A candidate technology for the next generation of tactical fighters nears readiness for flight demonstration

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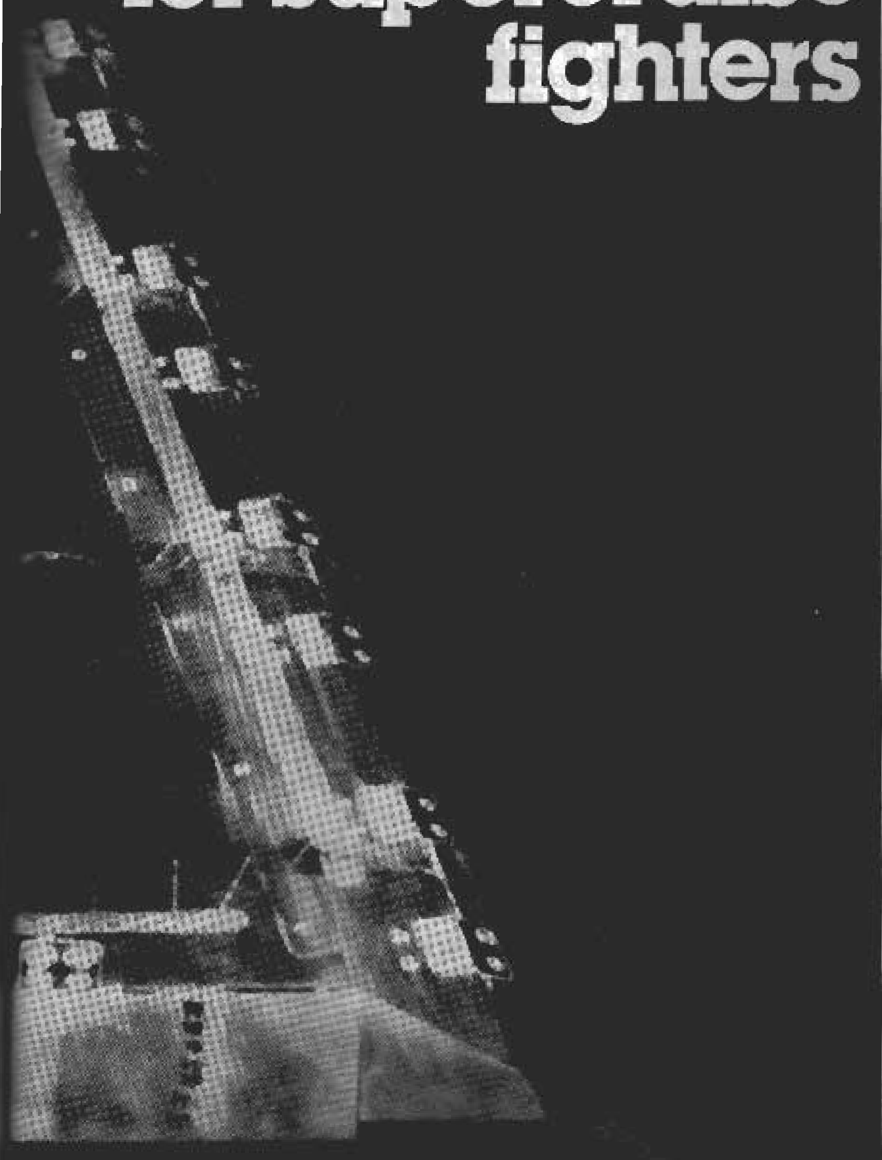
Vortex flaps —advanced control devices for supercruise fighters



Advanced fighters will need a blend of high supersonic-cruise efficiency and high maneuverability—a "supercruise" configuration encompassing heretofore unlinked mission requirements. A special leading-edge device, the vortex flap, spanning all or parts of the wing, may yield the needed aerodynamic control across the spectrum of such a fighter's performance. Design work on the vortex flap has begun to mature, supported by a variety of research. An immediate goal: meeting the performance requirements for the Advanced Technology Fighter (April 1983 *Astronautics & Aeronautics,* pp. 42-44).

