Free vibrations analysis of the aircraft IAR-99 HAWK based on a new and modern finite element model

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***Abstract**: For the doctoral study on the influence of the aircraft external stores over the aeroelasticity behavior of the IAR-99 HAWK, we have developed a new Finite Elements Model (FEM) with new state-of-the-art methods and technologies available at the end of 2020.*

After creating a new Finite Elements Model (FEM) of the aircraft IAR-99 HAWK using special elements, the team decided to validate the results by performing a free-free vibrations analysis on this model. In this presentation we have described the finite elements used and their peculiarities, the finite elements model obtained for the aircraft IAR-99 HAWK and the results of the free-free vibrations analysis obtained in the empty equipped configuration.

The results of the theoretical free-free vibrations obtained for the IAR-99 HAWK in the empty equipped configuration are presented and compared to those obtained from ground tests, thus confirming the accuracy of the new Finite Element Model (FEM).

The new Finite Element Model (FEM) of the IAR-99 HAWK will be versatile enough to provide insight into the structural behavior of the aircraft, regardless of the phenomenon for which it is analyzed: static stress, aerodynamic simulations, flutter, etc.

***Key Words**: finite element method, finite element model, aeroelasticity, free-free vibrations, empty equipped configuration, ground vibration tests, MSC PATRAN, MSC NASTRAN*

1. INTRODUCTION

The analysis of free vibrations in an aircraft is one of the most complex and difficult problems to solve in the design process of an aircraft. A fundamental aspect in the analysis of burst responses and aeroelastic phenomena is the investigation of frequencies and vibration modes. The surfaces of an aircraft are made up of thin-walled, uneven and arbitrary structures, which usually have arrow and dihedral angles and are trapezoidal in shape. These properties give rise to complicated effects that require complex structural modelling. There are different models that can be used for the structural analysis of an aircraft. These models are made up of one-

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dimensional (bars), two-dimensional (plates, shells) and three-dimensional (solid) elements, respectively. This paper presents a new FEM model for the Romanian trainer IAR-99, HAWK. This FEM model was simulated using MSC.PATRAN and MSC/NASTRAN, [2], [3] by applying appropriate boundary conditions to perform numerical modal analyses. The results of the numerical modal analysis were compared with the results of the theoretical and experimental approaches carried out in the 1980s and 1990s.

2. THE FEM MODEL OF THE IAR-99 PLANE, HAWK

2.1 General description of the IAR-99 HAWK, [1]

The IAR-99, Falcon aircraft is a single-engine, school-training and ground attack aircraft, designed for school and training units, for the training of pilots, in the transition phase from classic, low-speed aircraft, to high-speed jet aircraft, as well as for the advanced training of already trained pilots, in the second training group, with the possibility of performing specific missions of direct tactical air support.

