

Flutter Analysis Methodology for Military Aircraft with External Stores – IAR-99 HAWK

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Abstract: The new Finite Elements Model (FEM) allows the visualization of the results and the study of the behavior of the structure at the local level (frames stringers; spars; frame-body, shell-body and longeron-body interaction) in the case of global dynamical phenomena. After creating FEM of the aircraft IAR-99 HAWK in the empty equipped configuration using special elements, the team decided to extend the study of flutter to aircraft in different external stores configurations. The results of the theoretical free-free vibrations obtained for the IAR-99 HAWK in different external stores configurations 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 HAWK in external stores configurations aircraft was made using the Doublet Lattice Method (DLM) for subsonic flow, also considering the load-bearing wing/fuselage/pylon/store interference and aims to determine the generalized aerodynamic forces. The flutter calculation for the IAR-99 HAWK in external stores configurations 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. The V-g curves drawn lead us to flutter speeds outside the safety margin related to the maneuvering diagram, according to the regulations in force, both in the case of the plane in smooth configuration and the plane in the selected external storers variants.

Key Words: Aeroelasticity, Finite Element Model (FEM), Empty Equipped Configuration, External Stores Configurations, Subsonic Flow, Flutter, MSC.PATRAN, MSC.NASTRAN

1. INTRODUCTION

Attached stores can be defined as any object, such as engines, cannon and/or additional fuel tank or other types of armament, that are attached either to the wing in various positions in the wingspan and to the chord and/or under the fuselage. This diversified typology for couplings makes us think first about military aviation, in commercial aviation we can consider a variant

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with couplings, attached engines and some variants with additional tanks at the top of the plane. The analysis of the flutter with stores, viewed from the broader perspective of aeroelastic research, emerged after World War II in the field of aviation, when, on the one hand, many of the questions raised during the war began to be re-asked, and the designers' answers were expected and necessary [10]. The problems resulting from the interaction of wing/stores in aviation, especially in military aviation, become under these conditions a subject of maximum interest in the aeroelastic community. The complexity of the interaction between aerodynamics and structure makes researchers continue to develop truly reliable concepts, which can often eliminate the dangerous effects of self-induced oscillations that occur in the different wing/store configurations.

It has been found that flutter usually occurs when the fundamental frequency of wing bending is coupled with any of the torsional frequencies of the wing or with oscillation frequencies occurring during typical movements of some hitches or on the occasion of their release. With the evolution at increased speeds, there will be increases in dynamic pressure and there will be pitch oscillations of the hooked body and changes in the bending frequencies of the wing. Under these conditions, they can coincide with either or both of the torsional frequencies of the wings or stores. At this critical velocity, if two natural frequencies coincide, the probability of flutter occurrence increases. Mounted stores, which have the effect of reducing both the fundamental wing bending frequencies and the torsional frequencies at high speeds, can thus cause a critical speed resulting from the combination of the two frequencies, which is reached earlier, and the flutter can become a threat right inside the flight tire.

In the 1970s the wing/stores flutter became an interesting research topic and under these conditions many advances were made. Much of the research at the time was also carried out using the wind tunnel study on models and later the validation of the results obtained through flight tests. In 1973 Triplett et al. [7] of the McDonnell Aircraft Company investigated for the first time analytically the possibility of eliminating the appearance of the flutter on the wing/store assembly. Today the topic of wing/stores flutter continues to be of great interest, but especially from an analytical point of view. Most of the published research concerns the improvement of existing concepts in terms of reliability and structural robustness. The increased performance of computers provides reasons for advanced analysis and finding new numerical methods for determining limits and ways to eliminate flutter, [16].

2. The FEM Model of the IAR-99, Hawk in Different Store Configurations

2.1 General Description of the IAR-99 HAWK, in Different Store Configurations

The IAR-99 aircraft had its first flight on December 21, 1985. The aircraft was designed in accordance with the requirements of the military regulation MIL 8870-ASG. [15]. The flutter analysis was performed using a model in bar theory on which the free vibrations, the aerodynamic forces generalized by the DLM method were calculated, considering only the lifting surfaces and finally the V-g method was applied, [4].

The IAR-99, HAWK aircraft is a single-engine, school-training and ground attack aircraft, with various stores configurations [1], 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, Figure 1.

A military aircraft, by the nature of its evolutions and especially of the missions it has to fulfill, is characterized by the hooked stores it carries and the speed restrictions to which the

structure is subjected in the various variants of hooks.



Figure 1. The IAR-99 HAWK aircraft, in configurations with hooked stores

2.2 The New FEM Model of the IAR-99 HAWK Aircraft, in Different Store Configurations

Based on the methodology developed by MSC. NASTRAN, [2] has developed a new Finite Elements Model (FEM), based on the refinements developed in [9] for modeling and in [14] respectively, allows the visualization of the results and the study of the behavior of the structure at the local level (frames; stringers; spars; frame-body, shell-body and longeron-body interaction) in the case of global dynamical phenomena.

In the description of the new FEM model of the aircraft, in this case in attachment configurations, we consider first of all the attachment pylons under the wing:

Under these conditions, the wing with the two pylons will have the following image for FEM modelling:

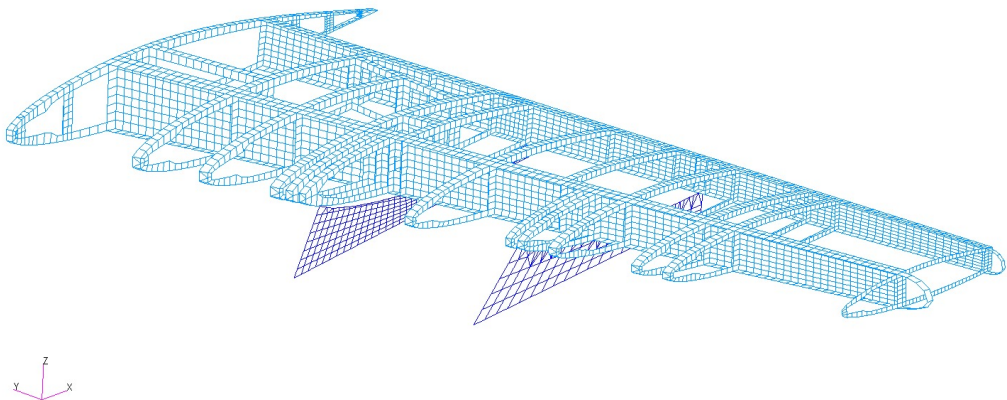


Figure 2. FEM model, wing detail with pylons

While the FEM model for the entire aircraft is:

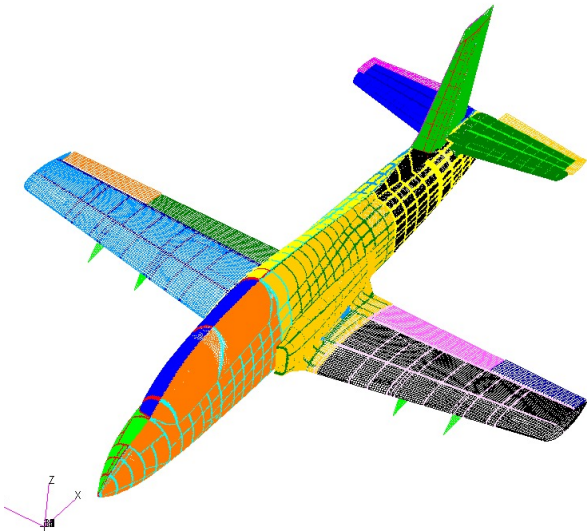


Figure 3. FEM model airplane with hooking pylons

Based on the FEM models of the hitches together with the FEM model of the IAR-99 Hawk aircraft, in smooth configuration, we will have the following FEM models of the aircraft in the configurations of stores chosen for analysis: Figures 4, 5, 6, 7, and Tables 1, 2, 3, 4.

