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BASIC STUDIES ON DELTA WING FLOW MODIFICATIONS BY MEANS OF APEX FENCES

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SUMMARY

The effectiveness of 'apex fences' on a 60-deg delta wing at low speeds has been experimentally investigated. Resembling highly swept spoilers in appearance, the fences are designed to fold out of the wing apex region upper surface near the leading edges, where they generate a powerful vortex pair. The intense suction of the fence vortices augments lift in the apex region, the resulting positive pitching moment being utilized to trim trailing-edge flaps for lift augmentation during approach and landing at relatively low angles of attack. The fences reduce the apex lift at high angles of attack, leading to a desirable nose-down moment.

The above projected functions of the apex fence device were validated and quantified through low-speed tunnel tests, comprising upper surface pressure surveys on a semi-span model and balance measurements on a geometrically similar full-span wing/body configuration. Fence parameters such as area, shape, hinge position and deflection angle were investigated. Typical results are presented indicating the apex fence potential in controlling the longitudinal characteristics of a tail-less delta.

SYMBOLS

AVERAGE CPU	- Span-averaged CPU at local station
CL	- Lift coefficient, based on total wing area
CM	- Pitching moment, based on total wing area and mean aerodynamic chord
CPU	- Upper surface pressure coefficient
C_R	- Root chord (inches)
L/D	- Lift-to-drag ratio
X	- Chordwise distance measured from apex (inches)
Y-LOC	- Spanwise distance from root nondimensionalized by the local semi-span
α(ALPHA)	- Angle of attack (degrees)

$\Delta CL\%$ - (CL, fence on - CL, fence off)/(CL, fence off) x 100

$\delta_{TE,ELEVATOR}$ - Trailing-edge flap deflection, inboard only (degrees)

δ_F - Fence deflection (degrees)

INTRODUCTION

The aerodynamics of pitch control and longitudinal trim of highly swept fighter configurations have received considerable attention in recent years. Close-coupled canards are currently popular because of their ability to generate powerful pitching moments and low trim drag. However, the canard downwash reduces wing efficiency, and at high angles of attack canards tend to lose pitch-down capability. The adverse interaction between canard and wing vortices in sideslip also leads to non-linearites and roll instability at high alpha (ref. 1). Unloading the canard above a critical angle of attack is made difficult by the strong upwash induced locally by the forebody and wing.

A different approach towards pitch control of highly swept wings, viz., to modulate vortex lift in the apex region, was explored in the apex flap concept (ref. 2). The appeal of this concept was the ability to undeflect the apex, for cruise flight conditions, and deflect downward for recovery from high alpha. Tests showed however that like the canard the up-deflected apex flap also generated strong downwash over the wing, and suffered a severe lift loss in the neighborhood of the transverse hinge-line. The wing-alone model tested in reference 2 also could not represent the fuselage interference which is likely to degrade apex flap effectiveness. These considerations led the second author to propose an alternate method of apex lift control, viz., the apex fence.

Resembling highly swept spoilers, the apex fences are hinged to the wing upper surface along the leading edges (fig. 1). When folded out vertically at low angles of attack, the fences generate an intense vortex pair whose suction augments lift in the apex region, resulting in a nose-up moment. Conversely, at high angles of attack the fence vortices are greatly weakened and also raised higher above the apex; the combined effect is to reduce apex lift in comparison with the basic wing, thus generating a desirable nose-down moment. The apex fences will not be subject to fuselage interference and they also avoid the adverse transverse corner of the apex flap hinge. A noteworthy advantage of apex fences is that they can be shaped and oriented for most efficient vortex-generation capability quite independently of the wing planform.

Exploratory small-scale wind tunnel investigations of the apex fence concept applied to a 74 and 65 deg delta wing have been reported in reference 3. Upper surface pressure surveys supplemented with oil flow and helium bubble visualization confirmed the existence of strong and stable vortices produced by apex fences. These promising early results encouraged a more comprehensive study of the concept applied to a 60-deg delta wing, this sweep angle being more in keeping with the current fighter design studies. This investigation was undertaken primarily to validate and quantify the hypothesized aerodynamics effects of apex fences in controlling the longitudinal characteristics of a tail-less delta through the angle-of-attack range.

MODELS AND TEST DETAILS

Pressure Model

Major dimensions of the generic semi-span 60 deg delta wing body model are shown in figure 2. This model incorporated four spanwise rows of pressure taps, the first row being well inside the apex region occupied by the fence. The model was mounted on a boundary layer bypass plate seven inches above the tunnel floor. Six fence shapes were tested on this model, only two shapes being presented herein (fig. 3). The test was conducted in the North Carolina State University Merrill Subsonic Wind Tunnel at a mean-aerodynamic-chord Reynold's number of 0.67 million, and angles of attack ranging from zero to 30 deg.

Force Model

Major dimensions of the force model are shown in figure 4. This model was geometrically similar to the pressure model and was fitted with four trailing-edge flaps. Only the inboard flap segments were deflected during the present tests. A total of eleven fence shapes were investigated, some at different mounting positions on the wing and some in asymmetric arrangement. Eight of the fences, all in symmetric configuration and mounted along the leading edge, are discussed herein. The fence shapes and their respective areas are presented in the figures with the results. Unless otherwise noted the fence deflection is 90 deg (i.e., perpendicular to the wing plane). The test was conducted in the Air Force Institute of Technology 5-Foot subsonic wind tunnel at a mean-aerodynamic-chord Reynolds number of 1.11 million. The sting was mounted in two alternate positions, giving a low (-6 to 30 deg) and a high (20 to 45 deg) angle-of-attack range.

