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Structural Analysis of a wing box

Structural behavior of aircraft IPUC001-CARCARÁwing

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Abstract

The structural analysis is an important tool that allows the research for weight reduction, the choose of the best materials and to satisfy specifications and requirements.

In an aircraft's design, several analyzes are made to prove that this aircraft will stand the set of maneuvers that it was designed to accomplish.

This work will consider the preliminar project of an aircraft seeking to check the behavior of the wing under certain loading conditions in the flight envelope.To get to this load set, it has been done all the process of specification of an aircraft, such as mission definition, calculation of weight and c.g. envelope, definition of the geometric characteristics of the aircraft, the airfoil choice, preliminary performance equations, aerodynamic coefficients and the aircraft's balancing for the equilibrium condition, but such things will not be considered in this article.

For the structural analysis of the wing will be considered an arbitrary flight condition, disregarding the effect of gusts loads. With the acquisition of the items mentioned, the main forces acting on the wing structure and their equations will be calculated.

The use of finite element method will enable the application of loads obtained just as the development of a method of calculation, along with the construction of a three-dimensional model that represents a chosen condition. The results will be discussed in order to explain the influence of the applied loads in the structural behavior of the wing principal structure.

Keywords: Structural analysis, finite element and wing.

I. INTRODUCTION

The finite element analysis of this paper was performed with the aid of the computer program Femap Nastran. The procedure for performing the analysis in the FEM method of a given structure typically follows three essential steps, firstly is made the geometric modeling of the structure (in this case, the wing), than is chosen the type of finite elements to be used in, the second step are applie loads and restrictions on the structure depending on the type of study and finally defines the type of analysis and do the solution generation.

The model developed in this study attempted to represent the closest as possible of a structure that would in fact exist, using existing studies (such as aircraft wing analysis of C-130) and similar aircrafts, while these similarities is suited specifications for this aircraft (the draft of the specific aircraft).

Thus was obtained a consistent positioning of various components and sections, but due to the structural complexity of the wing is always necessary that some structural approximations be made, connecting elements between sections have not been considered (such as rivets and screws), it was considered that the structural elements were welded and the position of the sections is approximated.

II. DEVELOPMENT

To analyze the a wing box was made the prelimar design of a new aircraft, with the following characteristics: Simplicity constructive, good stall flight characteristics, operational versatility, high performance, low cost, range compatible, preferential use of aluminum, classic design. According to the following requirements:

2.1 Requirements

Two standards could be used in the development of a project similar to the analyzed aircraft:

• FAR (Federal Aircraft Regulations) - Part 23 (US standards);

• JAR-VLA (joint Airworthiness Requirements - Very Light Aeroplanes - (European standard).

The FAR 23 includes four categories: normal, utility, acrobatic and "commuter". Normal is for aircraft with 11 seats or less and a maximum takeoff weight of 5670 pounds, not permitted aerobatic maneuvers. The utility category is for 11 seats or less and a maximum weight of 5670 pounds and allows for a limited number of acrobatic figures. The acrobatic category is also intended to 11 seats or less maximum weight of 5670 pounds and allows stunts without restrictions. The "commuter" is limited to propeller-driven aircraft, multi-motor to 21 seats or less and a maximum takeoff weight of 8620 pounds. The JAR, despite being widely used for light aircraft, was not used in this study because it does not suit the maximum characteristic of the aircraft. Although very extensive and containing a very large number of items that do not apply to the project the FAR 23 for teaching purposes was more instructive that the JAR. Table 1 shows the conditions used for the calculation of IPUC001-Carcará aircraft.

