First Level Release of 2GCHAS for Comprehensive Helicopter Analysis

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Abstract

The Second Generation Comprehensive Helicopter Analysis System (2GCHAS) is being developed by the Aeroflightdynamics Directorate of the U.S. Army Aviation Systems Command (AVSCOM) to provide a significant advance in rotorcraft analysis capability. The paper will describe recent progress that led to the completion of the First Level Release in December 1990. The paper will describe the project management approach, 2GCHAS engineering capabilities and features, documentation, and the user interface. System integration test results will be described.

Introduction

The Second Generation Comprehensive Helicopter Analysis System (2GCHAS) is a large, multidisciplinary, computer software system designed to analyze the performance, stability and control, aeroelastic stability, loads and vibration, aerodynamics, and acoustics characteristics of rotorcraft. Comprehensive rotorcraft analysis capability is an important, integral part of the broad-scale research and development (R&D) effort aimed at developing and improving rotary wing aircraft. Since existing rotorcraft analysis capabilities cannot adequately satisfy many application requirements, 2GCHAS is being developed by the Aeroflightdynamics Directorate of the U.S. Army Aviation Systems Command (AVSCOM) to provide a significant increase in rotorcraft analysis capability. The key objectives of the 2GCHAS Project are to develop a comprehensive, interdisciplinary rotorcraft analysis system to support rotorcraft R&D, design development, test, and evaluation activities, and to significantly improve modeling and analysis flexibility, prediction accuracy, user-friendly input and output, transportability, maintainability, and expandability. A significant recent milestone has been the completion of the First Level Release and a public user workshop in December 1990. This paper is intended to describe 2GCHAS and the current status of Project. Reference 1 provided a technical description of 2GCHAS, and described the program objectives, the project management approach, the methodology used in the development of the system, and the system integration and engineering validation phases of the 2GCHAS Project. Several other papers have also addressed 2GCHAS Project development (Refs. 2-7). The present paper will describe the project management approach, 2GCHAS engineering capabilities, documentation, user interface, and representative test results. This paper is a revised version of Ref. 2.

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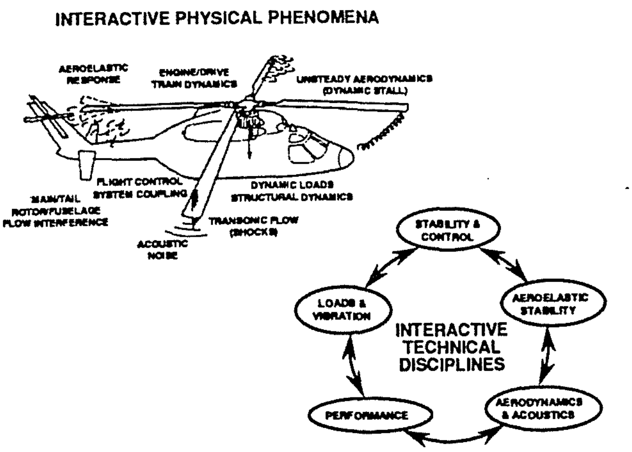
Role of Comprehensive Analysis

The need for comprehensive rotorcraft analysis arises from the fundamental interdisciplinary nature of rotary wing aircraft: both the physical system and the fluid envirnoment are separately and mutually interactive, Fig. 1. The rotor itself provides lift, propulsion, and control; functions performed by separate physical components for conventional aircraft. As a result, successful analysis requires integrated treatment of aerodynamics, dynamics, propulsion, and control systems. In similar fashion, the major technical disciplines in the rotorcraft field must interact to provide consistent results. These disciplines include performance, stability and control, aerodynamics, acoustics, loads and vibrations, and aeroelastic stability.

Analytical prediction methods and codes of all types are central to a broad range of R&D activities that build and apply the technology base that



- NATURE OF ROTORCRAFT PHYSICAL SYSTEM AND FLUID ENVIRONMENT IS INHERENTLY INTERACTIVE (ROTOR PROVIDES LIFT, PROPULSION, AND CONTROL)
- SUCCESSFUL ANALYSIS REQUIRES SIMULTANEOUS TREATMENT OF MULTIPLE DISCIPLINES

Fig. 1. - Rotorcraft technology is uniquely interdisciplinary.

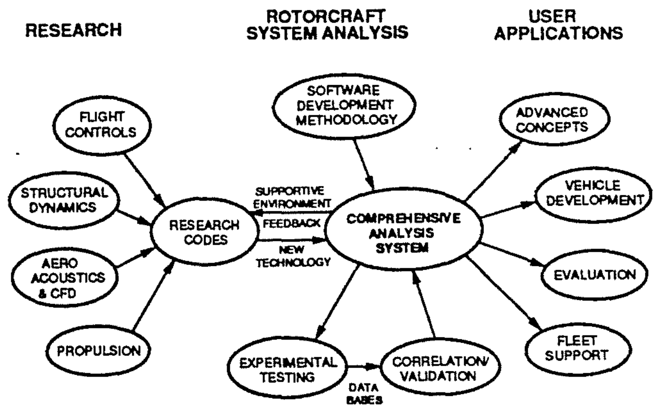


Fig. 2. - Role of comprehensive analysis is essential for development and application of rotorcraft technology.

serves to meet Army needs for rotorcraft research, vehicle design, flight test, and operational support. Prediction codes form the basis for design methodology, assist in the invention of new concepts, and, along with experimental research, help generate new fundamental knowledge about rotorcraft phenomena. Many times, these functions may be satisfied with specialized codes of limited scope. Other applications require the capability of a fully integrated analysis. The key role that a comprehensive rotorcraft analysis plays within this spectrum is illustrated in Fig. 2. While discipline-oriented research yields codes of limited scope, the comprehensive analysis integrates the analysis technology that is essential to meet broader user needs for advancing rotorcraft technology. A key benefit of the comprehensive analysis is that it also provides an interdisciplinary computational environment to support devlopment, testing, and evaluation of research codes.

In summary, then, comprehensive analysis is necessary for rotorcraft technology advancement because 1) rotorcraft are uniquely interdisciplinary, 2) prediction codes are a key element in rotorcraft R&D, and 3) comprehensive analysis is the key ingredient that enables the results of rotorcraft research to be most effectively integrated and applied to meet the user's needs.

Background

The history of the 2GCHAS development effort from 1977 until late 1989 was described in Ref. 1. Figure 3 presents the 2GCHAS contracts from 1983, through the completion of the development contracts, and continuing out to early 1996, the expected completion date for the current maintenance and enhancement contracts.

2GCHAS was designed with two major complexes; the Executive Complex (EC) and the Technology Complex (TC). The Executive Complex enables efficient execution of the Technology Complex and provides a user-friendly environment within the host computer. The Executive also facilitates the System development and includes a set of integrated software tools that provide utility and auxiliary System functions. The Technology Complex provides the capability for all trim, maneuver, stability, and aerodynamic analyses of the finite element-based system. The integration and system testing of the EC and the TC software was carried out by the System Integrator.

The System Integration of the Technology and Executive Complexes was completed in December, 1989. The resulting System delivery, called First Level Release 1 (FLR1), was available to the 2GCHAS contracting community and the Government for an extensive test period. The next integrated release, FLR 1.9, was released to the public in December, 1990. The 2GCHAS software and documentation will be updated on an approximate six to nine month cycle. The next update is targeted for a December 1991 release, FLR 2.0.

The Government intends to maintain, enhance, and validate 2GCHAS through the combined efforts of its inhouse staff and two companion contracts – the System Maintenance (SM) contract and the System Enhancement (SE) contract. The SM Contractor will provide maintenance amd configuration management of the publicly released versions of 2GCHAS. This will include periodic upgrades to the software and documentation, regression testing of the upgrades, responding to user System Trouble Reports (STRs), and generally improving the Executive functions and performance of 2GCHAS. The SM Contractor will

