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LANGLEY ROTORCRAFT STRUCTURAL DYNAMICS PROGRAM

Background, Status, Accomplishments, Plans

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LANGLEY ROTORCRAFT STRUCTURAL DYNAMICS PROGRAM
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EXECUTIVE SUMMARY

Excessive vibration is the most common technical problem to arise as a "show stopper" in the development of a new rotorcraft. Vibration predictions have not been relied on by the industry during design because of deficiencies in finite element dynamic analyses. A rotorcraft structural dynamics program aimed at meeting the industry's long-term needs in this key technical area was implemented at Langley in 1984. The subject program is a cooperative effort involving NASA, the Army, academia, and the helicopter industry in a series of generic research activities directed at establishing the critical elements of the technology base needed for development of a superior finite element dynamics design analysis capability in the U. S. helicopter industry.

Accomplishments which may be ascribed to the program to date are significant. For example, analysis methods can now provide a reasonable prediction of rotorcraft dynamic response up to about 15 Hz. These technical achievements have resulted in notable changes in industrial design practice. While progress has been made under the program, the analytical methods are still not sufficiently improved to permit routine use of finite element-based dynamic analyses with confidence during design. In particular, finite element predictive capability needs to be extended up through about the 25 to 30 Hz range to encompass the primary excitation frequencies of four-bladed rotors which constitute the majority of the current or planned helicopter fleet. This will require additional studies using both full-scale airframes and their components as well as small-scale generic models. There is also a need to develop analysis methods for damping which are suitable for use in airframe dynamics design work. The problem of coupled rotor-airframe dynamics needs further work. There is a need to establish the role which structural optimization can play in the airframe design process and to develop computational procedures useful in dynamics design work. Future emphasis under the program will be on addressing these identified needs. The program will continue to be a joint NASA/Army/university/industry effort. The in-house portion of the program will remain strong and university involvement is expected to expand. While all work will continue to be generic, emphasis under the program will be on establishing the technology base needed to support the development of advanced high-speed rotorcraft such as tilt rotors which are expected to be the focus of a new rotorcraft initiative by NASA.

INTRODUCTION

Excessive vibration is the most common technical problem to arise as a "show stopper" in the development of a new rotorcraft, either military or civilian. With only a few exceptions, past vibration problems were not identified and resolved until the flight testing phase of development. Solutions at this stage are usually add-on fixes which adversely impact cost, schedule, and vehicle performance. Currently, mathematical models based on the finite element method of structural analysis are widely used by the helicopter industry to calculate static internal loads and vibrations of airframe structures. The calculated internal loads are routinely used in design for sizing structural members. However, even though vibration is usually one of the significant problems of helicopter design, vibration predictions have not been relied on during design because of deficiencies in current methods of analysis. Vibration prediction is an industry-wide problem and remains a barrier to achieving the industry goal of a helicopter with a "jet smooth" ride. It is recognized that to attain this goal, vibrations need to be seriously addressed during the analytical phases of design. The advent of modern methods of computer analysis has provided the opportunity to achieve such a capability.

There are two aspects to the prediction and control of rotorcraft vibrations which need to be considered. First, the loads acting on the airframe must be determined along all load paths emanating from the rotor. This includes prediction of rotor harmonic loads which are transmitted along mechanical paths from the rotor to the airframe, as well as harmonic loads which are transmitted along aerodynamic transfer paths such as rotor wake impingement on the airframe. The accuracy of these loadings is mainly dependent upon the accuracy of the predicted aerodynamic loads. The prediction of aerodynamic loads is considered accurate enough for vehicle performance calculations but not accurate enough for vibrations work. Second, the quality of the predicted vibration levels is dependent upon the accuracy of the predicted forced response of the airframe which is a complex, lightweight, unsymmetric structure with large cutouts and heavy masses. Experimental evidence from ground vibration tests indicates that current dynamic analyses of helicopter airframes are only partly satisfactory below about 20 Hz and wholly unsatisfactory above that frequency.

Langley is addressing the vibration problem in four ways. First, basic aerodynamic and aeroelastic analyses and experimental studies are underway to improve the specific knowledge about airloads and to develop methods of minimizing hub shears and moments. Second, active and passive devices are being studied that offer reduced vibration albeit at a cost in complexity and increased weight. Work in these two areas is being conducted primarily by the Rotorcraft Aeroelasticity Group in the Configuration Aeroelasticity Branch. Third, a program has been initiated which has as its objective the development of an integrated, multi-disciplinary, optimization-based approach to helicopter rotor design. This work is being managed by the Interdisciplinary Research Office. And fourth, a rotorcraft structural dynamics program to exploit the full potential of finite element codes for dynamic analysis attempts to identify and correct the problems associated with applying modeling codes to typical rotorcraft structures.

This document discusses only the last of these four efforts, that is, the rotorcraft structural dynamics program.

BACKGROUND

The rotorcraft research program plan laid out by a NASA Rotorcraft Task Force in 1978 cited vibrations as one of the key technical areas in which the helicopter industry needed help. Because of difficulties the industry was having with vibration analyses based on the use of finite element models, the proposed vibrations task area contained an airframe modeling/test assessment activity to involve participation by NASA and the industry in a workshop environment conducive to thoroughly assessing and documenting industry modeling techniques and shake test procedures. NASA funding for the activity was approved and, as a result of a competitive procurement, a contract was awarded to Boeing Helicopters in 1980. The subject vehicle was the CH-47D tandem rotor helicopter. The work was completed in 1983. Based on this work, the need for improved finite element representation of secondary structural effects, mass distribution, and structural damping were identified as key technical issues.

The CH-47D work was the catalyst for the Langley Research Center to begin formulating a rotorcraft structural dynamics program to meet the long-term needs of the helicopter industry with respect to predicting and reducing airframe vibrations. As a culmination of considerable planning work by NASA and the industry, all in close coordination with the Army, the subject program was approved in 1983 and implemented in 1984.

