ICAS-96-7.6.2

THE STATIC AND DYNAMIC STRUCTURAL ANALYSIS OF AN AMPHIBIOUS AIRCRAFT

S.C. FARIA M.Sc Student and
A.C. CANALE M.Sc Ph.D
Aircraft Laboratory EESC - University of Sao Paulo Brazil

ABSTRACT

A static and dynamic structural analysis of an amphibious aircraft has been carried out in order to optimise its structure principally with a view to a reduction in weight. For the optimisation a finite element was used, where the structure was divided into 'beam' elements with 12 degree of freedom. Various loads were applied, corresponding to the several operational conditions of the aircraft. The natural frequency and vibrational nodes of the main structure are also obtained as part of the study of aircraft stability, structural fatigue of the elements, resonance and aeroelastic phenomena. The analysis procedure gives the design of an aircraft with tubular structures an elemental chart for each operational flight condition, permitting the optimisation of the structure and the comparison of equivalent stress levels with those obtained in the Laboratory. The results showed that this procedure permitted an economy in structural weight of 23%

INTRODUCTION

Brazil possesses a great variety of geographical conditions that require the use of different types of aircraft, always looking for the best service/cost ratio. Considering the size of the country (the largest reservoir of fresh water in the world) and the areas of difficult access, the need for amphibious aircraft, like the IPAI-33, is clear as much for passenger use as for cargo. The IPAI-33 is a high wing amphibian. although this makes it less manoeuvrable, it tends to increase stability. The propulsion unit consists of a single Automotive motor of 130 HP, developed by the FIPAI Foundation. The main aircraft structure, shown in Figure 1 is constituted of 115 thin walled tubular elements welded together to form a spaceframe. The tubes are of 4130 chrome molybdenum steel that gives high resistance and good welding characteristics.

The objective of this study is to optimise the structure, principally with a view to a reduction of the original weight of 134,5 kgf. For this optimisation the finite element method is used. The structure is divided into beam elements with 12 degrees of freedom. Various loads are applied, corresponding to the various operational conditions of the aircraft and a stress diagram of the structure is obtained. For the calculation of the elementar stresses, the Criterion of Distortion Energy in Strength of Materials adequate for application to steel is used, which obtains the maximum tensile stress for each element that is then compared directly with the limits of the material obtained in standard Laboratory traction tests.

Based on the diagram for the various loading situations, the tubular elements under the highest load are identified and, if necessary, their dimensions are increased. The opposite process is applied to those elements subjected to low loads.

The natural frequency and vibrational modes of the main structure are also obtained, this being important information for the study of aircraft stability, structural fatigue of the elements, resonance and aeroelastic phenomena.

DEVELOPMENT SEQUENCE:

The original main structure of the IPAI-33 was made-up of 115 tubular 4130 steel elements welded together. All the tubes had an outside diameter of 3.81 cm and a wall thickness of 0.15 cm. The total weight of the structure was 134,5 kgf. The structure was divided into 119 discrete beam elements, each with 12 degrees of freedom and 57 nodes resulting in a total of 342 degrees of freedom. Each welded joint was considered as a node and some of the elements being curved were divided into further straight elements. The geometric characteristics, (diameter, cross sectional, area, etc.) physical characteristics, (mass, inertia) and those of the material (density and Young's Module) allow for the calculations of the necessary structural properties and the finite element solution. Another important detail is the method of loading, the loads resulting from various operating conditions of the aircraft were applied at the nodes.

Four flight conditions were considered: large positive angle of attack, large negative angle of attack, inverted flight and landing. The loads considered came from the wings, the struts, the tail surfaces, the propeller and the landing gear.

Figure 2, 3, 4 ,5, 6, 7and 8 shows the points of application of the loads.

