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PARAMETRIC UPDATING OF A DGV200 FINITE ELEMENT MODEL FROM EXPERIMENTAL MODAL CHARACTERISTICS.

by

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O.N.E.R.A., FRANCE

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Abstract

Parametric updating consists in modifying the finite element model of a structure, thanks to experimental data of vibrational type, in order to obtain computed modal characteristics as close as possible to experimental ones (vibration eigenmodes, frequency response function, ...).

The method developed at O.N.E.R.A. is based on a cost function minimization. It tends to reduce both the difference between computed and measured modes over all the degrees of freedom of the model and the dynamic reaction forces.

We show, in this paper, the results of the parametric updating method applied to a DGV200 finite element model (with about 15000 degrees of freedom).

Introduction

The first difficulty of the problem of parametric updating is that experimental displacements are available at a reduced number of degrees of freedom (dof) and are, moreover, imprecise because of measure noise. The second one concerns the uncertainties of the finite element modelization, which is tied to simplifying hypotheses and an approximate knowing of material elastic characteristics.

The method developed at O.N.E.R.A. tends to reduce, on one hand, the difference between computed and measured modes over all the dof of the model and, on the other hand, the dynamic reaction forces. After localization of erroneous substructures and the calculation of corrective parameters, we determine a new modal basis by a RITZ method. In order to evaluate the increased accuracy of the model, we calculate a few eigenmodes coupling criteria, such as Modal Assurance Criteria (M.A.C., M.A.C.M. and M.A.C.K.), generalized coordinates, frequency errors, mode errors... and we represent graphically mode shapes at the measured dof. We do so until having a good coherence between measures and calculations.

We show, in this paper, the results of the parametric updating method applied to a DGV200 finite element model (with about 15000 d.o.f.). As ground vibration testing was performed on this helicopter [3], experimental data on low frequency modal characteristics (vibration eigenmodes) are available.

I Updating method :

Notations :

finite element data :

n	: number of d.o.f.
K, M	: stiffness and mass matrices
n_c	: number of computed modes
V_{com}	: computed modes
ω_{com}	: computed circular frequencies

experimental data :

n_{mes}	: number of measured d.o.f.
n_m	: number of measured modes
V_{mes}	: measured modes
ω_{mes}	: measured circular frequencies

We deal the case where $n_{mes} > n_c$, $n_{mes} << n$ and ${}^tV_{com} M V_{com} = I$.

I.1 expansion of measured modes :

We determine an expansion of V_{mes}, denoted V_{exp}, over all the d.o.f. of the model, by a Least Square projection on the computed eigenmodes basis, reduced to measured d.o.f. and denoted $V_{comréd}$:

$$V_{mes} \approx (V_{comréd}) \cdot Q$$

where Q are the generalized coordinates of V_{mes} on $V_{comréd}$.

Because $n_{mes} > n_c$, this system is over determined and we have :

$$Q = [({}^tV_{comréd}) \cdot (V_{comréd})]^{-1} \; {}^tV_{comréd} \cdot V_{mes}$$

By extrapolation to all the d.o.f., we have :

$$V_{exp} = V_{com} \cdot Q$$

N.B. : classically, the Least Square Method leads to a corrective smoothing at the measured points : it reduces the noise of the measures.

Our updating method needs computed and expanded modes having the same generalized mass. We consider therefore:

$$V'_{exp_i} = \frac{V_{exp_i}}{\sqrt{{}^tQ_i \cdot Q_i}} \qquad i = 1, n_m$$

and we have ${}^tV'_{exp_i} \, M \, V'_{exp_i} = 1$.

We calculate then the following difference vector :

$$V_{dif_{ij}} = V'_{exp_i} - V_{com_j} \qquad ij = 1, n_p$$

where n_p is the number of pairs of modes (i,j) brought together with regard to the highest generalized coordinate.

I.2 finite element updating :

We subdivide the structure into n_s realistic substructures. Then, we do a first order perturbation calculus and we write that :

$$\widetilde{V_{com}} = V_{com} + \sum_{l=1}^{n_s} \lambda_l \, \Delta V_l$$

$$\widetilde{\omega_{com}} = \omega_{com} + \sum_{l=1}^{n_s} \lambda_l \, \alpha_l$$

where λ_l, ΔV_l et α_l are respectively the corrective parameter (to be determined), the perturbations in shape and circular frequency of the substructure number l, relatively to the stiffness or mass matrices, K_l or M_l.

Then, we choose to minimize the following quadratic function [6] :

$$\text{Min } f(\lambda) = a_1 \sum_{ij=1}^{np} \frac{{}^t(V'_{exp_i} - \widetilde{V_{com_j}}) \cdot (V'_{exp_i} - \widetilde{V_{com_j}})}{{}^tV'_{exp_i} \cdot V'_{exp_i}} + a_2 \sum_{ij=1}^{np} \frac{{}^t(\omega_{mes_i} - \widetilde{\omega_{com_j}})^2}{(\omega_{mes_i})^2}$$

Deliberately, in our tests, we have only performed a minimization over the shapes, considering the big distance between computed and measured frequencies, in order to have an a posteriori verification of the results, both on the frequencies and dynamic reaction forces.

This leads to the resolution of a symmetric positive definite system, denoted :

$$A \Lambda = B$$

which is solved by a Conjugate Gradient Method [4], with realistic variation limits : [-0.5 ; 0.5]. The corrective parameters Λ so determined can give a first localization of the erroneous areas of the model.

I.3 Ritz method :

The previous calculus of the corrective parameters depends on the number and type of pairs of modes (measured, computed) which are considered. In order to avoid the computation of new eigenmodes over the whole system after each optimization, we can use a Ritz method which enables us to deal with reduced systems. The computation of the whole basis is done only once : for the best configuration obtained.

