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Airplane Independência: History, Model and Analysis

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Abstract. In 1922 by the time of the commemoration of first century of Brazilian Independence, the first bimotor assembled in South America was presented in Rio de Janeiro. It was constructed under the auspices of a French Mission commanded by Etienne Lafay. Assemblage took place at the installations of Henrique Lage industries, a Brazilian entrepreneur. The biplane could transport 5 passengers as it was powered with Clerget engines of 130 hp in a push-pull fashion. The airplane flew during years, without any accidents, but disappeared from history. Only a few photos remain. So from them, drawings and a structural model of the airplane was developed in computer. For the model, in an operational scenario, construction materials were assigned, associated loads imposed and a finite element analysis performed to render the response of the airplane. Strain and stress fields result. Based on the obtained results, safety and performance evaluations of the airplane show a good level of reliability.

Keywords: airplane Independência, drawings, model, analysis, evaluation.

1 Introduction

In September of 1919, Brazil, following a tendency among South American countries, contracted the services of a Military French Mission. Agreement reached allowed French military personal to assume control over several sectors - the school of Estado Maior (EEM), school of officers (EsAO) and others - with the objective of bringing modernization and professionalism to Brazilian armed forces. Among the military was captain Etienne Lafay, responsible for the training of the first pilots of military aviation in the country, Andrade [1].

In parallel, in 1920, Henrique Lage, a carioca entrepreneur turned attention to aeronautics. One of its enterprises, Companhia Nacional de Navegação Costeira, installed in Viana island, Guanabara bay, got into the aeronautics business. A saying of Lage summarizes his motives, “In the future, loads will go by ships and passengers by airplane”, Matos [2]

Still in 1920 a mono engine airplane named Rio de Janeiro was assembled and tested. This airplane, designed by Lafay, with the help and supervision of engineer Braconnot, presented good performance, transporting more than 200 passengers during years in activity. It broke the South-American airborne records.

Two years later, Lafay started working in the hangar of Lage´s industry on a bigger project. Biplane Independência was the first airplane to use two engines here. This airplane had about 12 m of wingspan and six seats placed in between wings, at center. It was equipped with two Clerget engines of 130 hp. These engines were mounted in the middle of the airplane on a push-pull configuration, being the foremost engine responsible for the push with the pull engine placed behind wings. They rendered a good performance to the airplane, even though these engines were considered updated at the time. Cantilever mounting was used, with wings in dihedral, interconnected by vertical struts with $3\frac{1}{2}$ bays, in each side, with 17 truss-type airfoils supported by two spars. A converging truss type fuselage was connected to the back of the wings. The empennage was fixed at the end of the fuselage. Gear trains had a pair of wheels disposed in symmetric form, supporting the lower wing spars,Fig.1.



Figure 1: Photo of biplane Independência

First flight of Independência took place on the 25th of May of 1922. Its design represents a modification of World War I, WWI, planes to carry passengers adding power, Caudron, [3]. It flew for some time, presenting great stability and reliability with many flights of long duration undertaken. As the amount of documents is scarce, few facts are known about this airplane after June of 1922, however. The Independência never got to series production, what was an unexpected fact. Low prices of many airplanes used in the WWI and bought by national armed forces, and lack of technology, prevented national aeronautics industry to develop at that time.

2 Drawings, Model and Analysis

Analysis of Independência is developed at level flight using a finite element discretization approach. A frame model of the airplane is chosen as dimensioning of the parts is required. This model comes from drawings inspired in the blueprints of the airplane.

2.1 Drawings

A frame model of Independência is required to dimension the structural elements of its structure. However, before a frame model can be constructed, a drawing of the structure is needed. To better understand the internal interactions, drawings of the sub-structures of the airplane are desired. Therefore drawings of the pair of front wings, of the fuselage, of empennage and gear trains are generated. In Figure 2, for example, the airfoil truss is represented. Each one weights less than one kilogram. In next figure, a drawing of the half *empennage* shows Eiffel solid airfoils, with 4^0 angle of attack, short chord and a split spar for *elevons* with symmetric airfoils for the rudder. Table 1 shows main characteristics of the airplane.

In this airplane, the central area was densely occupied, with cabin for pilot and passengers, placed seats in a two row form. The pilot was able to access the control surfaces of airplane by means of a set of pulleys and wires. Fuel tank was placed on top of upper wing, sustained in four points. The cabin, of cylindrical form, was placed in a narrow width space, with four points of support. This region, with large shear force discontinuity, uses reinforced elements kept at support points connected to the gear train, a double V-type arrangement for each axel, with wheels working in parallel by means of a horizontal axel.

