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SUMMARY

Fixed leading-edge devices were investigated on a 74-deg. delta wing model for alleviating the low speed pitch-up and longitudinal instability following the onset of leading edge separation. Wind tunnel tests showed Pylon Vortex Generators to be highly effective, compared to the leading-edge fences and slots also investigated. The best Pylon Vortex Generator arrangement raised the pitch-up angle of attack from 8 deg. on the basic wing to 28 deg., with negligible subsonic drag penalty.

INTRODUCTION

A review of research on the low-speed aerodynamics of highly swept wing configurations representative of supersonic-cruise aircraft designs indicates that a problem commonly observed is the so-called 'pitch-up', i.e., a discontinuous nose-up change in the pitching moment with increasing angle of attack. Pitch-up is caused by the onset of separation in the wing tip regions while the flow inboard is still attached, and has been of sufficient concern to dictate a compromize in the optimum supersonic-cruise planform shape in order to have acceptable low-speed flight characteristics. For instance, reduction of the sweep angle in the tip region, and the use of variable leading-edge droop or leading edge flaps (involving weight and complexity) have been considered. However these measures have generally been able to delay the pitch-up only by a few degrees angle of attack, as illustrated by wind-tunnel data measured on a typical supersonic-cruise configuration taken from ref. 1 and shown in fig. 1. Considerable interest therefore remains in devising more effective means of alleviating the tip separation on highly swept wings, preferably by the use of simple fixed devices on uncompromized supersonic planforms.

This report presents the results of an exploratory wind-tunnel investigation of a novel leading-edge device that we call a "Pylon Vortex Generator", on a 74-deg. delta research model. Longitudinal aerodynamic data are presented to show that in suitable arrangements this device has considerable potential for pitch-up alleviation in the angle of attack range of interest, with no significant penalty to the subsonic performance of the basic wing.

LEADING EDGE DEVICE CONCEPT

Although it was inspired originally by the vortex generator described in ref. 2, the development of the Pylon Vortex Generator followed a rather different rationale. Whereas its progenitor was devised as a viscous-flow manipulator (or boundary layer control device), the conceptual basis of the Pylon Vortex Generator is to utilize the induced velocity field of a longitudinal potential vortex in order to modify the spanwise variation of the effective angle of attack, which in turn inhibits the inboard spread of leading-edge separation on highly-swept wings. The initial application of this concept was to reduce the lift-dependent drag of a 60 deg. delta wing at higher angles of attack by preserving attached flow and leading-edge suction over a larger fraction of the span than possible on the basic wing (ref. 3). Not only did the Pylon Vortex Generators successfully reduce drag, but the controlled tip separation also alleviated pitch-up of the basic wing. It is this latter function of the device that is presently of interest.

The Pylon Vortex Generator may be described as a forward-swept vertical blade projecting down from the leading-edge (a la engine pylon) into the side-wash environment prevailing ahead of a lifting swept wing. It is believed that flow separation at the slanting upper edge of the pylon creates a streamwise vortex which is convected over the wing leading-edge. The rotation of this vortex would be such as to impose a downwash on the outboard side, where the effective angle of attack is accordingly reduced and the onset of leading-edge separation delayed in comparison with the basic wing. Inboard of the vortex, however, the effective angle of attack is increased leading to earlier separation. The altered local normal force characteristics on either side of the vortex on a swept-leading edge will generate a nose-down moment as high angles of attack, as graphically illustrated in fig. 2 based on data from ref. 4. Close inspection of these data suggested that in addition to the inviscid mechanism postulated above, the pylon vortex also served to energize the upper surface boundary layer in the leading-edge region to further enhance the separation control effectiveness of the device.

The Pylon Vortex Generator may be compared with a strake in its ability to influence the wing flow field through the agency of a streamwise vortex. An important difference however is that the loading on the vertical pylon cannot impart undesirable pitching moment characteristics to the aircraft as can happen with the strakes. Further, since the sidewash angle is considerably less than the angle of attack, the pylon vortex will continue to be active at the higher angles of attack when a strake vortex would probably have burst over the wing.

MODEL AND TEST DETAILS

The flat-plate delta wing model originally had symmetrically bevelled sharp leading edges swept at 74 deg. For the present tests, it was modified to a blunt leading-edge wing by means of wooden strips affixed along the bevel surfaces and snaped to a uniform semi-circular section normal to the leading edge (fig. 3). This modification allowed the model to qualitatively reproduce the aerodynamic characteristics typical of supersonic aircraft designs resulting from onset of outboard leading-edge separation, specifically the pitch-up. In addition, chordwise slots were cut into the leading edges at 25%, 50% and 75% semi-span positions to accommodate the devices.

