A PRESENTATION
ON
EXPERIMENTAL AND COMPUTATIONAL ANALYSIS OF DIFFERENT VORTEX GENERATOR (V.G.) PROFILE ON A SIMPLE SYMMETRICAL AIRFOIL.

PRESENTED BY

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What are vortex-generators?

Vortex generators are small components deployed on the wings and stabilizers surfaces. They modify the flow around this surfaces affecting boundary layer. Properly arranged, improve the performance and controllability of the aircraft, particularly at low flight speeds, climb, and high angles of attack.

Vortex generators will not fix incorrectly flying aircraft, wrong balanced, or having inadequate geometry. These are devices that clearly improve the characteristics and properties of the airplane near stall speed, while reducing the stall speed and increasing critical angle of attack. Vortex Generators from Aero-Service has been developed for ultra-light, LSA and experimental aircraft.

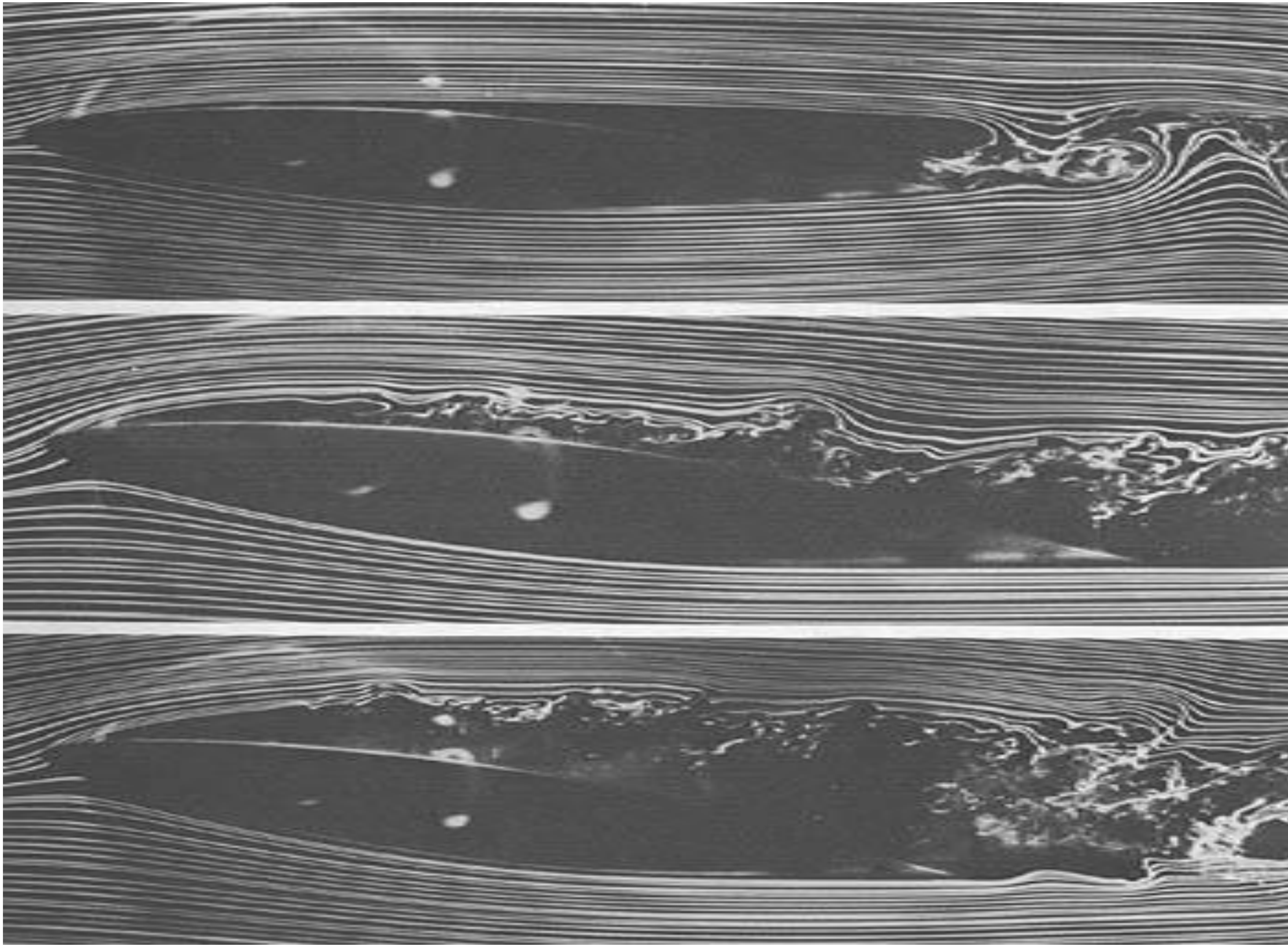

GENERAL

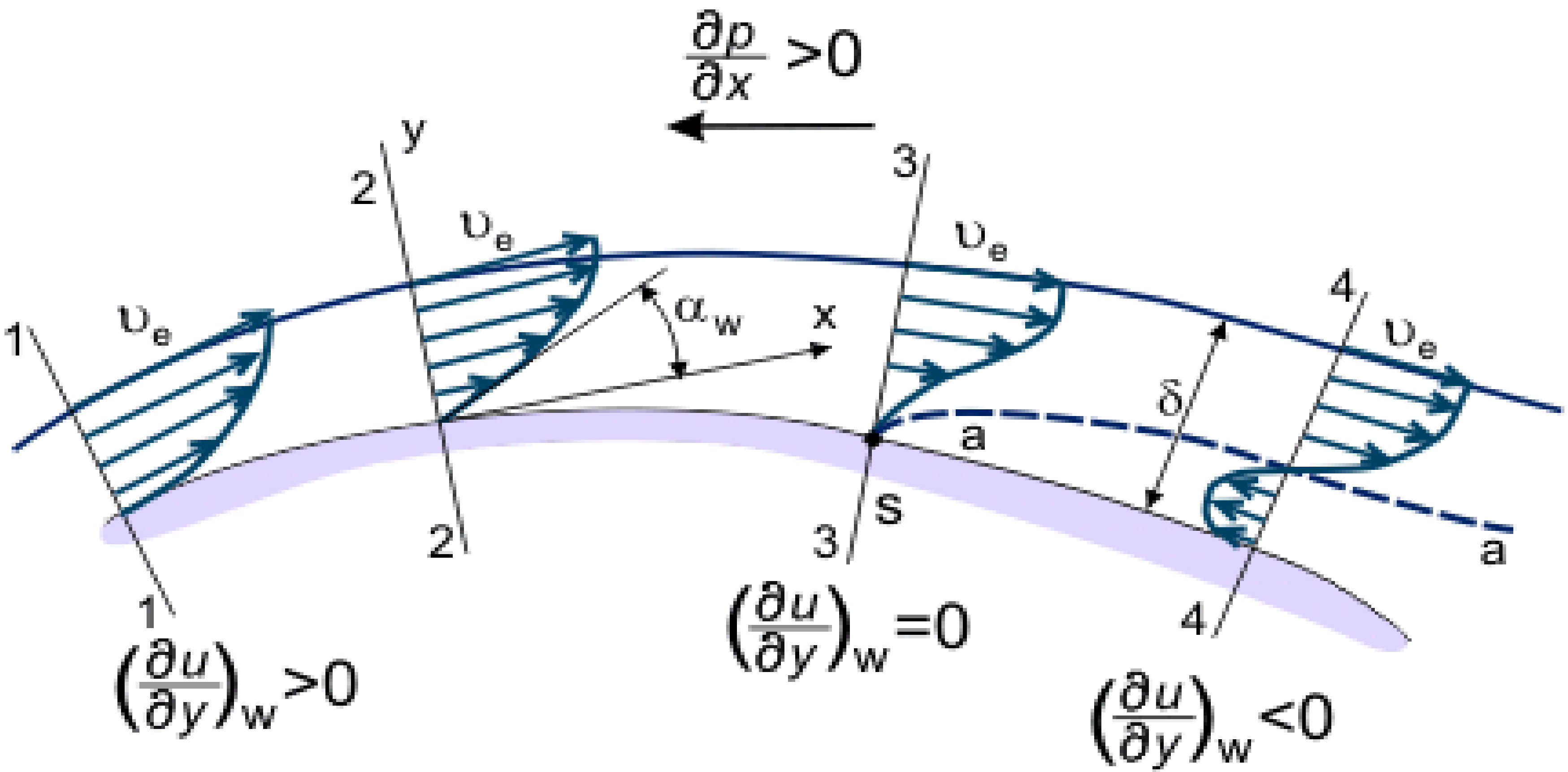
How do they work?

The vortex generators modify the boundary layer. To understand exactly how it works, we should start by understanding the term of flow and boundary layer. To explain these concepts we should look into case of flow around solid, and in our particular case - around wings.

Let's take a look to a part of flow area which is in close proximity to the surface of the flown block. This part of the flow is called the boundary layer. In the boundary layer significant are viscosity and friction forces. The viscosity of the fluid and the friction of the object surfaces generates high transverse velocity gradients. Therefore, the boundary layer is an area of particular importance. Outside the boundary layer, where viscous forces play a minor role, usually assume that the flow is invicid. The flow in the boundary layer can be either laminar or turbulent.

REAL BEHAVIOUR OF THE BOUNDARY LAYER





$\frac{\partial p}{\partial x} > 0$
y
2
3
υ_e
υ_e
υ_e
υ_e
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s
2
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$\left(\frac{\partial u}{\partial y}\right)_w = 0$
$\left(\frac{\partial u}{\partial y}\right)_w > 0$
$\left(\frac{\partial u}{\partial y}\right)_w < 0$

During the flight, the air flows around the wing. The viscosity of the air and the surface friction of the wings causes the air molecules in contact with surface of the wing have zero velocity. molecules slightly farther away from the wing surface moves in the direction of flow, but they are slowed by the still ones. The farther from the wing surface, air speed is greater, up to the point where the air has a constant speed, as the speed of the incoming air. The layer of air from the surface of the wing up to this point we take as the boundary layer.

