AN EXPERIMENTAL STUDY OF THE NONLINEAR STIFFNESS OF A ROTOR BLADE UNDERGOING FLAP, LAG AND TWIST DEFORMATIONS

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AMS Report No. 1194

January 1975

prepared for
U.S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Ames Research Center

Contract NAS 2-7615

ABSTRACT

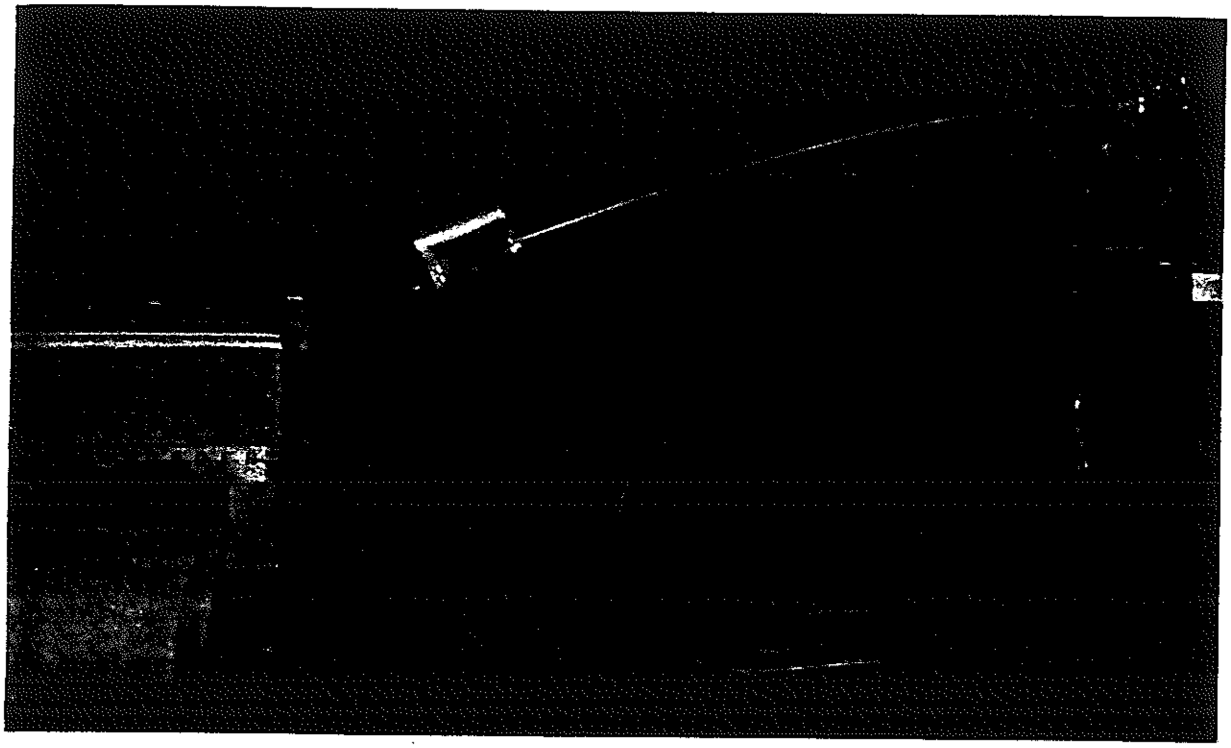
An experimental study of the large deformation of a cantilevered beam under a gravity tip load has been undertaken. The beam root is rotated so that the tip load is oriented at various angles with respect to the beam principal axes. Static twist and bending deflections of the tip and bending natural frequencies have been measured as a function of tip load magnitude and orientation. The experimental data are compared with the results of a recently developed non-linear structural theory and agreement is good for deflections small compared to the beam span with systematic deviations for larger deflections. These results support the validity and utility of the nonlinear structural theory for rotor blade applications.

1. INTRODUCTION

Hodges and Dowell[1,2] have formulated a nonlinear theory of hingeless rotor blade dynamics which indicates that the primary nonlinear effect is due to a nonlinear stiffness arising from mutual interaction among elastic flap, lag and twist. The goal of the present study has been to devise a simple experiment to measure the predicted effect and make a quantitative comparison of the results with the theoretical model.

