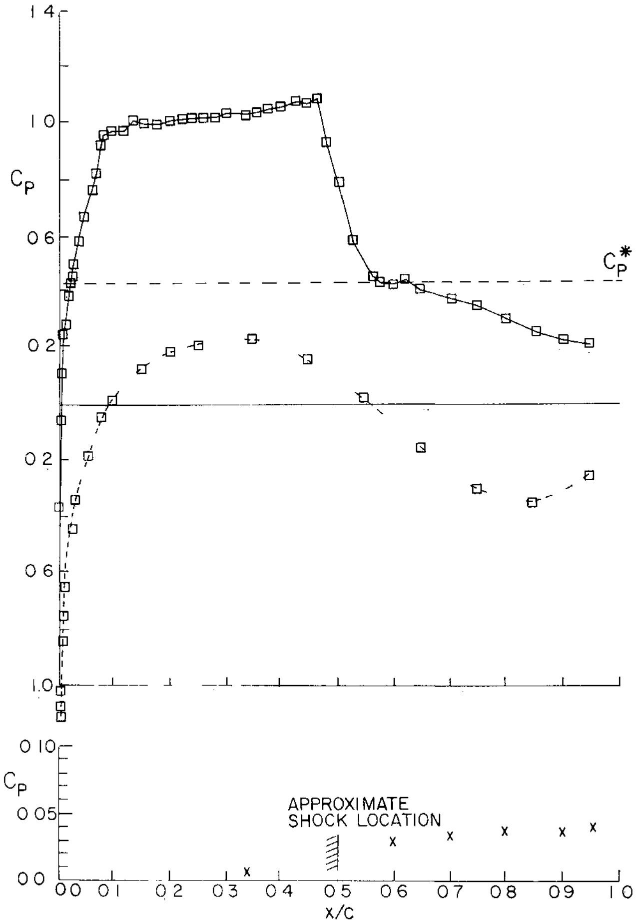

Fig 3 Normal force coefficient vs absolute angle of attack with and without ground effect

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

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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

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vestigating ground effect on various wing planforms are reported in Refs 2 5 These works however, did not address slender delta wings having an aspect ratio of less than unity Wings at high angles of attack ($\alpha > 25$) where large separated flow regions are known to exist were also not examined in Refs. 1 5 The experimental results for narrow delta wings are also limited and are concerned with aircraft like configurations [6] and with small delta winged aircraft models[7 9] (here the minimum Æ was 1 7) Further ex perimental studies deal with the landing conditions of more complex aircraft configurations such as the supersonic transport[10] or the supersonic bomber [11]

In the present Note, the effect of ground proximity is in vestigated for a very narrow delta wing (Æ=0 71) to high angles of attack ($\alpha < 40$ deg) Additionally, the investigation was extended to include negative incidences of the wing This condition occurs during the release of delta winged missiles from underneath the aircraft wing surface or when estimating the performance of certain delta shaped, negative lift devices used on high speed road vehicles such as racing cars.

Experimental Apparatus

The delta wing model was mounted on a sting balance which was capable of vertical transverse relative to the ground plane (as shown in Fig 1) The wind tunnel test section had a rectangular cross section which was effectively cut down by the ground plane to a cross section of 0 85 by 1 m During the test a constant airspeed of 15 m/s was maintained This velocity corresponds to a Reynolds number of 2×10^5 based on the wing chord The delta wing model had a small cylindrical centerbody which was connected to the six component sting balance as shown in Fig 1 The wing aspect ratio was 0 71, and its leading and trailing edges were machined to a bevel of 30 deg as shown in the lower section of Fig 1

Results and Discussion

All the experiments reported in this work were performed such that the wing lower surface (Fig 1) was facing the wind The effect of inverted wing configuration on the normal force is shown in Fig 2 In this case of "inverted wing" planform a noticeable reduction in the normal force was measured thus emphasizing the high sensitivity of the vortex lift to the wing leading edge geometry Because of this for the negative in cidences the wing bevel was reversed, thereby creating similar aerodynamic conditions (as in the left insert of Fig 2) for both the positive and negative angles of attack

