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Airfoil Roof in Buildings

Carlos Martin Walter and Jorge Luis Lässig
Faculty of Engineering, Universidad Nacional del Comahue, Neuquén 8300, Argentina

Abstract: In this paper an airfoil that is used on roofs was analyzed: Circular Arc Airfoil. The JavaFoil program for the calculation of aerodynamic parameters of the simulated wing airfoil and small AR (aspect ratio) was used. A wing roof scale model was constructed, and it was tested in the wind tunnel of the Laboratory of Environmental Fluid Dynamics, Universidad Nacional del Comahue. In the model, the AR was equal to 1.46. Thickness of the model was 32%. The tests were conducted at a Reynolds number of 1×10^5. The curves of the lift coefficient versus angle of attack were obtained, and the pressure coefficient Cp was determined for each surface. The lift coefficients and the Cp values differ from the theoretical profile; this shows the importance of using the wind tunnel to obtain experimental data to achieve a good structural design.

Key words: Wind tunnel, roofs, airfoils, aerodynamic loads.

1. Introduction

There is a visual and aesthetic tendency to build roofs for bus terminals, airports, supermarkets, etc., with aerodynamic shapes at their ends, which generates a true cantilever wing in the part of the structure (Fig. 1).

The loads generated by an aerodynamic profile are very sensitive to the angle of attack, and therefore sensitive to wind direction. In Fig. 2 it is exemplified and it can be observed that the total aerodynamic force is usually broken down into two: one perpendicular to the relative wind called lift force, and the other one of resistance in the direction of the relative wind called drag force.

The expressions of the lift and drag forces are:

$$L=1/2\rho V^2 C_L A \quad (1)$$

$$D=1/2\rho V^2 C_D A \quad (2)$$

where C_L is the lift coefficient (dimensionless), C_D is the drag coefficient (dimensionless), V is the relative wind velocity, ρ is the density of the air and A is the wing area and it is the product of the wing length (span) by the wing width (chord).

Corresponding author: Carlos Walter, Engineer, Professor, wind engineering; Jorge Lässig, Engineer, Ph.D., wind engineering.

The angle formed between the relative wind and the chord of the profile is called angle of attack (α), the latter being the imaginary line between the leading edge and the trailing edge of the aerodynamic profile.

As the angle of attack grows, the drag grows and the lift grows, although it has a maximum and then begins to decrease, and if the angle of attack continues to increase, it may disappear, which in aeronautics is called stall wing or profile.

An airfoil is a two-dimensional body, when a wing is built; it is three-dimensional and has length and width dimensions; this ratio (length/width) is called AR (aspect ratio). The characteristics of the C_L of a wing with great AR tend to resemble those of the profile, but as the elongation becomes small, it is far from the aerodynamic characteristics of the profile with which it was built.

Fig. 3 helps to understand these performance variations for wings with low elongation.

It is observed that as the AR decreases, the characteristics of the C_L also decrease. The small wings in the roofs have a low AR; reason why the calculation of the distribution of pressures on the surface must be corrected from the data of the aerodynamic profile used in its construction.

Fig. 1 (A) Bus terminal with concave-convex airfoil roof. (B) Supermarket with circular arc airfoil roof.

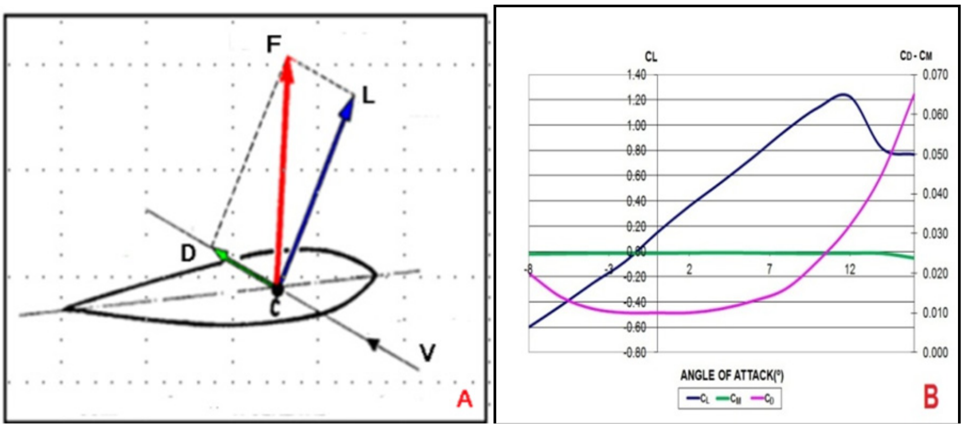

Fig. 2 (A) Aerodynamic forces on an airfoil. (B) Typical lift and drag curves in aerodynamic profiles.

