OLD DOMINION UNIVERSITY RESEARCH FOUNDATION

DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
SCHOOL OF ENGINEERING
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

(NASA-CR-164833) WIND-TUNNEL STUDIES OF ADVANCED CARGO AIRCRAFT CONCEPTS Final Report, 22 Jun. 1979 - 21 Jun. 1980 (Old Dominion Univ., Norfolk, Va.) 17 p HC A02/MF A01 CSCL 01A G3/02 N81-32117 Unclas 27514

WIND-TUNNEL STUDIES OF ADVANCED CARGO AIRCRAFT CONCEPTS

By

D.M. Rao

Principal Investigator: G.L. Goglia

Final Report
For the period June 22, 1979 - June 21, 1980

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Under
Cooperative Agreement NCC1-9
John B. Peterson, Jr., Technical Monitor
Subsonic-Transonic Aerodynamics Division

September 1981

DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
SCHOOL OF ENGINEERING
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

WIND-TUNNEL STUDIES OF ADVANCED CARGO AIRCRAFT CONCEPTS

By

D.M. Rao

Principal Investigator: G.L. Goglia

Final Report
For the period June 22, 1979 - June 21, 1980

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

Under
Cooperative Agreement NCCI-9
John B. Peterson, Jr., Technical Monitor
Subsonic-Transonic Aerodynamics Division

Submitted by the
Old Dominion University Research Foundation
P.O. Box 6369
Norfolk, Virginia 23508-0369

September 1981

WIND-TUNNEL STUDIES OF ADVANCED CARGO AIRCRAFT CONCEPTS

By

D.M. Rao*

INTRODUCTION

The principal accomplishments of this research effort are summarized as follows:

(1) Data analysis of wind-tunnel tests on novel leading-edge devices for drag-reduction on a 60-degree delta wing model at higher angles of attack was completed. A data report (NASA CR-159120) and an AIAA paper (No. 80-0310) highlighting the main results were prepared. This research was submitted as a Master's thesis by Mr. T.D. Johnson, Jr.

(2) A preliminary wind-tunnel test of the leading-edge vortex-flap concept on a 74-degree delta wing was documented (NASA CR-159161). Considerable interest has been generated within the aerospace industry in the potential of this device for improving the subsonic performance of supersonic cruise airplanes. A wind-tunnel test program was conducted by General Dynamics at NASA/Langley Research Center (LaRC) to evaluate vortex flaps on their fighter model. Vortex flaps were designed for a Boeing Recce-Strike model for testing at NASA/LaRC in March 1980.

(3) Results of subsonic wind-tunnel tests on a NASA arrow-wing supersonic transport configuration equipped with segmented vortex flaps were presented at the Langlev Supersonic Cruise Research Conference (SCR-79). The L/D improvements at lift coefficients corresponding to climb and landing-approach by the use of vortex flaps were confirmed during a follow-up test in the NASA/LaRC V/STOL tunnel with a larger scale model.

(4) A paper summarizing the vortex flap research was accepted for presentation at the International Council of Aeronautical Sciences (ICAS) Conference in Munich in October 1980.

---

* Research Professor, Department of Mechanical Engineering and Mechanics, Old Dominion University, Norfolk, Virginia 23508.

(5) Two new technology reports have also been prepared, and these are detailed in the following sections.

NEW TECHNOLOGY REPORT NO. 1

Description of the Problem

Highly swept slender wings employed on supersonic-cruise aircraft and missiles are characteristically inefficient in the subsonic phases of flight at high angles of attack (as in approach, climb, and combat maneuver). Flow separation from the leading edges generates vortices which provide additional lift but at a high cost in drag, resulting in poor lift/drag ratio. Als , the center of vortex lift moves towards the nose, causing pitch-up difficulties, particularly when vortex breakdown is encountered. The vortex behavior also influences lateral/directional stability and often interferes unfavorably with tail controls. Conventional means to delay separation and the onset of vortices, e.g., by deflecting the entire leading edge down in order to maintain attached flow to a higher angle of attack, are limited in practice by mechanical complexity and attendant weight penalty. The large deflection angles required raise the likelihood of flow separation inboard along the hingeline so that complete vortex suppression on the wing may not be possible by drooping the lead edges.

Description of the New Technology

The basis of the present aproach is not to prevent the natural tendency of flow separation and vortex formation on higher swept wings, but rather to utilize the vortex in a different way. Separation is allowed to occur on a highly deflected leading-edge flap and the resulting vortex held on the flap upper surface all across the span (see fig. 1). The vortex suction acting on the flap area then produces an aerodynamic thrust component which is responsible for drag reduction.

The optimum flow pattern conceived for the "vortex flap" requires flow attachment to occur just at the wing-flap junction, as indicated in figure 1. Thus, not only is the entire flap area brought under the influence of the vortex, but also the entry to the wing is smooth, resulting in attached flow conditions on the wing. This optimum flow, which can be approached by suitably adjusting the flap angle for any given angle of attack, can be exactly obtained with a planar flap only at one spanwise position due to the three-dimensional nature of the wing flow field However, by means of a segmented vortex flap, where each segment may be independently adjusted, the optimum flow condition may be closely approximated over a large portion of the span. Moreover, some degree of pitching moment adjustment for longitudinal trimming may be available by appropriate setting of the fore and aft segments, while still enjoying the drag-reduction benefit of the vortex flap principle in a good measure. Segmented flaps, as illustrated in figure 2, may also be found more practical from actuation considerations on large aircraft than a single-piece flap.

