Unsteady Pressures and Forces During Transonic Buffeting of a Supercritical Airfoil

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Introduction

SUPERCRITICAL airfoils have been found to have favorable buffet characteristics compared with conventional airfoils as observed from investigations in the National Aeronautical Establishment High Reynolds number 2D test facility [1] The Bauer Garabedian Korn No 1 airfoil was the first supercritical airfoil to be investigated at NAE and its buffet onset boundary was reported by Kacprzynski [2] His results were found to be in good agreement with theoretical predictions by Redeker and Proksch [3] using Thomas[4] buffet onset criterion The method used for determining experimental buffet onset was to observe the analog signal from a force element of one of the sidewall balances supporting the model and to note the flow conditions when oscillations first appear Other common methods used in determining buffet onset are to detect the divergence of the trailing edge pressure or the break in the lift curve slope These experimental techniques are rather straightforward requiring little sophistication in instrumentation

In order to gain a better insight into the aerodynamic aspects of buffet, not just buffet onset, detailed investigations of surface pressure fluctuations are necessary Such an investigation was carried out at NAE with the BGK No 1 airfoil in the Mach number range 0 5 to 0 8 at chord Reynolds number 15 to 21×10^6 Both constant incidence and step pause incidence runs were performed The constant incidence runs were of sufficiently long duration that spectral correlation, and coherence functions for force and pressure data could be obtained. The step pause runs were processed to give only rms values of the force and pressure fluctuations Reference 5 describes the experimental arrangements and procedure for data processing together with detailed statistical data In this Note only some representative results are presented

Test Facilities and Model

The NAE High Reynolds Number test facility is described in Ref 6 Those aspects of the facility and instrumentation relevant to the present investigation differing since Ref 6 was published are reported in Ref 7 The porosity of the top and bottom walls in these tests was 19 3%

The model was the same as that used by Kacprzynski [2] Six fast response miniature transducers were used for unsteady measurements Their locations, as marked by *A B F* on the top of Fig 1 were 0 3402, 0 6002 0 7001, 0 8003 0 9004 and 0 9500 chord respectively, from the leading edge of the 10 in chord model The frequency response of the installed transducers was found from calibration tests to be flat up to approximately 200 Hz The fluctuating force signal N_2 was obtained from one of the sidewall balance flexures[7] located at 0 725 chord which was close to the expected center of the buffet force All unsteady signals were recorded on FM tape and subsequently analysed digitally using the algorithms given in Refs 8 and 9 In converting from analog to digital data the sampling rate was 1 kHz The data were further filtered using a four pole low-pass active filter with rolloff at approximately 300 Hz

The tests covered Mach number range ($0\ 501 \leq M_\infty < 0\ 805$) incidence range ($-0\ 36 \leq \alpha \leq 11\ 74$ deg), and Reynolds number range ($15 < Re \times 10^{-6} \leq 21$)

The rms values for the pressures and normal force were expressed in coefficients as $C_p = p_{\text{rms}}/q_\infty$ and $C'_{N2} = N_{2\text{rms}}/q_\infty bc$, respectively Here q_∞ b and c are the free stream dynamic pressure model span and chord respectively

Results and Discussions

Figure 2 shows the fluctuating normal force coefficient C'_{N2} plotted vs M_∞ and C_L Redeker's and Proksch's[3] theoretical buffet onset prediction and Kacprzynski's[2] experimental results for the BGK No 1 airfoil are included to show the various regions in the vicinity of the buffet onset boundary where the present tests were conducted It is of interest to note

