International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 07 - Issue 01 || January 2022 || PP. 16-30

Fem Analysis on Spiroid and Split Winglet

Sivaraman S[1], Sanjayan M.A[2], Shyam Mohan M[3], Balaji S[4], Akash S.P[5]
[1]Assistant Professor, Dept. of Aeronautical Engineering,
Hindusthan College of engineering and technology,
Coimbatore, Tamilnadu, India

Abstract: The produced drag of a three-dimensional wing is tightly linked to wingtip vortices. To lessen induced drag, it's crucial to ignore wingtip vortices. Lift-induced drag can account for up to 40% of total drag at cruising and 80– 90% of total drag in take-off configuration, according to the drag breakdown of a typical transport aircraft. Wingtip devices are one approach to cut down on lift-induced drag. We examine spiroid wingtips, which resemble an extended blended wingtip that bends upward by 360 degrees to produce a huge rigid ribbon, by applying biomimetic abstraction of the idea behind a bird's wingtip feathers. A configuration of several winglets is investigated in this research. CATIA is used to create a model consisting of a wing, as well as the spiroid winglet, which is designed and affixed to the wing. ICEM-CFD is used to mesh the simulated wing. ANSYS FLUENT will be used to evaluate the mesh model. Finally, the analysis results are used to calculate the percentage decrease of wingtip vortices.

Keywords: Wing tip, Vortices, CATIA, Drag, Winglets, ANSYS FLUENT

Introduction:

Wingtip devices are usually intended to improve the efficiency of fixed-wing aircraft. There are several types of wingtip devices, and although they function in different manners, the intended effect is always to reduce the aircraft's drag by partial recovery of the tip vortex energy. Wingtip devices can also improve aircraft handling characteristics and enhance safety for following aircraft.

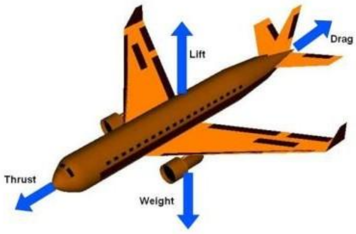
Such devices increase the effective aspect ratio of a wing without materially increasing the wingspan. An extension of span would lower lift- induced drag, but would increase parasitic drag and would require boosting the strength and weight of the wing. At some point, there is no net benefit from further increased span. There may also be operational considerations that limit the allowable wingspan. Wingtip devices increase the lift generated at the wingtip by smoothing the airflow across the upper wing near the tip and reduce the lift-induced drag caused by wingtip vortices, improving lift-to-drag ratio. This increases fuel efficiency in powered aircraft and increases cross-country speed in gliders, in both cases increasing range.

In aeronautical engineering, drag reduction constitutes a challenge and there is room for improvement and innovative developments. The drag breakdown of a typical transport aircraft shows that the lift-induced drag can amount to as much as 40% of the total drag at cruise conditions and 80–90% of the total drag in take- off configuration. One way of reducing lift induced drag is by using wingtip devices. By applying biomimetic abstraction of the principle behind a bird's wingtip feathers, we study spiroid wingtips, which look like an extended blended wingtip that bends upward by 360 degrees to form a large rigid ribbon.

Wingtip vortices are circular patterns of rotating air left behind a wing as it generates lift. One wingtip vortex trails from the tip of each wing. Wingtip vortices are sometimes named trailing or lift-induced vortices because they also occur at points other than at the wing tips. Indeed, vorticity is trailed at any point on the wing where the lift varies spanwise it eventually rolls up into large vortices near the wingtip, at the edge of flap devices, or at other abrupt changes in wing platform.

Wingtip vortices are associated with induced drag, the imparting of downwash, and are a fundamental consequence of three-dimensional lift generation. Careful selection of wing geometry as well as of cruise conditions, are design and operational methods to minimize induced drag Wingtip vortices form the primary component of wake turbulence. Depending on ambient atmospheric humidity as well as the geometry and wing loading of aircraft, water may condense or freeze in the core of the vortices, making the vortices visible.

Aerodynamics Force on Aircraft:



A force may be thought of as a push or pull in a specific direction. A force is a vector quantity so a force has both a magnitude and a direction. When describing forces, we have to specify both the magnitude and the direction. This slide shows the forces that act on an airplane in flight.

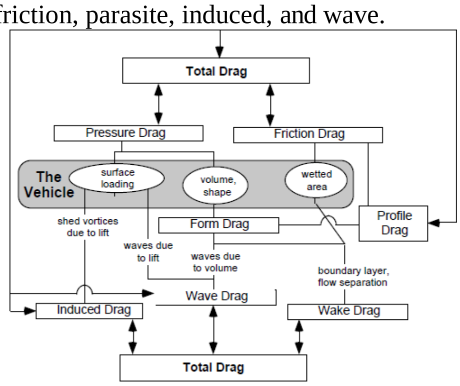
Weight:
Weight is a force that is always directed toward the centre of the earth. The magnitude of the weight depends on the mass of all the airplane parts, plus the amount of fuel, plus any payload on board (people, baggage, freight, etc.). The weight is distributed throughout the airplane. But we can often think of it as collected and acting through a single point called the centre of gravity. In flight, the airplane rotates about the centre of gravity.

Lift:
To overcome the weight force, airplanes generate an opposing force called lift. Lift is generated by the motion of the airplane through the air and is an aerodynamic force. "Aero" stands for the air, and "dynamic" denotes motion. Lift is directed perpendicular to the flight direction. The magnitude of the lift depends on several factors including the shape, size, andvelocity of the aircraft. As with weight, each part of the aircraft contributes to the aircraft lift force. Most of the lift is generated by the wings. Aircraft lift acts through a single point called the center of pressure. The center of pressure is defined just like the center of gravity, but using the pressure distribution around the body instead of the weight distribution.

