Flow Visualization aids Drag Reduction

Terry Schubert -
Jschuber@juno.com
EZ.org/CSA

Tweaking Your Airplane to Save Fuel

Efficiency improvement is affected by many things:

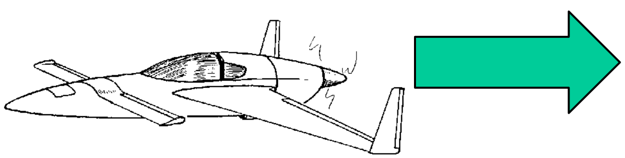
Pilot technique

Power plant characteristics

Airframe drag, which this presentation will address

Drag is found in many forms, including:

- **Induced** (lift related)
- **Parasite** (all other drag)
- Viscous (skin friction - shape related)
- Pressure (relates to dynamic pressure pushing against front of the airframe)
- Profile (Pressure drag & viscous drag combined)



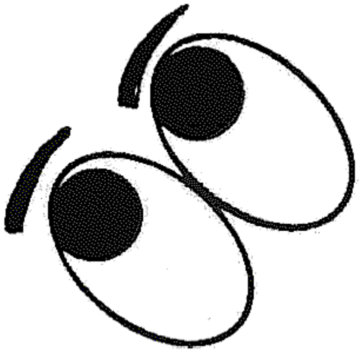
Slow
Down

Reducing speed reduces dynamic pressure drag thus improving MPG, but only to a point.

As pressure drag reduces, induced drag increases

Required fuel varies with the number of molecules to be moved near the airframe.

Few molecules moved = low fuel consumption
Lots of molecules moved = high fuel consumption



Look where the action is; it's in the area near the airframe surface. It is called the **boundary layer (BL)**

Boundary Layer (BL) may be thought of as: the region of air near the surface who's speed varies from zero at the surface to that of the surrounding air.

Let's look at the airflow behavior in the BL

BL has different states

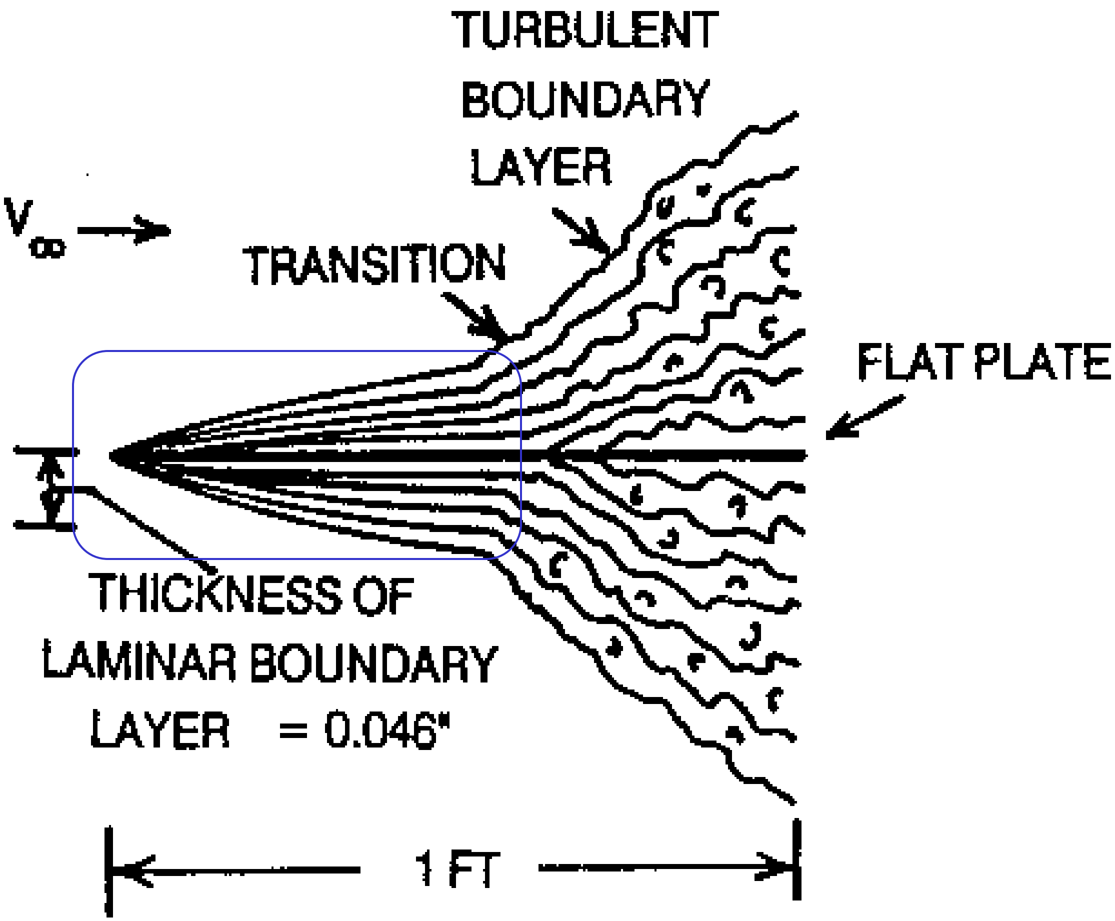
Laminar – molecules move in smooth parallel layers and do not mix with other molecules

Turbulent – molecules run into something and are deflected into other molecules. That stops the smooth flow, causing a drop in energy and sharp increase in drag

Laminar Flow -

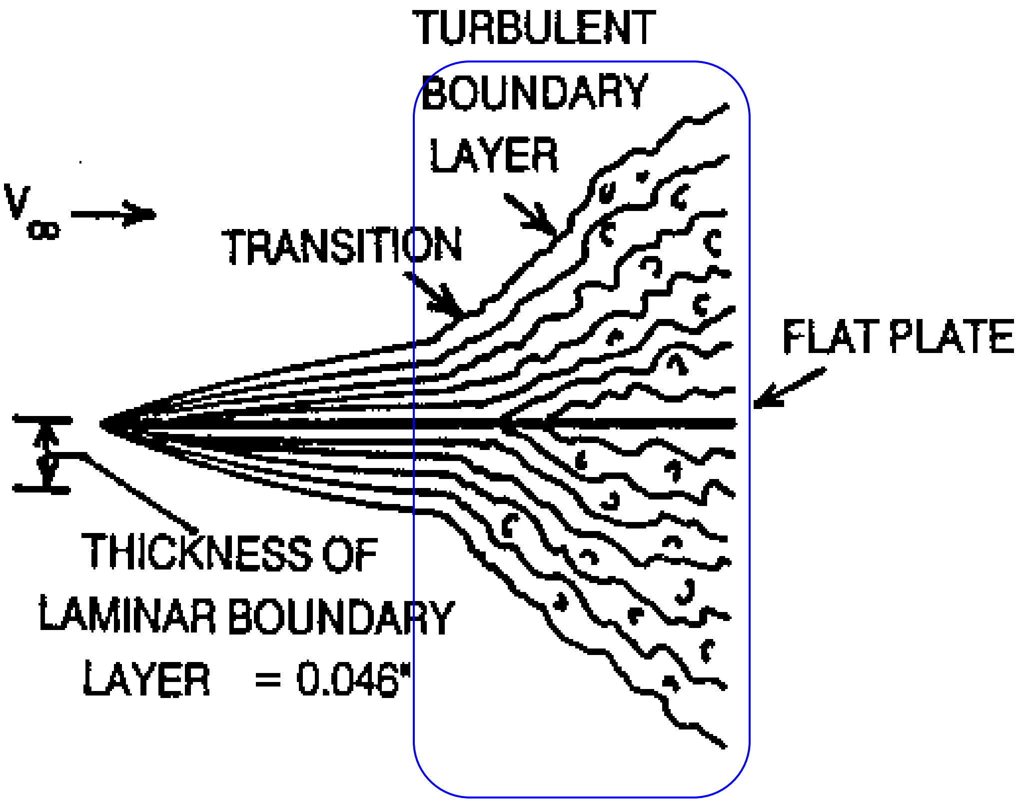
No mixing of layers
Smooth parallel flow
Thin speed gradient
Very low drag

Flow starts laminar but transitions to turbulent with distance and greater speed



Turbulent Flow -

- Flow is rougher and non-linear
- Thicker speed gradient
- Higher drag due to molecular interaction dragging more air along
- Mixing occurs between layers



If airflow gets turbulent enough, it will continue to lose energy and finally stops or stalls. Flow aft of that point is ***<u>Separated</u>***