Unique Features of the Technology and Results of Its Application

A unique feature of the vortex flap is that, throughout the angle of attack range, the flow type remains qualitatively unchanged. Accordingly, no large or sudden change in the aerodynamic characteristics, as happens when forcibly maintained attached flow suddenly reverts to separation, will occur with the vortex flap.

Typical wind-tunnel test data are presented in figure 3 to show the drag-reduction potential of the vortex flap concept applied to a supersonic cruise airplane configuration. The segmented vortex flap data are compared with an ideal leading-edge camber shape determined experimentally for fully attached flow. This ideal shape cannot be regarded as a practical variable-geometry leading-edge structure; by contrast, the vortex flaps are simple panels shaped to retract into the lower surface of the wing when not used. The vortex flaps produce the same order of lift/drag ratio improvements as the ideally cambered attached-flow leading edge over a range of lift coefficients appropriate to subsonic flight. In addition, they also alleviated significantly the excessive dihedral effect of the basic wing and so improved the cross-wind landing characteristics.

Comments

The vortex flap concept was proposed and initial results proving the principle obtained before a similar idea called the "vortex tab" was announced by Boeing in 1978. While Boeing has reported some flow visualization experiments to indicate the formation of the flap vortex, no data indicating the performance of the device have yet been presented. The vortex flap results measured at NASA/LaRC by Dr. D.M. Rao are the first to definitively establish the effectiveness and potential of the technology.

NEW TECHNOLOGY REPORT NO. 2

Description of the Problem

One of the limitations on subsonic maneuverability of highly swept, slender wing combat aircraft arises from degraded effectiveness of conventional ailerons and spoilers employed for roll control. These control surfaces, which are essentially dependent for efficient operation on attached flow over the wing upper surface, are rendered largely ineffective when large-scale separation occurs at the leading edges at high angles of attack. The loss of roll controllability in the high-lift condition, when lateral stability and roll-damping are also at reduced levels, progressively leads to determination of tracking ability, handling difficulties, and lowered resistance to departure.

Description of the New Technology

The new technology offers a means of aerodynamically augmenting the roll-control effectiveness on slender wings at higher angles of attack by manipulating the vortex flow generated from leading-edge separation.

The proposed manipulator takes the form of a flap hinged at or close to the leading edge, normally retracted flush with the wing upper suface to conform to the airfoil shape. In operation, the flap on either wing panel is raised to a suitable angle (see fig. 4). The flow patterns resulting from deployment of the flap are essentially of two types (A and B) depending on the angle of attack, as depicted in figure 5. Considering first the relevant high angle-of-attack case B, a system of two vortices is obtained, one on the flap upper surface and the other inboard on the wing. The redistribution of spanwise-lift caused by the vortex system B, also shown schematically in figure 5, moves the center-of-lift towards the wing panel with deployed flap and produces the desired rolling moment.

At low angles of attack the flow pattern A (where the first vortex occurs below the leading edge) is likely to produce an opposite rolling moment. While the low angle-of-attack case is not relevant to the roll-control function, it suggests another use for the upper-surface vortex flaps (viz as airbrakes) which will be described later.

A typical set of subsonic wind-tunnel test data (obtained in NASA/LaRC 7 × 10 ft high-speed tunnel) for an upper-surface vortex flap simulated on the left panel of a 74-degree delta wing research model is presented in figure 6.

The flap drag at low angles of attack (flow pattern A, fig. 5) is manifested as a positive side-force component which reduces to zero and then reverses sign as the flow pattern changes to B at a higher angle of attack and the suction of the first vortex begins to be felt on the flap. This also marks the origin of a positive rolling moment, increasing linearly with lift coefficient (up to $C_L = 0.8$ for the particular flap configuration), which is accompanied by an acceptable yawing moment.

As evident from the drag polar comparison shown in figure 6, flap deployment for roll control incurs no measurable drag penalty. It may be inferred that the thrust component of the flap force fully compensated the skin-friction drag of the flap surface.

Conventional elevons will still be needed for roll-control in the cruise phase of flight, and a combination of elevons and upper-surface vortex flap may therefore be considered for use at high angles of attack.

Wind-tunnel data presented in figure 7 shows that for the test configuration the two contributions to rolling moment were essentially additive. However, a synergistic effect is indicated in the C_L range from 0.6 to 1.0, which may be attributed to the suction induced by the inboard vortex as it passes over the down-deflected elevon.

In an alternate mode of operation, the upper surface vortex flaps on both wing panels may be deployed together. This typically affects the lift/drag characteristics as indicated in figure 8. A large drag is incurred at low lift coefficients (< 0.2) associated with the flow pattern A, which may be utilized for deceleration from high-speed flight. Pitching-moment measurements (fig. 8) indicate that there will be no trim change in symmetric flap deployment at high speed. In the range $C_L = 0.4$ to 0.6, the flow pattern B on the upper surface produces L/D improvements on the order of 10 percent. The magnitude of these effects is dependent on the flap size and deflection angle.