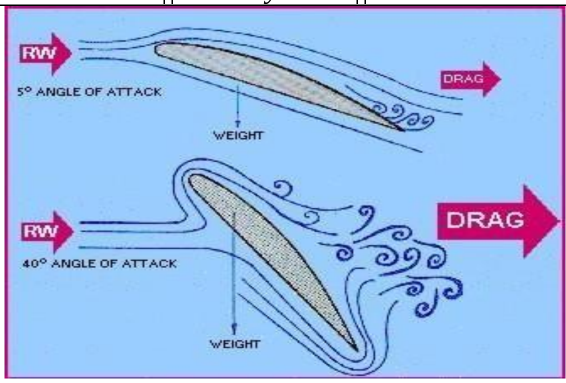
Drag:
As the airplane moves through the air, there is another aerodynamic force present. The air resists the motion of the aircraft and the resistance force is called drag. Drag is directed along and opposed to the flight direction. Like lift, there are many factors that affect the magnitude of the drag force including the shape of the aircraft, the "stickiness" of the air, and the velocity of the aircraft. Like lift, we collect all of the individual components' drags and combine them into a single aircraft drag magnitude. And like lift, drag acts through the aircraft center of pressure.

Thrust:
To overcome drag, airplanes use a propulsion system to generate a force called thrust. The direction of the thrust force depends on how the engines are attached to the aircraft. In the figure shown above, two turbine engines are located under the wings, parallel to the body, with thrust acting along the body center line. On some aircraft, such as the Harrier, the thrust direction can be varied to help the airplane take off in a very short distance. The magnitude of the thrust depends on many factors associated with the propulsion system including the type of engine, the number of engines, and the throttle setting.

Types of Drag:
Drag is generated by nine conditions associated with the motion of air particles over the aircraft. There are several types of drag: form, pressure, skin friction, parasite, induced, and wave.



Induced Drag:



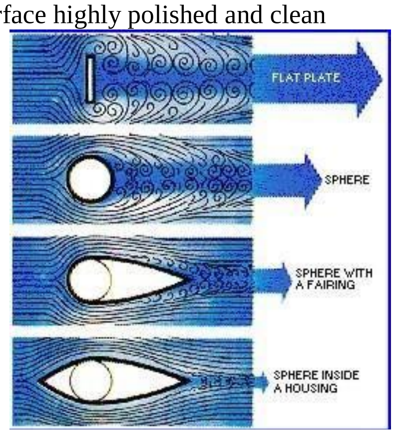
Induced drag is the drag created by the vortices at the tip of an aircraft's wing. *Induced drag* is the drag due to lift. The high pressure underneath the wing causes the airflow at the tips of the wings to curl around from bottom to top in a circular motion. This results in a trailing vortex. Induced drag increases in direct proportion to increases in the angle of attack. The circular motion creates a change in the angle of attack near the wing tip which causes an increase in drag. The greater the angle of attack up to the critical angle (where a stall takes place), the greater the amount of lift developed and the greater the induced drag.

Total Drag = Parasite Drag + Induced Drag

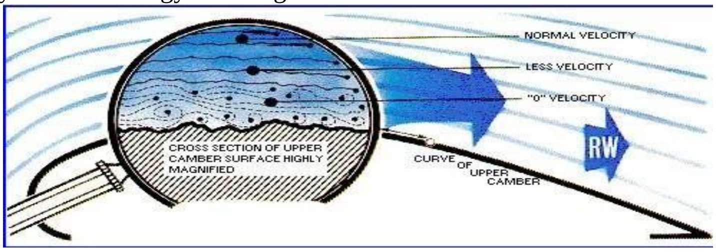
Parasite Drag:
The parasite drag of a typical airplane in the cruise configuration consists primarily of the skin friction, roughness, and pressure drag of the major components. There is usually some additional parasite drag due to such things as fuselage upsweep, control surface gaps, base areas, and other extraneous items. Since most of the elements that make up the total parasite drag are dependent on Reynolds number and since some are dependent on Mach number, it is necessary to specify the conditions under which the parasite drag is to be evaluated.

Form Drag:
Form drag and pressure drag are virtually the same type of drag. Form or pressure drag is caused by the air that is flowing over the aircraft or airfoil. The separation of air creates turbulence and results in pockets of low and high pressure that leave a wake behind the airplane or airfoil (thus the name pressure drag). This opposes forward motion and is a component of the total drag. Since this drag is due to the shape, or form of the aircraft, it is also called form drag. Streamlining the aircraft will reduce form drag, and parts of an aircraft that do not lend themselves to streamlining are enclosed in covers called fairings, or a cowling for an engine, that have a streamlined shape.

Skin Friction:
Skin friction drag is caused by the actual contact of the air particles against the surface of the aircraft. This is the same as the friction between any two objects or substances. Because skin friction drag is an interaction between a solid (the airplane surface) and a gas (the air), the magnitude of skin friction drag depends on the properties of both the solid and the gas. For the solid airplane, skin fiction drag can be reduced, and airspeed can be increased somewhat, by keeping an aircraft's surface highly polished and clean

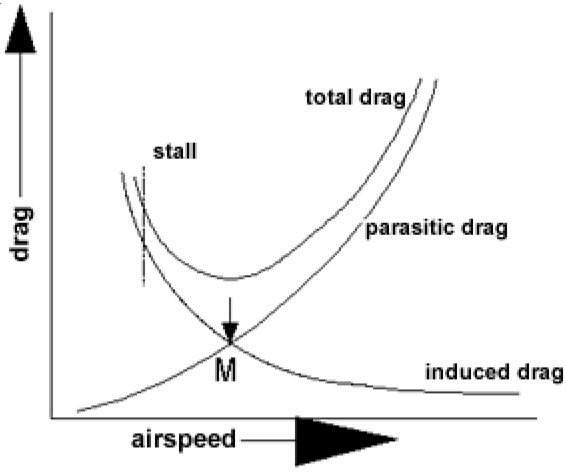


For the gas, the magnitude of the drag depends on the viscosity of the air. Along the solid surface of the airplane, a boundary layer of low energy flow is generated.

