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Design and Finite Element Analysis of Aircraft Wing Using Ribs and Spars

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ABSTRACT

A wing is a type of fin with a surface that produces aerodynamic force for flight or propulsion through the atmosphere, or through another gaseous or liquid fluid. As such, wings have an airfoil shape, a streamlined cross-sectional shape producing lift. A wing's aerodynamic quality is expressed as its lift-to-drag ratio. The lift a wing generates at a given speed and angle of attack can be one to two orders of magnitude greater than the total drag on the wing. A high lift-to-drag ratio requires a significantly smaller thrust to propel the wings through the air at sufficient lift.

The requirements for the aircraft wing are High stiffness, High strength, High toughness and Low weight.

In design and finite element analysis of aircraft wing using ribs and spars, an aircraft wing is designed and modeled in 3D modeling software Pro/Engineer. The wing is modified by attaching ribs and spars in order to increase the strength of the wing. The materials used for aircraft wings are mostly metallic alloys. In this thesis, the materials are replaced by composite materials S Glass, Kevlar 49 and Boron Fiber.

Static analysis is done to determine the stresses produced by applying loads. Modal analysis and random vibration analysis is done on the aircraft wing to determine the frequencies and directional deformations, stress due to frequencies. Buckling analysis is done to determine deformation and load multiplier. CFD analysis is done on the wing to determine the lift and drag forces at different velocities. Analysis is done in Ansys.

Keywords: aircraft wing using ribs and spars, Static analysis, Modal analysis, random vibration analysis, Buckling analysis, CFD analysis.

INTRODUCTION

AIRCRAFT STRUCTURE

In the 1960s, ever larger aircraft were developed to carry passengers. As engine technology improved, the jumbo jet was engineered and built. Still primarily aluminum with a semi monocoque fuselage, the sheer size of the airliners of the day initiated a search for lighter and stronger materials from which to build them. The use of honeycomb constructed panels in Boeing’s airline series saved weight while not compromising strength. Initially, aluminum core with aluminum or fiberglass skin sandwich panels were used on wing panels, flight control surfaces, cabin floor boards, and other applications. A steady increase in the use of honeycomb and foam core sandwich components and a wide variety of composite materials characterizes the state of aviation structures from the 1970s to the present. Advanced techniques and material combinations have resulted in a gradual shift from aluminum to carbon fiber and other strong, lightweight materials. These new materials are engineered to meet specific performance requirements for various components on the aircraft.

WINGS

Wings are airfoils that, when moved rapidly through the air, create lift. They are built in many shapes and sizes. Wing design can vary to provide certain desirable flight characteristics. Control at various operating speeds, the amount of lift generated, balance, and stability all change as the shape of the wing is altered. Both the leading edge and the trailing edge of the wing may be straight or curved, or one edge may

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be straight and the other curved. One or both edges may be tapered so that the wing is narrower at the tip than at the root where it joins the fuselage. The wing tip may be square, rounded, or even pointed. shows a number of typical wing leading and trailing edge shapes. The wings of an aircraft can be attached to the fuselage at the top, mid-fuselage, or at the bottom. They may extend perpendicular to the horizontal plain of the fuselage or can angle up or down slightly. This angle is known as the wing dihedral. The dihedral angle affects the lateral stability of the aircraft. shows some common wing attach points and dihedral angle.

TYPES OF WINGS

- Non planar wing or closed wing
- Box wing
- Annular (cylindrical)
- Joined wing
- Annular wing (planar)
    - i. Flat
    - ii. Rhomboidal wing

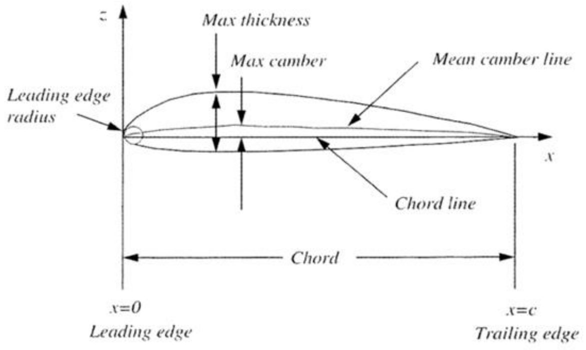
WING STRUCTURE

The wings of an aircraft are designed to lift it into the air. Their particular design for any given aircraft depends on a number of factors, such as size, weight, use of the aircraft, desired speed in flight and at landing, and desired rate of climb. The wings of aircraft are designated left and right, corresponding to the left and right sides of the operator when seated in the cockpit. Often wings are of full cantilever design. This means they are built so that no external bracing is needed.

They are supported internally by structural members assisted by the skin of the aircraft. Other aircraft wings use external struts or wires to assist in supporting the wing and carrying the aerodynamic and landing loads. Wing support cables and struts are generally made from steel. Many struts and their attach fittings have fairings to reduce drag.

AIRFOILS

An airfoils shape is defined by several parameters, which are shown in the figure below.



Airfoil shape parameters

Airfoil Definitions

Chord Line: Straight line drawn from the leading edge to the trailing edge

Chord Length (c): Length of the chord line

Mean Camber Line: Curved line from the leading edge to the trailing edge, which is equidistant between the upper and lower surfaces of the airfoil

Maximum (or Just) Camber: Maximum distance between the chord line and the mean camber line.

NACA AIRFOIL

During the 1930's several families of airfoils and camber lines were developed by the National Advisory Committee for Aeronautics (NACA). Many of these airfoil shapes have been successfully used over the years as wing and tail sections for general aviation and military aircraft, as well as propellers and helicopter rotors.

The ordinates for numerous specific airfoils of these series at a coarse set of data points were published in a series of NACA reports. However, when performing parametric studies on effects of such variables as thickness, location of maximum thickness, leading-edge radius, location of maximum camber and others, it is not always easy to obtain the ordinates of the desired shapes rapidly and accurately. To remedy this problem the NASA Langley Research Center sponsored the development of computer programs for generation of ordinates of standard NACA airfoils.