The geometry and dimensions of the leading-edge devices are also shown in fig. 3. Three Pylon Vortex Generator designs (VG1, VG2 and VG3) were tested; the first two were parallelogram shaped with different sweep angles, and the last was triangular in shape with a fence-like projection on the upper surface. A photograph of the model fitted with one of the Pylon Vortex Generator test arrangements is shown in fig. 4. In addition, two fence designs (F2 and F4) were also tested for comparison. The two types of fences essentially differed in the matter of projection forward of the leading edges; it was anticipated that the projecting fence F2 (unlike the flush fence F4) would have some vortex generating capability similar to the Pylon VG. Finally, a test was run with the devices removed and the slots left open to generate "fluid fences" on the upper surface (ref. 3).

The tests were conducted in the Langley 7- by 10-foot high speed wind-tunnel at Mach 0.2 and Reynolds number 2.7×10^6 based on a mean chord of 67.7 cms. Forces were measured by an internal six-component strain gage balance. The usual jet boundary and sting bending corrections were applied to the data. The tabulated data have been presented in ref. 4 as 'Test 46'.

PRESENTATION OF RESULTS

The pitching moment coefficients were measured about a reference point 58.42 cms aft of the wing apex (c.g. #1). These data were transferred to a c.g. location at 67.73 cms, corresponding to a position closer to the wing centroid (c.g. #2). A comparison of the original and the transformed pitching moment data plotted in fig. 5, indicates the appropriateness of the c.g. location #2 from aircraft balance considerations as well as for relaxed static stability design. More importantly the transferred pitching-moment characteristics clearly indicate the pitch-up phenomenon on the basic wing, allowing a proper appreciation of the problem under consideration.

Fig. 6 shows the results with vortex generators separately for each design. The effect of multiple devices (i.e. more than one on each leading edge) is also presented for VG1 and VG2.

Fig. 7 gives the pitching moments for fences, again separately for each design and also showing the effect of multiple arrangements (two or three per leading edge).

Fig. 8 presents the results for open slots. As in foregoing presentations, the basic wing result (dashed curve) is included for comparison.

Finally, fig. 9 compares the drag polars obtained for the 'best' device arrangement of each class with that of the basic wing.

DISCUSSION

The basic wing (with all slots sealed) showed a pitch-up at about 8 deg. angle of attack. A single Pylon Vortex Generator located at 50% semi-span on each leading edge produced a marked improvement in the longitudinal stability characteristics, delaying the onset of pitch-up to approximately 18 deg. angle of attack (fig. 6A). Among the three different designs of Pylon Vortex

Generators VG2 performed the best, followed by VG3 in reducing the magnitude of nose-up moment at high angles of attack.

In a multiple arrangement, the best effectiveness was obtained by two VG2s installed on each leading edge at 25% and 50% semi-span stations. Indeed, this arrangement produced an essentially zero pitching moment up to 28 deg. angle of attack. Addition of a third VG2 at 75% semi-span however degraded the longitudinal stability characteristics (fig. 6C).

A single fence on each leading edge at 50% semi-span also delayed pitch-up, but the ensuing instability was worse than that observed with single Pylon Vortex Generators (compare figs. 6A and 7A). The fences indicated a rather sudden loss of effectiveness at about 20 deg. angle of attack; beyond this point, the projecting fence (F2) produced somewhat smaller nose-up moment than the flush fence (F4). This improved high angle-of-attack performance of the projecting fence may be due to its ability to generate a vortex system from the sidewash ahead of the leading edge.

When used in multiples, addition of a third fence at 75% semi-span produced an adverse effect, just as in case of Pylon VG's. However, the pitching moment characteristics appeared less sensitive to the spanwise distribution of fences than with VG's (compare figs. 6B, C and 7B, C).

Finally, the open slots (three per leading edge) showed only minor improvement in the onset of pitch-up, delaying it by a mere 3 deg., but none in the longitudinal stability characteristics at the higher angles of attack. Although other slot arrangements were not tested, the available results suggest that the slots may not prove competitive with Pylon VG's or fences (compare with figs. 6C and 7C).

Drag measurements showed that the leading-edge devices produced negligible drag penalty at the subsonic Mach number of the test (fig. 9). Judging by the geometry of Pylon Vortex Generators viz. sharp edges, high sweep and pointed apex, it may be anticipated that the drag increment at supersonic cruise Mach numbers will also be small.

CONCLUSIONS

The Pylon Vortex Generator has been demonstrated to be a powerful device for delaying pitch-up and alleviating the longitudinal instability at high angles of attack on a 74 deg. flat plate delta wing. In this respect, it was found to be even more effective than leading-edge fences. The performance of the Pylon Vortex Generator was sensitive to its spanwise distribution. When suitably arranged however, the Pylon Vortex Generator is seen to have the potential of eliminating the pitch-up problem from the low-speed flight envelope of highly swept wing configurations.