I.4 how to estimate model improvement :

The three previous steps constitute, actually, an iterative process which can be controled thanks to several criteria, such as :

- generalized coordinates

- the M.A.C. (Modal Assurance Criterion), defined in [2] :

$$MAC(V'_{exp_i}, V_{com_j}) = \frac{({}^tV'_{exp_i} \cdot V_{com_j})^2}{\| V'_{exp_i} \|^2 \| V_{com_j} \|^2}$$

- the M.A.C.M. related to the mass matrix, defined as :

$$MACM(V'_{exp_i}, V_{com_j}) = \frac{({}^tV'_{exp_i} M V_{com_j})^2}{({}^tV'_{exp_i} M V'_{exp_i}) ({}^tV_{com_j} M V_{com_j})}$$

- the M.A.C.K. related to the stiffness matrix, defined as :

$$MACK(V'_{exp_i}, V_{com_j}) = \frac{({}^tV'_{exp_i} K V_{com_j})^2}{({}^tV'_{exp_i} K V'_{exp_i}) ({}^tV_{com_j} K V_{com_j})}$$

- frequencies errors

These criteria give us information about the pairs of modes (measured, computed) and on the eventual mode coupling.

Finally, in order to estimate the improvement of each eigen mode, we represent graphically, at the measured d.o.f., the computed modes of the current iteration and their corresponding measured ones.

Remarks :

1 For the M.A.C., only diagonal terms are significant; if $V_{exp_i} = V_{com_j}$ then M.A.C. = 1.

2 M.A.C.M. and M.A.C.K. give us information about the components of the measured basis on the computed one (and vice versa), relatively to mass and stiffness matrices. If $V_{exp_i} = V_{com_j}$ then M.A.C.M.$_{ij}$ = 1 and M.A.C.K.$_{ij}$ = 1 ; if the expanded basis is strictly identical to the computed one, then M.A.C.M. and M.A.C.K. are diagonal.

3 The number of modes used to do the expansion is the minimum one which ensures that, at measured points, difference between exact measured values and expanded ones is negligible.

II Application to D.G.V.200 :

The previous updating method has been applied to a high speed helicopter, called DGV200. We have considered two configurations : the first (respectively second) one represents the aircraft without (respectively with) the engines, the main rotor and the main gear box.

Concerning the first configuration, we have tried to update the first six elastic measured modes. For the second one, we have tried to update the first seven modes, which include four engine modes, two bendings (vertical and lateral) and a coupled engines-airframe mode. We have done a stiffness updating, knowing the fact that mass distribution errors were local.

II.1 configuration 1 : without the engines

II.1.1 definition of the test case :

The DGV200 has been substructured in 36 parts, which are taken into account in the finite element model. The underneath figure represents the first configuration of the aircraft :

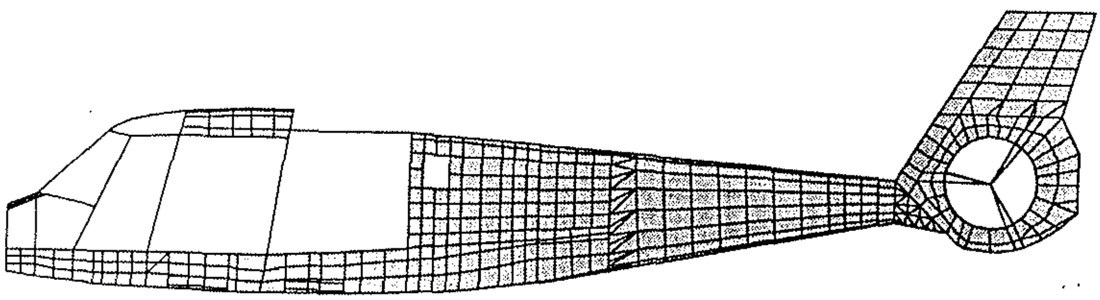


figure 1

mesh :
number of nodes : 2138
number of d.o.f. : 14941
number of elements : 3883
number of substructures : 36

experimentation :
number of measured nodes : 87
number of measured d.o.f. : 197

initial computed basis :
number of computed modes : 14
(including 6 rigid modes)

experimental basis :
number of measured modes : 6

II.1.2 characterization of the initial computed basis :

- generalized coordinates :

	Measured Modes Frequencies					
Computed Modes Frequencies	9.22 Hz	10.88 Hz	18.88 Hz	21.60 Hz	24.61 Hz	27.48 Hz
9.64 Hz	**0.951**	-0.026	-0.092	0.310	0.127	0.275
13.08 Hz	-0.017	**0.922**	-0.110	-0.062	0.252	0.021
21.19 Hz	0.006	-0.088	-0.211	-0.117	**0.864**	0.089
22.02 Hz	-0.200	0.081	-0.044	**0.677**	0.043	-0.152
29.26 Hz	-0.183	0.075	-0.215	0.332	0.149	**0.819**
29.88 Hz	-0.016	-0.080	**0.786**	0.156	-0.002	0.243

- M.A.C. :

For each of the six measured modes, we point out the associated computed mode and the corresponding M.A.C. value. We compute this M.A.C., on the one hand, over the measured d.o.f., with V_{mes} and $V_{com_{réd}}$ and on the other hand, over all the d.o.f., with V'_{exp} and V_{com}. These computations show that the mode expansion is correct : we can see a good coherence between the pairs of modes made on the reduced data and those made on the whole model.

* M.A.C. on the measured d.o.f. :

Measured Modes Frequencies (Hz)	9.22	10.88	18.88	21.60	24.61	27.48
MAC	0.869	0.908	0.417	0.462	0.497	0.385
Computed Modes Frequencies (Hz)	9.64	13.08	29.88	22.02	21.19	29.26

* M.A.C. on all the d.o.f. :

Measured Modes Frequencies (Hz)	9.22	10.88	18.88	21.60	24.61	27.48
MAC	0.854	0.830	0.848	0.651	0.951	0.602
Computed Modes Frequencies (Hz)	9.64	13.08	29.88	22.02	21.19	29.26

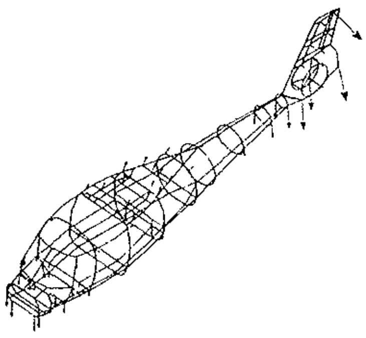
* M.A.C.M. :