Table1 – Requirements of IPUC0001-Carcará aircraft

Aircraft Requirements(utility category)		
Requirement		Unit
Aircraft will follow the specifications of FAR 23 regulations	FAR 23	-
Maximum takeoff weight (W_{TO}) ≤	850	kg
Maximum leveled speed	300	km/h
Cruising speed at 75% power(V_{cr})	270	km/h
Stall speed with flaps (V_s)≤	80	km/h
Maximum flight ceiling≤	10000	ft
Distance landing/takeoff on the ground (S_L) e (S_{TO}) ≤	450	m
Wing area (S)	9,2	m²
Wingspan (b)	8,5	m
Number of places	2	-
Mass each passenger	80	kg
Luggage weight	30	kg
Time of flight (E_{cr})	3	h
Rate of climb (RC)	2	m/s

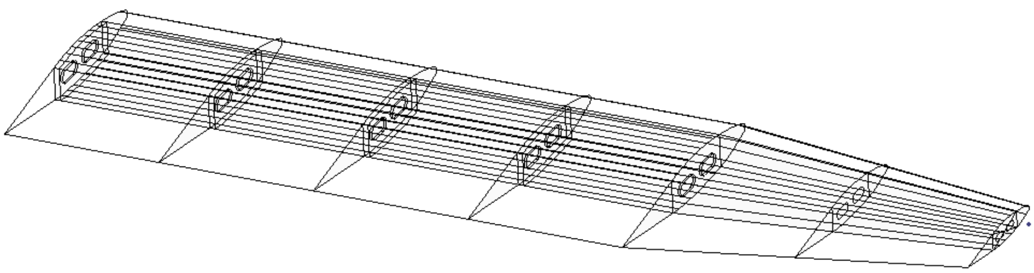
Source: AUTHOR

Obeying These Requirements Were Obtained Loads And This Was Applied To The Wing Boxstructure, Which Has The Specification To Be Manufactured In Aluminum Alloy. And Then It Was Analyzed And Discussed Of The Structural Behavior By The Results Of The Modeling Performed In Finite Element Software.

2.2 Technical Approach

The Wing Was Then Modeled By A Set Of Lines And Areas Describing The Position Of The Various Structural Components, This Model Is Shown In Figure 1.

Figure 1 - Model Of The Wing By A Set Of Lines And Areas



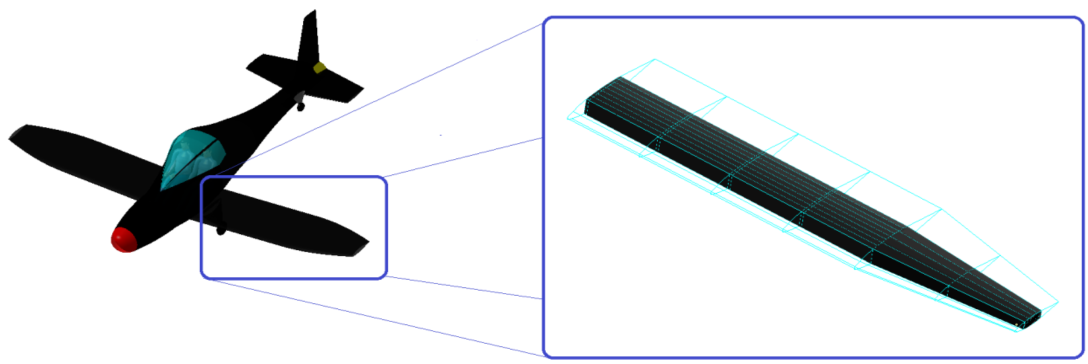
Source: AUTHOR

Once defined the geometry of the structure is necessary applie on each line and the area the corresponding characteristics of its components. For this kind of structural definition is used in the FEM program plate-like elements (Quad and Tria) to define surfaces and Beam type for beams. The Beam element is a linear element of 2 nodes with six degrees of freedom per node, displacements x, y, z and rotation about x, y, z respectively, is an element applied to beams in which you can set any type of section through the creation of sections command within the program itself. The plate element is a linear element used for applying layers of a structural model with different directions and each node of this element is defined by six degrees of freedom.

Set the type of areas elements that describe the structure is necessary to define the properties of each one. This step is performed in the program individually creating each type of property and equipment and storing the information with the name of the thickness and material used, thus constituting an appropriate library that is used when applying the mesh in the structure.