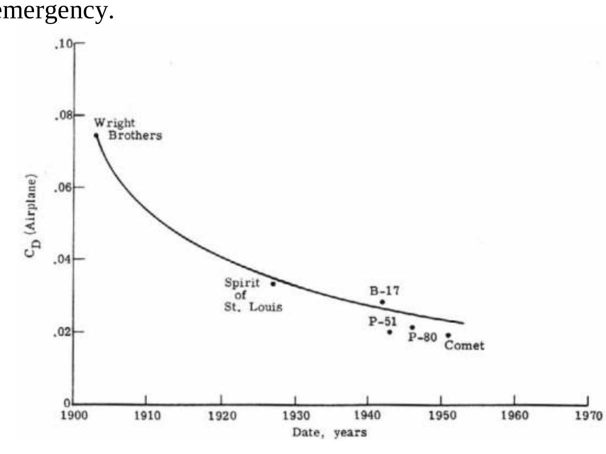


Lift Versus Drag:
An aircraft with a given total gross weight can be operated in level flight over a range of power settings and airspeeds. Since Lift and Weight must be equal in order to maintain level flight, it is obvious that there is a relationship between Lift (L), Airspeed (V), and Angle of Attack (AT). This relationship can be "generalized" with the following expression. (Note: the expression is not an exact equation).
Lift = Angle of Attack x Velocity

Since angle of attack and speed also have a relationship to Induced Drag and Parasite Drag, the relationship of Lift/Drag is shown by the graph below.



Parasite drag increases with speed. Induced drag decreases with speed. The SUM of the two drags (Total Drag curve) shows that there is only one airspeed for a given airplane and load that provides MINIMUM total drag. This is the point M which is the maximum lift over drag ratio (L/D). It is the airspeed at which the aircraft can glide the farthest without power (maximum glide range). This is the airspeed which should immediately be set up in the event of a power failure. This maximum glide airspeed is different for each aircraft design. The Pilot Operating Handbook should be consulted for this airspeed and the pilot should memorize it to eliminate need to search manuals during an emergency.



Wing Tips:

Wingtip vortices are circular patterns of rotating air left behind a wing as it generates lift. One wingtip vortex trail from the tip of each wing. Wingtip vortices are sometimes named trailing or lift-induced vortices because they also occur at points other than at the wing tips. Indeed, vorticity is trailed at any point on the wing where the lift varies span-wise (a fact described and quantified by the lifting-line theory); it eventually rolls up into large vortices near the wingtip, at the edge of flap devices, or at other abrupt changes in wing planform.

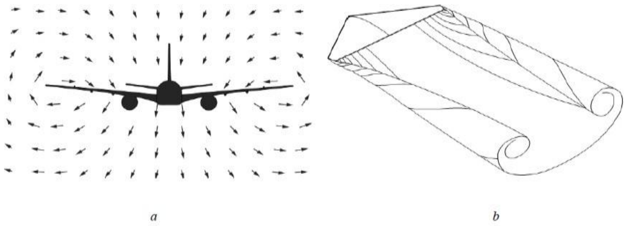
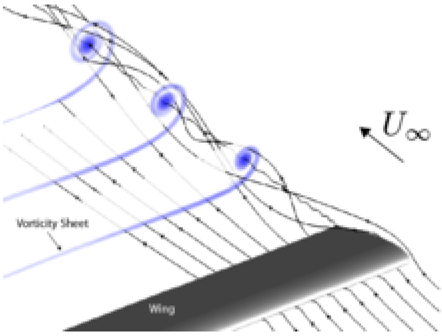


Figure 9 (a)Flow pattern of the velocity[20] (b)Vortex sheet from trailing edge[20]

Wingtip vortices form the primary component of wake turbulence. Depending on ambient atmospheric humidity as well as the geometry and wing loading of aircraft, water may condense or freeze in the core of the vortices, making the vortices visible.

Generation of Trailing Vortices:



Euler computation of a tip vortex rolling up from the trailed vorticity sheet. When a wing generates aerodynamic lift the air on the top surface has lower pressure relative to the bottom surface. Air flows from below the wing and out around the tip to the top of the wing in a circular fashion. An emergent circulatory flow pattern named vortex is observed, featuring a low-pressure core.

Three-dimensional lift and the occurrence of wingtip vortices can be approached with the concept of horseshoe vortex and described accurately with the Lanchester–Prandtl theory. In this view, the trailing vortex is a continuation of the wing-bound vortex inherent to the lift generation.

If viewed from the tail of the airplane, looking forward in the direction of flight, there is one wingtip vortex trailing from the left-hand wing and circulating clockwise, and another one trailing from the right-hand wing and circulating anti-clockwise. The result is a region of downwash behind the aircraft, between the two vortices.

The two wingtip vortices do not merge because they are circulating in opposite directions. They dissipate slowly and linger in the atmosphere long after the airplane has passed. They are a hazard to other aircraft, known as wake turbulence.

Literature Review:

History of Wingtip devices and Winglets:

Endplate theory was the first to propose wingtip device and was patented by Fredrick W. Lanchester, British Aerodynamicist in 1897. Unfortunately, his theory could not reduce the overall drag of aircraft despite reducing the induced drag. The increase in the viscous drag during cruise conditions outruns the reduction in induced drag. In July 1976, Dr. Whitcomb made research at NASA Langley research center and developed the concept of winglet technology. According to Whitcomb, winglet could be described as the small wing like vertical structures which extends from the wingtip, aiming at reduction in induced drag when compared to other wing tip devices or extensions. He also claimed in his research that the winglet shows 20% reduction in induced drag when compared to tip extension and also improved lift- to-drag ratio.

