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A NEW APPROACH TO ROTOR BLADE STALL ANALYSIS

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A NEW APPROACH TO ROTOR BLADE STALL ANALYSIS

by

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I. Introduction

Because of the limitations imposed on the performance of helicopters in high speed forward flight by blade stall the dynamic stall of helicopter rotor blades has been studied extensively. It has been shown (1) that the complex three dimensional flow over the rotor blades can be modeled by a two dimensional sinusoidally oscillating air stream over an airfoil oscillating in pitch. Many experimenters have studied the nature of this stall by observing pitching oscillating of airfoil profiles in steady flows and neglecting therby the effect of the periodic velocity changes in the free stream. A detailed summary of the results of these investigations has been presented by W. J. McCroskey in his 1976 ASME Freeman Scholar lecture (2).

Recent studies on stationary airfoils in oscillating flows (3,4) have shown that periodic changes in free stream velocity may have similar consequences as those caused by the pitching oscillation in steady flows. This suggests that for proper simulation of the helicopter rotor blade environment one must combine oscillations of the free stream velocity with synchronous fluctuations of the angle of attack with the maximum angle coinciding with the minimum velocity. Using facilities developed recently at IIT for such modeling, investigations of oscillating airfoils in fluctuating streams are now in progress. The results of the first set of these studies are described in the following.

II. Experimental Setup

The IIT facility used in the study presented here is a closed-circuit oscillating flow wind tunnel with 0.6 m x 0.6 m crossection, described in detail by Miller and Fejer (5). The oscillations of the free stream are generated by a set of rotating shutter blades mounted on horizontal shafts at the downstream end of the test section and driven by an AC motor through a gear box with adjustable speed ratio. Typical fluctuations of the velocity and static pressure produced in this manner in the test section are shown in Fig. 1. The periodic changes in angle of attack are accomplished by a mechanism devised by Hajek (6) which consists of a counter weight equipped crank, a connecting rod and an actuating lever which is attached to the airfoil. The length and position of these components relative to each other are adjustable providing thereby the capability of oscillating airfoil models with amplitudes of ±20° and mean angle of attack setup anywhere between 0° and 20°. The crank mechanism is

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driven by a printed circuit DC motor. Coupling of the motion of the airfoil with the oscillation of the free stream is accomplished electronically through an automatic phase locking circuit which controls the amplifier powering the DC motor. The input pulses actuating the circuitry are provided by two magnetic pick ups, one located on one of the shutter vanes, the other on the crank mechanism. The test setup is shown schematically in Fig. 2.

The instrumentation used in these experiments is made up basically of two systems: a surface pressure acquisition system comprising 24 static pressure orifices distributed chordwise on the surface of the airfoil and connected by flexible tubes of equal length through a Scanivalve S-9 pressure switch to a Setra-237 capacitance type pressure transducer mounted in a cavity inside the airfoil; a tungsten hot wire probe mounted on a remotely controlled traversing mechanism located on the top of the test section providing with the help of a constant temperature anemometer and a linearizer velocity measurements around the airfoil and in the wake. The mean velocity of the freestream was monitored by a Statham PM5TC pressure transducer, through a static pressure tap and a total head probe inside the tunnel (see Figure 2), while a Pitran PTM2 pressure transducer, mounted at the tunnel wall, measured the AC part of the unsteady freestream static pressure.

Signals proportional to the pressure obtained from the pressure transducer system were processed using the scheme shown in Figure 3. In most cases these signals were composed of periodic and random components. Periodic sampling and averaging techniques (eduction) were used to extract the periodic components. For a flow variable F(t), this averaging procedure is defined as

$$f_e(t) = \lim_{p \to \infty} \frac{1}{p} \sum_{n=1}^{n=p} F(t + nT) \qquad (1)$$

were p and n are integers and T is the time period of the freestream oscillation. The educted signals were compared with instantaneous signal traces shown by a DC coupled oscilloscope, and then recorded by a XY plotter.

The eduction was performed with the help of a Princeton Applied Research "Waveform Eductor" model TDH-9 which was used in the DC mode. The timing pulses triggering the eductor were provided by the magnetic pick-up referred to earlier. The number of cycles used for each eduction was of the order of 100, the actual number depending on the time required by the educted signal to reach a limiting value.

