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STRUCTURAL ANALYSIS OF STRUT-BRACED WING CONFIGURATION

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Trabalho Conclusão do Curso de Graduação em Engenharia Aeroespacial do Centro Tecnológico de Joinville da Universidade Federal de Santa Catarina como requisito para a obtenção do Título de Bacharel em Engenharia Aeroespacial.
Orientador: Dr. Marcos Alves Rabelo

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Sara Rodríguez Ferreiro

Structural analysis of strut-braced wing configuration

Este Trabalho Conclusão de Curso foi julgado adequado para obtenção do Título de Bacharel em Engenharia Aeroespacial na Universidade Federal de Santa Catarina, Centro Tecnológico de Joinville.

Joinville, 24 de Setembro de 2020.

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Todo esfuerzo tiene su recompensa

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RESUMO

Neste trabalho é realizado o estudo estrutural da conexão strut-asa de um avião com configuração SBW (Strut braced wing). O programa comercial utilizado é o ANSYS, principalmente o módulo de análise estrutural estática. A configuração SBW ainda não está presente em aeronaves de grande porte; portanto, uma aeronave menor será usada como referência: Cessna 182. O estudo foi realizado levando em consideração dois cenários possíveis durante a fase de voo de um Cessna 182. Os resultados obtidos, após a análise estrutural, foram realizados com sucesso obtendo resultados consistentes com a realidade. O objetivo principal da análise estrutural estática é a observação dos valores obtidos tensão-deformação levando em consideração as teorias clássicas de resistência dos materiais.

Palavras-chave: FEM. SBW. Análise estrutural.

ABSTRACT

In this study, the structural analysis of the strut-wing connection of an airplane with SBW configuration (Strut braced wing) is carried out. The commercial software used is ANSYS, mainly its static structural analysis module. The SBW configuration is not yet present in large aircraft, therefore, a smaller aircraft is used as a reference: Cessna 182. The study was carried out taking into account two possible scenarios during the flight phase of the Cessna 182. The results obtained were performed satisfactorily, obtaining results consistent with reality. The main objective of the static structural analysis is the study of the obtained stress-strain values, taking into account the classical theory of resistance of materials.

Keywords: FEM. SBW. Structural analysis.

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LIST OF ABBREVIATIONS AND ACRONYMS

CAD – Computer aided design
FEM – Finite Element Method.
SBW – Strut braced wing.
TBW – Truss braced wing.

LIST OF SYMBOLS

C_L – Lift Coefficient

D – Drag

D_i – Induced drag.

g – standard earth gravity

m – entire model structure mass

L – Lift

S_W – Wing area

T – Thrust

W – Weight

W_0 – Takeoff weight of Cessna 182

ρ – air density

v – cruise velocity

ε – longitudinal strains

σ – direct stresses

E – modulus of elasticity

σ – stress

σ_e – Tensile Yield Stress

F – force

S – area

τ – shear stress

M_f – Bending moment

ℓ – wing length

n – load factor

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1 INTRODUCTION

The world of design in engineering has been changing permanently since 1950's until nowadays. In the beginning, the first designs were made by hand and all the tests were done with empirical methods being impossible to do computational analysis before its construction. Thanks to the constant software development, new simulations and studies of different configurations could be done without building the whole structure or prototypes. All these improvements are necessary since the world of aviation is increasing constantly and planes are a very important way of transport for families, holidays or business.

Constantly, new simulation models have been studying to optimize the design and the performance of an aircraft. The principal aim of this final degree project is to study the structural behaviour of the connection between the fuselage and the strut-braced wing with ANSYS software, as well as its critical components. The Strut-Braced wing configuration is built with a thinner airfoil section with higher wing aspect ratio supported by a strut connected with the fuselage; this strut relieves bending moments as well. Although, there are different configurations within the strut-braced wing, in this project we will only study the one of Cessna 182. The different structural behaviour in the connection will be studied considering all flight phases.

The idea of Strut-Braced Wing (SBW) configuration was born in 1954 credit to Werner Pfenninger, who was studying how to reduce the drag effects in a wing (BARREDA, 2013). Even in 1953 there was already a plane with SBW design, the Hurel-Dubois HD.31, a civil aircraft produced in France. Besides, W. Pfenninger efforts continued until 1980's, whereas during 1980's and 1990's decades NASA researches tested a strut-braced wing for commercial airplanes in transonic flights using design software methods. Recently, the SUGAR project by NASA and Boeing is studying new technologies to apply for the future aircrafts. These configurations involve designs similar to SBW and they are called Truss-Braced Wing (TBW). The difference between SBW and TBW is a vertical truss between the wing and the strut.

Currently, the use of advanced computational software allows engineers to develop new structure aircraft configurations as well as its materials. The principal aim of all studies is to improve the efficiency of an aircraft, i.e. to decrease the fuel consumption and to reduce the fuel emissions, which is a very important task to do for the sake of our planet. All of these researches introduce new developments in structures, materials and manufacturing, being the latter, one of the most expensive and important steps. Thus, advanced computational software is extremely necessary to simulate the performance throughout the flight of an aircraft and test all its components subjected to aerodynamic forces.

Due to the ANSYS software, this project may study the structural behaviour of the connection between the fuselage and the strut-braced wing. Although this configuration is being studied by important aerospace industries such as Boeing or NASA, there are currently smaller planes such as Cessna 182, on which the model of this analysis will be based. Aerodynamic loads will be investigated. The purpose of this project is to analyze the stress and the strut-wing deflection when subjected to loads.

1.1 OBJECTIVES

1.1.1 General Objective

A structural analysis of a plane with strut-braced design attending mainly to the results in the strut.

1.1.2 Specific Objectives

This final degree project has the following specific objectives:

- Investigate the loads acting on the strut-braced design.
- Analyze the structural behaviour of the connection strut-wing under aerodynamic loads with ANSYS software.
- Estimate the stress and deflection in the strut-wing structure.
- Evaluate the data obtained by FEM software and verify strut-braced configuration effectiveness.

2 BIBLIOGRAPHIC REFERENCES

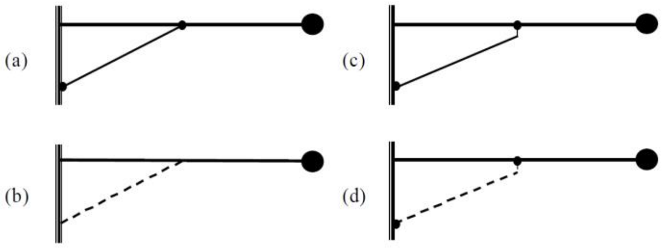
In this chapter will be presented all the details and information needed to carry out the study involved in this project such as theoretical concepts, types of external loads, structures of the aircraft and SBW configuration.

2.1 STRUT BRACED WING

SBW is a configuration is used mainly in small and medium aircraft. An important parameter to define is the induced drag, defined in Yechout (2003) as “the penalty paid for generating lift on a finite wing”. Thus, its reduction is directly related to efficiency, one of the best advantages of SBW, which involves a higher aspect ratio in the wing and a strut to prevent bending moments (CARRIER et al., 2012). It’s also associated with fuel consumption, i.e. if the aircraft reduced its D_i, a smaller amount of fuel will be needed, which implies a lower fuel consumption for the same distance as a conventional aircraft.

There are several configurations of SBW, as shown in Figure 1; the choice of one or other depends on various factors such as efficiency, dimensions or weight.

Figure 1 – Strut-braced configurations



Strut-braced wing design configurations (a) strut in tension with no offset (b) strut in compression with no offset (c) strut in tension with offset (d) strut in compression with offset.

Source: Naghshineh-Pour (1998, p. 12)

The main description of SBW was done in the introduction chapter, however it’s important to clarify the main reason of the use of the strut. With SBW, the principal change in the structure is that the wing is thinner, longer and consequently with greater aspect ratio. Thus, it’s important the presence of a kind of stringer (the strut) that will be able to support all the loads acting, mainly those that act perpendicular to the wing, and prevent wing deflection.

The configuration of Cessna 182 is item (a) according to the Figure 1; thus, this will be the one to analyze in this project. Besides, this is also the configuration that majority of airplanes present, consequently the most common and studied by researchers. It’s formed only by the strut, which connects the wing and the fuselage and it’s also placed before the half of the wing.

Three relevant factors are important to take into account when choosing which is better: the interaction between the connection of the wing, strut and fuselage; the capability of the strut to support all of the external loads and the drag generated from each configuration.

2.1.1 Advantages and Disadvantages of SBW against Cantilever Wing

Obvious that, if currently there aren’t commercial planes with SBW, is because there are some disadvantages in using this system.

One of its main effects is that, to use SBW a larger wing should be applied. This increase in wing size has some consequences: the cost of planes will be varied; and the majority of the worldwide airports aren’t designed to operate planes with these wing size.

On the other hand, there are several factors in terms of aircraft performance and effiency that deserve to be highlighted. Total drag generated will be critical to define either a classic cantilever wing or an SBW for future planes. This is the major advantage of SBW, its efficiency is higher, as commented in the last section. Most of the planes with SBW configuration are small and medium size because most airport terminals are more suitable for their operation than for a big aircraft.

2.2 THIN PLATE AND SHELL THEORY

A thin plate can be defined a sheet of material whose thickness is small compared with its other dimensions but which is capable of resisting bending in addition to membrane forces (MEGSON, 2007). In aeronautics, most aircraft structural components are fabricated from thin metal or composite sheet, with what is reasonable to apply this theory to our project.

The term shell is applied to bodies bounded by two curved surfaces, where the distance between the surfaces is small in comparison with other body dimensions […] The length of the segment, which is perpendicular to the curved surfaces, is the thickness (KRAUTHAMMER, 2001).

According to the theory, in this model we can apply the theory of thin plate for some areas of the fuselage and wings; and the shell theory for areas with curvature (strut, bottom of the fuselage). However, the software uses its own element to carry out the simulation: Shell 281, which will be detailed in 3.2. This will be the one used to run the analysis.

2.3 LOADS ON THE AIRCRAFT

It’s important to clarify the loads acting through the structures we will analyze: fuselage, wing and strut. The aerodynamic forces are lift, drag, thrust and weight; they all act on the structure during the flight. Thus, they are known as air loads that mainly depend on the flight attitude and weather conditions. Their study requires a high-level knowledge in aerodynamics, however; in this study we will only use them in terms of structure behaviour. The direction of greatest importance for the forces to be applied are those corresponding to the axis of the Lift and the aircraft's own weight due to the type of analysis.

Furthermore, to carry out this structural analysis will be crucial to consider some of these forces over the main structures; according to Megson (2007), all the loads mentioned previously are the resultants of the pressure distribution over the different surfaces. The load factor to apply will depend on the flight phase as indicated in Cessna Aircraft Company (1979) and its value can be calculated following FAR – PART 23 (2020). The resultants such as stress, shear, bending and the deformation produced in the model will be analyzed.

2.3.1 Stress

By the definition of stress, when forces are applied to the structure, they will produce stresses on it.

$$\sigma = \frac{F}{S}$$

Where,

σ =Stress

F = Force

S = Area

In addition, we must specify the plane on which the stress acts. So, we will have two types of stress: a normal component (σ) related with direct stress, and two in-plane components (τ_{ij}) related to shear stress.

All the stress values will be analyzed with the software. The most important value will be the maximum stress that the structure supports, which should not exceed the tensile strength of the material to avoid failure of the structure. This study will be done using the von Mises yield criterion, which means: Failure will occur when shear or distortion strain energy in the material reaches the equivalent value at yielding in simple tension (MEGSON, 2005).