Unique Features of the Technology and Results of its Application

The unique and advantageous features of the upper surface vortex flap as a roll-control device, as illustrated by preliminary wind-tunnel tests on a conceptual model briefly discussed under "Description of the New Technology," may be summarized as follows:

(1) It is not based on attached-flow requirement as are the conventional control surfaces, but operates by manipulating three-dimensional flow separation and vortices naturally present on highly swept slender wings at large angles of attack.

(2) Rolling moment increases linearly with lift coefficient up to high values of lift ($C_L \rightarrow 1.0$).

(3) Induced yawing moment is acceptable: i.e., it acts in the direction of the turn, therefore requiring little rudder assistance.

(4) No drag penalty is incurred due to control deployment.

(5) It augments roll power synergistically when used in combination with conventional elevons.

In addition, by deploying the surface vortex flaps symmetrically on both wing panels:

(6) A powerful airbrake effect is available for rapid and controlled deceleration from high speed with no trim change. The steady nature of the vortex flow field is expected to yield exceptionally low buffet level during deceleration and to avoid wake-excitation of empennage structures.

(7) Aerodynamic thrust effect from the vortex-induced suction on the flaps improves the lift/drag ratio by 5 to 10 percent in low-speed flight ($C_L = 0.4$ to 0.6).

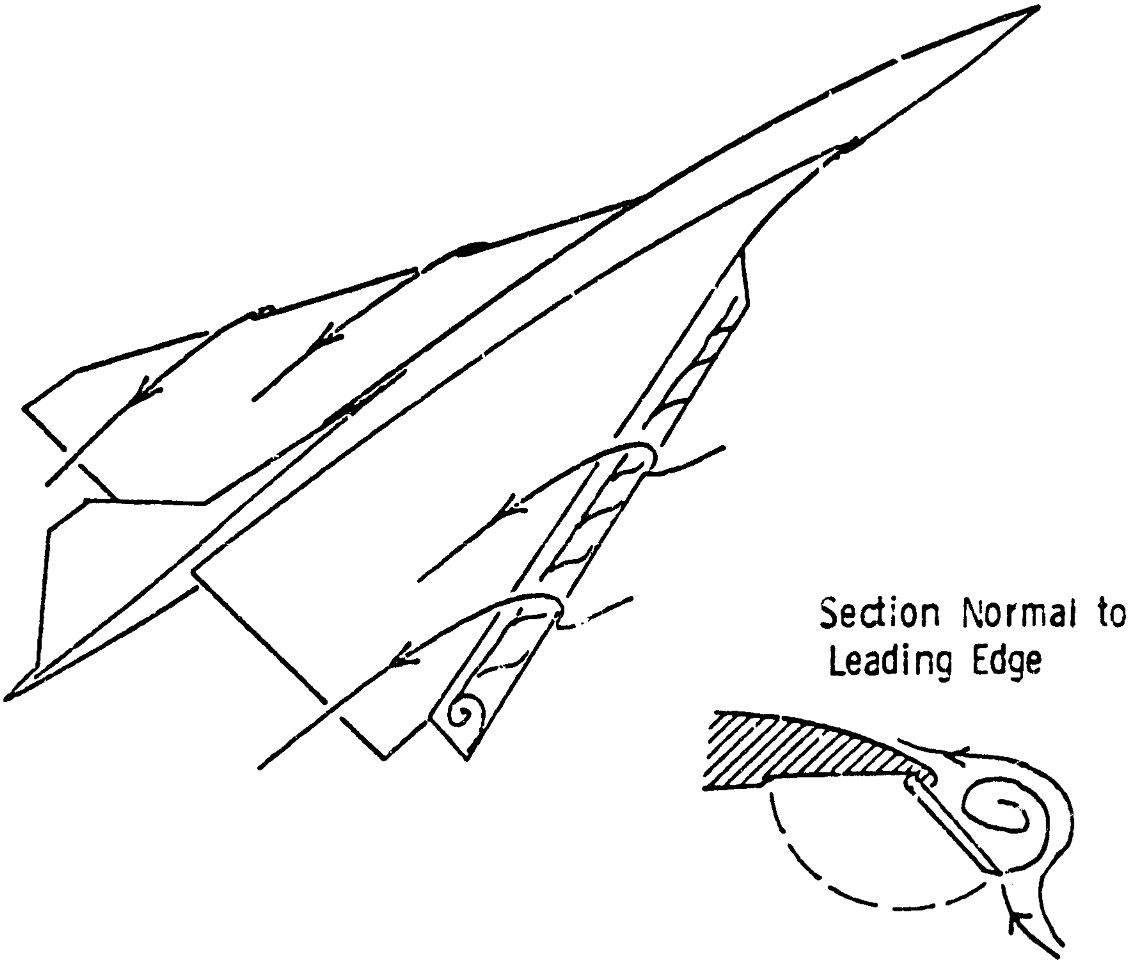
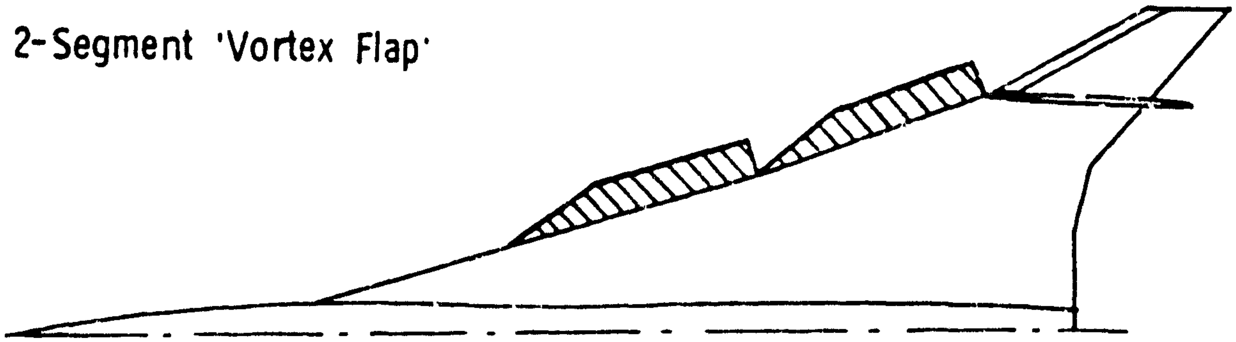
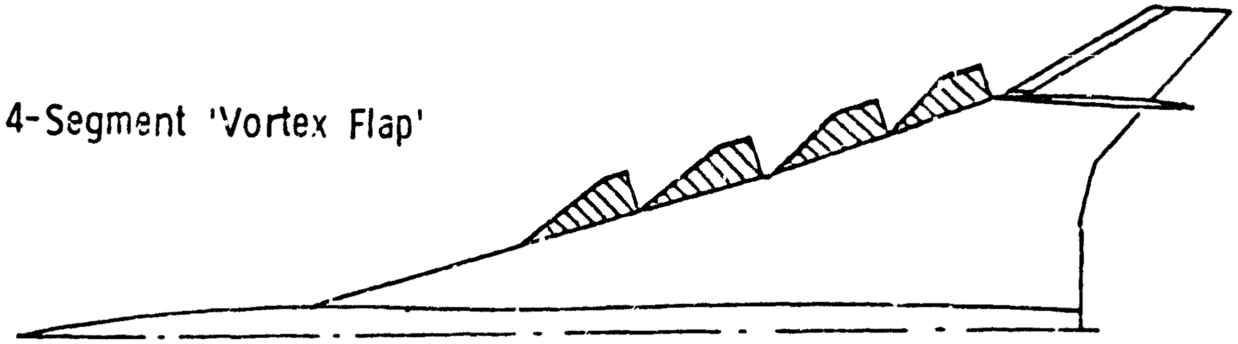