The simplest relevant experiment would appear to be a non-rotating uniform beam under a static point load. A measurement of the variation of static deflections in flap, lag (and twist) and also flap and lag natural frequencies with static load allows an evaluation of the theory. A strictly linear model would predict a linear variation of flap and lag static deflections with load and no twist. Also a linear model would predict no change in natural frequencies with static load. On the other hand, the Hodges-Dowell nonlinear model predicts nonlinear variations of static flap, lag and twist deflection with static load and a change in natural flap and lag natural frequencies with load. Hence, the proposed experiment does provide a critical test of the nonlinear theory.

How to provide a static point force to the beam without introducing additional dynamic effects is a delicate question, however. For example, if one uses a weight and gravity to provide the force, its inertial mass would also change directly the dynamic characteristics of the rotor blade. Similarly, for a spring induced static force, dynamic effects are inevitably introduced as well. In principle for a relatively long, heavy, flexible beam the mass effect may be made as small as desired. Conversely, for a relatively short, stiff beam and a relatively long, soft spring the dynamic effect of the spring may be made as small as desired. In practice neither option leads to rotor blades (beams) of convenient dimensions. Hence, we have chosen to use a gravitational force and incorporate the inertial effects of the weight in our mathematical model. The latter, though quantitatively substantial, are nevertheless non-controversial and readily accounted for theoretically. To make the experiment as simple as possible a tip weight was used whose dimensions are small relative to the radius of the uniform, rectangular cross-section rotor blade. Hence, the torsional frequency is substantially higher (greater than a factor of ten) than either the flap or lag frequencies. In the following, the experimental apparatus and method is described in some detail. Next, the theoretical method is briefly reviewed and the experimental data are presented and compared with the available theory. Finally, conclusions are drawn and recommendations for further work made.



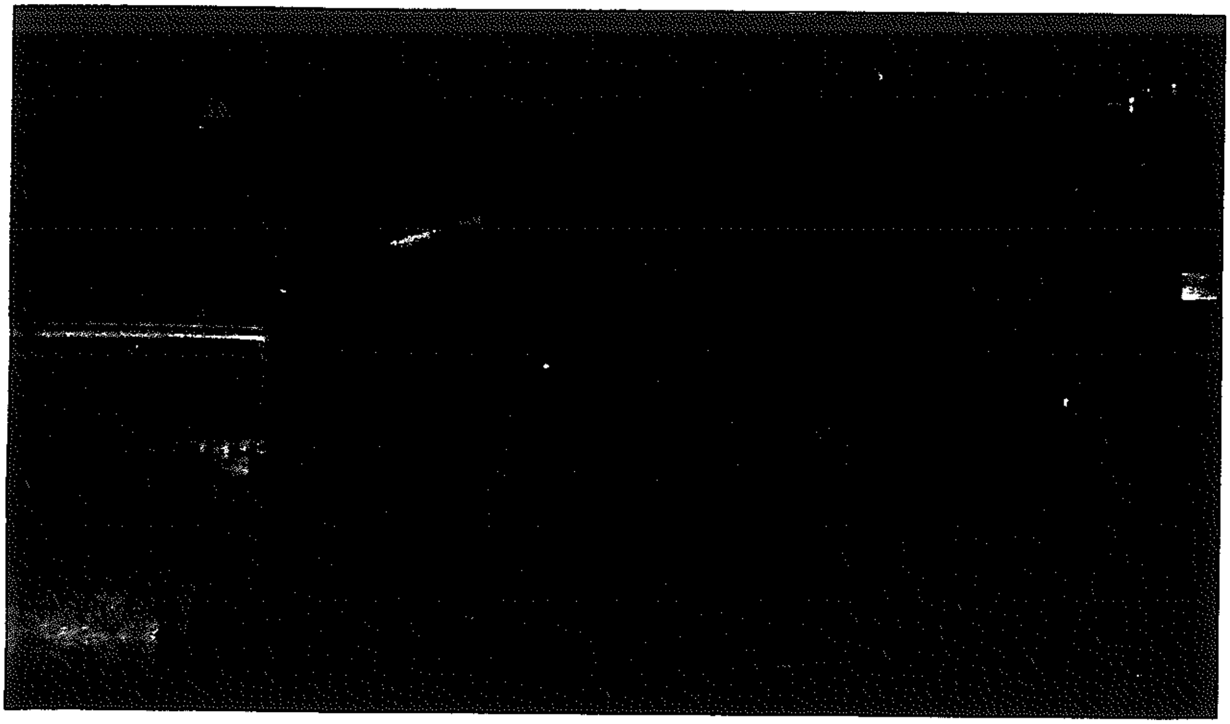


Figure 2.2. Photograph of Apparatus and Set-up for Frequency Measurement Experiments Showing Steady and Oscillating Conditions.

