AERODYNAMICS MEASUREMENTS IN A WIND TUNNEL

Naiara Fernandez Lopez and Jesus Morales Pastor
Universitat Politcnica de Catalunya
(Under the supervision of Dr. J.L. Gutierrez)

This paper is a set of methods to obtain several aerodynamic properties of bodies in a flux of air. We have use a wind tunnel to perform measurements with which we have been able to calculate drag and lift forces and coefficients, the pressure exerted in a body, the percentage of turbulence behind a cylinder and to show the layer separation in a winged profile.

Keywords: wind tunnel, winged profile, cylinder, drag, lift.

I. INTRODUCTION: WIND TUNNELS

The wind tunnel with which we have worked is approximately 4 m of length and has a form similar to a trumpet. Inside the tunnel there is the work chamber that has transparent walls and where you can put the studied object (in our case a winged profile and a cylinder). The tunnel has a fan that permit to accelerate the air until 120 km/h.

FIG. 1: Wind tunnel

This system works with the velocity in Hz with a linear relation with the velocity in m/s. 0 Hz corresponds to 0 km/h and 50 Hz corresponds to 120 km/h. If there is no object inside the tunnel, the flux of the wind will be laminar; but if there is, turbulence may appear.

II. DRAG ON A CYLINDER

The drag force is the component of the force in the direction where the air flow. There are different ways to calculate it:

1. Using the drag equation: $D = \frac{1}{2}\rho v^2 C_D S$. This method implies the calculation of the drag coefficient (C_D) for each studied velocity.
2. Using the balance fixed to the wind tunnel that give us directly the force.
3. Using the dynamic pressure to calculate it. In this case we can measure it with a digital manometer at different angles respect to the direction of the air.

We will focus on the two last methods. To do it we will use a cylinder that is 30 cm long and has a radius $r = 3.2$ cm. This cylinder has a hole that permit us to measure the pressure exerted by the wind.

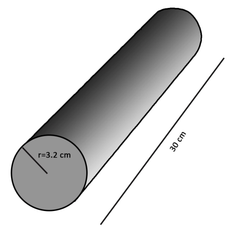


FIG. 2: Schematic draw of the cylinder

A. Methodology

The pressure exerted to the cylinder by the air of the tunnel has been measured for different orientations of the hole, starting at 0° every 10° until 180°, being 0° the angle for which the hold point towards the direction where the wind is coming. For each orientation, 40 measures have been take uniformly distributed in 20 seconds.
We can determinate the total force upon a cylinder as:

$$F = b\oint_C P(\theta)\cos\theta dl = \int_0^{2\pi} P(\theta)\cos\theta d\theta =$$

$$\int_0^{360} P\left(\frac{\alpha\pi}{180}\right)\cos\left(\frac{\alpha\pi}{180}\right)\frac{\pi r}{180}d\alpha$$

Where C is a circular path coaxial with the cylinder's axis. Since we do not have a continue of measurements and assuming that exist an even symmetry, we can do the following approximation:

$$F = \frac{r\pi}{180}\left[P(0^\circ) + 2\sum_{i=1}^{17} P(10i)\cos 10i - P(180^\circ)\right]$$

To do correctly the calculation we must taking into account the different errors committed during the measurements:

1. The error in the measurement of P is its standard deviation.
2. The angle α has an error of 0.5°.

This two errors are uncorrelated, i.e., one error does not depend on the other because we use different measurement systems.
This error can be calculated by the following formula:

$$\Delta F_\alpha = \sqrt{\left(\frac{dF}{dP}\Delta P\right)^2 + \left(\frac{dF}{d\theta}\Delta\theta\right)^2}$$

$$= r\sqrt{(\Delta P)^2 cos^2\theta + (\Delta\theta)^2 P^2 sin^2\theta}$$

$$= r\sqrt{(\Delta P)^2 cos^2\left(\frac{\alpha\pi}{180}\right) + \left(\frac{\pi\Delta\alpha}{180}\right)^2 P^2 sin^2\left(\frac{\alpha\pi}{180}\right)}$$

We could calculated the force per unit area taking into account that the pressure has been measured by a hole and that the direction of the wind is horizontal, so the area of the hole depend on the angle.

$$F_\alpha = P cos\alpha$$

B. Results

The force calculated using the previous formula give us a value of 1,2219±0,2039 N, i.e, a relative error of 16,7%. The force given by the balance is 1,3543 N, so the approximation done is reasonable This error could be because of the consideration of a infinite cylinder that we have done in the previous calculations.

