

OPTIMIZATION OF SWEEP DIHEDRAL AIRCRAFT WING UNDER STATIC LOAD CONDITION DURING CRUISE SPEED

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in
Aeronautical Engineering

By

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(DEEMED TO BE UNIVERSITY)

Accredited with grade "A" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **BHOYE HARSHAD BHARAT (Reg. No. 38260006)** and **DEVANG KISHOR SAINDANKAR (Reg. No. 38260036)** who carried out the project entitled **"OPTIMIZATION OF SWEEP DIHEDRAL AIRCRAFT WING UNDER STATIC LOAD CONDITION DURING CRUISE SPEED"** under our supervision from September 2021 to April 2022.

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DECLARATION

We **BHOYE HARSHAD BHARAT** (Reg. No. **38260006**) and **DEVANG KISHOR SAINDANKAR** (Reg. No. **38260036**) hereby declare that the Project Report entitled **“OPTIMIZATION OF SWEPT DIHEDRAL AIRCRAFT WING UNDER STATIC LOAD CONDITION DURING CRUISE SPEED”** done by us under the guidance of **Mr. Gokulnath. R**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Aeronautical Engineering.

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ABSTRACT

This project presents study of the structural characteristics of aircraft wing. A320 aircraft wing reference is used for this investigation. CATIA V5 is used to produce a computer-aided design (CAD) wing, while ANSYS is used for analysis. The analysis was performed on the wing, with one end of the wing (root chord) fixed and the other end (tip chord) free. To determine total deformation, a numerical validation technique is carried out using a workbench and finite element analysis software, together with structural analysis and model analysis. The deformation and the stress acting on the model of the wing have been studied by using different materials and changing the thickness of ribs. So, while designing an aircraft, structural strength of the wing has to be considered. The optimization tools CFD and FEA tools were used to study a subsonic passenger aircraft. The comparative results for different materials of wings and thickness of ribs is discussed in this project. Our project intends to present data derived from both fluid and structural interaction problems in computationally accelerated form. This will allow us the prediction of the nature of an aircraft wing during its operating load conditions more accurately. We will determine how the structure is deformed and how the stress distribution varies under various conditions.

Keywords: CATIA V5, Total Deformation, Wing Root, Wing Tip

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LIST OF SYMBOLS AND ABBREVIATIONS

FSI	Fluid Structure Interaction
CFD	Computational Fluid Dynamics
mm	Millimetre
MPa	Mega Pascal
N	Newton
FEA	Finite Element Analysis
GTOW	Gross Take Off Weight
JAR 25	European Joint Aviation Requirement
FAR 25	US Federal Aviation Requirement

CHAPTER 1

INTRODUCTION

Designing a real-life aircraft is a very critical task where various parameters and conditions have to be taken into account. The very basic designing procedure of an aircraft has been discussed in several books. The flow analysis was followed by a structural analysis of the aircraft, which was one of the most important analyses that should be considered while optimizing an aircraft. The basic characteristics of an aircraft, like as payload, cruising speed, and so on, play a significant impact in the design optimization process. Because the wing is the primary source of lift, wing optimization was prioritized during the aircraft optimization process. Subsequently, in this venture, we used progressed investigation approaches to concentrate on the exhibition of a wing when it is exposed to static burdens. To ensure that an airplane wing is solid, we select a definitive condition in the examination. We fostered our own wing in light of a subsonic traveler airplane. In our venture, we consider journey speed to ascertain airplane wing execution. To register airplane wing execution, we should think about both underlying disfigurement and stream circulation over a wing. Be that as it may, assuming we consider actually the primary and stream conveyance over an airplane are entomb connected with one another. Thus, in the event that we examination the airplane wing independently it won't give definite outcome. Subsequently, we are going through another investigation called Fluid Structure Interaction just called as FSI. Here, we broke down how the airplane wing structure will disfigure at outrageous condition. We use to plan the wing utilizing displaying programming and dissected utilizing Ansys workbench. From the project we thought about the outcomes from both the individual examination and consolidated FSI investigation. At last, we received the FSI data, which showed improved outcomes. In ongoing we are intended to consider the unique conduct of the FSI investigation utilizing interloop examination which could give significantly more exact outcomes. And furthermore, we intend to broaden this approach for entire airplane gathering in coming time.

1.1 MAJOR CAUSE OF FAILURE IN AIRCRAFT STRUCTURE:

It is paramount to investigate defects and failures in aircraft structures in order to prevent further incidents when a component of an aircraft fails, resulting in life loss and destruction of the aircraft. A failure occurs when a component or structure becomes unable to resist stresses during operation. Commonly, failures occur when stresses become concentrated. This can occur for several reasons, including:

- For example, holes, notches, and tight fillet radii may be the result of design errors;
- Inclusions, voids, and other microstructures can exist in the material
- Local stress concentrations can also be generated by corrosive attack on the material, such as pitting.

Thus, fatigue failure dominates the distribution in aircraft, proving that fatigue is the leading cause of failure in service. Although the process of detecting and correcting corrosion damage on an aircraft in service is more labor intensive than the process of repairing fatigue cracks. As corrosive failure is generally slower than fatigue attack, and usually easier to detect and rectify during routine maintenance, fatigue failure is more common because of its destructive characteristics.

1.2 DEFORMATION:

When a material deforms, Internal intermolecular forces emerge to counteract the imposed force. These forces resist deformation and allow the material to back to its initial state when the load is removed if the applied force is not too great. It is possible for a larger force to permanently deform the material or even cause structural failure.

1.2.1 Types of Deformation:

Different types of deformations can result from different types of materials, sizes, and forces applied. Types of deformations include:

- Elastic Deformation - Rubber, elastomers, and various types of memory metals like nitinol show large and various elastic deformation ranges.
- Plastic deformation - This can be irreversible. Soft thermoplastics have a rather large plastic deformation variance, as do ductile metals such as silver, copper and nickel.
- Metal fatigue - This happens in bars, columns, etc. Metal fatigue is the most common cause for failure in these metals, especially before the procedure was fully comprehended.
- Fracture - All materials eventually fracture if enough force is applied.

1.3 IMPORTANCE OF DEFORMATION STUDY IN AEROSPACE INDUSTRY:

Wing deformation is an important component of aerodynamic properties, structure design, and fatigue analysis in aircraft manufacturing, as well as a primary test factor for flutter certification. The deformation causes many problems, such as the external load distribution changing and the internal structure of the load distribution imbalance of the wings. All of these problems affect the airplane's performance, safety, and lifetime. It is critical that materials under service conditions maintain a steady load for prolonged periods of time. This deformation, known as creep, occurs as a result of prolonged exposure to steady loads. Flutter, is a perplexing and unsteady aeroelastic peculiarity, it is the outrageous exhibition of the wing distortion. Planes can get into a shaky state and be obliterated by an incredibly tremendous powerful burden in an exceptionally brief time frame when ripple occurs. Hence, how to recognize wing deformity and flight shudder is one of the main strides for airplane configuration, assembling, and airworthiness certificate.

1.4 VARIOUS OPTIMIZATION TOOLS

1.4.1 Ansys

Analysing structural dynamics and linear or non-linear linear systems is a breeze with Ansys Mechanical software. A range of engineering problems may be solved using the product's element behaviour and material models.

1.4.2 Nastran

Nastran is a finite element analysis (FEA) program which was developed by the U.S. government's Department of Defence for NASA in the year 1960s.

1.4.3 Abaqus

Abaqus is popular with academics and various research institution due to its wide material and modelling capabilities. Furthermore, it can be customized. The other standout feature of Abaqus is its ability to perform multi-physics simulations, such as coupled acoustic structural, piezoelectric, and various structural-pore simulations, making it a popular choice for simulations at the production level as various fields are involved.

1.4.4 LS-DYNA

LS-DYNA provides a broad range of Multiphysics simulation capabilities, but its roots are in highly nonlinear transient dynamic FEA, which is the heart of its core competence. LS-DYNA used by the construction, military, automobile, aerospace, manufacturing, and bioengineering industries.

1.4.5 Pam Crash

The Pam-Crash software package of the ESI Group is used by the automotive industry primarily for simulations of crashes and the design of the occupant safety systems. PAM-CRASH simulation allows automotive engineers to analyse the impact of various crash scenarios on the behaviour of proposed vehicle designs.

1.4.6 Matlab

A numerical computation environment and a programming language of the fourth generation, "MATLAB" is for numerical computing. It is used by math works to manipulate matrices, plot functions and data, implement algorithms, develop user interfaces, and interface with other languages. Math works also offers Fortran and C++.

1.4.7 Ansys Fluent

Ansys Fluent offers the broad physical modelling capabilities needed to simulate air flow over aircraft wings, combustion in furnaces, and bubble columns on oil platforms for industrial applications including air flow over aircraft wings, heat transfer, and reaction. In addition, the software can model in-cylinder combustion, aeroacoustics, multiphase systems and turbomachinery, due to special models.

1.4.8 StarCCM+

The STARCCM+ software package provides a single integrated solution for the simulation of flow, transfer of heat, and stress, including flow and solids. Beyond a CFD program, STARCCM+ provides an engineering process for resolving problems involving flow and heat transfer. With STARCCM+, problems with multiple physical interactions and complex geometries can be tackled in a way that is unrivalled.

1.5 VARIOUS MESHING SOFTWARES

1.5.1 Ansys ICEM CFD

Ansys ICEM CFD meshing software consists of various modern CAD/geometry readers and maintenance tools that enable users to easily and efficiently progress to geometry tolerant meshers. Advanced mesh diagnostics, interactive mesh editing, output from a wide range of CFD and FEA solvers, and Multiphysics post-processing capabilities are all included in ANSYS ICEM CFD. The purpose of ANSYS is to provide a set of tools that can work with any geometry and solver in a single, scriptable environment.

- Meshes created by inefficient CAD systems or faceted STL models can be modified
- Multi-dimensional, complex models can be meshed efficiently
- Hex mesh with advanced control (structural or unstructured)
- Provides output to a wide range of CFD and FEA solvers, as well as neutral formats

1.5.2 Gambit

With GAMBIT, Fluent's geometry and meshing software, almost all of Fluent's pre-processing technologies are available through a single interface. Model building sessions for parametric studies can be edited and played back using advanced tools for journaling. Pre-processing from CAD to excellent CFD meshes is among the fastest, easiest, and most straightforward thanks to GAMBIT's CAD integration, geometry clean up, decomposition, and meshing capabilities.

1.5.3 Hypermesh

Altair Hyper Mesh, which offers a highly interactive and visual interface for analysing design conditions with finite element solvers, is a high-efficient CFD pre-processor and post-processor. Using HyperMesh's graphical user interface, users can use existing finite element models as well as geometry from CAD. This allows for robust interoperability and performance. Users may automate mesh optimization based on a set of quality criteria, morph existing meshes, and produce mid-surfaces from models with various thicknesses using Hyper Mesh.

1.5.4 Ansa

With ANSA, you can process multidisciplinary CAE data, build full-models, generate input files for solvers in a single integrated environment, and blend CAD and solver data together. The list of productive and versatile features available in ANSA is long, as well as the many tasks and processes that can be managed using them. This makes it the users' preferred choice due to its rich features and tools.

CHAPTER 2

LITERATURE SURVEY

2.1 Parametric Study of a Genetic Algorithm using an Aircraft Design Optimization Problem

Andre C. Marta

In this work, genetic algorithms (GA) are used for generating a preliminary aircraft design. The major aircraft parameters are mapped onto chromosomes, including wing, tail, and fuselage geometry, and also thrust requirement, also operating parameters. In GA operator, the population of this kind of strings is created and natural selection should occur. The aircraft range is used as the fitness function to determine the best design. There is also an analysis of the effectiveness of different GA parameters, selection methods, and constraints on the performance of the algorithm.

An aircraft with the best design is a fast, efficient, quietest, cheapest one with the shortest field length. However, there is no such aircraft. We can only improve one thing at a time. The cheapest airplane probably would not be the fastest, and the most ergonomic airplane wouldn't be the most comfortable. That is to say, the overall airplane is always a compromise. There are numerous quantities that make up a figure of merit, which includes manufacturing, aerodynamics, weight, flight controls, structures, noise, and propulsions characteristics, the relative importance of which affects an aircraft's intended use.

It is vital to determine how the variables in the design relate to the goal once the definition of best has been determined. This can be a complex process in aircraft design. A complete description of an airplane requires a staggering number of parameters, making it necessary to combine approximation, experience, and statistical data from similar aircraft to reduce the parameters. The following two approaches to optimization are commonly used for choosing design variables that result in the best design: Numerical: most of the aircraft design problems involve iterations, complex computations and table look-ups. Analytical: very useful for fundamental studies but highly simplified (often oversimplified); very useful for fundamental studies but highly simplified (often oversimplified). There are four types

of direct search used in these cases, namely grid searches, random searches, and gradient searches and nonlinear simplex.

When constraints dictate the values of the design variables, such as in aircraft design, the objective function gradient is not zero when many constraints are active at the optimum. When constraints dictate the values of the design variables, such as in aircraft design, the objective function gradient is not zero when many of the constraints are active at optimum stage.

2.2 Value-Based Multidisciplinary Optimization for Commercial Aircraft Design and Business Risk Assessment Ryan Peoples

By minimizing takeoff weight, the goal of classic commercial aircraft design is to improve performance while reducing operational costs. When developing commercial aircraft, however, aircraft demand, market uncertainties, and development and production costs should all be considered. As part of addressing uncertain market demand and managerial flexibility, this research paper proposes a hybrid designing method which combines an aircraft performance model with a real-options-based program valuation approach. Combining performance and financial frameworks enables programmatic and technical decisions to be made in an integrated manner. Moreover, a methodology for specifying design needs and quantifying business and technical uncertainty is presented. In addition, a framework for specifying design objectives and quantifying business and technical uncertainty is provided.

Studies show that the focus on short-term cost reduction is a key factor causing decision makers to make poor long-term decisions. A stochastic approach suggests that spending money up front on the design process where ensuring long term profit is the smartest course of action.

A stochastic approach suggests that spending money up front on the design process to ensure long-term profitability is the smartest course of action. Many researchers have incorporated financial models into multidisciplinary design optimization (MDO) for aircraft in the past, such as life-cycle costs analysis and direct operating costs. NPV and IRR have also been used as value metrics. A multi-objective optimization approach is also possible to address the problem, balancing

the costs and performance. In the past, MDOs have resulted in deterministic solutions that can easily be translated into GTOW, value, or other objectives.

A multi-objective optimization approach is also possible to address the problem, balancing the costs and performance. In the past, MDOs have resulted in deterministic solutions that can easily be translated into GTOW, value, or other objectives. Probabilistic approach to increasing ROI and cost per passenger mile will aid in addressing design affordability and the balance of technical performance, cost, and risk. Furthermore, an approach based on estimation theory has been employed to minimize risk as well as to reduce risks throughout product development. Using the technique where discrete choice analysis has built a product-demand model, decision-based design is used in automotive applications to integrate technical and financial considerations.

2.2.1 Value-Based Design Optimization

A notional BWB program is optimized based on value-based design according to minimum gross take-off weight (GTOW) for a 7880 nmi range and 475 passenger capacity. 13.5 aircraft are initially expected to be ordered per year for this design. During value-based optimization, NPV is replaced with $E[GOW]$ after the design constraints have been sufficiently spelled out to ensure convergence of the optimization algorithm. $E[NPV]$ optimal refers to the design resulting from this method. It uses a large number of design variables, such as payload geometry, control surface deflections, and wing twist, chord length, and incidence angle distributions, to optimize an aircraft layout.

An aircraft conceptual-design optimization framework has been presented that incorporates technical design or value in the aircraft valuation of the framework. This methodology builds as previous work in aircraft valuation, and combines technical design with value. The framework serves to bridge the gap between technical design and financial analysis by giving engineers and managers with a thorough grasp of the financial consequences of design decisions, including programmed risk assessment. Despite the fact that financial analysts at aircraft companies can use state-of-the-art valuation methodologies to determine the value of future aircraft programs, these methods do not directly affect aircraft design. In a case study utilizing the BWB concept, We discovered that introducing financial models into a design-optimizing framework can increase the program's estimated net present value (NPV).

2.3 A RAPID GEOMETRY ENGINE FOR PRELIMINARY AIRCRAFT DESIGN

David L. Rodriguez¹ and Peter Sturdza²

Desktop Aeronautics, Inc., Palo Alto, CA, 94301

The rapid geometry engine (RAGE) creates complex aircraft configurations based on component-based approaches, thus eliminating the need for labor-intensive CAD support. Several geometry models with broadly varying geometries are shown, as well as the basics of creating them. The versatility of the geometry tool is illustrated by the analysis of a selected geometry model with various aerodynamic analytical methods, which range in fidelity. Example applications in optimization problems are also discussed. We also discuss the future of the geometry engine.

2.3.1 METHODOLOGY

Java is used for the construction of the geometry tool to ensure platform independence, as well as to fully exploit the object-oriented capabilities of Java which include aggressive use of abstract and interface classes. Users may, in effect, tailor the fast geometry engine to meet their individual requirements. For example, they can quickly add new capabilities and extensions. A component-based approach is used to accomplish this, as explained in the following section. Here, we discuss the underlying various algorithms of the primary RAGE components. On the following page, we discuss various analysis tools that can be used directly with these models as well as the output formats for current model outputs.

2.3.2 OPTIMIZATION

RAGE's ability to optimize is likely its most valuable feature. The tool may be simply coupled to a design analysis technique and an optimizer of the designers choosing since geometry is parameterized with a basic approach. It is possible to select practically relevant design variables with little effort, even unique variables, similar to works on optimization. This application to optimization has been demonstrated in previous published work. For completeness, we have included excerpts from these publications.

2.4 AERO-STRUCTURAL WING DESIGN OPTIMIZATION USING HIGH-FIDELITY SENSITIVITY ANALYSIS

Joaquim R. R. A. Martins and Juan J. Alonso

The calculation of coupled aero-structural sensitivity functions, which are required for aircraft design in which aero elastic interactions are relevant, is devised and implemented using a framework. For all aero-structural sensitivities, a coupled-adjoint technique is utilized, which integrates single discipline sensitivity information to determine the sensitivities. High-fidelity models of both the aerodynamics and the structure of the wing are used to calculate the aero-structural sensitivities. The sensitivities of the aero-structural adjoint approach to a set of form variables are computed in this work and compared to those obtained using complex-step derivatives and finite-differences. When gradients of a large number of design variables need to be calculated for a small number of functions, the aero-structural adjoint is both accurate and efficient. Two drag minimization problems with 190 shape design variables are presented as examples of the value of computing aero structural sensitivities based on the proposed method. Especially in swept-wing designs with conventional aerodynamics, aero-structural coupling is important.

Traditionally, aero structural analyses have been conducted by cutting and trying. A structure's jig shape is modified so that under a 1-g load, a deflected wing shape reflects the desired distribution of loads for aircraft designers to use. However, in certain more advanced designs with little expertise or if several design elements are part of the mission, the complexity of aero structural interactions might develop; this approach may not be enough for traditional swept-back wing designs. Simple beam theory models of wings cannot describe the structure of the wing in an accurate manner in both small and large supersonic transport aircraft. These aircraft must also sometimes cruise at higher speeds for a substantial portion of their flight. Various studies have stated that such aircraft configurations exhibit a variety of undesirable aeroelastic phenomena, which can only be curbed by accounting for aero-structural interactions in the early stages of design.

Most of the work that has been revealed thus far does not model the various disciplines well. Low-order models are beneficial for conceptual design, but they are insufficiently accurate for a variety of nonlinear phenomena like wave drag, which is important for design optimization. However, the recent work by Giunta and Maute et al. using higher-fidelity models to calculate aerostructure sensitivities is an exception to this trend.

It is the purpose of this work to develop techniques for cheaply computing high-fidelity coupled sensitivities of aero-structural problems in order to provide

realistic design information to a gradient-based optimizer. There are a variety of cost functions that may be utilised, including aerodynamic surface pressure integrals, structural weight, and primary stresses. The authors' MDO frameworks are based on their previous work on high-fidelity sensitivity analysis of aero structural structures. Outer-Mold Lines and structural elements are typically modified by shaping design variables.

2.5 MULTIDISCIPLINARY DESIGN ANALYSIS AND MULTI OBJECTIVE OPTIMIZATION APPLIED TO AIRCRAFT WING

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A high-tech system needs to be designed integrating the multiple physical phenomena that work together to influence its behavior. When aircraft wings are loaded aerodynamically, their structural deformation strongly interacts, resulting in an overall wing behavior that depends on how the two interact. From cruise through maneuver to takeoff, the balance must be examined for the various operational circumstances that the wing is subjected to. Additionally, aircraft wings can be designed based on numerous objectives and constraints, like drag, lift, weight, range, or fuel consumption. This depends on the main design goals. High flexibility in the selection of integrated design analysis findings is necessary to create a valid (constrained) optimization problem for the examined design situation. It presents a multidisciplinary approach to designing aircraft wings and its application for the analysis and optimization of design. The obtained findings show that the suggested method is successful and adaptable in increasing wing performance for various design aims.

In an aerospace industry, worldwide competition drives continuous product improvement. Simulators are essential for developing high-tech products like aircraft. Advanced collaborative, integrated, and analytical and design capabilities are a crucial enabler, on which the European Vision 2020 relies for setting ambitious targets for aircraft and aero engine designs by 2020. Multidisciplinary approaches are essential for improving designs, according to industry. In this paper, an advanced multidisciplinary and multi-objective optimization approach is described that unites consistent multidisciplinary analysis with multidisciplinary optimization.

To show the concepts and analyze the results, the design of aircraft wings is considered an appropriate case study.

The next section examines the role of multidisciplinary design optimization in early phases of design and explains the optimization approach and analysis conducted. To demonstrate the realism of the models utilized, a summary of the structural optimization component of the study is presented. Selected results are presented to demonstrate the benefits of multiobjective optimization. Finally, the last section discusses how collaborative enterprises will be enabled in the future.

2.5.1 STRUCTURAL OPTIMIZATION

By using representative load cases, Structural Optimization determines the size of primary structural elements of wings such as spars, ribs and covers. All load cases necessary to certify the aircraft structure according to the European Joint Aviation Requirements (JAR 25) or the US Federal Aviation Regulation (FAR 25) should be considered. The simulations are simplified by considering only one representative load case, a +2.5 g pull-up maneuver, in order to meet the strict calculating time requirements as stated in the given section. A full fuselage tank and maximum payload are also included in this load case, so the wing structure experiences the most bending moments.

2.5.2 OPTIMIZATION OF A SIMPLE AIRCRAFT WING

The optimizer considers two different optimization scenarios: (i) minimizing the weight of the wing, and (ii) maximizing the critical load on the wings. An elliptically distributed load is carried by a wing over its span. Dimensions of different parts of the structure as well as the position of ribs and spars are variables in its design. Optimization procedures have resulted in improvements to objective function.

A growing body of research has pointed to structural and multidisciplinary optimization as an effective design enhancement tool, especially during the earlier stages of product development. One of the pioneering applications can be seen in lightweight structural components used to reduce costs or increase payload capacity in the aerospace industry. In a 1999 study, Grihon and Mahé combined cruise drag and wing weight to minimize the operating costs of aircraft. As finite element models are used to model the entire wing structure, their work offers the unique advantage of directly assessing product efficiency very early. Alternatively, structures and aerodynamics are separated and a strategy devised that tackles each individually

until a given convergence criterion is reached. Due to the deformation of the wing, the aerodynamic load varies, which creates interface issues.

The optimization techniques described above are largely based on state-of-the-art algorithms and codes that demand a tremendous amount of computational power to resolve. The MSC Nastran commercial structural optimization algorithm is based on common continuous approaches such as feasible directions, sequential linear programming, and sequential quadratic programming (Vanderplaats, 1999). A significant part of the design of aerospace structures consists of eliminating weight and increasing critical loads, as well as ensuring quality and reliability.

When the goal is to design efficient structural components, structural optimization is a good choice (Powell, 1978), which relies on the Sequential Quadratic Programming algorithm to solve the nonlinear constrained optimization problem. Among other methods available in commercial code, this one provided better results for this particular investigation.

Design optimization is an effective technique but it's not widely used for a number of reasons. For example, engineers have little time to educate themselves on optimization, despite the fact that it has been proven effective. Rather than using optimization techniques to modify designs, those engineers usually modify and analyze their designs and make iterative changes. There is however great pressure on companies to speed up their "time to market" as well as improve the quality of their products at the various time, thus these attitudes get gradually changing and/or being influenced to change. Researchers and software developers are responsible for continuously improving optimization technology and the ease of use of optimizing tools by many engineers as possible are drawn to it.

2.5.3 THE CHOICE OF THE WING DESIGN VARIABLES

In addition, there are a variety of options available to specify the design variables in MSC, Nastran commercial code. A design variable may, for instance, be the size of a component or the grid location, or a linear or nonlinear combination of both.

A shape basis vector specifies how the structure can be altered. The engineer uses these vectors to describe the extent of the structural change. The optimizer adjusts the design variables in order to calculate the potential for structure change. In this article, the shape basis vectors are discussed using the Direct Input Shape technique. Externally produced vectors are used to define the shape basis vectors

in this method, and the externally generated vectors are provided via an auxiliary model analysis.