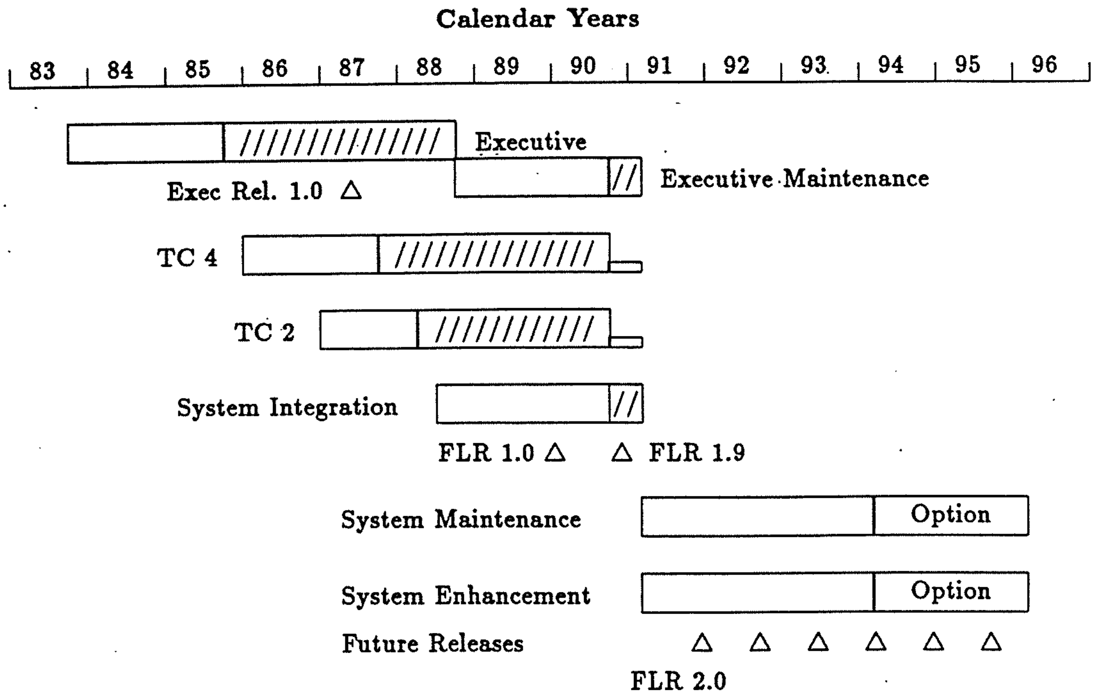


Fig. 3. - The 2GCHAS development schedule.

also be responsible for 2GCHAS ports to other operating systems such as UNIX. The System Enhancement (SE) Contractor is responsible for the overall design of the System to improve either generality or performance, adding functionality to enhance 2GCHAS, validating the System, and working with the SM Contractor to improve the data design and performance of the System. The SE contract will provide the software and documentation which will add new functionality to 2GCHAS.

The proposed near term enhancements to the System include the implementation of the following: 1) periodic shooting, 2) dynamic inflow, 3) impedance methods for rotor-body coupling, 4) direct matrix input, and 5) more efficient integration algorithms. Proposed longer-range enhancements include: 1) finite elements in time, 2) geometrically exact finite element formulation, 3) free wake analysis, and 4) implementation of CFD.

Originally a separate contract-supported engineering validation phase was planned to compare the 2GCHAS results with wind tunnel and flight test data. This activity was subsequently included as a separate task under the SE contract. The SE contractor as well as personnel from the 2GCHAS Project Office, AFDD, and other PO-approved organizations will carry out engineering validation by running 2GCHAS to obtain results necessary for comparison with specific data from existing validated software codes and experimental results. A description of the expected 2GCHAS Engineering Validation is discussed in Ref. 1.

2GCHAS was developed, and will continue to be enhanced, using modern software development methodology and a rigorous product assurance discipline. The 2GCHAS software development methodology is discussed in Ref. 1. This methodology requires that for each build each 2GCHAS developer (SE, SM, PO) will derive the mathematical basis, perform an analysis of the requirements, carry out preliminary and detailed designs, and then implement and acceptance test the software. The final phase of each build is the delivery of the documentation which includes updates to the final Software Design (Type C5) Specification, and the Theory, Programmer's, User's, and Applications Manuals.

System Description

This section describes the system from the standpoint of engineering analysis capabilities available to the rotorcraft specialist. To perform an analysis with 2GCHAS, the analyst must supply two sets of input data to the system: the mathematical model (structural and aerodynamic) and the analysis data. These data sets will be described. This section will also describe analysis options, the user interface, and documentation of the System.

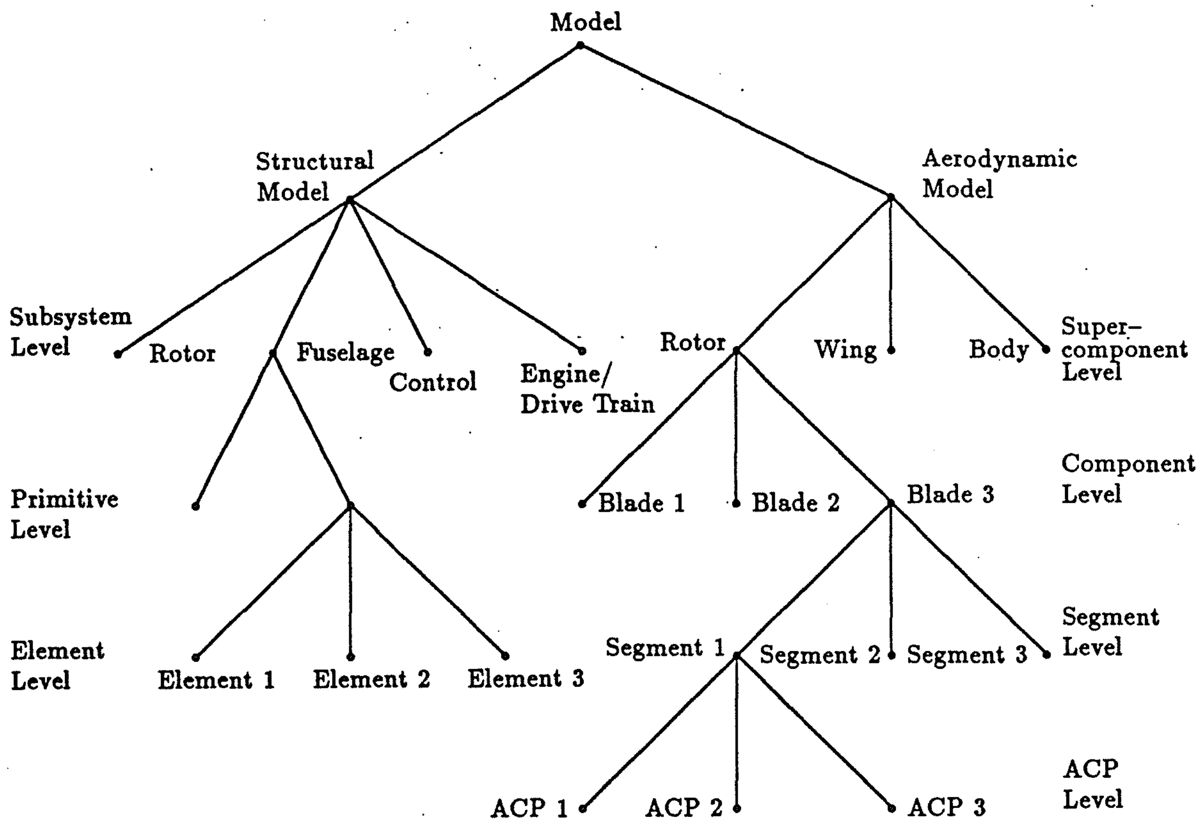


Fig. 4. - The model hierarchy for 2GCHAS.

Structural Model

The structural model of 2GCHAS, illustrated schematically in Fig. 4, is specified hierarchically and all components of the hierarchy must be defined by the user in order for the system to perform an analysis. The four levels of the hierarchy are *structural model*, *subsystem*, *primitive*, and *element*. The *structural model* is at the top level of the hierarchy, and embraces the full structural model. The next level is the *subsystem*. Four types of subsystems can be specified: fuselage subsystem, rotor subsystem, control subsystem, and engine/drive train subsystem. The user has the option of specifying which subsystems to include, but at least one subsystem must be present in the model. Each subsystem is composed of an arbitrary number of *primitives*. A primitive is a collection of leaf finite elements, and serves several purposes. It facilitates user definition of the structural model by providing a means for grouping related elements, such as the elements in a rotor blade, and it facilitates the mapping of aerodynamic forces to the structural model. The lowest level of the hierarchy is the *element*. Elements are the fundamental building blocks of the structural model, and the ability to couple elements to form structural models of arbitrary topology is a major strength of 2GCHAS. The element library (Table 1) accommodates various types of structural behavior that are useful in defining a complete structural model. The element library also includes special elements such as a transfer function element that may be used to model aircraft control systems. Also, a dynamic inflow element is provided that is based on the linearized dynamic inflow equations, and furnishes a finite state model of inflow dynamics that may be used in aeroelastic stability analyses. With proper combinations of elements and constraints, all conventional rotor and rotorcraft configurations, such as articulated, semi-articulated, tandem, coaxial, hingeless, bearingless, teetering, and tiltrotor models can be accommodated.

To describe a subsystem of the structural model the user must define the subsystem frame motion, the nodes that bear the subsystem degrees-of-freedom, the element connectivities, the properties of the materials in the elements, and the constraints. Frames are used to impart prescribed, rigid body motion to structural components, and are essential for modeling inertial effects that result from rotor spin. The prescribed frames used in 2GCHAS are the *Inertial* frame, the *Global* frame, which moves with the steady-state motion of the fuselage, and the *Rotor* frame, which is attached to the global frame and moves with the steady-state spin of the rotor. Presently, only constant speed rotors are permitted, although the presence of an engine/drive train subsystem permits small perturbations in rotor speed to be modeled. Constraints model the coupling of the elements and rotorcraft components, and special constraints are available to represent the unique attributes of rotorcraft. The most basic constraint is the element connectivity constraint, which

Table 1. - The 2GCHAS library of elements.

