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Preliminary study of the effects of vortex generators in ultralight aircraft

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Grau en Enginyeria en Tecnologies Aeroespacials (GRETA)

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1. Y+ wall distance mathematical approach

The y+ estimation and first cell height mathematical calculation is based in five steps explained in reference [1]. Even if online calculators automatically deliver the result, the theory behind that calculation is important can be found below:

1. Reynolds number is computed with the input data.

$$Re = \frac{\rho \cdot U_{freestream} \cdot L_{boundary\ layer}}{\mu}$$

2. Skin friction is estimated using the Schlichting skin-friction correlation or any other valid model.

$$C_f = [2\log_{10}(Re_x) - 0.65]^{\ -2.3}\ \ for\ Re_x < 10^9$$

3. Wall shear stress is computed.

$$\tau_w = C_f \cdot \frac{1}{2} \cdot \rho U_{freestream}^2$$

4. Friction velocity is computed afterwards.

$$u_* = \sqrt{\frac{\tau_w}{\rho}}$$

5. So, according to the y+ definition, y can be isolated and calculated:

$$y = \frac{y^+ \mu}{\rho u_*}$$

2. Gross and landing weight increase due to VGs

[2] The gross weight increase offered by the VG STC is a direct result of the reduction in stall speed. Under the FARs, light twins are required to have an engine-out rate-of-climb (in feet/minute) equal to .027 times the square of Vso (in knots). If you lower Vso by a few knots, the required single-engine ROC goes down. At the same time, the VGs actually increase single-engine ROC by increasing the maximum lift coefficient of the wings at high angles-of-attack. Thus, the aircraft now has more single-engine climb performance than the regs require. The solution: increase the gross weight!

Landing weight is a different story. It has structural implications, not just aerodynamic ones. For an STC to obtain a landing weight increase would involve a landing gear beef-up and a series of very costly "drop tests" to prove that the aircraft could handle the additional weight without structural damage. BLR actually did this for the Piper Chieftain, but it required strut modifications and new torque links, and was quite expensive. It's therefore understandable why none of the twin Cessna VG STCs offer a landing weight increase.

3. Why are VG kits so pricey?

Extracted from an interesting testimonial in reference [3]:

"While I had Bob's ear, I figured I might as well go for broke and ask him the $2,500 question: why do VG kits cost so much when the materials cost is clearly not very great? Of course, I already knew the answer — it costs a lot to get the FAA to certify these things — but Bob gave me some details that helped put things into true perspective.

He said that it can easily cost between $250,000 and $500,000 to get a VG kit certified. Why so much? In essence, the FAA requires that almost all of the airplane's original flight testing be repeated. For instance, for twins that were certificated for known-icing (i.e., most of them), the icing tests have to be reflown (which means finding sufficiently bad natural icing condition, flying behind a spray plane, or gluing styrofoam "shapes" to the unbooted areas of the aircraft to simulate ice). For singles, the spin tests have to be reflown (which means fitting the aircraft with a spin chute and water ballast).

To make matters worse, the market for most of these costly-to-get STCs is depressingly small. BLR's first VG STC was for the Beech Duke, of which only about 500 are flying. You might think the situation would be a lot better with more popular models like the Cessna 310, but you'd be wrong. Separate STCs (and flight tests) are required for the "tuna tank" models, the narrow-chord aileron models, wide-chord aileron models, the long-nose R-model, and the turbocharged models. So the market for each of those STCs is still pretty small. To make matters worse, the popular models like Barons and Twin Cessnas have two or three companies competing for the limited market."

4. Alto 912 manufacturer chart

2D chart of the Alto 912 aircraft model provided by the manufacturer (Direct Fly). [4]

