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STATIC AND DYNAMIC HELICOPTER AIRFRAME ANALYSIS WITH NASTRAN

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SUMMARY

The use of NASTRAN at Bell Helicopter Company for structural static and dynamic analysis of a helicopter airframe is described. Analysis of airframe internal loads, main rotor isolation systems, and airframe vibration is discussed. The use of each rigid format for these types of analysis is summarized. Suggested improvements to NASTRAN to increase its effectiveness in performing helicopter airframe analysis are given.

INTRODUCTION

Before the availability of large finite element programs, internal loads were calculated from two-dimensional shear and moment diagrams and the dynamic behavior was approximated with a Myklestad-type beam analysis. After the development of NASTRAN, and other similar programs, more exact analyses could be performed. However, before NASTRAN can be executed, the helicopter airframe must be represented as a three-dimensional finite element model which involves generation of a large amount of input data to define the structure. A typical airframe structural model is shown in figure 1. In addition to developing a structural model, the problem of distributing structural and nonstructural weight to the appropriate areas of the finite element model proved to be a time consuming and tedious task requiring many judgmental decisions. An automated procedure for distribution of weight items to the structural model was devised so that NASTRAN could be used efficiently for both static and dynamic structural analysis.

AIRFRAME STATIC ANALYSIS

A static analysis of a helicopter airframe involves the determination of internal loads and stresses using NASTRAN[1]. To facilitate the use of NASTRAN various preprocessor and postprocessor computer programs were written. The preprocessor programs include automatic data generation of finite element models of certain types of structure such as the tail boom, elevator, and vertical tail as shown in figure 2. The representation of the inertia loads is provided with an interface program to NASTRAN.

The interface program calculates six load vectors which represent the inertia reactions for independently applied unit translation and angular accelerations at the helicopter center of gravity. By scaling the inertia reactions to balance the applied loads and applying a set of determinant constraints, a NASTRAN static analysis can be done.

Postprocessors are used to calculate shear flows and adjusted rod loads for rod-shear panel type structure, to scan the output from several subcases and determine the critical loading condition for each element, and to present the output data in a report format.

Alternate output from the inertia distribution program is concentrated weights punched on data cards in NASTRAN format. These weights may be used directly in a static analysis with inertia relief, natural frequency analysis, or dynamic response analysis.

AIRFRAME DYNAMIC ANALYSIS

Main Rotor Isolation

Dynamic analysis of the helicopter involves evaluating different methods of isolating the excitation of the main rotor from the airframe. These methods include a focused pylon[2] for isolation of horizontal main rotor excitation and nodal beam[3] for isolation of vertical excitation. A sketch and brief explanation of these systems is shown in figure 3. NASTRAN models of these systems are developed using bars, linkages (rods), scalar springs, multipoint constraints, and concentrated masses.

Vibration response characteristics of the isolation system can be evaluated by attaching it to a rigid body fuselage. Natural frequencies, mode shapes, and frequency response characteristics of the main rotor isolation system can then be determined without having to consider the added complexity of elastic and dynamic effects of the fuselage. After having developed and tuned this type of model, the isolation system is incorporated into a structural dynamic airframe model to do a vibration analysis of the entire coupled system.

Airframe Vibration

The airframe dynamic response analysis is performed by combining the main rotor pylon and isolation system with the elastic airframe model. The airframe model will be either an elastic axis representation made up of bar elements with fuselage section properties or a built-up three-dimensional representation using bars, rods, shear panels, and membrane elements to model the structure. The elastic axis models have from 300 to 400 degrees of freedom and the three-dimensional models usually have 1200 to 1400 degrees of freedom maximum.

A modal approach is most often used for a vibration analysis of the airframe where the system degrees of freedom are reduced below 200 and the natural frequencies and mode shapes are computed using the GIVENS eigenvalue extraction method. This method is used primarily because of the number of modes required for low frequency (0 to 50 hertz) vibration response analysis, usually at least 30 modes.

The principal types of dynamic analysis done with the airframe model are the following:

(1) Tuning the airframe natural frequencies with respect to main rotor excitation harmonics by making structural and weight changes.

(2) Determining the steady state frequency response characteristics of the airframe where forces and moments are applied separately at degrees of freedom having excitation sources and the forcing frequency is swept over the range of interest (usually 0 to 50 hertz).

(3) Determining the steady state response to in-flight rotor harmonic excitation.