Element Name	Degrees of Freedom	Element Features	Primary Applications
Spring	2	Includes translation, rotation & nonlinearities	Hinge springs, ground, rods
Damper	2	Includes translation, rotation & nonlinearities	Elastomeric bearings, snubbers
Rigid body mass	6	Includes frame motion terms	Rigid fuselage, stores, blade tuning masses
Linear beam	12	Includes frame motion terms	Fuselage components, simple blades
Nonlinear beam	15†	Rotational terms, geometric nonlinearity & material anisotropy	Rotor blades
Direct matrix input	user defined		Allows M,C,K,F from other codes; e.g., NASTRAN
Transfer function	user defined	Required for control	Control system & engine/drive train models
Direct control	4	Single swashplate element	Control subsystem optional model
Mechanical applied loads	6	Time varying & external loads	Wind tunnel & weapons firing
Rigid blade*	7	Simplest blade, 6 blade & 1 hub dof	Preliminary design
Dynamic inflow**	3	Aero collective & cyclic inflow dofs	Unsteady aero for stability analyses

†The nonlinear blade element has 15 default degrees-of-freedom (dofs) by using interior nodes. The user may specify a higher order shape function and increase the number of interior dofs.

* Not tested.

** Not implemented.

is implicit in user defined element connectivity data. Degrees-of-freedom within a given primitive structure may be constrained using the *single point* constraint, which constrains particular degrees-of-freedom, and the *multipoint constraint*, which defines a linear relationship between degrees-of-freedom. Special linear constraints are available that constrain degrees-of-freedom of different primitives. Constraints between subsystems include the rotating-nonrotating constraints, a control subsystem-to-rotor constraint, and an engine/drive train-to-rotor constraint.

Aerodynamic Model

There are two parts to modeling aerodynamics with 2GCHAS. The first part involves specifying the aerodynamic model, which defines the entities that generate lift and drag and moment forces from the flow of air. Like the structural model, these entities are arranged hierarchically as shown in Fig. 4. The top level is the full aerodynamic model, which is subdivided into *supercomponents*. A supercomponent may be a wing, rotor, or aerobody, or mutually interfering supercomponent. A supercomponent is further divided into *components*, which may be lifting surfaces, or bodies. An aerobody supercomponent cannot contain lifting surface components; i.e., components that generate vortex flows. Examples of components are the left and right portions of an airplane wing, and the individual blades of a rotor. Components are subdivided into *aerosegments*, which are the basic elements that generate aerodynamic forces from the air flow. The System computes aerodynamic forces at discrete points on the aerosegments called *Aerodynamic Computation Points* (ACP's), which are at the lowest level of the model. Linkage between the structural and aerodynamic models is accomplished by the user specifying the correspondence between aerodynamic components and structural primitives, and the locations of ACP's relative to the structural elements.

The second part of aerodynamic modeling involves the specification of the induced flow model and airloads model. Presently, inflow may be modeled using momentum theory, dynamic inflow, or a vortex wake. Momentum theory inflow combines classical actuator disk theory assuming uniform inflow with blade element theory. The inflow obtained from this theory can be corrected for rotor-rotor interference. Dynamic inflow, which has not yet been implemented, is based on the Pitt-Peters model. When integrating transient response equations, the nonlinear dynamic inflow equations are processed by the 2GCHAS aerodynamics software, but when performing an aeroelastic stability analysis, the linearized form of the dynamic inflow equations are represented using the special finite element mentioned earlier.

The vortex wake is a presently a prescribed wake that uses so-called classical wake geometry. The wake model assumes that 2GCHAS is in a constant time step interval, and that tip speed and flight speed are constant. The wake is defined by a finite number of straight trailing filaments that are functions of the lifting line positions, the blade azimuth, the wake age, and the transport velocity based on momentum velocity. Wake roll-up is modeled by assuming that rolled-up inboard filaments defining the wake surface coalesce into the tip filament at the tip filament location. The roll-up process is governed by user-supplied parameters for a simple model based on the number of filaments and the wake ages at the time roll-up coalescence begins and ends.

More advanced wake models that will be implemented shortly are a generalized wake, and a maneuver wake. The generalized wake uses semi-empirical envelope functions to distort the axial coordinate of the tip vortex, while the inboard wake retains its classical geometry. In the maneuver wake model, the wake is dropped off in space behind the rotor blade path and the trailing vortices move with induced velocity based on momentum theory and prescribed wind gusts.

The wake model for nonrotating wing surfaces is assumed to be a subset of the rotor wake, and is modeled analogous to the maneuver wake, but the momentum induced velocity is assumed to be zero for the wing.

Airloads for lifting surfaces, such as wings and bodies, are computed using a two-step process. Basic airloads are based on a two-dimensional, steady model and are obtained from tables supplied by the user that relate airloads to angle-of-attack for specified Mach numbers. At present, basic airloads are corrected for radial flow and unsteady flow, and corrections for tip loss will be implemented in the near future. Unsteady effects are based on a model by Leishman. The model uses an indicial response function that consists of a noncirculatory part obtained from piston theory, and a circulatory part which is a semi-analytical, exponential decay function similar to the Wagner function. To account for dynamic stall, the indicial response function is extended into the stall regime by introduction of empirical parameters. Simple, quadratic functions for lift, moment, and drag versus angle-of-attack are provided for lifting bodies that do not generate vortex wakes.

Airloads for bodies may be specified by the user with look-up tables, but special parametric models will be available for special cases. For fuselage airloads, high angle equations and low angle equations are provided, and equations are available that provide a smooth transition between these regions. For simple wing and tail surfaces, a simple model is provided that represents lift, moment and drag coefficients as linear functions of angle-of-attack below stall, linearly interpolates from stall values for angles-of-attack beyond stall.

Analysis Options

Analysis options determine the analysis that the system performs and how the results are postprocessed and presented. The analysis and postprocessing options available to the user are summarized in Fig. 5.

The basic analyses available to the user comprise comprehensive rotorcraft analysis; i.e., trim, stability, nonlinear transient response, and linearized response. The trim options include free flight and wind tunnel trim. In free flight, the options include straight and level flight (hover, forward, rearward or sideward flight). The wind tunnel conditions assume the shaft angles are fixed. There are several wind tunnel options to determine the pilot controls δ_0, δ_c, and δ_s for given thrust, side, and drag forces, and cyclic flap angles. Both the free flight and wind tunnel trim conditions can be applied to either a rotor or a complete aircraft model.

The trim analyses are currently done in the time domain, and the determination of the trim state is a two step process. First, a given set of trim input controls is assumed, and a periodic solution is determined by direct integration using the Newmark-Beta method; i.e., the equations of motion are integrated until the transients die out and a periodic steady state is reached. If the periodic solution is not an equilibrium solution for the model, a sensitivity matrix is generated that relates changes in the applied forces to the trim controls, and new values of trim controls are obtained using the Newton-Raphson method. The iteration process stops when equilibrium is achieved to within a specified tolerance.

The nonlinear transient response analysis is generally used for vehicle maneuvers. Typically, the maneuver analysis calculates response to specified pilot control inputs for the full (generally nonlinear) physical model starting from a trim state. Transient response is computed using the Newmark-Beta method,

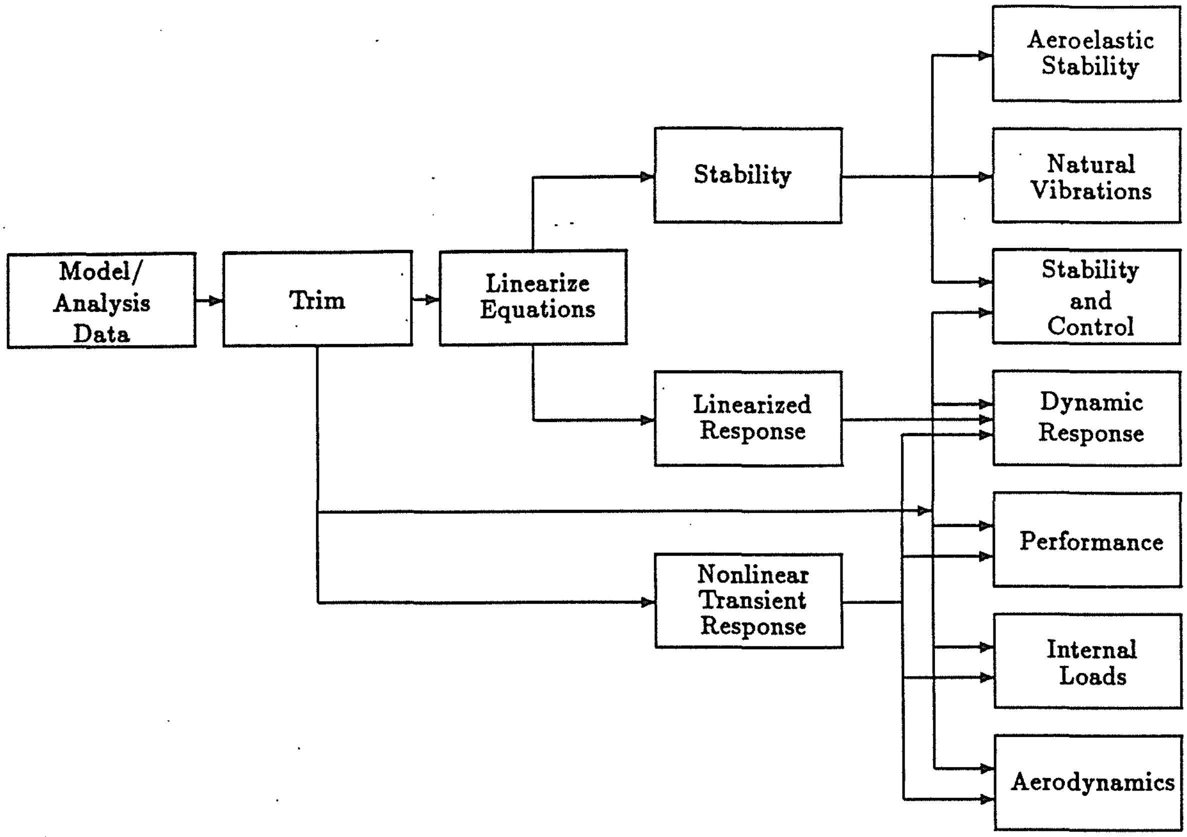


Fig. 5. - 2GCHAS analysis options.

