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A Stall Flutter Of Helicopter Rotor Blades: A Special Case Of
The Dynamic Stall Phenomenon

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STALL FLUTTER OF HELICOPTER ROTOR BLADES: A SPECIAL CASE OF THE DYNAMIC STALL PHENOMENON*

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Introduction

Recent studies described in Refs. 1 and 2 have shown that the negative damping in pitch associated with airfoils oscillating at high mean angles of attack can lead to torsional instability of helicopter rotor blades under certain conditions. The mechanism of the instability was shown in Ref. 2 to consist of the adverse time phasing of the aerodynamic pitching moment associated with the loss of blade bound vorticity as the dynamic stall occurs.

Subsequent unpublished tests, Ref. 3, have indicated that the same mechanism is found for the case of airfoil linear angle of attack change through high angles of attack. The nature of these results indicates several important conclusions not only with respect to the analysis of rotor blade stall flutter instability, but also with respect to the general nature of the aerodynamic loading of an airfoil experiencing transient angle of attack changes of large magnitude.

Discussion

A typical time history of the pressure variation acting at one spanwise station of a model helicopter rotor blade experiencing stall-induced oscillations while operating in the static thrust condition is shown in Fig. 1, reproduced from Ref. 2. The figure shows the initiation of a pressure disturbance in the region of the leading edge as the blade section approaches maximum angle of attack, and the subsequent motion of this disturbance in the chordwise direction, at considerably less than free stream velocity. The character of the disturbance suggests that it consists of free vorticity introduced into the blade flow field from the neighborhood of the blade leading edge as the blade loses bound vorticity during the dynamic stall process. The results indicate that the dynamic stall phenomenon has far different characteristics than those associated with the classic trailing edge separation during static stall of a blunt airfoil.

Subsequent integration of the pressures shown in Fig. 1 led to the quarter chord pitching moment time history shown in Fig. 2. This figure illustrates the origin of the stall flutter

instability. The negative pressure peak generated by the pressure disturbance moving aft from the leading edge leads to a nose down pitching moment component in phase with the nose down motion of the airfoil. Since this nose down moment is generated once per pitching cycle, it is seen that the nonlinear aerodynamic moment variation due to pitching motion at high mean angles of attack is such as to sustain the motion. This self-excited, self-limiting motion is termed "stall flutter".

Another method of presenting the pitching moment data is shown in Fig. 3, in terms of pitching moment versus pitching angle. It is seen that the nose down moment occurring in phase with the airfoil motion leads to the hysteresis loop in the moment curve. It can be shown that the area of counter-clockwise loops in the curve represents energy removed from the motion, while the area of clockwise loops represents energy added to the motion. When the area of the two loops is equal for a given blade section, that section is capable of self-sustained motion at the given amplitude and reduced frequency.

The above results suggested that the same stall mechanism would be found in the general case of large transient blade angle of attack changes. Accordingly, an experimental investigation was commenced at MIT to study large linear angle of attack changes of a two-dimensional wing (Reference 3). Preliminary results are shown in Figs. 4 to 6 for the case of a nearly linear angle of attack change to a maximum angle of thirty degrees (subsequently held constant) at a maximum pitching velocity of ten radians per second. The variation of airfoil lift coefficient with time and associated angle of attack is shown in Fig. 4. Comparison of the dynamic lift variation with the corresponding values of static lift at the same angles of attack indicates that the maximum dynamic lift achieved is substantially higher than the maximum static lift, and that a high value of lift is sustained for several hundredths of a second (approximately equivalent to one eighth of a rotor revolution) subsequently dropping off to the steady state value.

The corresponding pitching moment variation is shown in Fig. 5. A very large, sustained, transient nose down moment is seen to occur in the high angle of attack region.

