CAFE FOUNDATION

AIRCRAFT RESEARCH REPORT

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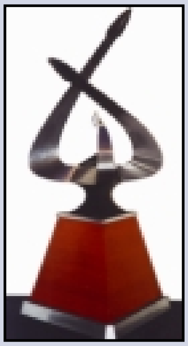
Local Flow Control I

BY BRIEN SEELEY AND THE CAFE BOARD

INTRODUCTION

"Aircraft are built, not designed" is a famous quotation attributed to Donald Douglas. What he meant was that most aircraft ultimately *evolve* from a 'cut and try' process rather than being perfect right off the drawing board. Evidence supporting his comment is found in the wide variety of aerodynamic 'fixes', or local flow control devices, that are applied to many aircraft after they begin test flying.

These photo essays are a result of the late Lyle Powell's decades of fascination with "ramp walking" at general aviation airports. As a dedicated perpetual student of aerodynamics, Lyle collected these photographs to show the many ways that aircraft drag, stability and control can be modified *after* an aircraft is built and flown. Lyle's ramp walking often included interviews with the owners of the parked aircraft to inquire about the purpose and effects of their modifications. Over the last 20 years, he successfully used many of these mods on his own homebuilts and diligently encouraged others to try them as well. Homebuilders can generally rest assured that when an airflow



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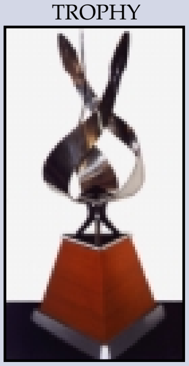


Aerostar rudder with flow guide and VG's.

control device appears on a high performance military aircraft, its effectiveness was established after rigorous and expensive research and development.

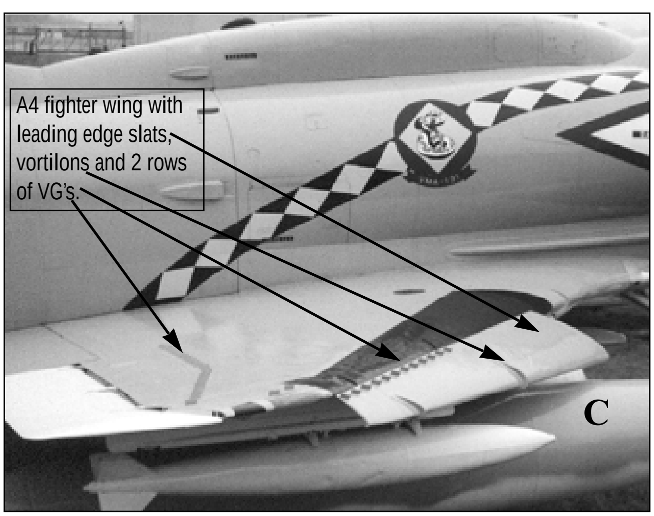
Local Flow Control Part I will focus on devices that influence flying surfaces and Part II will cover air inlets/exits and miscellaneous airflow controls. Local Flow Control Part III will present before and after flight tests of such devices.

FLOW SEPARATION

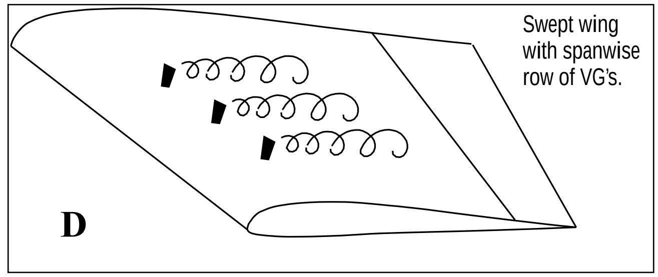
Flow separation is the enemy of aircraft designers. It causes large increases in drag and hampers the aircraft surface's ability to shape its local airflow. As it moves aft on the aircraft, separated flow produces other unwanted effects such as diminished ram recovery, loss of lift and loss of control surface effectiveness and 'feel'.

Airflow separation occurs when the air moving over an aircraft surface loses its attachment to that surface and thereby can no longer follow the surface contour such as when the airflow is asked to turn around too sharp a corner. It can also occur when the boundary layer airflow next to a surface loses too much energy due to slowing by viscous effects and friction. When such a de-energized flow encounters a bend in the surface, it is unable to follow that bend and separates from the surface instead.

