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PLAN, FORMULATE AND DISCUSS A NASTRAN FINITE ELEMENT MODEL OF THE AH-64A HELICOPTER AIRFRAME

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MCDONNELL DOUGLAS HELICOPTER COMPANY
Mesa, Arizona

Contract NAS1-17498
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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

FOREWORD

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 planning, development, documentation, and initial checkout of a NASTRAN finite element vibrations model of the AH-64A helicopter airframe.

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1.0 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 aformentioned rotorcraft structural dynamics program has been given the acronym DAMVIBS (Design Analysis Methods for VIBrationS).

As a major helicopter manufacturer, McDonnell Douglas Helicopter Company is participating in this program. This report documents the work done by MDHC to plan, formulate, and discuss a NASTRAN finite element model (FEM) of the AH-64A airframe. The finite element analysis model is to be suitable to predict both static internal loads and vibrations. The procedures used to generate the model are to be suitable for domestic helicopter design projects, and to help assure that, it is required that at specific stages of progress the plans, results, and experiences will be presented to representatives of the major helicopter airframe manufacturers. An additional task will be conducted at the conclusion of this effort to evaluate the finite element analysis model through comparison with ground vibration test results. This report contains a discussion of modeling plan objectives, followed by a description of the AH-64A aircraft including all general features, major components, and primary and secondary structure definition. Following the aircraft description, a discussion of modeling guidelines and model checkout procedure are provided. Finally, the results, schedule, and planned versus actual manhours for this work are presented.

2.0 MODELING PLAN OBJECTIVES

MODELING PLAN OBJECTIVES

There are two major objectives to the modeling plan. First, the guidelines for the preparation of a finite element model will be presented. The guidelines will cover the generation of the static model, addition of mass to the model, and the changes necessary to make a static model useful for vibration analysis. Second, the resources necessary to prepare and execute the modeling plan will be estimated.

MODELING PLAN OBJECTIVES

- GUIDELINES FOR THE PREPARATION OF THE FEM
  - STATIC MODELING
  - MASS MODELING
  - VIBRATION MODELING

- DEFINE RESOURCES FOR PREPARATION OF FEM
  - PLAN THE MODELING TASK
  - EXECUTE THE PLAN

3.0 DESCRIPTION OF AH-64A HELICOPTER

AH-64A VEHICLE DESCRIPTION

The AH-64A Apache is a twin engine, four bladed rotary wing aircraft operated by a tandem seated crew of two. It is intended for use by Army attack helicopter units. The airframe is a redundant semi-monocoque construction representing a fail-safe, damage tolerant design. The aircraft is equipped with main and tail landing gears which are functional for both normal landings and crash attenuation. Provisions are made for a nose mounted weapon system and for the carriage of wing mounted external stores.

The T700-GE-701 engines on the Apache are mounted high on the outside of the airframe. The engines are widely separated to reduce the risk of both engines sustaining combat damage. The rotor blades consist of multiple fiberglass spar tubes and stainless steel outer skin. This construction results in a ballistically survivable blade. The main rotor hub is fully articulated with redundant lead-lag dampers on each blade and stainless steel straps are used for blade retention. An M230 30mm chain gun is mounted on the bottom of the airframe between the crew stations. Hellfire missiles and/or 2.75 in. FFAR rockets can be carried on the wing mounted pylons. The sighting for the weapon systems is performed by the Target Acquisition and Designation System (TADS) and the Pilot Night Vision System (PNVS) located in the front of the airframe.

The photograph below shows an AH-64A in its primary mission configuration with 8 Hellfire missiles, 38 FFAR rockets, and 600 rounds of 30mm ammunition.

DESCRIPTION OF AH-64A HELICOPTER

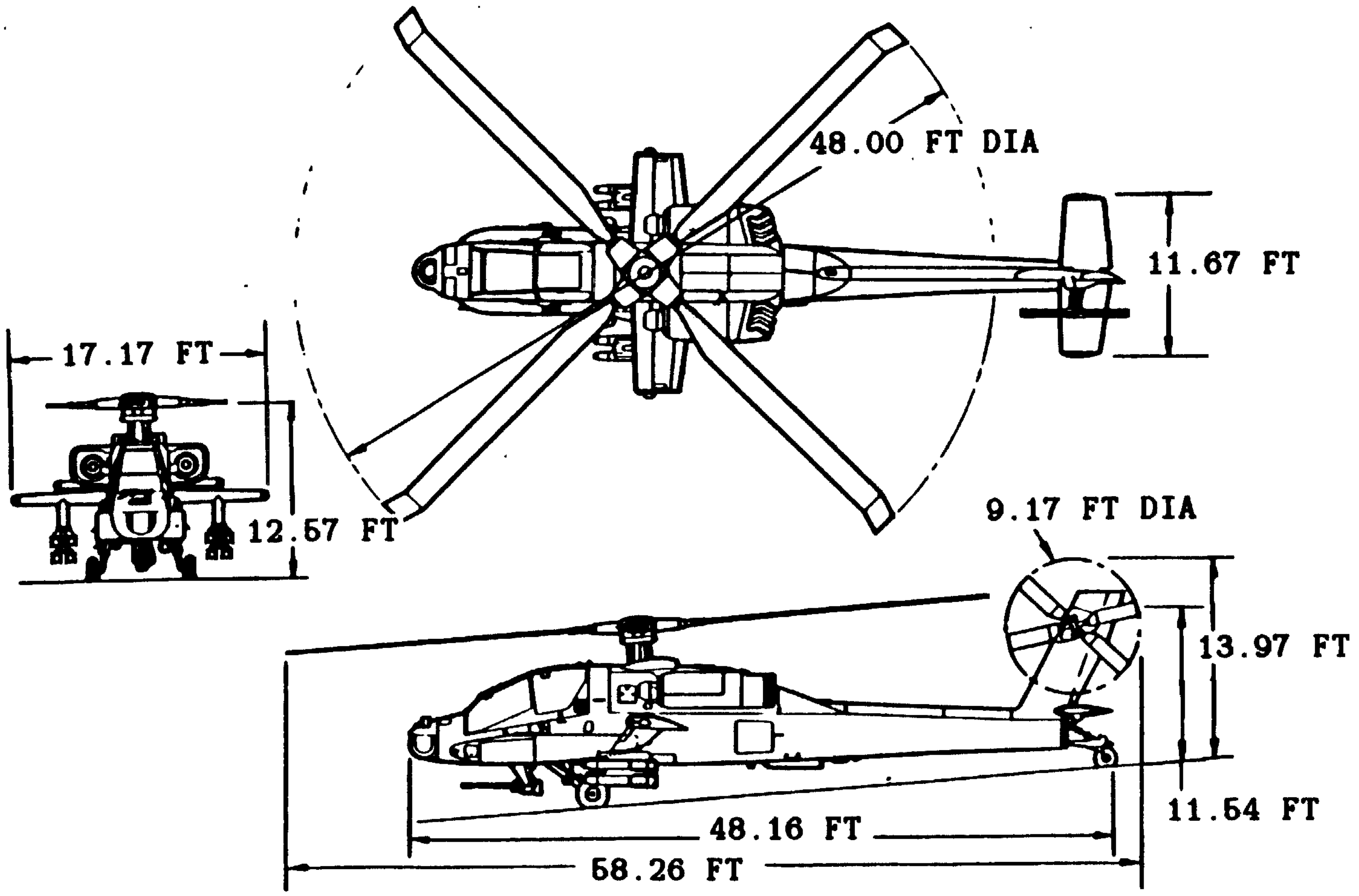
AH-64A OVERALL DIMENSIONS

The accompanying three view drawing shows the overall dimensions for the AH-64A aircraft.

General Data:

Primary Mission Gross Weight	14,694 lb.
Basic Structural Design Gross Weight	14,660
Maximum Alternate Mission Gross Weight	17,650
Ferry Mission Gross Weight	21,000
Main Rotor RPM	289
Tail Rotor RPM	1,403
V_{ne}	204 kn
V_h	164
V_{lat}	45
V_{aft}	45
Flight Maneuver Limits	+3.5g to -0.5g

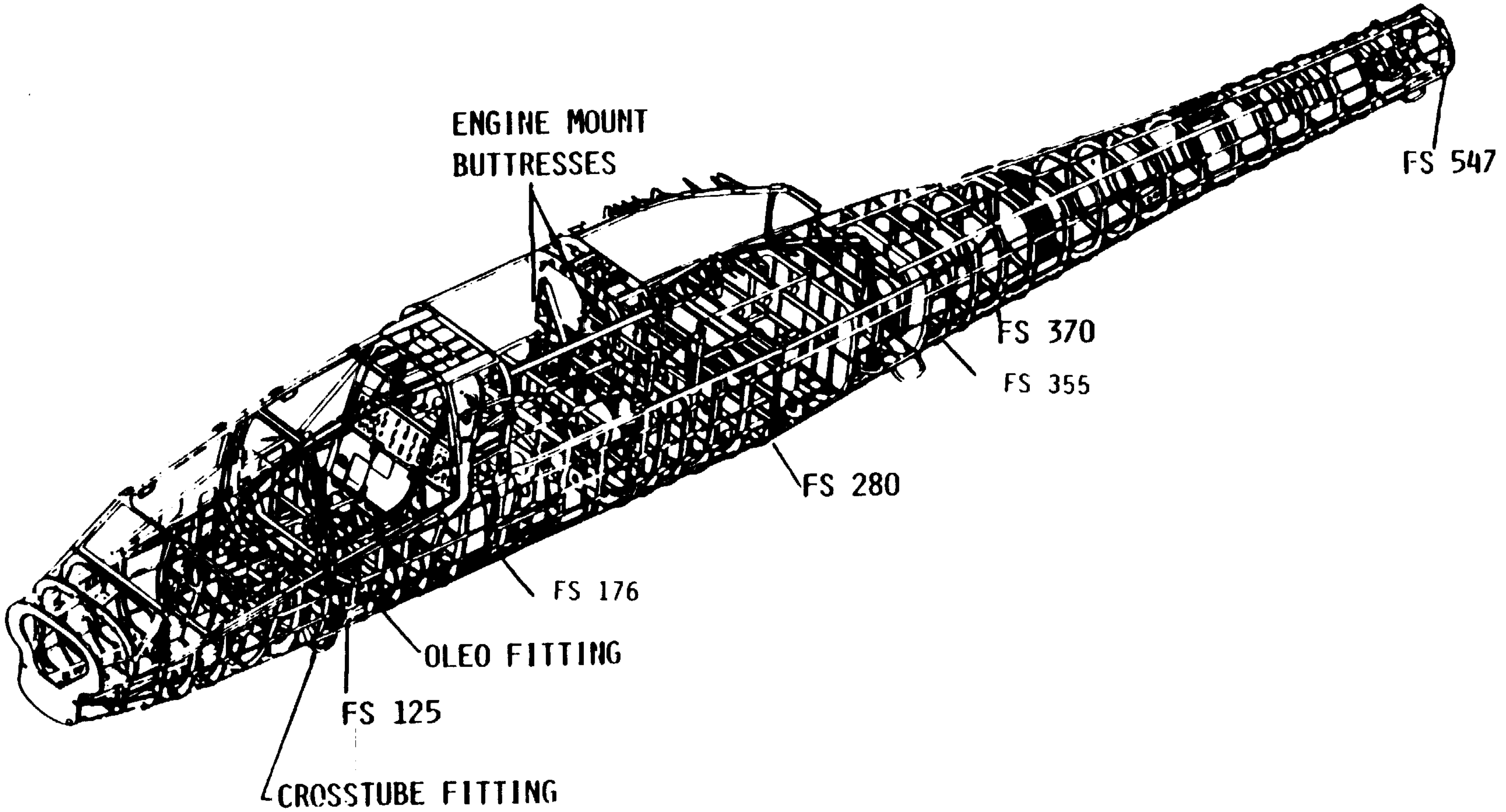
AH-64A OVERALL DIMENSIONS



PRIMARY FUSELAGE STRUCTURE

The fuselage of the AH-64A is of semi-monoque construction consisting of frames, bulkheads, longerons, and stringers covered with stressed skin. Frames and bulkheads are the transverse members and stringers and longerons are the longitudinal members. The main transmission and main rotor are supported by the rotor support structure. The engines, nose gearboxes, and nacelles are supported by the engine mount buttresses. Each main landing gear is attached to the airframe by a crosstube and an oleo fitting. The tail landing gear is attached to the airframe at the bulkhead at FS 547. Manufacturing breaks are located at fuselage stations 125, 280, and 370.

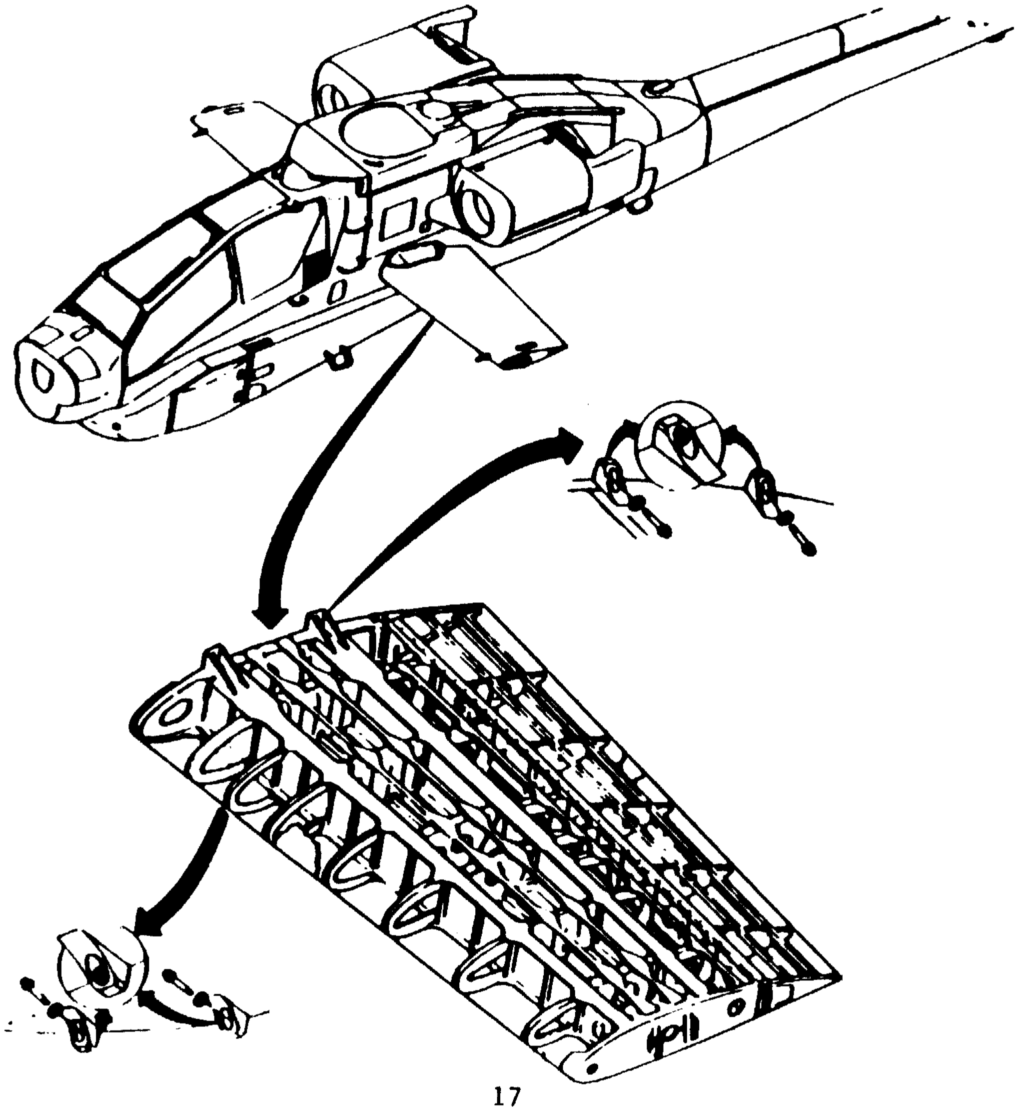
PRIMARY FUSELAGE STRUCTURE



WING STRUCTURE

The wing is constructed in a conventional manner using ribs, spars, and skins. The spars are located at 20, 50, and 70 percent chord. The wing is attached to the airframe with four bolts and two shear pins per wing. Two bolts and a shear pin are located on the 20 percent spar. The others are on the 50 percent spar. The close tolerance shear pins locate the wing on the airframe and are the load paths for wing shear into the airframe. The bolts on the spar caps are the load paths for the axial loads in the caps into the airframe. The primary function of the wings is to support the pylons and mission equipment (missile launchers, rocket pods, and fuel tanks).

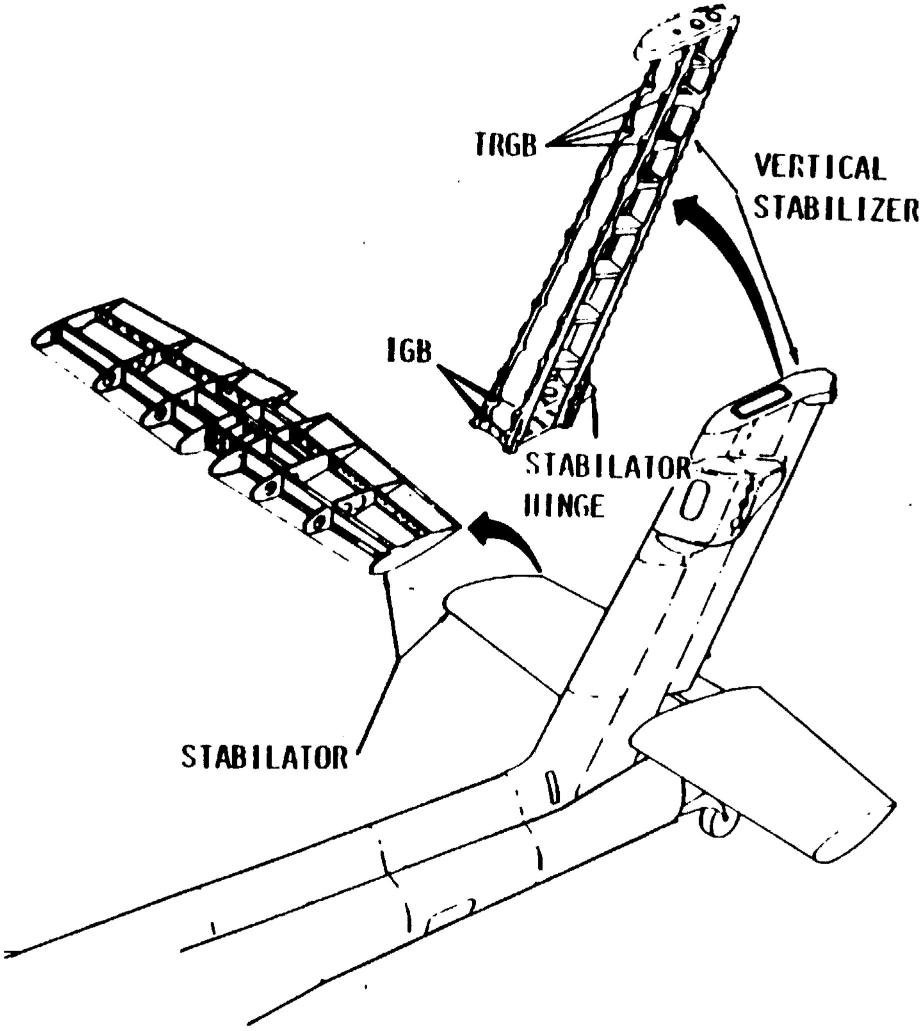
WING STRUCTURE



EMPENNAGE

The empennage assembly consists of the vertical stabilizer and the stabilator. Both are constructed in a conventional manner using spars, ribs, and skins. The stabilator hinge fittings are on the aft spar of the vertical stabilizer and the forward spar of the stabilator. The upper end of the stabilator actuator attaches to the stabilator and the lower end attaches to the tailboom. The intermediate gearbox (IGB) and the tail rotor gearbox (TRGB) attach to the front spar of the vertical stabilizer. The vertical stabilizer bolts to the tailboom. The leading and trailing edges of the vertical stabilizer are fairings.