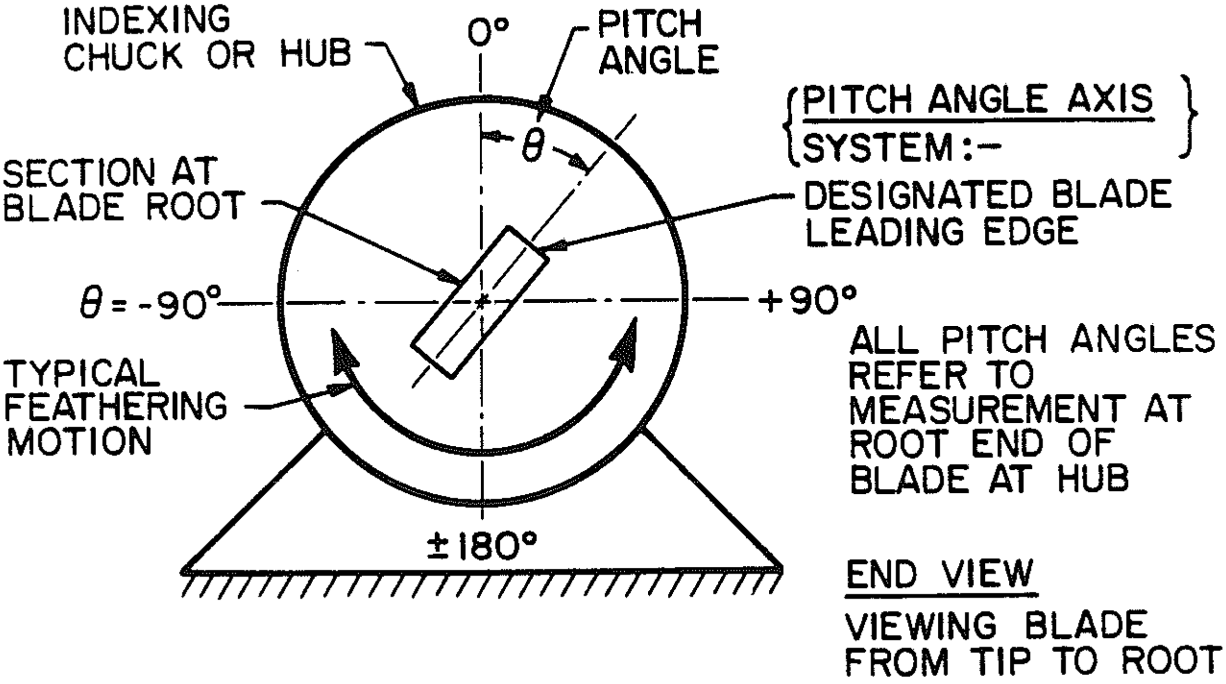


FIGURE 2.3· AXIS SYSTEM AND NOTATION

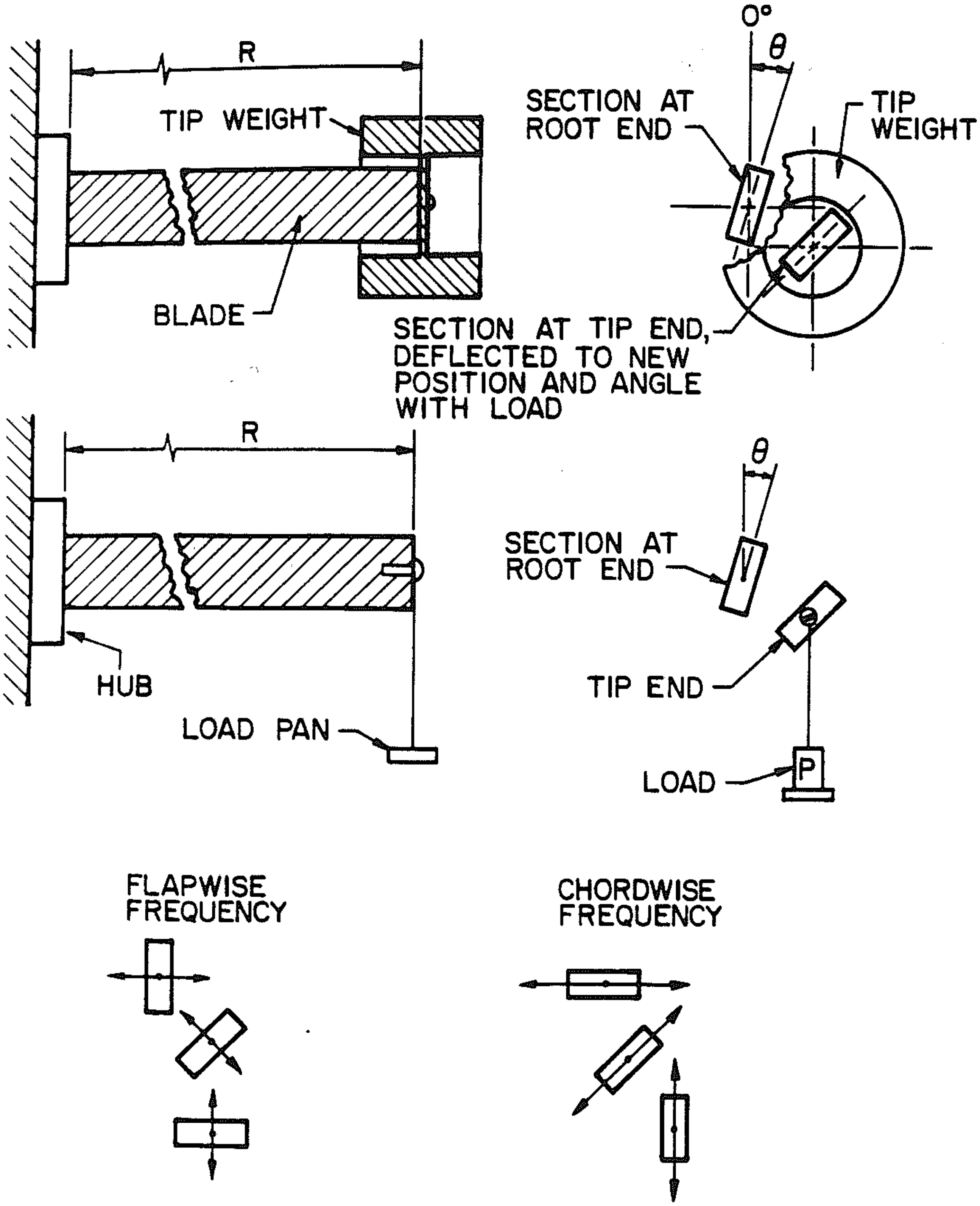