Designers strive to avoid regions of separation during conceptual design of the aircraft as a whole. If regions of unwanted separation are discovered during initial flight tests, they can often be "fixed" by using local flow control devices.



A4 fighter wing with leading edge slats, vortilons and 2 rows of VG's.

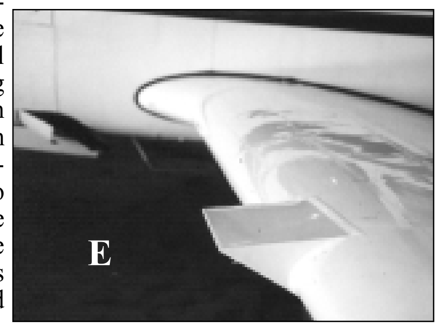


Swept wing with spanwise row of VG's.

VORTEX GENERATORS

A vortex is a spiral of airflow that has low pressure at its center and a high speed, high energy airflow circulating at its periphery. Hurricanes and tornadoes are examples of vortices. Vortices tend to maintain their circular shape due to the offsetting forces of low pressure suction at the central core of the vortex versus the centrifugal force on the circling outer layers of swirling air.[1]

"Bad" vortices created by airflow separation trap energy from the freestream in proportion to the drag penalty that they impose on the aircraft. Small, "good" vortices can be generated by attaching small, flat plates perpendicular to the aircraft surface and angled relative to the local airflow. (See **B, D**). Such plates are called "vortex generators" or VG's. Their small vortices can inject energy into a locally separated boundary layer to reattach it. VG's are one of the most commonly used local flow devices. Nearly all flow control devices generate some kind of vortex as a part of their effect.



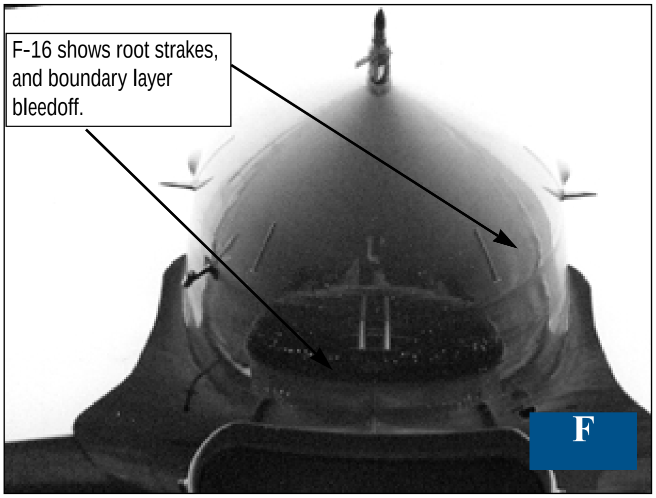
The optimum locations for VG's are determined by trial and error involving taping or gluing them to a surface and then test flying the aircraft. The goal is to set the angle of the VG to the relative wind and its height/width and chordwise/spanwise location so that the VG's high energy wake is maximally directed into a region of separated airflow. This results in the desired reattachment of airflow to the surface and improves that surface's intended aerodynamic function.

Fortunately, the parasite drag caused by a well-placed VG is usually small compared to the large drag reduction obtained by eliminating unwanted separation. This is because most of the VG's frontal area resides in the slow moving boundary layer of air next to the surface.

VG's are often placed in spanwise rows at a certain chordwise location on flying surfaces to assure that a moveable control surface at the trailing edge retains its authority at high angle of attack or at transonic flight speeds. (See **B, C, D**). The Turbo Bonanza uses an odd-looking outboard wing leading edge VG/strake to improve aileron function during flight at high altitudes and higher angles of attack. (**E**).

VG's are also used upstream of regions of interference drag where two surfaces join at an acute angle that would otherwise tend to cause a region of separation, as shown in the vintage jet's tail outlet in photograph **A**.

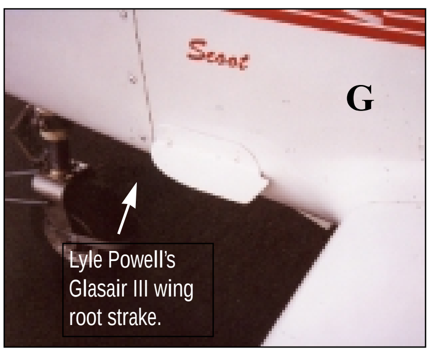
VG's may be useful on the backside of canopies or cabin roofs where the airflow is unable to turn sharply downward onto the turtledeck or aft fuselage. Another use is to re-attach the low speed swirling airflow just aft of a cowl flap or oil cooler exit.