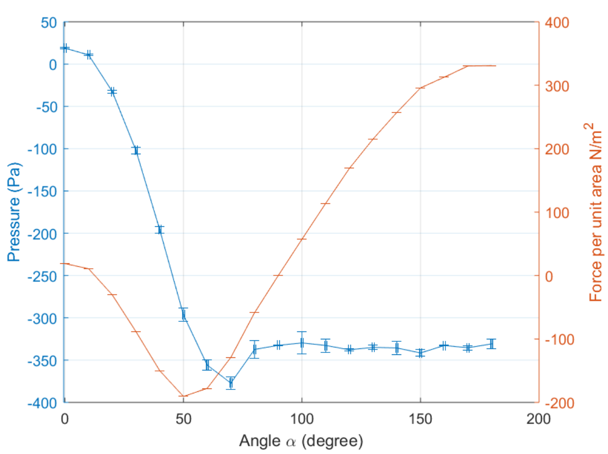


FIG. 3: Pressure and force per unit area respect to α

III. LIFT AND DRAG COEFFICIENTS OF A WING VERSUS ANGLE OF ATTACK

This experiment consist in measuring the lift and drag coefficients respect to the angle of attack. The wing used is symmetric and it is 30 cm of span and 15 cm of chord. For performed this experiment we will use the AFA TQ Equipment, a balance with three component that can measure the lift (L) and the drag (D) forces.

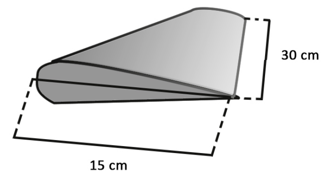


FIG. 4: Schematic draw of the wing

Once you have these two values, we can calculate C_L and C_D with this expressions:

$$L = \frac{\rho v_\infty^2 S C_L}{2} \rightarrow C_L = \frac{2L}{\rho v_\infty^2 S}$$

$$D = \frac{\rho v_\infty^2 S C_D}{2} \rightarrow C_D = \frac{2D}{\rho v_\infty^2 S}$$

Where $\rho = 1,225\frac{km}{m^3}$ is the density of the air, v_∞ is the velocity of the air far away from the wing and S is the surface of the wind.

We assume that v_∞ is the velocity of the air that pass through the wind tunnel.

A. Methodology

The measurement were done for four different velocities: 13.33 m/s (20 Hz), 20 m/s (30 Hz), 26.66 m/s(40 Hz)and 33.33 m/s (50 Hz). For each velocity, the angle of the wing was varied from -10° to 25° making measures every 5°.

To calculate the errors of this experiments, we took into account this two errors:

1. The error of L and D in each measure.
2. The error of the velocity v_∞ of 1 m/s.

We used again the following formula:

$$\Delta C_L = \sqrt{\left(\frac{dC_L}{dL}\Delta L\right)^2 + \left(\frac{dC_L}{dv_\infty}\Delta v_\infty\right)^2}$$

$$\Delta C_D = \sqrt{\left(\frac{dC_D}{dD}\Delta D\right)^2 + \left(\frac{dC_D}{dv_\infty}\Delta v_\infty\right)^2}$$

B. Results

On one hand, the graph of the lift coefficient is linear dependent for $-10° < \alpha < 10°$. That is true for the four velocities.For $\alpha > 10°$ the slope decreases notably.