(4) Determining the transient response of the airframe to weapon firing using NASTRAN and a hybrid computer. The NASTRAN normal mode data for the airframe model is input to a hybrid computer program which computes the airframe response. A simplified flow diagram of the hybrid analysis is shown in figure 4.

SUMMARY OF THE USE OF NASTRAN RIGID FORMATS FOR AIRFRAME ANALYSIS

Rigid Format 1 - Static Analysis

Rigid format 1 is used to calculate the internal loads of the helicopter for the different design loading conditions. The static structural model typically contains 2500 to 3000 degrees of freedom and is modeled primarily with rods, bar, and shear panels. The initial run, when the stiffness matrix is decomposed, takes about 60 cpu minutes on an IBM 360-65 computer. Each succeeding loading condition takes approximately 20 cpu minutes.

Rigid Format 2 - Static Analysis With Inertial Relief

The weight distribution of the helicopter is checked with this rigid format. It performs a static analysis of a free helicopter in flight with steady loads applied. The results from rigid format 2 can be compared with those obtained using format 1 to ensure a correct inertial representation is achieved.

Rigid Format 3 - Normal Mode Analysis

This rigid format is used for tuning of the airframe natural frequencies with respect to predominant excitation frequencies. The natural frequencies and normal mode data output from NASTRAN are also used in other programs such as the hybrid computer program previously discussed or combined with main rotor analysis programs to determine the response of the coupled rotor and airframe.

The flexibility matrix ($[K]^{-1}$) and mass matrix are output and used in a flutter program. The natural frequencies and mode shapes for the zero velocity case are compared to the NASTRAN results as a check on the flutter program.

Rigid Format 4 - Static Analysis With Differential Stiffness

Rigid format 4 has been used for designing the static stops for the main rotor pylon support system. The use of differential stiffness reduced the loads caused by crash conditions, thus saving weight in the design. The inclusion of second order differential stiffness effects would allow NASTRAN to be used to solve several other structural problems such as tension stresses developed in membrane plates due to transverse pressures.

Rigid Format 5 - Buckling

The stability analysis in NASTRAN is used on a limited basis. Many degrees of freedom are required to obtain an accurate solution to a built-up three-dimensional model. A buckling analysis was performed on a helicopter tail boom. For a model containing 1800 degrees of freedom, NASTRAN predicted an eigenvalue of 6 when using the limit design loads. The analysis took over 4 cpu hours. It was felt this eigenvalue was too high, but to remodel finer and probably reduce the eigenvalue would take excessive cpu time.

Rigid Format 6 - Piecewise Linear

The piecewise linear solution in NASTRAN has never been used successfully. It could be a very helpful analytical tool if it functioned properly.

Rigid Format 7 - Direct Complex Eigenvalue Analysis

This rigid format is time consuming. An improved complex eigenvalue routine is desired, a preferred method would be a QR algorithm such as the available ALLMAT routine[4].

Rigid Fo- ·· 8 - Direct Frequency Response Analysis

Internal osc::l::tory loads and stresses for the response to rotor harmonic excitation ... calculated with rigid format 8. This rigid format would seldom b... if the mode acceleration technique in rigid format 11 worked on th... 15.1 version of NASTRAN.

Rigid Format 9 - Direct Transient Response

Rigid format 9 is used to calculate transient internal loads and stresses for such problems as panel response to blast overpressures, airframe response to gun recoil, and landing loads. As with rigid format 8, this rigid format would seldom be used if the mode acceleration technique worked in rigid format 12.

Rigid Format 10 - Modal Complex Eigenvalue Analysis

As in rigid format 7, run times have been excessive. An improved complex eigenvalue method is needed to make use of this rigid format practical.

Rigid Format 11 - Modal Frequency Response Analysis

Rigid format 11 is used to analyze steady state response of the airframe to harmonic excitation with varying frequencies to simulate shake test results. It is also used to analyze steady state response to in-flight rotor harmonic excitation. Mode acceleration is required to obtain internal loads. In our current level, 15.1, it does not work. Therefore, to get the internal loads, rigid format 8 must be executed.

Rigid Format 12 - Modal Transient Response Analysis

This rigid format is used to analyze transient response problems as described in rigid format 9.

DMAP Approach

DMAP programming has been found difficult to use. However, some DMAP alters are made. DMAP alters are used to obtain special output to be used in other analyses. Mode printout and normal mode plotting are altered into rigid format 11. DMAP is used to add differential stiffness to real eigenvalue analysis to determine centrifugal stiffening effects on rotor blades.