Table 1. FEM, A Configuration

	No. of knots	No. elements	CTRIA3	CQUAD4
SMOOTH CONFIGURATION	565551	584794	26164	558630
2 * ADDITIONAL TANK	528	504	4	500
2 * LAUNCHER 16*57	1456	1498	90	1408
TOTAL	567535	586796	26258	560538

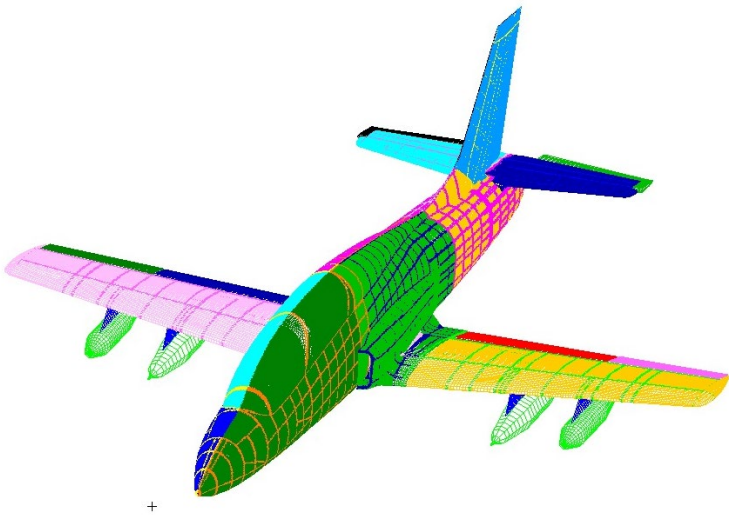


Figure 4. A Configuration

Table 2. FEM, B Configuration.

	No. of knots	No. elements	CTRIA3	CQUAD4
SMOOTH CONFIGURATION	565551	584794	26164	558630
4 * B-250	2888	2192	0	2192
TOTAL	568439	586986	26164	560822

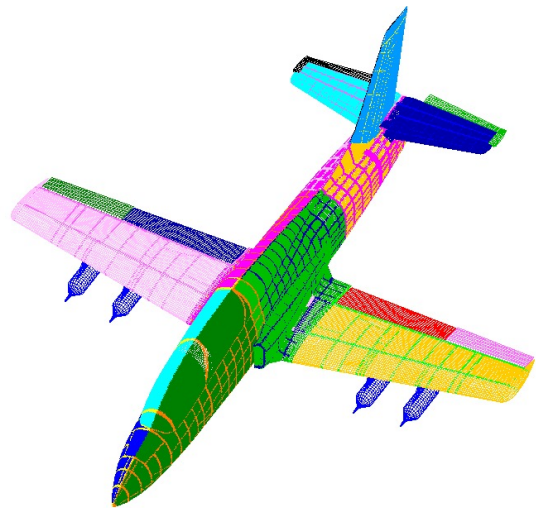


Figure 5. B Configuration

Table 3. FEM, C Configuration

	No. of knots	No. elements	CTRIA3	CQUAD4
SMOOTH CONFIGURATION	565551	584794	26164	558630
4 * 2 * B-100	10868	10438	304	10132
TOTAL	576419	595232	26468	568764

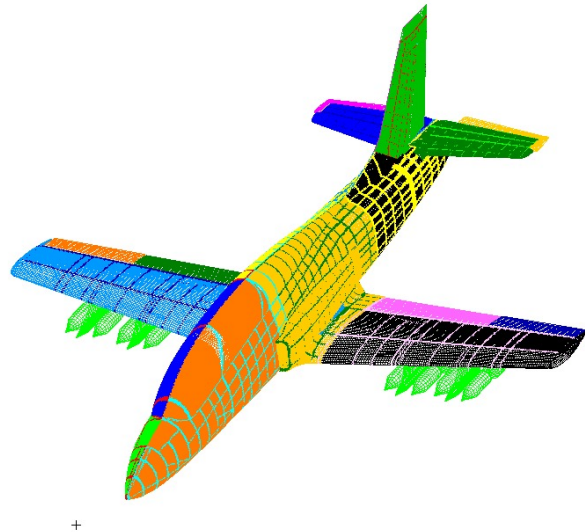


Figure 6. C Configuration

Table 4. FEM, D Configuration.

	No. of knots	No. elements	CTRIA3	CQUAD4
SMOOTH CONFIGURATION	565551	584794	26164	558630
2 * 2 * B-100	5434	5218	152	5066
2 * LANSATOR PR 32*42	2464	2408	0	2408
TOTAL	573449	556420	26316	566104

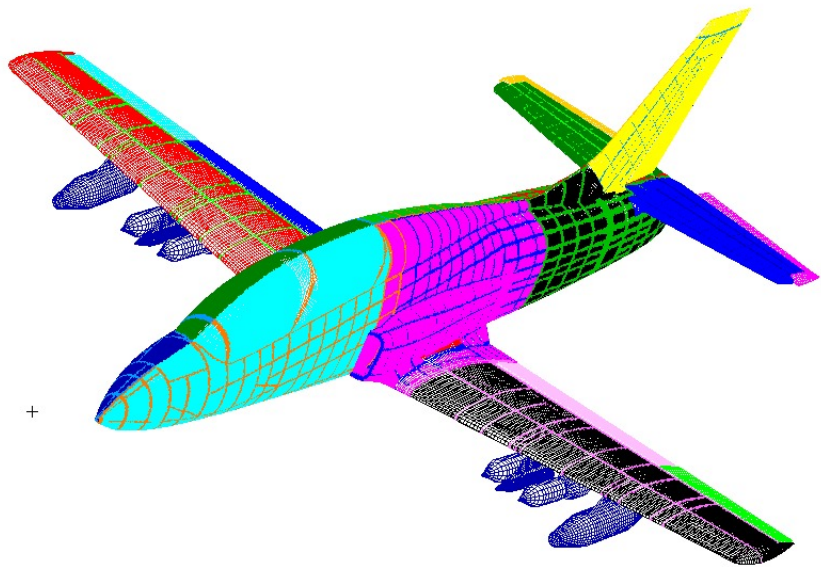


Figure 7. D Configuration

3. VIBRATIONS, [3]

3.1 Vibration Characteristics, A Configuration

Patran 2020 11-Nov-24 13:12:40
Fringe: SC1.DEFAULT, A1.Mode 1: Freq=0.000533691, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SC1.DEFAULT, A1.Mode 1: Freq=0.000533691, Eigenvectors, Translational,

