

AD-A146 312

STOCHASTIC MOTOR BLADE DYNAMICS(U) ILLINOIS UNIV AT
URBANA DEPT OF AERONAUTICAL AND ASTRONAUTICAL
ENGINEERING Y K LIN ET AL JUL 84 AAE-84-3

1/1

UNCLASSIFIED

ARO-15193.9-EG DAAG29-81-K-0072

F/G 1/3

NL

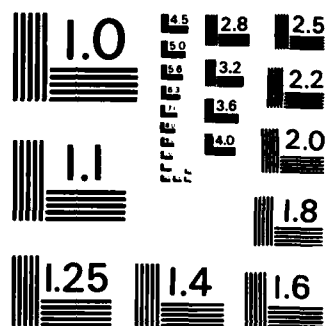


END

FILMED

-

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ARO 15193.9-EG

ARO 17830.5-EG

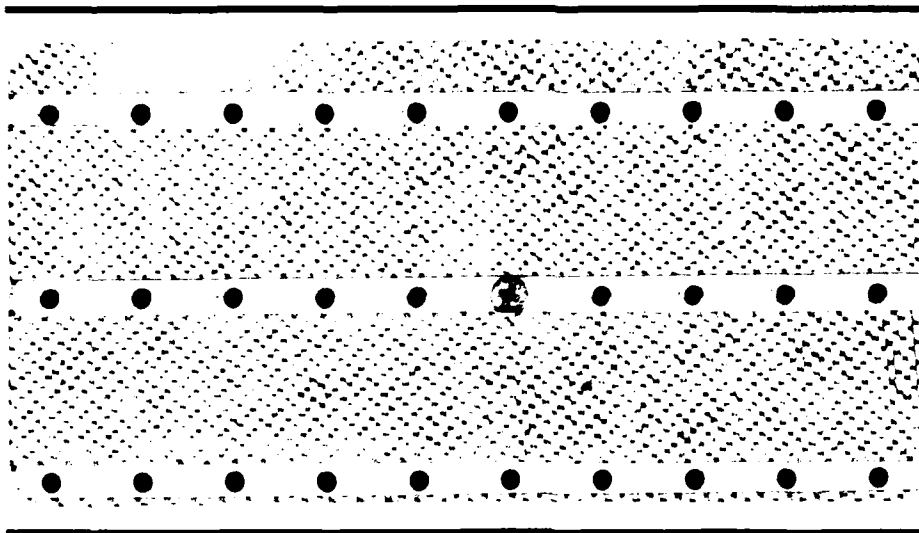
②

AAE 

AERONAUTICAL AND ASTRONAUTICAL ENGINEERING DEPARTMENT

AD-A146 312

DTIC FILE COPY



2
DTIC
ELECTE
SEP 28 1984
S
D
E

ENGINEERING EXPERIMENT STATION, COLLEGE OF ENGINEERING, UNIVERSITY OF ILLINOIS, URBANA

This document has been approved
for public release and sale; its
distribution is unlimited.

84 09 25 112

Aeronautical and Astronautical Engineering Department

University of Illinois at Urbana-Champaign

Urbana, Illinois

Technical Report AAE 84-3
UILU ENG 84-0503

STOCHASTIC ROTOR BLADE DYNAMICS

Final Report

by

Y. K. Lin and J. E. Prussing

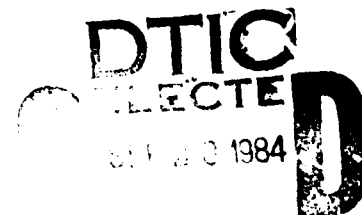
Prepared for

U.S. Army Research Office

Grant DAAG-29-78-G-0039
Contract DAAG-29-81-K-0072

July 1984

Approved for Public Release;
Distribution Unlimited



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARO 15193.9-EG ARO 17830.5-EG	2. GOVT ACCESSION NO. N/A	3. RECIPIENT'S CATALOG NUMBER N/A
4. TITLE (and Subtitle) STOCHASTIC ROTOR-BLADE DYNAMICS		5. TYPE OF REPORT & PERIOD COVERED Final Report (December 1977 to June 1984)
7. AUTHOR(s) Y. K. Lin and J. E. Prussing		6. PERFORMING ORG. REPORT NUMBER N/A
9. PERFORMING ORGANIZATION NAME AND ADDRESS Dept. of Aeronautical & Astronautical Eng. University of Illinois at Urbana-Champaign Urbana, IL 61801		8. CONTRACT OR GRANT NUMBER(s) DAAG 29-78-G-0039 DAAG 29-81-K-0072
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office Post Office Box 12211 Research Triangle Park, NC 27709		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS ARO Form 22 DD Form 2222
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) N/A		12. REPORT DATE July 1984
		13. NUMBER OF PAGES 7
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) N/A		
18. SUPPLEMENTARY NOTES The view, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Helicopter rotor dynamics, random vibration, stochastic stability, stochastic response.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The results of a theoretical investigation into the effects of atmospheric turbulence on the dynamical behavior of helicopter rotor blades are reported. Turbulence is found to destabilize the uncoupled flapping and coupled flapping-torsional motions; however, it stabilizes the coupled flapping-lagging motion by effectively increasing the damping in the least stable lead-lag mode. When a motion is stable, turbulence contributes to random		