CONCLUSIONS

NASTRAN has been found to be very useful in performing aircraft structural analysis. When coupled with preprocessor and postprocessor programs, it has been used very efficiently and effectively in the design environment. It is felt, though, that NASTRAN's effectiveness can be greatly enhanced for our use with the following incorporations:

(1) Fix the mode acceleration technique in rigid formats 11 and 12.

(2) An improved complex eigenvalue solution is needed in rigid formats 7 and 10.

(3) Add rotating beam dynamic effects such as the addition of Coriolis acceleration terms.

(4) Add rotary transformation from rotor blade rotating system to the fixed airframe system.

(5) Rotor blade aerodynamics should be included along with (3) and (4) for analysis of the coupled rotor and airframe.

(6) Second order differential stiffness terms need to be added in rigid format 4.

(7) Piecewise linear analysis should be improved.

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3. Shipman, D. P., White, J. A., and Cronkhite, J. D.: Fuselage Nodalization. 28th Annual National Forum of the American Helicopter Society, Washington, D.C., May 1972.

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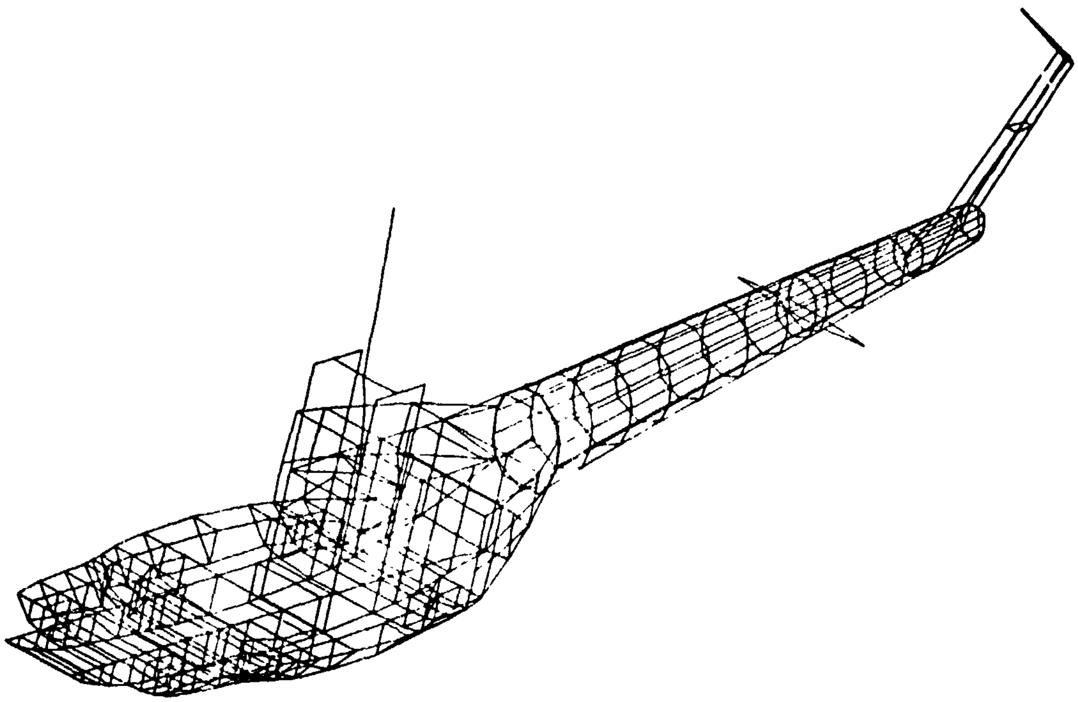