2.3.2 Strain

The external and internal forces cause linear and angular displacements in a deformable body. These displacements are generally defined in terms of strain. Throughout this project, the hypothesis of small displacements has been considered. Longitudinal strains are associated with direct stresses and relate to changes in length (MEGSON, 2007).

$$\varepsilon = \frac{\sigma}{E}$$

Where,

ε = longitudinal strains

σ = direct stresses

E = modulus of elasticity

It is important to consider the stresses produced in the middle plane by in-plane tensile, compressive or shear loads. If these stresses are of sufficient magnitude, will affect the bending of the plate.

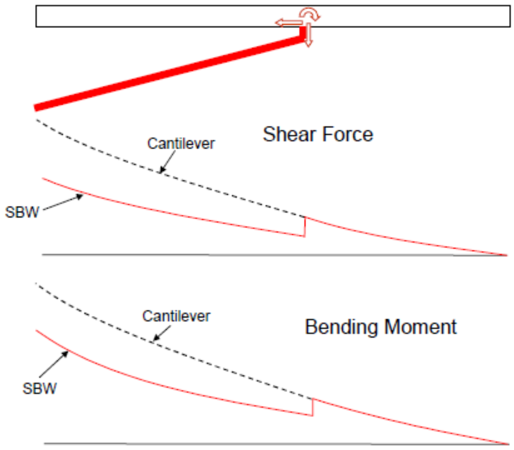
2.3.3 Bending

Generally bending moments are present in all surfaces of the airplane; however, it would be desirable for this project to analyze it in the strut. This connection, the strut, will be suffer all the stress produced by flight maneuvers, taking-off and landing. The procedure to calculate bending moments in the strut as well as in the wing will be done modelling these structures as shells.

According to Megson (2007), the direct stresses vary linearly across the thickness of the plate, and their magnitudes depending on the curvatures (i.e. bending moments) of the shell elements. Mostly, pure bending moments arise through the application of other types of load (i.e. shear forces).

Although the bending analysis of the wing won’t be done, it’s important to consider it to analyze the connection with the strut; which is in the scope of this project. Because of the fact that if the wing behaves wrongly or it senses all the external forces acting on its surface, consequently these bending moments or others will influence in the strut as we can appreciate in Figure 2.

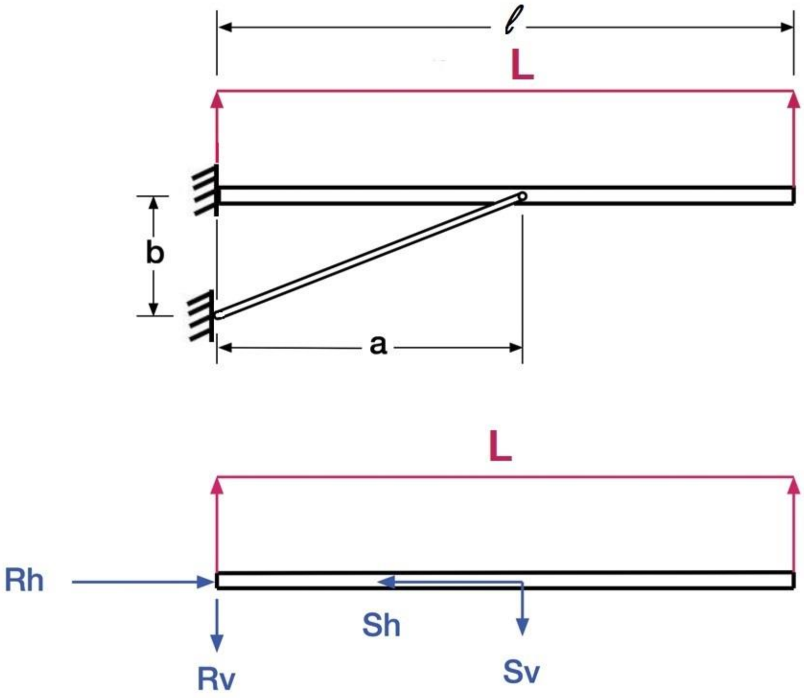
Figure 2 – Relation between shear and bending in the wing



Source: Gundlach (1999, p. 3)

Bending moment with strut-braced configuration in an aircraft can be calculated using the classical theory of Strength of Materials, as shown in Figure 3:

Figure 3 – Strut reactions



Source: Adapted of Paule (2015)

Applying the following equation, the bending moment is:

$$M_f = \frac{1}{2} L(\ell - a)^2$$

2.3.4 Shear

Shear loads act perpendicularly to the axis of a structural member (MEGSON, 2007). Thus, shear stresses would produce changes in angle, known as shear strains (γ). Due to this thin-walled (shell) structure, the shear stress can produce shear distortions of sufficient magnitude to redistribute the direct stresses due to bending, and this phenomenon is known as shear lag (MEGSON, 2005).

The product *stress*×*thickness* gives the shear force per unit length in the walls of the section; known as the shear flow, it is a particularly useful parameter in this project. According to Bendaña (2018), the shear flow represents how the distribution of stresses is in a section when it is subjected to a shear stress.

This load is extremely important to the structure analyzed in this project because it tries to cut or slice the wing, which produces an important damage in the structure. To sum up; the applied load, shear force and bending moment are related. Thus, for example, uniformly distributed loads produce linearly varying shear forces and maximum values of bending moment coincide with zero shear force (MEGSON, 2005).

3 FEM

Currently, in major engineering problems isn’t possible to obtain analytical mathematical solutions. They are solved thanks to powerful computational calculation tools as the finite element method. Its modern development began in the 1940s in the field of structural engineering by Hrennikoff, and important method advances were found in early 50s. The finite element method is a numerical method for solving problems of engineering and mathematical physics (LOGAN, 2007). With some basic concepts which will be introduced, this method is the basis of all the calculation done with ANSYS software. The steps that are carried out in the method can be reduced in:

I. Discretize the real structure in a theoretical model, using mesh elements consistent with the structure to be analyzed.
II. Calculate the stiffness matrix of each mesh element is essential for the method to be accomplished. Stiffness matrix is defined by Logan (2007), as a matrix that relates the nodal displacements and forces of a single element.
III. Assemble the global stiffness matrix considering the contributions of each element. The size of the matrix will be defined by the number of degrees of freedom of the structure, this step shows the greatest complexity of the method.
IV. Once the structure stiffness matrix is established, the boundary conditions will be applied. In the scope of this project, the boundary conditions are all those forces to which the aircraft is subjected, as well as its constraints.
V. The complete solution of the problem will be found when the displacements in each joint and the forces or reactions are calculated.

Once we know the forces and reactions, we are able to calculate tensions as well as to evaluate all the effects or loads described in section 2.2 that the structure, or specifically, the strut, will suffer.

ANSYS has several finite element analysis (FEM) solvers available. In this project the structure will be analyzed using a static structural analysis. Thus, we will be able to simulate loading conditions on the model and determine its response to them.

3.1 GEOMETRY

In order to execute a FEM analysis in the software we need a geometry. In accordance with this project, the following geometry of a Cessna 182, shown in Figure 4, has been the basis of the model used.

Figure 4 − CAD model Cessna 182

Source: Adapted of Shermon (2015)

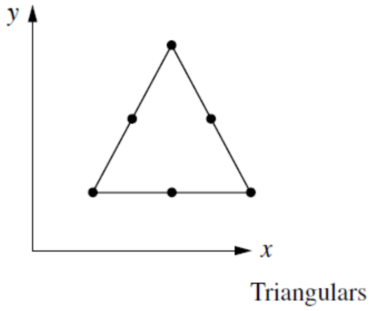
The model has numerous details and the geometry is very complex, therefore to carry out this study the geometry will be simplified as will be specified in section 4.1.

3.2 MESH

The mesh is the most important element to carry out the analysis. It is the representation of the geometric model on which the software will calculate, that is, the FEM uses the mesh to calculate all the parameters. There are numerous parameters that are taken into account to make a mesh such as the shape of the initial geometry, whether it is very curved or not; the type of mesh element and its order etc.

The quadratic triangular element is used in this project, which in the FEM theory it corresponds to the Figure 5:

Figure 5 – Quadratic Triangular element



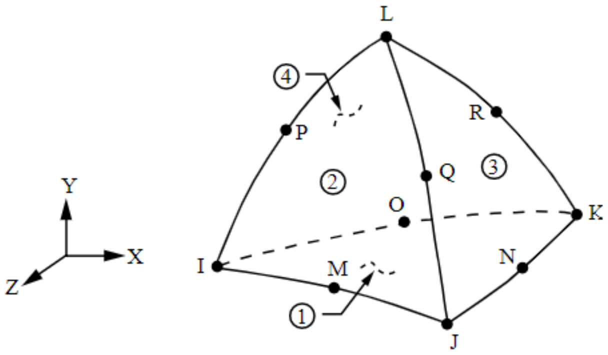
Source: Logan (2007, p. 10)

However, Ansys in its internal code has numerous elements to create a mesh. These elements are chosen based on the CAD model or the best representation to the mesh. In this case the element is Shell 281, which has six nodes and six degrees of freedom per node (translations in the x, y, and z axes; and rotations about the x, y, and z axes). According to ANSYS FLUENT 12.0 User's Guide (2009), the element Shell 281 incorporates initial curvature effects in its formulation. Thus, in the calculation for effective curvature change, accounts for both shell-membrane and thickness strains. The formulation generally offers excellent accuracy in curved-shell-structure simulations.

In addition, the wings have been modeled as solid. This decision has been carried out for two main reasons: The first, applying the knowledge acquired from the classical theory of resistance of materials, to model the wings as beams. Second, by carrying out previous analyzes, modeling the model as a shell, results were inconsistent with reality due to unrealistic deformations were obtained.

Consequently, for better results in the software, the wings have been modeled as solids using the SOLID 187 element from Ansys, shown in Figure 6:

Figure 6 – Solid 187 Element



Source: Ansys User’s Guide (2009)

4 STRUCTURAL ANALYSIS ON ANSYS

In this section all the steps and simplifications made to fulfil the structural study will be detailed.

The type of analysis to be performed is Static Structural. This type of analysis has been chosen, mainly in order to represent the airplane as truly as possible in a certain phase of real flight.