The vortex flap differs from a typical attached-flow flap by using the leading-edge vortices generated by sharp-edged swept wings for other than lift enhancement, as described by P.J. Bobbitt of NASA's Langley Research Center. Most of the early work centered on this lift and its distribution and, because of the flow type which led to its development, the effect came to be called "vortex lift."

Vortex lift confers many benefits: greater lift for takeoff and maneuvers, better control of aerodynamic center, similar flow fields over a wide range of angle of attack and Mach number, and less gust response and buffet intensity.

Concorde, SR-71 wings

Designers have demonstrated these benefits in operational aircraft. The basic wing planform of the supersonic transport Concorde was designed with vortex flows in mind. Moreover, Concorde uses vortex lift in off-design conditions because of its smaller Reynolds-number dependence than attached flows. Vortex advantage gives Concorde high controllable lift at takeoff and landing at low speed. The resulting structural loads can thus be lower in the leading-edge region due to the vortex system moving the local load center inboard at off-design conditions.

B. R. Rich of Lockheed has described how the strategic reconnaissance aircraft SR-71 uses vortex flows to pro-

In NASA Langley Research Center wind tunnels, seven single full-span leading- and trailing-edge flaps produced almost same drag improvement as transonically cambered wing.

duce high lift during low-speed flight, to reduce the size of the vertical tails by promoting a favorable forebody interaction, and to control the aerodynamic-center movement through nonlinear loading on the highly swept portion of the wing. Transonic maneuvering fighters, such as the F-16, use vortex flow to provide maneuver lift through the favorable interaction of the strake-generated vortex system and wing at high incidence. This lift is generated with significantly less structural weight than would be required if the lift were generated from attached flow alone, since an attached flow solution would require a much larger wing area. Supercruise fighters, similar in type to the F-16XL built by General Dynamics, use vortex flow for the necessary lift at many points in the flight envelope, especially at low speeds for takeoff and landing and at transonic speeds for maneuvering.

One major difference distinguishes vortex-flow applications for the transonic fighter from those for a supercruise fighter: the extent of the vortex lift available. The supercruise fighter, having more of the wing highly swept, develops significantly higher levels of this lift, as demonstrated in the lift/dynamic pressure (L/q) graph here. Only a small amount of the increase in L/q comes from the attached-flow potential lift difference (see graph; note the supercruise wing area is double that of the transonic wing's and its aspect ratio is almost 50% smaller). The larger vortex lift for the supercruise fighter also increases its instantaneous load factors—up to 50%—compared to the transonic fighter's, as demonstrated by the F-16XL.

All of these vortex-lift benefits entail a "problem": lost leading-edge thrust (or suction). This aerodynamic force, available for wings with a subsonic leading edge, acts in the flight direction but is "lost" with the onset of vortex flow. However, it *reappears* as an additional normal force, as Polhamus of NASA-Langley demonstrated with his famous suction analogy. The skilled designer can develop procedures or mechanisms for recovering a portion of this "effective suction" while retaining the necessary aircraft stability and control. He can reorient the resultant vortex-force vector forward and away from normal to the chord plane.

Twist and camber aid flow

The graph on the next page shows the variation of drag due to lift with aspect ratio at a high lift coefficient. It can be deduced that a very slender delta would not need to keep the flow attached to obtain low drag. However, practical configuration limitations require the more "draggy" but needed lower-aspect-ratio wings (even similar to current fighters), and for these to operate nearer the attached-flow lower bound shown in the graph. For a fixed wing with vortex flow, the designer can use twist and camber with vortex flow to acquire the desired vortex-force vector reorientation and the associated improved performance. In 1978, before the F-16XL development, NASA-Langley and General Dynamics jointly studied such twist and camber in a cranked planform referred to as "Pre-Scamp." The goal was to achieve efficiently an equivalent 4-*g* transonic maneuver, which Lamar and his associates at

