NASA Contractor Report 187449

FINITE ELEMENT MODELING OF THE HIGHER HARMONIC CONTROLLED OH-6A HELICOPTER AIRFRAME

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Mesa, Arizona

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

FORWARD

The McDonnell Douglas Helicopter Company (MDHC) has been conducting a study of finite element modeling of helicopter airframes to predict vibration. This work is being performed under U.S. Government Contract NAS1-17498. The contract is monitored by the NASA Langley Research Center, Structures Directorate.

This report summarizes the work done to form a NASTRAN finite element vibrations model of the Higher Harmonic Controlled (HHC) OH-6A helicopter. Key NASA and McDonnell Douglas Helicopter company personnel are listed below.

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1. INTRODUCTION

INTRODUCTION

The NASA Langley Research Center is sponsoring a rotorcraft structural dynamics program with the overall objective to establish in the United States a superior capability to utilize finite element analysis models for calculations to support industrial design of helicopter airframe structures. Viewed as a whole, the program is planned to include efforts by NASA, Universities, and the U.S. Helicopter Industry. In the initial phase of the program, teams from the major manufacturers of helicopter airframes will apply extant finite element analysis methods to calculate static internal loads and vibrations of helicopter airframes of both metal and composite construction, conduct laboratory measurements of the structural behavior of these airframes, and perform correlations between analysis and measurements to build up a basis upon which to evaluate the results of the applications. To maintain the necessary scientific observation and control, emphasis throughout these activities will be on advance planning, documentation of methods and procedures, and thorough discussion of results and experiences, all with industry wide critique to allow maximum technology transfer between companies. The finite element models formed in this phase will then serve as the basis for the development, application, and evaluation of both improved modeling techniques and advanced analytical and computational techniques, all aimed at strengthening and enhancing the technology base which supports industrial design of helicopter airframe structures. Here again, procedures for mutual critique have been established, and these procedures call for a thorough discussion among the program participants of each method prior to the applications and of the results and experiences after the applications. The aforementioned rotorcraft structural dynamics program has been given the acronym DAMVIBS (Design Analysis Methods for VIBrationS).

This report summarizes work done to form a NASTRAN finite element vibration model of the Higher Harmonic Controlled OH-6A (HHC OH-6A) for use by NASA Langley in various in-house research projects. The HHC OH-6A is basically the OH-6A model which has been altered to incorporate a Higher Harmonic Control System. This report summarizes the work done to develop and validate a NASTRAN finite element vibrations model of the HHC OH-6A helicopter airframe.

2. OBJECTIVE

OBJECTIVE AND APPROACH

The objective was to produce a verified, running dynamic finite element model of the HHC OH-6A. The approach to achieving this objective was to first generate an MSC/NASTRAN finite element model of the OH-6A production aircraft vehicle which does not include the Higher Harmonic Control system. Second, efforts were spent to identify and take into account the mass properties of the secondary structural components and non-structural mass items. The mass of these components are being represented by NASTRAN CONM2 bulk data records. Third, verify the OH-6A model, by making comparisons with results obtained from a ground vibration test performed in 1981. Finally, modify the OH-6A model to represent the HHC configured OH-6A.

OBJECTIVE AND APPROACH

DEVELOP A VERIFIED DYNAMIC NASTRAN MODEL OF THE HHC OH-6A

1) PREPARE STRUCTURAL MODEL OF OH-6A

2) GENERATE MASS MODEL

3) VERIFY MODEL USING EXISTING GROUND VIBRATION TEST RESULTS

4) MODIFY OH-6A MODEL TO REPRESENT HHC CONFIGURED OH-6A

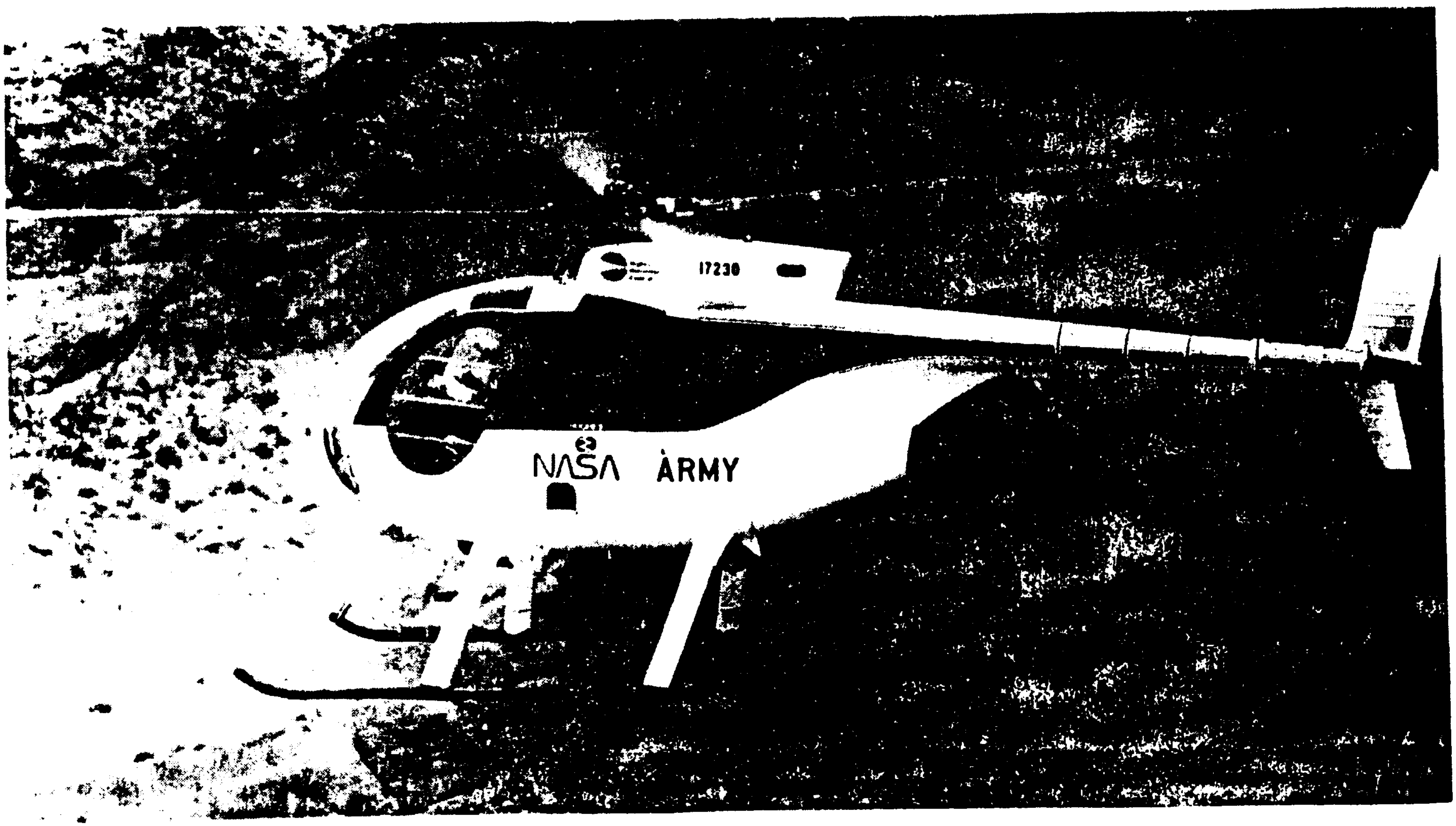
3. VEHICLE DESCRIPTION

OH-6A VEHICLE DESCRIPTION

The OH-6A is single engine, four bladed rotary wing aircraft operated by a crew of two. It originally was constructed as a U. S. Army scout aircraft. The OH-6A has a main rotor RPM of 470 and tail rotor RPM of 3029. It has a design gross weight of 2550 lbs., maximum gross weight of 2700 lbs., and can perform flight maneuvers with limits of -0.5 g to +2.4g at a speed, Vne, of 110 kn. The aircraft is equipped with a skid landing gear system which is functional for both normal landings and crash attenuation. The empennage is of an asymmetrical V tail configuration.

