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Department of Aerospace Engineering
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FLAP-LAG-TORSIONAL DYNAMICS OF HELICOPTER ROTOR BLADES IN FORWARD FLIGHT

DAA/AMES

IN-16758

FINAL REPORT

NASA GRANT NAG 2-274

PERIOD COVERED : JANUARY 1984 - JUNE 1986

PRINCIPAL INVESTIGATOR : M.R.M. Crespo da Silva,
Professor

NASA TECHNICAL OFFICER FOR THIS GRANT :
Dr. Dewey H. Hodges
Aeroflightdynamics Directorate
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BRIEF SUMMARY OF THE WORK

A perturbation/numerical methodology to analyze the flap-lead/lag motion of a centrally hinged spring restrained rotor blade that is valid both for hover and for forward flight was developed. The methodology, which is described in detail in [1], was presented in [2]. Some of the work supported by this Grant was also presented in [3].

The work supported by this Grant is now conducted entirely in a Symbolics 3670 Machine using MACSYMA to carry out all the lengthy symbolic manipulations. This includes the derivation of the nonlinear differential equations of motion and the analysis of the stability of the steady state response of the blade. It also includes generation of the fortran codes and of plots of the results. The Fortran codes used to obtain numerical results based on the equations obtained from the perturbation analysis were developed with the aid of MACSYMA. The Symbolics Machine and MACSYMA, which were funded by a DoD/University Instrumentation Grant in support of this research, played an essential role in all phases of the work supported by this Grant.

To develop the perturbation methodology presented in [1], the simpler case where both pre-cone and pith-flap and pitch-lag coupling were neglected was considered for simplicity. The methodology is valid both for hover and for forward flight since it avoids using the advance ratio as the expansion parameter. This is an improvement over the perturbation analyses presented in the literature by other authors who use the advance ratio as the perturbation parameter, thus making their multiple-time scale analyses invalid for the case of hover. In addition, the new methodology bypasses Floquet theory for analyzing the stability of the trimmed response of the rotor blade and has proven to be very efficient when compared to Floquet theory. It also yields a set of algebraic equations that can be used to solve the trim problem, thus bypassing other methodologies to address that problem separately.

Floquet theory was also applied to the differential equations of motion in order to compare results with those obtained from the perturbation analysis. The results obtained from the perturbation methodology and from Floquet theory were found to be very close to each other, which demonstrate the usefullness of the perturbation methodology.

A series of MACSYMA-extensions had to be developed to allow several aspects of this research work to be conducted. This included the writing of a package to code summations into fortran and to generate fortran expressions that contain a maximum of nineteen continuation lines as allowed by standard fortran. An efficient method to average a periodic function (which includes powers of trigonometric functions) over a period had also to be developed. In addition, a number of fortran routines that were running on an IBM main frame before the installation of the Symbolics Machine also had to be adapted to compile and run on that Machine.

The latest numerical results that are still being generated seem to indicate that there is a small region in the neighborhood of unity lead/lag frequency where a convergence problem exists when determining the boundary of the stability region in the flap-lag frequency space. To determine whether this problem is due to numerical convergence, the use of double precision arithmetic is in order. To implement this, however, further work to make the IBM version of the routines compile and execute on the Symbolics Machine is needed.

Another problem under study consists in the analysis of the influence of higher order terms in the response and stability of a flexible rotor blade in forward flight using Computerized Symbolic Manipulation and a perturbation technique to bypass Floquet theory. The derivation of the partial differential equations of motion for this problem, using Computerized Symbolic Manipulation, is published in [4]. These equations are stored on disk in the Symbolics Machine for further research. A summary of some of the work and problems associated with the development of these equations is included in [5]. To make the Symbolic Manipulator apply Galerkin's procedure to the equations for the flexible rotor blade several MACSYMA extensions had to be developed to handle this special application. Some of the extensions that were developed are also described in [5].

The work in [4] makes use of Computerized Symbolic Manipulation with MACSYMA to derive the highly complex equations of motion of a flexible helicopter rotor blade in forward flight. Moderately large deformations are considered so that the nonlinearities in the equations are expanded in terms of a small parameter that is introduced only for bookkeeping purposes. The resulting equations, which are truncated to retain nonlinearities up to cubic order in the ordering parameter, contain a very large number of terms which make them difficult, if not impractical, to be handled without the use of Computerized Symbolic Manipulation. In [4], the perturbation analysis of the flapping motion of a rigid rotor blade in forward flight is also carried out, via Computerized Symbolic Manipulation, by a method that bypasses Floquet theory. The characteristic exponents associated with the motion are determined analytically by the perturbation method and also by Floquet theory for comparison purposes. The MACSYMA set of commands for the derivation of the equations of motion for the flexible rotor blade and for obtaining the characteristic exponents for the flapping motion of a rigid blade are included in two Appendices in [4]. These equations were previously derived "by hand" before the Symbolics Machine and MACSYMA became available for this work. The earlier work, which has been applied to the simpler case of hover, is published in [6,7]. It was also conducted under NASA sponsorship.

Further work on this research program will be conducted at the Rensselaer Polytechnic Institute (R.P.I.) where the principal investigator will be joining the activity in Rotorcraft Dynamics at the ARO-sponsored Rotorcraft Technology Center. It is expected that this research effort will be continued at R.P.I. under NASA sponsorship. The Symbolics equipment and other externally sponsored computing equipment that has been funded in support of this and related work conducted by the principal investigator at the University of Cincinnati will be part of a Symbolic Computation Laboratory dedicated to this activity at R.P.I.

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