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A VIBRATION STUDY OF THE LYNX AIRFRAME  
USING THE FINITE-ELEMENT METHOD

A. McLAUGHLIN

G.M. VENN

A.J. BARNARD

WESTLAND HELICOPTERS LTD., U.K.

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A. McLaughlin, G.M. Venn, A.J. Barnard  
Westland Helicopters Ltd., U.K.

ABSTRACT

This paper describes a study to compute the normal modes of vibration and forced response characteristics of the Lynx helicopter. The NASTRAN finite-element system with the automatic substructuring technique was used. The overall model contained approximately 10,000 degrees-of-freedom. Condensation (Guyan reduction) of the model was performed at two levels, leaving the final model with 318 degrees-of-freedom. A 'free-free' dynamic analysis was performed on this reduced model to extract the normal modes of vibration in the frequency range of 0 to 50Hz. Using these modes, the responses at several points on the airframe to sinusoidal forcing moments input at the rotor head were calculated. The finite-elements results were compared with results obtained from multi-point excitation shake tests performed on the aircraft. Good agreement between the NASTRAN and experimental natural frequencies and mode shapes was achieved. However, less than good agreement for forced response results was obtained and further work is now being performed in this area.

1. INTRODUCTION

The work described in this paper forms a part of a larger programme of research into the reduction of helicopter vibration levels. The overall objective of the programme is to enable the ab initio design of a helicopter, which possesses an acceptable level of vibration.

In an earlier phase of this research the normal modes and forced response characteristics of a Lynx tailcone assembly were investigated. Comparisons between multi-point shake test results (ref. 1) and NASTRAN finite-element results (ref. 2) were encouraging.

In the current phase of work the dynamic characteristics of a complete Lynx helicopter were studied. The finite-element analysis employed a substructuring approach with the tailcone model used in the above phase of work becoming one of the nine substructures. Again the NASTRAN results were compared with those obtained from shake tests for the normal modes and frequency response. A brief outline of the experimental work is given in this paper: full details may be found in reference 3.

In parallel with the work described in this paper a complementary research study is being performed into 'Structural Manipulation'. This work is aimed at developing a technique to pinpoint areas of a structure where modifications to stiffness and/or mass will most efficiently reduce vibration levels in particular regions of interest.

2. FINITE ELEMENT IDEALIZATION

This section describes the idealization of the Lynx helicopter using the MSC/NASTRAN finite-element system (refs. 4, 5 and 6).

MSC/NASTRAN is a general-purpose structural analysis computer program with the ability to handle statics, dynamics, heat transfer, acoustics and non-linear problems. In the field of structural dynamics the MSC/NASTRAN system is particularly strong. Capabilities include normal modes, complex eigenvalues, forced response, random response and transient response analyses. Either finite-element or direct matrix input formulations may be employed. The present programme of research utilizes only the normal mode and forced response capabilities and employs the finite-element formulation.

The NASTRAN program was originally written in the United States for NASA and a commercial version is currently being augmented and marketed by the MacNeal-Schwendler Corporation. The system mounted on the CDC6600 computer at S.I.A. Ltd. in London was used in the current work.

The helicopter was modelled using the MSC/NASTRAN substructuring technique. This approach allows the modelling of parts (or sub-structures) of the whole structure to be performed, to a large extent, independently of each other. These substructure models are later joined together to form the complete model which is then analysed to find its eigenvalues and eigenvectors (see Section 3).

### Structural State of the Helicopter

The aircraft modelled by NASTRAN and used in the experimental shake tests was development-standard Lynx number XW835. This aircraft has some stiffening schemes fitted to simulate the stiffnesses expected on the production aircraft. The masses of the pilots were represented by weights on the seats. The equivalent mass which represented the main rotor head and servo jacks had a 2.75 metre long aluminium beam attached to its top. This allowed either roll or pitch moments to be input to the head by means of antiphase forces at the ends of the beam. The complete helicopter assembly had a mass of 3689 Kg.

### Selection of Elements

The principal element types used in the model are as follows:-

- BAR. Beam element with extensional, torsional, and bending properties together with associated shears.
- ROD. Simplified BAR element with extensional and torsional properties only. In general, the torsional degrees-of-freedom of the element was not used.
- SHEAR. Two-dimensional quadrilateral element which resists in-plane shear and which can be augmented to carry in-plane direct loads.
- TRMEM, QDMEM2. Triangular and quadrilateral membrane elements with finite in-plane stiffness and zero bending stiffness.
- TRPLT, QDPLT. Triangular and quadrilateral plate elements with finite bending stiffness and zero in-plane stiffness.
- TRIA2, QUAD2. Triangular and quadrilateral plate elements with finite in-plane stiffness and finite bending stiffness.
- RBAR, RBE2. Rigid bar element and general rigid-body element.