The Higher Harmonic Control configured OH-6A, shown in the figure, is a production OH-6A which has had its flight control system modified to accept higher harmonic control inputs from an onboard computer.

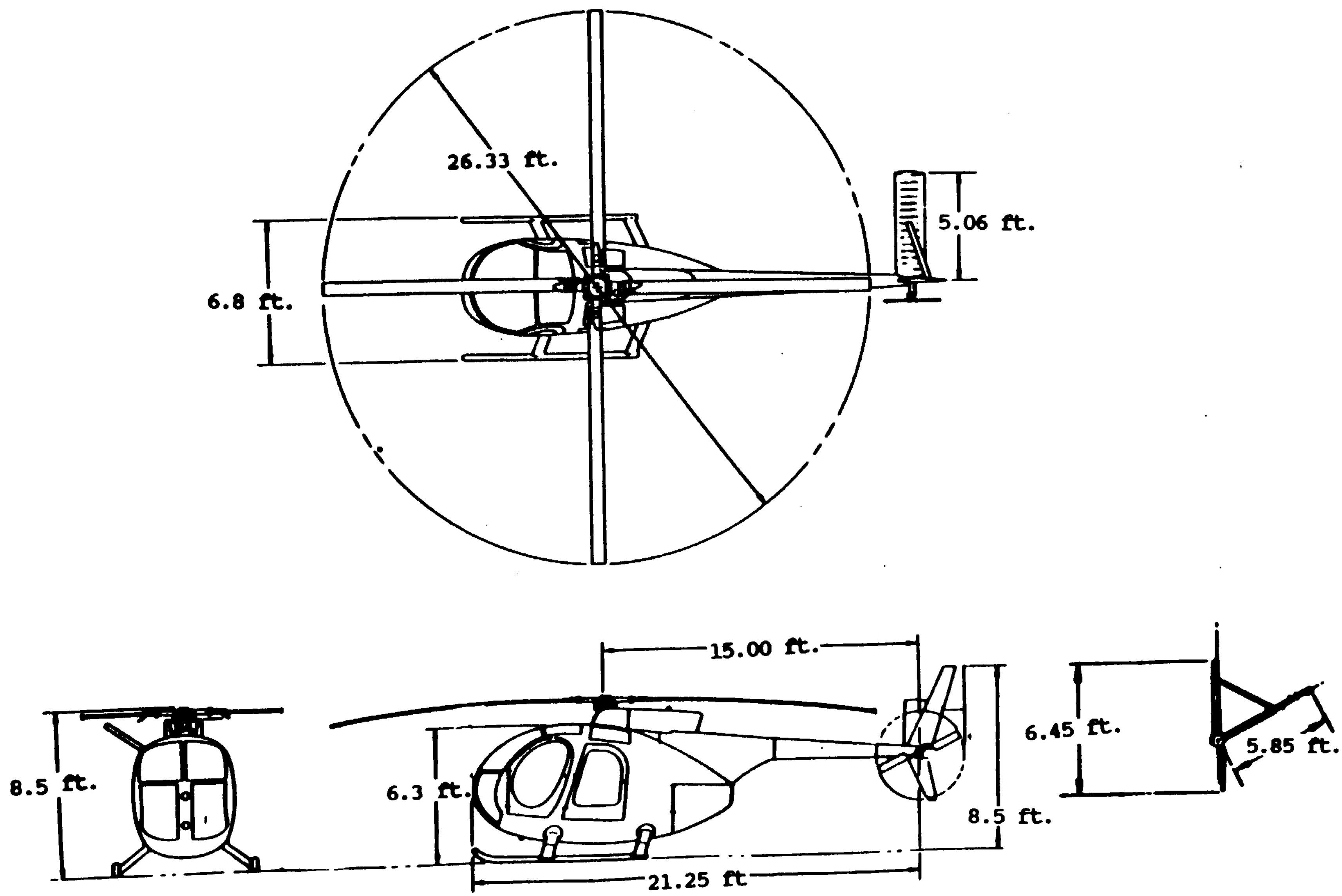
OH-6A VEHICLE DECRIPTION



OH-6A OVERALL DIMENSIONS

General data concerning the overall dimensions of the OH-6A are shown in the figure below. The OH-6A has an overall length of 30.3 ft., height of 8.5 ft., and width, excluding the stabilizer and skid gear, of 4.57 ft. The fuselage length is 21.25 ft. with a main rotor to tail rotor distance of 15.00 ft.

