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AEROMECHANICAL STABILITY ANALYSIS OF COPTER

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Abstract

A plan has been formed for developing a comprehensive, second-generation system with analytical capabilities for predicting performance, loads and vibration, handling qualities, aeromechanical stability, and acoustics. This second-generation system named COPTER (COmprehensive Program for Theoretical Evaluation of Rotorcraft) is designed for operational efficiency, user friendliness, coding readability, maintainability, transportability, modularity, and expandability for future growth. The system is divided into an executive, a data deck validator, and a technology complex. At present a simple executive, the data deck validator, and the aeromechanical stability module of the technology complex have been implemented. This paper describes briefly the system, discusses the implementation of the technology module, and presents correlation data. The correlation includes hingeless-rotor isolated stability, hingeless-rotor ground-resonance stability, and air-resonance stability of an advanced bearingless-rotor in forward flight.

Introduction

Each helicopter manufacturer has employed several analytical methods of varying complexity to determine loads and vibrations, aeroelastic stability, stability and control, performance, and acoustics. It was the consensus of the U.S. Army and the U.S. helicopter industry that these first-generation methods had limited capability, since they were not generally applicable to all types and sizes of helicopters, were difficult to maintain and improve, and were not truly comprehensive. In 1976, a decision was made by USAAMRDL at Fort Eustis to develop the Second-Generation Comprehensive Helicopter Analysis System (2GCHAS) using modern software design techniques and modules for the technology complex. In order to maintain its competitive position in the technical community and assist the government in the development of 2GCHAS, Bell Helicopter Textron Inc. (BHTI) initiated the COmprehensive Program for Theoretical Evaluation of Rotorcraft (COPTER).

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The COPTER System

The COPTER system is designed for operational efficiency, user friendliness, coding readability, maintainability, transportability, modularity, and expandability for future growth. The system is divided into an executive, a data deck validator, and a technology complex. The source is coded in VS FORTRAN to take advantage of the structured programming features. Each subprogram has a prologue to explain its function, inputs and outputs, computational method and sequence, creation/modification dates, and authors. Various built-in diagnostic options are available throughout the program.

A user can invoke the executive of the system at a TSO (IBM's Time Sharing Option) terminal by typing the command "COPTER." The executive then presents a menu on the screen with options available to the user. These options include editing input data, running programs interactively, browsing outputs, and submitting batch jobs. The executive can also prompt the user for inputs and interface interactively with the user.

The executive takes advantage of the System Productivity Facility (SPF), an IBM product, to invoke the editing and browsing options. This allows full-screen editing and scrolling of the input data and browsing the output immediately after running the programs. Any error messages will be displayed on the terminal screen.

The executive drives two programs. The first program is the Data Deck Validator (DDV), which reads inputs, interprets key words, checks for errors, and generates error messages wherever appropriate. It also retrieves block data from the master data base, creates the run data base, and generates an annotated echo of the input data. The second program contains the technology modules of the COPTER system. It reads the run data base as its input, executes the user-specified technology modules, and generates engineering data that can be printed or plotted. The flow chart in Figure 1 summarizes the COPTER system.

Aeromechanical Stability

In recent years, the helicopter community has been challenged by the development of hingeless and bearingless rotors. The area of greatest challenge has been predicting aeroelastic stability characteristics for such rotors. As a result, the U.S. Army awarded several methodology assessment contracts to helicopter companies in 1981. The results were encouraging, but inconclusive (References 1 and 2).

Bell has been working toward the development of viable hingeless and bearingless rotor systems for over a decade. The effort has led to an experimental hingeless rotor (Reference 3), two production hingeless rotors (e.g., Reference 4), and a successful advanced bearingless rotor (Reference 5).

Recognition of Bell's in-house design requirements and the lack of a comprehensive capability in analyzing stability characteristics of hingeless and bearingless rotors resulted in the decision that the aeromechanical stability module should be the first technology module to be implemented in the COPTER system.

Analytical Model

Modal representations are used for the rotor and the airframe dynamics. A two-dimensional, strip, quasi-steady theory is employed for the blade aerodynamics. The effects of compressibility, reverse flow, and stall are modeled using the aerodynamic table look-up technique. A dynamic inflow model similar to the one discussed in Reference 6 is included as an option. Dynamic coupling between the rotor and the airframe is achieved by using time-invariant mass matrix methodol-