- Drag increases dramatically

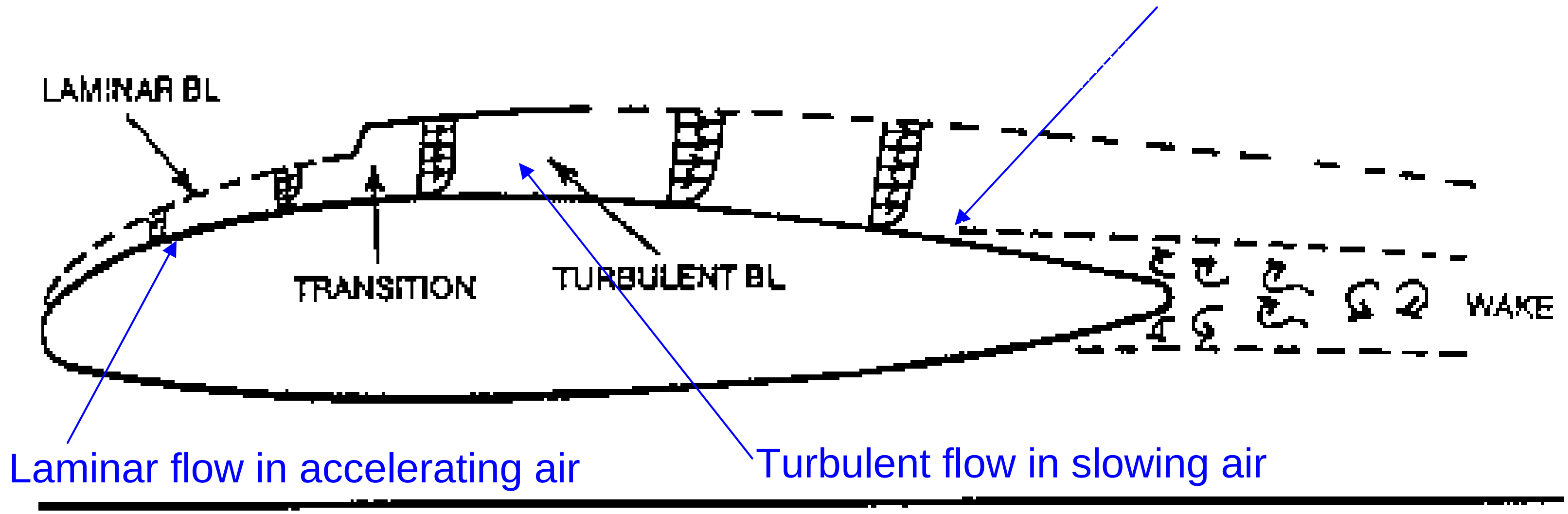
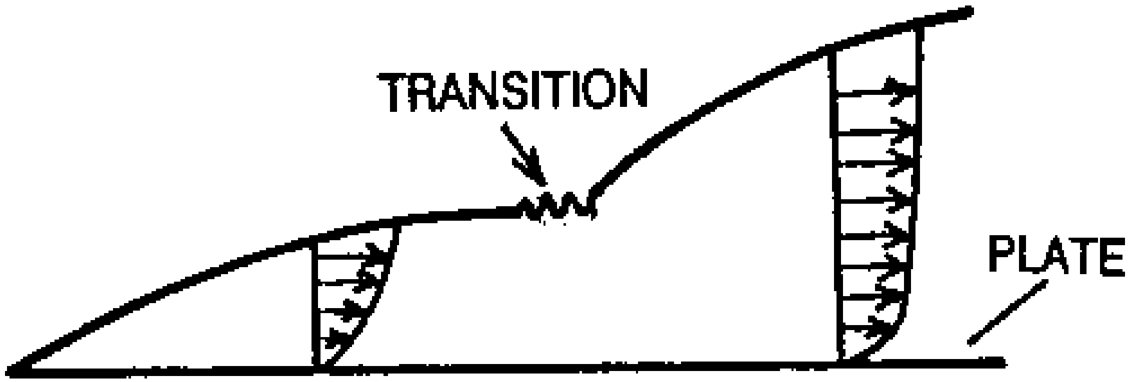
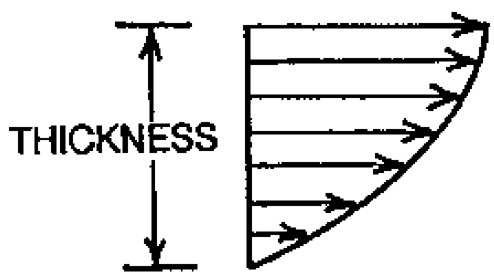


Fig. 5.24 An enlarged view of the boundary layer above a lifting airfoil

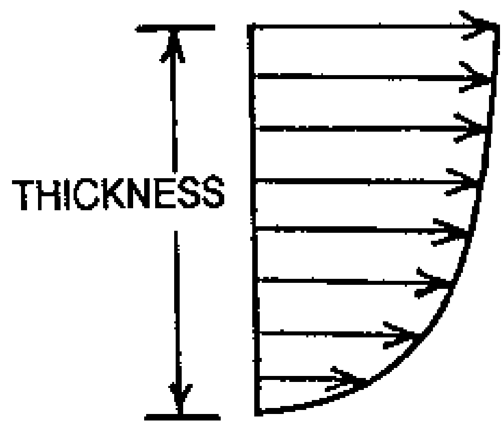
Velocity Profile symbol

- Symbol location designates a chord location and depicts speed and BL thickness





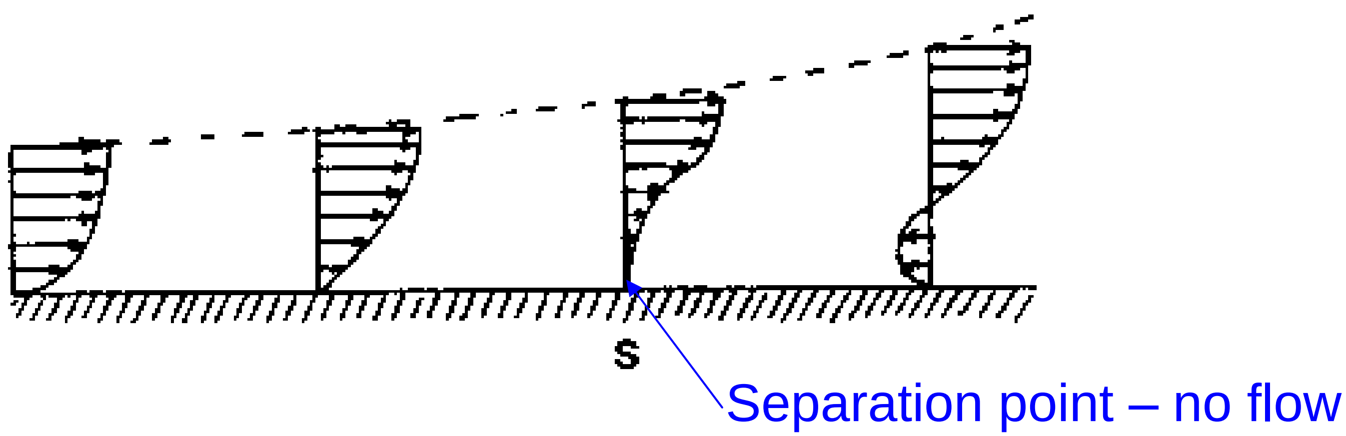
Laminar boundary layer



Turbulent boundary layer

Separated Flow –
When airflow slows, relative to the surface and stops

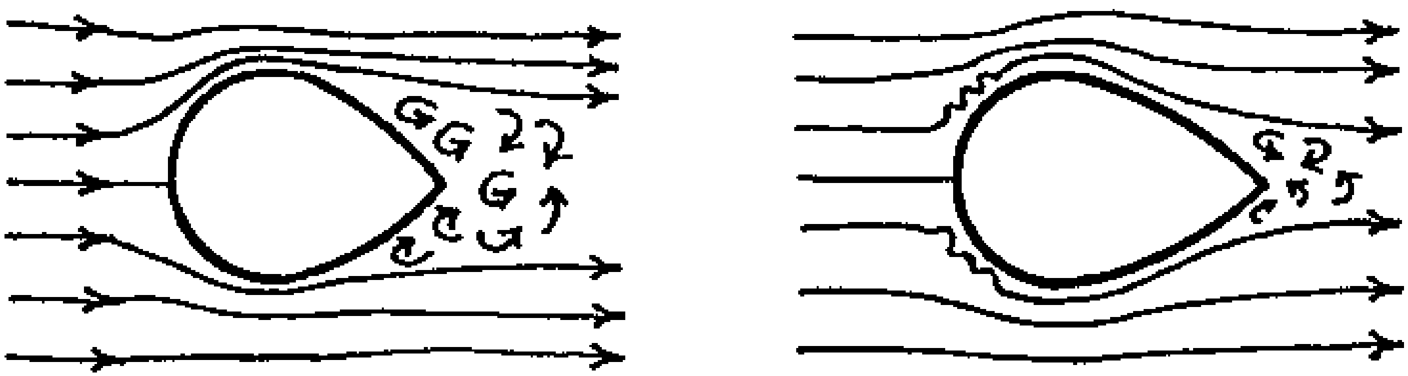
- Separation point's location depends upon Reynolds Number (includes distance traveled from LE)
- Shape of the object determines how rapidly pressure changes occur



Turbulent BL isn't all bad

- It consumes more energy than laminar flow, but having more energy, ***it separates later*** than laminar BL .

- If BL turns turbulent before thickest camber it allows BL to stay attached farther along surface – ***results in less pressure drag*** than laminar BL flow

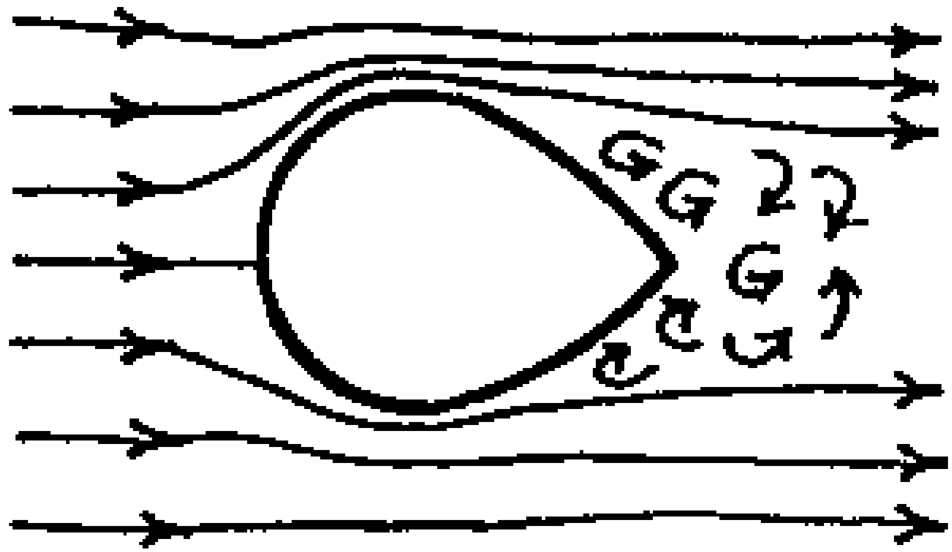


Laminar BL allows more pressure drag than Turbulent BL

Separation Wake

Unstable, and turbulent vortex filled area aft of the separation point

If the wake is large, caused by early separation, the dynamic pressure will be much higher than on the rear and pressure drag will be very large compared to viscous drag.