The educted pressure data were recorded as functions of time at discrete spacewise locations. Such educted plots were used to compute ensemble averaged "instantaneous" chordwise surface pressure distributions at various phases of the freestream oscillation cycle and corresponding angles of attack. Figures 4a and 4b show sets of ensemble averaged "instantaneous" boundary layer profiles Normal force coefficients at various instants of the oscillation cycle were determined by evaluating the areas enclosed by the instantaneous pressure coefficient distributions. The signals were also observed on a DC coupled oscilloscope and recorded photographically.

III. Experimental Results and Discussion

The experiments described here were made with a 0.3 m chord NACA 0012 airfoil in three modes of operation: (a) steady flow at an angle of attack $\alpha=6^\circ$ and free stream velocity of U=13.4 m/sec (Re = 270000); (b) stationary airfoil set at $\alpha=6^\circ$ in an oscillating free stream having a mean velocity of 9.3 m/sec and amplitude of oscillation of ±1.7 m/sec representing a reduced frequency k=0.224 (approx. 14 Hz); (c) airfoil oscillating about a mean angle of 10° with an amplitude of $\pm 6^\circ$ in a free stream having a mean velocity of 8.4 m/sec and oscillating with an amplitude of ±2.4 m/sec with both oscillations having the same reduced frequency k=.224. The steady flow tests at fixed angle of attack were providing the reference base for comparison with changes due to the fluctuations that were under study.

Good agreement was found between the performance of the stationary airfoil in steady flow and in oscillating flow i.e., only minor differences were found between the dimensionless pressure distributions (based on the instantaneous velocity) at the various instants of the cycle and the pressure distribution obtained in steady flow. This can be readily seen from the pressure distribution shown for an angle of attack of 11° in Fig. 5 which has been obtained by Saxena (3). Thus the oscillating flow can be treated under these conditions as quasi-steady.

When there is a simultaneous oscillation of the flow and the airfoil the flow is no longer quasi-steady as readily determined by comparing the instantaneous pressure distributions shown in Fig. 4a when the angle of attack is increasing with the pressure distribution at the same instantaneous angle of attack when the angle of attack is decreasing (Fig. 4b). As a consequence of these differences there appears a hysteresis loop when the normal force coefficient C_N is plotted against the angle of attack (Fig. 6). When the oscillation of the airstream is stopped the hysteresis loop disappears and the flow becomes more or less quasi-steady. This can be implied from Fig. 7 which shows the periodic changes in C_N with α that have been observed by Carr (7) on an NACA 0012 airfoil oscillating in steady flow at the same reduced frequency as used in the present tests with an amplitude of $\pm 6^\circ$ around a mean angle of 11°.

The dramatic departure from quasi-steady behaviour and the hysteresis in the lift curve associated with it is a well known feature of the dynamic stall of airfoils and has been investigated in detail by McCroskey and Philippe (8) and others. However the interaction between the flow around the oscillating airfoil and the oscillating stream documented here for the first time is a matter for concern. Since this interaction may produce, especially near stall, a significant departure from the expected behaviour of a given profile studies of the dynamic stall of helicopter blade profiles and of the events leading up to it should be made in the presence of oscillations of the airfoil as well as the flow.

IV. Uncertainty Estimate

The data used in the preparation of this paper are from two sources: surface pressures measured with transducers and flow velocities measured with hot wires. The accuracy of the pressure data is approximately ±1.5%, that of the velocity data is approximately 0.5%.