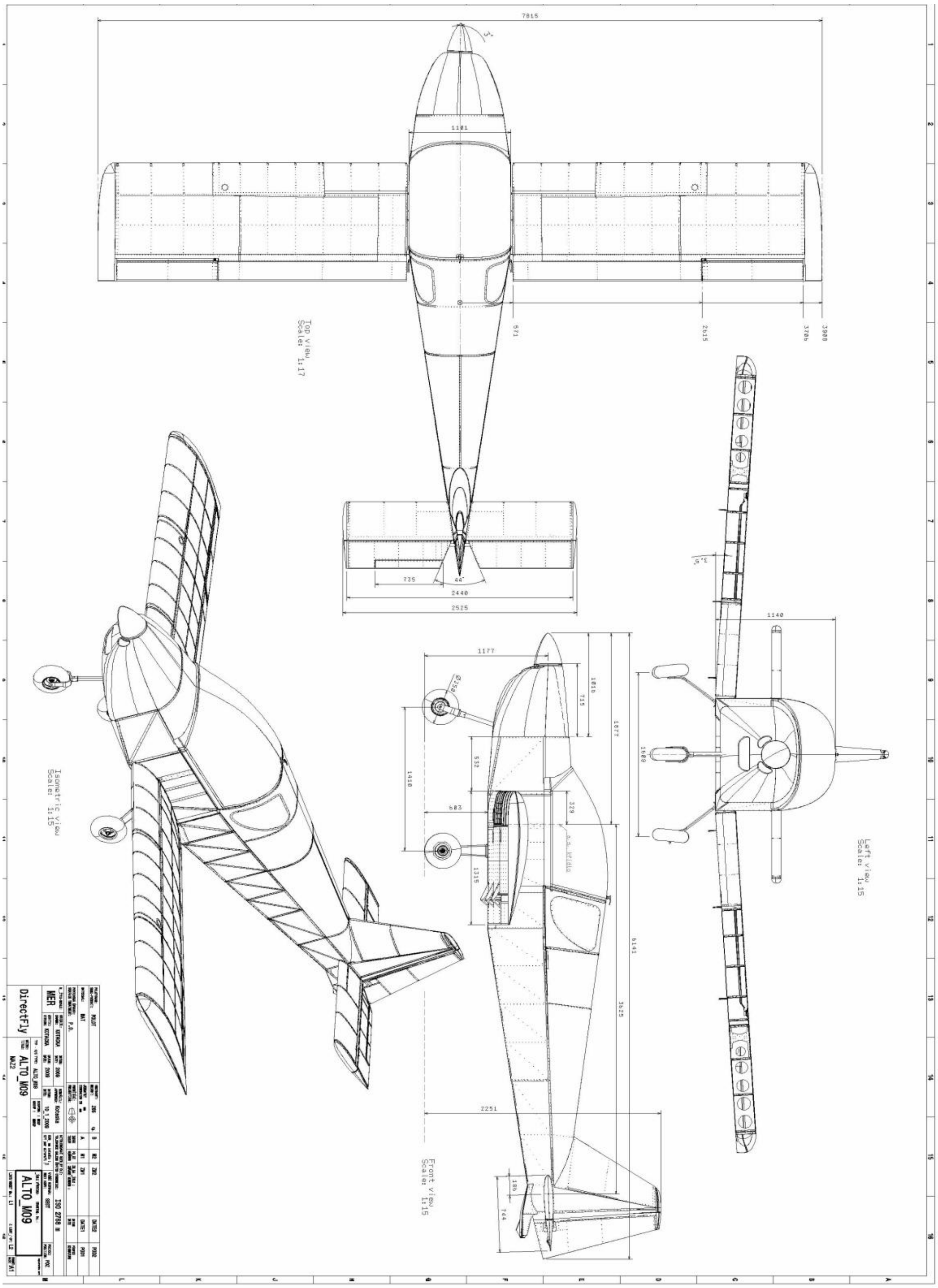

Figure 1: ALTO912 chart provided by manufacturer. Source [4].

5. Experimental flying license

Experimental flying license for the EC-XKN Alto 912TG ultralight model where experimental tests will be carried out.

Ejemplar nº 2

Nº A-1514

ESPAÑA
AGENCIA ESTATAL DE
SEGURIDAD AÉREA

CERTIFICADO DE AERONAVEGABILIDAD ESPECIAL RESTRINGIDO

1) Nacionalidad y matrícula	2) Constructor y designación de la aeronave	3) Nº de serie
EC-XKN	MARIO JORGE ARREGUI HOLGADO Y ANTONIO MARCOS GONZÁLEZ ALTO TG912	12034-2646

4) Categorías PRIVADO (3) ESPECIAL - ULM

5) El presente Certificado de Aeronavegabilidad, se otorga de acuerdo con la O.M. de 31 de mayo de 1982 (Reglamento de Construcción de Aeronaves por Aficionados), para la aeronave antes mencionada, que se considera reúne las condiciones de aeronavegabilidad, mientras se mantenga y utilice de acuerdo con lo que antecede y las limitaciones de utilización pertinentes.