To simplify the analysis and focus efforts, was only studied the wing box, the region that is between the spars and that really concentrated the efforts of the wing. Thus the model received mesh only in this region as shown in Figure 2 and the cutting shown in Figure 3:

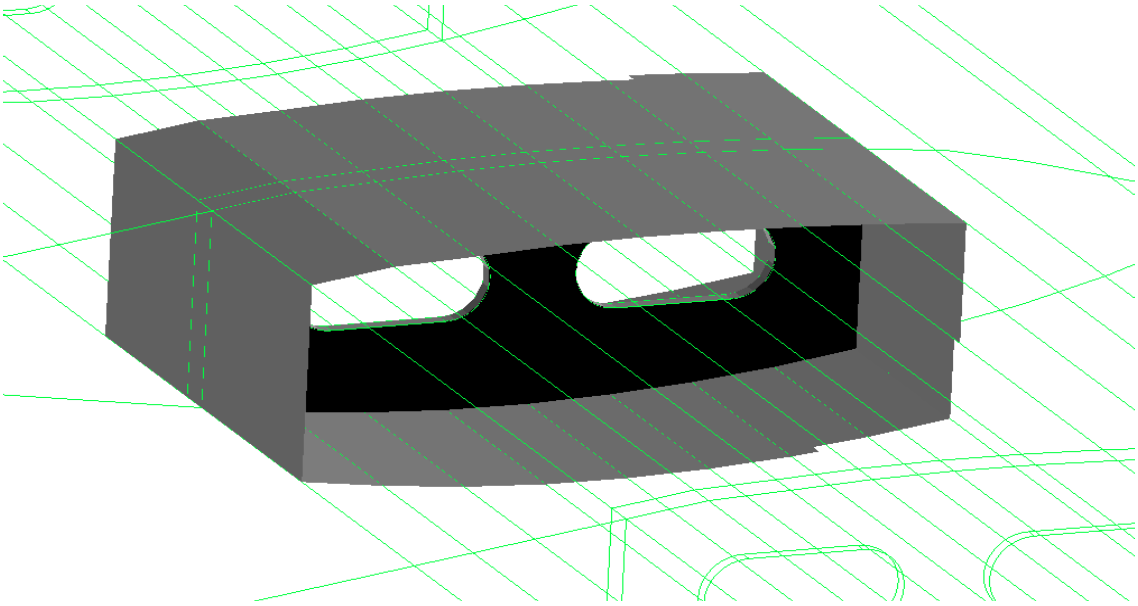
Figure 2 –FEM Model of the wing box



Source: AUTHOR

This region was modeled using two materials, aluminum 2024 and 7075, with the thicknesses of 2 mm, 1.5 mm and 5 mm. Since the spar was shaped with the 7075 aluminum having a thickness of 5 mm, because structural request is higher in this structure, and the ribs and the stringers were modeled and 2024 aluminum with 2 mm thickness and 1.5 mm respectively, this alloy perform better in fatigue and better conformability.