Wake area

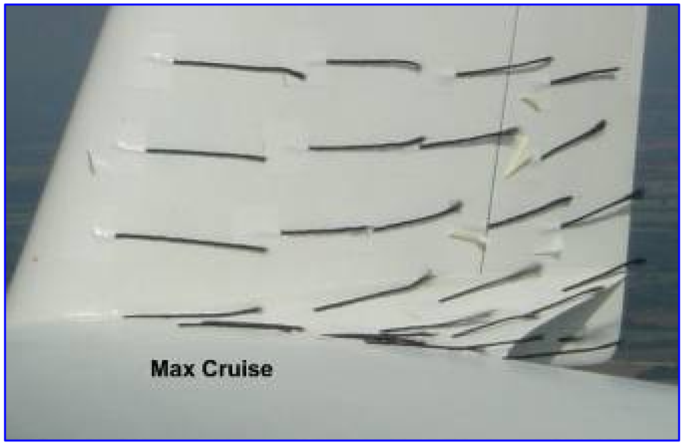
- BL has stopped flowing
- Airflow reverses
- Surface friction/viscous drag is bad, but it is much better than pressure drag.
- No viscous drag but very high pressure drag

Separation must be stopped but it **has to be found** first

Finding Separation

Visualizing flow techniques utilize:

- Sublimation coatings
- Yarn tufts
- Oil flows



Sublimation coatings

- Sublimates (change to gaseous state) in turbulent flow due to energy transfer
- The line between sublimation and non sublimation is the transition point
- Process is more expensive, less available and harder to analyze than some techniques
- Spray it on and fly it. Take pictures after landing.

Yarn Tufts

- Yarn is on surface
- Shows stability & velocity
- Time consuming to set up
- Represents one velocity point
- Depicts minor 3D aspects
- Tape attachment can alter local flow
- Chase plane or video camera is needed to view tufts in action

Oil Flows

- Show average flight flow
- Messy but fast
- On surface flow
- Still photos taken immediately after 10-30 minute flight
- Dab on forward of test area, may be mixed with Tempra powder for color & greater definition.

Test Analysis

- Sublimation – coating is on in laminar area. Klaus discovered his VGs were mounted too high after many years of flight test.

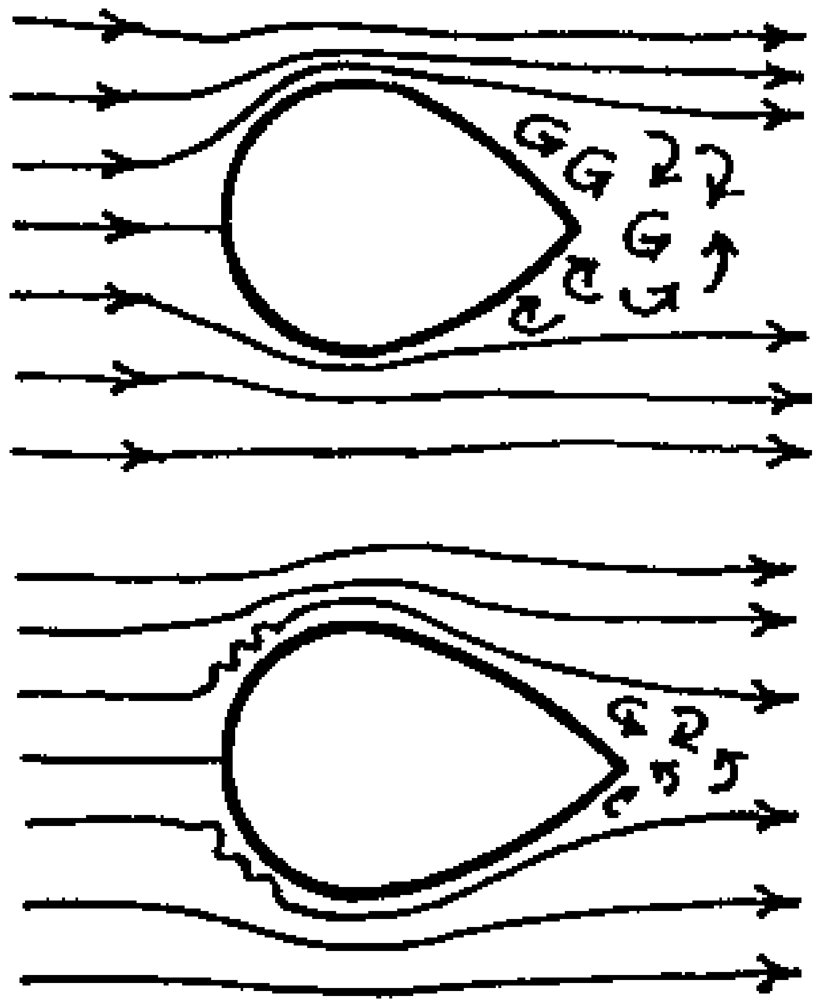
- Tufts – dynamic visual presentation. Tuft stability shows activity & flow direction.

- Oil flow – Note trace path, stability & width
  - Thin/straight – fast Laminar BL
  - Wider/wavering line – slower, less energy Turbulent BL
  - No oil/reverse flow – minimal energy, Separated BL

The BL Fix to Prevent Separation

- Separation occurs at low energy – no movement – Add energy to prevent/reduce separation

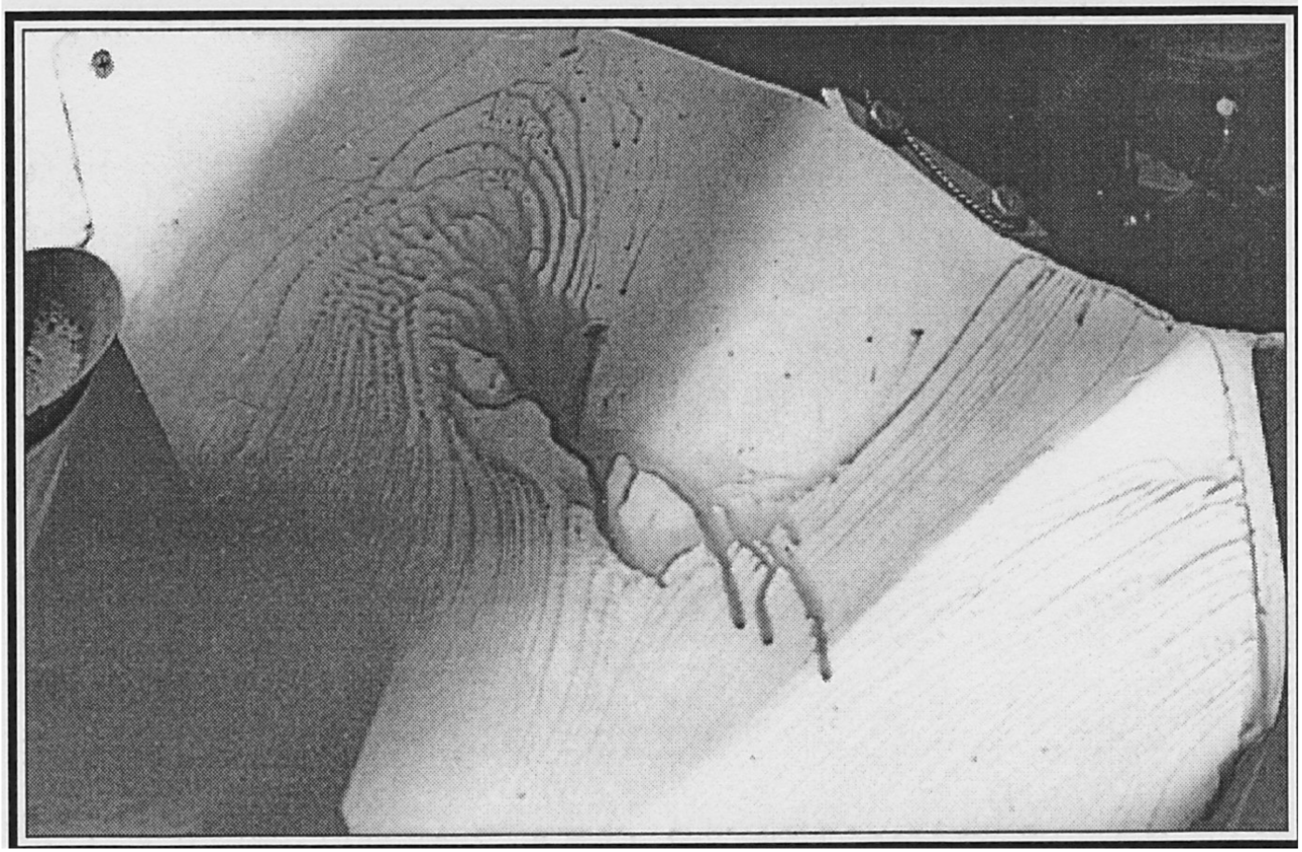
- Trip Laminar flow to Turbulent flow - adds energy with small drag increase