OBJECTIVE, SCOPE, APPROACH

The overall objective of the subject rotorcraft structural dynamics program is to establish in the U. S. a superior capability for utilizing finite element models to support the dynamic design of helicopter airframe structures. The scope of the program as laid out in 1984 is indicated in figure 1. Viewed as a whole, the program is a cooperative effort involving NASA, the Army, academia, and the helicopter industry in a series of inter-related generic research activities in rotorcraft structural dynamics. The activities are aimed specifically at: (1) Discovering and removing technology barriers to analytical modeling for rotorcraft vibrations; and (2) Establishing critical elements of the technology base for development of a superior finite element dynamics design analysis capability in the U. S. helicopter industry. The program has two essentially parallel phases. Phase I is primarily a contracted effort in which teams from the four major manufacturers of helicopter airframes (Bell Helicopter Textron, Boeing Helicopters, McDonnell Douglas Helicopter Company, and Sikorsky Aircraft) conduct finite element modeling, analysis, measurement, and correlation studies on real aircraft of both metal and composite construction. The work is vehicle specific and of an applied research nature with emphasis on identifying important structural dynamic contributors to airframe vibratory response and developing advanced finite element modeling techniques for improved prediction of those vibrations. Phase II is primarily an in-house effort which employs the airframe finite element models developed by the contractors as the basis for the development of advanced design analysis techniques in such areas as coupled rotor-airframe vibrations and airframe structural optimization under vibration constraints. The work is generic and of a basic research nature. Because the focus of the industry phase of the program is on establishing and improving the airframe finite element modeling techniques required to make useful analytical predictions of vibrations during design, that phase of the rotorcraft structural dynamics program is usually referred to as DAMVIBS (Design Analysis Methods for VIBrationS).

The industry participants, working under task-type contracts, have each been issued several tasks related to forming NASTRAN finite element models of metal and composite airframes, conducting ground vibration measurements and correlations, and carrying out coupled rotor-airframe vibration analysis of a common vehicle. NASA/industry meetings to review results and experiences of completed work were held at Langley in September 1984; October 1985; December 1986; and May 1988. The Phase I (DAMVIBS) work is nearing completion. The Phase II activities are well underway. University participation has been initiated. The status of the various elements comprising the program is described below in more detail. This is followed by a summary of major accomplishments and future needs.

PROGRAM ELEMENTS

The subject rotorcraft structural dynamics program has seven key elements. A brief description and status of these elements are presented here.

AIRFRAME FINITE ELEMENT MODELING - Basic finite element modeling is being developed for internal loads analysis and vibrations analysis of airframes of both traditional sheet-metal construction and airframes with major composite components. The activities include modeling, ground vibration tests, and analysis/test correlations. The main technical products of this series of studies include: (1) Basic modeling guides; (2) Validated models of significant airframes; and (3) Identification of needed research tasks. Six airframes--three metal and three composite--varying significantly in both size and construction are being studied (figure 2). Work on the Boeing CH-47D, McDonnell Douglas AH-64A, Sikorsky UH-60A, Bell D292 (ACAP), and the Boeing Model 360 has been completed. Work on the Sikorsky S75 (ACAP) is underway. Test/analysis comparisons for the airframe studies which have been completed indicate that agreement is good up to about 10 Hz, only partly satisfactory between about 10-20 Hz, and generally unsatisfactory above about 20 Hz. Results also show that composite airframe dynamics are more difficult to predict than for metal airframes. No additional modeling of complete airframes is planned. However, studies have been initiated on the modeling and testing of airframe components. Under a grant, ground vibration tests and companion finite element analyses are underway on the tail boom of a Sikorsky S-55 helicopter. An in-house activity has been initiated (using small models) to investigate, both theoretically and experimentally, finite element modeling techniques.

DIFFICULT COMPONENTS - Typically, only the primary (major load carrying) structure is represented fully (stiffness & mass) when forming the FEM of an airframe. As depicted in figure 3, there are many components (e.g., transmissions, engines, and stores) and secondary structure (e.g., fairings, doors, and access panels) which are represented only as lumped masses. This may be a major contributing factor to the poor agreement noted between analysis and test at the higher frequencies. The aim of this activity is to identify the effects of such "difficult components" on airframe vibratory response and to develop improved techniques for representing these components.

The first such difficult components study was conducted by Bell utilizing an AH-1G helicopter. To isolate the effects of each component on overall vibratory response, multiple ground vibration tests were conducted with each test representing a progressive removal of the suspect difficult component until only the primary airframe structure remained (figure 4). At each stage, correlations were performed using an existing FEM of the airframe modified as necessary to reflect the specific configuration tested. In addition to the aircraft tests, separate tests were conducted on several of the components. The list of suspects for poor correlation at the higher frequencies has been considerably reduced because of this study. For example, it was found that tightly fastened secondary structure and windows need to be modeled. An elastic line model of the beam-like tailboom structure was determined to be inadequate for representing the dynamics at the higher frequencies. The effects of nonproportional damping were found to be significant at higher frequencies. On the other hand, the nonlinear effects of thrust stiffening and elastomeric mounts were found to be important only at low frequencies. Because some of the effects are configuration dependent, plans are to conduct similar type studies using the Bell D292 (ACAP) and the Sikorsky S-75 (ACAP) in cooperative programs with the Army Aviation Applied Technology Directorate at Fort Eustis. Work on the Bell D292 has been recently initiated. Studies of airframe components and small-scale models are also planned.

COUPLED ROTOR-AIRFRAME ANALYSIS - The aim here is both to evaluate existing analysis methods and to develop new computational procedures for the analysis of coupled rotor-airframe vibrations. With respect to the first activity, initial evaluation of existing industry codes for calculation of coupled rotor-airframe vibrations has been completed. In this study, the industry participants independently applied different analysis methods, using a common AH-1G airframe finite element model, to calculate the flight vibration levels and then to correlate with existing flight vibrations data. These studies represent the first comparative evaluation of industry codes applicable to the computation of coupled rotor-airframe vibrations. The results obtained (fig. 5) indicate that current methods of analysis do not yield the level of accuracy needed to rely on analytical predictions of vibration during design. It is clear that further work is needed in this area to identify and understand the reasons for the unacceptable predictions, to reconcile them and, ultimately, to correct the deficiencies causing them. With respect to the second activity mentioned above, work has been initiated in-house to develop the aeroelastic equations of motion for an articulated rotor in forward flight. These equations include the six degrees of freedom at the hub and will be tailored to support numerical studies related to the computation of rotor hub impedances and the practical analysis of the rotor and the airframe as a coupled system.

AIRFRAME STRUCTURAL OPTIMIZATION - The intent here is to develop computational procedures for structural optimization which are applicable to finite element models of helicopter airframes and which properly and effectively take into account vibration constraints. The methods must ultimately be applicable to large order systems and be compatible with typical design practice for airframe systems. A system of integrated programs called DYNOPT for dynamics optimization of airframes subject to both frequency and dynamic response constraints has been developed at Langley. The DYNOPT code features a unique operational combination of the MSC/NASTRAN structural analysis code and a state-of-the-art optimizer, and appears to be well suited to support airframe dynamics design work. Applications of the code to airframe configurations using both elastic-line and three-dimensional finite element models are underway. These studies have indicated the need for a basic understanding of the airframe structural design process on the part of the analyst developing the optimization tools. Industry and university participation is planned.

