : The fluid selected is air. The properties of which are predefined in the fluent application.
3. Boundary conditions :
Velocity Inlet = 15 m/s in the x direction
Pressure Outlet = 0 Pa
Under the boundary conditions the inlet is selected as a velocity inlet. The magnitude and direction of the velocity is specified. The outlet is selected and given as pressure outlet and the magnitude of pressure is specified as 0 Pa.
4. Reference value: Under this section of the boundary condition the following is specified.
Compute from : inlet
Select body : solid
5. Monitors : Lift and Drag Monitors are turned on. The report monitors are used to obtain the plots for lift and drag for the specified number of iterations. Print to console mode is selected.
6. Initialisation : Hybrid Initialization
7. Calculation : Run for 500 iterations.

5.3 One Way FSI Analysis

In one way FSI the fluent module is coupled with the static structural module and the pressure loads from the fluent module are imported onto static structural module and the analysis is carried out. The solution algorithm used for One Way Fluid Structure Interaction Analysis is shown in Figure 9.

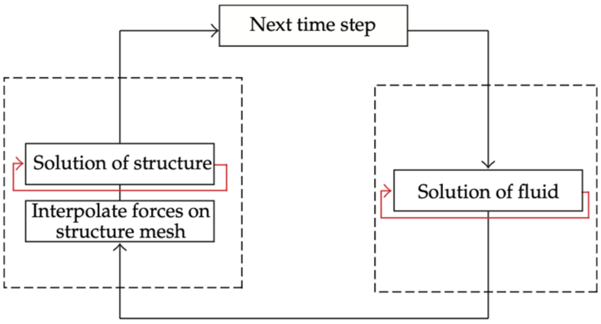

Fig-9 : Solution Algorithm for One Way FSI

- The Fluent Module setup is as given below:

1. Viscous Model: There are various viscous models which can be chosen to carry out the CFD analysis.
2. Materials : The fluid selected is air. The properties of which are predefined in the fluent application.
3. Boundary conditions :
Velocity Inlet = 15 m/s in the x direction
Pressure Outlet = 0 Pa
Under the boundary conditions the inlet is selected as a velocity inlet. The magnitude and direction of the velocity is specified. The outlet is selected and given as pressure outlet and the magnitude of pressure is specified as 0 Pa.
4. Reference value: Under this section of the boundary condition the following is specified.
Compute from : inlet
Select body : solid
5. Monitors : Lift and Drag Monitors are turned on. The report monitors are used to obtain the plots for lift and drag for the specified number of iterations. Print to console mode is selected.
6. Initialisation : Hybrid Initialization
7. Calculation : Run for 500 iterations.

- The Static Structural Module setup is as given below:

1. Fixed Support : The geometry of the fixed support has one face such that one end of the wing is fixed and the wing acts as a cantilever beam.
2. Loading : A uniformly distributed load of 750 N is applied on the upper face of the wing in a vertically downward direction.
3. Fluid-Solid Interface : The geometry of the fluid solid interface has 4 faces. The fluid solid interface defines the faces over which fluid and solid interacts, therefore, except for the fixed face of the wing all the other faces form the interface between fluid and solid. The fluid-solid interface is shown in figure 10 below:

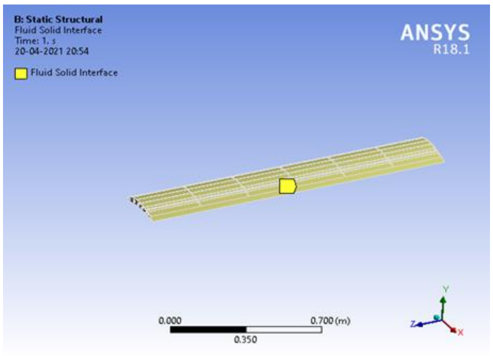

Fig-10: Fluid-Solid Interface

4. Imported Pressure : The pressure loads are imported from Fluent Module onto the structure so as to determine the deformation of the structure as an effect of the pressure filed of the surrounding fluid. Care must be taken to ensure that orientation of the structure is the same as that defined in the Fluent Module so as to ensure that the loads are imported accurately. 100% of the pressure loads is imported on the structure. The imported pressure is shown in figure 11 below:

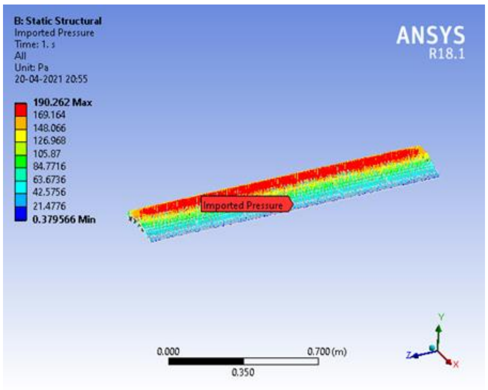

Fig-11 : Imported Pressure

6. GRID INDEPENDENT STUDY

The grid independence study was conducted on ANSYS R18.1 Workbench to nullify the influence of the grids or their sizes on the computational results. The study is conducted by varying the element size. The element size is first considered as 0.03 and the number of elements and number of nodes for the element size is noted and the lift obtained is 57.27 N. The size of the element is decreased to 0.02 and the number of elements and number of nodes corresponding to this element size is noted and the lift obtained is 57.5 N. The size of the element is further decreased to 0.01 and the number of elements and number of nodes corresponding to this size is noted and the lift obtained is 55.6 N. The theoretical lift is calculated using :

$$L = \frac{1}{2} C_L \rho v^2 S$$

Where, ρ : Density (kg/m³) = 1.225 kg/m³

L : Lift (N)

C_L : Lift Coefficient = 1.1 (at 0º Angle of Attack)

S : Wing Reference Area (m²) = 0.386 m²

v : Velocity (m/s) = 15 m/s

On calculation, the theoretical lift is found to be 58.5 N. Since the lift obtained using element size 0.02 is 57.5 N which is the closest to the theoretical value, the element size of 0.02 is selected. The table below indicates the values of number of elements, number of nodes and the lift value for the element size 0.03, 0.02 and 0.01 respectively.

Table-5 : Grid Independence Study

Element Size	0.03	0.02	0.01
Number of Elements	581694	851661	1899629
Number of Nodes	113250	160226	338613
Lift (N)	57.27	57.5	55.6

7. RESULTS

7.1 Static Structural Analysis Results

- **Total Deformation**

The total deformation of the structure is the square root of the sum of squares of the displacements in the x, y, z- axis. The wing is considered as a cantilever beam and thus the maximum deformation produced is towards the free end which is indicated by the red contour, the minimum deformation is towards the fixed end and is indicated by the blue contours. The total deformation results are obtained at two angles of attack that is for 0° and for 12.25° since 12.25° is the stall angle. The total deformation at 0° and 12.25° for the two materials is as given in the Table 6 below:

Table-6 : Total Deformation

Angle of Attack	Material	Total Deformation
0°	GFRP	Min : 0 m
		Max : 0.097645 m
	AMC	Min : 0 m
		Max : 0.011758 m
12.25°	GFRP	Min : 0 m
		Max : 0.095569 m
	AMC	Min : 0 m
		Max : 0.011862 m