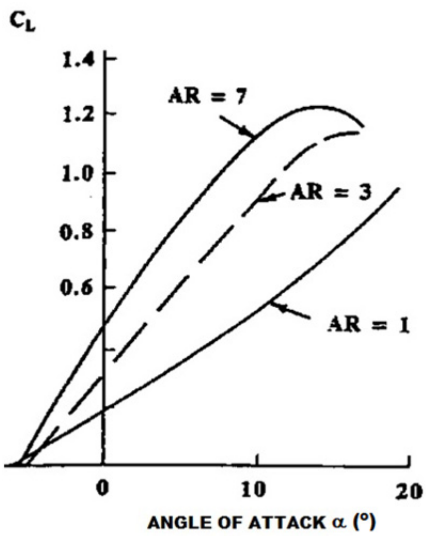

Fig. 3 Comparison for wings of the same profile but different AR and the effect on the lift curve (C_L versus α).

Fig. 4 Schematic drawing of the wing end vortex.

This is because the low wingspan generates a greater vortex at the end of the wing, therefore there is more drag, less lift and a complex pattern of flow over the tip of the roof.

Fig. 4 illustrates how the wing end vortex is generated, which must also occur in a cantilevered roof.

Finally, it should be noted that the profile theory assumes a uniform flow of the relative wind upstream of it, and without intensity of turbulence, but a roof is in an urban environment and the conditions are totally different: a wind profile according to the atmospheric boundary layer of the place, with high intensity of turbulence.

The atmospheric boundary layer is defined as the part of the troposphere that is directly influenced by the presence of the earth's surface, and this can reach a maximum of 1,000-1,500 m in height, where the characteristics from the fluid dynamic point of view are that the wind intensity grows with height and has a high intensity of turbulence (Fig. 5).

Fig. 5 Schematic drawing of velocity distribution.

It is common to describe the wind velocity profile by potential law in engineering applications and especially when the atmospheric stability is of the neutral type.

According to Sutton [1]:

$$u(z) = u_1 \left(\frac{z}{z_1}\right)^P \tag{3}$$

where u_1 and z_1 are the velocity and height at 10 m.

Davenport [2] suggested the next equation taking into account the Geostrophic Wind V_G at the Geostrophic Height z_G.

$$u(z) = V_G \left(\frac{z}{z_G}\right)^P \tag{4}$$

These equations are less precise and can adjust reasonably well in a range of small heights. The exponent P is taken constant with the height and depends on the roughness of the terrain.

In engineering standards or regulations are used to determine the characteristics of the wind in buildings, for example ASCE 7-10.

The intensity of turbulence in an urban environment is much higher than in flat terrain. Li et al. [8] made measurements in a tower of 325 m high with 15 anemometers during windstorms. The TIx longitudinal turbulence intensity was 0.346 at a height of 47 m, 0.254 at a height of 120 m, and 0.155 at a height of 280 m. On the other hand, the flow models that are used in the aerodynamics of airplanes define a uniform velocity with intensity of turbulence very low or zero, because these are the conditions of the upper troposphere.

2. Method and Materials

In the present work, an airfoil that is used in roofs was analyzed: the Circular Arc airfoil. Although this profile was studied in the mid-1950s by NACA [3, 4] with the aim of seeing its qualities at high speeds, nowadays it has been studied again due to its potential use in the control of vortices [5].

In our work we resort to the JavaFoil [6] program (open access) for the calculation of the aerodynamic parameters of the airfoil.

The roof to be simulated will be the Circular Arc airfoil with a thickness of 32% of its chord, which is used on both roofs and buildings in Neuquén region.

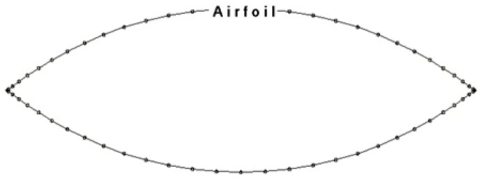

Fig. 6 Shape of the circular arc airfoil of 32% thickness.

The calculations were made with the Java Foil [6] program mentioned and run at a Reynolds of 10^5, the same as that tested in the wind tunnel.

The geometry of the airfoil is shown in Fig. 6. The aerodynamic characteristics C_L vs. α in Fig. 7, and C_L/C_D in Fig. 8, have been made without loss and with the Eppler Standard transition model [7, 8].