Tests were carried out (ref. 7) to determine which type of element would be the most suitable for the modelling of the skins. The results showed that either membrane elements or augmented shear elements could be used provided the element mesh size was fine enough. A fine mesh ensures that the approximations made in the lumping of the end-load carrying capacity of the augmented shear element into equivalent rods around its boundary has negligible effect on its in-plane bending stiffness. These elements (SHEAR) were finally selected because the available membrane elements were significantly more expensive in the formation of their stiffness matrices. The newer NASTRAN general-purpose plate element, QUAD4, has shown considerable improvements in efficiency over previous membrane elements and in future idealizations is likely to be preferred to the augmented shear-panel element.

The modelling of the main rotor gearbox presented an especially difficult problem. It is a complicated magnesium casting with many internal components. Modelling directly from the drawings proved to be extremely difficult and time-consuming so a more practical approach was taken. A gearbox casing was obtained and the nodal points and elements were marked onto it. The co-ordinates of these nodes were obtained using a three-dimensional digitizing machine. The thickness of the casing associated with each element was found using an ultrasonic thickness gauge and micrometers.

The gearbox shell model generated in this manner employed superimposed QDMEM2 and QDPLT elements to give the required membrane and bending stiffnesses. Where the casing geometry made it necessary, triangular plate and beam elements were also used. The internal components of the gearbox were considered to be very stiff when compared with the shell. These were modelled by rigid bars (RBAR) and general rigid body elements (RBE2). Extensive use was made of cylindrical co-ordinate systems to allow accurate definitions of degrees-of-freedom at the interfaces between shafts and casings. Rigid body elements were also used to model the other comparatively stiff parts of the aircraft.

In general, the NASTRAN mass matrix was generated by using the mass-density parameter on the material property cards. The masses were allocated to the nodes by simple lumping. Non-structural masses (e.g. batteries and instruments) and some structural masses were represented by the lumped-mass element CONM2. In addition all masses associated with rigid elements were defined by CONM2 elements.

### Substructuring Philosophy

When the modelling of the helicopter began there were two distinct analysis techniques available in MSC/NASTRAN for normal mode analysis. The helicopter could be modelled and analysed as a single structure (the 'one-shot' approach) or the substructuring approach could be used. In the latter approach the structure is first modelled as a number of separate parts (or substructures) which are later assembled to form the complete idealization.

The substructuring technique was chosen for several reasons:-

- a) The final model was to be very large, having about ten thousand degrees-of-freedom. A model of this size would be difficult to handle if it were modelled as a single structure. For instance, a large computer elapsed time would render the analysis more prone to computer 'down' problems.
- b) A number of different people were to work on the modelling. Using the substructuring technique these modellers could, to a large extent, work independently of each other. Compatibility of the substructure models has to be achieved only at their common boundaries.
- c) The aircraft is produced from sub-assemblies with the drawings arranged accordingly. One or more sub-assemblies could be selected to form a substructure making the extraction of information from the drawings easier.
- d) Error checking is easier. The data prepared for each substructure can be checked more readily if the number of data items is not too large. The dynamic characteristics and the quality of the stiffness matrix for each substructure can be checked relatively cheaply using the COMPLETE option to solve for the substructure normal modes and natural frequencies.
- e) Modifications to the model can be made more easily if the substructuring technique is used. The data is much easier to handle and the cost of modifications is less because the whole structure need not be re-analysed if alterations are made only to a few of the substructures. However the additional complications in tape handling and data manipulation must be borne.
- f) There is no loss in accuracy when using the substructuring approach compared with the one-shot approach.

The aircraft was divided into nine substructures, two of which (the seats) were identical. Details of the substructures together with element types and numbers are given in Table 1. There are 5131 structural elements and 9906 degrees-of-freedom in the overall model. The assembled substructures are shown in Figure 1.

### 3. ANALYSIS TECHNIQUES

#### Data Generation and Checking Programs

Pre-processing programs written at WHL played an important part in the data generation and checking for this study. Four programs proved particularly valuable. These were used for:

- i) generating and checking NASTRAN mass data cards
- ii) plotting substructure geometry and element connectivity
- iii) generating NASTRAN MPC (multi-point constraint) data cards
- iv) checking the extent of warping of planar elements.

Further details on these programs are given in reference 8.

Significant cost savings were achieved by the use of the MSC/NASTRAN pre-processing program WAVEFRONT. This program defines the internal resequencing of node numbers necessary to minimize the computational times for matrix manipulations.

#### Normal Mode Substructure Analysis

The normal mode analysis is performed in three phases. A summary of the method is given below. A full explanation can be found in references 6 and 8.

##### Phase 1

The complete structure is modelled in parts or substructures. The substructures are then analysed to derive their mass and stiffness matrices. A Guyan Reduction (see ref. 5) is (optionally) performed to reduce the number of degrees-of-freedom to those on the common boundaries together with those internal freedoms required to define the substructures physically or dynamically.