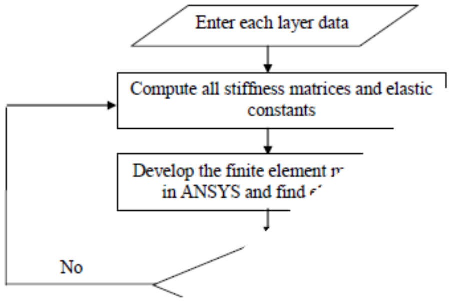
In 1994 Aviation Partners Inc. (API) developed an advance design of winglet called blended winglet. Louis B. Gratzer from Seattle has the patent for blended winglet and intention of the winglet is to reduce the interference drag due to sharp edges as seen in the Whitcomb's winglet [11]. Also, Gratzer has the patent for the invention of spiroid-tipped wing in April 7, 1992 [12]. Later, "wing grid" concept was developed by La Roche from Switzerland in 1996 and got the patent for his invention [13]. The main purpose of all the above inventions was to decrease the strength of wake vortex and to reduce induced drag.

Methodology:

The following methodology is being adopted to carry out the above-mentioned objectives:

1. The Ansys achieved by aircraft landing gear and CAD model was designed by CATIA V5
2. Using ANSYS the overall load are computed and tried to validate with classical theory.
3. Using these equivalent properties of the composite the natural frequency computations are done.

Fig.3.1 shows present methodology.



Introduction to Catia:

CATIA which stands for computer aided three dimensional interactive applications is the most powerful and widely used CAD (computer aided design) software of its kind in the world. CATIA is owned/developed by Dassault system of France and until 2010, was marketed worldwide by IBM.

The Following general methodologies and best practices can be followed in the modelling of components in CATIA. The Below methodologies and best practices followed will help in capturing the design intent of the Feature that is to be Modelled and will make the design robust and easy to navigate through.

- Specification tree structuring
- Renaming appropriate features & bodies in specification tree
- Handling input data & foreign bodies
- Dimensioning & constraining in sketches
- Parameters and relations.

Specification Tree Structuring:

a) The SPECIFICATION TREE is the place where the histories of the features modelled are captured. So, it is highly important to have an organized tree structure which gives ease for navigation of the features when any modification takes place.
b) The SPECIFICATION TREE in a structured manner. The Machining Body features are grouped under one body and base block features in another and so on with appropriate feature operations.
c) It is also important in structuring the reference and construction element in the tree in an orderly manner.
d) The points that would be often used (like the Global Origin Point 0, 0, 0,) can be created under Points GEOMETRICAL SET and any reference planes defining legal limits can be created in the planes GEOMETRICAL SET.

Renaming Appropriate Features & Bodies in Specification Tree:

a) The renaming of features within the design becomes mandatory as it will be useful for the end users to by far identify things for modification.

b) For instance, an end user who wants to identify the M5 holes on the model the SPECIFICATION TREE helps easily in identifying the M5 holes in the model there by making modifications easy.
c) Also renaming all the features every now and then as it is created will easy things at the end.
d) "Base Block Sketch" and "Base Block" is which will be useful in identifying them at a later stage.
e) Renaming the Bodies also helps in navigation.

Finite Element Analysis:

Introduction to Finite Element Analysis:

Finite Element Analysis (FEA) was developed in 1943 by R. Courant, who used the Ritz method of numerical analysis and minimization of variation calculus to obtain approximate solutions for systems of vibration. Shortly after, an article published in 1956 by MJ Turner, RW Clough, HC Martin, and LJ Topp established a broader definition of numerical analysis. The paper centered on the "stiffness and deformation of complex structures".

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in the design of new products, and refinement of the existing product. A company is able to verify a proposed design and will be able to perform the specification of the client before fabrication or construction. Modifying an existing product or structure is used to qualify the product or structure of a new condition of service. In the case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

The Lagrangian is widely used. In an analysis of Lagrange, grid mesh deforms with the material, while in the Eulerian analysis grid is fixed in space. The Lagrangian analysis simulates the entry, exit, stages of intermittent and discontinuous chip formation, while the Eulerian cannot simulate the phases of intermittent and discontinuous chip formation. However, the Eulerian formulation eliminates the need for a chip criterion of division and to avoid distortions of the mesh

In this project work modelling and analysis is done using **ANSYS** in which we doing static and modal analysis.

Modal Analysis:

Modal analysis is the study of the dynamic properties of structures under vibrational excitation.[10] When a structure undergoes an external excitation, its dynamic responses are measured and analysed. This field of measuring and analysing is called modal analysis. Modal analysis can be used to measure the response of a car's body to a vibration when vibration of an electromagnetic shaker is attached, or the pattern created by noise because of a loudspeaker which acts as an excitation. In structural engineering, modal analysis is applied to find the various periods that the structure will naturally resonate at, by using the structure's overall mass and stiffness. The modal analysis is very important in earthquake engineering, because the periods of vibration evaluated helps in checking that a building's natural frequency does not coincide with the frequency of earthquakes prone region where the building is to be constructed. Incase a structure's natural frequency coincidently equals an earthquake's frequency; the structure suffers severe structural damage due to resonance.

Natural Frequency:

All models have a natural frequency. If a model is subjected to dynamic load that is close to its natural frequency, the model oscillates to a large extent than in normal condition. The results of a modal analysis help determine whether a model requires more or 3 | P a g e less damping to prevent failure. Modal analysis can be used to find the frequency at which resonance occurs, under specific constraints.