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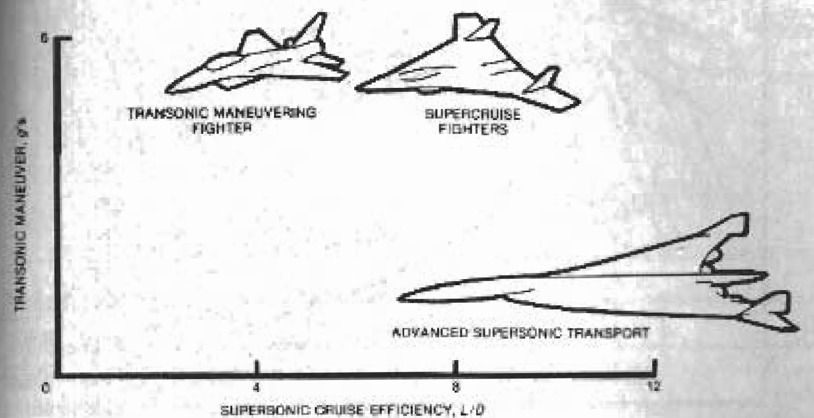
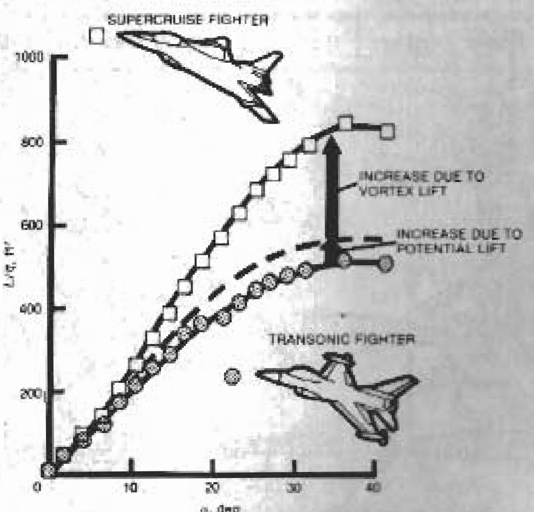
Desired supercruise fighter traits

Advanced fighter concept blends high supersonic cruise efficiency and high maneuverability. Vortex flap may yield the aerodynamic control needed across the spectrum of performance for such a "supercruise" fighter. Chart indicates desired combination of maneuvering acceleration and cruise efficiency.



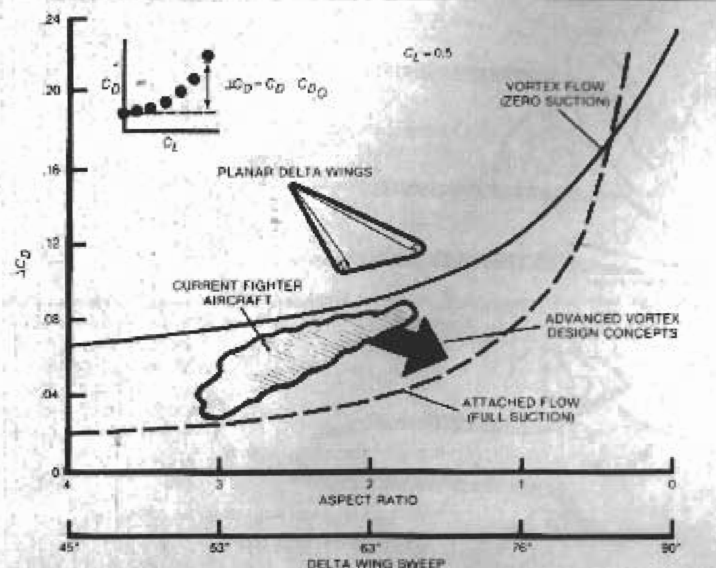
Vortex lift increases lift efficiency

Data show increase above normal potential lift (dashed curve).



Drag variation at high lift

Slender delta can have low drag with detached (vortex) flow at low speed



Langley did. But that work had the limits of a fixed wing, which introduced severe drag penalties at other lift coefficients and Mach numbers, especially supersonic. Logic then directed thought to the benefits of vortex action at all flight conditions by making the leading-edge region deflectable—a "vortex flap."

Consideration of vortex flaps for drag reduction can be traced to the Pre-Scamp Langley test in which the planar planform had simple full-span leading- and trailing-edge flaps deflected. A particular combination produced almost the same drag improvements at a lift coefficient (C_L) of 0.5 and Mach number of 0.80 as did the transonically cambered wing, as shown in the graph on the next page. This early implementation of the vortex-flap concept also produced—

—Nearly the same supersonic-cruise L/D as the supersonic designed wing and better than the F-16's.