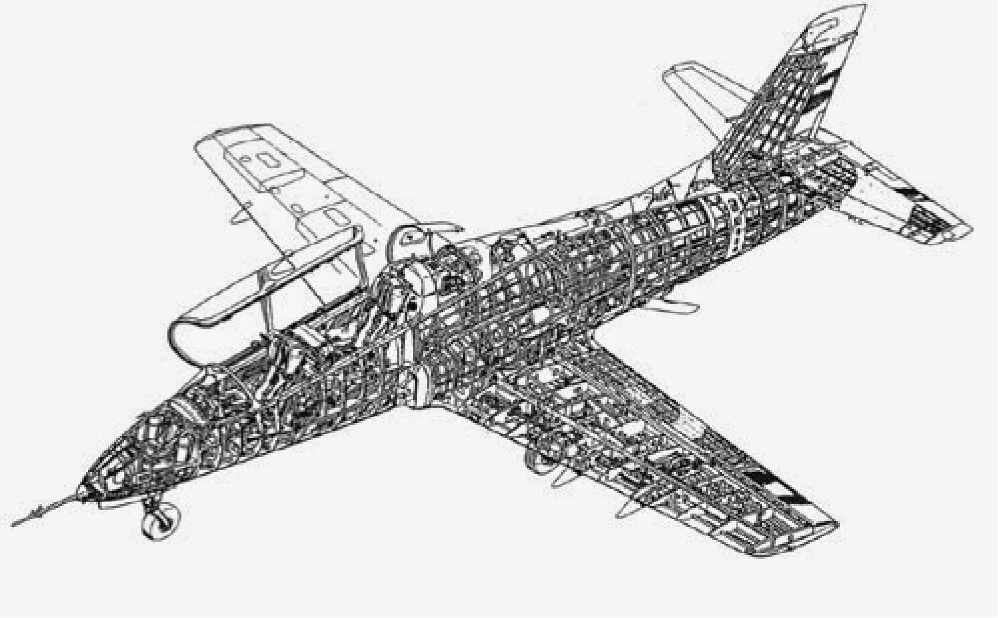


Fig. 1 Plane structure configuration, empty equipped

2.2 Philosophy and application of the FINITE ELEMENT METHOD

The finite element method has been perceived from the beginning as having a major potential and being a definite promise in modelling several complex mechanical applications, mainly related to the aerospace industry and civil engineering in general.

Applications of the finite element method begin to reach their true potential when applied to coupled problems, such as those related to fluid-structure interaction. We present the number of nodes, the number of elements and the types of elements used in the new FEM model.

The elements used are standardized MSC. NASTRAN® and the properties of these elements used in this case, are explained in Chapter 2, of [5] and the materials used.

Table 1. The number of nodes and elements and their typology, used in the new FEM model of the IAR-99 aircraft, HAWK

	No. of KNOTS	**No. ELEMENTS**	**CTRIA3**	**CQUAD4**
WING	24572	76582	174	76408
REAR FUSELAGE	72340	64164	1594	62570
CENTRAL FUSELAGE	74776	35092	2282	64018
POSTERIOR FUSELAGE + AMPPENAGES	337484	167448	0	113652
SKIN	56379	241508	22114	241982
TOTAL	565551	584794	26164	558630

Table 2. The materials defined in the FEM model

MATERIAL	**MODULUS OF ELASTICITY [MPa]**	**DENSITY [g/mm³]**
2024T3 – T2	$73.1*10^3$	$2.789*10^{-3}$
Al 6065	$73.1*10^3$	$2.720*10^{-3}$
STEEL	$200\text{-}207*10^3$	$6.6\text{-}7.86*10^{-3}$
PLEXIGLASS ACRYLIC	$2.76\text{-}3.3*10^3$	$1.18\text{-}1.19*10^{-3}$

2.3 Particularities and special complexity of the new model developed in MSC.NASTRAN

This approach has attempted to model the FEM taking into account the geometric position of the vertices and the real behavior of thin-walled structures used in aviation.

Thus, the designed model allows the visualization of the results and the study of the behavior of the structure at the local level (frames; beams; frame-shell, smooth-shell and spars-shell interaction) in the case of global dynamic phenomena. The typology of the structural elements used, one-dimensional (1-D), two-dimensional (2-D) or three-dimensional (3-D) as well as their practical use and connection between these elements, interconnection are presented in [5].