Table 1: Main dimensions of Independência

|Wingspan [m]	B	12
Length [m]	L	7
Height [m]	H	3

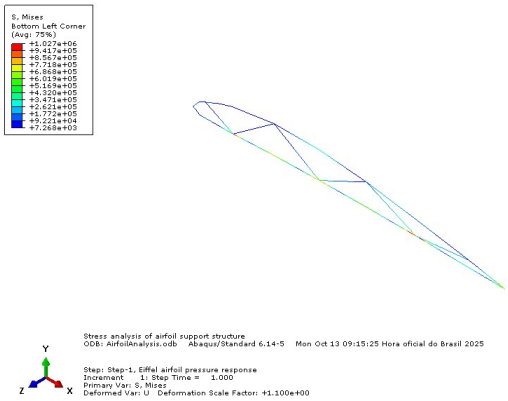


Figure 2: Eiffel Bleriot 428 truss type airfoil model

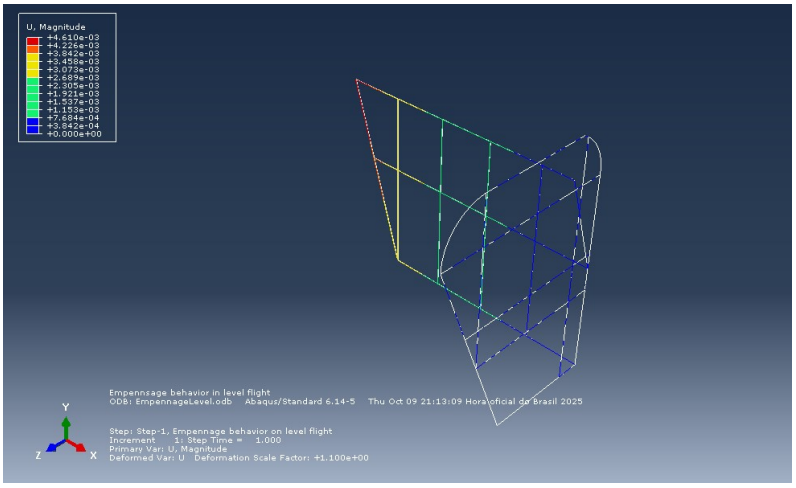


Figure 3: Displacement field of empennage

2.2 Model

The model of each sub-structure involves choosing materials, profiles, loading and interactions among parts. For simplicity two types of materials were assumed in the construction of the airplane. Pine was used for the structural elements with ropes required to tie elements in diagonal. Pine was used on those days due to its flexibility and light weight. This material is inherently anisotropic, with main material direction corresponding to longitudinal fibers, table 2. Ropes were made of natural fiber as linen.

Table 2: Mechanical Properties of humid pine

Density ρ . Kg/m3	425.00
Longitudinal Elastic Modulus E_l, GPa	10.00
Transverse elastic modulus, E_t, GPa	0.60
Poisson ratio, ν	0.40
Longitudinal strength, S_L, MPa	100.00
Transverse strength, S_t, MPa	40.00

The main wings of the biplane are placed in parallel, with 17 airfoils in each side, and a central one, with regular separation. Possibly Eiffel airfoils of the truss type were used in the airplane. For these, maximum

thickness of 9% takes place a 30% of the chord. Maximum camber appears at 40% chord. Airfoil polars show a maximum lift coefficient C_L of circa 1.45 at 13^0 of angle of attack. For level flight, with angle of attack around 5^0, C_L is close to 0.90, whereas drag coefficient C_D is close to 0.015 and C_M approximately -0.085. These values are used to determine the loading of front and rear spar.

Figure 4 shows the drawing of the fuselage of the Independência, with addition of the ropes made of canvas of linen, $\phi = 5$ mm. Fuselage is held at frame F5, left and right of double wing plane. It contains 5 frames, in a wedge design. Parts have rectangular profile for upper and lower elements, and circular for the truss elements, $\phi_t = 25$ mm.