Problem Description

In the service life of a helicopter, numerous encounters with clear-air or thunderstorm turbulence can be expected. Furthermore, because of the very nature that lift is generated by blade rotation, some level of self-created turbulence is also unavoidable. Therefore, random turbulence in the atmosphere should be included in a realistic analysis of helicopter dynamics.

The theoretical investigation reported in this document is concerned with the behavior of rotor blades in a turbulent flow. Specifically, answers are sought to two questions: (1) how does turbulence affect the motion stability of a blade system? (2) if the motion is stable, then by what amount does it deviate from that computed from a deterministic analysis in which the turbulence is ignored?

Mathematical Models

A. Structural Models

- A-1. Three types of motion are considered: uncoupled flapping, coupled flapping and torsion, coupled flapping and lagging.
- A-2. For flapping and lagging, the blades are assumed to be rigid and centrally hinged, with elastic restraints at the hinge. The degree of structural coupling between flapping and lagging is represented by a coupling parameter.
- A-3. For torsional motion, the blades are assumed to be elastic and the torsional angle varies spanwise linearly.
- A-4. The mass and elastic centers coincide along the one-quarter chord line.

B. Aerodynamic Models

- B-1. Flow is incompressible and sectionally two dimensional; i.e. the

spanwise flow is neglected.

B-2. Forces acting on a blade are computed from the steady aerodynamic theory for flapping and lagging motions, and from the quasi-steady aerodynamic theory for torsional motion.

B-3. The lift slope is the same constant in the normal and reversed flows.

B-4. Flow separation and stall do not occur.

C. Turbulence Model

C-1. Turbulence field is statistically stationary in time and homogeneous in space; i.e. the statistical properties are unchanged with respect to the change of time and spatial coordinate origins.

C-2. The speed of a rotor blade (rotation plus forward motion) is much greater than the convection speed of the turbulence; therefore, the turbulence has a short correlation time when observed on a moving blade.

These simplifying assumptions are made to enable a meaningful and useful analysis of a complicated dynamic system to be completed with a reasonable length of time, while capturing the essential features of the physical phenomena involved.

Summary of Important Results:

- (1) Turbulence plays two distinct roles in rotor dynamics: (a) as parametric excitations which affect the motion stability, and (b) as external excitations which cause random deviation from the idealized motions predicted by deterministic analyses in which turbulence is ignored.

- (2) Parametric random excitations appear in the coefficients in the equations of motion. In contrast, external excitations appear in the inhomogeneous terms on the right hand sides of the equations.
- (3) Uncoupled flapping and coupled flapping-torsion are essentially linear phenomena for which the turbulence components in the plane of blade rotation (horizontal components) are parametric and the turbulence component normal to the rotational plane (vertical component) is external.
- (4) Horizontal turbulence components de-stabilize the uncoupled flapping and coupled flapping-torsional motions. However, since these motions are extremely stable for usual helicopter blade configuration and flight conditions, the turbulence level must be unusually high in order for unstable motion to occur.
- (5) Coupled flapping-lagging motion is nonlinear. However, turbulence induced random perturbation from the idealized no-turbulence motion is essentially linear. In the linearized equations for the perturbed motion, the vertical turbulence dominates, and it appears both in the coefficients and as inhomogeneous terms.
- (6) The vertical turbulence component stabilizes the coupled flapping-lagging motion by increasing the damping in the least-stable, lead-lag mode. It has the same effect as an increase in the profile drag coefficient.
- (7) When a motion is stable, turbulence contributes to the random fluctuation from the average system response. Under a trim condition which suppresses the first harmonics of flapping response, the effect of turbulence, as measured by the standard deviation of the response, is of the same order of magnitude as the second harmonics in the deterministic

(i.e. idealized turbulence free) solution.

- (8) The constant coefficient approximation using the method of multiblade coordinates yields essentially the same stability results whether one time-averages both the stochastic and deterministic terms or time-averages only the stochastic terms. The constant coefficient approximation was found to be accurate only for trimmed rotors.