MATERIALS

S-GLASS: E-Glass has been used extensively in polymer matrix composites, commonly termed “fibreglass”. These materials exhibit good mechanical properties, however, these have not been sufficient in some instances. Consequently, the E-glass composition has been modified to produce more desirable properties. A higher stiffness material resulting from this is S-Glass.

KEVLAR ® 49: Kevlar is an aramid, a term invented as an abbreviation for aromatic polyamide. The chemical composition of Kevlar is poly para-phenyleneterephthalamide, and it is more properly known as a para-aramid. Aramids belong to the family of nylons. Common nylons, such as nylon 6,6, do not have very good structural properties, so the para-aramid distinction is important. The aramid ring gives Kevlar thermal stability, while the para structure gives it high strength and modulus. The University of Southern Mississippi Department of Polymer Science has a good description of aramid chemistry, including drawings of the chemical structure.

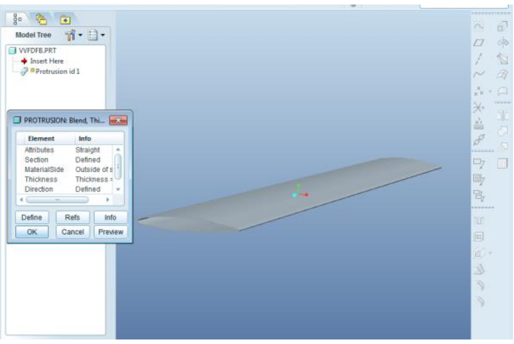
BORON FIBER : Boron fiber (also commonly called "boron filament") is an amorphous elemental boron product which represents the major industrial use of elemental (free) boron. Boron fiber manifests a combination of high strength and high modulus. A common use of boron fibers is in the construction of high tensile strength tapes. Boron fiber use results in high-strength, lightweight materials that are used chiefly for advancedaerospace structures as a component of composite materials, as well as limited production consumer and sporting goods such as golf clubs and fishing rods. In the production process, elemental boron is deposited on an even tungsten wire substrate which produces diameters of 4.0 mil (102 micron) and 5.6 mil (142 micron). It consists of a fully borided tungsten core with amorphous boron.

INTRODUCTION TO CAD & PRO/ENGINEER

Computer-aided design (CAD), also known as computer-aided design and drafting (CADD), is the use of computer technology for the process of design and design-documentation.CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals. The modern ubiquity and power of computers means that even perfume bottles and shampoo dispensers are designed using techniques unheard of by engineers of the 1960s. Because of its enormous economic importance, CAD has been a major driving force for research in computational geometry, computer graphics (both hardware and software), and discrete differential geometry.

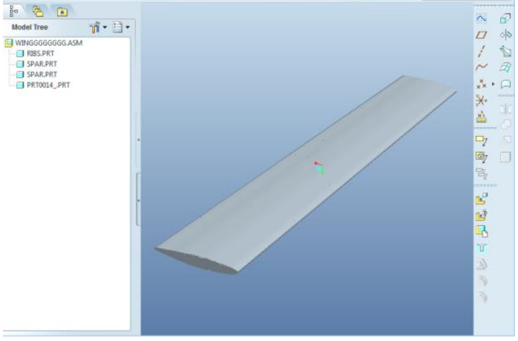
MODELS IN PRO/ENGINEER

ORIGINAL MODEL



Element	Info
Attributes	Straight
Section	Defined
MaterialSide	Outside of s
Thickness	Thickness =
Direction	Defined

MODIFID MODEL (WITH RIBS AND SPARS)



INTRODUCTION TO FEA

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variational calculus to obtain approximate solutions to vibration systems. Shortly thereafter, a paper published in 1956 by M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Topp established a broader definition of numerical analysis. The paper centered on the "stiffness and deflection of complex structures".

Results of finite element analysis

FEA has become a solution to the task of predicting failure due to unknown stresses by showing problem areas in a material and allowing designers to see all of the theoretical stresses within. This method of product design and testing is far superior to the manufacturing costs which would accrue if each sample was actually built and tested.
In practice, a finite element analysis usually consists of three principal steps:

1. Preprocessing:
2. Analysis:
3. Post processing:

INTRODUCTION TO ANSYS

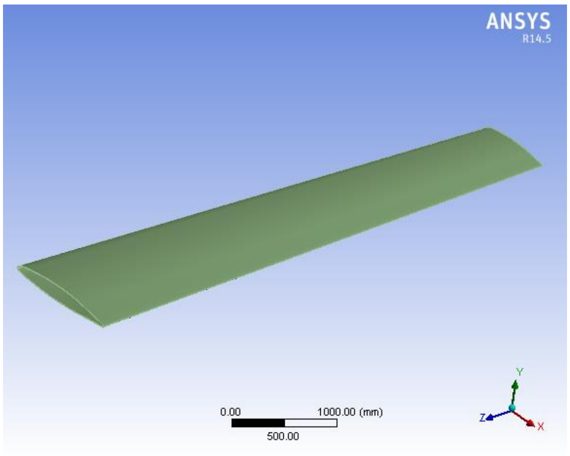
ANSYS stands for Analysis System product. Dr. John Swanson was the founder of ANSYS Inc. In the year 1970 ANSYS was founded in order to establish a technology that facilitates several companies/industries to compute or simulate analysis issues. ANSYS is a general-purpose finite element analysis (FEA) software package that is extensively used in industries to resolve several mechanical problems. FEA is a method of fragmenting a composite system in to small pieces called elements. The ANSYS software carries out equations that regulate the performance of these elements and solves them resulting in an overall description of how system works integrally. The obtained results are displays in a tabulated or graphical form.