which can be made unconditionally stable (i.e., stable for all integration stepsizes) for linear systems. In general, the method is only conditionally stable for nonlinear systems, but experience has shown that the method generally remains stable for time steps that are of practical interest.

Stability analysis is undertaken in two parts: first, the equations must be linearized about some trim state, and then the linearized equations are processed either with an eigenanalysis or a transient response analysis. The linearization is done numerically, and may be followed with model order reduction involving state space reduction or Guyan reduction. The equations may be left in periodic coefficient form, or the states in the rotating system may be transformed to the fixed system using the multiblade coordinate transformation. If the equations are in constant coefficient form, an eigenanalysis may be applied directly, but if the equations are periodic, the eigenanalysis must follow generation of the Floquet transition matrix. Linearized response analysis (transient or frequency response) may be carried out using the linearized system equations.

The postprocessor serves two functions. It directly prints or plots computed results, but it also postprocesses these results so that they may be presented in forms that meet the special needs of rotorcraft engineers. The basic output categories are listed in Fig. 5. Outputs for the stability functions (aeroelastic stability and stability and control) include tabular reports of eigenvalues and eigenvectors, vector plots, and root locus plots. Natural vibration outputs include tabular reports of dominant degrees-of-freedom, eigenvalues, eigenvectors, and plots of dominant degree-of-freedom mode shapes. Performance outputs include reports and plots of loads and load harmonics, and tabular reports of trimmed state parameters and aerodynamic performance parameters. The internal loads outputs consist of reports and plots of time histories of element nodal reactions and element force response. The aerodynamics outputs includes reports and plots time histories of aerodynamic forces and moments at ACP's, induced velocities at ACP's, bound circulations, aerosegment loads, and Mach numbers. Dynamic response outputs include maneuver response and linearized transient response for the case of unsteady response, and includes plots of time histories of modal and nodal degrees-of-freedom. Steady-state response outputs also include reports of harmonic response (Cartesian and polar forms) and histogram plots of harmonics.

User Interface

The user interface is fully interactive and menu driven. The user interacts with the system using *menus* and *screens*. The function of menus is to guide the user through selection of analyses and inputing the data. Menus are arranged hierarchically and each menu selection leads either to a menu one level further down in the hierarchy or to a screen. Options in menus may pertain to *global operations* such as printing data, saving and restoring portions of input data, or supplying actual input data. Screens are the interface where input data is actually typed in by the user. Each screen has on-line help which can be accessed by simply typing HELP *. The help screens provide information on what type of data is needed, its form, and theoretical background information that explains how the screen data is used in the 2GCHAS solution algorithm. Although the user interface is interactive, it is not necessary to supply all the input data in a single interactive session. A restart capability is available that allows the user to stop the input process at any point and then resume at a later time.

To illustrate the workings of the menu system, it would be helpful to describe a hypothetical problem set up. For example, consider the response of a three-bladed fully articulated rotor in forward flight with a vortex wake. The first step is to select menus and screens to identify a rotor subsystem and a fuselage subsystem and define their orientation relative to a global frame. The next step is to select one of these subsystems, e.g., the rotor subsystem, in order to define its components (primitive structures) such as the blades and the hub. Each primitive is then defined in detail, for instance, for a blade, the orientation, beam element type, node location, connectivity constraints and material properties are defined. The systematic ordering of the menus and screens is designed to automatically lead the user down through each level. The primitive structure definition occurs at the lowermost levels in the menu tree hierarchy. Thus far, only the structural model has been defined. Next, the aerodynamic model will be defined. As a first step, an aerodynamic supercomponent is identified and its components defined. For example, the orientation, aerodynamic node location, and aerodynamic section definition are defined for the aerodynamic component of each blade. The analytical attributes of the supercomponent such as the inflow and vortex wake models are then defined.

Next, the analysis data can be defined by first selecting the type of analysis desired. In this hypothetical problem, a periodic solution analysis will be selected. Thus a set of related input screens are accessed to define input necessary for the analysis, e.g., Newmark-Beta integration constants and convergence tolerance parameters. Finally, a user may specify the kind of 2GCHAS output desired, e.g., plots and reports of the steady state response at specified nodes on a blade, or of the segment airloads at specified aerodynamic computation points on a blade. The user is not restricted to inputing the data in any specified order as long as a complete input data set is finally achieved.

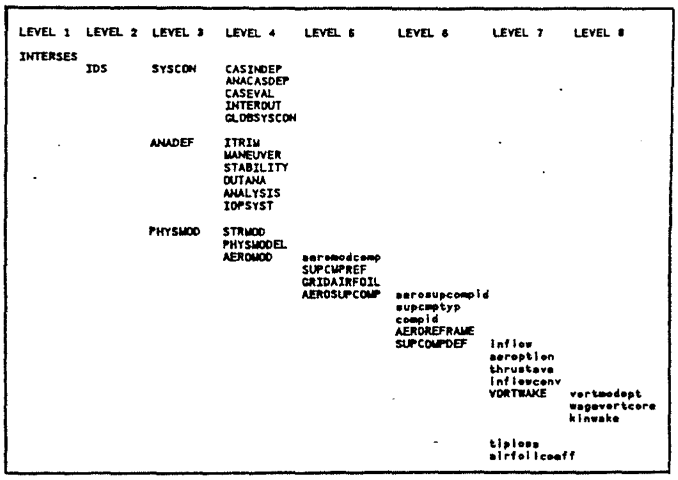


Fig. 6. - A portion of the menu hierarchy.

A more detailed illustration of the use of menus and screens to supply input data is shown in the following example, which describes the path leading to screen WAGEVORTCORE (Wake AGE and VORtex CORE data). In this example, an abbreviated top level menu is shown (Fig. 6), with menus and screens denoted by uppercase and lowercase characters, respectively. At the top of the hierarchy is menu INTERSES (INTERactive user SESsion) where the user selects the option IDS (Interactive Data Set), which is the top menu for defining input data. The options in this menu are SYSCON (SYStem CONtrol), ANADEF (ANAlysis DEFinition), and PHYSMOD (PHYsical MODel). SYSCON governs multiple-run analyses, such as trim at various advance ratios, while ANADEF and PHYSMOD correspond to the subdivision noted earlier between analysis data and physical model data. Since the present example deals with part of the aerodynamic model, the appropriate menu selection is PHYSMOD, and the appropriate selection in the following menu is AEROMOD (AEROdynamic MODel.) The other options in menu PHYSMOD pertain to the structural model (STRMOD), and operations pertaining to saving and restoring RDB data associated with the physical model. Menu AEROMOD presents options for listing aero supercomponents (AEROMODCOMP) and defining supercomponent coordinate systems (SUPCMPREF), evenly gridded airfoil tables (GRIDAIRFOIL), and the actual supercomponents (AEROSUPCOMP). Menu AEROSUPCOMP presents the user with options for defining

Menu VORTWAKE

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MENU:    "VORTWAKE", library "......."

              INPUT PARAMETES FOR VORTEX WAKE MODELING

Select available modeling options using entry 1.  Select entries 2 and 3
to input modeling parameters.  Select entry 4 if roll-up is to be modeled.

1)  Select vortex wake modeling options (Screen VORTMODOPT)

2)  Input wake age data and vortex core parameters (Screen WAGEVORTCORE)

3)  Input data for control of wake generation (Screen KINWAKE)

4)  *Input wake roll-up parameters

Enter:  selection number, HELP, BACK, TOP, MENU, COMMAND, or LOGOFF.
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USAGE NOTES

General -

Selection of the entries on this menu invokes screens on which the data required to define the vortex wake model of the current Supercomponent are input. Specificly:

Select vortex wake modeling options: Select the available modeling options including vortex curvature, core type, roll-up, and vortex shedding location.