OH-6A OVERALL DIMENSIONS

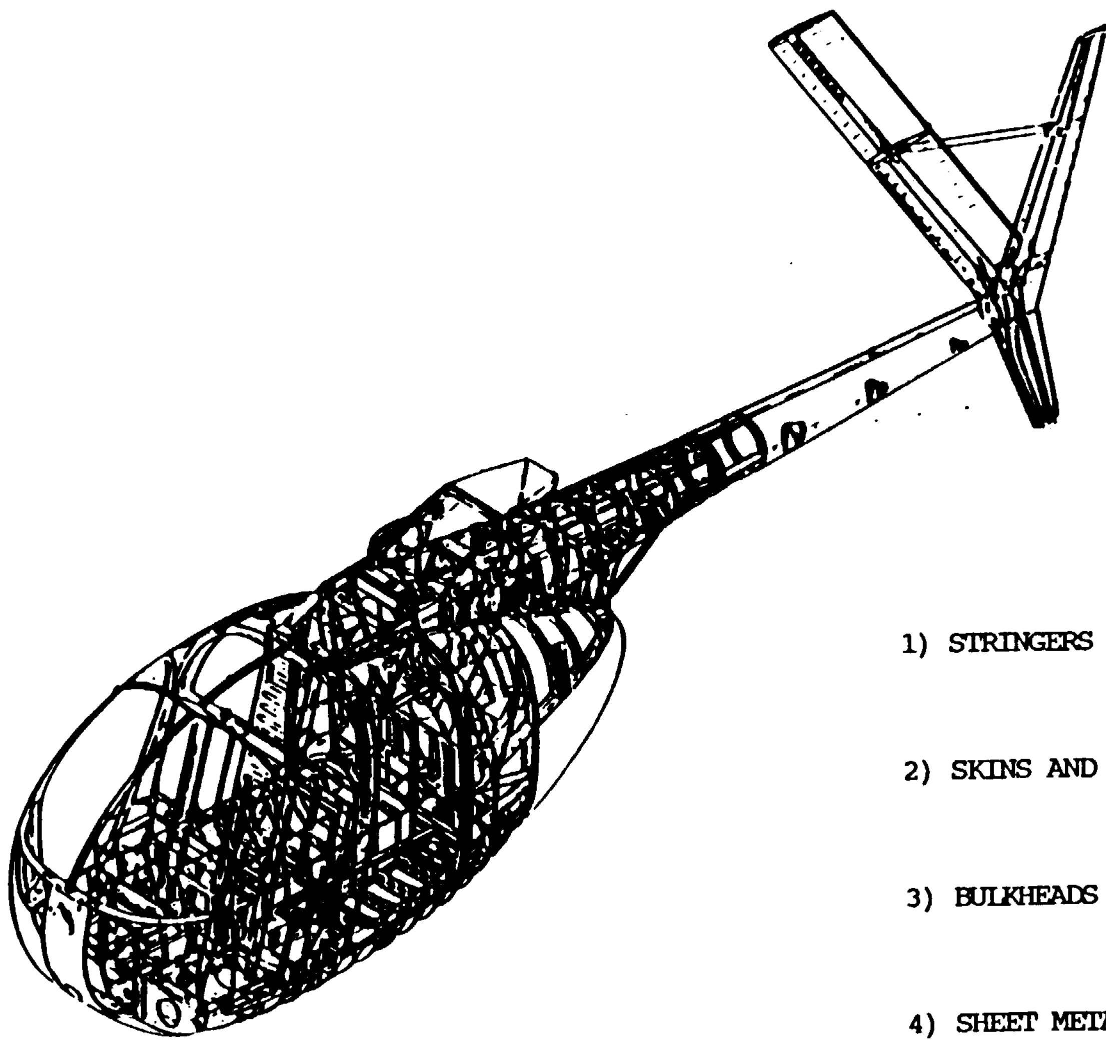


4. STRUCTURAL MODELING

ASSUMPTIONS FOR STRUCTURAL MODELING

The OH-6A airframe is of typical semi-monocoque construction consisting of frames, bulkheads, and stringers covered with stressed skins. It is assumed that stringers and longerons carry axial loads only. Skins and webs are assumed to carry shear and axial loads. The extensional skin area is considered fully effective for dynamic analysis. Bulkheads and machined frames are modeled using rods and shear panels. Sheet metal frames are modeled with bars. In general, frames are modeled to carry in-plane loads only.

ASSUMPTIONS FOR STRUCTURAL MODELING



1) STRINGERS AND LONGERONS CARRY AXIAL LOADS ONLY

2) SKINS AND WEBS CARRY SHEAR AND AXIAL (EFFECTIVE SKIN) LOADS

3) BULKHEADS ARE MODELED AS RODS AND SHEAR PANELS

4) SHEET METAL FRAMES ARE MODELED AS BARS

MODELING GUIDES

The following pages provide information on the modeling practices used to form the OH-6A NASTRAN model. These guidelines include the numbering schemes for the grid points, elements, properties, and materials. Also, specific information concerning element selection for the frames, bulkheads, stringers and skin is included.

MODELING GUIDES

GUIDES FOR STRUCTURAL MODELING

1) NUMBERING SCHEMES

   A) GRIDS

   B) ELEMENTS

   C) PROPERTIES AND MATERIALS

2) ELEMENT SELECTION

   A) FRAMES

   B) BULKHEADS

   C) STRINGERS AND SKINS

NUMBERING SCHEME - GRID POINTS

The grid point identification numbers were chosen according to the location of the point in the fuselage. The first part of the ID is the fuselage station of the grid point. The last part of the ID is numbered sequentially by even numbers. This is done so that grid points may be added easily without disrupting the sequence. An example of this would be the ID for GRID 13742, which is a grid point located on the frame at fuselage station 137.5, and is given its unique ID 42. In addition, areas of the ship which cannot conform to this convention were given a special numbering scheme. These areas include the mast structure which has points labeled 100xx, the upper and lower vertical stabilizers, the horizontal stabilizer, and the landing skids which were numbered 310xx, 320xx, 330xx, and 35xxx, respectively. The values of the grid point IDs were kept below 65000 for compatibility with PATRAN.

NUMBERING SCHEME - GRID POINTS

FUSELAGE GRID POINTS

1 3 7 | 4 2

FUSELAGE STATION — INDIVIDUAL ID

SPECIAL CASES:

1) MAST	100xx
2) LOWER VERTICAL STABILIZER	310xx
3) UPPER VERTICAL STABILIZER	320xx
4) HORIZONTAL STABILIZER	330xx
5) LANDING SKIDS	35xxx

NUMBERING SCHEME - ELEMENTS

The element IDs were numbered sequentially as they were modeled. The first digit of the four digit ID number identifies the type of element being used. The digit "1" denotes a CROD, "2" denotes either a CBEAM or a CBAR, "3" denotes either a CTRIA3 or a CQUAD4, "4" denotes a CSHEAR, and "5" denotes a rigid element. The last three digits are for the individual element identification.

NUMBERING SCHEME - ELEMENTS

2 | 1 4 5

ELEMENT TYPE INDIVIDUAL ID

ELEMENT TYPES:

1 CROD

2 CBAR AND CBEAM

3 CTRIA3 AND CQUAD4

4 CSHEAR

5 RIGID ELEMENT

NUMBERING SCHEME - PROPERTIES AND MATERIALS

The property identification numbers were picked so that ample information pertaining to that property could be obtained quickly. Property IDs are five digit numbers. The first digit references the type of material. The number "1" was used for aluminum, "2" for titanium, and "3" for steel. The second digit indicates the type of element which references this property. The final three digits represent other properties, such as thickness or cross sectional area, depending on the element type.