For additional information, the reader is referred to the publications listed in the next section.

Publications

1. Fujimori, Y., "Effects of Turbulence on the Stability of a Lifting Rotor Blade," Ph.D. Thesis, University of Illinois at Urbana-Champaign, October 1978.
2. Lin, Y. K., Fujimori, Y., and Ariaratnam, S. T., "Rotor Blade Stability in Turbulence Flows, Part I," AIAA Journal, Vol. 17, No. 6, June 1979, pp. 545-552.
3. Fujimori, Y., Lin, Y.K., and Ariaratnam, S. T., "Rotor Blade Stability in Turbulent Flows, Part II," AIAA Journal, Vol. 17, No. 7, July 1979, pp. 673-678.
4. Lin, Y. K., "Stochastic Theory of Rotor Blade Dynamics," Transactions of the 24th Conference of Army Mathematicians, ARO Report 79-1, 1979, pp. 377-394.
5. Hong, C-Y.R., "Rotor Blade Dynamics in Hovering Flights," M.S. Thesis, University of Illinois at Urbana-Champaign, May 1979.
6. Prussing, J. E., "Stabilization of an Unstable Linear System by Parametric White Noise," Journal of Applied Mechanics, Vol. 48, No. 1, pp. 198-199, March 1981.
7. Prussing, J. E., "Orthogonal Multiblade Coordinates," Journal of Aircraft, Vol. 18, No. 6, pp. 504-506, June 1981.
8. Klingberg, R. D., "An Experimental Study of Rotor Blade Flap-Lag Stability," M.S. Thesis, University of Illinois at Urbana-Champaign, August 1981.
9. Lin, Y. K. and Hong, C-Y.R., "Turbulent-Excited Flapping Motion of a Rotor Blade in Hovering Flight," in Advances in Aerospace Structures and Materials, ed. S. S. Wang and W. J. Renton, AD-01, ASME, 1981, pp. 149-153.

10. Prussing, J. E. and Lin, Y. K., "Rotor Blade Flap-Lag Stability in Turbulent Flows," Journal of the American Helicopter Society, Vol 27, No. 2, pp. 51-57, April 1982.
11. Lin, Y. K. and Prussing, J. E., "Concepts of Stochastic Stability in Rotor Dynamics," Journal of the American Helicopter Society, Vol. 27, No. 2, pp. 73-74, April 1982.
12. Fuh, J. S., Hong, C-Y.R., Lin, Y. K. and Prussing, J. E., "Coupled Flap-Torsional Response of a Rotor Blade in Forward Flight due to Atmospheric Turbulence Excitations," Journal of the American Helicopter Society, Vol. 28, No. 3, July 1983, pp. 3-12.
13. Prussing, J. E. and Lin, Y. K., "A Closed-Form Analysis of Rotor Blade Flap-Lag Stability in Hover and Low-Speed Forward Flight in Turbulent Flow," Journal of the American Helicopter Society, Vol. 28, No. 3, July 1983, pp. 42-46
14. Fuh, J. S., "Flapping-Torsional Response of Helicopter Rotor Blades to Turbulence Excitation," Ph.D. Thesis, University of Illinois at Urbana-Champaign, 1983.
15. Prussing, J. E., Lin, Y. K. and Shiau, T-N., "Rotor Blade Flap-Lag Stability and Response in Forward Flight in Turbulent Flow," accepted for publication in the Journal of the American Helicopter Society.
16. Shiau, T-N.B., "Rotor Blade Flap-Lag Stability and Response in Forward Flight in Turbulent Flows," Ph.D. Thesis, University of Illinois at Urbana-Champaign, 1984.
17. Franke, M. M., "A FORTRAN V Symbolic Derivation of First and Second Stochastic Moment Coefficient Matrices for Linear Systems," M.S. Thesis, University of Illinois at Urbana-Champaign, 1984.

Participating Scientific Personnel:

Y. K. Lin (Professor, Co-Principal Investigator)
J. E. Prussing (Professor, Co-Principal Investigator)
S. T. Ariaratnam, (Visiting Professor, 1977-1978)
K. R. Sivier (Associate Professor)
Y. Fujimori (Graduate Assistant, Ph.D. 1978)
C. Y. Hong (Graduate Assistant, M.S. 1979)
M. Happ (Graduate Assistant)
R. D. Klingberg (Graduate Assistant, M.S. 1981)
H. F. Borges (Graduate Assistant)
J. S. Fuh (Graduate Assistant, Ph.D. 1983)
T-N.B. Shiau (Graduate Assistant, Ph.D. 1984)
M. M. Franke (Graduate Assistant M.S. 1984)

END

FILMED

10-84

DTIC