INTRODUCTION TO CFD

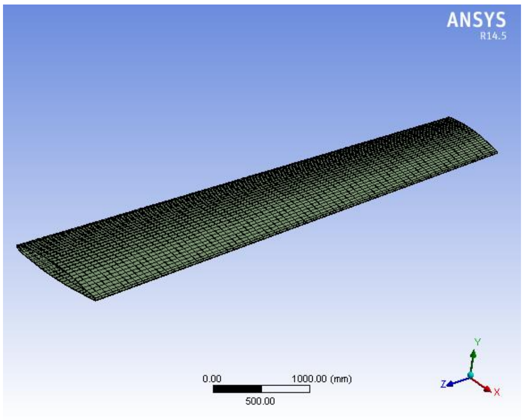
Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. With high-speed supercomputers, better solutions can be achieved. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. Initial experimental validation of such software is performed using a wind tunnel with the final validation coming in full-scale testing, e.g. flight tests.

ANALYSIS OF AIRCRAFT WING

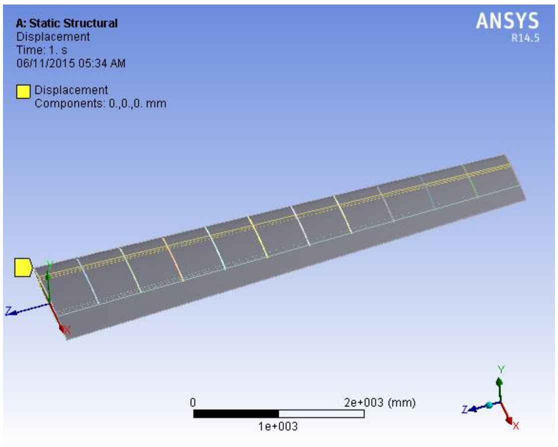
STATIC ANALYSIS OF ORIGINAL MODEL



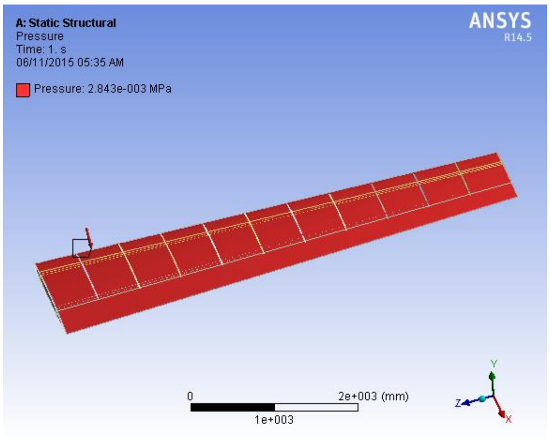
Imported model



Meshed model



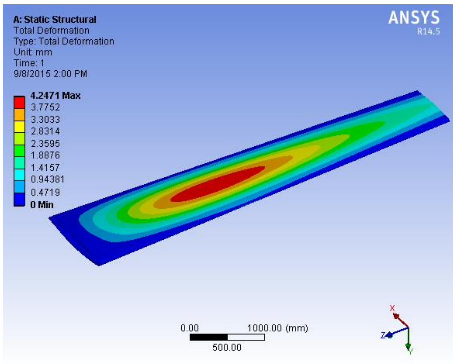
Displacement



Pressure

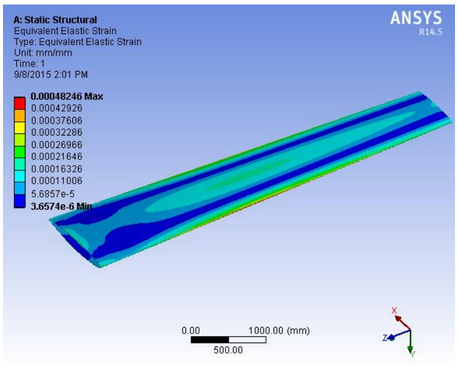
S GLASS

DEFORMATION



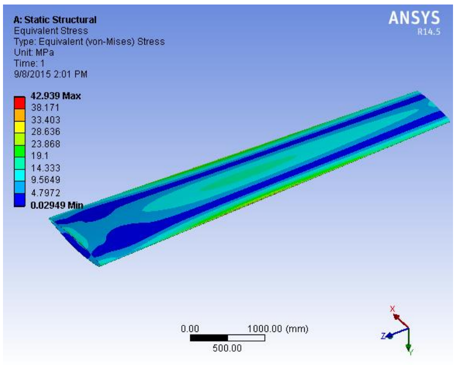
Deformation

STRAIN



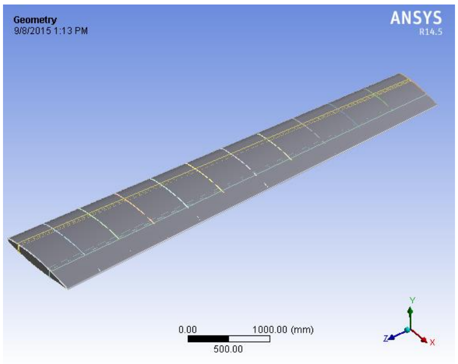
Strain