MACM	Measured Modes Freq. (Hz)					
Computed Modes Freq. (Hz)	9.22	10.88	18.88	21.60	24.61	27.48
9.64	**0.904**	0.001	0.008	0.096	0.016	0.075
13.08	0.000	**0.850**	0.012	0.004	0.064	0.000
21.19	0.000	0.008	0.045	0.014	**0.747**	0.008
22.02	0.040	0.007	0.002	**0.459**	0.002	0.023
29.26	0.033	0.006	0.046	0.110	0.022	**0.671**
29.88	0.000	0.006	**0.617**	0.024	0.000	0.059

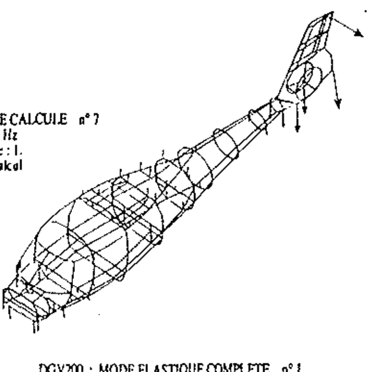
* M.A.C.K. :

MACK	Measured Modes Freq. (Hz)					
Computed Modes Freq. (Hz)	9.22	10.88	18.88	21.60	24.61	27.48
9.64	**0.636**	0.000	0.001	0.025	0.004	0.011
13.08	0.000	**0.894**	0.003	0.002	0.030	0.000
21.19	0.000	0.021	0.033	0.017	**0.912**	0.006
22.02	0.146	0.019	0.002	**0.628**	0.002	0.017
29.26	0.216	0.030	0.064	0.267	0.052	**0.885**
29.88	0.002	0.035	**0.897**	0.061	0.000	0.081

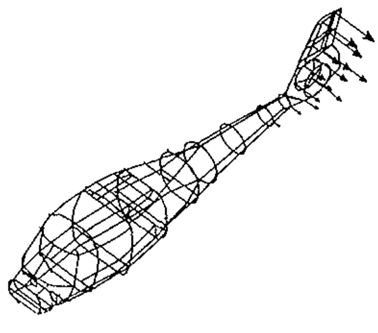
- drawings of mode shapes on the measured d.o.f. : In order to make easy the interpretation of the drawings, we have done a simplified mesh including the measurement points. We show here the first two measured and computed modes : vertical and lateral bendings.



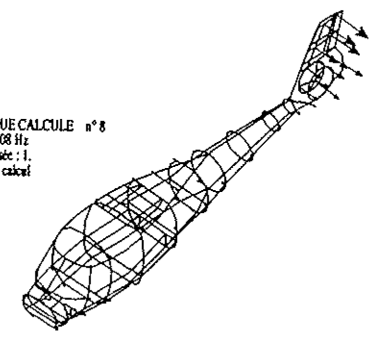
DGV200 : MODE ELASTIQUE CALCULE n° 7
fréquence : 9.64 Hz
masse généralisée : 1.
base initiale de calcul



DGV200 : MODE ELASTIQUE COMPLETE n° 1
fréquence : 9.22 Hz
masse généralisée : 1.
base initiale de calcul



DGV200 : MODE ELASTIQUE CALCULE n° 8
fréquence : 13.08 Hz
masse généralisée : 1.
base initiale de calcul



DGV200 : MODE ELASTIQUE COMPLETE n° 2
fréquence : 10.88 Hz
masse généralisée : 1.
base initiale de calcul

II.1.3 computation of corrective parameters :

The corrective parameters found are very high (but still in [-0.5 ; 0.5]) on the following substructures : the fenestron, the tail boom, the cockpit windshield, the cabin floor the tail cone and the longitudinal beam frame. We must say that the DGV200 has been split into 69 parts and that we have check the results stability with regard to the substructuration. This can provide a better localization of erroneous areas : only a few elements of a substructure are really wrong.

We have then computed another localization, thanks to reaction forces :

$$R_i = (K - \omega^2_{mes_i} M) V'_{exp_i} \qquad i = 1,n_m$$

We noticed that the same substructures were erroneous and that the localization obtained was the same for all the measured modes considered.

II.1.4 characterization of the new computed basis :

- generalized coordinates :

Computed Modes Frequencies	Measured Modes Frequencies 9.22 Hz	10.88 Hz	18.88 Hz	21.60 Hz	24.61 Hz	27.48 Hz
9.49 Hz	**0.979**	0.020	0.020	-0.191	-0.173	-0.205
11.21 Hz	0.067	**0.936**	0.564	0.048	0.341	0.119
20.52 Hz	0.091	0.079	-0.085	**0.793**	-0.116	0.148
21.56 Hz	0.034	-0.023	-0.150	0.064	**0.770**	0.160
27.41 Hz	-0.005	-0.063	**0.759**	0.077	0.180	-0.008
30.04 Hz	0.079	0.018	-0.024	0.145	0.337	**0.830**

* M.A.C. on the measured d.o.f. :

Measured Modes Frequencies (Hz)	9.22	10.88	18.88	21.60	24.61	27.48
MAC	0.920	0.938	0.714	0.589	0.515	0.416
Computed Modes Frequencies (Hz)	9.49	11.21	27.41	20.52	21.56	30.04

* M.A.C. on all the d.o.f.. :

Measured Modes Frequencies (Hz)	9.22	10.88	18.88	21.60	24.61	27.48
MAC	0.925	0.900	0.887	0.841	0.793	0.912
Computed Modes Frequencies (Hz)	9.49	11.21	27.41	20.52	21.56	30.04

