AIRCRAFT RESEARCH REPORT

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Local Flow Control II

BY BRIEN SEELEY AND THE CAFE BOARD

INTRODUCTION

In this second photo essay on local flow control devices, we focus on inlets and exits as well as some miscellaneous techniques.

INTERNAL FLOW GUIDES

The airspeed inside most internal ducts is usually less than half that of the aircraft. Nevertheless, a worthwhile drag reduction can be obtained by properly shaping internal ducts to smoothly direct their airflow. For inlets, the airflow should be diverged while for exits it should be converged.

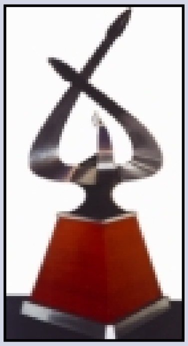
Diverging the airflow diffuses the incoming air, and decelerates it so as to convert its dynamic pressure to useable static pressure. This must be done smoothly and gradually to avoid 'stalling' the inlet. Inlet stall occurs when the airflow separates from the duct wall and forms wasteful static vortices. See Figure (**B**). A stalled inlet will have poor 'ram recovery', meaning that the static pressure recovered at the end of the duct will be low compared to the external freestream dynamic pressure. Well designed air inlet ducts should achieve at least 85% ram recovery in order to provide adequate working pressure for air cooling, cabin ventilation, etc.

The diverging internal duct walls of the smile inlet shown above achieve 105% ram recovery during climb. Their divergence angle is about 10 degrees and their surface contour is a scaled down version of the upper surface of a thin, highly laminar, low camber wing section. (**A**).

AIR EXTRACTORS

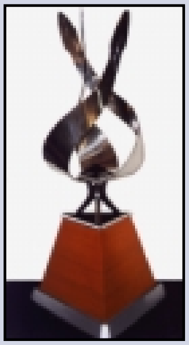
The two bulges on the bottom of the cowling shown in photo **A** are air exits for the engine cooling system. These 'bluff bodies' are shaped to suck exiting air out of the cowl into the freestream using the locally negative pressure generated by their convex, cambered shape. The suction so generated can be quite strong and is additive to the working static pressure recovered by the inlet.

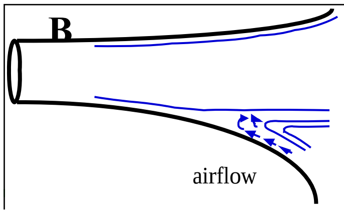
The best shape for this type of exit bluff body is that of the