In the present work the Phase 1 analyses were performed using MSC/NASTRAN version 36, with Rigid Format Alter RF3£37£1. After Guyan reducing the stiffness and mass matrices of the substructures, their eigenvalues and eigenvectors were extracted by the Givens Method. This was not an essential step, but was one which proved extremely valuable in checking the quality of the stiffness matrix. In particular, six 'rigid-body' modes with near-zero frequencies were sought for each substructure, plus any mechanisms present prior to connection of the substructures. Failure to find such modes and mechanisms indicated modelling deficiencies. The reduced mass and stiffness matrices for each substructure were stored on tape ready for use in Phase 2.

##### Phase 2

The mass and stiffness matrices derived in Phase 1 are combined to form single mass and stiffness matrices which describe the complete structure. Extra structure can be added at this stage. A further (optional) Guyan reduction is performed to reduce the number of the substructure boundary degrees-of-freedom and any internal degrees-of-freedom that the user may not wish to carry through to the eigensolution. The eigenvalues and eigenvectors are then extracted for this reduced model.

Rigid Format Alter RF3£37£2 was used for this phase of the study. A Guyan reduction was used to reduce the number of degrees-of-freedom from 1483 to 318. Assembling the substructures and ill-conditioning caused some problems, but when these were overcome (see ref. 8) the Givens method successfully extracted 318 eigenvalues and the first 45 eigenvectors.

##### Phase 3

The eigenvectors obtained in Phase 2 relate to the reduced number of degrees-of-freedom. In Phase 3 the remaining eigenvector coefficients for all the Phase 1 degrees-of-freedom can be evaluated if desired.

A Phase 3 analysis was not performed in the current study.

## Response to Sinusoidal Forcing

The forced-response calculations were made using Rigid Format RF11£37A (modal frequency response with substructuring). Pitch and roll moments of 847.5 Nm were input to the main rotor head as separate load cases. The responses to these moments were calculated at the tail-rotor gearbox, the intermediate gearbox and the co-pilot's seat mounting points for the frequency range of 5 to 50Hz.

All of the NASTRAN modes were used in this calculation and viscous modal damping was assumed. Where there was a direct correspondence between the NASTRAN mode and an experimental mode, the value of damping obtained from the experiments was used. Where there was no correspondence the average value of damping obtained in the experiments was used.

The real and imaginary components of the velocity responses were calculated for comparison with the experimental results.

### 4. EXPERIMENTAL WORK

In this section an outline of the experimental work is given. A full report appears in reference 3.

The shake tests were conducted using the MAMA system. MAMA is an acronym for Manual/Automatic Multi-point Apparatus. The system was originally designed at RAE, Farnborough for fixed-wing applications and has been further developed for helicopters by WHL. The apparatus controls up to six electro-magnetic vibrators which are suspended from mobile supports and which can transmit independent forces of up to 62N to any point on the structure under test. The excitation frequency is automatically controlled to maintain the velocity response in phase with the exciting force at one point on the structure, whilst the distribution of the forces is controlled manually. Previous shake tests performed on the Wessex helicopter are reported in reference 9.

The aircraft was suspended from an overhead gantry by a heavy-duty rubber rope attached to the rotor head. This gave an approximately free-free condition as the suspension modes were of low frequency when compared to the elastic modes.

Prior to the isolation of the normal modes an overall "feel" for the dynamic characteristic of the helicopter was required. This was achieved by recording the complex frequency response of the structure, at a number of positions, to single-point excitation. A number of exciter positions were used to produce a panorama of sensitive frequencies.

There were 121 monitoring points on the airframe. A roving accelerometer was used to measure the airframe acceleration components in the vertical, lateral and fore-and-aft directions at these points, giving a response vector of order 363. The accelerometer signal was integrated by the MAMA system so that velocity components were recorded.

Complex response plots were obtained for each mode shape and the modal damping factors were estimated. Two methods were used: the rate of change of phase with frequency around the resonance and the half-power method.

### Isolation of Normal Modes

The excitation of a normal mode of vibration of a structure requires the finding of mono-phase sinusoidal force distribution and a frequency for which a mono-phase response occurs throughout the structure, with the displacement response in quadrature with the force input.

When isolating the normal modes a philosophy of 'minimum complexity' was employed, consistent with acceptable results. Where possible single-point excitation was used, but up to five MAMA channels were employed. Force levels were kept as low as possible. The acceptability or otherwise of each mode was based upon the characteristic phase-lag criterion with, in general, an allowable phase error of  $\pm 10^\circ$  in total in-phase velocity response at all points.