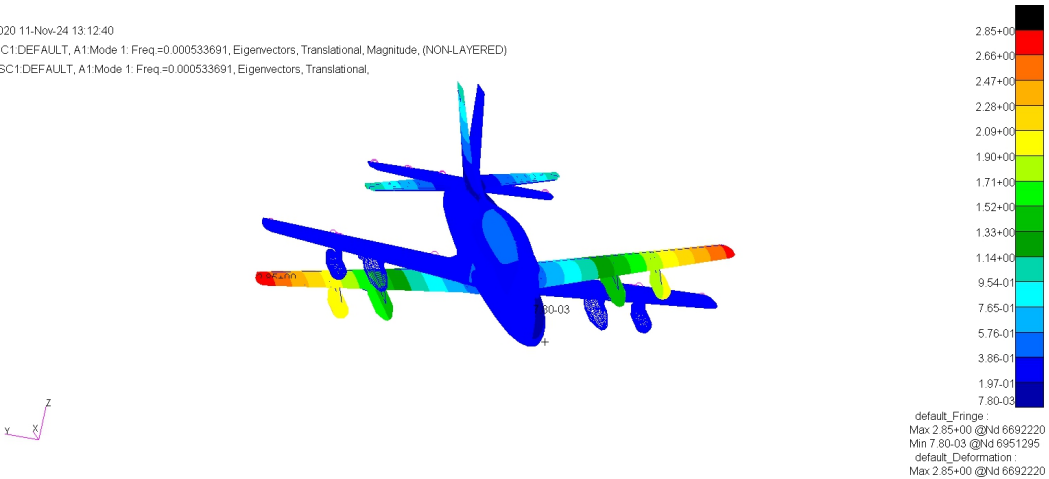


Figure 8. Rigid Mode – Roll: f = 0.000533691 Hz

Patran 2020 11-Nov-24 13:17:58
Fringe: SC1.DEFAULT, A1.Mode 15: Freq.=15.9148, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SC1.DEFAULT, A1.Mode 15: Freq.=15.9148, Eigenvectors, Translational,

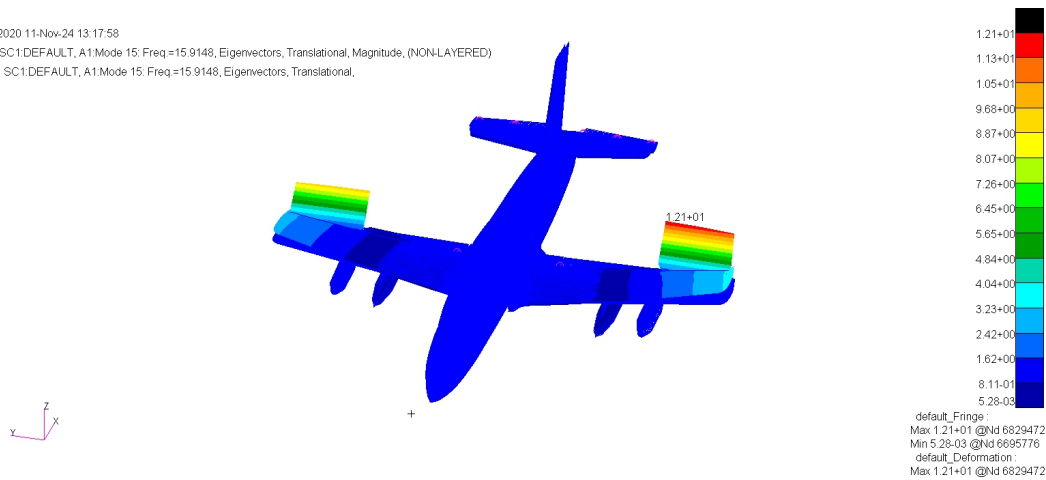


Figure 9. Symmetrical wing bending: $f = 15.9148$ Hz

Patran 2020 11-Nov-24 13:20:42
Fringe: SC1.DEFAULT, A1.Mode 26: Freq.=40.2935, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SC1.DEFAULT, A1.Mode 26: Freq.=40.2935, Eigenvectors, Translational,

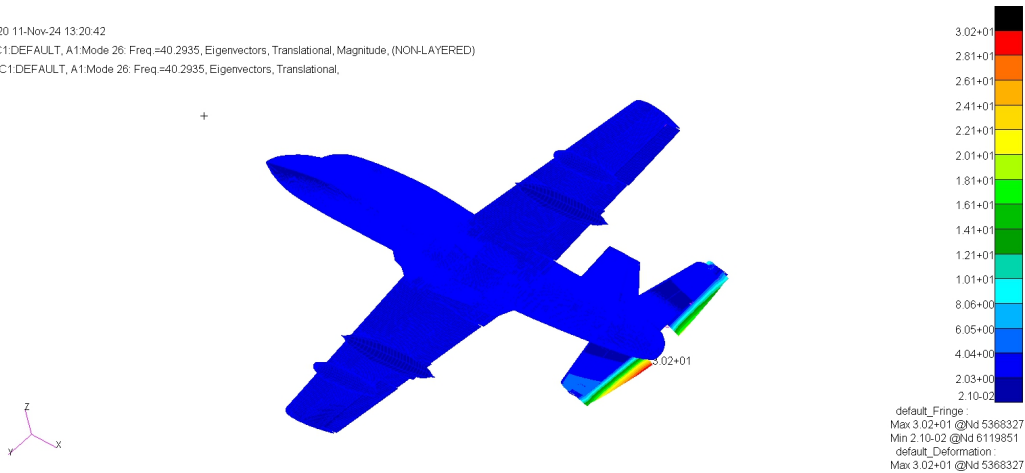


Figure 10. Elevator symmetrical rotation: $f = 40.2935$ Hz

3.2 Vibration Characteristics, B Configuration

Patran 2020 11-Nov-24 21:31:10
Fringe: SC1.DEFAULT, A1.Mode 4: Freq.=0.00190711, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SC1.DEFAULT, A1.Mode 4: Freq.=0.00190711, Eigenvectors, Translational,