Add energy with low profile tools and see the effects

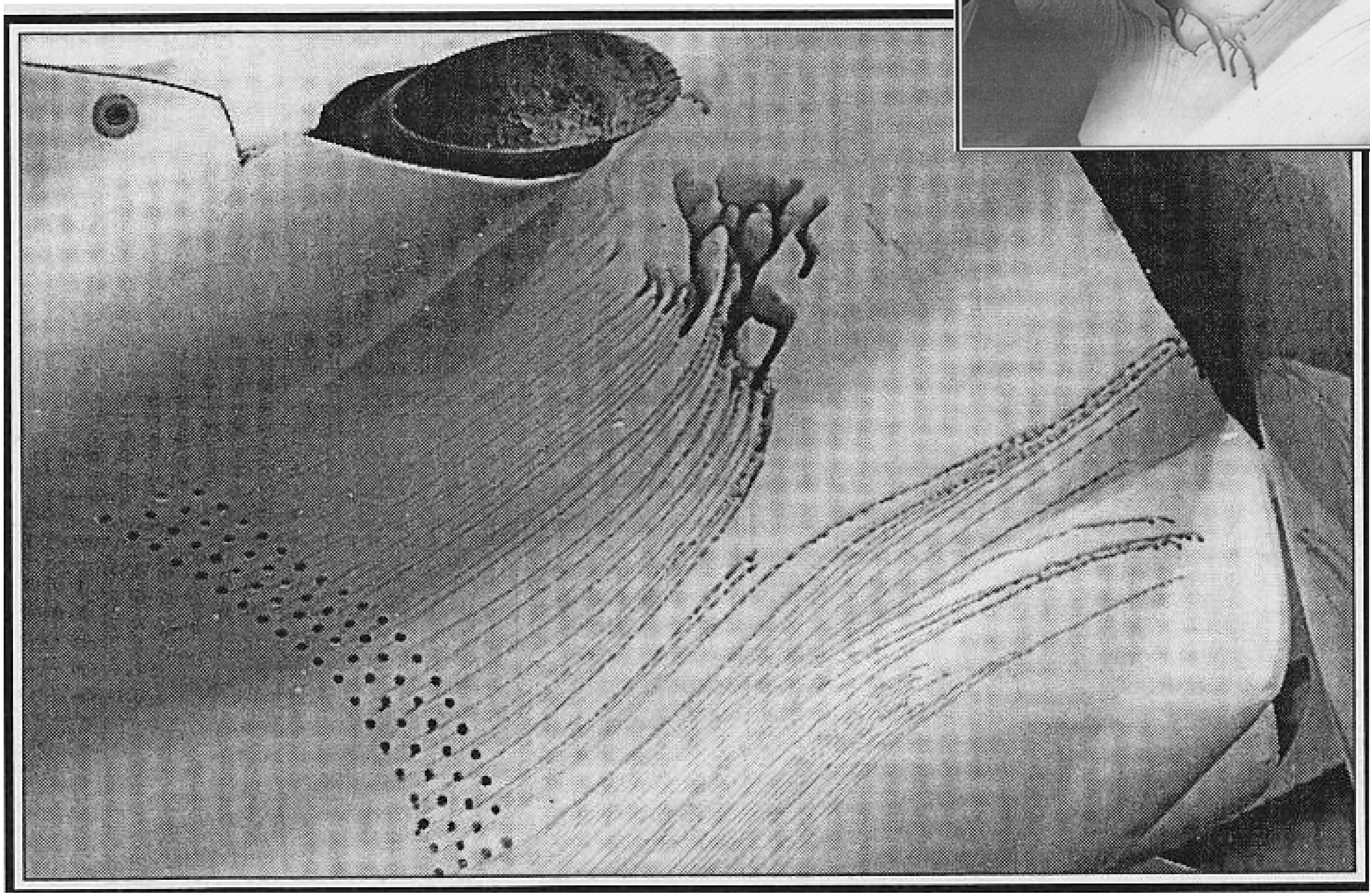
- Use of low profile dimples, diamonds, grit strips, zig zag turbulator strips

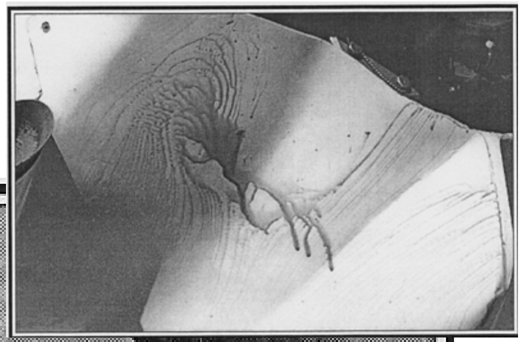
(See Vol. # 50 page 26 CSA Newsletter for tool details)