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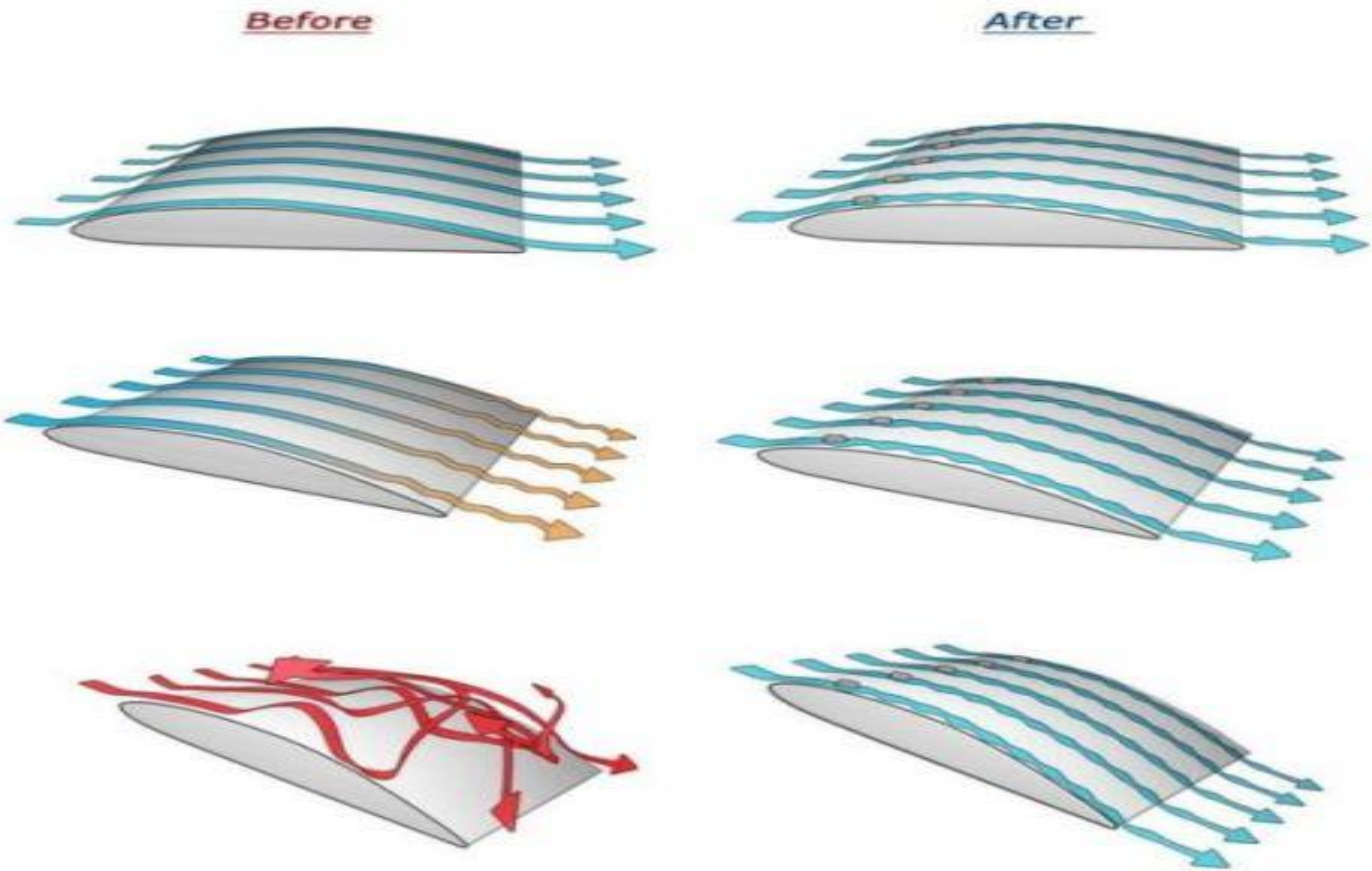
Another aspect is to explain is the nature of the flow in the boundary layer. It can be laminar or turbulent. The flow in the laminar boundary layer is "orderly and gentle". In this layer do not appear moves, perpendicular to the direction of flow, or any turbulences. Air molecules move along the gently curved paths, imposed by the flow boundaries - in our case, these paths dictates the profile of the wing. Moving air molecules to form successive layers, sliding against each other, which, despite the difference in speed, they do not mix with each other. This is because the mass and momentum transfer between the layers occurs only at the microscopic level, in a macroscopic scale, this transfer is not affected. Randomly generated disturbances are immediately damped, because the viscous forces dominate over inertial forces here. Laminar flow is called also stable flow.

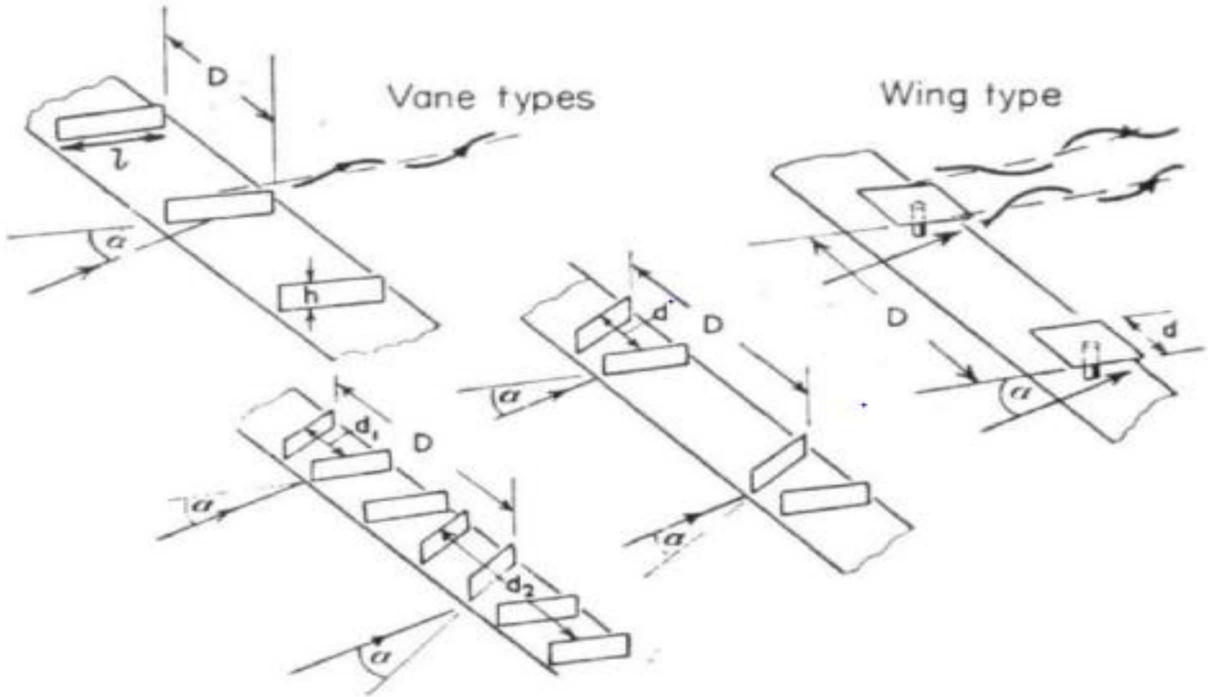
In the turbulent flow particles of fluid in addition to the main movement also oscillate. Layers also move perpendicular to the direction of flow. Created are vortex structures. This flow is also called rough.