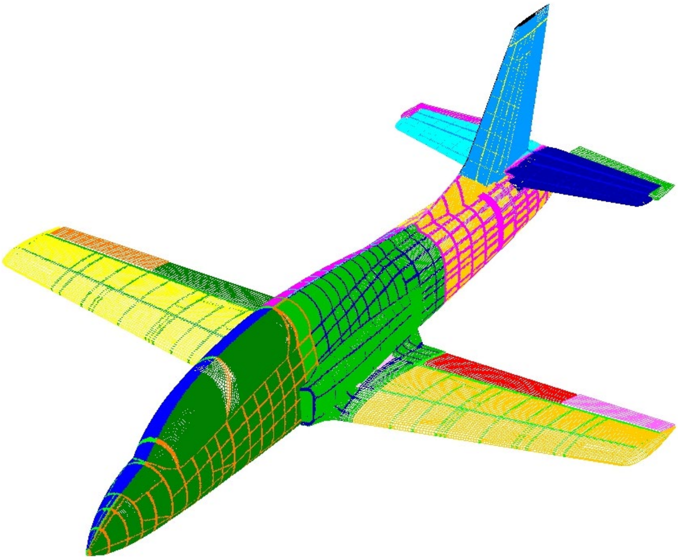


Fig. 2 FEM model for airplane configuration empty equippe

To exemplify the complexity of the new FEM model, produced for the IAR-99 HAWK aircraft, we present in Fig. 3 the FEM model, central fuselage-central caisson-wing assembly, interior view and in Fig. 4 the FEM model, rear fuselage-engine-horizontal empennage-vertical empennage assembly.