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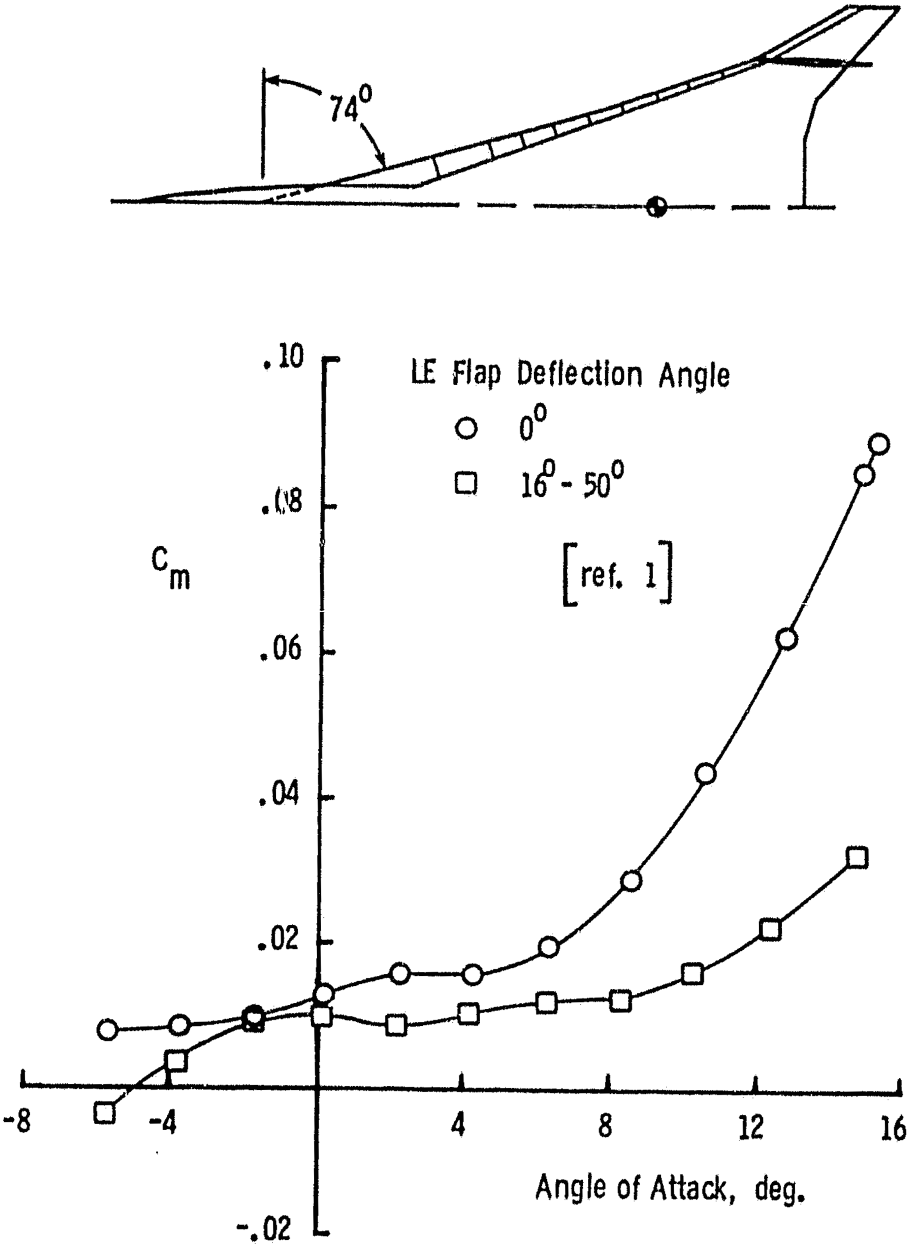

Fig. 1 - Longitudinal Stability Characteristics of a Typical Supersonic-Cruise Configuration, Showing Effect of Leading Edge Deflection for Attached Flow