The influence of the ground proximity on the normal force coefficient of the delta wing is shown in Fig 3 Here the wing was held at $z/b = 0$ such that its trailing edge was almost touching the ground (actually a clearance of 1 mm was maintained) for the range of positive angles of attack Ac cordingly for the negative incidence as indicated by the in serts in Fig 3 the wing apex was held close to the ground with a similar clearance of 1 mm The general effect for both incidence ranges was an increase of the lift over the whole range of $|\alpha|$ The earlier stall of the wing with the presence of the ground plane, however resulted in a reduction of the maximum lift, compared to the tests without the ground plane Through this work the normal force data is presented not the lift since this enables a simple first order estimation of the lift and drag coefficients Thus the maximum lift coef ficient without ground effect is $C_{nor} \cos(\alpha) \sim 1.45$ When the wing apex is held near the ground (negative α) and the pitch axis is at the apex, as shown by the insert in Fig 3 the in crease in the normal force is smaller than that measured for the positive α range This is due to the relatively larger distance between most of the wing area and the ground Flow visualizations made with the hydrogen bubble technique indicated that the separated vortex cores are not dislocated by the ground, apart from a limited disturbance at the vicinity of the wing apex in the case of negative α Consequently the vortex lift effect is not disturbed by the ground in this case When the angle of attack sweep is performed relative to the wing trailing edge (positive α) the increase in the normal force was higher, since a larger section of the wing surface was closer to the ground In this situation too the separated vortex system above the wing was not disturbed

The variation of the normal force as the wing approaches the ground is shown for positive angles of attack in Fig 4 and

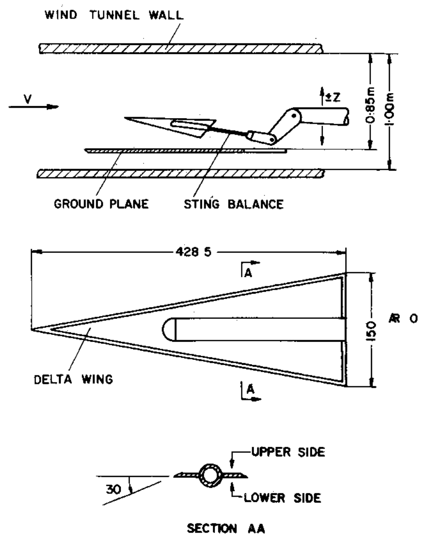

Fig 1 Delta wing and its mounting in the wind tunnel test section

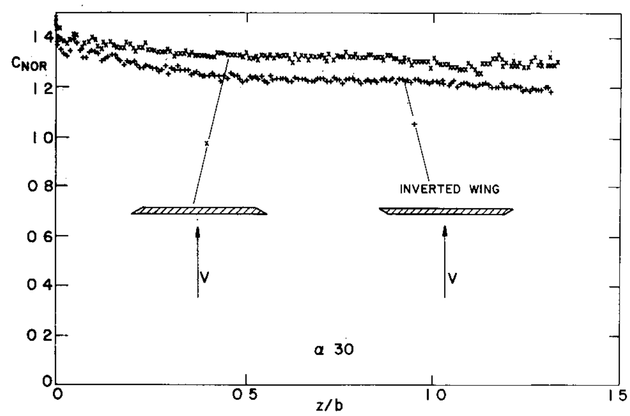

Fig 2 Effect of inverted wing planform on the normal force

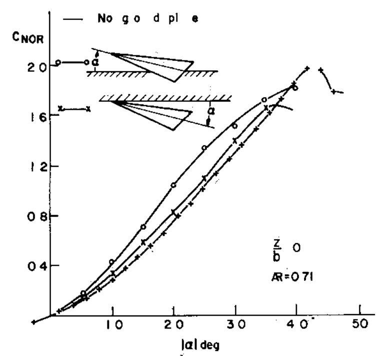

Fig. 3 Normal force coefficient vs absolute angle of attack with and without ground effect