In the case of flow around a wing, boundary layer near the leading edge is thin and laminar. With the movement toward the trailing edge, gradually increasing its thickness. At a certain distance from the leading edge is a transition region in which the boundary layer changes its nature to turbulent. Despite the turbulent nature of this area, right on the wing surface, there is still a thin laminar sub layer where there is no turbulence. This is due to the dampening effects of previously mentioned viscosity. This sub-layer slows down and becomes the cause of separation and reverse flow, and thus the wing stall. To avoid separation, but rather delay the formation and reduce the intensity of separation, we should the accelerate and "energize" slowing layer. Over the years many solutions have been designed to control and influencing the boundary. A very effective yet simple solution is to use turbulators/ Vortex generators. Each of these small elements creates a swirling wake who places a energy in the boundary layer of the wing. The result is a higher critical angle of attack, a lower stall speed, gentle stall characteristics, and less tendency to "drop the wing".


Before
After

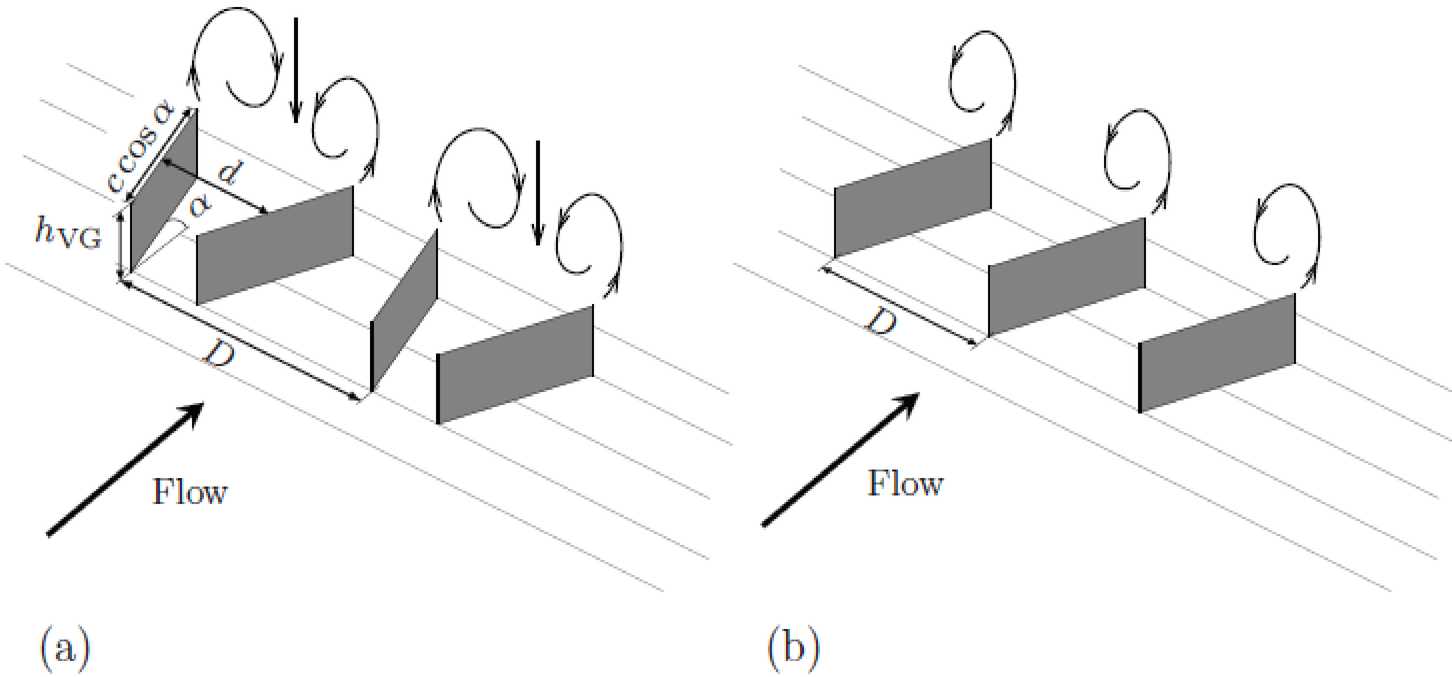
ACTIVE VORTEX GENERATOR

- Pearcey (1961) suggested certain design criteria for successful boundary layer flow control with VVGs. His studies encompassed different VVG designs as for example corotating and counter-rotating VGs, multiple-row systems, and VVGs of different geometries. “Counter-rotating” setups, typically contain VVG pairs with vanes mounted in a mirror-inverted manner so that vortices with opposite-rotational directions are generated. This arrangement is common for the application of flow-separation control in two-dimensional flows when the span wise velocity component is zero,



Types and notation of Pearcey's VVGs. [From Pearcey (1961).]

In contrast to that are “co-rotating” setups,where VVG vanes are installed in the same manner regarding alpha and therefore, produce vortices with the same rotational directions.



VVG setups and the notation that is used in
this thesis: (a) counter-rotating common-flow-down, and (b)
corotating (d = 0) configurations.

More recent studies (Lin 2002; Yao et al. 2002) have shown that so-called subboundary-layer VVGs (SBVGs) have major advantages compared to standard VVGs with vane heights in the order of the local boundary-layer thickness i.e., hVG/99 =1. SBVGs have a typical device height of 0.1 < hVG/99< 0.5, thus mixing the mean-flow momentum only within the boundary layer.

This has been shown to be very efficient compared to standard VVGs. The VVGs which were studied in this project can be considered as SBVGs (although, hVG/99= 0.65 for the defined baseline VVG position in von Stillfried et al. (2011b,a)).

Godard & Stanislas studied previous results by several research groups and started from the optimal parameters given in Lin et al. (1991). By successively varying the VVG parameters and measuring the overall performance in terms of skin-friction distributions at two spanwise symmetry planes, they could define optimum settings both for the counter- and the corotating systems. In terms of hVG, Godard & Stanislas identified that the skin-friction distributions increased with increasing hVG, which is in contrast to some results in existing literature.