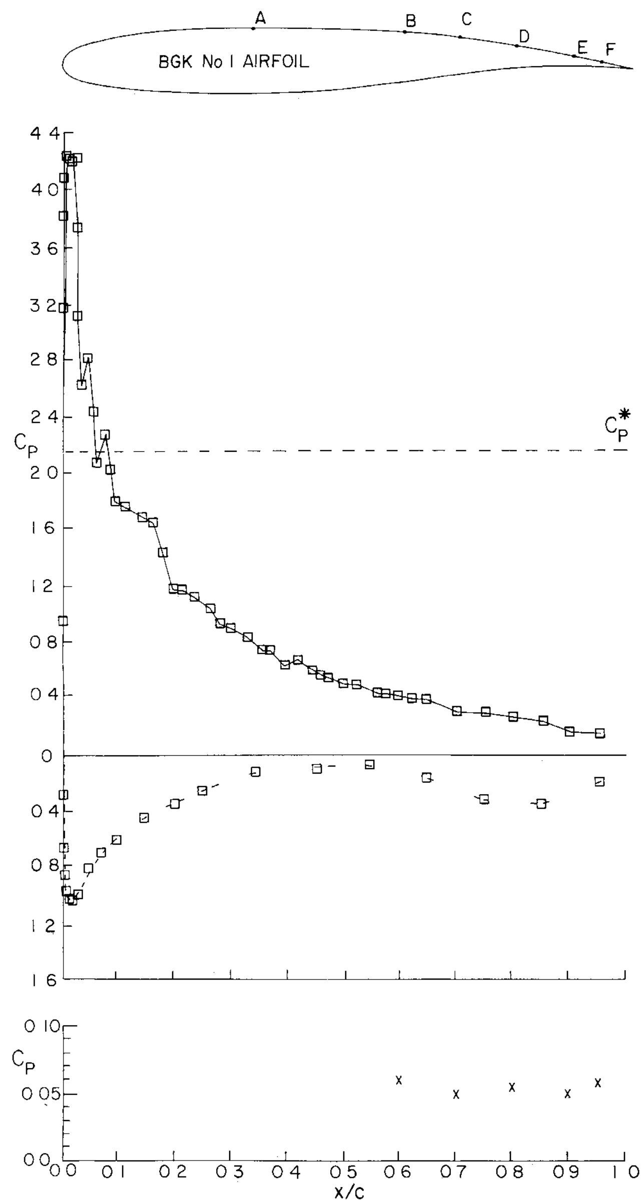

Fig 1 Steady and unsteady pressure coefficients along airfoil chord for $M_\infty = 0\ 501$, $C_L = 1\ 124$, $\alpha = 11\ 7$ deg, and $Re = 21 \times 10^6$

Received Nov 12 1982; revision received Dec 14 1983

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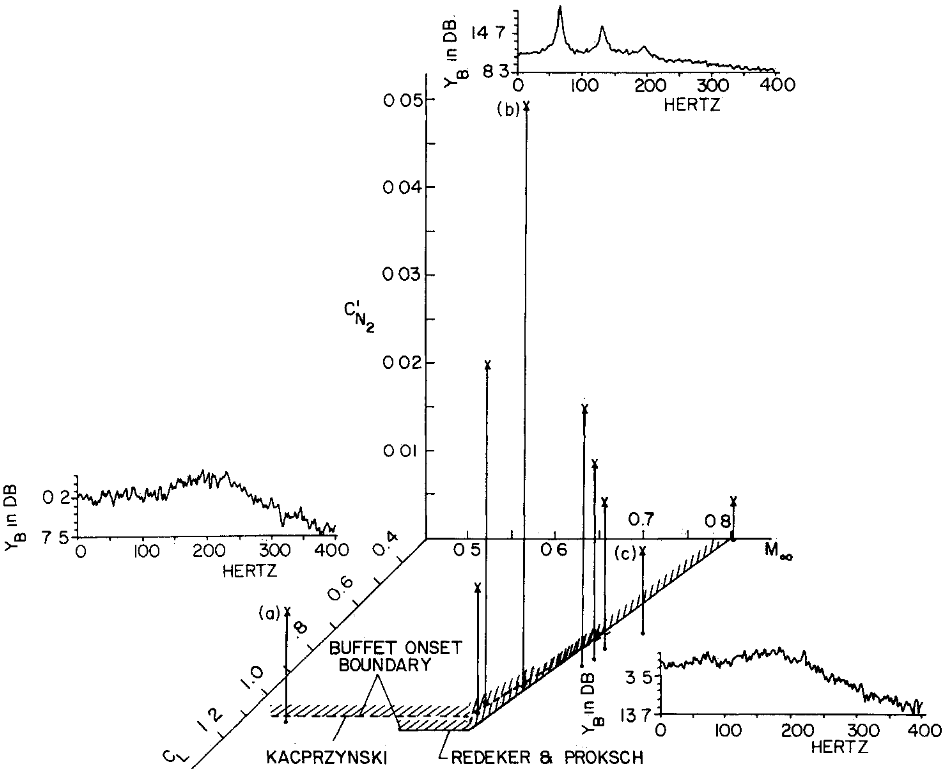