—Subsonic-cruise L/D nearly as good as the F-16's and better than the fixed supersonic design's.

—Transonic-maneuver L/D midway between the F-16's and the fixed supersonic wing.

The typical vortex flap used for drag reduction, a lower-surface device, has been found to be effective at transonic speeds in the angle-of-attack range generally between 10° and 15°. The illustration on the next page shows typical devices—folding, hinged, tabbed—with accompanying flow sketches. A small controlled vortex is of interest for drag reduction. It should be entirely captured on the flap, with the flow reattachment occurring along the flap hinge-line or wing shoulder, as shown. If the reattachment line occurs away from the hinge-line, or shoulder, the flow will be off-design and prevent full drag-reduction benefits. Deflecting an apex or upper-surface vortex flap upward can generate large amounts of lift at low angles of attack.

Transonic maneuver, one of the key needs for future fighters, concerns only lower-surface devices. (Note that the vortex flap may play a multimission role and even promote STOL-like performance.)

The sketches depict a simple hinged leading-edge device that works in conjunction with trailing-edge flaps to yield benefits over the entire flight envelope. The vortex flap deflected down, causing a forward rotation of the vortex force vector, yields the best sustained maneuvering ability. An undeflected flap gives the best takeoff and instantaneous-maneuver lifts. The flap deflected up increases lift and drag for landing. Deflecting the flap down orients the vortex on the back side, increasing drag and inducing negative lift on the wheels for rollout after landing. At subsonic and supersonic cruise, the flow *may be* attached, and then the flap functions like a cambering surface.

Flap efficiency improved

Success of the Pre-Scamp tests inspired studies of several vortex-flap concepts for which we now have both experimental and theoretical results.

The sketches illustrate characteristics of the lower-surface-flap geometry changes. D. M. Rao of Vigyan Research Associates demonstrated that reducing the length inboard improves flap efficiency. In addition, shaping the flap inboard improves the vortex formation. Shaping outboard promotes vortex-flap reattachment at the hinge line. Both reduce drag and delay pitch-up. Rao and, independently, Schoonover of Langley and Ohlson of Boeing showed that increasing flap size delays the inboard movement of the vortex, and that, together with increased flap frontal area, reduces drag.

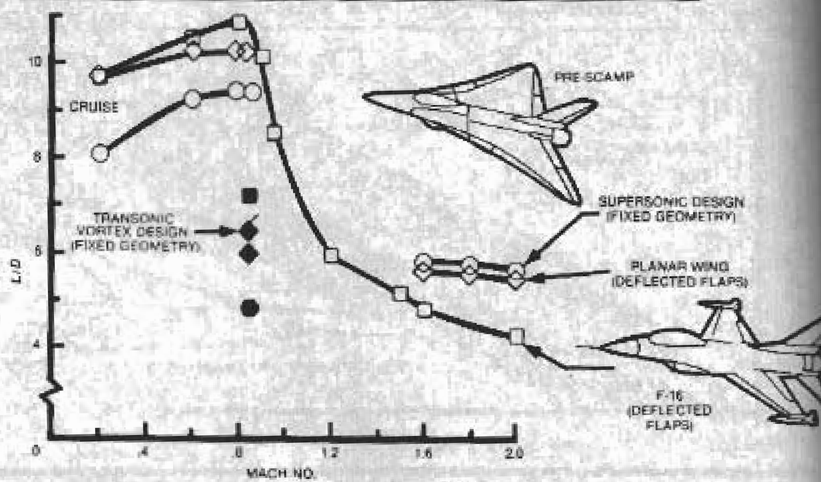
In recent model studies on an arrow wing and a cropped-delta wing, Rao demonstrated that flap segmentation can reduce flap area while achieving the same L/D as without segmentation. The flap segments generate multiple vortices that remain closer to the leading edge, improving the efficiency of the vortex flow in the tip region, which delays tip stall and improves longitudinal stability.