## Response to Sinusoidal Forcing

A 890N vibrator was attached to each end of the aluminium 'I' beam on top of the mock-up rotor head. Moments were then input to the structure by driving these vibrators in anti-phase. Pitch and roll moments were input by rotating the 'I' beam through 90° in azimuth. In-phase and quadrature components of the velocity responses to 847.5 Nm pitch and roll moments respectively were then measured at discrete points of interest on the airframe over the frequency range 0 to 50Hz.

### 5. RESULTS

The NASTRAN analysis extracted 318 eigenvalues which ranged from 1.641E-04 to 2.521E+08. The lowest 32 of these lay in the frequency range of 0 to 50Hz which was the range in which the experimental results were obtained.

Figure 2 is a chart of the NASTRAN and experimental mode comparisons. The 'Mode Shape Description' refers to the NASTRAN mode shape and is for identification purposes only. It is not a complete description of all the activity in the mode. The modal damping is given by the 'Q' factor (the dynamic magnifier) for each mode of vibration. These values were obtained from measurements made in the shake tests. Where there were no direct comparisons between the NASTRAN and experimental modes an average value of 25 is quoted for Q.

It can be seen that the NASTRAN modes have slightly higher frequencies than the experimental modes. This is primarily because NASTRAN uses the displacement approach in its element formulation. The displacement method determines a minimum potential energy solution from a set of assumed displacement patterns and yields a lower bound in displacements. Hence the frequencies will converge from above as the model is refined. A second reason is the additional 'stiffening' caused by the 97% Guyan reduction which was performed. However it has been demonstrated in reference 10, where a similar degree of reduction (95%) was performed in extracting the normal modes of a gearbox casing, that the Guyan reduction error can be the smaller contribution in the lower frequency modes. A study on the Lynx tailboom (ref. 11) has also shown that a large Guyan reduction (98%) yields small errors in the lower modes. A third reason could be that, due to the experimental technique used in the isolation of normal modes, the natural frequencies can in some circumstances converge to the true solution from below as the phase error is reduced (ref. 9).

The largest off-diagonal term in the NASTRAN generalized mass matrix is 4.7E-08. This occurs between modes 19 and 20 which have frequencies of 29.542Hz and 29.558Hz respectively. These are the two closest frequencies and correspond to two modes of the tailcone-to-fin struts. All the other terms in the matrix are less than 1.0E-12.

The thirty-two NASTRAN modes compare with eleven experimentally derived modes. The six theoretical rigid body modes should have zero frequencies. The small eigenvalues associated with these modes arise from the inability of the Givens method to extract equal roots, the large range of eigenvalues extracted, and a small amount of spurious energy in the model.

Figure 3 shows the theoretical and experimental mode shapes for the first elastic mode. This is the fundamental vertical bending mode of the fuselage. Lack of space precludes the inclusion of more mode shape comparisons.

Initial forced response results derived from the above modes have proved disappointing. The range 20Hz-35Hz is the most obvious area of discrepancy. It is thought that a major factor here is a deficiency in the modelling of the engine area. Relatively minor errors in mode shapes, especially in the areas of force input or response measurement, can result in significant errors in the forced responses. Work is continuing, however, to improve the model and hence the response predictions (see figure 4).

## 6. CONCLUSIONS

The ultimate objective of this programme of research is to enable the ab initio design of a helicopter which possesses an acceptable level of vibration. The research work described in this report has made significant progress towards this aim, in giving WHL the capability of performing large-scale dynamic analyses using the finite-element method. Comparisons between MAMA shake tests and the MSC/NASTRAN finite element results have shown good agreement for frequencies and mode shapes.

Of the three eigensolution procedures available at present in NASTRAN the Givens approach was chosen as the best for the current study. Owing to spillage-from-core considerations and the corresponding escalation in costs there is an upper limit of approximately 350 on the number of degrees-of-freedom which can be included in the final analysis set. This restriction means that a large condensation (Guyan reduction) must be applied before the final solution is performed. In the present work the retained degrees-of-freedom were chosen manually, although a semi-automatic procedure is now being added to the program. In either case an additional source of inaccuracy is introduced into the analysis. A new eigensolution technique which avoids the need for Guyan reduction and which is cheap and straightforward to use would be a valuable addition for MSC/NASTRAN.

The substructuring technique was found to be awkward to use, largely due to very poor documentation and problems associated with the manipulation of large numbers of magnetic tapes. The key advantage of substructuring over a 'one-shot' approach is the ability to make structural modifications at a substructure level relatively cheaply and easily. The expected advantage of allowing different people to work independently on particular substructures was not fully realized, as a good deal of interaction between personnel modelling adjacent substructures is essential in order to achieve compatibility across the substructure boundaries. It is thought that the super-element approach must be given serious consideration for use on future projects of this type.

Two features of MSC/NASTRAN which have been found to be particularly valuable in the present work are:

- i) the excellent restart and data retrieval system
- ii) the multi-point constraint capability and the various rigid body elements

One serious weakness is to be found in the MSC/NASTRAN documentation. Although voluminous, it is frequently ambiguous and has a very poor index and cross-referencing system.