RESULTS AND DISCUSSION

Pressure Results

Typical spanwise distributions resulting from vertical apex fences placed at the leading edge of the delta wing will be examined at a constant angle of attack of 10 deg (representative of the 'low-alpha' range). The Gothic (18.7 percent area) fence (fig. 5) results in broadening of the vortex suction footprint at the first two pressure stations (A and B), and a significant increase of the span-averaged local -CPU above the basic wing value with the load center shifted inboard. At the downstream stations (C and D) the spanwise distribution is similarly altered but the average -CPU is somewhat reduced. The Delta (11.7 percent area) fence (fig. 6) produces more accentuated suction peaks while the vortex footprints in this case are not as broad as with the Gothic fence. Nevertheless, the resulting -CPU average is practically equal with both fence configurations. At the aft station, the pressure fields due to the Gothic and Delta fences are almost identical.

The longitudinal variation of -CPU AVERAGE presented in figure 7 clearly shows the augmented apex suction due to both fences at alpha = 10 deg. Just the opposite effect is evident at alpha = 30 deg (representing the high-alpha case), when the apex suction is reduced below the basic wing value. Accordingly, a nose-up moment increment at low alpha and a nose-down effect at high alpha are to be expected due to fence deployment, as postulated. This trend was encountered in varying degrees with all the fence configurations tested.

Oil-Flow Study

Typical oil-flow photographs of the basic wing and the wing with the delta fence on at ALPHA = 9.5 deg on the force model are presented in Figure 8. In this comparison, the oil streaks in the apex region are longer and more highly curved in a spanwise direction, indicating a significantly stronger vortex with the fence on. An inboard shift of the fence vortex is evident downstream and a separate leading-edge vortex appears, as observed in the foregoing pressure results.

Balance Results

The Gothic and Delta fences studied on the semi-span pressure model were initially tested on the balance model. The lift and pitching moment characteristics are compared with the basic model in figure 9. The lift increment due to fences in the low-alpha range is evident, as is the nose-up pitching moment anticipated from the foregoing pressure results. Between the two fence shapes compared, the Gothic generates higher pitching moment increments; however, since this fence was also nearly 60 percent larger in area than the Delta, it was decided to study the area effect in some detail on these two fence shapes.

The original Gothic fence area was reduced serially in two steps: the height was reduced at constant length, and then the length was shortened. The result of height reduction (fig. 10) shows virtually no change in lift characteristics and a relatively small reduction in moment; length reduction results in a visible drop in lift and a more pronounced reduction in the pitching moment.

The Delta fence was cut in length in two successive steps. The results (fig. 11) show a roughly proportional drop in lift as well as pitching moment in the low-alpha range, the moment increments narrowing towards higher angles of attack.

To obtain a broader picture of the effect of fence area, the lift increments with various fence configurations at a constant angle of attack of 12 deg, with and without trailing-edge flap deflection for trim, are compared with the basic model (or fence-off case) in figure 12. Included in this comparison is a Double-Gothic fence shape, in which the rear half was tapered down to zero width. Most of the fences increased the untrimmed lift, with the exception of the smallest fences in each shape family which showed a lift loss at this angle of attack. However, all fences irrespective of size and shape produced marked increases in the trimmed lift due to down-deflected trailing-edge flaps (as indicated by the blackened portion of the bars). Generally, reduction of fence area also reduced the trimmed lift increment.

In an attempt to separate out the fence shape and area effects on the trimmed lift capability, the incremental lift at ALPHA 12 deg is plotted versus fence area ratio for the three shape families in figure 13. An almost linear increase of trimmed lift coefficient with fence area is evident, an outstanding exception being the large Double-Gothic fence. Note that the smaller Double-Gothic fence was not geometrically similar, having a convex aft taper in contrast to a concave taper of the larger Double Gothic. While the present data are quite inadequate to draw conclusions regarding the Double-Gothic fence, their potential as an area-efficient fence shape is worthy of further investigation.

As already mentioned, the vortex load on the apex fences produces a drag component. While drag increment in combination with lift augmentation is a desired feature during approach and landing, it is of interest to examine the aerodynamic efficiency of apex fences as a trimming device. This may be done by comparing the L/D at a constant lift coefficient with and without the fences (see Table 1). The corresponding trailing-edge flap deflections for trim and angle of attack are also given. Because the basic delta wing requires an up-deflected trailing-edge flap to trim with a positive static margin, the angle of attack must be increased to obtain the same lift coefficient. In contrast, fence deployment allows a down deflection of trailing-edge flap for trim and therefore the angle of attack can be reduced for the same approach speed. For example, the Gothic fence provided a nearly 6 deg reduction in angle of attack from ALPHA = 18 deg of the basic delta. The consequent wing drag reduction compensates for the fence drag to a large extent, as indicated by the relatively small decrease in L/D.

The foregoing results pertained to vertically deployed apex fence, i.e. δ_F = 90 deg; in practice, the hinged fences may be actuated to a smaller or a larger angle. The effect of varying fence deflection on either side of 90 deg is presented in figure 14 for the case of the large Double-Gothic fence. The results indicate that the fence angle controls the pitching moment in an almost linear fashion.

In some tests the high-alpha range was explored to observe the apex fence effect on pitching moment. A typical result is shown in figure 15 using Gothic fences, where a reversal of the longitudinal moment is evident at high angles of attack. Thus the apex fence can be viewed as a natural alpha-limiting device.

CONCLUSIONS

Exploratory low-speed wind tunnel investigations were conducted to evaluate the effects of apex fences on a 60 deg delta wing/body configuration. An initial test program surveyed upper surface pressures on a semi-span model including the apex region between the fences, followed by balance measurements on a geometrically similar full-span model with trailing-edge flaps. The scope of the investigation covered varying fence shape, area and deflection angles.

The apex fences produced opposite effects over the wing apex region in the low-alpha and high-alpha regimes. At low angles of attack fence vortices augmented the suction level over the apex, whereas at high angles of attack the apex suction was reduced from the basic wing case. Balance data showed corresponding lift increase together with a nose-up pitching moment at low alpha, and lift loss with a nose-down moment at high alpha.