NUMBERING SCHEME - PROPERTIES AND MATERIALS

1 | 4 | 0 4 4

MATERIAL ELEMENT TYPE THICKNESS

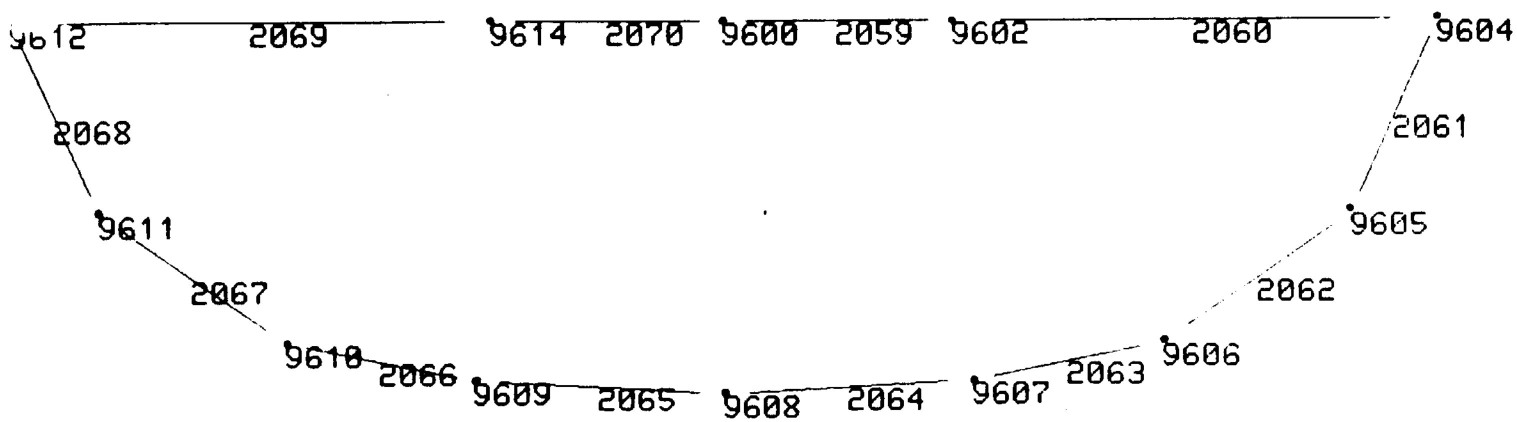
THE ABOVE PROPERTY REPRESENTS AN ALUMINUM SHEAR ELEMENT WITH A THICKNESS OF .044

MATERIAL PROPERTY IDS

ALUMINUM	1
TITANIUM	2
STEEL	3

MODELING GUIDES - FORMED SHEET METAL FRAMES

The figure below shows the NASTRAN model of a typical formed sheet metal frame. This type of frame is modeled with CBAR elements. The frame is modeled to carry only inplane loads. The out of plane bending is assumed to be restrained by the stringers and skins attached to the frame. The grid points in the frame model are located at the inner mold line of the ship. A typical cross section of a frame is of a "C" or a "Z" section. Effective skin is not included in the frame section properties. A reference grid point, which defines the orientation of CBAR or CBEAM bending planes, is located in the plane of the frame and near its geometric center. An RBE3 element connects this point to the grid points around the frame.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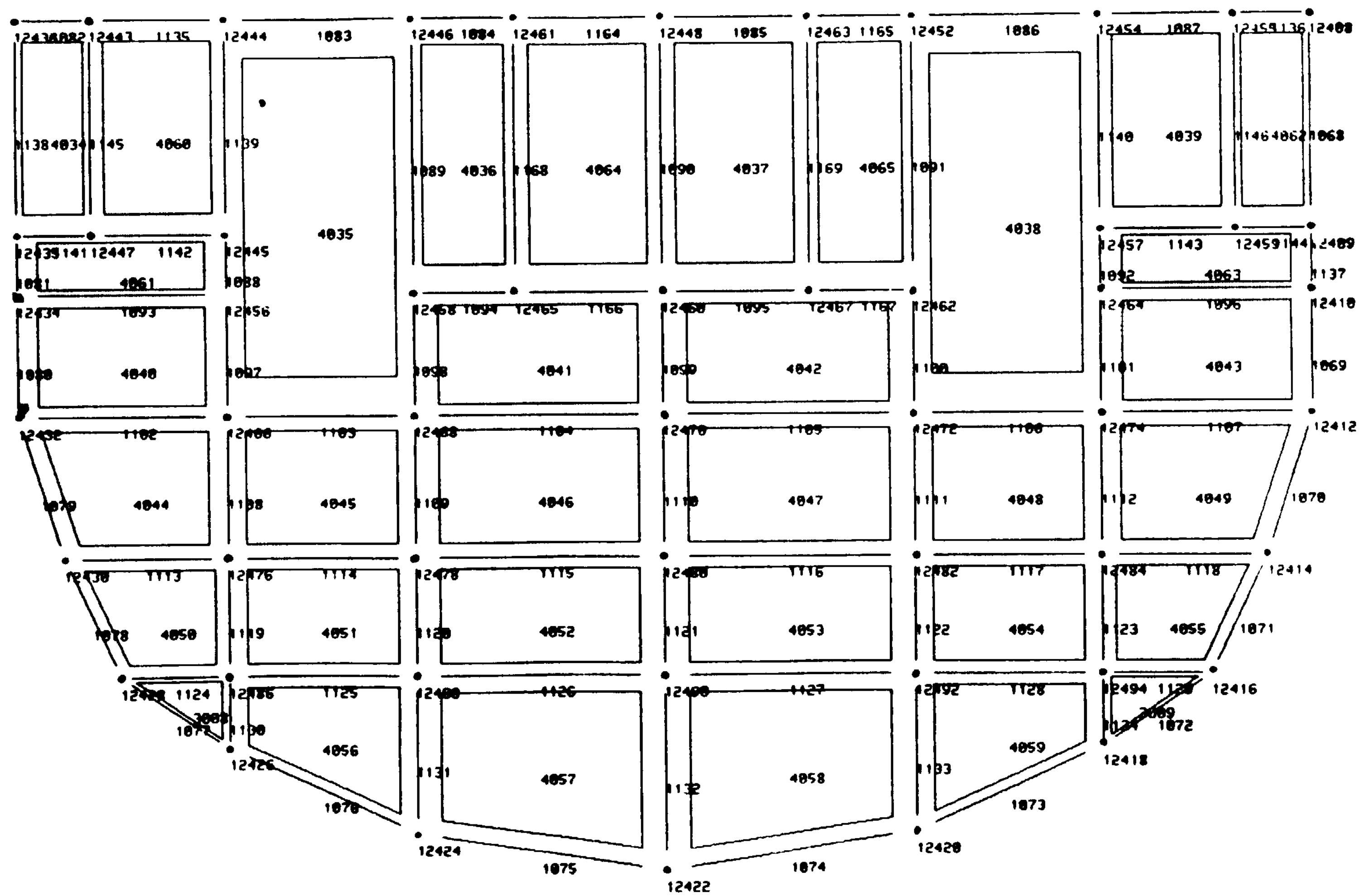
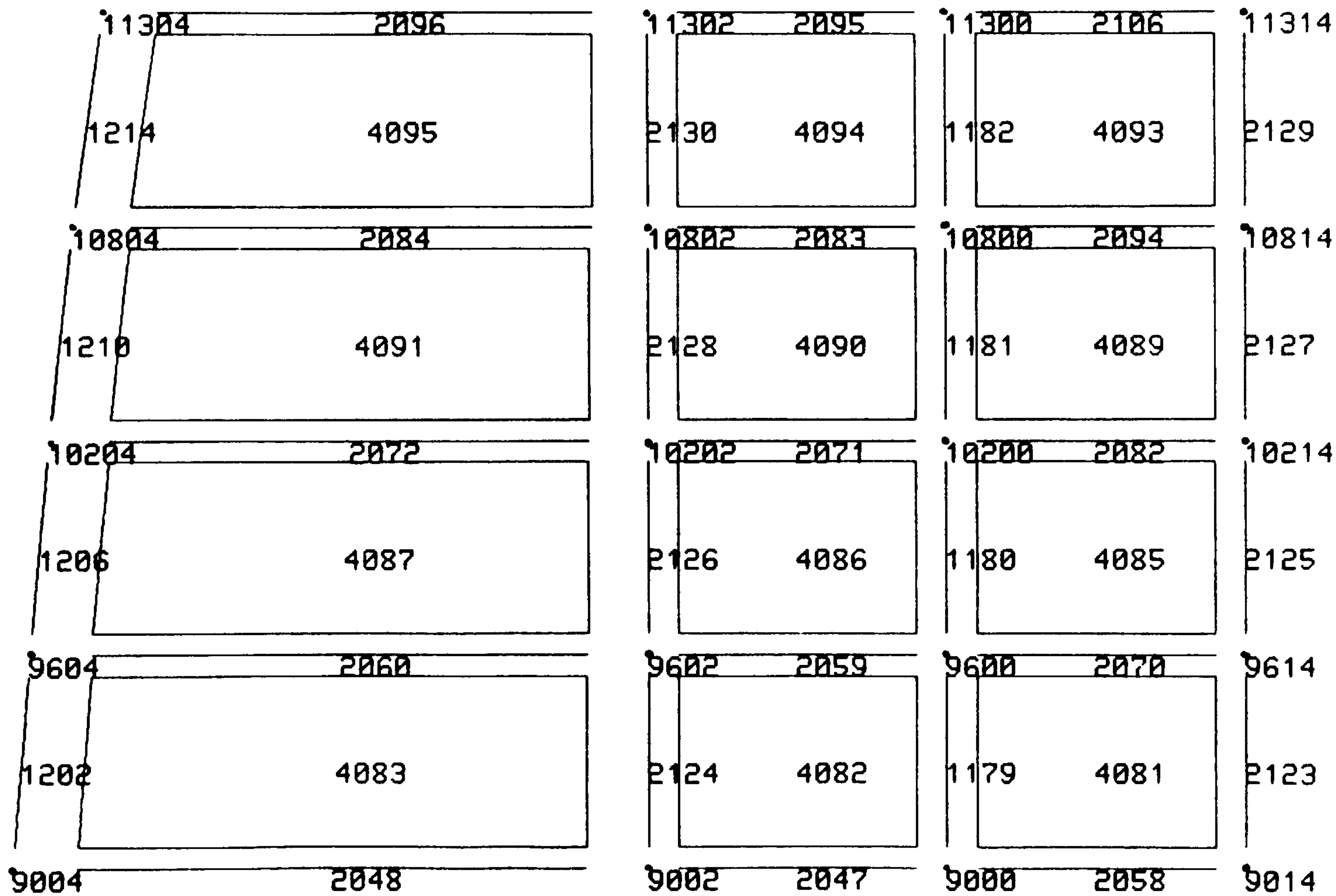
MODELING GUIDES - BULKHEADS