The origin of these effects is shown in

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the corresponding chordwise pressure variations shown in Fig. 6. Dynamic stall begins to occur at $\alpha = 20^\circ$, as indicated by the drop in leading edge suction of the $\alpha = 21.6^\circ$ pressure trace. A negative pressure disturbance moving aft from the leading edge simultaneously increases the suction in the mid-chord region. Subsequently, at $\alpha = 29.2^\circ$, the pressure disturbance has moved further aft, and is still of considerable magnitude. The delay in the occurrence of stall (as evidenced by loss of leading edge suction) due to the high rate of change of angle of attack and the sustained upper surface suction associated with the chordwise passage of the vorticity shed during the stall process, both contribute to the high sustained lift values of Fig. 4. In addition, the increasingly aft center of pressure due to the aft motion of the shed vorticity generates the extreme nose down pitching moment of Fig. 5. Finally, the nature of the pressure distribution is such as to indicate greatly increased pressure drag on the airfoil. This drag may be a transient analog of the "vortex drag" due to the leading edge vortex of a slender delta wing at low speed and high angle of attack.

Conclusions

The above results lead to several important conclusions with respect to stall flutter and airload prediction of high speed and/or highly loaded helicopter rotor blades.

1. The stall of an airfoil section during rapid transient high angle of attack changes is delayed well above the static stall angle and results in a large transient negative pressure disturbance leading to large transient lift and nose down pitching moment.
2. The magnitude of the pitching moment of (1) is such as to generate substantial nose down pitching displacements of the blade. These pitching displacements can substantially alter the angle of attack distribution of the rotor blade based on steady state conditions used in the stall flutter analyses of Refs. 1 and 2. It appears that transient pitching displacement of the blade in response to the initial stall-induced pitching moment acting on the blade should be included in subsequent stall flutter analyses.
3. The dynamic stall phenomenon of a helicopter rotor blade can be separated into three major phases:
 - a) A delay in the loss of blade leading edge suction to an angle of attack far above the static stall angle, with associated airloads of the type described by classical unsteady airfoil theory.

- b. A subsequent loss of leading edge suction accompanied by the formation of large negative pressure disturbance (due to the shedding of vorticity from the vicinity of the blade leading edge) which moves aft over the upper surface of the blade. Associated with this phase are high transient lift, drag, and nose-down pitching moment associated with the greatly altered pressure distribution on the airfoil.

- c. Complete upper surface separation of the classic static type, characterized by low lift, high drag, and moderate nose-down pitching moment.