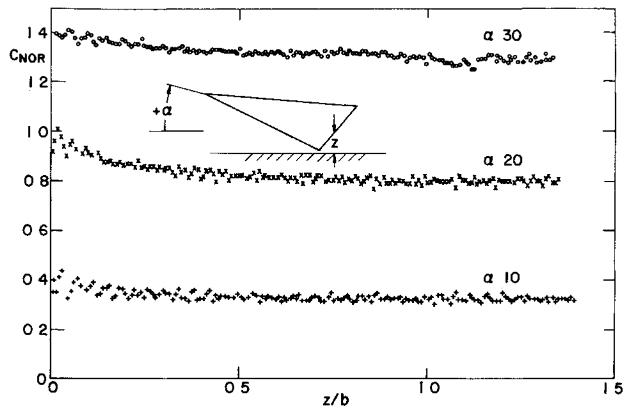

Fig 4 Normal force coefficient variation with ground clearance ($^z/b$) positive α

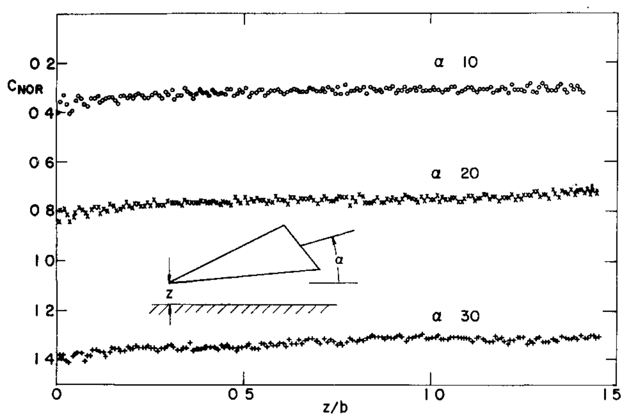

Fig 5 Normal force coefficient variation with ground clearance ($^z/b$) negative α

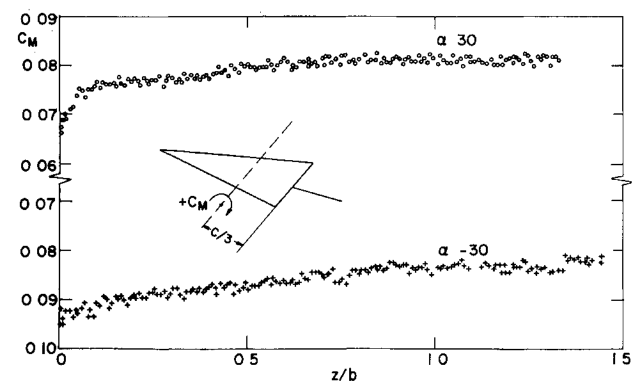

Fig 6 Pitching moment coefficient variation with ground clearance

for negative angles of attack in Fig 5 In these experiments the wing angle of attack was held constant while a tran sversing mechanism reduced the distance z between the wing trailing edge and the ground (for positive α) or between the apex and the ground (for negative α) In both figures an increase in the absolute normal force is detected near the ground but as shown in Fig 3 this effect is smaller for negative angles The variation of the pitching moment C_m as the wing approaches the ground is given in Fig 6 for one positive and one negative α The effect of ground proximity as it is shown in the positive α range is to reduce the pitch up tendency Consequently the center of pressure must travel backward, toward the reference pitching axis located at two thirds of the wing chord For the negative angles of attack an increase in the magnitude of the pitching moment was found This is due to the combined effect of the increase in the normal force shown in Fig 5 and to a limited forward motion of the center of pressure

Concluding Remarks

The major conclusion from the data presented herein is that the ground effect maintains the classical influence of in creasing the wing lift even for vortex induced lift of delta wings The lift increase was larger for positive angles of attack than for negative angles of attack This difference is probably a result of a small displacement in the location of the leading edge vortices which are trapped between the wing and the ground surface

Acknowledgment

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