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FINAL REPORT TO CLOSE OUT NASA GRANT NGR-39-009-111

by

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submitted to

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(NASA-CR-139594) [ROTOR BLADE-VORTEX INTERACTION] Final Report (Pennsylvania State Univ.) 10 p CSCL 01B
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The purpose of this grant was to investigate the phenomenon of rotor blade-vortex interaction. As such, the project was both analytical and experimental in nature. We received this grant on April 1, 1968 and it continued until March 31, 1972. During this period, in addition to a fraction of my time, this project supported three graduate students, resulting in the completion of three M.S. theses and one Ph.D. thesis. Two NASA CR's were also published as given below.

1. Surendraiah, Makam, "An Experimental Study of Rotor Blade-Vortex Interaction", May, 1970. NASA CR 1573.

2. Padakannaya, Raghuveera, "Experimental Study of Rotor Unsteady Airloads Due to Blade-Vortex Interaction", November, 1971. NASA CR 1901

In addition to these two CR's, a third CR is presently in the process of being published. This low number CR will present Dr. Padakannaya's Ph.D. thesis entitled, "The Vortex Lattice Method for the Rotor Vortex Interaction Problem." Also, two papers were presented at annual Forums of the American Helicopter Society, one, based on Mr. Surendraiah's M.S. thesis and the other on Dr. Padakannaya's M. S. thesis.

The Ph.D. thesis by Dr. Padakannaya summarizes the technical findings of this project. This dissertation presents a numerical solution for predicting the unsteady airloads induced on an aircraft rotor as it interacts with a vortex shed from a preceding blade. Comparisons are made with the experimental results obtained by Surendraiah as well as measured airloads reported by other investigators. Generally Padakannaya's predictions based on his vortex lattice method predict fairly well the measured results. However, certain limitations and inadequacies in the method are pointed out in Padakannaya's conclusions and recommendations. For example, he notes the sensitivity of the predicted peak lift coefficients to the chosen interval between successive time steps in the numerical solution to the unsteady aerodynamic problem. Also, for a case where the blade tip is in close proximity to the vortex, accurate information is required on the relative positions of the blade and vortex if one is to make an accurate prediction of the unsteady airloads. Also the vortex core size is an important parameter in the predicting of vortex induced loads.

Originally it was proposed on this grant to perform noise measurements for a model rotor interacting with a vortex shed from a fixed wing upstream of the rotor. These measurements were then to be correlated with the actual unsteady airloads measured on the rotor. For this purpose an anechoic chamber was procured which enclosed our open test section. Unfortunately time and money did not permit this part of the proposed program to be completed. It is hoped in the future that some additional work along these lines can be performed. Although the anechoic chamber has not been used for the purpose of this project, it should be pointed out that other investigations related to aerodynamic noise have been performed using the chamber which was designed and made specifically to fit our wind tunnel.

In closing, I would like to thank NASA Langley for their support of this research and I hope that the results which we achieved as reflected by the various theses and reports which were published justify NASA's confidence in this Department.

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Experimental Study of Rotor Unsteady Airloads Due to

Blade-Vortex Interaction

NASA CR-1909

by: Raghuveera Padakannaya

ABSTRACT

Additional measurements of unsteady, rotor-blade airloads and their time derivatives are presented for a rotor blade intersecting a completely rolled-up vortex. These results, taken at the blade spanwise station of 0.9R, 0.85R, and 0.75R, complement measurements previously reported for the 0.95R station in CR-1573. Incremental values in the section lift coefficient as high as 1.17 were obtained at the 0.75R station. Generally, these values decreased with increasing radius.

The Vortex Lattice Method for the Rotor-Vortex Interaction Problem

Ph.D. Thesis

Raghuveera Padakannaya

December 1973

## ABSTRACT

This study is concerned with the rotor blade-vortex interaction problem and the resulting impulsive airloads which generate undesirable noise levels. A numerical lifting surface method to predict unsteady aerodynamic forces induced on a finite aspect ratio rectangular wing by a straight, free vortex placed at an arbitrary angle in a subsonic incompressible free stream is developed first. In this vortex lattice method both the spanwise and the chordwise loadings are made stepwise discontinuous. Unsteady airloads on the wing are obtained by starting the system from rest. Using a rigid wake assumption, the wake vortices are assumed to move downstream with the free stream velocity. Unsteady load distributions are obtained which compare favorably with the results of planar lifting surface theory.

The vortex lattice method has been extended to a single bladed rotor operating at high advance ratios and encountering a free vortex from a fixed wing upstream of the rotor. The predicted unsteady load distributions on the model rotor blade are generally in agreement with the experimental results.

This method has also been extended to full scale rotor flight cases in which vortex induced loads near the tip of a rotor blade were indicated. In both the model and the full scale rotor blade airload calculations a flat planar wake was assumed which is a good approximation at large advance

ratios because the downwash is small in comparison to the free stream at large advance ratios. The tip vortex from the preceding blade was placed at a specified height below the plane of the rotor. The large fluctuations in the measured airloads near the tip of the rotor blade on the advance side is predicted closely by the vortex lattice method.

