Flutter Analysis Based on the New Numerical Model IAR-99 HAWK Empty Equipped Configuration Aircraft

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Abstract: *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 aerodynamic idealization of the IAR-99 aircraft was made using the DLM method for subsonic flow, also considering the load-bearing surface/fuselage interference and aims to determine the generalized aerodynamic forces that occur on one mode of vibration due to the influence of another mode of vibration. The flutter calculation for the IAR-99 HAWK empty equipped configuration aircraft was made using the p-K methodology presented in the MSC.Nastran program, using the vibration modes obtained on the basis of the new finite element model and the matrix of generalized aerodynamic forces in subsonic flow.*

Key Words: *aero elasticity, finite element method, finite element model, free-free vibrations, empty equipped configuration, ground vibration tests, subsonic flow, generalized aerodynamic forces, flutter, MSC. Nastran*

1. INTRODUCTION

A special place in the aeroelastic phenomenology is occupied by the phenomenon of flutter, which represents a type of aeroelastic instability in which the structure extracts energy from the airflow and its unstable self-excited oscillation can lead to catastrophic structural deformations. During flight, the aircraft structure is constantly subjected to intense dynamic

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pressure changes of varying magnitudes. The variable pressures exerted on the geometry, mainly of the load-bearing surfaces, can cause the appearance of redundant vibrations that can translate into aeroelastic instabilities, as it happens in the case of the flutter phenomenon.

Ever since the flight of the Wright brothers, Orville Wilbur Wright noticed the appearance of deformations of the wings of their biplane as an effect of the movement of the ailerons in flight. They were also aware of the occurrence of a negative effect at the time of twisting the propeller blades that led to their loss. They discovered that the propeller under high tensile loads twisted to partially discharge the accumulated energy.

The first major record of flutter was later considered to have belonged to the prominent British engineer and scientist F. W. Lanchester during World War I in the incident that occurred on the Handley Page 0/400 biplane bomber, as a result of the occurrence of violent antisymmetrical oscillations of the fuselage and tail, due to the chaotic movement of the depths. The right and left elevators of the aircraft were essentially independent, being flexibly connected to the stick by separate cables. Lanchester described the phenomenon on three pages, considering that the oscillations that appeared were not the result of resonance induced by possible vibratory sources, but were self-excited and it was necessary to increase the torsional rigidity of the depths by simply coupling the controls and thus the problem could also be eliminated. Only a year later, the de Havilland DH-9 experienced another tail flutter, which resulted in the death of the pilots and was solved by applying a treatment identical to that suggested by Lanchester, i.e. the realization of a rigid torsional connection between the elevator controls, a solution used in the design since then, Fig. 1.

Fig. 1 Bomber biplane, HANDLEY PAGE 0/400

We can consider the moment of the appearance of the "AEROELASTICITY" domain with the definition of Collar [2], [3], of the famous "Aeroelastic Triangle" and from that moment the problem of the aerodynamic interaction with the deformations of the structure, including inertial effects, was really raised.

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

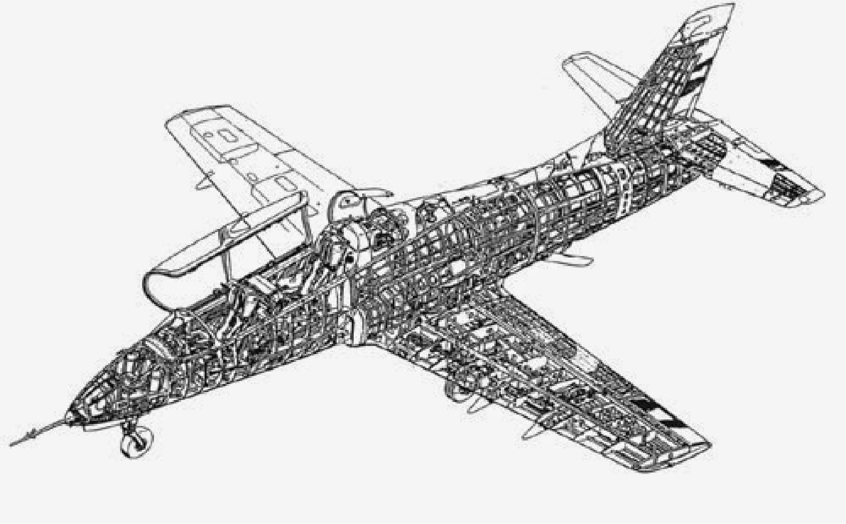


Fig. 2 Plane structure configuration, empty equipped

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 standardised 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 behaviour of thin-walled structures used in aviation.