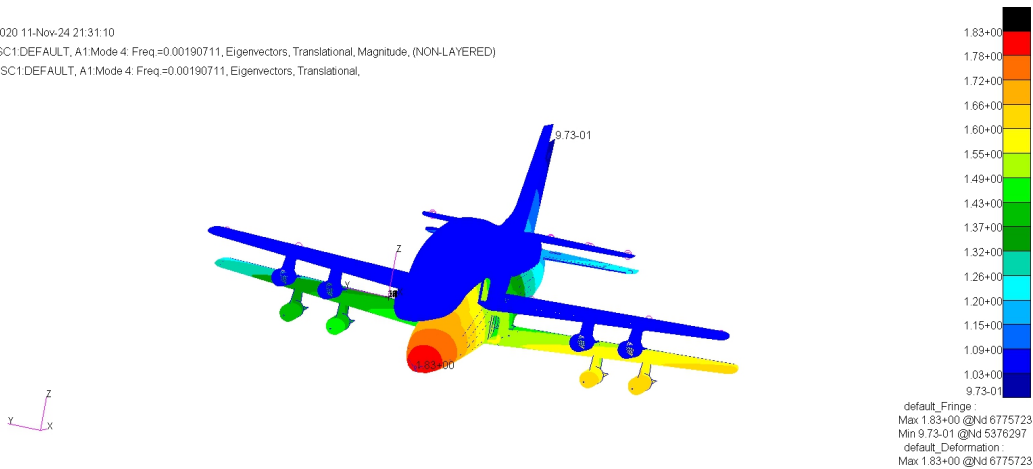


Figure 11. Rigid Mode – Vertical Displacement on OZ: $f = 0.00190711$ Hz

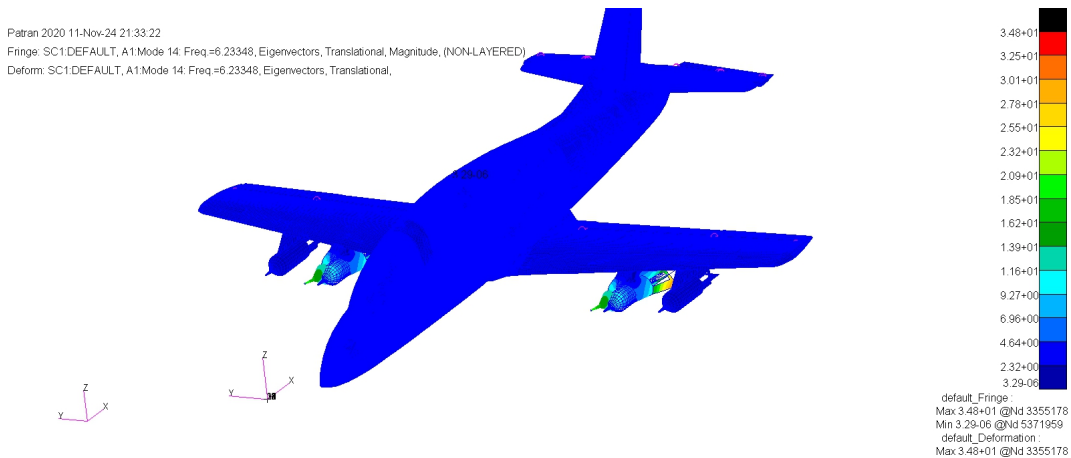


Figure 12. Antisymmetrical Interior Bombs Gyration: $f = 6.23348 \text{ Hz}$

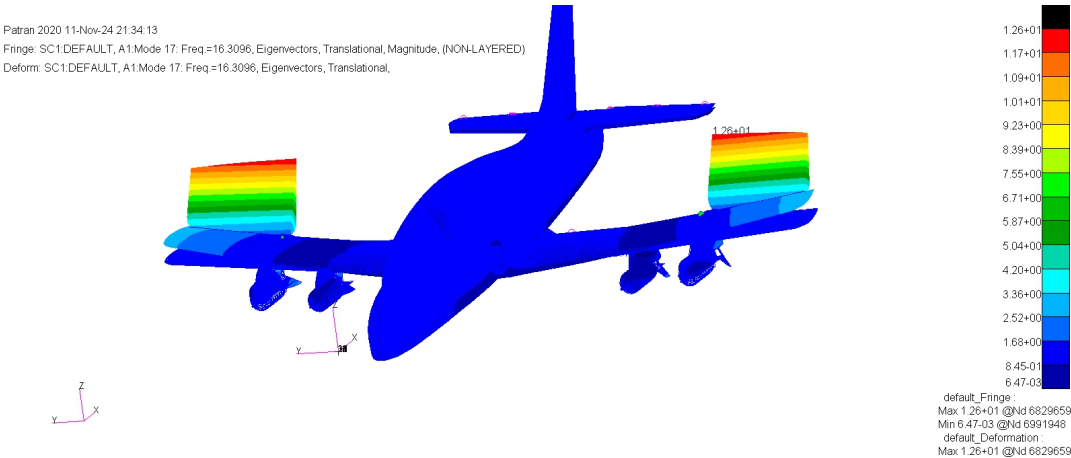


Figure 13. Symmetrical wing bending: $f = 16.3096 \text{ Hz}$

3.3 Vibration Characteristics, C Configuration

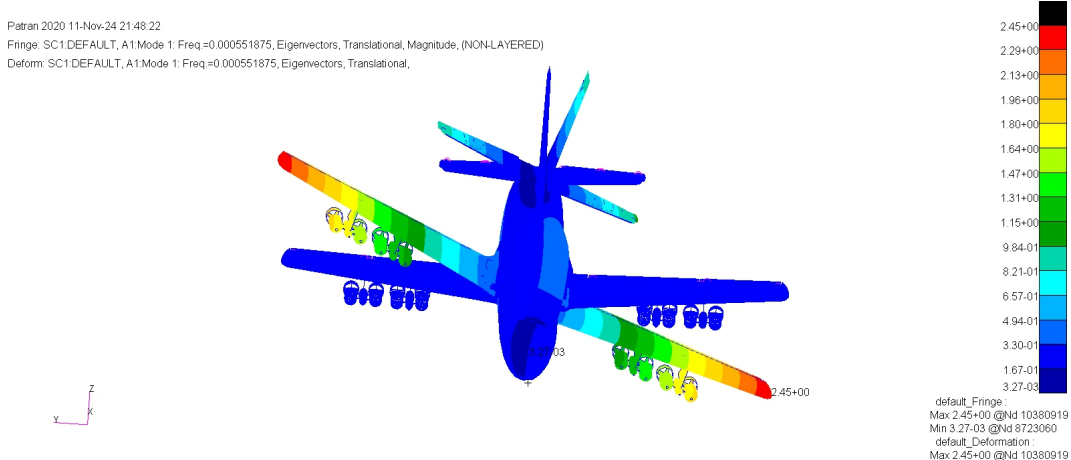


Figure 14. Rigid Mode – Roll: $f = 0.000551875 \text{ Hz}$

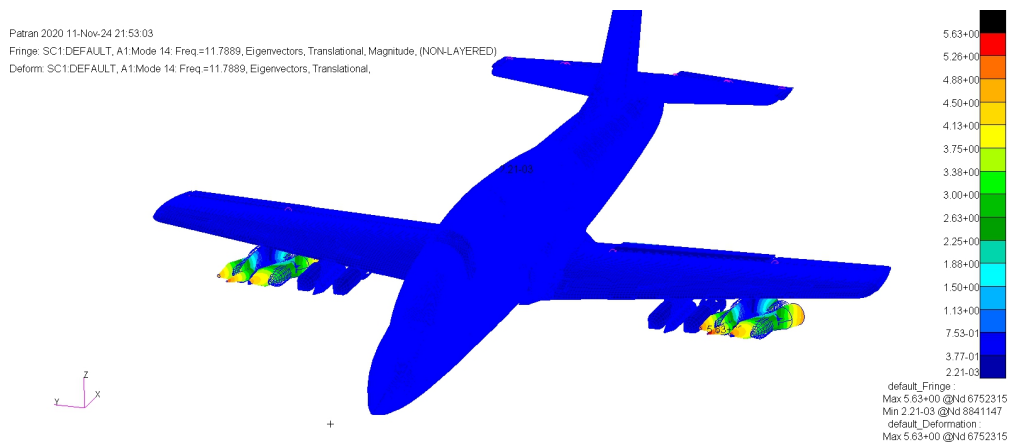


Figure 15. Antisymmetrical External Bomb Gyration: $f = 11.7889$ Hz

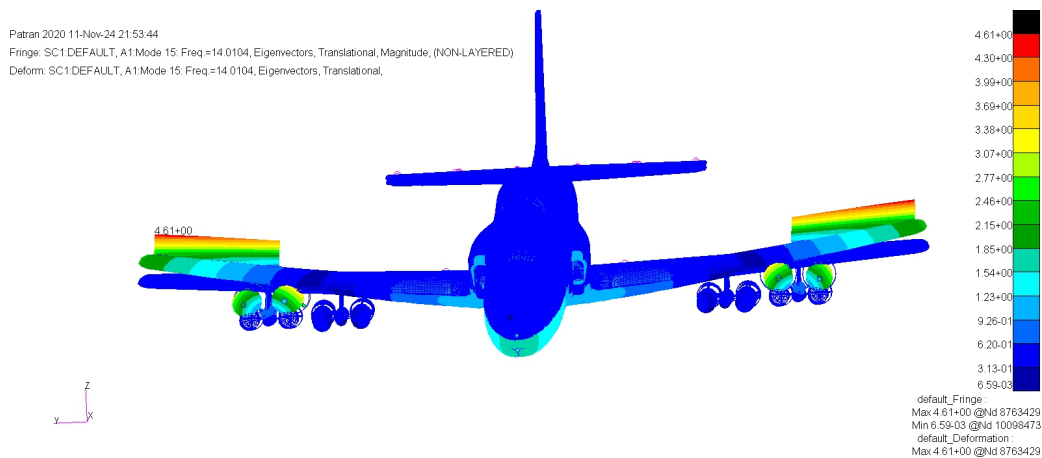


Figure 16. Symmetrical wing bending:: $f = 14.0104$ Hz

3.4 Vibration Characteristics, D Configuration

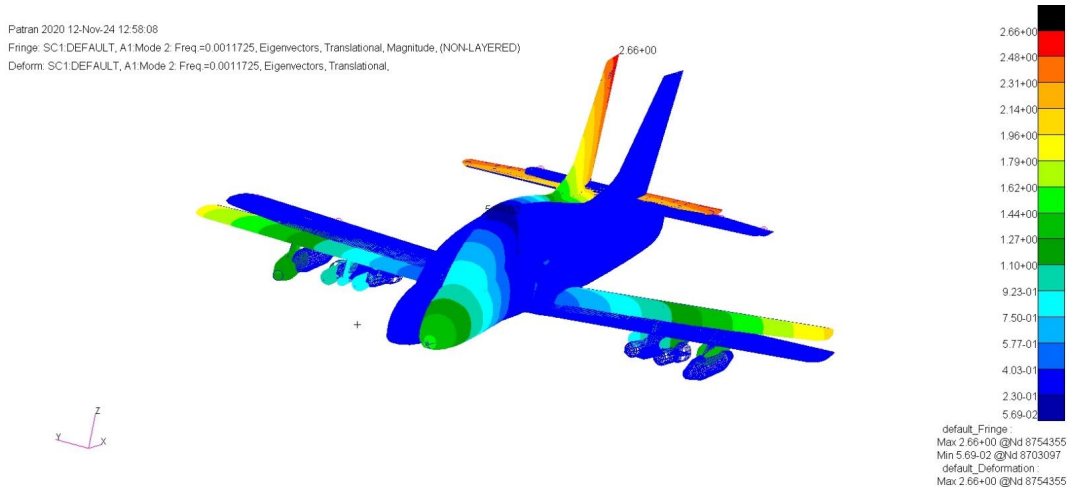