STRESS



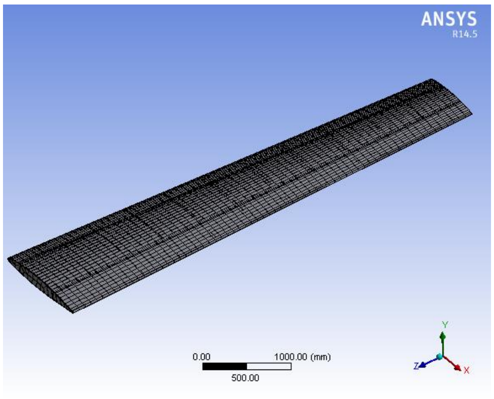
Stress

STATIC ANALYSIS OF MODIFIED MODEL



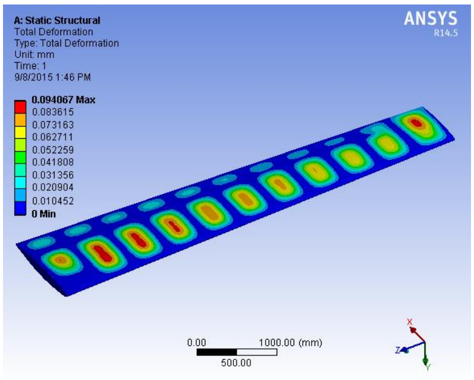
Imported model

Meshed Model



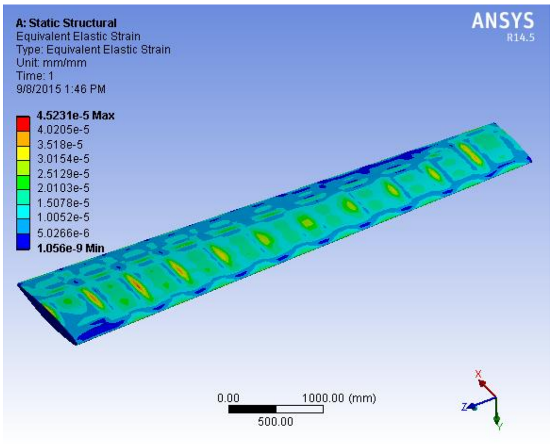
Meshed model

DEFORMATION



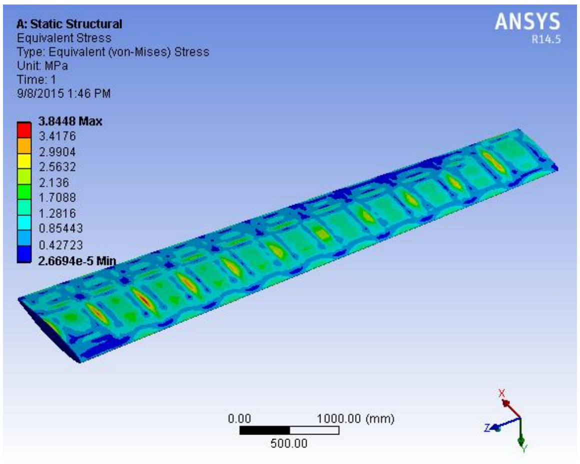
Deformation

STRAIN



Strain

STRESS

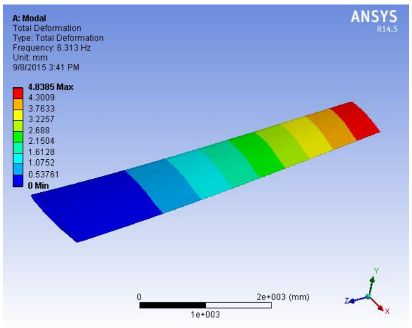


Stress

MODAL ANALYSIS OF ORIGINAL MODEL

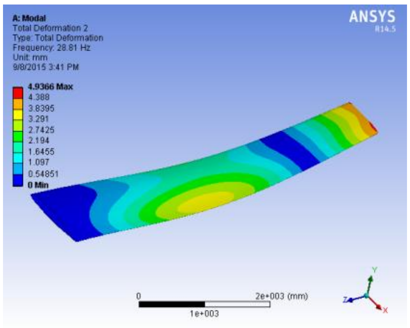
S - GLASS

Mode 1



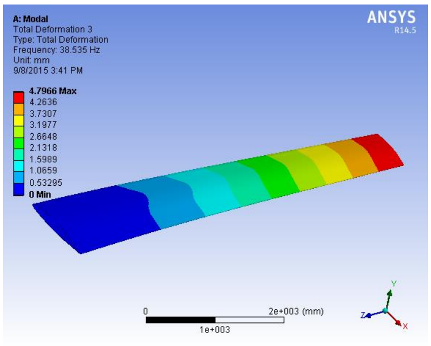
Modal 1

Mode 2



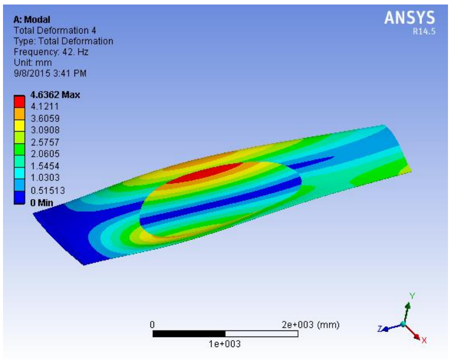
Modal 2

Mode 3



Modal 3

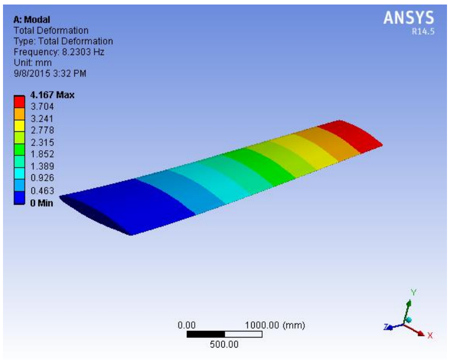
Mode 4



Modal 4

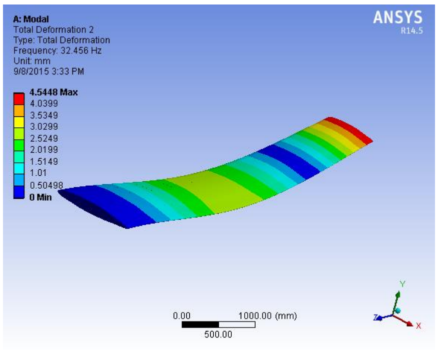
MODAL ANALYSIS OF MODIFIED MODEL

Mode 1



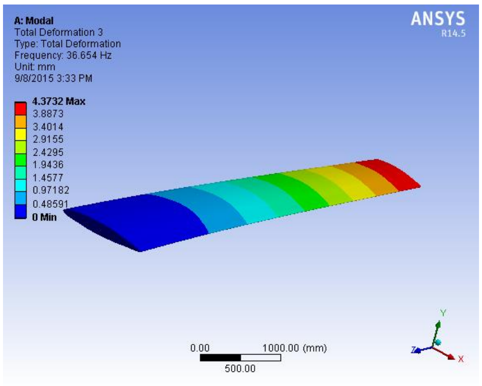
Modal 1

Mode 2



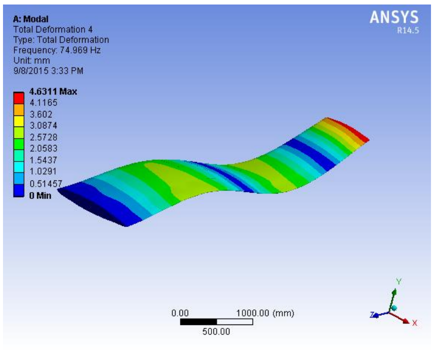