Thus, the model developed 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 the connection between these elements, interconnection are presented in [5].

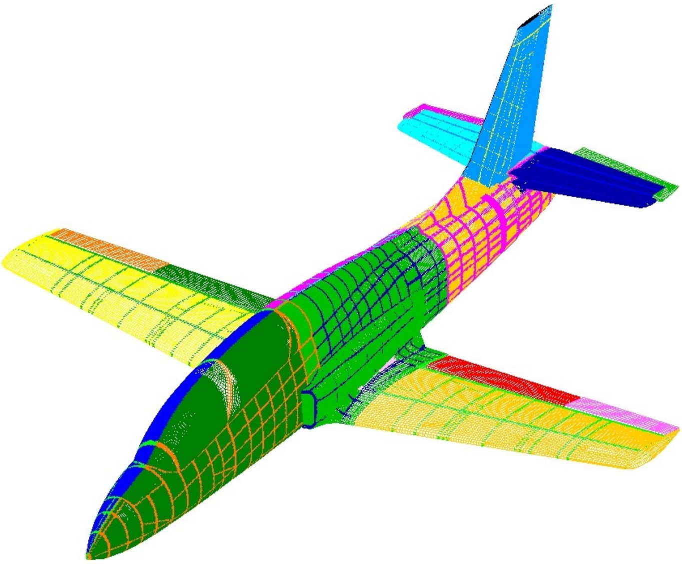


Fig. 3 FEM model for airplane configuration empty equippe

To illustrate the complexity of the new FEM model, produced for the IAR-99 HAWK aircraft, we present in Fig. 4 the FEM model, central fuselage-central caisson-wing assembly, interior view and in Fig. 5 the FEM model, rear fuselage-engine-horizontal empennage-vertical empennage assembly.