MODEL IMPROVEMENT - The dynamic analysis of helicopter airframe structures is usually based on some type of finite element model. These analytical models are rather large (usually containing several thousand finite elements) and their formation involves considerable effort. Results obtained from these models often do not correlate well with experimental data, particularly at the higher frequencies. The objective of this research activity, which is closely related to the difficult components activity, is to discover the reasons for the discrepancies between analysis and test. Possible sources of difficulty include the representation of the structure (stiffness matrix), the inertia (mass matrix), and the structural damping (damping matrix). The focus of this activity is on modeling the stiffness and the mass. There are two possibilities here. One is that the modeling techniques which are employed are not adequate. Another is that the mathematical assumptions which have been made in the derivation of the finite elements have fundamental limitations. The intention is to address these possibilities both theoretically and experimentally. In-house studies have just recently been initiated which are aimed at determining the advantages which might be associated with the use of different types of finite elements in the finite element model. Plans are to fabricate a series of small built-up structures of increasing structural complexity and experimentally determine their natural frequencies. These results will be used to assess the validity of companion finite-element models developed using different modeling techniques and finite-elements based on different mathematical representations. Future industry and university involvement is planned.

STRUCTURAL DAMPING - Airframe structural damping plays an important role in airframe vibrations. Because of the complex nature of most damping mechanisms, the industry practice is to use the same assumed value of modal damping for each mode when computing airframe responses. There has been little attention directed either at devising methods suitable for quickly evaluating the effects of localized damping treatment in preliminary design analyses or at formulating mathematical models of real damping mechanisms suitable to being incorporated in finite-element models. Research aimed at addressing the former need has recently been initiated at Langley. A method has been developed for predicting the effective modal damping ratios in forced vibrations using undamped modal vectors. The calculations are simple and permit a rapid and inexpensive preliminary design procedure which determines the effect of specific local, as well as distributed, damping treatments on a mode-by-mode basis. Initial applications of the method to the axial vibrations of a rod have indicated that the method is valid for damping values up to about 10-percent of critical. The intention is to extend the method to other basic structural elements (beams, membranes, plates, etc.) and to combinations of these basic structural elements. A companion experimental program will be initiated to verify the procedures developed. University participation is planned.

BLADE AEROELASTIC TAILORING - Recent interest has been shown in using aeroelastic tailoring to design composite rotor blades with extension-twist coupling to take advantage of the increment in radial centrifugal force due to the change in rotor blade rotational speed associated with tilt-rotor operation in the two different modes of flight. The work is motivated by the fact that twist distributions employed in the blades of tilt-rotor aircraft are a compromise between the conflicting requirements dictated by the need to operate the rotors in both helicopter and airplane modes of flight. An in-house Army program, which was not part of the subject rotorcraft structural dynamics program as originally defined, is underway to investigate, both experimentally and analytically, the use of extension-twist structural coupling. Recent analytical studies using the XV-15 tilt-rotor aircraft with extension-twist coupling indicated substantial performance improvements in both hover and forward flight. Static and dynamic testing of a series of tubular, spar-like composite specimens exhibiting extension-twist structural coupling are underway. Companion analytical studies are also underway. The ultimate goal is to design, build and test a model composite tilt-rotor blade which incorporates extension-twist coupling for improved performance.

SUMMARY OF MAJOR ACCOMPLISHMENTS

The accomplishments which may be attributed to the program (particularly the DAMVIBS portion) to date are varied and many, and encompass both technical achievements and notable changes in industrial design practice. The major accomplishments are summarized below.

(1) **Industry-wide standards for basic finite element modeling have been established.** Modeling procedures for composite airframes have been demonstrated to be similar to those for metal airframes except for the determination of material properties, which are significantly more difficult to determine for composite airframes. The increased importance of properly modeling both distributed and concentrated masses has been underscored.

(2) **Comparisons of the results of finite element analyses with results from ground vibration tests of both metal and composite airframes have demonstrated an improved capability for prediction of the low frequency responses up through about 10 Hz.** These same comparisons have clearly established that the range of acceptable agreement extends only up to about 15-20 Hz. Results from two airframes significantly different in both size and construction have shown that composite airframe dynamics are more difficult to predict than for metal airframes. Damping levels have been found to be essentially the same in both

metal and composite airframes. Support system dynamics were shown to be important and have underscored the need to include these effects in the finite element models which are employed in correlations with ground vibration tests.

(3) **A difficult components investigation of a stripped-down metal airframe has shed new light on the importance of many airframe components on vibratory response.** For example, tight secondary structure and glass were identified as important contributors to the response at higher frequencies. This indicates that finite element models for dynamics analysis may need to be more detailed than the models for static internal loads analysis.

(4) **The importance of up-front planning of static and dynamic finite element models before modeling begins has been demonstrated.** This planning has allowed the formation of common static and dynamic models for reduced modeling effort and improved the quality of the models.

(5) **Technical interchange between companies has been significantly increased because of the work-in-progress meetings which have been held in connection with the activities.** These meetings have provided a unique forum for technology transfer. For example, model check out procedures have been significantly enhanced throughout the industry because of these technical interchanges.

(6) **Industry internal research and development (IRAD) dealing with vibration has been revitalized and refocused.** The industry has also established new ties with universities and has begun to work with them on vibrations-related research problems.

(7) **Vibrations research at the three university rotorcraft centers of excellence** (Georgia Institute of Technology, Rensselaer Polytechnic Institute, and the University of Maryland) **has been refocused and coordinated with work being conducted under the program.**

(8) **Significant progress has been made on in-house studies.** For example, a computer program system called DYNOPT for dynamics optimization of airframes subject to frequency and dynamic response constraints has been developed. Notable progress has also been made toward designing, building and testing a model composite tilt-rotor blade which incorporates extension-twist structural coupling for improved aerodynamic performance.

WHAT NEEDS TO BE DONE

Notable progress has been made in advancing the technology base needed for the prediction of airframe vibrations. In particular, airframe designers can now use finite element models with confidence to avoid frequency placements which would result in resonance with rotor excitation frequencies up through about 10 Hz. This frequency range encompasses both the once-per-revolution (l/rev) frequency of all practical rotor systems and the twice-per-revolution (2/rev) frequency of typical two-bladed rotors. However, most new or planned helicopters have rotors with four (or more) blades and have predominant excitation frequencies which extend well above 20 Hz. Thus, to encompass even the lowest excitation frequencies of typical four-bladed rotors which are at 4/rev, the predictive capability of finite element models needs to be extended up through about 25-30 Hz. To achieve such a modeling capability as well as to establish the necessary advanced dynamics design analysis techniques which utilize these models, additional work is needed in several areas. The major needs are summarized below.