In combination with down-deflected trailing-edge flaps, fences in the low alpha range produced marked increases in the trimmed lift capability of the configuration. The trimmed lift increment was essentially proportional to fence/wing area ratio in case of Gothic and Delta fences. An exception was the Double-Gothic fence of 8.8 percent area, which indicated an area efficiency almost twice as high as the others.

Varying fence deflection angle (on either side of the nominal 90 deg position) was found to control the pitching moment in an almost-linear fashion, showing the apex fence to be a promising pitch control and trimming device. The effectiveness of asymmetric fence deployment in lateral and directional control is currently being evaluated.

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Table 1

TRIMMED $C_L = 0.82$

FENCE TYPE	AREA RATIO FENCE / WING	$\delta_{TE,ELEVATOR}$	L/D	ALPHA
FENCE OFF	----	-2.1°	2.92	17.9°
GOTHIC FENCE	18.7 %	26.8°	2.21	12.0°
DELTA FENCE	11.7 %	14.7°	2.64	14.0°

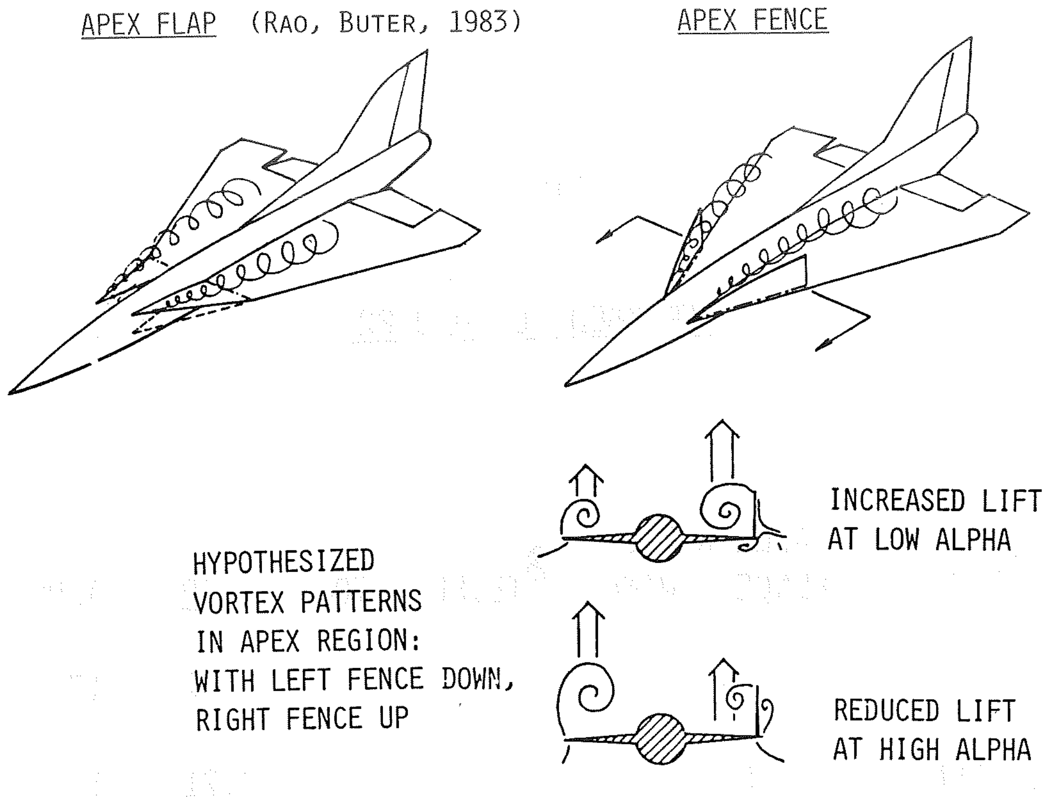

Fig. 1. Apex fence concept.

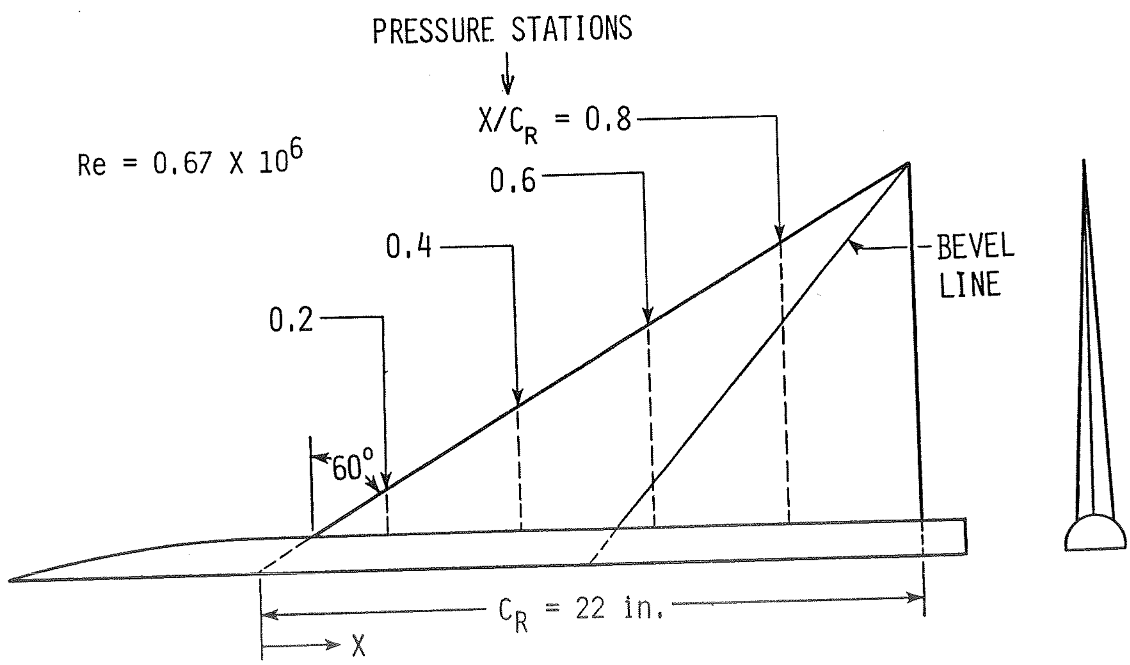

Fig. 2. 60-deg delta semi-span pressure model.