Madrid, 14 de ENERO de 2014

EL DIRECTOR DE SEGURIDAD DE AERONAVES

EL JEFE DE LA DIVISIÓN DE CERTIFICACIÓN

Anula y sustituye al ejemplar anterior

- Jorge Nieto Recio -

Modelo 1107

Figure 2: Picture of the experimental flying license for the ALTO 912 EC-XKN ultralight

6. Airfoil data pre-processing

Fluent and Solid Works communicate well with files that have an .IGS extension, but being accurate with the real airfoil and the simulation process is a must. There is a brief explanation of the steps followed below:

- NACA airfoil generator.
    - *Input*: NACA 3415
    - *Output*: 200 two-dimension points .txt file of a NACA 3415 airfoil with a unitary chord length.
- MATLAB program. As Solid Works can only create curves with 3D input .txt data, a third dimension consisting of a third row of *zeros* has to be added to the .txt file. All dimensions could also be multiplied by any number in order to increase chord length, but Fluent already allows scaling the problem. This program can be found in the next Annex section.
    - *Input*: 2D points .txt file of a generic NACA 3415 airfoil.
    - *Output*: 3D points .txt file of a NACA 3415 airfoil with the desired chord length.
- Solid Works.
    - *Input:* 3D points .txt file of the real airfoil.
    - *Output*: 2D sketch of the airfoil where the geometry modeling will be based.

7. Airfoil data MATLAB software

This section shows the code to transform a 2D .txt airfoil data file into a 3D .txt airfoil data file with a given chord value.

The input would be a airfoilcoordinates.txt file such as:

0.999941	0.001636
0.999216	0.001851
0.998008	0.002209
…	

And after this code:

```
clc
clear
chord=1;
file= fopen('airfoil.txt','r');
formatSpec='%f %f';
C=textscan(file,formatSpec,'Delimiter',''); %Read the .txt
rocketdata=cat(1,C{:,1});
 rocketdata2=cat(2,C{:,2});
fclose(file);
file2=fopen('coordinate2','w');
for i=1:201
fprintf(file2,'%.12f \n',
rocketdata2(i));
end
fclose(file2);
```

For a chord of 2m, the output file airfoilcoordinates3D would be:

1.99988	0.003272	0.000000
1.998432	0.003702	0.000000
1.996016	0.004418	0.000000
…		

This is the .txt format that Solid Works can import so the geometry can be created. Otherwise the points forming the airfoil should have to be introduced manually to the geometry software.

8. Mesh creation process

According to a good meshing strategy [5], this would be a process to efficiently and accurately build reliable meshes for this project's simulations:

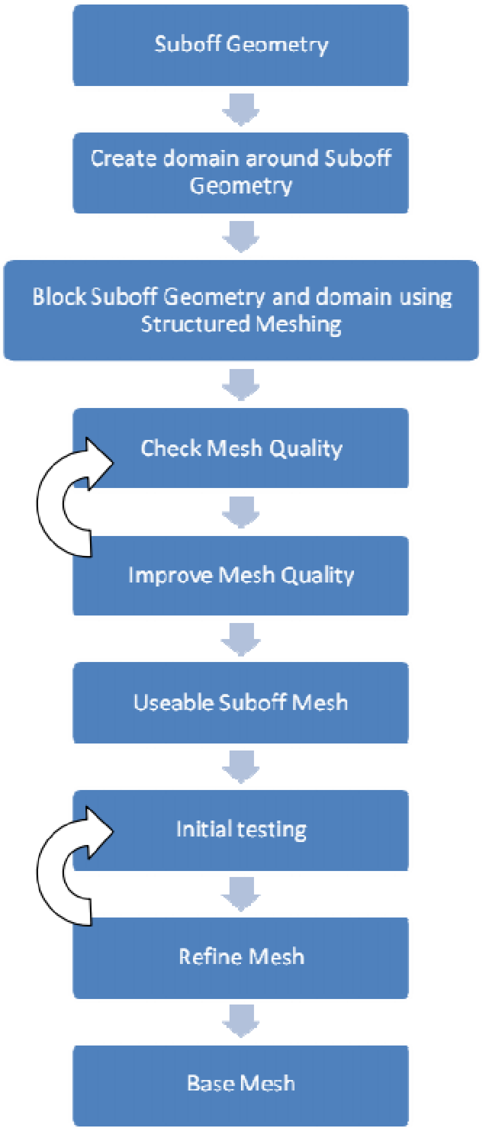

Figure 3: Mesh creation iterative process for CFD simulations

9. NACA 3415 Airfoil Data

Experimental data for a clean NACA 3415 was found in reference [6]

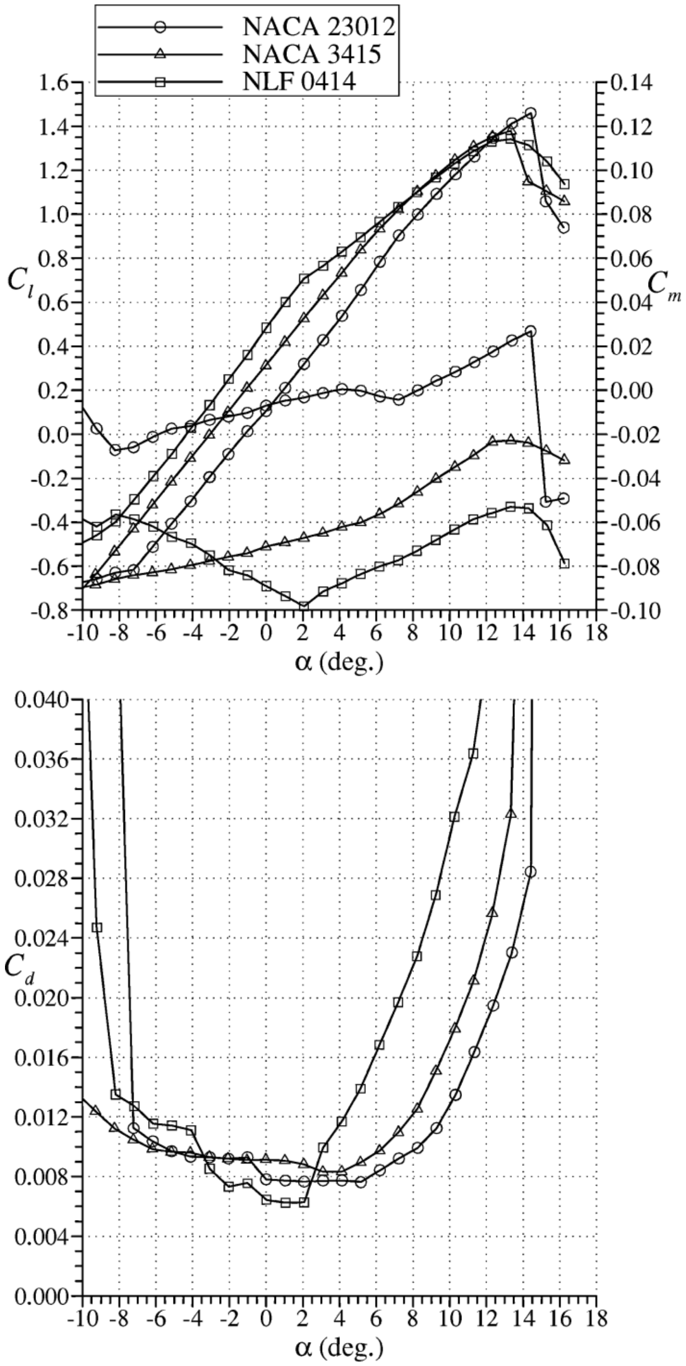

Figure 4: Lift and drag coefficient vs AoA experimental data (NACA 3415 airfoil)

10. 3D Wing with a NACA3415 airfoil

In Figure 5 and Figure 6, wing lift coefficients are plotted according to data found in [7][8]. Wing coefficients are necessary to contrast data with the results of the 3D simulation stage. Note the differences with airfoil lift coefficients, as they are very important in real life aircraft performances.