References

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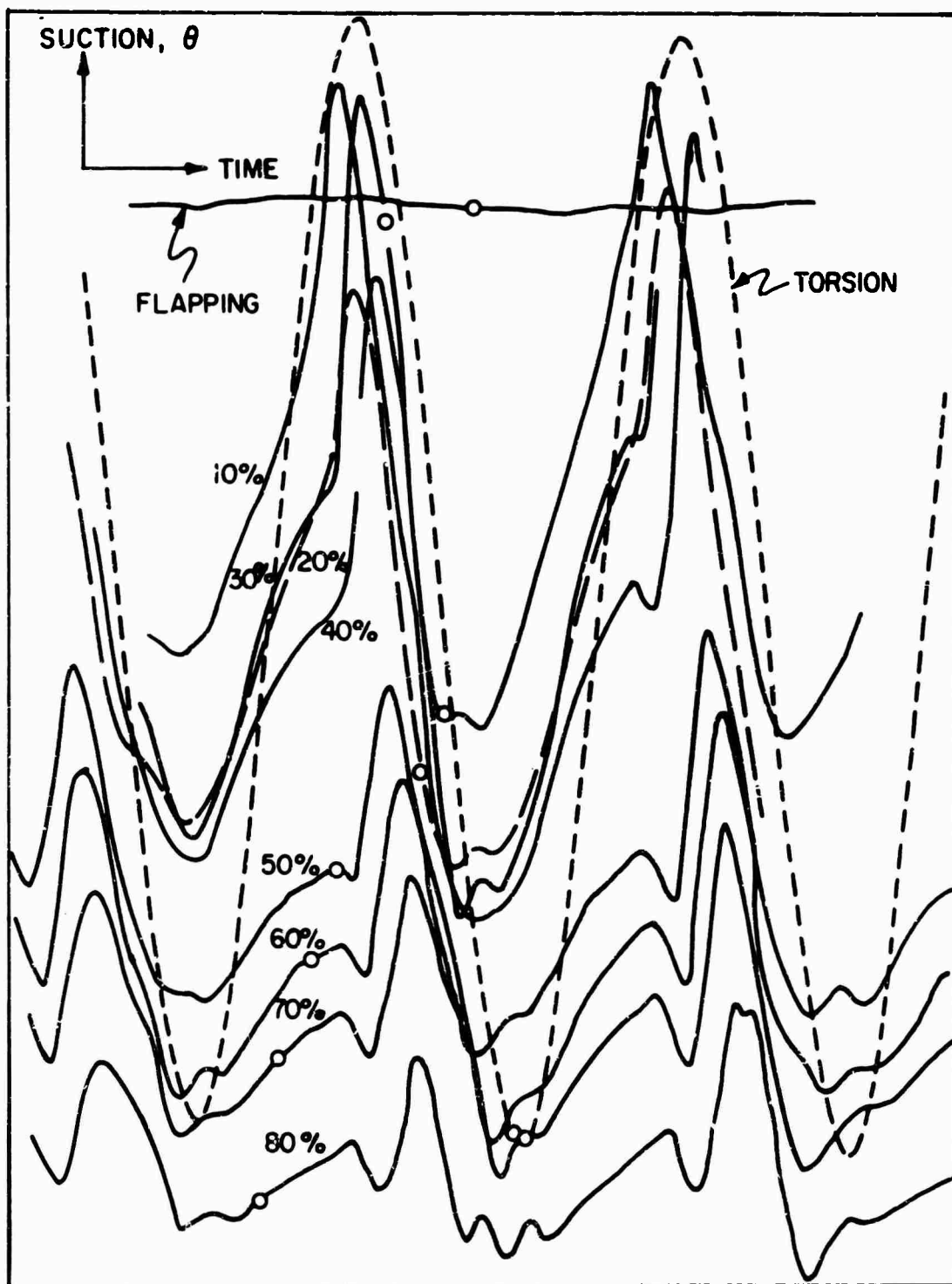