The elements that constitute the primary structure are submitted to a state of complex tension, combining tension or compression stresses, bending in two planes and torsion around the longitudinal axes. Considering that the elementar deformations due to the loading are small compared to the dimensions of the structure, and that the material of which it is made is solicited within the linear range of stresses and deflexions, it is possible to obtain longitudinal or axial deformations and forces separately due to both tensile and compressive stresses, as shown by Canale(1)

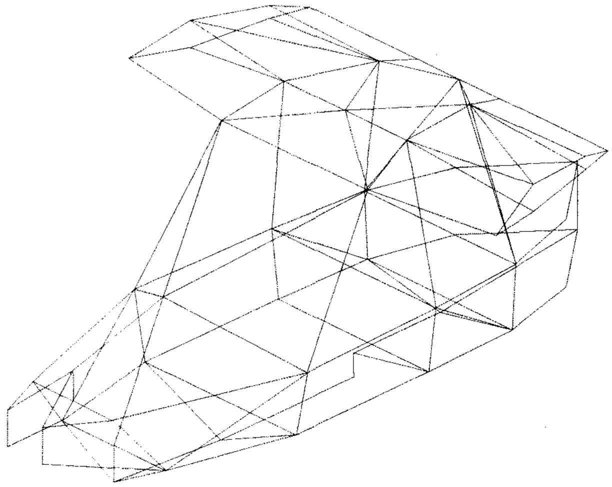

Figure 1 The IPAI-33 main structure

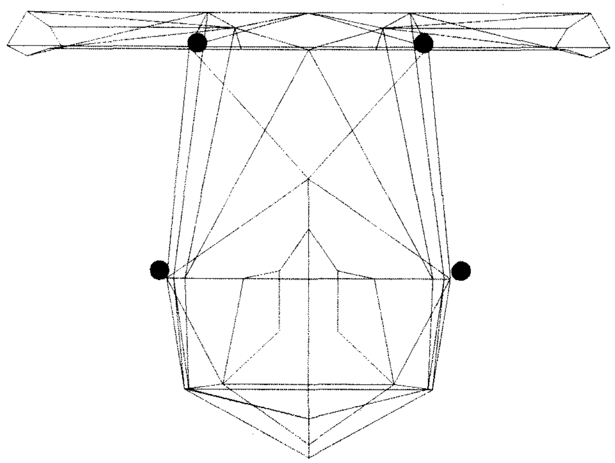

Figure 2 Load points from the wing and the struts at the front spar

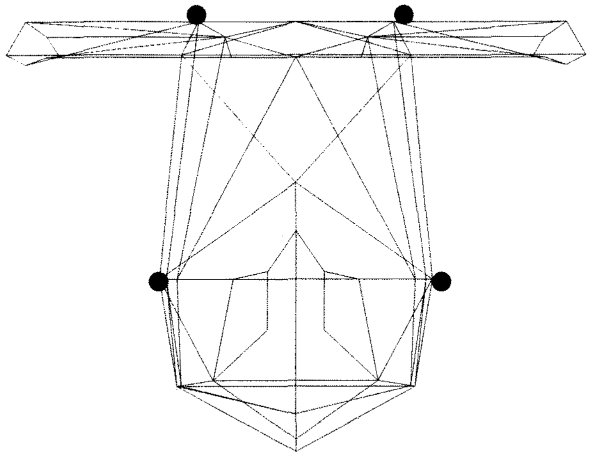

Figure 3 Loads due to the wing and strut at the rear Spar

Based on the loads applied at he corresponding structural nodes and considering the tubes to have thin walls, the maximum longitudinal and axial tensile stresses, σ^f and Q^f due to bending in both xy and xz planes were able to be obtained. The tensile stress σ_x^f was added to stress due to the elementar stresses resulting in an equivalent tensile stress σ_x^{ft}. The shear stress due to the elementar bending in two planes Q^f was added to the shear stress due to torsion, resulting in the total elementar axial tensile stress Q^{ft}.