In this paper, the author investigates two optimization problems. Although both problems use the same basic geometry and set of design variables, the problem sensitivity varies radically. With problem I, it is the sizing variables that possess a high degree of sensitivity; however, in problem II, it is the shape variables that exhibit the greatest degree of sensitivity. An early sensitivity study might be quite useful in finding relevant subgroups that will be most sensitive. Nonetheless, predicting which subset of design factors will be significant in terms of sensitivity is difficult.

CHAPTER 3

AIM AND SCOPE

3.1 AIM

A goal of this project is to reduce structural deformation of the wings, caused by loads applied to the wings, by increasing the rib size and modifying the material.

3.2 SCOPE

We learned from the literature review that aircraft life is influenced by both structural behaviour and fluid flow distribution. Due to air flow distributions that generate lift on the wing structure, the aircraft structure's life has been lowered. Because of the aforementioned issue, we decided to employ the FSI methodology (Fluid Structure Interaction). The interconnection of CFD and FEA findings will make the analysis more realistic, and we will be able to obtain more accurate results. Thus, by finding the alternate change in design or minor modification can lead to an optimized wing with better results.

3.3 PROBLEM SPECIFICATION

We learned from the literature review that aircraft life is influenced by both structural behavior and fluid flow distribution. However, we no longer consider the combined dynamic behavior of the aircraft structure and fluid flow distribution when optimizing aircrafts. Due to air flow distributions that generate lift on the wing structure, the aircraft structure's life has been lowered. Furthermore, the life of the supporting structures had been shortened as a result of the lift stress operating on the aircraft wings during cruise. The connecting structures at the wing root and fuselage will be severely stressed in such circumstances. If we used FEA to analyses the wing structure statically, there would be a difference. The load distribution over the wing structures will be different. Due to the high-speed air flow, it may vary depending on the pressure distribution over the wing. The purpose of the research is to develop an optimized dihedral swept wing with a high strength-to-weight ratio under subsonic flow conditions. Furthermore, fluid

structural interaction of a wing model is believed to provide useful physical knowledge during the design of any wing structure.

3.4 OUR PROPOSAL

We chose the FSI methodology as a result of the difficulty that was discussed in the previous article (Fluid Structure Interaction). The boundary condition was taken from the CFD study, and the FEA will solve for structural deformation and stress distribution using these inputs. The pressure distribution results were obtained using Fluent CFD software. Because these outcomes are linked, the analysis will be more realistic, and we will be able to obtain more accurate results. This method's major goal is to obtain a realistic pressure distribution over the aircraft wing. This interface between CFD and structural analysis will also provide accurate stress and deformation data owing to wing fluttering.

CHAPTER 4

MATERIALS AND EXPERIMENTAL METHOD

4.1 METHODOLOGY

We used literature surveys for the inputs for the CFD analysis of a subsonic flow over an aircraft wing. Considering the gap found, the analysis objective was defined. To start, we used a subsonic passenger aircraft wing as a basis for the analysis. An ANSYS FLUENT simulation is run on the CAD model of the wing structure to determine pressure load distribution. We conducted pre-processing as well as defining appropriate boundary conditions before running the simulation. Then we used the Fluid solver to determine the flow pressure, velocity, and temperature distributions on the wings. ANSYS Mechanical exported the pressure load generated by the CFD simulation.

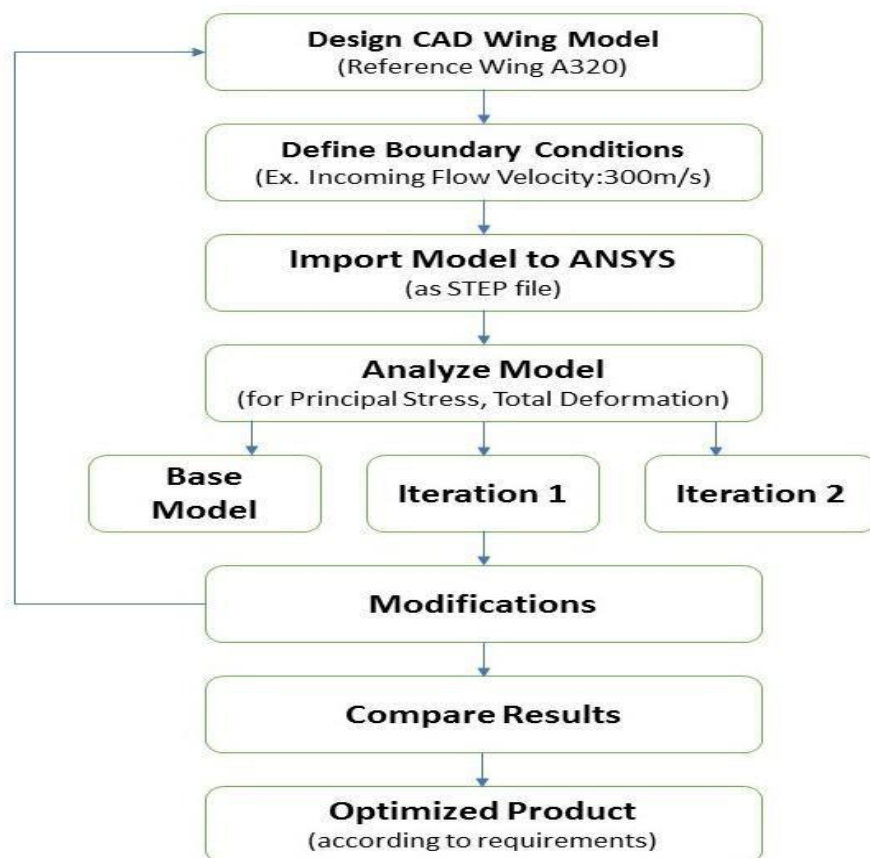


Figure 4.1: Flow Process Diagram

Geometric defeaturing, meshing, and material properties defined before FEA simulation initiated. Structural analysis was carried to obtain deformation, stress and strain values. Based on the obtained stress value from the simulation, corresponding modifications were done for next iteration. Finally, the optimized swept back dihedral wing model was designed in a such a way that the yield strength of the wing structure comes below the yield strength of wing material.

4.1.1 Fluid Structural Interaction

Fluid-structure interactions (FSI), or the interactions of a moveable or deformable structure with an internal or surrounding fluid flow, are one of the most important and difficult multi-physics tasks in terms of modelling and computing. Such interactions can be either stable or oscillatory, and they play a big role in the design of a lot of technical systems, especially aeroplanes. Failure to consider the effects of FSI, especially in large-scale buildings and those composed of fatigue-prone materials, can be fatal.

Fluid-structure interactions can be classified into three groups:

- 1) Transport of suspended solids in a liquid matrix is an example of zero strain interactions.
- 2) Constant strain steady flow interactions: The key mechanisms for causing vibration in the wing in this category are oscillatory interactions.
- 3) Oscillatory interactions: The strain created in the solid structure leads it to move, reducing the source of strain, and the structure returns to its original state, only to repeat the process. The key mechanisms for causing vibration in the wing in this category are oscillatory interactions.

4.1.2 Computational Fluid Dynamics

We chose computational fluid dynamics as an optimization method for our exterior aerodynamics. The discipline of determining a numerical solution to the governing equations of fluid flow while advancing the solution through space and time to get a numerical description of the entire flow field of interest is known as computational fluid dynamics (CFD).

Since the invention of the digital computer, CFD has gotten a lot of attention as an emerging science all across the world. The subject has two aspects that appeal to

me. To begin with, there is a desire to be able to represent physical fluid phenomena that are difficult to mimic or detect using physical experiments, such as weather systems or hypersonic aerospace aircraft. Second, the need to be able to explore physical fluid systems in a more cost-effective and time-efficient manner than is possible using experimental approaches. The development and application of computational fluid dynamics (CFD) to all elements of fluid dynamics has seen significant progress. CFD programmes are now widely used in industry as standard numerical tools for design and development. As a result, there is a high demand for experts in the field to apply and improve CFD methods in engineering firms and research institutions. CFD's current situation in industry is comparable to that of structural analysis a decade ago, when it was also in its infancy. The average company selling Finite Element structural analysis products at the time had a turnover that was an order of magnitude more than the largest CFD provider. Finite Element programmes are now widely used in industry as part of the standard design and analysis process, and they are available on nearly every computing platform. Similarly, Computational Fluid Dynamics has evolved into a mainstream industry tool that now sits alongside CAD and FE software. Both business and research organisations use CFD as a tool for design analysis. The course provides a solid foundation for graduates to be able to use CFD as a design tool for engineering applications in an educated manner. For graduates who want to pursue a doctorate. The course provides a good foundation for subsequent specialisation in both numerical methods and physical models development and implementation.

4.1.2.1 Pre-processing

Geometry clean up and fluid domain extraction

The first phase in the CFD process is geometry clean, which involves removing any undesired thickness or geometry that does not have a significant impact on fluid flow. This is known as fluid domain extraction, and it ensures that the fluid domain is completely closed.

4.1.2.2 Domain discrimination

Grid generation is the next step in the procedure. The discretization of a fluid domain into finite volumes is known as grid generation. Discretization is the process of transforming partial differential equations into algebraic equations. To improve the quality of the volume mesh, a surface mesh for the domain is

generated first, followed by the final volume mesh after the appropriate surface mesh adjustments.

4.1.2.3 Boundary conditions:

Setting the boundary conditions is the final stage in the pre-processing process. The mesh is examined and resized, and the domain's boundary conditions are specified.

4.1.2.4 Solution

The solution is obtained after setting the solution monitors, convergence criteria, and the number of iterations.

4.1.2.5 Post Processing

The answers are shown as needed graphs, contour plots, vector plots, path lines, or numerical reports can be generated.

4.2 MATERIALS USED

The first digit represents the principal alloying element, the second digit represents a specific alloy modification, and the third and fourth digits represent arbitrary numbers assigned to individual alloys in the series. Advanced alloys improve the performance and cost of today's aircraft by imparting desirable properties to metals used in today's aircraft, such as weight reduction, fatigue resistance, and corrosion resistance. Steel and iron are difficult to work with because of their weight. Both of these metals are heavier than aluminium, which limits an airplane's ability to take off and fly. Aluminum is reported to make up as much as 80% of the materials used in modern planes.

4.2.1 7040-T7651 Aluminum Alloy

Alcan 7040 is an Al-Mg-Zn-Cu-Zr alloy with a superior strength-toughness balance than the 7010 and 7050 alloys. The alloy is used in aerospace structures. A high-strength aircraft aluminium alloy with good stress-corrosion fracture resistance in thick sections. 7040 is usually available in the following tempers: T7451 - Heat-treated solution, stress-relieved by controlled stretching, and artificially aged (between T73 and T76).

4.2.2 2024-T3 Aluminum Alloy

The yield strength of T3 temper 2024 sheet is at least 270–280 MPa (39–40 ksi), and the ultimate tensile strength is 400–430 MPa (58–62 ksi). It has an elongation of 10–15%. General 2024 characteristics and applications (according to Alcoa): Machinability and surface finish qualities are excellent. This is a high-strength, workable substance. In terms of structural applications, 2018 has largely surpassed 2017.

4.3 GEOMETRY DETAILS

The various sections of the wing model, such as ribs, spars, fuel tank, control systems, and other control mechanisms, are all included. Due to their complexity, it is difficult to model all of the sub-assemblies using an analysis-oriented approach.

The software CATIA V5 was used to model this wing. For analysis, simplified geometry is modelled.

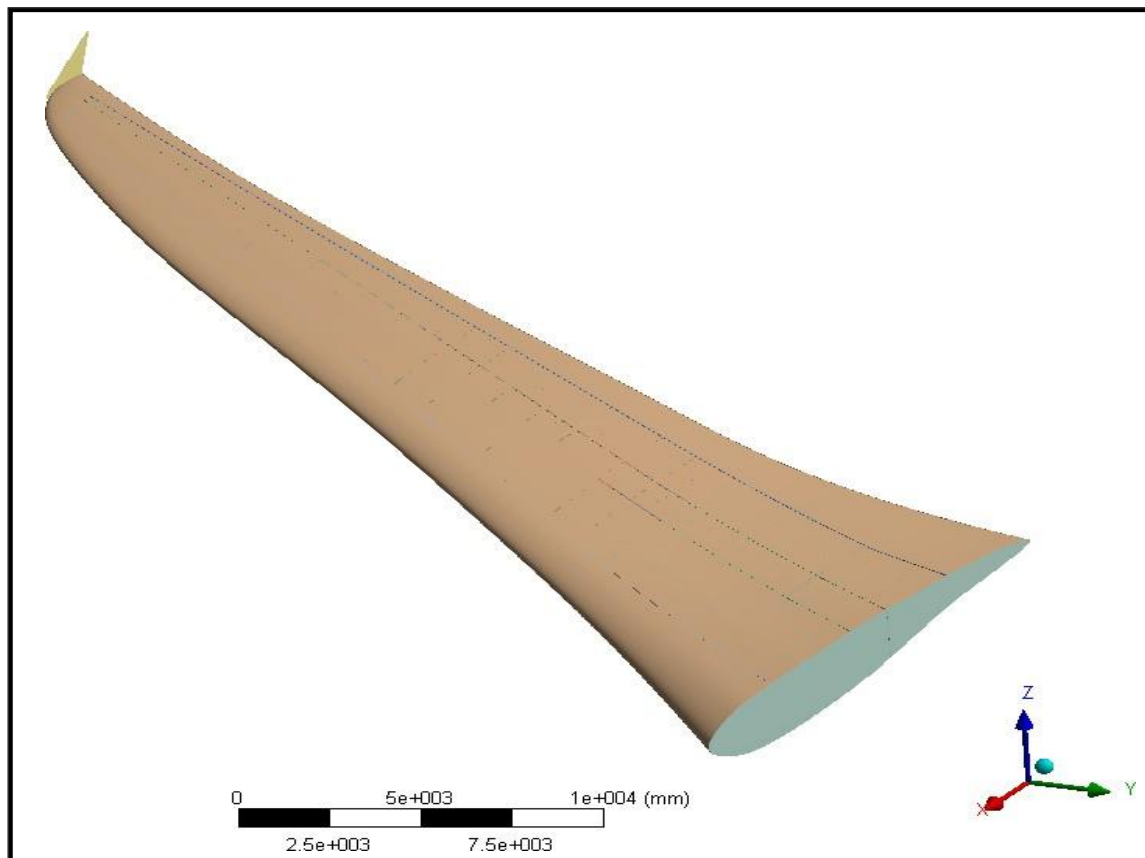


Figure 4.2: Isometric View of The Model

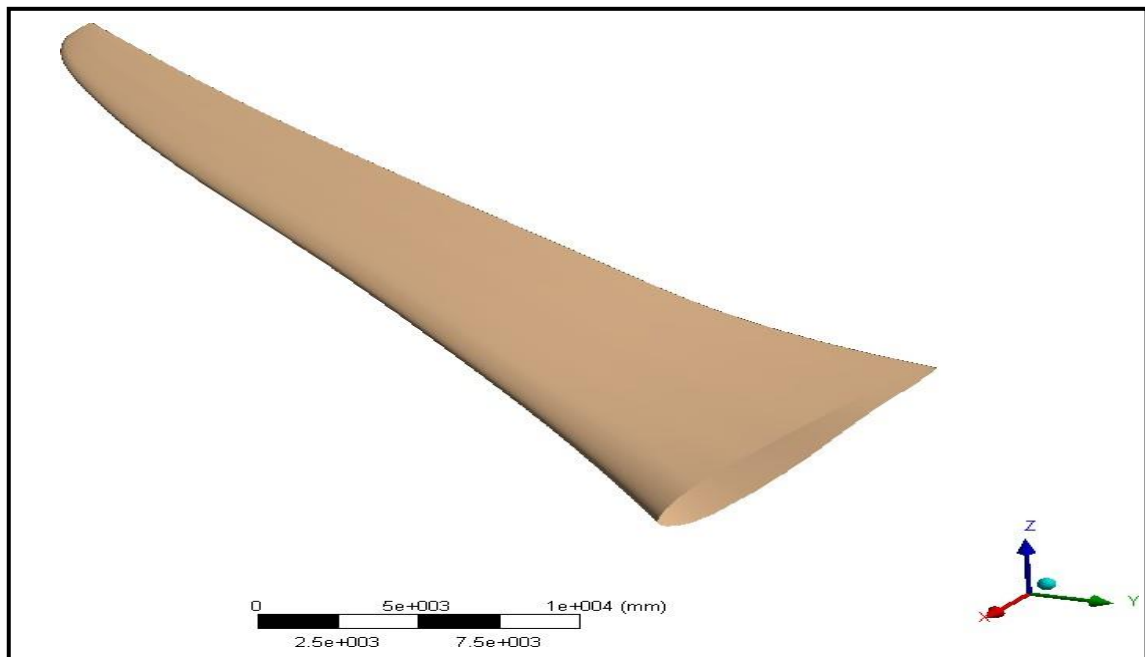


Figure 4.3: Wing Skin of The Wing Model

Ribs and spars are modelled because they are the most important structural integrity assemblies in wing structures for reducing deformation in all directions.

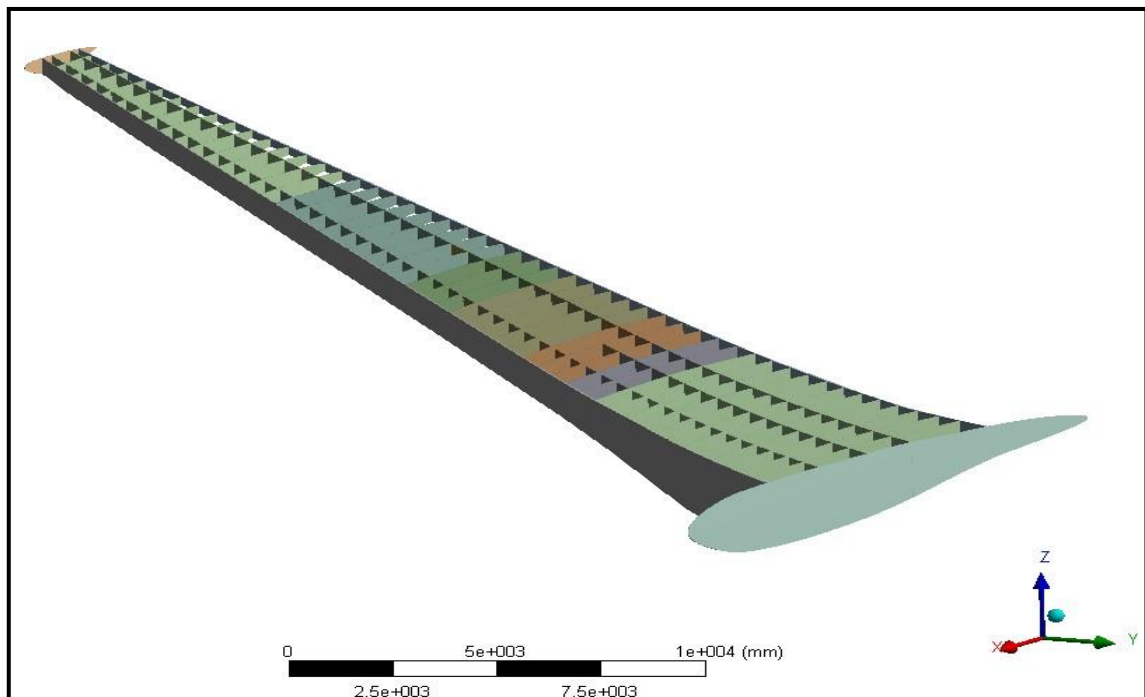


Figure 4.4: Rib Structure of The Wing Model

CHAPTER 5

RESULTS AND DISCUSSION

5.1 ANALYSIS

5.1.1 Analysis of Base Model

5.1.1.1 CFD Analysis:

First step of analysis includes creation of fluid domain in which air is defined as fluid medium. Velocity at inlet is considered 300 m/s. Wing root is mounted to the wall of fluid domain. So, the wing root remain out of contact from fluid.

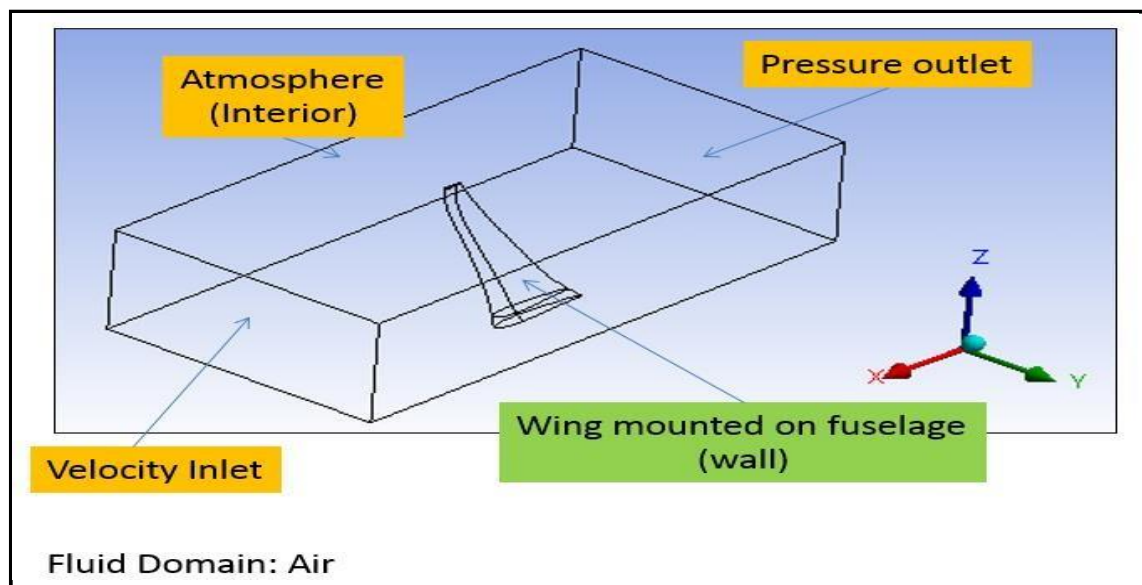


Figure 5.1: CFD Simulation Model (Base Model)

Wing is meshed very fine in order to capture the flow properties over the wing surfaces accurately. Here we have used tetrahedral type of meshing in order to get accurate and more detailed results. Tetrahedral elements can fit better complex geometry. However, when you integrate the shape functions with points of Gauss it is less accurate than hexahedral elements. In addition, one of the factors that determines the quality of your mesh is the distortion of your elements.

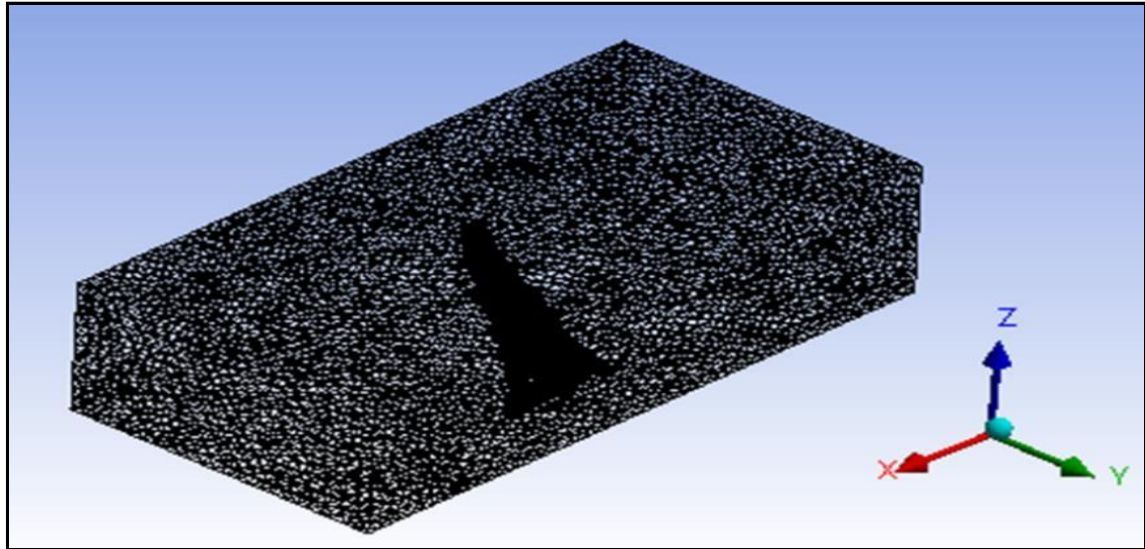


Figure 5.2: CFD Simulation Meshed Model (Base Model)

5.1.1.2 CFD Simulation Results

Static pressure is evaluated to get CFD analysis more realistic and thus we can see the following two results which demonstrates the distribution of pressure values over the wing from root to the tip of wing. Here we can see that the pressure distribution is varying in tremendous quantity. Value of pressure on bottom side of the wing is more as compared to the top side of the wing.