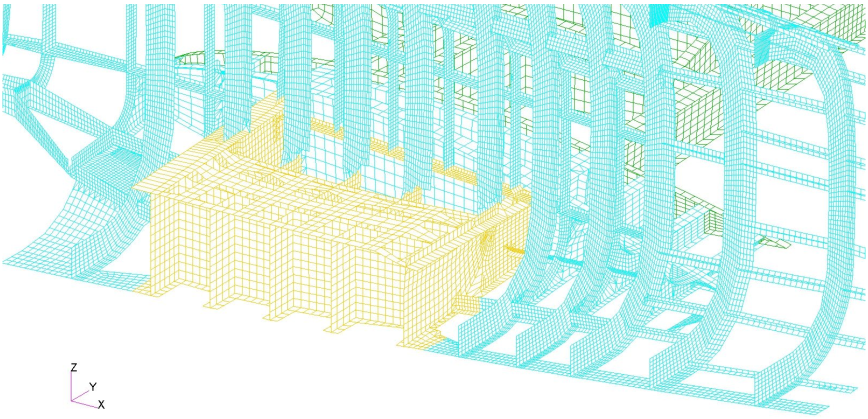


Fig. 4 FEM model, central fuselage-central caisson-wing assembly, interior view

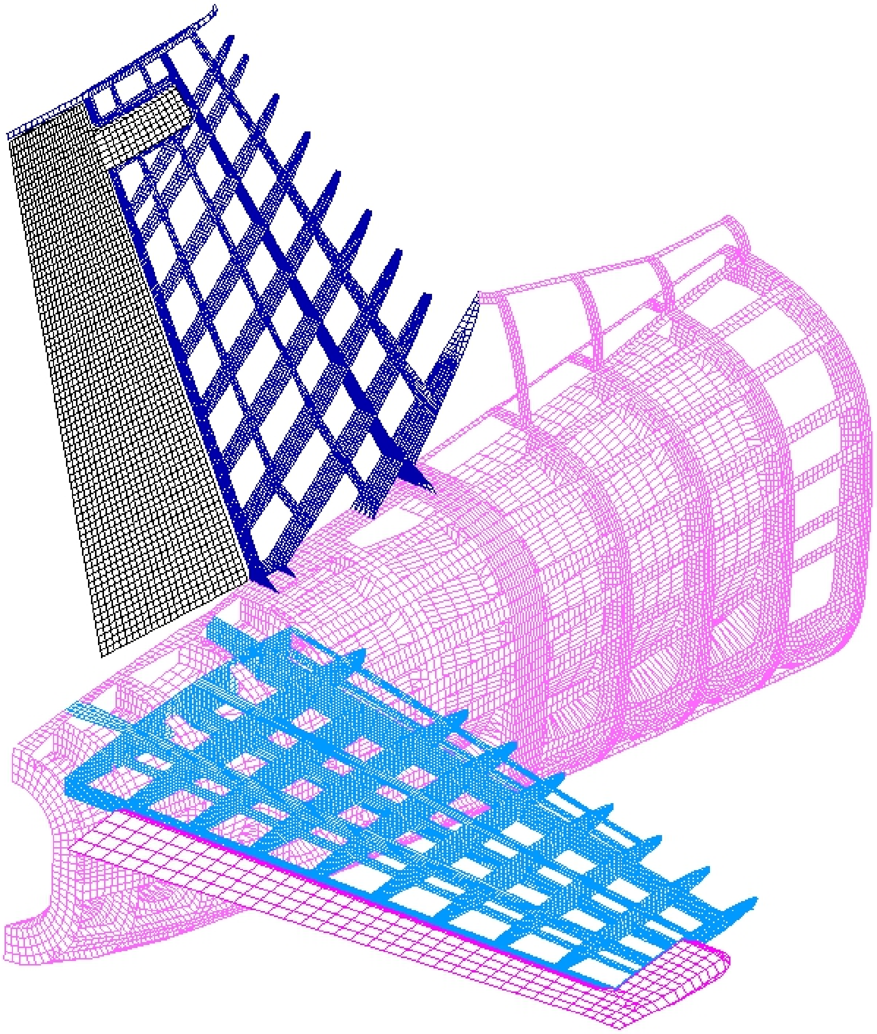


Fig. 5 FEM model, rear fuselage-engine-horizontal empennage-vertical empennage assembly

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 modes represented 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