FIGURE 2.4 · SCHEMATIC SHOWING TYPICAL LOADING PROCEDURES AND EXCITATION/DEFLECTION SENSE

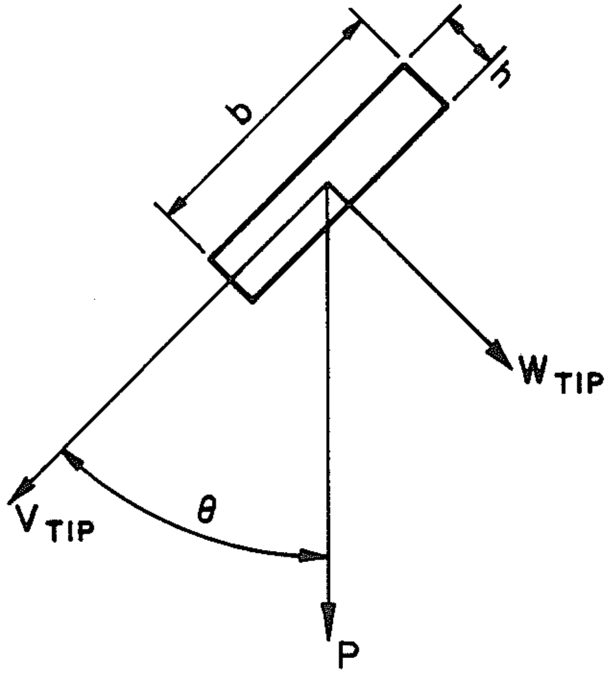