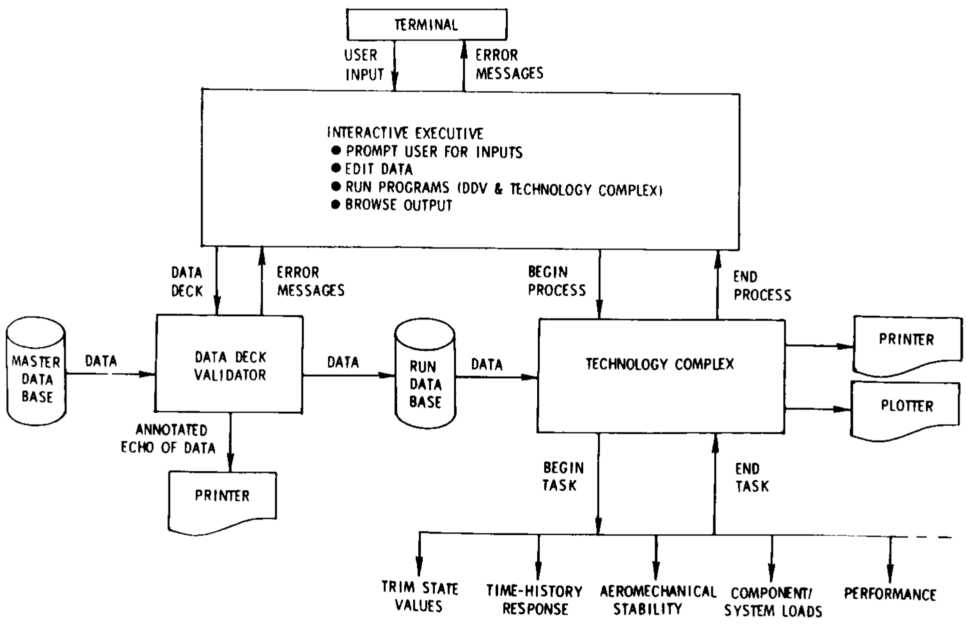

Figure 1. The COPTER system.

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ogy (Reference 7). The time-invariant mass matrix capability also facilitates the modeling of various hub types, such as bearingless, hingeless, gimbaled, and teetering rotors. Hub loads are calculated by either the mode-deflection or the force-integration method. At present, the analysis interfaces with the C81 computer program to obtain trim values.

Two methods of solution are available to the analysis: multiblade coordinate transformation and Floquet transition matrix. The multiblade coordinate transformation is used for multibladed rotors in hover, while the Floquet method is used for two-bladed rotors and all forward-flight conditions. The solution is presented in eigenvalue and eigenvector forms.

Correlations

Validation is one of the most important phases in the development of any analytical design tool. The aeromechanical stability analysis has been validated by comparing the results with those of established computer programs and by correlating with measured model data. The correlations shown in this paper include a hingeless-rotor isolated stability, a hingeless-rotor ground resonance, and stability of an advanced bearingless rotor with simulated body degrees-of-freedom in forward flight.

The hovering data of a hingeless-rotor isolated stability were obtained from cases A/2 and A/4 of the Army Integrated Technology Rotor (ITR) methodology assessment contract. A complete description of the two-bladed rotor model is presented in Reference 1. Case A/2 was for a uniform blade with a soft feathering flexure, but with no precone or droop. Case A/4 was for the same blade as case A/2, but with a 5° hub precone. Measured and computed blade lead-lag damping values vs blade pitch angles were plotted at a rotor speed of 1000 rpm and are shown in Figures 2 and 3 for case A/2 and case A/4, respectively. For both cases, it was found that the effect of the dynamic inflow on the blade inplane damping was small. Analytical data shown in Figures 2 and 3 were obtained without employing the dynamic inflow model.

A correlation with ground-resonance data measured on a model-scale, three-bladed hingeless rotor, coupled with body pitch and roll degrees-of-freedom, was performed. Descriptions of the experimental model, experimental results, and analytical representation of the model hardware can be found in Reference 1. This was case C/1 of the ITR methodology assessment contract. System frequencies,

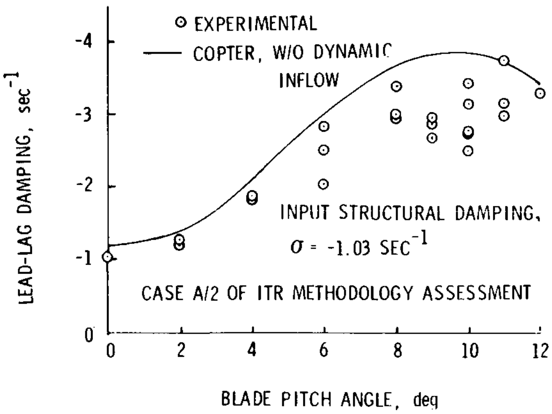

Figure 2. Lead-lag damping vs blade pitch angle, no precone or droop, soft feathering flexure, 1000 rpm, isolated two-bladed hingeless rotor.