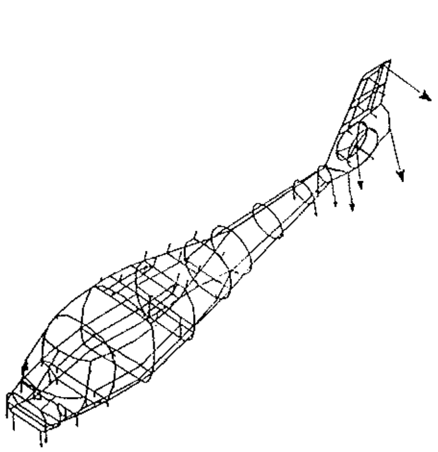
* M.A.C.M. :

MACM	Measured Modes Freq. (Hz)					
Computed Modes Freq. (Hz)	9.22	10.88	18.88	21.60	24.61	27.48
9.49	**0.958**	0.000	0.000	0.037	0.030	0.042
11.21	0.004	**0.876**	0.318	0.002	0.116	0.014
20.52	0.008	0.006	0.007	**0.629**	0.013	0.022
21.56	0.001	0.001	0.022	0.004	**0.593**	0.026
27.41	0.000	0.004	**0.575**	0.006	0.032	0.000
30.04	0.006	0.000	0.001	0.021	0.114	**0.689**

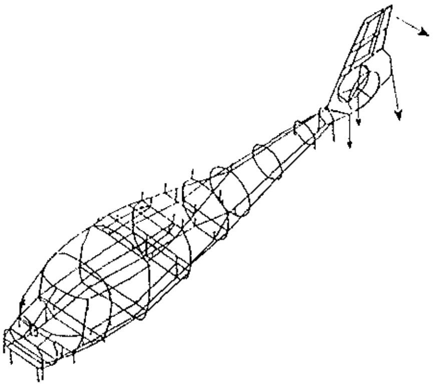
* M.A.C.K. :

MACK	Measured Modes Freq. (Hz)					
Computed Modes Freq. (Hz)	9.22	10.88	18.88	21.60	24.61	27.48
9.49	**0.894**	0.000	0.000	0.011	0.006	0.006
11.21	0.006	**0.947**	0.082	0.001	0.034	0.003
20.52	0.036	0.023	0.006	**0.902**	0.013	0.014
21.56	0.006	0.002	0.021	0.006	**0.648**	0.018
27.41	0.000	0.025	**0.889**	0.015	0.057	0.000
30.04	0.058	0.002	0.001	0.064	0.241	**0.959**

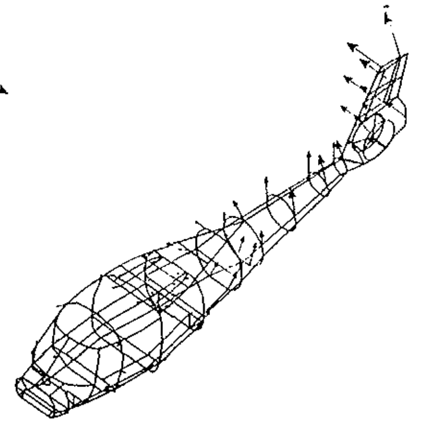
- drawings of mode shapes on the measured d.o.f. : we show here the same modes as in part II.1.2 (first two vertical and lateral bendings). We represent, at the same scale, the computed and measured modes and their difference, for which the scale is 5 times the previous.



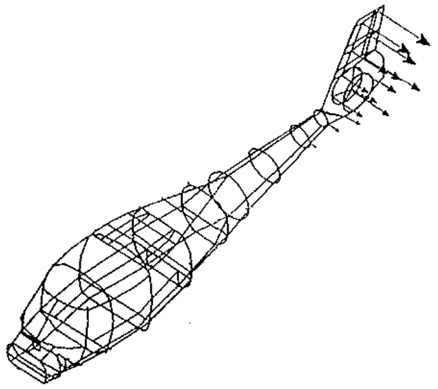
DGV200 : MODE ELASTIQUE CALCULE n° 7
fréquence : 9.49 Hz
masse généralisée : 1.
nouvelle base de calcul



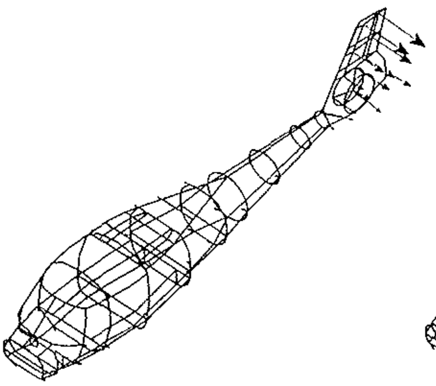
DGV200 : MODE ELASTIQUE COMPLETE n° 1
fréquence : 9.22 Hz
masse généralisée : 1.
nouvelle base de calcul



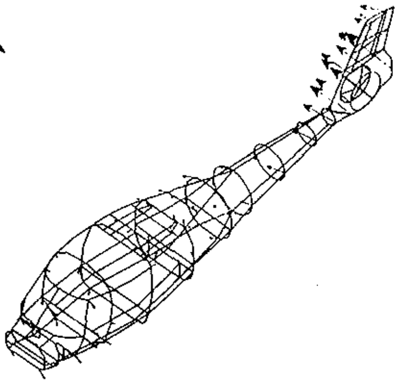
DGV200 : DIFFERENCE (COMPLETION - CALCUL) n° 1
fréquence calculée : 9.49 Hz fréquence mesurée : 9.22 Hz
masse généralisée des modes : 1.
échelle multipliée par 5
nouvelle base de calcul



DGV200 : MODE ELASTIQUE CALCULE n° 8
fréquence : 11.21 Hz
masse généralisée : 1.
nouvelle base de calcul



DGV200 : MODE ELASTIQUE COMPLETE n° 2
fréquence : 10.88 Hz
masse généralisée : 1.
nouvelle base de calcul



DGV200 : DIFFERENCE (COMPLETION - CALCUL) n° 2
fréquence calculée : 11.21 Hz fréquence mesurée : 10.88 Hz
masse généralisée des modes : 1.
échelle multipliée par 5
nouvelle base de calcul

II.2 configuration 2 : with the engines

II.2.1 definition of the test case :