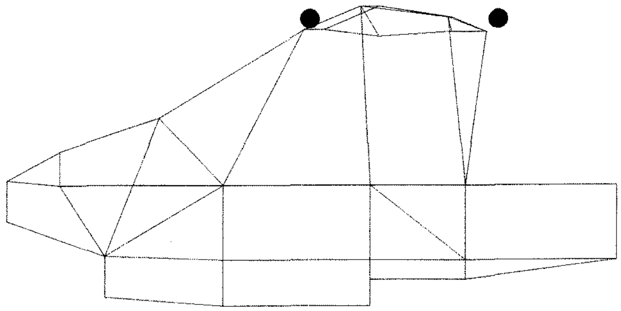

Figure 4 Loads due to the tail unit

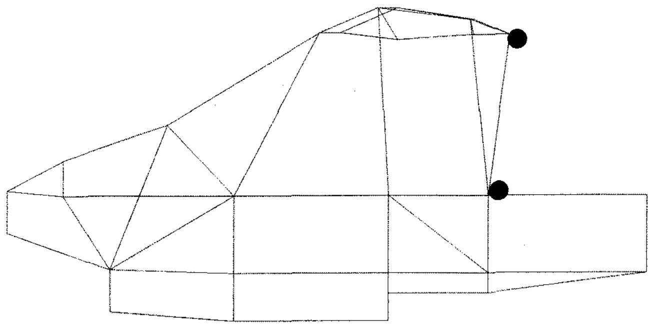

Figure 5 Loads due to the pusher propeller

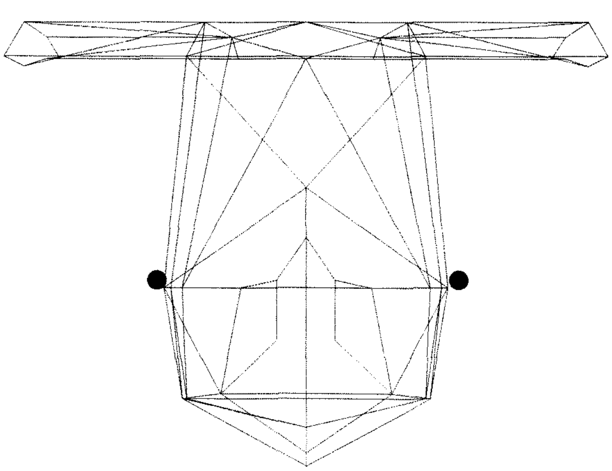

Figure 6 Loads due to the Landing Gear

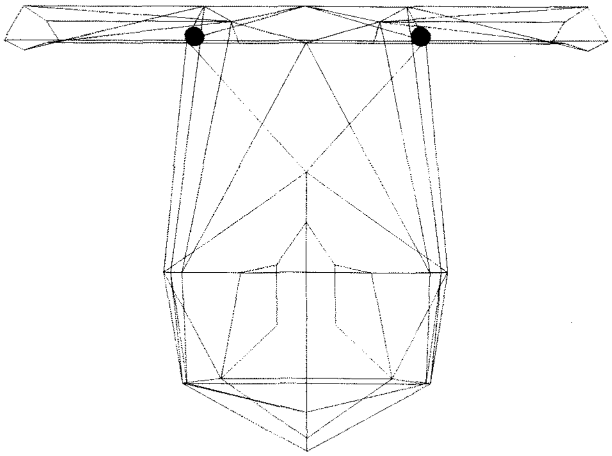

Figure 7 **Loads in the direction of the wing chord at the front Spar.**

The elementar tensile stresses σ_x^{ft} and Q^{ft}, for each loading state being known, the Distortion Energy Criteria for Strength of Materials was applied. This Criteria obtains and equivalent tensile stress σ_e, conjugating σ^{ft} and Q^{ft} as shown in equation 1. To this maximum equivalent elementar tensile stress was added a safety factor of 1.5, that considers dynamic overloads, fatigue etc. This resulted in a total tensile stress σ that may be directly compared with the stresses obtained in standard tests on the material. For 4130 steel, the rupture stress in tension is $\sigma_r = 7030$ kgf/cm^2. The designer will this have a chart of maximum elementar stresses for each loading combination, being thus able to identify the elements that are highly solicited or not, comparing them with the yield or rupture stresses of the material.