Input wake age data and vortex core parameters: Input the number of wake periods to retain, and the on-blade and off-blade vortex core radii.

Input data for control of wake generation: Input the increment less than which the wake will not be updated.

Input wake roll-up parameters: If wake roll-up is selected under entry 1, input the parameters defining the roll-up model.

For vortex wake for the current Supercomponent, entries 1-3 are always required. Entry 4 is required only if roll-up is to be modeled.

1 Select vortex wake modeling options:

Select to use straight or curved vortex segments; to use zero velocity or Rankine core models for on- and off-blade vortices; to model root and tip roll-up; to have the vorticies shed from the lifting line, trailing edge, or 3/4 chord; and to save geometric influence coefficients (Screen VORTMODOPT).

If the current Supercomponent utilizes a vortex wake model, this information must always be provided.

2 Input wake age data and vortex core parameters:

Input the number of wake periods to retain, and the on- and off-blade vortex core radii as a function of chord at .75R (Screen WAGEVORTCORE).

For vortex wake, these data are always required.

3 Input data for control of wake generation:

Input the increment less than which the wake will not be updated (Screen KINWAKE).

For rotors, the wake azimuthal increment is input. For wings, the input is the fraction of wing length.

Fig. 7. - Menu VORTWAKE.

Screen WAGEVORTCORE

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Key: WAGEVORTCORE

           INPUT WAKE AGE DATA AND VORTEX CORE PARAMETERS

Input the number of wake periods to retain in terms of the number of
rotor revolutions for rotors, or the number of wing lengths for wings;
the on-blade vortex core radius in terms of the fraction of chord at 3/4
span and the off-blade core radius in feet.