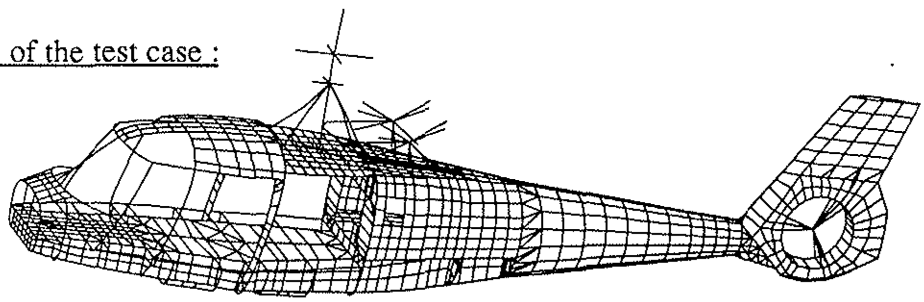


figure 2

mesh:
number of nodes : 2193
number of d.o.f. : 15377
number of "elements ": 3960
number of substructures : 37

experimentation :
number of measured nodes : 118
number of measured d.o.f. : 245

initial computed basis :
number of computed modes : 13
(including 6 rigid modes)

experimental basis :
number of measured modes : 7

II.2.2 characterization of the initial computed basis :

- generalized coordinates :

Computed Modes Frequencies	Measured Modes Frequencies 6.66 Hz	7.05 Hz	8.67 Hz	10.65 Hz	13.98 Hz	15.14 Hz	15.29 Hz
6.75 Hz	**0.947**	0.272	0.006	-0.011	-0.002	0.013	0.000
7.16 Hz	-0.318	**0.957**	-0.029	-0.129	-0.008	-0.024	-0.023
9.02 Hz	-0.011	0.016	**0.932**	-0.005	-0.467	0.001	0.078
12.92 Hz	-0.018	0.078	-0.029	**0.909**	0.137	-0.021	-0.038
14.93 Hz	-0.002	-0.014	0.308	-0.145	**0.813**	-0.025	-0.189
18.21 Hz	-0.010	0.026	0.073	-0.035	0.264	0.124	**0.953**
19.27 Hz	-0.030	0.010	0.015	0.041	-0.007	**0.989**	0.187

* M.A.C. on the measured d.o.f. :

Measured Modes Frequencies (Hz)	6.66	7.05	8.67	10.65	13.98	15.14	15.29
MAC	0.832	0.855	0.844	0.861	0.358	0.878	0.825
Computed Modes Frequencies (Hz)	6.75	7.16	9.02	12.92	14.93	19.27	18.21

* M.A.C. on all the d.o.f. :

Measured Modes Frequencies (Hz)	6.66	7.05	8.67	10.65	13.98	15.14	15.29
MAC	0.773	0.912	0.939	0.906	0.571	0.949	0.913
Computed Modes Frequencies (Hz)	6.75	7.16	9.02	12.92	14.93	19.27	18.21

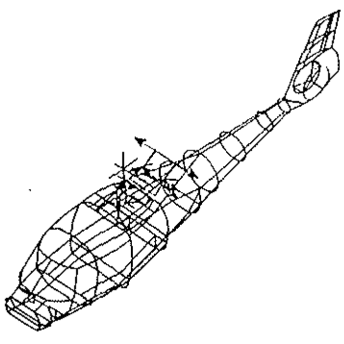
* M.A.C.M. :

MACM	Measured Modes Freq. (Hz)						
Computed Modes Freq. (Hz)	6.66	7.05	8.67	10.65	13.98	15.14	15.29
6.75	**0.897**	0.074	0.000	0.000	0.000	0.000	0.000
7.16	0.101	**0.915**	0.001	0.017	0.000	0.001	0.001
9.02	0.000	0.000	**0.868**	0.000	0.219	0.000	0.006
12.92	0.000	0.006	0.001	**0.826**	0.019	0.000	0.001
14.93	0.000	0.000	0.095	0.021	**0.661**	0.001	0.036
18.21	0.000	0.001	0.005	0.001	0.070	0.015	**0.909**
19.27	0.001	0.000	0.000	0.002	0.000	**0.978**	0.035

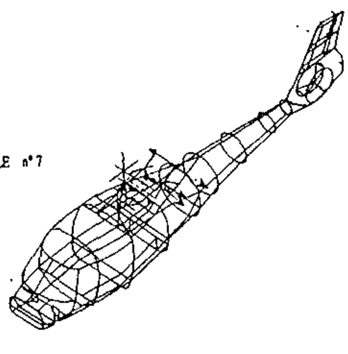
* M.A.C.K. :

MACK	*Measured Modes Freq. (Hz)*						
Computed Modes Freq. (Hz)	6.66	7.05	8.67	10.65	13.98	15.14	15.29
6.75	**0.879**	0.065	0.000	0.000	0.000	0.000	0.000
7.16	0.111	**0.908**	0.000	0.006	0.000	0.000	0.000
9.02	0.000	0.000	**0.753**	0.000	0.093	0.000	0.002
12.92	0.001	0.020	0.002	**0.954**	0.016	0.000	0.001
14.93	0.000	0.001	0.225	0.032	**0.770**	0.000	0.025
18.21	0.001	0.004	0.019	0.003	0.121	0.014	**0.933**
19.27	0.007	0.001	0.001	0.004	0.000	**0.985**	0.040

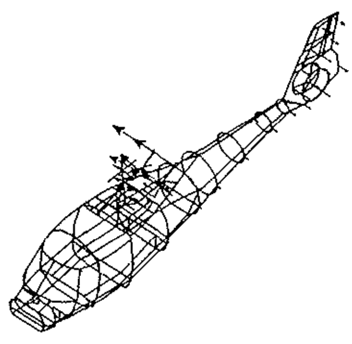
- drawings of mode shapes on the measured d.o.f. : we show the first two engine modes (expanded and computed) and the first vertical bending.