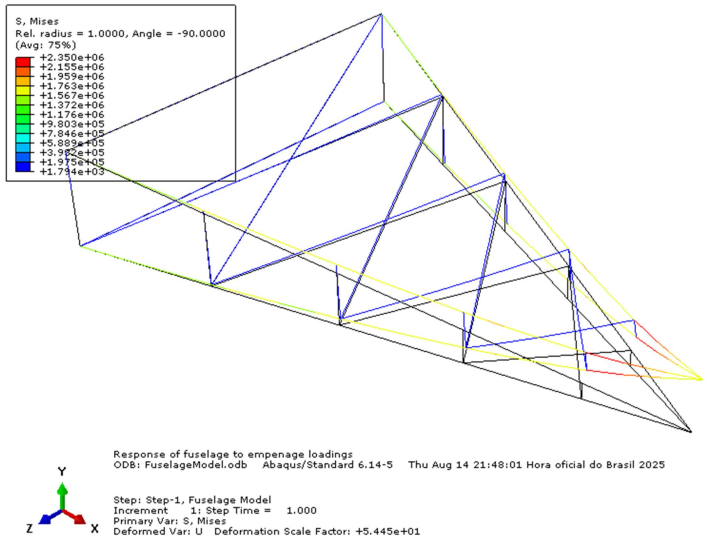


Figure 4: Drawing of the fuselage with Mises stress field and large amplification of displacements

2.3 Dimensioning

In order to find out the initial dimensions of the structural components of airplane, loading and boundary conditions must be set. Loading is established initially from an estimation of the weight of the Independência. Taking the weight over power relation at value 12, weight of the airplane results about 1.4 e+04 N, Raymer, [4]. With the wing area, at level flight of 47.5 m2, with empennage of 4 m2, a wing pressure of 224 Pa results. Or a load per airfoil of 185 N. With this load, with front spar at 15% of chord, whereas rear spar is at 74% of chord, if center of pressure is at 30%, the relation height over width of each spar may be drawn. It results for front spar, $\frac{h}{b} = 11.8$. For rear spar this ratio decreases to 10. Frame analysis allows finding internal efforts < N, S, M, T > in each bay of the wing frame. It turns out that the critical bay is central one, as it holds most of the loading. There the mass of passangers, 5x80=400 kg, as well as the mass of the engines, 2x173 kg, and fuel tank mass, 200 kg , are placed. Thrust force from each engine is 3990 N. With critical value of bending moment written as M_c .Setting values to the allowable flexural stress - $\sigma_a = \frac{S_l}{n}$ for n=1.5, a crítical seccional modulus $W_c = \sigma_a / M_c$ is determined. The weigth of the pair of double wings, without canvas and linen, is150 kgf.

Formally the same procedure may be applied to the fuselage structrure, to find the dimensions of the longitudinal elements of the frame. In such a case, fuselage is supposed to be fixed to the main wing system, at the rear side only, at frames F5, on each side, superior and inferior wings. Loading comes from action of the empennage at level flight in the scenario of disegn. In such a case, empennage lift is supposed centered at main spar of empennage.

With main dimensions of the elements of the sub-structures computed in this manner, dimensions to generate drawing profiles and sections is ready. With loading, with weigth W and lift L acting in the airplane,

in vertical plane, and drag and thrust in the horizontal plane, may be used in the level flight to model the response of the airplane.

2.4 Finite Element Analysis

In order to qualify the model developed to represent the structural behavior of Independência, a frame analysis of its structural elements was developed. As the model is supposed symmetrical with respect to the longitudinal central plane $< X_b Z_b >$, only half model needs to be considered. The situation to be dealt with is the level flight. This airplane is made so as to be at the horizontal plane at start. This results from tail lift L_t action on arm d_t^G to the central of gravity G of airplane, that must equilibrate the contributions from front wing set - $< L_l, L_u >$. Front wheels reaction sum R_f and tailpipe R_r have to equilibrate lower total lift:

$$L_t + (L_l + L_u) + V_f + V_r = W; \tag{1}$$

$$(T_f + T_r) - D - \mu(V_f + V_r) = ma \tag{2}$$

$$(L_t + R_r) d_t^G = (L_l + L_u) d_w^G + R_f d_g^G \tag{3}$$

When takeoff occurs, $R_f = 0$ and lift assumes the function of the land gear action, avoiding failure of the critical loaded region where mechanical parts are placed. Acceleration on the runway is denoted as a.