(1) **There is a need to continue the difficult components studies to identify further what portions and components of an airframe are contributing to the lack of correlation at the higher frequencies.** This needs to be done by a combination of tests with both full-scale airframes and their components as well as small-scale generic models. Both the Bell D292 and Sikorsky S75 ACAP vehicles are to be studied. These full-scale studies will be joint Army/NASA/industry studies, with all testing to be conducted in the vibration test facility at the Army Aviation Technology Directorate, Fort Eustis. Work on the Bell D292 has recently been initiated. These large-scale studies will be complemented with similar studies using small-scale built-up models designed and tested in-house. As with the large-scale studies, companion finite element models would be formed to correspond to each of the configurations tested. Basic modeling procedures need to be re-examined critically with respect to both static and dynamic requirements.

(2) In addition to the need for a systematic approach to understanding the weaknesses of finite element models, **there is a need for devising practical methods for improving (or adjusting) models at the finite element level using test results.**

(3) Damping is a major stumbling block to improved correlation over all frequencies. **There is a need to develop analysis methods which more realistically account for damping and which are suitable for use in airframe design work.**

(4) **More work is needed in the area of rotor-airframe coupling.** The reasons for the rather unacceptable predictive capability of existing industry codes for analysis of coupled rotor-airframe vibrations need to be identified and corrected. Computational procedures suitable for the repetitive analyses required in design studies need to be developed. Eventually, another validation study of analysis methods for coupled rotor-airframe vibrations will be needed. This assessment should be done on the helicopter being used in the NASA/AEFA Black Hawk flight test program.

(5) The final analytical verification of a design for vibrations will require the use of a complex rotor math model. However, it appears that useful predictions of airframe vibration can be made during design using simpler models. **There is a need to establish the level of sophistication required in the representation of the rotor system for computation of the rotor impedances which are needed for use in design-oriented coupled rotor-airframe vibration analyses.** This can be done by systematic parametric studies using existing codes to evaluate the effects of rotor aerodynamic and structural modeling assumptions on predicted airframe vibrations. Such information would allow the development of rotor math models which are better suited for the repetitive analyses required during airframe dynamics design work.

(6) **Work needs to be continued on establishing the role structural optimization can play in the airframe design process and developing computational procedures useful for dynamics design work.** A key need here is at least a rudimentary understanding of the airframe structural design process to allow the structural optimization engineer to properly and adequately formulate the types of design models required for industrial design optimization work. This information would allow the development of practical methods for the use of optimization in airframe design work related to both frequency placement and reduction of forced response.

(7) **There is a need to continue the work on demonstrating the potential for improving the aerodynamic performance of composite tilt-rotor blades through the use of extension-twist structural coupling.**

FUTURE DIRECTION OF PROGRAM

All of the major needs listed above are currently being addressed by the program. It is expected that the remaining work associated with the Phase I portion of the program will be completed in about two years. Current plans are to continue all other work being conducted under the program. Particular attention will be directed at the key technical areas indicated in figure 6. The projected schedule is given in figure 7. While all of the work will continue to be rotorcraft generic, emphasis under the program will be on establishing the technology needed to support the development of advanced high-speed rotorcraft such as tilt rotors, as suggested by figure 6. This research is intended to serve as a bridge between the Phase I portion of the program and a new high-speed rotorcraft program (tilt rotor) which is expected to be initiated by NASA in FY91 (figure 8). As before, the program will continue to be a joint NASA/Army/university/industry effort. The in-house portion of the program would be strengthened and university involvement would be expanded.

ROTORCRAFT STRUCTURAL DYNAMICS PROGRAM

1984

TECHNOLOGY AREAS

- Finite element modeling
- Difficult components
- Airframe structural optimization
- Coupled rotor-airframe vibrations
- Structural damping
- System identification
- Force determination
- Advanced analysis methods
- Internal loads
- Fatigue loads

PARTICIPANTS

- NASA
  - Langley
  - Ames
- ARMY
  - ASTD
  - AATD
- Academia
- Industry
  - Bell Helicopter Textron
  - Boeing Helicopters
  - McDonnell Douglas Helicopter Co.
  - Sikorsky Aircraft