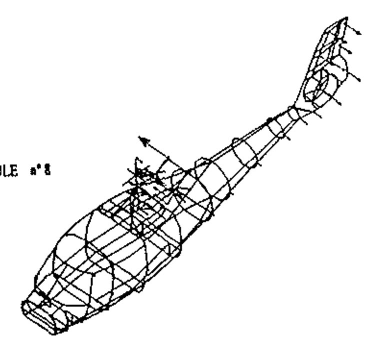
DGV200 : MODE ELASTIQUE CALCULE n° 7
fréquence : 6.75 Hz
masse généralisée : 1.
base initiale de calcul



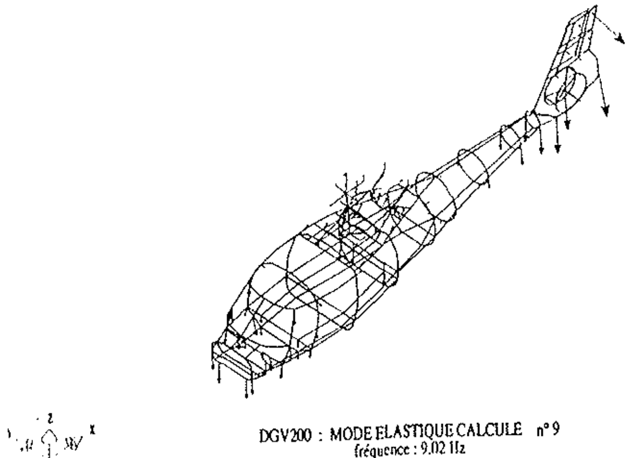
DGV200 : MODE ELASTIQUE COMPLETE n° 1
fréquence : 6.66 Hz
masse généralisée : 1.
base initiale de calcul



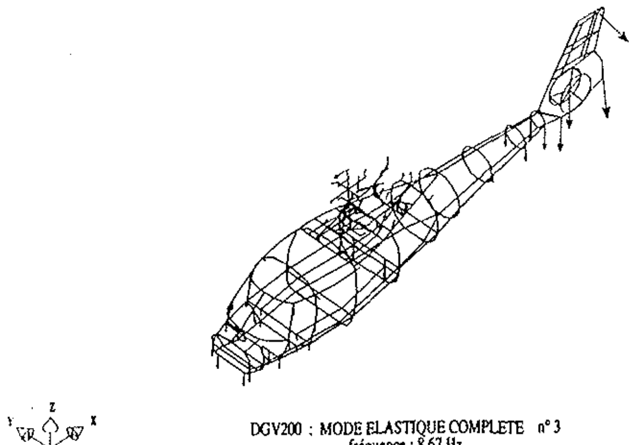
DGV200 : MODE ELASTIQUE CALCULE n° 8
fréquence : 7.16 Hz
masse généralisée : 1.
base initiale de calcul



DGV200 : MODE ELASTIQUE COMPLETE n° 2
fréquence : 7.05 Hz
masse généralisée : 1.
base initiale de calcul



DGV200 : MODE ELASTIQUE CALCULE n° 9
fréquence : 9.02 Hz
masse généralisée : 1.
base initiale de calcul



DGV200 : MODE ELASTIQUE COMPLETE n° 3
fréquence : 8.67 Hz
masse généralisée : 1.
base initiale de calcul

II.2.3 computation of the corrective parameters:

The engines are substructured into 29 parts. An updating made on these substructures leads to correct two main areas which are : the motor suspensions (in a vertical and lateral way) and the connexions between the main gear box and the engines floor. We still use here the parameters obtained for the first configuration.

II.2.4 characterization of the new computed basis :

- generalized coordinates :

	Measured Modes Frequencies						
Computed Modes Frequencies	6.66 Hz	7.05 Hz	8.67 Hz	10.65 Hz	13.98 Hz	15.14 Hz	15.29 Hz
6.63 Hz	**0.999**	0.010	-0.014	0.021	0.000	-0.019	-0.007
7.07 Hz	0.037	**0.998**	-0.028	0.099	0.008	-0.019	-0.023
8.76 Hz	0.008	0.010	**0.977**	-0.013	0.425	-0.008	0.008
10.71 Hz	-0.005	-0.028	0.072	**0.926**	0.107	0.013	0.019
13.95 Hz	0.003	0.020	-0.111	-0.077	**0.793**	0.038	0.452
15.12 Hz	0.030	0.008	0.006	-0.028	0.049	**0.982**	0.149
15.26 Hz	0.009	0.016	0.085	0.058	-0.322	0.167	**0.872**

- M.A.C. :

* M.A.C. on the measured d.o.f. :

Measured Modes Frequencies (Hz)	6.66	7.05	8.67	10.65	13.98	15.14	15.29
MAC	0.942	0.932	0.903	0.891	0.335	0.861	0.656
Computed Modes Frequencies (Hz)	6.63	7.07	8.76	10.71	13.95	15.12	15.26

* M.A.C. on all the d.o.f.. :

Measured Modes Frequencies (Hz)	6.66	7.05	8.67	10.65	13.98	15.14	15.29
MAC	0.986	0.985	0.973	0.924	0.707	0.908	0.658
Computed Modes Frequencies (Hz)	6.63	7.07	8.76	10.71	13.95	15.12	15.26

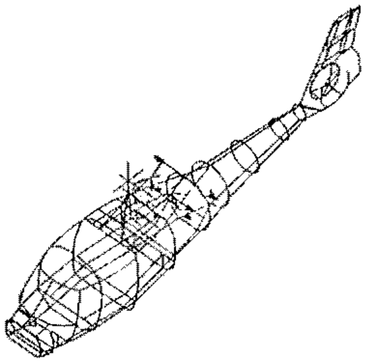
* M.A.C.M. :

MACM	Measured Modes Freq. (Hz)						
Computed Modes Freq. (Hz)	6.66	7.05	8.67	10.65	13.98	15.14	15.29
6.63	**0.997**	0.000	0.000	0.000	0.000	0.000	0.000
7.07	0.001	**0.995**	0.001	0.010	0.000	0.000	0.001
8.76	0.000	0.000	**0.955**	0.000	0.181	0.000	0.000
10.71	0.000	0.001	0.005	**0.858**	0.012	0.000	0.000
13.95	0.000	0.000	0.012	0.006	**0.629**	0.001	0.204
15.12	0.001	0.000	0.000	0.001	0.002	**0.963**	0.022
15.26	0.000	0.000	0.007	0.003	0.104	0.028	**0.760**

