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DYNAMIC ANALYSIS USING SUPERELEMENTS FOR A LARGE HELICOPTER MODEL

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SUMMARY

Using superelements (substructures), modal and frequency response analysis was performed for a large model of the Advanced Attack Helicopter (AAH) developed for the U. S. Army. Whiffletree concept was employed so that the residual structure along with the various superelements could be represented as beam-like structures for economical and accurate dynamic analysis. A very large DMAP alter to the rigid format was developed so that the modal analysis, the frequency response, and the strain energy in each component could be computed in the same run.

INTRODUCTION

The helicopter model shown in figure 1 consists of 13 substructures having 1000 grid points and 4000 structural elements. The dynamic analysis was performed using the residual structure, which represented a beam-like structure along the centerline of the aircraft at its nominal elastic axis, with appendages in the form of other beams. The residual structure was connected to the superelements by rigid elements in a sort of "whiffletree" form. This is an interesting, newly developed concept in that it allows dynamic analysis with the efficiency of a "stick" model, resulting in significant cost saving while at the same time retaining more involved effects accounted for in the detailed finite element model.

In order that normal mode analysis as well as frequency response computations could be executed in the same run, a special alter to the rigid format was developed. The alter was extended to further include calculations of strain energies in each component, so that the critical parts of the structure for each model could be easily identified. To determine the most sensitive mode to the rotor excitation, rotor impedance factors were calculated using eigenvectors generated from NASTRAN run.

The structural contributions due to the different subsystems, designed by other companies, were incorporated into the main helicopter model by employing the NASTRAN general elements (GENEL). To better evaluate the interaction between the basic structure and the subsystem, transient response analysis due to gun firing forces and frequency response analysis due to the rotor excitation were conducted by utilizing the results computed by the normal mode analysis.

Separate set of values obtained from the analytical approach were found to be in very good agreement. Harmonic analysis is being currently performed using the time history output from the transient response analysis to determine the frequency content.

DESCRIPTION OF THE MODEL

The Advanced Attack Helicopter consists of the fuselage, the wing and the vertical tail, all composed of typical skin-stringer construction. The horizontal stabilizer is a semimonocoque structure utilizing beaded skin construction. The complete finite element model is shown in figure 1. This consists primarily of simpler elements in NASTRAN library. This model was divided into 10 primary superelements and three secondary (image) superelements. Advantages of substructuring and its limitations were fully considered in selecting this particular scheme of dividing up the model. Figures 2 and 3 show a more detailed definition of a typical superelement representation. Table I provides the element breakdown for each of the superelements in the model. As can be seen, this is definitely not a small model for dynamics. For the convenience of the users, table II shows the various set sizes for each superelement.

The dynamic analysis is performed using the a-set points, which in the superelement concept is defined as the residual structure or superelement 0. This structural model is a beam-like structure along the centerline of the vehicle with appendages in the form of other beams and/or GENEL elements. This residual structure is not a normal structure consisting of a-set points but is connected to the other superelements by means of a unique set of rigid elements. This concept is given the name of "whiffletree," further described in the next section.

WHIFFLETREE CONCEPT

Dynamics analysis involves some form of technique to reduce the size of problem from the statics analysis model. Most people are very familiar with the "stick" or beam or EI/GJ models and even today are quite content using those models. With NASTRAN users, Guyan reduction has become quite a popular technique for achieving the smaller model. Whiffletree concept uses rigid elements or, more appropriately, MPCs for the same goal; namely, the smaller model. MPC or the multipoint constraints can be used such that the behavior of several grid/mass points is represented by one single grid/mass or a scalar point.

Figure 4 shows a typical whiffletree arrangement for one of the bulkheads in the AAH model. As can be seen, the point in the middle (does not have to be located there) is "connected" to the more important grid points on the bulkhead using a general rigid element RBE3. This single point now represents the average behavior of that complete bulkhead without any matrix reduction. Continuing in this fashion the end product is a pseudo stick model that would predict the dynamic characteristics of the complete structure. Figure 5 shows this model.

These points were all left in the residual or boundary structure and thus they were in the a-set of each superelement. As a matter of fact, the residual structure consists of this kind of points only. Because of this technique it was possible to keep the size of a-set points well within control for high efficiency while retaining in the solution the more complex behavior of the total structure. Certainly MCE1 and MCE2 modules are not that inexpensive but, compared to the exponential cost increase of SMP1 and SMP2 modules, this approach was found to be more cost-effective.

ALTERS FOR CONVENIENCE

One of the major tasks undertaken to complete this project consisted of formulating an Alter to the Rigid Format so that the following three analyses could be performed in the same run:

(a) Normal modes analysis with frequency response,

(b) Rotor impedance factors computation,

(c) Modal strain energy distribution.

All three alters are merged into one large alter to make it a production tool. Although it is not easy to keep up the alter compatible with the newer versions of MSC/NASTRAN, successful transition was made from CDC 6600 Version 32 to IBM Version 38; and, presently, efforts are in progress for adopting the alter to the latest IBM Version 46.

Natural Frequencies and Modes

As shown in table II, the total dynamic degrees of freedom (a-set) add up to the matrix size of 177. Grid points with dynamic degrees of freedom (a-set) are shown in table II. The modes are identified in somewhat arbitrary manner by looking at the deformed shape of the structure in a particular mode in conjunction with the computed mode shapes and strain energy distribution. The isometric views of the deformed structure are shown in figures 6 and 7.

Rotor Impedance Factors

The rotor impedances are calculated from the relation

$$\frac{1}{\text{rotor impedance}} \propto \phi_i^{\,2}$$

where ϕ_i is the eigenvector at the main rotor head in the i^{th} direction, and are plotted in figure 8 as $\phi_i^{\,2}$ versus the significant modes in their relative order of modal strength. The modes with the lowest impedance (i. e., the highest inverse ratio) are most sensitive to rotor excitation.