Fig 2 Variation of the fluctuating normal force coefficient C'_{N2} with Mach number and steady state lift coefficient

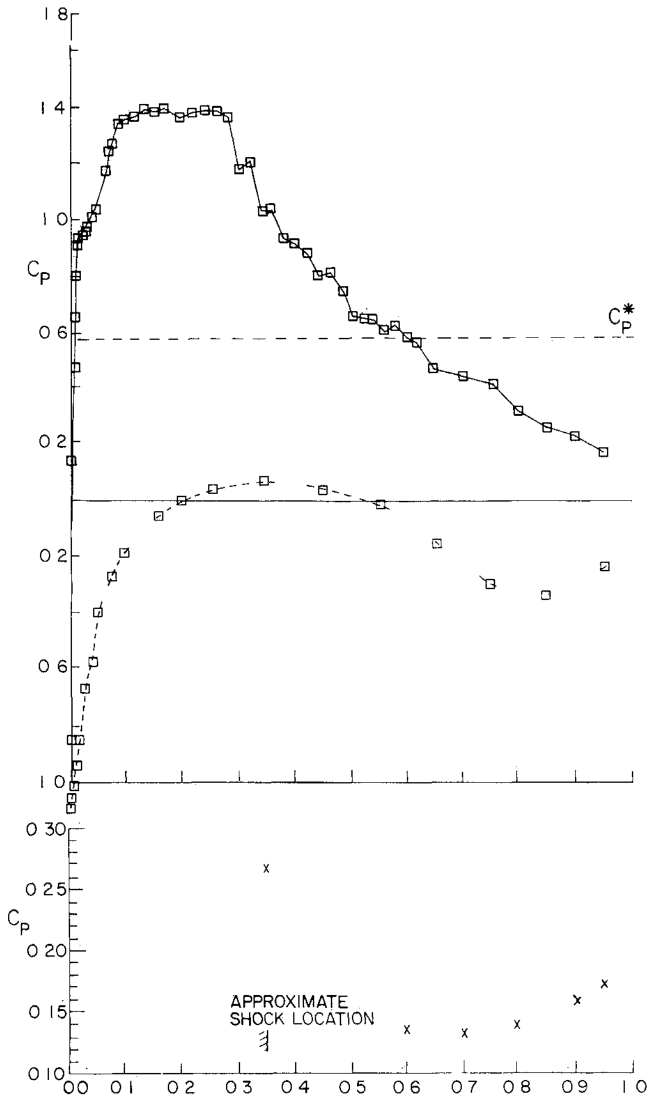

Fig 3 Steady and unsteady pressure coefficients along airfoil chord for $M_\infty = 0\ 755$, $C_L = 0\ 945$, $\alpha = 5\ 6$ deg, and $Re = 21 \times 10^6$