The MSC/NASTRAN system is being continually improved and expanded. One unfortunate consequence of this policy is that new versions of the system appear very frequently and each new version inevitably has new 'bugs'. It is usually the user who discovers these bugs and this means delays, sometimes extra cost and always frustration.

More work is required to establish better ways of evaluating damping factors. If this could be achieved, improvements in the forced response results would be anticipated. The estimation of damping factors from experiments is dependent on modal purity and every care should be taken to ensure that all monitoring points fall within the phase tolerance. It is felt that a blanket limit of  $-10^\circ$  may be too large for the characteristic phase lag.

In parallel with the work described in this report a complementary research study on Structural Manipulation is also being performed. This work is aimed at developing a technique to pinpoint areas of a structure where modifications to stiffness and/or mass will most efficiently reduce vibration levels in particular regions of interest. It is believed that these programmes of research will together provide the tools to achieve, through the use of Computer-Aided Design techniques, significant reduction in helicopter vibration levels.



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8. REFERENCES

1. R.J. Parker and S.T. Parkinson. Investigation of Lynx Tailcone Normal Modes. WHL Research Paper RP.519. June 1976.
2. A. McLaughlin. Structural Dynamics Research Using Finite Elements. WHL Research Paper 522, June 1976.
3. R.J. Parker and S.T. Parkinson. Investigation of Lynx Fuselage Normal Modes. WHL Research Paper 520. June 1976.
4. Caleb W. McCormick. MSC/NASTRAN Users' Manual. The MacNeal-Schwendler Corporation, 7442 North Figueroa St., Los Angeles.
5. Richard H. MacNeal. The NASTRAN Theoretical Manual. The MacNeal-Schwendler Corporation, 7442 North Figueroa St., Los Angeles.
6. Jerrard A. Joseph. MSC/NASTRAN Application Manual for CDC6600 Series. The MacNeal-Schwendler Corporation, 7442 North Figueroa St., Los Angeles.
7. A.J. Barnard. The Finite-Element Analysis of Skins in Semi-Monocoque Constructions. WHL Research Memorandum RM.297. June 1975.
8. A. McLaughlin., G.M. Venn and A.J. Barnard. An Investigation of Helicopter Structural Dynamics using MSC/NASTRAN. WHL Research Paper RP.556, July 1977.
9. R.J. Parker, T. Yarker and R. White. Investigation of Helicopter Airframe Normal Modes. WHL Research Paper 459. 1974.
10. A.J. Barnard. The Finite Element Analysis of a Lynx Main Gearbox Casing. WHL Research Memorandum RM.377. September 1976.
11. A. McLaughlin. Effect of Extent of Guyan Reduction on Dynamic Analysis Using NASTRAN. WHL Research Memorandum RM.279. 1975.

Substructures		Degrees-of-freedom			Major Element Types										
Substructure No. and Name	Adjoining Substructure Numbers	Total No.	Reduced No.	% Guyan Reduction	BAR	ROD	SHEAR	TRMEM	QDMEM2	TRPLT	QDPLT	TRIA2	QUAD2	RBAR	RBE2
1 Nose	2,3	692	231	75	170	23	52	89		26	4				1
2 Forward Cabin	1,3,4	705	180	80	110	272	214	31							
3 Underfloor and Undercarriage	1,2,4,6,7,8	545	315	63	54	205	204	95				8	26		3
4 Rear Cabin	2,3,5,8	859	279	75	82	107	169	66				20	101		1
5 Gearbox	4,8	2189	57	97.5	67				290		290	338		108	8
6 and 7 Seats	3	401	63	87	104		36	24		24					
8 Rear Fuselage	3,4,5,9	1866	201	90	637	2	322	108							6
9 Tailcone	8	765	94	89	107	103	178	40							3
TOTALS		8423	1483	85	1435	712	1221	477	290	74	294	366	132	108	22