Modal Strain Energy Distribution

The MSC/NASTRAN computer program with this alter has the capability to compute and print out strain energy distribution in each flexible mode. This is very helpful in identifying the critical parts of the structure for each mode.

The program computes the strain energy in percentage form in each superelement for the desired modes.

The results are shown by MATRIX SPT in figure 9. The column number identifies the mode number (e.g., col 7 means mode 7) and the rows 1 through 10 denote the corresponding superelements 1 through 10. The strain energy in superelement number zero is computed separately under MATRIX RPT; however, it is included in figure 9 for convenience.

FREQUENCY AND TRANSIENT RESPONSE

Frequency Response

Alternating aerodynamic forces acting on rotor blades and on the fuselage and nonrotating parts of the vehicle are the major source of vibrations. Variations in these forces are periodic and all the steady alternating force inputs to the rotor hub occur in even multiples of the rotating speed such as 1/rev (1P), 2/rev (2P), 3/rev (3P), etc. However, only alternating forces and moments which are integral multiples of the number of blades are transmitted to the rotor hub. This helicopter has four-bladed rotor, therefore 4/rev, 8/rev, etc., are the only input to the hub. The 4/rev (4P) excitation forces which are the major contributor to the input at the hub were considered for this analysis. These excitation forces are obtained from DART (Dynamic Analysis Research Tool) program for various forward speeds of the helicopter and are multiplied by 4/rev response loads per unit excitation at rotor hub (computed by NASTRAN PROGRAM) to obtain total response at crew, stabilized sight and various other desired locations.

The effect of rotor speed variation on pilot and copilot station vibrations assuming no change in rotor forces is shown in figures 10 and 11.

Transient Response

Transient response due to gun firing is computed at several locations, such as crew stations, stabilized sight and gun center of gravity. The input impulse time history is shown in figure 12, and a typical response time history in figure 13.

CONCLUSIONS

A large model for dynamic analysis has been successfully used for the AAH project. Once again it is clear that NASTRAN is capable of solving a rather complex analysis scheme in a production manner provided proper resources are put into planning and writing some interesting DMAPs. The concept of MPCs and/or rigid elements is a very powerful tool that seems to provide new answers to several old problems.

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TABLE I – VARIOUS ELEMENTS IN THE MODEL

Element Type \ Superelement No.	1	2	3	4	5	6	7	8	9	10	0
Bar	158	84	76	4	4	38	6	25	25	29	36
Con Rod	660	372	6	1	1	-	1	1	1	-	31
Rod	122	108	224	44	44	-	-	-	-	221	16
Shear	202	165	100	10	10	-	-	-	-	119	-
TRMEM	26	-	8	5	5	-	-	-	-	2	-
QDMEMI	64	24	-	-	-	-	-	9	9	32	-
Con M1	-	-	-	-	-	-	-	-	-	-	3
Con M2	-		-	-	-	-	-	-	-	-	123

TABLE II – VARIOUS MATRICES IN THE MODEL

Matrix Size \ Superelement No.	1	2	3	4	5	6	7	8	9	10	0
Grid	363	211	140	37	37	50	7	27	27	145	145
n-set	2178	1266	840	222	222	300	42	162	162	870	870
m-set	215	42	54	30	30	60	0	68	68	134	36
f-set	1210	774	511	95	95	240	36	68	68	430	648
o-set	940	492	397	59	59	186	24	56	56	382	471
a-set	270	282	114	36	36	54	12	12	12	48	177

