Engineering Notes

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Experimental Investigation of Dynamic Stall for a Pitching Airfoil

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Introduction

THE experimental study of dynamic stall can be traced back to at least 1932 in the work of Kramer,[1] and has appeared with increasing abundance up to the present One might think that the literature need not be burdened with still another report but for two facts: first, the inconsistency of the findings (noted as early as 1942 by Scheubel[2]); and second, the lack of consistent experimental conditions In regard to the second, the experimental conditions range from the effect of a constant rate of change of angle-of attack (constant $\dot{\alpha}$) gust[1], to constant $\dot{\alpha}$ pitching at various points of rotation,[3] to various nonconstant $\dot{\alpha}$ pitching, the most common of which being oscillatory motion [4]

In order to provide a consistent set of data for theoretical studies,[5] we felt it necessary to provide our own set of data for the narrow case of dynamic stall for an airfoil pitching about the midchord at constant rate in a uniform flow. Because the initial theoretical studies focused on the unsteady boundary layer, we were interested in dynamic separation as an indicator of dynamic stall rather than dynamic stall itself In this regard, we arbitrarily defined stall to be the angle at which the flow was just separated at the quarter-chord To determine this angle we used both flow visualization and pressure data In order to obtain a wide range of Reynold's numbers, smoke visualization was used at the lowest velocities (where pressure information was below the level of reliable measurement), and pressure data were used at the higher velocities (where it was difficult to interpret the smoke traces) In the intermediate velocity range both smoke and pressure data were used

Experimental Approach

A smoke tunnel with a 5 ft × 3ft × 0 25 ft test section and a velocity range from approximately 10 ft/s to approximately 50 ft/s was used A 1 02 ft chord NACA 0015 airfoil instrumented with four 2-psi (full range) pressure transducers located at 6 2, 14 8, 21 7, and 34 2% chord, respectively, was made to rotate about a rotation shaft located at the midchord The airfoil assembly was mounted via the shaft at approximately the center of the test section and spanning the width of the tunnel A high torque, constant speed motor was attached to the rotation shaft to provide constant $\dot{\alpha}$ pitching rates from 30-90 deg/s, depending on the voltage applied Angular position information was provided by sensing the wiper voltage of a ten turn potentiometer attached to the rotation shaft via a gear train

A high speed motion picture camera equipped with an internal system for placing timing marks on the film was used to record the flow visualization data The angular position, separation point, and time data could be obtained by frame by frame viewing of the developed film In this way flow velocity, angular rate, and dynamic angle of attack for separation at the quarter chord $(\alpha_s)_{dyn}$, were obtained

Pressure and position data were obtained using a microcomputer based data acquisition system built around an S 100 bus box housing a single card Z 80 computer, 64K RAM board, disk-controller board, and an A/D converter board. Software was written in MicroSoft FORTRAN (with a single machine language subroutine for addressing the A/D channels) to collect the data (including 4 pressure transducer voltages, position voltage, and internal clock time) at the rate of approximately 4000 samples/s, write the data to disk, and ultimately reduce the data Correlation between smoke data and pressure data was accomplished for those runs where both were collected by sinking the position data For more details see Ref 6

Results

A total of 76 data runs were made ranging in flow velocity from 12 3-47 ft/s. Of these runs 21 were with smoke data only (12.3-17.6 ft/s), 39 were with both smoke and pressure data (18 34.7 ft/s), and 16 were with pressure data only (42.8-47 2 ft/s) For all runs, except those with pressure data only, each flow velocity and angular rate combination was run three times, and for the pressure only cases each combination was run two times For each flow velocity a static separation at quarter-chord angle, $(\alpha_s)_{st}$, was determined prior to collecting $(\alpha_s)_{dyn}$ data. After averaging the duplicated runs, a total of 28 cases were obtained

By comparing the results of the pressure data to that of the smoke data, where both were available, we were able to learn the characteristics of the pressure signal which indicated