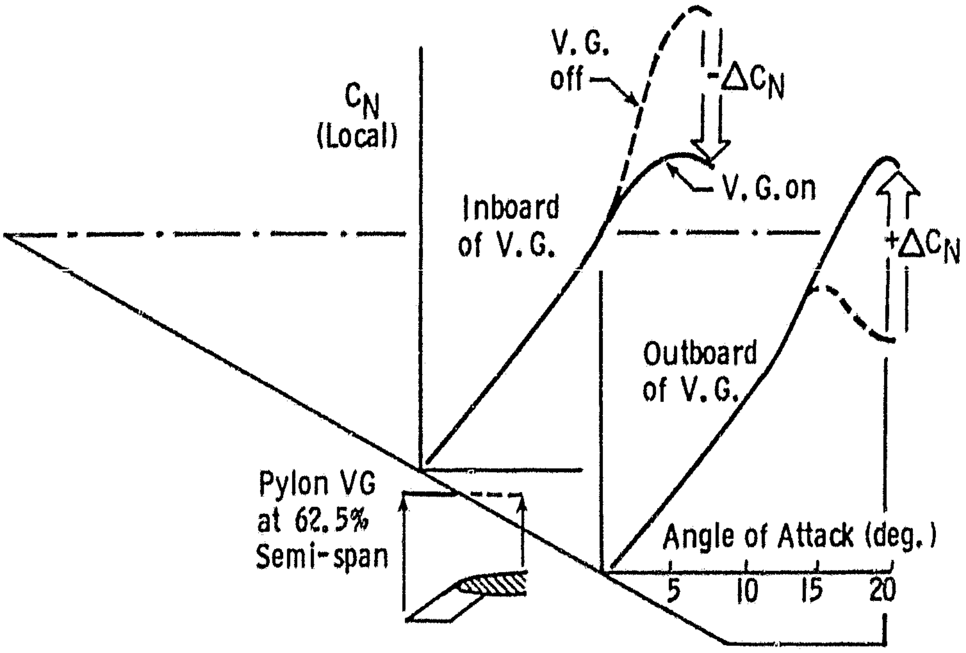

Fig. 2 - Leading-Edge Normal Force Increments Inboard and Outboard of Pylon Vortex Generator on a 60 deg. Cropped Delta (Data from Ref. 4)