$$\sigma^2 = (\sigma_x^{ft})^2 + 3.(Q^{ft})^2 \qquad [1]$$

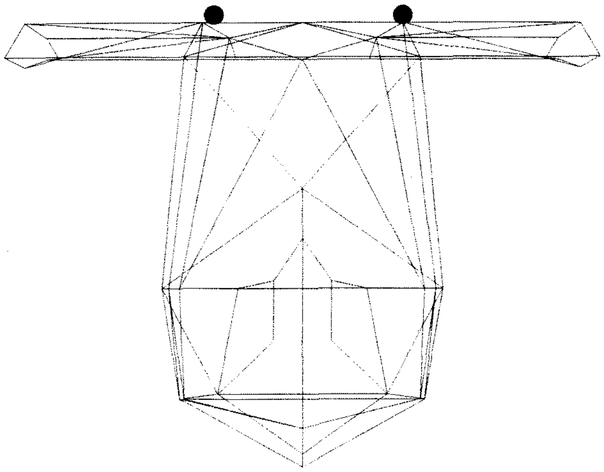

Figure 8 Loads in the direction of the wing chord at the rear Spar.

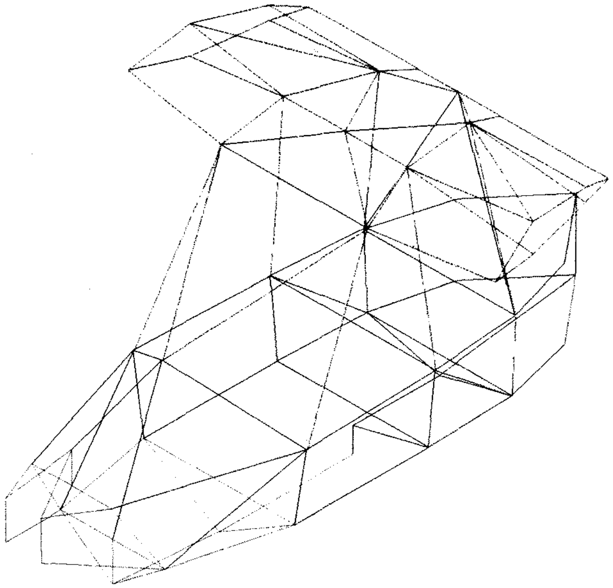

Figure 9 Undersized elements

This making it possible to localise the oversized or undersized tubes, as illustrated in Figures 9 and 10. The dimensions of the tubes would then be adequate for the levels of maximum stress to which the element is submitted. A structural optimisation is thus able to be performed, resulting normally in a reduction of the weight of the structure. Applying this procedure to the structure of the IPAI-33, it was possible to reduce the weight of the structure by 23%.

Figure 11 shows the final configuration of the structure with regard to the thickness of the tubes.