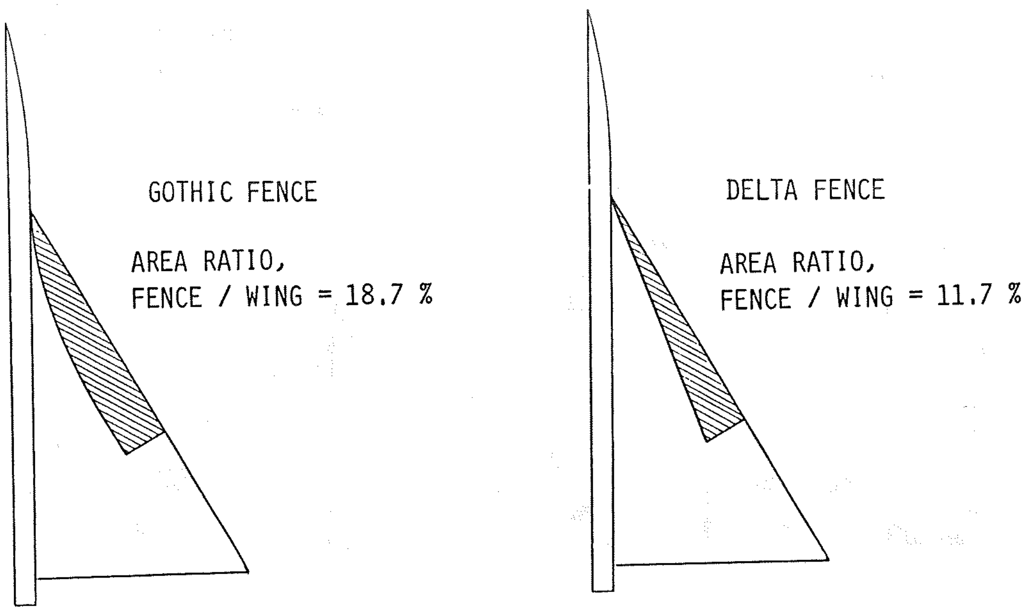

Fig. 3. Typical fence shapes tested on semi-span delta model.

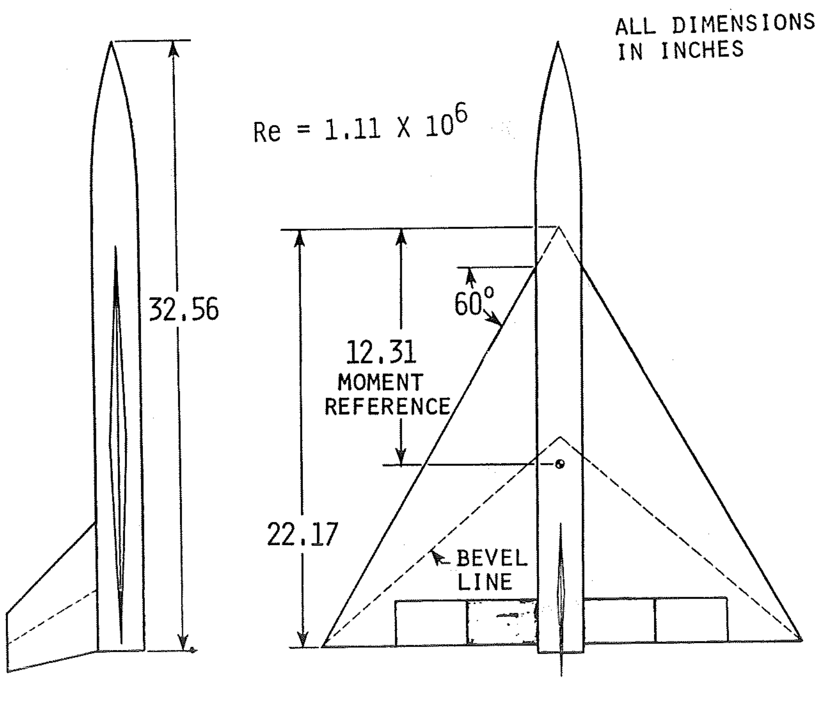

Fig. 4. 60-deg delta full-span force model.