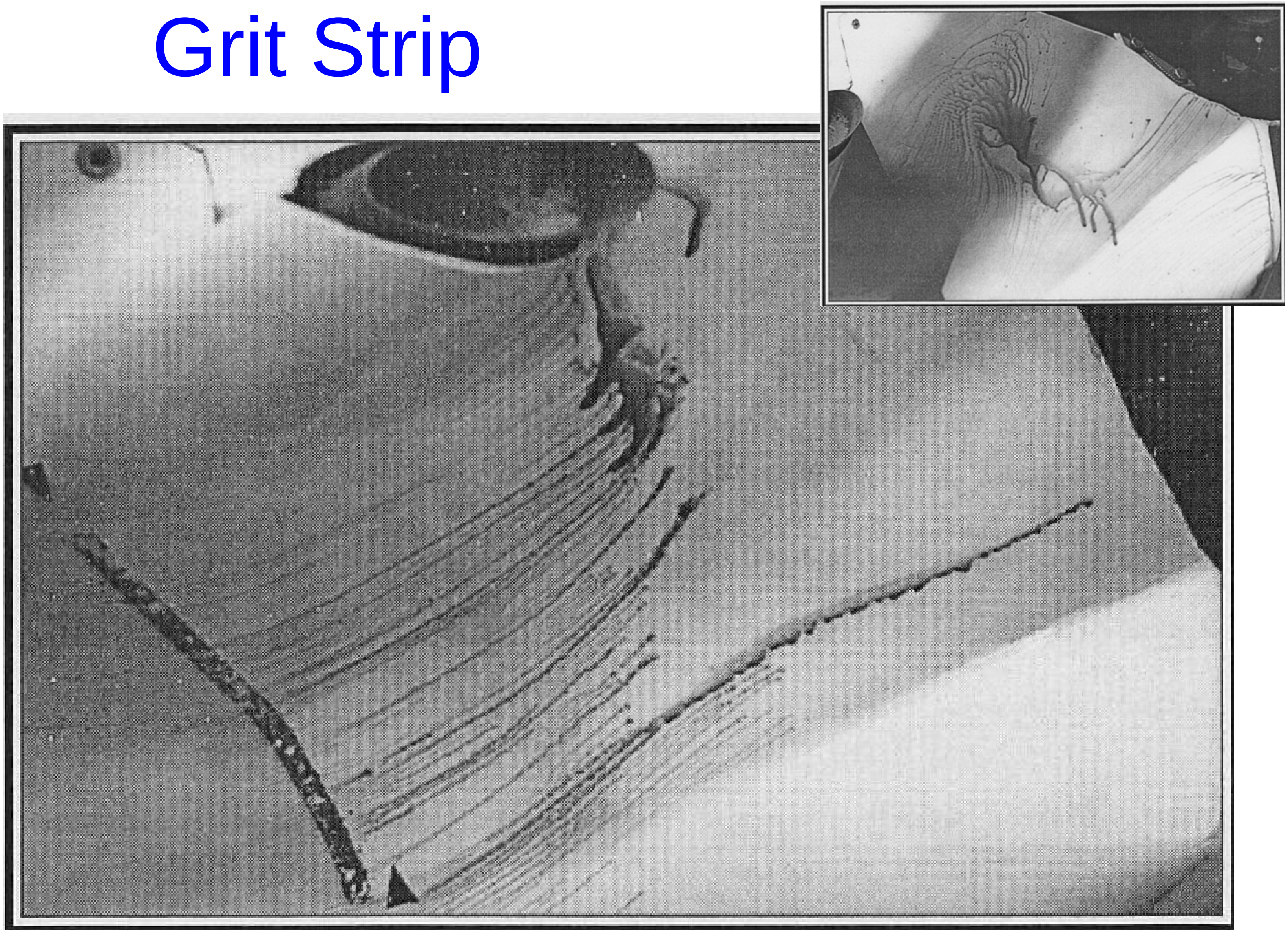
•Start with no treatment on aft cowl

Dimples

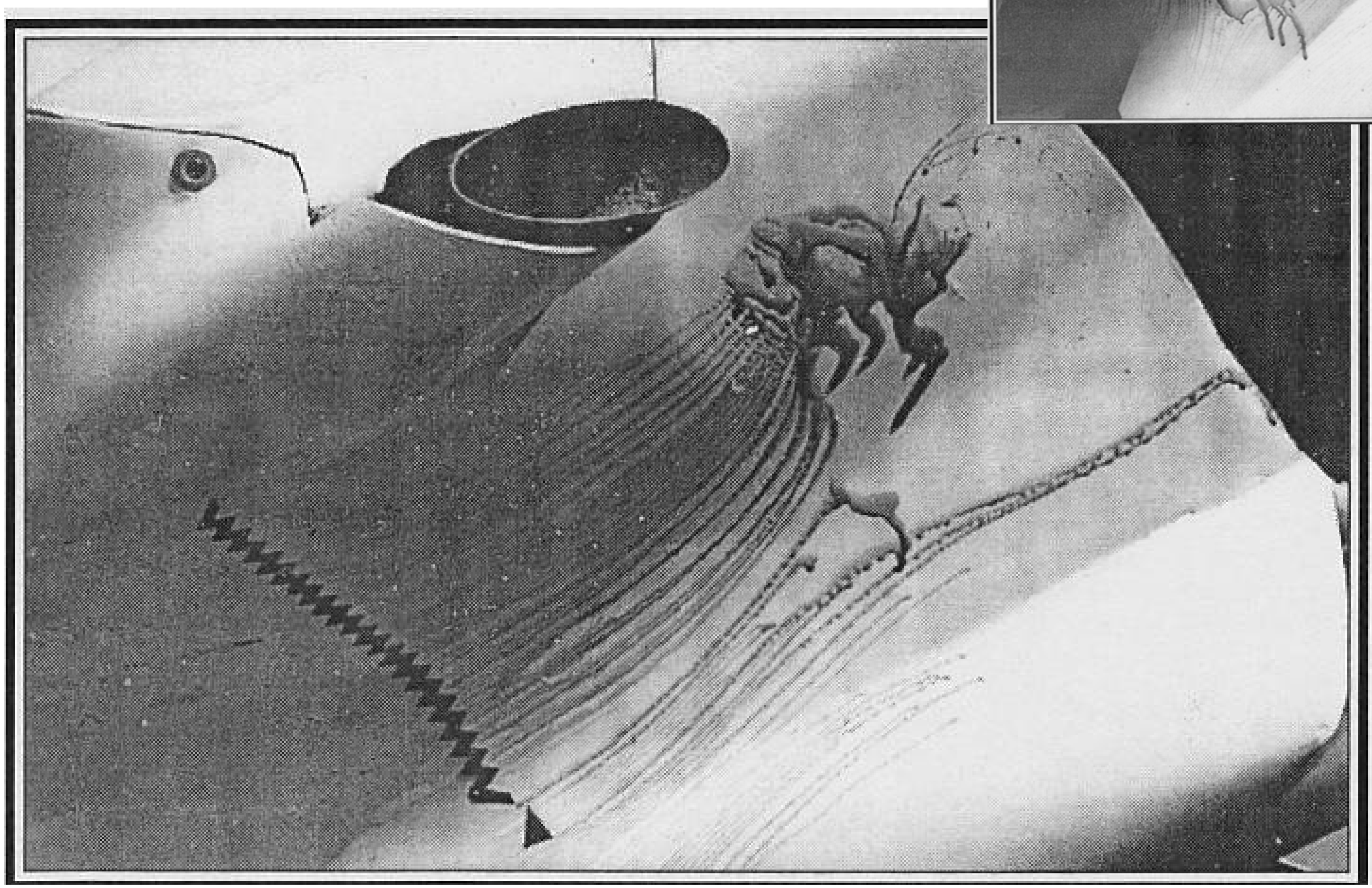


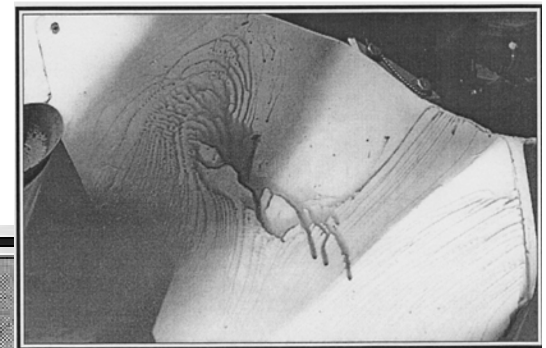


Grit Strip

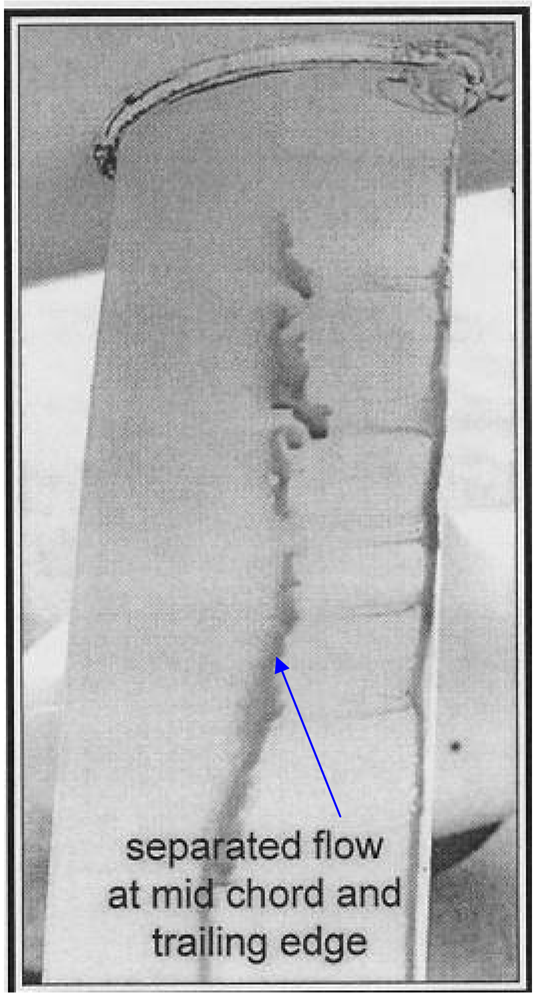


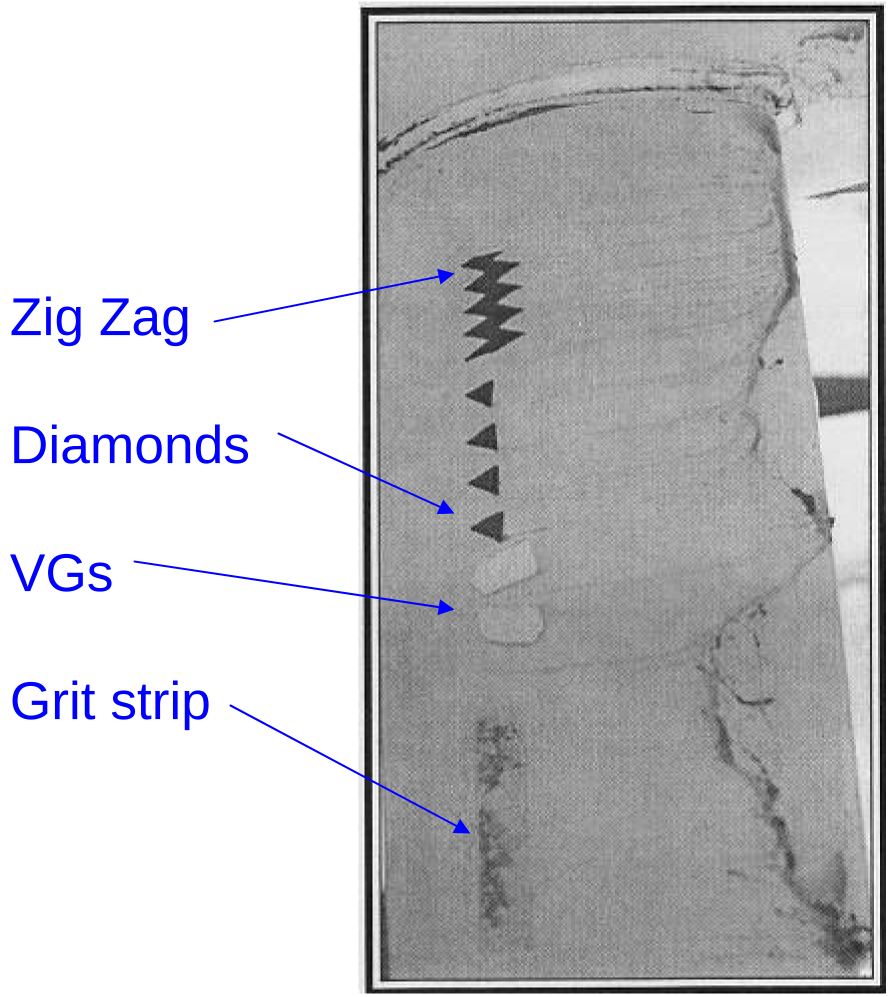
Diamonds & Zig Zag Turbulator





Strut Application





Separated BL wake may require more aggressive tools like vortex generators (VGs)

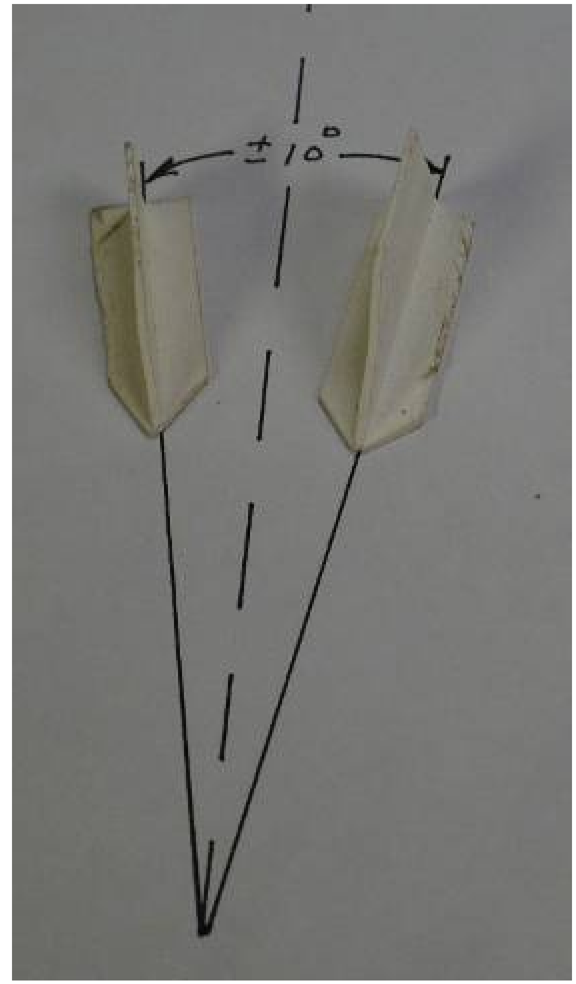
- Reach away from surface to get high velocity to re-energize the BL

- VG height varies with BL thickness (VG height never more than BL thickness) ¼" VG gets about 99% of the energy in a turbulent 2" thick BL near the cowl

(See Vol. # 54 page 8 CSA Newsletter for VG details)

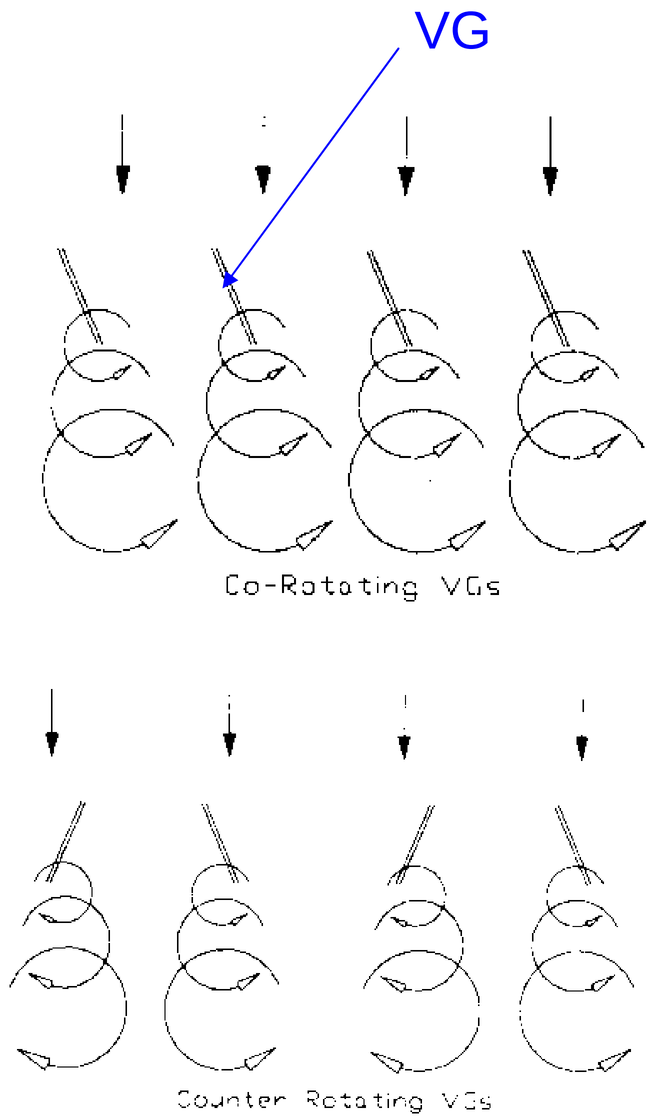
VG pattern design is VERY complex

- Too tall gives severe high drag
- Too low doesn't energize the BL
- Too great an angle will stall VG
- Start with 10 degree angle to **<u>local flow</u>** angle & look for effect
- Oil flow to determine local flow
- Use minimal impact fix