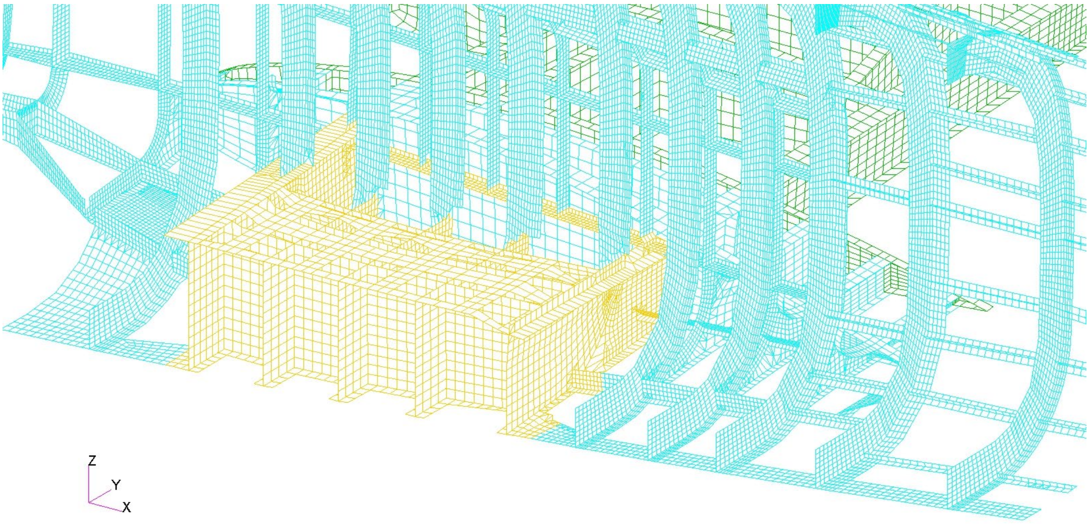


Fig. 3 FEM model, central fuselage-central caisson-wing assembly, interior view

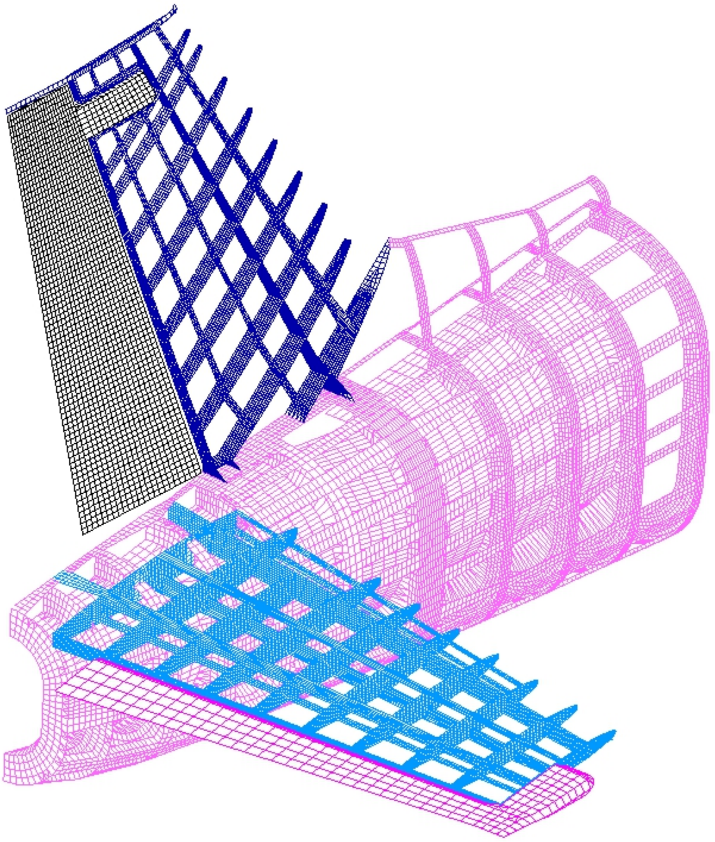


Fig. 4 FEM model, rear fuselage-engine-horizontal empennage-vertical empennage assembly

3. VIBRATION CHARACTERISTICS, BASED ON THE NEW NUMERICAL MODEL OF THE IAR-99 AIRCRAFT, EMPTY EQUIPPED

The calculation of the free vibrations, based on the new FEM model of the IAR-99 aircraft, SOIM, gives the following vibration modes.

The vibration modes obtained were compared with those obtained from the ground vibration tests and with those calculated using the beam theory for the aircraft in the empty equipped configuration presented in [4].

From what is shown in Tab. 1, we can see the complexity of the new FEM model created in this analysis. The number of nodes and elements in which the structure has been discretized has been chosen in order to obtain a very good correlation of the model with the real structure of the IAR-99, HAWK aircraft.

We present the table of the results obtained as well as the represented modes obtained in the vibration calculation using the new FEM model.

Table 3. Comparison table with the frequencies obtained in the vibration analysis

No.	Mod Name	FREQUENCY [Hz]		
		THE NEW FEM MODEL	EXPERIMENTAL VALUES [4]	THEORETICAL VALUES IN BEAM THEORIES [4]
1	Rigid mode - Pitching	0.000057930		
2	Rigid mode –Lateral Displacement on OY	0.000706855		
3	Rigid mode - Roll	0.000799054		
4	Rigid mode – Vertical Displacement on OZ	0.000706855		
5	Rigid mode – Front/Rear Displacement on OX	0.000702710		
6	Rigid mode - Giration	0.000825792		
7	Elevator Symmetrical Rotation	11.75	8.824	2.930
8	Ruddder Rotation	7.84	9.755	9.390
9	Symmetrical Wing Bending	11.23	10.151	10.320
10	Vertical Empennage Bending	17.32	14.878	14.560
11	Antisymetrical Horizontally Empennage Bending	19.62	18.864	17.320
12	Symmetrical Horizontally Empennage Bending	21.32	19.849	18.000
13	Vertical fuselage bending	18.30	20.581	24.550
14	Lateral fuselage bending	22.67	21.433	21.330
15	Antisymetrical Wing Bending	24.68	22.854	39.220
16	Antisymmetrical flap rotation	32.24	23.855/26.351	32.180/32.390
17	Antisymmetrical aileron rotation	19.36	34.200/36.304	25.110/25.750