Figure 1.- Finite Element Model of Helicopter Airframe

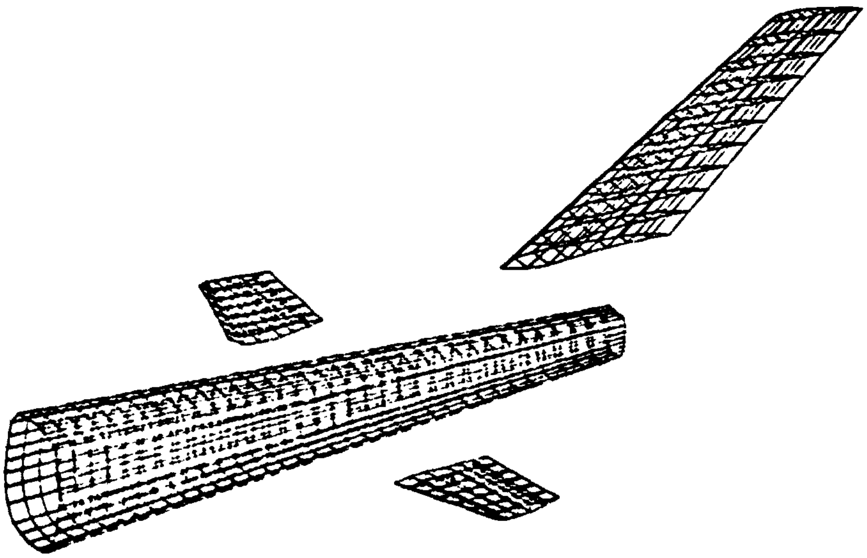

Figure 2.- Computer Generated Model

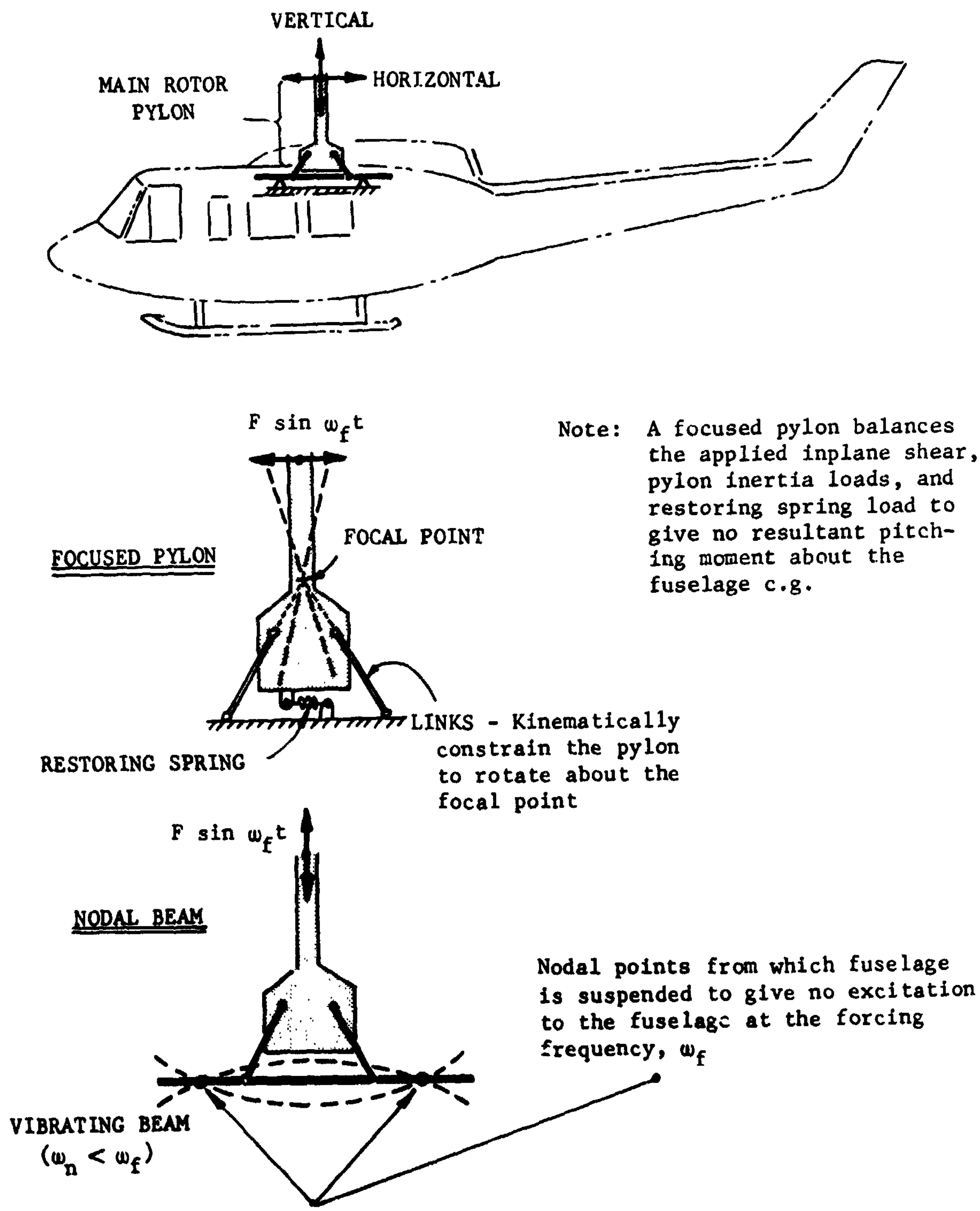

Figure 3.- Focused Pylon and Nodal Beam - Used for Isolation of the Airframe From Main Rotor Excitation