Figure 1. Vortex flap concept.



2-Segment 'Vortex Flap'



4-Segment 'Vortex Flap'

Figure 2. Segmented variations of vortex flap.

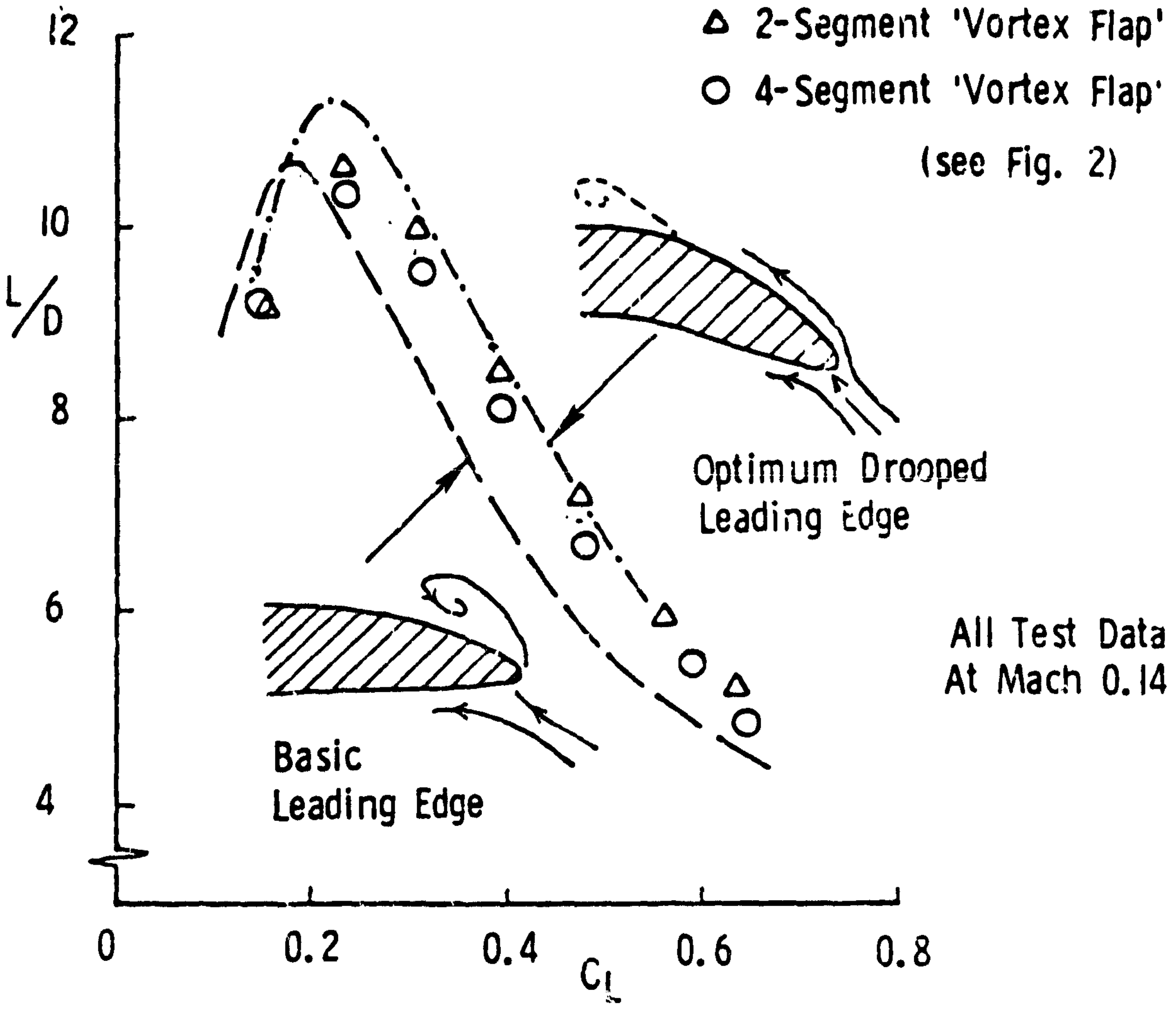