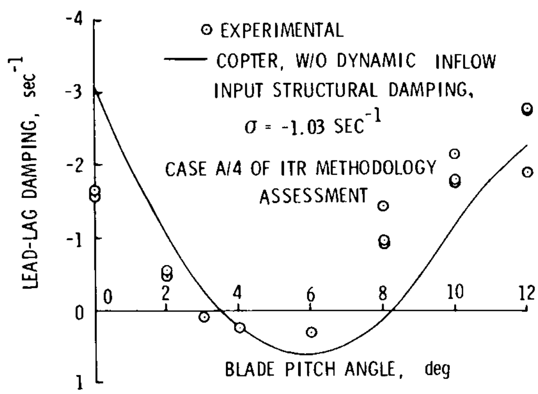

Figure 3. Lead-lag damping vs blade pitch angle, 5° precone, soft feathering flexure, 1000 rpm, isolated two-bladed hingeless rotor.

damping values of lead-lag regressing mode, and body pitch and body roll modes were plotted as rotor speeds varied from 0 to 1000 rpm. The blade was untwisted with 0° blade pitch angle. The analysis was conducted with and without the dynamic inflow. For this case (coupled rotor/body), including the dynamic inflow in the analysis improved the correlation.

Data in Figures 4 through 7 show correlations of system frequencies, lead-lag regressing mode damping, body pitch mode damping, and body roll mode damping, respectively. Analytical results, with and without the dynamic inflow, are presented in Figures 5 through 7. Computed system frequencies depicted in Figure 4 were obtained with the dynamic inflow included in the computation; those calculations without the dynamic inflow were not as good. To avoid further cluttering of the data in Figure 4, computed frequencies without the dynamic inflow were deleted from this figure.

It should be pointed out here that the analytical data shown in these figures were obtained by using the force-integration technique in the calculation of hub forces and moments. The results showed distinct frequency shifts in the body/lead-lag crossings when the mode-deflection method was used. The difference in the results between the mode-deflection method and the force-integration method was attributed to the fact that the mode-deflection method did not include the complete dynamic coupling terms.

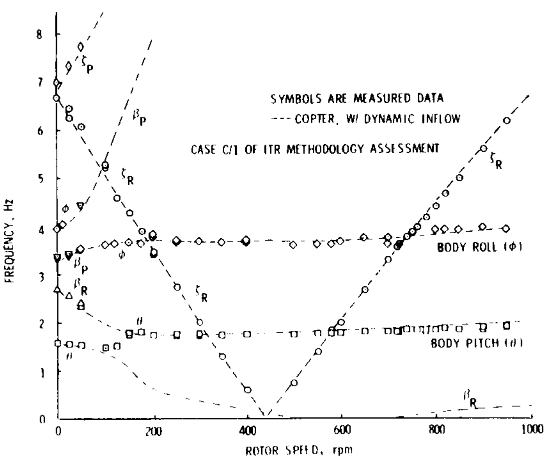

Figure 4. Correlation of ground resonance frequencies, flat pitch.

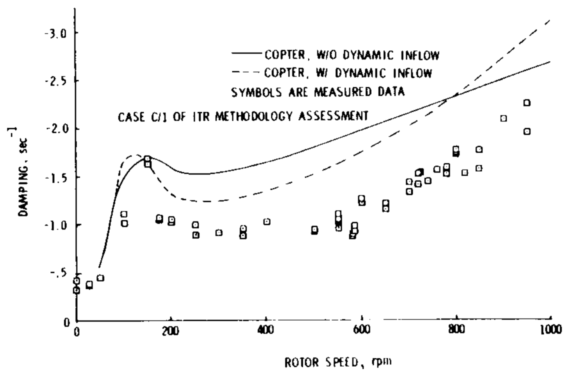

Figure 6. Correlation of body pitch damping, flat pitch.

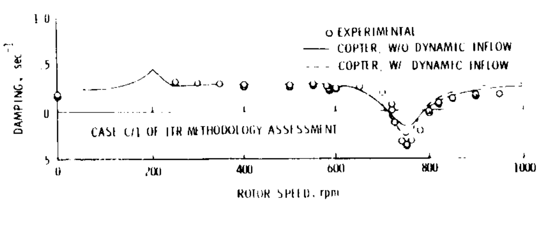

Figure 5. Correlation of lead-lag regressing mode damping, flat pitch.

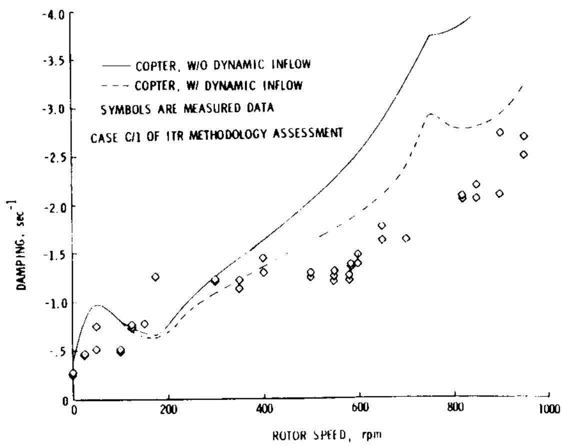

Figure 7. Correlation of body roll damping, flat pitch.