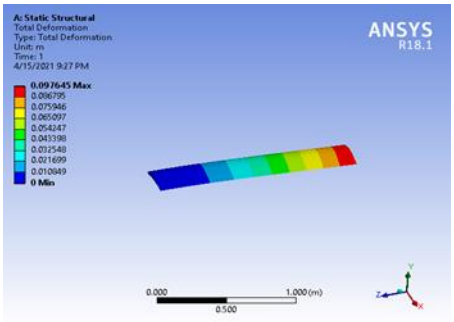

Fig-12 (a) : Total Deformation for 0º for GFRP

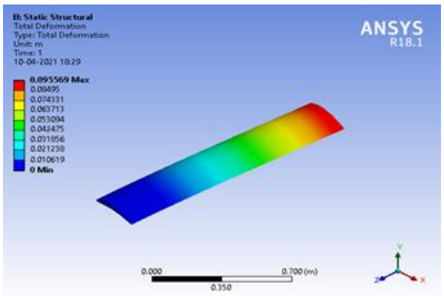

Fig-12 (b) : Total Deformation for 12.25º for GFRP

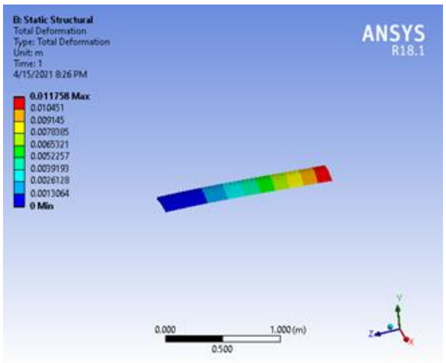

Fig-13 (a) : Total Deformation for 0º for AMC

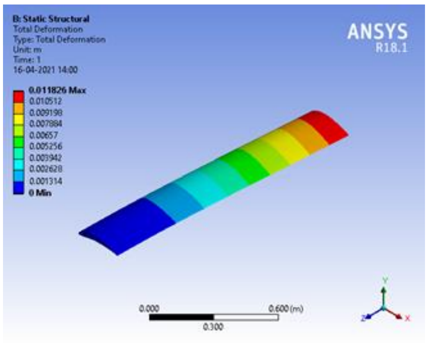

Fig-13 (b) : Total Deformation for 12.25º for AMC

- **Equivalent Von-Mises Stress**

It is used to indicate the stress distribution over the span of the wing, it is used to determine if a given material will yield or fracture. According to the Von-Mises Criterion if the Von-Mises stress of a material under load is equal or greater than the yield limit of the same material under simple tension then the material will yield. The maximum stress is towards the fixed end of the wing and is indicated by the red and light green contours. the minimum stress is towards the free end and is indicated by the blue contours. The Equivalent Von-Mises stress values for 0º and 12.25º angle of attack is tabulated below in Table 7:

Table-7 : Equivalent Von-Mises Stress

Angle of Attack	Material	Equivalent Von-Mises Stress
0º	GFRP	Min : 9964.1 N/m²
		Max : 1.467e8 N/m²
	AMC	Min : 8063 N/m²
		Max : 1.534e8 N/m²
12.25º	GFRP	Min : 10551 N/m²
		Max : 1.519e8 N/m²
	AMC	Min : 10097 N/m²
		Max : 1.524e8 N/m²

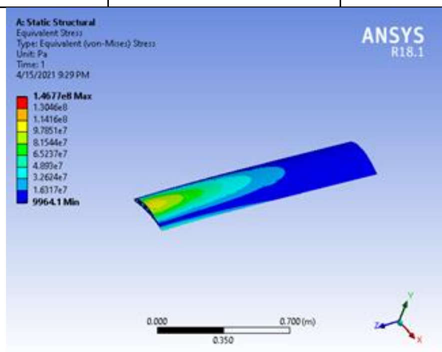

Fig-14 (a) : Equivalent Von-Mises Stress for 0º for GFRP

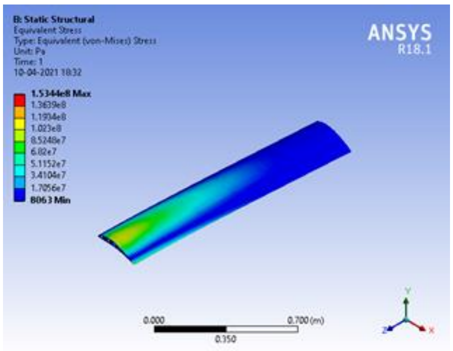

Fig-14 (b) : Equivalent Von-Mises Stress for 12.25º for GFRP

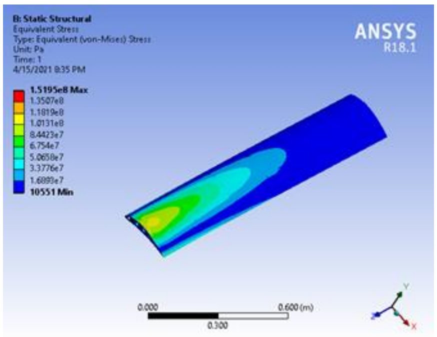

Fig-15 (a) : Equivalent Von-Mises Stress for 0° for AMC

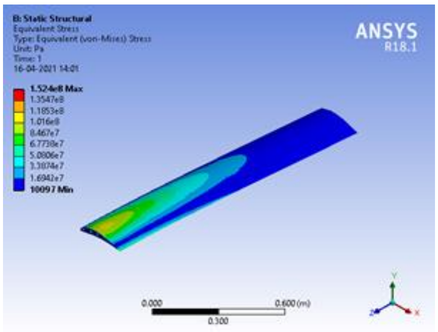

Fig-15 (b) : Equivalent Von-Mises Stress for 12.25° for AMC

- **Equivalent Strain**

It is used to define the state of strain in solid materials. Strain is defined as the ratio of change in length of the structure to the original length therefore strain is a dimensionless quantity. The maximum strain occurs at the fixed end and is indicated by red and light green contours. The minimum strain is indicated by blue. The Equivalent strain values for 0° and 12.25° angle of attack is tabulated below in Table 8:

Table-8 : Equivalent Strain

Angle of Attack	Material	Equivalent Strain
0°	GFRP	Min : 6.3949e-7
		Max : 0.0048713
	AMC	Min : 6.0537e-7
		Max : 0.0050926
12.25°	GFRP	Min: 7.6022e-8
		Max : 0.00060781
	AMC	Min : 7.5983e-8
		Max : 0.00060959

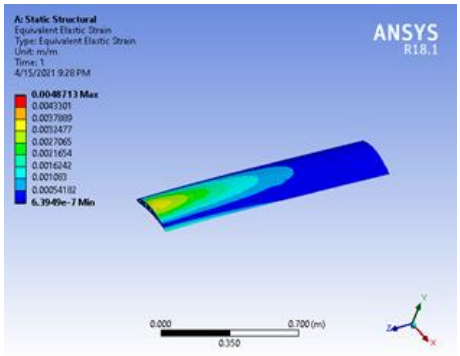

Fig-16 (a) : Equivalent Strain for 0° for GFRP

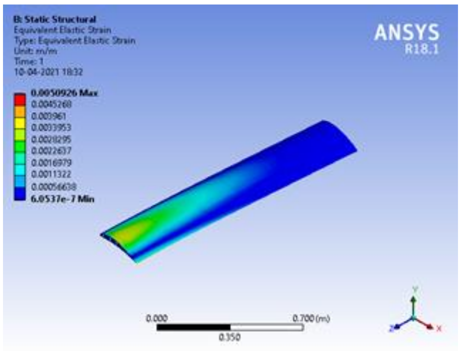

Fig-16 (b) : Equivalent Strain for 12.25° for GFRP

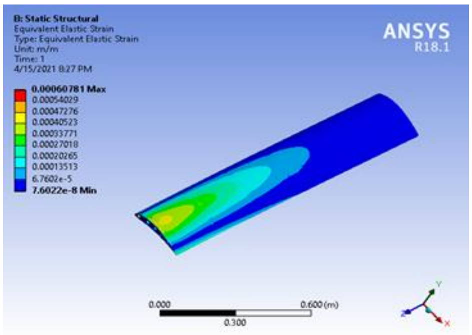

Fig-17 (a) : Equivalent Strain for 0° for AMC

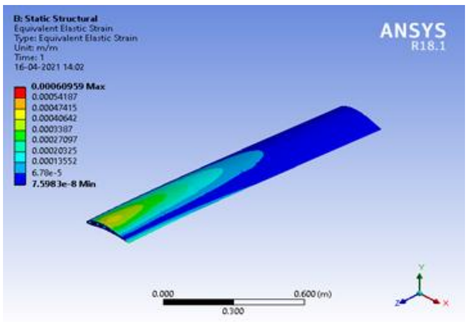

Fig-17 (b) : Equivalent Strain for 12.25° for AMC

7.2 CFD Analysis Results

The calculation was run for 500 iterations and the solution converged at 315th iteration. Lift and Drag monitors were obtained for 0° and 20° Angle of Attack given in Table 9 :

Table-9 : Lift and Drag Monitors

Angle of Attack	Drag (N)	Lift (N)	Lift/Drag
0^o	1.6968	57.506	33.89085
2^o	1.8443	68.219	36.9891
4^o	2.1903	77.575	35.41752
6^o	2.6503	86.269	32.55065
8^o	3.4663	92.16	26.58743
10^o	4.2136	97.832	23.21815
12^o	5.5651	99.398	17.86095
12.25^o	5.8682	99.432	16.94421
12.5^o	5.9424	99.07	16.67172
14^o	7.72793	97.635	12.63404
15^o	8.2639	97.24	11.76684
15.25^o	8.2271	97.006	11.79103
15.5^o	8.2689	97.995	11.85103
15.75^o	8.6901	94.992	10.93106
16^o	9.4205	93.125	9.885356
18^o	11.189	93.415	8.348825
20^o	14.71	83.277	5.661251

The 3-dimensional aerodynamic characteristics (lift, drag and lift to drag ratio) for various angles of attack are obtained from ANSYS R18.1 and the resultant graphs are plotted which are shown from Figure 18-20.