VG Quantity Varies

- Co-rotating - spaced 15 heights apart
- Counter-rotating has twice the drag but is effective in half the distance – for desperately tight situations only due to high drag

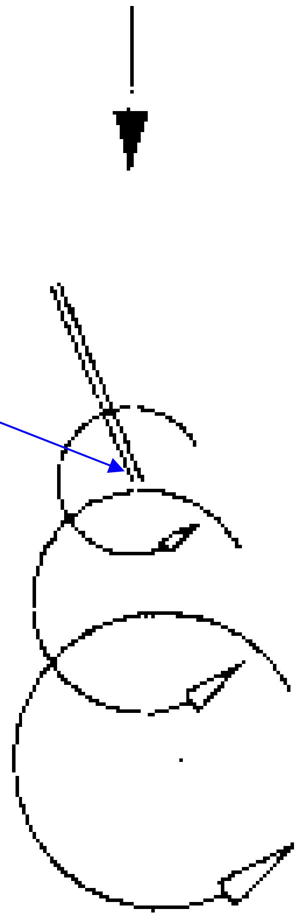


VG Operation & Placement

Has high pressure on one side which flows to low on other side like a wing tip

Vortex originates at tip and scrubs a flat surface about 9 VG heights down stream

VG should be that distance forward of separated area



BL tools are a fix for poor design

Design it right to avoid the effort

Reduce taper angles - 7 degrees max (single axis)

Move internal parts to flatten curves

Stagger retreating surfaces (wing/winglet)
as on Long-EZ VS E-Racer

Trip laminar flow to add energy

BL tool Guidelines

Separation is BAD.
Fix it!

- Cowl separation adds drag and reduces prop efficiency; a double whammy

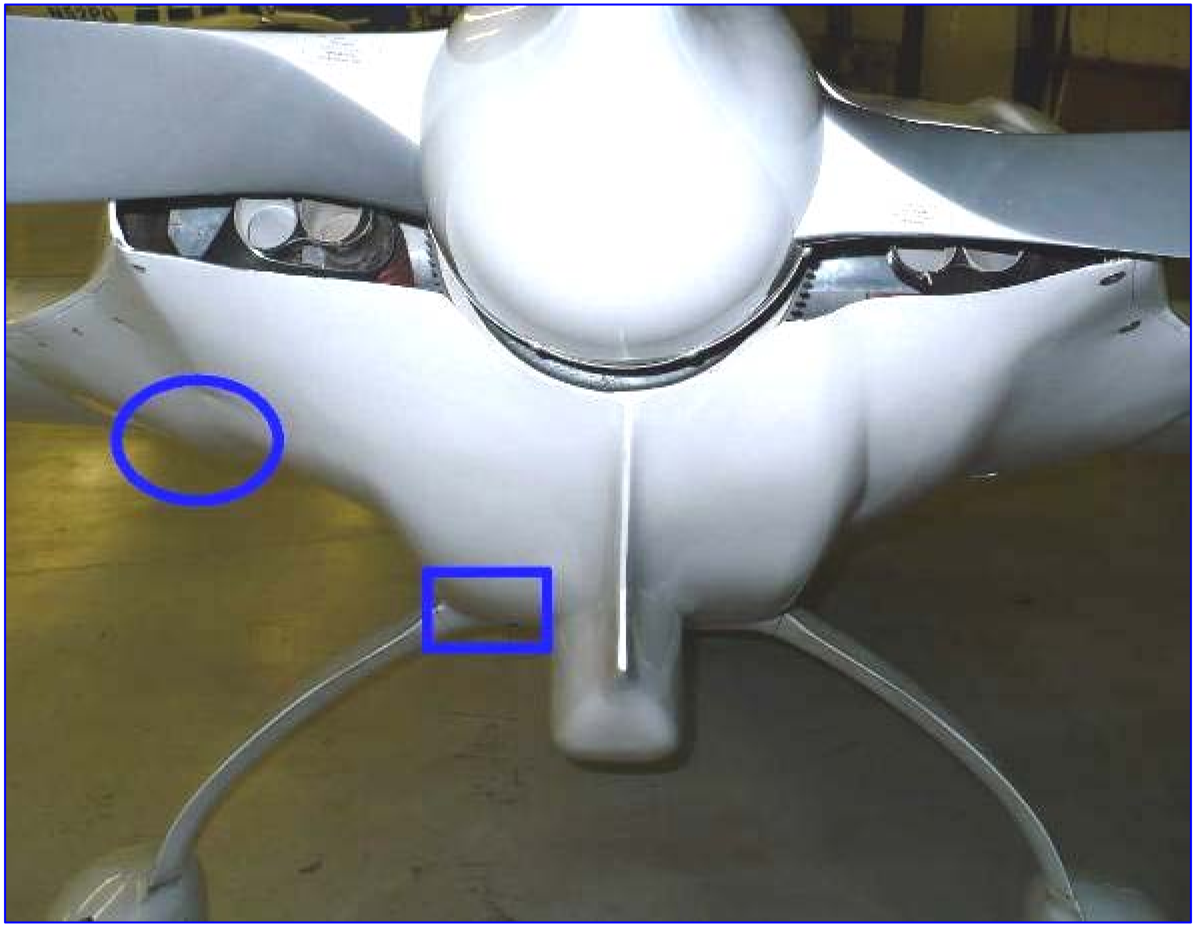
(See Vol. # 54 page 8 CSA Newsletter for effects/details)

- Separation causes vibration & noise

- Separation caused also by aero interference – edge & cabin/cowl leaks

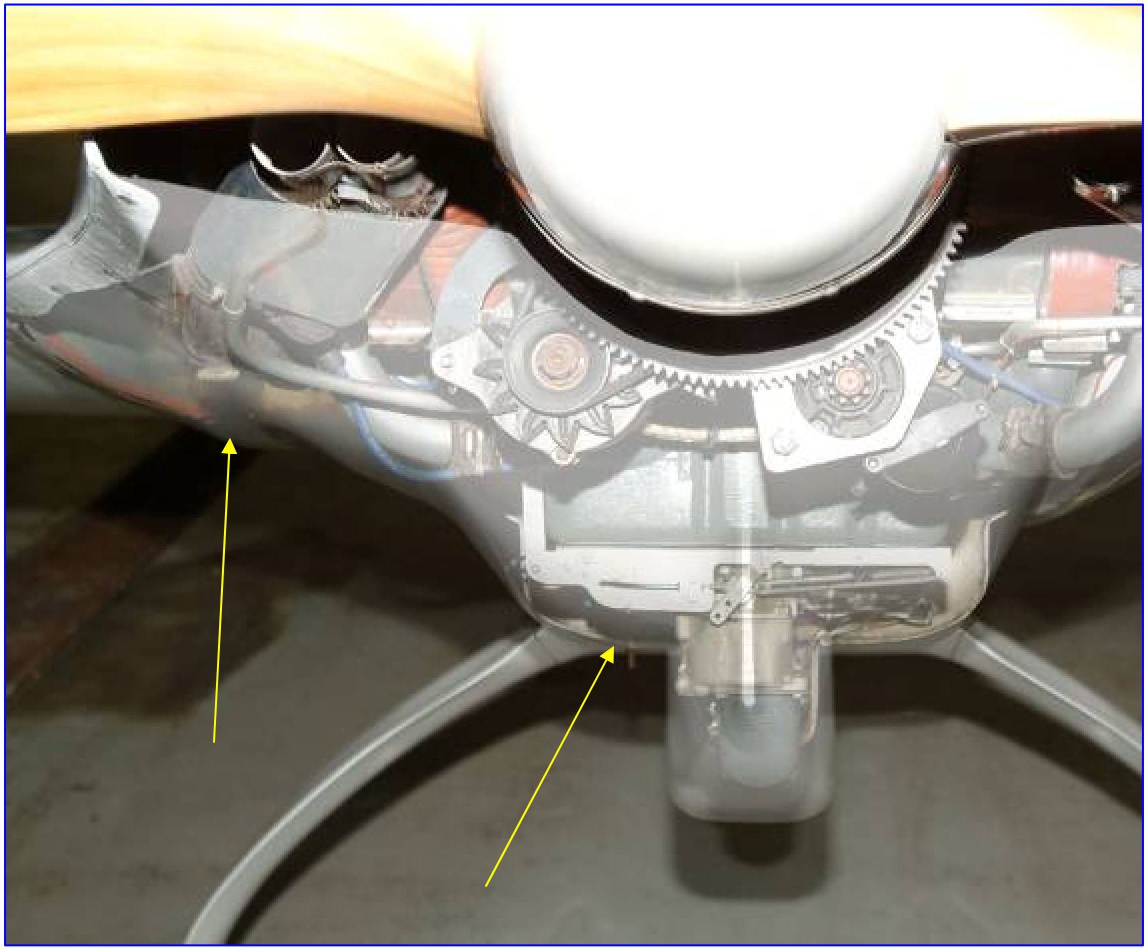
Application Examples

- Look at the airplane for obvious errors.
- Bump & low blister are noted



What can be changed to decrease curve?

- Examine clearances
- Can you change protrusions
- Double exposure



Verify Modification Need

- Tuft or
- Oil flow

- Identify areas of needed profile change

Install contour slats to verify shape

Check inside clearance too

Fabricate BID insert over foam contour slats to insert in cowl

Note:

Decrease in cowl curve should resist separation better

Flat panels can be easily added

2 ply BID panel is easily fabricated and inserted in original cowl. 3rd BID ply overlays and ties it all together

Check for exhaust clearance

Fabricate EZ heat shield with 3/8” flox stand offs & THIN stainless steel sheet

Assure engine clearance

Completed profile

It looks better, but does it work?

