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Research Paper

Wind in Curved Buildings

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ABSTRACT: *In this paper an airfoil that is used on buildings was analyzed, Circular Arc Airfoil, as an advance of research on the action of the wind in aerodynamic buildings. Su forma aerodinámica could generate lift and drag loads typical of such devices. It seeks to analyze the flow pattern of winds that occur in the environment of aerodynamic buildings, determine the static and dynamic loads produced by the wind, trying to find a mathematical model that generalizes these types of loads. The methodology used is based on tests in the atmospheric boundary layer wind tunnel. Se compara el parámetro adimensional coeficiente de presión Cp en un edificio curvo con un edificio rectangular. The results of the research will allow a better understanding of wind loads on non-conventional buildings and could be applied to the norms of the Argentine Regulation of Wind Action on Constructions CIRSOC 102.*
KEYWORDS: *Wind tunnel, Roofs, Airfoils, Aerodynamic loads*

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I. INTRODUCTION

In the world of architecture, there are new forms and designs for buildings with the aim of breaking schemes and creating structures that attract attention. One of the most striking and challenging designs is that of curved buildings. In Cipolletti, Argentina, there are curved buildings with a circular arc airfoil of different heights (Figure 1).

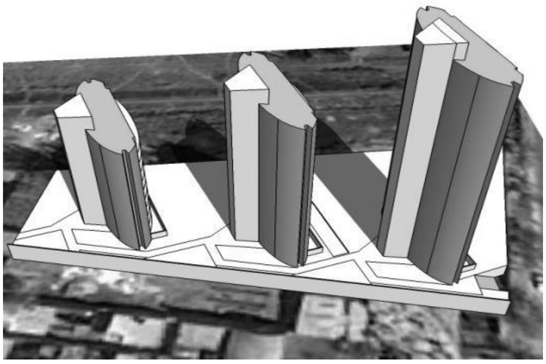

Figure 1: Curved Buildings, with circular arc airfoil 32%, Cipolletti, Argentina

When a tall building is built, it is presented as an obstacle to the existing wind current, so the air flow must border it three-dimensionally, with the characteristic that the wind has a velocity profile represented by the atmospheric boundary layer, which increases its velocity with height. In Figure 2, Morosi et al [1], it can be seen that the wind current at height is more intense, and when it finds the building it must distribute its flow over the roof, the sides and downwards. Behind the building a series of vortices are generated, and therefore an area of reduced pressure that will act as a sucker, accumulating dust, leaves, papers and any light body, in addition to being annoying due to the presence of eddies. On the sides, high velocities and crouching vortices are generated at pedestrian level. Figure 2 illustrates these patterns of wind flow behind and to the sides of a rectangular building.

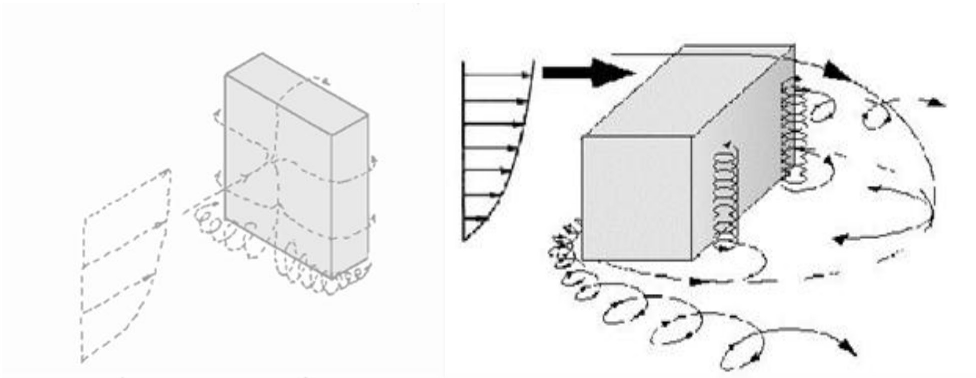

Figure 2: Wind flow and vortices around a rectangular building

On a body, the airflow in the boundary layer loses momentum due to frictional forces. When the external pressure gradient is favorable, the outer layers of fluid continuously transfer a momentum to the layers adjacent to the obstacle, so that the air in the boundary layer maintains a positive velocity. However, in an adverse pressure gradient, this transfer is less, and a point is reached where the lower layers have lost all their impulse and stop. The layers adjacent to these must flow over stationary air, and consequently separate from the surface (Schlichting [2]). This phenomenon is called "separation" or "shedding", which plays an important role in the development of wind configurations around buildings and the consequent forces on them (Figure 3).