EMPENNAGE


TRGB
VERTICAL STABILIZER
IGB
STABILATOR HINGE
STABILATOR

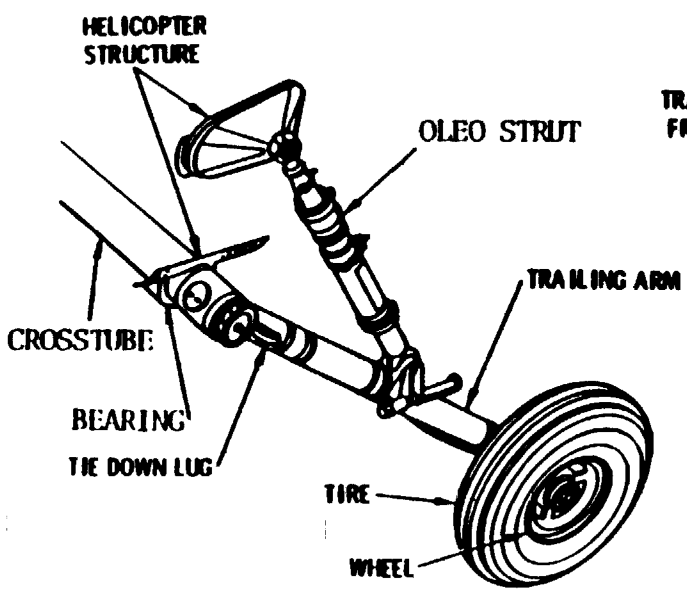
LANDING GEAR

The main landing gear is a non-retracting trailing arm type using high flotation tires. The assembly consists of two trailing arms (one per side), two oleo struts (one per side), and a crosstube. A trailing arm is attached to each end of the crosstube. The crosstube is supported by bearings at each end to transfer vertical and longitudinal shear into the airframe and a thrust bearing in the center of the tube (not shown) to transfer lateral or axial loads in the tube into the airframe. The oleo fitting at the upper end of the oleo strut transfers the loads from the oleo into the airframe.

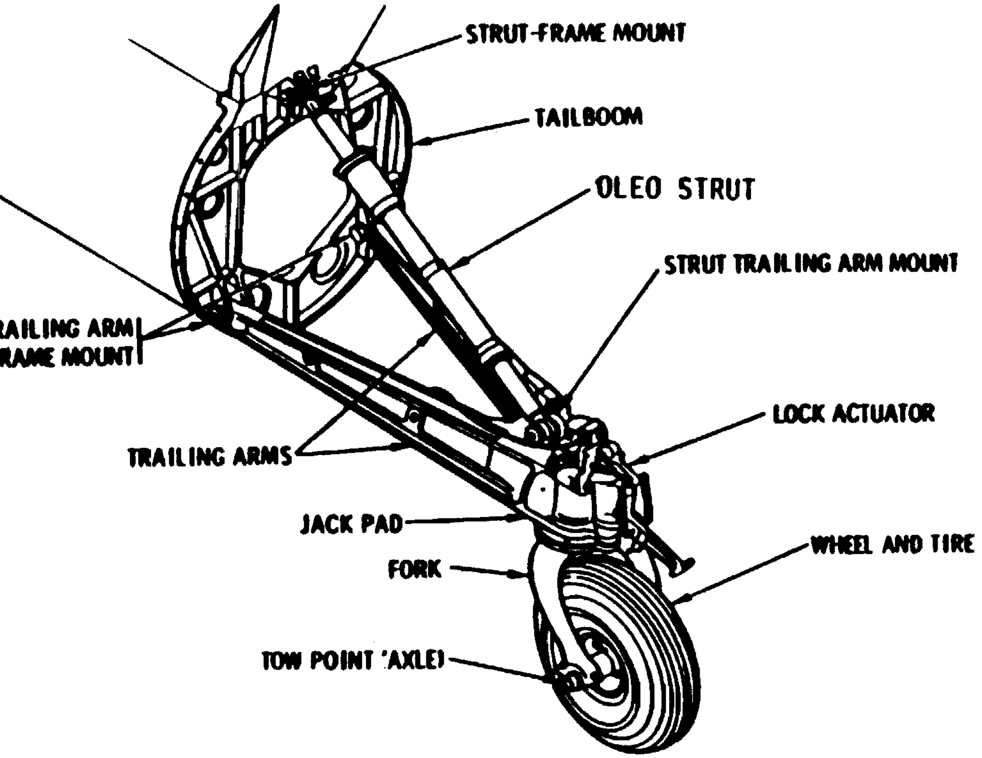
The tail landing gear is a non-retracting trailing arm type using a high flotation tire. The assembly consists of two trailing arms and a single oleo strut. The landing gear is attached to fittings on the bulkhead at FS 547.

LANDING GEAR

MAIN LANDING GEAR



TAIL LANDING GEAR



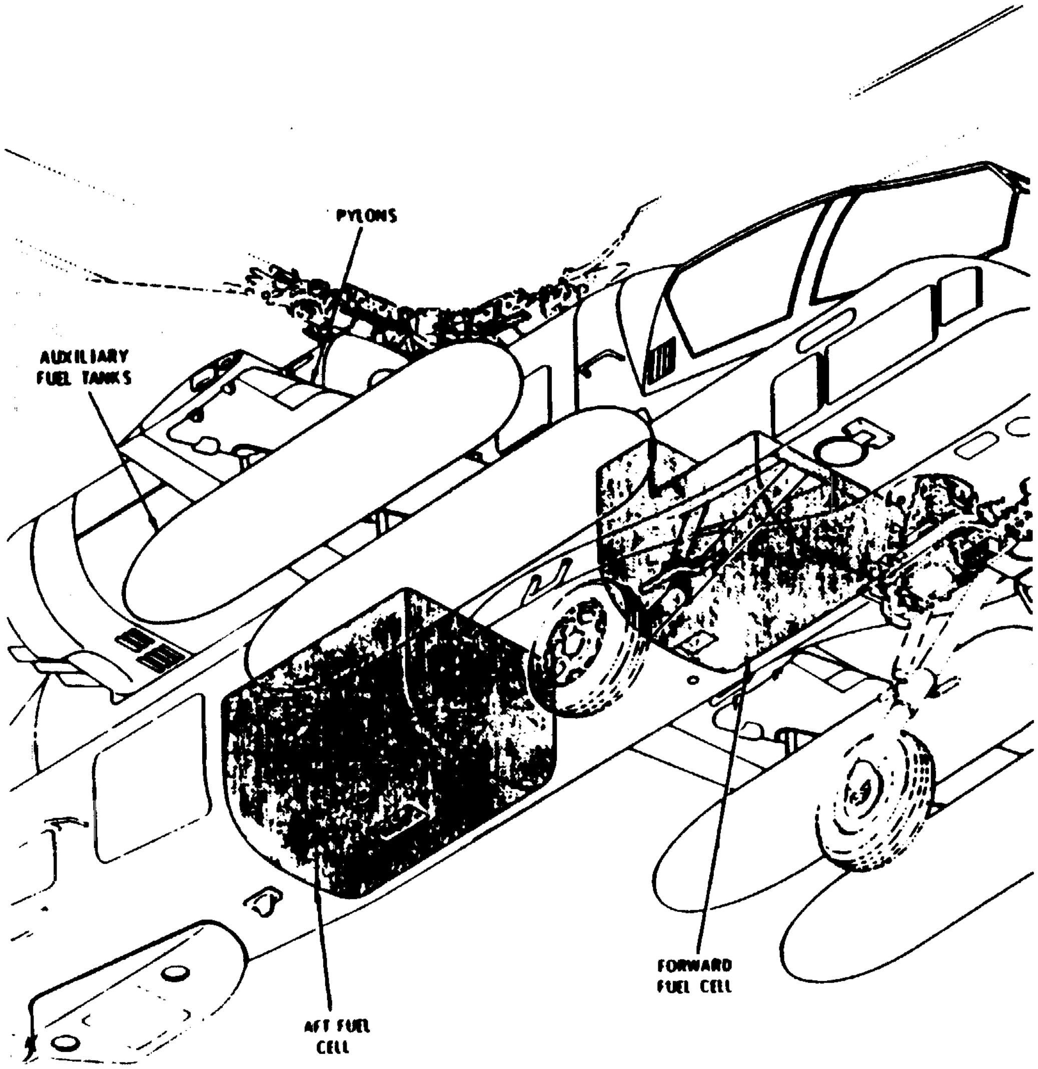
FUEL CELL ARRANGEMENT

Crashworthy fuel cells are located in the center section of the fuselage. The forward fuel cell, located between FS 135 and FS 176, contains 155 gallons. The aft fuel cell, located between FS 230 and FS 290, contains 220 gallons. The fuel cells are supported by the fuselage frames. The voids between the frames are filled with ballistic foam. Fire suppression is performed by a nitrogen inerting system. For the ferry mission, four 230 gallon auxiliary fuel tanks are carried under the wings.

The range of the AH-64A is as follows:

Primary mission	1.83 hrs
Full internal fuel	235 nm
Ferry Mission (4 230 gal ext. fuel tanks)	828 nm

FUEL CELL ARRANGEMENT

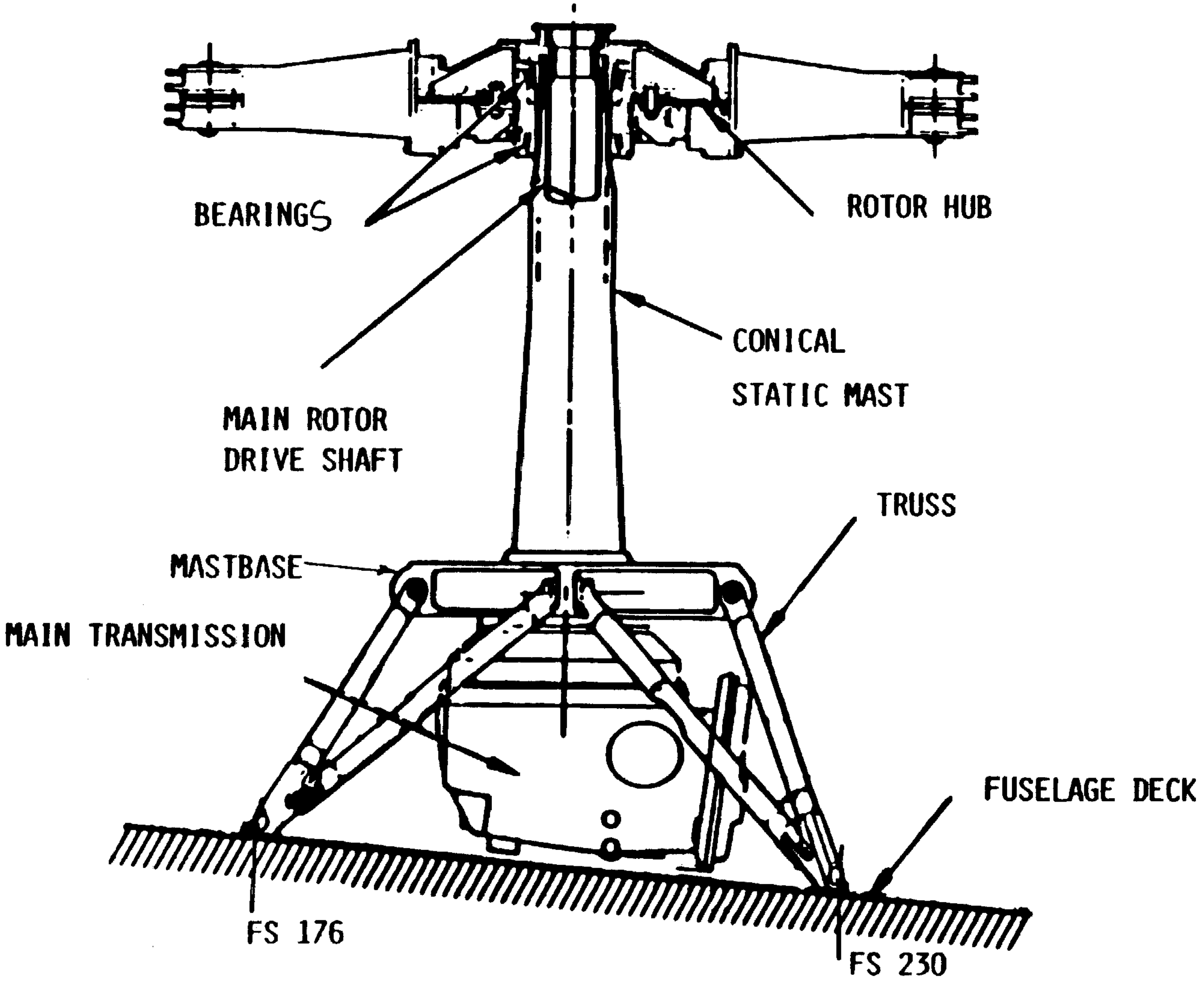


MAIN ROTOR SUPPORT STRUCTURE

The main rotor support structure consists of three components - the static mast, the mast base, and the truss. The main rotor rotates on a pair of bearings at the upper end of the mast. The main rotor drive shaft is inside the static mast. The static mast bolts to the mast base, which is in turn bolted to the truss. The truss is bolted to the airframe at FS 176 and FS 230. The main transmission attaches to the lower surface of the mast base. The five hub flight loads (lift, two shears, and two moments) have a load path through the static mast, mast base and truss into the airframe. Transmission torque is reacted by the mast base, truss, and into the airframe. The main rotor and rotor support structure used on the AH-64A have several unique design features. These features include a fully articulated rotor hub, the tilted static mast, and the fail safe design approach used on the rotor and rotor support structure.

The AH-64A hub is fully articulated. It has separate flapping, lead-lag, and feathering hinges. The blades are attached to the hub with a strap pack consisting of 22 laminates made of .016 inch thick steel. This strap pack is soft in torsion while being stiff in tension. This strap pack is fail safe since the pack will function with up to eight laminates failed. The use of the static mast is a key feature of the AH-64A rotor system. This system reduces the vibration in the airframe and allows the safe landing of the aircraft if the main rotor drive shaft fails. The entire rotor support structure is tilted forward 5 degrees. This allows the controls to be in a neutral position when the aircraft is on the ground. It is thought that this also reduces fatigue loads in the rotor system. The mast and mast base are designed to be invulnerable to both 12.7mm and 23mm HEI rounds. The mast base and truss are a fail safe design such that any one of the eight bolts that attach the truss to the mast base and airframe can fail without affecting the safe operation of the aircraft.

MAIN ROTOR SUPPORT STRUCTURE



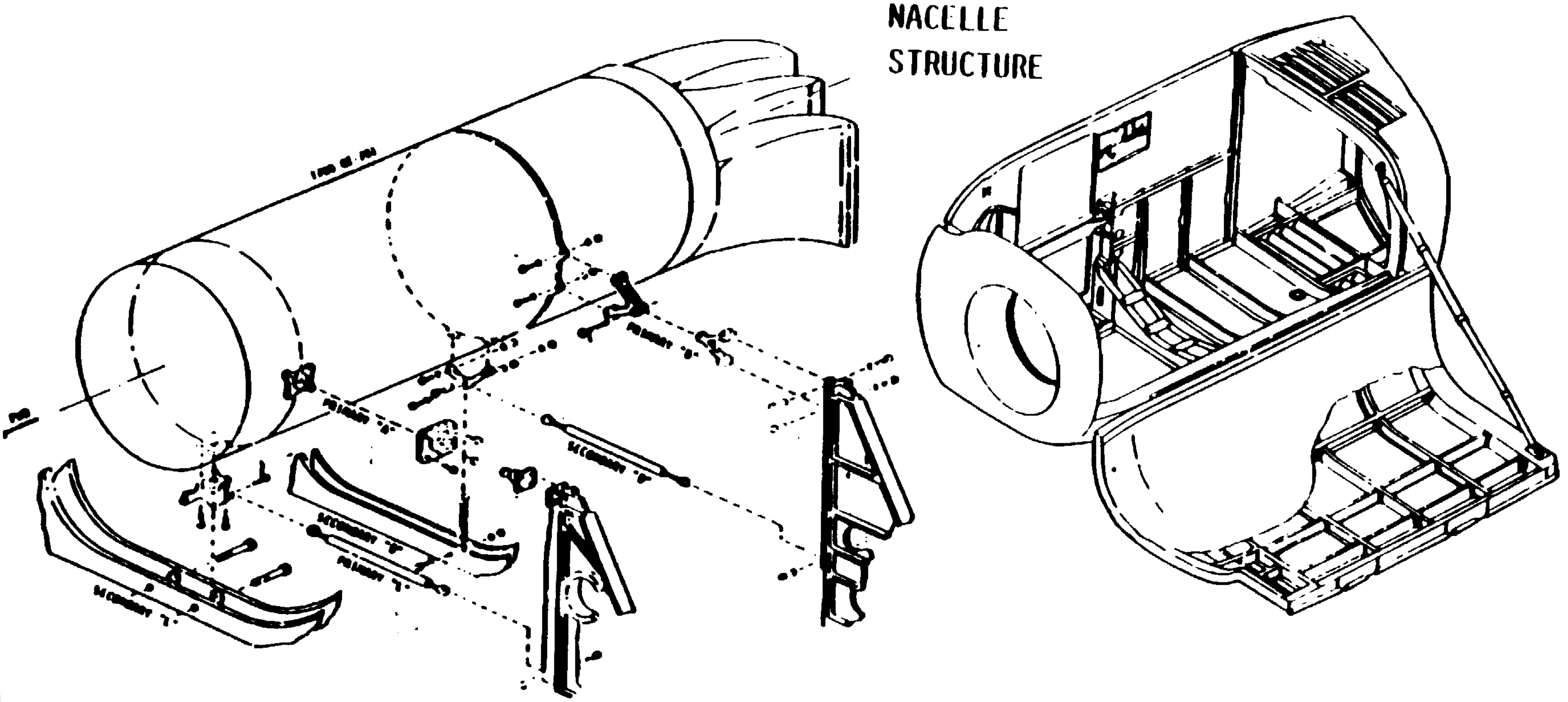
PRIMARY AND SECONDARY ENGINE MOUNTS

The engine has a primary and secondary or fail safe mounting system. The primary mounting system has statically determinate load paths; therefore, the secondary mounts pick up load only when a primary mount fails or during a crash condition. The engine mount loads are transferred to the fuselage through two buttresses. The buttresses are bolted to the frames at FS 230 and FS 247.71.