Figure 17. Rigid Mode – Gyration: $f = 0.0011725$ Hz

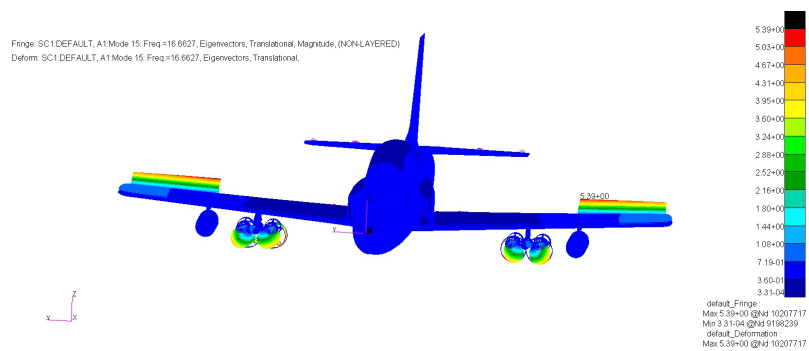


Figure 18. Roll Symmetrical Bombs: $f = 16.6627 \text{ Hz}$

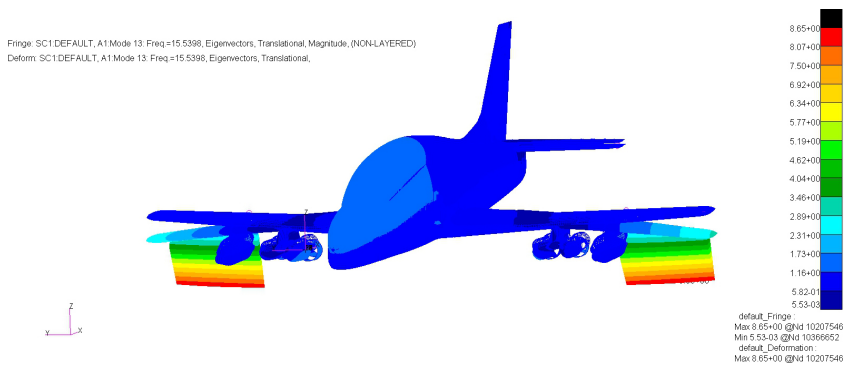


Figure 19. Symmetrical wing bending: $f = 15.53980 \text{ Hz}$

4. APPLICATION OF THE DLM METHOD TO THE CALCULATION OF GENERALIZED AERODYNAMIC FORCES, [3] IN THE IAR-99, HAWK AIRCRAFT IN DIFFERENT CONFIGURATIONS OF STORES, [12]

For all the load-bearing surfaces: wing, empennages and respectively the bodies considered, we will apply the methodology presented in [6] and developed in [8] for the aircraft with stores. we will idealize the surfaces and bodies from an aerodynamic point of view, generating aerodynamic surfaces that will cover the geometric surfaces of the FEM model.