that the buffet intensities as indicated by the fluctuations from the normal force balance are most severe in the Mach number range from 0 7 to 0 78 for C_L between 0 8 and 1 1 In this transonic Mach number range, observations of the steady state C_p plots[5] indicate fairly strong shocks and flow separations extending from the shock to the trailing edge Also shown in the figure are the power spectra of the pressure fluctuations at Station B on the airfoil For light buffeting (Cases a and c) outside the speed range of $0\ 7 \leq M_\infty \leq 0\ 78$, the power spectral density curves do not exhibit distinct frequency peaks However in the region of strong buffet (Case b) distinct frequency peaks are observed These peaks have a fundamental frequency which increases with M_∞ along the buffet boundary (approximately 45 Hz at $M_\infty = 0\ 703$ to 70 Hz at $M_\infty = 0\ 784$) and the first harmonic is also detected in most cases This frequency is substantially lower than the model resonance frequency and flow studies of the wind tunnel do not reveal any oscillations in this frequency range Experiments correlating the shock motion with the oscillations in the pressure measurements downstream will undoubtedly shed more light on the nature of the frequency peaks detected in the power spectral density curves

Figures 1, 3 and 4 show the steady and unsteady pressure coefficients along the airfoil chord The steady and unsteady runs were performed separately but the run conditions were almost identical Figure 1 is typical of results at low Mach number and high C_L along the buffet onset boundary, where C_p is almost constant along the chord For Case b the large C'_p shown in Fig 3 for transducer A is, in all certainty, due to shock oscillation Generally, the C_p in this Mach number and C_L range increases downstream from the shock and attains a maximum value at transducer F closest to the trailing edge which is $x/c = 0\ 95$ for these tests Figure 4 corresponds to the high Mach number and lower C_L region on the buffet onset boundary (Case c) The steady state C_p distribution shows the presence of a shock wave However C_p increases only slightly from the shock to the trailing edge

The correlation between individual transducers with the force balance output[5] indicates that within the range $0\ 7 \leq M_\infty \leq 0\ 78$ the coherence between transducer and force balance measurements is strong in the frequency range where

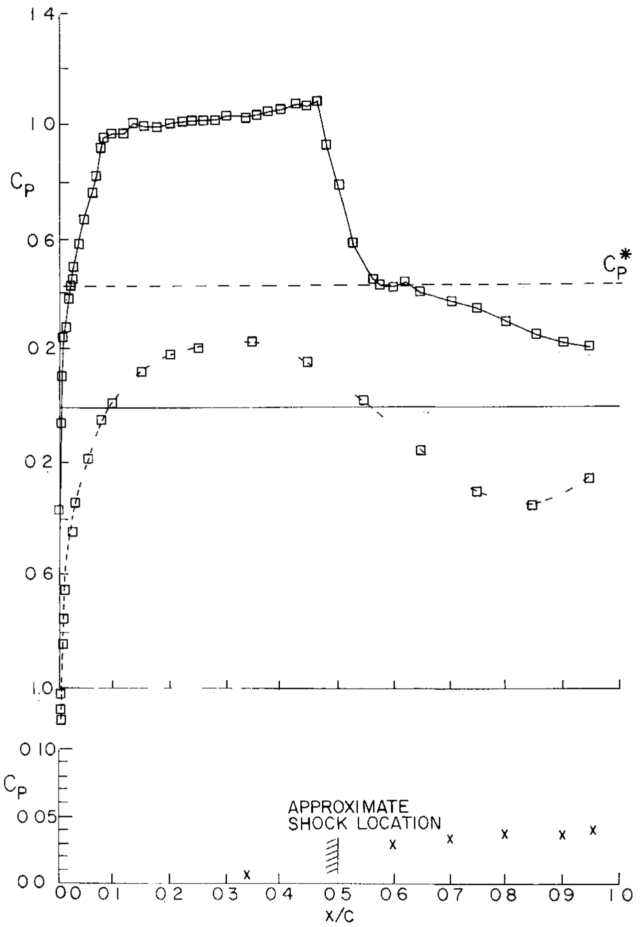

Fig 3 Normal force coefficient vs absolute angle of attack with and without ground effect

noticeable oscillations in the unsteady pressure field are detected It is clear that the unsteady normal force is primarily due to pressure fluctuations in the separated flow region on the airfoil from the shock to the trailing edge