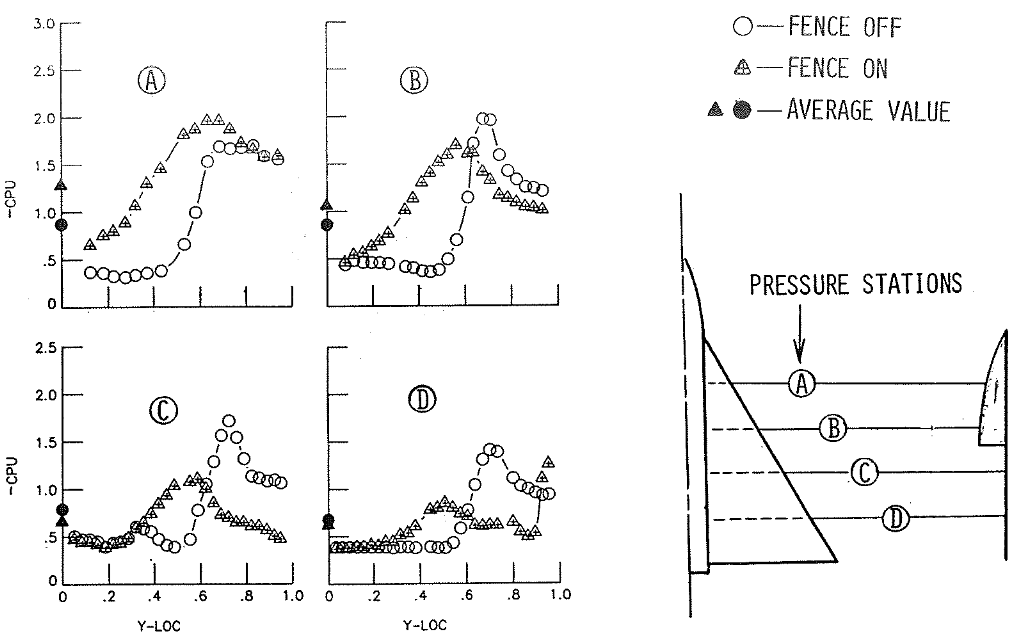

Fig. 5. Spanwise upper surface pressure distributions at 10 deg alpha with gothic fence.

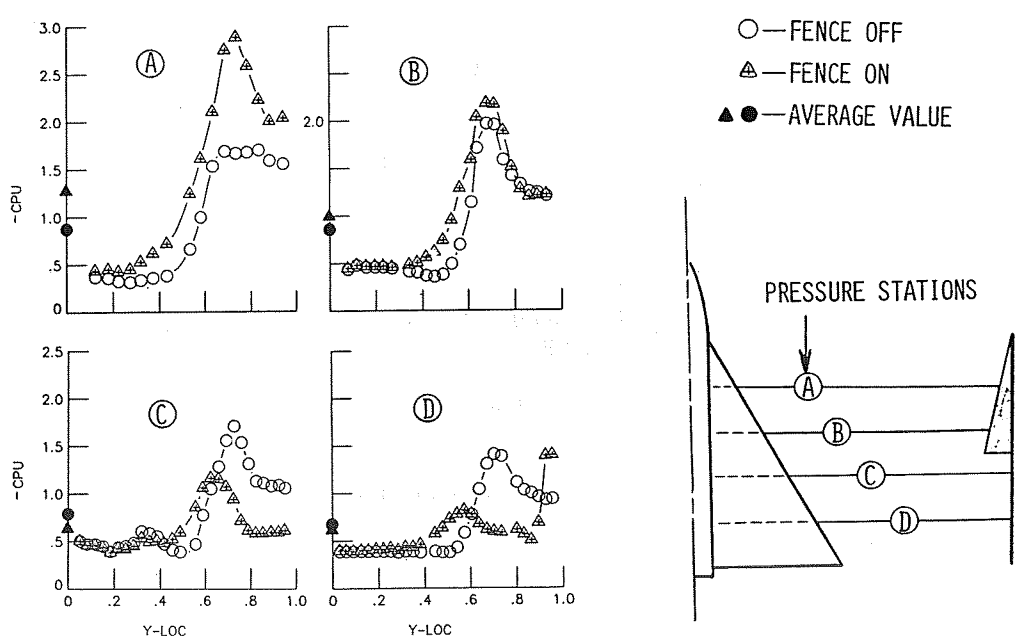

Fig. 6. Spanwise upper surface pressure distributions at 10 deg alpha with gothic fence.

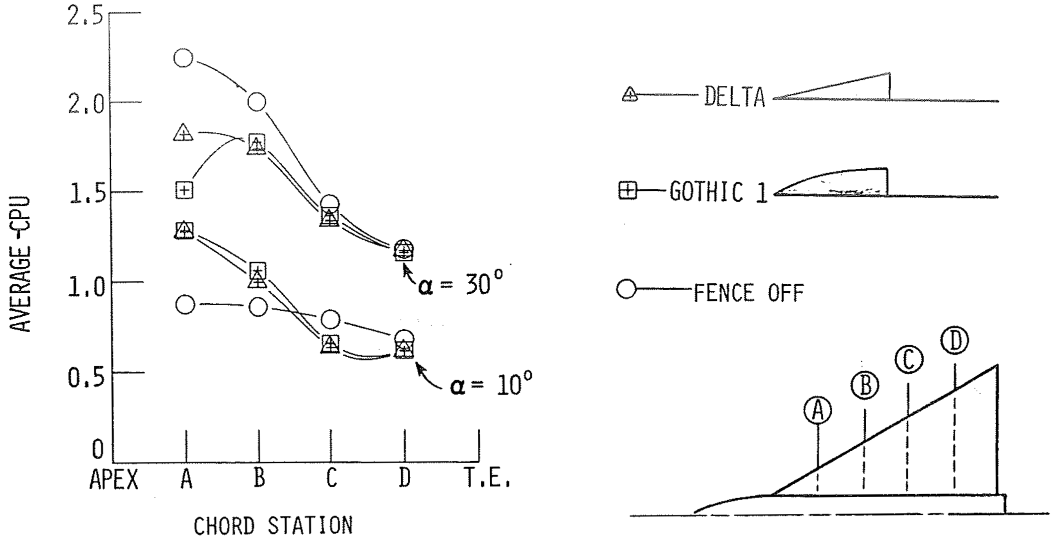

Fig. 7. Longitudinal distributions of span-averaged upper surface pressure coefficients.