FIGURE 4.1 - GEOMETRY

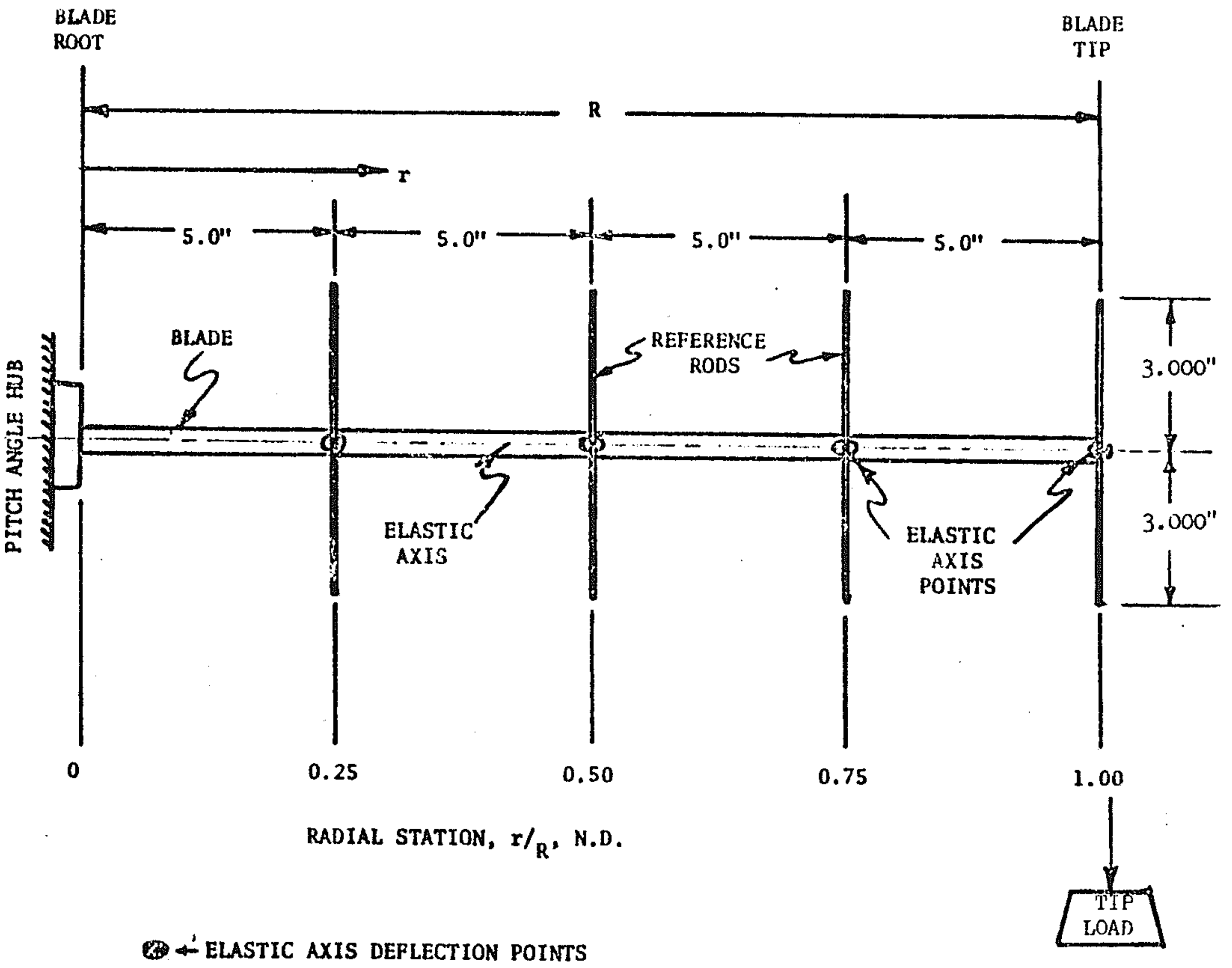


FIGURE 3A BLADE SCHEMATIC SHOWING REFERENCE RODS AND RADIAL STATION LOCATIONS