Figure 3 – Cutway of FEM Model



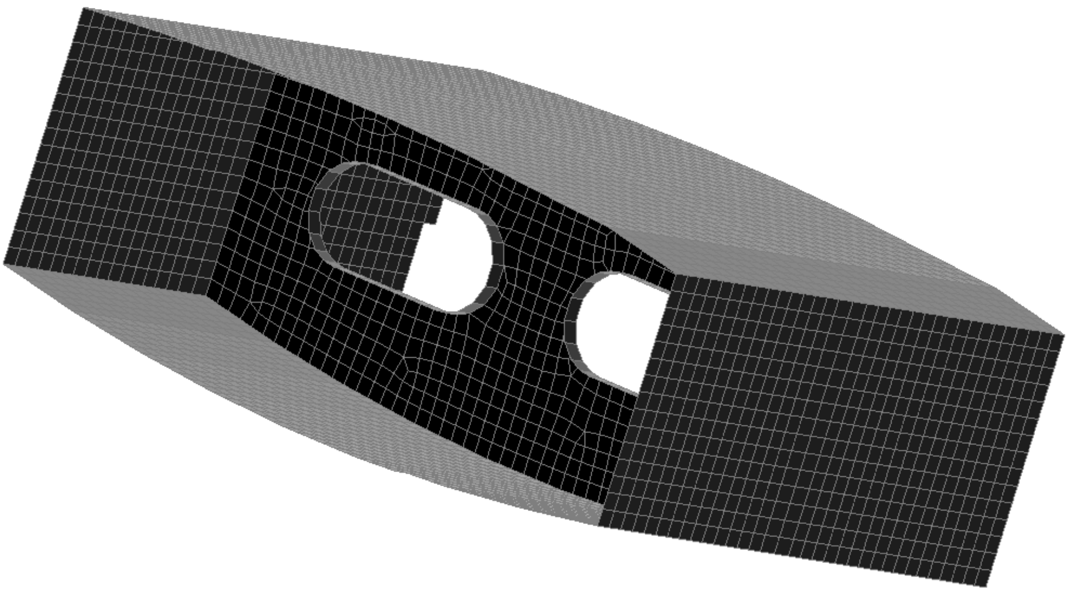
Source: AUTHOR

Defining the elements thereby the calculating the inertia and products of inertia moments are performed automatically by the software,the only concern is with the convergence and refining of the mesh.

In order to examine the validity of the mesh used is made of a refinement study. For this we chose the simplest method is to consider the size of the element as a variable parameter in refining due to the different size of the structural components. Can be so much lower error and can make a reasonable choice of the mesh and its associated error. An analysis of a fixed region of the structure is made, for distribution of stresses in the region will vary with the mesh refinement.

Therefore, after the convergence examination can choose a grid with elements 1cm hand, since the additional computational cost of a mesh of elements with smaller dimensions do not justify the increased precision in the results obtained.

Figure 4 –FEM wing Modelo



Source: AUTHOR

2.2 Boundary condition

To study of the tension distribution, the wing is clamoed to the base, that is, the connection points between the wing and the fuselage are prevented from any degree of freedom (displacements and rotations), thus requiring the cantilever condition on the basis of wing under study. This type of boundary condition is not the closiest to the real, because due to it will emerge high tension regions along the cantilever. This fact is because the wing can not transfer the tensions to the fuselage (which absorb this tension with some deformation), but this type of condition is most commonly used and is the most conservative.

Figure 5 - FEM wing Model, restrictions

Source: AUTHOR

2.3 Bending and loading

For the study will be imposed on the wing a representinglift load, distributed throughout the wing which this force acts (across the spanwise). For this intensity of the loading condition will be registered linearly increased of load values until the tip of the wing. The torsional loads are applied on the ribs, the total weight of the wing was distributed on wingbox and weight of the fuel has been applied only in the region where it is located.

Figure 6 - Model in Finite elements,lft loads (red) and weight of fuel (blue)

Source: AUTHOR

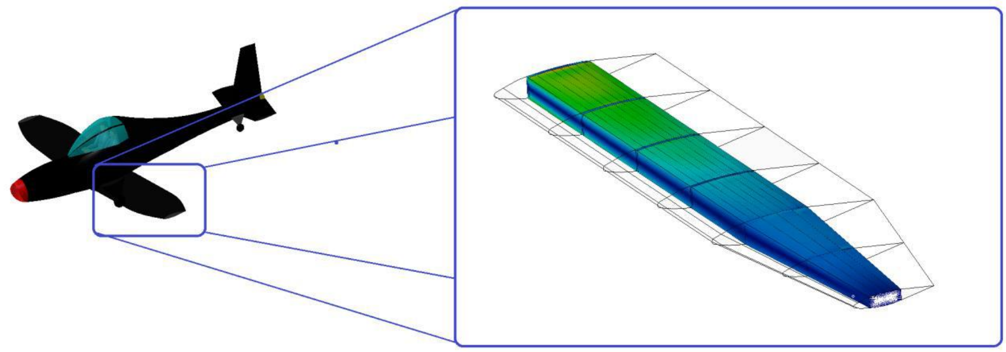
The behavior of the structure has to be proportional to the applied loads that are distribution of lift obtained in the calculations for level flight to 10 degrees, the inertial loads and torsion loads.