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A correlation of aeromechanical stability in forward flight was made by using experimental data measured on a one-fifth scale model rotor with an advanced bearingless hub. Descriptions of the experimental apparatus and procedures are presented in Reference 8. The particular rotor and body used for this correlation effort were the baseline rotor and the baseline fuselage configurations identified as R-1 and F-2, respectively, in Reference 8. The rotor had a hub precone of 2.75° with no blade droop or sweep.

Correlation of blade regressing inplane frequency (fixed system) and lead-lag damping (rotating system) vs rotor speed at a tunnel speed of 27.7 kn and 1g rotor thrust is shown in Figure 8. Measured data for body pitch and roll mode frequencies were not available. However, computed body pitch and roll frequencies are included in Figure 8 to indicate the rotor speeds where the regressing inplane mode crosses the body modes.

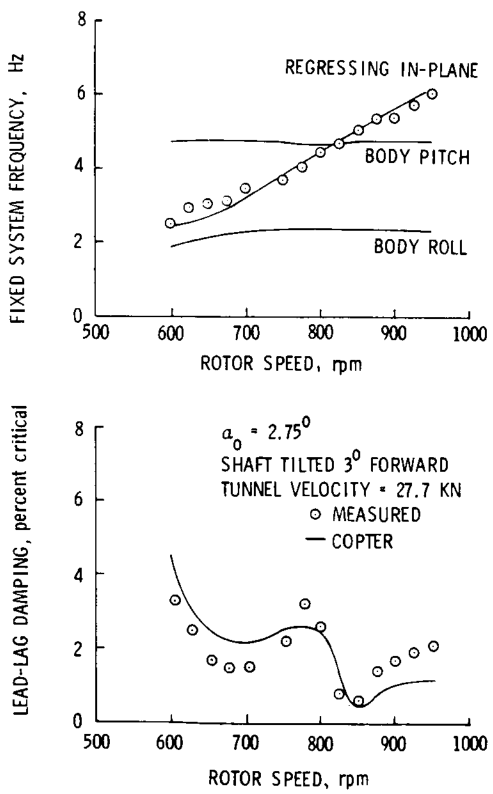

Figure 8. Correlation of frequency and damping vs rotor speed in forward flight, 1g thrust.

A correlation of regressing inplane frequency (fixed system) and blade lead-lag damping (rotating system) vs rotor thrust at 750 rpm and a 27.7-kn tunnel speed is presented in Figure 9.

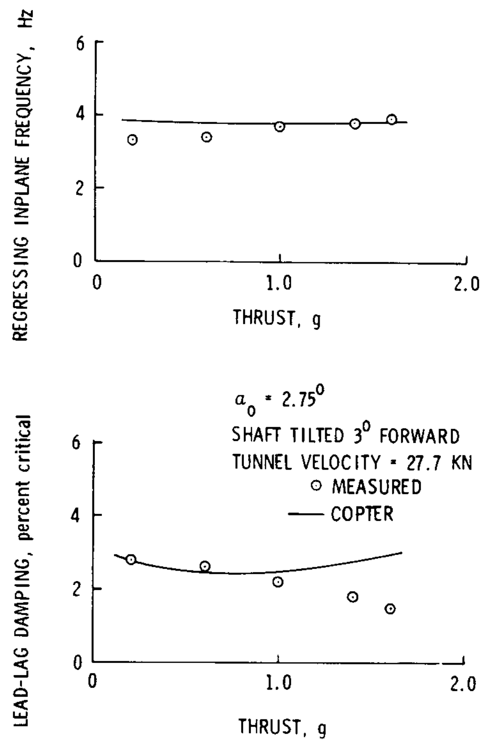

Figure 9. Correlation of inplane frequency and damping vs rotor thrust in forward flight, 750 rpm.

Concluding Remarks

A second-generation comprehensive aeromechanical stability analysis has been developed as part of the overall technology capabilities of the COPTER system. The technology complex of the system is modularized. The system, therefore, has great potential for growth and improvement, and new physics can be incorporated at any point of the COPTER life cycle.

The use of dynamic inflow improves the ground-resonance correlation.

The mode-deflection method usually does not include the complete dynamic coupling terms, as does the force-integration method. Its application to the ground-resonance analysis may lead to erroneous rotor/body crossing and incorrect damping.

Application of the Floquet transition matrix to aeromechanical stability in forward flight produces eigenvalue and eigenvector solutions. This eliminates most of the shortcomings associated with a time history solution.

Acknowledgement

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