Conclusions

A study of the buffet characteristics of the BGK No 1 airfoil was carried out by measuring the fluctuating pressures along the airfoil chord and the normal force balance outputs The tests were performed in various regions along the buffet onset boundary In the range $0\,7 \leq M_\infty \leq 0\,78$ and $0\,8 \leq C_L \leq 1\,1$ balance measurements show the buffet in tensity to be fairly large relative to other regions even though all the tests were performed very close to the onset boundary Typical characteristics of the flow in the high intensity region are: a monotonic increase in the fluctuating pressure coef ficient downstream of the shock to the trailing edge, a significant increase in fluctuating pressure level when a shock wave is located close to a measuring station, and the ap pearance of distinct frequency peaks in the power spectral density curves Also a strong coherence is observed between the fluctuating pressures in the separated flow region and the force balance outputs

References

[1]Ohman L H The Role of the NAE 5 ft×5 ft Wind Tunnel in the Development of Modern Airfoil Sections AIAA Paper 75 959 Aug 1975

[2]Kacprzynski J J , 'An Experimental Investigation of the Shockless Lifting Airfoil No 1 NAE Laboratory Report LR 569 National Research Council of Canada Aug 1973

[3]Redeker, G and Proksch H J , The Prediction of Buffet Onset and Light Buffet by Means of Computational Methods North Atlantic Treaty Organization Advisory Group for Aerospace and Development AGARD CP 204 1977

[4]Thomas F , Der Ermittlung det Schüttelgrenzen von Tragflügeln im Transsonischen Geschwindigkeitsbereich ' *Jahrbuch der Wissenschaftliche Gesellschaft fur Luft und Raumfahrt*, 1966, pp 126 144 translated by Aircraft Research Association (ARA) Bedford The Determination of the Buffet Boundaries of Aerofoils in the Transonic Regime ARA Library Translation No 19 (1969)

[5]Lee B H K and Ohman L H Unsteady Pressure and Force Measurements Associated with Transonic Buffeting of a Two Dimensional Supercritical Airfoil National Research Council Canada NAE AN 14 June 1983

[6]Ohman L H , The NAE High Reynolds Number 15″×60″ Two Dimensional Test Facility NAE Laboratory Technical Report LTR HA 4 Part 1 National Research Council of Canada April 1970

[7]Ohman L H Supplementary Investigation of the BGK No 1 Airfoil: Wall Interference Study Part 1, NAE Laboratory Technical Report LTR HA 5×5/0127 National Research Council of Canada April 1981

[8]Rabiner L R, Schafer R W and Dlugos D Periodgram Method for Power Spectrum Estimation Programs for Digital Signal Processing, ed by the Dig Signal Processing Committee *IEEE Acoustics Speech and Signal Processing Society* IEEE Press New York 1979 pp 2 1 1 2 1 10

[9]Carter, G C and Ferrie J F , A Coherence and Cross Spectral Estimation Program Programs for Digital Signal Processing edited by the Digital Signal Processing Committee, *IEEE Acoustics Speech and Signal Processing Society* IEEE Press New York 1979 pp 2 3 1 2 3 18

Measurements of Ground Effect for Delta Wings

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Nomenclature

AR	= wing aspect ratio
b	= wing span
c	= wing chord
C_m	= pitching moment coefficient
C_{nor}	= normal force coefficient (in wing fixed coordinates)
V	= wind tunnel airspeed
z	= height of wing, closest part to the ground plane from the ground
α	= angle of attack

Introduction

THE influence of ground proximity on the aerodynamic performance of lifting configurations is an important factor in the design of high speed ground vehicles and in the landing configurations of aircraft As the landing aircraft approaches the ground this effect influences the wing's lift and its longitudinal stability; therefore the classical problem[1] of a lifting surface approaching the ground has been ex tensively investigated Other analytical methods for in

Received Oct 17 1983; revision received Dec 13 1983

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