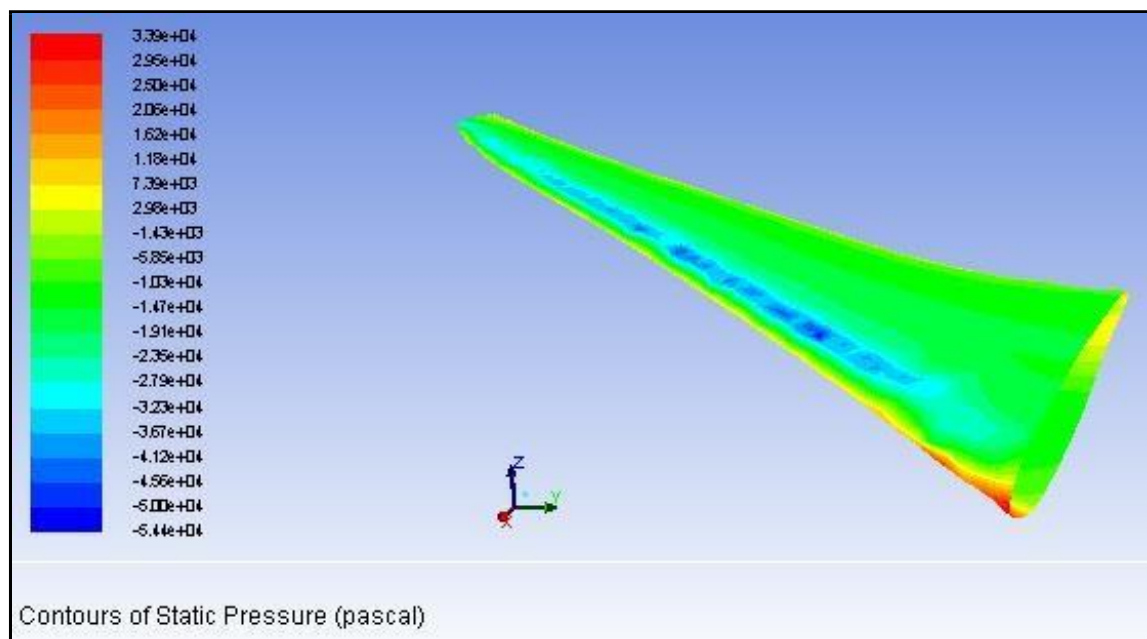


Figure 5.3: CFD Simulation Results - Top Wing (Base Model)

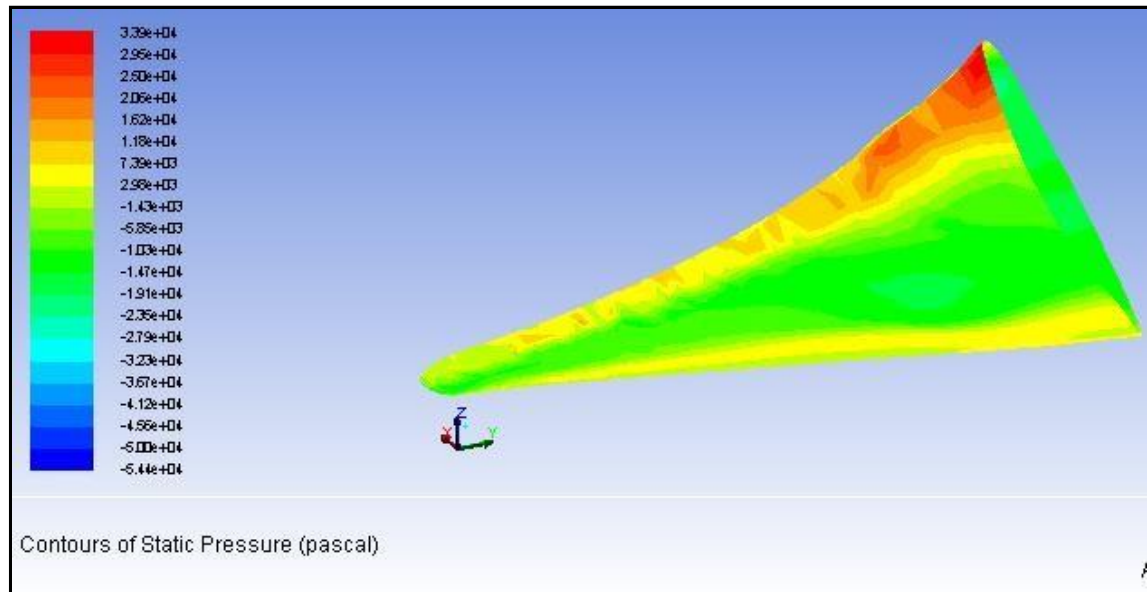


Figure 5.4: CFD Simulation Results - Bottom Wing (Base Model)

5.1.1.3 FEA Simulation

Wing skin plays very essential role during the finite element analysis as it is the key component of wing which is in contact with the fluid and thus during the simulation has greater role for more accurate results. Here we have used steel structure metal to allocate to the outer skin of the wing and thus was helpful for getting smooth skin and thus simultaneously resulting in smoother flow over the surfaces of wing.

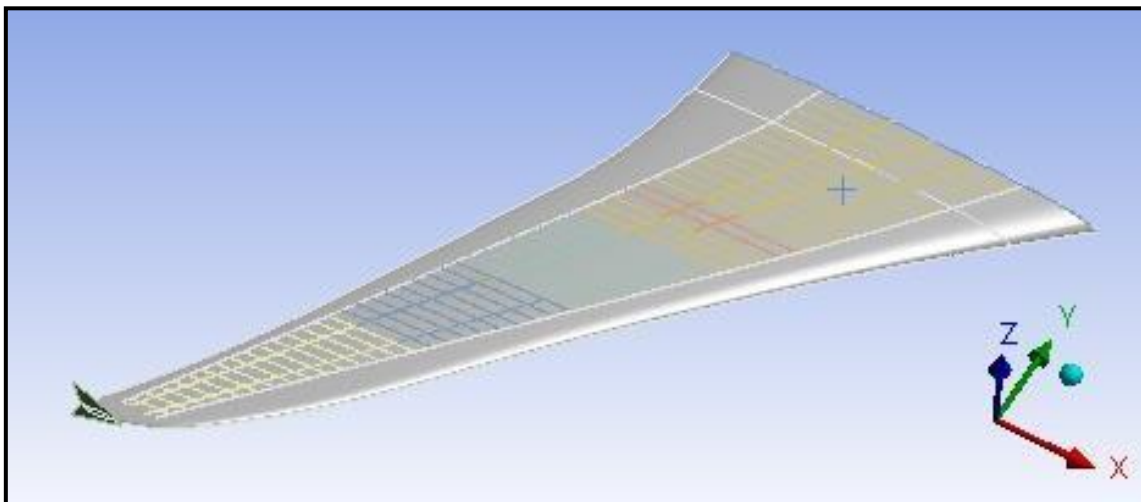


Figure 5.5: Wing Skin (Base Model)

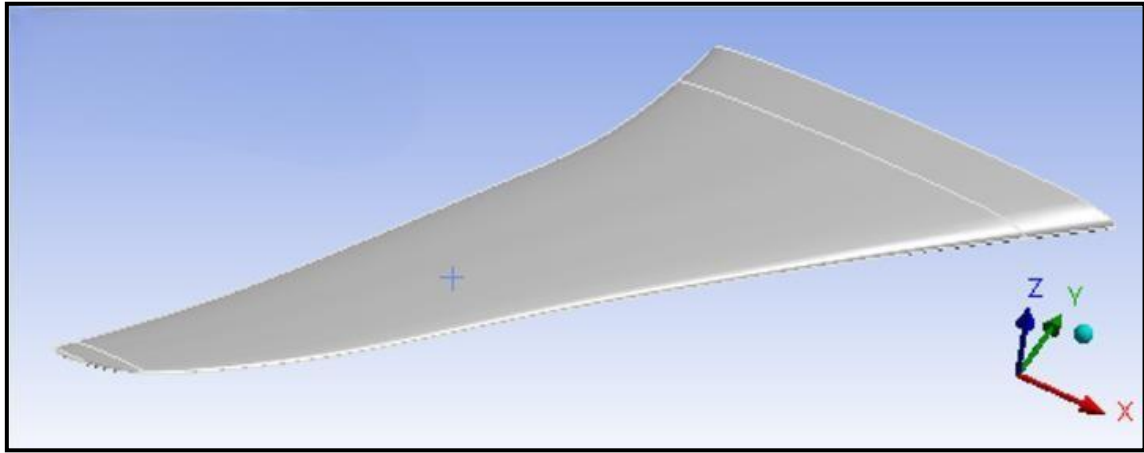


Figure 5.6: Wing Skin (Material: Structure Steel) (Base Model)

As the internal structure of real-life wing A320 is very much complex and consists of numerous various parts. But due to limitations and to keep wing design simple and lucid, we have used a simple yet effective internal structuring component system which effectively performs for the simulations performed at static load during cruise condition. We have assigned aluminum alloy 7040-T7651 as material to the internal structure of the wing. Here we have considered this material due to it's load bearing capacity and as we expected, it gave good and satisfactory results during the fluid element analysis. Also, we gave detailed analysis for the structural thickness as during the structural deformation it was the essential component as thus can cause greater degree of deformation if not paid more attention to it. The following image show how the internal structure is kept so the results determined should be as desired

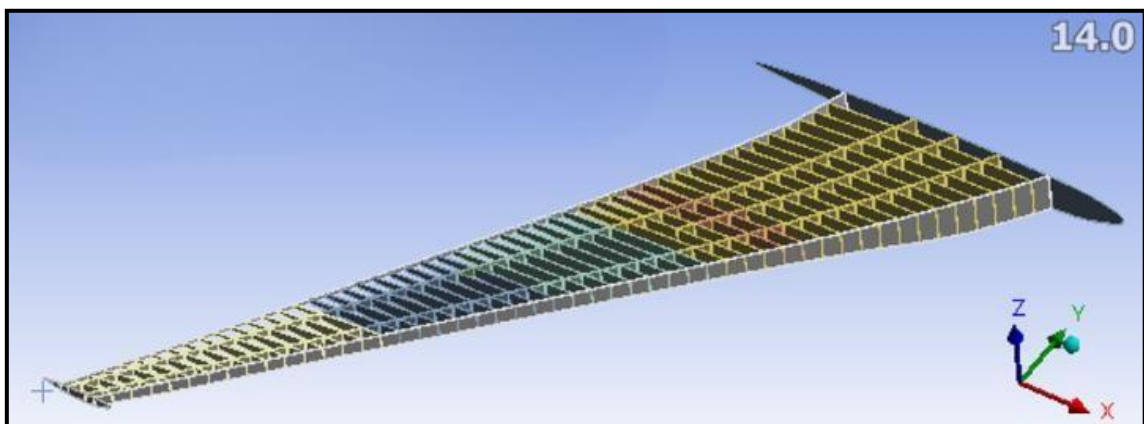


Figure 5.7: FEA Simulation Model (Base Model)

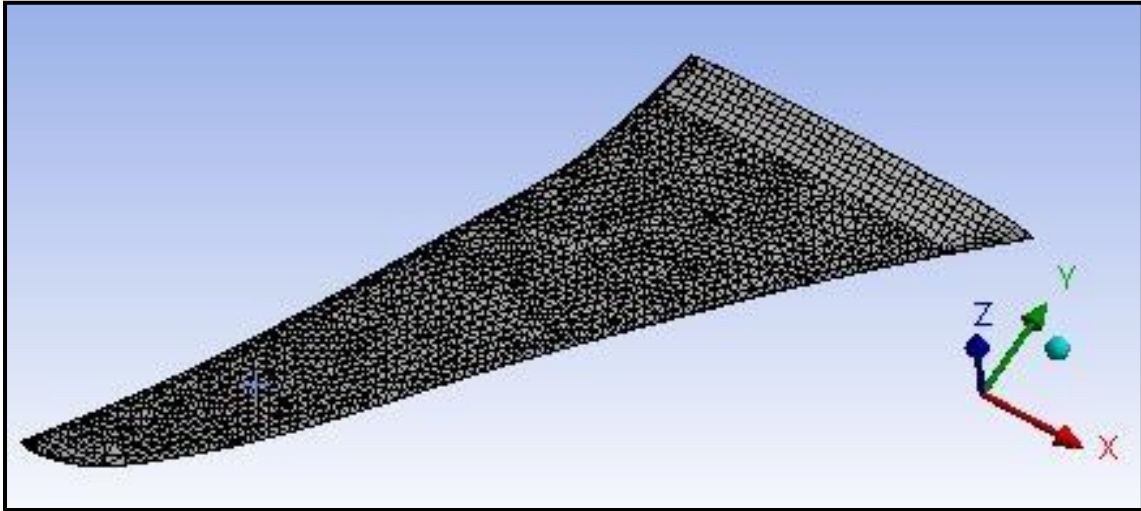


Figure 5.8: Meshed Model of Base Model (Base Model)

Wing was meshed in tetrahedral meshing pattern as mentioned above. It was more useful during the simulation and because of it very accurate analysis was done. Tetrahedral Meshing covered most of the complex structure and thus very much to real life conditions were applicable during the entire project analysis. Mesh density is a significant metric used to control accuracy (element type and shape also affect accuracy). Assuming no singularities are present, a high-density mesh will produce results with high accuracy.

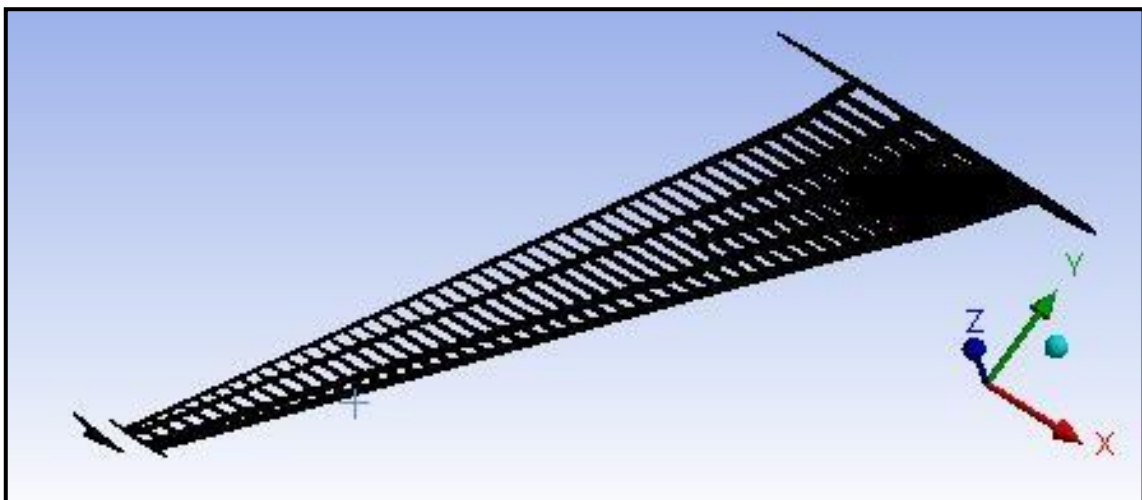


Figure 5.9: FEA Simulation Meshed Model (Base Model)

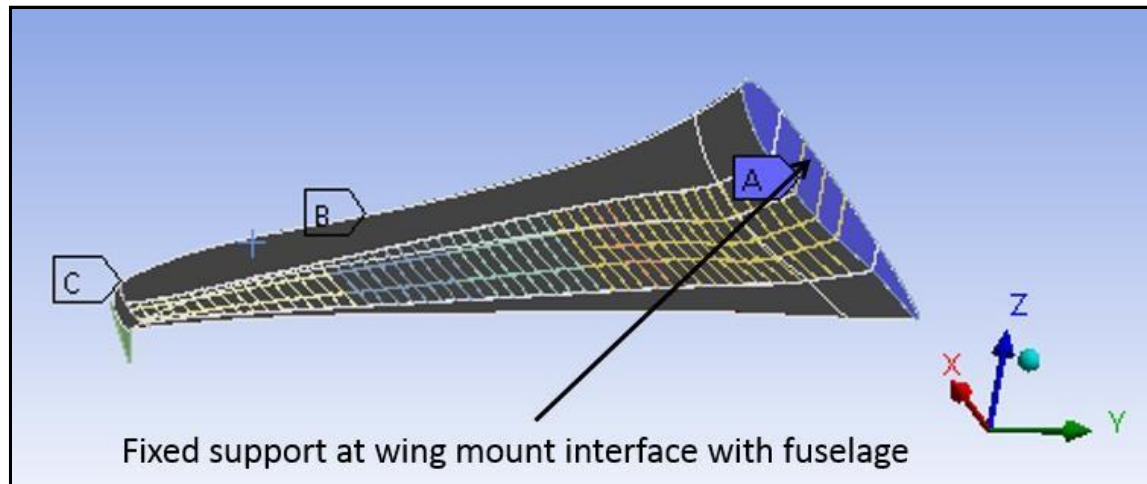


Figure 5.10: Wing Mount Interface with Fuselage (Base Model)

As mentioned earlier, during the simulation pressure plays important role in determining the load over a certain body or its components. Here we can see the pressure values are imported from previous simulation, which was performed to determine the overall pressure distribution.

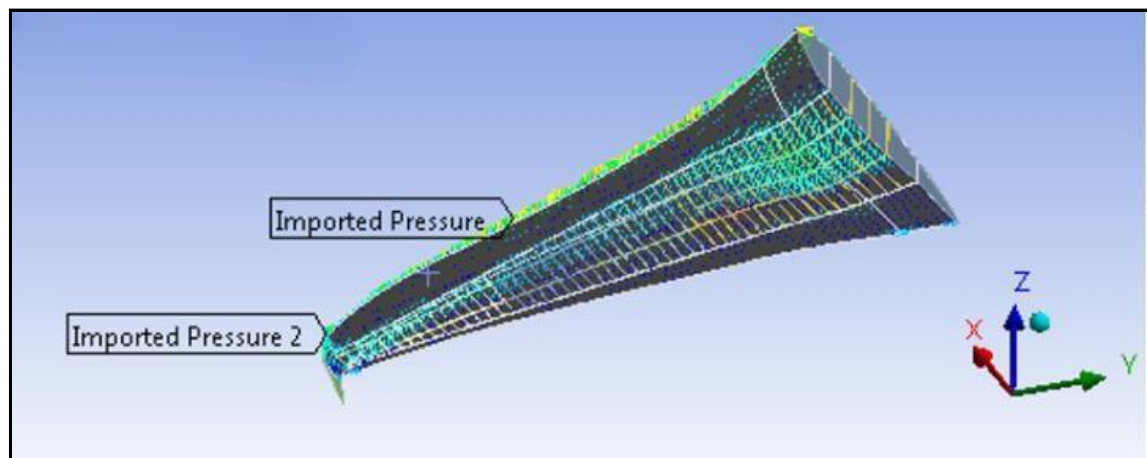


Figure 5.11: Boundary Condition (Base Model)

Pressure imported are then used for further simulation of structural analysis and to determine the value of deformation in the wing material during the static load condition. Pressure is varying on both top and bottom side and thus we have imported it in two phases.

5.1.1.4 FEA Simulation Results

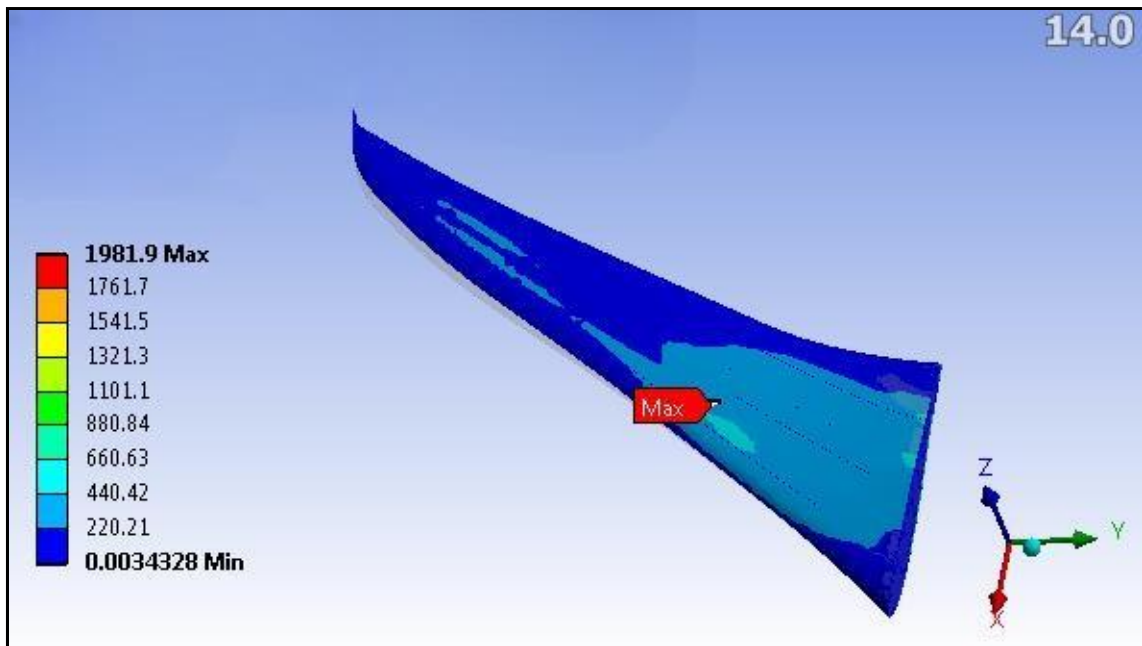


Figure 5.12: Von Mises Stress Results 1 (Base Model)

Von mises stress is also known as equivalent tensile stress. Von Mises stress is a value used to determine if a given material will yield or fracture. It is mostly used for ductile materials, such as metals. The von Mises stress is often used in determining whether an isotropic and ductile metal will yield when subjected to a complex loading condition. This is accomplished by calculating the von Mises stress and comparing it to the material's yield stress, which constitutes the von Mises Yield Criterion.

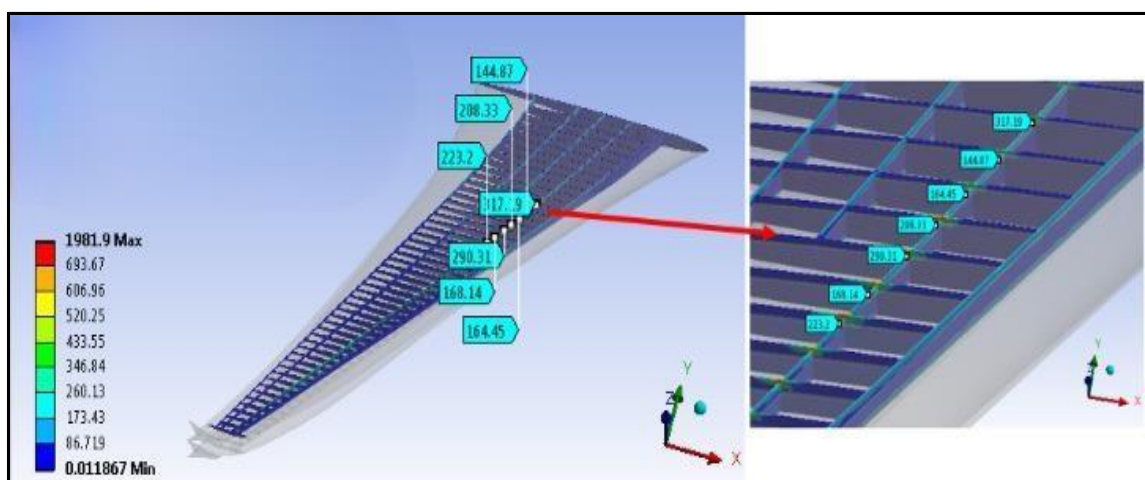


Figure 5.13: Von Mises Stress Results 2 (Base Model)

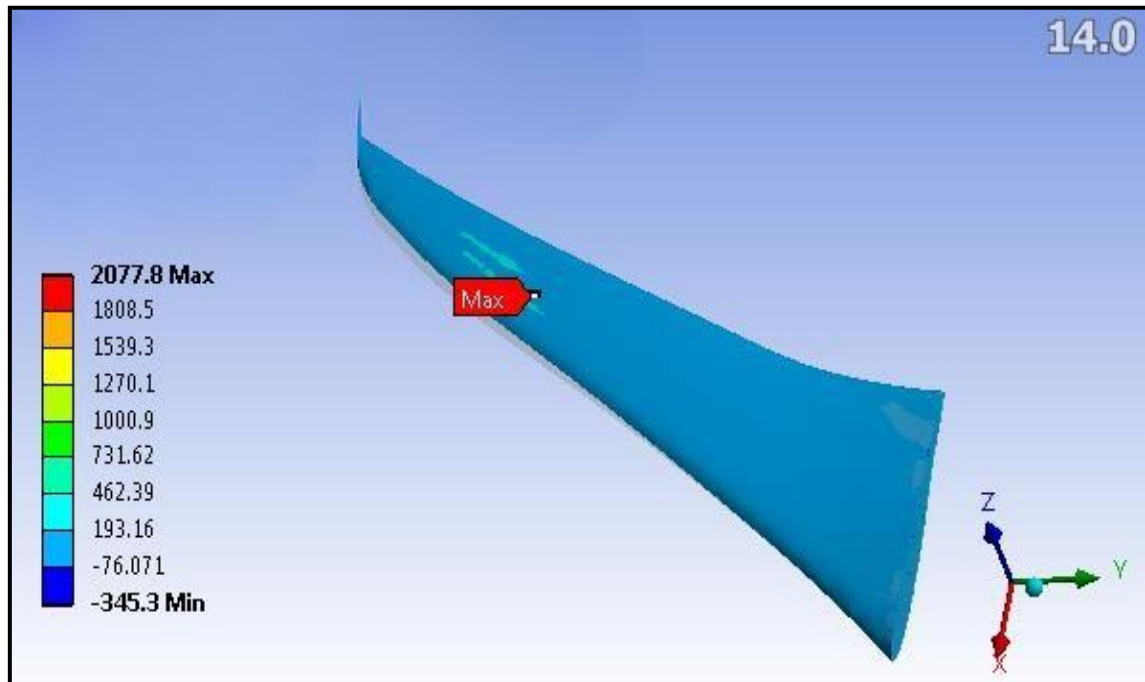


Figure 5.14: Max Principal Stress Results (Base Model)

Values of maximum principal stress along the wing varies greatly from the minimum value of -345.3 MPa to maximum value of 2077.8 MPa. On an average the principal stress values are evenly spread along the whole wing and thus resulting in non-concentrated stress.