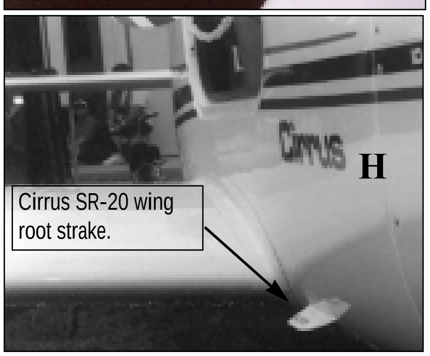


STRAKES

Strakes are small swept wings of very low aspect ratio. They may be forward extensions at the wing root's leading edge or they may stand alone, usually perpendicular to the surface of the fuselage. (Photos **F, G, H, J, K**). At high angles of attack, they serve as large vortex generators. At low angles of attack, they can provide lift, increase local effective sweep angle and enhance pitch and yaw stability. On supersonic aircraft such as the F-16 and F-18, radically long strakes (also known as leading edge extensions or LEX) help avoid shock wave formation at the wing root. They also serve to increase lift and pitch rates at high angles of attack by providing added lift at a more forward fuselage station. (Photo **F**). Marked sweepback reduces the drag penalty of these strakes.[2]

In 1995, Lyle Powell built wing root strakes onto his Glasair III. (**G**). He found them to make the stall payout less abrupt, allowing the aircraft to be more smoothly flared during landing. Similar strakes were later adopted on the new Cirrus SR-20. (**H**). Lyle later substituted a wing root flow guide that worked slightly better and also lowered stall speed significantly. (**I**). The high speed drag penalty of these devices is small relative to the benefits they provide.



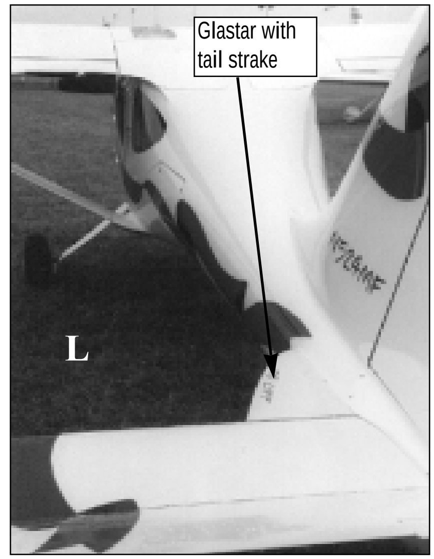


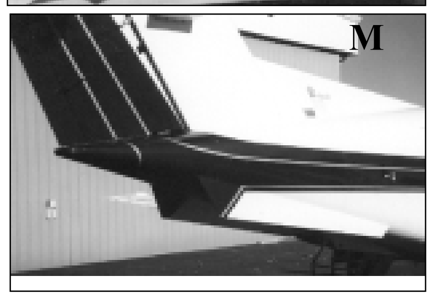
The vortices from the wing root leading edge strakes used on the A36 Bonanza help keep the airflow over that large root chord area attached during flight at high angles of attack. (**J**).

Strakes can also augment wing area and provide more volume for fuel tanks, as found on the Longeze, Cozy, Velocity and Berkut. (Photo **K**).

The horizontal tail strakes found on the Glastar increase its tail volume and help keep flow attached at high angles of attack. (**L**).

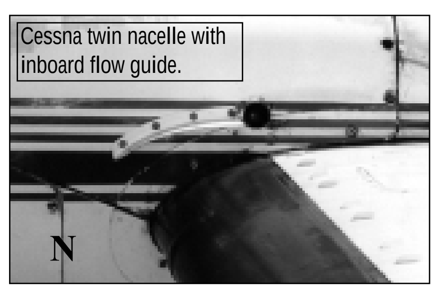
Ventral tail fuselage strakes on the KingAir improve its pitch and yaw stability and reduce required tail downloads at high angle of attack. (**M**). Similar ventral fins are found on the F-14 Tomcat. A single, fixed midline ventral tail fin can be used to increase vertical tail volume and yaw stability as well as to cleanly house a tailwheel assembly or tail skid. (**A**).