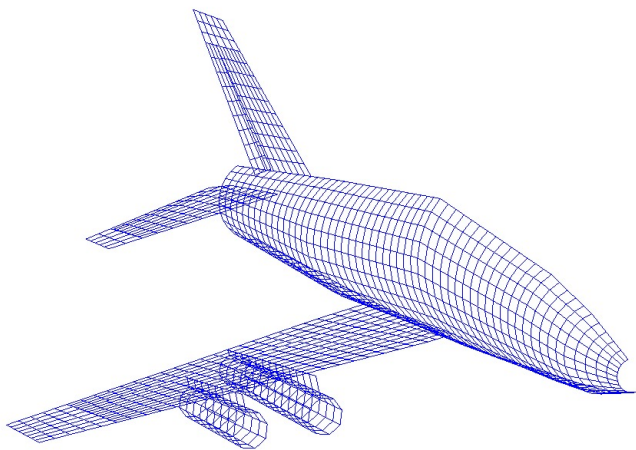


Figure 20. Aerodynamic idealization A configuration

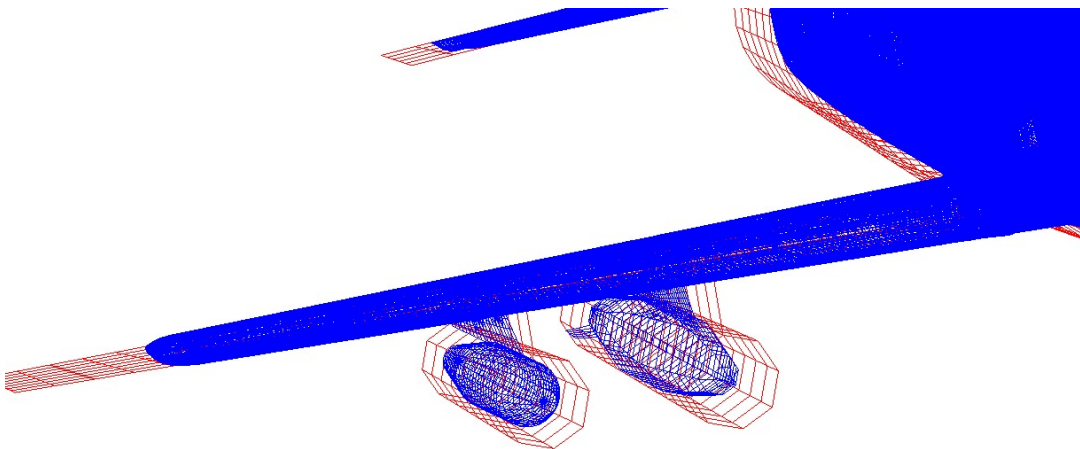


Figure 21. Aerodynamic idealization overlay with FEM, A configuration

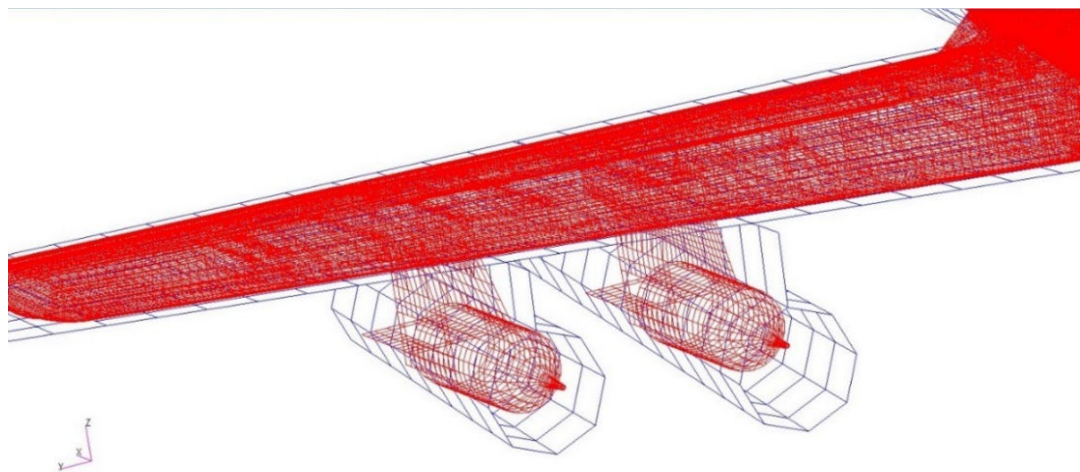


Figure 22. Aerodynamic idealization overlay with FEM, B configuration

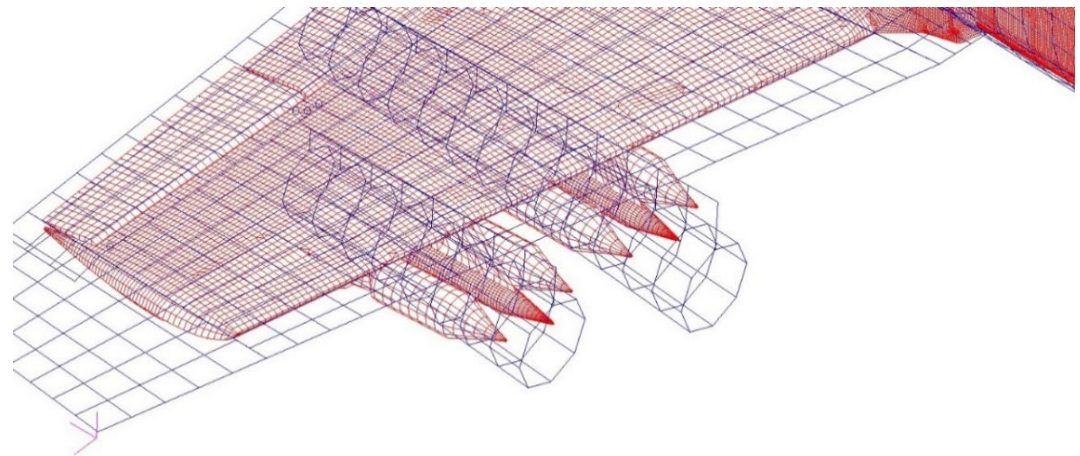


Figure 23. Aerodynamic idealization overlay with FEM, C configuration

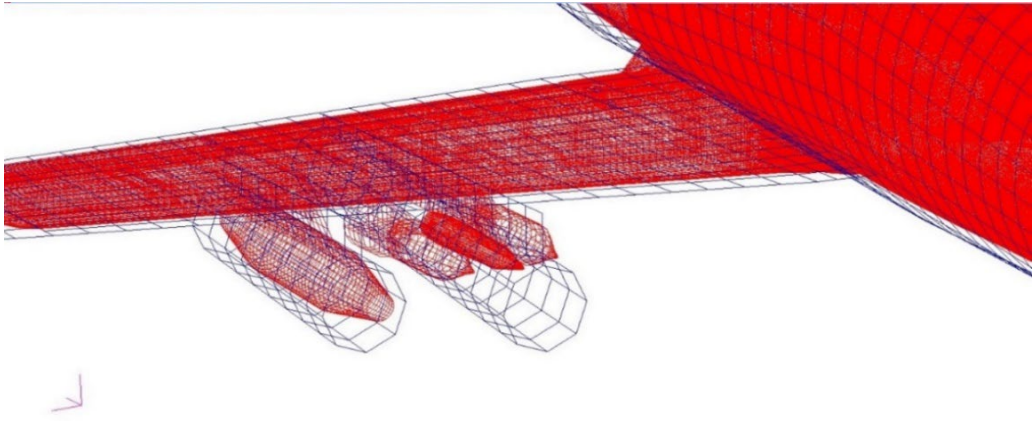


Figure 24. Aerodynamic idealization overlay with FEM, D configuration

5. RESULTS OF THE ANALYSIS OF THE IAR-99 HAWK AIRCRAFT, IN DIFFERENT STORE CONFIGURATIONS, [12]

It can be noted that by any of the flutter analysis methods: K, KE or PK, V-g curves (velocity – structure damping) will result for each vibration mode in the respective flutter combination studied [13]. The p-K method was used, described in detail in Chapter 2 of the paper [5], in accordance with [3]. The results of the flutter calculation are related to the maneuver diagrams presented in [11]. The design of the IAR-99, HAWK aircraft was made using [15], so the limitations of this regulation are the basis of the safety margin that the evolution of the aircraft must respect. The flutter combination must contain as many vibration modes as possible for a very complete analysis and then it can be established which are the two modes responsible for the appearance of the flutter phenomenon, namely the excited mode, which leads to $g=0$ and the exciting mode that induces the loss of damping on this excited mode.