The primary engine supports consist of a ball and socket joint on the top and rod at the bottom of the FS 230 buttress and a link assembly at the top of the FS 247.71 buttress. The ball and socket joint carry F_x, F_y, and F_z loads. The lower rod carries F_y loads. The link assembly at the top of the FS 247.71 buttress carries F_y and F_z loads.

The secondary mounts consist of a link between the engine and the nacelle structure at FS 230 and a link between the engine and the nacelle structure and a rod to the bottom of the FS 247.71 buttress. The link at FS 230 reacts F_x, F_y, and F_z. The link and rod at FS 247.71 react F_y and F_z. The secondary mounting system alone is not statically determinate.

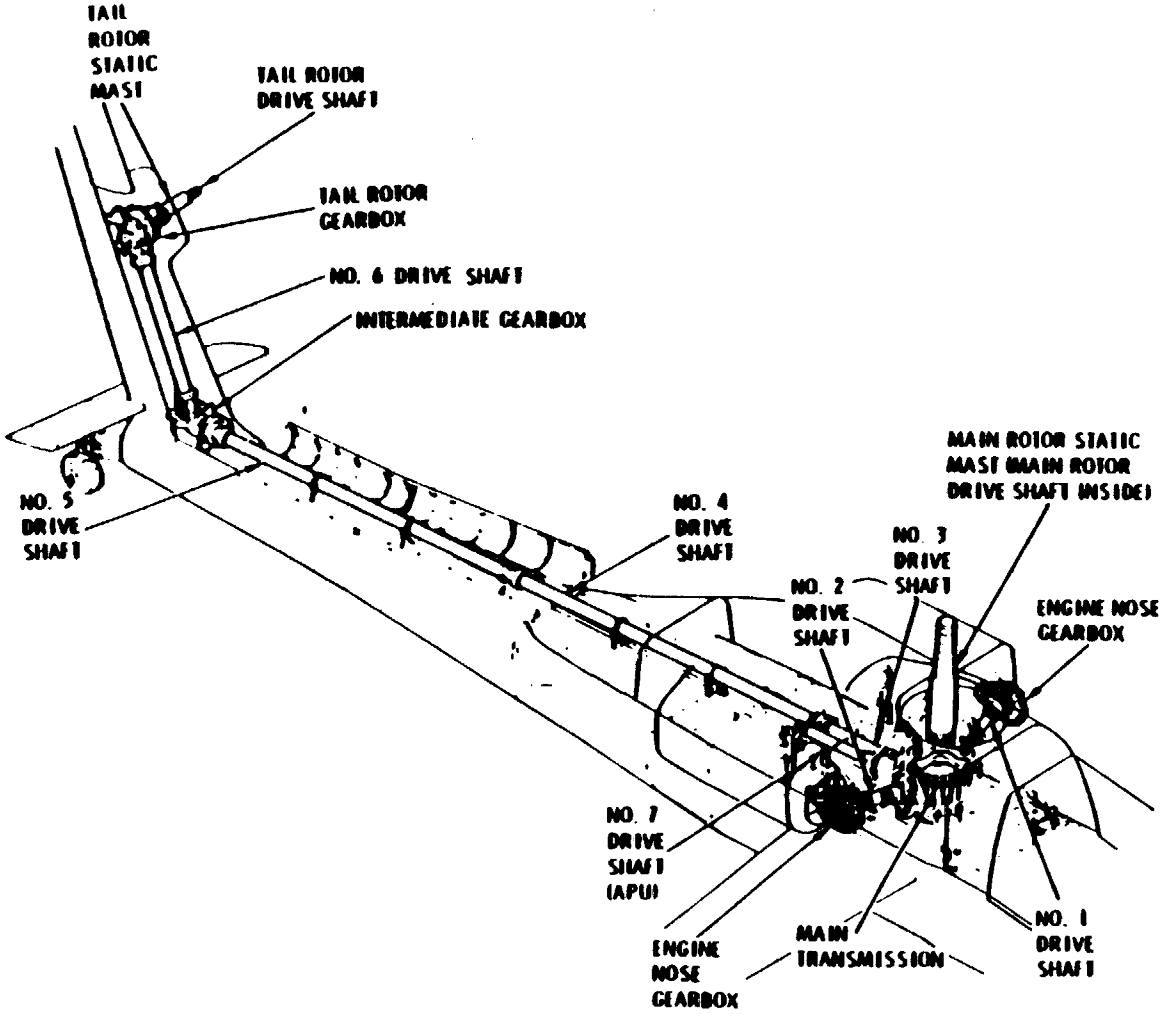
PRIMARY AND SECONDARY ENGINE MOUNTS



DRIVE SYSTEM ARRANGEMENT

The accompanying figure illustrates the location of the drive system components. Shown are the gearboxes, main transmission, intermediate gearbox, tailrotor gearbox and the associated drive shafts. Bendix couplings are used on the drive shafts to prevent airframe deflections from affecting the alignment of the drive shafts. As a result, the shafts are considered nonstructural.

DRIVE SYSTEM ARRANGEMENT

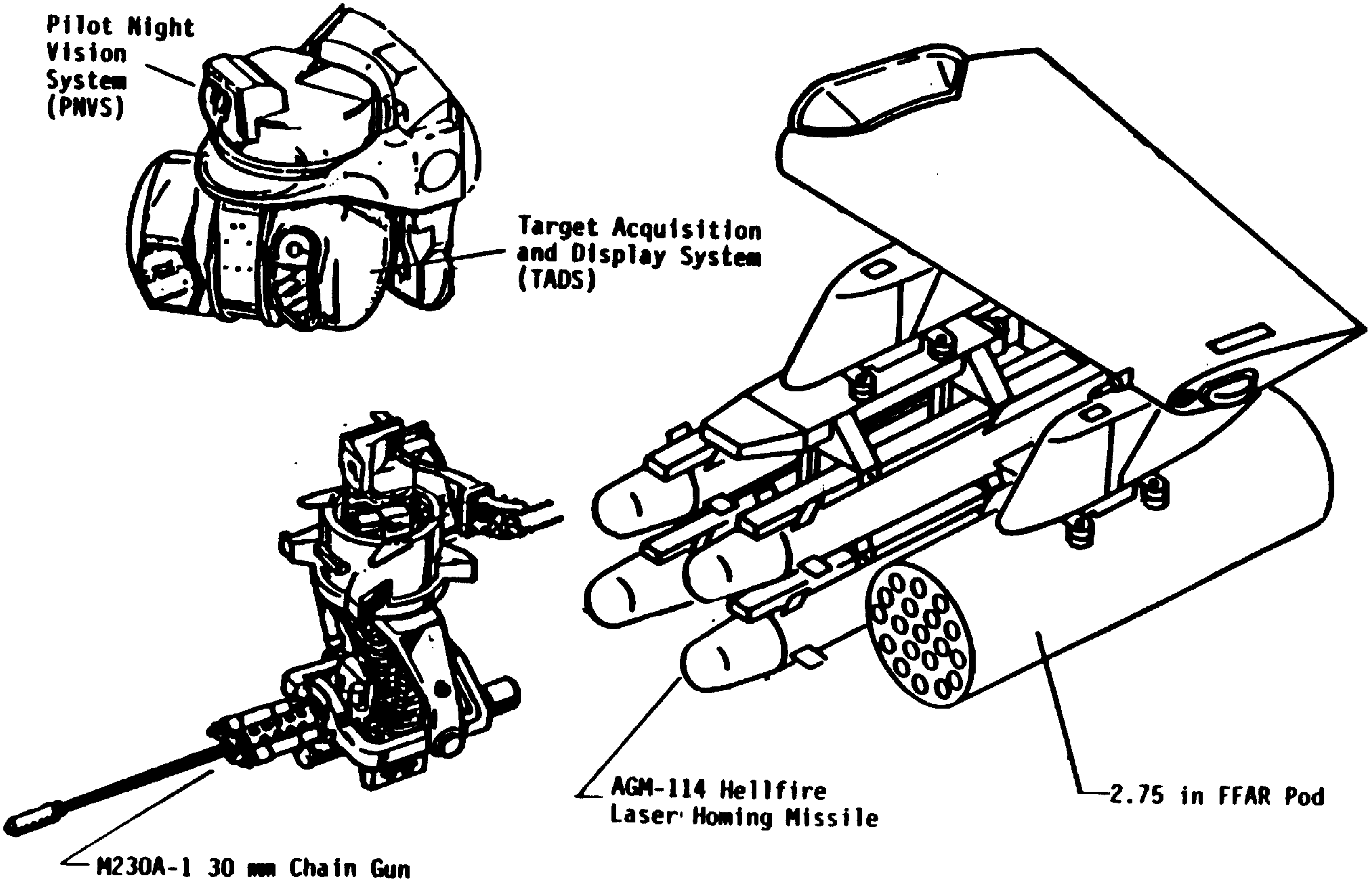


MISSION EQUIPMENT

The AH-64A Apache is equipped with three weapon systems and a two-part sighting system. The weapon systems are the M230A-1 30mm Chain Gun, the AGM-114 HELLFIRE laser homing missile system, and 2.75 in. FFAR. The Chain Gun turret is attached to the bottom of the aircraft between FS 115 and FS 125. Rocket and missile pods are interchangeable on the inboard and outboard pylons attached to the wings.

The sighting system consists of the Target Acquisition and Display System (TADS) and the Pilot Night Vision Sensor (PNVS). The TADS turret consists of a day television system, a forward looking infrared sight and a laser target designator/range finder. The PNVS provides real time thermal imagery for night operations. The TADS and PNVS are attached to the FS 35.5 bulkhead.

MISSION EQUIPMENT



WEIGHT SUMMARY

The table below summarizes the weight breakdown for the AH-64A helicopter in the primary mission configuration.

WEIGHT SUMMARY

GROUP	WT (POUNDS)
Wing Group	166.70
Rotor Group	1212.80
Tail Group	293.10
Body Group	1546.20
Alighting Group	518.90
Nacelle Group	203.90
Air Induction Group	36.40
Propulsion Group	2700.10
Flight Control Group	835.70
Auxilliary Power Plant Group	136.10
Instrument Group	140.10
Hydraulics and Pneumatics Group	202.50
Electrical Group	404.30
Avionics Group	260.20
Armament Group	1734.60
Furnishings and Equipment Group	207.70
Air Conditioning Group	101.20
Anti-Icing Group	17.00
Load Handling Group	2.70
Manufacturing Variation	-90.40
Weight Empty	10629.30
Useful Load	4030.70
Basic Structural Design Gross Weight	14660

4.0 MODELING GUIDES

MODELING GUIDES

This section provides information to aid modelers in performing static, mass, and vibration modeling. Included is specific information on the details for each type of model. Numbering schemes for grid points and elements, methods for modeling structural details such as frames, stringers, and skins, as well as guides for modeling non-structural items such as engines, transmissions, and mission equipment are described. Guides for modeling distributed and concentrated mass items are provided. Finally, the conversion of a model used for static analysis to one that can be used for dynamic analysis is covered.

MODELING GUIDES

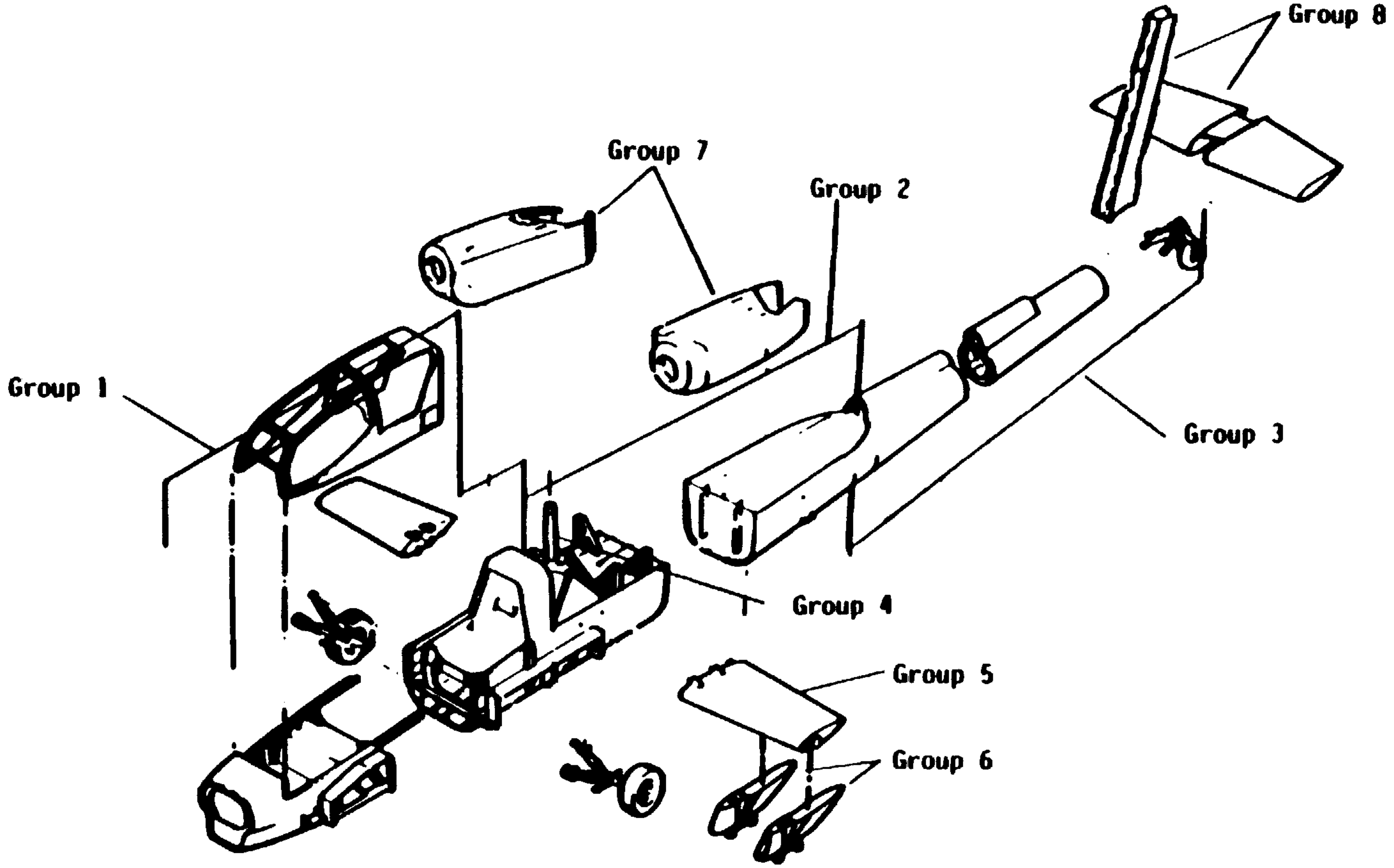
- GRID AND ELEMENT NUMBERING SCHEME
- STRUCTURAL ELEMENT SELECTION
- NON-STRUCTURAL DETAILS
- CONCENTRATED AND DISTRIBUTED MASSES
- CONVERTING STATIC TO DYNAMIC MODEL

STRUCTURAL BREAKDOWN FOR MODELING

The aircraft structure is broken down into eight groups for modeling. The number of groups is determined by the limitations of the model display software and to simplify the conversion to superelements, if necessary. The structural components in each group are shown below.

Group 1	Forward fuselage from FS 35.5 to FS 176 including the canopy and forward avionics bay.
Group 2	Center and aft fuselage from FS 176 to FS 370
Group 3	Tailboom from FS 370 to FS 547
Group 4	Main rotor support
Group 5	Wings
Group 6	Stores pylons
Group 7	Engine supports
Group 8	Vertical stabilizer and stabilator

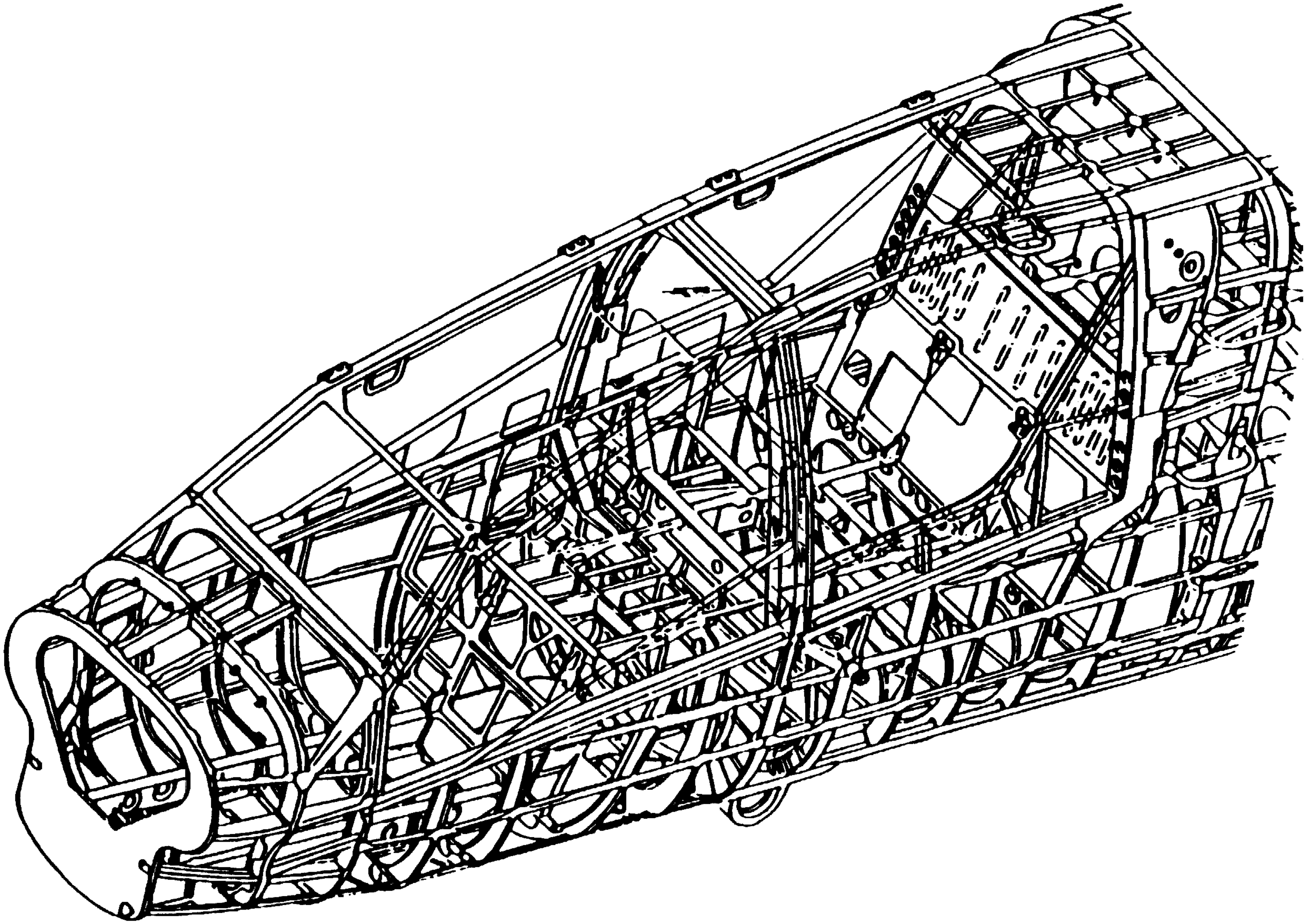
STRUCTURAL BREAKDOWN FOR MODELING



STRUCTURAL BREAKDOWN

The figure below shows the structural details of Group 1, the forward fuselage. Assemblies included in Group 1, but not shown, are the main landing gear and the forward avionics bay. This group includes accommodation for the forward fuel cell, the oleo fittings, and the bearings for the main landing gear crosstube.