Figure 3. Typical vortex flap performance results.

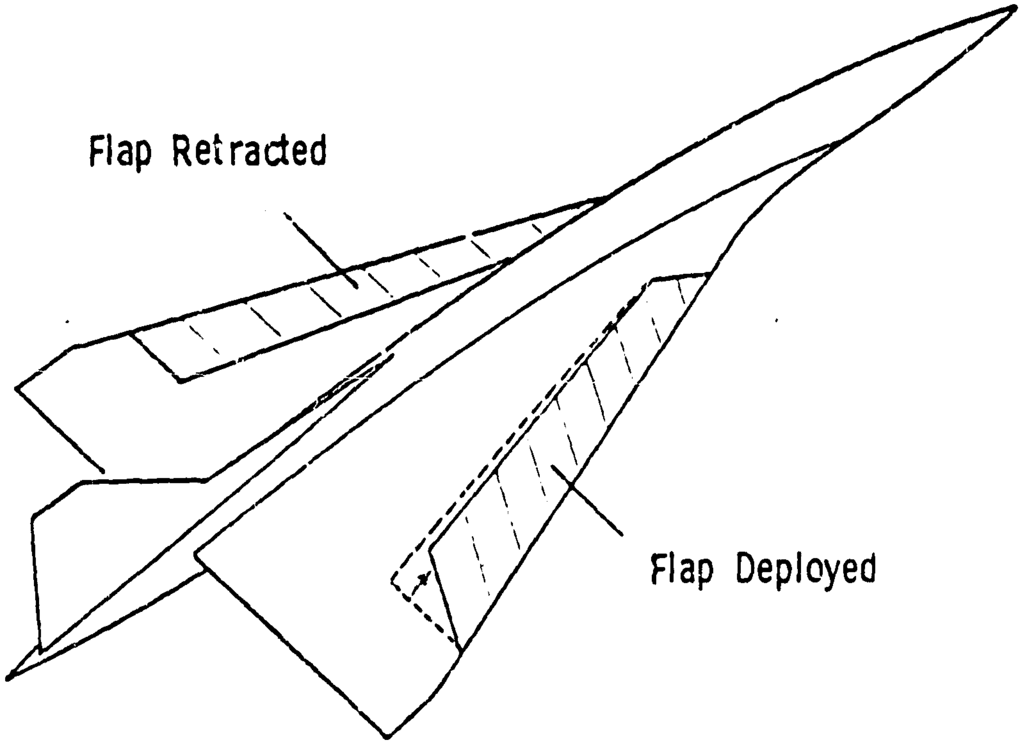
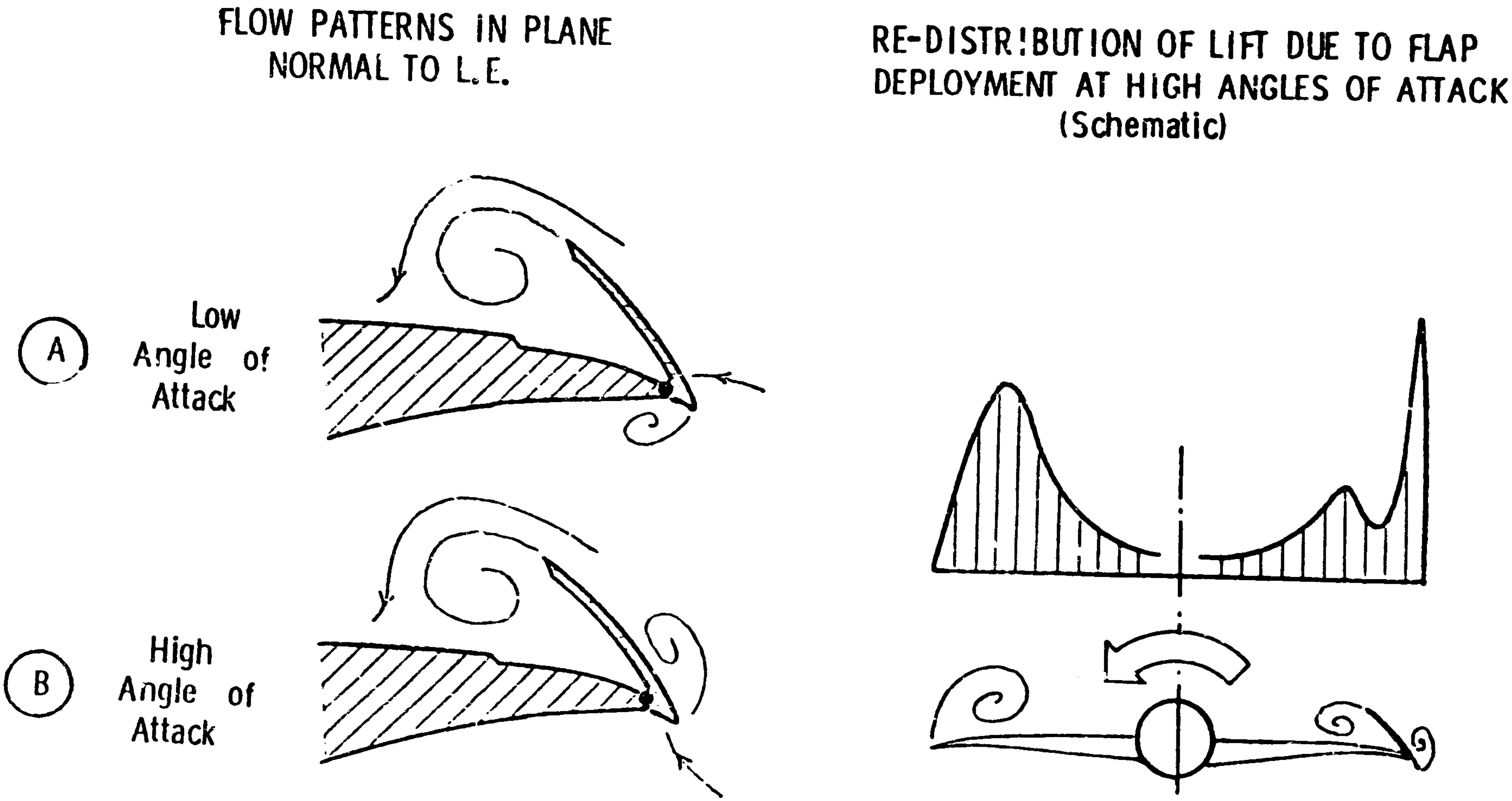