Total degrees-of-freedom = 9906

Approximate number of degrees-of-freedom on substructure boundaries = 850

Approximate number of substructure internal degrees-of-freedom = 633

21-9

TABLE 1

NASTRAN PHASE 1 STATISTICS

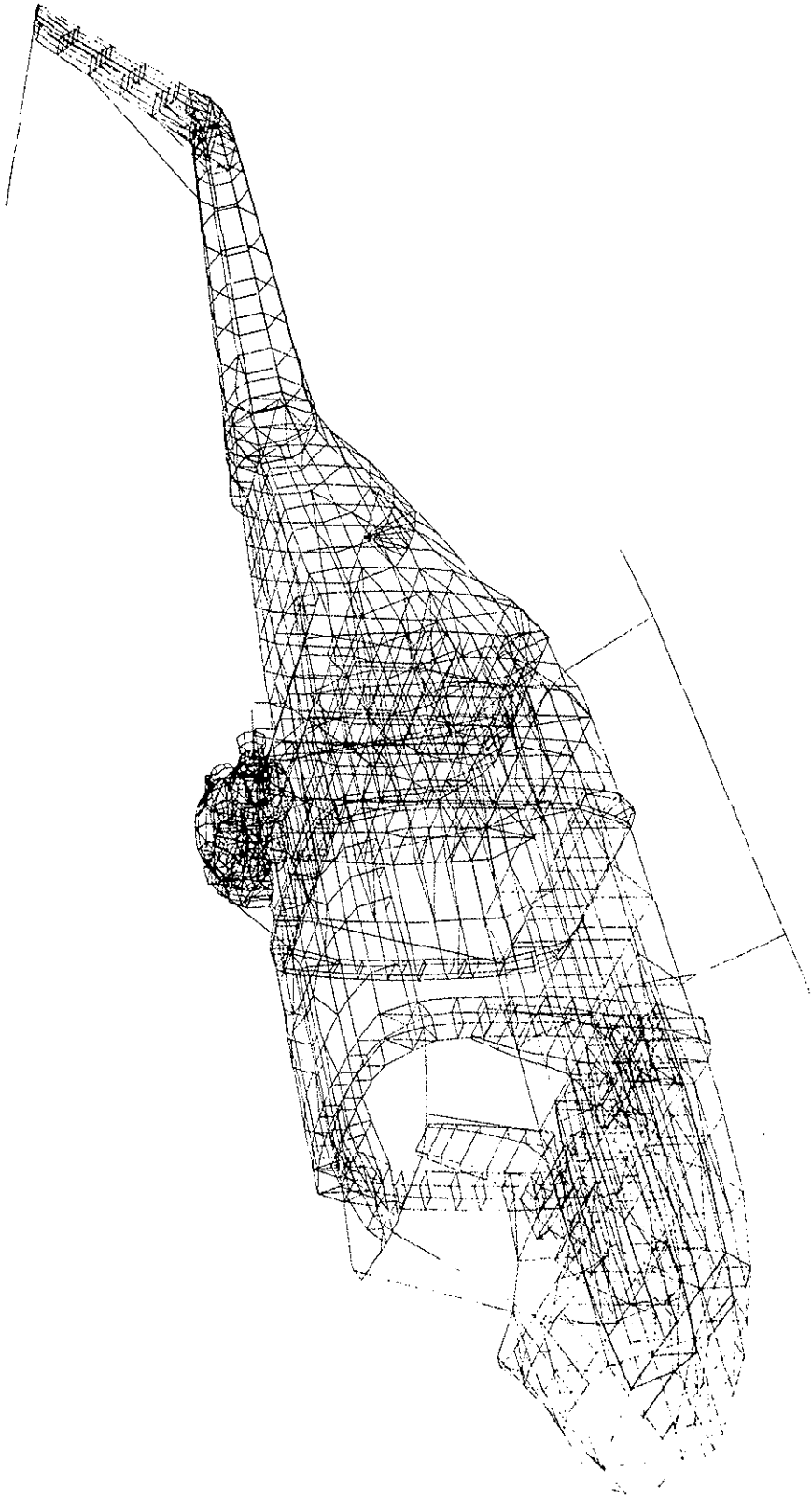
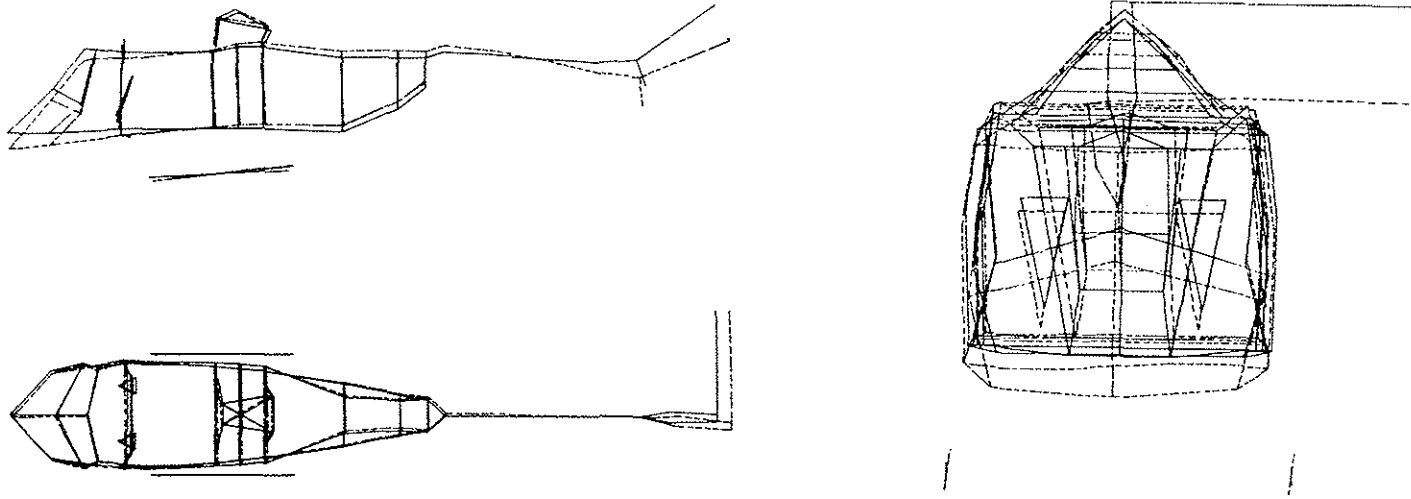


