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STATIC AND DYNAMIC PROPERTIES OF COMPOSITE BLADES WITH STRUCTURAL COUPLINGS

Final Report for period: 1 Feb. 1987 to 30 June 1990

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The present report briefly summarizes research to study analytically and experimentally, the static and dynamic behavior of helicopter rotor blades made of composite materials. A new analytic model was developed for handling arbitrarily large deflections of composite blades based on an Euler angle representation. Results for both large static deflections and small amplitude vibrations about the large static deflections, agreed well with experimental results from a series of structurally coupled composite blade models constructed to verify the analysis. The analytical model was later extended to include large amplitude, nonlinear vibrations about the large static positions. It was found that both static deflections and large amplitudes influenced greatly the fore-and-aft (lead -lag) and torsion modes, but had little effect on the bending modes.

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FOREWORD

The present report briefly summarizes research that was performed at the Massachusetts Institute of Technology under Contract No. DAAL 03-87-K-0024 for the U.S. Army Research Office. The work took place from 1 February 1987 through 30 June 1990. The principal investigator was Professor John Dugundji of the Department of Aeronautics at M.I.T. Two graduate students and two undergraduates participated in this work. The Army Research Office Technical Monitor was Dr. Gary L. Anderson.

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A. STATEMENT OF PROBLEM STUDIED

The objective of this work is to study analytically and experimentally, the static and dynamic behavior of helicopter rotor blades made of composite materials. Because of their anisotropic nature, composite blades can be manufactured which exhibit some new types of behavior such as the coupling between bending and twist or between extension and twist deformations. There is a growing interest in using such effects to improve the overall performance of helicopter rotors.

The project aims to provide improved analysis methods and design criteria for aeroelastically tailored composite blades. Also, experimental data is generated to verify these methods and illustrate these new types of behaviors. The specific effects studied are the above mentioned bending-twist and extension-twist structural couplings, the influence of large nonlinear static deflections, and cross section shear deformation.

B. SUMMARY OF IMPORTANT RESULTS

A new, analytical blade model was developed for handling arbitrarily large deflection behavior of beams. The model is based on an Euler angle representation, and can account for structural couplings such as bending-twist and extension-twist, which are introduced by composite materials. A finite-difference iterative procedure was used to solve the resulting twelve first-order, nonlinear differential equations. The model first determines the large deflection behavior under static loads, then a linearized version of the model is used to determine the small amplitude vibrations of the blade about their large static deflected position. Both techniques were implemented in a computer code that was fast and efficient. A new method to calculate the beam stress-strain properties of box-beams made of anisotropic composite material laminates was also developed, as well as a procedure to include shear deformations in the beams.

A number of small composite blade models consisting of thin flat graphite/epoxy laminates with tailored structural couplings, and some box beam models were built and tested both for static deflections and for vibration behavior. These experiments showed good agreement with the analysis for both the large static deflections and the vibration behavior. It was noted that the static vertical deflections of the blades had only a small effect on the bending vibration modes, but had a large effect on the torsion and fore-and-aft modes. This was true even for small blade deflections.

A detailed summary of the above analytical and experimental results can be found in the technical report, M.I.T. TELAC Report 89-7A, by Pierre

J. Minguet, listed in Section C (Publications, Presentations, and Technical Reports). Shorter published versions by P.J. Minguet and J. Dugundji, can also be found in the AIAA Journal and AIAA Conference Proceedings, also listed in Section C.

The nonlinear structural model developed above, was later extended to include large amplitude nonlinear vibrations about the large static deflected blade positions. A harmonic balance method, combined with a finite difference technique and a Newton-Raphson method was used to solve the resulting nonlinear equations. It was found that both large static deflection and large amplitudes can affect the fore-and-aft (lead-lag) and the torsion modes significantly, but that the bending modes were little influenced by the geometric nonlinearities. The effects of nonlinear amplitudes seemed most prominent for moderate static deflections.

A detailed summary of the above results for large vibrations can be found in the technical report M.I.T. TELAC Report 90-14, by Taehyoun Kim and John Dugundji, listed in Section C. Also included in that report, for interest, is a reduction of the arbitrarily large, Euler angle formulation of Minguet to the commonly-used moderately large deflection model in terms of displacements v, w, and twist ϕ.

C. PUBLICATIONS, PRESENTATIONS AND TECHNICAL REPORTS

1. Minguet, P.J., "Static and Dynamic Behavior of Composite Helicopter Rotor Blades Under Large Deflection," Ph.D. Thesis, Department of Aeronautics and Astronautics, M.I.T., May 1989. Also, M.I.T. TELAC Report 89-7A, May 1989.

2. Minguet, P.J., and Dugundji, J., "Experiments and Analysis for Large Deflections of Composite Blades with Structural Couplings," presented at 2nd Technical Workshop on Dynamics and Aeroelastic Stability Modeling of Rotorcraft Systems, sponsored by U.S. Army Research Office and Florida Atlantic University, Boca Raton, Florida, Nov. 18-20, 1987.

3. Minguet, P.J., and Dugundji, J., "Static and Dynamic Behavior of Composite Helicopter Blades Under Large Deflections," presented at 14th Annual Mechanics of Composites Review, sponsored by Materials Laboratory of the U.S. Air Force Wright Research and Development Center, Dayton, Ohio, Oct. 31 - Nov. 1, 1989.

4. Minguet, P.J., and Dugundji, J., "Experiments and Analysis for Structurally Coupled Composite Blades Under Large Deflections. Part 1 - Static Behavior. Part 2 - Dynamic Behavior," presented at 30th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, Mobile, Alabama, April 3-5, 1989, AIAA Papers 89-1365, 89-1366.

5. Minguet, P.J., and Dugundji, J., "Experiments and Analysis for Composite Blades Under Large Deflections Part 1: Static Behavior, Part 2: Dynamic Behavior," to be published in *AIAA Journal* about September 1990.

6. Kim, T. and Dugundji, J., "Nonlinear Large Vibration of Composite Helicopter Rotor Blade at Large Static Deflection," M.I.T., Technology Laboratory for Advanced Composites, TELAC Report 90-14, July 1990.

D. PARTICIPATING SCIENTIFIC PERSONNEL

1. Professor John Dugundji - Principal Investigator.

2. Pierre J. Minguet - Graduate student. Received Ph.D. degree, May 1989. Presently at Boeing Helicopter Co.

3. Taehyoun Kim - Graduate student. Studying towards Ph.D. degree.

4. Adam Sawicki - Undergraduate student.

5. Michael Sadlowski - Undergraduate student.