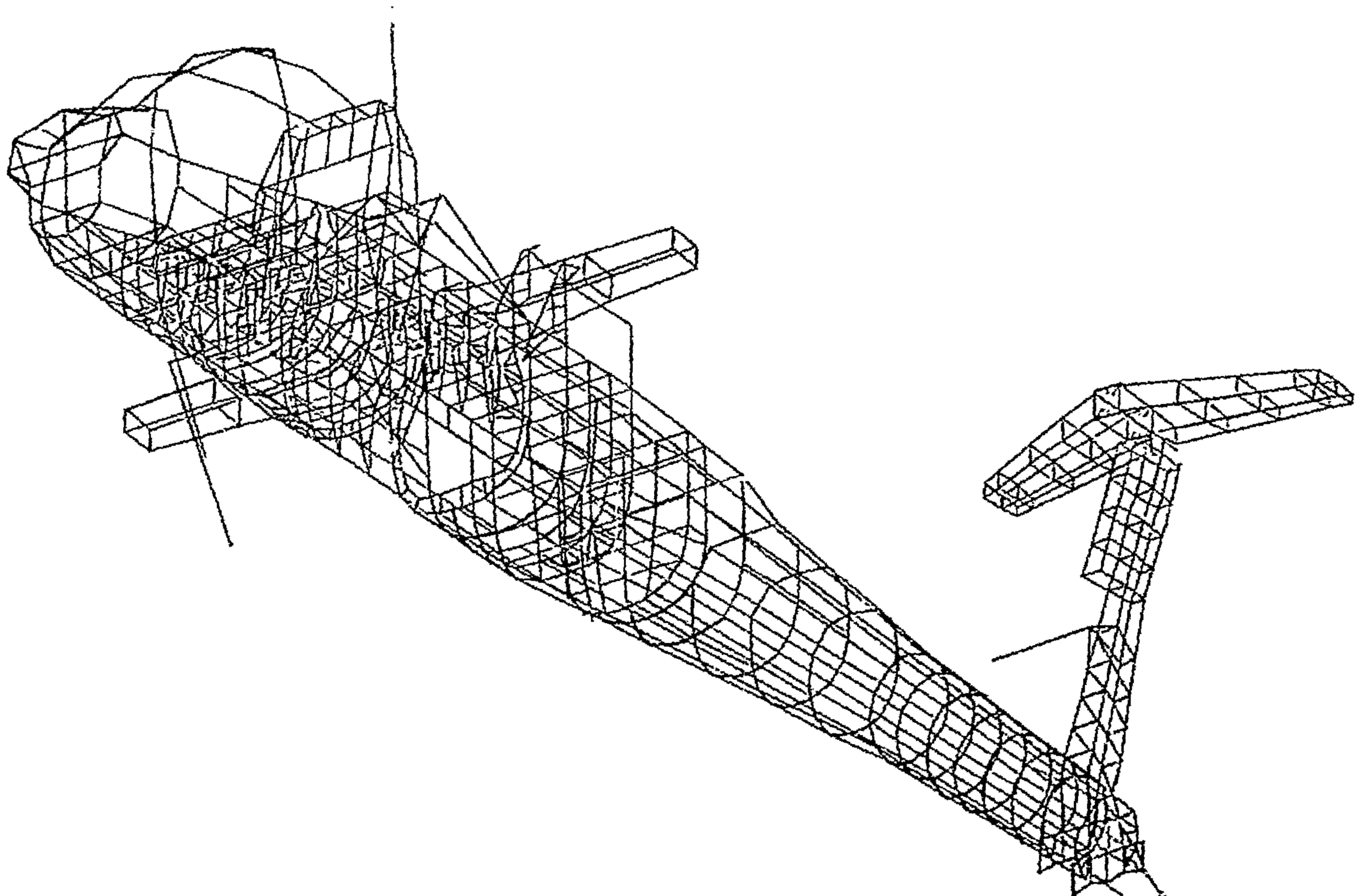

Figure 1. Advanced Attack Helicopter Model

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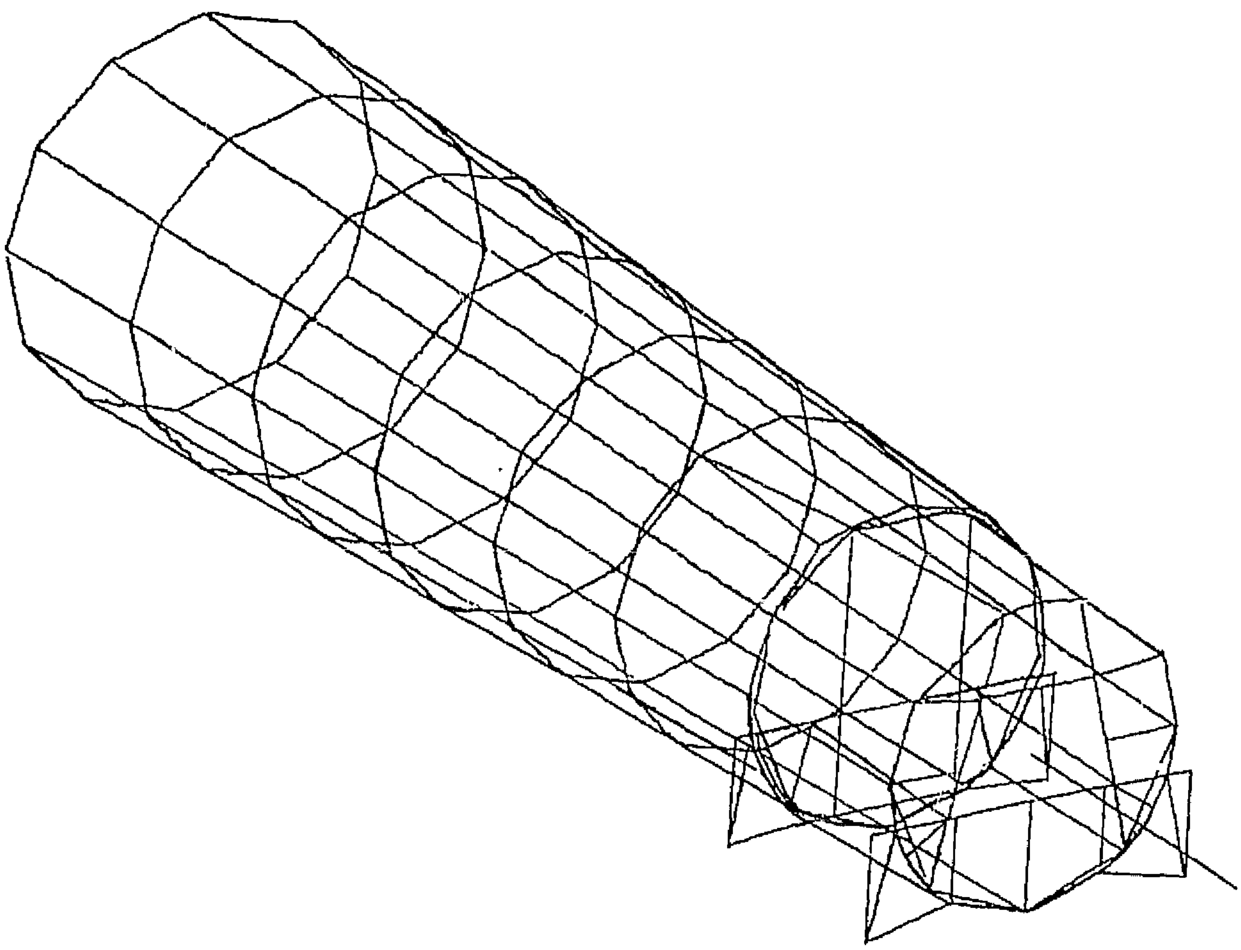