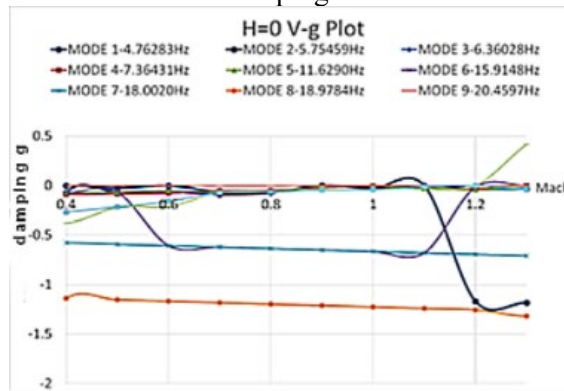


Figure 25. Curves V-g, H=0 m, for the combination of vibration modes, A configuration

For Hooking A Configuration, the following are identified:

- excited mode – Symmetrical rotation of the ailerons – $f = 20.8283$ Hz;
- excitatory mode – Vertical empennage bending – $f = 18.9784$ Hz;

for which at $H = 0$ m, the flutter velocity occurs at the value of Mach 1.2, a value in the supersonic flow regime, well outside the safety margin in the evolution of the IAR-99 aircraft with hooks.

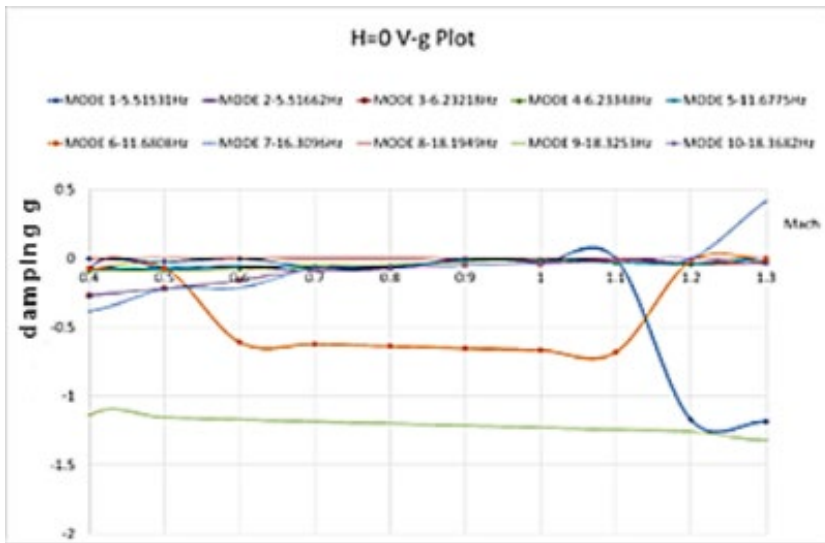


Figure 26. Curves V-g, $H = 0$ m, for the combination of vibration modes, B configuration

For Hooking B Configuration, the following shall be identified:

- excited mode – Symmetrical wing bending – $f = 16.3096$ Hz;
 - excitatory mode – Symmetrical pitch of external bombs – $f = 18.3253$ Hz;
- for which at $H = 0$ m, the flutter velocity occurs at the value of Mach 1.2, a value in the supersonic flow regime, well outside the safety margin in the evolution of the IAR-99 aircraft with hooks.

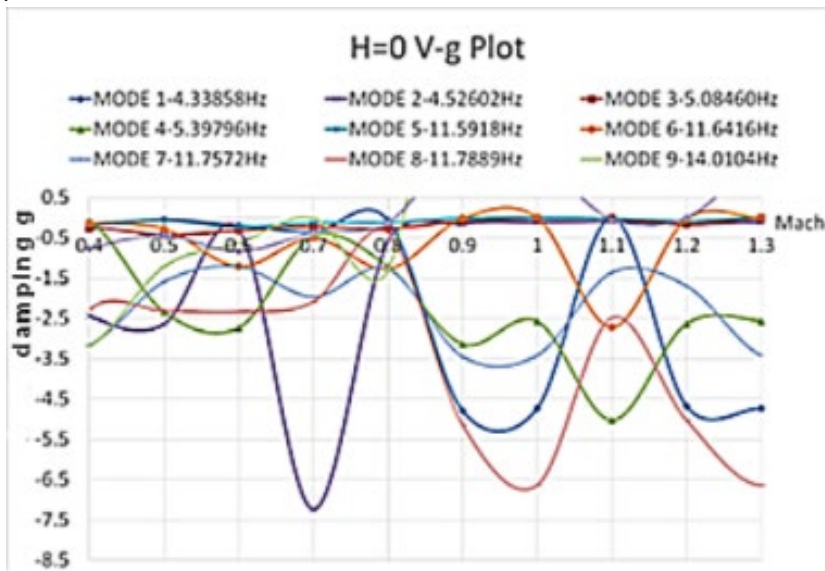


Figure 27. Curves V-g, $H = 0$ m, for the combination of vibration modes, C configuration

For Hooking Configuration C, the following are identified:

- excited mode – Antisymmetrical vibration mode for hooks – $f = 15.8692$ Hz;
 - excitatory mode – Symmetrical gyration of external bombs – $f = 11.7572$ Hz;
- for which at $H = 0$ m, the flutter speed appears at the value of Mach 0.82, a value outside the safety margin in the evolution of the IAR-99 aircraft with hooks.