Modal 2

Mode 3



Modal 3

Mode 4



Modal 4

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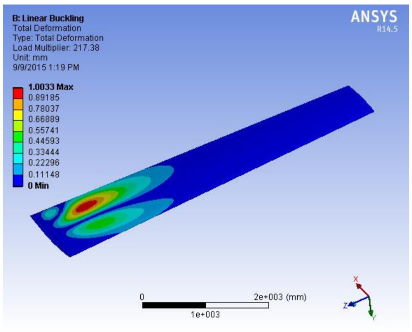
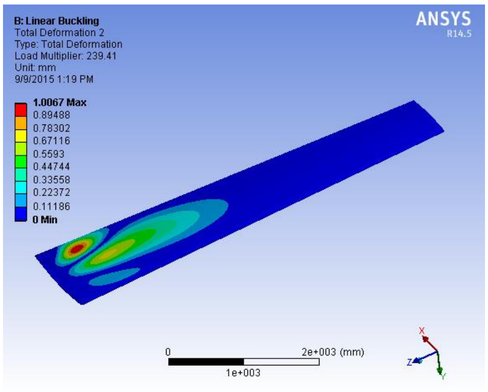
BUCKLING ANALYSIS OF ORIGINAL MODEL -S - GLASS

DEFORMATON 1



Deformation 1

DEFORMATON 2



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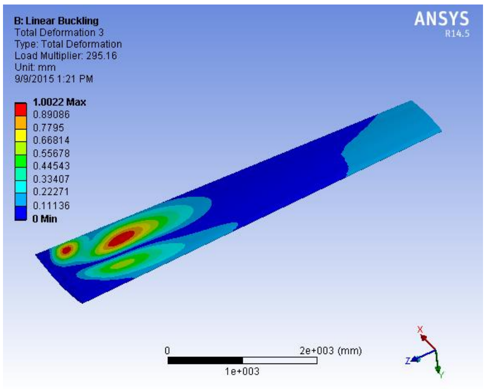
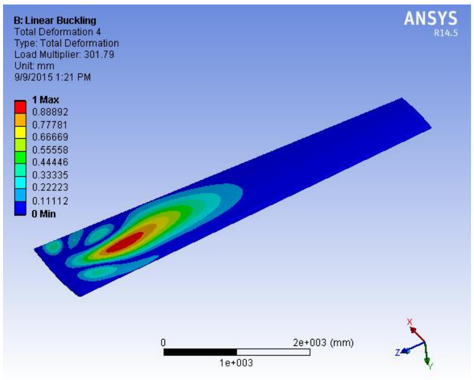
DEFORMATON 3



Deformation 3

DEFORMATON 4

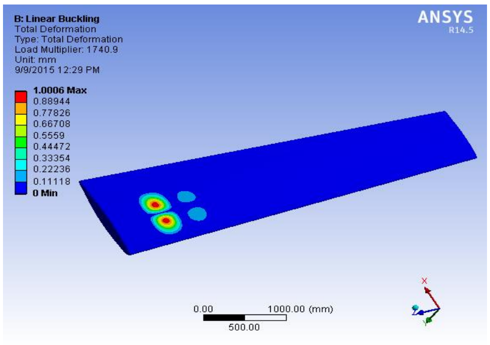


Deformation 4

BUCKLING ANALYSIS OF MODIFIED MODEL

S - GLASS

DEFORMATON 1



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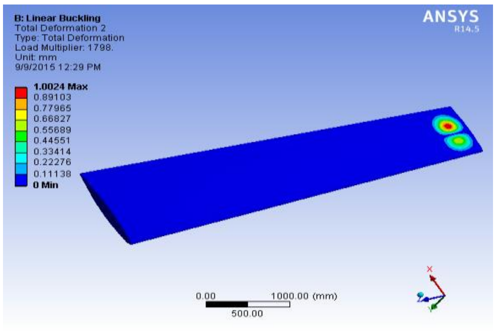

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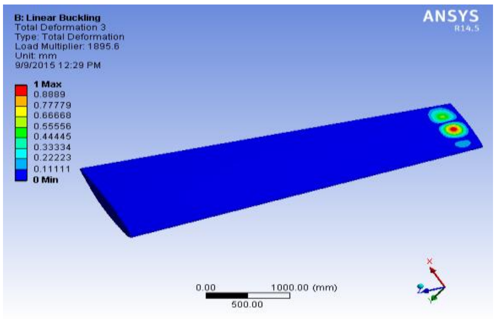
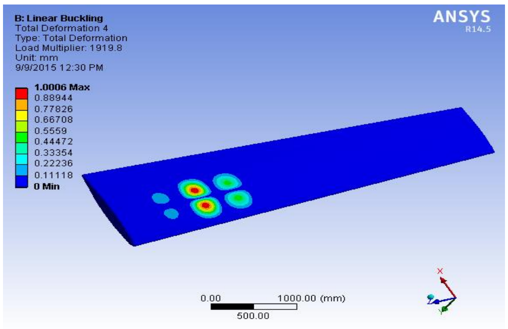