The figure below shows a NASTRAN model of a typical bulkhead. This type of structure is modeled with shear and axial elements. Outer grid points are located at the inner mold line of the bulkhead. Interior grid points are located at the centerline of stiffeners and at stiffener intersections. Caps and stiffeners are represented with CROD elements. Webs are represented with CSHEAR and CTRIA3 elements. The CSHEAR elements have 100% extensional stiffness. The web thicknesses are reduced to give equivalent shear area when a hole is present.



MODELING GUIDES - SKINS, STRINGERS AND FLOORS

All stringers and longerons are modeled. The figure below is an example of a floor model. Skin and stringers as well as the keel beam are modeled in the same manner as bulkheads. Skins and floors are modeled using CSHEAR elements. The stringers and longerons are modeled using CROD elements. The elements are generated using the grid points on the inner mold line at each frame location. The skin is assumed to be 100% effective. The thickness of the shear elements is adjusted for holes and cutouts in the same manner as the bulkheads.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MODEL ASSEMBLY - PREPROCESSING

Initially, the individual frames and bulkheads were modeled first. The frames and bulkheads were then assembled by adding stringers, skin, and appropriate floor sections.

The first frames to be modeled were the major bulkheads at 78.5 and 124.0. These bulkheads are the major load carrying members of the ship, taking loads from the main rotor as well as the tailboom, cargo floor and pilot floor. After these bulkheads were confirmed as being correct, each individual section of the fuselage was then modeled. First, the forward fuselage (forward of the 78.5 bulkhead) was modeled, followed by the mid-fuselage (between 78.5 and 124.), aft-fuselage and finally the tailboom. After the fuselage structure was modeled appendages such as the mast, landing gear, and the horizontal and vertical stabilizers were then modeled and incorporated with the fuselage model.

The finite element model of each assembly was plotted with PATRAN. With the use of color graphics, areas of the ship which had missing elements, improperly connected elements and improper orientation of 2D elements were easily identified. Checking the model in this manner minimized the task of identifying errors in the bulk data.

MODEL ASSEMBLY - PREPROCESSING

1) MODELED INDIVIDUAL FRAMES AND BULKHEADS

2) ASSEMBLED FRAMES AND BULKHEADS WITH STINGERS AND SKIN

3) USED PATRAN COLOR GRAPHICS CAPABILITY TO:

   A) DETERMINE MISSING ELEMENTS

   B) IDENTIFY IMPROPERLY CONNECTED ELEMENTS

   C) IDENTIFY IMPROPER ELEMENT ORIENTATION

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5. MASS MODELING

MASS MODELING

Creating the dynamic model of the OH-6A consisted primarily of distributing mass to grid points of the structural model. The mass information includes structural weight data for both the primary and secondary structure. In addition to the structural weight, non-structural weight representing equipment and useful load items were included. Masses peculiar to the shake test configuration and the HHC configured OH-6A were then generated and included in the model. First, the masses for the suspended shake test were included. The dynamic results of the model were compared to a ground vibration test. This was done in order to verify the structural model of the OH-6A helicopter. Then the weight distribution for the Higher Harmonic Controlled system was included to represent the HHC OH-6A. There were no structural changes which had to be made in conjunction with these mass modifications.

MASS MODELING

1) STRUCTURAL MASSES

   A) PRIMARY STRUCTURE

   B) SECONDARY STRUCTURE

2) NON-STRUCTURAL MASSES

3) SPECIAL TEST CONFIGURATIONS

   A) GROUND VIBRATION TEST

   B) HHC OH-6A

STRUCTURAL WEIGHT

The structural weight consists of two groups, primary and secondary. The primary structure weight consists of the weight of the structural members. This weight is generated by NASTRAN via the mass density parameter on the MAT1 bulk data card. The weight of the secondary structure was obtained from the OH-6A weight report. These weights are modeled as lumped masses via CONM2 bulk data cards, which were generated by an automated mass distribution program.

STRUCTURAL WEIGHT

1) WEIGHT OF THE PRIMARY STRUCTURE WAS GENERATED BY NASTRAN USING MASS DENSITY

2) SECONDARY STRUCTURE

   A) DETERMINED FROM WEIGHT REPORT

   B) LUMPED WITH AUTOMATED MASS DISTRIBUTION PROGRAM

NON-STRUCTURAL WEIGHT

After the structural weight has been applied, the weight of non-structural items was then added. The latter represents the useful load items such as fuel, cargo, pilot, and passengers. Other non-structural weight, such as equipment, was included with the secondary structure and lumped using the mass distribution program.