Figure 1

FINITE ELEMENT MODELS

METAL AIRFRAMES

COMPOSITE AIRFRAMES

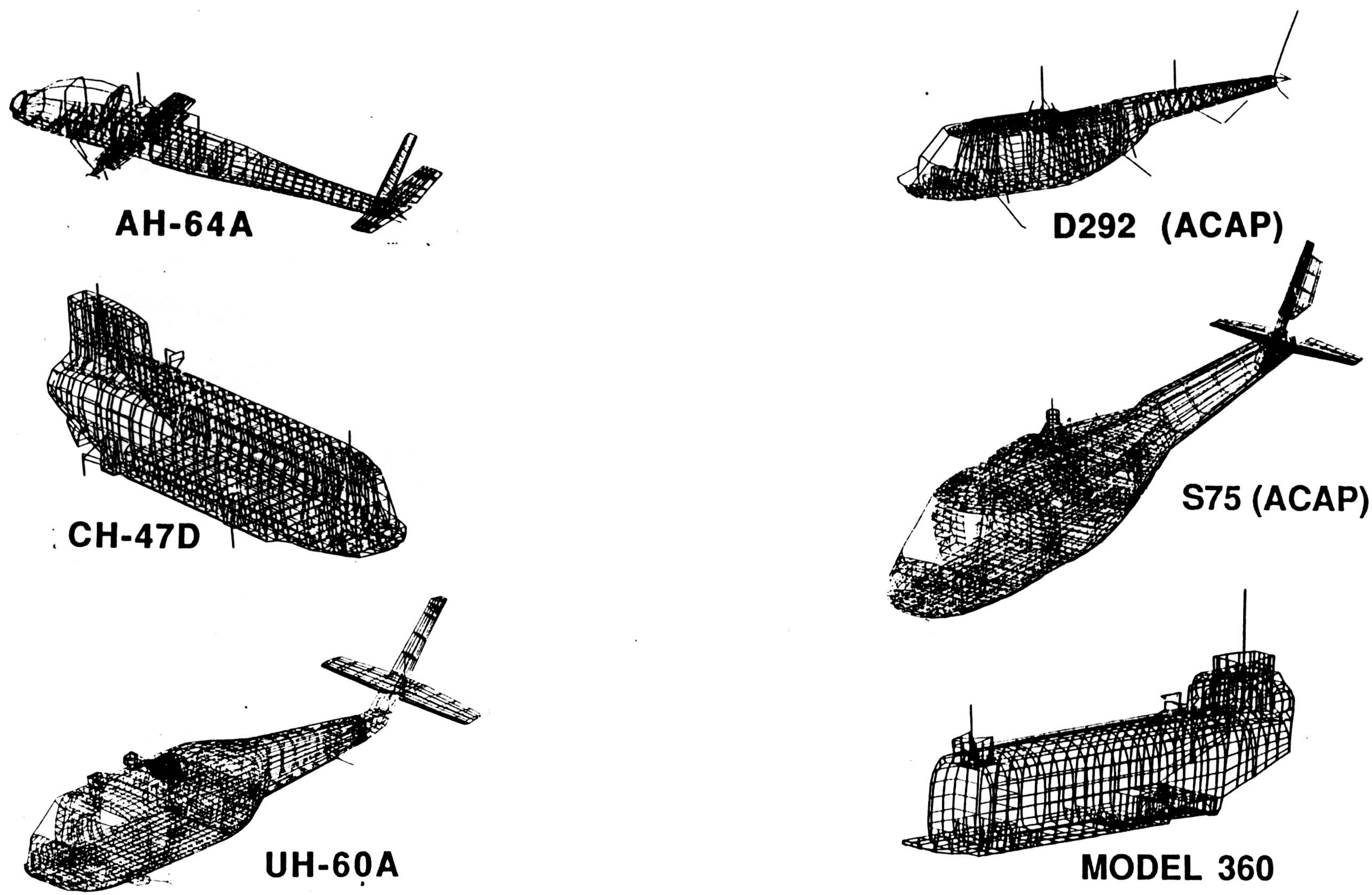


Figure 2

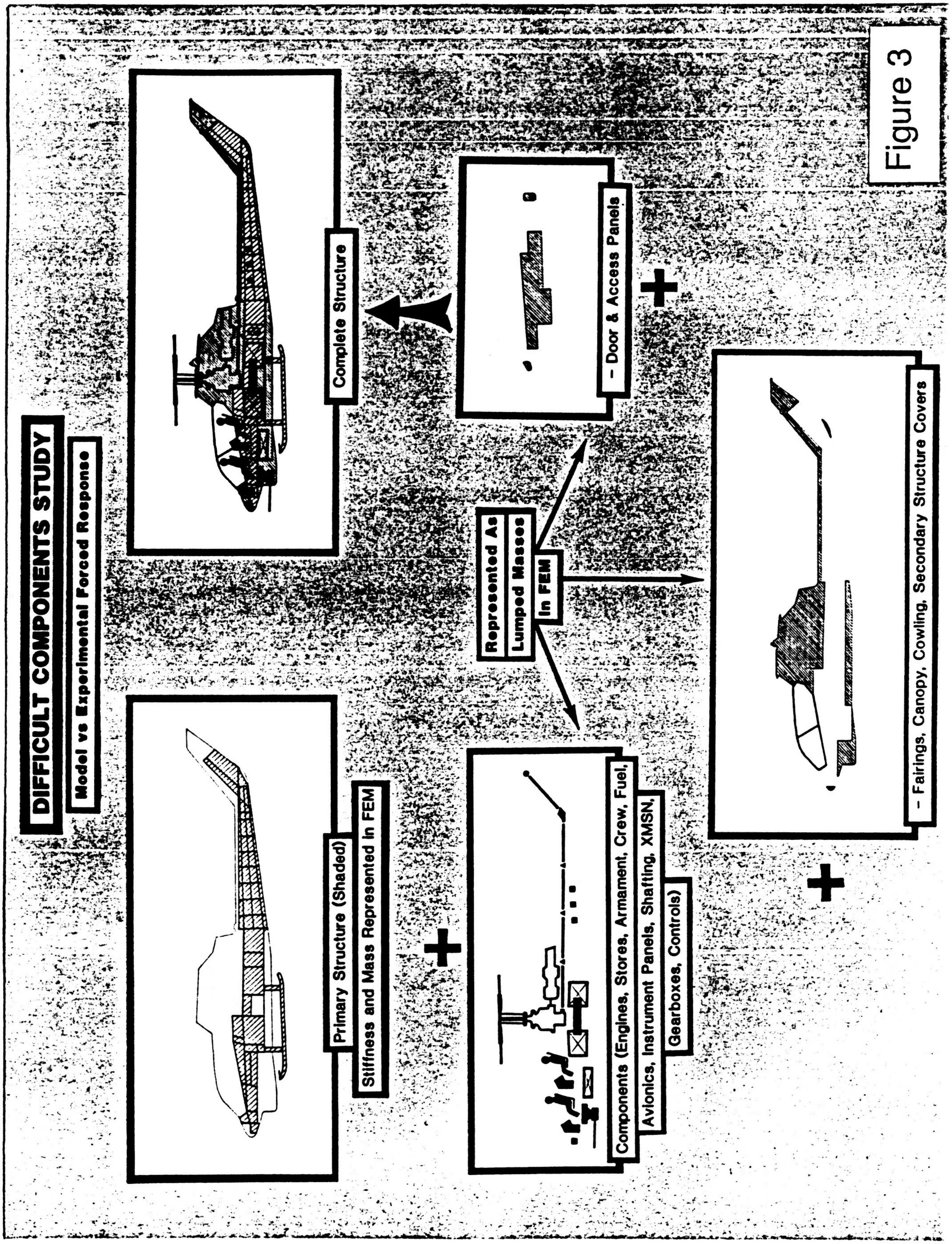
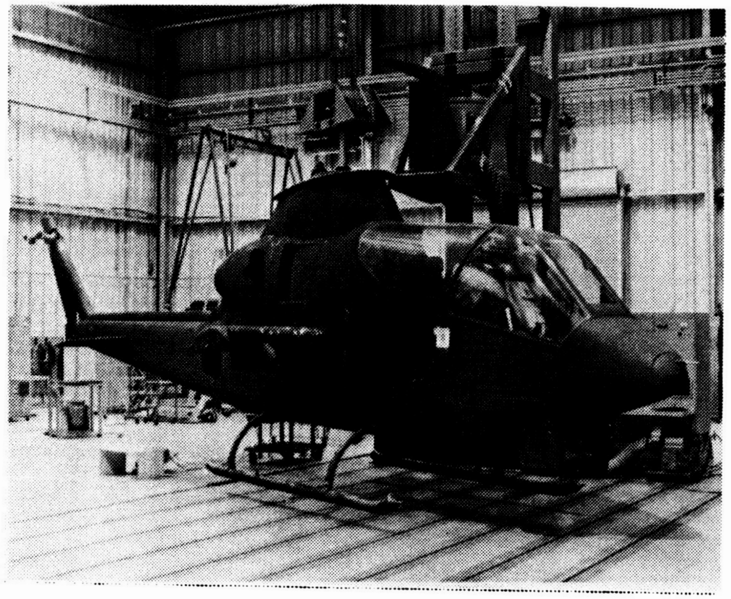
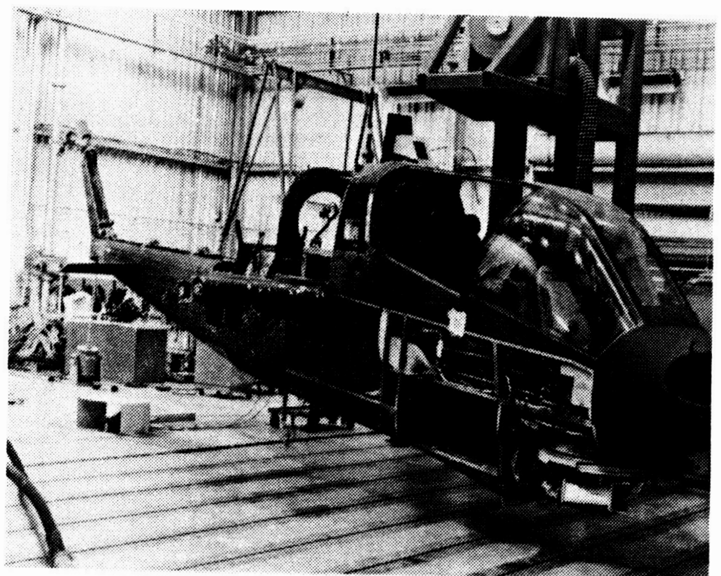