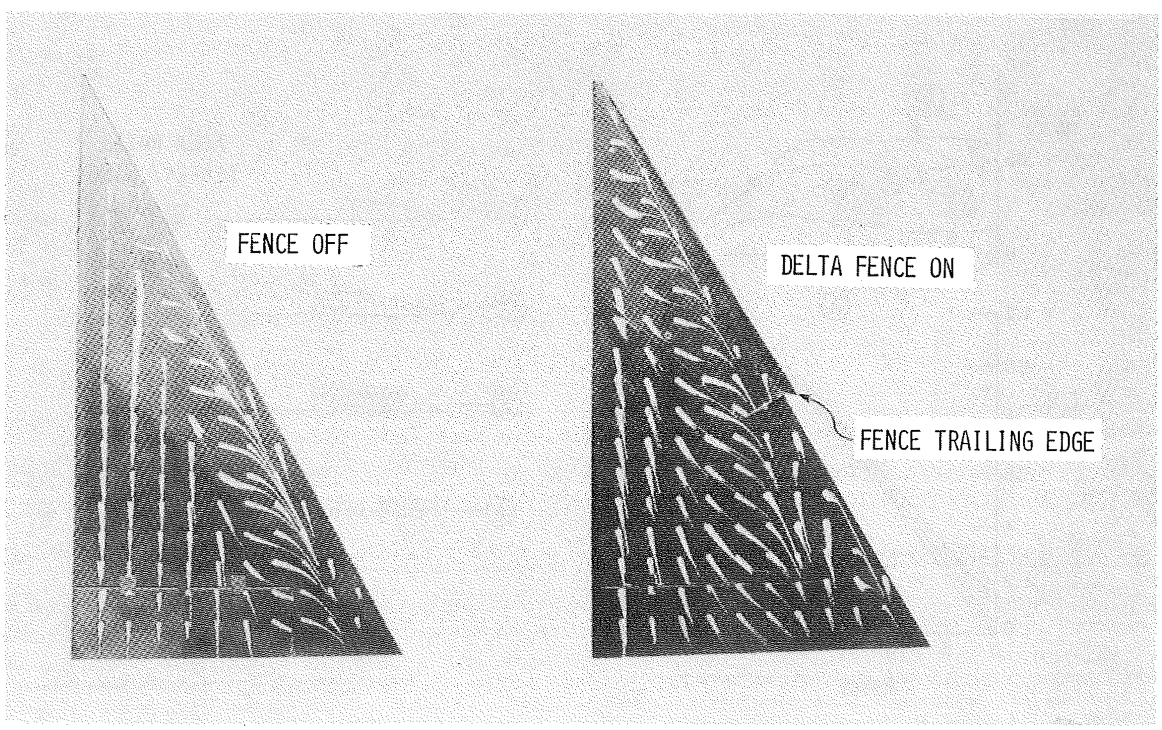

Fig. 8. Typical oil-flow patterns on force model, showing fence effect at 95 deg alpha.

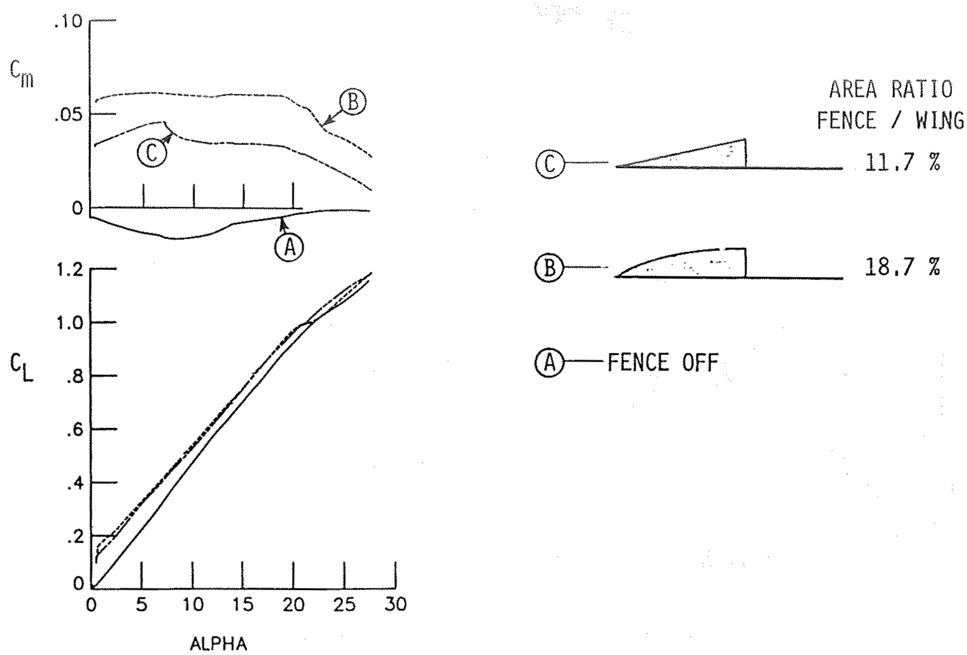

Fig. 9. Lift and pitching moment effects of longest delta and gothic fences.