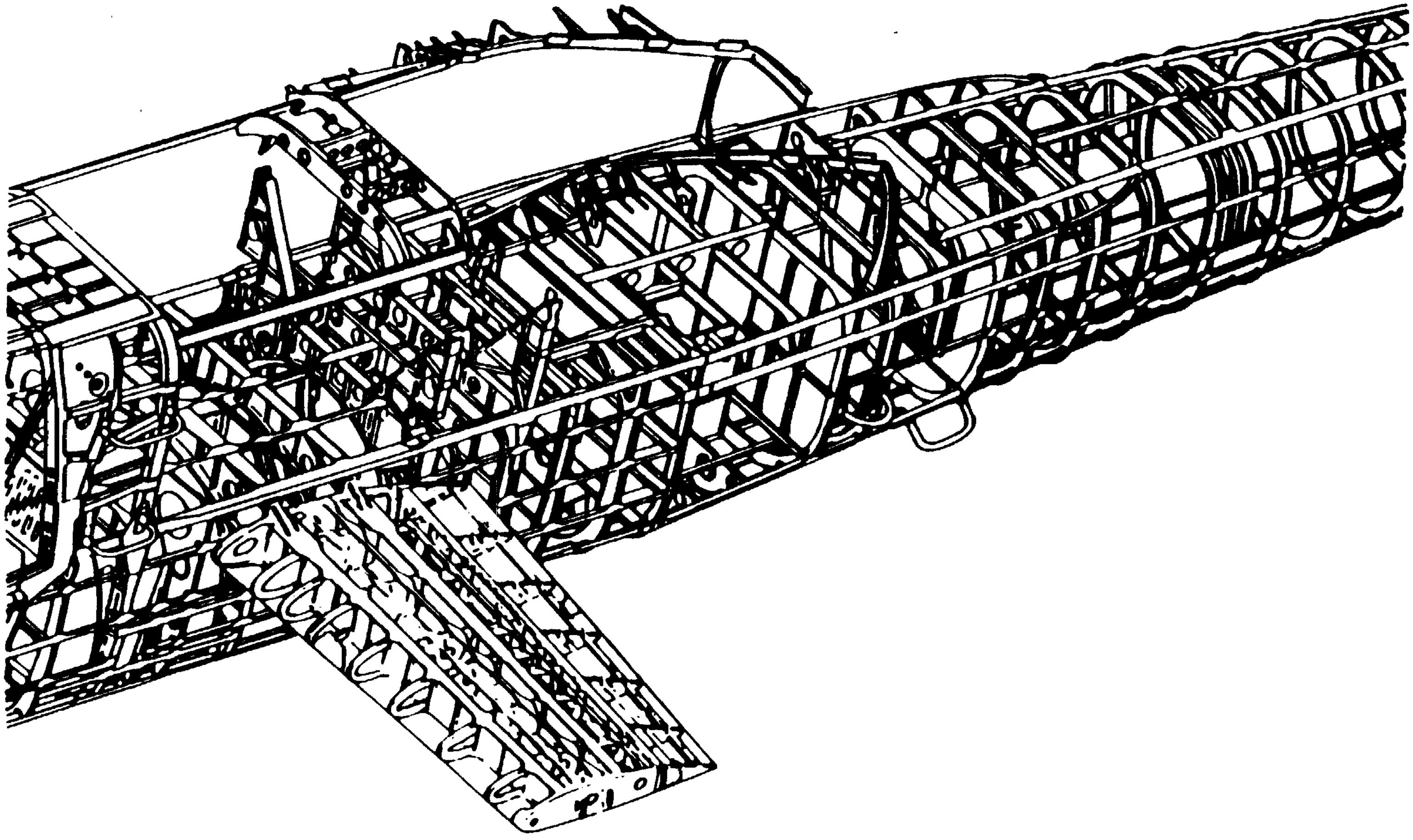
STRUCTURAL BREAKDOWN



STRUCTURAL BREAKDOWN (Continued)

The figure below shows the structural details of Group 2, the center and aft fuselage, and Group 5, the wing. Details in Group 2 include provisions for the aft fuel cell, the ammunition magazine for the M230 30mm Chain Gun, and the aft avionics and storage bays.

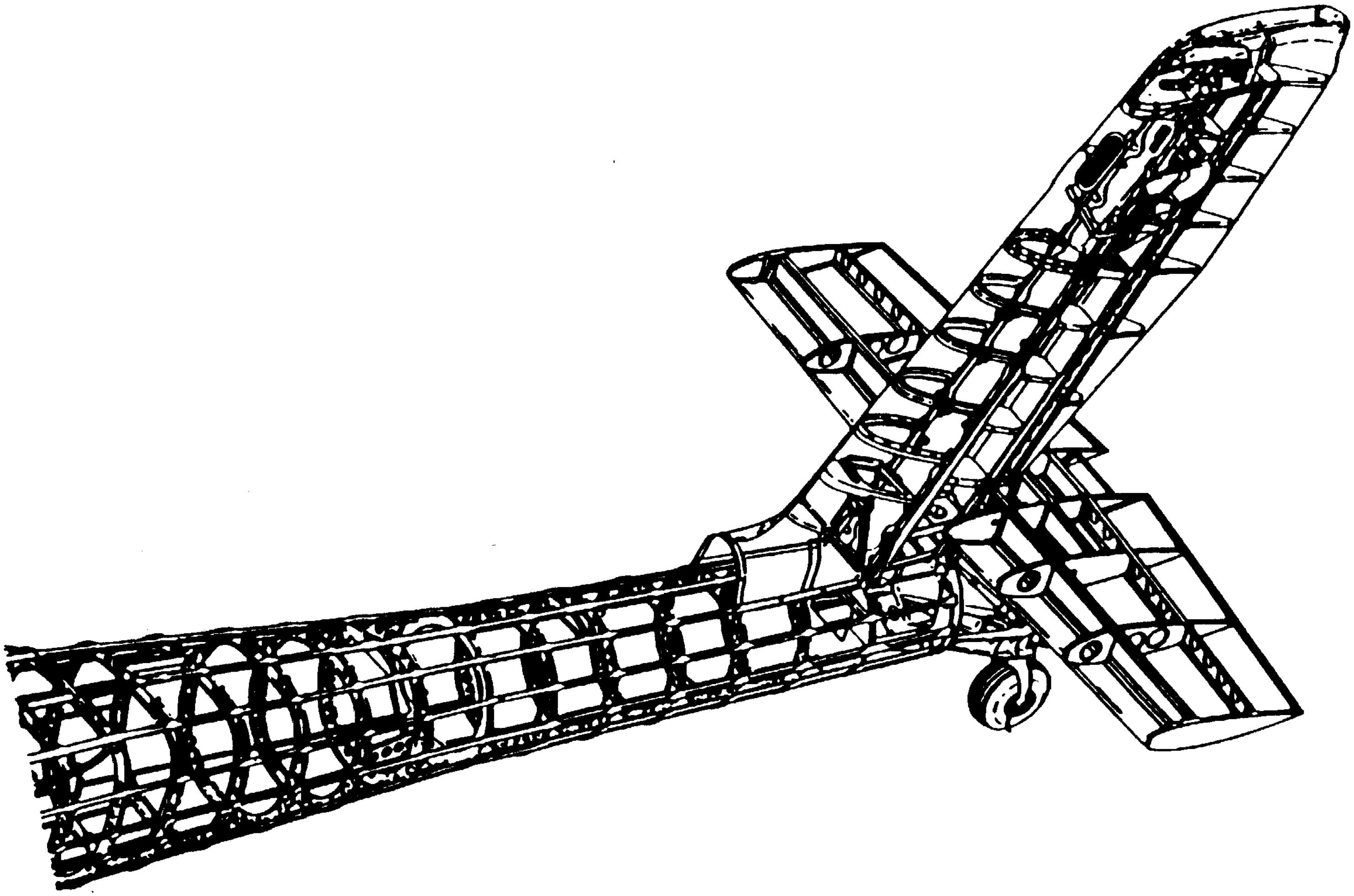
STRUCTURAL BREAKDOWN (Continued)



STRUCTURAL BREAKDOWN (Continued)

The figure below shows the structural details of Group 3, tailboom, and Group 8, vertical stabilizer and stabilator. Details include the attachments for the tail landing gear on the tailboom and attachments for the intermediate and tail rotor gearboxes on the vertical stabilizer.

STRUCTURAL BREAKDOWN (Continued)



4.1 STATIC MODELING

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STATIC MODELING

The AH-64A airframe is of typical semi-monocoque construction. It is assumed that stringers and longerons carry axial loads only. Skins and webs carry shear and axial loads. Effective axial skin area for webs and skins will be $32t^2$ for statics and fully effective for dynamics. Bulkheads and machined frames are, in general, not modeled to take out of plane loads. Bulkheads and machined frames are modeled using rods and shear panels. Sheet metal frames are modeled with bars.

STATIC MODELING

- TYPICAL SEMI-MONOCOQUE STRUCTURE
  - STRINGERS AND LONGERONS CARRY AXIAL LOADS ONLY
  - SKINS AND WEBS CARRY SHEAR AND AXIAL (EFFECTIVE SKIN) LOADS
- BULKHEADS AND MACHINED FRAMES ARE MODELED AS RODS AND SHEAR PANELS
- SHEET METAL FRAMES ARE MODELED AS BARS

STATIC MODELING

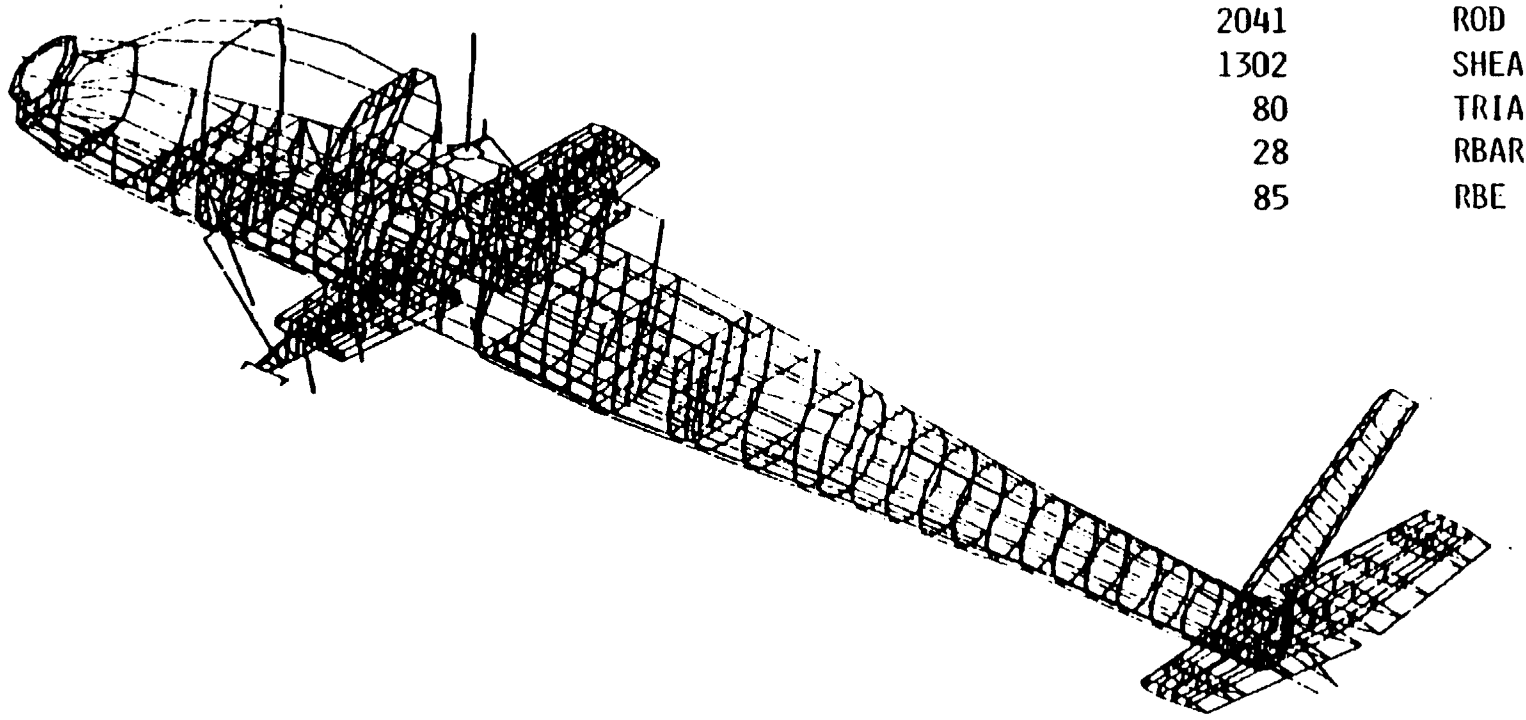
NASTRAN FEM OF THE YAH-64

A NASTRAN finite element model of the prototype YAH-64 aircraft is shown in the figure below. The number and types of elements used in the model are also summarized.

STATIC MODELING
NASTRAN FEM OF THE YAH-64

MODEL STATISTICS
1635 GRID POINTS
4498 ELEMENTS
951 MASS ITEMS

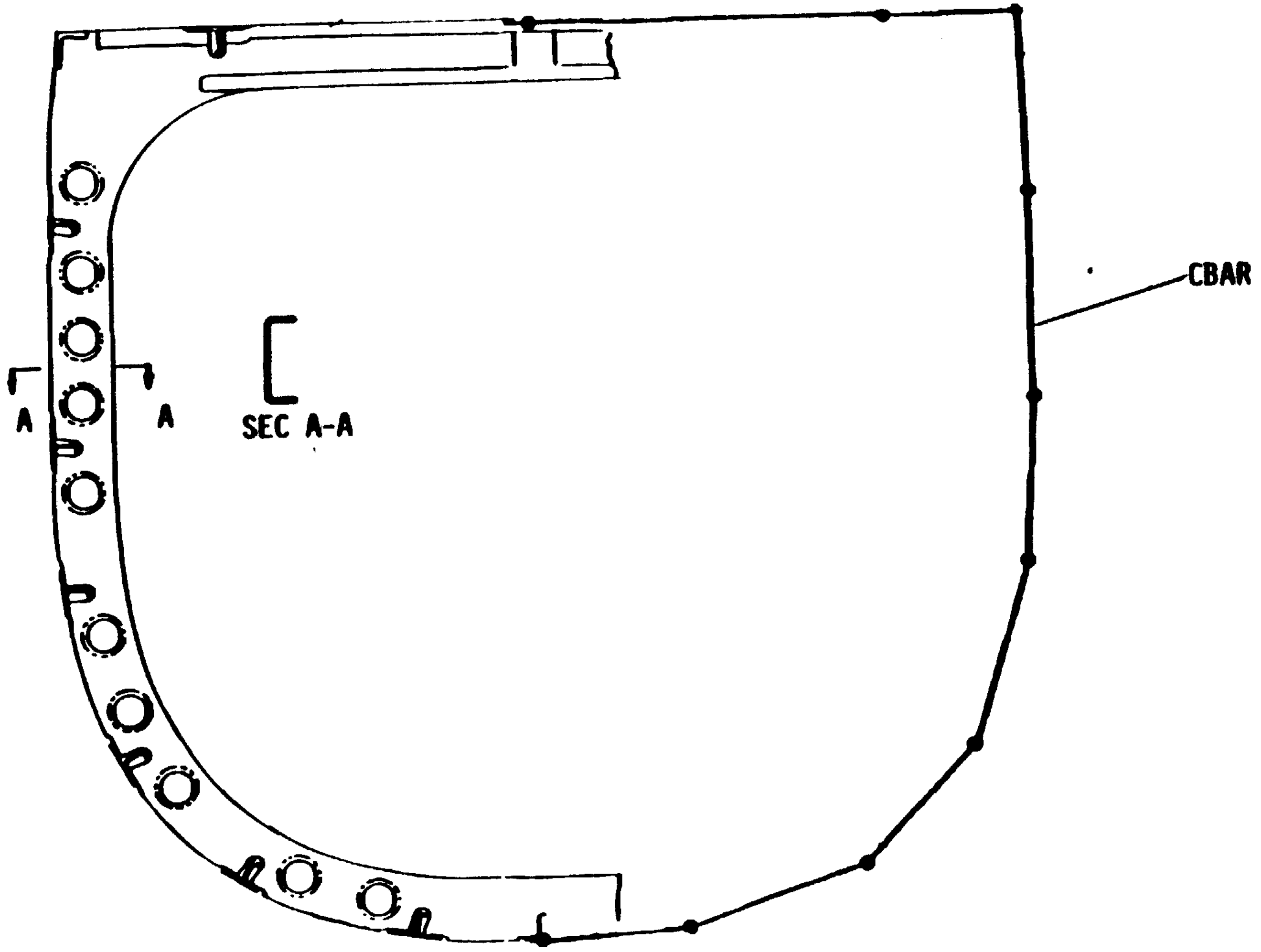
No OF ELEMENTS	TYPE
872	BAR
53	BEAM
2041	ROD
1302	SHEAR
80	TRIA3
28	RBAR
85	RBE



STATIC MODELING
SHEET METAL FRAMES

The figure below shows a typical sheet metal frame and the corresponding NASTRAN model. This type of frame is modeled with bar elements. Frames are modeled to carry in-plane loads only. Grid points for frames are located at the inner mold line (IML). Offsets are used to "move" the bar section properties to the neutral axis of the frame section. Effective skin is not included in the bar section porperties. The reference grid point for this frame, which defines the orientation of the bar properties, is located in the plane of the frame at BL 0.0 and WL 129.2.