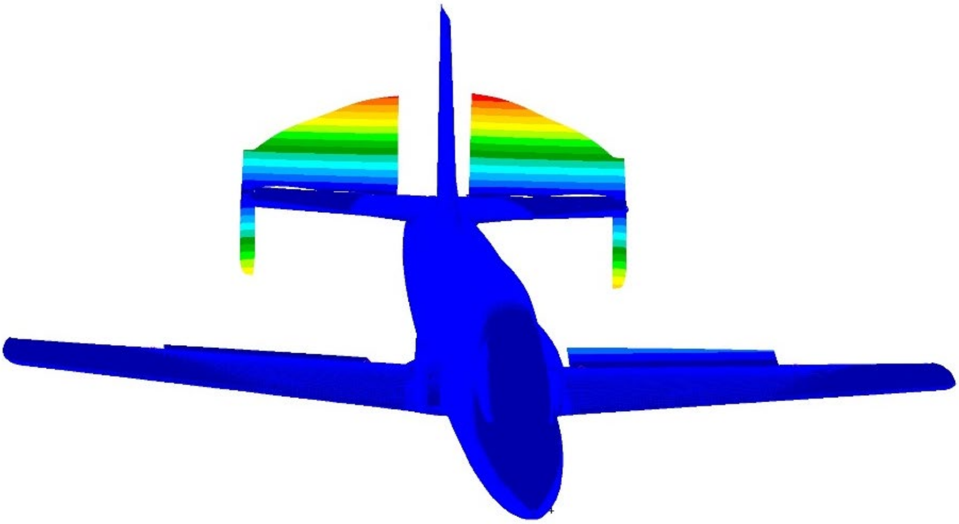


Fig. 5 Elevator Symmetrical Rotation: f = 11.75 Hz

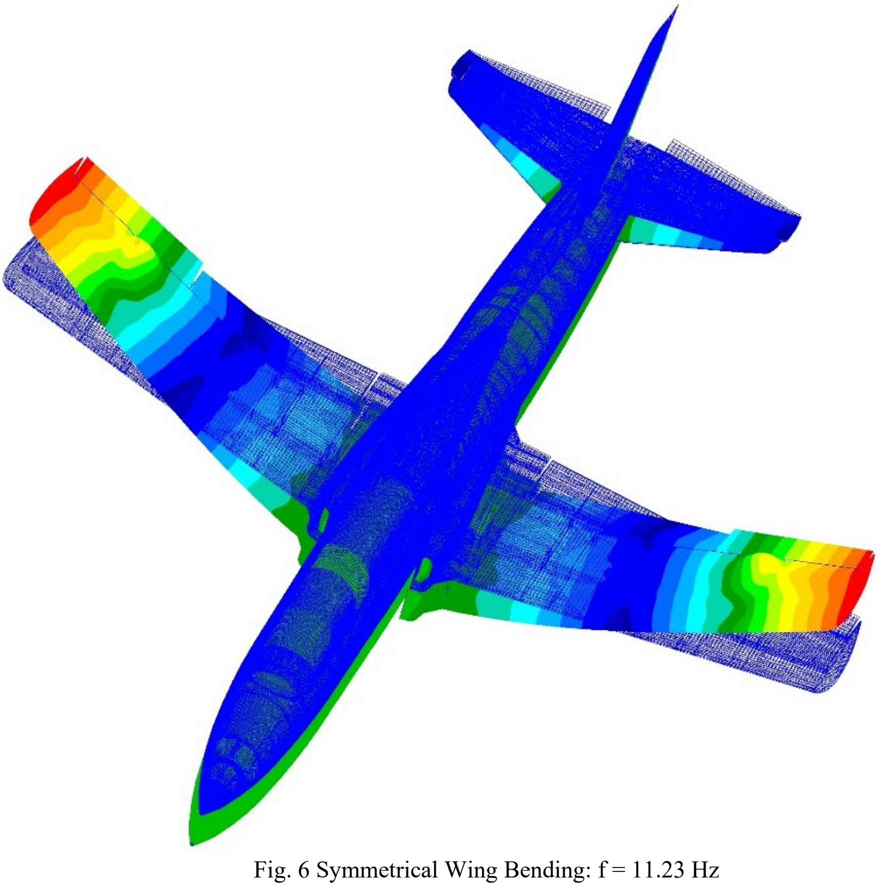


Fig. 6 Symmetrical Wing Bending: f = 11.23 Hz