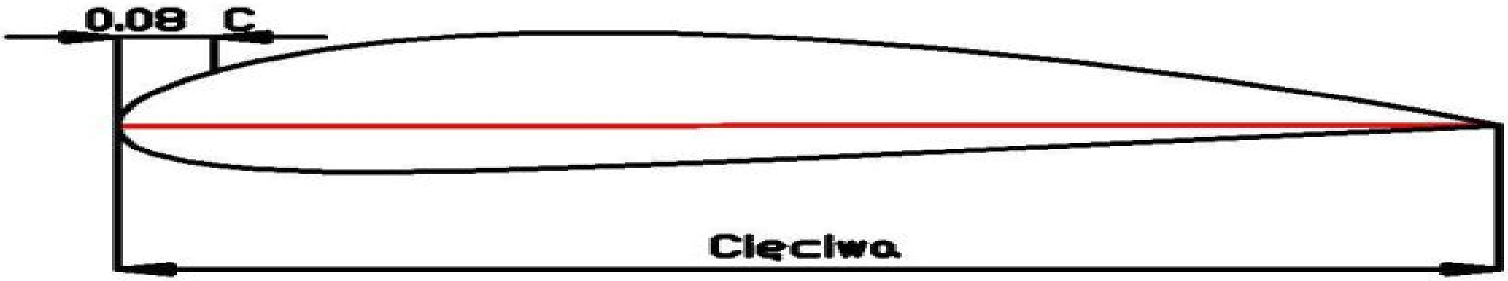
As a result of the study, Godard and Stanislas found that “the counter-rotating configuration is twice as efficient as the corotating one,which is already quite efficient”.

Pauley & Eaton (1988) have experimentally investigated VVG pairs and
arrays with a ratio hVG/99 = 1.5, mounted in a zero-pressure-gradient (ZPG)
flat-plate boundary layer, and mainly investigated spanwise vorticity contours.
Different VVG setups were examined, as for example counter-rotating common flow-up/down, pairs with different height ratios hVG/99, corotating and alternating arrays. They varied the angle of incidence as well as the spacing d,
and could show that a strong interaction of neighbouring vortices caused a decrease of peak vorticity, whereas then streamwise development of the vortex circulation was primarily connected to the interaction with the wall and thus, skin friction. Vortices that were located closer to the wall (for example, counter-rotating common-flow-down setups) caused a larger skin-friction variation which, in turn, diminished the circulation. A conclusion of their work is that VVG pairs should be arranged in such a way that they produce common-flow-down vortex structure

arrays should provide a certain minimum distance D because vortex velocities
may cancel out each other if VVGs are located too closely to each other

Installation of Vortex Generators

- The greatest influence on the effectiveness of vortex generators, is their location on the wing. If they are placed too far away from the leading edge, their performance during the stall will be negligible. This is due to the boundary layer, and the separation. If vortex generators are placed too close to the leading edge, it can cause increased drag. It´s better to mount farther forward than too far aft leading edge.
  Vortex generators from Aero-Service, should be mounted on the wing just 7-9% of the chord length measured from the leading edge to the front of vortex generator.



- This is the distance that gives the best and certain results. The permissible range is considered to be 6-10% of wing chord back from the leading edge to the front of vortex generator proper assembly is greater than 6 and up to 10% of the chord length.

Installation on wings

- 1. First, determine the mounting location of vortex generators. Calculate 7% (or more) of wing chord. For tapered wings, calculations and measurements are made for two positions: at the wing tip, and at the root. For wings with rectangular outline at just one.

  2. Mark calculated length on the wing. Aircraft should be leveled. Measure from a vertical line extended above the leading edge. A carpenter's level is very useful for this work.