Modes:

Modes measure the vibration of an object at a particular frequency. Each mode is assigned a number. The lowest speed at which a structure vibrates after all external loads are removed is assigned to mode 1. This mode is called the free vibration mode because it is not damped. Mode shape: In the study of vibration in engineering, the expected curvature (or displacement) of a surface at a particular mode due to vibration is the mode shape. To determine the vibration of a system, Multiplying the mode shape by a time- dependent function, the vibration if a system is found out. Thus the mode shape always describes the time-to-time curvature of vibration where the magnitude of the curvature will change. The mode shape depends on two factors: 1) on the shape of the surface 2) the boundary conditions of that surface.

Steps Required Analysis:

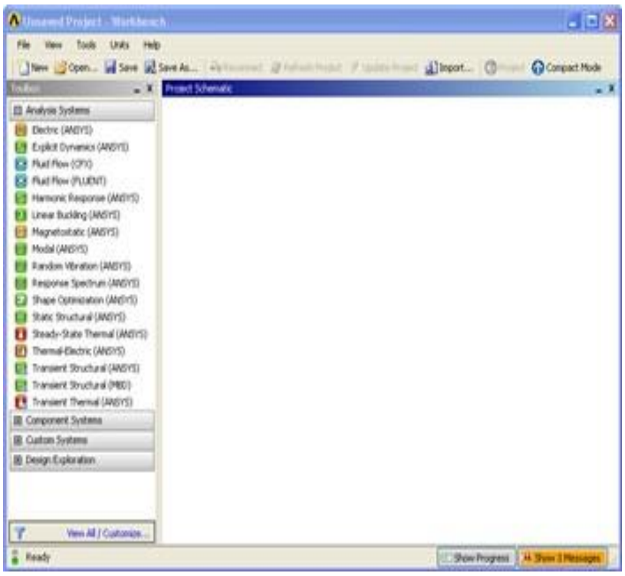
The FEM Solver Contain three major steps Following are

1. Pre processor
2. Solver
3. Post Processing

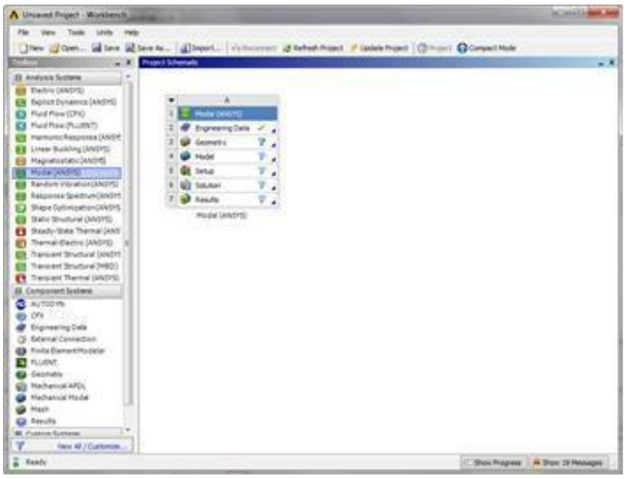
Pre-Processor:

Open ANSYS Workbench

Open ANSYS Workbench by going to Start > ANSYS > Workbench. This will open the start- up screen seen as seen below

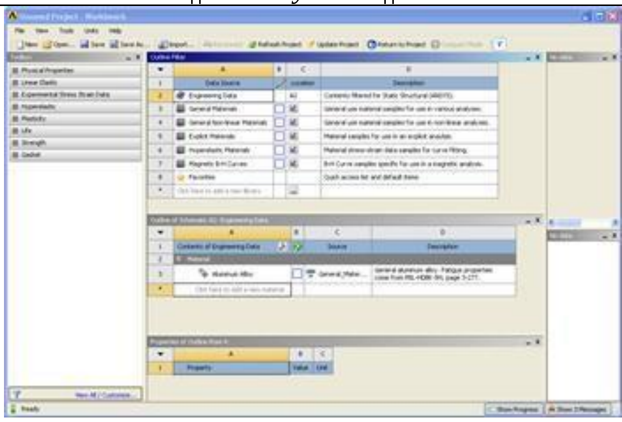


To begin, we need to tell ANSYS what kind of simulation we are doing. If you look to the left of the start-up window, you will see the Toolbox Window. Take a look through the different selections. We are doing a modal analysis simulation. Load the Modal (ANSYS) box by dragging and dropping it into the Project Schematic.



Name the project Modal Analysis. Engineering Properties

Now we need to specify what type of material we are working with. Double click Engineering Data and it will take you to the Engineering Data Menus.

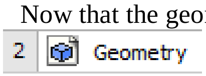


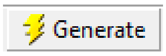
If you look under the Outline of Schematic A2: Engineering Data Window, you will see that the default material is Structural Steel. The Problem Specification states we will be using Aluminium 6061-T6. To add a new material, click in an empty box labelled Click here to add a new material and give it a name. Our Material is Al 6061-T6. On the left-hand side of the screen in the Toolbox window, expand Linear Elastic and double click Isotropic Elasticity to specify E and in the Properties of: Al 6061-T6 window, Set the Elastic Modulus units to Pa., set the magnitude as 1E7, and set the Poisson Ratio to 0.33. We will need to define the density as well. Expand Physical Properties and double click density. In the Properties of: Al 6061-T6 window, a density bar will have appeared. Define it as being 2700 kg/m^3.

Geometrical Configuration:

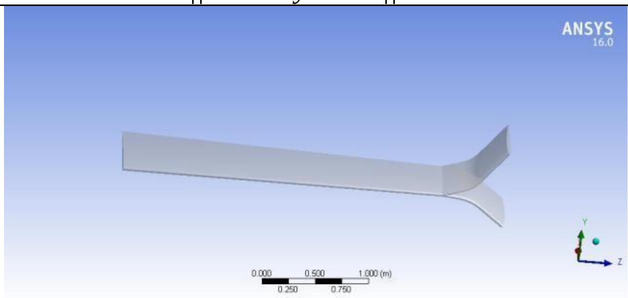
To open the file in ANSYS, go to File > Import. Browse to the geometry location on your computer. If you do not see the file, make sure you are browsing for geometry files (the pull-down menu at the bottom right of the browsing window for computers running Windows 7). 40

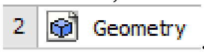
Select the Geometry and click Open. This will import your geometry into ANSYS. Your project window should now include the main project, and the newly imported geometry (see below).