III. ANALYSIS AND DISCUSSION OF RESULTS

3.1 Initial Analysis

With the model created with the front and rear spar, the ribs and the covers, and the loads applied, the region was analyzed:

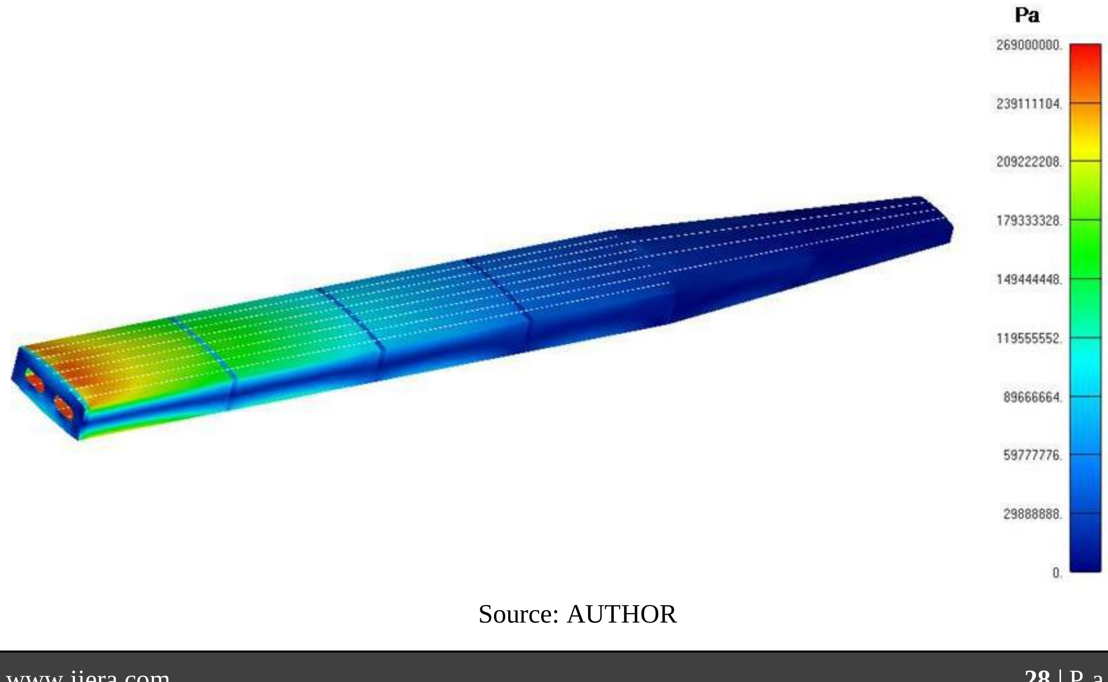
Figure 7 - Analyzed Region



Source: AUTHOR

The following figures show the distribution of stresses in the wings box, where it can be seen that the highest stresses occur in the region near the zone opposite to the wing tip which is crimped (simulating the connection to the fuselage). The maximum value comparison is the yield stress (transition region between the elastic range and plastic material) of more brittle material multiplied by a safety factor and the minimum would be a zero tension.