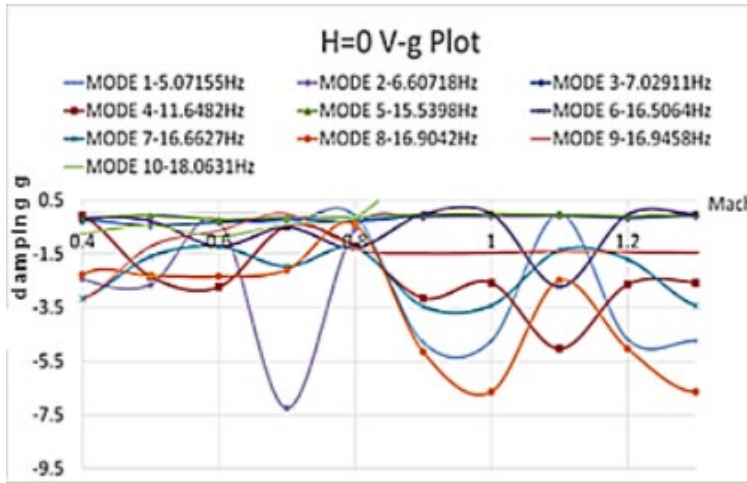


Figure 28. Curves V-g, $H = 0$ m, for the combination of vibration modes, D configuration.

For Hooking Configuration D, the following are identified:

- excited mode – Vertical empennage bending – $f = 18.0631$ Hz;
- excitatory mode – Symmetrical bomb roll – $f = 16.6620$ Hz;

for which at $H = 0$ m, the flutter speed appears at the value of Mach 0.82, a value outside the safety margin in the evolution of the IAR-99 aircraft with hooks.

6. CONCLUSIONS [5]

All research, papers, studies, reports and/or doctoral theses that touch, at least tangentially, the subject of fluttering with hooks propose a solution for eliminating this aeroelastic phenomenon in the event of its appearance in the flight envelope of the aircraft, in accordance with its design requirements.

Whatever path a researcher takes in the field of the study of flutter with hooks, 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.

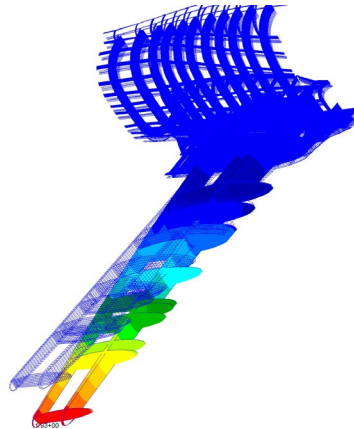


Figure 29. Symmetrical wing vibration. Structure of the central fuselage – wing

The portion of the central fuselage comprising the wing-fuselage junction is easily isolated from the overall model. 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 behavior 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 and in different docking variants, we can exemplify on the symmetrical bending mode of the wing, the behavior of the wing – central caisson assembly, the displacement in different selected nodes can be easily read and the appearance of the behavior of the wing structure and/or the central fuselage at the wing bending frequency can be visualized:

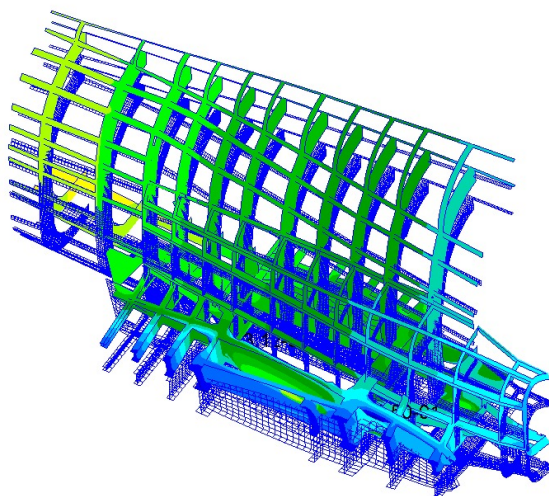


Figure 30. Symmetrical wing vibration. The structure of the central fuselage – central caisson and later from this the central caisson is individualized

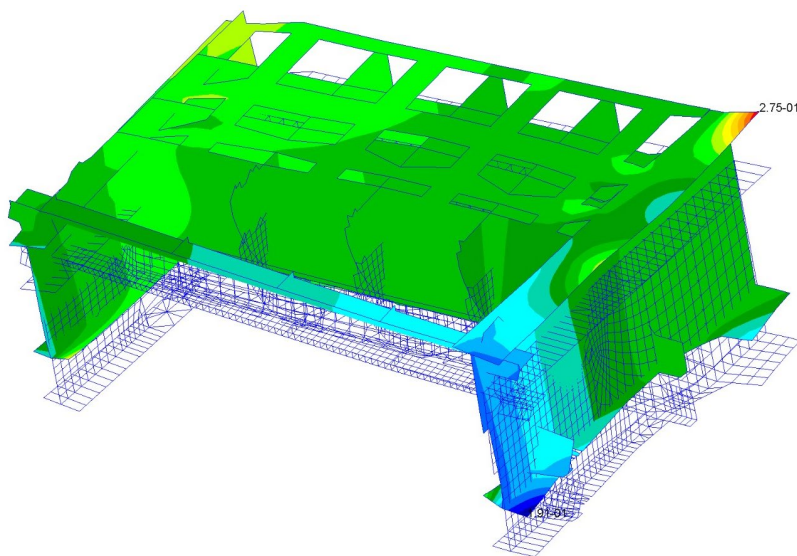


Figure 31. Symmetrical wing vibration. The structure of the central caisson

This advantage is given by the new FEM model, which allows this analysis 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 vibration 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.

The use of analytical methods for the analysis of free vibrations, 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. Nastran program.

The results of the simulations presented show a vibration behavior as well as the forecasted limits of the flutter, sensitive to: the flight altitude; the mass variation of the hooked bodies; the position in the span and respectively chord, of the hooked bodies; the stiffness of the wing/pylon/hook joints;

The DLM method used for subsonic non-stationary aerodynamic idealization provides a very good approximation for obtaining results for load-bearing surface configurations and interference with thin bodies. Under these conditions, the DLM method is also used to introduce the hooks in the aerodynamic idealization presented for the smooth plane that is well structured, allowing a flutter analysis of the IAR-99 plane in the different docking variants, making possible a subsequent laborious analysis on the influences of the hooks on the flutter speed.

The flutter analysis performed on the new FEM model of the IAR-99 HAWK aircraft, 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.

The V-g curves drawn highlight first of all the fact that in the smooth configuration, the IAR-99 aircraft is free of flutter, the speed of 1.2 MACH places us in the Maneuver Diagram well above the Safety Margin calculated. From the present flutter calculation, we get a flutter velocity in the supersonic area and a binary flutter analysis, considering the excited mode and the excitant mode respectively is not relevant in the subsonic regime.

The continued operation of the IAR-99 HAWK aircraft, used to train pilots even for the transition to the F-16, may be useful, after equipping with appropriate equipment and specific hooks, a professional aeroelastic analysis on the new IAR-99 aircraft. It is necessary to validate the results of the flutter analysis through flight tests on smooth configuration and various docking configurations and/or subsequent docking variants that have not been considered of interest so far.

It will be of further interest to analyze aeroelastic and other dynamic phenomena, dynamic response, order reversal speed, etc. using the present FEM model, the most complete and complex ever made.

ABBREVIATIONS

GVT	Ground Vibration Test
V-g	Velocity – structural damping
DLM	Doublet Lattice Method
FEM	Finite Elements Model

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