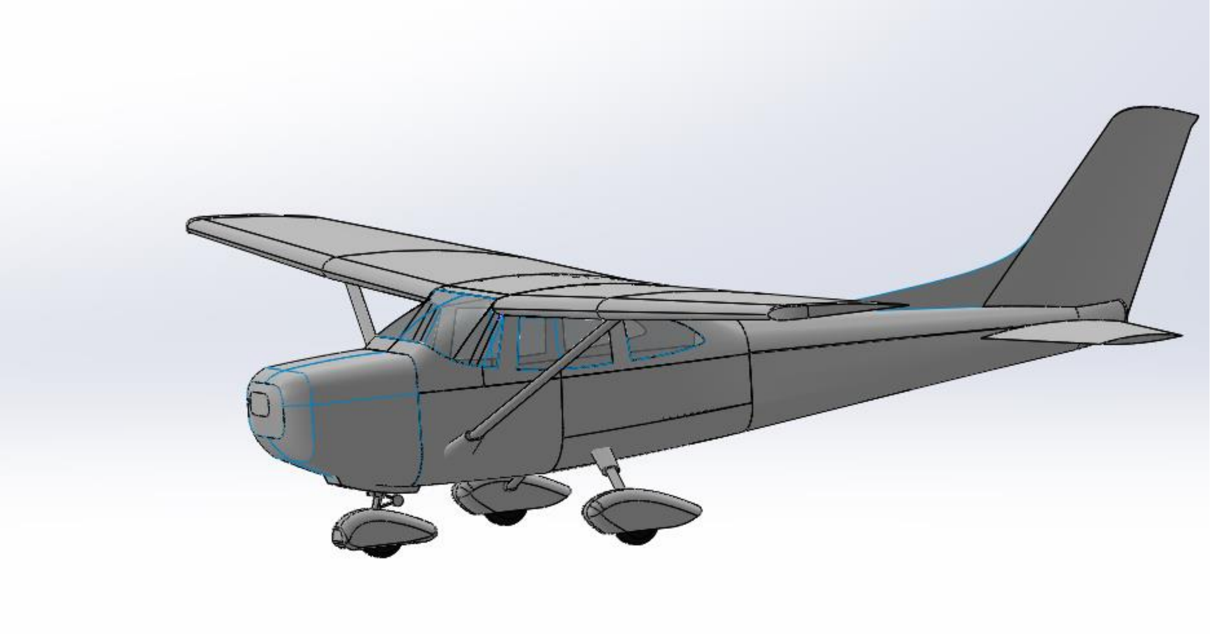
4.1 CAD MODEL

As we can see in Figure 4, the CAD model has numerous elements and with a high-quality appearance equal to the airplane in reality. However, it is evident that to conduct the structural analysis the model has to be simplified. This is mainly due to the following reasons:

- Time and computational cost, more detail the model has, more computational capacity will be needed.
- The previous item is connected to the number of elements of the mesh, that is, more elements and knots the mesh has, more computational cost is required.
- Specifically, in the software the mesh is where the analysis will be performed. Thus, the mesh must be as similar as possible to the CAD model. If the CAD model has many details, the mesh will have to represent all those details with more elements.

Consequently, numerous elements of the real model were removed to be able to perform the analysis: landing gear, ailerons, flaps, glasses and propeller mainly. Besides, modeling the structure as shell element adopting a construction similar to monocoque, (except for the wings modeled as solids). The first studies were carried out with the model shown in Figure 7.

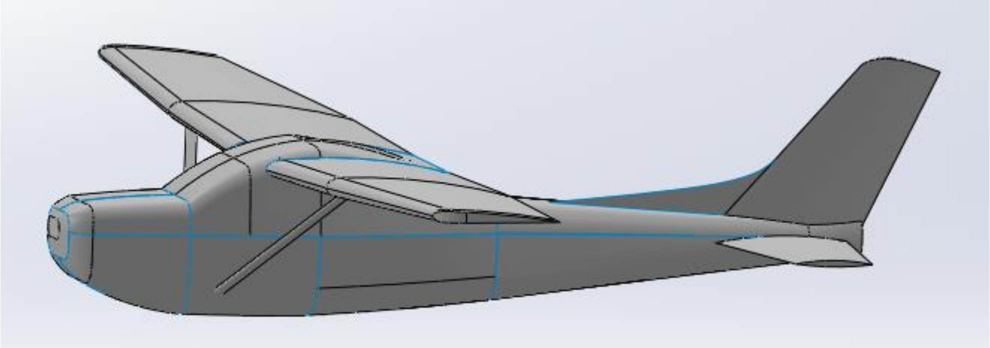
Figure 7 – First CAD model



Source: The author (2020)

However, it can be seen that elements with abrupt curvatures still remained, which supposed error in the generation of mesh and subsequent results. The final model used for the analysis is the one shown in Figure 8.

Figure 8 – Final CAD model simplified



Source: The author (2020)

In the model previous shown in Figure 8, it is important to observe the part that connects the wing to the fuselage. This piece is an idealization of the CAD model, in reality usually this piece is part of the fuselage and the wing is connected to it by the wing's own spars. This piece will be really important in the results of the FEM analysis.

Once we have the simplified model, it is important to clarify that almost all geometry is modeled by shell elements and not as solid. This decision has been made due to different advantages that the shell models have:

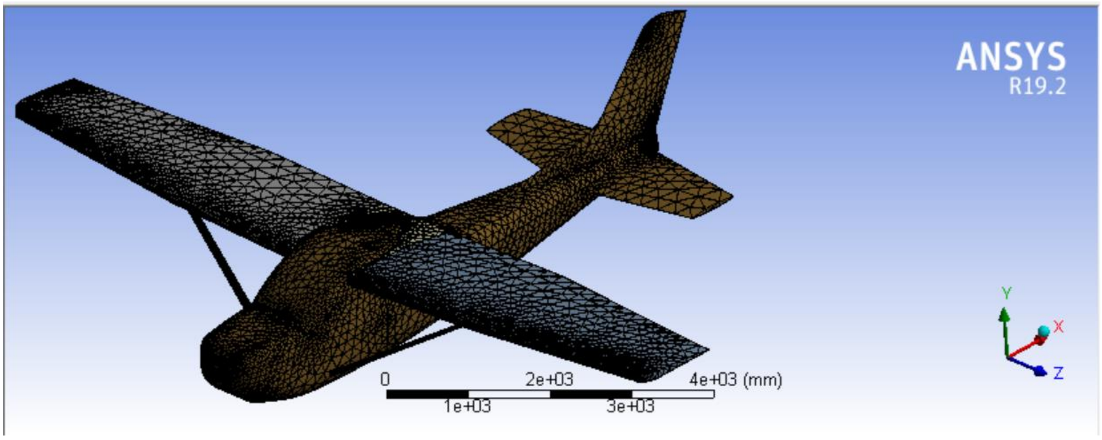
- Computational time reduction
- In general, in the aeronautical industry the structure skin is modeled by shell elements

Consequently, the thickness of each part of the structure is an important parameter to know and even to set in Ansys. After checking the manufacturer's information Cessna Aircraft Company (1997); many components of the structure have been found to share the same thickness. Due to the simplification done of the CAD model to perform the study; it has been decided to apply the same thickness, and in agreement the same material, for the entire structure. The thickness value is equal to 0.508 mm (0.02 in) as Wolter (2014) recommends.

4.2 MESH

The mesh has been generated in Ansys with second order triangular elements, as shown in Figure 9:

Figure 9 – Mesh

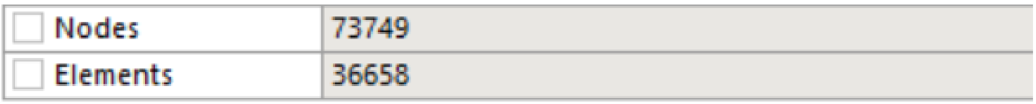


Source: The author (2020)

The option of having chosen a mesh with triangular elements is mainly due to the complexity of the geometry, besides; whenever we can use second-order triangular elements, linear ones should be avoided.

In the following parts: wing, fuselage connection and strut; a mesh refinement has been applied with Ansys 'Sizing' option. The mesh has the following characteristics specified in the Figure 10:

Figure 10 – Mesh characteristics

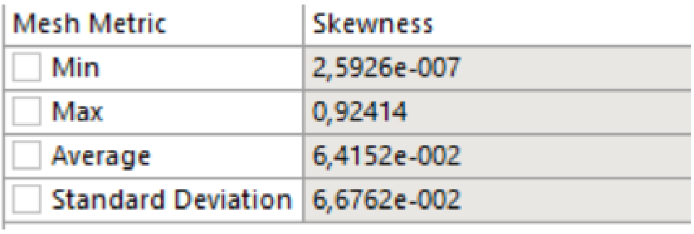


☐ Nodes	73749
☐ Elements	36658

Source: The author (2020)

The quality of the mesh plays a significant role in the accuracy and stability of the numerical computation, the skewness parameter has been used as shown in Figure 11. Skewness is defined as the difference between the shape of the cell and the shape of an equilateral cell of equivalent volume. A general rule is that the maximum skewness for a triangular/tetrahedral mesh should be kept below 0.95, with an average value that is less than 0.33. (Ansys Fluent 12.0 User's Guide, 2009).

Figure 11 – Mesh skewness



Mesh Metric	Skewness
☐ Min	2,5926e-007
☐ Max	0,92414
☐ Average	6,4152e-002
☐ Standard Deviation	6,6762e-002

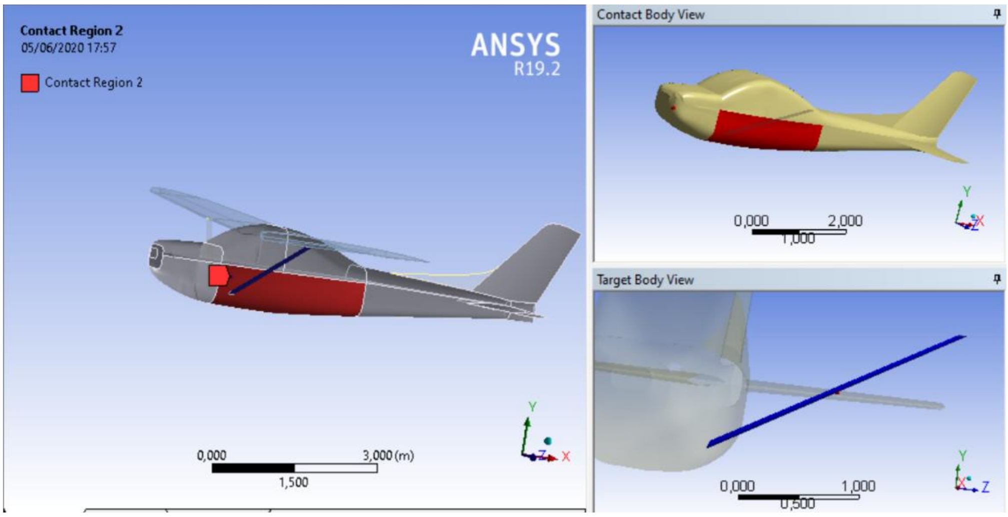
Source: The author (2020)

4.3 CONNECTIONS

In our CAD working model, one of the most important parts is the connection of the wing with the fuselage and the strut with both.

Therefore, it is necessary to create contacts between these components. The type established for the contacts are 'Bonded'; that is, they keep the components together and do not allow sliding between them. An example is shown in Figure 12.

Figure 12 – Contacts



Source: The author (2020)

4.4 MATERIAL

In the aeronautical industry, aluminium alloys are of great relevance for all types of aircraft. They have great advantages, mainly their resistance and lightness, two of the most important parameters for materials in aviation.

The Cessna 182 model has different versions, they are mainly made up of 2024 and 7075 aluminium alloys. The difference between them are minimal and they are shown in Table 1:

Table 1– Materials Properties

Material Type	**Properties**		
	Density [g/cm³]	**E [GPa]**	**R_m [MPa]**
7075	2,81	71	517
2024	2,79	73	458
6061	2,70	69	336
Epoxy resin	1,13	5	70
R glass fiber	2,50	84	4400

Source: Adapted from Sliwa (2015)

Due to the simplification of the CAD model to be studied as mentioned in section 4.1, the same material has been applied to the entire piece. The material finally chosen is the 2024, the main reason is that consulting Cessna Aircraft Company (1997) and suppliers of Cessna it has been verified that aluminium 2024 is the one used mainly in most variants of the Cessna 182. This type of aluminium has little resistance to corrosion, so that it’s very common to coat the surface with a thin layer of another aluminium alloy. Thus, making the surface more resistant to corrosion.

4.5 SAFETY FACTOR

The safety factor is a parameter of extreme importance for the calculation and design of the aircraft structure. The FAR – PART 25 Subpart 25.303 states that:

> Unless otherwise specified, a factor of safety of 1.5 must be applied to the prescribed limit load which are considered external loads on the structure. When a loading condition is prescribed in terms of ultimate loads, a factor of safety need not be applied unless otherwise specified. (FAR - PART 25, subpart 25.303, 2014).