FIGURE 1. PRESSURE DATA

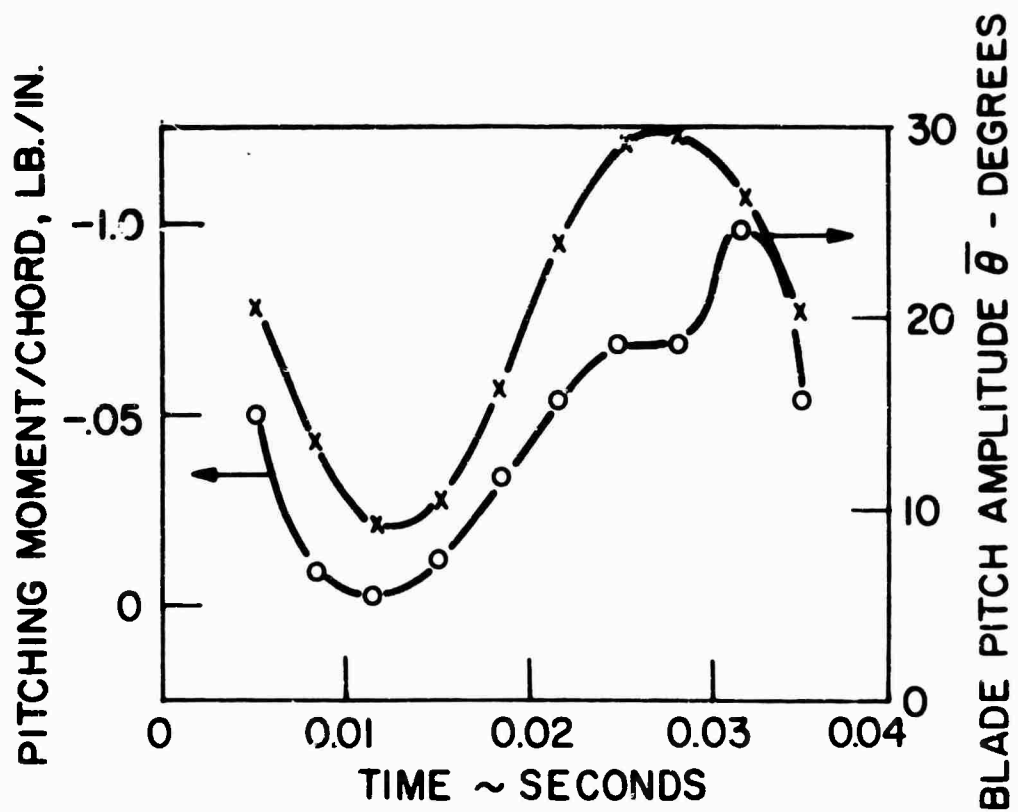


FIGURE 2

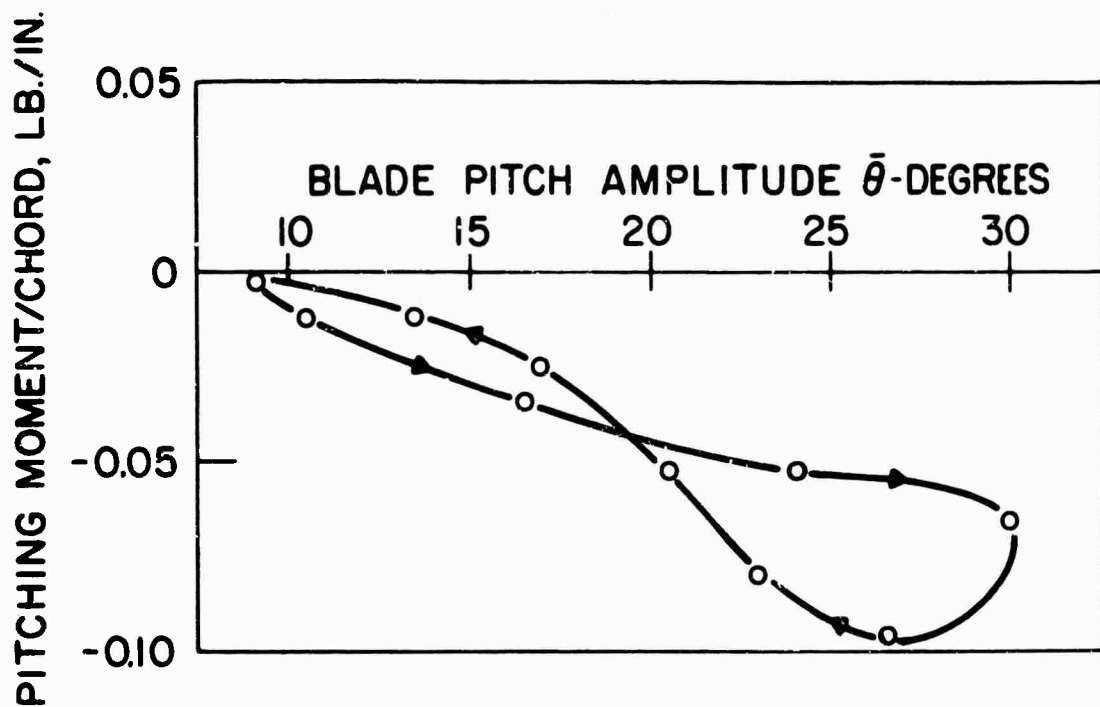


FIGURE 3

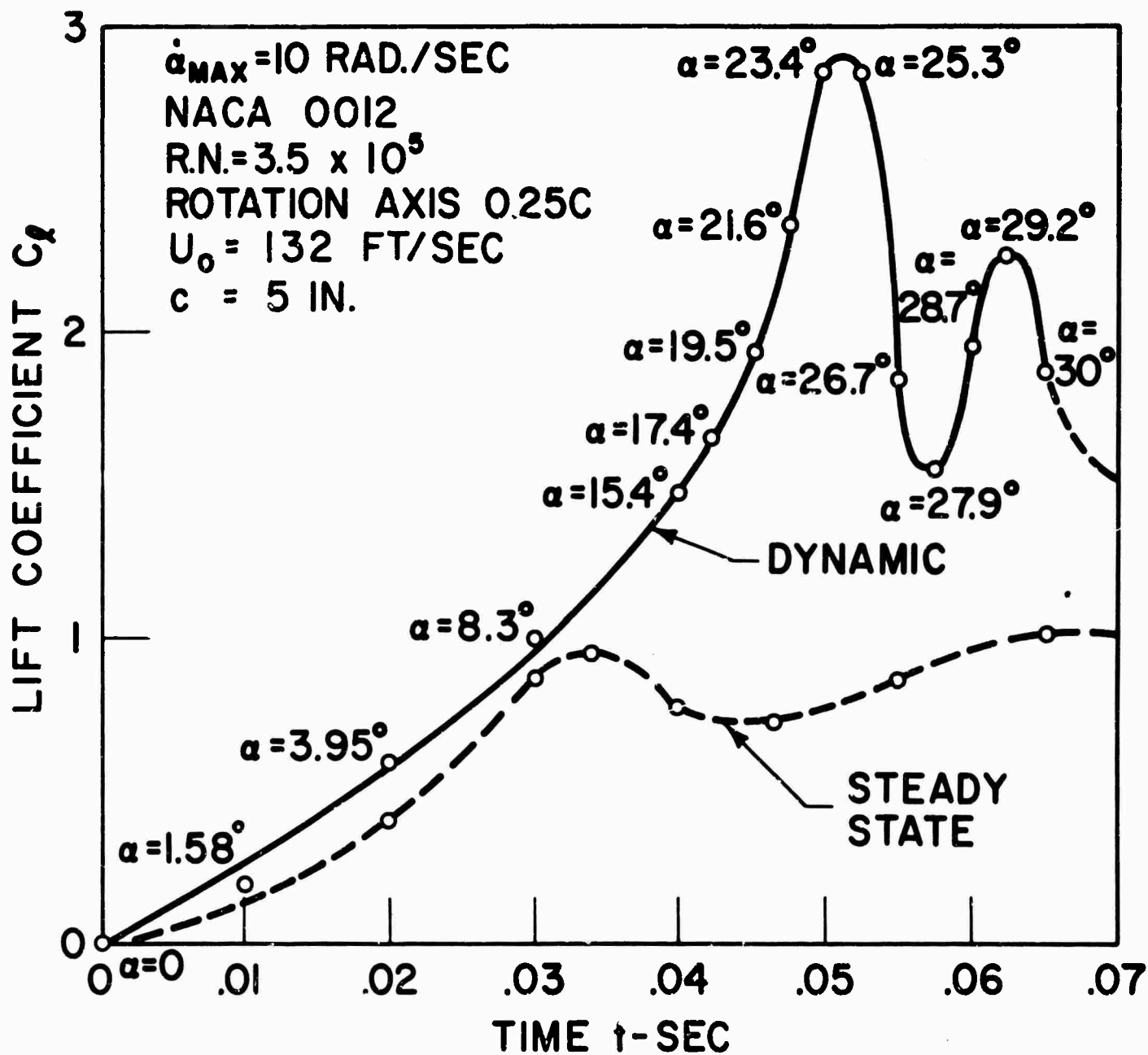


FIGURE 4. LIFT COEFFICIENT vs TIME AND ANGLE OF ATTACK

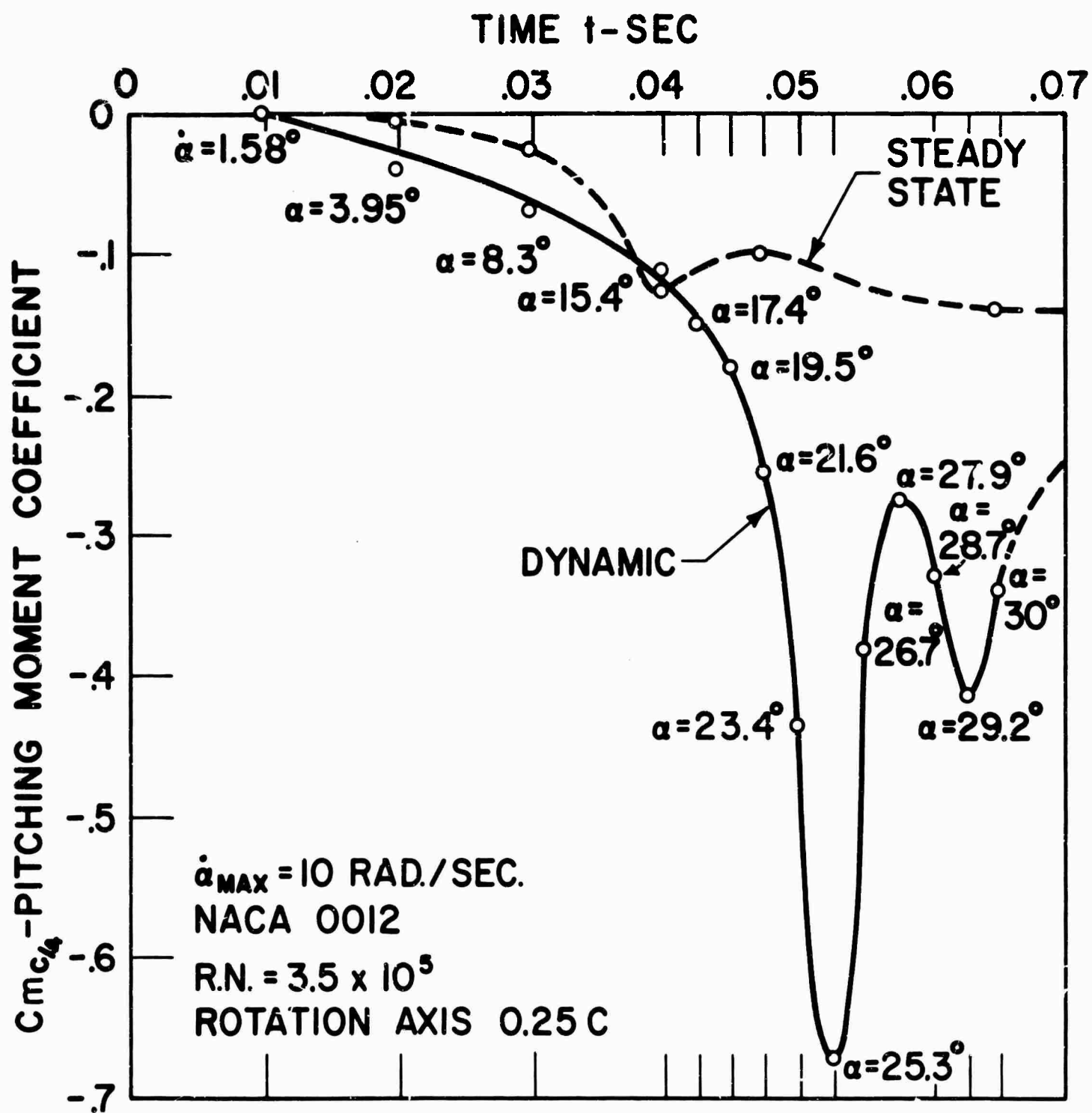


FIGURE 5. PITCHING MOMENT COEFFICIENT vs TIME AND ANGLE OF ATTACK