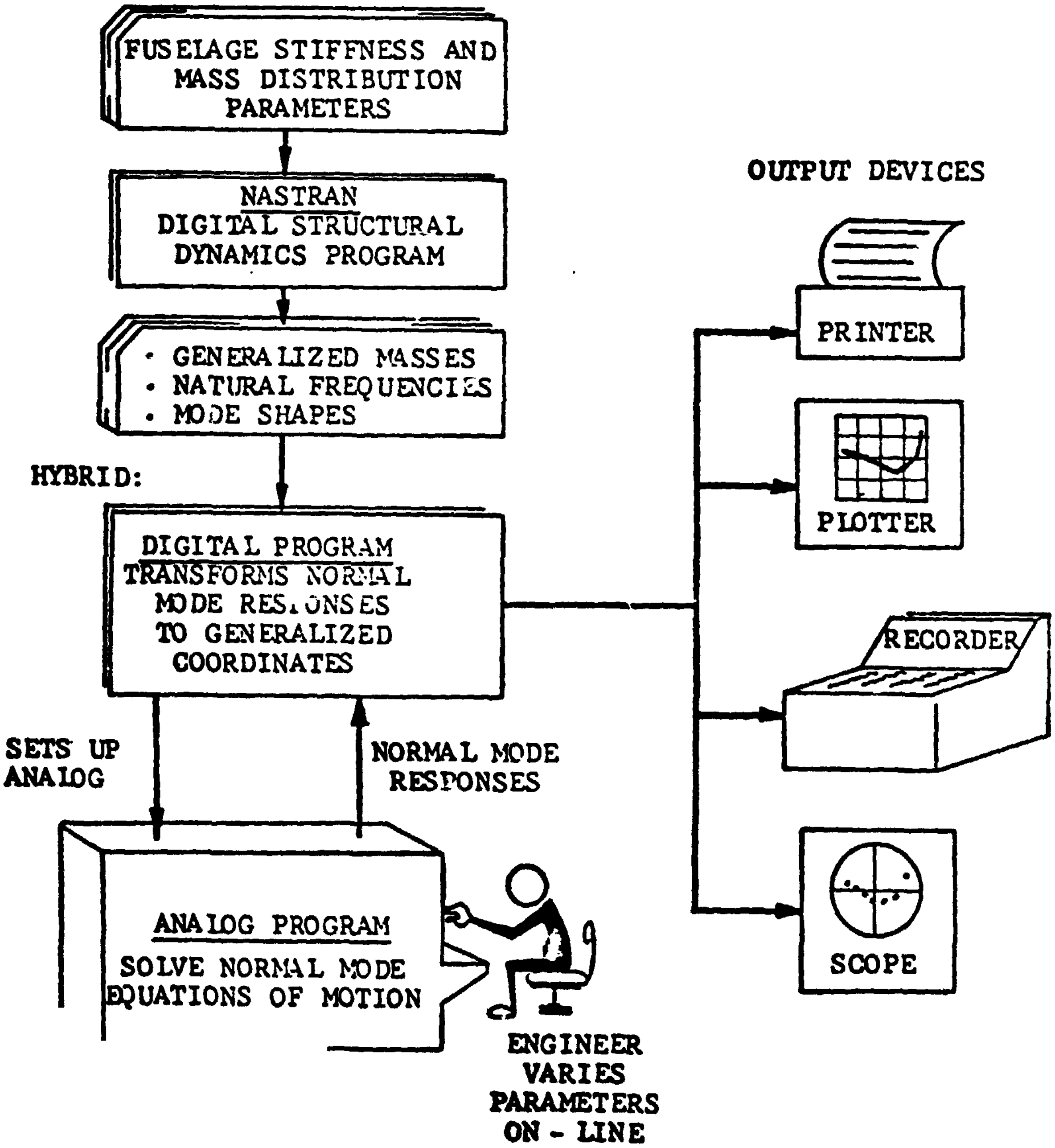

Figure 4.- Flow Diagram of the Dynamic Analysis on the Hybrid Computer