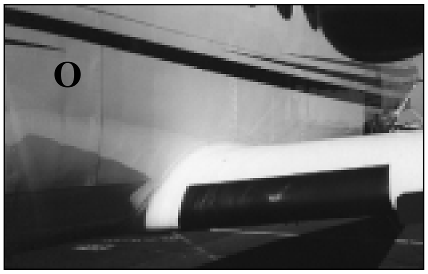
EXTERNAL FLOW GUIDES

Small, cambered, wing-like surfaces can redirect the local flow toward regions of separation. Their action involves deflecting the local flow by using their "downwash". These are often placed on the side of the fuselage, nacelle or vertical fin. (**B, I, N**).



LOCAL AIRFOIL MODIFICATION

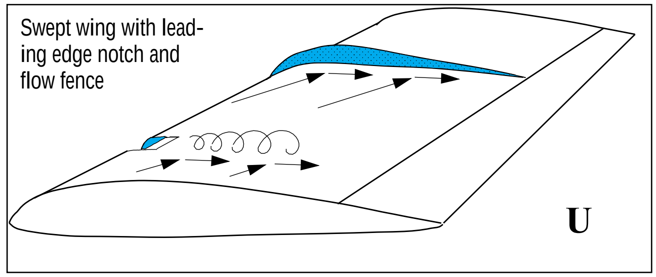
Along the span of a wing, differing airfoil sections may be grafted on or applied as a 'glove' in order to tailor the local flow as desired. Some aircraft, such as the KingAir use extremely cambered, high lift sections at the wing root and sections of lower lift coefficient nearer the wing tip. (**O**). This allows the distribution of lift and the stall progression along the span to be tailored without the use of wing twist. It may also reduce airflow separation at the fuselage/wing root junction.



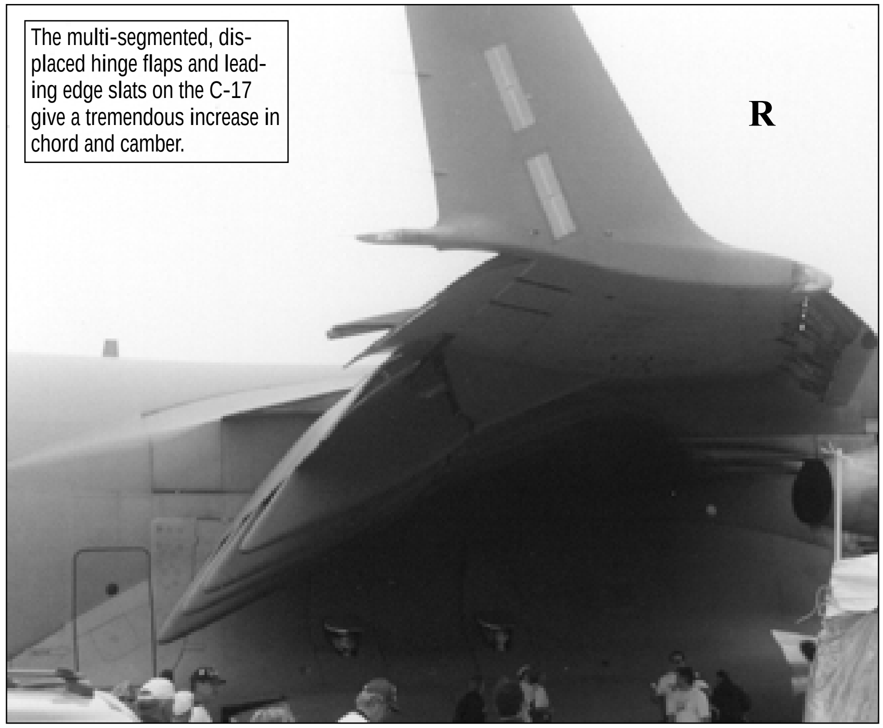
One variation of this is leading edge droop. **(P)**. This produces a local increase in the lift coefficient and is a part of many STOL kits for production aircraft. It typically improves the ability of its local portion of the wing to keep flying when other, non-drooped portions of the wing have stalled. The drooped portion is often forward of an aileron and thus helps the aileron to remain effective during a stall.