Figure 4. Upper-surface vortex flap concept for roll control.



FLOW PATTERNS IN PLANE NORMAL TO L.E.

RE-DISTRIBUTION OF LIFT DUE TO FLAP DEPLOYMENT AT HIGH ANGLES OF ATTACK (Schematic)

Figure 5. Flow patterns and lift redistribution due to upper-surface vortex flap deployment for roll.

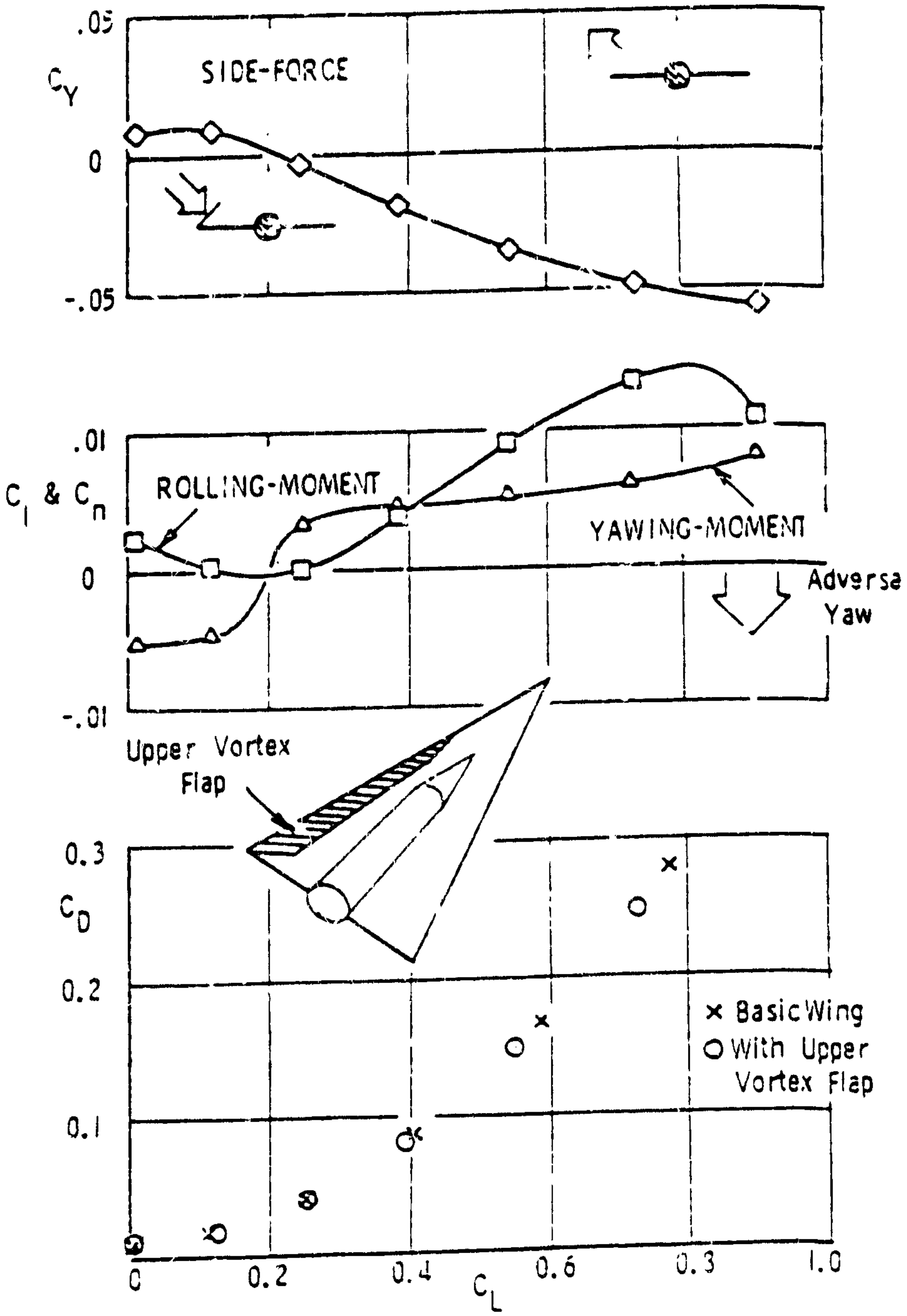


Figure 6. Typical aerodynamic characteristics with upper-surface vortex flap deployed for roll control.