*

     No. Wake        On-Blade Vortex     Off-Blade Vortex
     Periods          Core Radius          Core Radius
    to Retain           Factor                (ft)
```

INPUT WAKE AGE DATA AND VORTEX CORE PARAMETERS

Input the number of wake periods to retain in terms of the number of rotor revolutions for rotors, or the number of wing lengths for wings; the on-blade vortex core radius in terms of the fraction of chord at 3/4 span and the off-blade core radius in feet.

Data Type: Dependent
RDB Record Name: <SCID>.Vort_Wake_Params
DDE Name: TL5694_Vort_Wake_Mod_Params

COLUMN	VARIABLE TYPE	INPUT FORMAT	VALID RANGE	DEFAULT UNITS
1	Integer	I2	1:99	-
2	Real	F10.0	0.0:1.0	-
3	Real	F10.0	>0.0:positive	ft

GENERAL INFORMATION:

This data is required if vortex wake is to be used for the current Supercomponent.

In column 1, input the number of wake periods to retain. For rotors, one period is one rotor revolution, and thus an input of 3 implies that 3 revolutions of rotor wake will be retained. For wings, a "period" is defined by a wing length, and therefore an input of 3 implies that wake trailed from the wing as it advances 3 wing lengths in the flow is retained.

In column 2, define the on-blade vortex core radius by the fraction of the geometric chord at 3/4 span. A suggested value is 0.5, or fifty percent of the chord at 3/4 span. The off-blade vortex core radius is given in feet in column 3. A suggested value is 4 percent of the blade radius or wing span.

INPUT DATA DESCRIPTION BY SCREEN COLUMN:

COLUMN	TITLE	DESCRIPTION
1	Number of wake periods to retain	For rotors, the number of rotor rev.s. For wings, the number of wing lengths.
2	On-Blade vortex core radius factor	On-blade vortex core radius in terms of the fraction of the chord at 3/4 span.

Fig. 8. - Screen WAGEVORTCORE.

the supercomponent type (SUPCMPTYP), and specifying analytical attributes of the supercomponent (SUPCOMPDEF). Selecting menu SUPCOMPDEF presents the user with options for supercomponents attributes such as inflow (inflow), tip loss (tiploss), and vortex wake (VORTWAKE). The selections under menu VORTWAKE (Fig. 7) are screen wagevortcore (Fig. 8) along with other screens for selecting vortex modeling options (vortmodopt) and controlling wake generation (kinwake). After entering the necessary data in wagevortcore, typing EXIT returns the user to menu SUPCOMPDEF, where the user may select other screens or return through the menu hierarchy to input more data.

Documentation

A significant deficiency of many first generation codes is their inadequate supporting documentation. In contrast, the extensive 2GCHAS documentation produced during development was a direct result of the 2GCHAS software development methodology: the timely publication of supporting design and user documentation throughout the software development cycle. The primary 2GCHAS documentation includes the 2GCHAS Theory Manual, 2GCHAS User's Manual, 2GCHAS Programmer's Manual, 2GCHAS Applications Manual, and 2GCHAS Installation Manual (Refs. 8–12).

The 2GCHAS Theory Manual (Ref. 8) describes the equations of the 2GCHAS mathematical model and the algorithms used to solve them. Also, the Theory Manual clearly defines the assumptions and limitations of the 2GCHAS analysis processes, and thereby allows users to understand the theoretical limitations and constraints on the System.

The 2GCHAS User's Manual (Ref. 9) describes the set up for finite element and aerodynamic models, the various operational modes including menu, screen, and command modes, the graphics and analysis output, user language commands and input menus and screens and associated HELP information.

The 2GCHAS Programmer's Manual (Ref. 10) describes 2GCHAS' external interfaces, i.e., those portions of the software which are of interest to the 'programmer user'. This manual contains discussions of operating concepts, data concepts, procs, data transfer, graphics concepts, user support features, batch operations, and the programmatic interface. This material focuses on interface descriptions and on the organization and operation of both the Executive and Technology Complexes.

The 2GCHAS Applications Manual (Ref. 11) is a repository of example rotorcraft engineering problems. This manual contains sample problems to illustrate various features of 2GCHAS. Each sample problem includes a description of the problem, a listing of its input files, and representative results.

The 2GCHAS Installation Manual (Ref. 12) describes how to install the 2GCHAS software. It describes what tailoring must be done to the host system in order for 2GCHAS to run. Currently installation instructions are only provided for a VAX with the VMS 5.0 operating system.

System Testing

To aid in system testing, a comprehensive set of test problems was selected to thoroughly test the system capabilities. The test problems are arranged in order of increasing complexity and size. Each problem has a stated objective, model description and a specified set of structural and aerodynamic data. Each problem is divided into several scenarios which are again designed in order of increasing complexity. There are currently a total of 123 scenarios. For each scenario, comparison data are generated for validation of the 2GCHAS results. Benchmark programs such as NASTRAN and CAMRAD/JA are used wherever appropriate. A sampling of test results is presented to show a few of the analysis capabilities of 2GCHAS, to illustrate the testing methods, and to provide some idea of the status of the testing process.

Rotor Blade Frequencies in Vacuo

Two rotor blade structural dynamics examples are described here. The first is a complex multi-element cantilever blade (Prob. 2-9) modeled with eight linear beam elements (Fig. 9). This example represents some of the characteristics of a bearingless rotor blade. It also includes series spring and damper elements at the blade root, a spring restrained pitch hinge near the outer end of the blade, and a 45° swept tip. The nonrotating frequencies for this blade are compared in Table 2 with results from a special-purpose finite element program.