LEADING EDGE SLATS

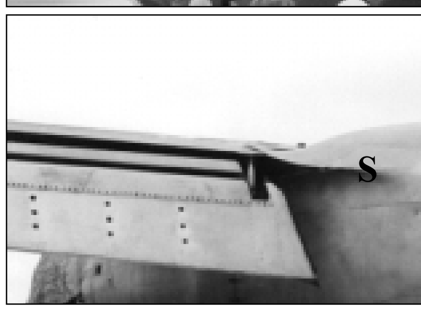
The Falcon jet and the C-17, show the use of leading edge slats. (**Q, R**). These can increase a wing's lift coefficient by up to 40%. Unlike trailing edge flaps, which allow the tilting of the fuselage nose-down for better visibility during approach, leading edge slats do the opposite. They enhance lift when the aircraft operates at higher angles of attack. Consequently, aircraft designed for maximum lift at low speed typically use leading edge slats in conjunction with trailing edge flaps.

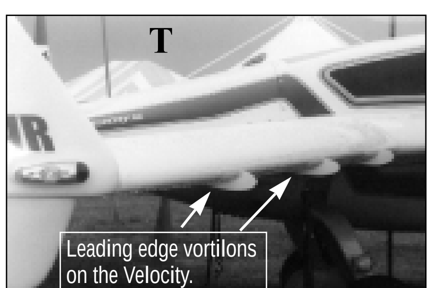


Swept wing with leading edge notch and flow fence



The multi-segmented, displaced hinge flaps and leading edge slats on the C-17 give a tremendous increase in chord and camber.



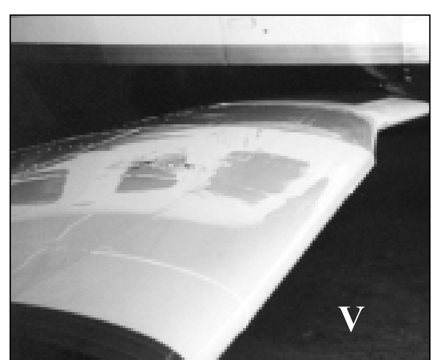


Leading edge vortilons on the Velocity.

SLOTTED FLAPS

A dramatic expression of the use of slotted flaps is found in the C-17. The fully deployed flaps provide a huge increase in wing camber and lift coefficient that are essential to this aircraft's superb slow flight and STOL capabilities. (**R**).

The flaps on the B-25 bomber used a double slot design that increases lift more than a single slot. (**S**). Such a detail contributed to its success in being able to take off in the very short distance available on the U.S.S. Hornet's carrier deck during Doolittle's Raid.



VORTILONS

A vortilon is a combination of a vortex generator and a flow fence. It is a small, flat, forward projecting surface on the lower portion of the leading edge. It has been used on the Velocity and Cozy to reduce spanwise flow on the swept rear wing and to increase control surface effectiveness at high angles of attack. (**T, C**).

LEADING EDGE NOTCHES

A notch or wide slit can be made in a wing leading edge to generate a vortex on the aft portion of that section of the wing. The vortex so formed can have a dual purpose of both keeping the aft flow attached and acting like a flow fence to block unwanted spanwise flow at that location. (**U**).

FLOW FENCES

The flow fence is typically used on swept wings where spanwise flow occurs in proportion to sweepback angle. It consists of a longitudinal 'wall' placed on a flying surface to block unwanted spanwise airflow. It is usually placed on the wing's upper cambered surface but is occasionally used on both upper and lower surfaces. An engine nacelle or a wingtip fuel tank on swept wing aircraft serve somewhat like flow fences. (**U**).

LOCAL SWEEPBACK

Locally increasing the leading edge sweepback angle increases local spanwise flow, reduces drag and reduces the lift coefficient. It also allows that portion of the wing to operate at a higher angle of attack before stalling. Accordingly, segmental variation of sweep angle along a wing's span can be used to tailor the local behavior of each spanwise wing segment, as seen on the Piper Cherokee. (**V**).

CONCLUSION

It is hoped that Lyle's photo collection on local flow devices will inspire homebuilders to make future enhancements to the performance and flying qualities of their homebuilt aircraft. Each device must be tested to determine its cost/benefit ratio. As always, any significant airframe modification must be built structurally sound and must be inspected and tested by qualified test pilots.

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[2]Raymer, Daniel P., Aircraft Design: A Conceptual Approach, Third Edition, 1999. AIAA Education Series. pages 182-183.

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