Using conformal transformation methods an exact analysis of the effects of thickness on the lift due to a two-dimensional wing-vortex interaction is presented.

NOTE: This thesis is in the process of being published as a low number NASA CR.

Effect of Wing Tip Configuration on the Strength and Position of a Rolled-Up Vortex[1]

M.S. Thesis

Raghuveera Padakannaya

March 1970

ABSTRACT

This thesis studies the effects of different wing tip configurations on its rolled-up vortex. The spanwise load distribution on plain rectangular wings and on wings with drooped tips was calculated by vortex lattice theory, to determine the effects of the droop on the strength and the location of the vortex. The load distribution on wings with drooped tips shows that the stronger vortex moves from the tip of the wing to the hinge of the drooped tip as the droop angle increases. The experimental program was to determine how the vortex sheet shed initially from the wing's trailing edge rolls up and how these trailing vortices dissipate downstream of the wings. The results were obtained for wings with 0°, 70°, 80°, 90°, 110° droop angles, at approximately the same lift coefficient. The experimental results confirmed the movement of the stronger vortex from the tip of the wing to the hinge of the drooped tip as the droop angle increases.

The experimental results are presented as contours of constant vorticity to show the rolling-up of the trailing vortex sheet behing the different models. Results are also presented to show the strength and the induced velocity profiles of the rolled-up vortex generated by the models.

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1 A paper based on this thesis, entitled, "The Effect of a Drooped Wing Tip of its Trailing Vortex System" was presented by B. W. McCormick and R. Padakannaya at the Aircraft Wake Turbulence Symposium, Boeing Scientific Research Laboratories, Seattle, Washington, September 1-3, 1970.

A Numerical Solution of the Unsteady Airfoil with Application to the Vortex Interaction Problem

M.S. Thesis

Wylie E. Rudhman

December 1970

ABSTRACT

A numerical method for the computation of unsteady aerodynamic forces on a thin airfoil has been developed. The method has been compared to the linear theories of Theodorsen for an oscillating airfoil and Wagner for an impulsively started airfoil and satisfactory agreement obtained.

The numerical method has been applied to the vortex interaction problem by calculating the section lift coefficient as a potential vortex passes near an airfoil representing a helicopter blade section. The calculated results were compared with experimental measurements. Generally these confirmed the validity of the numerical approach.

An Experimental Study of Rotor

Blade-Vortex Interaction[1]

M.S. Thesis

Makam Surendraiah

December 1969

## ABSTRACT

Results of an experimental investigation of the instantaneous blade airloads and their time derivatives are presented for a rotor blade intersecting a completely rolled up trailing vortex. Parameters such as the rotor RPM, vortex strength, and intersection angle were examined at a spanwise station of 0.95R.

An unsteady section lift coefficient value as high as 0.7 and its time derivative, 0.6 x $10^3$/sec, were measured during the vortex sweep. The values were found to decrease with radial distance from the center of the vortex. The commonly heard helicopter blade slap or bang was clearly heard in the present tests. Test results indicated vortex interaction is negligible for rotor plane positions beyond approximately one and one-half blade chord lengths from the vortex center.

The rotor blade experienced as much negative lift as positive lift during its encounter with the tip vortex. Sample photographic records are presented in order to show the influence of the tip vortex on the blade loading.

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[1] This thesis was also published as NASA CR-1573

# A Study of Rotor Blade-Vortex Interaction

Preprint No. 421

American Helicopter Society 26th Annual National Forum

June 1970

Barnes W. McCormick

Makam Surendraiah

ABSTRACT

An experimental and analytical study of the rotor blade-vortex interaction problem has been conducted under the auspices of the NASA Langley Research Center. Using miniature, flush mounted pressure transducers, time-dependent surface pressures were measured on a model rotor blade as it passed through a vortex generated by a fixed wing mounted upstream of the rotor. In addition to obtaining details of the chord-wise pressure distribution, the pressures were integrated to obtain the time-wise variation of the rotor section lift coefficients. The geometry of the test setup was varied in order to study the effect of such parameters as the distance of the vortex axis from the rotor plane, the angle at which the rotor blade intersects the vortex, the vortex size and strength, and the rotor rpm. Results of an approximate quasi-steady and unsteady two-dimensional analysis are compared with the measured section lift-coefficients. The significance of the findings of this study in relation to rotor noise is discussed. A brief sound movie has been made which permits the viewer to simultaneously observe both aurally and visually the results of the rotor blade intersecting the vortex. As the rotor is moved progressively nearer the vortex, the viewer observes the development of a sharp pressure spike on

an oscilloscope and hears simultaneously the developing impulsive noise produced by the interaction.