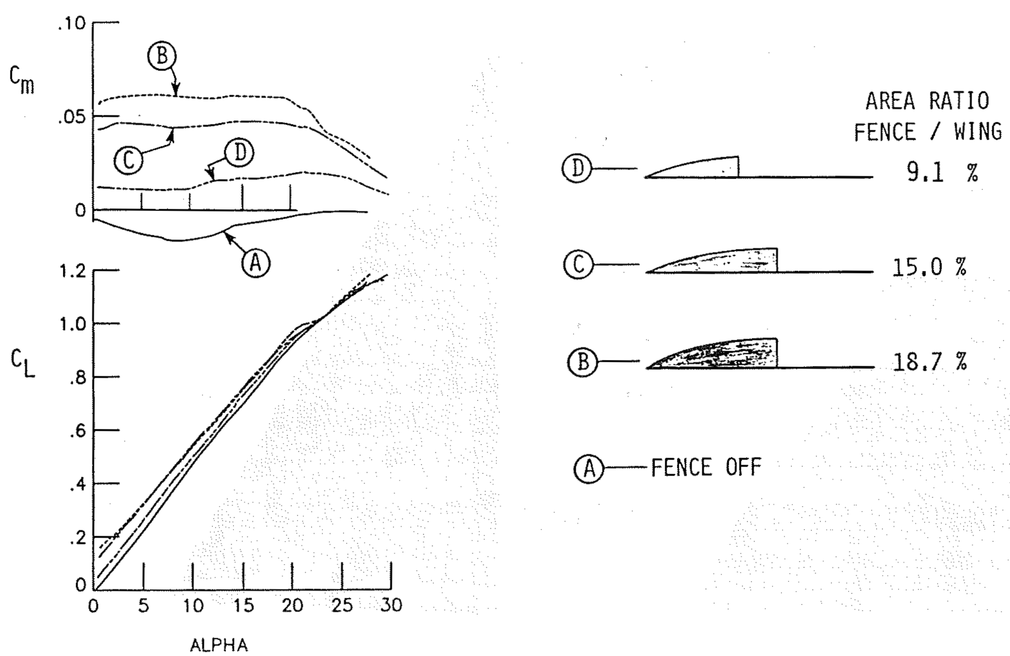

Fig. 10. Lift and pitching moment effects of gothic fence variations.

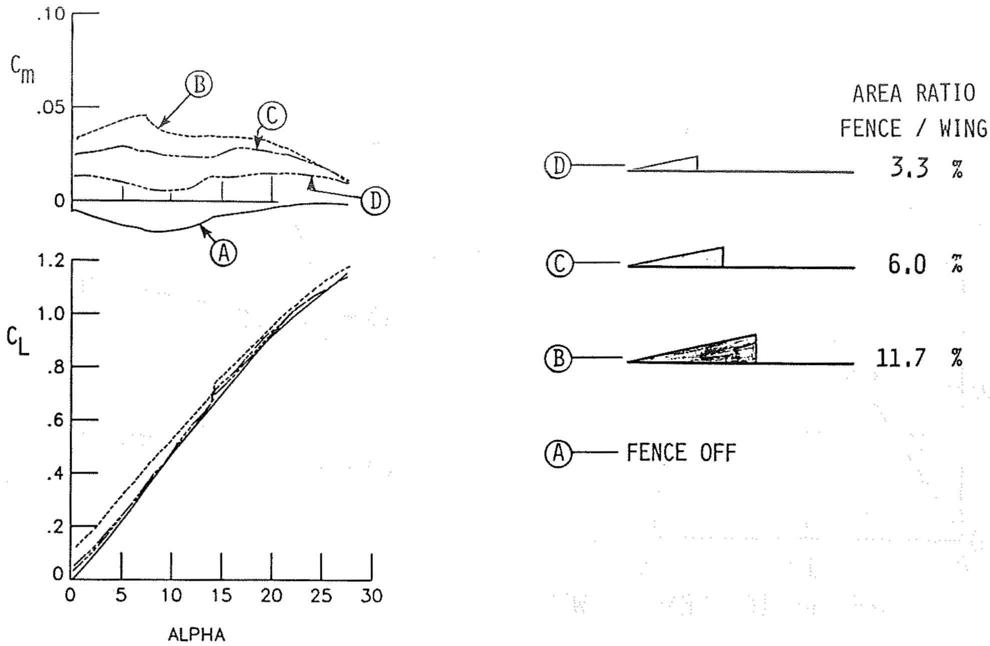

Fig. 11. Lift and pitching moment effects of delta fence variations.

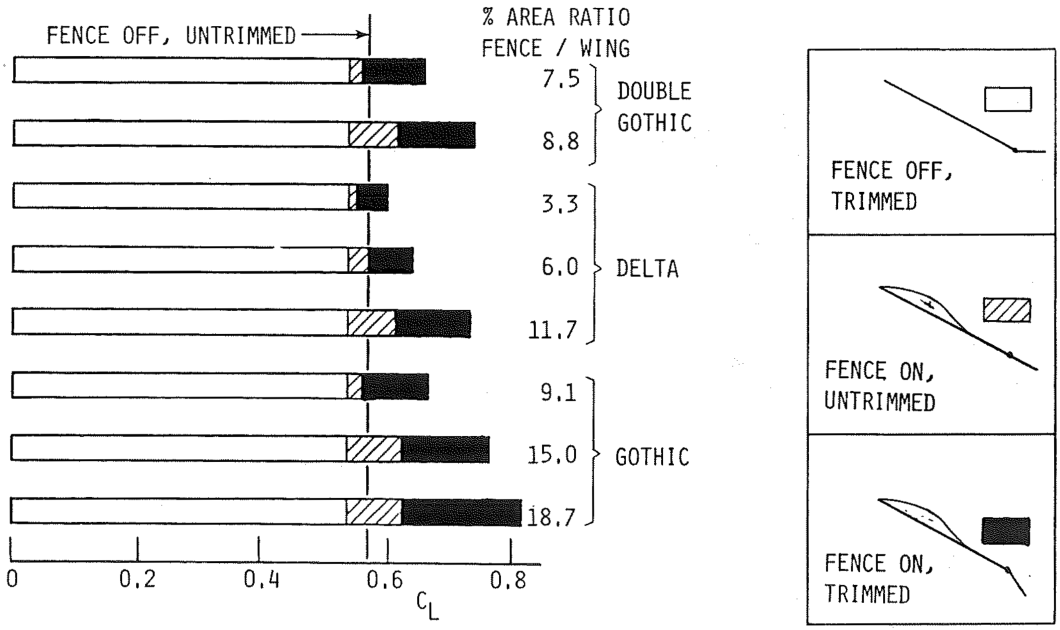

Fig. 12. Trimmed and untrimmed lift increments due to various fences at 12 deg alpha.