4.6 BOUNDARY CONDITIONS

Determining the boundary conditions is one of the most important items for carrying out the simulation.

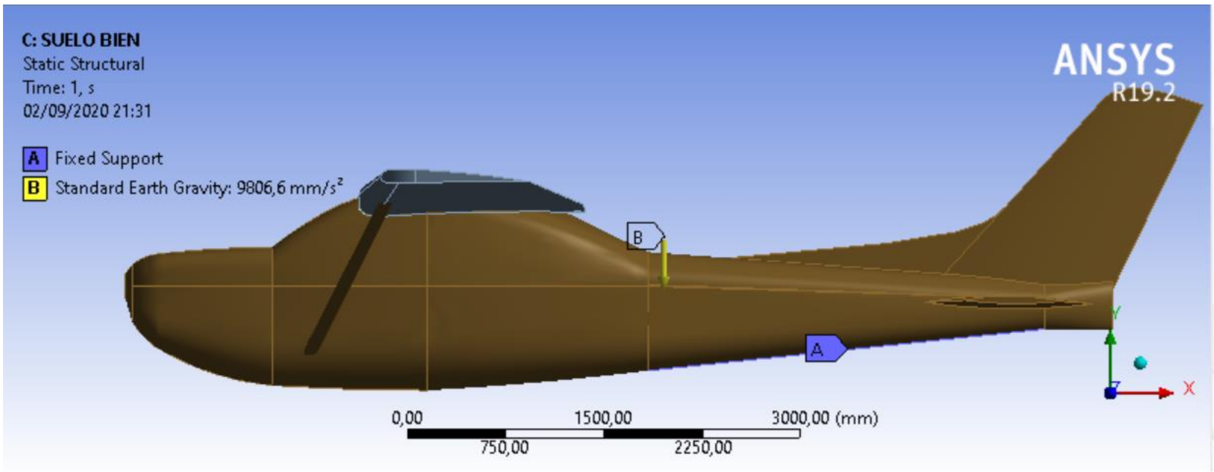
During the flight of an aircraft, flight phases with different and variable boundary conditions can be differentiated. For example, the loads applied to the aircraft are very different during take-off than during cruise flight; and consequently, the response of the aircraft structure will also be different. Therefore, in order to perform the static structural analysis in Ansys, two different scenarios have been established:

- The plane still on the ground
- The plane in cruise flight, stopped at an instant *t* of time

4.6.1 Plane still on the ground

This situation represents the plane motionless on the ground, so the boundary conditions will be quite simple, as shown in Figure 13:

Figure 13 – Plane motionless



Source: The author (2020)

Due to the fact that the plane is static, no aerodynamic force is acting on it. Hence, the boundary conditions are:

- Weight of the complete airplane structure.
- Fixed Support established on the bottom surface of the structure.

This fixation is necessary so that the software can solve the system with the stiffness matrix of the structure as explained in section 3. Since if no support or fixation is applied; the system to be solved with the stiffness matrix of the structure will be indeterminate, consequently the software will alert of an error and will not provide any solution.

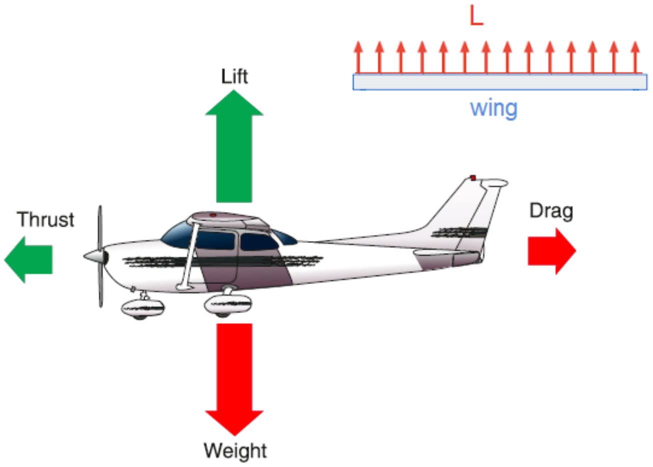
This fixation could have been applied in the landing gear, however due to the simplification of the CAD model explained in section 4.1; This part has been removed to simplify the model and to perform a simulation with lower computational cost.

4.6.2 Plane in cruise flight

In this situation the airplane is represented in cruise flight. In order to carry out the simulation, the plane is represented in an instant of time *t*.

The boundary conditions are established by balancing forces, represented in Figure 14.

Figure 14 – Balancing forces in cruise flight



Source: Bendaña (2018)

As we can see, at this moment, when the plane is stopped, L = W and T = D:

- Lift: aerodynamic force applied evenly distributed to the wings, as shown in Fugure 14, calculated using the following formula (Yechout, 2003):

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

Where:

L = Lift

C_L = Lift Coefficient

ρ = air density

v = cruise velocity

S_w = wing area

The calculation of the value of the lift force has been taken into account with the following load factor:

$$n = {}^{L}/_{W_0} = 6,6$$

Where:

W_0 = Takeoff weight of Cessna 182 (CESSNA AIRCRAFT COMPANY, 1979)

We observe that the requirements specified in section 2.3 are fulfilled.

- Weight: total weight of the entire model structure.

$$W = mg$$

Where:

m = entire model structure mass

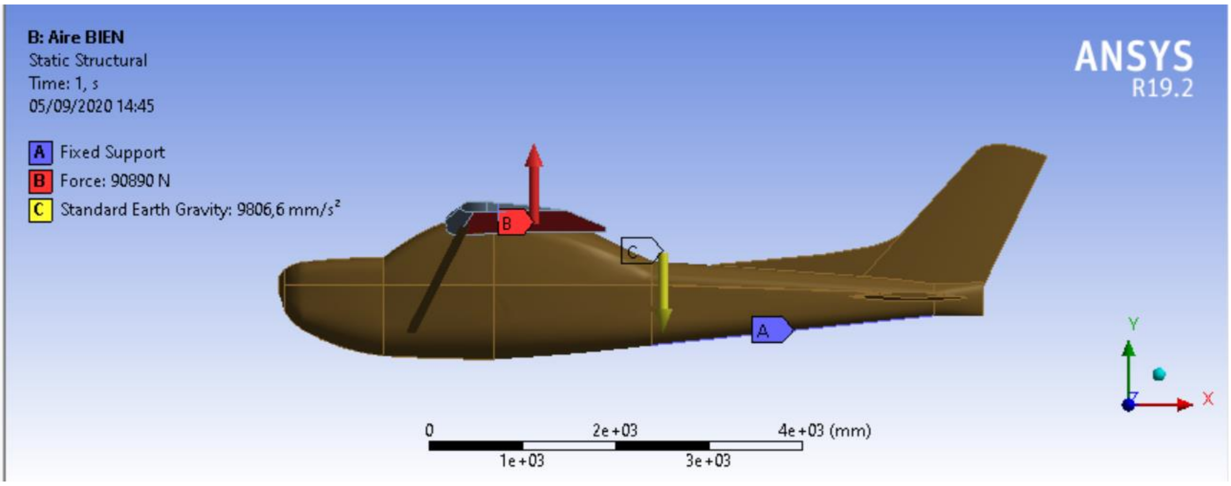
g = standard earth gravity

In the software there is a direct option to apply this force without the need to do the calculation, as shown in Figure 15.

- Thrust and Drag: these forces have been neglected compared to the value of Lift force, at an instant t of time (static structural analysis) during cruise flight.

- Fixed support: necessary as in the previous case 4.5.1, to perform the simulation.

Figure 15 – Cruise flight boundary conditions



B: Aire BIEN
Static Structural
Time: 1, s
05/09/2020 14:45

A Fixed Support
B Force: 90890 N
C Standard Earth Gravity: 9806,6 mm/s²

Source: The author (2020)

5 RESULTS

Once the structural analysis has been fulfilled, in this section we present the results obtained. The main parameters to study were:

- Displacements in the study area wing-strut-fuselage
- Strains in the study area wing-strut-fuselage
- Stress values according to the von Mises yield criterion
- Shear stress in the study are

Due to the shell configuration of almost all the model, it has not been possible to carry out a bending analysis in Ansys. Correspondingly, it can be calculated by analytical methods considering the maximum stresses obtained in the model.

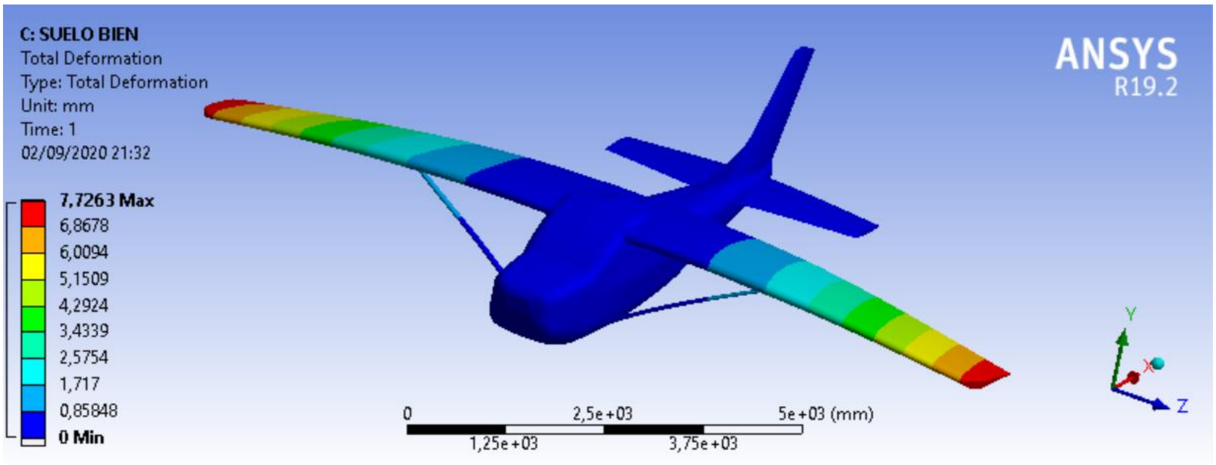
5.1 PLANE ON THE GROUND

The results of the first analysis performed following the boundary conditions specified in section 4.6.1 are presented.

5.1.1 Displacements

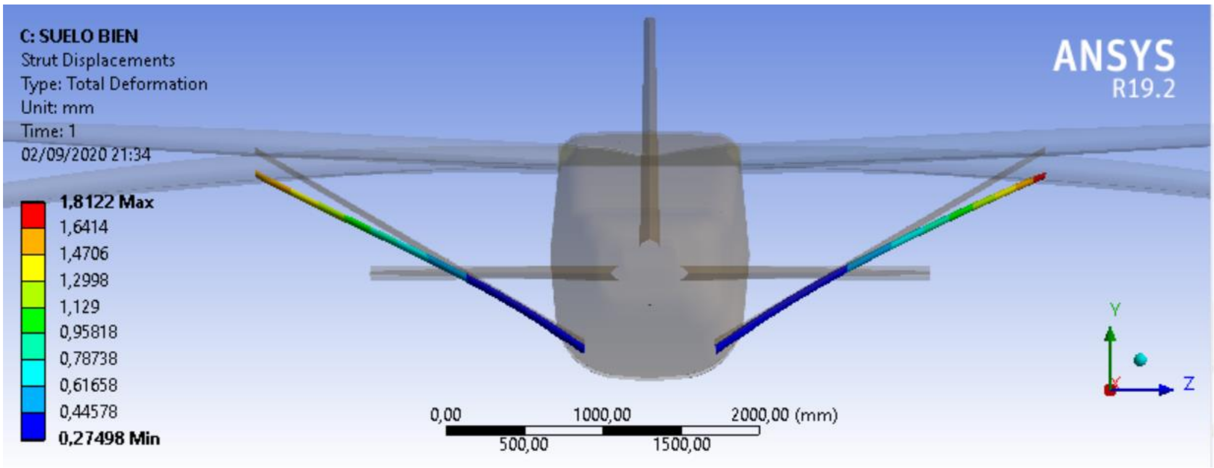
First, results of the displacements obtained are shown in Figure 16 and Figure 17. It is important to take into consideration that displacements in Ansys are showed as *Total Deformation*.