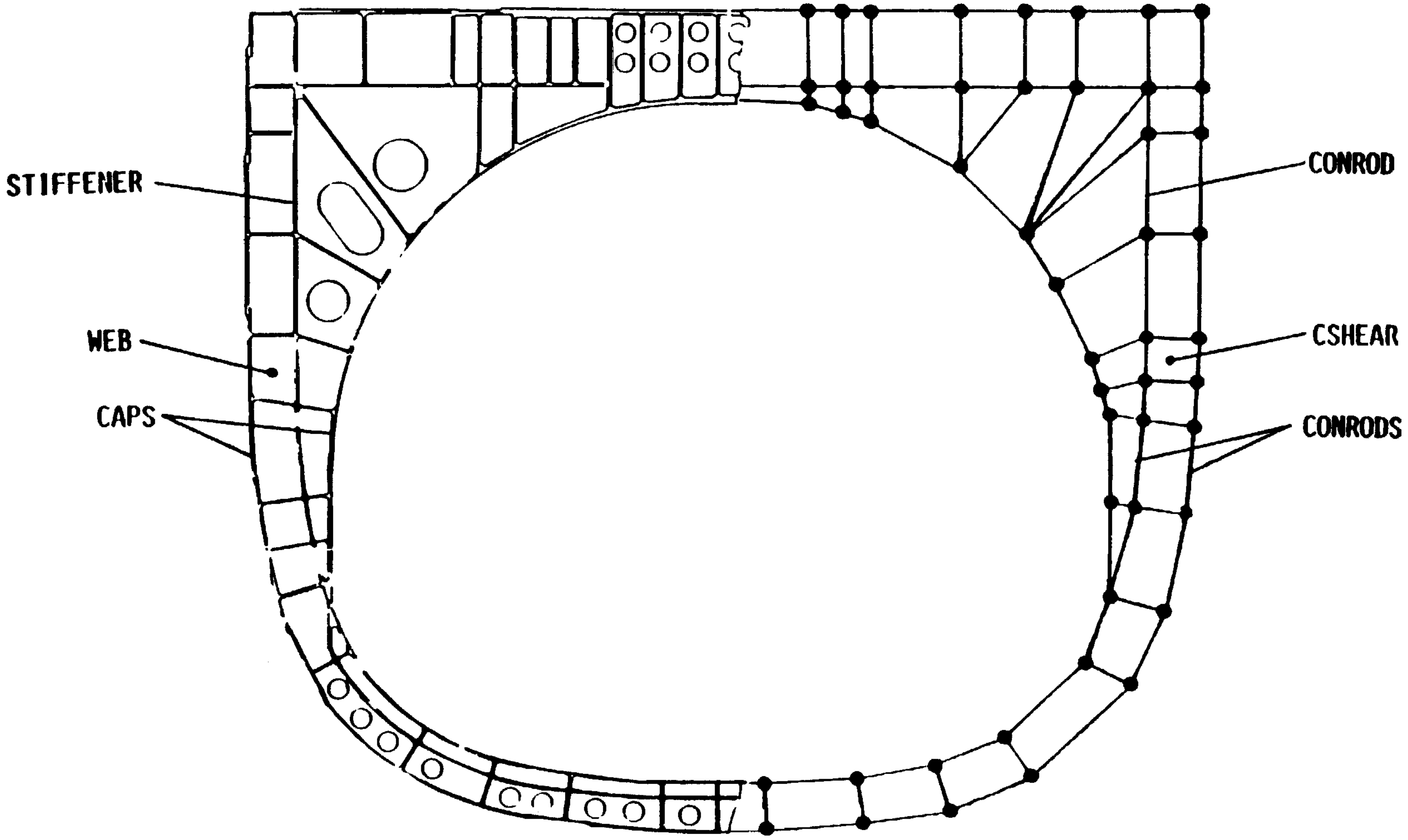
STATIC MODELING
SHEET METAL FRAMES



STATIC MODELING
MACHINED FRAMES AND BULKHEADS

The figure below shows a typical machined frame and the corresponding NASTRAN model. This type of structure is modeled with rods and shear panels. Outer grid points are located at the IML. Interior grid points are located on the center line of stiffeners and at stiffener intersections. Caps and stiffeners are represented with rod elements. Webs are represented with shear elements. The webs are shear resistant and the axial skin area of $32t^2$ is included using the effective skin parameter on the PSHEAR card. The web thicknesses are reduced to give an equivalent shear area when a hole is present.

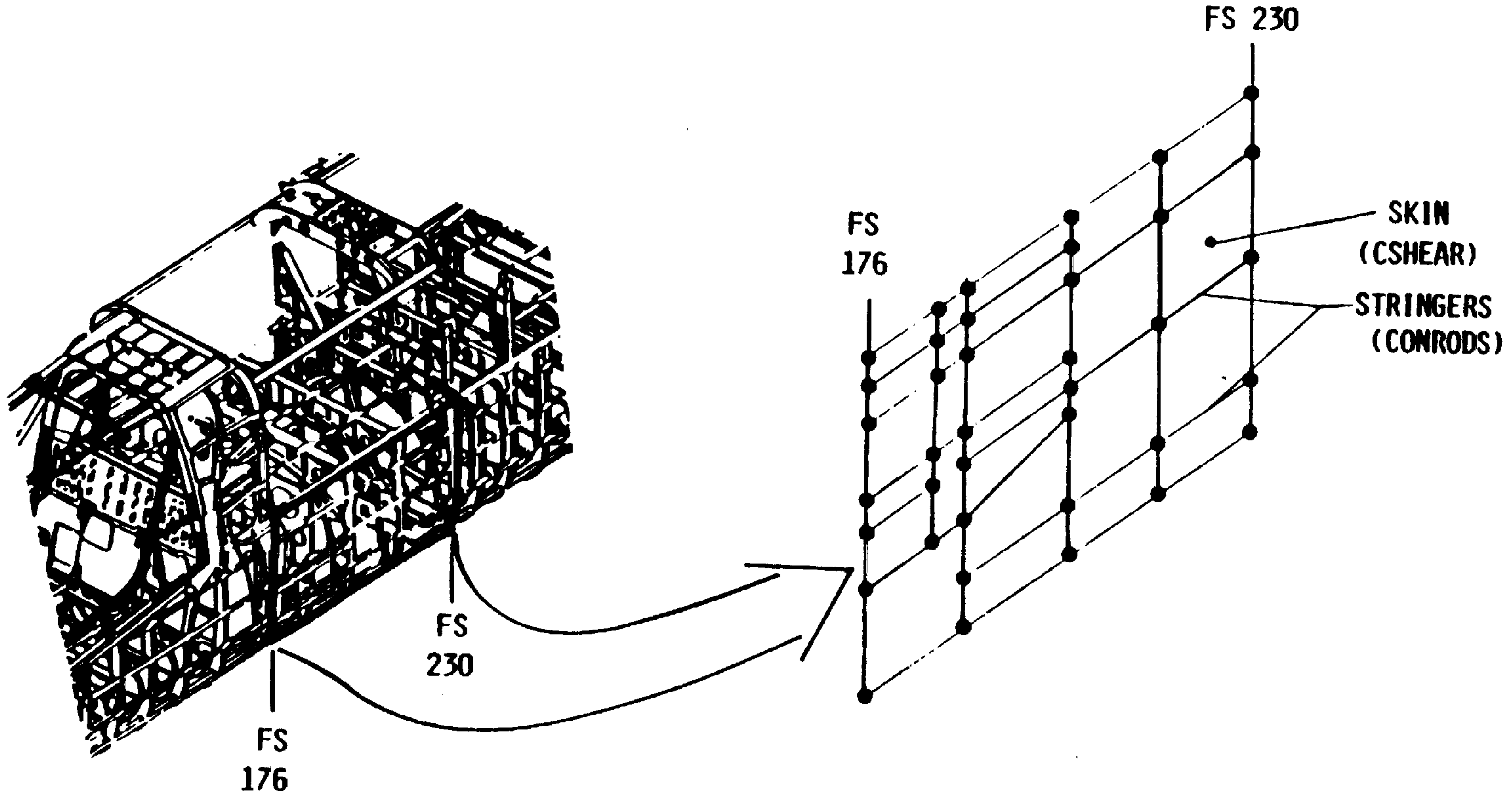
STATIC MODELING
MACHINED FRAMES AND BULKHEADS



STATIC MODELING
SKINS, STRINGERS, AND DECKS

The figure below is an example of skin and stringer modeling. Decks are modeled in a similar manner. Skins and decks are modeled using shear elements. Stringers and longerons are modeled using rod elements. Elements are generated connecting the grid points on the IML at each frame. The effective skin parameter is on the shear element property card (PSHEAR). The thickness of the shear elements is adjusted for holes and cutouts in the same manner as the frames. All stringers and longerons are modeled.

STATIC MODELING
SKINS, STRINGERS, AND DECKS

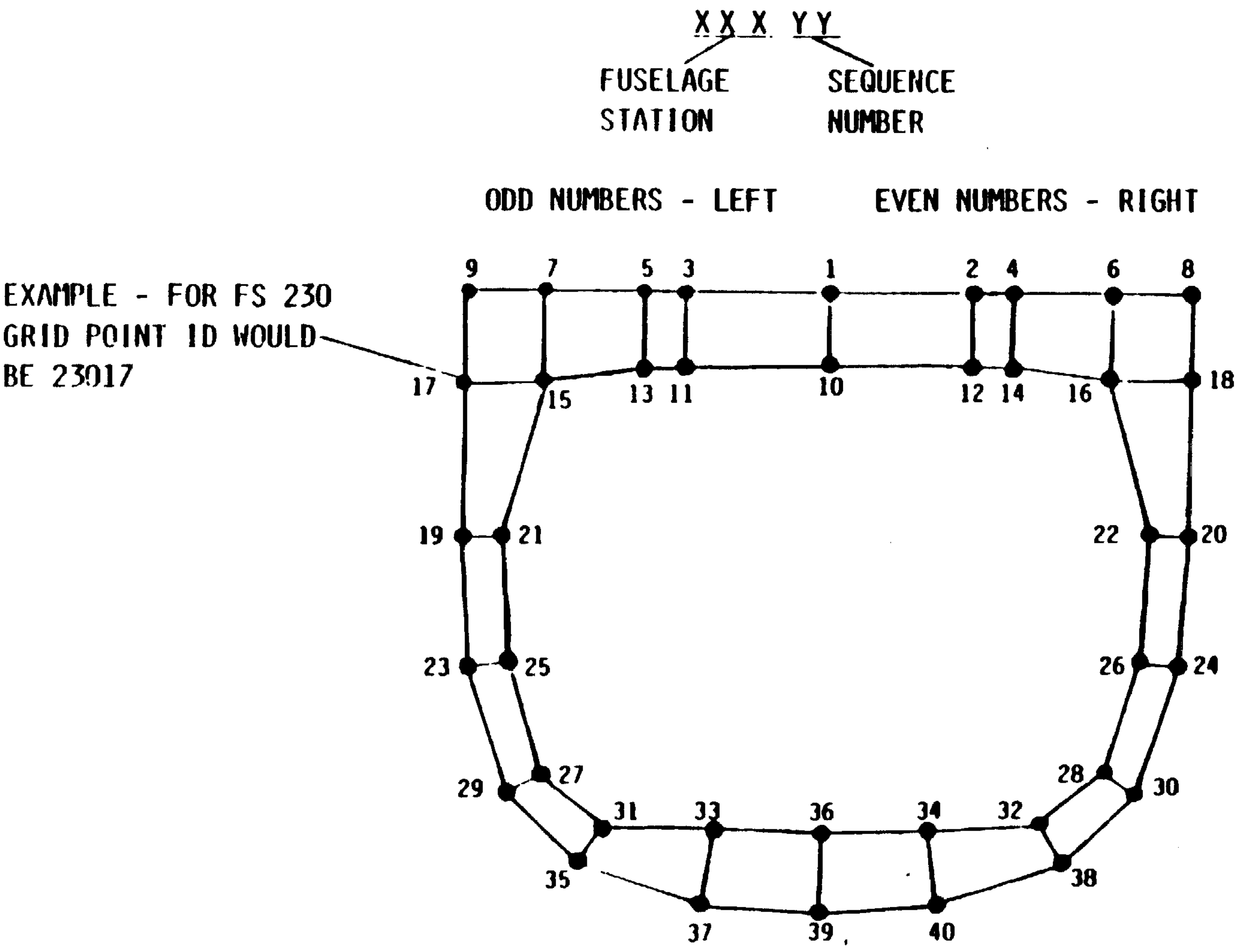


STATIC MODELING

GRID POINT NUMBERING PLAN FOR THE FUSELAGE

The grid point numbering system was developed to aid the analyst in determining the location of a grid point by the grid point I.D. number. The first two or three digits in the grid I.D. is the fuselage station of that grid point. The last two digits are the numbered position of that grid at the particular fuselage station. The I.D. numbers progress from higher to lower waterlines with the odd numbers are on the left side of the aircraft and the even on the right. The programs now in use at MDHC to generate models from CAD data automatically generate grid I.D.s and do not support user defined grid I.D.s.

STATIC MODELING
GRID POINT NUMBERING PLAN FOR THE FUSELAGE



XXX YY

FUSELAGE STATION — SEQUENCE NUMBER

ODD NUMBERS - LEFT EVEN NUMBERS - RIGHT

EXAMPLE - FOR FS 230
GRID POINT ID WOULD
BE 23017

STATIC MODELING

GRID POINT NUMBERING PLAN FOR THE WINGS, EMPENNAGE, AND STABILATOR

The grid point numbering system for the wings, empennage, and stabilator is similar to the one used for the fuselage. The first two digits in these I.D.s is the wing station (WS) measured spanwise, with WS 0.0 at the centerline of the aircraft. Again, odd numbered I.D.s are on the left side and even on the right. The numbers progress from the upper to the lower surface, then chordwise.

STATIC MODELING
GRID POINT NUMBERING PLAN FOR THE WINGS, EMPENNAGE, AND STABILATOR

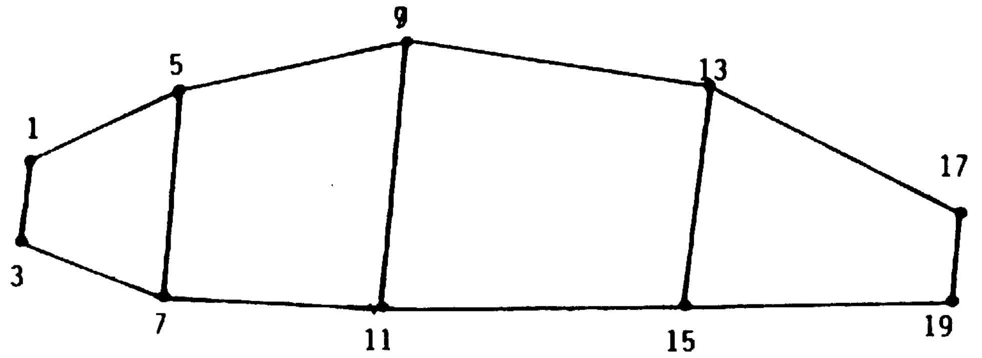
WINGS AND EMPENNAGE

XX YY

YY — SEQUENCE NUMBER

EVEN NUMBERS - RIGHT WING, RIGHT SIDE OF STABILATOR
ENTIRE VERTICAL STABILIZER

ODD NUMBERS - LEFT WING, LEFT SIDE OF STABILATOR



STATIC MODELING
ELEMENT NUMBERING PLAN

The element sequence numbers are assigned in a similar manner to the grid numbers. The first digit is the element type code. The second digit is the structural breakdown group. The last three digits are the element sequence number. All element I.D.s are assigned with odd numbers on the left side and even numbers on the right side. Frames and skins are numbered top to bottom. Stringers and longerons are numbered forward to aft, then top to bottom. Decks are numbered center out, then forward to aft.

Code	Element Type
1	CONROD and CROD
2	CBAR and CBEAM
3	CTRIA3
4	CQUAD4 and CSHEAR
5	CELAS1, RBE, and RBAR

STATIC MODELING
ELEMENT NUMBERING PLAN

ELEMENT ID NUMBER

A	B	CCC
ELEMENT TYPE CODE	GROUP NUMBER	SEQUENCE NUMBER

ELEMENT TYPE CODE:

1. CONROD, CROD
2. CBAR, CBEAM
3. CTRIA3
4. CQUAD4, CSHEAR
5. CELAS, RBE, RBAR

EVEN NUMBERED ELEMENTS ON RIGHT SIDE AND ON VERTICAL STABILIZER

ODD NUMBERED ELEMENTS ON LEFT SIDE

STATIC MODELING
PROPERTY CARD NUMBERING GUIDES

The numbering guides for property cards provide aid to the analyst in determining the type of material a particular element represents as well as the geometric configuration of the particular element. The first digit is the material code. For this model, 1 is used for aluminum, 2 for steel, and 3 for titanium. The last three digits represent the area of a rod element or the thickness of a shear element.