V. Acknowledgement

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VI. References

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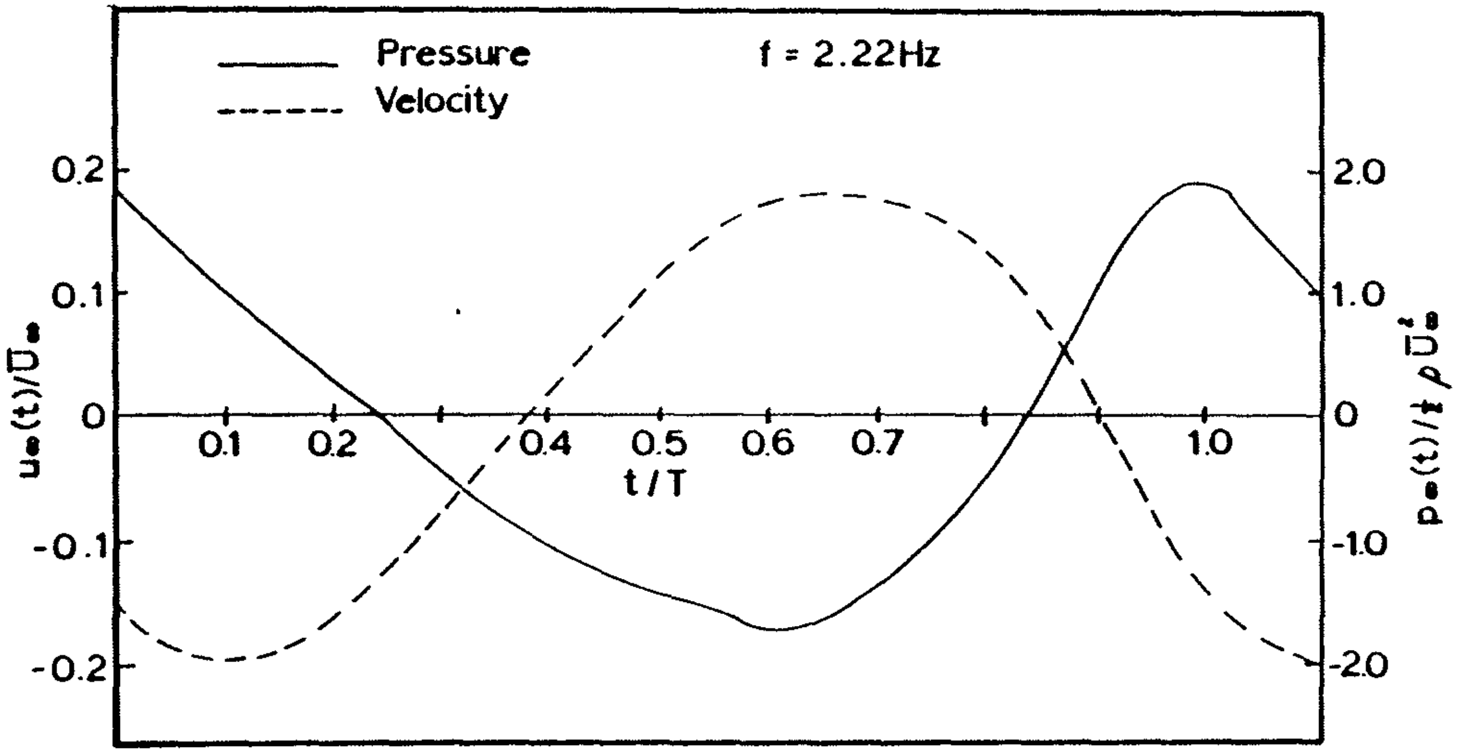

Figure 1. Freestream Velocity and Static Pressure Oscillations in Test Section, f = 2.22 Hz