NON-STRUCTURAL MASSES

1) USEFUL LOAD ITEMS ARE LUMPED BY HAND

   A) FUEL

   B) CARGO

   C) PILOT AND PASSENGERS

2) EQUIPMENT TREATED AS SECONDARY STRUCTURE IS LUMPED BY A MASS LUMPING PROGRAM

6. MODEL CHECK-OUT

MODEL CHECKS

Once the finite element model has been assembled, it must be checked and verified before the results of the model may be used with any degree of confidence. The initial procedure for model checkout is to run a number of NASTRAN checks that will point to potential modeling errors. These checks include static checks as well as dynamic checks. The NASTRAN checks include the Cholesky Decomposition DMAP, enforced displacement, a 1g gravity test, static behavior test, and the Multi Level Strain Energy DMAP. Once the above model checkouts have been completed the model is free of any finite element modeling errors.

The Cholesky Decomposition DMAP is an MDHC developed DMAP alter for NASTRAN solution 24. This DMAP alter is used to identify mechanisms and near singularities within the model. Following the Cholesky Decomposition Check, an enforced displacement check is performed on the model. This check is run by imposing a unit displacement or rotation on the unconstrained model and inspecting the element strain energy output from NASTRAN. Ideally, the the element strain energy should be zero. Large strain energy values are indicative of overconstraint(s) at the corresponding point(s). The 1g gravity test will identify the reaction forces due to masses connected to grid points which are overconstrained. The check involves constraining the model in a statically determinate fashion and applying a gravity load. Also, a static behavior check is used to ensure that the general behavior of the model under a static load condition is reasonable. Typically, the model is supported at one end in a cantilever fashion. Unit loads are then applied to the structure to determine if the deflection behavior of the structure is physically realistic. Finally, an MDHC developed Multi-Level Strain Energy DMAP alter is applied to the model. The Strain Energy DMAP is a solution 3 alter which checks the model for ill conditioning and overconstraints at each of the three different NASTRAN levels of model formation. The three levels checked are the G-set, with all degrees of freedom, the N-set, with multipoint constraint equations applied, and the F-set, where the SPCs are applied.

MODEL CHECKS

1) **CHOLESKY DECOMPOSITION (DMAP)**
2) **ENFORCED DISPLACEMENT**
3) **1G GRAVITY TEST**
4) **STATIC BEHAVIOR**
5) **MULTI-LEVEL STRAIN ENERGY (DMAP)**

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7. VERIFICATION

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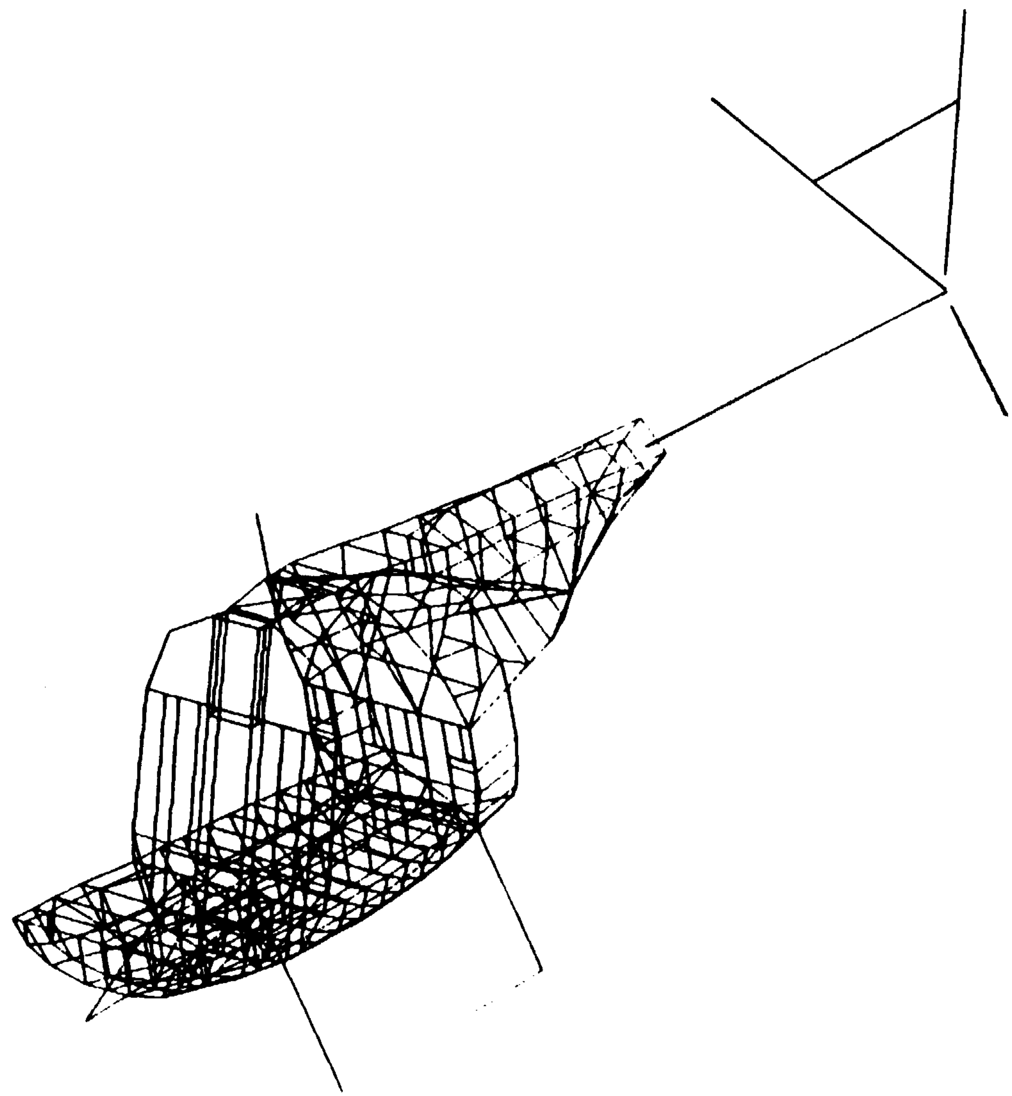
OH-6A NASTRAN MODEL

The figure below shows the NASTRAN model of the OH-6A airframe showing all of the structural elements except rigid elements (RBE). 414 grid points, 1096 elastic elements, and 376 concentrated lumped masses were used to generate the finite element model. There were 2484 total degrees of freedom, 1844 degrees of freedom after the application of MPCs and SPCs. Generalized dynamic reduction (GDR) was employed to reduce the resulting model to 84 ''generalized'' dynamic degrees of freedom for dynamic analysis.

OH-6A NASTRAN MODEL

GRIDS	414
CROD	416
CBEAM	18
CSHEAR	301
CELAS1	6
CQUAD4	8
CBAR	255
CTRIA3	92
RBE2	12
RBE3	15



SHAKE TEST CORRELATION

After NASTRAN check outs have been run on the model, comparison of frequencies of normal modes of vibration were made with results from a ground vibration test performed on an OH-6A in March, 1981. Results from the shake test include natural frequencies and mode shapes. Because of the approximate nature of the measured modes, the ensuing results only show the mode shapes determined from analysis.