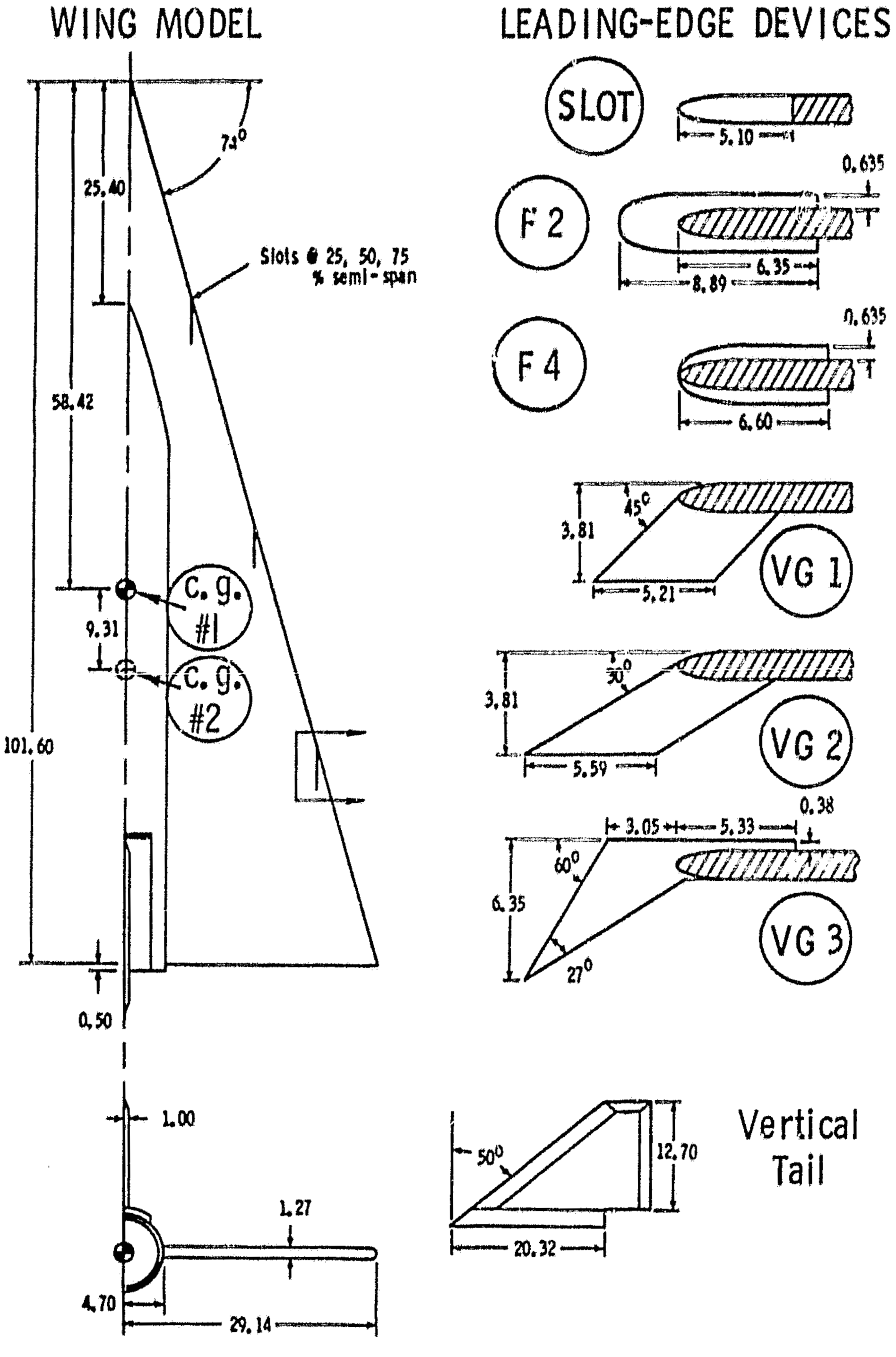

Fig. 3 - Delta Wing Model and Leading Edge Devices
(Dimensions in cm)

Fig. 4 - Photographs Showing General View of Model and (Inset) One of the Pylon VG Arrangements Tested

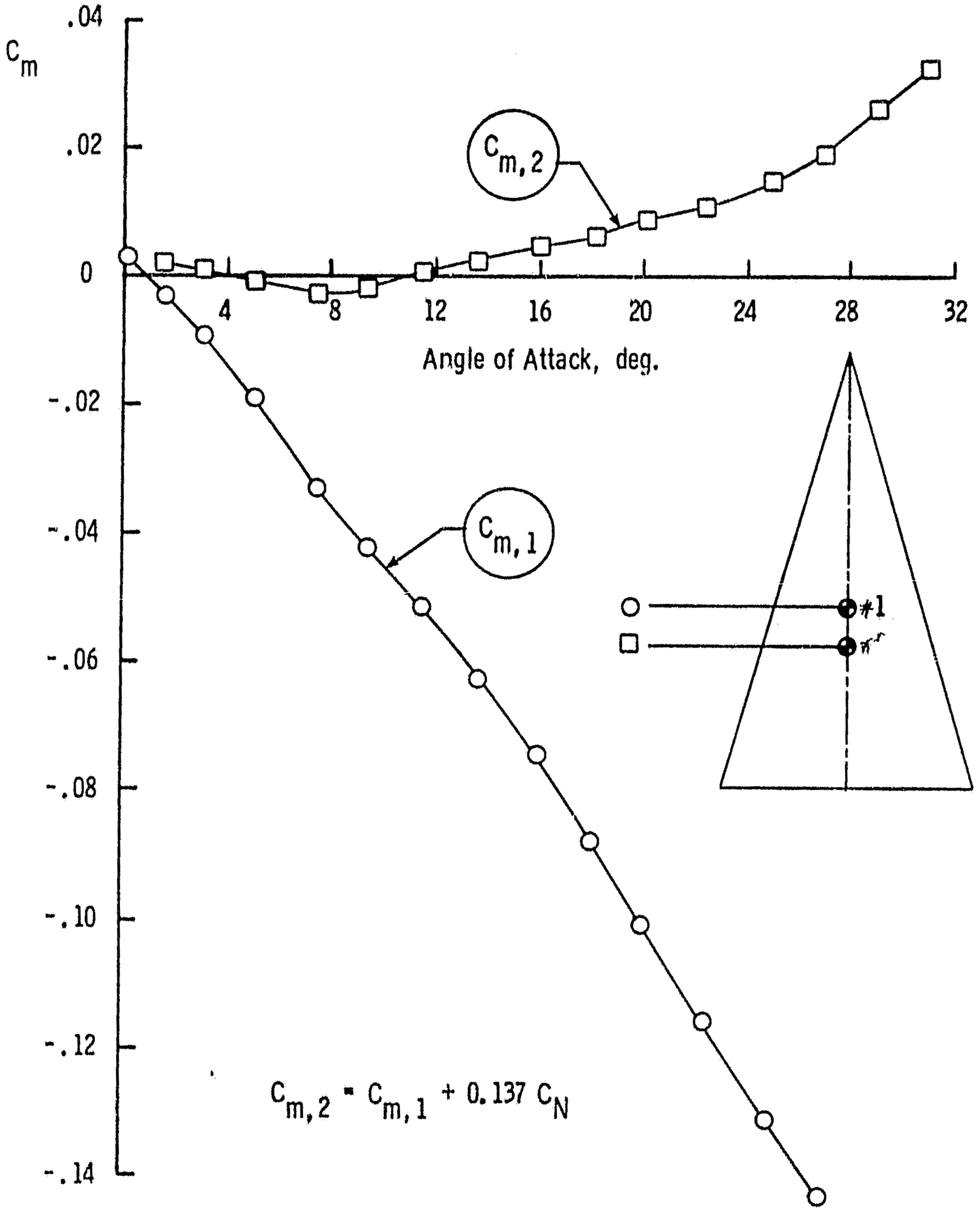

Fig. 5 - Basic Wing Pitching-Moment Characteristics;
$C_{m,1}$ - As Measured About c.g. #1,
$C_{m,2}$ - As Transformed to c.g. #2