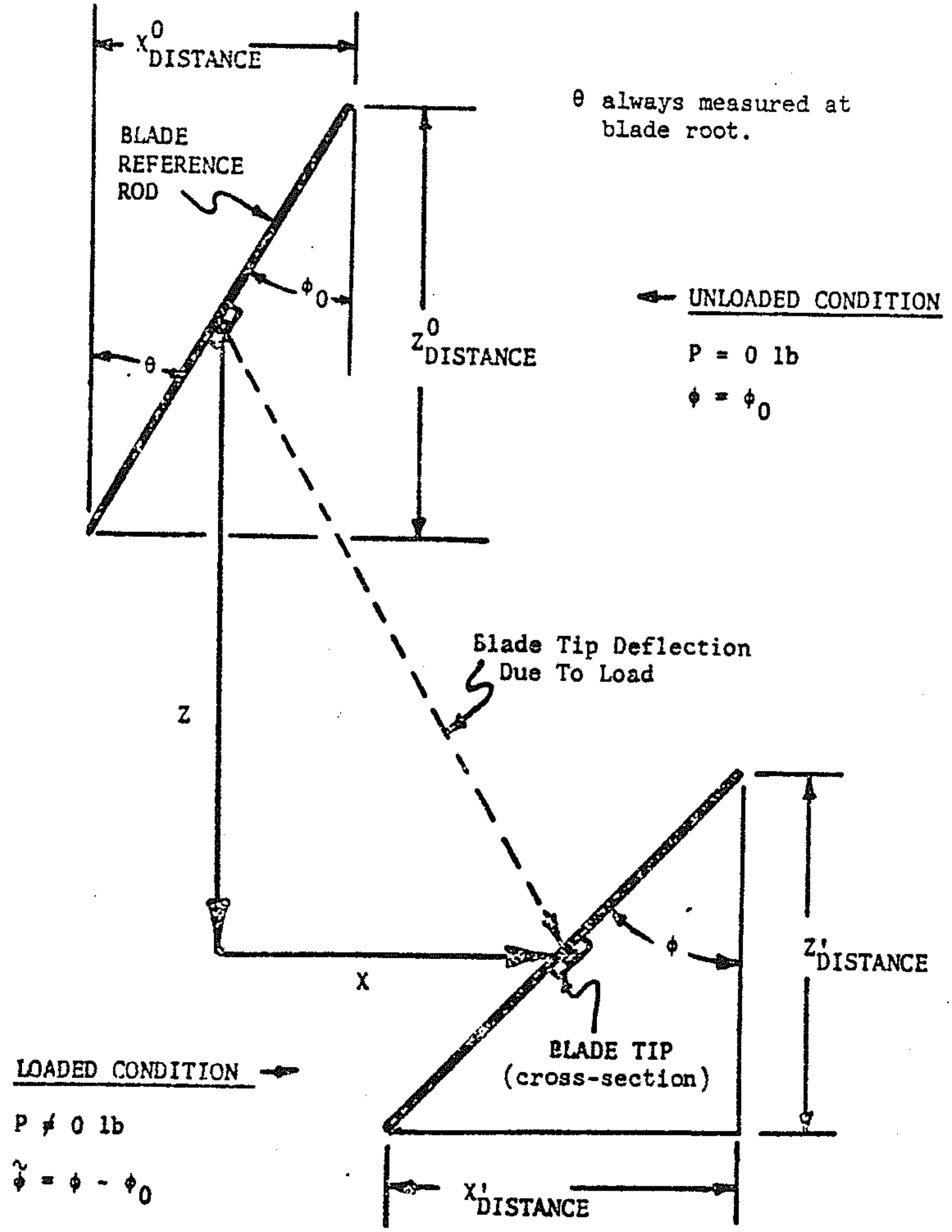


FIGURE 3C END VIEW SHOWING TYPICAL MEASURED QUANTITIES AND NOTATION AT BLADE TIP.