SHAKE TEST CORRELATION

1) **CORRELATION OF OH-6A NASTRAN MODEL WITH RESULTS FROM A GROUND VIBRATION TEST PERFORMED IN 1981.**

2) **CORRELATION CRITERIA:**

   A) NATURAL FREQUENCIES
   B) QUALITATIVE NATURE OF MODE SHAPES

SHAKE TEST CONFIGURATION

With the exception of the removal of the main rotor blades, the aircraft was configured for normal flight with full fuel and the two front seats occupied. Ballast was installed in the aft compartment as required to maintain the desired aircraft weight and center of gravity. In addition, for the shake test additional masses were added to simulate a mast mounted sight and a simulated rocket pod.

The table below summarizes the weight and CG location differences between the test aircraft and the standard production vehicle which was modeled. The NASTRAN model was appropriately altered to represent the shake test configuration.

SHAKE TEST CONFIGURATION

ITEM DESCRIPTION	WEIGHT (LB)	FUS. STA. (IN)
SHIP AS WEIGHED	1369	105.1
CREW (2) BALLAST	420	73.5
FUEL (FULL) BALLAST	400	98.3
ADDITIONAL BALLAST	220	118.5
	55	94.5
	55	106.5
TOTAL	2519	99.7
NASTRAN	2520	100.4
DIFFERENCE	1	0.7

FREQUENCY COMPARISON

The following table shows a comparison of frequencies determined by test and by NASTRAN. The name assigned to each normal mode is a description of the primary motion of the coupled modes, but doesn't necessarily describe the entire motion. For example, the modes described as second fuselage bending also have a considerable amount of mast bending.

FREQUENCY COMPARISON

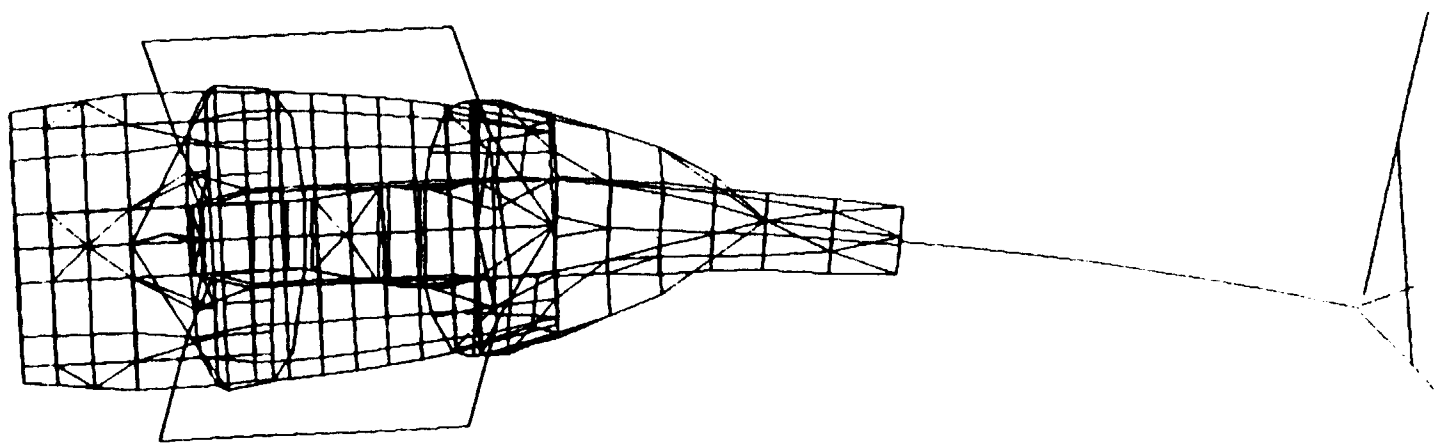
SUMMARY OF IMPORTANT AIRFRAME NORMAL MODES

MODE	TEST (HZ)	NASTRAN (HZ)	% ERROR
FIRST LATERAL	8.40	8.69	3.4
FIRST VERTICAL	9.30	9.81	5.4
FIRST TORSION	14.40	14.41	0.1
AFT. VERTICAL	15.50	15.56	0.4
SECOND VERTICAL	20.70	19.97	-3.5
SECOND LATERAL	26.40	24.61	-6.8

MODE SHAPES - FIRST LATERAL BENDING

The figure shows the first lateral bending mode calculated for the OH-6A in its test configuration.

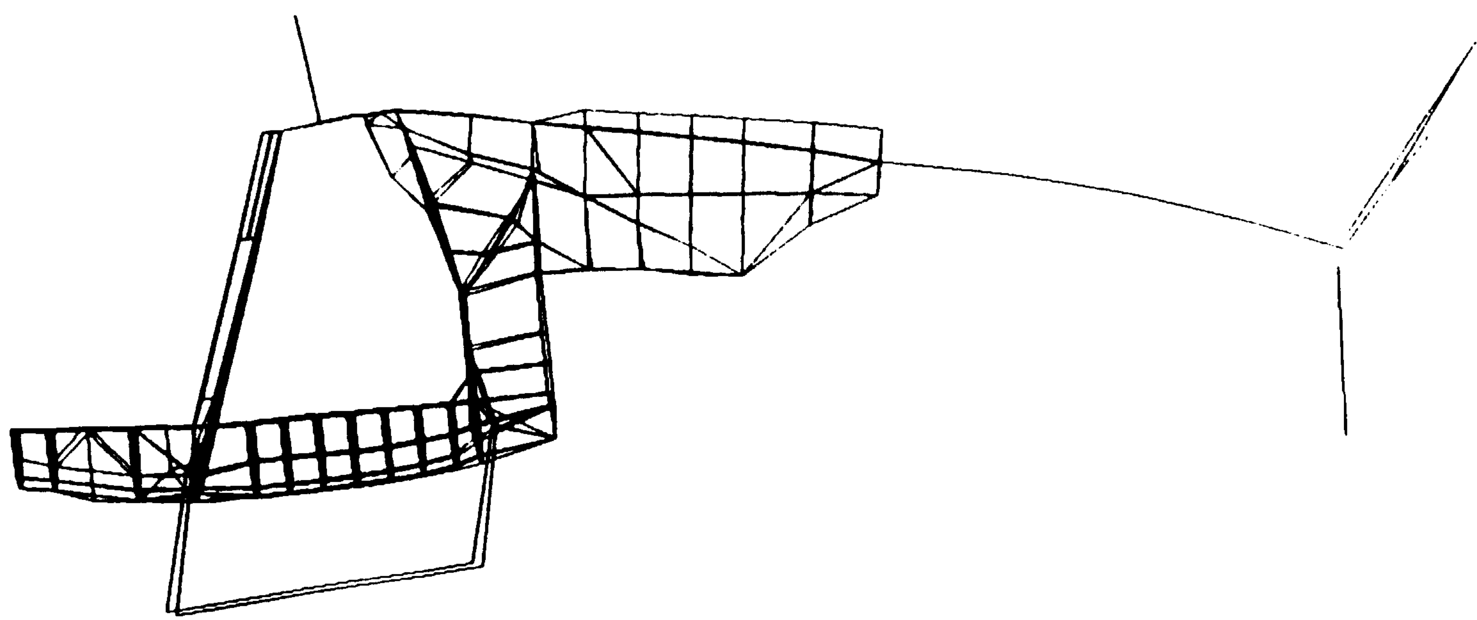
MODE SHAPES - FIRST LATERAL BENDING



MODE SHAPES - FIRST VERTICAL BENDING

The figure shows the first calculated airframe vertical bending mode.