Now that the geometry has been imported, let's open the file and make sure everything is in order! Double click 

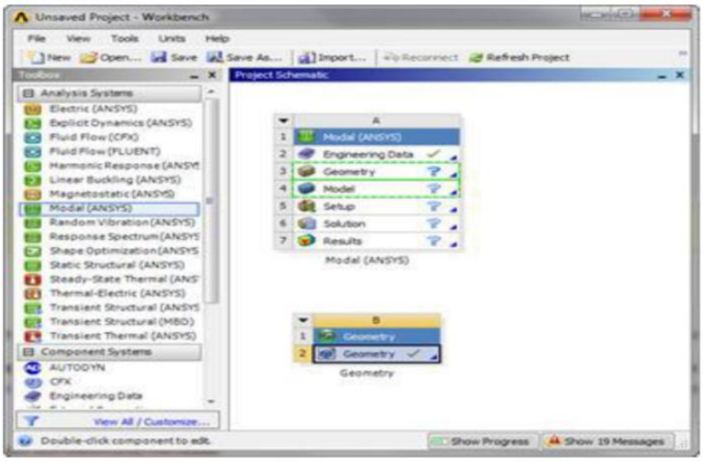
. This will open the design modeller. When you are prompted, select Meter as your standard unit of measurement. The first thing you should notice is that the geometry is not there, so click 

to generate the geometry. When the geometry finally generates, you should see the screen below.

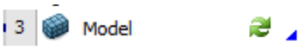


Once we are satisfied with our geometry, we can close the design modeler. Now, we should be looking at the Project window. To connect the geometry to the project, click and drag 

. As soon as you drag the box, ANSYS will highlight the geometry and model boxes in the main project.



Mesh:
Open the Mesher

To open the Mesher, double click the Model box 

in the Project Outline window. This will load ANSYS Mechanical. You should now be able to see the air foil geometry.

The first thing we are going to need to do when the Mesher opens is specify the thickness of the aerofoil walls. In the Outline window, expand Geometry and select Surface Body. In the Details window, change the thickness to 0.01 m. We also need to specify the material. In the Outline window. In the Details window, select Material > Assignment > Al 6061-T6. The material has now been specified.

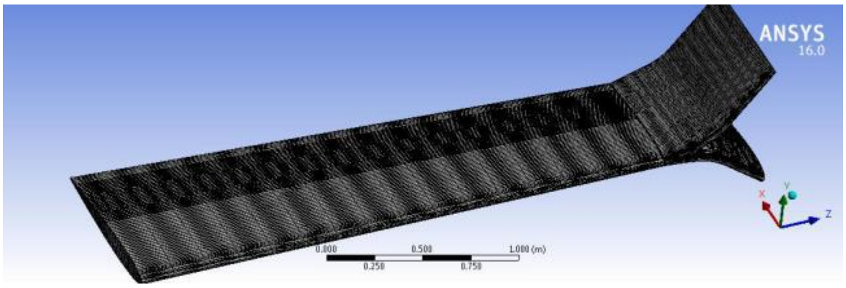
Mapped Face Meshing:
To apply a mapped face meshing, first click on Mesh in the Outline window. This will bring up the Meshing Menu Bar at the top of the screen. Next, select Mesh Control > Mapped Face Meshing. Select the 2 faces of the mesh by holding down the left mouse button and dragging over the entire geometry. In the Details window, click Geometry > Apply - it should say 2 faces are selected.

Relevance Center	Coarse
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	1.2926e-004 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272

Maximum Layers	5
Growth Rate	1.2
Statistics	
Nodes	57334
Elements	32867

Edge Sizing:

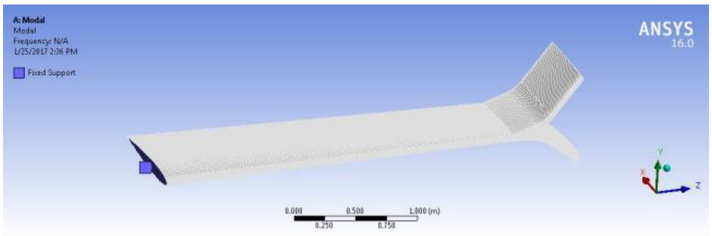
In the Meshing Menu, click Meshing Control > Sizing. Click the edge selection filter . Select the 4 curved edges on the outside of the geometry that make up the shape of the Airfoil as the picture shows:



In the details window, select Geometry > Apply, and select Type > Number of Divisions. Change the Number of Divisions to 10. Also, change Behavior > Hard.

Fixed Support

Next, we will apply the boundary conditions to the geometry. In the graphics window, click the positive Z-Axis on the compass to look at one side of the airfoil.



Solution:

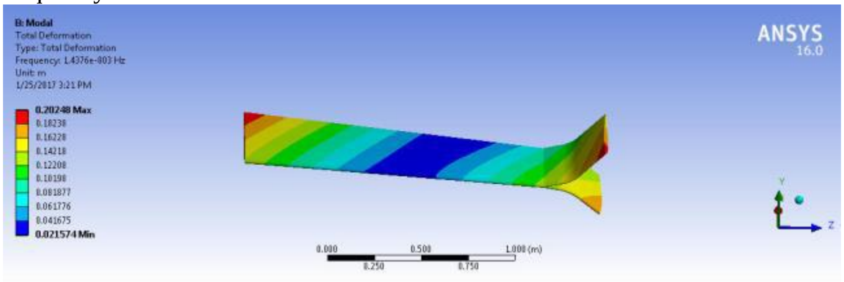
ANSYS will by default solve for the frequencies of the first 6 vibration modes; however, we would also like to see how this affects the geometry. We can accomplish this task by looking at the total deformations of the airfoil to see where the nodes occur and how the geometry deforms. To tell ANSYS to solve for the deformation, first select Solution in the Outline window to bring up the Solution Menu bar. In the Solution Menu, select Deformation > Total. In the Details Window, notice that the deformation is solving for Mode 1. Rename Total Deformation to Mode Shape 1.