Figure 16 – Displacements plane on the ground



Source: The author (2020)

Figure 17 – Strut displacements plane on the ground



Source: The author (2020)

We can appreciate that the wings flex consequently, the strut is acting under compression. This is logical, since in this case we only have the model's own weight acting in (−) Y direction.

It is observed in Figure 16 that the maximum values are at the wingtip reaching a value of approximately 8 mm. Which is a very small value compared to wingspan of the Cessna 182 (cad model), equal to 11m.

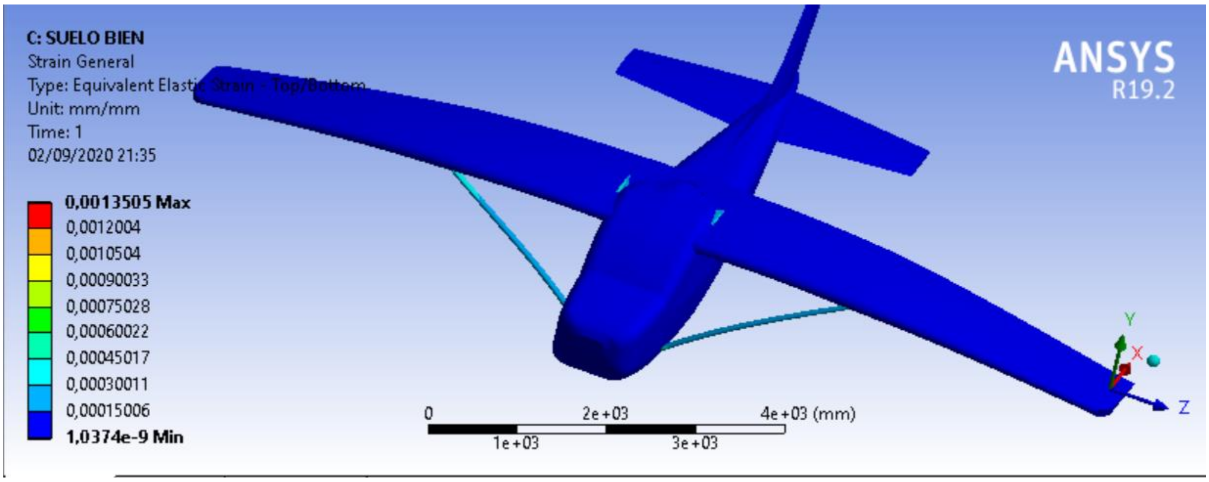
Besides, in the strut area of study, the maximum value occurs in the connection with the wing, however it is a very small value of just 2 mm.

In this first study, we can highlight then, that the displacements obtained in the strut are not as relevant as they are in the tip of the wing, where they reach the maximum values. Consequently, the strut-wing-fuselage connections do not undergo significant displacements.

5.1.2. Strain

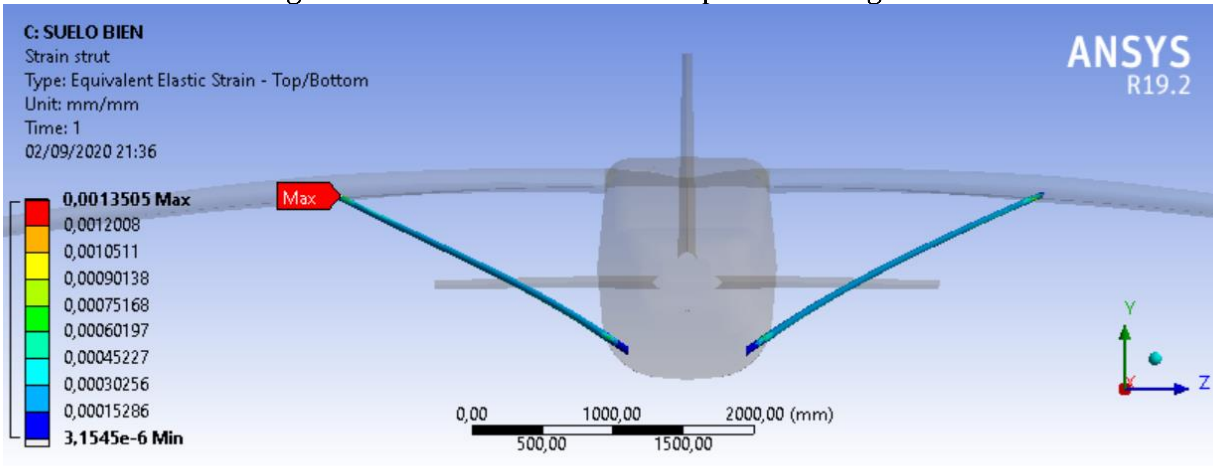
The strain values obtained in the model are shown below in Figure 18 and Figure 19:

Figure 18 – Strain plane on the ground



Source: The author (2020)

Figure 19 – Strut maximum strain plane on the ground



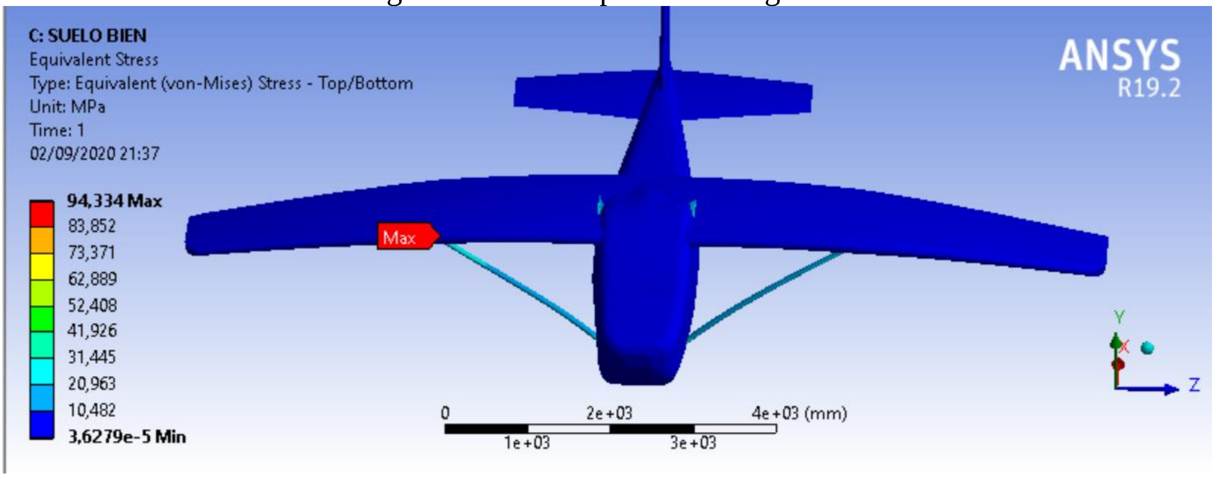
Source: The author (2020)

We can observe that the most affected areas are the wing-fuselage and wing-strut connections. This is logical since it is where the structure is most requested under the external load. If we watch the values, they are not very large so the structure does not suffer significant damage.

5.1.3 Stress

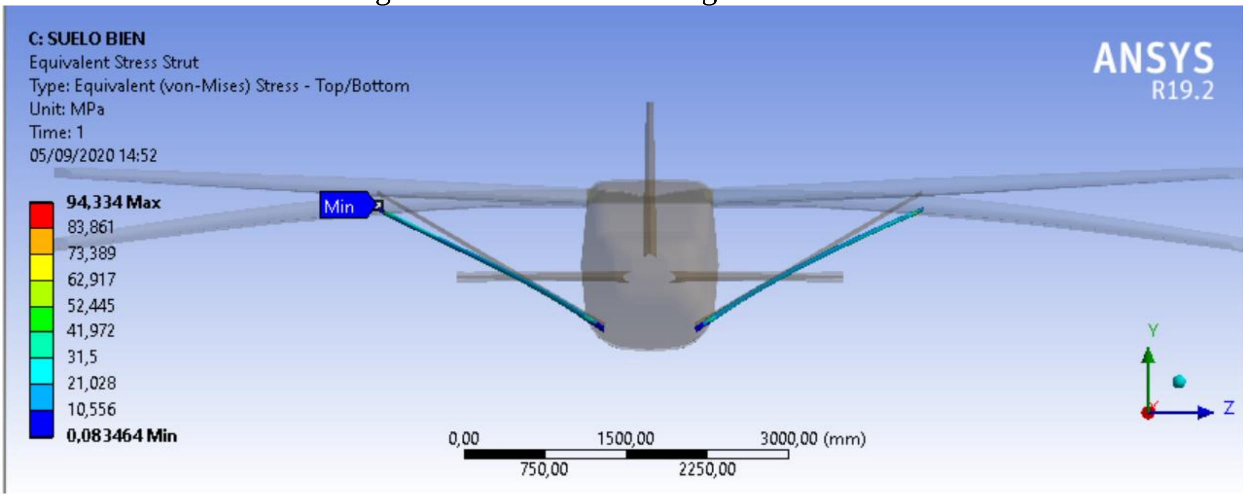
The stress values following the von Mises yield criterion are shown below in Figure Figure 20 and Figure 21:

Figure 20 – Stress plane on the ground



Source: The author (2020)

Figure 21 – Strut stress wing connection



Source: The author (2020)

We can observe that the maximum stress value is reached at the strut-wing connection. Besides, in the wing-fuselage area are values not very high.

The highest value in this analysis is 95 MPa, with the elastic limit of the material being σ_e = 280 MPa. It can be seen that this value occurs within the elastic limits of the material.

5.1.4 Shear

The shear stress values are smaller than the ones obtained by the von Mises yield criterion. The shear stress values are shown down below in Figure 22 and Figure 23.