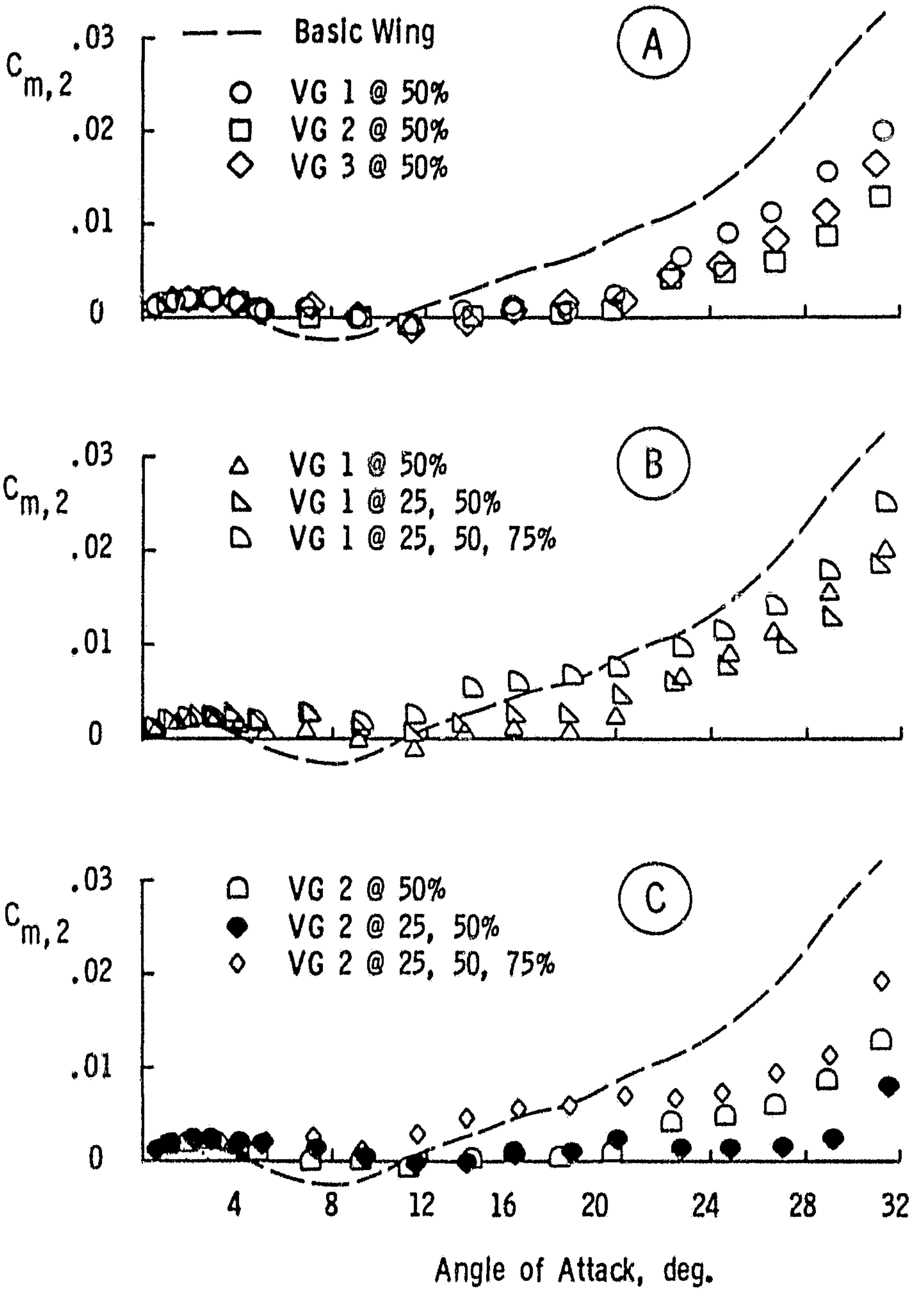

Fig. 6 - Pitching-Moment Characteristics with Various Pylon VG Arrangements

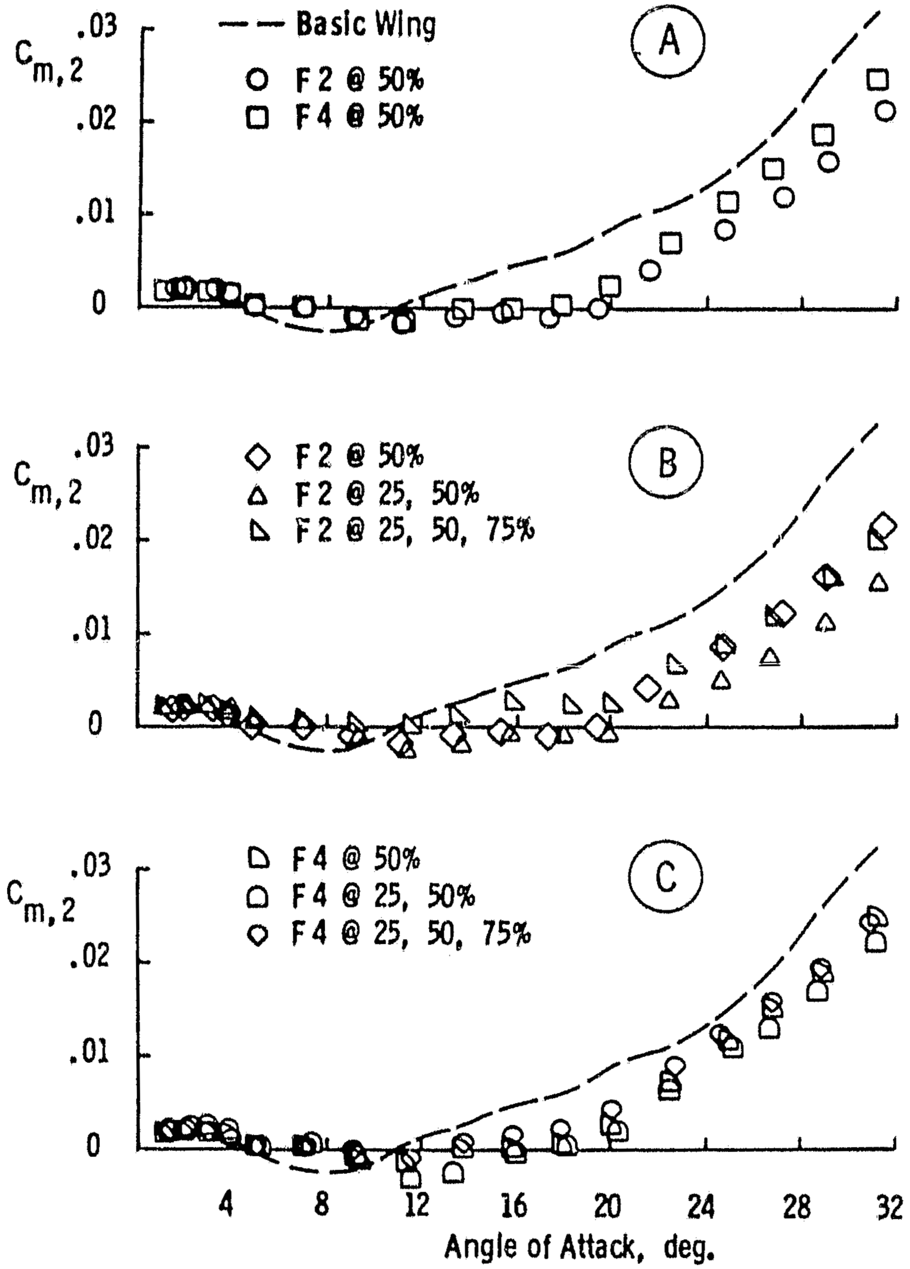