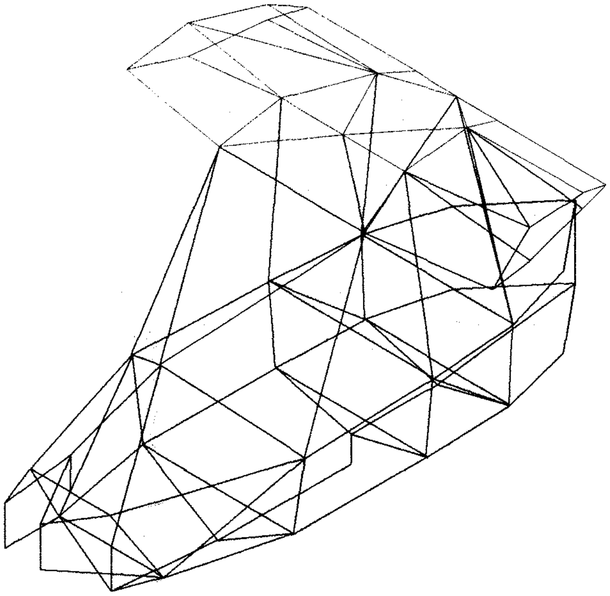

Figure 10 Oversized elements

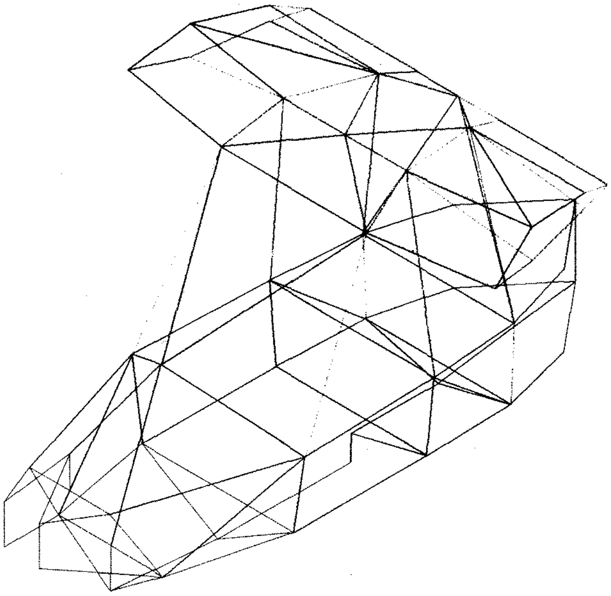

Figure 11 **Final element configuration**

TUBE	DIAMETER (CM)	THICKNESS (CM)	COLOR
1	2.540	0.18	■
2	3.175	.024	■
3	3.810	0.29	■
4	4.220	0.45	■
5	4.445	0.53	■
6	4.760	0.53	■

***Table 1* Element Configuration.**

DYNAMIC ANALYSIS

Using the same finite element modelling technique, the natural frequencies of the structure and its respective vibrational modes were determined. These results are important for the future analysis of phenomena such as resonance and auto-excitation such as flutter and divergence, as well as vibrations of the control surfaces. The centre of gravity of the structure was also found by this program. This being important data form the evaluation of stability and performance characteristics of the aircraft. In order to simulate the structure as a free body, it was suspended by springs, (within the computational configuration), the springs are made sufficiently flexible to permit a mathematical solution using finite elements. Without introducing significant rigidity at the nodes, they were fixed without altering the natural frequencies and the vibrational modes of the elastic structure of the aircraft. The rigidity of the springs was calculated so that the first six frequencies of the rigid body structure was 100 times lower than the first frequency of the elastic body. This fact can be seen in table 1. This model will also be useful for the validation of the mathematical model during the structural tests of the aircraft.

CONCLUSIONS

This analysis procedure gives the designer of aircraft with tubular structures an elementar chart for each operational flight condition, permitting the optimisation of the structure and the comparison of equivalent stress levels with those obtained in tests of the material in the Laboratory. In the case of the IPAI-33 this procedure permitted and economy in structural weight of 23% (final weight of 103 kgf). As well as the structural optimisation, dynamic data of natural frequencies and vibrational modes will held to validate the static model when a prototype is tested in the Laboratory. Other interesting possibilities to consider for future optimisation, such as asymmetric loads such as landings with sideslip. It is never possible to consider an optimisation as finished, however. There are aircraft constructed, homologated and flying, the structures of which are still being optimised as the aim is always to produce a structure with the lowest cost and highest safety level.

REFERENCES

1. Canale, A. C. - “An Experimental and Theoretical Study using an Aircraft Scale Model Fuselage Structure in Spacial Frame , Static and Dynamic Analysis , Msc Theses USP Sao Carlos Brazil, 1983.
2. Timoshenko, S. P. - “Resistência dos Materiais”, Vol 1, 1967.