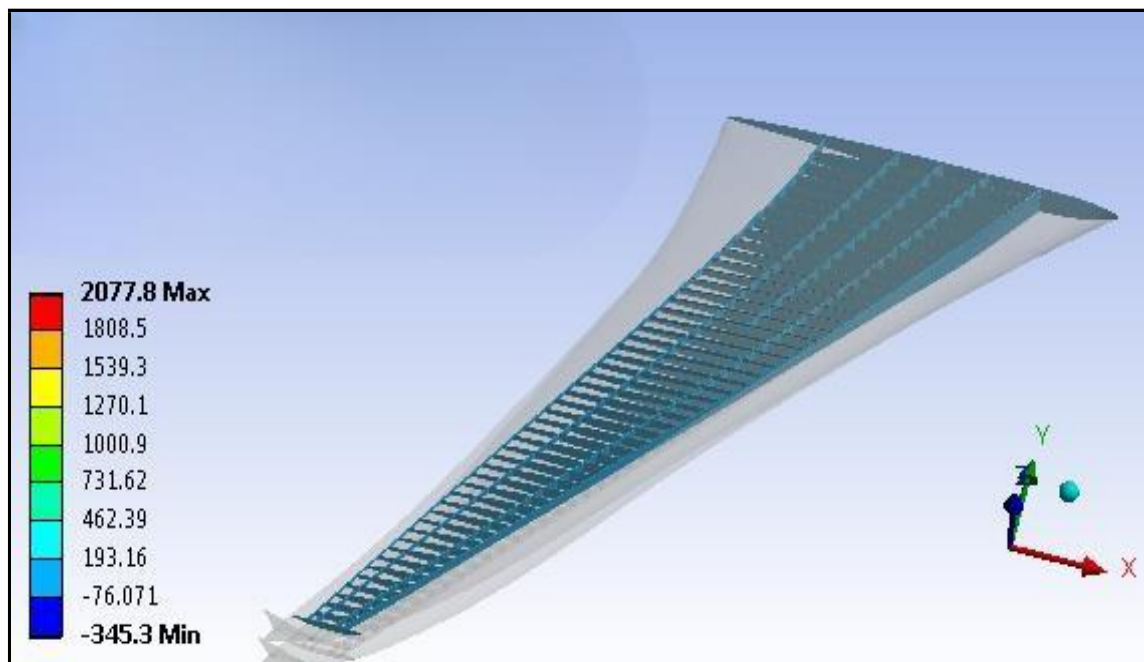


Figure 5.15: Max Principal Stress Results-Ribs (Base Model)

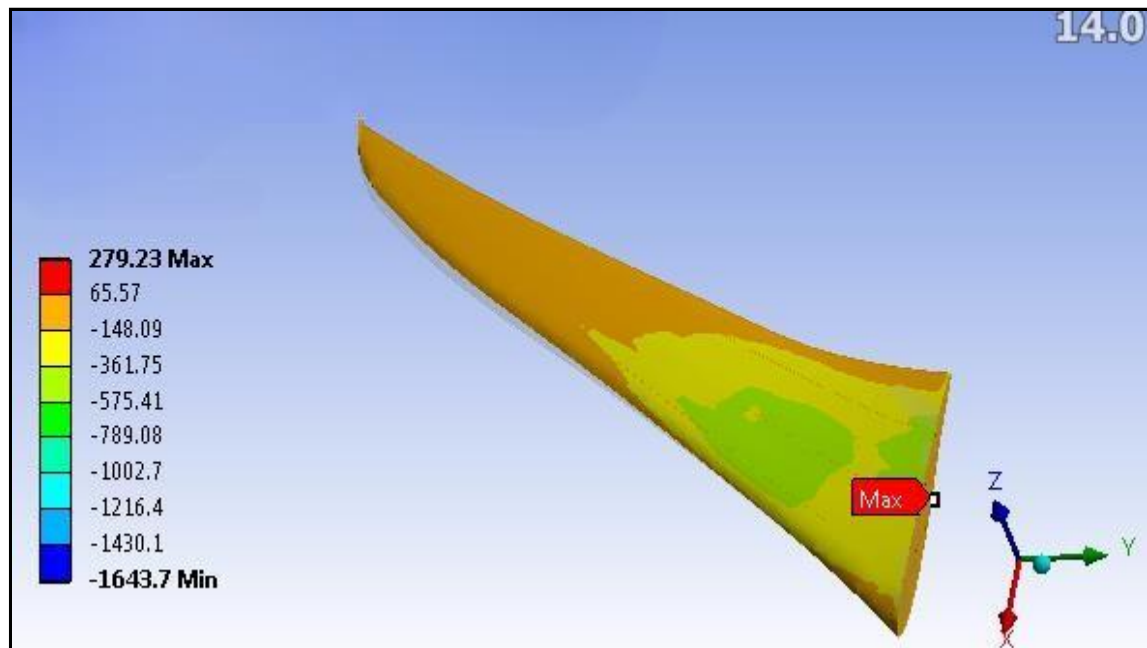


Figure 5.16: Minimum Principal Stress Results (Base Model)

Vice versa of the maximum principal stress, which is compressive in nature, the minimum value lies to the -1643.7 MPa and the maximum value is 279.23 MPa. Whereas if we see the results for structural component's minimum principal stress value then we can conclude that the most of compressive stress is concentrated on the wing root.

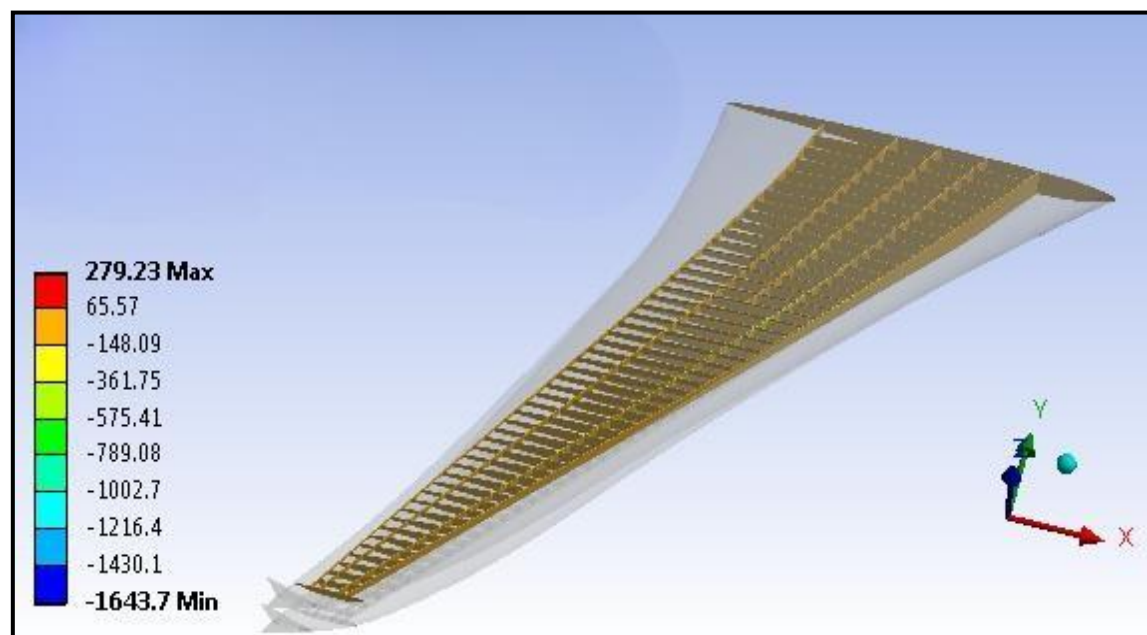


Figure 5.17: Minimum Principal Stress Results-Ribs (Base Model)

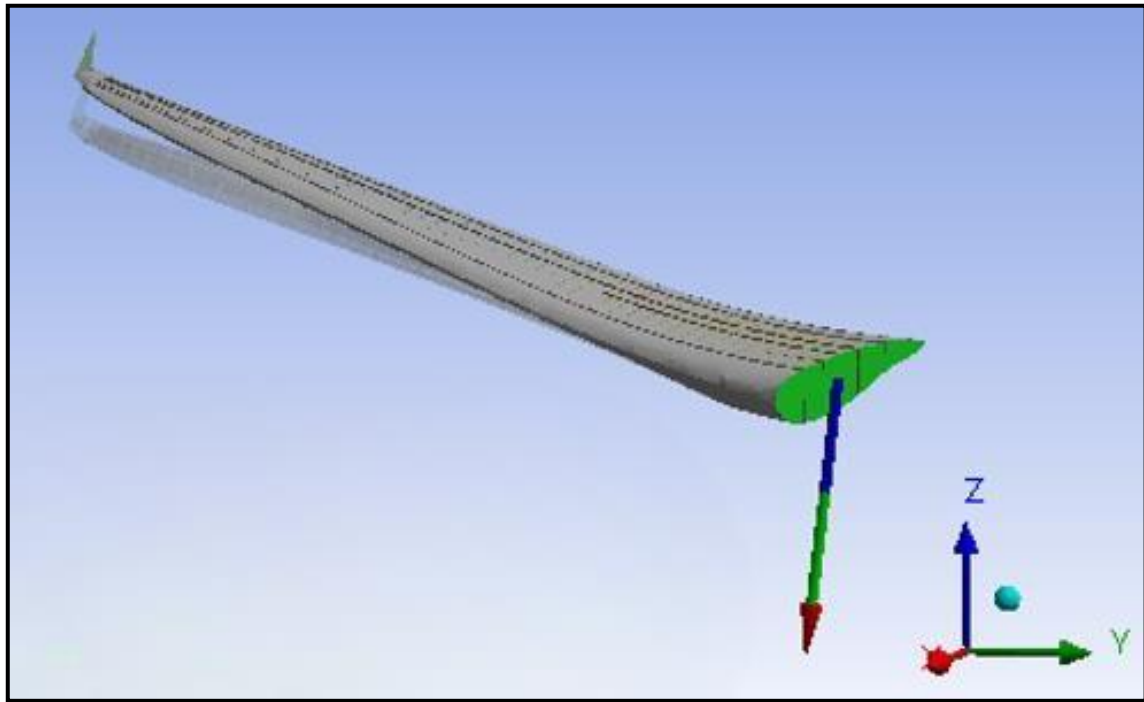


Figure 5.18: Force Reaction (Base Model)

The drawing of a free-body diagram is an important step in the solving of mechanics problems since it helps to visualize all the forces acting on a single object. The net external force acting on the object must be obtained in order to apply Newton's Second Law to the motion of the object. The free body diagram allows you to set up the problem properly so that you can correctly solve for unknowns such as forces, and acceleration.

☐ X Axis	-16642 N
☐ Y Axis	-5.0846e+005 N
☐ Z Axis	-3.6463e+006 N
☐ Total	3.6817e+006 N

Table 5.1: Values of Force Reaction (Base Model)

Above diagram simplifies all the forces acting on it, the force's direction and magnitude is given in the table above. According to the Newtons law of motion, every action has equal and opposite reaction and thus we can see the force reaction diagram denotes direction of the action force and the table 5.1 denotes their magnitude and overall total magnitude.

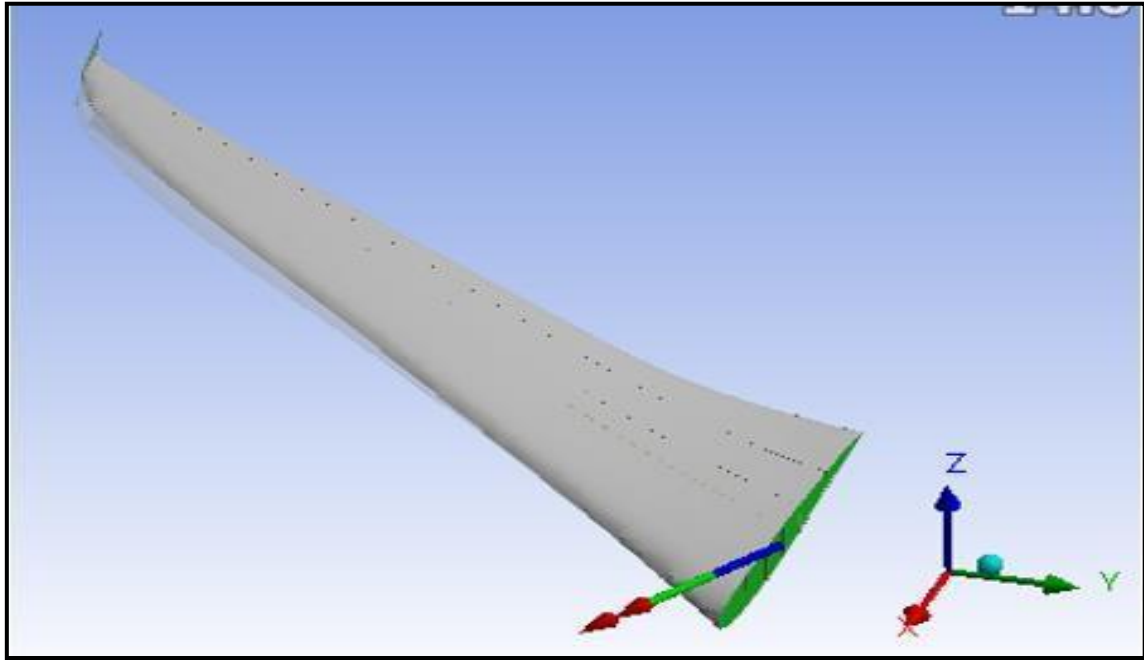


Figure 5.19: Bending Reaction (Base Model)

Bending reaction denotes, as the name mentions, value of force which can result in bending of structure. Shear and bending moment diagrams are analytical tools used in conjunction with structural analysis to help perform structural design by determining the value of shear force and bending moment at a given point of a structural element.

☐ X Axis	5.2369e+010 N·mm
☐ Y Axis	-2.1047e+010 N·mm
☐ Z Axis	4.6018e+009 N·mm
☐ Total	5.6627e+010 N·mm

Table 5.2: Values of Bending Reaction (Base Model)

Table 5.2 denotes the value of bending reaction in the unit of Newton-Millimeter

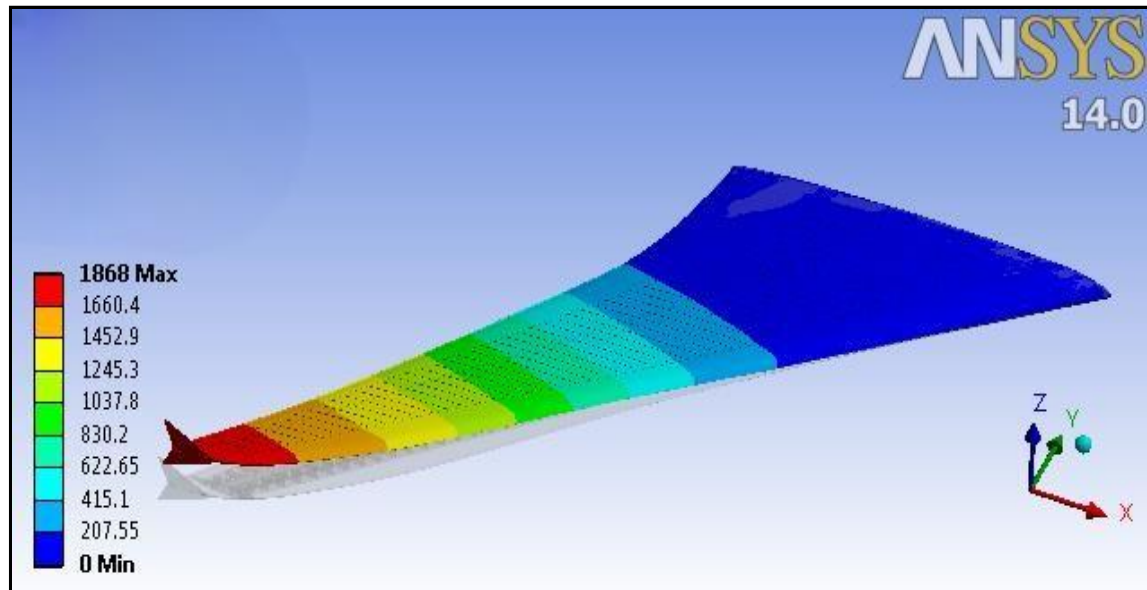


Figure 5.20: Total Deformation Results (Base Model)

Finally, we got the results for maximum total deformation. From above diagram we see that the value of total deformation lies in between the 1868 mm as maximum and 0 mm as minimum. Also, the above diagram gives clear picture of distribution of total deformation along the whole wing. Wing tip side has maximum deformation whereas wing root side has minimum. So, we can conclude that we need to do certain modifications in order to decrease value of maximum total deformation. We decided to make some changes in the material of the wing so that less deformable material can be allotted. And thus, next analysis was made in order to achieve project's aim and objective.

5.1.2 Analysis for Model 1

5.1.2.1 CFD Analysis:

With certain modifications, we again performed the similar procedure as of performed for the previously mentioned model viz., base model. Again, fluid domain was created in order to perform the further simulations and the domain properties were as mentioned below:

Fluid Inflow Velocity: 300m/s

Fluid Domain: Air

Most of the procedure was performed very similar to the previously performed simulations.

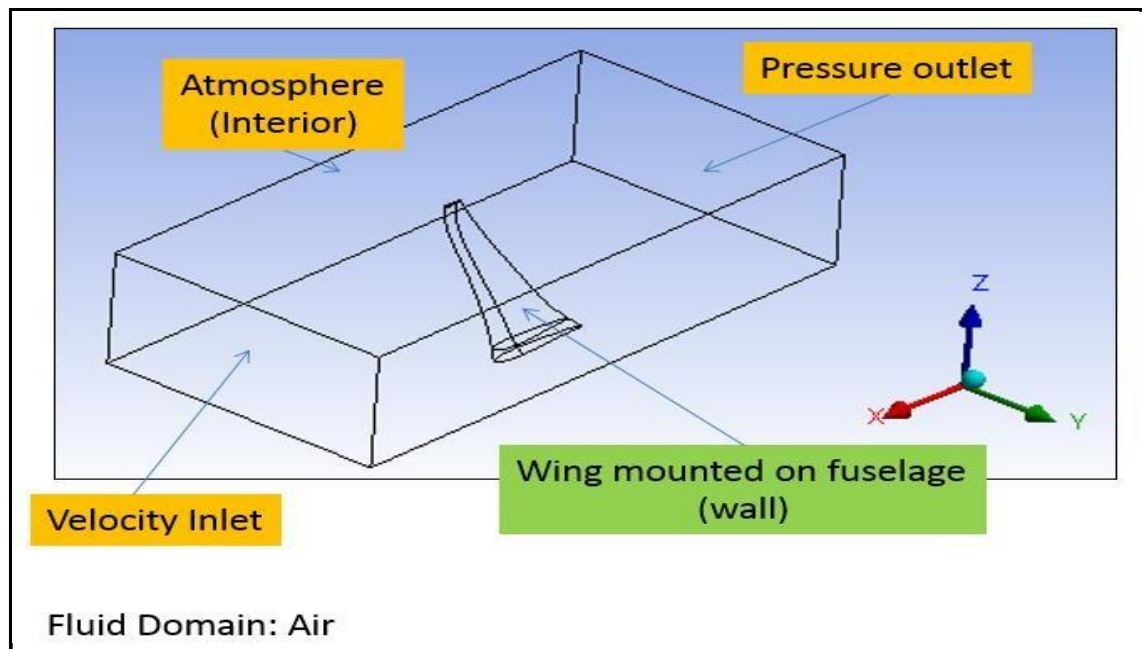


Figure 5.21: CFD Simulation Model (Model 1)

Using CFD, we were able to analyze complex problems involving fluid-solid interaction. Engineering fields where CFD analyses are frequently used are for example aerodynamics and hydrodynamics, where quantities such as lift and drag or field properties as pressures and velocities are obtained. Here too we kept the wing root affixed to the wall of the fluid domain. Then the next step included the meshing.

Meshing Type: Tetrahedral Meshing

This type of meshing was helpful for better result compared to other meshing type.

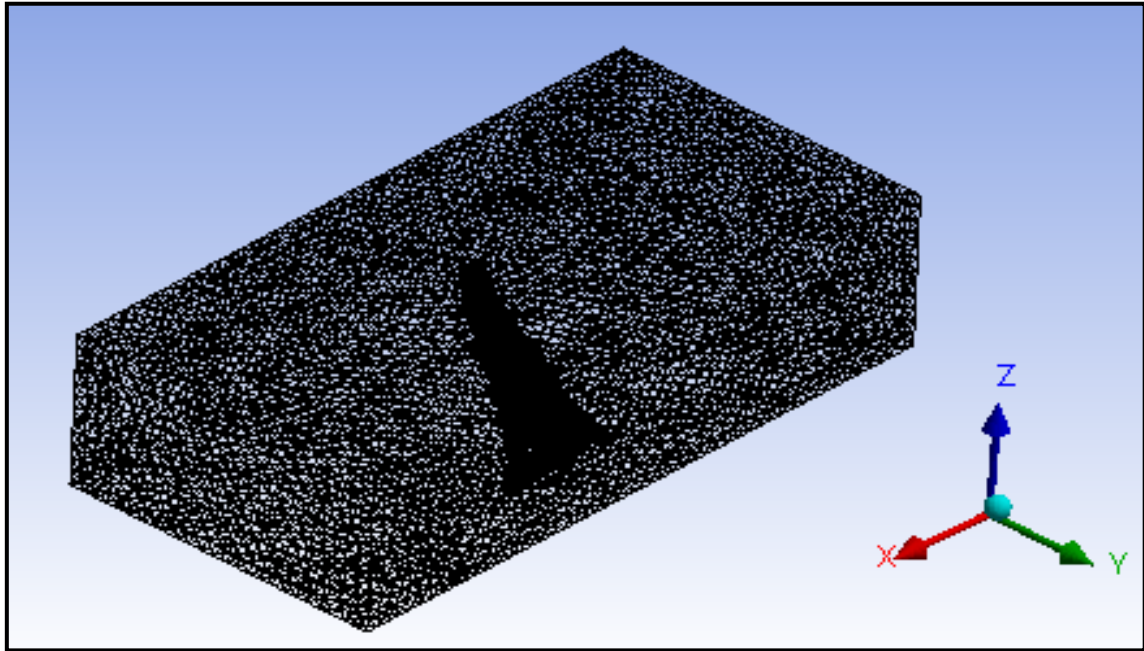


Figure 5.22: CFD Simulation meshed Model (Model 1)

To accurately capture the flow characteristics over the wing surfaces, the meshing is done in very fine details.

5.1.2.2 CFD Simulation Results

CFD simulation were very much similar to that of the base model results with few

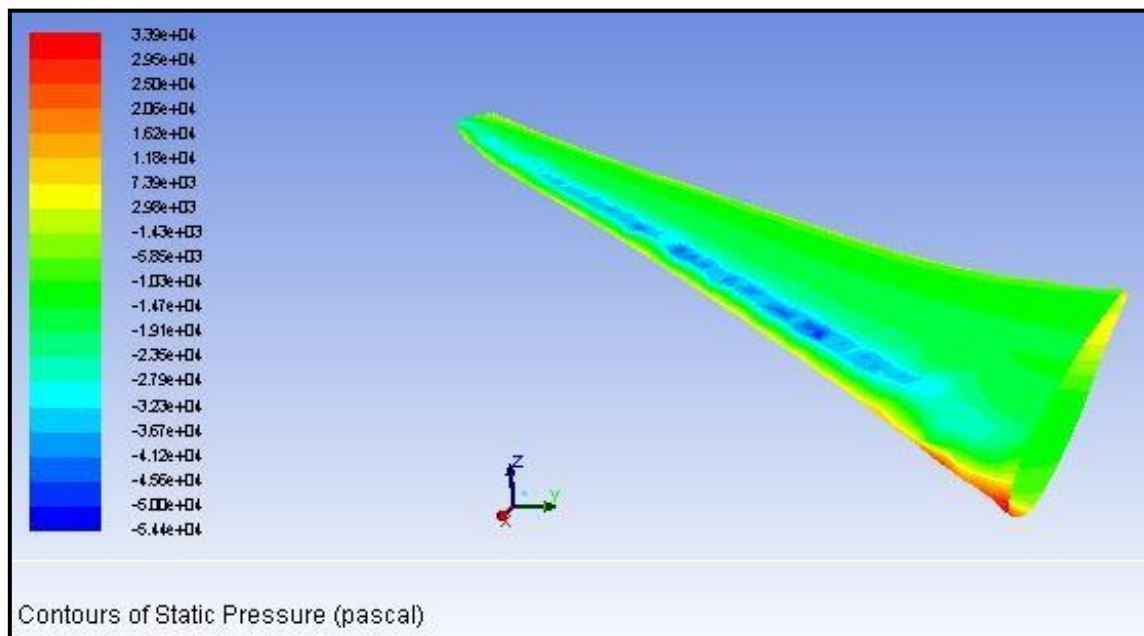


Figure 5.23: CFD Simulation (Model 1)

exceptions and which indicated a clear progress towards the aim of the project ie., to minimize deformation.