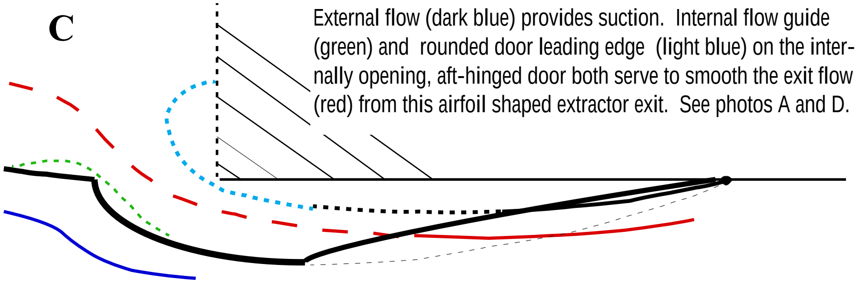
TRIAVIATHON TROPHY

CHALLENGE TROPHY

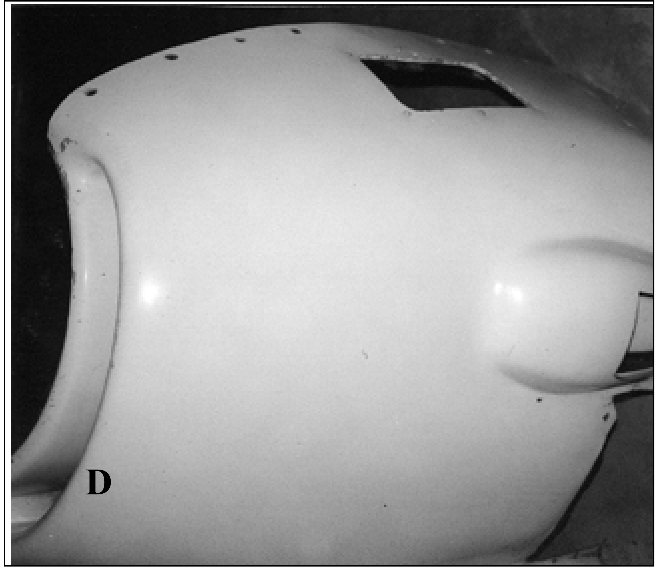


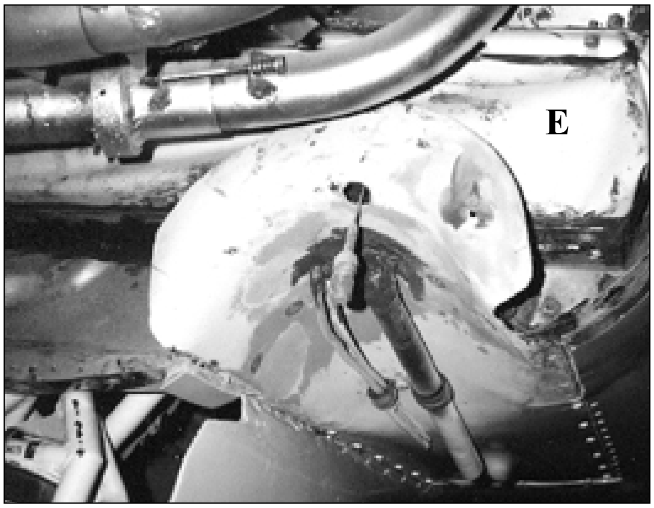


Upper inlet duct wall maintains attached flow. Lower wall diverges too steeply and an unwanted vortex forms.



External flow (dark blue) provides suction. Internal flow guide (green) and rounded door leading edge (light blue) on the internally opening, aft-hinged door both serve to smooth the exit flow (red) from this airfoil shaped extractor exit. See photos A and D.

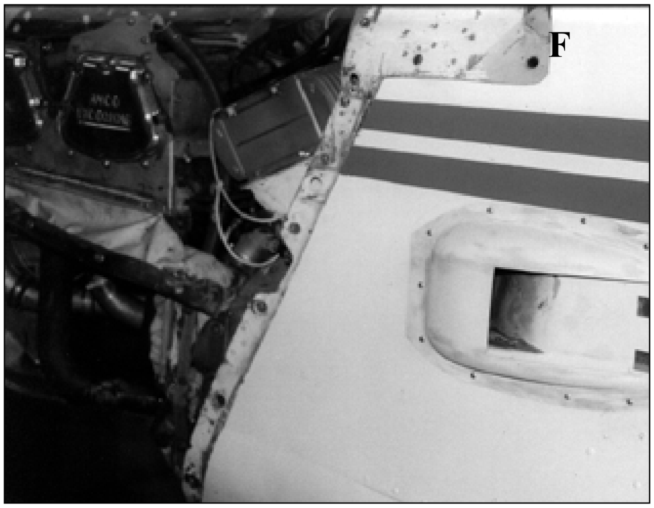


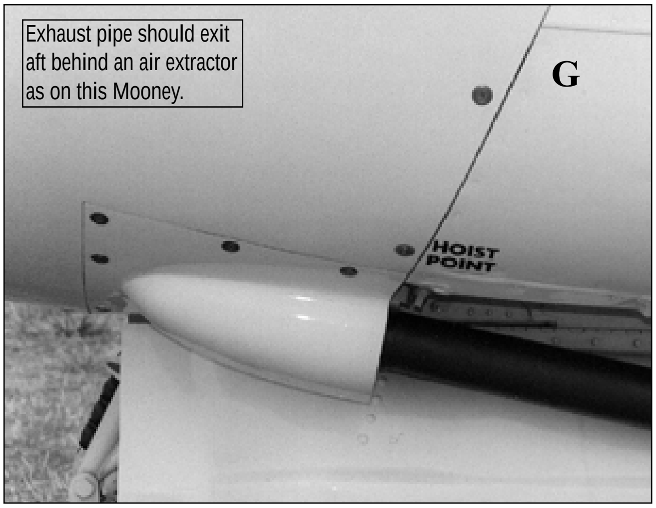


upper surface of an airfoil section that generates high lift over a wide range of angles of attack, including negative angles of attack. Its thickness to chord ratio should be about 18-25% so that the resulting body shape will have a length to diameter ratio ('fineness ratio') of between 6 to 1 and 4 to 1.