SOLA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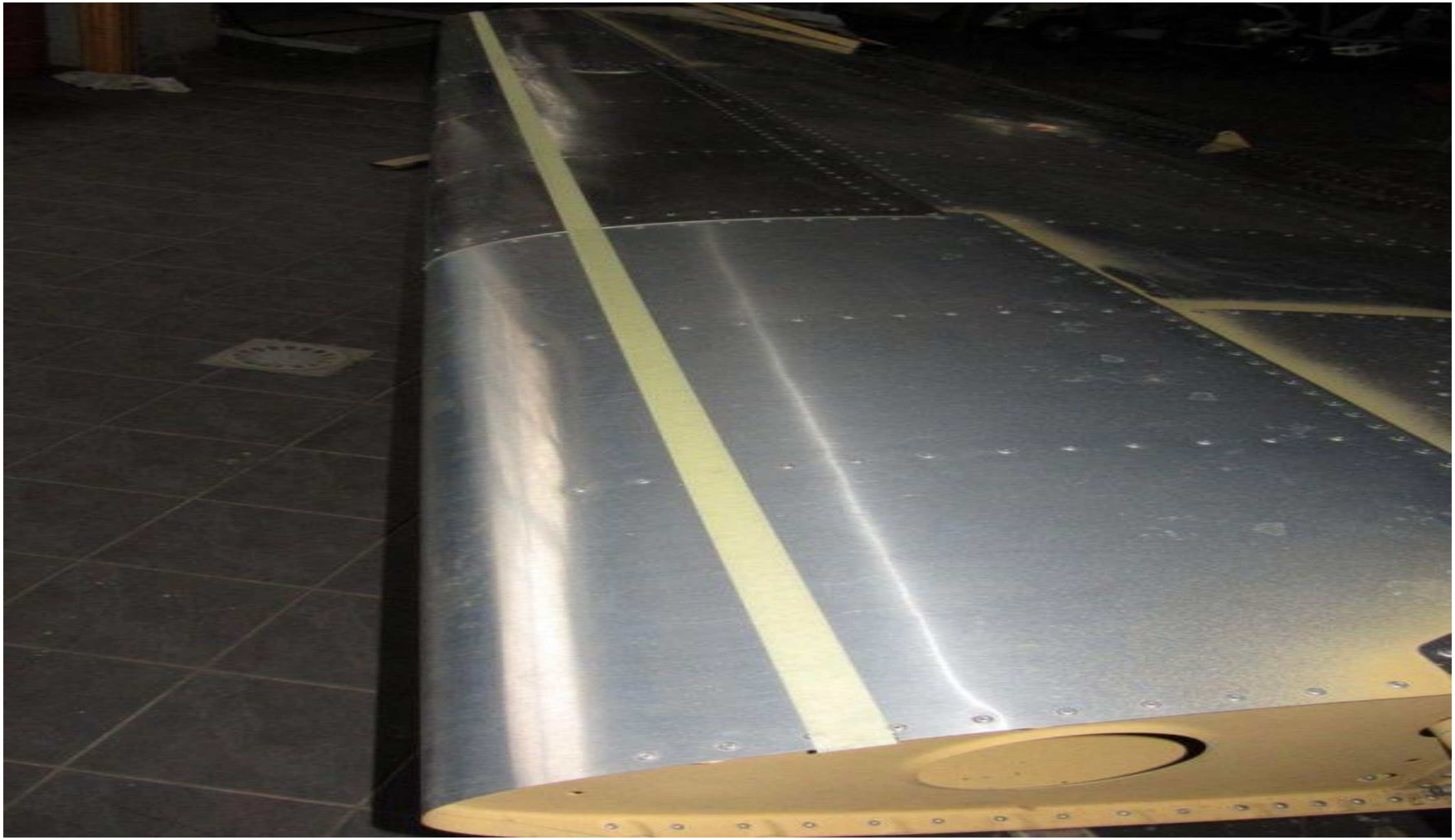
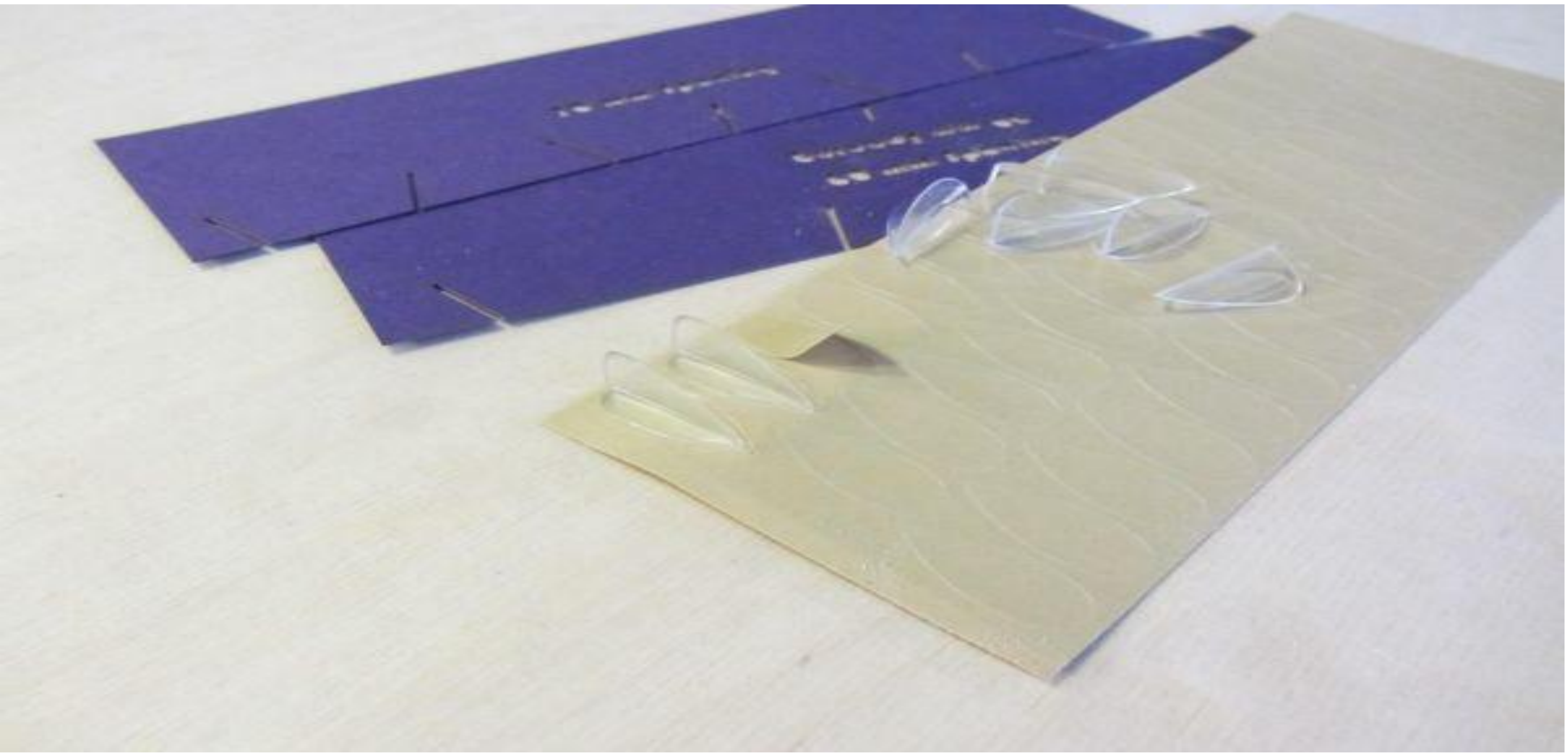
In most cases (rectangular wing contour), dimension at the tip will be the same as at the root. Then we mark a line along two measured points. We can do this for example with masking tape. The resulting line is a place where we install front tip of vortex generators.