The second configuration (Prob. 7-2) is a fully articulated rotor blade with flap and lead-lag hinges,

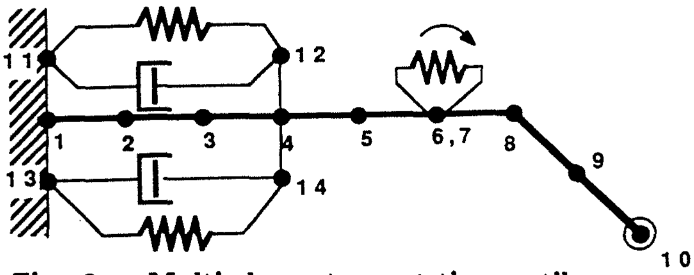

Fig. 9. - Multi-element swept-tip, cantilever blade model.

Table 2. - Nonrotating natural frequencies of a multi-element cantilevered blade.

Natural Frequencies		
No.	2GCHAS	Target
1	0.0000	0.0000
2	6.7526	6.7526
3	37.785	37.785
4	79.864	79.850
5	83.885	83.885
6	190.30	190.30
7	224.00	224.00
8	359.70	359.70
9	475.49	475.49
10	536.13	536.13
11	582.82	582.82
12	763.38	763.38
13	856.95	856.95
14	1098.1	1098.1
15	1406.6	1406.6

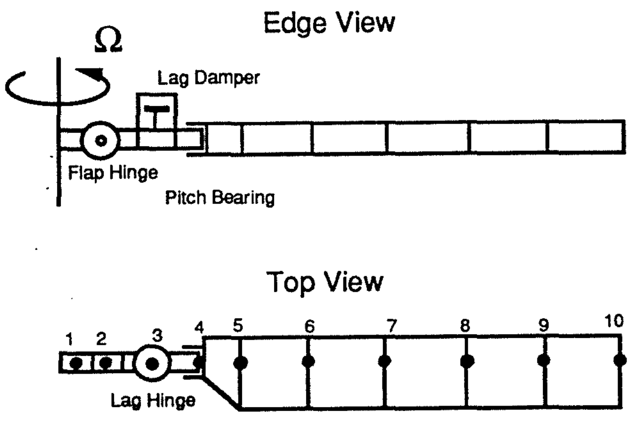

Fig. 10. - Articulated rotor blade finite element model.

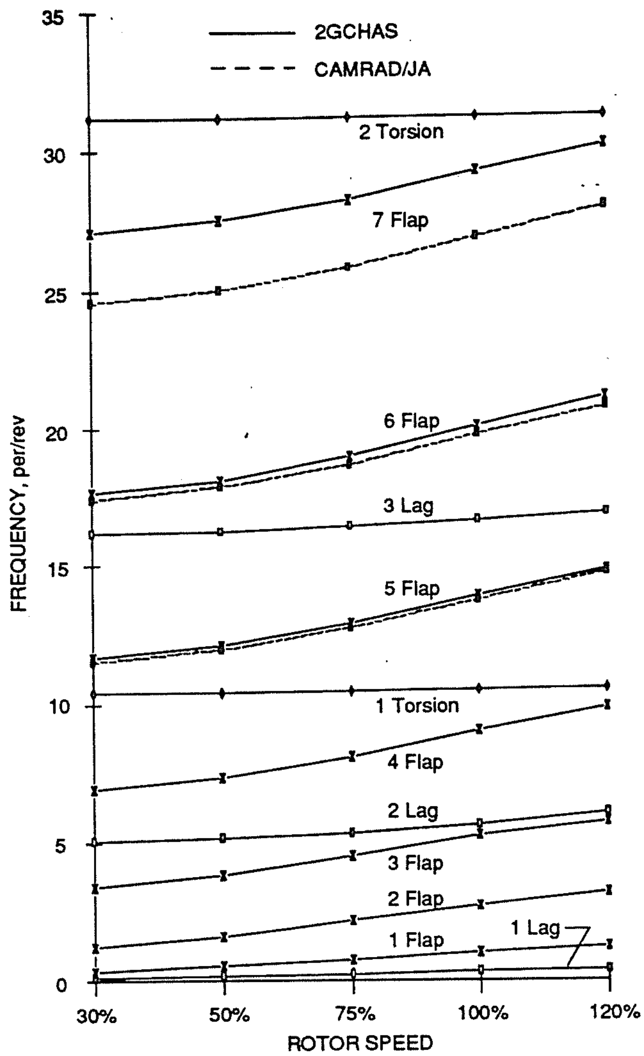

Fig. 11. - Articulated blade frequencies.

modeled with eight nonlinear beam elements having elastic flap, lead-lag, torsion, and axial motions (Fig. 10). Rotation at the feather hinge is constrained to zero by the control system element. The blade mass and stiffness distributions are uniform. The blade structural twist is $-10°$ and the collective pitch angle is $10°$. The blade modal frequency results without the lag damper are obtained from eigensolution of the linearized equations and are shown in Fig. 11 together with CAMRAD/JA calculations. The results show the expected behavior for flap, lead-lag, and elastic flap, lead-lag, and torsion modes and they are in close agreement except for the two highest flap bending modes. The difference may be due to accuracy limitations arising from the number of elements included in the 2GCHAS model.

Ground Resonance in Vacuo

A simple ground resonance problem (Prob. 9-2) demonstrates the eigensolution capability of

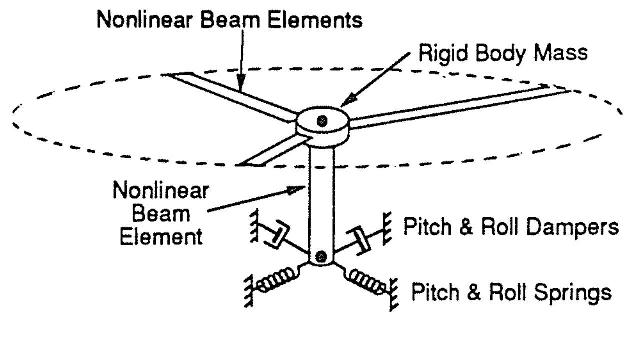

Fig. 12. - Ground resonance model.

2GCHAS for a coupled rotor-body dynamic system (Fig. 12). The rotor subsystem is a three-bladed semi-articulated rotor with lead-lag hinges attached to a hub (rigid body mass element). The blades are modeled with a single nonlinear beam element (having elastic, lead-lag, and axial degrees of freedom; flap and torsion motion are constrained out). The blades have no twist or collective pitch. The fuselage subsystem consists of a nonrotating pylon modeled by a nonlinear beam attached to ground with pitch/roll springs and dampers. After the elements are assembled in both the nonrotating and rotating system, the static equilibrium condition is computed based on a specified centrifugal force. The equations are numerically linearized, transformed to multiblade coordinates, and the eigenanalysis is performed. Typical results are shown in Fig. 13 for the modal frequencies and lead-lag mode damping over a range of rotor speeds. The 2GCHAS and CAMRAD/JA results are nearly identical, as would be expected from linear dynamic analysis of a non-complex configuration without aerodynamics.

Fixed Wing Aerodynamic Response

Basic fixed wing aerodynamic results illustrate the coupling of the finite element wing structure with a vortex wake. The physical model is a straight wing modeled with two beam elements and attached to ground with spring and damper restrained pitch and heave degrees of freedom (Fig. 14). The solution is obtained by time domain integration of the system equations with an initial wing pitch angle and a velocity step input. The equilibrium wing response is obtained at the end of the time history. A sample result (Prob. 6-2) for the wing spanwise bound circulation is shown in Fig. 15. The system equations are numerically linearized and are used to obtain frequency response due to a sinusoidal gust velocity component. The amplitude and phase for wing pitch frequency responses (Prob. 5-4) are shown in Fig. 16. In this case only quasi-steady aerodynamics is included.

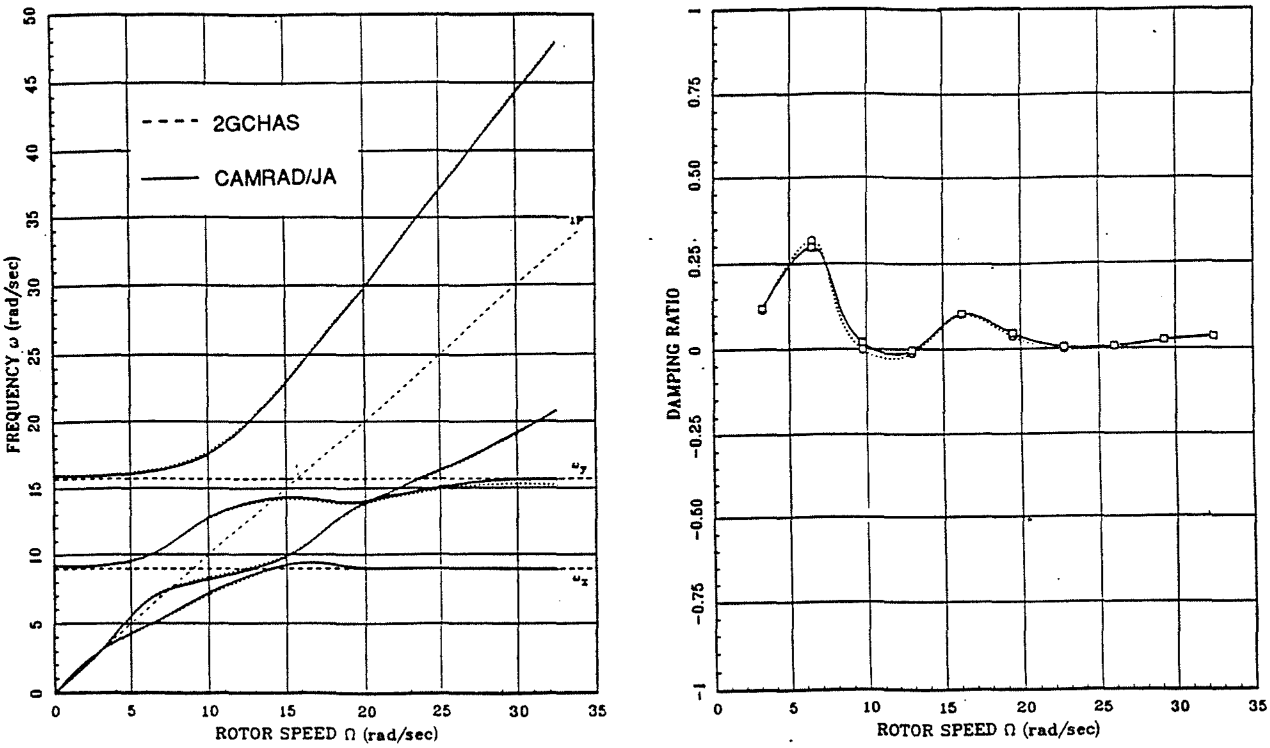

Fig. 13. - Ground resonance frequency and damping results.

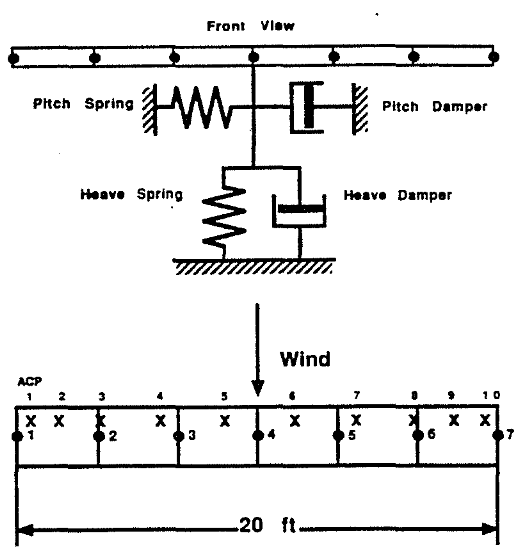

Fig. 14. - Fixed wing aeroelasticity model.

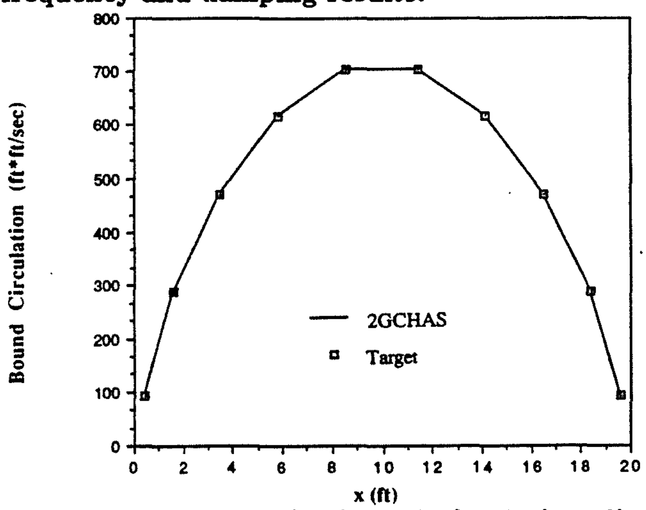

Fig. 15. - Spanwise bound circulation distribution of fixed wing calculated with vortex wake system.

Helicopter Free Flight Trim in Forward Flight

The problem of helicopter trim in forward flight is a standard but non-trivial problem in helicopter analysis. It is generally comprised of the numerical solution of a large system of equations having strong nonlinearities (structural, inertial, airfoil airloads, and rotor wake phenomena) with multiple nested analysis loops and solution constraints. The present test problem results treat a case (Prob. 14-1) that, while lacking the complexity of the full unsteady blade airloads and vortex wake modeling, nevertheless addresses a fairly challenging analysis problem. A fully coupled rotor-fuselage system (Fig. 17), composed of finite elements, and having nonlinear blade airloads, is trimmed in free flight about five axes at a forward flight velocity of 150 kts. The yaw axis is not trimmed since the tail rotor is not modeled. The rotor consists of three blades, each modeled with two nonlinear beam elements that retain only elastic flap and axial degrees of freedom. The blades include flap hinges only and include structural damping and −10° twist. A rotating rigid body mass element represent-

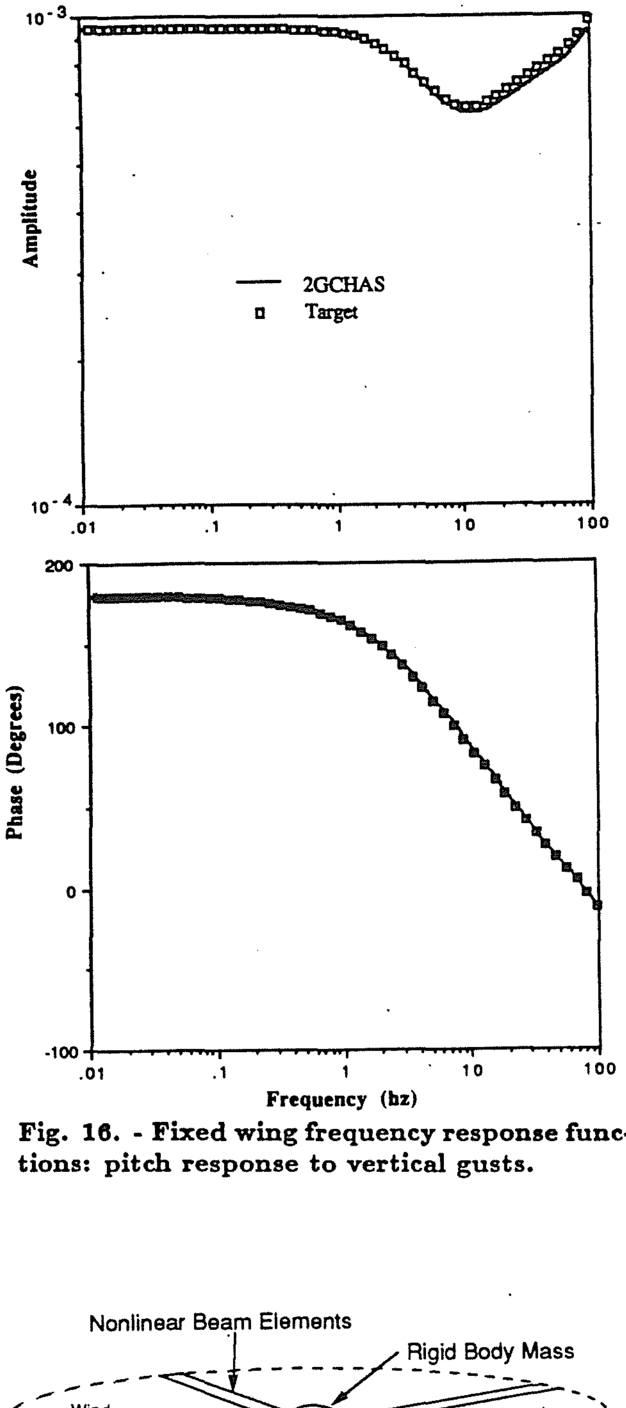

Fig. 16. - Fixed wing frequency response functions: pitch response to vertical gusts.

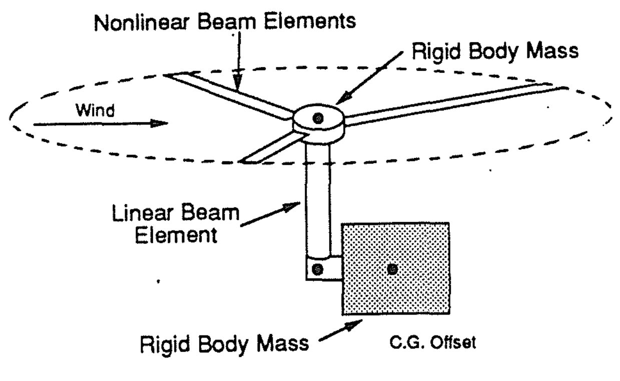

Fig. 17. - Helicopter model for free flight trim in forward flight.