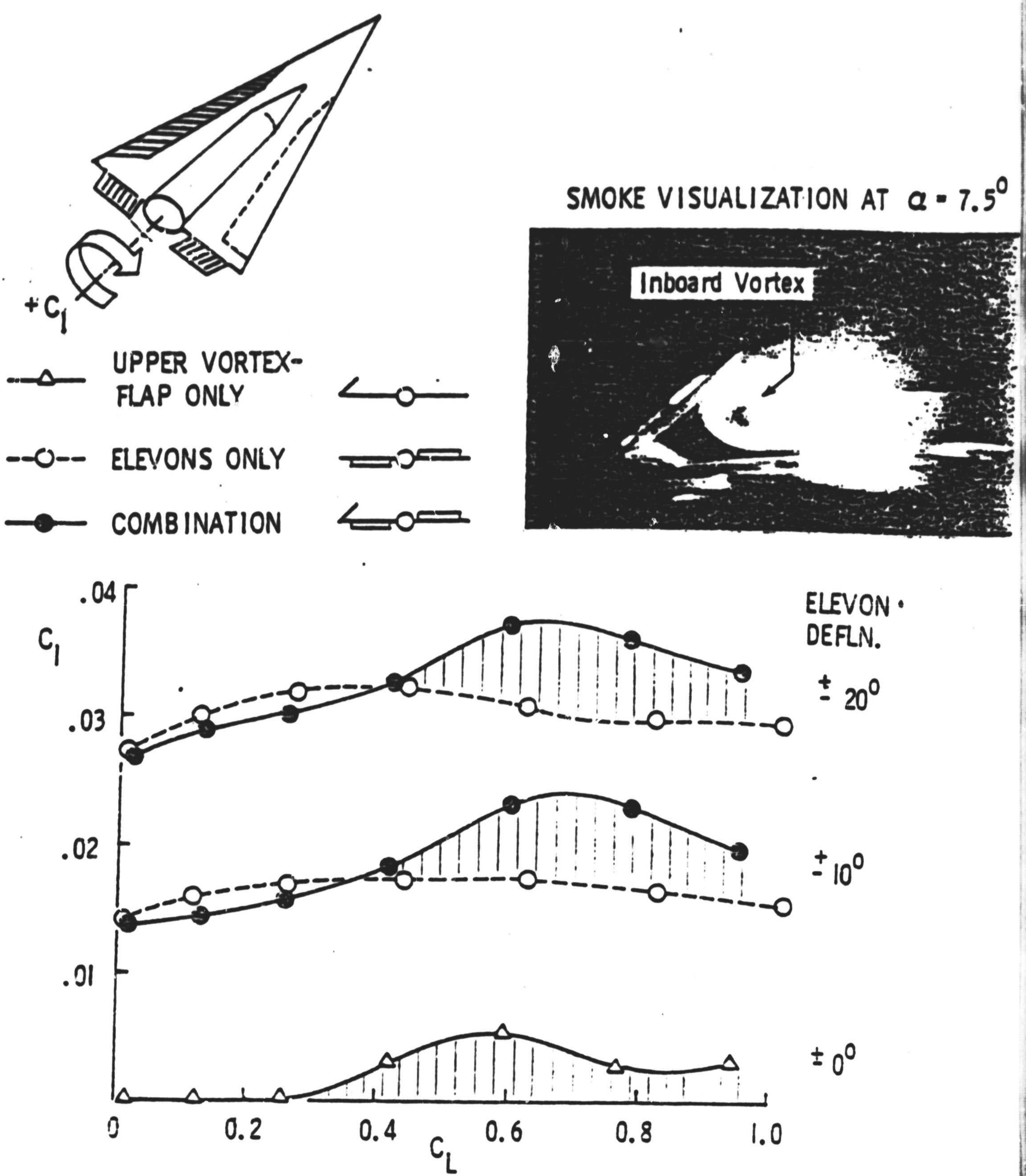


Figure 7. Augmentation of elevon roll power with upper-surface vortex flap.

ORIGINAL PAGE IS OF POOR QUALITY