Deformation 3

DEFORMATON 4

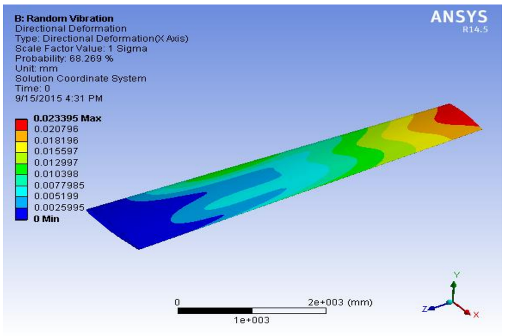


Deformation 4

3.2.7 RANDOM VIBRATION ANALYSIS OF ORIGINAL MODEL

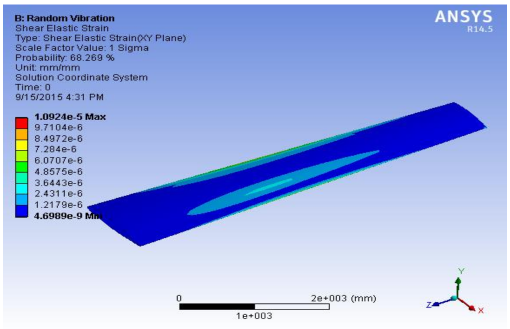
S - GLASS

DIRECTIONAL DEFORMATION



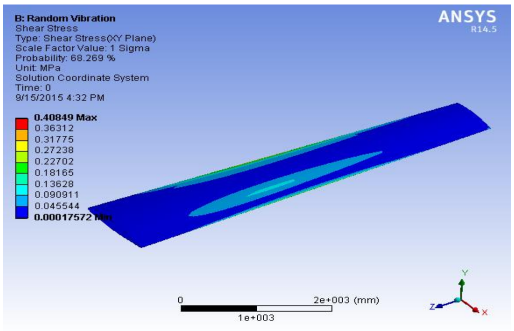
Directional Deformation

SHEAR STRAIN



Shear Strain

SHEAR STRESS

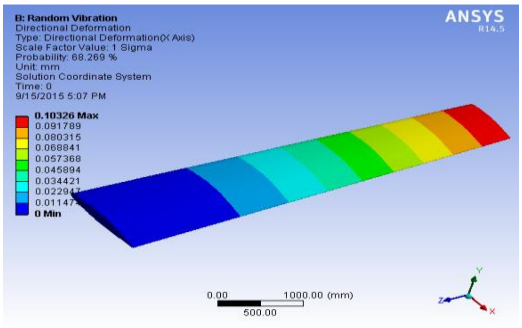


Shear Stress

3.2.8 RANDOM VIBRATION ANALYSIS OF MODIFIED MODEL

S - GLASS

DIRECTIONAL DEFORMATION



Directional Deformation

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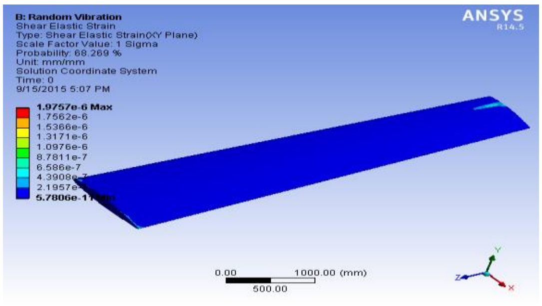
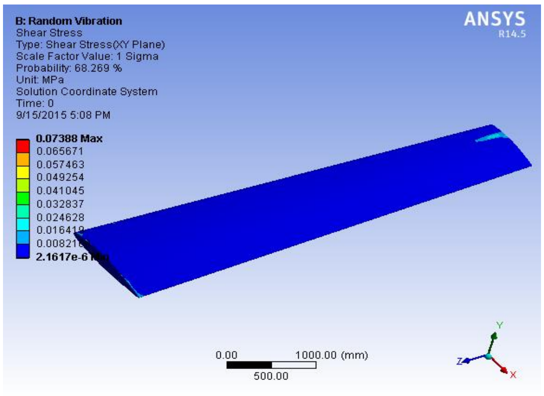
SHEAR STRAIN