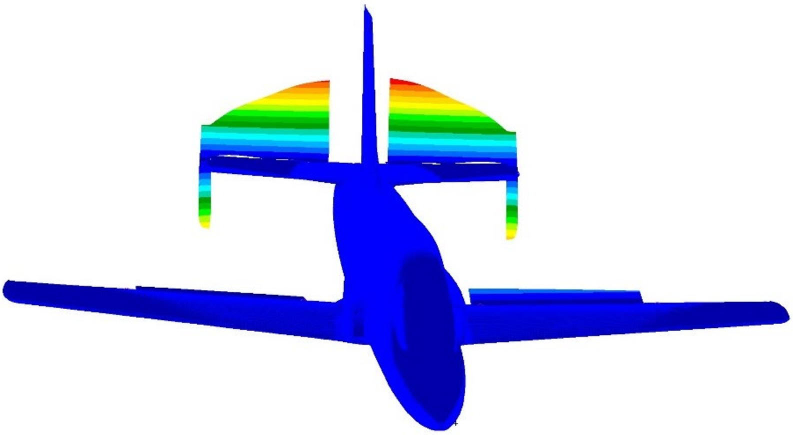


Fig. 6 Elevator Symmetrical Rotation: f = 11.75 Hz

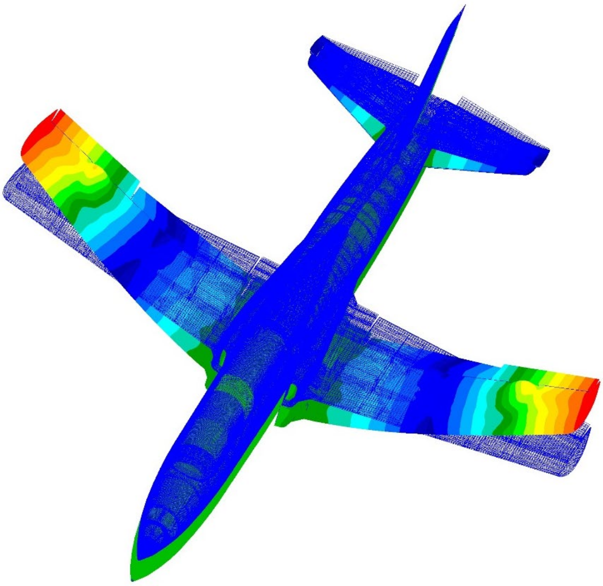


Fig. 7 Symmetrical Wing Bending: f = 11.23 Hz

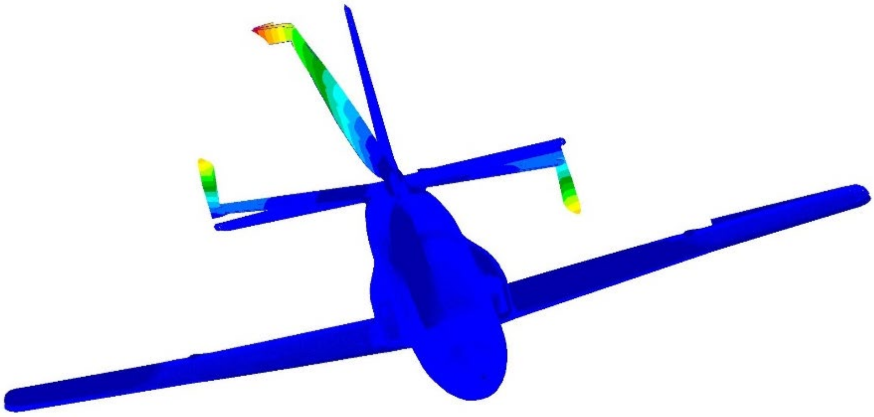


Fig. 8 Vertical Empennage Bending: f = 17.32 Hz

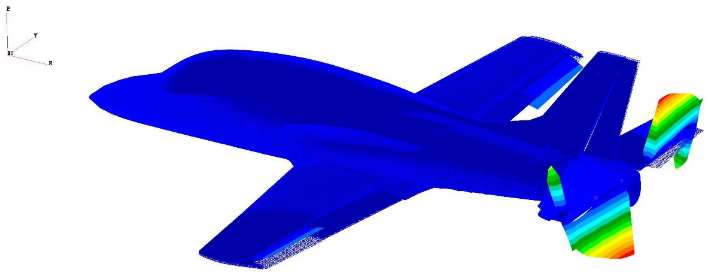


Fig. 9 Symetrical Horizontally Empennage Bending: f = 21.32 Hz

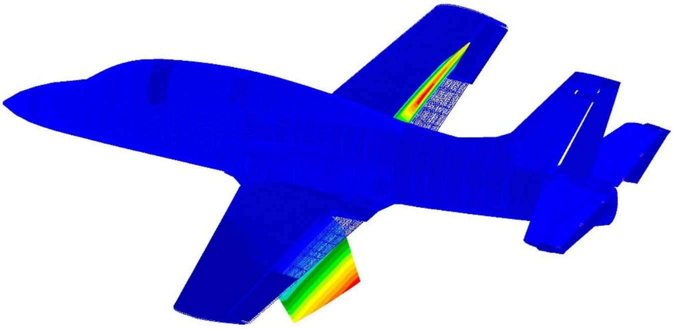


Fig. 10 Antisymmetrical flap rotation: f = 32.24 Hz

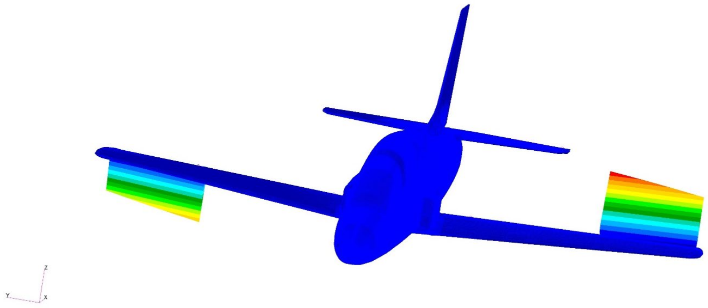


Fig. 11 Antisymmetrical aileron rotation f = 19.36 Hz

4. APPLICATION OF THE DLM METHOD TO THE CALCULATION OF GENERALIZED AERODYNAMIC FORCES ON THE IAR-99, HAWK AIRCRAFT, IN SMOOTH CONFIGURATION

Starting from the description of the aerodynamic modelling methodology in the DLM method, it is possible to define, for all the surfaces and aerodynamic bodies considered: wing, empennages and fuselage of the aircraft, the surfaces and the interference bodies, respectively