On the other hand, the graph of the drag coefficient is approximately symmetrical with respect to $\alpha = 0$. This is consistent with the fact that the wing has a horizontal plane of symmetry, so if neglect the effect of gravity the air flow will follow the same trajectory for angles positives and negatives. You can also see that the drag coefficient increase with higher angles, this is because the surface of the wing exposed to direct wind gets bigger as we increase the angle.

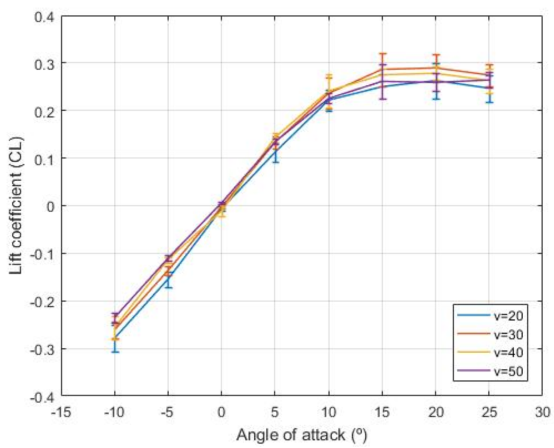


FIG. 5: Lift coefficient for different velocities respect α

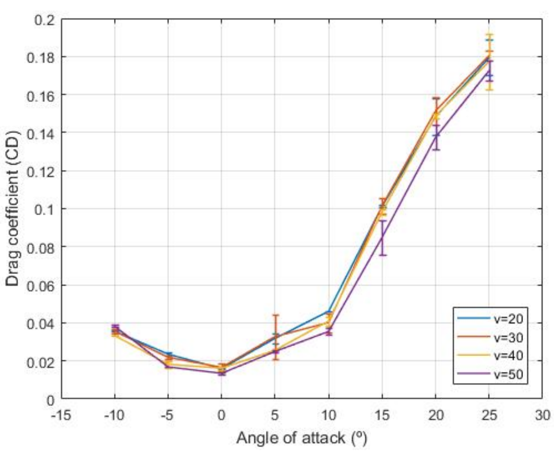


FIG. 6: Drag coefficient for different velocities respect α

The following equation relate the slope of $C_L(\alpha)$ with the sizes of the wing:

$$\frac{dC_L}{d\alpha} = \frac{2\pi}{1 + 2\pi/\pi AR} = \pi$$

Where $AR = \frac{a}{b}$, where a and b are the sizes of the wing.

For this wing, $AR = \frac{a}{b} = \frac{30cm}{15cm} = 2$. To check the measurements done, the slopes of the C_L graphs have been calculated by linear regression.

$$\begin{cases} y1 = 3.2698x - 0.0472 \\ y2 = 3.2593x - 0.0136 \\ y3 = 3.2249x + 0.0021 \\ y4 = 3.0064x + 0.0089 \end{cases}$$

You can see that the four slopes are close to π. This result is consistent with what we had said.

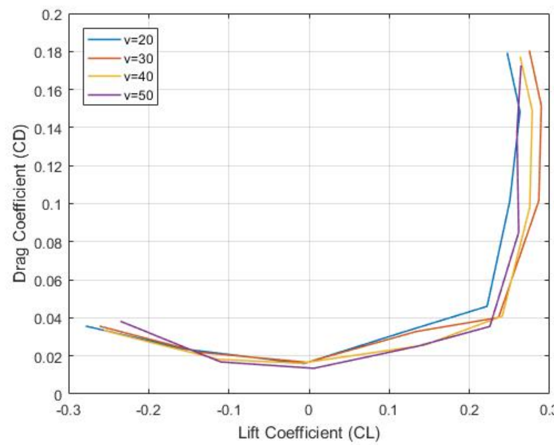


FIG. 7: Drag coefficient vs Lift coefficient

IV. WIND SPEED AND TURBULENCE

The third experiment consist in measuring the wind speed and the percentage of turbulence using a hot wire anemometer or constant temperature anemometer. This device have a thin wire of metal that is electrically heated at a certain temperature, the flowing air cools the wire, because of the losses of radiation heat nearby. This cooling of the wire suppose a change in its electrical resistance, so using this relation, characteristic of each metal, and the voltage used to maintains the wire at a constant temperature the wind speed can be calculated. Note that the information given by the anemometer is just the modulus of the velocity and not the direction, so it is possible that when the measurements are done in a turbulent zone the values given are not reflecting the reality in this point.