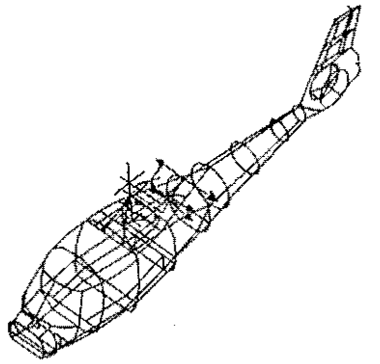
* M.A.C.K. :

MACK	Measured Modes Freq. (Hz)						
Computed Modes Freq. (Hz)	6.66	7.05	8.67	10.65	13.98	15.14	15.29
6.63	**0.993**	0.000	0.000	0.000	0.000	0.000	0.000
7.07	0.002	**0.995**	0.000	0.005	0.000	0.000	0.000
8.76	0.000	0.000	**0.939**	0.000	0.086	0.000	0.000
10.71	0.000	0.002	0.008	**0.973**	0.008	0.000	0.000
13.95	0.000	0.002	0.031	0.011	**0.754**	0.001	0.180
15.12	0.005	0.000	0.000	0.002	0.003	**0.970**	0.023
15.26	0.000	0.001	0.022	0.008	0.149	0.029	**0.797**

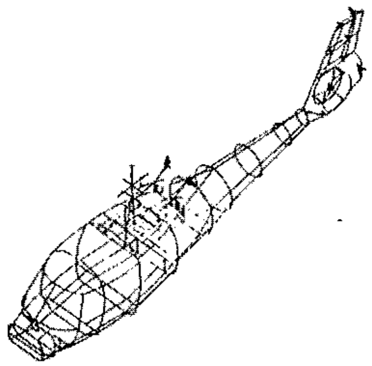
- drawings of mode shapes on the measured d.o.f. : we show the same modes as in part II.2.2 and the difference vectors (scale * 5).



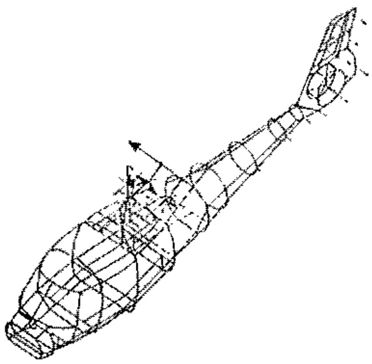
DGV200 : MODE ELASTIQUE CALCULE n° 7
fréquence : 6.63 Hz
masse généralisée : 1.
nouvelle base de calcul recalée



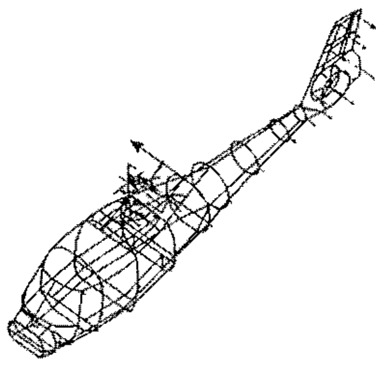
DGV200 : MODE ELASTIQUE COMPLETE n° 1
fréquence : 6.66 Hz
masse généralisée : 1.
nouvelle base de calcul recalée



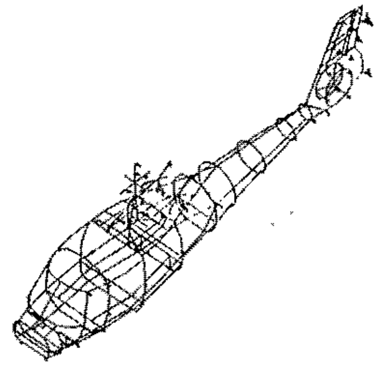
DGV200 : DIFFERENCE (COMPLETION - CALCUL) n° 1
fréquence calculée : 6.63 Hz fréquence mesurée : 6.66 Hz
masse généralisée des modes : 1.
échelle multipliée par 5
nouvelle base de calcul recalée



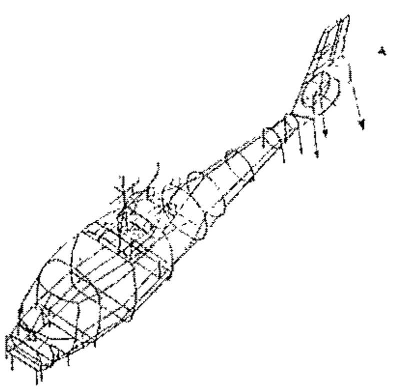
DGV200 : MODE ELASTIQUE CALCULE n° 8
fréquence : 7.07 Hz
masse généralisée : 1.
nouvelle base de calcul recalée



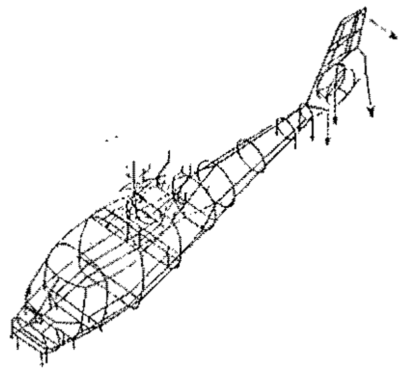
DGV200 : MODE ELASTIQUE COMPLETE n° 2
fréquence : 7.05 Hz
masse généralisée : 1.
nouvelle base de calcul recalée



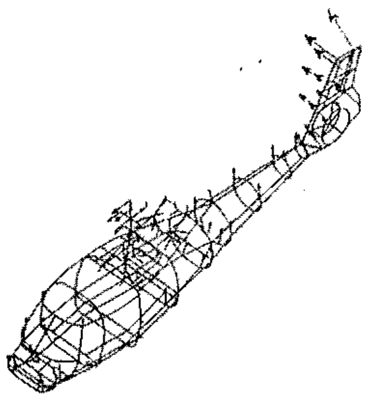
DGV200 : DIFFERENCE (COMPLETION - CALCUL) n° 2
fréquence calculée : 7.07 Hz fréquence mesurée : 7.05 Hz
masse généralisée des modes : 1.
échelle multipliée par 5
nouvelle base de calcul recalée