Figure 2. Advanced Attack Helicopter Tail Cone (Superelement 3) Model

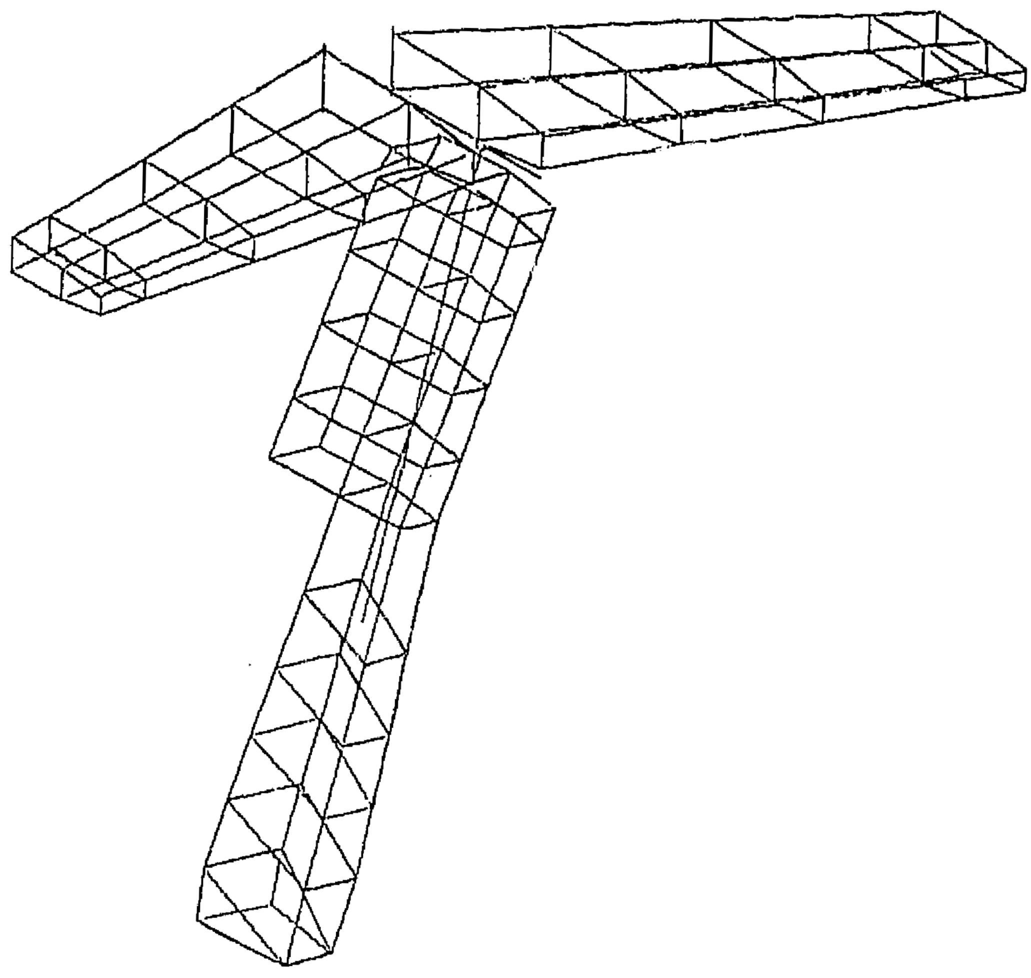

Figure 3. Advanced Attack Helicopter Model
Empennage (Superelement 10)

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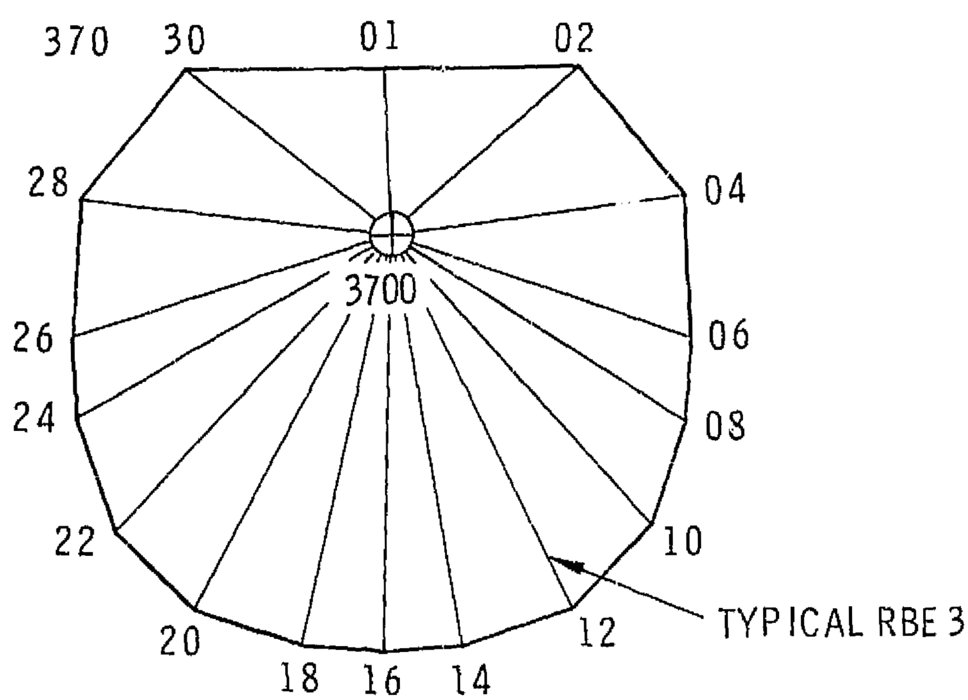