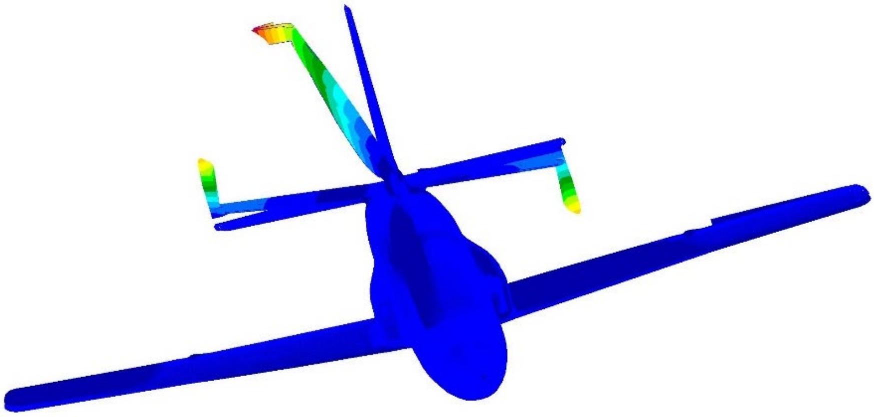


Fig. 7 Vertical Empennage Bending: f = 17.32 Hz

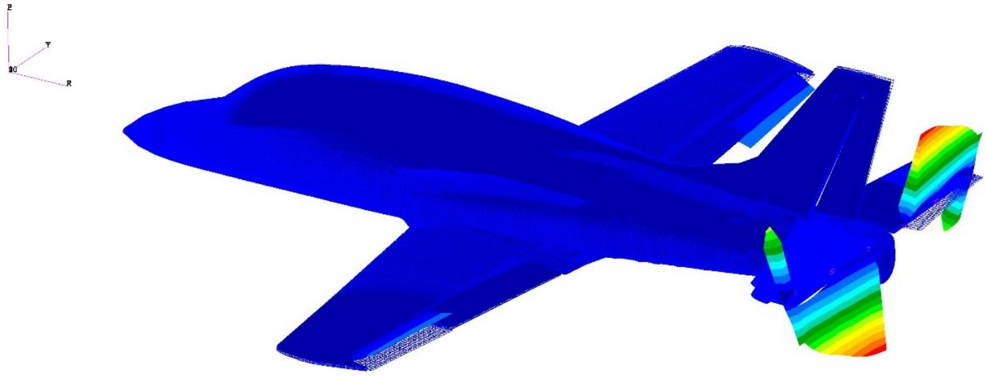


Fig. 8 Symetrical Horizontally Empennage Bending: f = 21.32 Hz