STATIC MODELING
PROPERTY CARD NUMBERING GUIDES

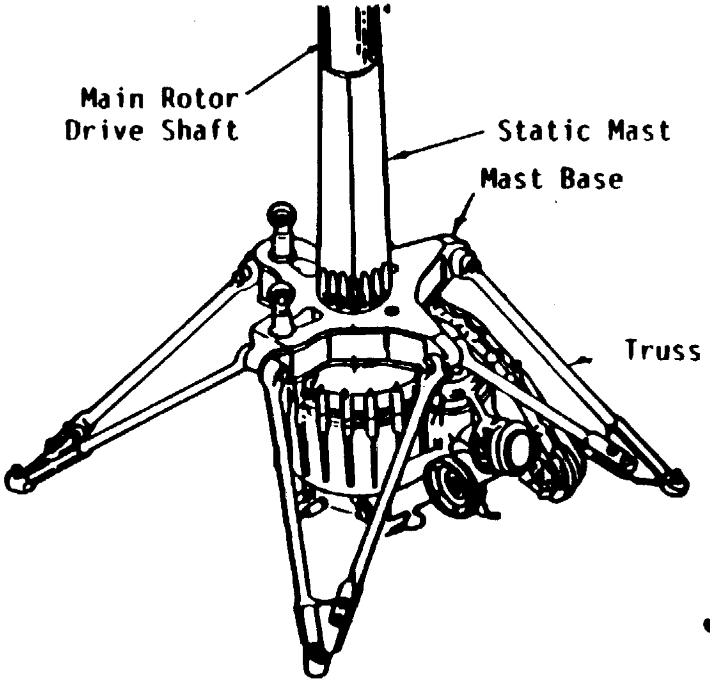
A	B B B
MATERIAL CODE	AREA OR THICKNESS

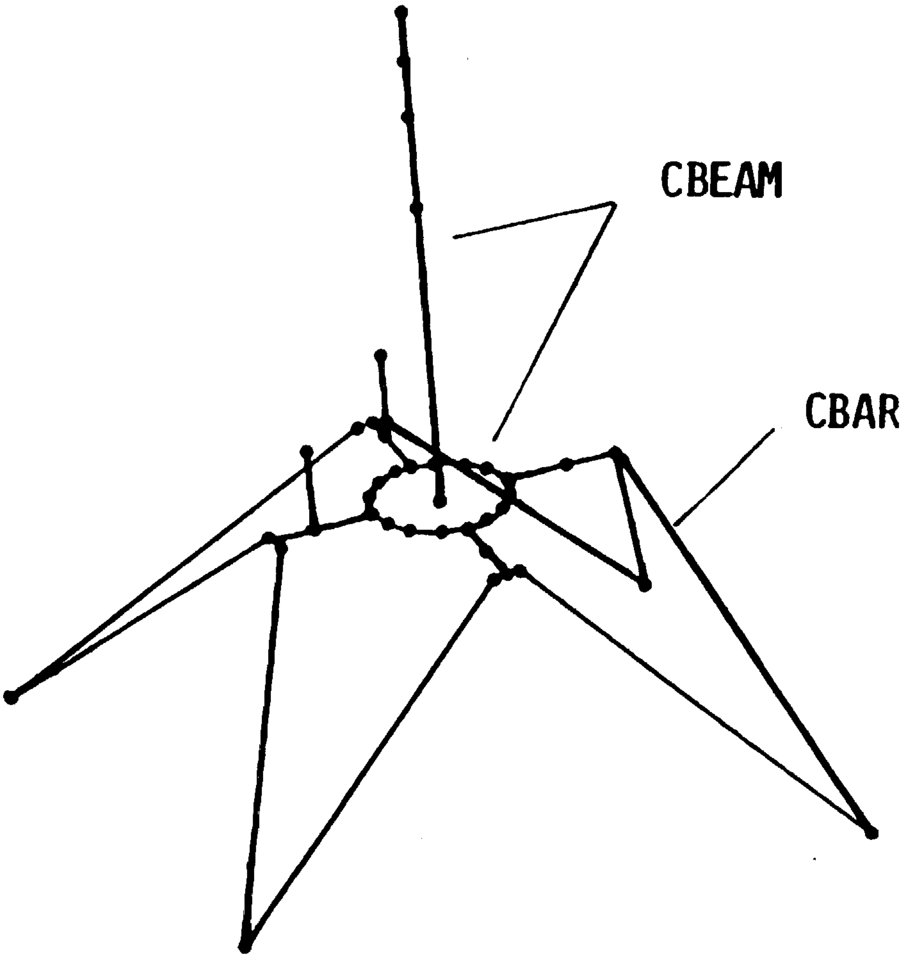
STATIC MODELING

MAIN ROTOR SUPPORT STRUCTURE

The Main Rotor Support Structure consists of a conically tapered steel mast, aluminum mast base, and aluminum truss. The assembly is bolted together and bolted to the airframe. The main transmission is bolted to the bottom of the mast base. The mast and mast base are modeled with beam elements to represent the tapered sections. An RBE2 rigid element "wagon wheel" is used to represent the connection between the mast and mast base. The truss legs carry axial load only and are modeled with rod elements. The bolted connections between the mast base and the truss, and the truss and the airframe are represented with multipoint constraints (MPC). MPCs are used to run several fail-safe conditions with bolt failures within a single submission of the NASTRAN deck.

STATIC MODELING
MAIN ROTOR SUPPORT STRUCTURE

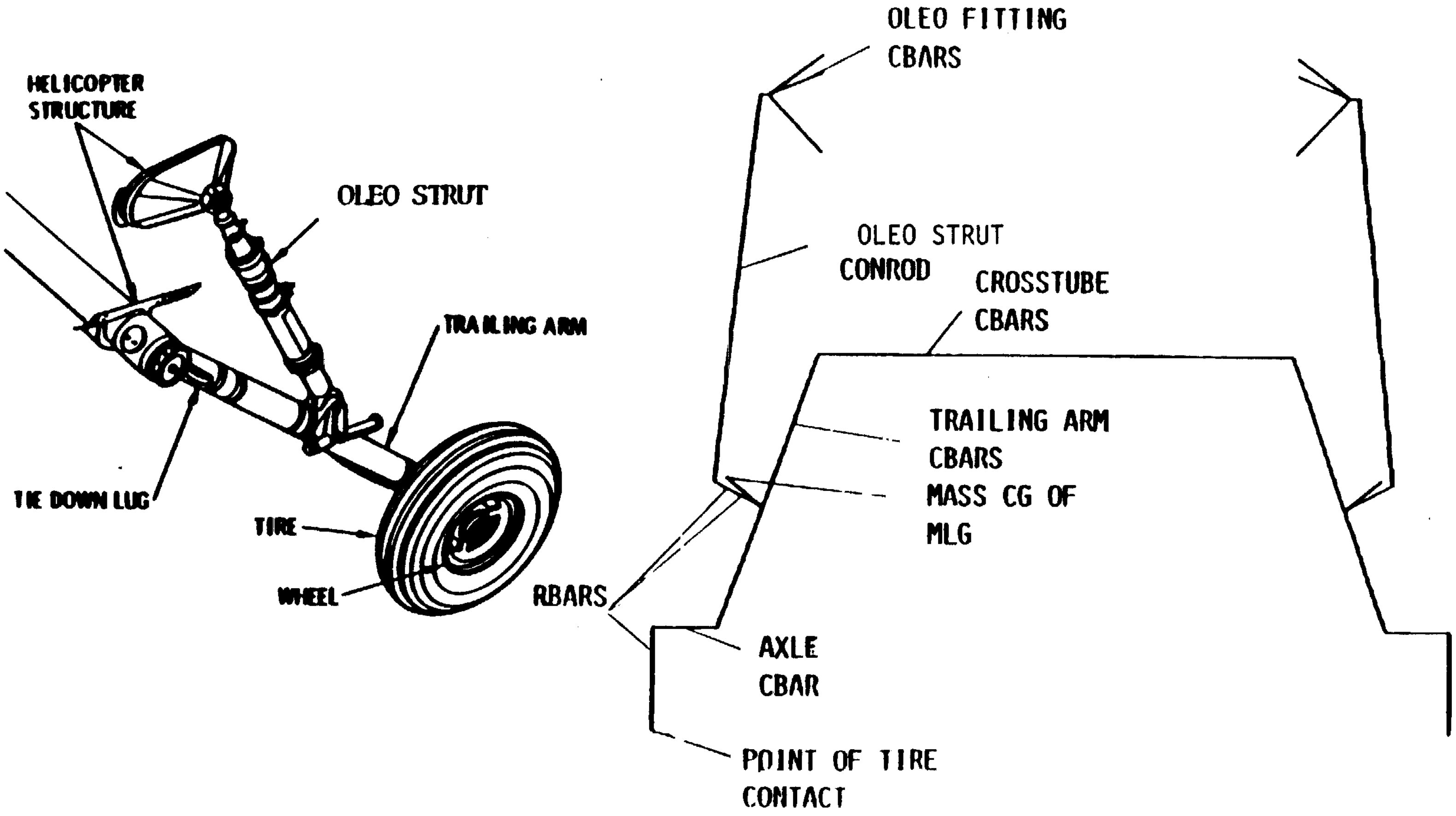




STATIC MODELING
LANDING GEAR

The figure shows the NASTRAN model of the Main Landing Gear (MLG). The MLG and the Tail Landing Gear are both trailing arm configurations. The same technique is used to model both types of landing gears. Bars are used to represent the trailing arms and the MLG crosstube. Rods are used to represent the oleos. The area of the rod is calculated to give the rod the same spring rate as the oleo. Rigid elements are used to connect the location of the tire contact patch to the landing gear and to connect the centerline of the trailing arm to the centerline of the oleo.

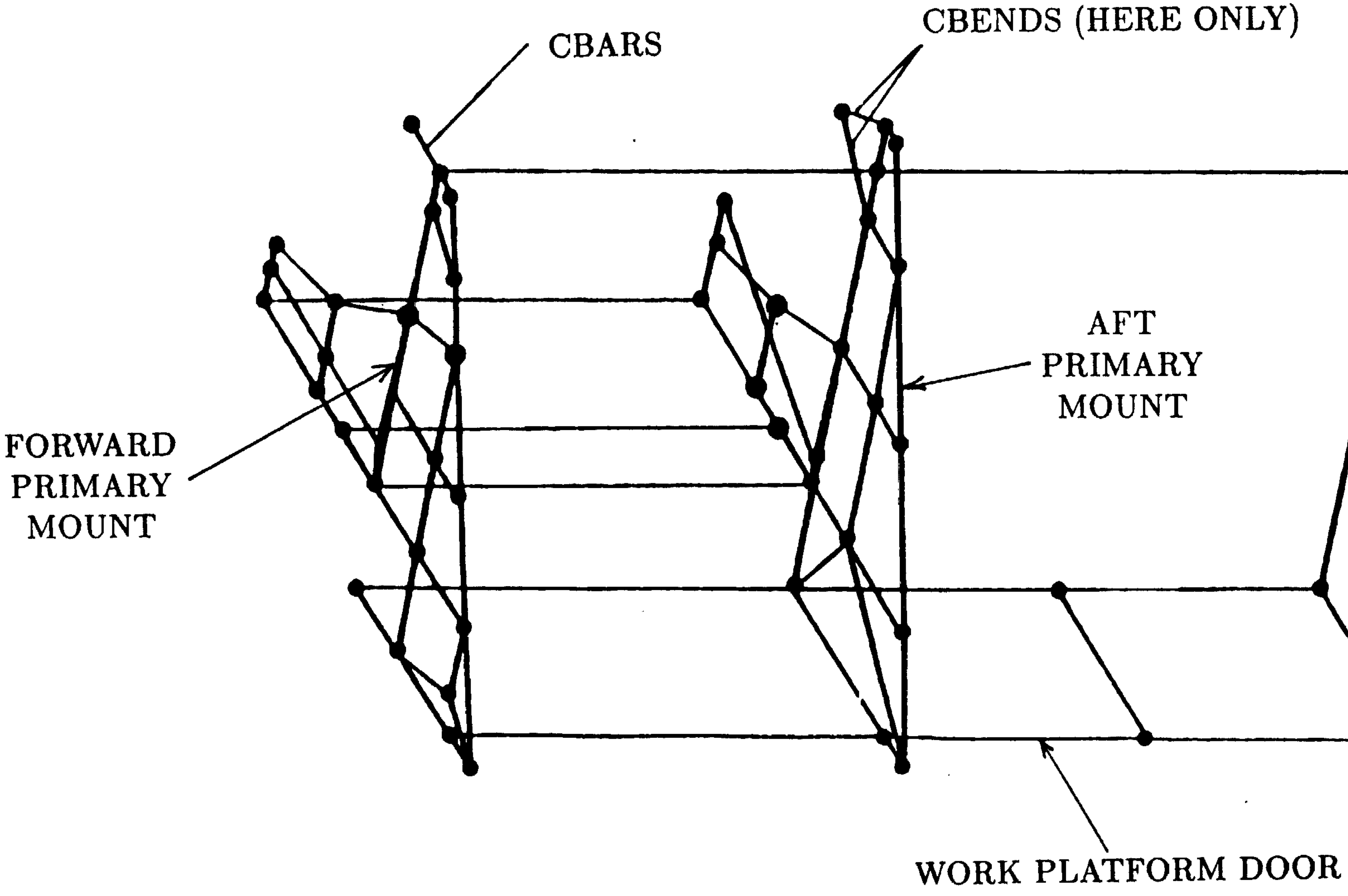
STATIC MODELING
LANDING GEAR



STATIC MODELING
ENGINE SUPPORTS

The figure below shows the NASTRAN model of the engine support structure. The model includes the buttresses, firewall, bottom of the nacelle, and the primary and secondary engine mounts. The buttresses and the nacelle bottom are modeled in the same manner as machined frames and fabricated bulkheads. These sturctures are modeled with rod and shear elements. The forward primary mount (primary A) is modeled with bar elements. The aft primary mount (primary B) is modeled with CBEND elements. The work platform door is attached to the nacelle with a piano hinge and two latches and is assumed to be non-structural in the closed position for flight loads. An RBE2 is used to connect the mass of the engine, located at the engine C.G., to the engine mount.

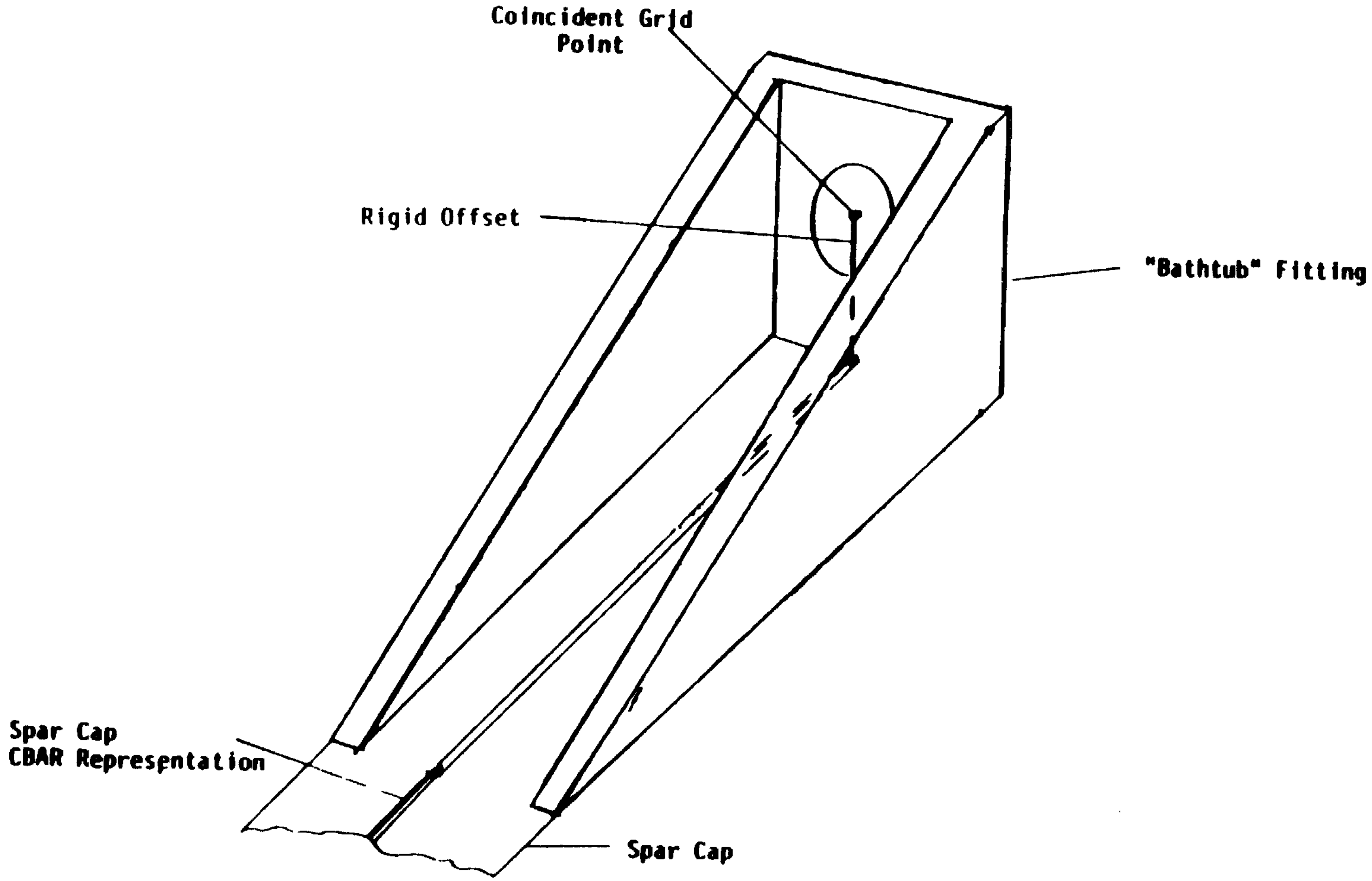
STATIC MODELING
ENGINE SUPPORTS



STATIC MODELING
ATTACHMENT FITTINGS

Several structural components are bolted to the airframe structure. These components include the wings, vertical stabilizer, rotor support, engine mounts, and pylons. Many of these interfaces use a type of tension fitting commonly called a "bathtub" fitting as shown in the figure below. The offset between the bolt centerline and the spar cap is modeled with a rigid element. The bolt is modeled with three zero length springs. The springs will give output of the two shears and the axial load acting on the bolt. The method of modeling the bolt with three zero length springs is typical for any joint at which bolt loads are required.