Flat now

Same height now

Flow stays attached longer. Drag is reduced. Prop efficiency is increased

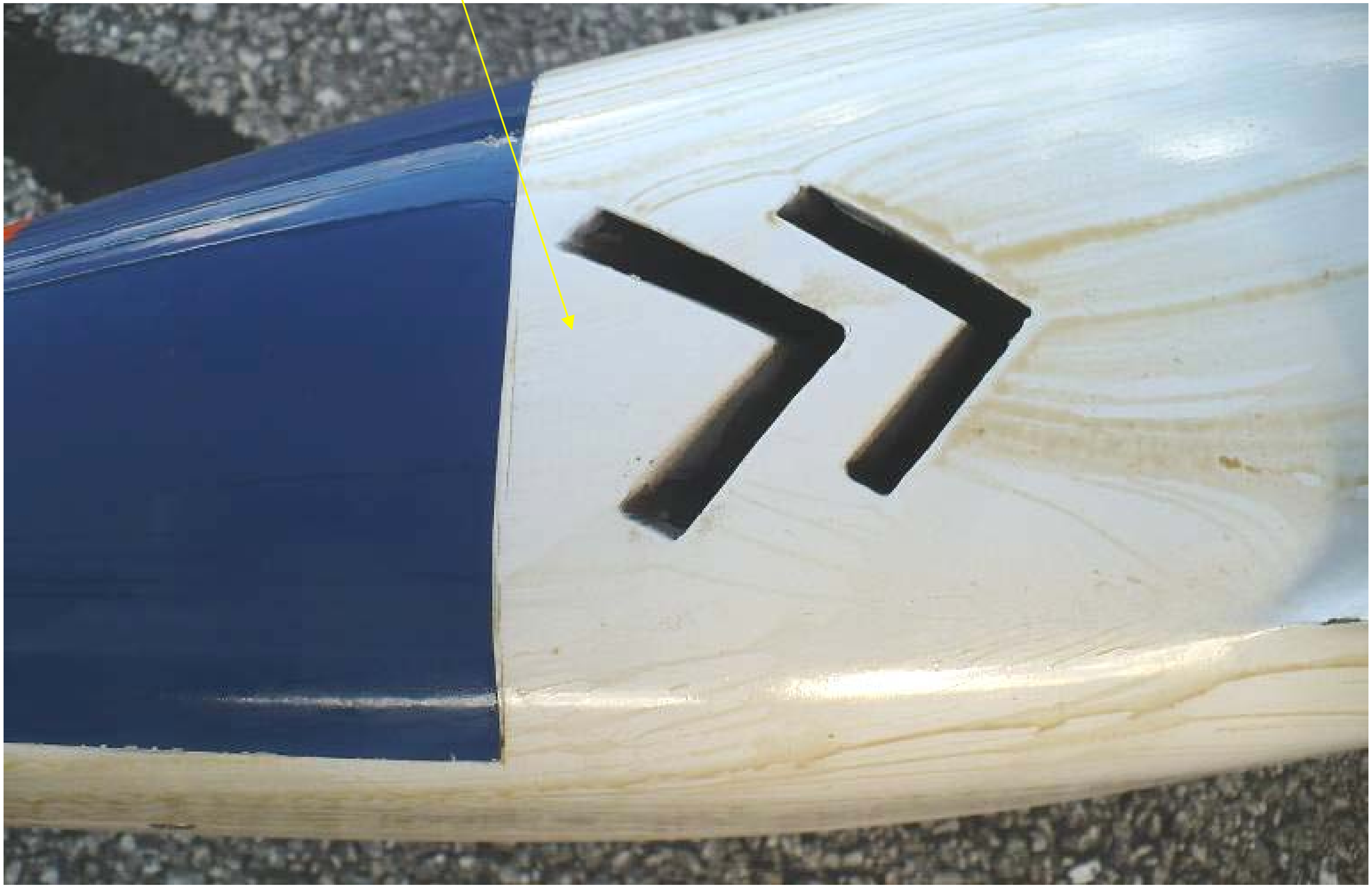
Other examples

- Drag increasing vortex generators (VGs), fences, diverters, boundary layer strippers add energy to re-attach flow

Flow visualization

How much oil is needed? This spread out in 15 minute flight

Pant vents spoil flow



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Area aft of tire is separated

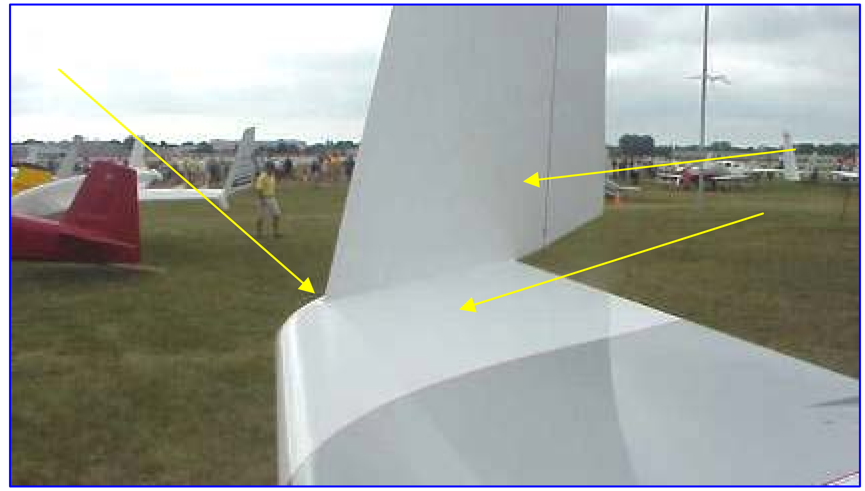
More complex fixes - Blended wing/winglet

Blend offers greater advantage at higher speed
540 powered RG Mark IV produces double digit gain

Blend & fillets can reduce separation

Blend reduces design problem impact - both surfaces expand at same time

•E-Racer winglet & wing
•leading edges align
•Surfaces expand together



•Long-EZ winglet & wing leading edges are staggered

•Surface expansion is staggered


Terry Schubert -
Jschuber@juno.com
EZ.org/CSA

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EZ.org/CSA

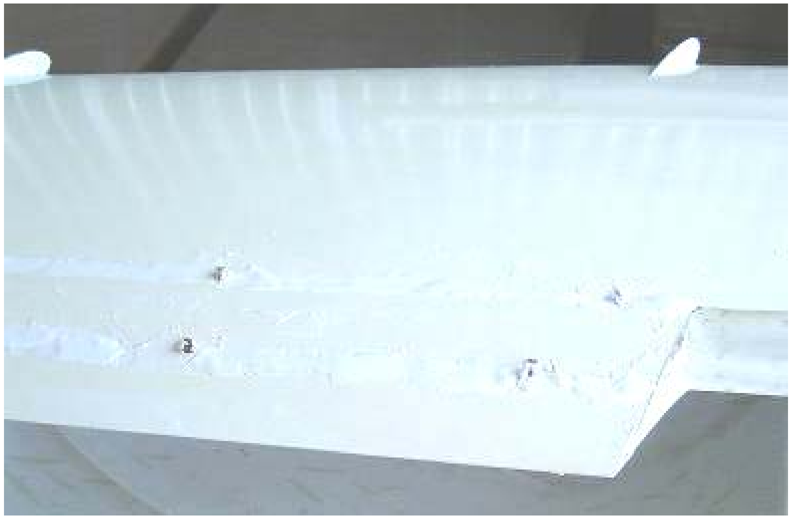
LE Trim Sequence

- Block out appropriate rudder to center ball
- Remove roll trim springs and note aileron input required to level wings in cruise
- Add washers to lower outer bolt to decrease angle of attack on “light” wing to attain neutral roll trim
- Readjust rudder trim as required

Vari Eze Trim Sequence

- Block out appropriate rudder to center ball
- Roll trim AC, using servo driven trim tab
- For large trim requirements, add roll trim tab on opposite wing of approximate size and opposite in direction
- Readjust rudder trim as required
- Wing surgery may be necessary for large trim requirements
- Guerny flaps are acceptable for small trim requirements.

VE wing surgery

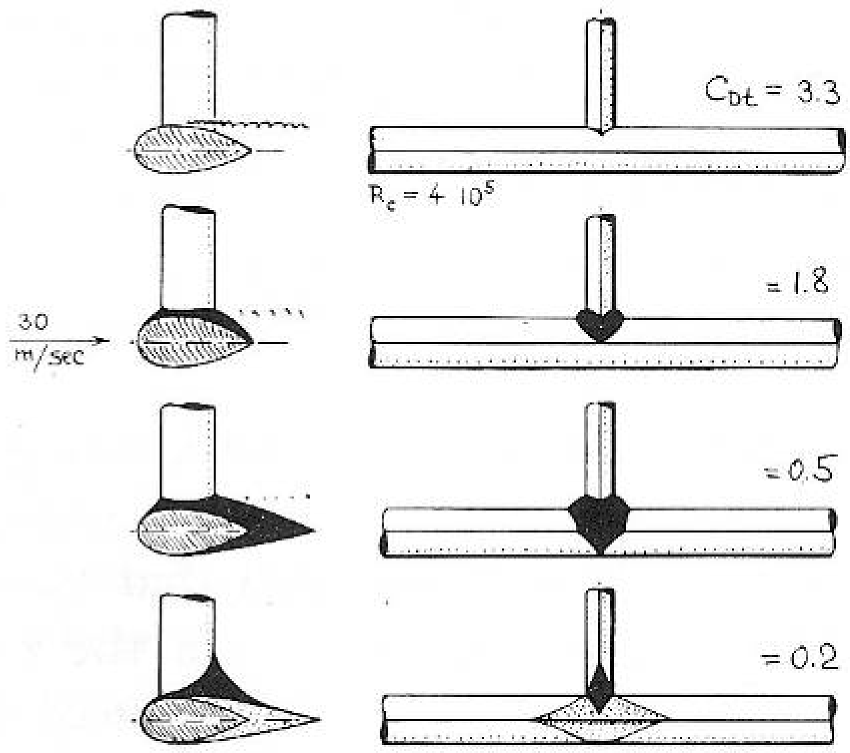


CPs contain more detail on process

Intersection fillet design

- Intersection drag occurs where ever two surfaces meet
- Drag is highest at acute angles
- A well designed fillet can reduce the losses by filling in separated areas