Figure 4. Typical Whiffletree Arrangement

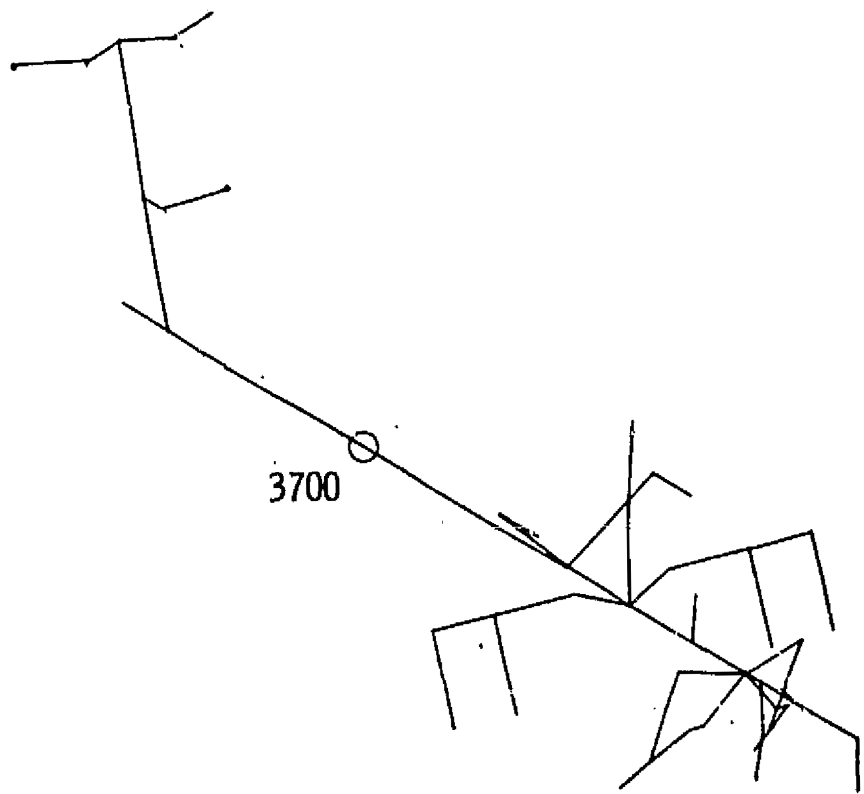

Figure 5. Complete Whiffletree Model

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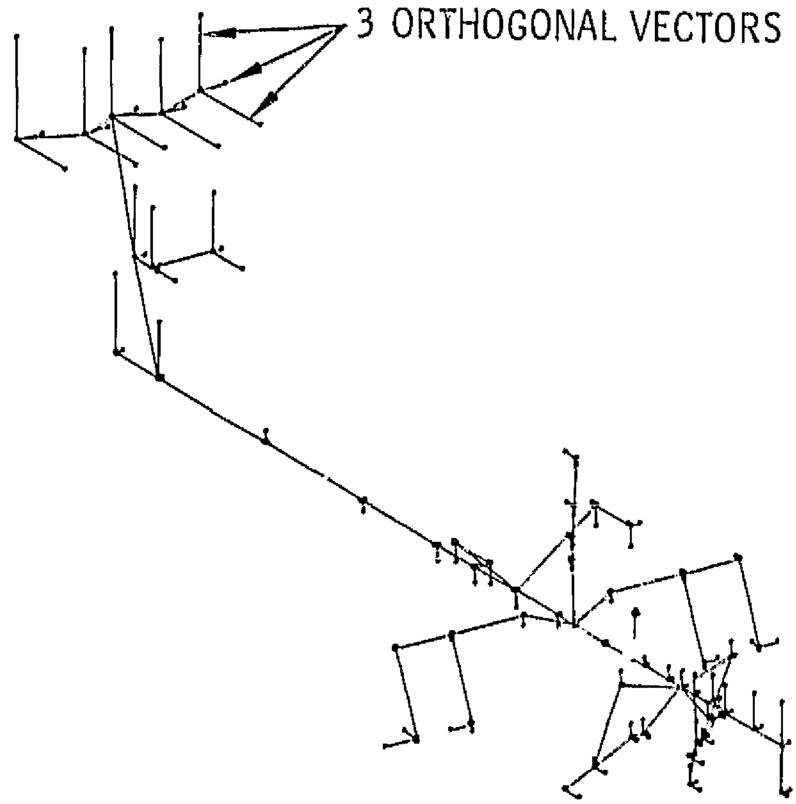