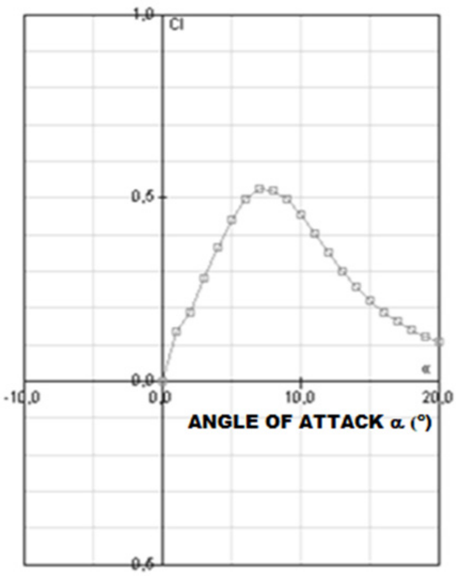

Fig. 7 C_L-α curve for circular arc profile 32% thickness, Re = 10^5, Java Foil [6] program.

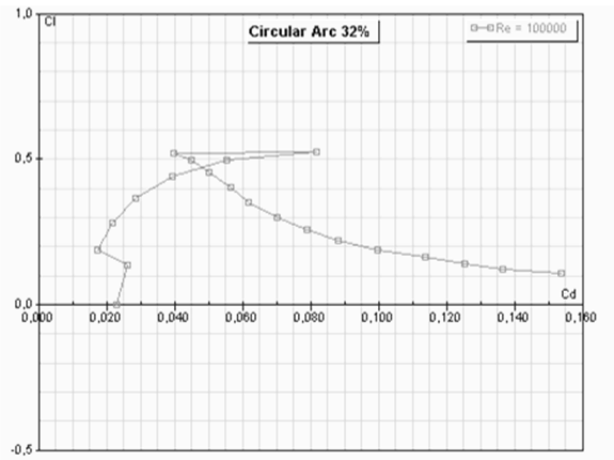

Fig. 8 C_L-C_D curve for circular arc profile 32% thickness, Re = 10^5, Java Foil [6] program.

Fig. 9 The roof model inside the wind tunnel.

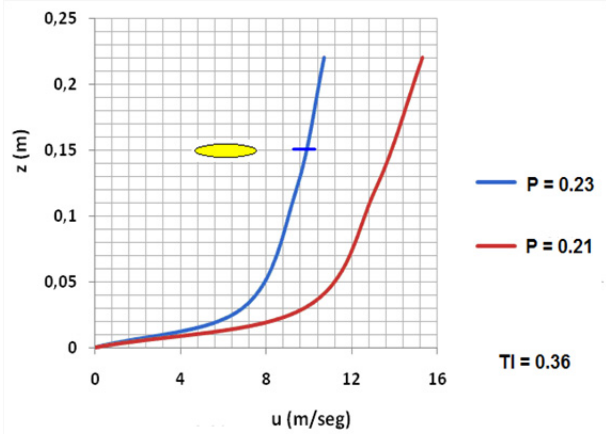

Fig. 10 Velocity distribution inside the wind tunnel.

A model of wing roof was built: chord 150 mm and span 220 mm, and it was tested in the wind tunnel of the Environmental Fluid Dynamics Laboratory of the Universidad Nacional del Comahue (Fig. 9). In the model the AR was equal to 1.46 and the thickness was 32%. The test was performed at a Reynolds number of 10^5.

The percentage of blockage in the test to measure the lift varied between 3% and 6%, and for the test of measurement of the pressures on the surfaces of the roof was between 5% and 10% of the surface of the test section.

The test was carried out with a vertical velocity distribution by Sutton [1], with exponent P = 0.23, and with a turbulence intensity of 0.36 (Fig. 10), thus simulating a typical atmospheric boundary layer of urban environment [8].

$$u(z) = u_1 \left(\frac{z}{z_1}\right)^P \qquad (5)$$

The wind speed was 10 m/s and was measured with a hot wire anemometer TSI Incorporated Model 8330-M, the lift was measured by means of an electronic balance, and the pressures by means of Piezoelectric Pressure Gauges PS2164 registered with a data logger GLX.

The lift measurement was made with a load cell, and the values of C_P were obtained from pressure measurements in 14 static taps. The static taps were located in the center of the tested wing where they would represent the characteristics of the airfoil.

3. Results

The results obtained from the wind tunnel tests and their comparison with those obtained from the profile theory (using the Java Foil [6] program) are shown below.