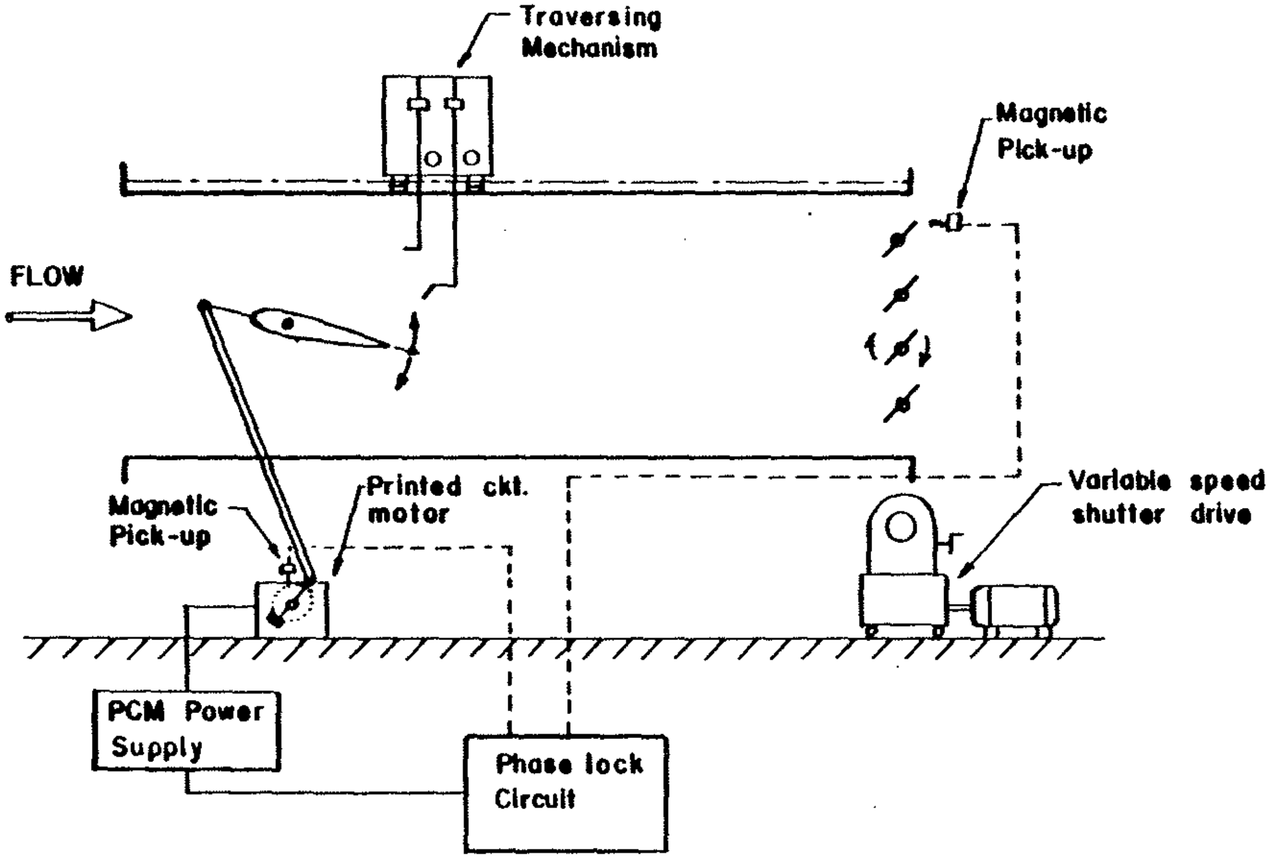

Figure 2. Schematic of Proposed Setup

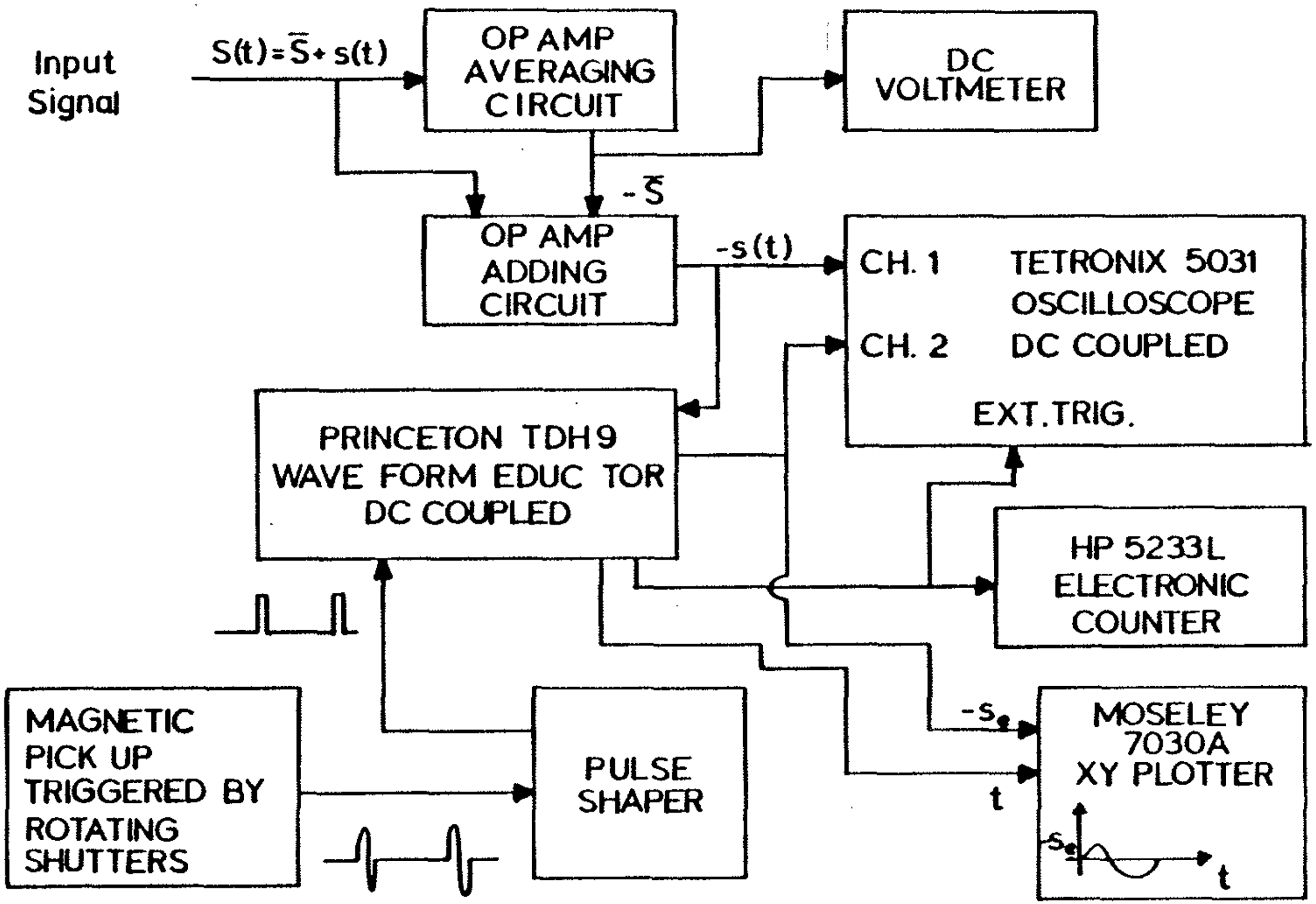

Figure 3. Instrumentation Schematic for Signal Processing