Figure 6. First Vertical Mode

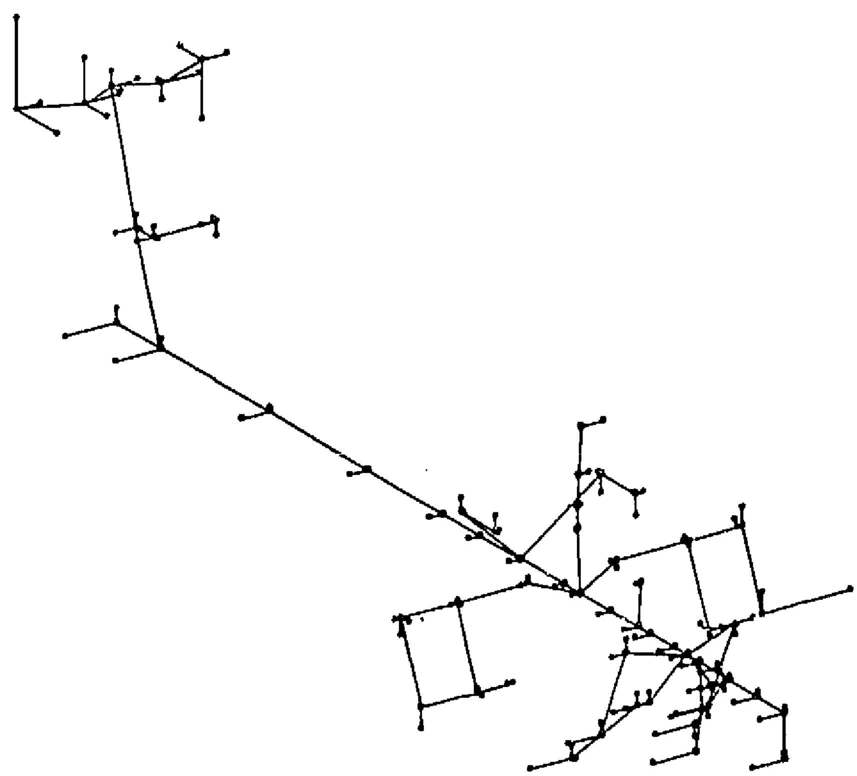

Figure 7. First Lateral Mode

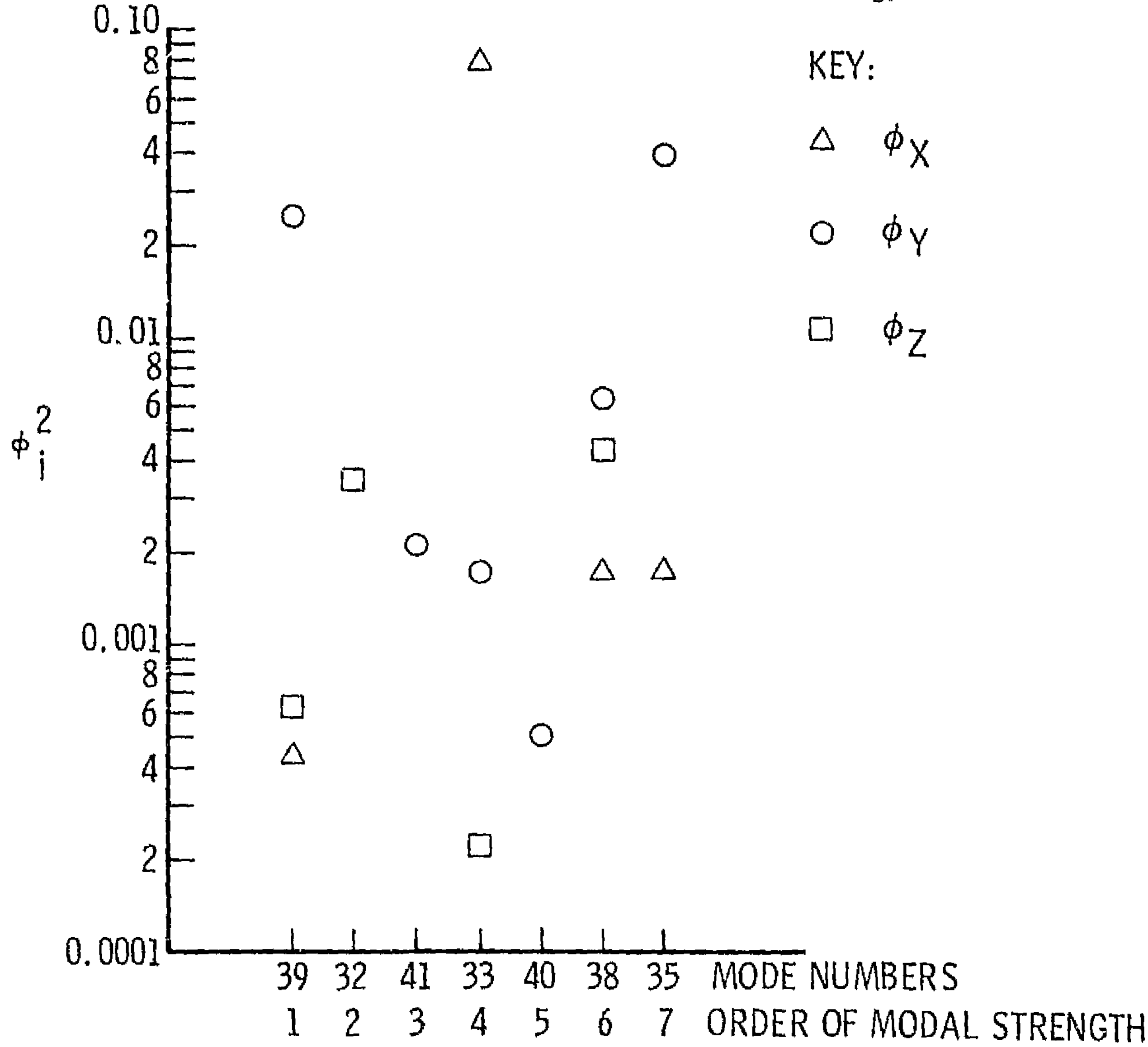

Figure 8. Rotor Impedance Factors

ADVANCED ATTACK HELICOPTER,
MODEL 41, 4 ROCKET PODS

APRIL 28, 1978

SAME AS MOD. 40 EXCEPT WITH 4 ROCKET STORES

MATRIX SPT (GTNO NAME 101) IS A REAL 50 COLUMN X 11 ROW RECTANG MATRIX.