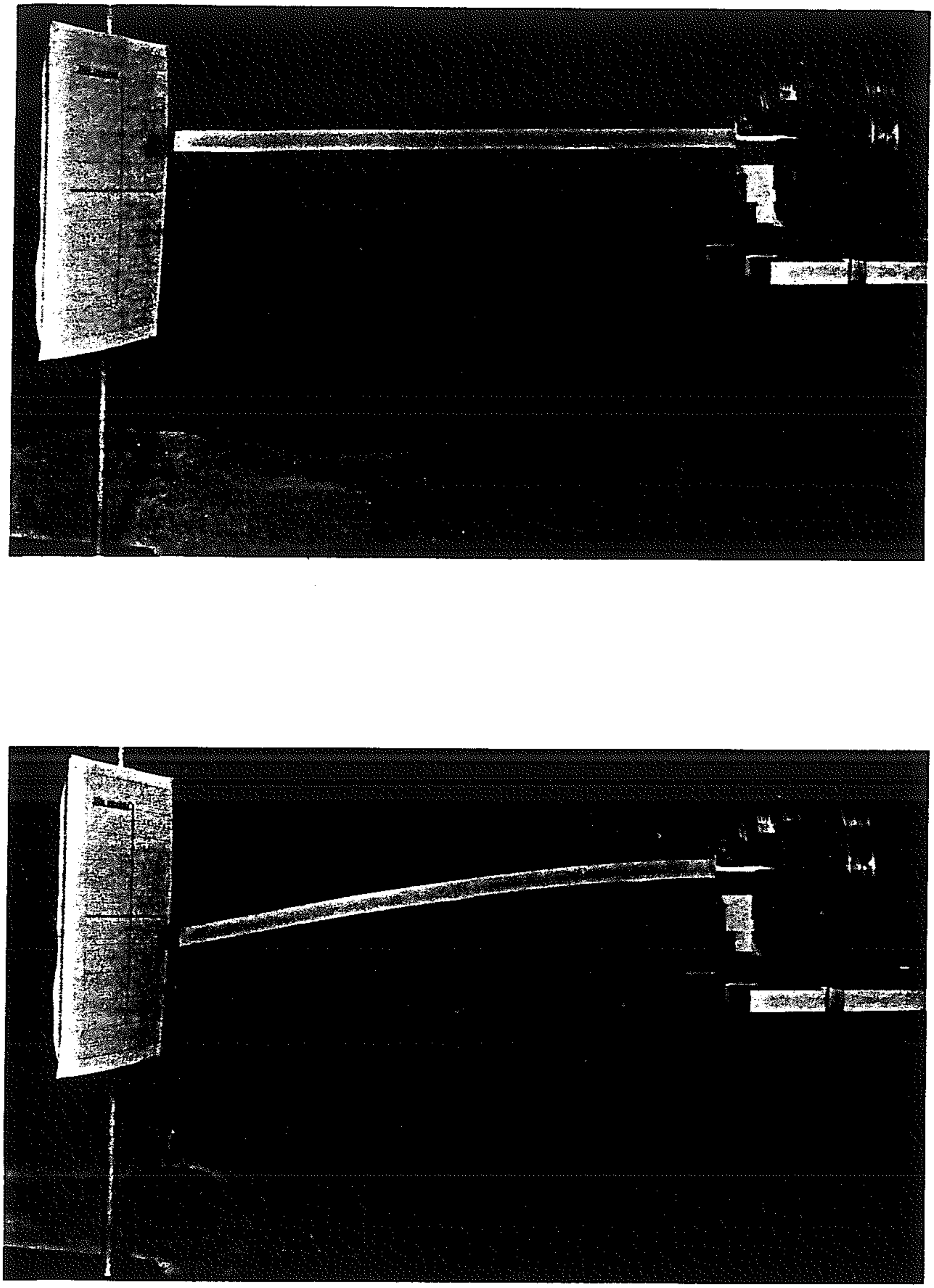


Figure 2.1. Photograph of Apparatus and Set-up for Static Deflection Experiments Showing Loaded and Unloaded Conditions.