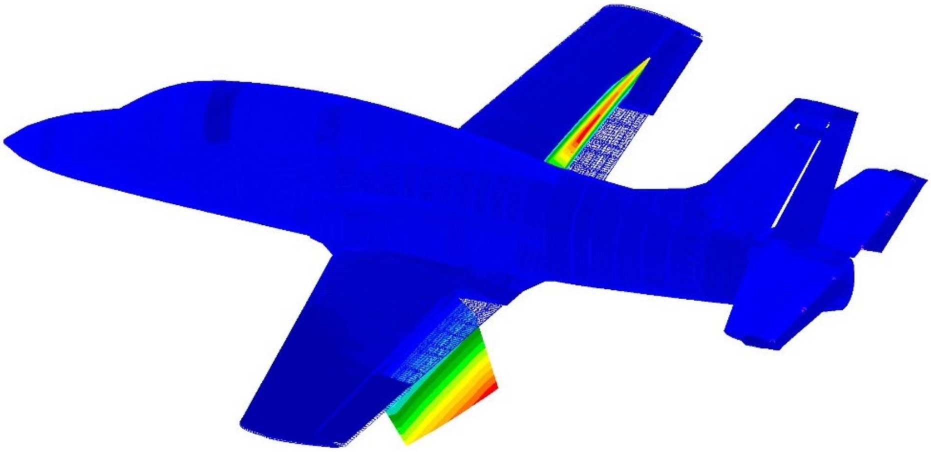


Fig. 9 Antisymmetrical flap rotation: f = 32.24 Hz

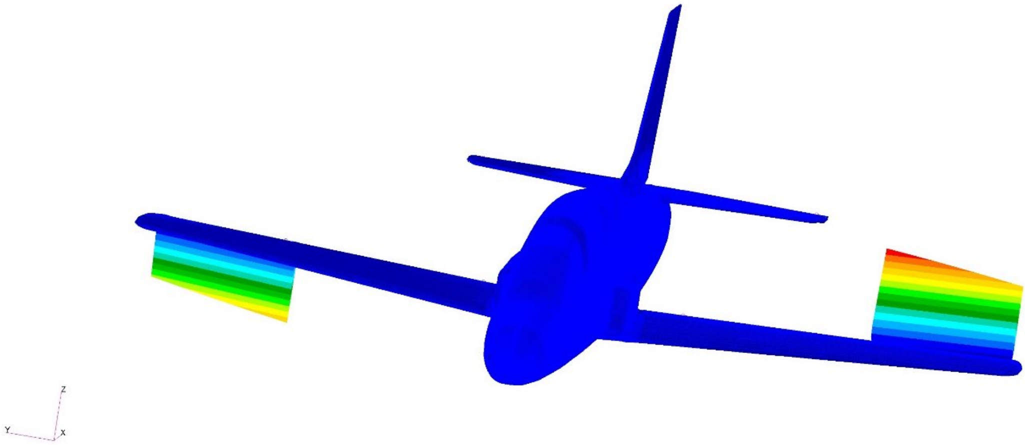
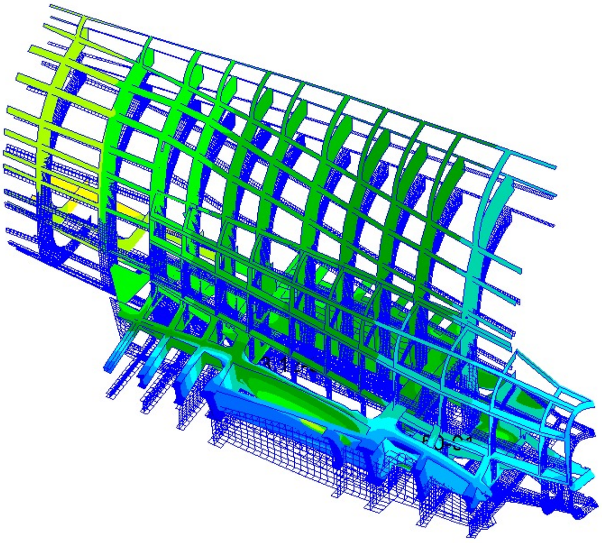
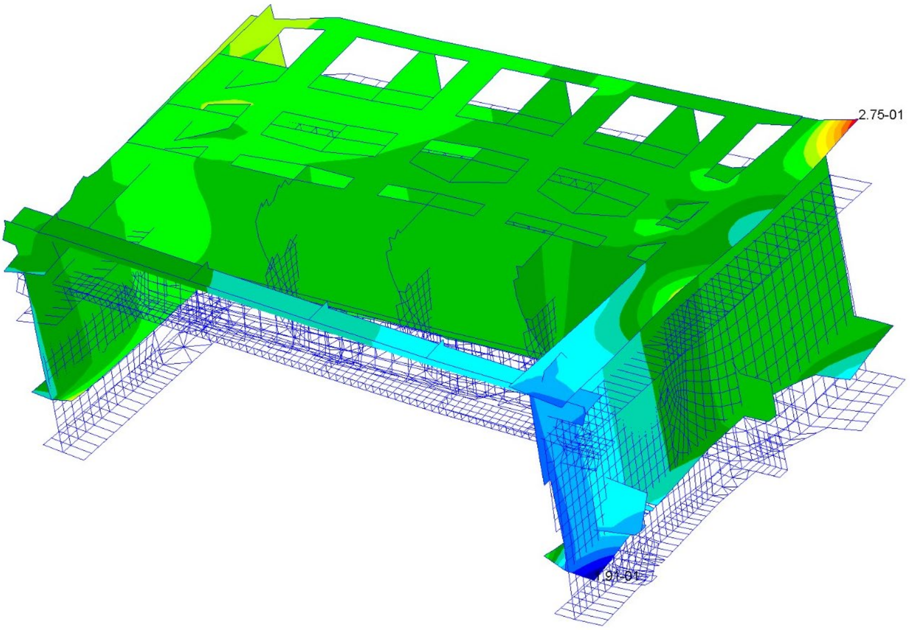