Figure 22 – Shear stress plane on the ground

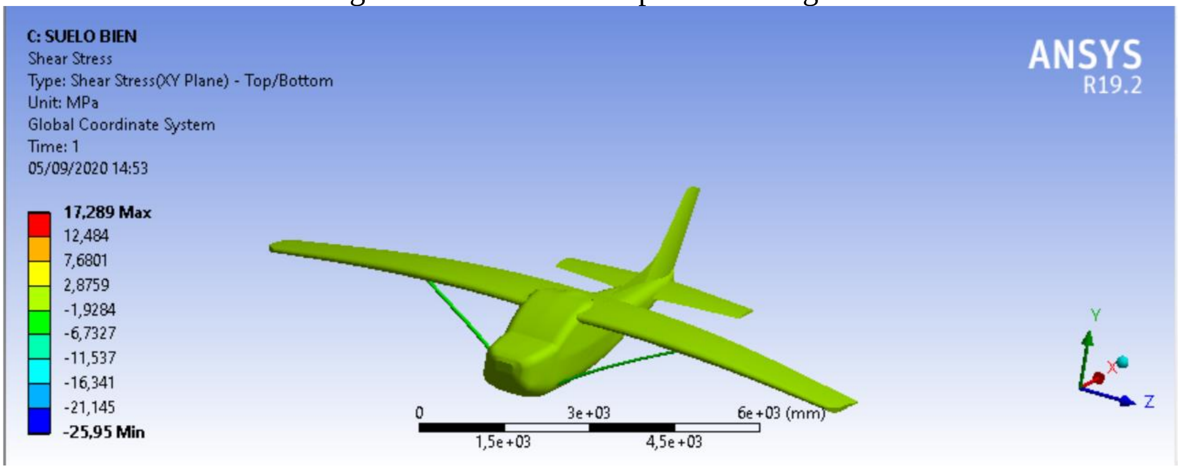
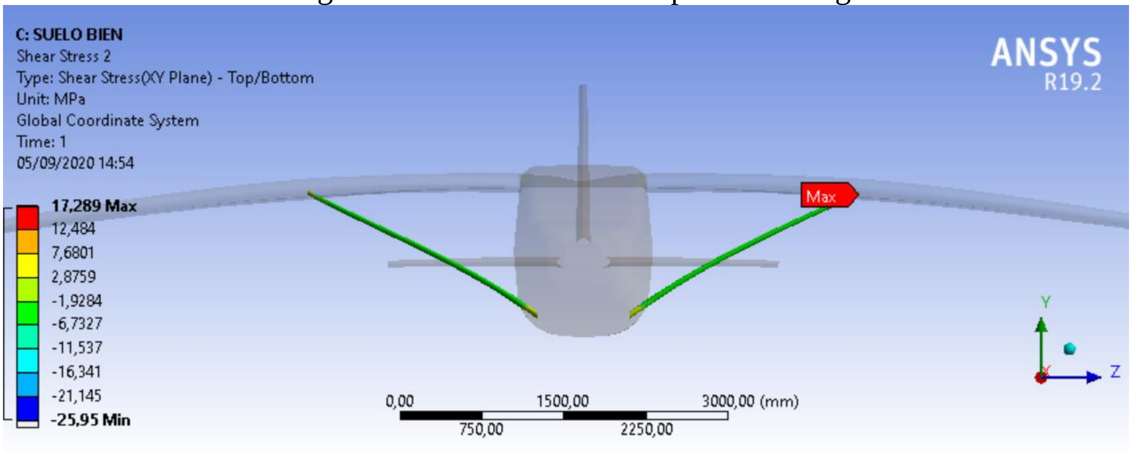


Figure 23 – Strut shear stress plane on the ground



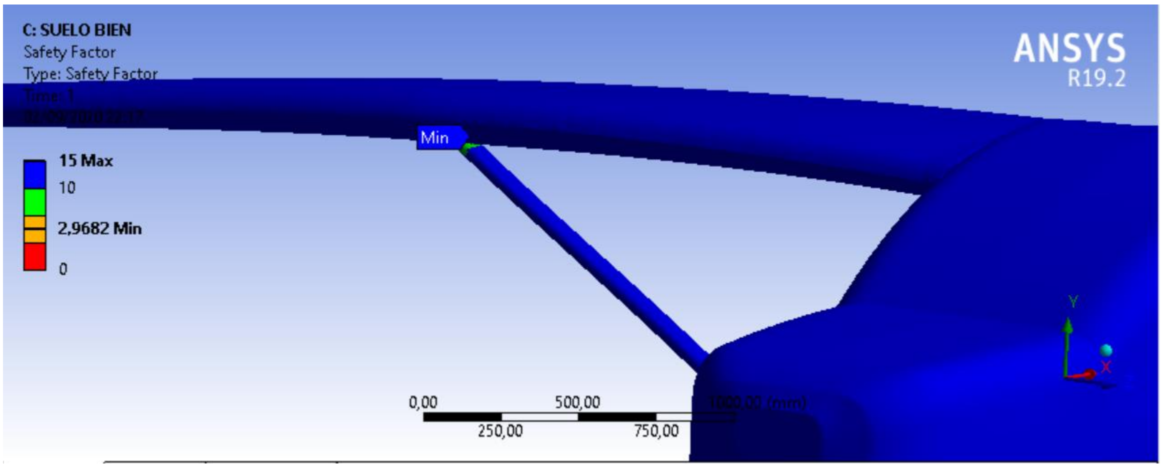
Source: The author (2020)

The maximum value once again occurs in the part that connects the strut with the wings. This value shows the effect of shear stress throughout the wing.

5.1.5 Safety Factor and Safety Margin

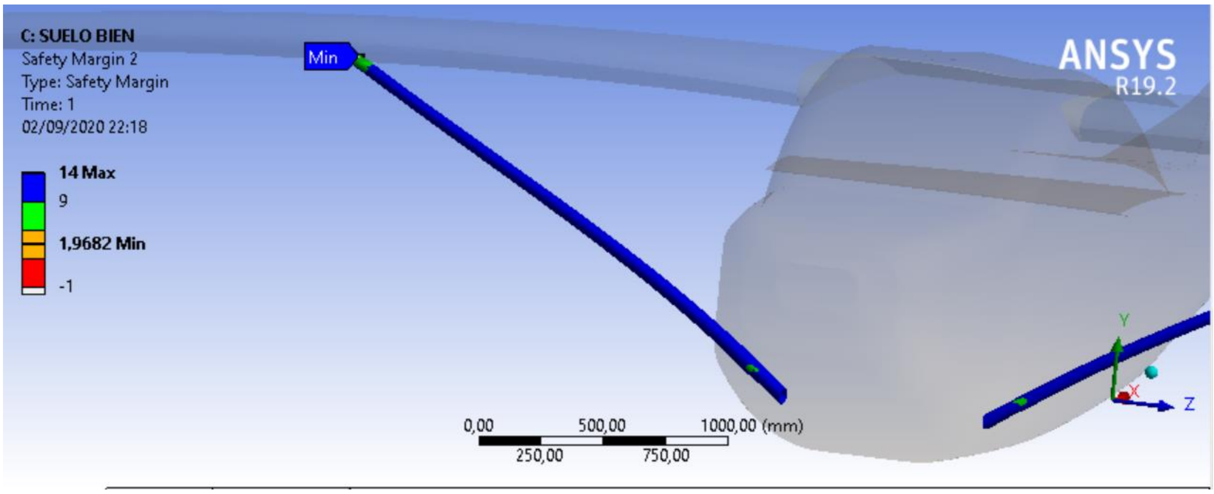
In order to compare the values of the maximum stress obtained and analyze the structural behavior in terms of critical values, an analysis of the safety factor and safety margin has been made as shown in Figure 24 and Figure 25:

Figure 24 – Safety Factor Ground Analysis



Source: The author (2020)

Figure 25 – Safety Margin plane on the ground



Source: The author (2020)

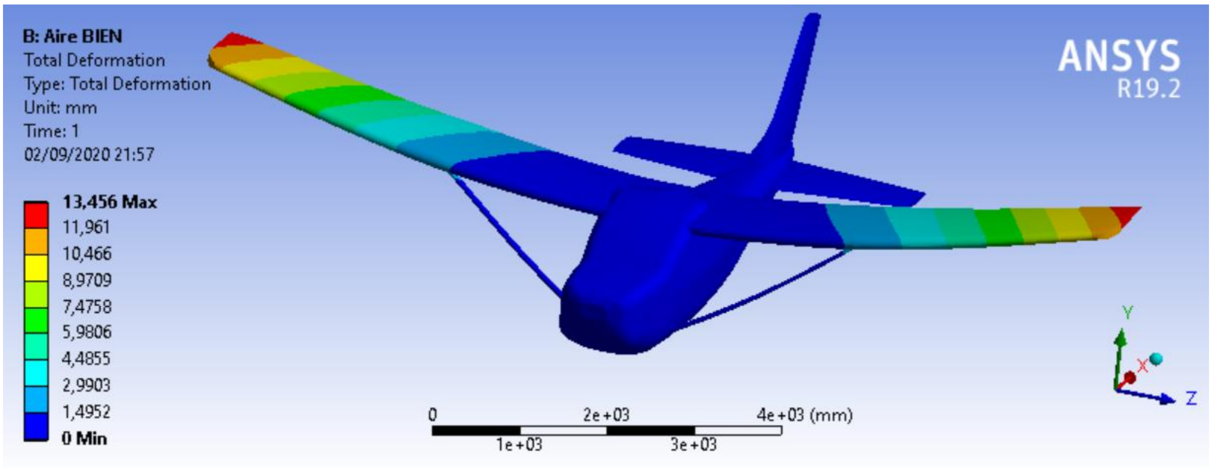
5.2 PLANE STILL ON THE AIR

The results of the second analysis performed following the boundary conditions specified in section 4.6.2 are presented.

5.2.1 Displacements

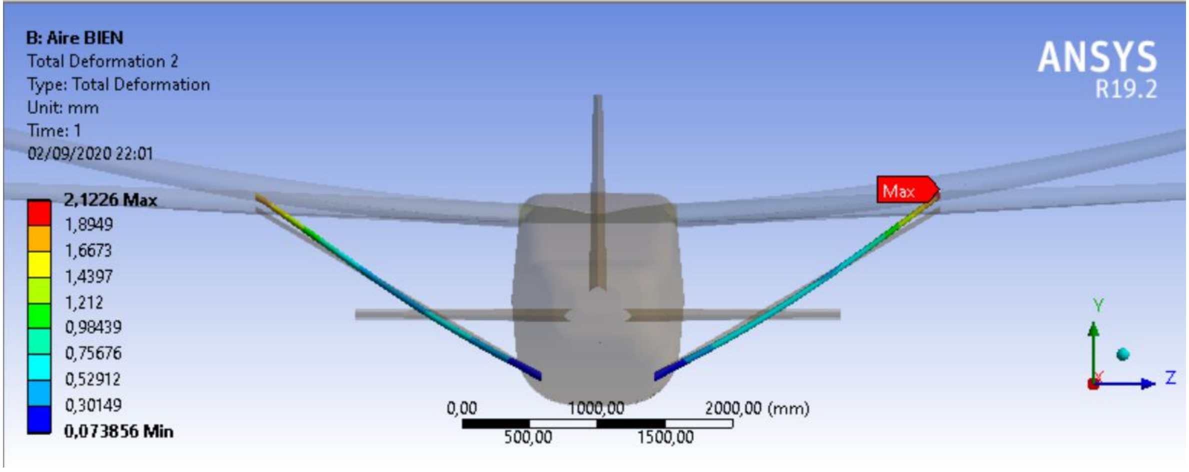
In the Figure 26 and Figure 27 the results obtained for the displacement in Ansys are shown, specifically in the Figure 27 the deformed and undeformed model can be observed.