ing the rotor hub contains the rotating/nonrotating interface. The nonrotating portion of the hub element is attached to a fixed shaft (linear beam element) that is in turn attached to a fuselage modeled by a rigid body mass element. The body mass center of gravity offset is zero for the results presented. The total system contains 54 degrees of freedom. The rotor aerodynamics includes nonlinear airfoil airloads (SC1095) with uniform inflow. The fuselage aerodynamic forces are not included for this problem.

The solution procedure and the results are clearly illustrated by the time history results in Fig. 18. Here, the three fuselage displacements (X, Y, Z) and the blade flapping angle are plotted as a function of time while several different steps in the trim procedure are carried out in sequence. The solution procedure begins with assembly of the system equations of motion, followed by direct time domain integration (with fixed controls) until the transient dynamic response converges to a periodic solution. Beginning from zero states, this step requires approximately eight rotor revolutions. Figure 18 shows that fuselage translation and rotor flapping undergo a relatively low frequency transient response to a steady state condition together with the superposed periodic motion. Following the initial periodic response, the trim algorithm independently perturbs each control variable in sequence to obtain the control response sensitivity matrix. Following each control perturbation, the time history computation proceeds until periodic response is achieved. After the sensitivity matrix has been obtained, revolutions 8 to 31 approximately, the solution proceeds to the actual trim procedure. Using a Newton-Raphson method, the controls are adjusted until the desired equilibrium free flight trim constraints are satisfied to the specified tolerance. This requires three separate control adjustments and takes approximately 21 rotor revolutions.

It is of interest here to note that the free flight trim algorithm in 2GCHAS makes use of artificial trim springs to restrain vehicle motion while the time history trim procedure is carried out. The trim spring stiffnesses are selected to facilitate the numerical stability of the trim solution process and to avoid coupling with the structural dynamics of the rotor- fuselage system. The X, Y, Z displacements are in fact the trim spring deformations that are driven to zero in order to satisfy the force-free free flight trim condition. The residual displacements in Fig. 18 represent the user-specified tolerance on trim accuracy. Note that the fuselage displacements are zero at time zero, depart from zero during the trim process, and are driven back to zero at the end of the trim process. The entire trim sequence requires approximately 52 rotor revolutions, approximately 3600 time steps. The rotor speed is 32.5 rad/sec.

Some details of the trimmed solution are shown in

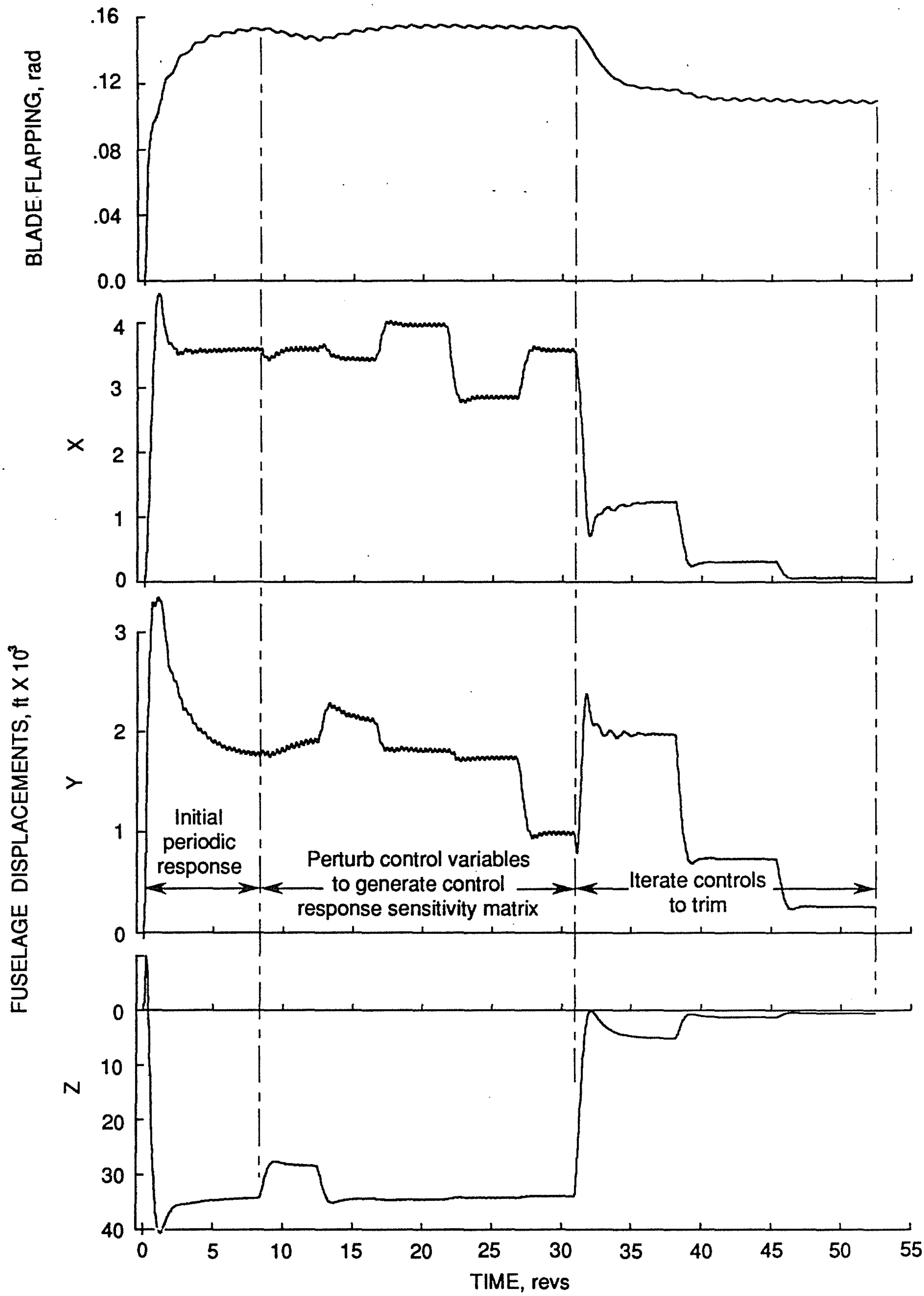

Fig. 18. - Time domain response during free flight trim solution procedure for coupled rotor-fuselage in forward flight at 150 kts.

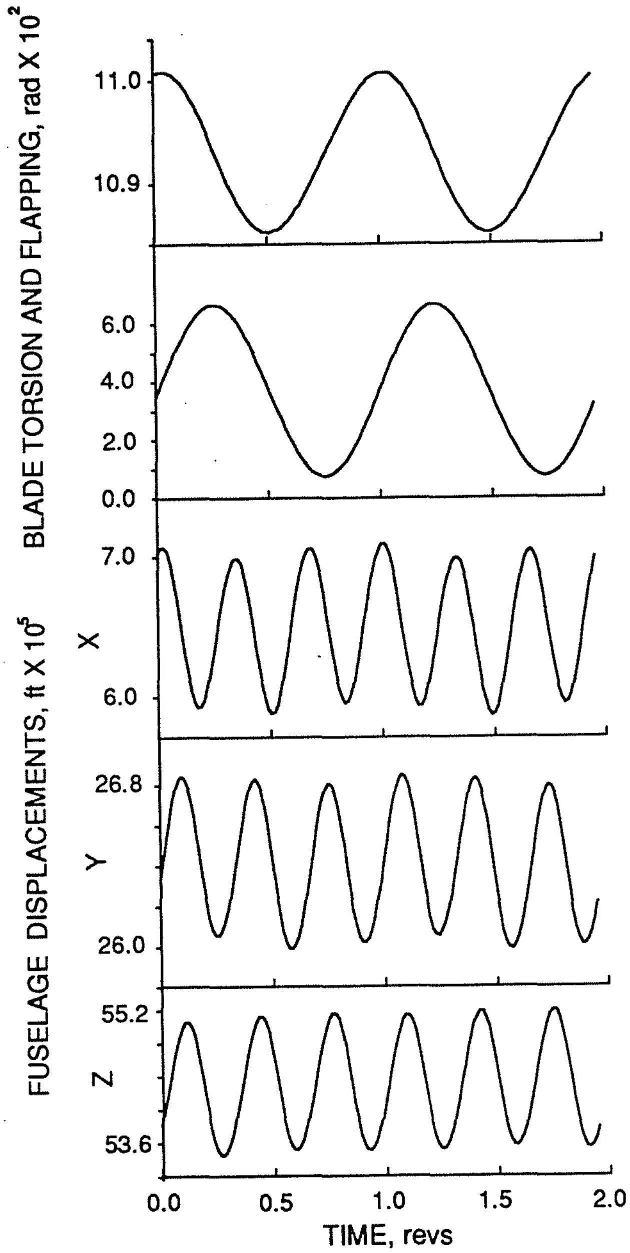

Fig. 19. - Trimmed dynamic response time histories of coupled rotor-fuselage model.

Fig. 19, which gives time histories of fuselage translation, blade flapping, and blade elastic torsion for two revolutions at the final trim condition. Note that blade flapping and torsion motion are of nearly pure 1/rev content, although blade flapping exhibits a small amount of 2/rev response. The steady blade flapping (coning) is about 7 degrees. The flapping and torsion response also reflect the relatively low thrust coefficient, uniform inflow, and nearly linear airfoil aerodynamic characteristics for this operating condition. The very low cyclic flap amplitude ($\sim 0.1°$) reflects the zero hub moment trim condition. The fuselage displacement represents the vibration response in the fixed system and the 3/rev content of the response is characteristic of a vehicle with a three-bladed rotor.

Concluding Remarks

The progress of the 2GCHAS Project over the last several years led in December 1990 to the first public release (FLR2) and a training session for Government/industry/academia users. The released System includes tested software together with Theory, User's, Programmers, and Applications Manuals.

2GCHAS has rotorcraft analysis capabilities that go beyond those available with current systems, including a finite element basis that will accommodate virtually any rotorcraft configuration and hub design. In areas where technical features are not fully developed, the System has the capacity to accept more advanced analysis technology as it becomes available. Thus, one of the principal objectives of the 2GCHAS Project has been realized – a strong basis for a broad-based comprehensive analysis has been established that should stimulate and encourage further development of rotorcraft analysis technology.

While the current version of 2GCHAS represents an important new stage in rotorcraft analysis development, it is clear that it does not fully satisfy all of the user community's needs. It does not provide all of the engineering analysis capabilities the user may expect and not all of its present capabilities are as yet fully tested. The runtime of the System on the VAX development computer is relatively slow. Moreover, since it is currently only available on the VAX, the practical problem size is limited.

The 2GCHAS Project has now entered a new phase with the completion of the technology development contracts and the initiation of the System Maintenance and System Enhancement contracts in March 1991. The immediate major thrust of the Project is to make significant improvements in the runtime efficiency and user interface capabilities of 2GCHAS. The current port to a UNIX workstation environment will provide opportunities to improve the user interface through the implemention of such features as XWINDOWS. In addition, future ports to large UNIX mainframes such as the CRAY or CONVEX will ease any problem size limitations.

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