1 FOREBODY	2 MIDBODY	3 TAIL BOOM	4 RH ENGINE	5 LH ENGINE	6 MAST	7 GUN	8 RH PYLON	9 LH PYLON	10 EMPENNAGE	0 RESIDUAL
COLUMN 7	ROWS	1 THRU	10							
1,08505E+01	3,28566E+01	1,61150E+01	1,19587E-02	2,31849E-02	1,36959E-01	7,94538E-03	2,50542E+00	2,96324E+00	1,03065E+01	1,56900E+01
COLUMN 8	ROWS	1 THRU	10							
3,64225E+01	7,24255E-01	9,60606E-02	9,39502E-03	1,86068E-02	1,40263E-02	4,77110E-04	3,00968E+00	2,97164E+00	3,50264E-02	4,13727E+01
COLUMN 9	ROWS	1 THRU	10							
5,46679E+00	9,38937E-01	1,31929E-01	2,16397E-02	1,90812E-02	2,71306E-02	3,55040E-04	2,50160E+01	1,74656E+01	1,73573E-02	1,98235E+01
COLUMN 10	ROWS	1 THRU	10							
2,16722E+00	3,78037E+00	2,08015E+00	5,61191E-03	1,43732E-02	4,50601E-02	6,25391E-03	3,02564E+01	4,77730E+01	1,77607E+00	2,42154E+00
COLUMN 11	ROWS	1 THRU	10							
2,31511E-01	3,01653E-01	1,20460E+01	2,81355E-03	2,29848E-03	4,33319E-03	3,61426E-04	3,71927E+01	6,70512E+00	9,52429E-02	1,46943E+00
COLUMN 12	ROWS	1 THRU	10							
1,50201E+00	1,31389E+00	7,88449E-01	2,46119E-03	6,34529E-03	1,84286E-02	5,40994E-03	5,12660E-01	2,37786E+01	7,03844E-01	4,22361E+00
COLUMN 13	ROWS	1 THRU	10							
8,47383E+00	1,05215E+01	5,34165E+00	1,32769E-01	4,38941E-03	2,39782E-01	7,80420E-03	7,22833E+00	9,52037E-01	5,49466E+00	3,60770E+01
COLUMN 14	ROWS	1 THRU	10							
8,92168E+00	7,55696E+00	2,66655E+00	1,90300E-02	1,32307E-01	1,47329E-01	2,33965E-03	3,71012E+00	6,86447E+00	2,14255E+00	3,02318E+01
COLUMN 15	ROWS	1 THRU	10							
1,78278E+01	4,56231E+01	1,23314E+01	3,52700E-01	3,84216E-01	6,30589E-01	1,06693E-02	1,52411E+00	7,89611E-01	2,50942E+00	1,09513E+01
COLUMN 16	ROWS	1 THRU	10							
1,73978E+01	3,68366E+00	6,98647E-01	1,25266E-01	2,51580E-01	7,91227E-01	1,56678E-01	3,04305E+00	5,04241E+00	2,17450E+00	3,56372E+01
COLUMN 17	ROWS	1 THRU	10							
9,15962E-01	3,26315E-01	4,56974E-02	7,45369E-03	7,68367E-03	3,67268E-02	1,83568E-03	3,44554E+01	2,97451E+01	1,84741E-01	1,56726E+01
COLUMN 18	ROWS	1 THRU	10							
9,25085E-01	2,11533E-01	7,95934E-02	6,56889E-03	9,43121E-03	3,45248E-03	7,04527E-04	3,02618E+01	3,51790E+01	4,63025E-02	1,55943E+01