DIFFICULT COMPONENTS STUDY
Model vs Experimental Forced Response
Complete Structure
Primary Structure (Shaded)
Stiffness and Mass Represented in FEM
- Door & Access Panels
Represented As
Lumped Masses
In FEM
Components (Engines, Stores, Armament, Crew, Fuel,
Avionics, Instrument Panels, Shafting, XMSN,
Gearboxes, Controls)
- Fairings, Canopy, Cowling, Secondary Structure Covers

Figure 3

AH-1G DIFFICULT COMPONENTS STUDY



COMPLETE AIRFRAME



COMPONENTS REMOVED

KEY FINDINGS

- Stiffening effects of tightly fastened secondary structure and glass not negligible
- Elastic line representation of tailboom structure is inadequate at higher frequencies
- Effects of non-proportional damping significant at higher frequencies
- Nonlinear effects of thrust stiffening and elastomeric mounts important at low frequencies

Figure 4

AH-1G COUPLED ROTOR-AIRFRAME VIBRATORY RESPONSE

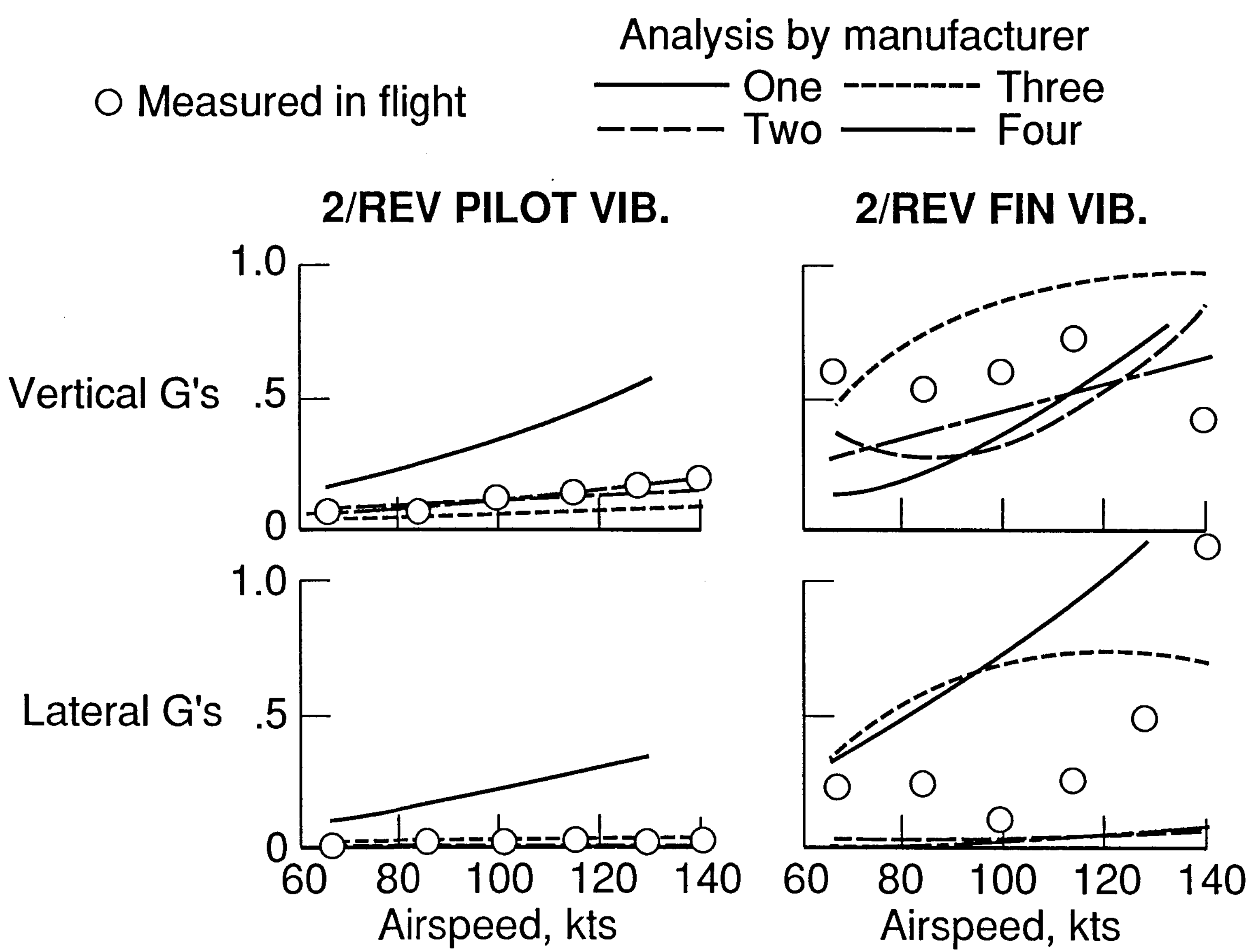


Figure 5

ROTORCRAFT STRUCTURAL DYNAMICS PROGRAM
1989

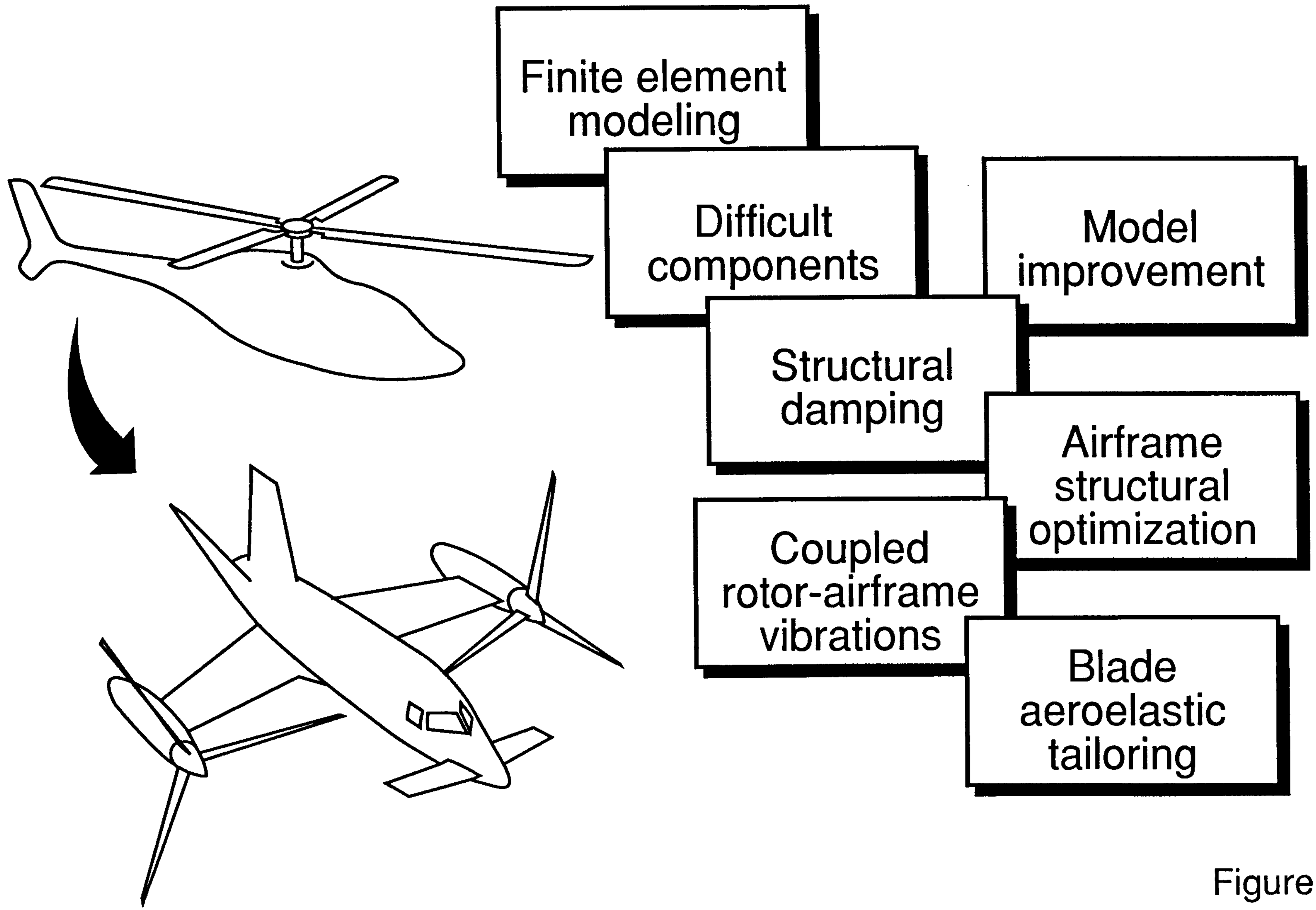


Figure 6

ROTORCRAFT STRUCTURAL DYNAMICS PROGRAM

Schedule

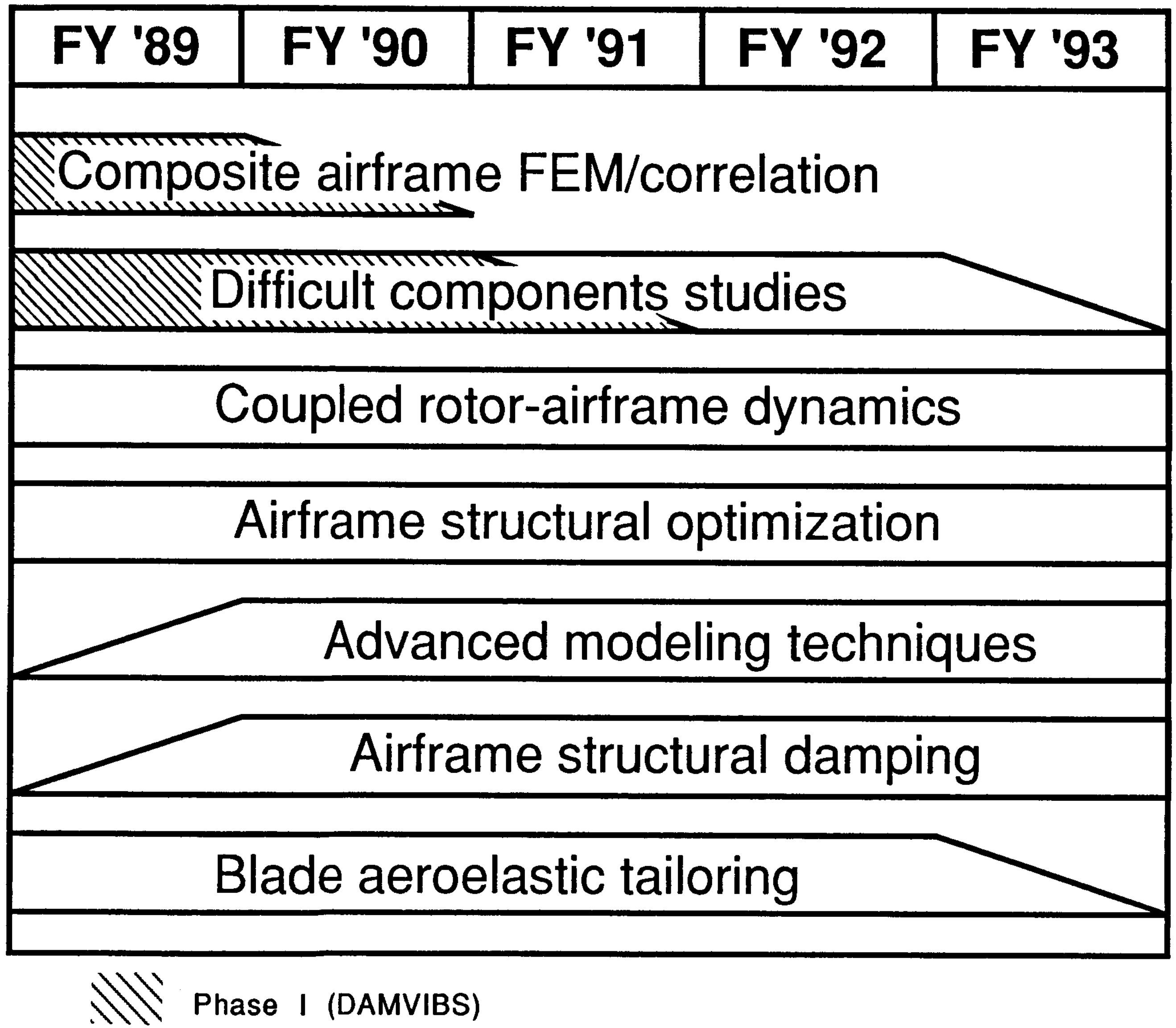


Figure 7

ROTORCRAFT STRUCTURAL DYNAMICS PROGRAM

Distribution of effort

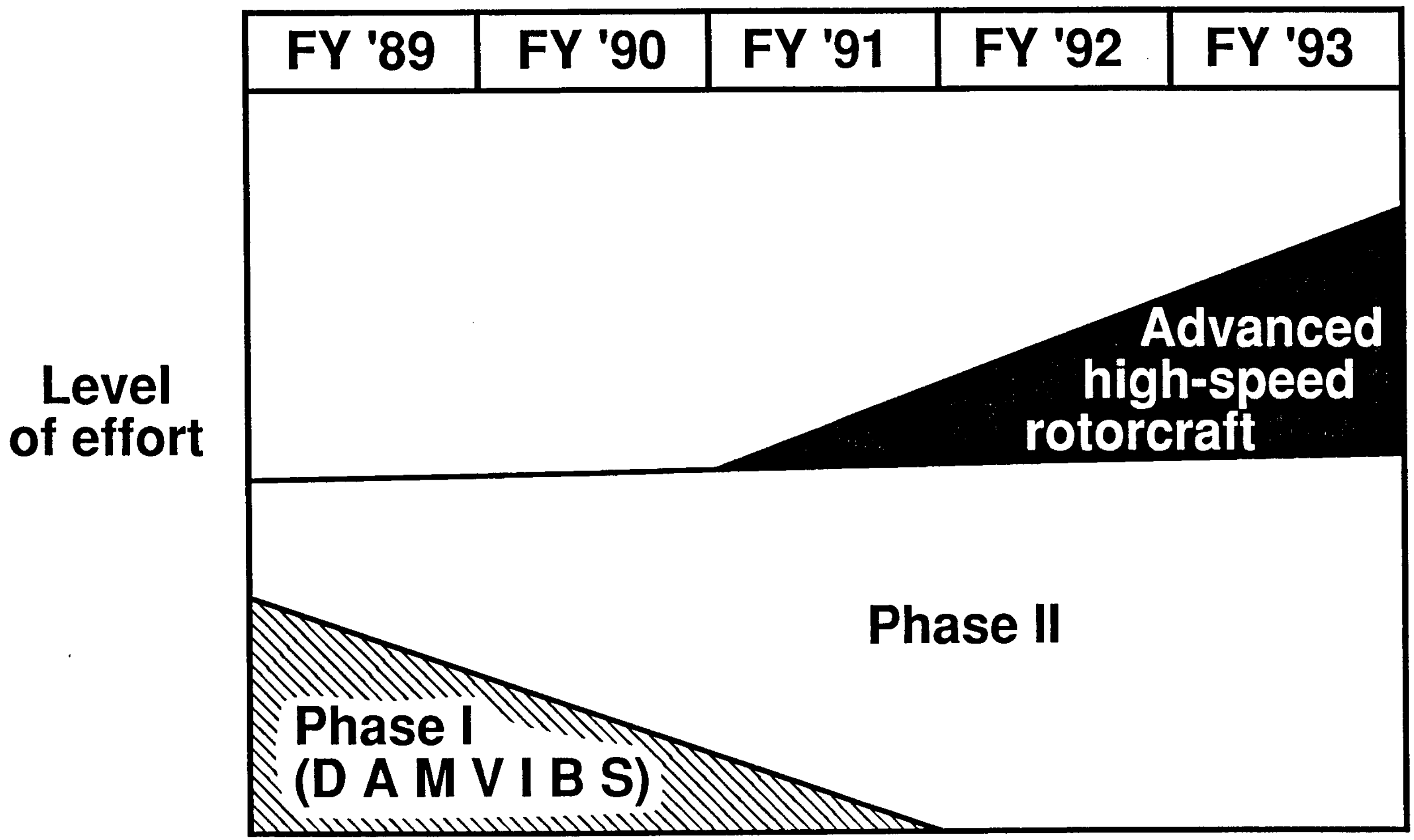


Figure 8

NASA
National Aeronautics and Space Administration

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15. Supplementary Notes

16. Abstract

Excessive vibration is the most common technical problem to arise as a "show stopper" in the development of a new rotorcraft. Vibration predictions have not been relied on by the industry during design because of deficiencies in finite element dynamic analyses. A rotorcraft structural dynamics program aimed at meeting the industry's long-term needs in this key technical area was implemented at Langley in 1984. The subject program is a cooperative effort involving NASA, the Army, academia, and the helicopter industry in a series of generic research activities directed at establishing the critical elements of the technology base needed for development of a superior finite element dynamics design analysis capability in the U. S. helicopter industry. The purpose of this report is to present an executive overview of the background, status, accomplishments, and future direction of this program.

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