Fig. 10 Antisymmetrical aileron rotation f = 19.36 Hz

4. CONCLUSIONS

1. The new finite element model has been designed so that the geometric position of the rivets on the shell corresponds to the geometric position of the vertices in order to capture the real behavior of thin-walled structures used in aviation.
2. The model allows the visualization of the results and the study of the behavior of the structure at the local level (frames; lises; spars; frame-shell interaction, smooth-shell and spars-shell) in the case of global dynamic phenomena. Thus, it is possible to use a single model for simulating dynamic phenomena, in order to be able to draw conclusions at the local level of the structure with a global phenomenon, compared to the model in [6].
   For illustrative purpouses we can read the displacement and see the behaiviour of a the wing structure and the central fusselage at the wing bending frequency:

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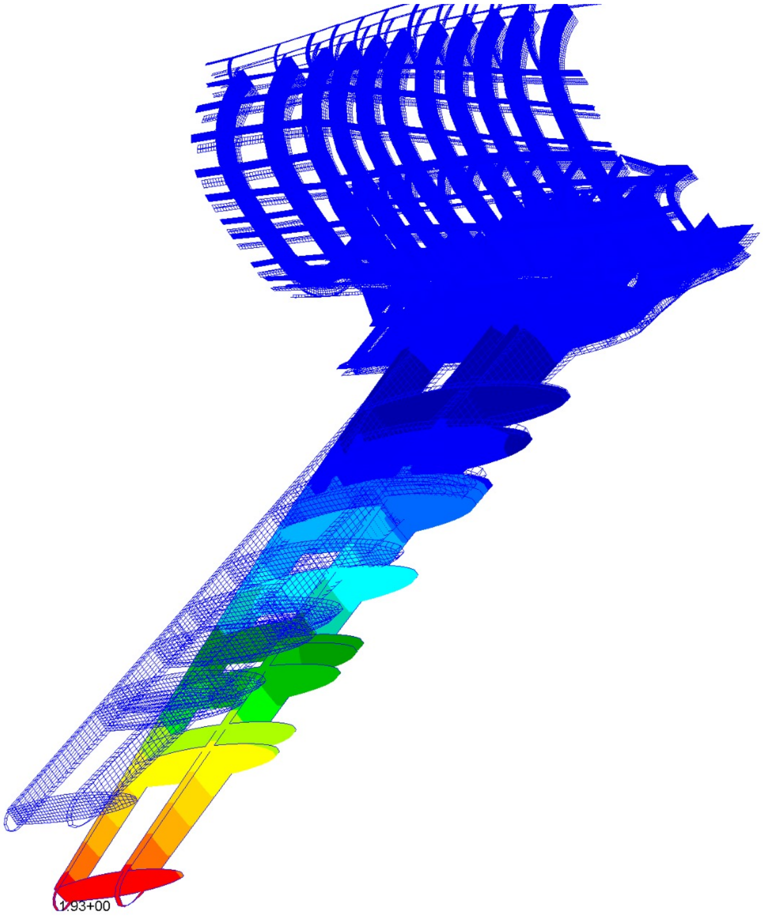
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3. The choice of a large number of nodes and elements ensures a particularly detailed FEM model and implies that the results obtained will be very close to the experimental findings from the ground vibration tests and the results of the dynamic analysis based on these tests.

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