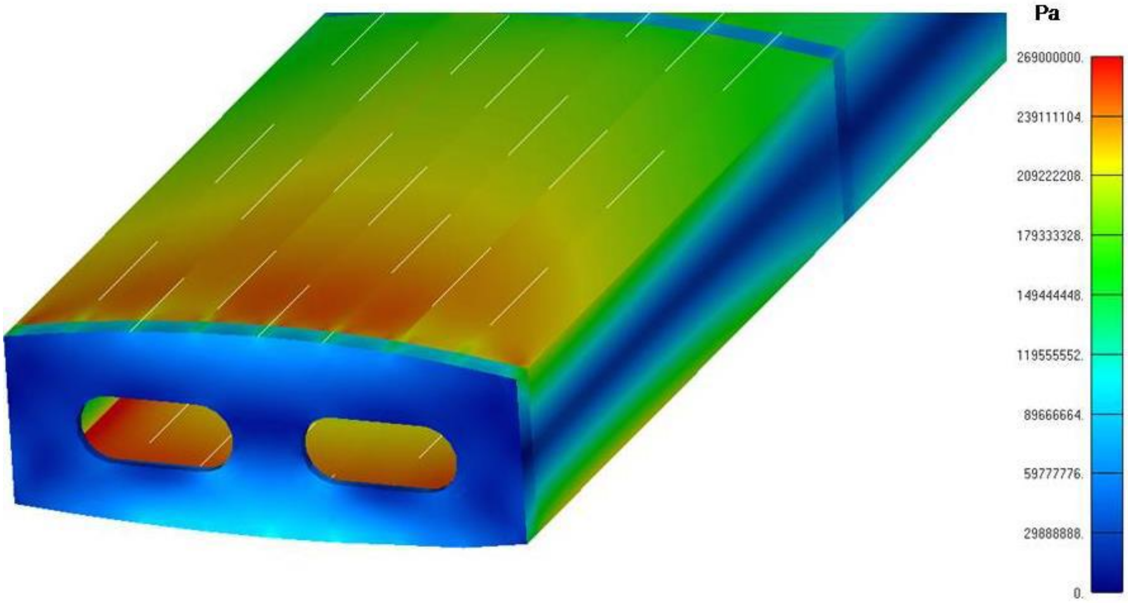
Figure 8 - Distribution of tensions in the analyzed region



Source: AUTHOR

This stress analysis registereda very high tension value and near the admissible (tension limit the images shown, 80% of the flow of the alloy used more fragile), going as shown in Figure 8 on cantilever region. As can be seen with the corner is a high tension gradient, this is caused by the cantilever which prevents the transmission of the efforts. Since this fact resulting from the approximation used in the wing root need this figure shows the addition of reinforcers, to improve the cover's resistance.

Figure 9 - Distribution of tensions in the region near the root



Source: AUTHOR

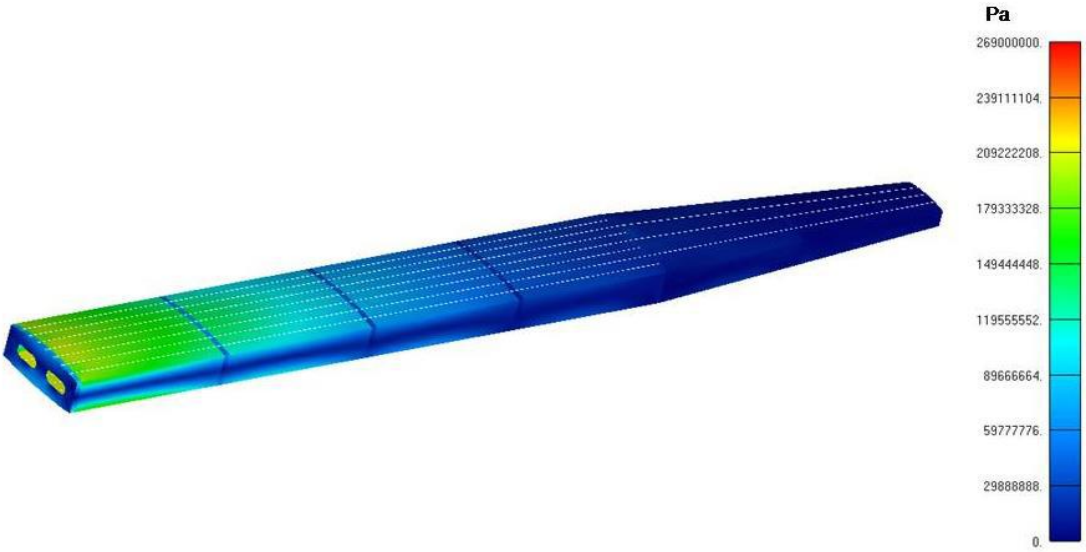
Stress analysis identifies that the compressive stress at the top of the wing and traction on the bottom were the most critical, both of which act mainly on the covers.