into which they are divided. The input data for these idealizations of surfaces and bodies considered thin are respectively the chord and the span for the load-bearing surfaces and the length together with the thickness that define the bodies. It should be noted that the load-bearing surfaces as well as the thin bodies always cover the geometric surfaces considered in the FEM structural modelling of the aircraft.

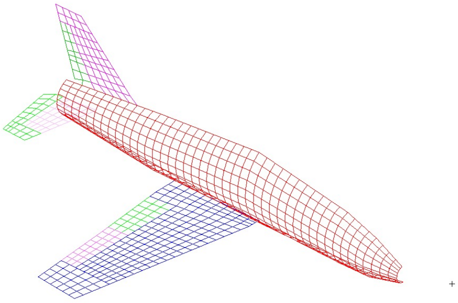


Fig. 12 The DLM methodology applied to the IAR-99 aircraft, in smooth configuration.

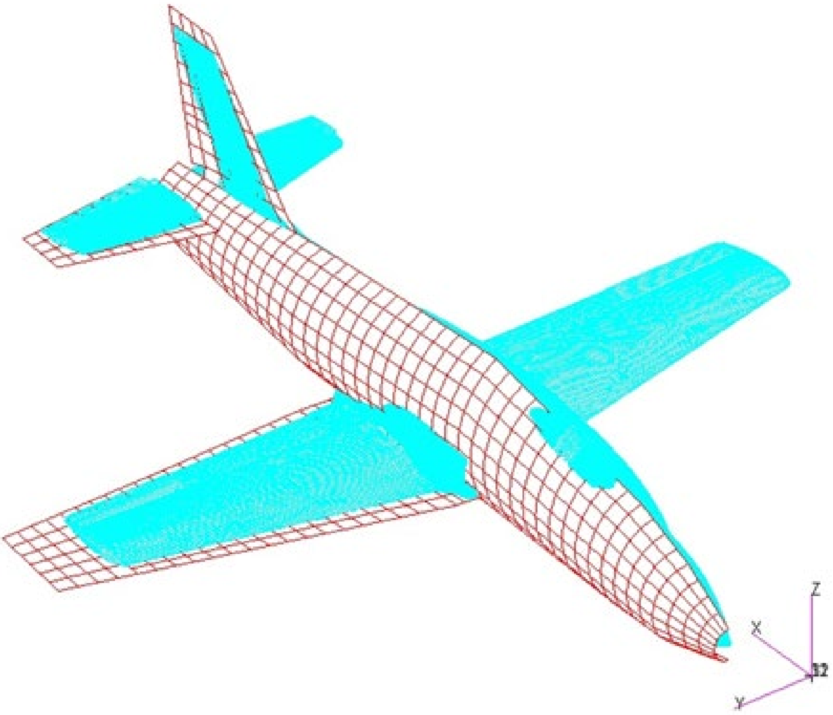


Fig. 13 Overlay of the DLM model over the FEM structural model, for IAR-99 aircraft, in smooth configuration.

5. RESULTS OF THE FLUTTER ANALYSIS OF THE IAR-99 HAWK AIRCRAFT, IN SMOOTH CONFIGURATION

It should be noted that by any of the flutter analysis methods: K, KE or PK, V-g curves (velocity – structure damping) are obtained for each vibration mode in the respective flutter combination studied.