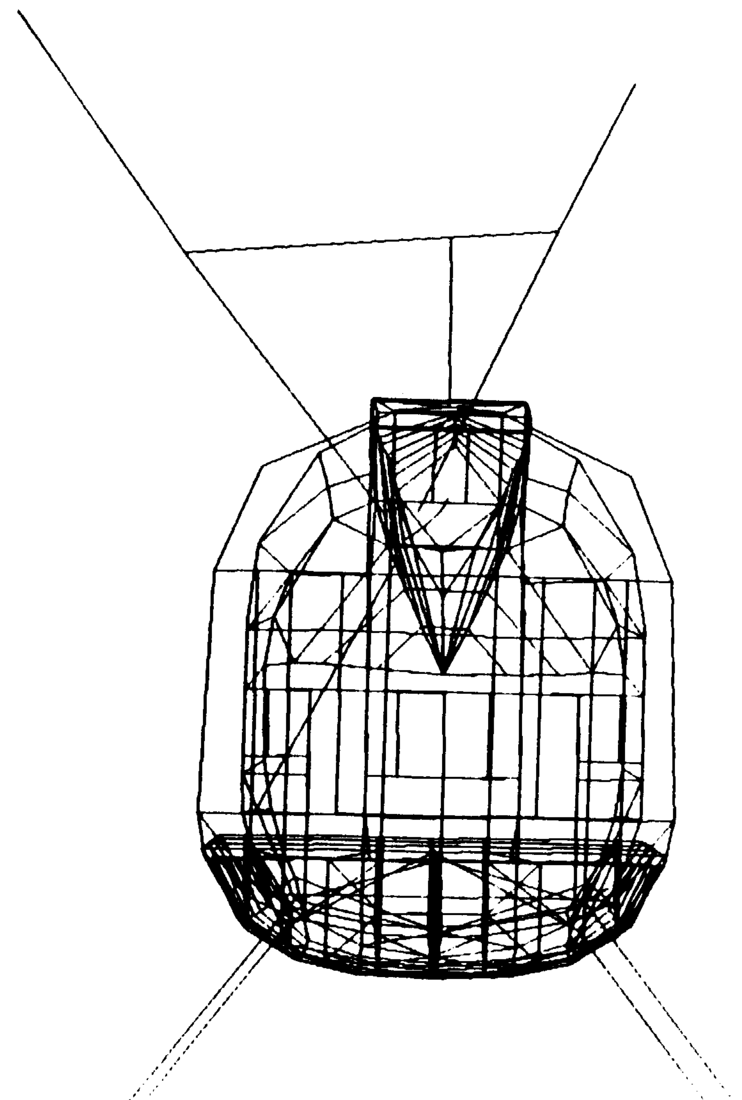
MODE SHAPES - FIRST VERTICAL BENDING



MODE SHAPES - TAILBOOM TORSION

This is the tailboom torsion mode. The motion, although not obvious, is primarily torsion of the tailboom with very little motion in the rest of the aircraft.

MODE SHAPES - TAILBOOM TORSION



8. HHC MODIFICATIONS

HHC OH-6A MASS MODIFICATIONS

Incorporation of the HHC system on the OH-6A aircraft required several changes which resulted in changes only to the mass model. These items included stiffened flight controls, flight computer, actuators and hydraulic lines, an Airborne Data Acquisition System (ADAS) package, and various brackets and attachments. In addition, the amount of fuel used in the flight test vehicle weighed approximately 230 lbs. instead of the 400 lbs. simulated in the ground vibration test. Below is a list of the mass changes used in the model. Included in the bulk data of the HHC OH-6A was an additional 177 lbs inside the cargo hold which cannot be accounted for within the HHC weight statement.

HHC OH-6A MASS MODIFICATIONS

COMPONANT	MASS (LB)
STIFFENED FLIGHT CONTROLS	20.2
HHC HYDRAULIC PUMP AND DRIVE	27.0
THREE HHC ACTUATORS	18.0
TWO HEAT EXCHANGERS	6.4
RESEVOIR/MANIFOLD AND ACCUMULATOR	15.0
HYDRAULIC LINES AND FLUID	15.0
FOUR DOOR FANS	6.0
ASSOCIATED WIRING AND INSTALLATION	30.0
ELECTRONIC CONTROL UNIT	9.0
FLIGHT COMPUTER	11.6
INSTRUMENTATION	
NOSE	5.2
COCKPIT	24.4
ADAS PACKAGE	218.4
TRANSDUCERS	16.4
AIRSPEED BOOM	16.0
BRACKETS AND ATTACHMENTS	9.6
TOTAL	448.2
DIFFERENCE IN FUEL	-170.0

HHC OH-6A FREQUENCIES

The natural frequencies calculated for the HHC OH-6A airframe are in general agreement with those obtained from the shake test (see table below), with the exception of the torsion and aft fuselage vertical bending modes. Both of these modes couple with the motion of the large mass used to represent the simulated rocket pod. Because this mass is offset laterally from the side of the fuselage, it couples with the torsion of the ship as well as the mast bending. The 14.7 percent difference in the aft fuselage vertical bending mode is due mainly to the weight of the simulated rockets where in this mode the aft fuselage vertical bending is coupled with the mast longitudinal bending.

HHC OH-6A FREQUENCIES

MODE	OH-6A/TEST (HZ)	HHC (HZ)	% DIF.
1ST LAT.	8.69	8.83	1.6
1ST VERT.	9.81	9.94	1.3
TORSION	14.41	15.63	8.5
AFT FUS VERT.	15.56	17.84	14.7
2ND VERT.	19.97	20.02	0.2
2ND LAT.	24.61	25.33	2.9

9. CONCLUDING REMARKS

CONCLUDING REMARKS

An MSC/NASTRAN finite element model of the Higher Harmonic Control configured OH-6A helicopter fuselage was developed for use by NASA Langley as part of its in-house research in rotorcraft structural dynamics. The presentation includes a brief description of the vehicle, a description of the techniques employed in forming the structural and mass models for the airframe, and a summary of the various checks employed to verify the integrity of the finite element model.

CONCLUDING REMARKS

1) OH-6A IN BASELINE CONFIGURATION MODELED WITH NASTRAN

2) MODEL ADJUSTED FOR CORRELATION WITH MARCH 1981 SHAKE TEST

3) BASELINE MODEL RECONFIGURED TO REPRESENT THE HHC OH-6A AIRCRAFT

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15. Supplementary Notes

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16. Abstract

An MSC/NASTRAN finite element model of the higher harmonic control configured OH-6A helicopter fuselage has been developed.

This finite element model has been verified by performing various model checkouts and correlation with results from a ground vibration test.

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Finite Element Modeling, OH-6A, Helicopter, HHC, Airframe	Unclassified - Unlimited Subject Category 39

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