DGV200 : MODE ELASTIQUE CALCULE n° 9
fréquence : 8.76 Hz
masse généralisée : 1.
nouvelle base de calcul recalée



DGV200 : MODE ELASTIQUE COMPLETE n° 3
fréquence : 8.67 Hz
masse généralisée : 1.
nouvelle base de calcul recalée



DGV200 : DIFFERENCE (COMPLETION - CALCUL) n° 3
fréquence calculée : 8.76 Hz fréquence mesurée : 8.67 Hz
masse généralisée des modes : 1.
échelle multipliée par 5
nouvelle base de calcul recalée

II.3 analysis of the results

II.3.1 configuration 1 :

The performed updating helped us to localize substructures governing differences between computational results and modal measurements. Moreover, several tests have been performed to accurate the localization (mainly the division into 36 sections to the division into 69 sections). These tests have effectively confirmed the first localization obtained but did not improve the first updating.

Substructures to correct first are : the feneston, the tail boom, the cockpit windshield, the cabin floor the tail cone and the longitudinal beam frame.

The suggested updating has improved in a significant way the correlation between the first two computed and measured eigenmodes : vertical and lateral bendings. The computed and measured eigenfrequencies are also very close. Indeed, frequencies given in section II.1.4 result from a Ritz approximation. The computation of the updated model leads to the following eigenfrequencies :

mode 7	mode 8	mode 9	mode 10	mode 11	mode 12
9.27 Hz	10.84 Hz	19.97 Hz	20.80 Hz	26.83 Hz	29.37 Hz

The M.A.C., M.A.C.M., M.A.C.K... criteria resulting from this modal basis are not modified in a significant way.

About the higher frequency, mode shapes (3, 4, 5, 6) correlation has been greatly improved, much more for stiffness than for mass. At this time, it would be interesting to perform a mass updating. However, considering the magnitude of stiffness changes, it does not seem realistic to go on updating stiffness as well as mass without performing a preliminary analysis of the presumed deficient substructures. This analysis would lead to a better knowledge of the finite element model deficiencies. We could so correct or adjust the modelization before reruning updating.

II.3.2 configuration 2 :

For the second configuration, we have started from the updated model obtained previously and have added the engine parameters. For this configuration, we have tried to update the first seven eigenmodes : 2 lateral engine modes, 2 lateral and vertical bendings, 1 coupled engine-airframe mode and 2 vertical engine modes.

We have not tried to identify eigenmodes of highest rank, considering the results obtained for the first configuration.

We must notice that the updating made with the first configuration has improved the correlation between computed and measured first two bendings, both for the shapes (M.A.C., M.A.C.M., M.A.C.K.) and for the frequencies. We have so a verification of the first updating. We did not find any influence of engine parameters on these two modes.

We have split the engines into 29 parts. the updating performed has point out two erroneous substructures : the motor suspensions (in a vertical and lateral way) and the connexions between the main gear box and the engines floor. We must say that frequencies result from the updating of the shapes and constitute, here too, an a posteriori verification.

The modifications that we suggest lead to a very good updating on the lateral engine modes (6.66 Hz and 7.05 Hz) and a good one on the antisymmetric engine mode (15.14 Hz). The symmetric mode (15.29 Hz) is well identified in frequency but not in shape : its improvement depends on the improvement of the updating of the 13.98 Hz mode. This suppose airframe modifications that we did not take into account in that configuration. However, for the 13.98 Hz mode we found a great influence of the fenestron and the tail boom, as for the first configuration.

Conclusion

This work has shown that it was possible to do the parametric updating of high number of degrees of freedom systems. Indeed, the final configuration of the DGV200, which contains the engines, the main gear box and the main rotor, is so that the first seven measured modes are close to their similar computed ones and in the same order. We can notice that generalized coordinates, M.A.C.M. and M.A.C.K. matrices are nearly diagonal, that M.A.C. values are, generally speaking, close to unity and that frequencies are obtained within a less than 1.1 % error margin.

This parametric updating has enabled us to characterize the substructures of which modification has the highest influence on the reduction of the difference between measures and calculations. The corrections have been quantified, as a whole.

Before going on in such a way, an analysis of the DGV200 modelization should be done, in order to suggest some modifications, thanks to the results of the different tests performed.

Finally, it should be interesting to do a trial of modal identification of both substructures which are incriminated the more by the updating (tail boom and fenestron), first separately and then assembled, in order to do a more accurate updating of these substructures. We could so verify if it is posssible to conceive a best connection between updating and modelization procedures : this could enable to check and change the finite element modelization, as soon as possible.

Bibliographie

[1] H. BERGER, R. OHAYON, L. BARTHE and J.P. CHAQUIN : "Parametric updating of finite element models using experimental simulation. A dynamic reaction approach".Modal Analysis Conference I.M.A.C. 8, Orlando (Fl-US) January 29 - February 1, 1990.

[2] D.J. EWINS : "Modal Testing : Theory and Practice."Research Studies Press LTD, Taunton, Somerset, England.

[3] L. GIRARD and P. LUBRINA : "Ground vibrations tests for the high speed dolphin helicopter".American Helicopter Society ; 49th Annual Forum, St. Louis, Missouri, May 19-21 1993.

[4] D.A.H. JACOBS : "Generalization of the Conjugate Gradient Method for solving non symmetric and complex systems of algebraic equations".Central Electricity Research Laboratories - note n°RD/L/N/70/80.

[5] P. LUBRINA : "Essai de vibrations au sol de l'hélicoptère DGV200".Contrat Eurocopter n° 21/R81-992

[6] M. NASH : "An approach to the Correlation of Finite Element and Modal Test Studies".Proceedings of StruCoMe 1988 pp. 949-964.