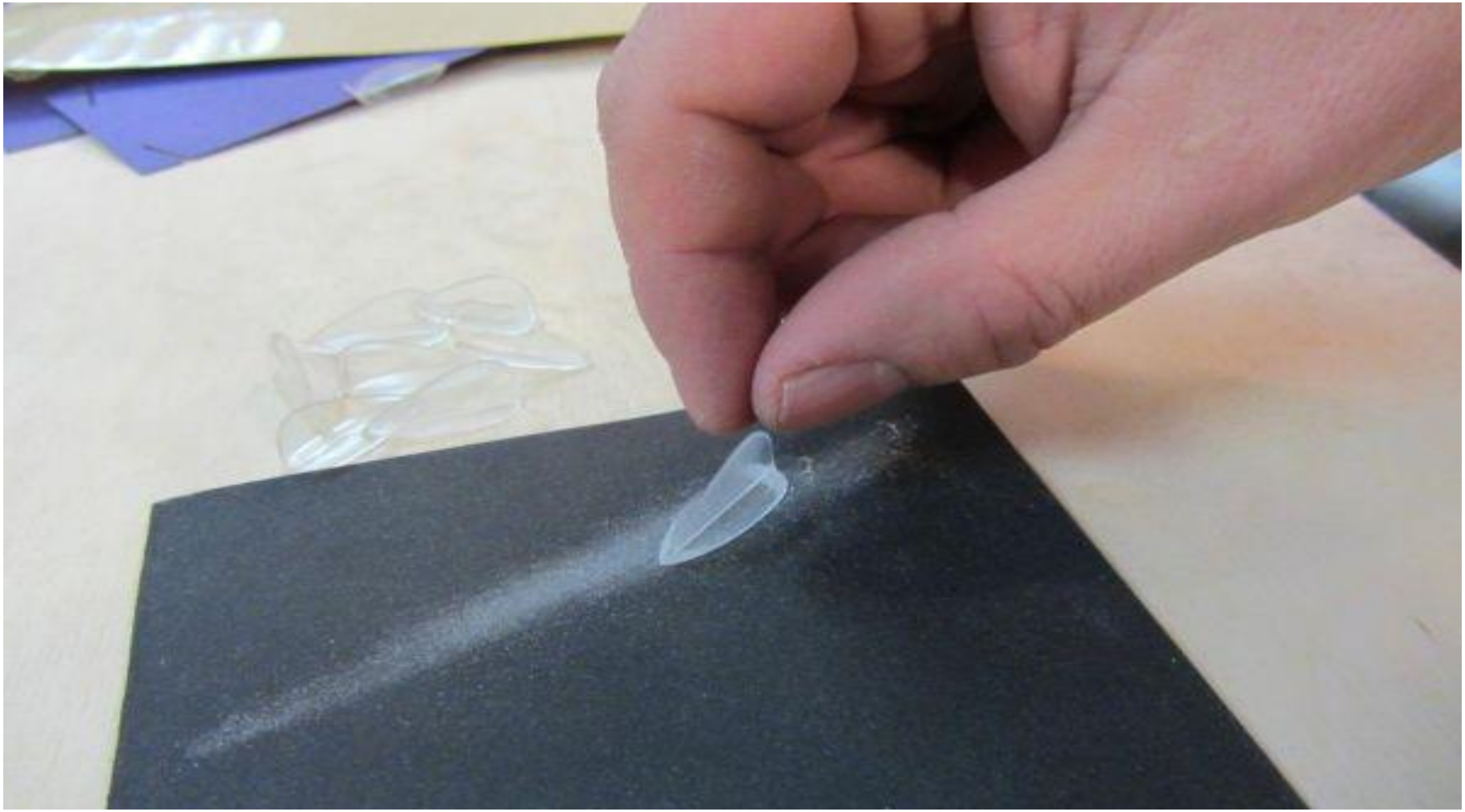


Note: In the case of a tapered wings, place vortex generators at angle of 15° to the leading edge

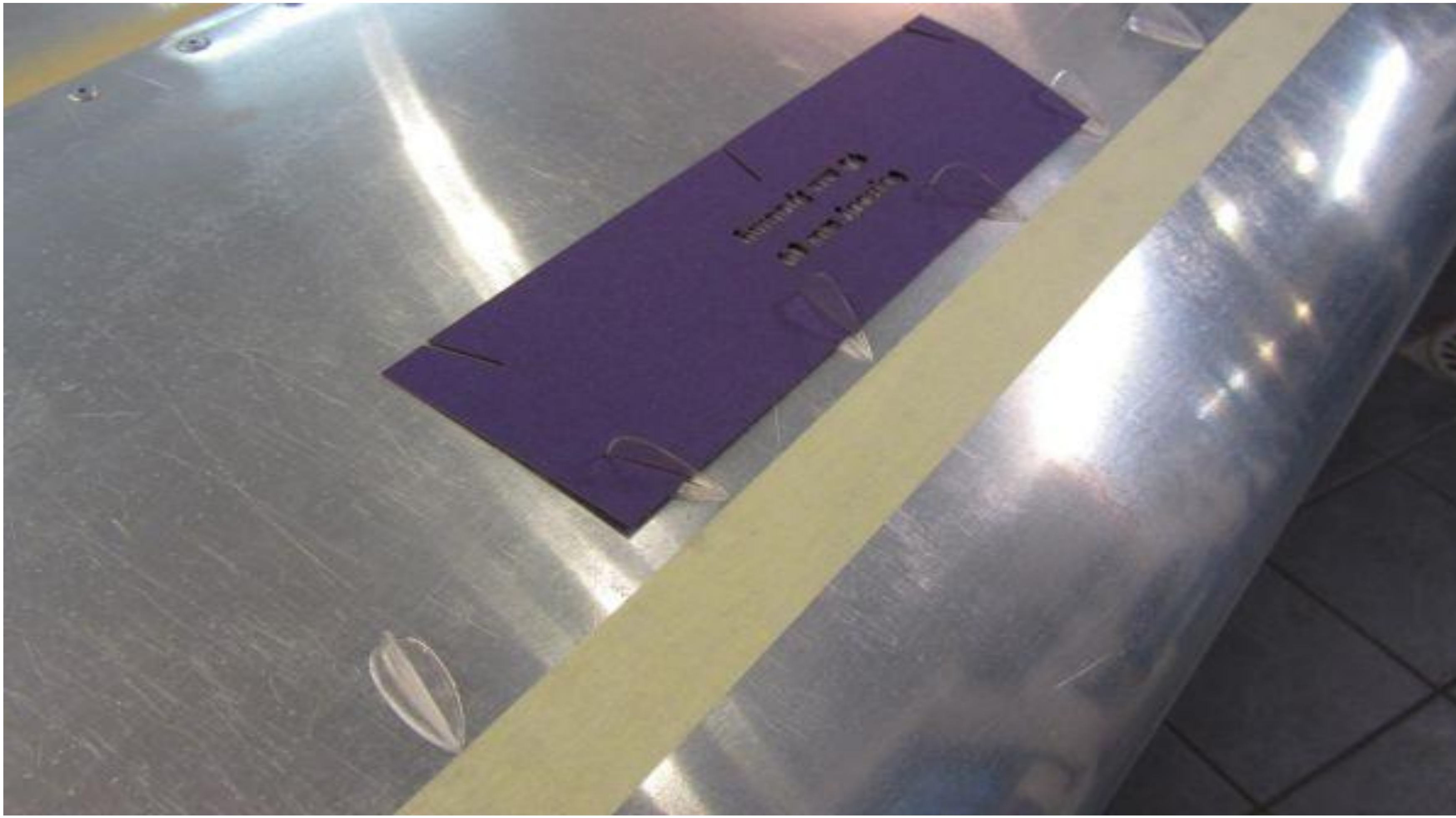
3. Now you have to prepare vortex generators included in the kit, special self-adhesive sheets, and surfaces of wings and / or stabilizers. Surfaces should be clean and free of grease. Self-adhesive sheets are specially cut to facilitate and speed up the installation process.