The flutter combination must contain as many vibration modes as possible for a very complete analysis and then it can be determined which are the two modes responsible for the appearance of the flutter phenomenon, namely the excited mode, that leads to g = 0 and the exitation mode that induces the loss of damping on this excited mode.

The V-g curves were plotted for a first 10 elastic vibration modes to make it easier the flutter analysis which was carried out at H = 0; 1500; 3000; 5000 m to comply with the data in the Maneuver Diagram and the limits given by the Flutter Safety Margin, representing 1.15*DV.

The V-g curves plotted firstly highlight the fact that the IAR-99 aircraft is flutter free in the smooth configuration, the speed of 1.2 MACH placing us well above the Safety Margin in the Manoeuvering Diagram. From the present flutter calculation we get a flutter velocity in the supersonic range and a binary flutter analysis, considering the excited mode and the excitant mode respectively is not relevant in the subsonic range.

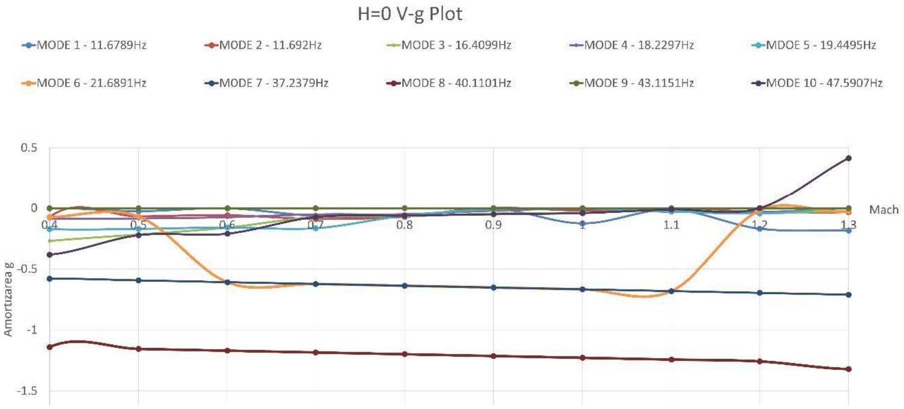


Fig. 14 Curves V-g, H=0m, for the combination of modes 1-10, Table 3.

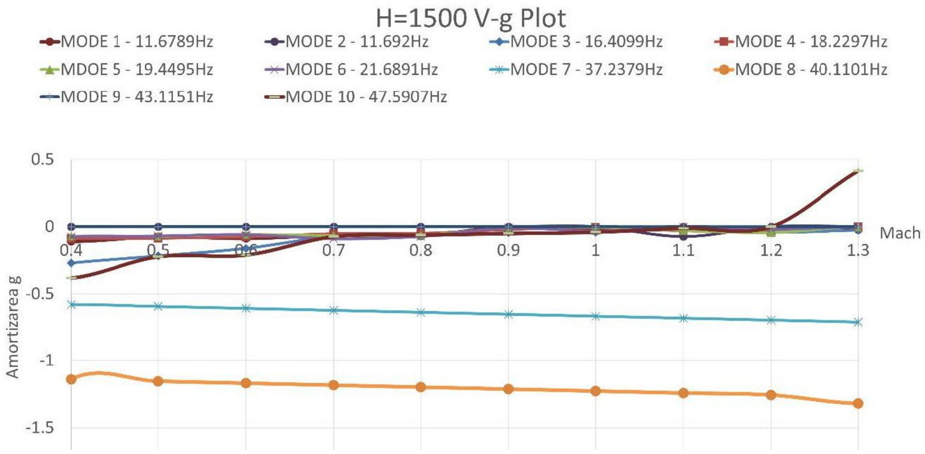


Fig. 15 Curves V-g, H=1500 m, for the combination of modes 1-10, Table 3.