Figure 26 – Displacements plane on the air



Source: The author (2020)

Figure 27 – Strut displacements plane on the air



Source: The author (2020)

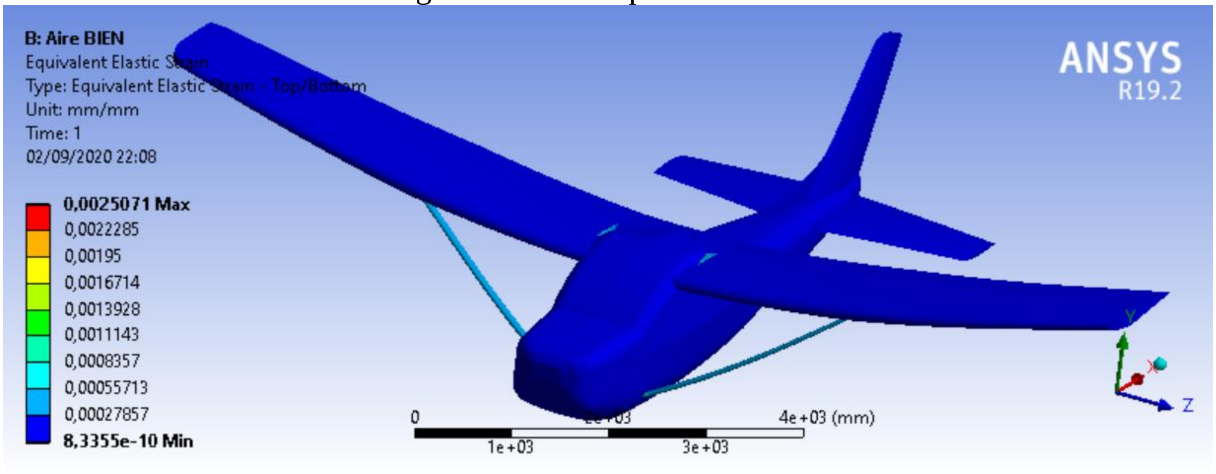
The maximum value obtained is approximately 14mm, which is reached as in the previous case in the tip of the wing. In the previous figures it can be seen that the wing deforms upwards, this is due to the lift force applied to the wings. This value is higher than the one obtained in the previous case of section 5.1, since now there are 2 applied forces: W and L.

We can also appreciate the effect that the lift has of 'pulling up' the wings of the aircraft. Once again, the values reached are small compared to the model dimensions.

5.2.2. Strain

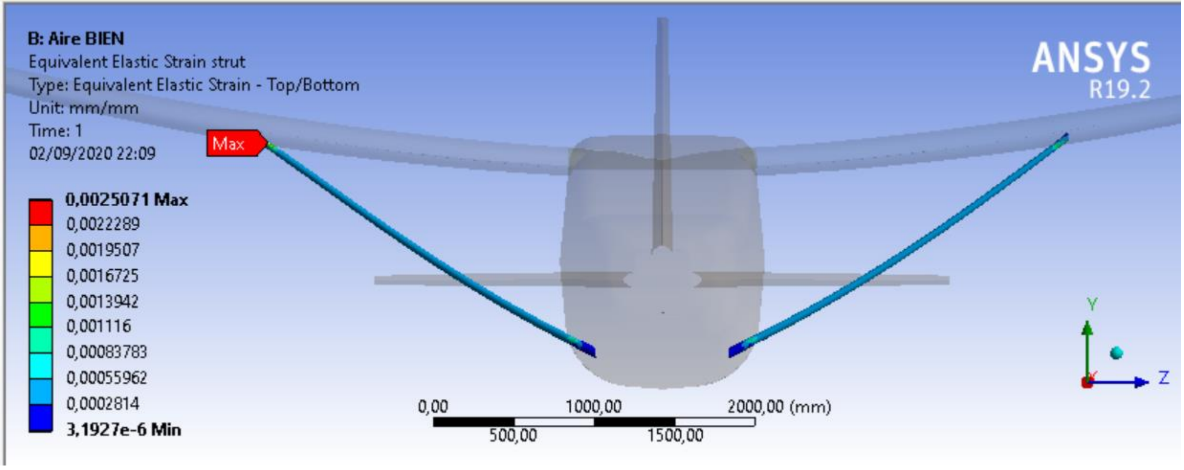
The strain values obtained in the model are shown next below in Figure 28 and Figure 29:

Figure 28 – Strain plane on the air



Source: The author (2020)

Figure 29 – Strut strain plane on the air



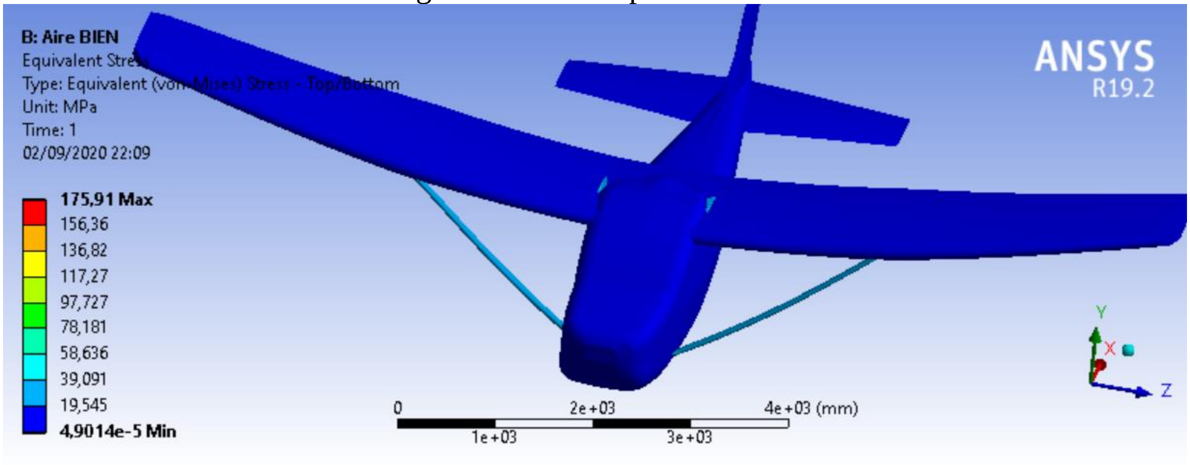
Source: The author (2020)

The maximum value is obtained in the strut-wing connection area of interest. The deformations (strain) obtained reach very small values, so the structure does not suffer significant damage.

5.2.3 Stress

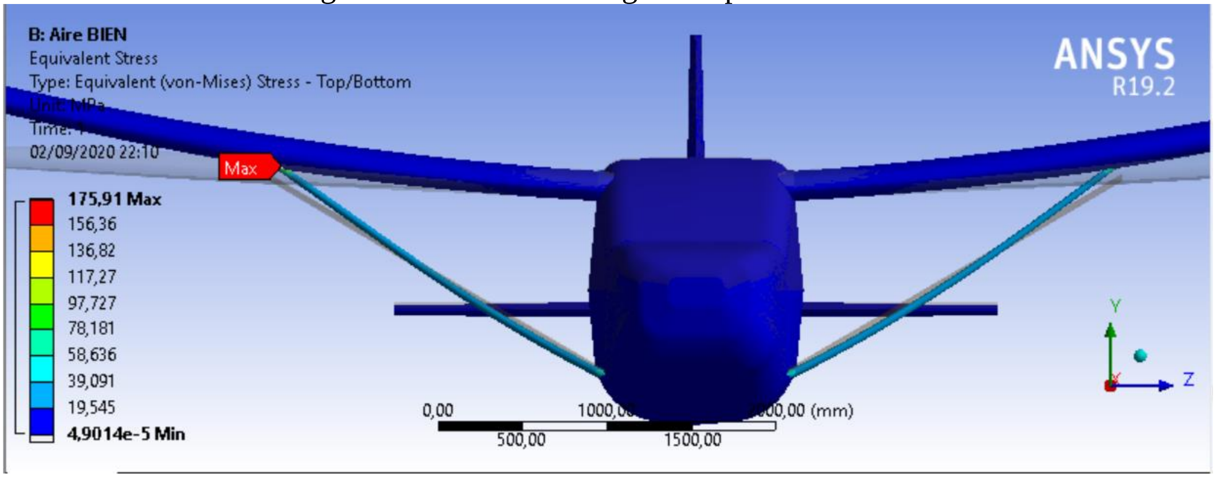
The stress values following the von Mises yield criterion are shown in Figure 30 and Figure 31:

Figure 30 – Stress plane on the air



Source: The author (2020)

Figure 31 – Strut and wing stress plane on the air



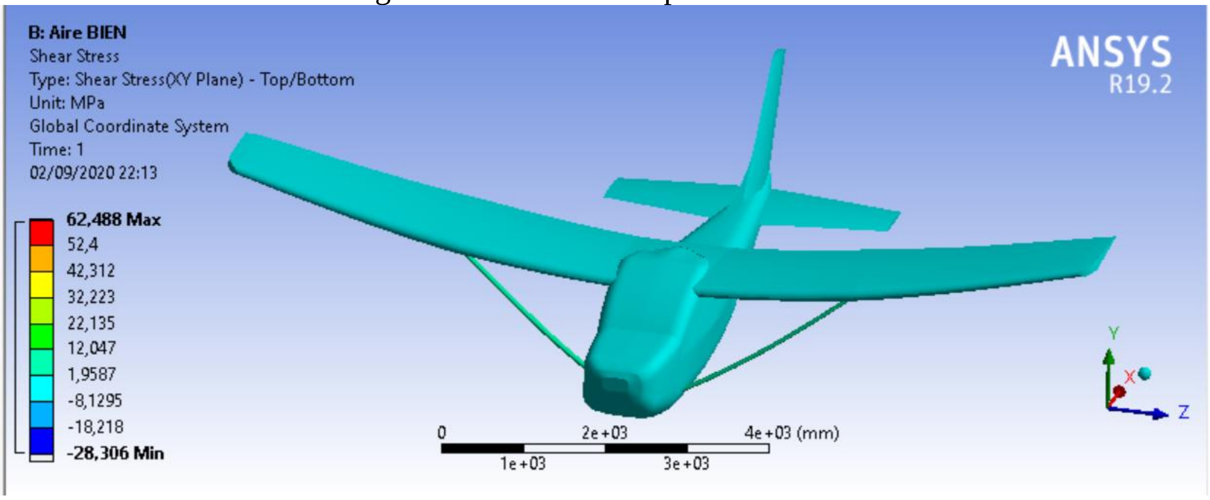
Source: The author (2020)

The maximum value occurs in the part that connects the strut with the wings. It is 176 MPa, which, despite being a high value; must be taken into account the elastic limit of the material is σ_e = 280 MPa.