Before placing VG´s to adhesive their base should be degreased. The ambient temperature for the use of adhesive may not be less than 15°C. In the case of bonding at a lower temperature, the manufacturer does not guarantee a permanent bonding.



4. Start placing VG´s about 50mm from each wing tip. From the tip, place 16 VG´s with 60mm spacing. On the remaining portion of the wing place VG´s with 90mm spacing



Boundary Layer thickness formula

The **boundary layer thickness, δ**, is the distance across a boundary layer from the wall to a point where the flow velocity has essentially reached the 'free stream' velocity, u_0. This distance is defined normal to the wall, and the point where the flow velocity is essentially that of the free stream is customarily defined as the point where:

$$u(y) = 0.99u_o$$

For laminar boundary layers over a flat plate, the Blasius solution gives:

$$\delta \approx 4.91\sqrt{\frac{\nu x}{u_0}}$$

$$\delta \approx 4.91x/\sqrt{\mathrm{Re}_x}$$

For turbulent boundary layers over a flat plate, the boundary layer thickness is given by:

$$\delta \approx 0.382x/{\mathrm{Re}_x}^{1/5}$$

where

$$\mathrm{Re}_x = \rho u_0 x/\mu$$

δ is the overall thickness (or height) of the boundary layer

Re_x is the Reynolds Number

ρ is the density

u_0 is the freestream velocity

x is the distance downstream from the start of the boundary layer

ν is the kinematic viscosity

μ is the dynamic viscosity

The velocity thickness can also be referred to as the Soole ratio, although the gradient of the thickness over distance would be adversely proportional to that of velocity thickness.

Calculation for vortex generator height

chord length = 20 cm

6 % of 20 = 1.2 cm

7 % of 20 = 1.4 cm

8 % of 20 = 1.6 cm

9 % of 20 = 1.8 cm

Boundary layer thickness

$$\delta = \frac{4.91 \times x}{(Re_x)^{1/2}}$$

for 6 % of chord length

$$\delta = \frac{4.91 \times 1.2 \times 10^{-2}}{\sqrt{\frac{1.23 \times 25 \times (1.2) \times 10^{-2}}{1.79 \times 10^{-5}}}} = 4.103 \times 10^{-4} m = 0.401 mm$$

for 7 % of chord length

$$\delta = \frac{4.91 \times 1.4 \times 10^{-2}}{\sqrt{\frac{1.23 \times 25 \times 1.4 \times 10^{-2}}{1.79 \times 10^{-5}}}} = 4.432 \times 10^{-4} M = 0.432 MM$$

for 8 % of chord

$$\delta = \frac{4.91 \times 1.6 \times 10^{-2}}{\sqrt{\frac{1.23 \times 25 \times 1.6 \times 10^{-2}}{1.79 \times 10^{-5}}}} = 4.73 \times 10^{-4} m = 0.473 mm$$

for 9 % of chord length

$$\delta = \frac{4.91 \times 1.8\times10^{-2}}{\sqrt{\dfrac{1.23\times25\times1.8\times10^{-2}}{1.79\times10^{-5}}}} = 5.025\times10^{-4}\,m = 0.5025\,mm$$

for subboundary layer vane vortex generator

$$\frac{h_{VG}}{\delta_{99}} = 0.65$$

$$h_{VG} = 0.65\times\delta_{99}$$

for 6 % of chord line

→ $h_{VG} = 0.260$ mm

for 7 % of chord line

$h_{VG} = 0.2808$ mm

for 8 % of chord line

$h_{VG} = 0.30745$ mm

for 9 % of chord line

$h_{VG} = 0.326625$

Benefits and features

- Shorter takeoff run.
- Lower stall speed.
- Lower approach speed.
- Higher angle of attack.
- Gentle stall characteristics.
- Increased stability at low speeds.
- Higher rate of climb.
- More effective control.
- Easy and quick installation.

Graphs of 0012 NACA AIRFOIL