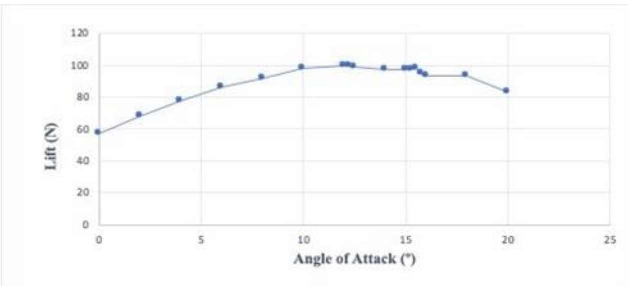

Fig-18 : Lift Vs Angle of Attack

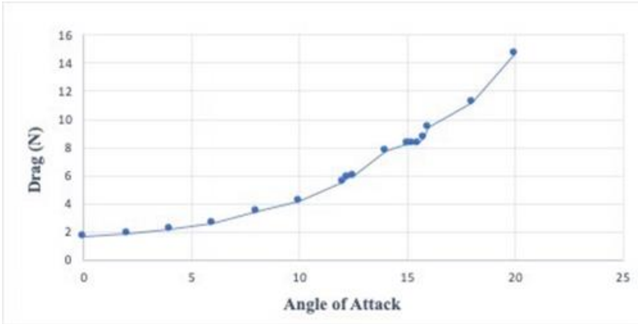

Fig-19 : Drag Vs Angle of Attack

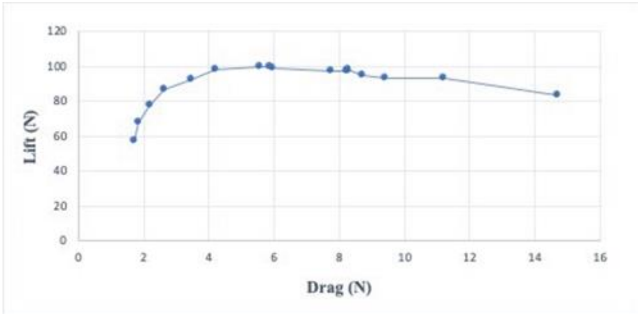

Fig-20 : Lift Vs Drag

- **Velocity Contours**

From the velocity contour, we can observe that the velocity is minimum at the leading edge of the wing which is represented by the blue contour. The maximum and minimum values of velocity obtained from the fluent analysis for an AOA of 0^o and 12.25^o is given in Table 10 below:

Table-10 : Velocity Plot

	Velocity (m/s)	
Angle of Attack 0^o	Minimum	0.000e+000
	Maximum	2.224e+001
Angle of Attack 12.25^o	Minimum	0.000e+000
	Maximum	2.791e+001