Figure 9. Typical Strain Energy Output

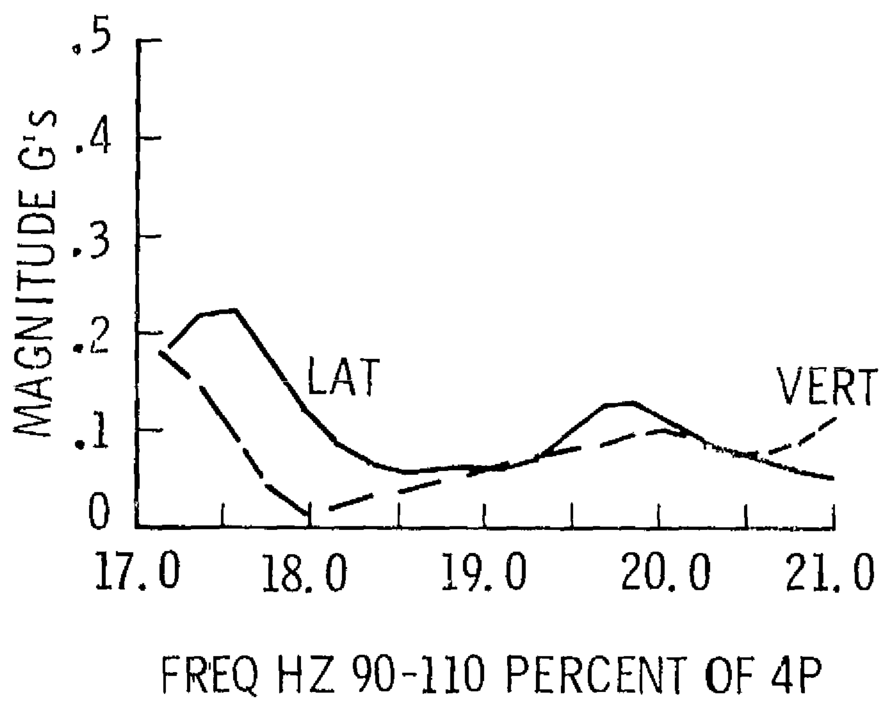

Figure 10. Frequency Response at Pilot Seat

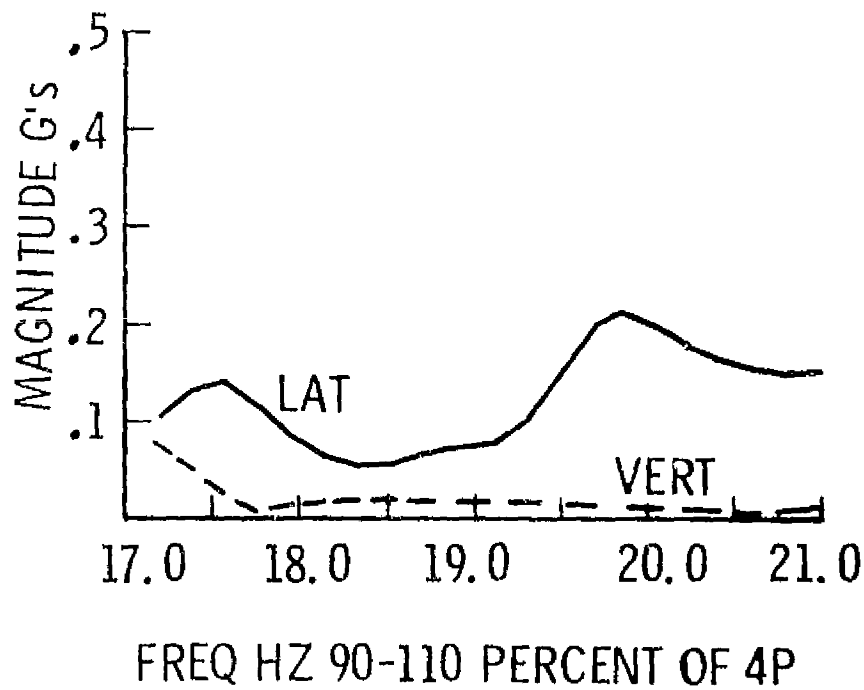

Figure 11. Frequency Response at Copilot Seat

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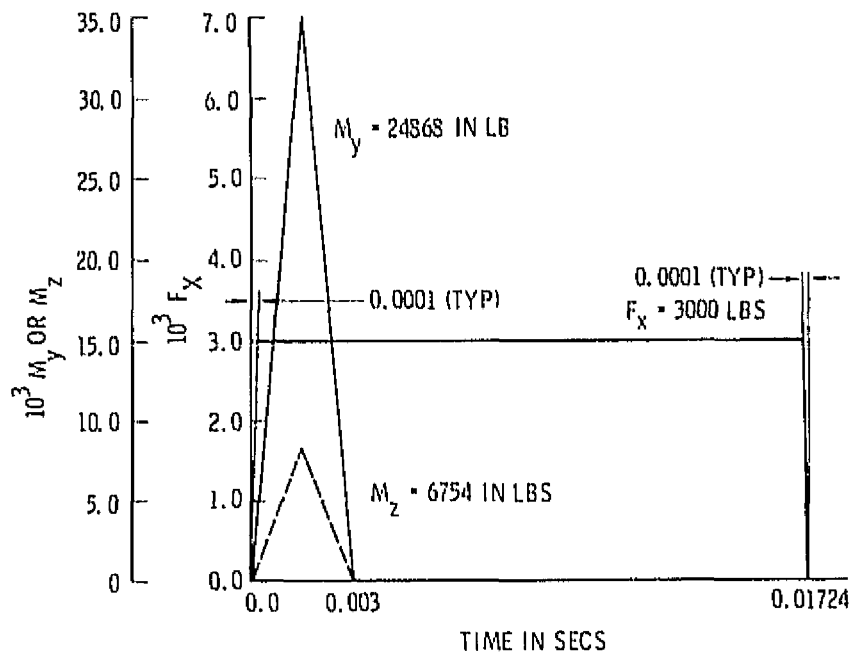

Figure 12. Input Impulse Due to Gun Firing

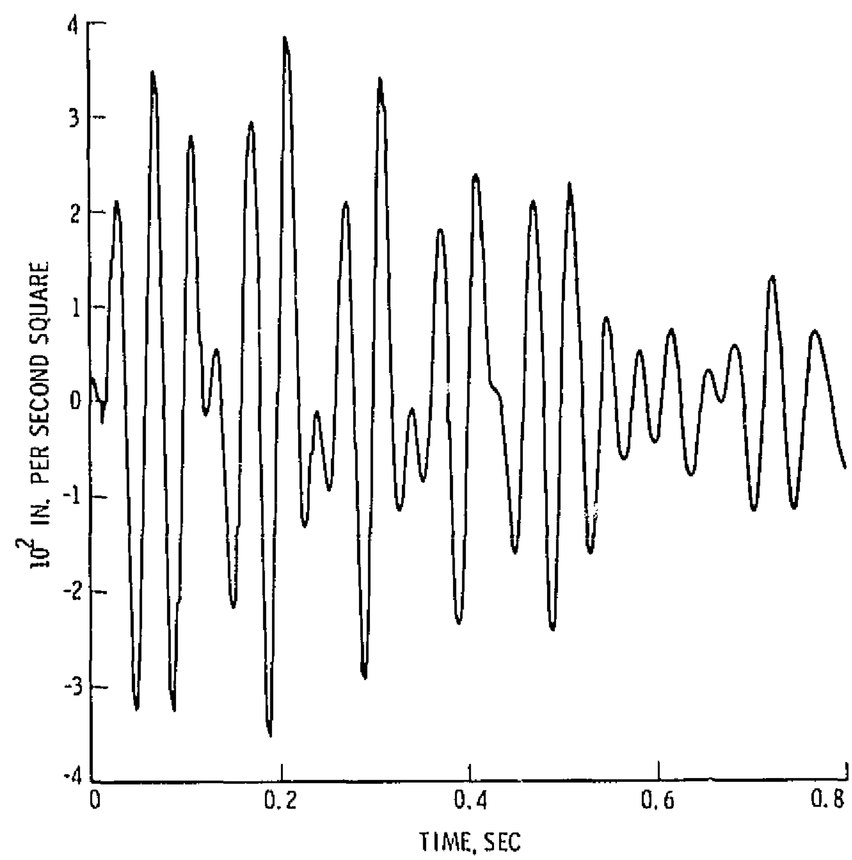

Figure 13. Transient Response at Gun Stabilized Sight