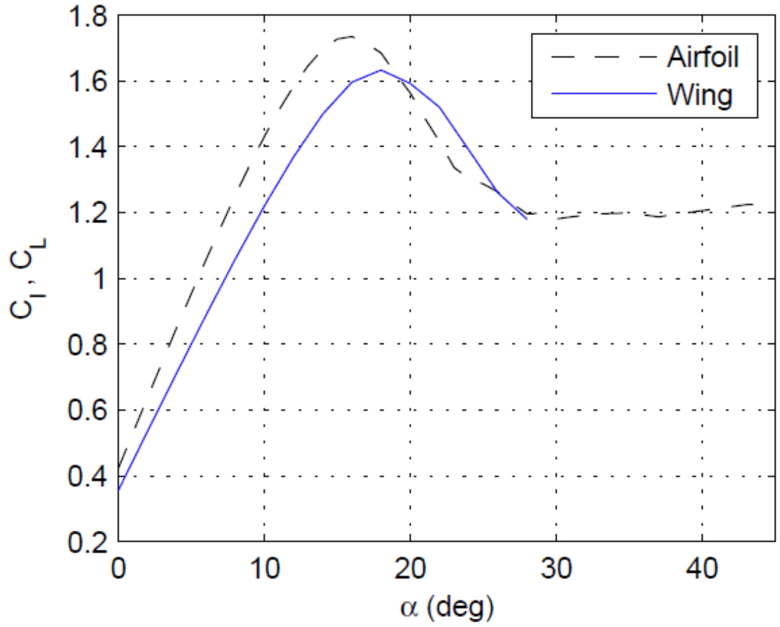

Figure 5: Lift coefficients for both airfoil and wing for a NACA 3415 profile

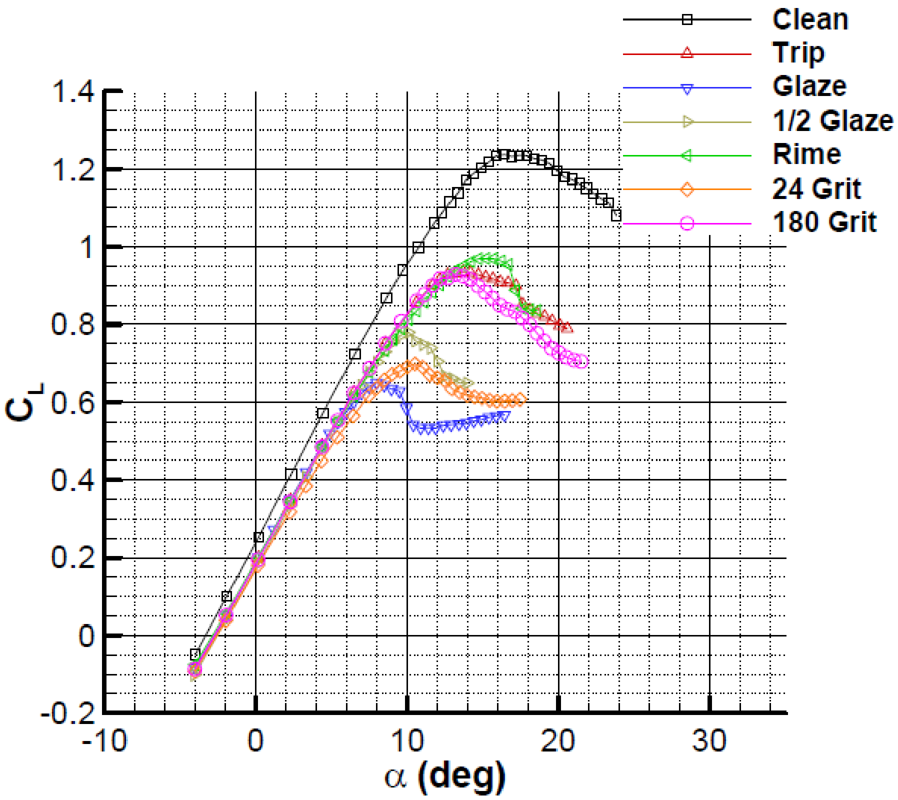

Figure 6: Wing lift coefficient vs AoA curve for a NACA3415 airfoil (clean)

11. 2D simulation convergence

Figure 7 shows the 2D simulation residuals for every iteration. The residuals are the error magnitudes for equations as iterations progress. The equations include the governing equations. The residual is the difference between the previous result and the current results, and when the errors are decreasing the equation results are reaching values that are changing less and less; the solution converges. When errors begin to increase, the solution is said to be diverging.