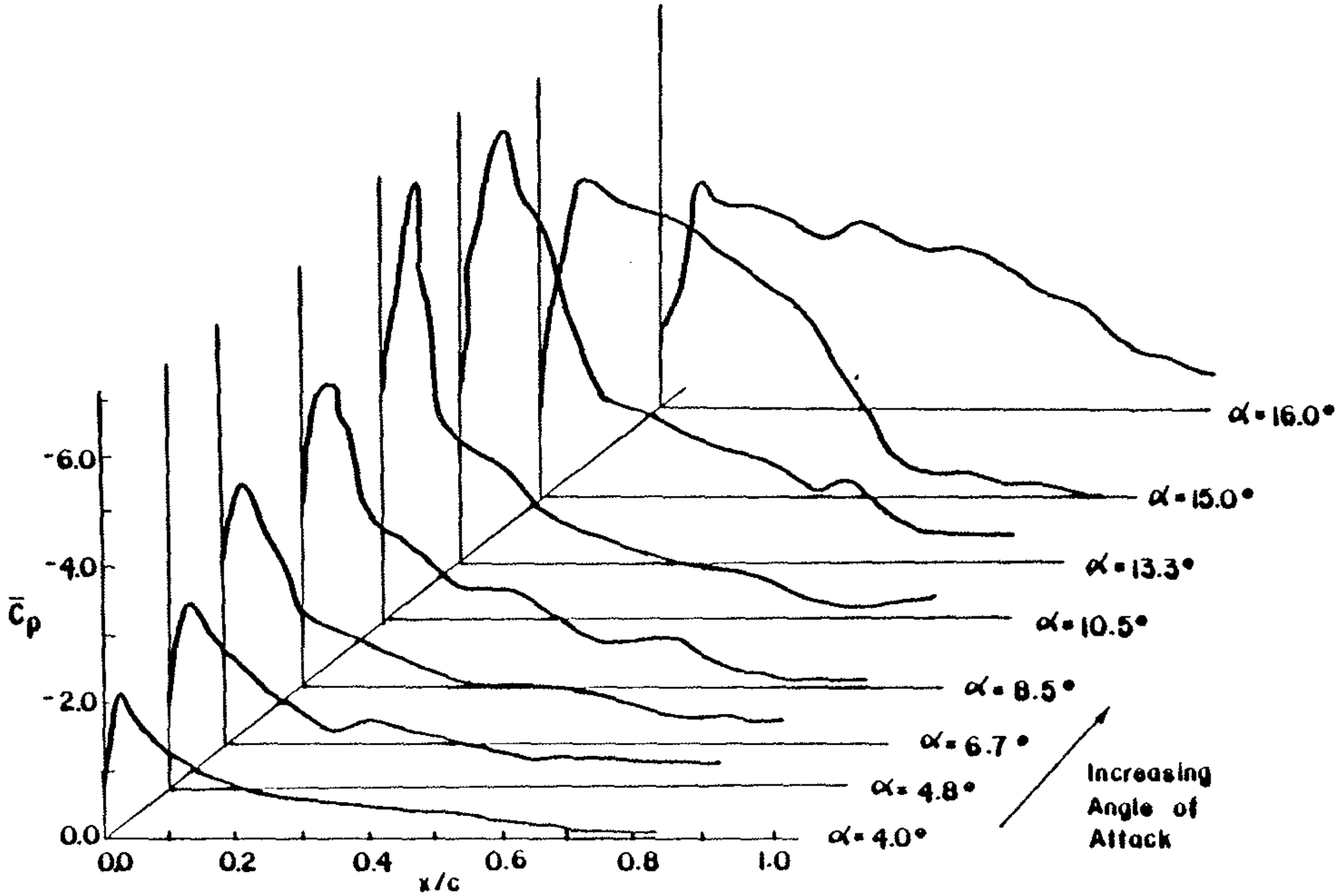

Figure 4a. Pressure Distribution Changes with Increasing Angle of Attack