3.1 Lift Coefficients

The C_L of the wing was calculated with AR equal to 1.46, from the tests in the wind tunnel. The comparisons between the lift measured in the wing (roof) and the theoretical one of the airfoil are indicated in Fig. 11, both at the same Reynolds number.

3.2 Pressure Coefficients

The C_P pressure coefficient was determined on each surface for two angles of attack: 5° and 15°, for the circular arc airfoil of 32% thickness. Figs. 12 and 13 show the results.

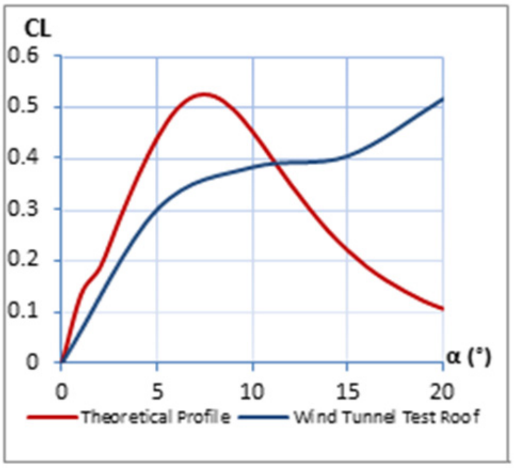

Fig. 11 Lift coefficient in function of angle of attack *α*: theoretical airfoil and wind tunnel test roof.

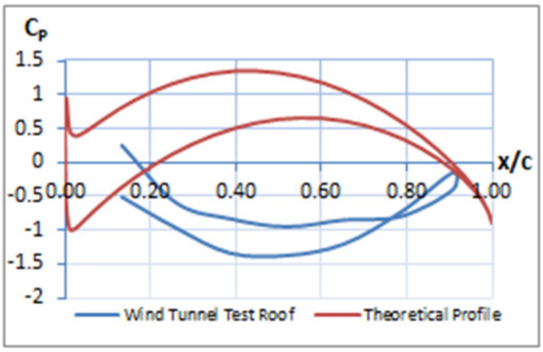

Fig. 12 Distribution of pressures on both wing surfaces with a circular arc airfoil of 32% thickness at an angle of attack of 5°: theoretical airfoil and wind tunnel test roof.

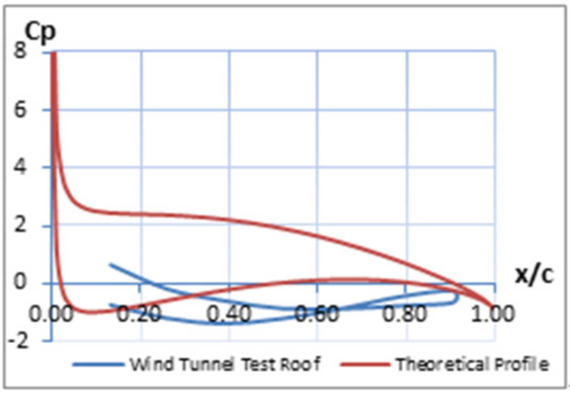

Fig. 13 Distribution of pressures on both wing surfaces with a circular arc airfoil of 32% thickness at an angle of attack of 15°: theoretical airfoil and wind tunnel test roof.

4. Analysis

Observing the lift coefficient curve of the roof model and comparing it with the values obtained from the theoretical airfoil (Java Foil [6] program), an increase of the C_L in the roof is observed in function of the angle of attack, while for the theoretical airfoil, a decrease occurs from 7°.

When we see in Figs. 12 and 13 the values of CP for different angles of attack of the original profile (Theoretical Profile, red), and compare the results of the test in wind tunnel (Wind Tunnel Test Roof, blue) for roof with 1.46 AR, we observe a great discrepancy between both. These differences are due to the fact that the actual flow that occurs on a roof has the characteristics of the atmospheric boundary layer of the place, which increases the intensity of velocity with height, transporting great turbulence, everything opposite to the theory of aerodynamic profiles.

The contradictory results in the lift, probably due to the differences of the incident flow in the two models, while in the aerodynamic model the flow is uniform, in the roof, the atmospheric boundary layer hits the upper surface of the roof at higher velocity than on the lower surface of the roof.

5. Conclusions

For this type of roof, the determination of the aerodynamic loads on it must be made from tests in boundary wind tunnels, because they are subjected to non-uniform velocities due to the atmospheric boundary layer, and turbulence intensities very different (greater) from the theories of airfoil which assume a uniform flow and without intensity of turbulence.

Acknowledgments

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