N. T. Frink of Langley and his associates recently performed a subsonic experiment to evaluate effects of wing sweep on vortex-flap effectiveness. On a fighter fuselage they mounted a family of planar delta wings (sweeps of 50°, 58°, 66°, and 74°) having constant-chord vortex flaps. Increasing sweep decreased L/D for a given flap deflection; increasing flap deflection increased L/D for any sweep; and flap deflection proved more effective at the lower sweeps. Complementary theoretical studies have been pursued by Frink, both with a simple vortex-lattice method coupled with the suction analogy to obtain overall forces and moments and with the free-vortex sheet method to obtain detail pressures.

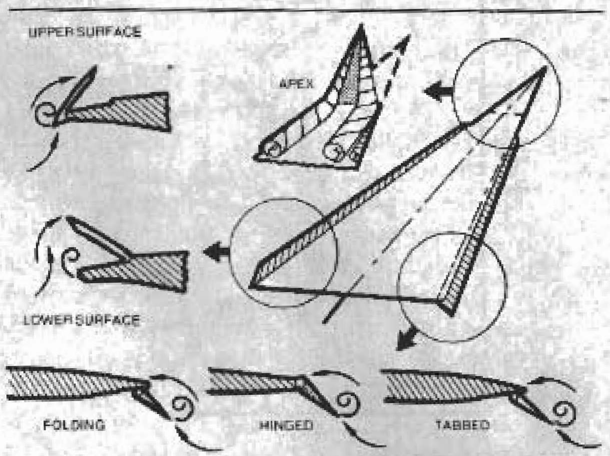
The graphs here give some results obtained by Frink for a constant-chord flap

Articulated flaps need not increase drag

Solid points are for 4-g maneuver at 30,000 ft. All points except square are for Pre-Scamp.

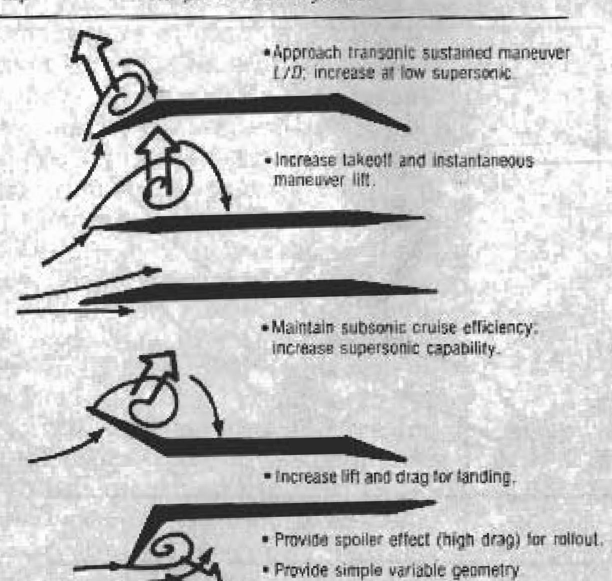


Flow patterns with various vortex flaps

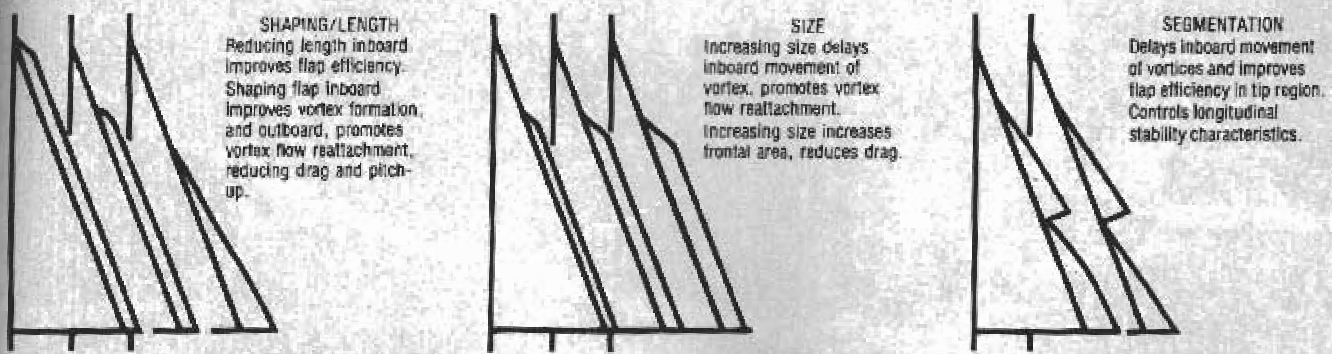


Benefits of simple hinged leading-edge flap

Compared to current production fighters.