Create another instance total deformation and rename it Mode Shape 2. Select it, and change Mode > 2. Now, you will be solving for the deformation of the 2nd Mode. Repeat this step until you are solving for the total deformation of all 6 modes.

Solutions for Al 7075-T651 with Split Winglet:

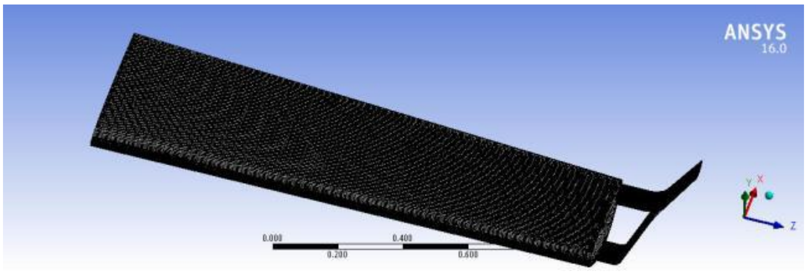
Mode	Frequency [Hz]
1.	9.3922
2.	53.902
3.	70.566
4.	85.736
5.	143.13
6.	263.

Deformation for frequency 9.39HZ



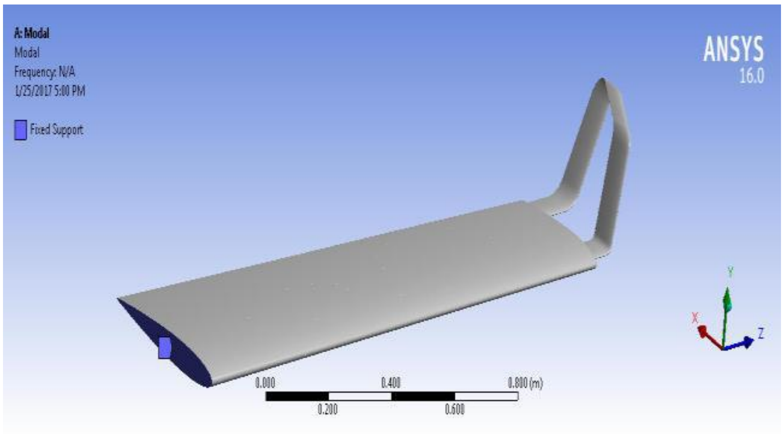
Result For Spiroid Winglet With AL 7075-T651:

Mesh Files:

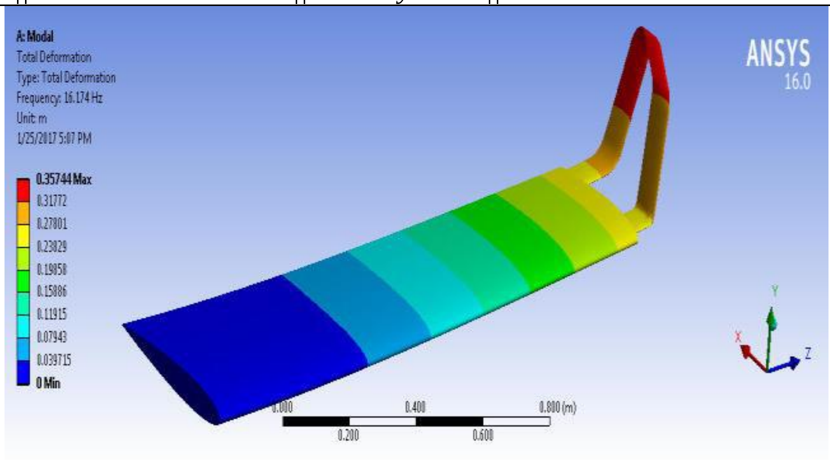


Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	2.0475e-005 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2

Setup:



Solution:



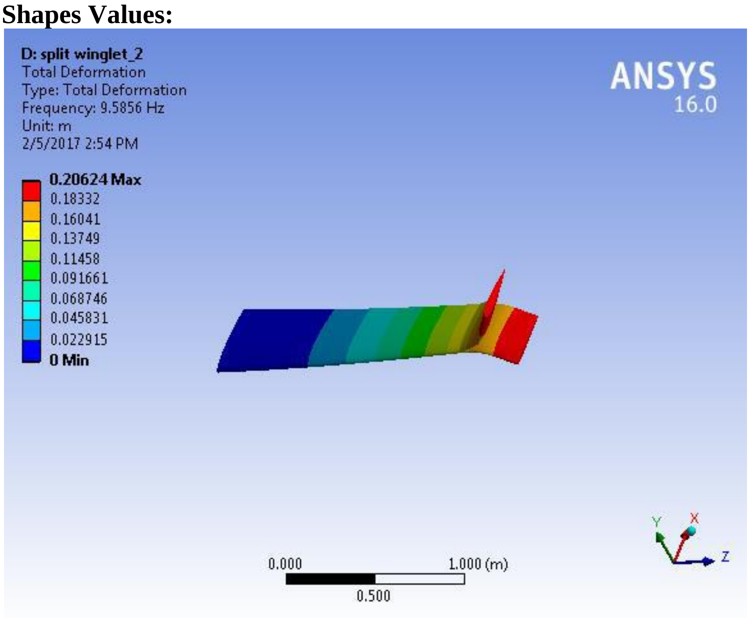
Mode	Frequency [Hz]
1.	16.174
2.	50.23
3.	88.237
4.	112.63
5.	132.46