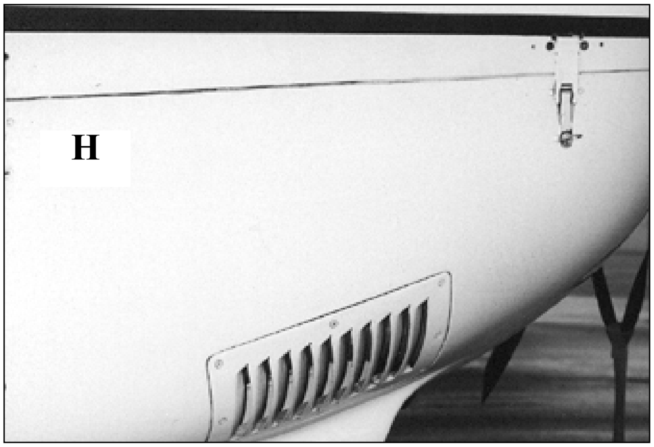
The chordwise location for the air exit on the surface of the bluff body should be near the point of maximum suction (negative pressure) for that airfoil shape. This point is usually found at between 15-35% of chord but varies with angle of attack. The ideal location can best be found during flight test by using a water manometer. The manometer can sample the air pressure on external skin surface at several flush 3/32" diameter holes drilled at locations between 15% and 35% of chord along midline of the bluff body.

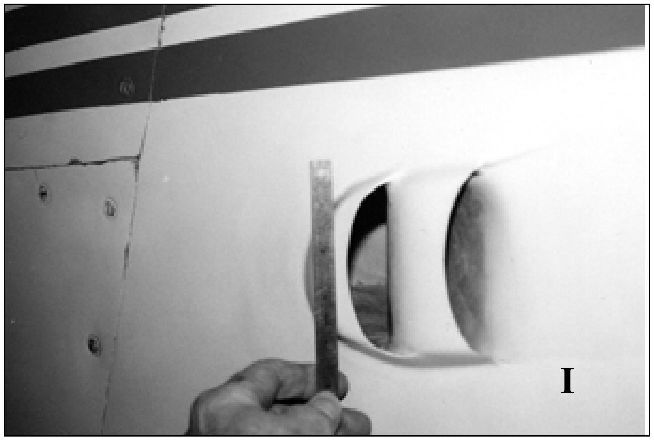
Because its suction is applied over a very limited spanwise



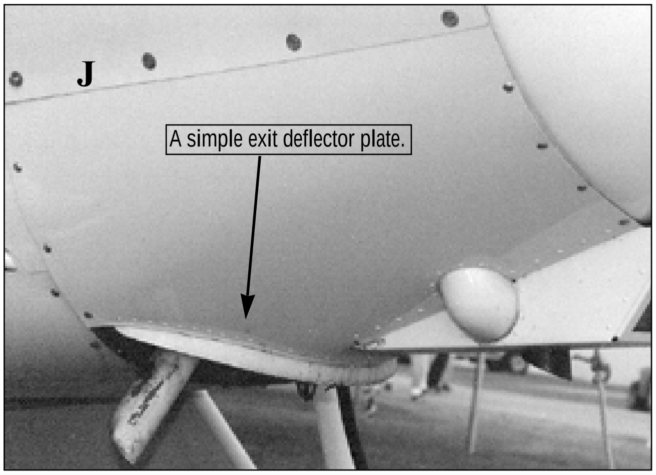


Exhaust pipe should exit aft behind an air extractor as on this Mooney.