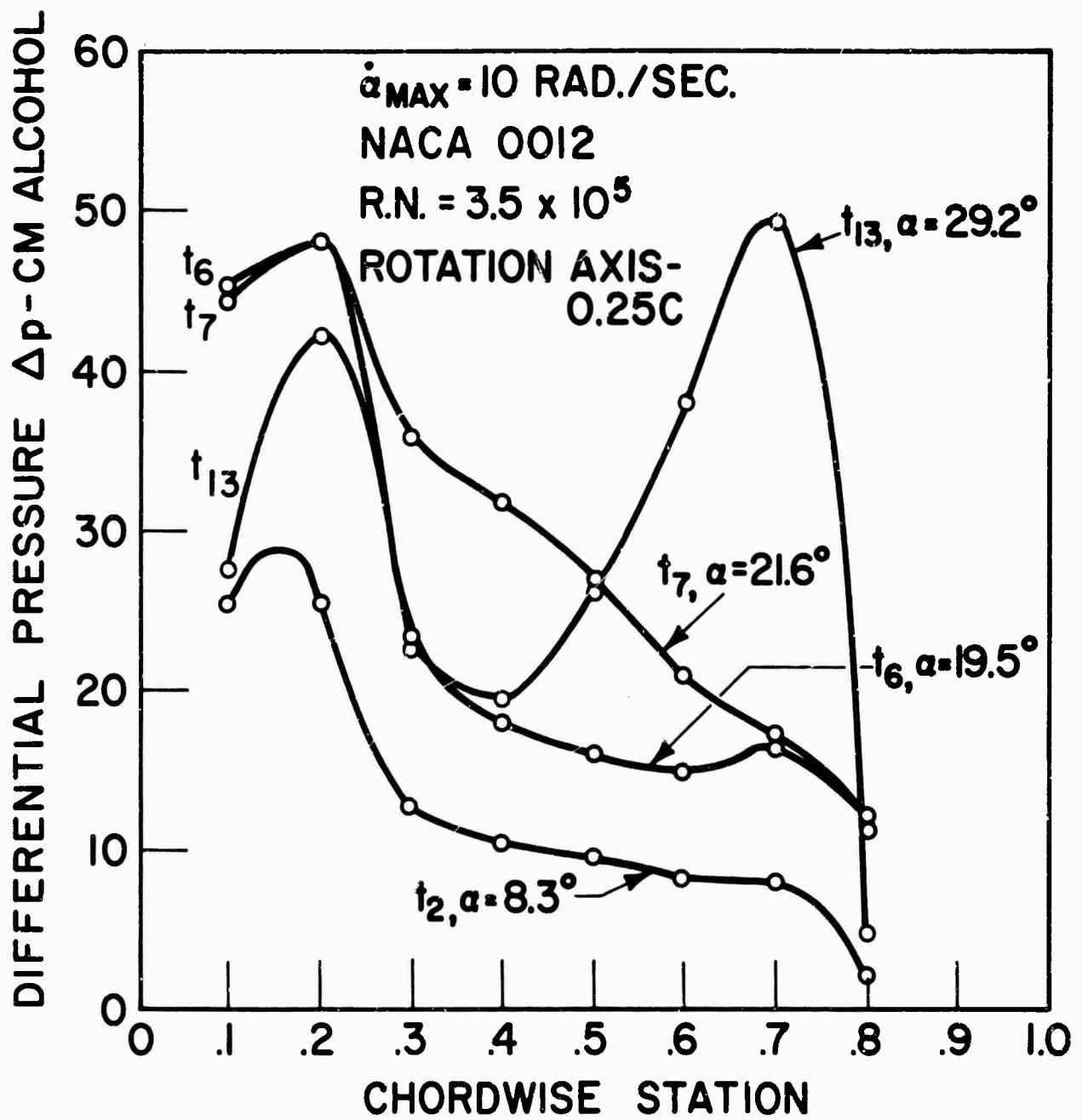


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<p>Recent studies have shown that the negative damping in pitch associated with airfoils oscillating at high mean angles of attack can lead to torsional instability of helicopter rotor blades under certain conditions. The mechanism of the instability was shown to consist of the adverse time phasing of the aerodynamic pitching moment associated with the loss of blade bound vorticity as the dynamic stall occurs.</p> <p>Subsequent unpublished tests have indicated that the same mechanism is found for the case of airfoil linear angle of attack change through high angles of attack. The nature of these results indicates several important conclusions not only with respect to the analysis of rotor blade stall flutter instability, but also with respect to the general nature of the aerodynamic loading of an airfoil experiencing transient angle of attack changes of large magnitude.</p>		
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