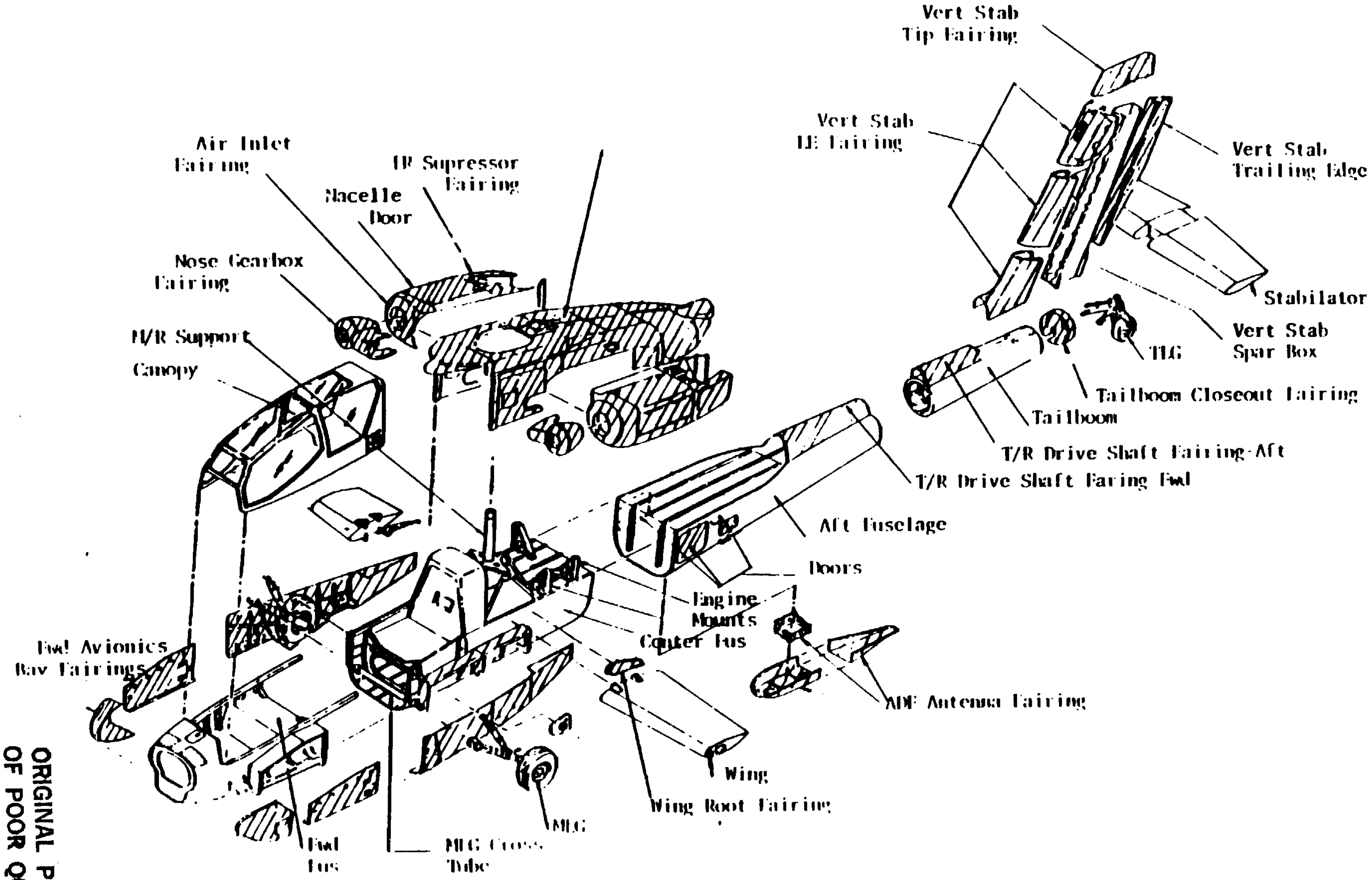
STATIC MODELING
ATTACHMENT FITTINGS



STATIC MODELING
STRUCTURE NOT MODELED

Several components of the aircraft are not included in the structural model of the airframe because they do not contribute to the overall structural stiffness of the airframe. However, the mass associated with these items is accounted for as discussed later. Components not modeled include aerodynamic fairings, pilot and copilot doors, driveshafts, nacelle doors, main and tail rotor systems, flight controls, non-structural doors and access panels, and all powerplants. The structure not modeled is shown cross hatched in the figure.

STATIC MODELING
STRUCTURE NOT MODELED



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4.2 MASS MODELING

MASS MODELING
GENERAL GUIDELINES

Generation of the mass model of the AH-64A finite element model consists of the following steps:

1. Generation of a detailed weights tape for the weight empty flight configuration.
2. Generation of a detailed listing of useful load weights, c.g.'s, and inertias.
3. Distribution of primary structure weight via material density parameter
4. Manual distribution of large concentrated mass items such as:
    a. Main Rotor and Transmission
    b. Engines
    c. Pilot and Copilot
    d. Fuel
    e. Wing Pylon Store Weights (Missiles,Rockets,etc.)
    f. 30mm Gun and Ammo
    g. Tail Rotor Gear Box
    h. TAS/NVPS
    i. Landing Gear
5. Automatic distribution of remaining mass data usings MDHC's mass lumping program.

MASS MODELING
GENERAL GUIDELINES

- DETAILED WEIGHTS TAPE GENERATION
- DETAILED USEFUL LOAD LISTING GENERATION
- DISTRIBUTION OF PRIMARY STRUCTURE WEIGHT
- MANUAL DISTRIBUTION OF LARGE WEIGHT ITEMS
- AUTOMATED DISTRIBUTION OF DETAILED WEIGHTS

MASS MODELING
MASS LUMPING PROGRAM

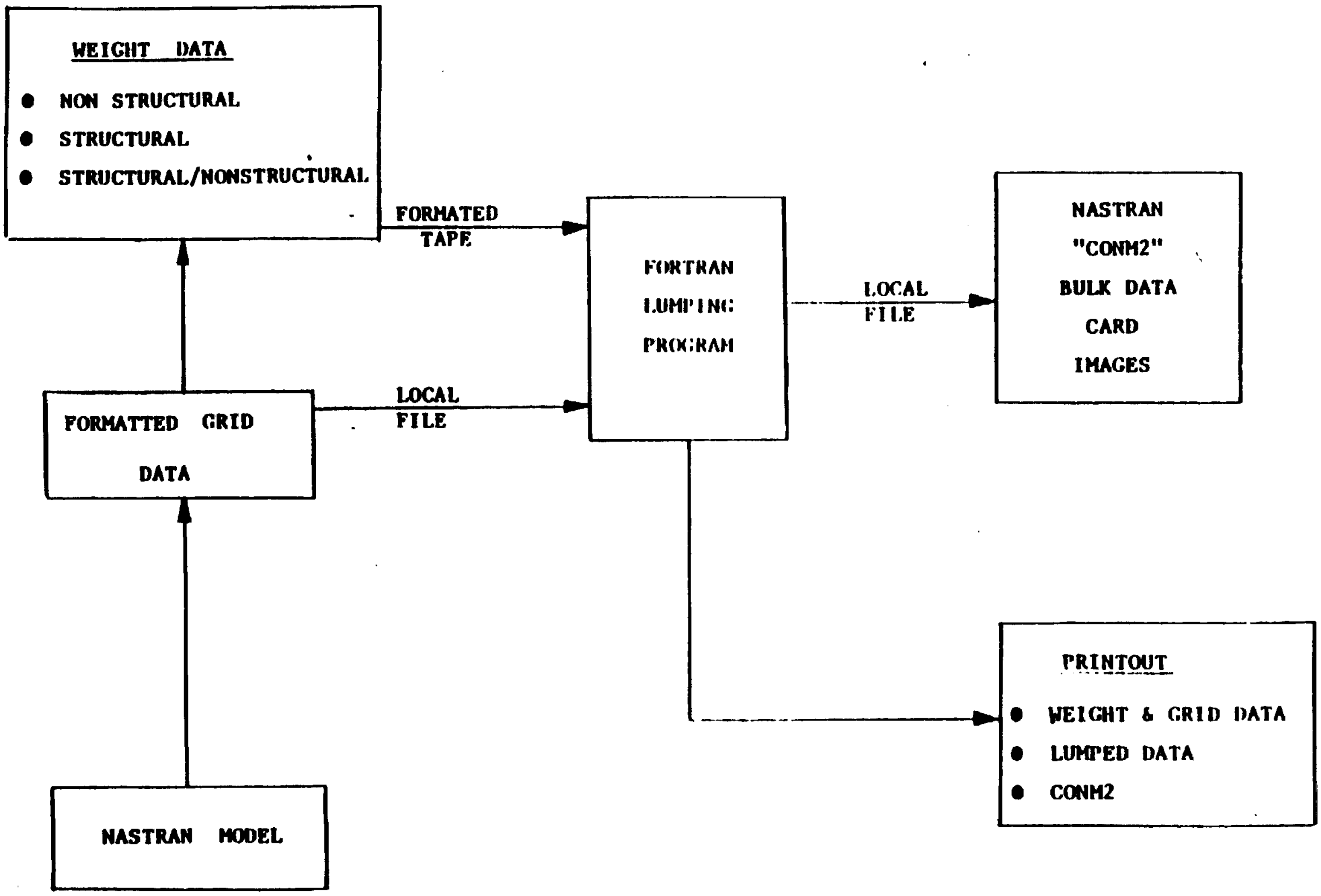
The figure illustrates the input and output streams of the automated mass lumping program. The program was developed to support the FEM analysis of helicopter structures by automatically distributing mass items to model grid point locations. Although the program can accommodate structural mass input, the primary intent in the development of the program was to distribute nonstructural mass items (e.g. fasteners, wire bundles, etc.) to model grid point locations. The "CONM2" cards are generated by the program, eliminating human input error, and input to the NASTRAN data deck. The structural mass (e.g. skins and stringers) is calculated via material density cards internally within NASTRAN to form the total mass matrix.

The mass item properties and their locations are provided by the mass properties group via magnetic tape. These items are distributed to NASTRAN model grid points where local inertia properties are maintained by appropriate transformations.

As shown, input data consists of formatted grid and weight data. The structures and dynamic groups share the common NASTRAN model grid points. After grid points used exclusively as reference points have been removed, the grid data is ready for use in the lumping program.

Grid points and weight data are read into the lumping program by tape or local file. Output is generated as NASTRAN bulk data "CONM2" card images. The "CONM2" bulk data cards which define concentrated weight and inertia at grid points are added to the model bulk data. A complete listing of input weight data and lumped weight data is provided by the program, with grid points, locations, inertia properties, and "CONM2" bulk data cards specified.

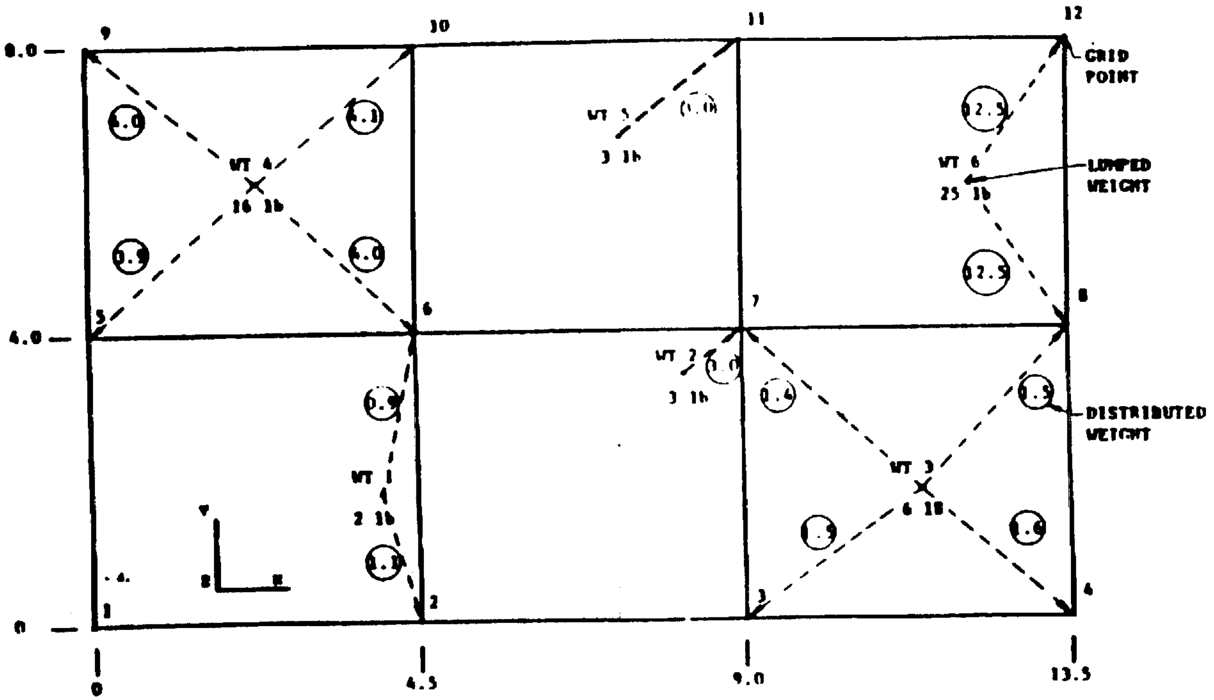
MASS MODELING
MASS LUMPING PROGRAM



MASS MODELING
MASS LUMPING PROGRAM EXAMPLE

The diagram illustrates a typical problem for the mass lumping program. The mass input data is shown as six weight items (provided by the mass properties group). The grid data are the twelve grid points modeled in the frame (provided by the structures group). The results that follow show mass proportionally distributed, based on distance ratios, to all grid points within a proscribed tolerance. (Mass shown in circle indicates amount of mass distributed to each point.)

MASS MODELING
MASS LUMPING EXAMPLE PROBLEM



MASS MODELING

MASS LUMPING PROGRAM - INDIVIDUAL DISTRIBUTION OUTPUT

This table illustrates the distributions of each individual portion of mass at a grid point. Every grid point is shown with each individual mass item it receives, the location of that mass item prior to lumping, the amount of weight partitioned from that item and additionally, for checking capabilities, the "P, C, & L #" for that item. The "P, C, & L #" is a reference number assigned each piece of mass by the mass properties group. Through this reference number the individual contributions of weight at each grid point may be identified as a wire bundle, fuel, etc.

MASS MODELING
MASS LUMPING PROGRAM - INDIVIDUAL DISTRIBUTION OUTPUT

```
                    LISTING OF WEIGHT DISTRIBUTION TO GRIDS

              WEIGHT   COORDINATES
        ------------------------------------
GRID      X          Y          Z          WT PCC          WT          P,C, & L #

  2      4.000      1.800      0.000         1            1.094        1 321
  3     11.450      1.800      0.000         3            1.482        1A323
  4     11.450      1.800      0.000         3            1.651        1A323
  5      2.300      6.100      0.000         4            3.865        12 444
  6      4.000      1.800      0.000         1             .906        1 321
  6      2.300      6.100      0.000         4            3.958        12 444
  7      8.200      3.400      0.000         2            3.000        1 322
  7 .   11.450      1.800      0.000         3            1.368        1A323
  8     11.450      1.800      0.000         3            1.498        1A323
  8     12.150      6.000      0.000         6            12.50        12 298
  9      2.300      6.100      0.000         4            4.035        12 444
 10      2.300      6.100      0.000         4            4.141        12 444
 11      7.330      6.660      0.000         5            3.000        12B935
 12     12.150      6.000      0.000         6            12.50        12 298
```

MASS MODELING
MASS LUMPING PROGRAM - SUMMED MASS OUTPUT

The weight distributions obtained from the mass lumping program for the previous example is summarized in this table. The tabulation reflects the grid identification numbers, their locations, sum of the distributed weight items at those grid point(s), and summations of inertia and products of inertia. The overall ship's weight, calculated inertias and center of gravity for the lumping program's distribution are verified with those provided by the mass properties group.

MASS MODELING
MASS LUMPING PROGRAM - SUMMED MASS OUTPUT

```
LUMPED WT, CG AND INERTIA DATA      55.00       9.18        5.41        0.00  .66245E+03  .26087E+04  .21192E+04

GRID        X        Y        Z        WEIGHT       IXX         IYY        IZZ      IXY          IYZ          IZX        SEID

   1      0.000    0.000    0.000      0.000         0.          0.         0.  0.             0.           0.          0
   2      4.500    0.000    0.000      1.094        16.         11.         4. -1.4730E+01    0.           0.          0
   3      9.000    0.000    0.000      1.482        21.         21.        14. -7.2965E+00    0.           0.          0
   4     13.500    0.000    0.000      1.651        23.         20.        12. -8.1311E+00    0.           0.          0
   5      0.000    4.000    0.000      3.865        19.        167.        37. -2.4544E-01    0.           0.          0
   6      4.500    4.000    0.000      4.864        34.        178.        41. -1.2449E+01    0.           0.          0
   7      9.000    4.000    0.000      4.368        34.         21.        18. -4.1507E+00    0.           0.          0
   8     13.500    4.000    0.000     13.998        80.        217.        86.  5.8717E+01    0.           0.          0
   9      0.000    8.000    0.000      4.035        16.        174.        36. -2.5624E-01    0.           0.          0
  10      4.500    8.000    0.000      4.141        17.        177.        35. -2.6297E-01    0.           0.          0
  11      9.000    8.000    0.000      3.000        11.         12.        14.  2.3799E+00    0.           0.          0
  12     13.500    8.000    0.000     12.500        56.        199.        73.  6.6094E+01    0.           0.          0
```

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4.3 VIBRATION MODELING

VIBRATION MODELING
GENERAL GUIDELINES

The finite element dynamic model will consist of two parts: a static model which defines the structural stiffness and a mass model. The static model contains approximately 1600 grid points, 4000 structural elements, and 10,000 degrees of freedom (dof).

The static model is provided by the structures group. It is primarily used for internal loads and internal stress calculations due to applied static loads. The model is constructed from a variety of structural elements, such as bars, shear panels, plates and rigid elements. The bulk data for the model is made available to the dynamics group through a common computer data-base. Prior to its use, a few grid points are added to accommodate large mass items, such as engines and fuel tanks. In addition, for dynamic analysis, the skins are considered fully effective in tension. This is accomplished with a simple change on the PSHEAR card. With the advent of fast eigenvalue extraction routines, it is no longer necessary to reduce the model in size through the commonly applied static condensation reduction technique.

VIBRATION MODELING
GENERAL GUIDELINES

- DYNAMIC MODEL MADE UP OF TWO PARTS:
  - STATIC (STRUCTURAL) MODEL
  - MASS MODEL

- CHANGES TO STATIC MODEL FOR DYNAMICS:
  - GRID POINTS FOR LARGE MASS ITEMS ADDED
  - SHEAR PANELS MADE FULLY EFFECTIVE IN TENSION

4.4 MODEL CHECKOUT

MODEL CHECKOUT
BASIC NASTRAN FEM CHECKOUT TOOLS

With an ever increasing transfer of system and subsystem data between organizations, companies, and departments, as well as the solving of larger more complex structural models, the dynamicst is becoming more and more divorced from the structural model, and to a certain extent from the mass model. Therefore, it has become necessary to develop tools which can quickly and efficiently check a finite element model. These checks must be thorough enough to not only flag a problem but, more importantly, point to the area in the structure where the problem exists. For these reasons, the Multi-Level Strain Energy and Cholesky decomposition DMAP checks were developed. Details of these checks, along with other diagnostic checks used by MDHC, such as connectivity, 1g static , and enforced displacement, are presented in Reference 1. A check used for aid in modal identification is the kinetic energy distribution DMAP discussed in Reference 2.

BASIC NASTRAN FEM CHECKOUT TOOLS

- MULTI-LEVEL STRAIN ENERGY CHECK
- CHOLESKY DECOMPOSITION CHECK
- CONNECTION CHECK
- 1g STATIC CHECK
- ENFORCED DISPLACEMENT CHECK
- KINETIC ENERGY DISTRIBUTION

5.0 RESULTS

RESULTS

The first evaluation of the modelling effort (stiffness model and mass model) is determined by the inspection of the frequencies and mode shapes. The table below shows some of the results of the initial modal analysis. The table indicates some of the primary modes and the comparison with results from the NASTRAN Model of the YAH-64 and/or existing test data. Realizing that some major differences between the configurations in each column exist, it is seen that reasonable correlation was obtained without any tuning of the model. The mode shapes corresponding to these frequencies are shown in the subsequent figures. It should be noted that "soft spots" which would appear as a single point with a relatively large displacement do not occur. This adds further confidence to the conditioning of the mass matrix, stiffness matrix, and the reliability of the aforementioned checks. Finally, the current finite element model of the AH-64A with appropriate statistics is shown in the figure following the mode shape figures.