FIGURE 1  
ASSEMBLED PHASE 1 - NASTRAN MODEL

NASTRAN MODE No.	FREQUENCY		MODAL DAMPING 'Q' FACTOR	MODE SHAPE DESCRIPTION (For identification only)
	NASTRAN	Hz EXPERIMENT		
1	0.002			Vertical 'rigid-body' translation
2	0.014			Lateral 'rigid-body' translation
3	0.057			Fore-and-aft 'rigid body' translation
4	0.261			'Rigid-body' pitch rotation
5	0.340			'Rigid-body' yaw rotation
6	1.302			'Rigid-body' roll rotation
7	6.824	6.414	36.22	Fundamental vertical bending of fuselage
8	6.962	6.607	43.82	Fundamental lateral bending of fuselage
9	11.760	11.395	33.15	Vertical bending of tailplane
10	14.648	13.789	24.07	Second vertical bending of fuselage
11	17.895	16.956	48.10	Fore-and-aft bending of tailplane
12	22.485	21.299	14.25	) Torsion of forward fuselage, with second ) lateral bending, and engines antisymmet- ) rically fore-and-aft
13	23.760		14.25	
		23.551	13.40	Experimental: engine vertically antisym- etric
		25.486	24.18	Experimental: engine vertically symmetric
14	25.810		25.0	Cabin roof vertically symmetric
15	26.231		25.0	Gear-box yaw
16	26.389		13.40	Windscreen shear
17	27.529		24.18	Engines fore-and-aft symmetrically
18	28.678	29.905	25.0	) Tailcone joint struts and tailcone ) ) Tailcone-joint struts )
19	29.542		102.5	
20	29.558		102.5	
21	29.678		102.5	
22	30.100		102.5	
23	33.432		25.0	Symmetric deformation of cockpit glazing structure.
24	33.628	33.311	90.85	Cockpit glazing structure and control frame lateral.
25	34.851		25.0	Cabin roof vertically antisymmetric
26	35.435		25.0	Engines symmetrically lateral
27	37.684		25.0	Instrument panel fore-and-aft
28	38.228		25.0	Instrument panel lateral and cockpit glazing lateral.
29	41.262		25.0	Instrument panel vertical
30	41.908		25.0	Torsion of fuselage and lateral bending
31	43.136		25.0	Gear-box pitch and vertical bending of fuselage
32	48.869	43.498	23.9	Second vertical bending of tailplane

FIGURE 2. NASTRAN AND EXPERIMENTAL MODE SHAPE COMPARISONS

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MODE 1  
FREQ. 6.824 HZ  
MAX. DEF. 0.067