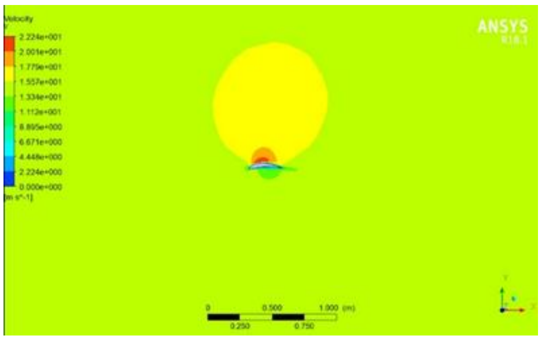

Fig-21 : Velocity Contours for 0^o

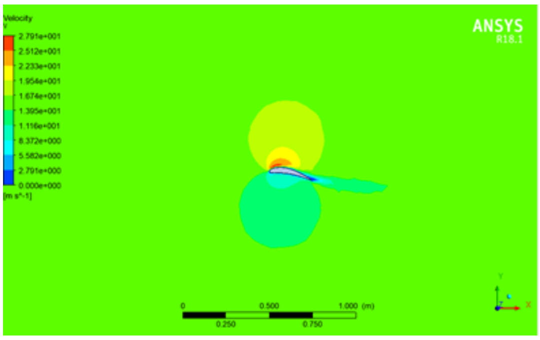

Fig-22 : Velocity Contours for 12.25°

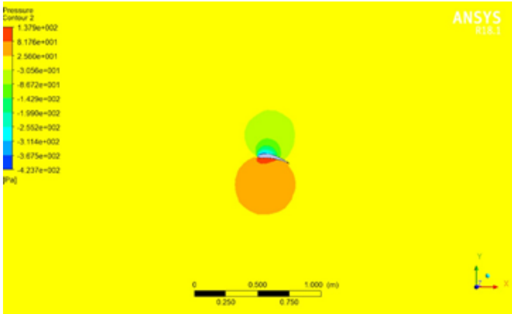

Fig-24 : Pressure Contours for 12.25°

- **Pressure Contours**

From the pressure contours it is observed that the pressure is maximum at the leading edge which is indicated by the red contour. This pressure is called stagnation pressure and the velocity is minimum at this point. The maximum and minimum values of pressure for 0° and 12.25° AOA obtained from the fluent analysis is given in table 11 below:

Table-11 : Pressure Plot

	Pressure (Pa)	
Angle of Attack 0°	Minimum	-1.960e+002
	Maximum	1.2251e+002
Angle of Attack 12.25°	Minimum	-4.237e+002
	Maximum	1.379e+002

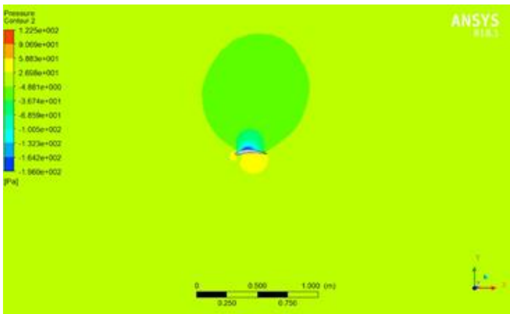

Fig-23 : Pressure Contours for 0°

7.3 One Way FSI Analysis Results

- **Total Deformation**

The total deformation of the structure is the square root of the sum of squares of the displacements in the x, y, z- axis. The wing is considered as a cantilever beam and thus the maximum deformation produced is towards the free end which is indicated by the red contour, the minimum deformation is towards the fixed end and is indicated by the blue contours. The total deformation results are obtained at two angles of attack that is for 0° and for 12.25° since 12.25° is the stall angle. The total deformation results for two angles of attack 0° and 12.25° is given in table 12 below :

Table-12 : Total Deformation

Angle of Attack	Material	Total Deformation
0°	GFRP	Min : 0 m
		Max : 0.088896 m
	AMC	Min : 0 m
		Max : 0.010698 m
12.25°	GFRP	Min : 0 m
		Max : 0.080659 m
	AMC	Min : 0 m
		Max : 0.009707 m