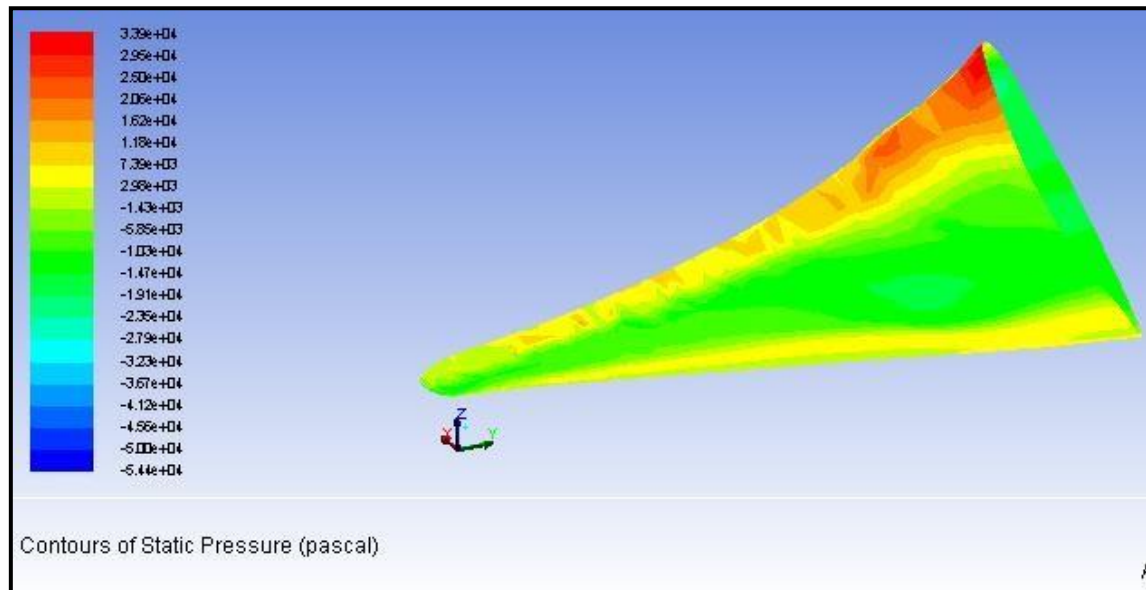


Figure 5.24: CFD Simulation results - Bottom Wing (Model 1)

5.1.2.3 FEA Simulation

When the finite element analysis is carried out, wing skin plays an important role since it is the main part of the wing in contact with the fluid and therefore more critical to getting accurate results.

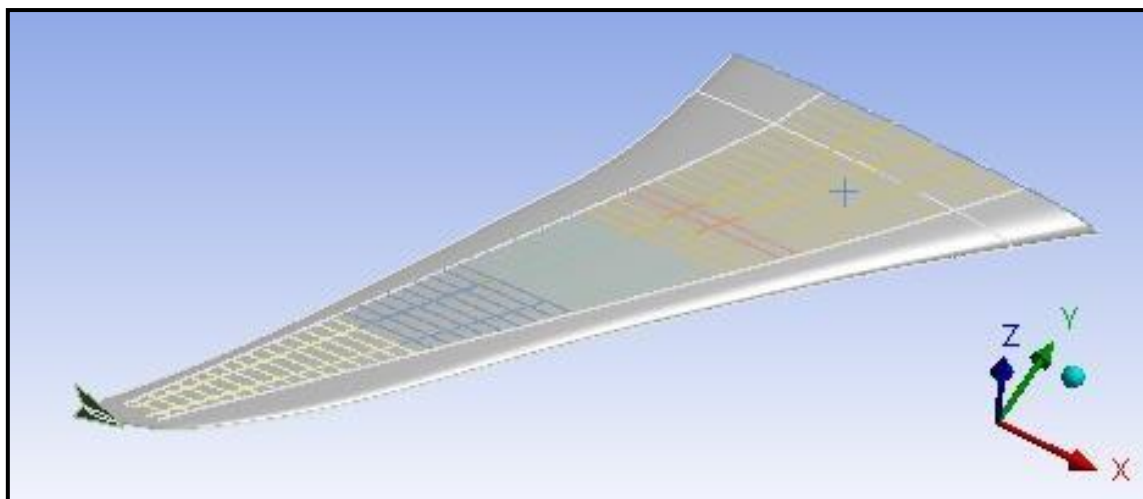


Figure 5.25: Wing Skin (Model 1)

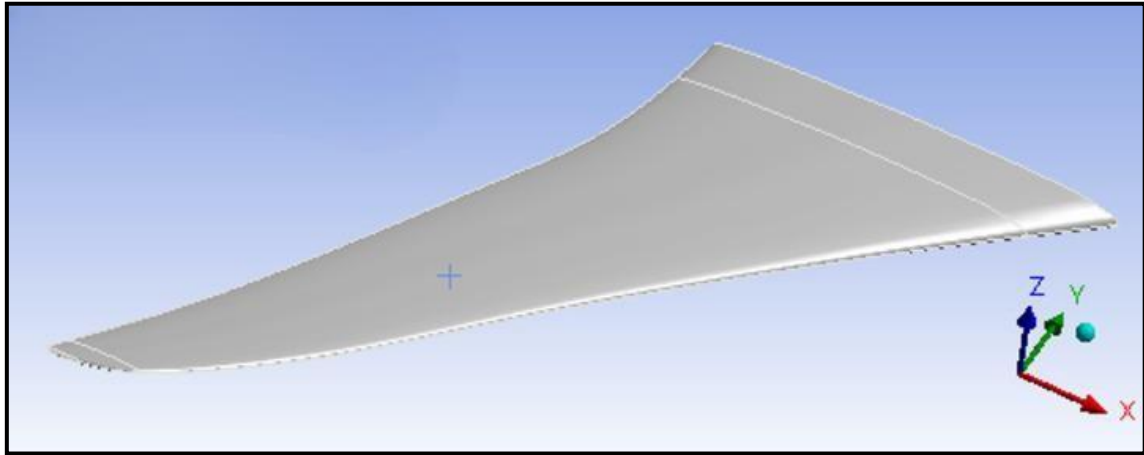


Figure 5.26: Wing Skin: Structure Steel (Model 1)

Because real-life A320 wings are complex and consist of a wide variety of parts, we can expect their internal structure to be very complex as well. To meet limitations and to maintain the simplicity of wing design, we used a simple yet effective system for internal structure which will perform effectively for simulations of static loading during cruise. Following image shows the changes made in the base model.

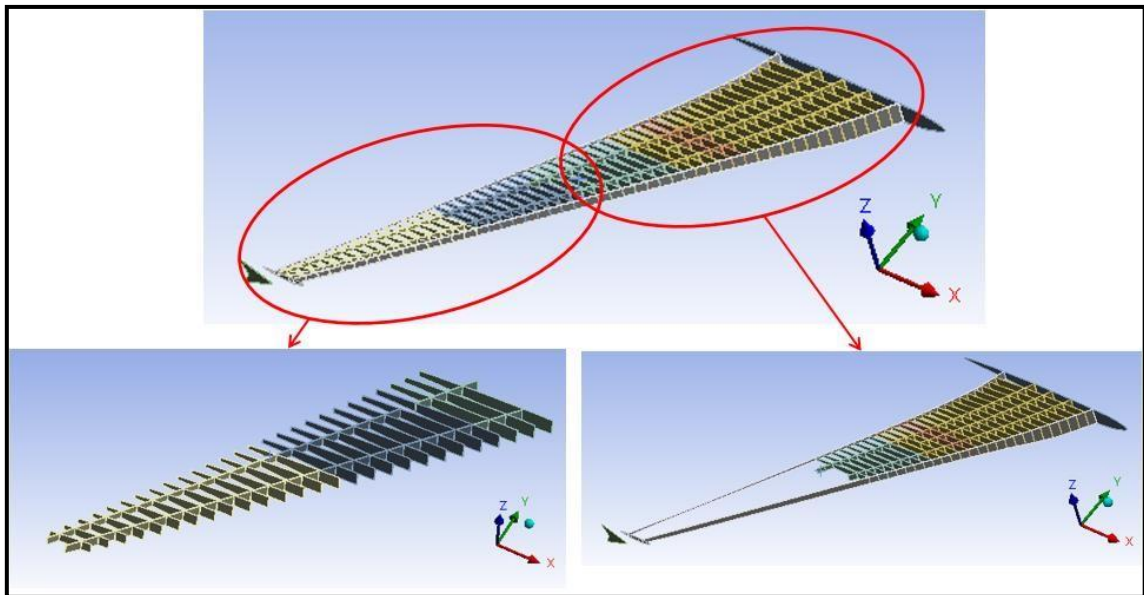


Figure 5.27: FEA Simulation Model (Model 1)

- Wing Skeleton Structure (Near Wing tip)
Material: Aluminum Alloy (7040-T7651 ALLOY)

- Wing Skeleton Structure (Near Wing Root)
Material: Aluminum Alloy (2024-T3 ALLOY)

Our internal structure for the wing is composed of aluminum alloy 7040 T7651. A lot of consideration was given to this material because of its high load bearing capacity, and the analysis showed satisfactory results. Here the changes were made in allocation of material and as mentioned earlier the wing root and wing tip were allocated different materials.

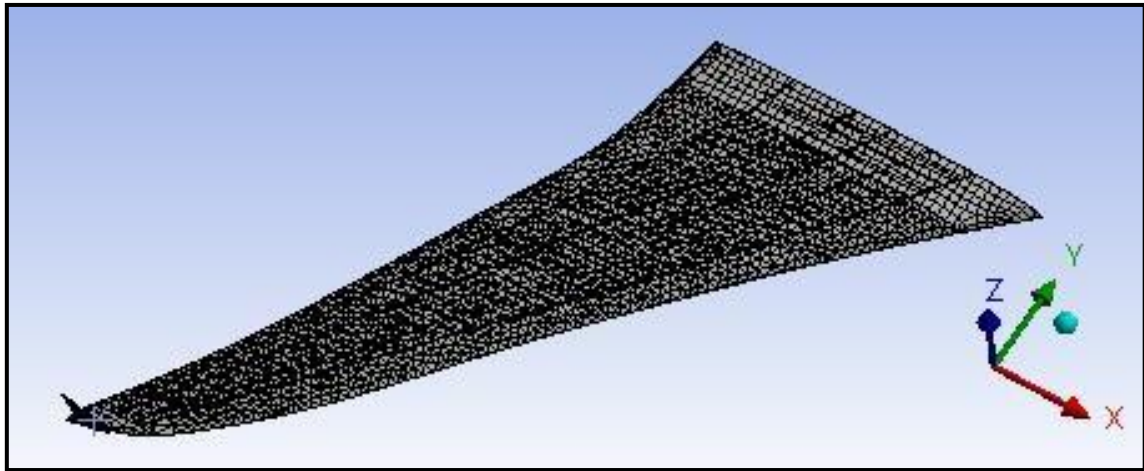


Figure 5.28: Meshed Model 1 (Model 1)

Additionally, we provided a detailed analysis of the structural thickness because it was the most important component during the structural deformation as a result it

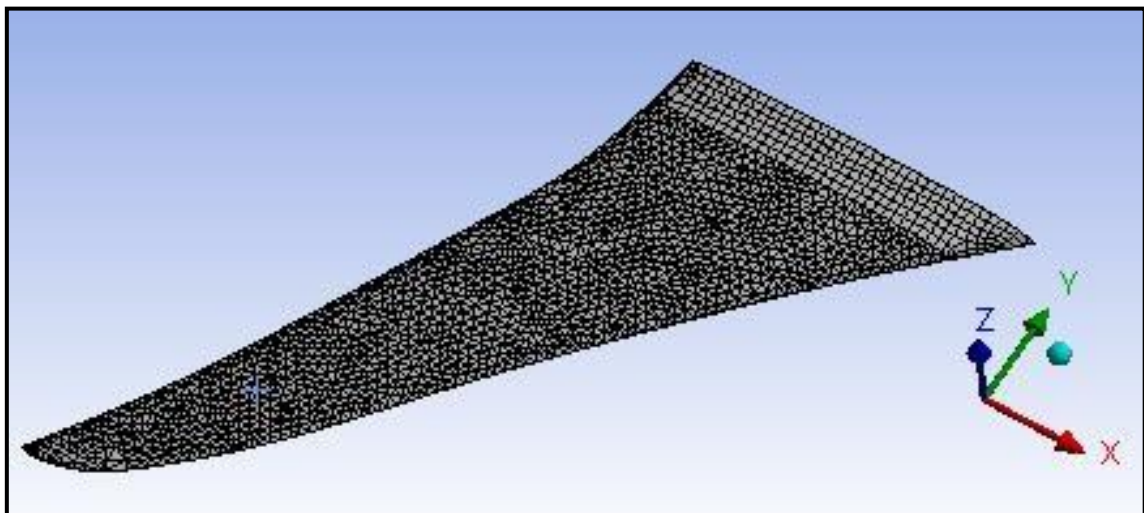


Figure 5.29: Meshed Model 2 (Model 1)

can cause greater deformation if not properly analyzed.

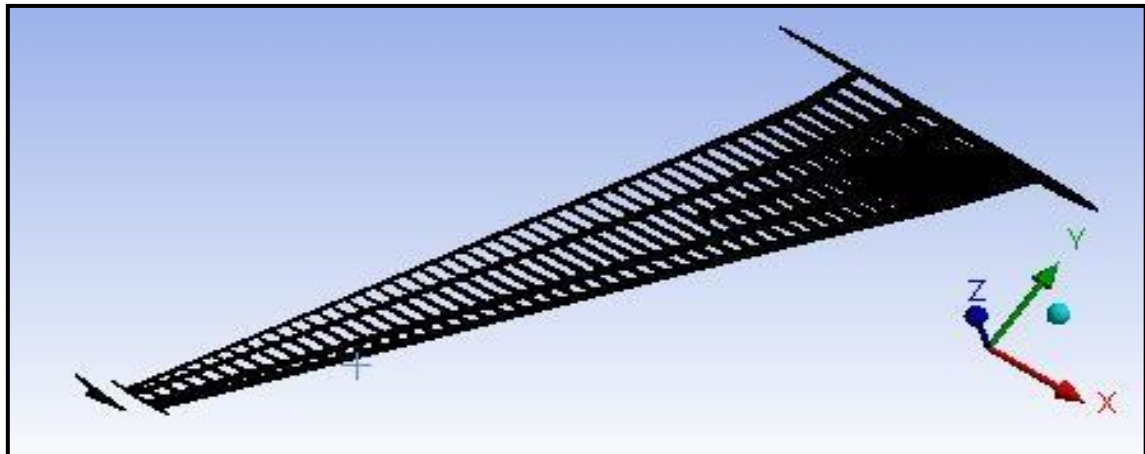


Figure 5.30: FEA Simulation Meshed Model (Model 1)

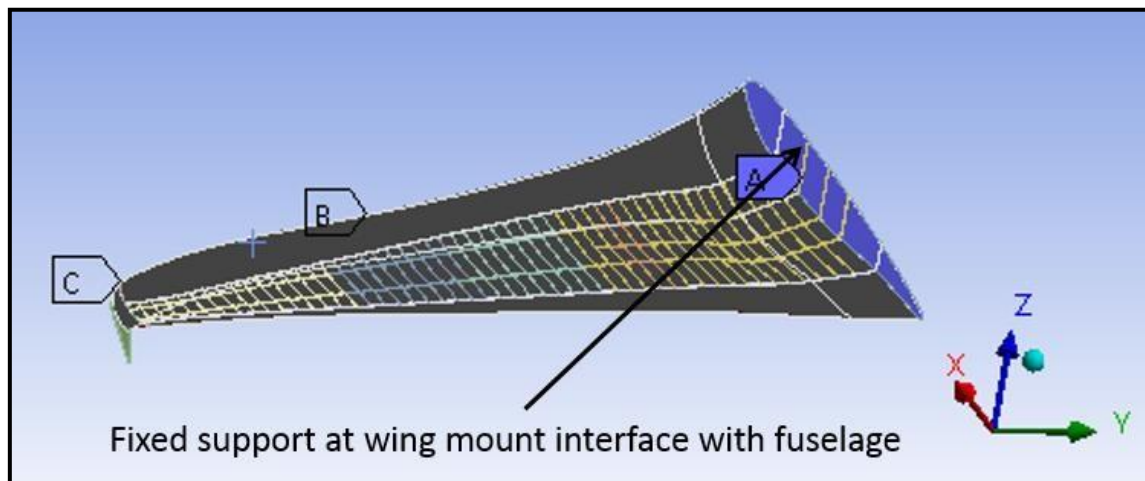


Figure 5.31: Wing Mount Interface with Fuselage (Model 1)

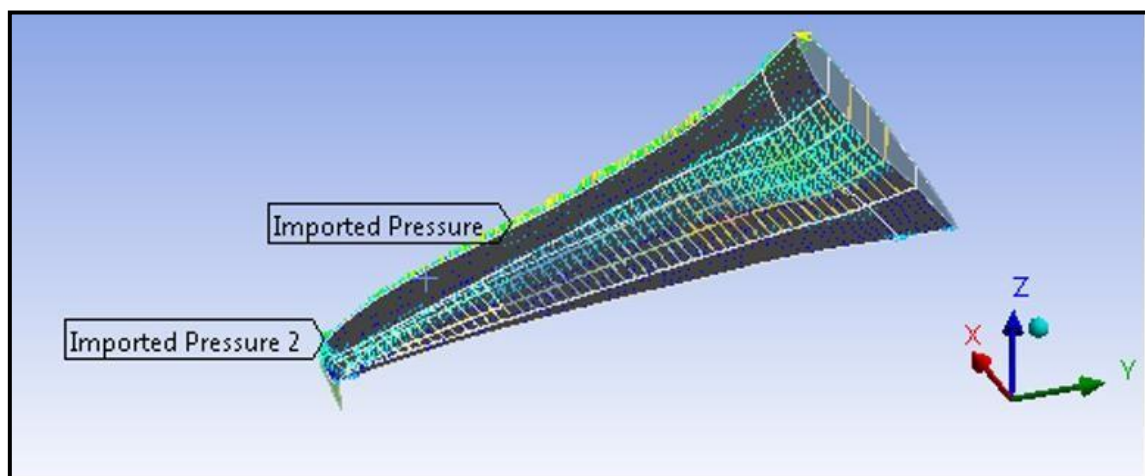


Figure 5.32: Boundary Condition (Model 1)

5.1.2.4 FEA Simulation Results

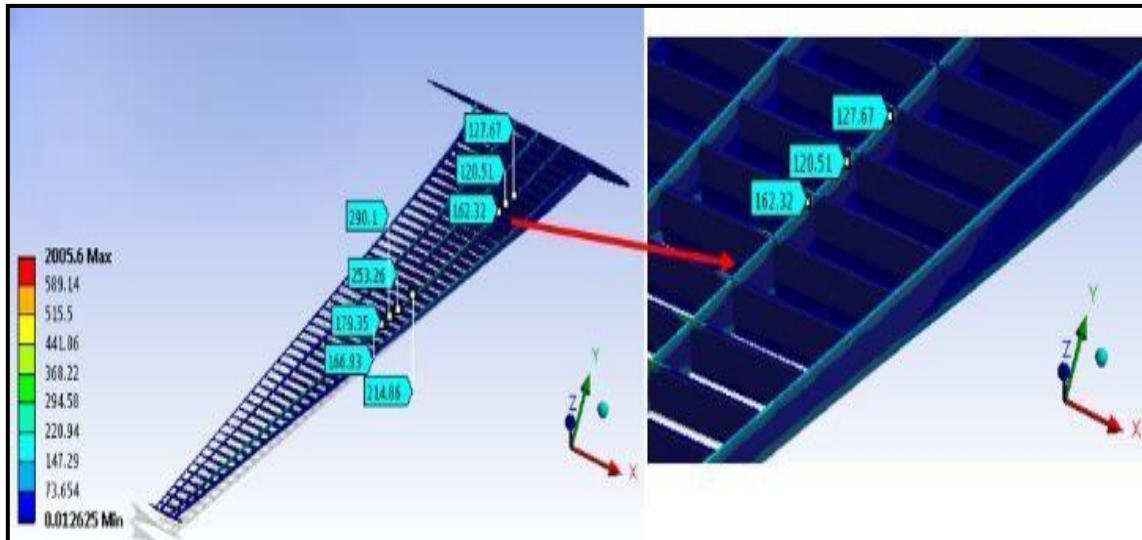


Figure 5.33: Von Mises Stress Results (Model 1)

It is also known as equivalent tensile stress. Von Mises stress is an indicator used to determine whether a particular material will yield or fracture. Von Mises stress is usually used when determining the yield strength of heavy metals.



Figure 5.34: Max Principal Stress Results (Model 1)

An isotropic and ductile metal can be tested for yielding by measuring the von Mises stress after an unusual load is applied.

A von Mises yield criterion, which correlates the von Mises stress with the yield stress of the material, is used to determine this.

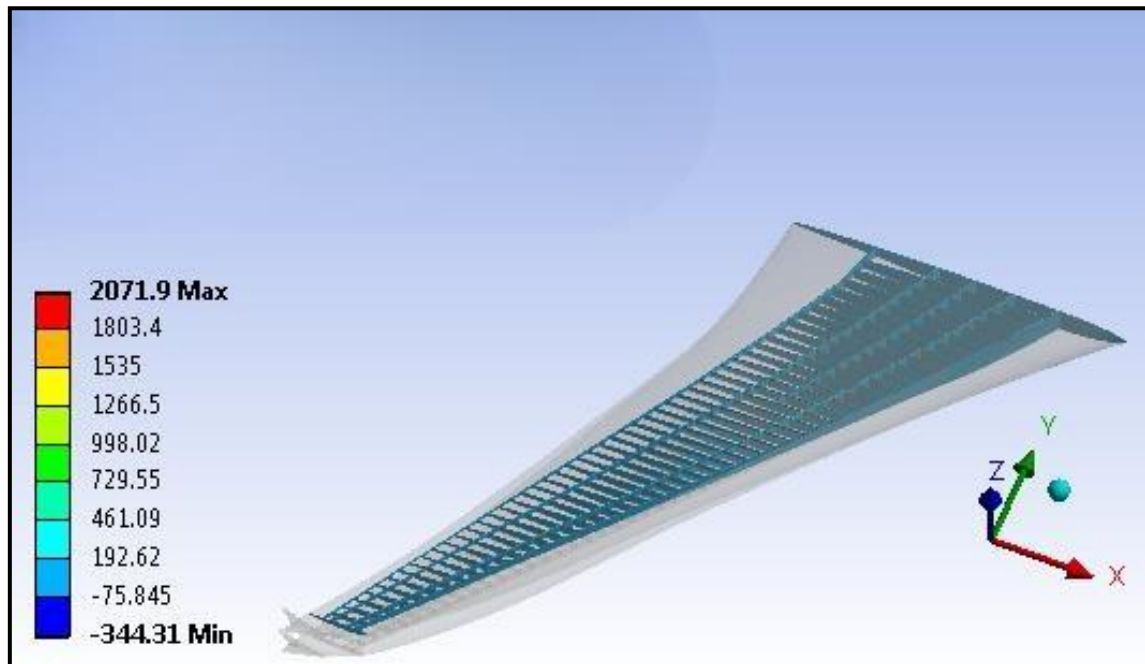


Figure 5.35: Max Principal Stress Results-Ribs (Model 1)

Among the maximum principal stress values along the wing, -344.31 MPa is the minimum value and 2071.9 MPa is the maximum. The maximum principal stress

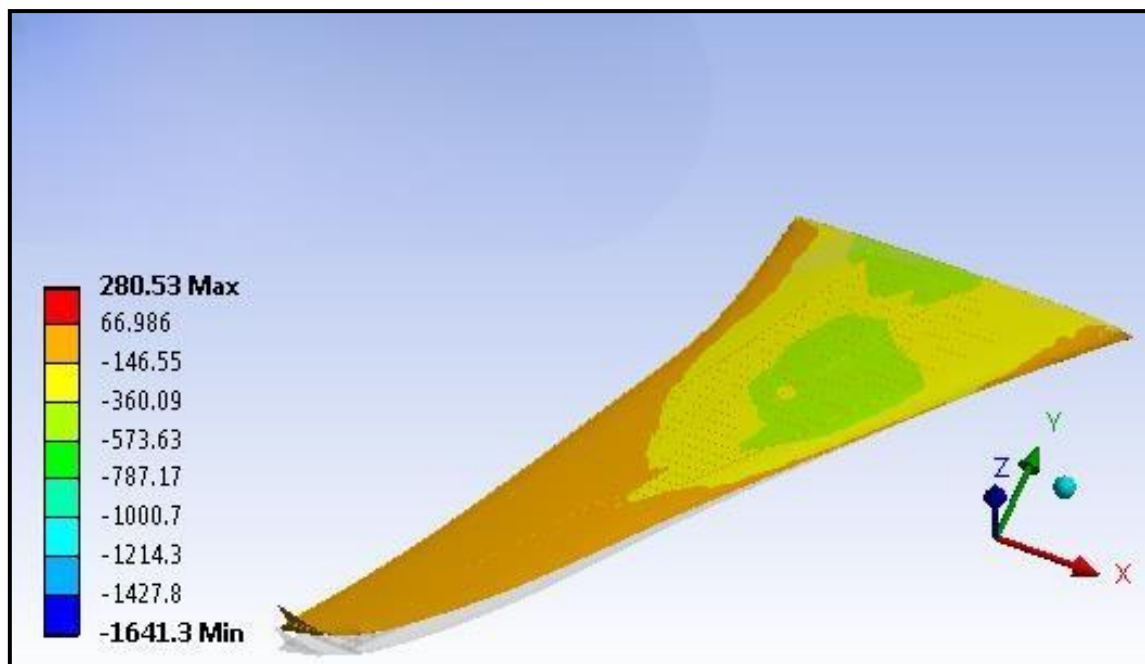


Figure 5.36: Minimum Principal Stress Results (Model 1)

values are evenly distributed along the entire wing, so that there are no concentrated stresses. Here we were able to find out that there was reduction in the value of the maximum principal stress.