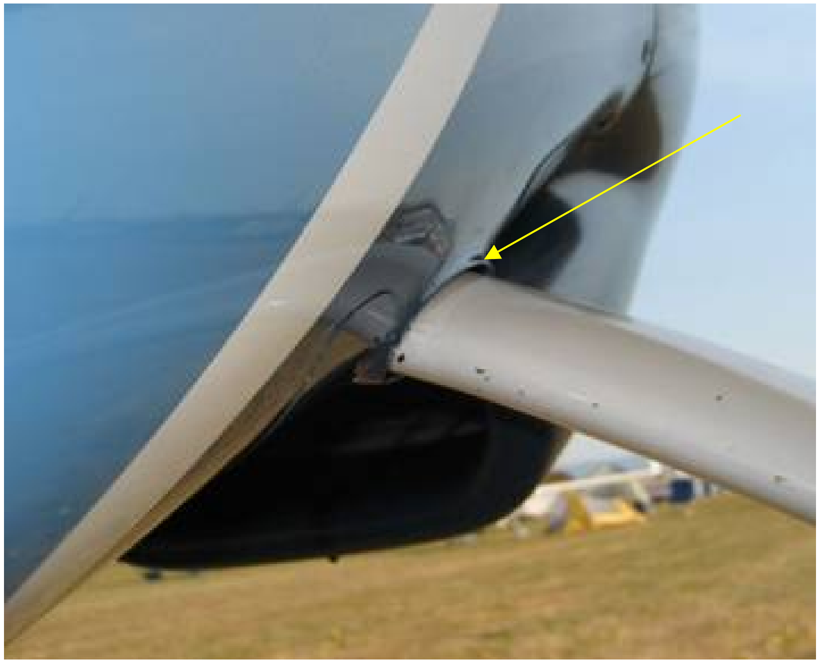
Correctly designed fillets dramatically reduce interference drag



90º intersection requires little fillet

Incorrectly applied fillets increase frontal area

Acute angle intersections pose a design challenge



Wheel pant design has improved

- Original "football" wheel pant possessed adverse pressure gradient
- Flow migration from the sides to top and bottom
- Large wheel opening promotes flow circulation

A consistent pressure gradient prevents flow migration

- Planform view looking down from the top is a good laminar flow symetrical airfoil such as a 65025, 25% thick*.
- Side view is the same airfoil but separated along the centerline sufficiently to house the wheel

*Hoerner specifies 3.7 to 1 t/c or 27% thick for an optimum trade between profile and skin friction drag

Pressure gradients not optimum

Wheel pants provide a good $ spent/mph gained ratio

Central States mold	11.4x5	~$25 and several hours to build
James Aircraft Jamesaircraft.com	11.4x5 5.00x5 6.00x6	$225 $225 $250
Lightspeed Engr. Lightspeedengineering.com	11.4x5 5.00x5	$345 $375

EZ gear struts are high drag

- Gear strut thickness to. chord ratio is less than. optimum.
- Forward gear sweep places. inboard portions at ~8° angle. of attack.
- Fairings can streamline the. strut to 0° AOA at cruise flight attitude.

Gear fairings can be made or purchased

- CSA Newsletter Apr 2005 provides a description of DIY strut fairing.
- Prefab struts fairings are available from LSE.

Spinners are a mixed bag

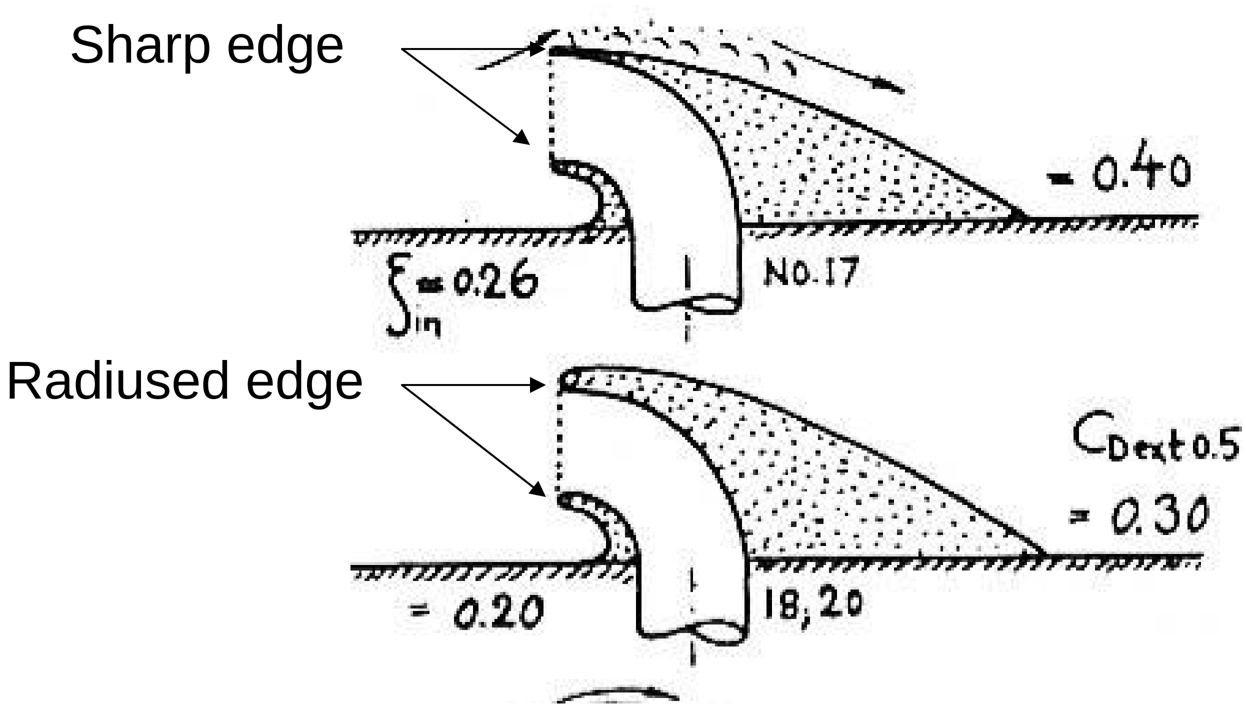
Plus

- Sex appeal
- Small speed

Minus.

- Increased weight.
- Poor prop bolt access.
- Increased maintenance.
- Potential for loosing spinner and damaging prop and aircraft.

Inlet lip radii important



A 25% reduction in drag coefficient

Cowl design critical
Some design criteria

- No bumps to disturb flow
- Upper cowl exit no higher than crankshaft centerline

Extend cowl trailing edge

- Permits more gradual close out angle
- Delayed or eliminates separation

Reduced wetted and frontal area will lower drag

A few of my favorite EZ cowls

Dick Patschull's Vari Eze

Terry Schubert's Long-EZ

Terrence Scherman's cowl

Steve Volovsek's Long-EZ

Engine performance improvements

- Three types of fuel delivery systems available
  - Standard Marvel updraft carburetor
  - Throttle body Injection – Ellison
  - Fuel injection –Bendix, AirFlow Performance and others

Each system has its strengths and weaknesses

Updraft Carburetor

- Very reliable.
- Tolerant of inlet conditions.
- Poor mixture distribution at part throttle.
- Prone to carb icing.

Ellison TBI

- Light weight
- Lower pressure drop at WOT
- Good mixture distribution at part throttle
- Marginal mixture distribution at WOT
- Good icing tolerance
- Very sensitive to inlet conditions

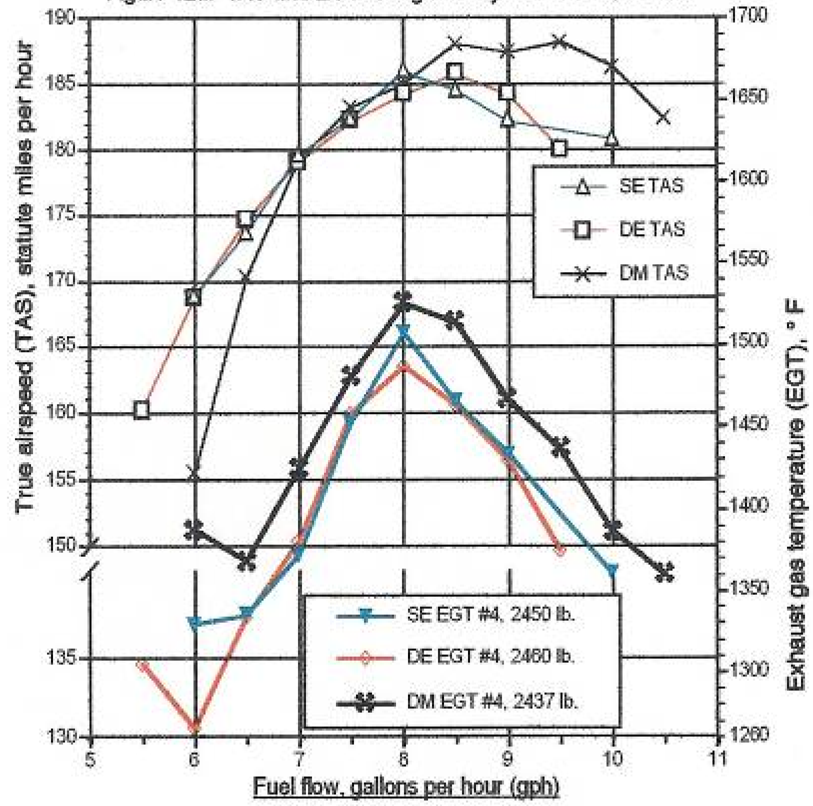
Fuel Injection

- Excellent mixture distribution at all throttle settings – best fuel economy
- Carb icing not an issue
- Requires high pressure pump
- More expensive than other options.

Electonic Ignition

- Improved starting and idle operation
- Improve low power high altitude cruise fuel consumption
- Excellent research done by the CAFÉ Foundation http://cafefoundation.org/v2/research_reports.php

Figure 12a. TAS and EGT of 3 ignition systems at 15,000 feet



Mooney N6057Q at 15,000' density altitude, wide open throttle, 2550 RPM, wing Barograph #3. Cowl flaps fully opened. Mags @ 25° BTDC. Electroair EIS-1 electronic @ 41° BTDC. EGT from cylinder #4 (leanest).
DE = dual electronic. SE = single electronic. DM = dual magnetos.