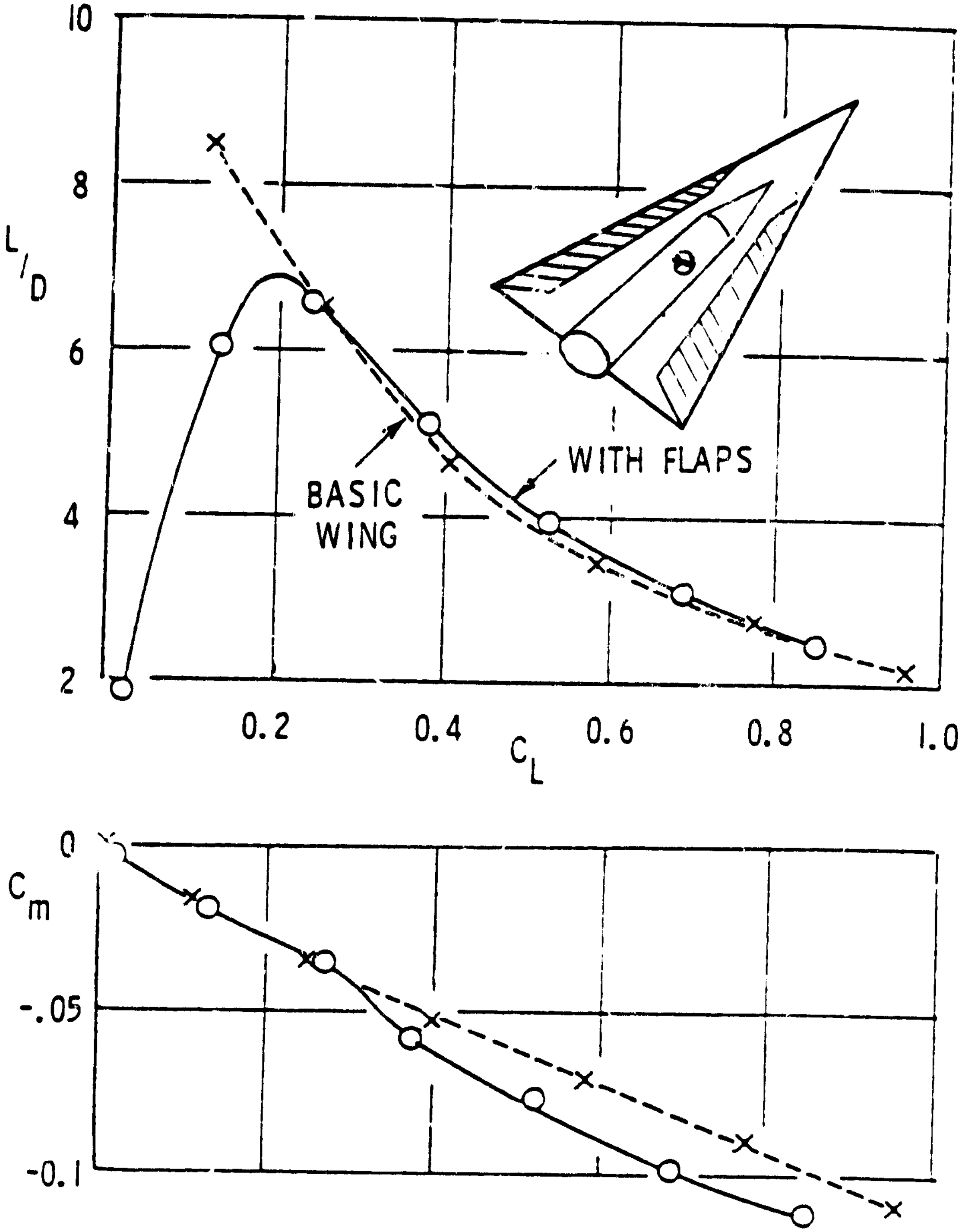


Figure 8. Typical longitudinal aerodynamic characteristics with symmetric deployment of upper vortex flaps.