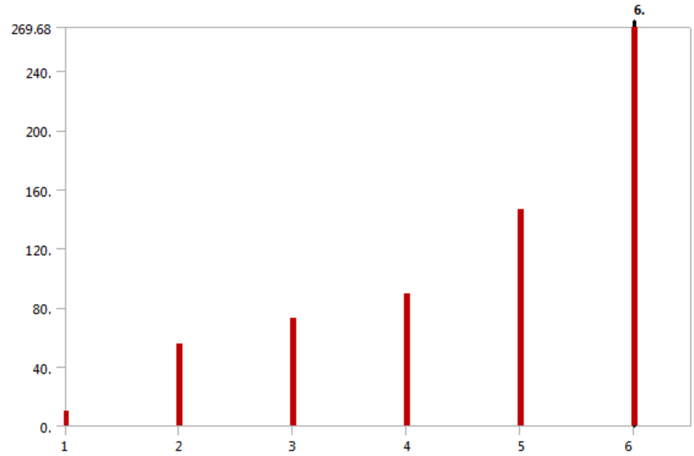
Aluminum Metal Matrix Composite (Al 7075+15%Flyash)

Material Properties:

Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa	Tensile Ultimate Strength Pa
7.5e+010	0.28	5.6818e+010	2.9297e+010	3.1e+008

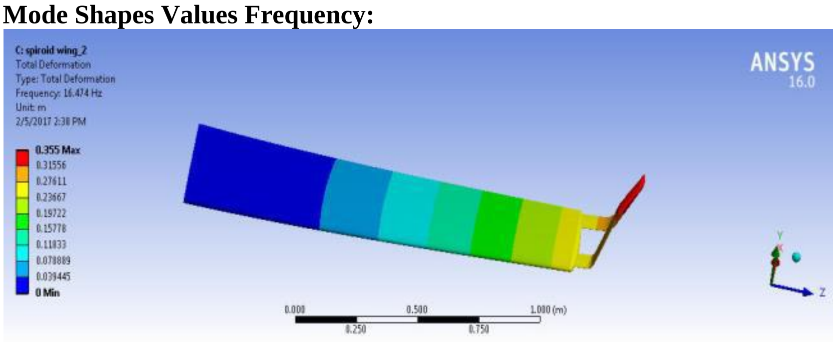
Split Winglet Mode Shapes Values:



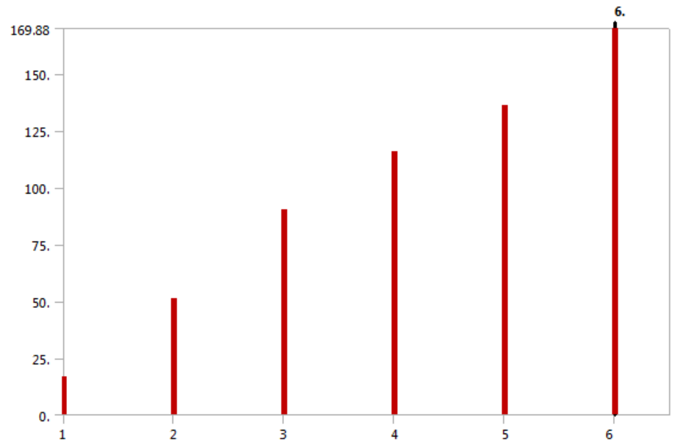


Mode	Frequency [Hz]
1.	9.5856
2.	55.047
3.	72.635
4.	89.152
5.	146.4
6.	269.68

Spiroid Winglet Mode Shapes Values Frequency:



Model (C4) > Modal (C5) > Solution (C6)



Mode	Frequency[Hz]
1.	16.474
2.	51.132
3.	89.936
4.	115.93
5.	136.1
6.	169.88

Conclusion:

S.no	Winglet	Al 7075-T651	Al 7075+15% Fly Ash MMC
1	split winglet	9.3922	9.5856
2	spiroid winglet	16.174	16.474

Compare this result Spiroid winglet having high natural frequency due to that this winglet having more stiffness strength to controlling vibration

when using Al 7075+15% Fly Ash MMC material instead of Al 7075-T651that natural frequency level also increasing. That means it controlling structural stiffness at more vibration.

References:

[1]. The Design of Winglets for Low-Speed Aircraft, Mark D. Maughmer, The Pennsylvania State University Park, Pennsylvania 16802.

[2]. An Experimental Study on Wingtip Devices for Agricultural Aircraft, Rogerio F . F. Coimbra's and Fernando M. Catalano Aircraft ́s Laboratory, University of Sao Paulo, Sao Carlos, BRAZIL.

[3]. Aerodynamic Efficiency Study of Modern Spiroid Winglets, Tung Wan Hung-Chu Chou Kuei-Wen Lien, Department of Aerospace Engineering, Tamkang University, Taiwan, R.O.C.

[4]. Drag Analysis of an Aircraft Wing Model with and without Bird Feather like Winglet, Altab Hossain, Ataur Rahman, A.K.M. P. Iqbal, M. Ariffin, and M. Mazian (2011)

[5]. Reduction of Wingtip Vortex from Suction at Wingtip, Sangram Keshari Samal & P.K. Dash, Aeronautical Department, Hindustan Institute of Technology and Science, Padur, Chennai, India, Department of Aerospace Engineering, University of Petroleum and Energy Studies, Dehradun, India.

[6]. CFD Analysis of Winglets at Low Subsonic Flow, M. AAzlin, C.F Mat Taib, S. Kasolang and F.H Muhammad, July 6 -8, 2011, London, U.K

[7]. Saravanan Rajendran, Design of Parametric Winglets and Wing tip devices –A Conceptual Design Approach.