RESULTS

Primary Modes	Current FEM	AV06 Test Data	Early FEM (YAH-64)
Tailboom Torsion	3.70	4.59	3.96
First Vertical Bending	4.41	5.76	5.31
First Lateral Bending	8.93	9.37	8.83
Symmetric Wing Bending	6.70	--	6.68
Anti-Symmetric Wing	7.46	--	7.83

RESULTS (Continued)

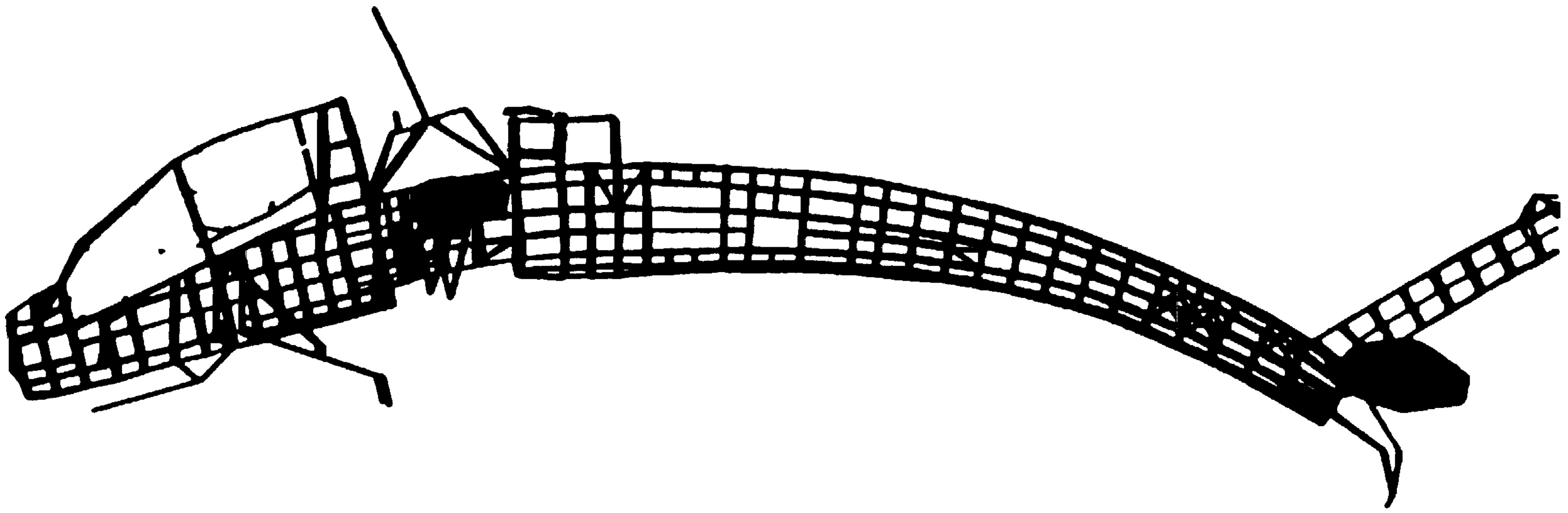
The following five figures show deflected shapes of the first five primary modes.

RESULTS (Continued)

TAILBOOM TORSION

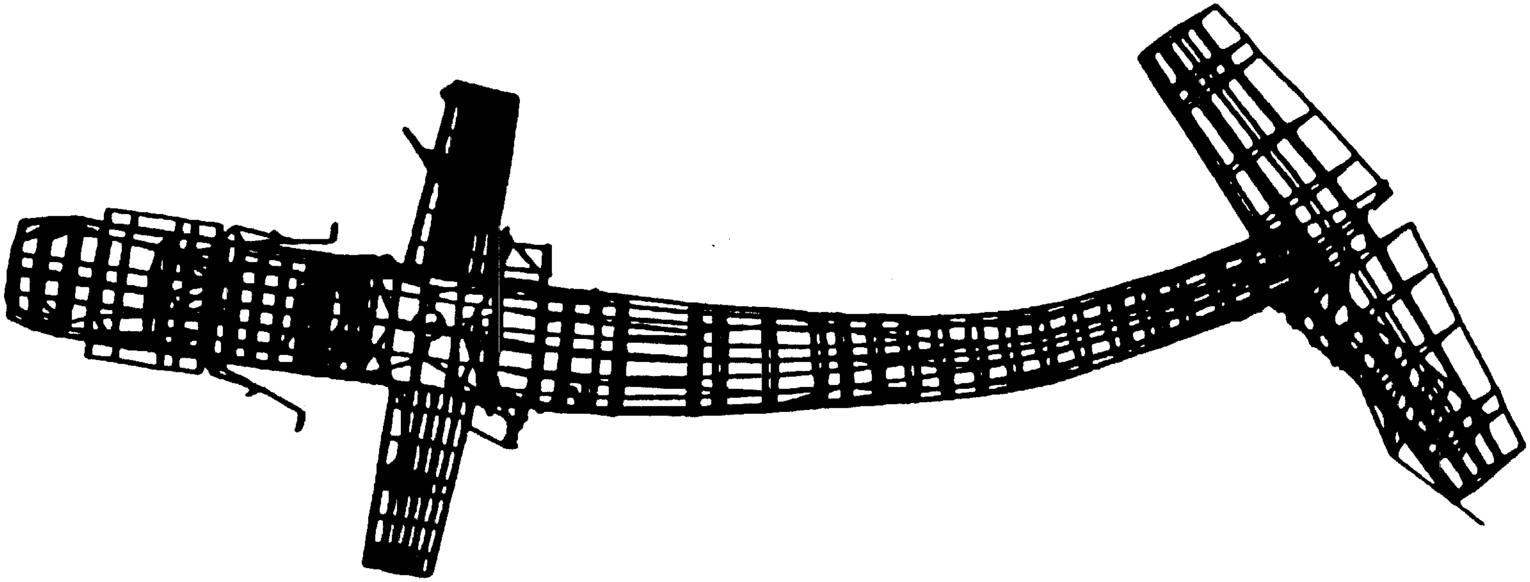
3.70 Hz

RESULTS (Continued)



FIRST VERTICAL BENDING
4.41 Hz

RESULTS (Continued)



FIRST LATERAL BENDING

8.93 Hz

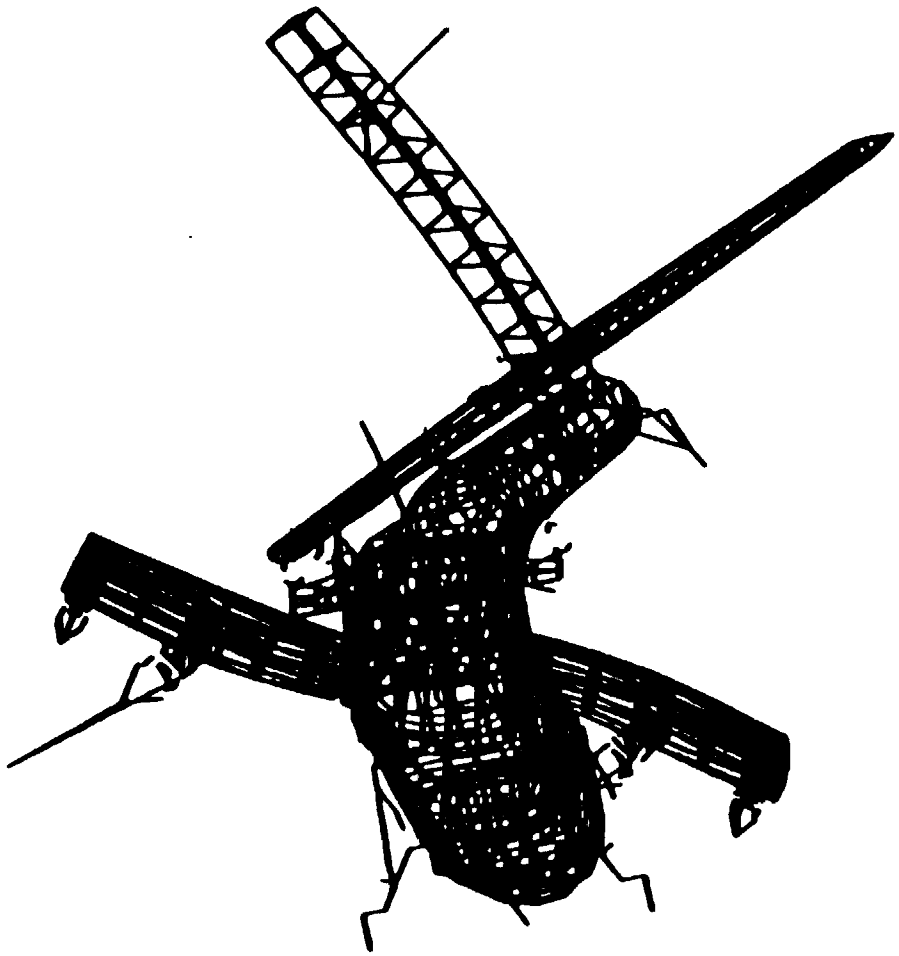
RESULTS (Continued)

SYMMETRIC WING BENDING

6.70 Hz

C-2

RESULTS (Continued)



ANTI-SYMMETRIC WING BENDING

7.46 Hz

NASTRAN FEM OF THE AH-64A

A NASTRAN finite element model of the AH-64A aircraft is shown in the figure below. The number and types of elements used in the model are also summarized

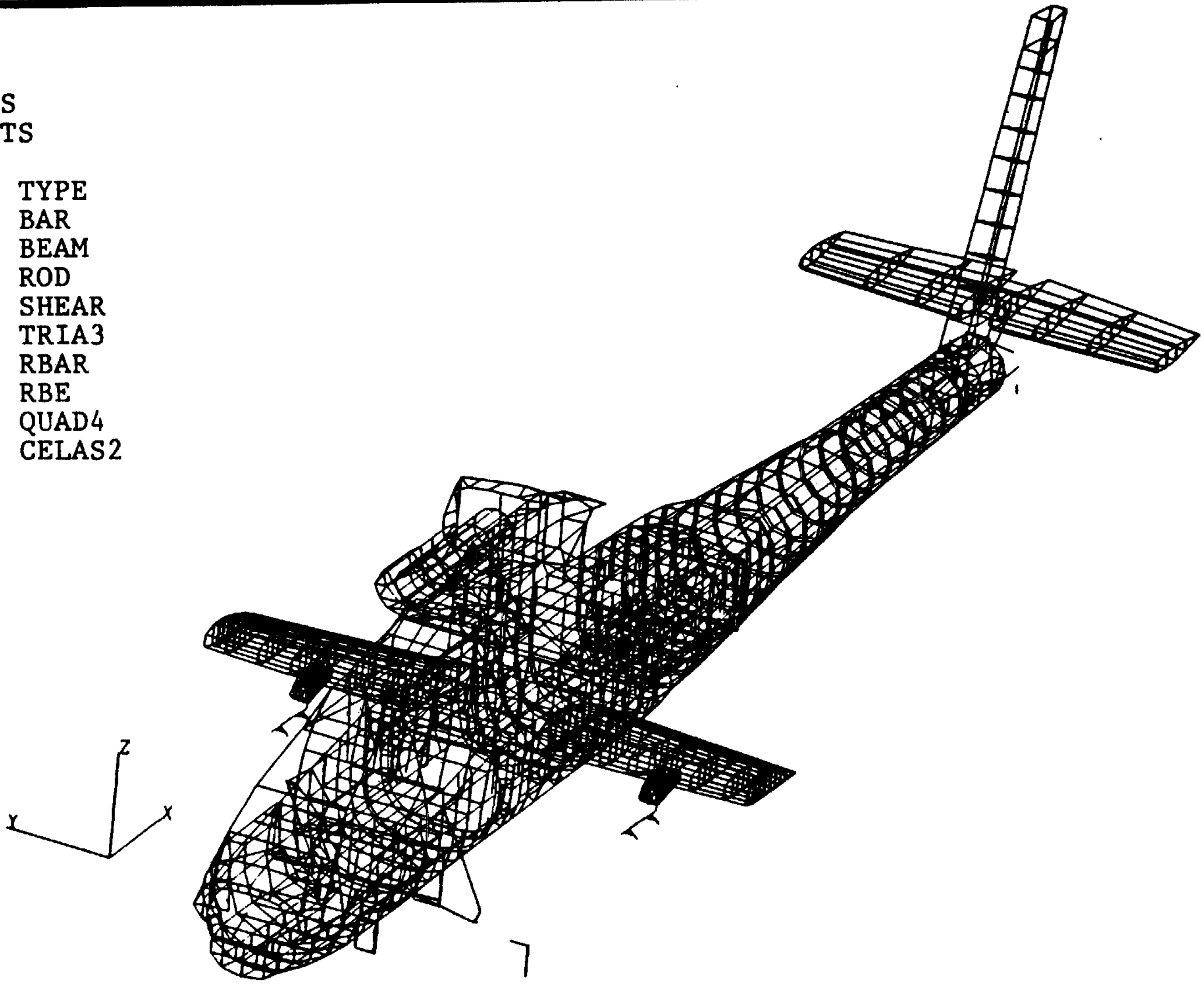
NASTRAN FEM OF THE AH-64A

MODEL STATISTICS

2581 GRID POINTS

6532 ELEMENTS

NO OF ELEMENTS	TYPE
1476	BAR
74	BEAM
2410	ROD
1759	SHEAR
430	TRIA3
47	RBAR
67	RBE
313	QUAD4
66	CELAS2



6.0 SCHEDULE AND MANHOURS

SCHEDULE AND MANHOURS

PLANNED VS. ACTUAL MAN-HOURS FOR MODELING

The table below shows the estimated and actual man-hours for the generation of the NASTRAN static model of the AH-64A airframe. The estimate was based on using an existing YAH-64 model for the aircraft. However, little of the existing model was used since a majority of the airframe components had been changed from the prototype YAH-64 to the production AH-64A. The additional unplanned hours resulted in an increase in the model checkout effort. This increase in modeling effort caused the actual man-hours to exceed the planned man-hours by 38%. The planned hours were 3100 and the actual hours were 4279. The actual hours provide a good basis for estimating other modeling efforts of similar size.

SCHEDULE AND MANHOURS
PLANNED VS ACTUAL MAN-HOURS FOR MODELING

ACTIVITY	NUMBER OF GRIDS	NUMBER OF ELEMENTS	MAN-HOURS PLAN	MAN-HOURS ACTUAL
1. CONNECTIVITY GENERATION				
PLAN			80	20
GENERATE FWD FUSELAGE	350	850	230	350
GENERATE CTR AND AFT FUSELAGE	450	1200	200	300
GENERATE TAIL BOOM	300	1000	75	114
GENERATE WING	250	800	145	20
GENERATE VERT STAB & STABILATOR	150	675	100	10
2. PROPERTY CALCULATION				
FUSELAGE AND TAILBOOM		3050	1390	2118
WING, VERT STAB		1475	680	1036
3. CHECK OUT			200	309
TOTAL			3100	4279

SCHEDULE AND MANHOURS

PLANNED VS. ACTUAL SCHEDULE FOR MODELING

The figure below shows the estimated and actual schedule for the generation of the NASTRAN model of the AH-64A airframe. The estimated schedule was based on using an existing YAH-64 model. Due to the changes made in the structure between prototype and production configurations, little of the existing fuselage model was used. This unplanned modeling resulted in a lengthening of the schedule. The property calculations were done concurrently with the connectivity generation rather than separately.

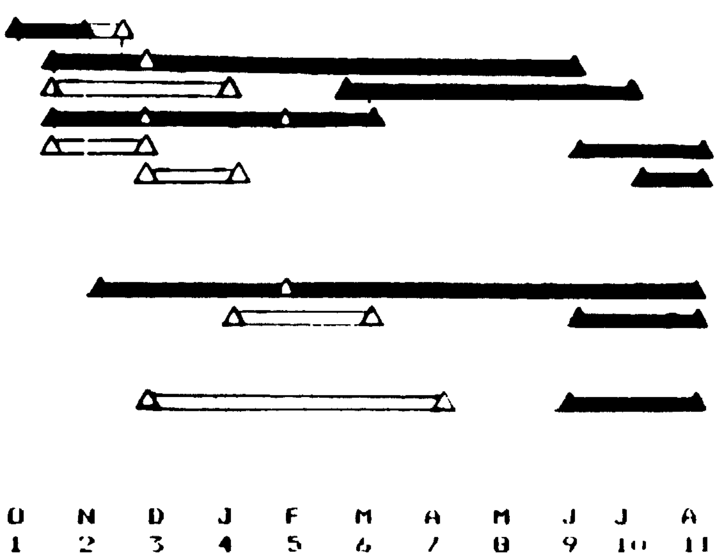
SCHEDULE AND MANHOURS PLANNED VS. ACTUAL SCHEDULE FOR MODELING

ACTIVITY

1. CONNECTIVITY GENERATION
   - PLAN
   - GENERATE FWD FUSELAGE
   - GENERATE CTR AND AFT FUSELAGE
   - GENERATE TAIL BOOM
   - GENERATE WING
   - GENERATE VERT STAB & STABILATOR

2. PROPERTY CALCULATION
   - FUSELAGE AND TAILBOOM
   - WING, VERT STAB

3. CHECK OUT



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7.0 CONCLUSIONS

CONCLUSIONS

A NASTRAN finite element model was developed for both static loads and dynamic vibration analysis of the AH-64A helicopter. This effort required close cooperation between the static, dynamic and mass properties engineers in order to produce an FEM that would meet the needs of both types of analysis. A plan was defined for formulating the model prior to its development. Guidelines were established for static, mass and vibration modeling as well as model checkout procedures.

CONCLUSIONS

- DEFINED A PLAN FOR FORMULATING A NASTRAN MODEL OF THE AH-64A
  - WORK REQUIRED COOPERATION BETWEEN STATIC, DYNAMIC AND MASS PROPERTIES ENGINEERS
- BUILT FEM ACCORDING TO PLAN
- DESCRIBED FINAL MODEL
  - STATICS MODEL
  - MASS MODEL
  - VIBRATION MODEL
- PERFORMED MODEL CHECKS

8.0 REFERENCES

REFERENCES

1. Hashemi-Kia M., Kilroy K. and Parker G., "Development and Applications of A Multi-Level Strain Energy Method For Detecting Finite Element Modeling Errors", NASA Contractor Report 187447, October 1990.

2. Parker G.R. and Brown J.J., "Kinetic Energy DMAP for Mode Identification," MSC/NASTRAN User's Conference Proceedings, March 18-19, 1982, Pasadena, CA.

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16. Abstract

A discussion of modeling plan objectives, followed by a description of the AH-64A aircraft including all general features, major components and primary and secondary structure definitions are presented. Following the aircraft description, a discussion of the modeling guidlines and model checkout procedure are provided. The NASTRAN finite element analysis is set up to be suitable to predict both static internal loads and vibrations. Finally, the results, schedule, and planned versus actual manhours for this work are presented.

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