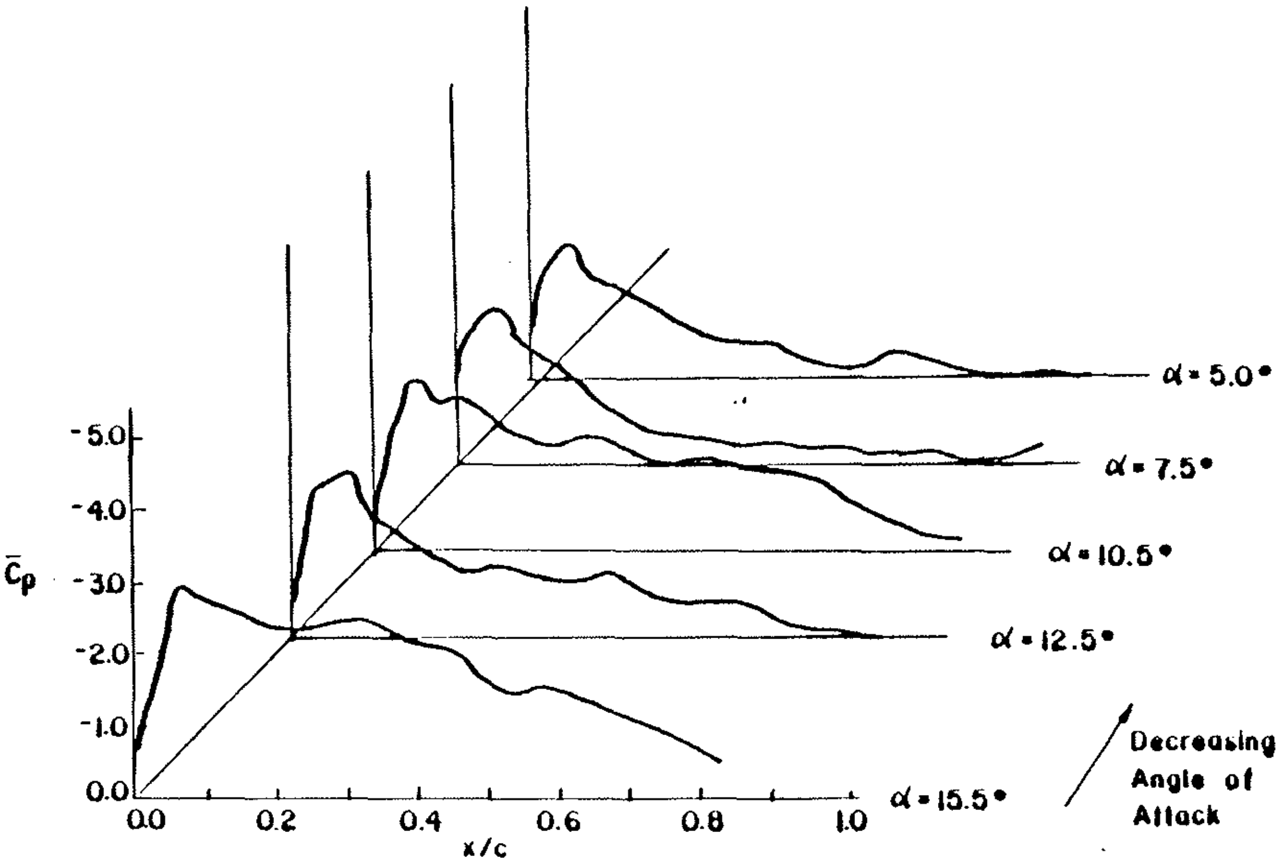

Figure 4b. Pressure Distribution Changes with Decreasing Angle of Attack

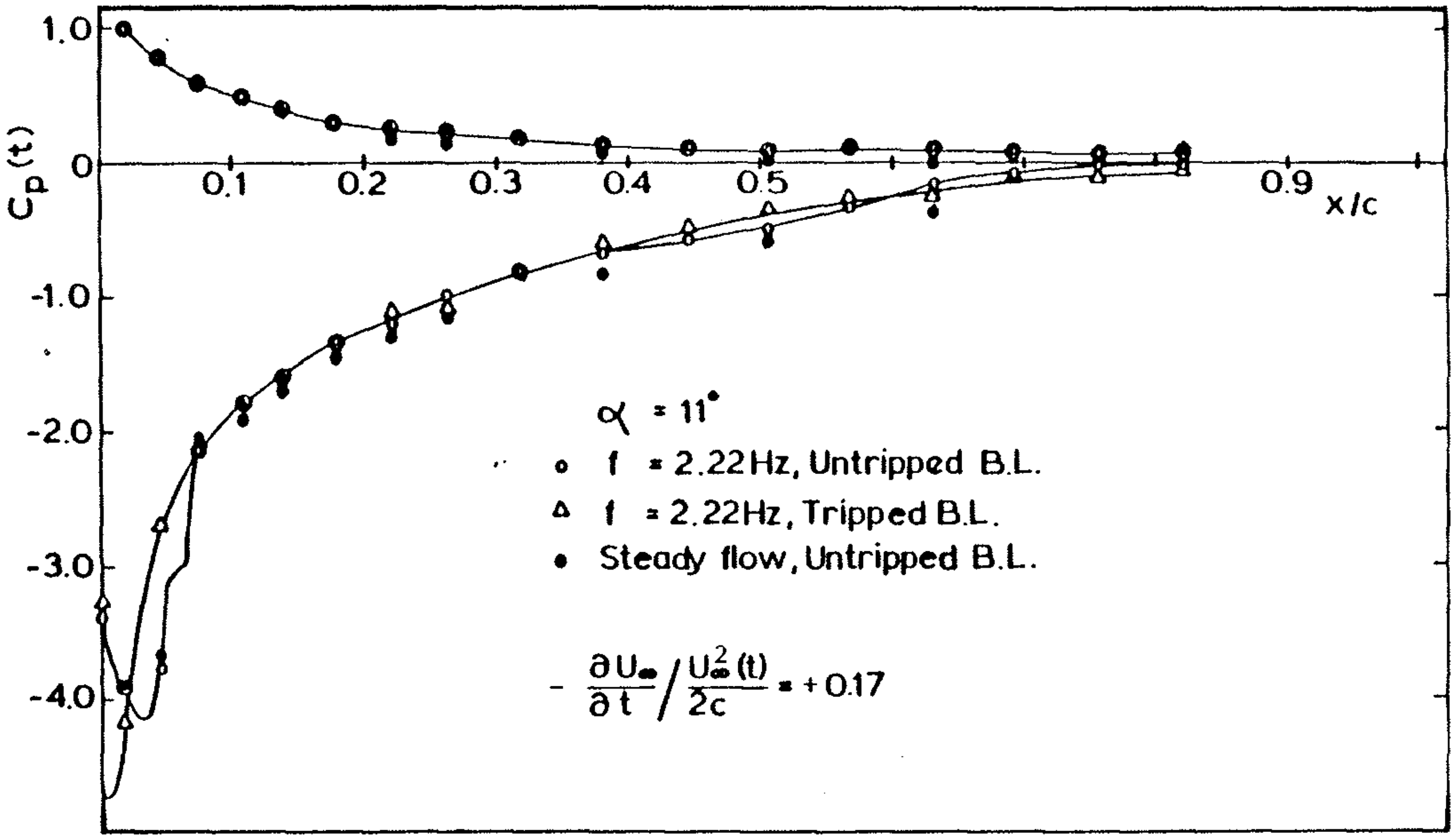

Figure 5. Chordwise Distribution of Instantaneous Pressure Coefficients at the Instant of Maximum Flow Deceleration with an Unsteady Adverse Pressure Coefficient Gradient of 0.17