Flow was simulated across a NACA 3415 airfoil with 11.5 degrees of angle of attack, during 600 time steps and 3 seconds of flow time. Simulation took around 30 minutes.

At the beginning of the simulation, the flow has not settled around the airfoil and that is why at earlier flow times the solution takes a lot more to converge. Once the flow is steadier, residuals decrease and only 4 or 5 iterations are needed for every time step, as the solution converges rapidly.

Special attention has to be paid to convergence parameters and criteria, as a good simulations setup with bad convergence criteria can entail to diverging solutions or slow processing.

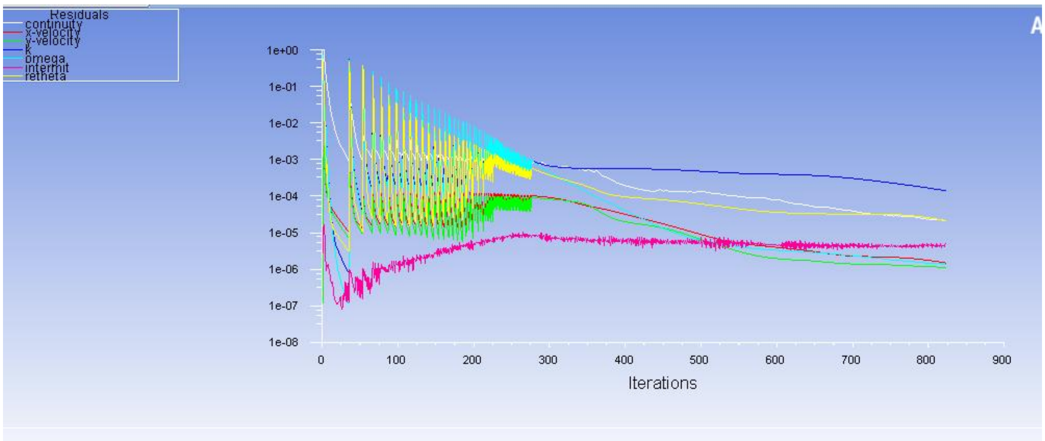

Figure 7: Residuals convergence in every iteration of a 600 time step 3 seconds flow time 2D simulation

12. VG implementation process

Pictures of the VG implementation process in the ultralight aircraft can be found in this section.

VGs are built using an aluminum plate. Dimensions were copied from other VGs in order to implement realistic state of the art devices.

Figure 8: Aluminum base piece to create the VGs

The aluminum plate is cut using the left tool of Figure 9 and then blended 90 degrees twice along the red marking with the right tool.

Figure 9: Tools used to cut and bend the aluminum piece

The final result is one piece that acts as a couple of VGs, as the two vertical fins have an angle of attack respect to the freestream velocity. The piece is then added a double-faced sticker so it can be glued to the wing. This VG is very practical to mount and unmount from the aircraft, and it is great for experimental tests.

Figure 10: Various VGs constructed ready to be mounted on the wing

The 0.08 times the chord distance is measured and marks every 10cm are placed in order to stick the VGs perpendicularly to the leading edge. 19 VGs are placed in the outer part of each wing – every 10 cm. Wing surface where to place the sticker has to be cleaned first with alcohol to ensure that the VG is glued properly.

Figure 11: Process of cleaning the leading edge and sticking the VGs to the aircraft wing

The final result can be seen in Figure 12. All the VGs are placed and the four rows of tapes are also glued to the wing, ready to reproduce the flow characteristics in the extrados of the wing.

Figure 12: Final result of the wing used to carry out the experimental tests

13. References

[1] "Y plus wall distance estimation" [Online]. Available: http://www.cfd-online.com/Wiki/Y_plus_wall_distance_estimation. [Accessed: 25-May-2015].

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[7] J. PETRILLI, R. PAUL, A. GOPALARATHNAM, AND N. FRINK, "A CFD Database for Airfoils and Wings at Post-Stall Angles of Attack," *AIAA Pap.*, no. 919, 2013.

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