area, the wake and therefore the drag of the bluff body extractor exit can be kept small. The internal walls of the exit should create a convergent path for the air to accelerate it as it exits. The extractor shown in **A**, **C** and **D** incorporates an adjustable cowl flap consisting of an internally-opening, aft-hinged door. The sides of the door move against internal fixed vertical sidewalls to assure that the exit flow does not spill out sideways. The door tapers, narrowing aft, to converge the exit flow. When such a door is nearly closed, the exit air velocity increases and cooling drag decreases, with an attendant rise in CHT. A flow guide on the internal leading edge of the door helps smoothly converge the airflow. (**C**) A fixed internal flow guide to smooth the exit contours is also helpful. (**C**, **F**)



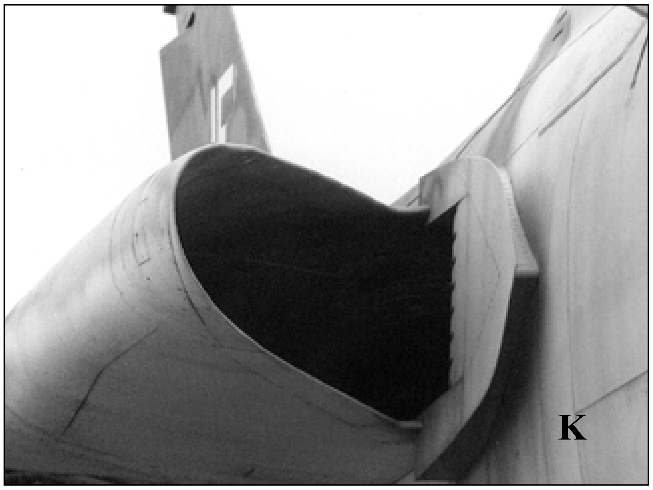
The oil cooler exit used on the CAFE Foundation's testbed aircraft is similarly designed. (**F**). Mooney uses a well shaped bluff body extractor at the cowl exit. (**G**)

Louvered exits can be either flush (**H**) or proud (**I**) to the external surface and are much simpler and cheaper to build. They should be aimed so that the airflow exits in the direction of the freestream to prevent a sideways plume of low energy airflow from producing a large, high-drag wake on the aircraft. Louvers cannot rival the suction of a well-designed airfoil-shaped extractor.

A very simple, cheap type of air extractor is a sharp-edged deflector plate that serves to trip the external flow at the exit. (**J**).

BOUNDARY LAYER BLEEDOFF

As the airflow next to an aircraft surface slows down due to friction, there forms an ever thicker boundary layer of de-energized, lower velocity air. If allowed to enter an air inlet, such a boundary layer will disturb the controlled diffusion and ram pressure recovery of that inlet. Because of this, inlets are often designed to stand off from the fuselage surface by an inch or two in order to not inhale the boundary layer. The F-105 engine inlets used a boundary layer bleedoff fence that enclosed a flow dividing 'prow'. (**K**).

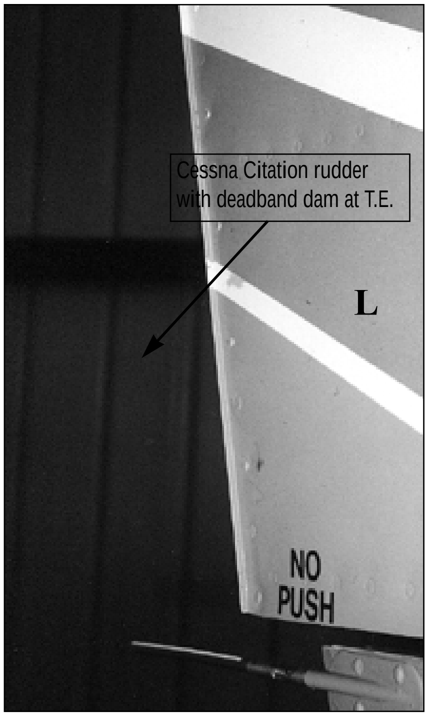


BOUNDARY LAYER COMPRESSORS

The thickness of a boundary layer can be reduced by forcing it to accelerate over a bluff body so that it 'squishes' as it merges with a more external, higher velocity airstream layer. Such compression of the boundary layer is the purpose of the propeller spinner afterbodies used on the engine cowlings of the Lockheed Constellation and on Rare Bear, the F8F Reno Racer. Another example of this is shown in photo **A**. Here, the boundary layer on the 20" prop spinner is accelerated over a 0.65" tall bluff body before it enters the smile-shaped cooling inlet. Spinner boundary layers vary with spinner diameter and RPM and are kept smallest by assuring that the spinner turns true with minimal runout.[1]