### NASTRAN DYNAMIC ANALYSIS OF LYNX COMPARISON WITH SHAKE TEST

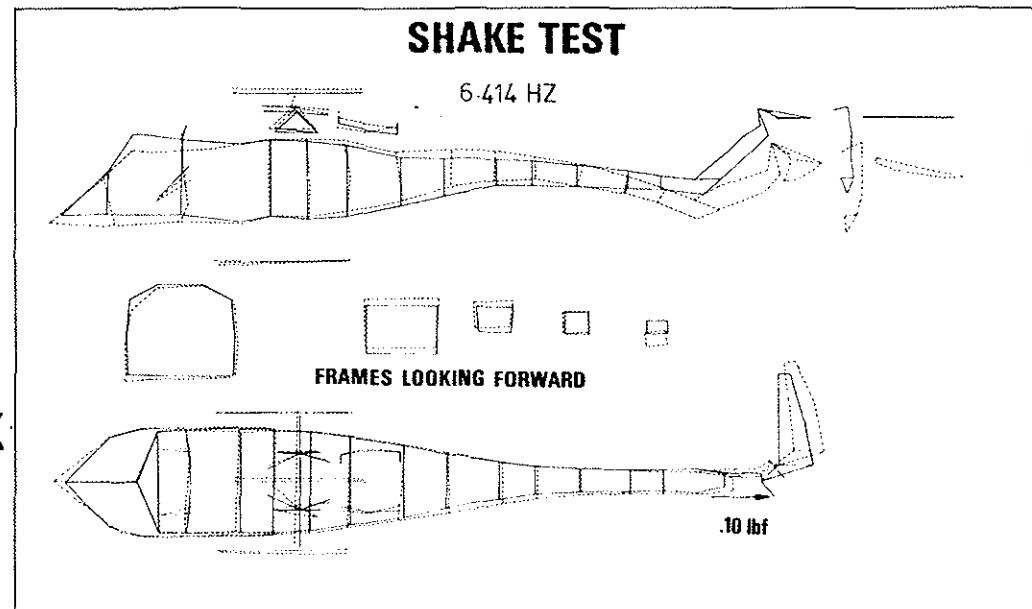
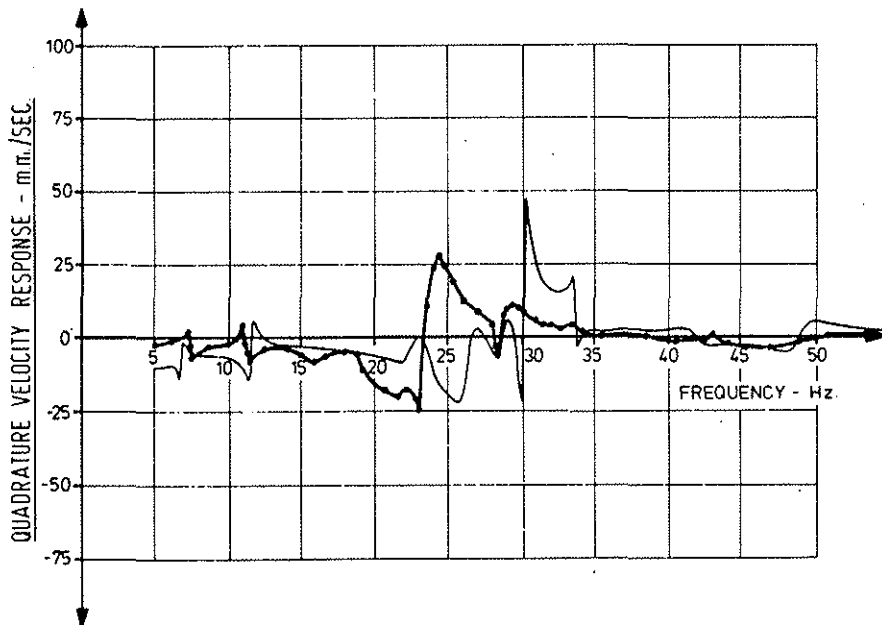
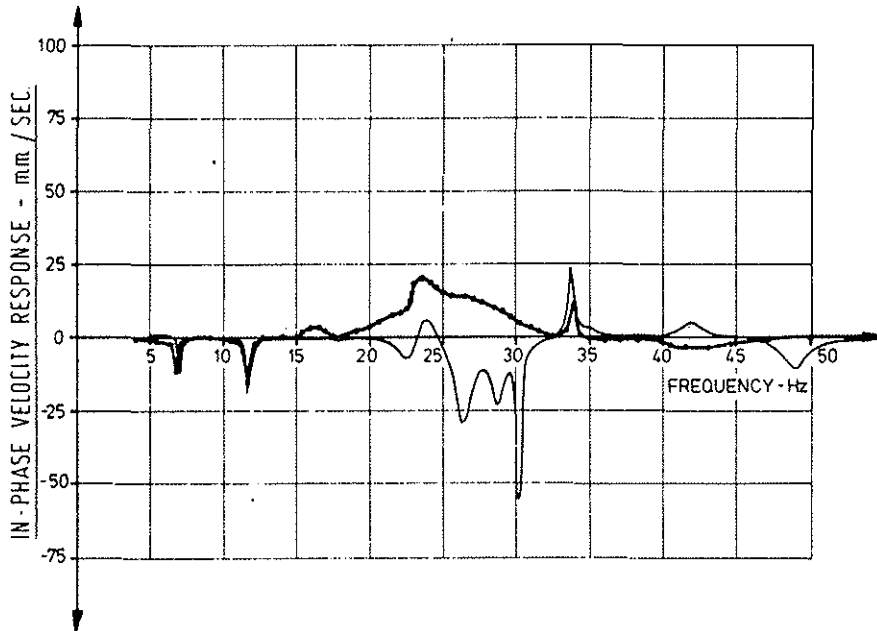


Fig. 3 First Elastic Mode Shape

FIGURE 4  
FORCED RESPONSE RESULTS

LATERAL RESPONSE - mm./SEC. AT INTERMEDIATE  
GEARBOX TO 847 N.M. ROLL MOMENT AT ROTOR HEAD.



..... SHAKE TEST

———— NASTRAN