The resultant of the pressure distribution over each sector of wing tissue results in loading of each airfoil, what in turn gives rise to point loads in wing spars. Upper and lower semi-wings have different spar loadings. Load transfer from lower to upper wing is also produced by the set of struts and cables of front and back frame. Apart this, interaction with tail region of fuselage – force $\mathbf{F}_t$ - loading from the central region where mechanical parts, pilot and passenger are – loads $< W_m, W_p, W_l >$ - and landing gear. Symmetry requires no rotation in the semi-wing connection, thought vertical displacements are possible. Bending action is taken into the inner part where due to the symmetry, <X,Z> displacements are null at the center, as well as the rotations about X and Z. Finite element modeling of this wing frame, Zienkiewcz [5], leads to:

$$\mathbf{KD} = \mathbf{F} \tag{4}$$

being $\mathbf{K}$ the semi-wing frame structural matrix, $\mathbf{D}$ the displacement vector and $\mathbf{F}$ the loading vector, contact and field resultants, global matrix. Level flight scenario loading is considered and results for shear forces, for example, are included in figure 5 over assembled half-plane, with carriage and empennage.

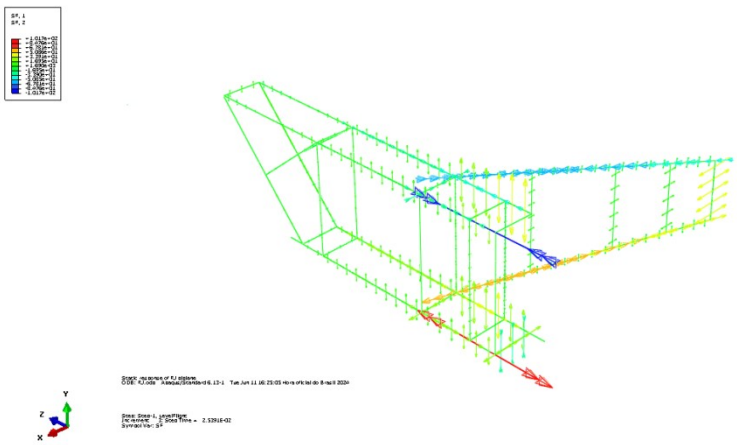


Figure 5: Shear force distribution over front frame.

2.5 Results

Most important sub-structure in this airplane is the double wing area. The frame analysis using the finite element method leads to internal bending moment field shown in Figure 5. In it, over the deformed configuration large flexural loads appear in central area, where double beam for spars is used. Even though large displacements occur at the far ends of the frame, most of the stress appears concentrated in the inner side, where most of the loading is applied.

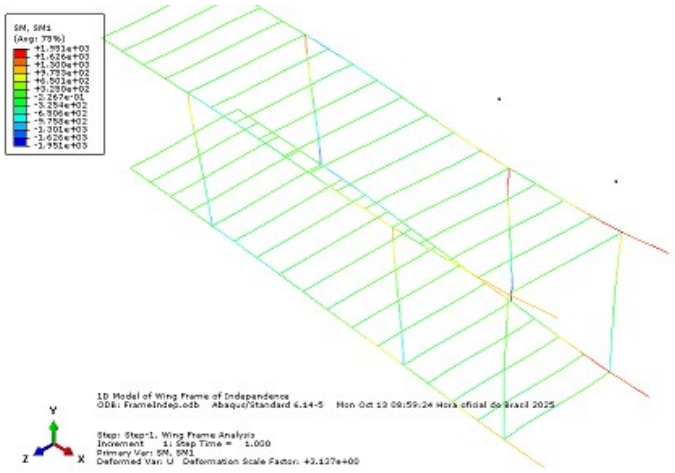


Figure 6: Semi-double wing bending moments on level flight

3 Conclusions

Drawing, designing and analyzing the main structure of Independência biplane led to a possible design of the airplane. The produced drawing resembles the original one to great quality and teaches a lot about the main principles behind the conceptual design. The weight of the model is close to the weight of the original. Stresses are under the elastic range. Analysis of wings at level flight, carriage at take-off, and empennage under turns show good results. Harder flying conditions would show limitations, but an 4000 N structural weight, with taken safety factors, shows a well-balanced airplane.

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References

[1] Andrade, Roberto Pereira de**,** A Construção Aeronautica no Brasil (1910/1976)**,** São Paulo, Brasiliense, 1976

[3] Lage, Henrique, https://pt.wikipedia.org/wiki/Henrique_Lage, access May/2024

[3]Caudron G.3, https://www.museudoar.pt, available at https://www.museudoar.pt/pagina-001.003.002.003-caudron-g-3,. Access in February, 2, 2021

[4] Raymer, Daniel D., Aircraft Design: A Conceptual Approach,. Design Dimension Press, USA, 2007

[5] Zienckiewicz and Taylor, 1977, "The Finite Element Method", McGraw-Hill, USA