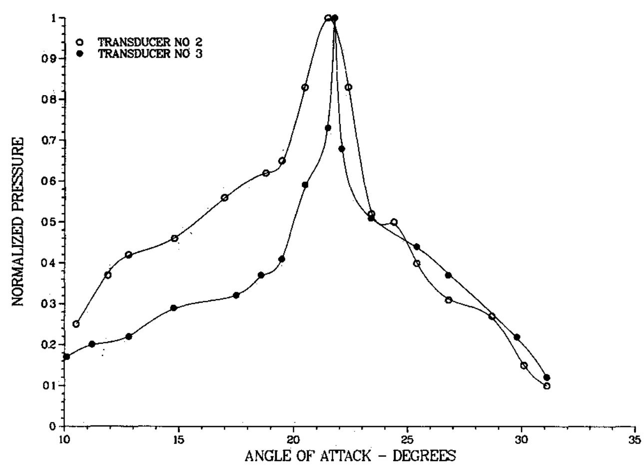

Fig 1 Normalized pressure transducer readings for a typical dynamic run

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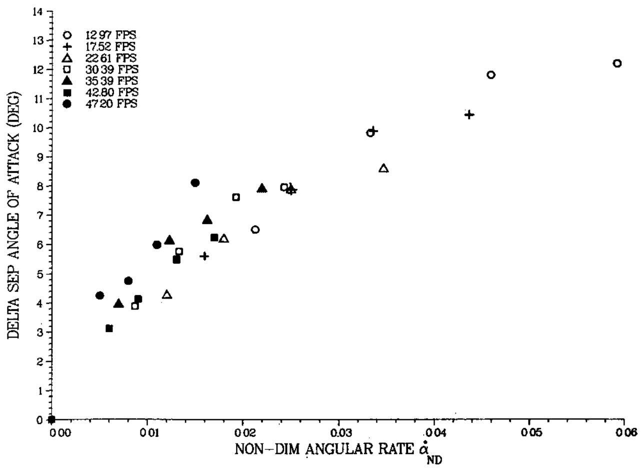

Fig 2 Change in quarter chord separation angle of attack vs nondimensional angular rate (present study only)

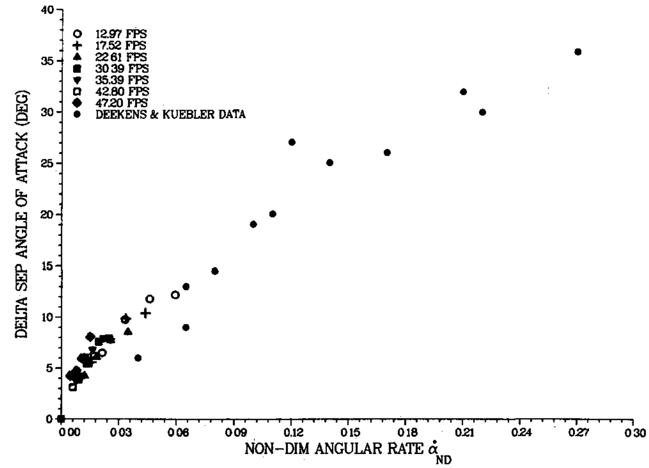

Fig 3 Change in quarter chord separation angle of attack vs nondimensional angular rate (including data from Ref 7)

separation at the quarter chord The signals from the second and third pressure transducers located ahead of the quarter-chord point were found to give marked indications of separation at the quarter chord; the indication from tran sducer No 3 was used to determine separation Figure 1 shows the normalized signal as a function of angle of attack for a typical dynamic run For the run shown in Fig 1, the smoke data indicated a quarter chord separation angle of 22 deg The smoke visualization determination was somewhat more subjective than that of the pressure data, but was judged to be accurate to ±0 5 deg

The angular rate and flow velocity were incorporated into a single nondimensional angular rate, $\dot{\alpha}_{ND}$, by the equation

$$\dot{\alpha}_{ND} = \frac{\frac{1}{2}c\dot{\alpha}}{U_\infty} \tag{1}$$

where c is the chord length and U_∞ the flow velocity A change in angle of quarter chord separation, $\Delta\alpha_s$, was ob tained by subtracting the static-separation angle from the dynamic separation angle for the particular flow velocity Figure 2 shows $\Delta\alpha_s$ vs $\dot{\alpha}_{ND}$

Taken alone Fig 2 appears to have some scatter, but indicates a general trend of the effect Confidence in the trend is considerably strengthened by adding the results of an earlier study[7] to those of this study These combined data are shown in Fig 3

It is our feeling that the general trend in the dynamic quarter chord separation data represents a viable data set against which theoretical predictions of dynamic separation may be compared The Reynold's number (based on chord) range represented by the present study is from 78,300 for the 12 3 ft/s run to 301 000 for the 47 2 ft/s run The data from Ref. 7 were for a flow velocity range from 2 7 6 ft/s If these data are considered, the trend represented in Fig 3 appears valid over a range of Reynold's numbers from 15 000 300,000

Acknowledgment

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