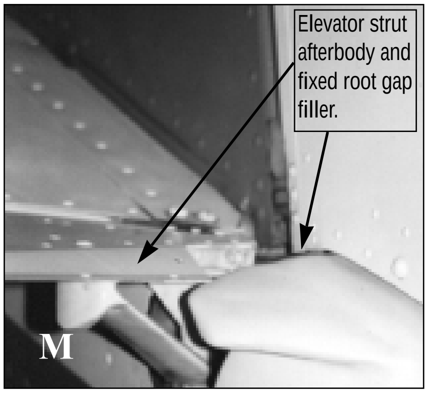
DEADBAND DAMS

A thick boundary layer is often present on the surfaces of the rudder. The result is a rudder whose movement left or right of neutral position has little or no effect on yaw and that offers poor force feedback to the pilot. Such a condition is called rudder deadband. A strip of metal or a length of small tubing attached along the rudder's trailing edge can 'dam up' the local flow, increasing the local pressure on its surfaces. This technique restores the rudder's feel and effectiveness at small deflection angles and produces only a small drag penalty. Deadband dams are used on the Cessna Citation and Mooney. (**W**).



AFTERBODIES

Struts and antennae that have a circular cross-section generate high drag unless an afterbody is provided to approximate

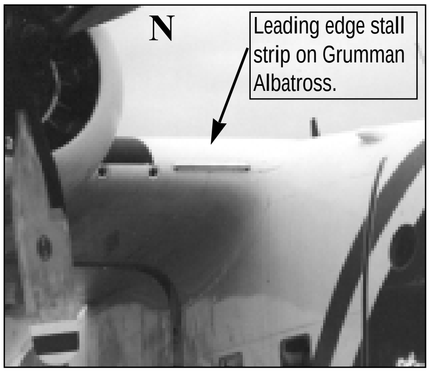


Elevator strut afterbody and fixed root gap filler.

an airfoil-like shape.[1] This can be accomplished by glueing piece of foam onto the aft face of a strut or antenna and then shaping the foam to taper with a 3 or 4 to one fineness ratio. (**M**)

STALL STRIPS

Leading edge stall strips are small, sharp edged, triangular shaped flow trippers that are attached to the front of the wing leading edge close to its stagnation point. (**N**). These shed a vortex at high angles of attack so as to both selectively initiate stall at that wing station and to send a buffeting vortex aftward to tremble the tail control surfaces and thus provide a stall warning to the pilot.



Leading edge stall strip on Grumman Albatross.

TUFT TESTING

Yarn tufts can be taped onto aircraft surfaces and examined in flight to see if they lie flat or lift up off of the surface. (**O**). If they lift up, they are revealing a local region of flow separation. Such separation should be fixed with local flow devices whenever possible.

SEALING CONTROL GAPS

The air gap between fixed flying surfaces and moveable control surfaces is often one of irregular shape with sharp-edged corners. In flight, the air pressure difference across such a gap produces airflow through the gap that can be of significant volume and velocity. This airflow often exits the gap as a turbulent jet that can cause separated flow on the adjacent control surface. This makes the gap flow a significant source of both 'leakage' and interference drag.

Taped control gap

Rudder tufts on a Sea Fury.

Taping or sealing the control gap so as to block the gap airflow can greatly reduce the drag. (**O**) This must be done with care to preserve full control surface travel and not unduly increase control friction forces. Sealing the control gap often increases the control surface effectiveness and is likely to increase the control forces required.

CONCLUSION

There are many local airflow control devices that can enhance the performance and flying qualities of aircraft. Each device requires careful study and testing to achieve an optimum design. Any significant airframe modification must be made structurally sound and be inspected and tested by qualified test pilots.

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IMPORTANT NOTICE

ACKNOWLEDGEMENTS

This study was supported by grant funding from the Experimental Aircraft Association and by FAA Research Grant Number 95-G-037. The CAFE Foundation gratefully acknowledges the assistance of Steve Penning, Wyman Shell, EAA Chapter 124, and the Sonoma County Airport FAA Control Tower Staff.

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