A. Methodology

A CTA is introduced in the chamber of the tunnel wind. We have been taken measurements for different heights which are been determined using a ruler. Using that we are able to measure the velocity all over the chamber, specially behind the cylinder, i.e, how an object can modify the flow of air. We are working with a tunnel frequency of 30 Hz, so the velocity inside the chamber is roughly 70 km/h (20 m/s).

B. Results

The percentage of turbulence and the speed of wind are represented in FIG. 8. It can be seen that when the velocity is higher the turbulence are minimum and the other way round. Also we can notice that the standard deviation is much larger when the turbulence increase, that is because of the effect commented below, at turbulent zones the air flows in all direction and the anemometer measure the average speed but not the direction.

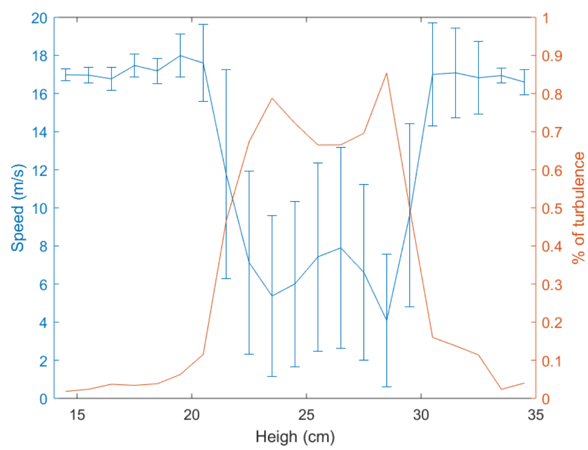
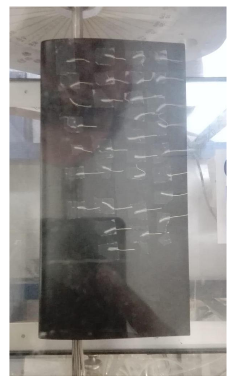


FIG. 8: Turbulence and wind speed respect to the height

V. OBSERVATION OF THE BOUNDARY LAYER SEPARATION

This final part of the project is a qualitative analysis of the boundary layer separation. The boundary layer of a fluid is the area where the movement of the fluid is disturbed by the presence of a solid with which it is in contact. The boundary layer can be laminar or turbulent.
Depending on the angle of attack, the boundary layer can be detached. If the boundary layer separates, the fluid flow will separate from the surface of the object, and takes the forms of eddies and vortices. This phenomenon occurs due to a adverse pressure gradients around aerodynamic bodies. In this experiment, the angle of attack of the wing was increased until observing turbulence. To measure that angle, the wing has some filaments that goes in the direction of the wind. When the boundary layer separates, the direction of these filaments varies. We show you two images of the wing seen from above. You can observe the difference between the laminar flux and turbulence flux.
The angle of the boundary separation that we observed is 16°.



(a) Laminar Flux

(b) Turbulent flux

VI. CONCLUSIONS

Wind tunnel is an equipment that can be used to measure many aerodynamics properties, but also to study the behavior of a body inside the chamber at different velocities that can help to design prototypes of wings. This work has taught us some difficulties that have experimental work where in each measure there are several errors to taking into account. A part of these errors, it must be considered how the setups have to be made and the state of the devices used. An other thing to keep in mind when you work with a wind tunnel is the possibility of turbulence at some zones.

VII. ACKNOWLEDGEMENTS

We would like thank Dr. Gutierrez for their help with this project. He has supported us with the measurements, with the material and with results. We also thank the EETAC for providing us with his wind tunnel.

VIII. REFERENCES

John D. Anderson. Fundamentals of aerodynamics, McGraw-Hill (2011)