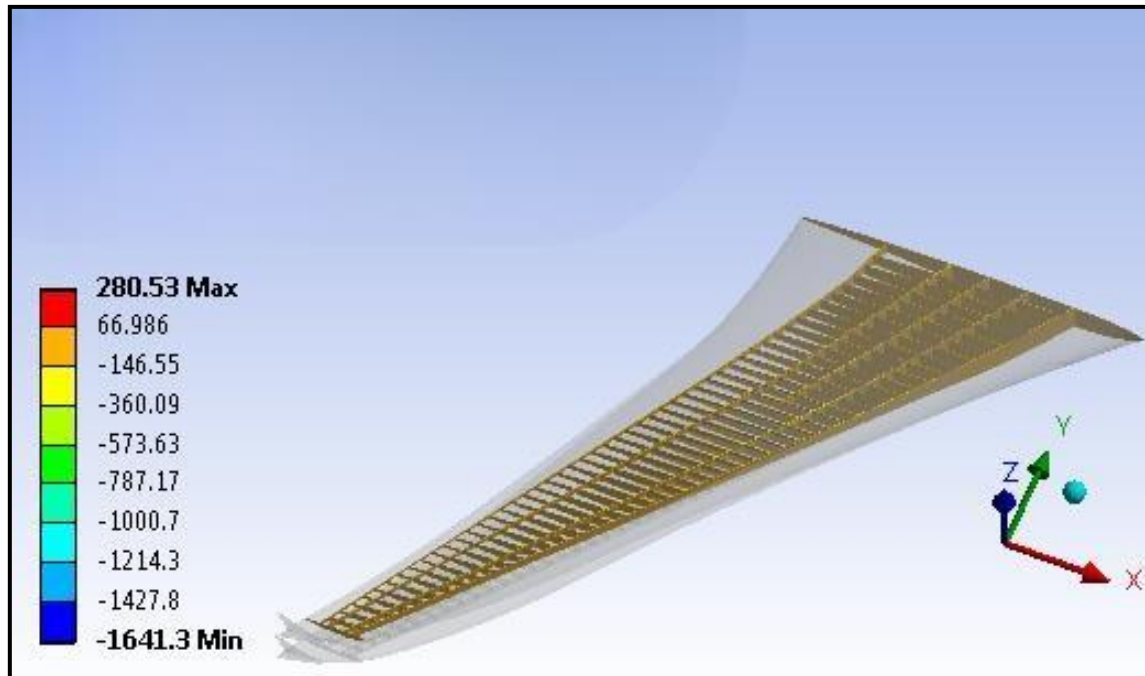


Figure 5.37: Minimum Principal Stress Results-Ribs (Model 1)

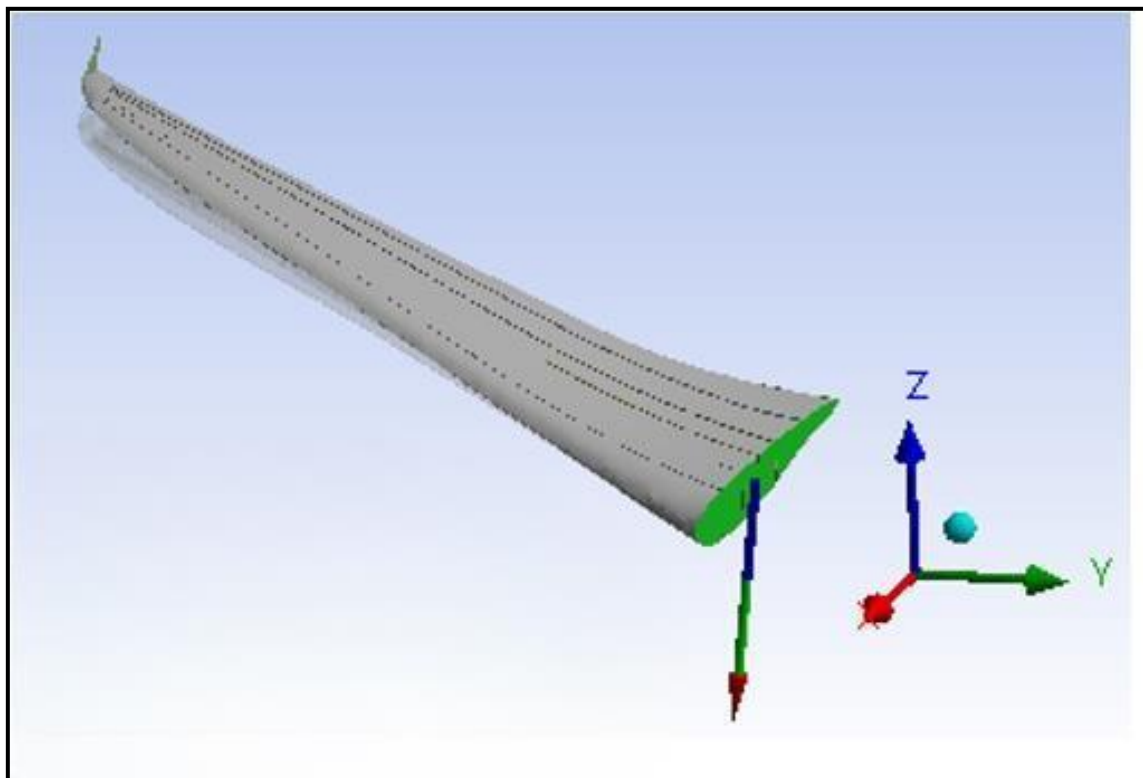


Figure 5.38: Force Reaction (Model 1)

A free-body diagram helps visualize all the forces acting on a single object in mechanics problems. Drawing a free-body diagram is a crucial step in the solution of a mechanics problem. Using the free body diagram, you can achieve the correct setup of the problem so that you can solve for unknowns such as forces and acceleration. The net external force that acts on the object must be obtained before Newton's Second Law can be applied to the motion of the object.

Maximum Value Over Time	
☐ X Axis	-15807 N
☐ Y Axis	-5.0852e+005 N
☐ Z Axis	-3.6467e+006 N
☐ Total	3.6821e+006 N

Table 5.3: Values of Force Reaction (Model 1)

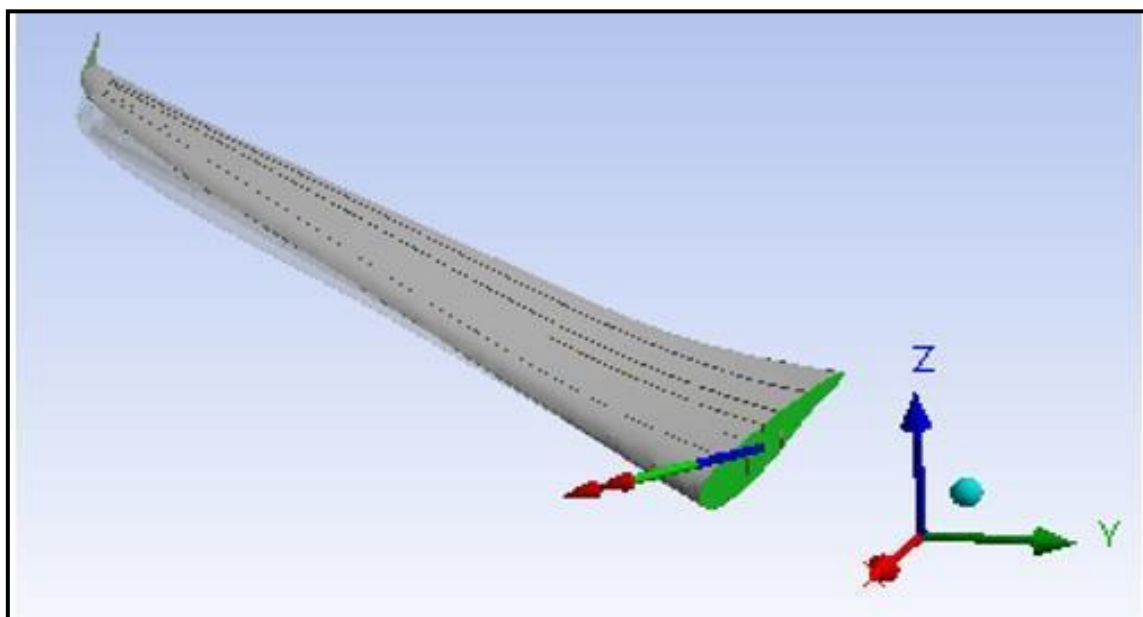


Figure 5.39: Bending Reaction (Model 1)

Maximum Value Over Time	
☐ X Axis	5.236e+010 N·mm
☐ Y Axis	-2.1052e+010 N·mm
☐ Z Axis	4.6011e+009 N·mm
☐ Total	5.6621e+010 N·mm

Table 5.4: Values of Bending Reaction (Model 1)

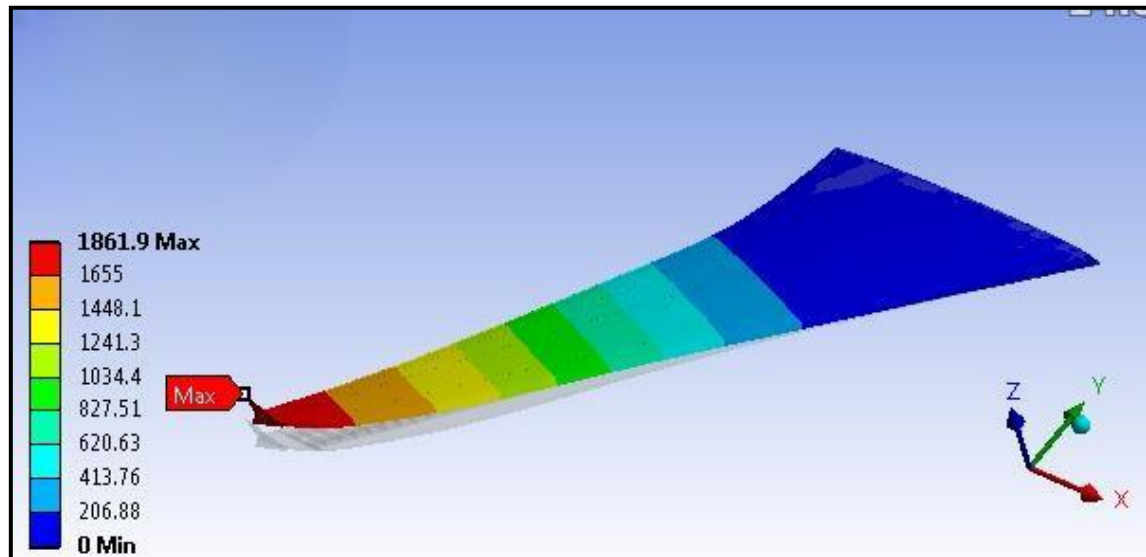


Figure 5.40: Total Deformation Results (Model 1)

The last result was the maximum total deformation. From the above graph we can see that the maximum total deformation was 1861.9 mm, while the minimum was 0 mm.

Decrease in the maximum total deformation: 6.1 mm

5.1.3 Analysis for Model 2

(Thicker section near wing root and weaker section near wing tip)

Additional to the material change, change in thickness of spars and ribs were made in the wing internal structure to amplify the results.

5.1.3.1 CFD Analysis:

This step involves defining an analytical fluid domain in which air is the fluid medium. The velocity at the inlet is set to 300 m/s. The wing root is then mounted to the wall of the fluid domain.

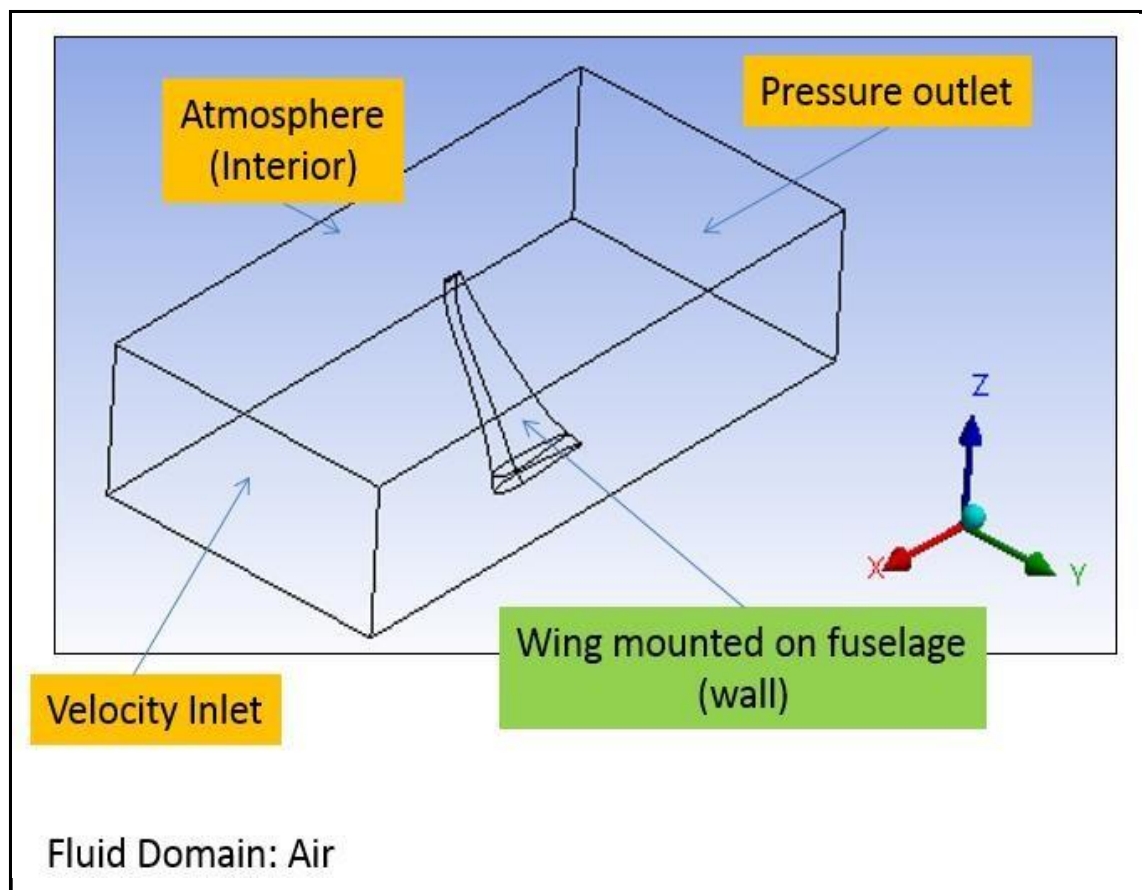


Figure 5.41: CFD Simulation Model (Model 2)

Using the domain used to simulate the base model and model 1 was very much similar to that used to simulate the domain. The only difference was that the domain was covered in different materials towards the root of the wing as opposed to the tip of the wing.

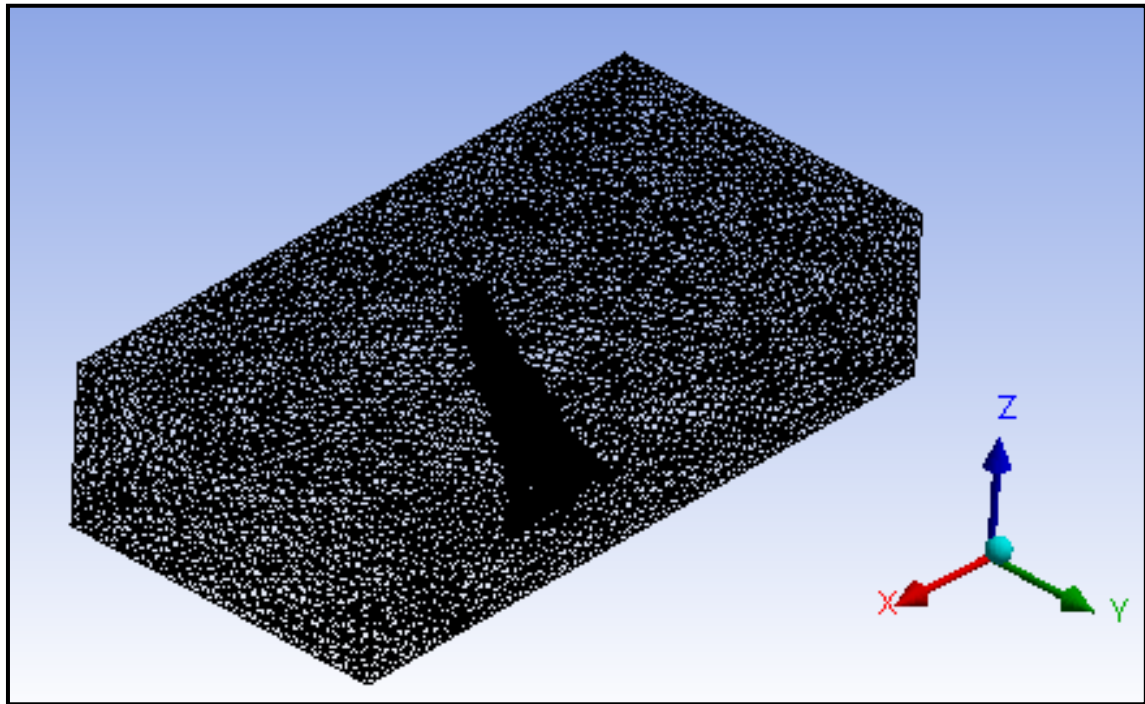


Figure 5.42: CFD Simulation Meshed Model (Model 2)

Wing is meshed very fine in order to capture the flow properties over the wing surfaces accurately.

Meshing Type: Tetrahedral Meshing.

5.1.3.2 CFD Simulation Results

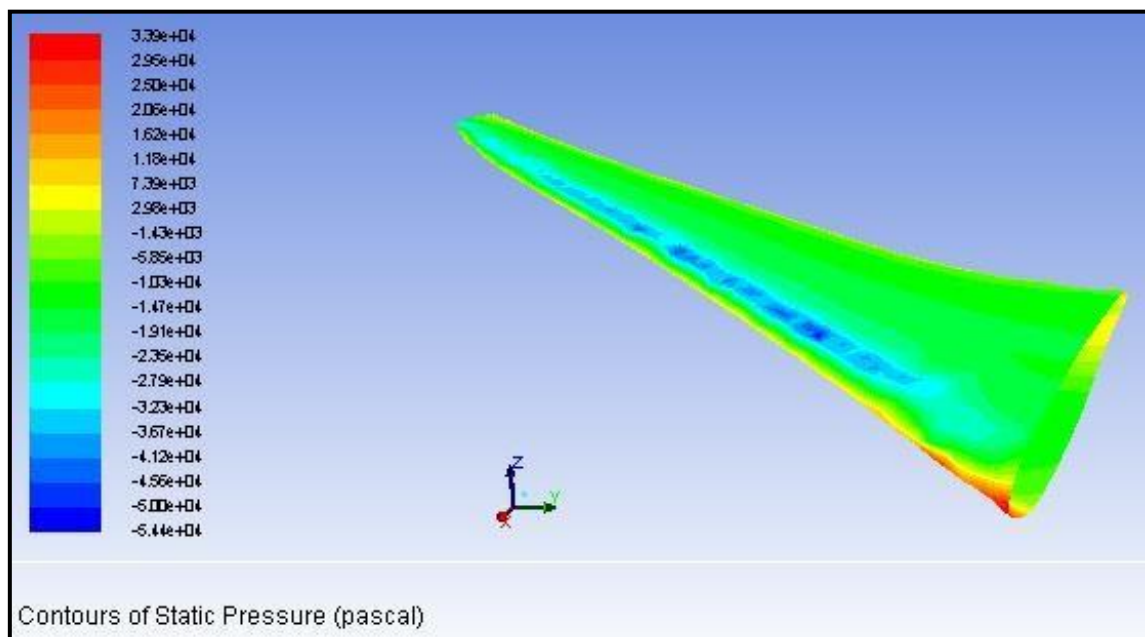


Figure 5.43: CFD Simulation results - Top Wing (Model 2)

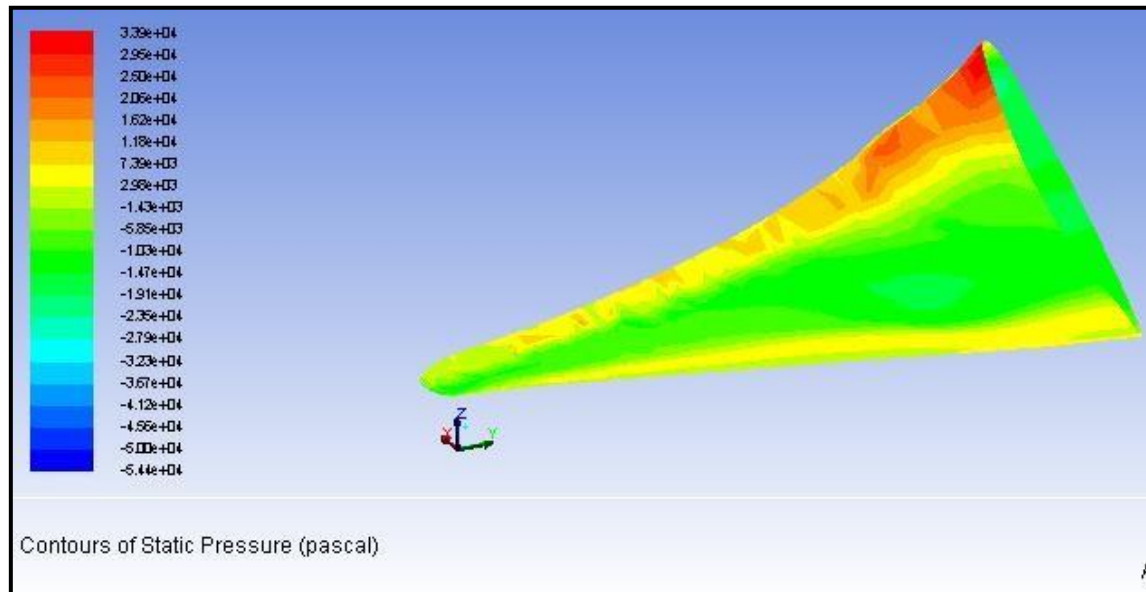


Figure 5.44: CFD Simulation results - Bottom Wing (Model 2)

Airplane wings are shaped to make air move faster over the top of the wing. When air moves faster, the pressure of the air decreases. So, the pressure on the top of the wing is less than the pressure on the bottom of the wing. The difference in pressure creates a force on the wing that lifts the wing up into the air and therefore pressure is the key element while doing this project. We can clearly see that there is a difference in the pressure over and below the wing and thus it gives us a green signal perform further.