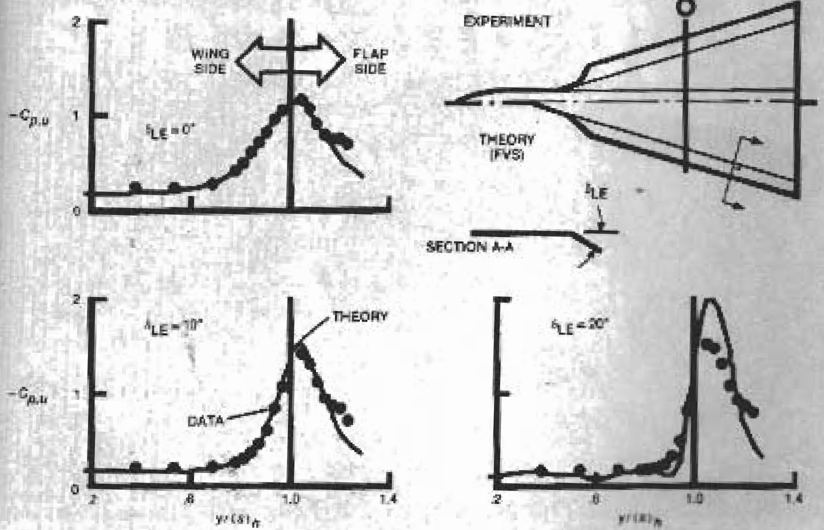


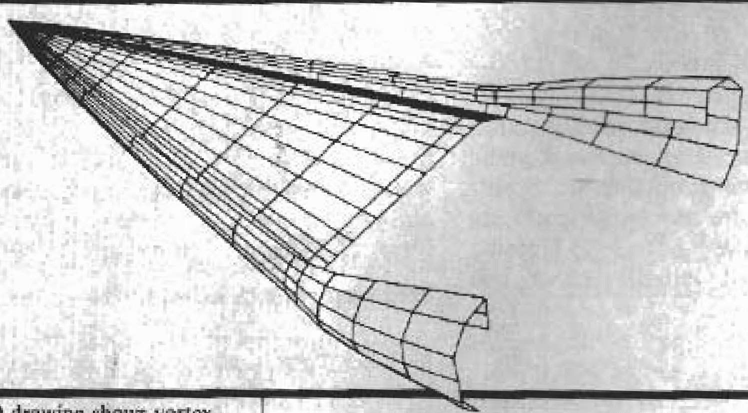
Benefits of lower-surface flap geometries



Theory and experiment agree on flap performance

Deflection range of about 20° for a 74° delta at Mach 0.3 and α of 14°.





CAD drawing shows vortex generation for constant-chord flap on a 74° delta. Analysis backs expectation that suction peak pressure can be kept on flap to maximize thrust.

mounted on a 74° delta. The agreement with data over a leading-edge deflection range of 20° is encouraging. These pressures suggest that a suitable deflection angle exists to keep all of the suction peak pressure (associated with the vortex) on the flap so as to maximize its "effective suction" benefit. Studies have also been done to alter the shape of the flap to control the vortex strength and keep the vortex near the edge. Finally, the CAD drawings show one of Frink's solutions for vortex generation on the 74° delta.

While the usefulness of the vortex flap has been demonstrated, the experimental data-base and theoretical methods need expansion. The goal: an early successful flight demonstration. A NASA-Langley committee is now making recommendations in this area. It is hoped that, if a flight-research program were undertaken, the vortex flap would become a technology option for the Advanced Technology Fighter project.

Additional reading

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Schoonover, W.D., Jr., and Ohlson, W.E., "Wind-Tunnel Investigation of Vortex Flaps on a Highly Swept Interceptor Configuration," ICAS 82-6.7.3, 1982.

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