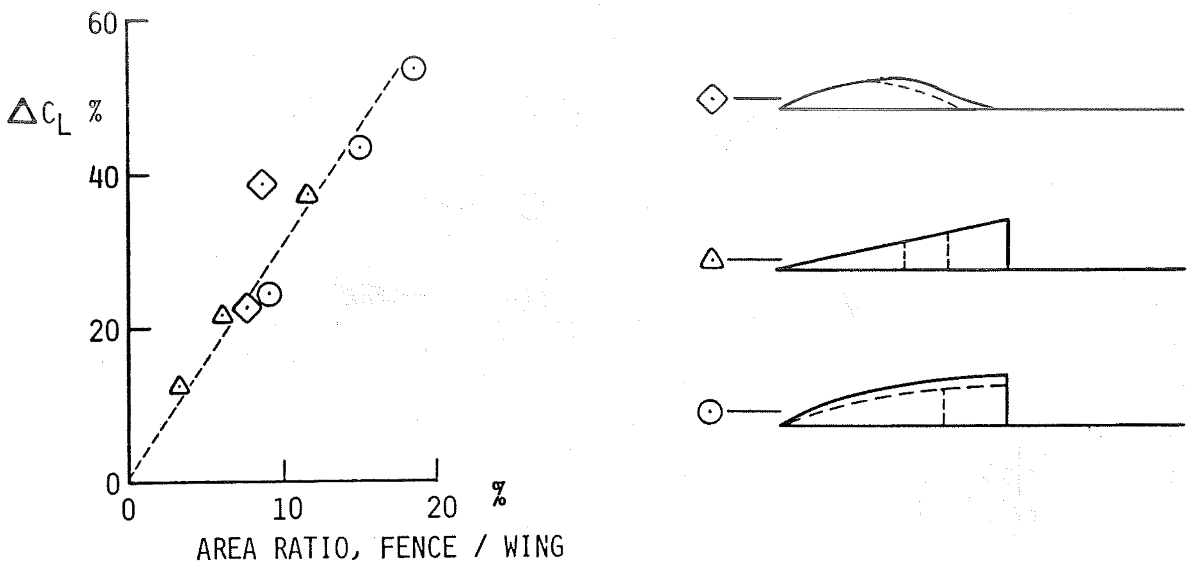

Fig. 13. Fence area effect on trimmed lift increment at 12 deg alpha.

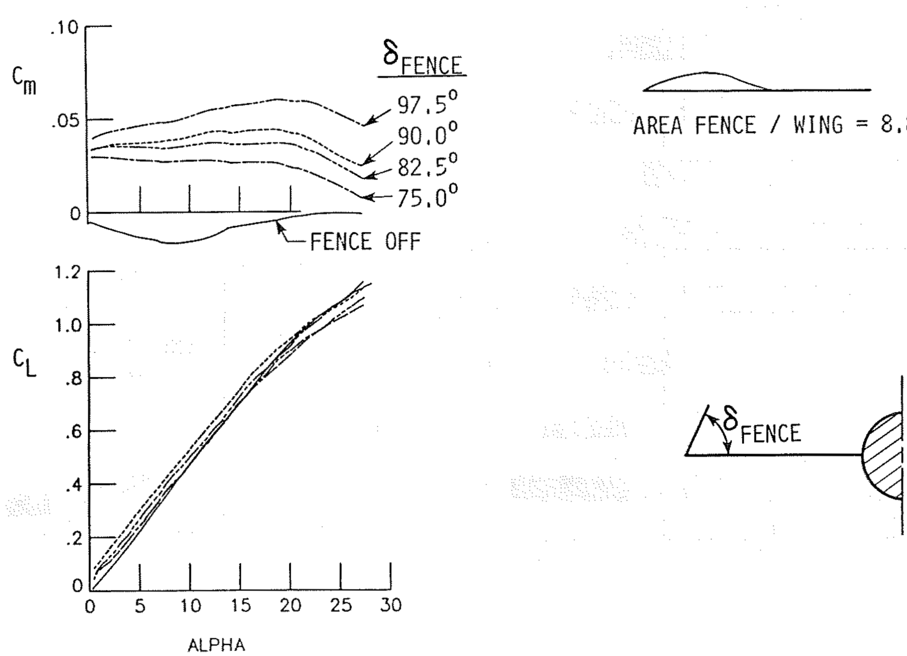

Fig. 14. Lift and pitching moment effects of fence deflection.

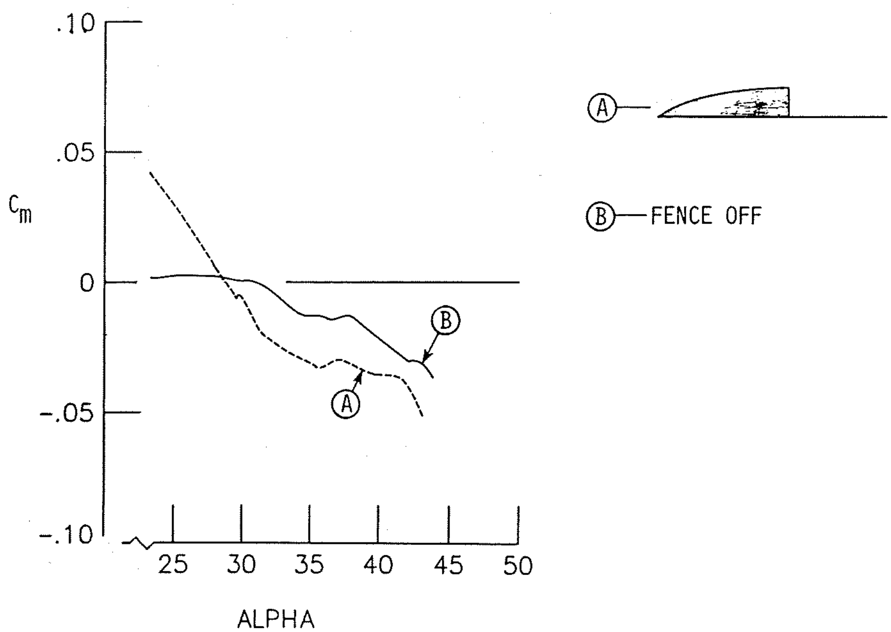

Fig. 15. Fence effect on pitching moment at high alphas.