5.2.4 Shear

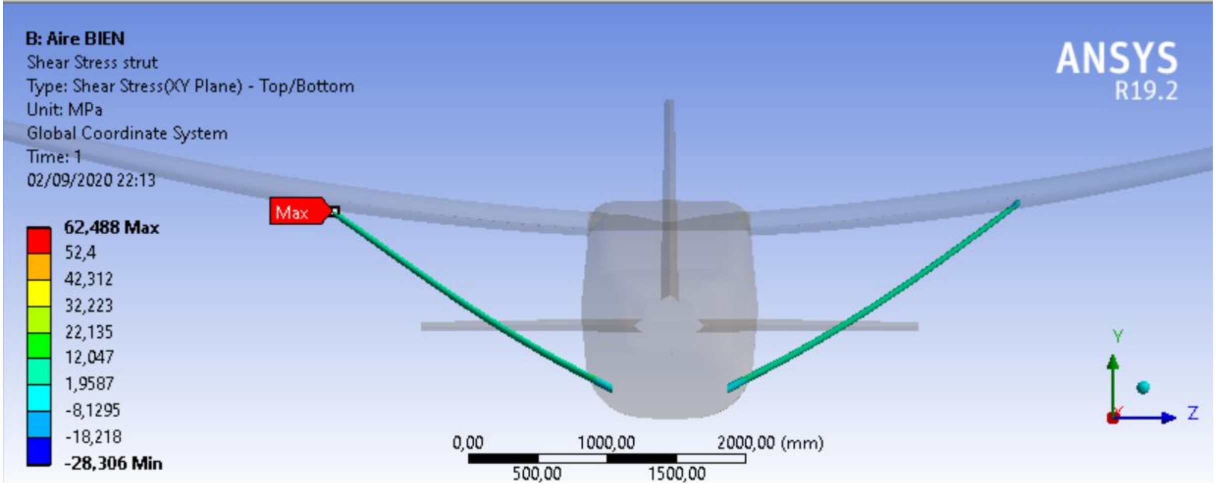
The shear stress results are shown in Figure 32 and Figure 33:

Figure 32 – Shear stress plane on the air



Source: The author (2020)

Figure 33 – Strut shear stress plane on the air



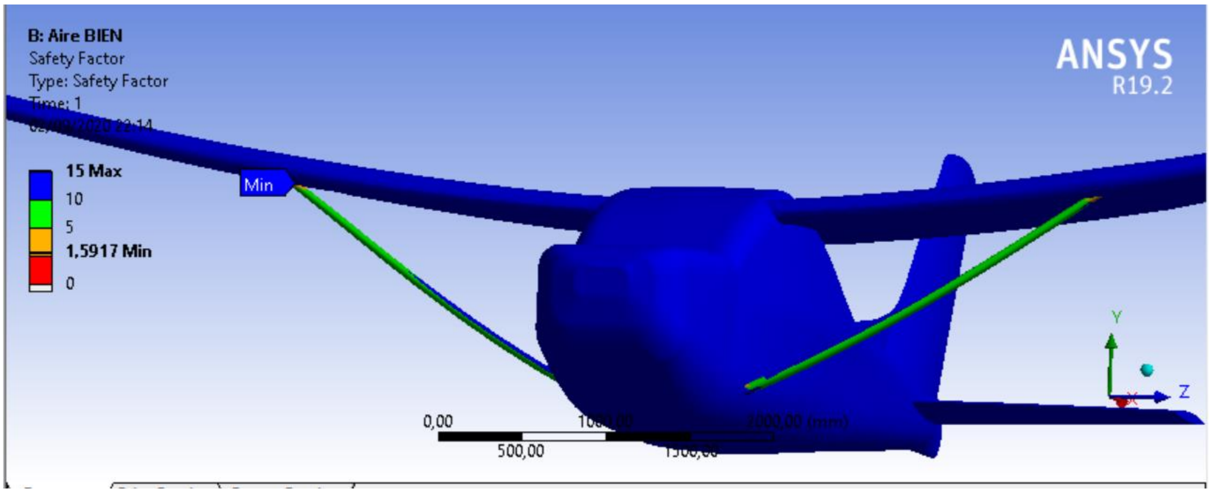
Source: The author (2020)

We observe that we have shear stress throughout the entire model. The maximum value is obtained at the wing-strut connection, consequently it is the area of greatest stress and strain values.

5.2.5. Safety Factor and Safety Margin

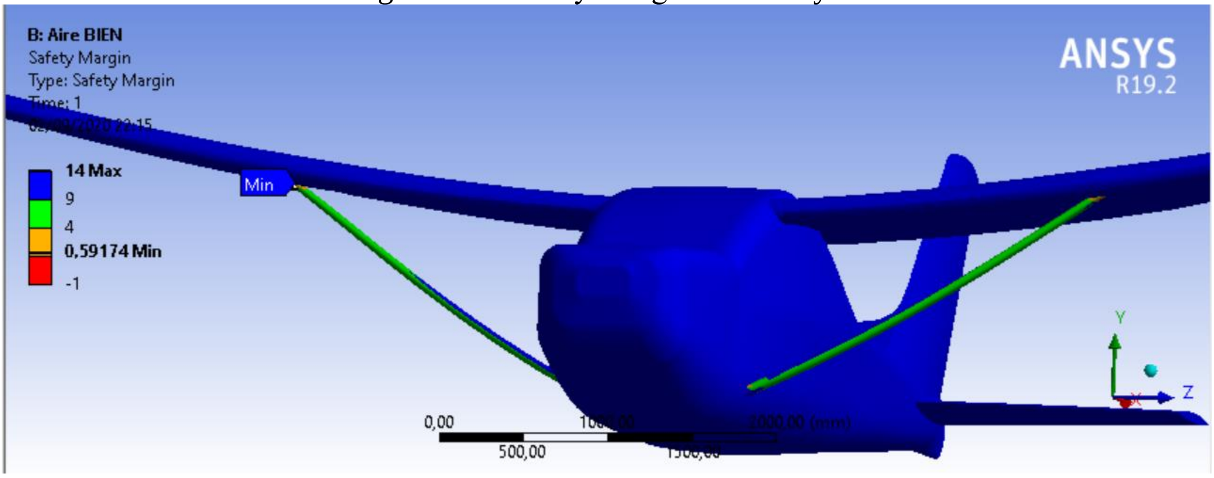
Following the same procedure as in the previous analysis, in order to compare the values of the maximum stress obtained and analyze the structural behavior, an analysis of the safety factor and safety margin has been made as shown in Figure 34 and Figure 35:

Figure 34 − Safety Factor Air Analysis



Source: The author (2020)

Figure 35 − Safety Margin Air Analysis



Source: The author (2020)

6 CONCLUSIONS

Once the results are presented, the following conclusions can be established:

- Both studies of the plane, on the ground and in the air an instant *t* of time, are represented. This is an idealization of reality to be able to carry out the static structural analysis in Ansys. Hence, all the results obtained are for a static analysis at a certain time *t*, with the boundary conditions applied to each of them.
- The fact of having modeled the wing as a solid and the rest of the model as a shell, was to obtain better results with the software. In previous analyzes carried out modeling the entire shell-type model, results were not consistent with reality and not very rigorous.
- In the calculation of the Lift, the parameters for a cruise flight of the Cessna 182 have been taken into account. Likewise, for the calculation of the weight, the mass of the model has been considered.
- The values obtained for the stresses in the analysis never exceed the elastic limit of Aluminum material, which means the model behaves in the zone of linear deformation. Under no circumstances, the results obtained reach critical values as shown in the Figure 24 and Figure 34.
- Besides, it is observed in previous Figure 24 and Figure 34 that safety factor always remains above 1.5, following the recommendation of FAR – PART 25 Subpart 25.303.
- Another important parameter in the study is the safety margin. This has been obtained for the two analyzes, specifically in the strut, shown in Figure 25 and Figure 35.
- The values obtained in both loads and displacements are higher in the second analysis performed. This is logical, since there are more external forces acting on the model, all in the Y direction.
- A bending moment analysis was not fulfilled due to the shell element, the software only allows to analyze the bending moment in beam type elements. Consequently, the values for the bending moment can be calculated as explained in the section 2.3.3.

- A torsion analysis wasn’t performed in order to simplify the analysis, and no moment was applied directly in the boundary conditions of both studies. Thus, the software does not provide results for torsion.

As a final conclusion, it can be noted that the analysis has been carried out under some hypotheses, idealizing the model. However, at all times an analysis has been tried in accordance with reality and trying to capture real flight stages with the Cessna 182.

6.1 SUGGESTIONS FOR FUTURE WORK

The structural analysis done can be complemented with other studies or works related to it.

Firstly, the CAD model has been obtained adapted from Shermon (2015). The study can be improved by refining the CAD model, especially in the fuselage-wing connecting piece or by adding stiffeners to the wings. However, it is important to bear in mind that the level of detail of the model must be in accordance with the computational capabilities available for carry out the structural analysis.

In addition, to improve the analysis and obtain values close to the real model, the wings can be designed as a shell element by lightening it, and subsequently adding internal reinforcements typical of the Cessna182, such as ribs and stringers.

Another good analysis is a bending moment study. It could be performed if the wings and struts are modeled as beam type. In this work, only the bending moment associated with the Equivalent stress can be calculated in the software.

As has been repeated several times, this is a static structural analysis. Regarding the same model, a dynamic analysis of the model could be made, which requires greater detail in the boundary conditions and greater complexity of analysis. Nevertheless, this would be a more realistic analysis in which defined flight stages could be studied

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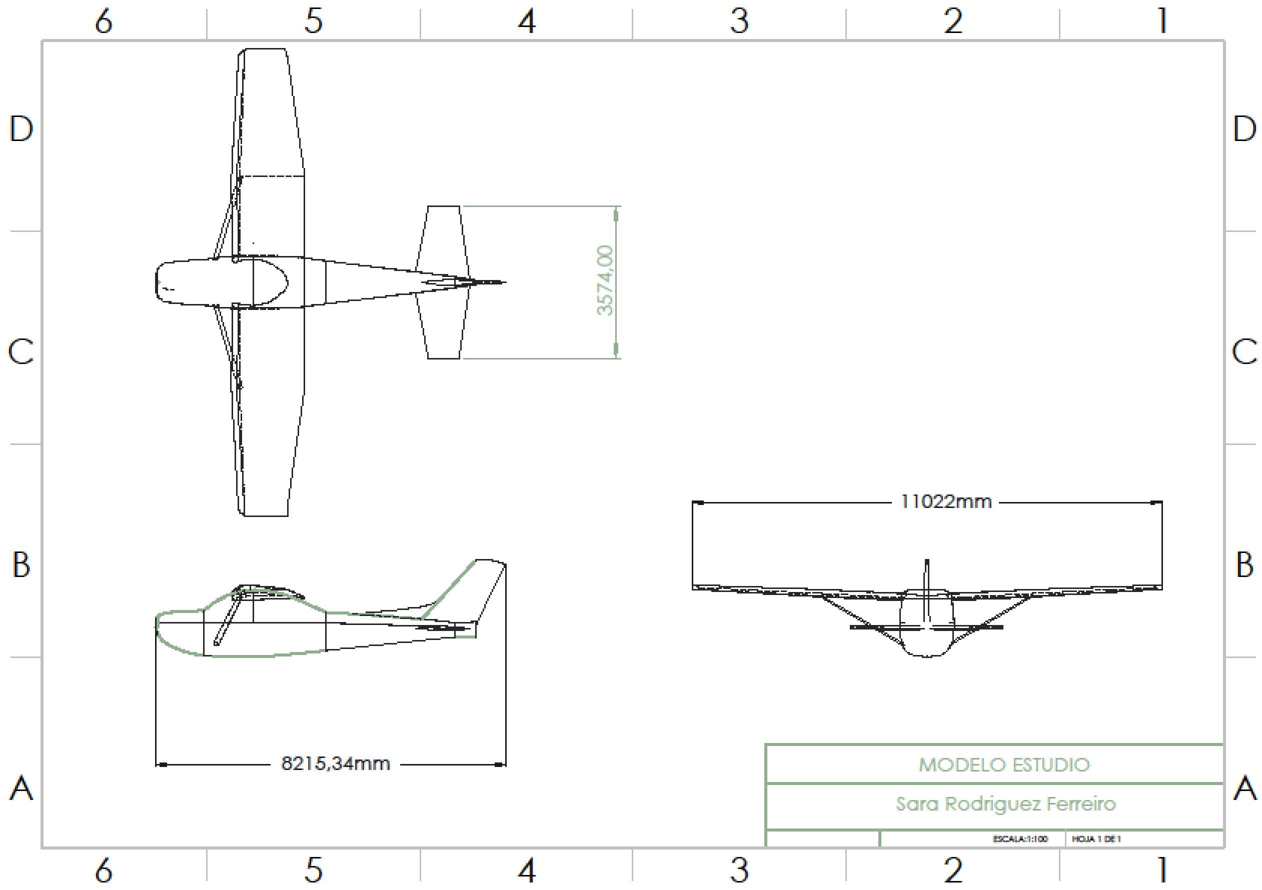
ANNEX I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