5.1.3.3 FEA Simulation

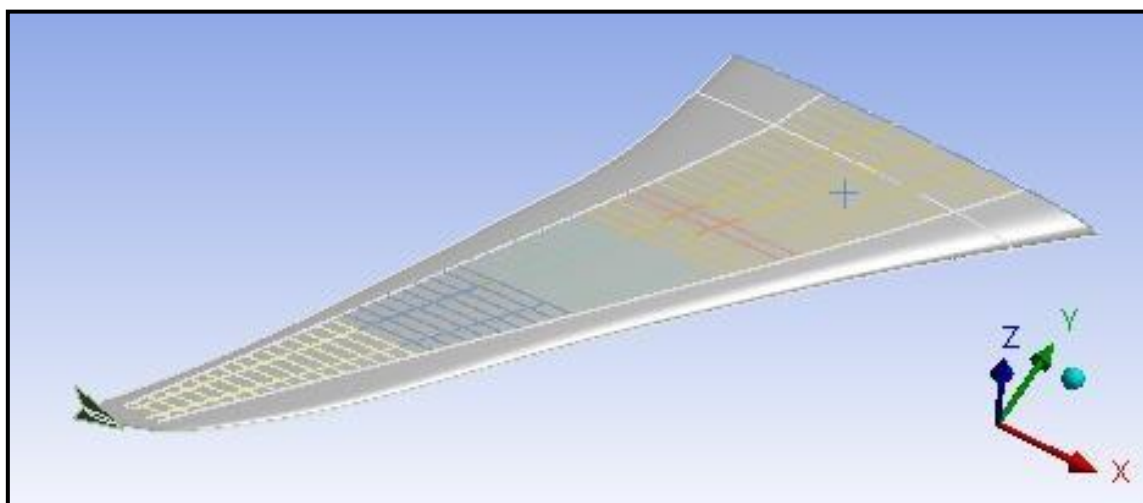


Figure 5.45: Wing Skin (Model 2)

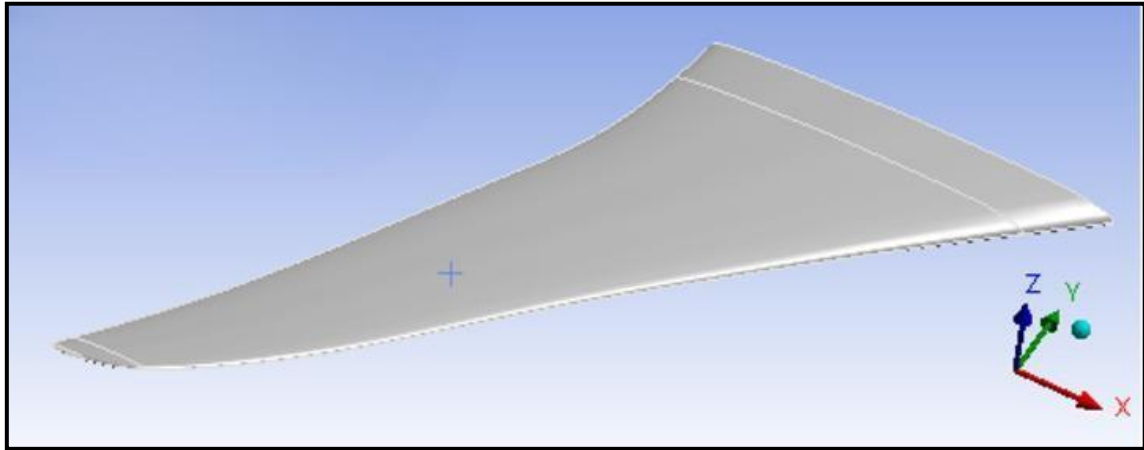


Figure 5.46: Wing Skin (Material: Structure Steel) (Model 2)

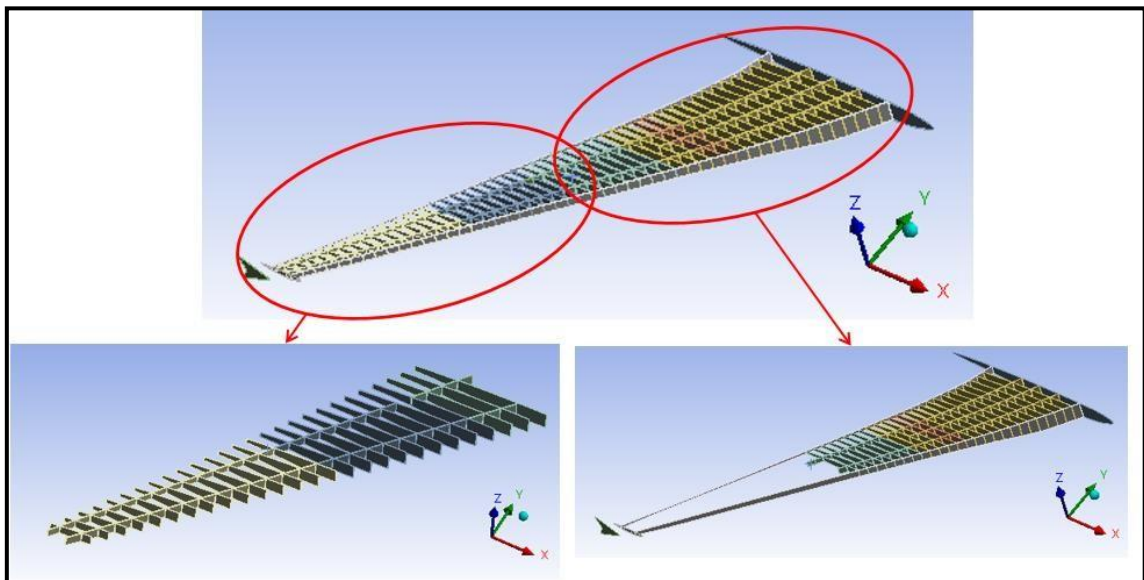


Figure 5.47: FEA Simulation Model (Model 2)

- Wing Skeleton Structure (Near Wing tip)
Material: Aluminum Alloy (7040-T7651 ALLOY)
- Wing Skeleton Structure (Near Wing Root)
Material: Aluminum Alloy (2024-T3 ALLOY)

Addition to the change in material this time we tried to change the thickness of the spars and ribs as shown in the figure above. Changes are as follows:

- Wing Skeleton Structure (Near Wing tip)
Change in rib thickness from 2.8 mm from 0 mm
- Wing Skeleton Structure (Near Wing Root)
Change in rib thickness from 5 mm to 2.8 mm

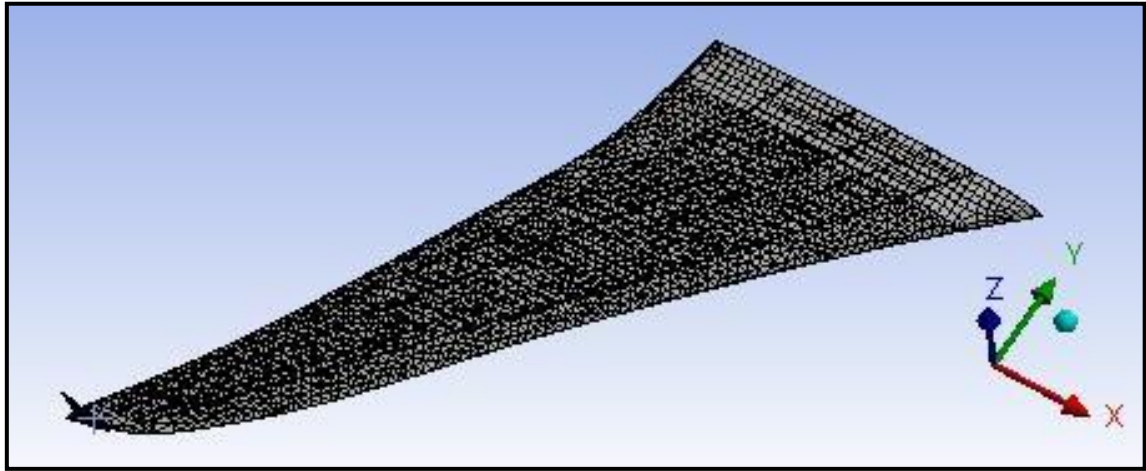


Figure 5.48: Meshed Model 1 (Model 1)

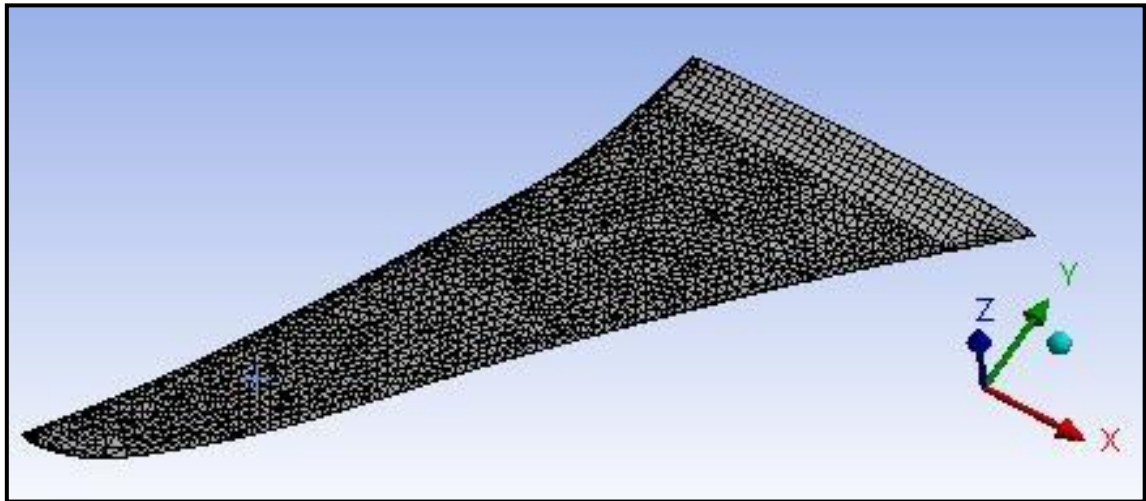


Figure 5.49: Meshed Model 2 (Model 1)

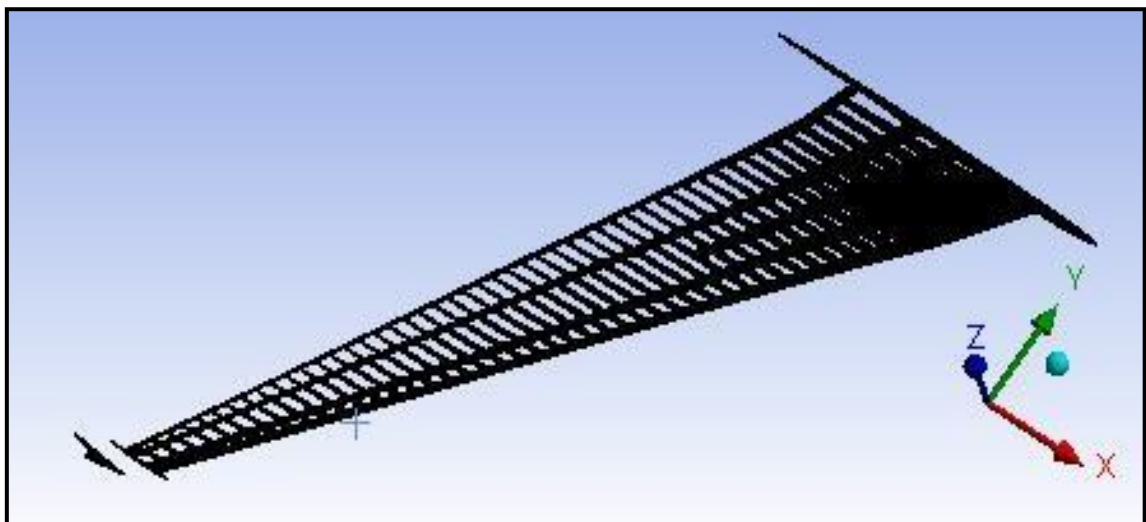


Figure 5.50: FEA Simulation Meshed Model (Model 2)

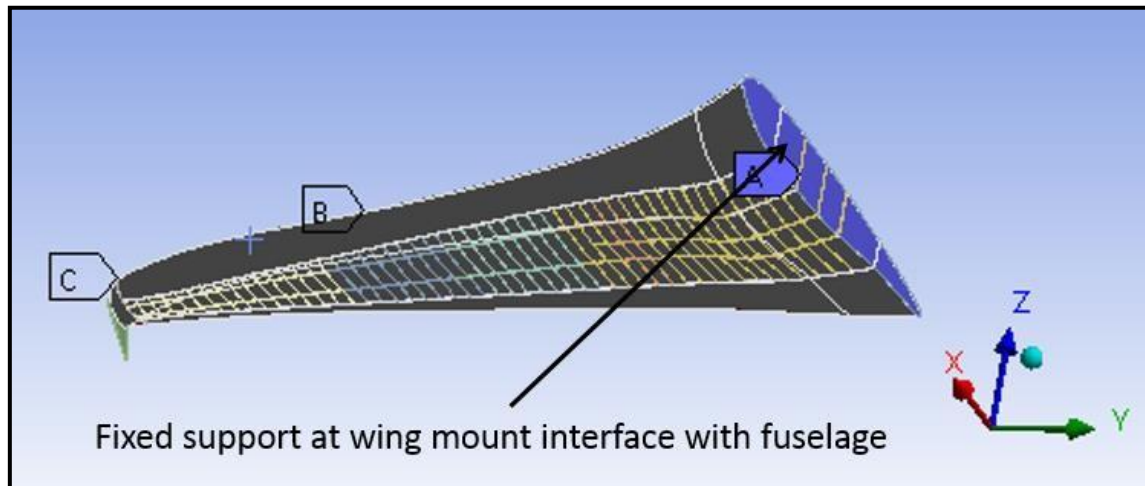


Figure 5.51: Wing Mount Interface with Fuselage (Model 2)

Here we can see that the pressure values are imported from the previous simulation that was done in order to determine an overall pressure distribution across the body. In our previous simulation, the pressure values played an important role in determining the load over a specific body or its components. Pressure is imported from the previously performed simulation.

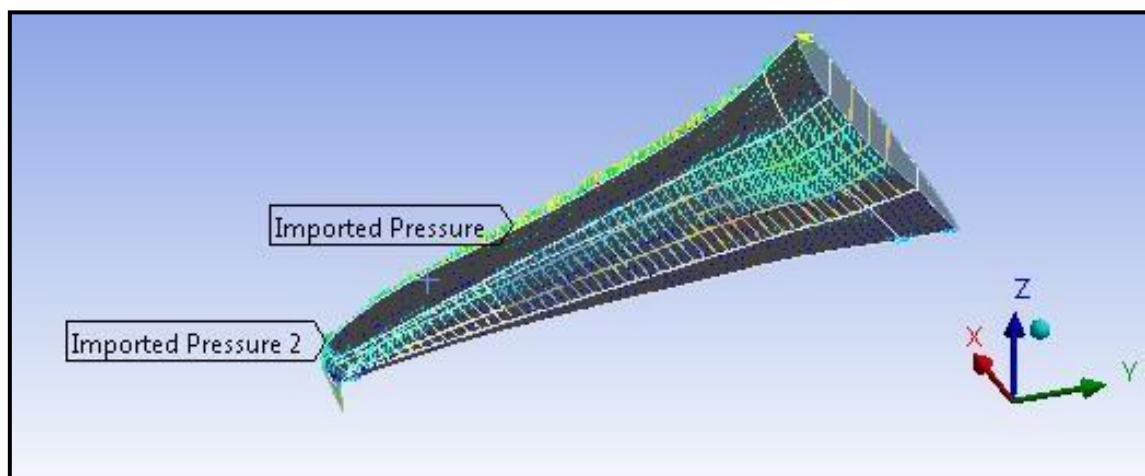


Figure 5.52: Boundary Condition (Model 2)

In this phase, the pressures imported are used to simulate the structural analysis and determine the value of deformation in wing materials under static loads. The pressure varies on both the top and bottom sides as a result of its two-phase importation.

5.1.3.4 FEA Simulation Results

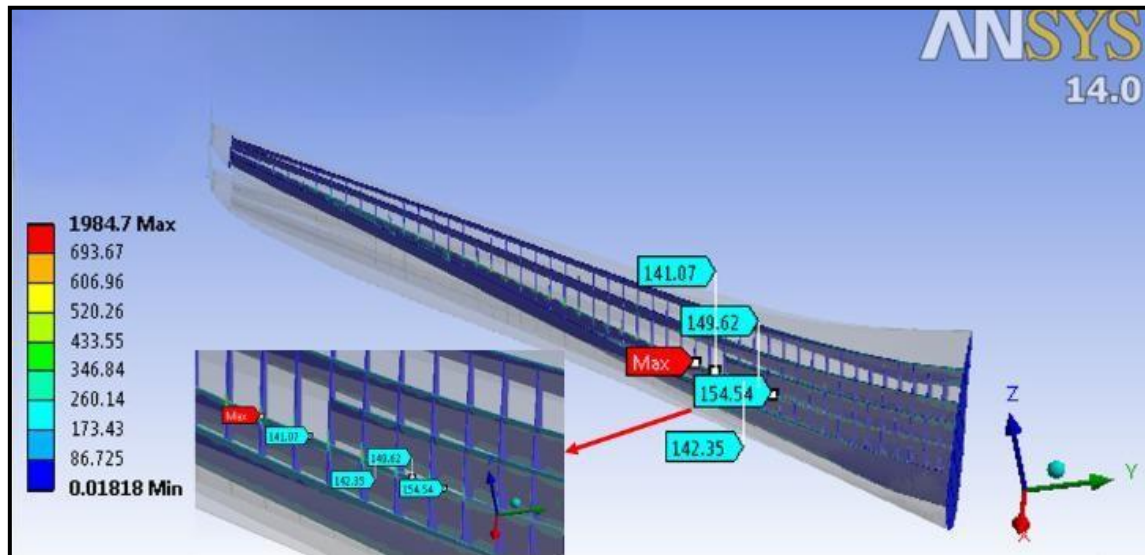


Figure 5.53: Von Mises Stress Results (Model 2)

In theory, Von Mises stress serves as a measure of yield strength and is applied when determining the yield strength of heavy metals. It is also referred to as equivalent tensile stress or equivalent tensile force.

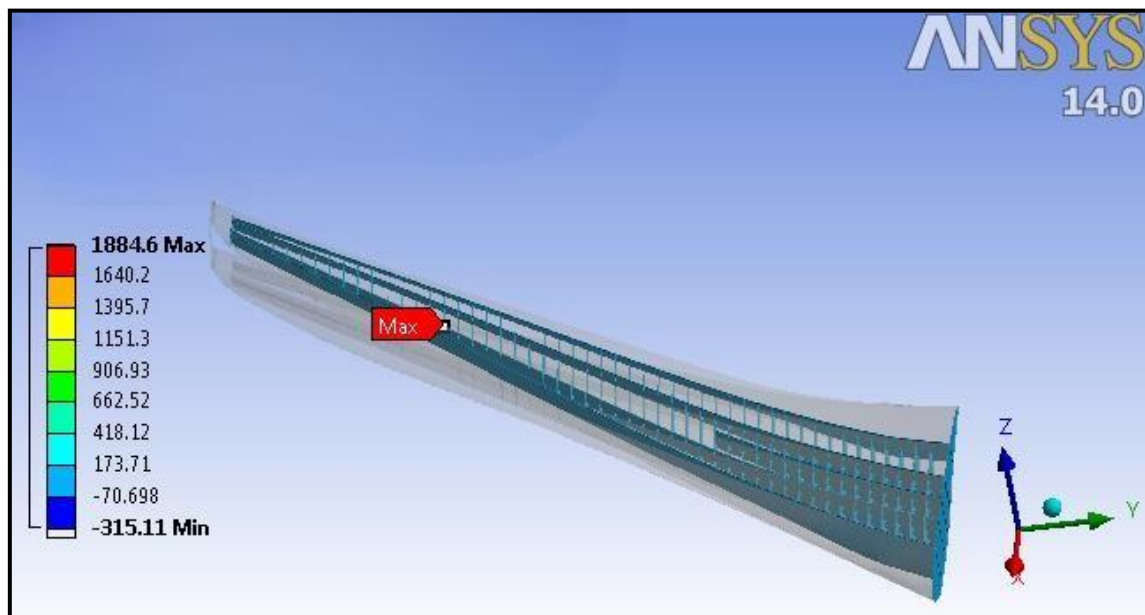


Figure 5.54: Max Principal Stress Results (Model 2)

In order to determine the yielding of an isotropic and ductile metal, one measures the von Mises stress after an unusual load is applied. The von Mises yield criterion, which correlates the von Mises stress with the yield stress of the material,

is used in order to determine the yielding of the metal after an unusual load is applied.

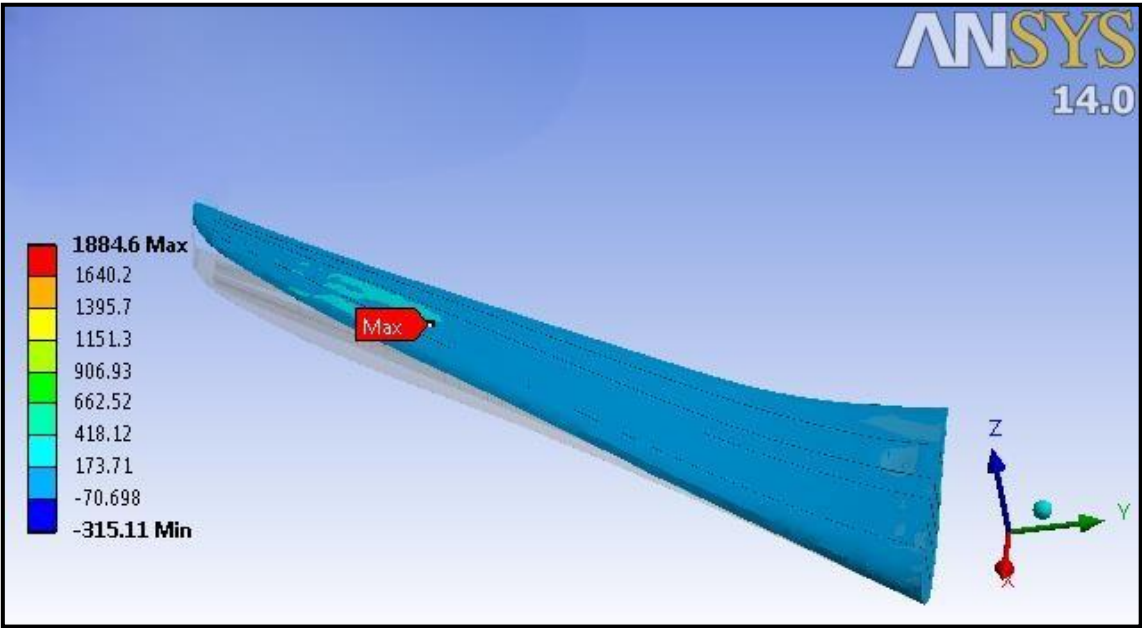


Figure 5.55: Max Principal Stress Results-Ribs (Model 2)

Among the maximum principal stress values along the wing, -315.11 MPa is the minimum value and 1884.6 MPa is the maximum. It is reported that the maximum principal stress values on the whole wing are evenly distributed, therefore there

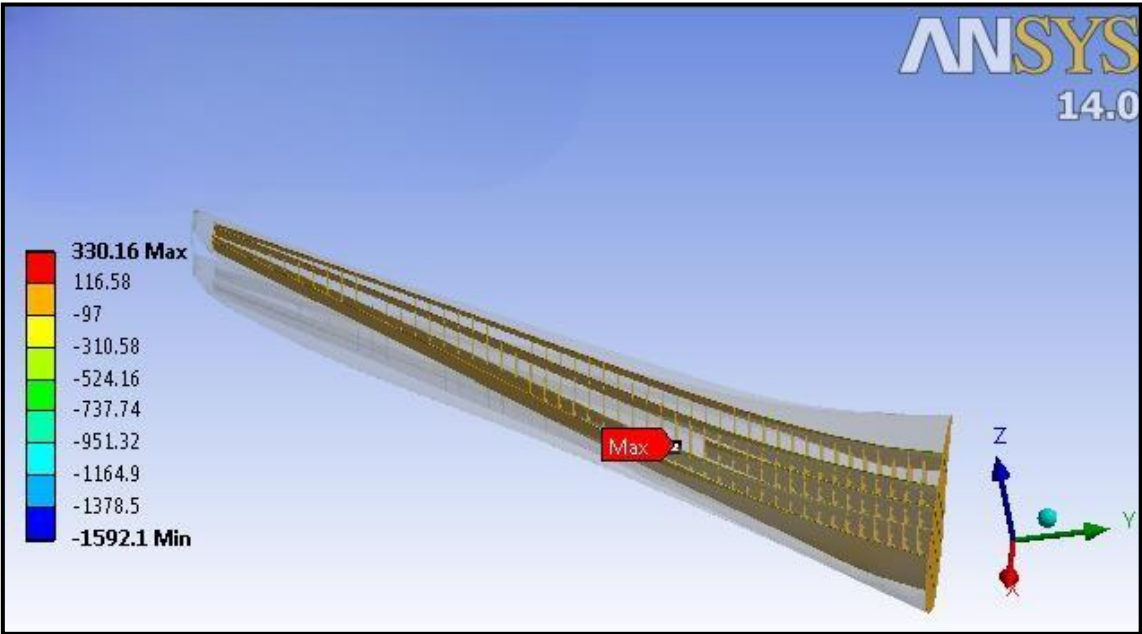


Figure 5.56: Minimum Principal Stress Results (Model 2)

are no concentrated stresses. Here we were able to determine that the maximum principal stress was reduced.