Fig. 7 - Pitching-Moment Characteristics
with Various Fence Arrangements

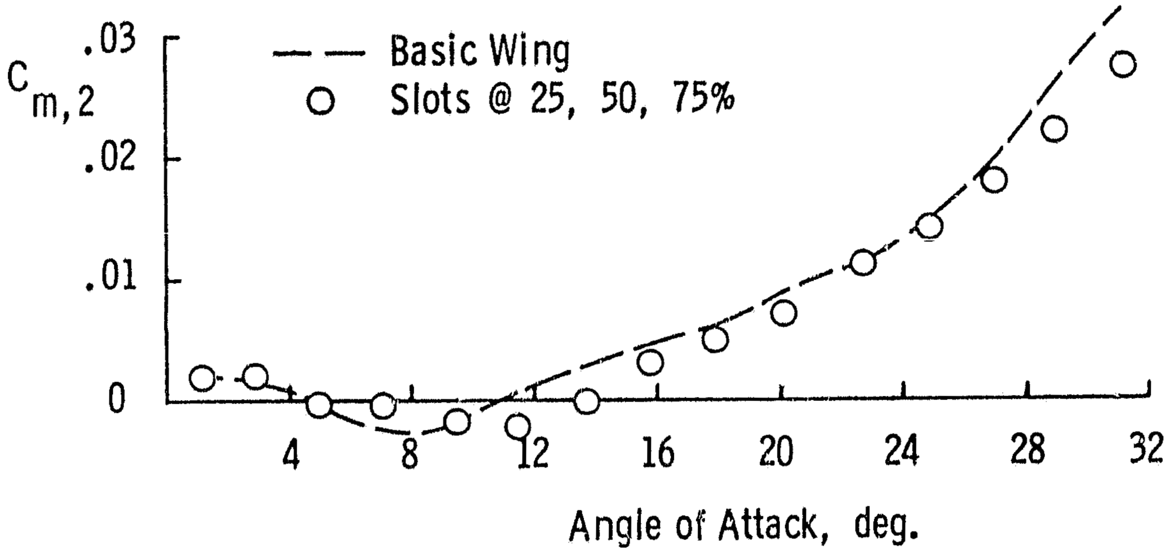