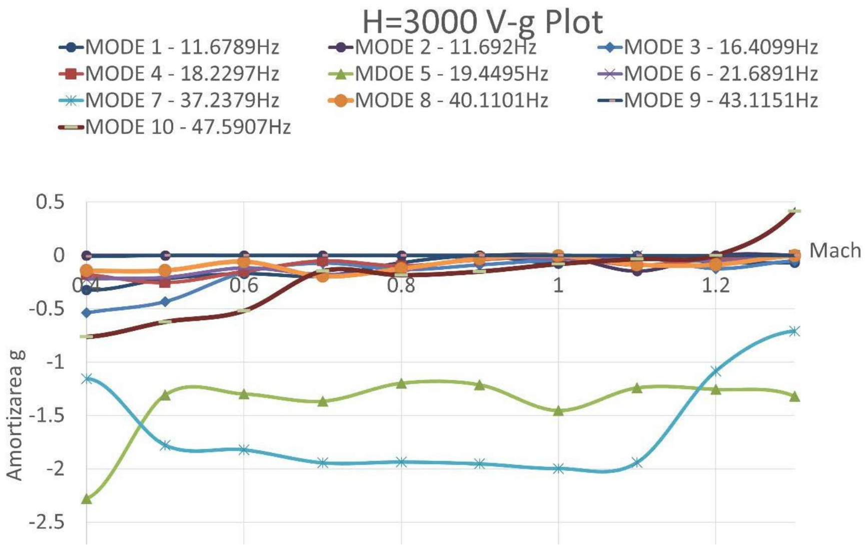


Fig. 16 Curves V-g, H=3000 m, for the combination of modes 1-10, Table 3.

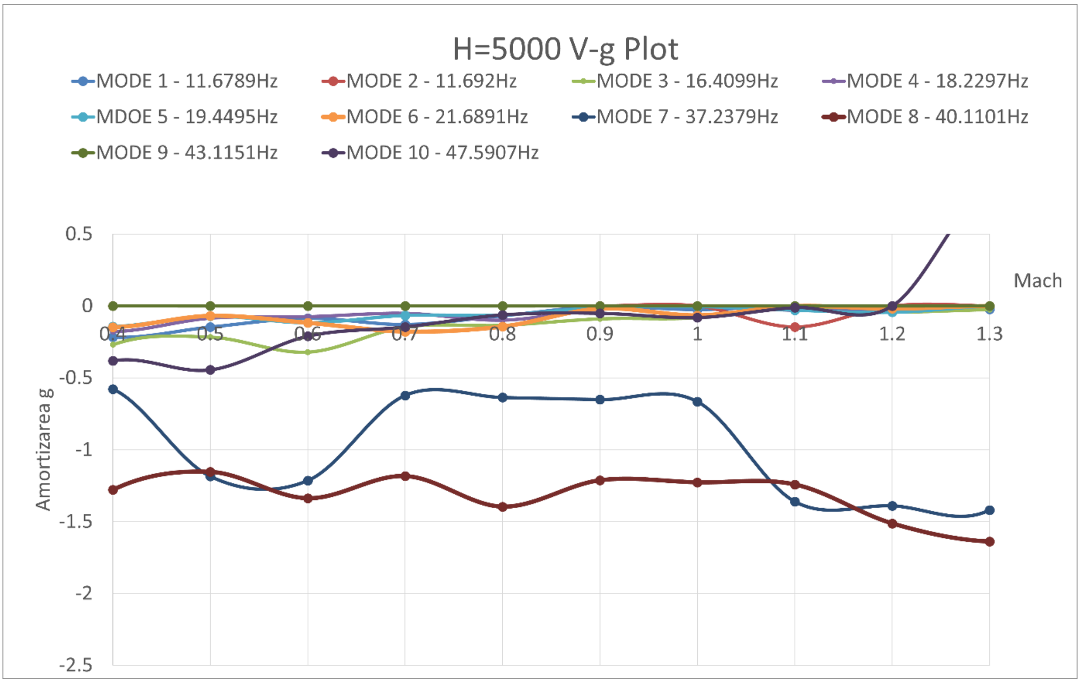


Fig. 17 Curves V-g, H=5000 m, for the combination of modes 1-10, Table 3.