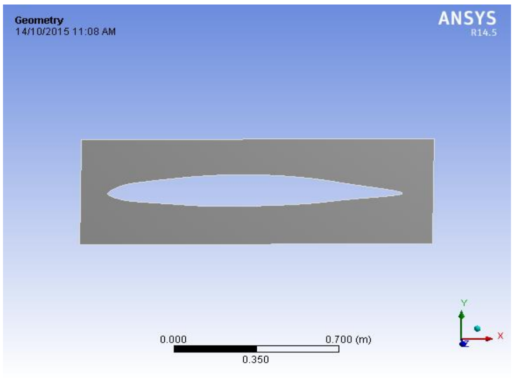
Shear Strain

SHEAR STRESS

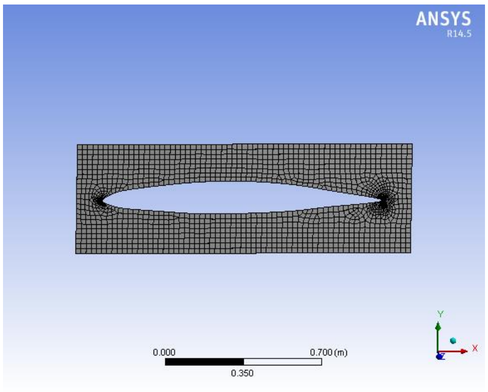


Shear Stress

3.2.9 CFD ANALYSIS OF ORIGINAL MODEL

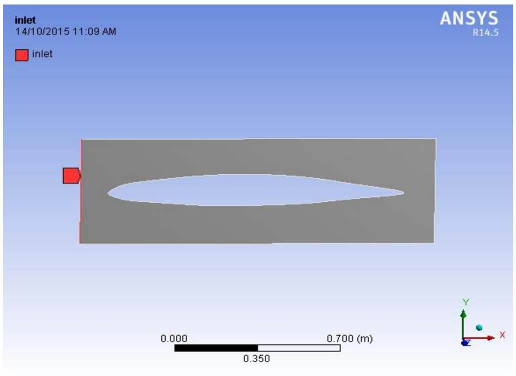


Imported model



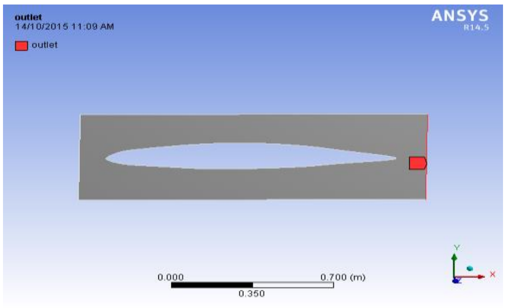
meshed model

Inlet



Inlet

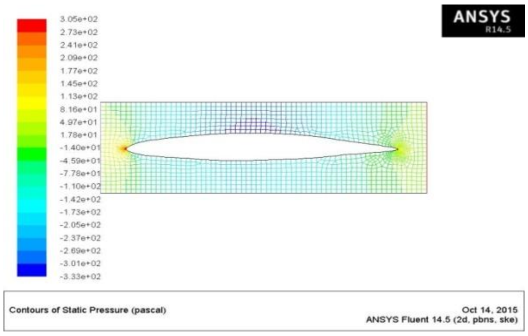
Outlet



Outlet

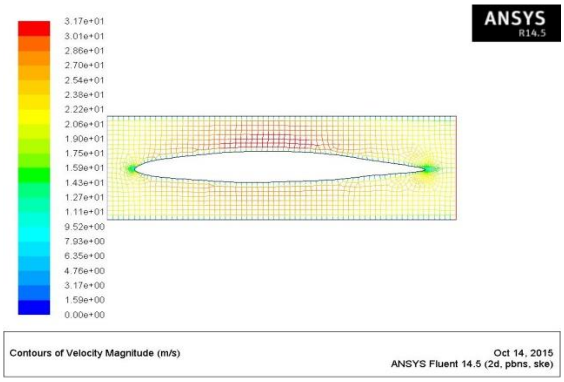
4.3.1ORIGINAL MODEL - VELOCITY – 20m/s

Static Pressure



Static Pressure

Velocity



Velocity Magnitude

Lift

```
"Force Report"

Forces
            Forces (n)                                                    Coefficients
Zone          Pressure                 Viscous                Total
Pressure                 Viscous                 Total
wall-_trm_srf    (9.1830397 5.9699268 0)         (14.81855 -0.048807424 0)         (24.00159
5.9211194 0)           (14.992718 9.7468193 0)          (24.193551 -0.079685589 0)
(39.186269 9.6671337 0)
-------------------------------- ------------------------------------
Net            (9.1830397 5.9699268 0)         (14.81855 -0.048807424 0)          (24.00159
5.9211194 0)           (14.992718 9.7468193 0)          (24.193551 -0.079685589 0)
(39.186269 9.6671337 0)

Forces - Direction Vector (1 0 0)
            Forces (n)               Coefficients
Zone          Pressure    Viscous    Total    Pressure    Viscous    Total
wall-_trm_srf    9.1830397    14.81855    24.00159    14.992718    24.193551    39.186269
----------------------- -------------- -------------- -------------- Net            9.1830397    14.81855    24.00159
14.992718    24.193551    39.186269
```

Drag

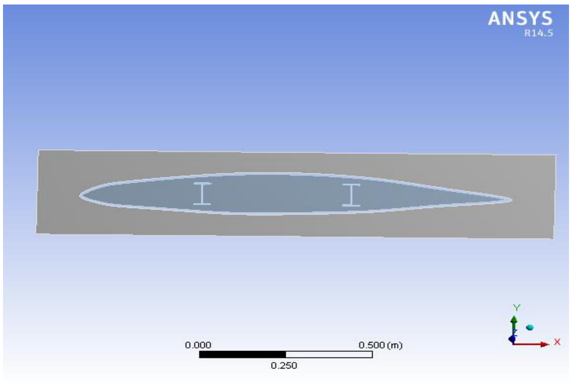
```
                 "Force Report"

Forces
            Forces (n)                                                    Coefficients
Zone          Pressure                 Viscous                Total
Pressure                 Viscous                 Total
wall-_trm_srf    (9.1830397 5.9699268 0)         (14.81855 -0.048807424 0)         (24.00159
5.9211194 0)           (14.992718 9.7468193 0)          (24.193551 -0.079685589 0)
(39.186269 9.6671337 0)
------------------------- -------------------------------------------- --
Net            (9.1830397 5.9699268 0)         (14.81855 -0.048807424 0)          (24.00159
5.9211194 0)           (14.992718 9.7468193 0)          (24.193551 -0.079685589 0)
(39.186269 9.6671337 0)

Forces - Direction Vector (0 1 0)
            Forces (n)               Coefficients
Zone          Pressure    Viscous    Total    Pressure    Viscous    Total
wall-_trm_srf    5.9699268    -0.048807424  5.9211194    9.7468193    -0.079685589  9.6671337
------------------------- -------------- -------------- --------------
Net            5.9699268    -0.048807424  5.9211194    9.7468193    -0.079685589  9.6671337
```