Fig. 8 - Pitching-Moment Characteristics with Leading Edge Slots

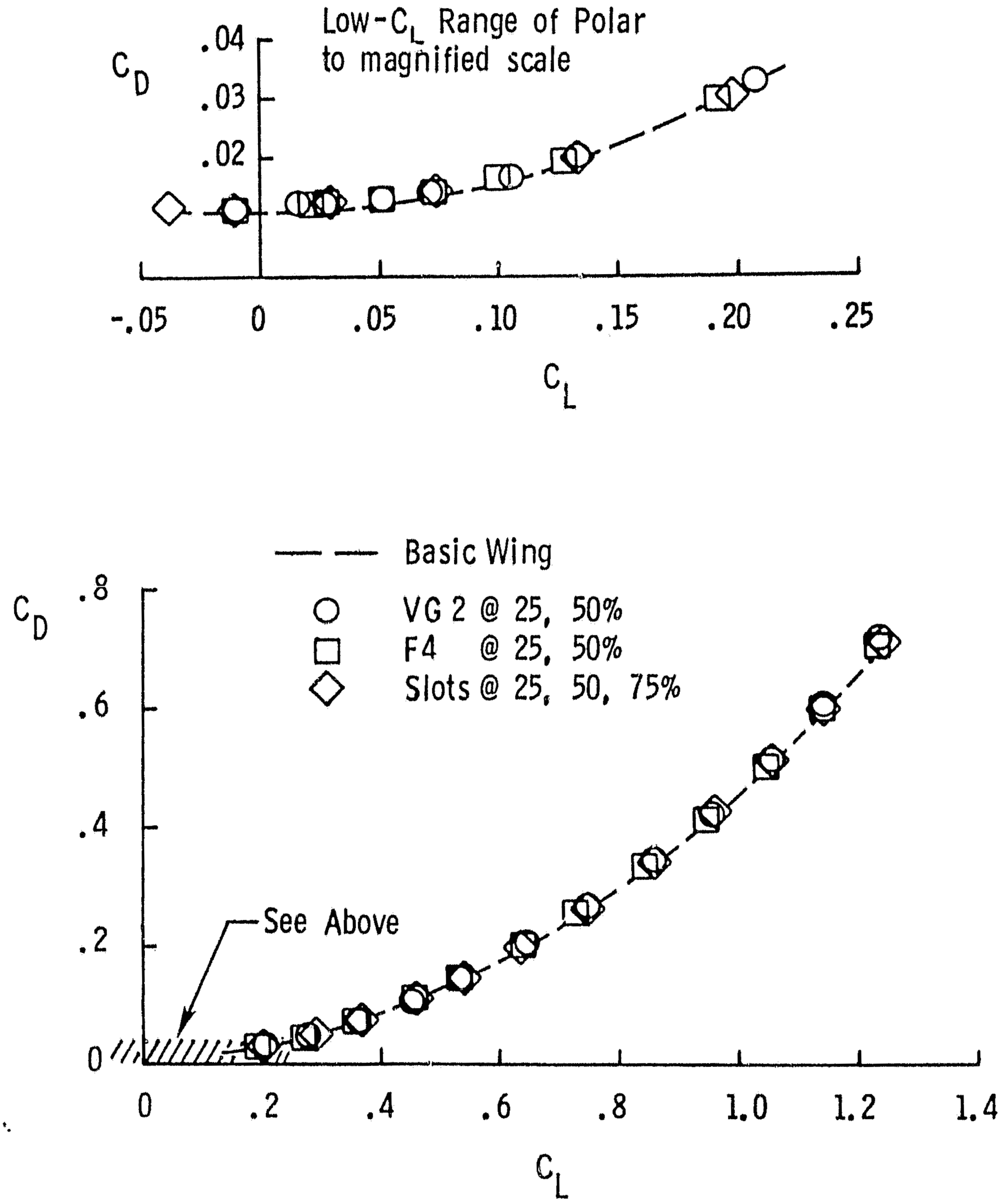

Fig. 9 - Drag Polar with 'Best' Leading Edge Devices