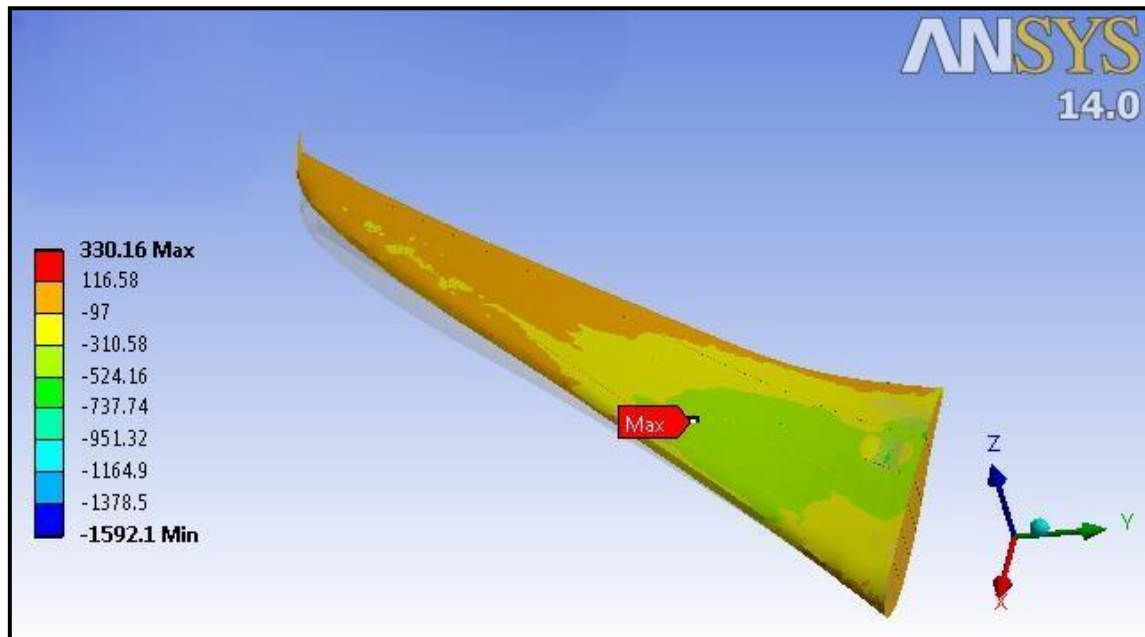


Figure 5.57: Minimum Principal Stress Results-Ribs (Model 2)

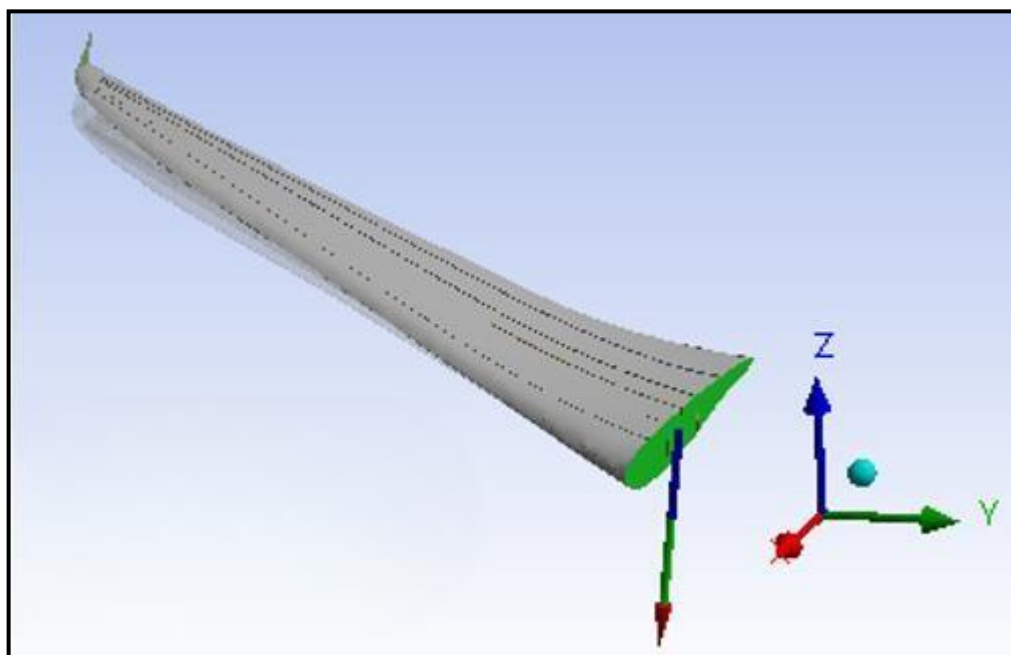


Figure 5.58: Force Reaction (Model 2)

A free-body diagram is a crucial element in solving mechanics problems as it gives a clear visual representation of all the forces acting on a single object. Using the free body diagram, you can very easily set up the problem so that you can solve

for unknowns like forces and acceleration. Newton's Second Law of Motion can be applied to the motion of objects by applying the net external force on them.

☐ X Axis	-11874 N
☐ Y Axis	-5.0599e+005 N
☐ Z Axis	-3.8327e+006 N
☐ Total	3.866e+006 N

Table 5.5: Values of Force Reaction (Model 2)

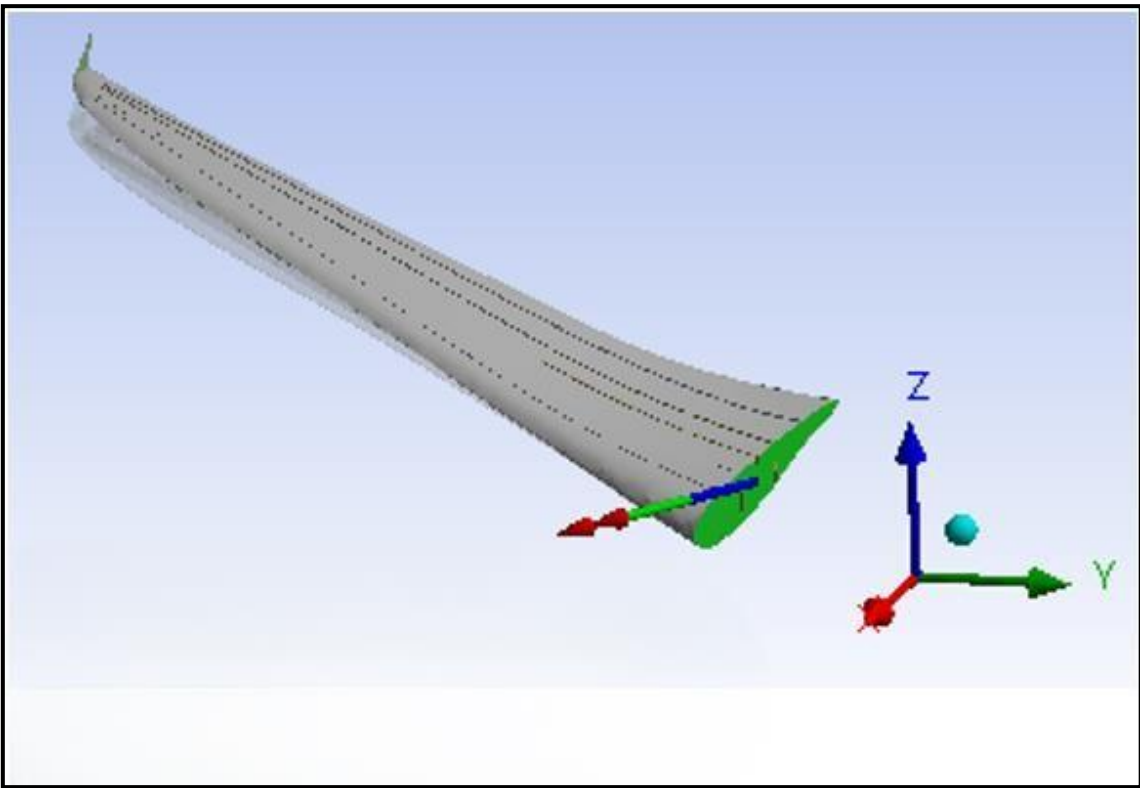


Figure 5.59: Bending Reaction (Model 2)

☐ X Axis	5.2002e+010 N·mm
☐ Y Axis	-2.0049e+010 N·mm
☐ Z Axis	4.4273e+009 N·mm
☐ Total	5.5908e+010 N·mm

Table 5.6: Values of Bending Reaction (Model 2)

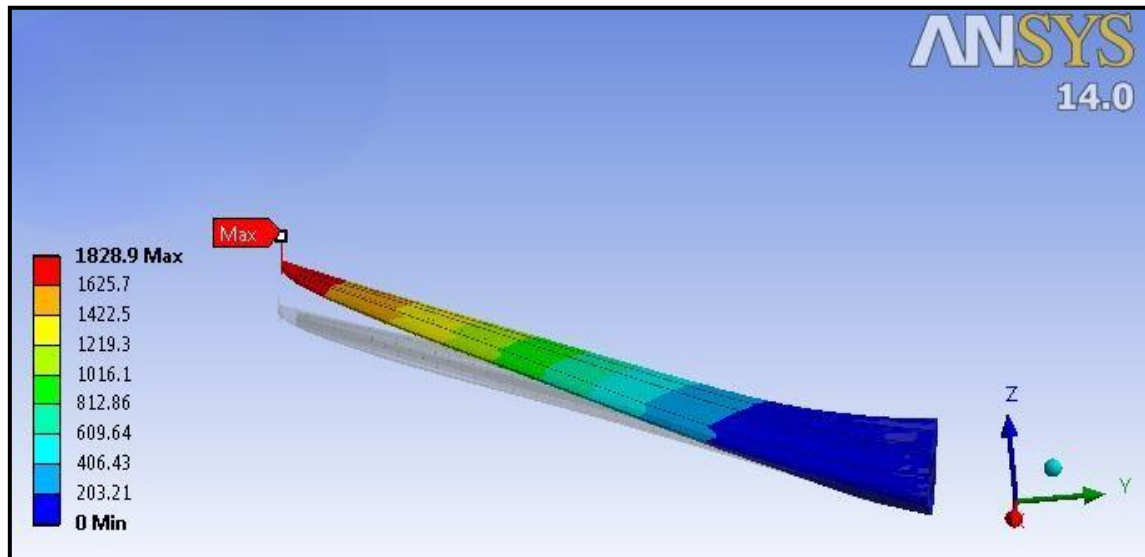


Figure 5.60: Total Deformation Results (Model 2)

Last but not least, we have the results for maximum total deformation. As you can see on the diagram, the maximum total deformation lies between 1828.9 mm and 0 mm. Further, the above diagram clearly displays the distribution of total deformation along a wing, with maximum deformation occurring at the tip of the wing whereas the least occurs at its root. Finally, this was the maximum decrease possible in the material deformation as further reduction would lead to more stiffness causing various problem. Result of the simulation is discussed in following section.

5.2 RESULT

Finally, when we compare the graphs of base model with modified models, we have found a big difference in the total deformation value. It shows that the total deformation for the Model 2 model is less with comparison to base model. Graphical comparison of these values is as follows:

Properties	Base Model	Model 1	Model 2
Material	Aluminium Alloy 7040-T7651	1. Near wing tip: Aluminium Alloy 7040-T7651 2. Near wing root: Aluminium Alloy 2024-T3	1. Near wing tip: Aluminium Alloy 7040-T7651 2. Near wing root: Aluminium Alloy 2024-T3
Thickness	No change in thickness (0.2 mm)	No change in thickness (0.2 mm)	1. Near wing tip: 2.8 mm to 0 mm 2. Near wing root: 5 mm to 2.8 mm
Total Deformation (Max)	1868 mm	1861.9 mm	1828.9 mm

Table 5.7: Various Changes Made in Properties During Project Work

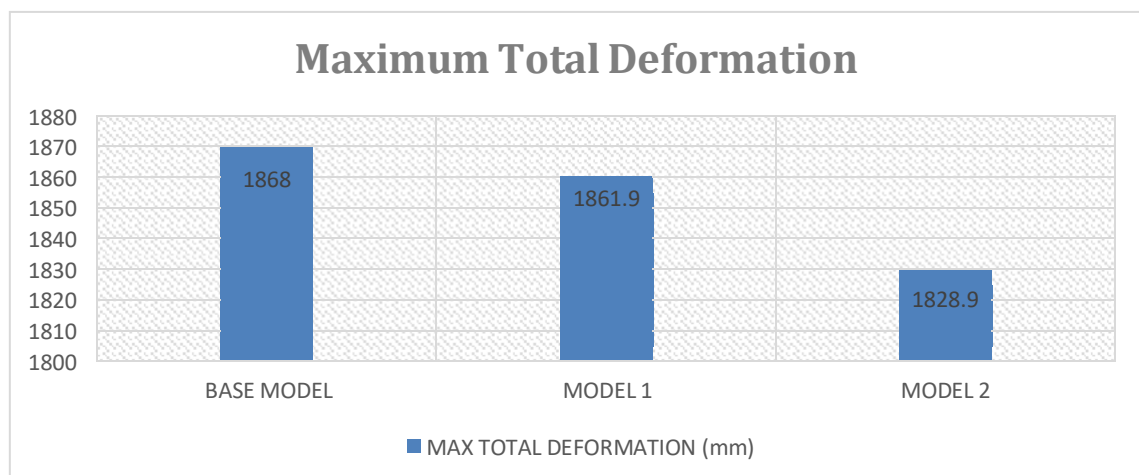


Figure 5.61: Comparative Maximum Total Deformation Result

The total deformation graph clearly indicates that by changing the material and thickness of spars/ribs, total deformation can be reduced drastically. Model 1 involved change of material near wing root whereas Model 2 involved change in thickness of spars/ribs accompanied by the changes made in Model 1.

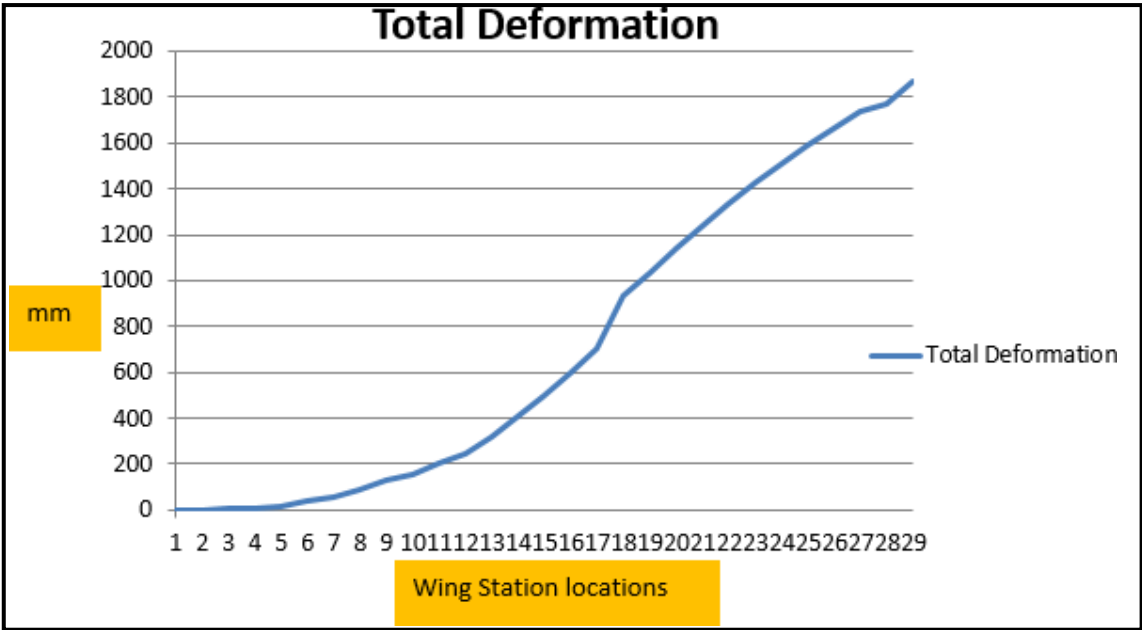


Figure 5.62: Baseline Model Results

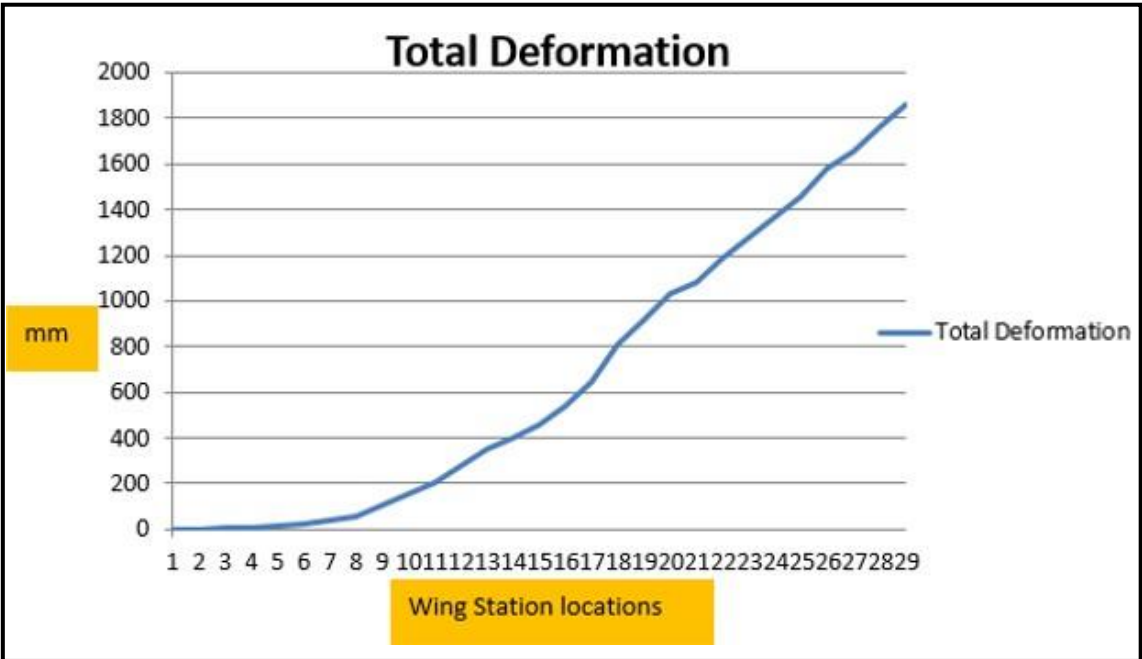


Figure 5.63: First Iteration Model Results

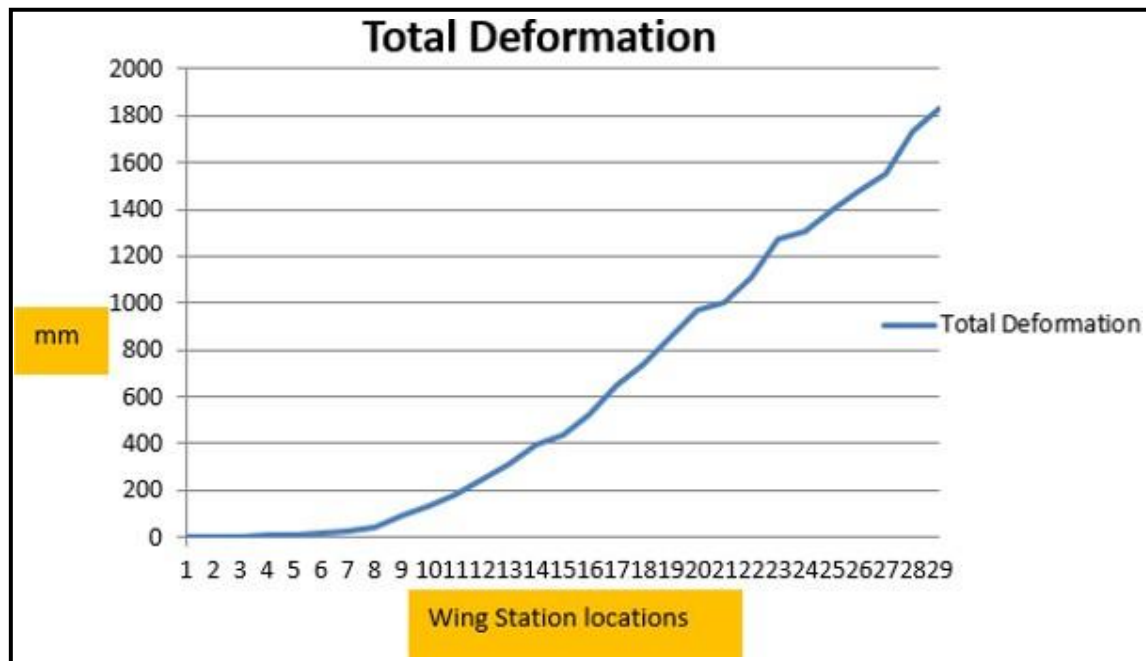


Figure 5.64: Second Iteration Model Results

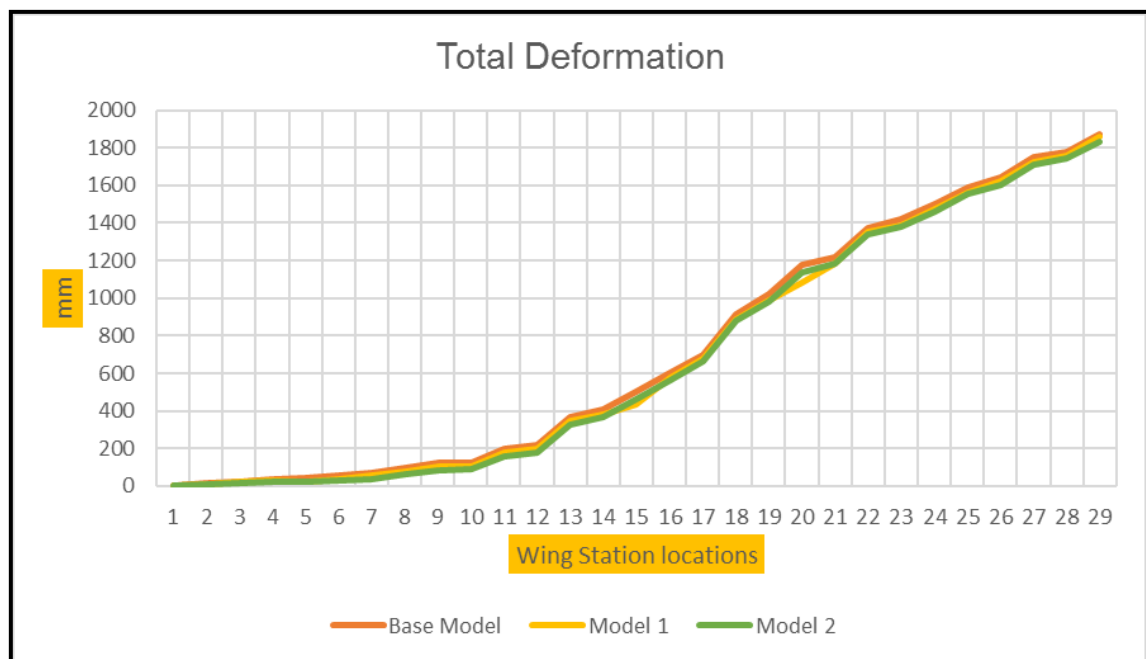


Figure 5.65: Total Deformation Comparison Graph for Base Model, Model 1 and Model 2

As the above figure indicate the decrease in the total deformation value of the wing by changing the material and thickness. And therefore, we came to the conclusion that changing material and thickness of ribs are effective in reducing deformation.

CHAPTER 6

CONCLUSION

In this project we studied the wing model by utilizing the Fluid- Structural Interaction approach, which yielded accurate results, as described earlier in the results.

The project's main goal is that this analysis be used to improve the aircraft's structural efficiency. We learned from the aforementioned data that deformation varies depending on the material and thickness of the ribs. From the results we can conclude that when we change the material from Aluminium Alloy 7040-T7651 (Base Model Material) to Aluminium Alloy 2024-T3 for the wing roots while keeping the material same near wing tip we get the deduction in total deformation by 0.3276%. For the Iteration 2 we kept the material same to that of the Iteration 1 but structural thickness of ribs were increased around 2.8 mm to 0 mm near wing tip and 5 mm to 2.8 mm near wing root which lead to a drastic decrease in total deformation of 2.1378% as compared to the total deformation of base model.

Hence, we can conclude that by changing the material and thickness of the ribs, we can reduce the total deformation of wing up to certain limits.

REFERENCE

- [1] Christopher L. Rumsey, Susan X. Ying et al, "A CFD Prediction of High Lift: review of present CFD capability", Elsevier, Progress in Aerospace Sciences, volume 38, issue 2, February 2002.
- [2] Ganesh M., G Hima Bindu and A. Sai Kumar, "Modeling and Analysis of a Composite Wing for Missile Structure", International Journal of Mechanical Engineering and Technology 8, 2017: 338– 347.
- [3] Hisayoshi Naka, Yuta Sunami and Hiromu Hashimoto. "Development of the Artificial Wing Suitable for Flapping Micro Air Vehicle Based on Dragonfly Wing", The 3rd International Conference on Design Engineering and Sciences, ICDES 2014 Proceedings: 78-83.
- [4] K.P. Singh, J. S. Mathur, V. Ashok, and Debasis Chakraborty, "Computational Fluid Dynamics in Aerospace Industry in India", Volume 60, Number: 6, Defense Science Journal, 2010.
- [5] Krishnamurthy T, "Frequencies and Flutter Speed Estimation for Damaged Aircraft Wing Using Scaled Equivalent Plate Analysis", NASA Technical Reports Server, 2010.
- [6] Marcos Vanella, Timothy Fitzgerald, Sergio Preidikman, Elias Balaras and Balakumar Balachandran, "Influence of Flexibility on the Aerodynamic Performance of a Hovering Wing", Journal of Experimental Biology 1212, 2009: 95-105.
- [7] Mueller, T. J., (editor), "Aerodynamic characteristics of low aspect ratio wings at low Reynolds numbers" presented at the conference on fixed, flapping and rotary wing vehicles at very low Reynolds numbers, Notre Dame, IN, June 5-7, 2000.
- [8] Nathan Logsdon, Dr. Gary Solbrekken, "Procedure For Numerically Analyzing Airfoils And Wing Sections" Volume 2, Issue 2 doctoral diss., University of Missouri – Columbia, December 2006. [5] F. X. Wortmann, "The Quest for High Lift at Low Reynolds Number", AIAA Paper 74-1018, MIT- Cambridge, Sept. 1974.

[9] NarendiranathBabu T, Prasanth, E. Raj Kumar, R. Mageshvaran, T. Shankar and D. Rama Prabha. "Structural Analysis on Wing Box Spliced Joint for an Aircraft Using Finite Element Method", International Journal of Civil Engineering and Technology 8, 2017: 302– 313.

[10] Takashi Misaka, Frank Holzapfel and Thomas Gerz, "Large Eddy Simulation of Wake Vortex Evolution from Roll-Up to Vortex Decay" on 49th AIAA Aerospace Science meeting including the New Horizons forum and Aerospace Exposition(AIAA 2011 1003), 4-7 January 2011, Orlando, Florida.