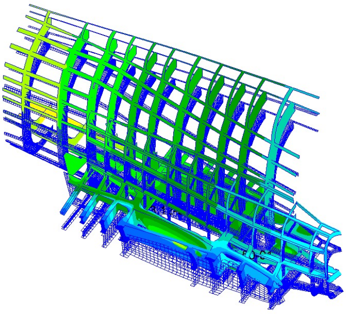
6. CONCLUSIONS

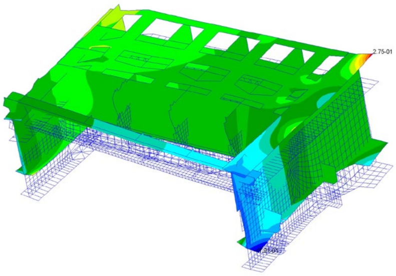
1. Any research, papers, studies, reports and/or doctoral theses that touch, at least tangențiala, on the subject of flutter shall propose a solution to eliminate this aeroelastic phenomenon when it occurs in the flight envelope of the aircraft, in accordance with its design requirements.

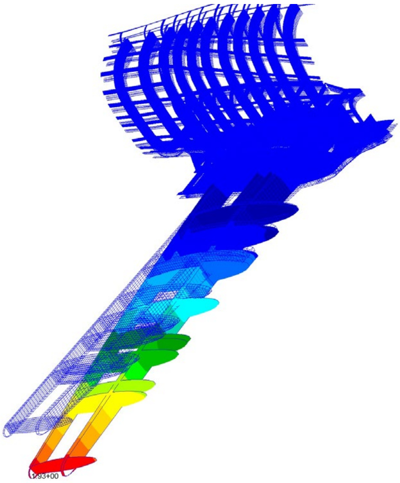
2. Whatever path a researcher takes in the field of flutter study, he will permanently combine analytical methods with experimental methods. Going through some stages of numerical analysis: the mass model; the elastic model; the calculation of free vibrations; the calculation of the stationary aerodynamic forces; the flutter calculation; will be validated or updated by experimental methods: ground vibration tests; wind tunnel tests on scale models; in-flight flutter tests.

3. The new FEM finite element model presented in this thesis allows both the visualization of the results and an analysis of the behavior of the structure up to the local level (frames; lises; spars; frame-body, shell-body and longeron-body interaction) in the case of global dynamical phenomena. Thus, it is possible to use a single FEM model for the simulation of dynamic phenomena, in order to be able to draw conclusions on the behaviour of the structure up to the local level in the case of studying a global aeroelastic phenomenon.

In the present case regarding the flutter analysis of the IAR-99 HAWK, aircraft, smooth configuration, we can exemplify on the symmetrical bending mode of the wing, the behaviour of the wing – central caisson assembly, the displacement in different selected nodes can be easily read and the appearance of the behaviour of the wing structure and/or the central fuselage at the wing bending frequency can be visualized:







This advantage is given by the new FEM model, which allows this analysis to be carried out on structural elements and nodes.

Under these conditions, the proposed flutter analysis methodology based on the new FEM model also has a very useful feedback, starting from the mode(s) responsible for flutter, for the excited elastic and the exciting mode, respectively, the displacements that occur in different nodes or precisely individualized elements can be identified.

4. The use of analytical methods for the analysis of free vibrations, the calculation of stationary aerodynamic forces and flutter calculation aims to reduce the high costs involved in ground vibration tests, tests on models in wind tunnels and last but not least in-flight flutter tests. These analytical methods are previously validated, as is the case with the MSC program. Nastran.

5. The DLM method used for unsteady aerodynamic idealization in subsonic mode provides a very good approximation for obtaining results for load-bearing surface configurations with interference bodies (e.g. fuselage).

6. The flutter analysis performed on the new FEM model of the IAR-99 aircraft, FALCON in smooth configuration and in different variants of hitches, leads us to the conclusion that in any analyzed configuration the aircraft is free of flutter inside the maneuver diagram [6], [7].

7. The V-g curves plotted firstly highlight the fact that the IAR-99 aircraft is flutter free in the smooth configuration, the speed of 1.2 MACH placing us well above the Safety Margin in the Manoeuvering Diagram. From the present flutter calculation we get a flutter velocity in the supersonic range and a binary flutter analysis, considering the excited mode and the excitant mode respectively is not relevant in the subsonic range.

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