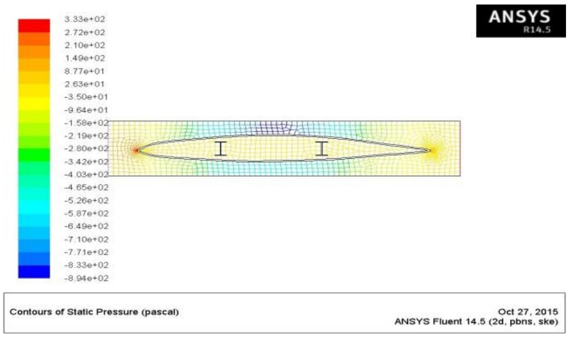
3.2.10 CFD ANALYSIS OF MODIFIED MODEL

VELOCITY- 20 m/s



Imported model

PRESSURE



Static Pressure

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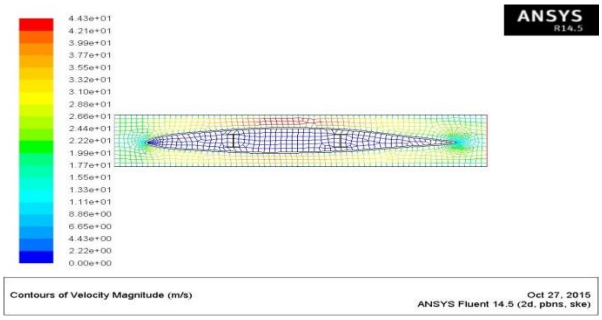
VELOCITY



Velocity Magnitude

LIFT

```
                 "Force Report"

Forces
                 Forces (n)                                              Coeffic
Zone             Pressure                Viscous                Total
Pressure                   Viscous                Total
wall-_trm_srf      (11.192978 0.90947813 0)          (10.771148 -0.028365484 0)          (21.96412
0.88111264 0)          (18.27425 1.4848622 0)          (17.585547 -0.046310993 0)
(35.859797 1.4385513 0)
------------------------ ------------------------------------------ --
Net              (11.192978 0.90947813 0)          (10.771148 -0.028365484 0)          (21.964126
0.88111264 0)          (18.27425 1.4848622 0)          (17.585547 -0.046310993 0)
(35.859797 1.4385513 0)

Forces - Direction Vector (0 1 0)
                 Forces (n)                  Coefficients
Zone             Pressure     Viscous     Total       Pressure     Viscous     Total
wall-_trm_srf      0.90947813    -0.028365484   0.88111264    1.4848622    -0.046310993    1.4385513
------------------------ -------------- -------------- --------------
Net              0.90947813    -0.028365484   0.88111264    1.4848622    -0.046310993    1.4385513
```

DRAG

```
                 "Force Report"

Forces
                 Forces (n)                                              Coe
Zone             Pressure                Viscous                Total
Pressure                   Viscous                Total
wall-_trm_srf      (11.192978 0.90947813 0)          (10.771148 -0.028365484 0)          (21.96
0.88111264 0)          (18.27425 1.4848622 0)          (17.585547 -0.046310993 0)
(35.859797 1.4385513 0)
------------------------ ------------------------------------------ --Net          (11.192978 0.90947813 0)
(10.771148 -0.028365484 0)          (21.964126 0.88111264 0)          (18.27425 1.4848622 0)
(17.585547 -0.046310993 0)          (35.859797 1.4385513 0)

Forces - Direction Vector (1 0 0)
                 Forces (n)                  Coefficients
Zone             Pressure     Viscous     Total       Pressure     Viscous     Total
wall-_trm_srf      11.192978     10.771148     21.964126     18.27425      17.585547     35.859797
------------------------ -------------- -------------- --------------
Net              11.192978     10.771148     21.964126     18.27425      17.585547     35.859797
```

CONCLUSION

- In this thesis, an aircraft wing is designed and modeled in 3D modeling software Pro/Engineer. The wing is modified by adding ribs and spars.
- The materials used for aircraft wings are mostly metallic alloys. In this thesis, the materials are replaced by composite materials S Glass, Kevlar 49 and Boron Fiber. The advantage of using composite materials is their high strength to weight ratio.
- Static analysis is done on the wing by applying air pressure for three materials. By observing the analysis results, the deformation and stresses are less for wing with ribs and spars than compared with that of original wing. When compared the results between materials, the stresses are less for Boron Fiber.
- Modal analysis is done on the aircraft wing to determine the frequencies. By observing the results, the frequencies are more for modified model but deformations are less. So the vibrations are more for modified model. The frequencies are less for S Glass. By observing the random vibration analysis, the shear stress is less for modified model than original model. The shear stress is less for S Glass for modified model.
- By observing the buckling analysis results, the load multiplier is more for modified model than original model (i.e), the modified model buckles only when the present applied load is multiplied with that of load multiplier. The material S Glass is better.
- By observing the CFD analysis results, the drag force is more modified model than original model. This increases the force on the aircraft. By CFD, it can be concluded that original model is better.
- It can be concluded that adding ribs and spars to the wing increases the strength of the wing and material S Glass is better.

FUTURE SCOPE

In the present thesis, the load considered for analysis is only air pressure. But more loads will be acted on spars like upward bending loads resulting from the wing lift force that supports the fuselage in flight, downward bending loads whilst stationary on the ground due to the weight of the structure, fuel carried in the wings, and wing-mounted engines if used, Drag loads dependent on airspeed and inertia, Rolling inertia loads and Chord wise twisting loads due to aerodynamic effects at high airspeeds often associated with washout, and the use of ailerons resulting in control reversal.The effect of these forces on the wing can substantially change the results, so the present work can be extended by applying the above forces also.

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