3.2 Analysis with inclusion of stringers

To improve the condition of stress concentration, were added stringers in the covers, to improve their resistance. These stringers are T beams 1mm thick and 10mm height and base, and because of its geometry generates a weight ratio higher of resistance rather than increasing the cover thickness.

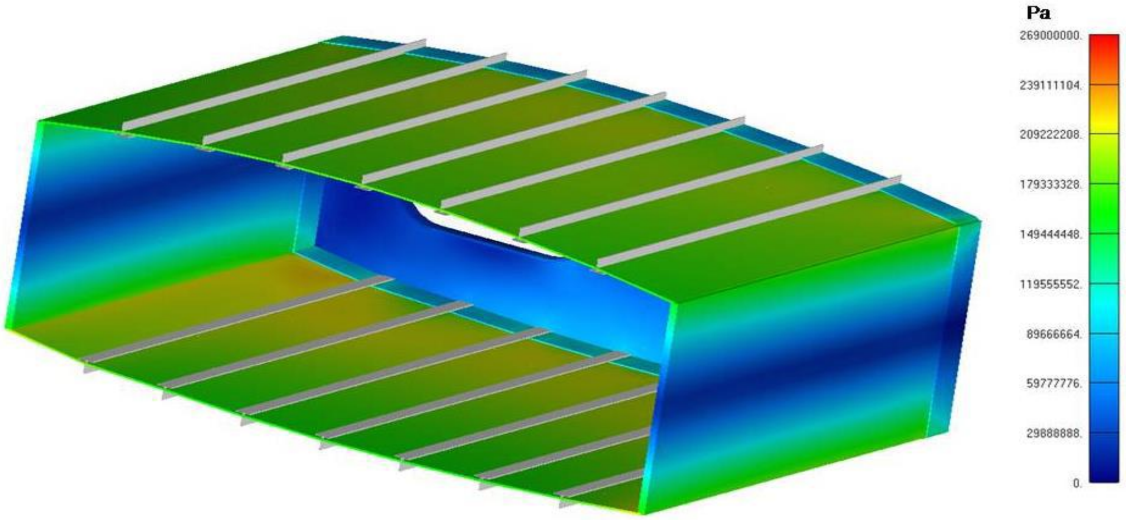
Analyzing the structure with the addition of these stringers can be observed that the stresses are more consistent with the wing box should behave in the specified load case as shown in the figures below:

Figure 10 - Distribution of tensions in the wing box with stringers



Source: AUTHOR

Figure 11 - Distribution of tensions in the wing box with stringers, near the root



Source: AUTHOR

IV. CONCLUSION

To achieve the analysis is very important to understand how the loads required for sizing an aircraft structure are obtained. And for reaching these loads must go through a long process of detailing and specifying a aircraft as well as their performance and aerodynamic calculations, among others. For this reason was made a very detailed draft of a new aircraft, IPUC001-Carcará specified the mission that it should do and from this point were made the necessary calculations to get the balance of load that should be applied to structure to analyse the behavior of its wing box.

Because it is a complex structure, the case of modeling required a number of approaches, as arbitrate a particular flight case on the envelope of operation and simplify the modeling of some components in the finite element software. These approaches have proved to be satisfactory for the proposed trial. Condition approached the border of the wing root by a cantilever, although this does not portray the reality and the results revealed good approximation.

The wing model created on finite element was tested for level and ascending flight condition. The results obtained are in good agreement with the aircraft operating conditions and validate the numerical model created. It was found that critical areas of the flight condition were analyzed: the cover panels in the connection region to the fuselage and consequently the flanges of the spars close to the root. For this reason were adopted reinforcing on the covers, stringers on spanwise direction.

Further improvements should be made to the finite element model to provide an even better approximation to the actual results. Other tests should also be done to reveal the structure is really able to withstand the maximum aerodynamic loads for which it was specified, its safety factor for flight condition. It should apply the weight of the entire aircraft on the wings, multiplying the load factor.

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