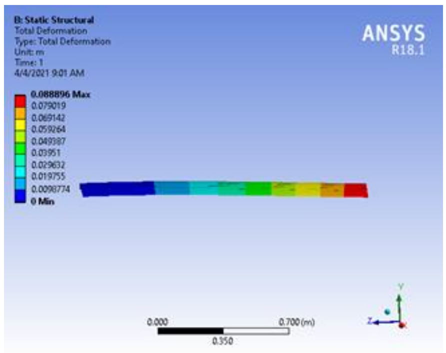

Fig-25 (a) : Total Deformation for 0° for GFRP

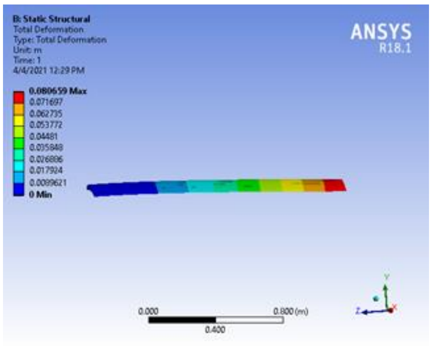

Fig-25 (b) : Total Deformation for 12.25º for GFRP

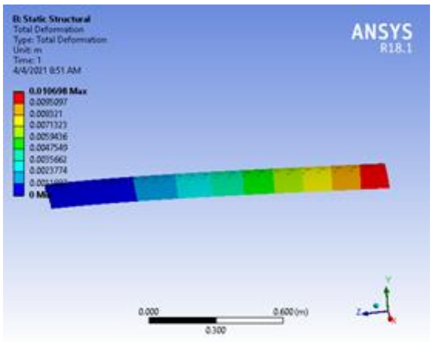

Fig-26 (a) : Total Deformation for 0º for AMC

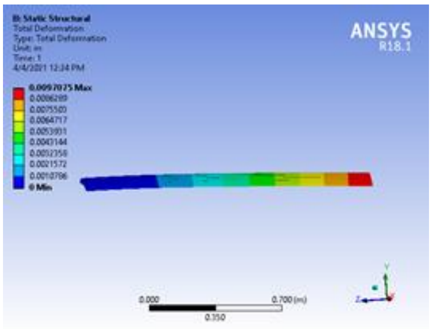

Fig-26 (b) : Total Deformation for 12.25º for AMC

- **Equivalent Von-Mises Stress**

It is used to indicate the stress distribution over the span of the wing, it is used to determine if a given material will yield or fracture. According to the Von-Mises Criterion if the Von-Mises stress of a material under load is equal or greater than the yield limit of the same material under simple tension then the material will yield. The maximum stress is towards the fixed end of the wing and is indicated by the red and light green contours. The minimum stress is towards the free end and is indicated by the blue contours. The Equivalent Von-Mises stress values for 0º and 12.25º angle of attack is tabulated below in Table 13:

Table-13 : Equivalent Von-Mises Stress

Angle of Attack	Material	Equivalent Von-Mises Stress
0º	GFRP	Min : 7103.2 N/m²
		Max : 1.15e8 N/m²
	AMC	Min : 7526.4 N/m²
		Max : 1.15e8 N/m²
12.25º	GFRP	Min : 7471.4 N/m²
		Max : 1.01e8 N/m²
	AMC	Min : 7762.7 N/m²
		Max : 1.02e8 N/m²

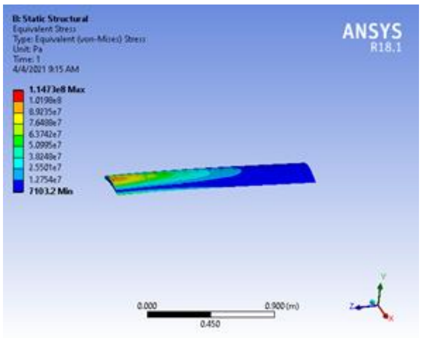

Fig-27 (a) : Equivalent Von-Mises Stress for 0º for GFRP

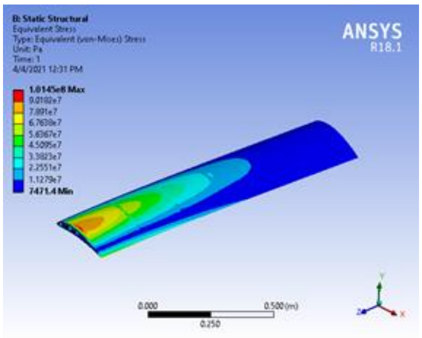

Fig-27 (b) : Equivalent Von-Mises Stress for 12.25º for GFRP

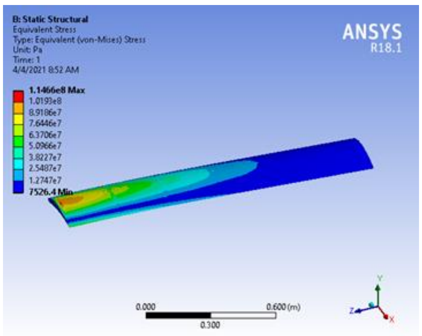

Fig-28 (a) : Equivalent Von-Mises Stress for 0º for AMC

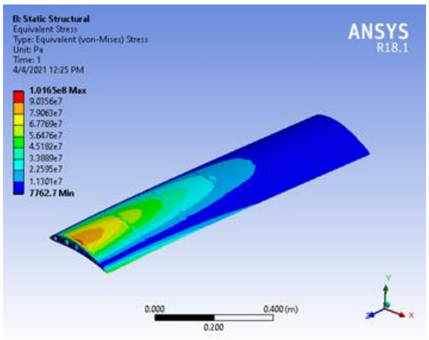

Fig-28 (b) : Equivalent Von-Mises Stress for 12.25° for AMC

- **Equivalent Strain**

It is used to define the state of strain in solid materials. Strain is defined as the ratio of change in length of the structure to the original length therefore strain is a dimensionless quantity. The maximum strain occurs at the fixed end and is indicated by red and light green contours. The minimum strain is indicated by blue contours. The equivalent strain for 0° angle of attack is given in the Table 14 below:

Table-14 : Equivalent Strain

Angle of Attack	Material	Equivalent Strain
0°	GFRP	Min : 2.36e-7
		Max : 0.0038438
	AMC	Min : 3.01e-8
		Max : 0.00046194
12.25°	GFRP	Min: 2.48e-7
		Max : 0.0033877
	AMC	Min : 3.11e-8
		Max : 0.00040923

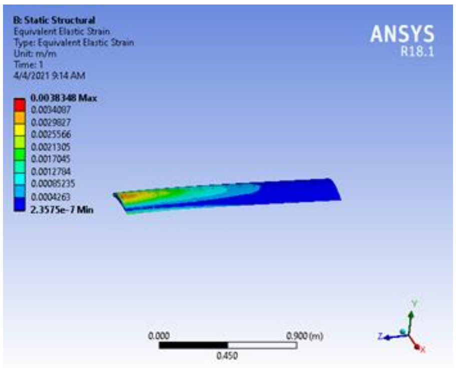

Fig-29 (a) : Equivalent Strain for 0° for GFRP

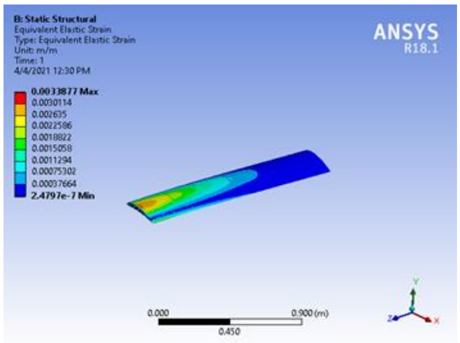

Fig-29 (b) : Equivalent Strain for 12.25° for GFRP

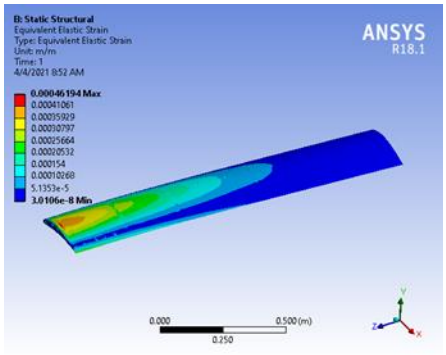

Fig-30 (a) : Equivalent Strain for 0° for AMC

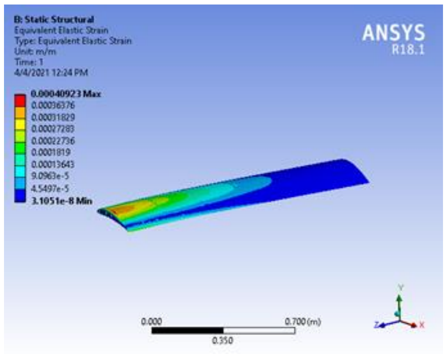

Fig-30 (b) : Equivalent Strain for 12.25° for AMC

8. CONCLUSIONS

The airfoil used in this work is Eppler 423. After selecting the airfoil, the wing was designed on Catia V5 by importing the airfoil polars. The static structural analysis, CFD analysis and FSI analysis was carried out on ANSYS R18.1. The materials used for comparison are GFRP and AMC. 2 iterations was conducted which includes 2 materials in order to get a better understating of the behavior of the wing structure when it is considered as a rigid structure and when it is considered flexible. Results for Equivalent Von-Mises stress, Equivalent Strain, Deformation was conducted on ANSYS R18.1. A comparative study is carried out for the results obtained by static structural analysis and that obtained by one way FSI analysis. From the analysis carried out it can be observed that the wing structure with AMC has material properties which are better compared to that of GFRP since the deformation in AMC for the same loading condition is lesser when compared to GFRP. Consequently, the stresses developed in AMC is higher which is required to prevent the structure from deforming which in turn results in a lower strain in comparison with GFRP. Additionally, the imported pressure loads acting on the structure reduces the effective loads acting on the it which reduces the deformation for both the materials in comparison with the single mode analysis.

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