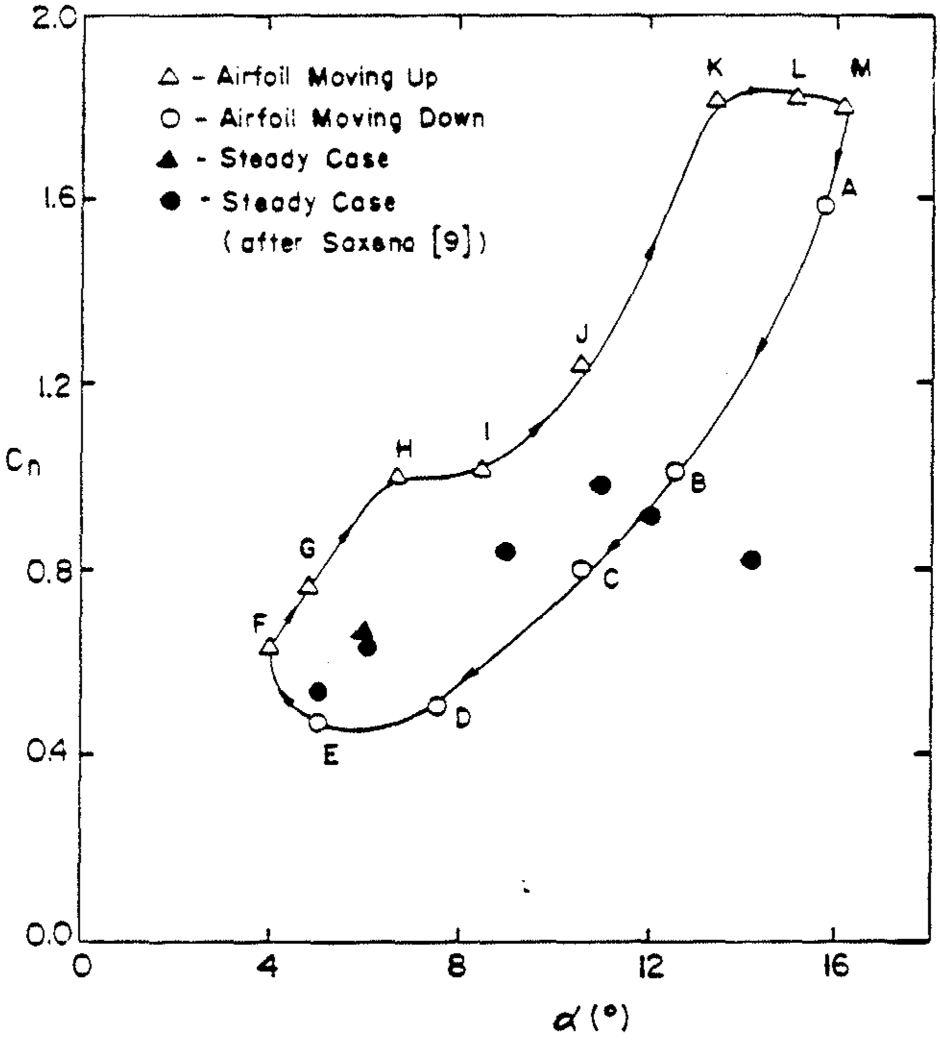

Figure 6. Force Coefficient on NACA 0012 Airfoil Oscillating in a Fluctuating Stream

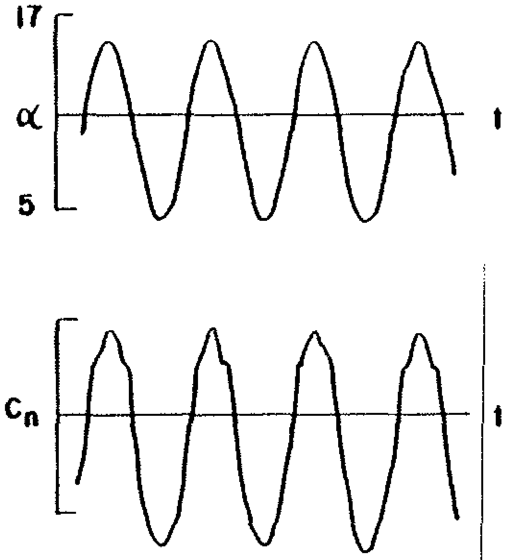

Figure 7. Oscillations of α and C_N for NACA 0012 Airfoil in a Steady Stream