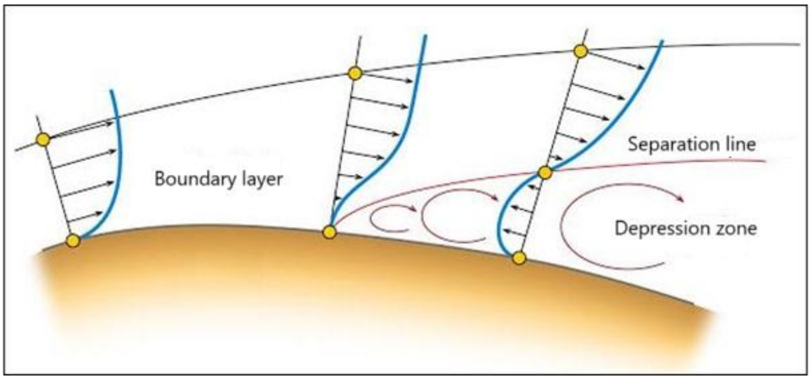

Figure 3: Separation of atmospheric boundary layer

In cylindrical or rounded sections, the separation point depends, among other things, on whether the boundary layer is laminar or turbulent, and this is determined by three factors: the Reynolds number (Re), the wind turbulence intensity (TI), and the coefficient of friction (μ). The critical Re value at which the laminar-to-turbulent transition is triggered is approximately $3.5x10^5$ for cylinders in non-turbulent air with a smooth surface. If the wind contains turbulence and the object's surface is rough, then the critical Re value is reduced to around 10^4.

The flow pattern that follows the separation of the boundary layer is very important in the study of forces on buildings. The point at which this displacement occurs depends on the wind speed, the level of turbulence, the surface roughness and the geometry of the wind. This greatly complicates the studies that are carried out in wind tunnels because the Re of the prototype will be one to two orders of magnitude greater than those that can be obtained in the wind tunnel with the models (Figure 4).

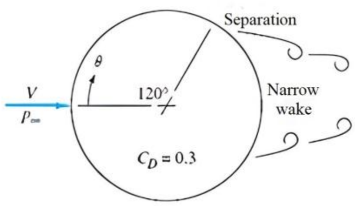

Figure 4: Separation of atmospheric boundary layer on a cylinder

In civil constructions, it is common to use sharp-edged (non-rounded) sections. For these sections, separation occurs at the first edge the flow must navigate, regardless of the Re, surface roughness, and wind characteristics. The wind action on these constructions can be investigated in the wind tunnel with reliable results, as the different configurations can be reproduced (Figure 5).

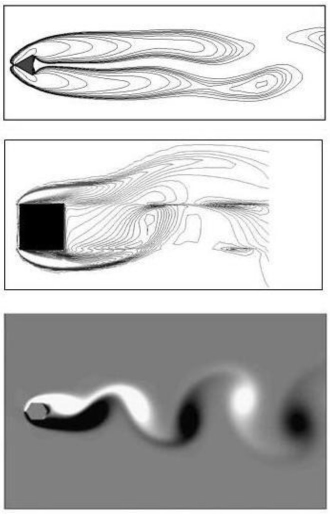

Figure 5: Separation of atmospheric boundary layer on sharped-edged sections

If the building is curved, the separation is more difficult to predict.

There are no stationary loads on buildings due to the very nature of the wind, which is entirely turbulent, causing wind loads to be fluctuating. When a construction is very rigid, oscillating loads can occur due to variations in the wind, a fluctuating flow pattern around sections with certain characteristics, or a combination of both causes. The methodology for analyzing these cases (constructions with very high rigidity) is to assume that their movements are negligible and study them in a quasi-static manner, with pressure and velocity values averaged or integrated over time, and with maximum design loads having a low probability of occurrence within a time frame greater than the expected service life of the construction

The loads generated by an airfoil are very sensitive to the angle of attack (α), and therefore sensitive to wind direction. In Figure 6 it is exemplified and it can be observed that the total aerodynamic force (F) is usually broken down into two: one perpendicular to the relative wind called lift force (L), and the other one of resistance in the direction of the relative wind called drag force (D).

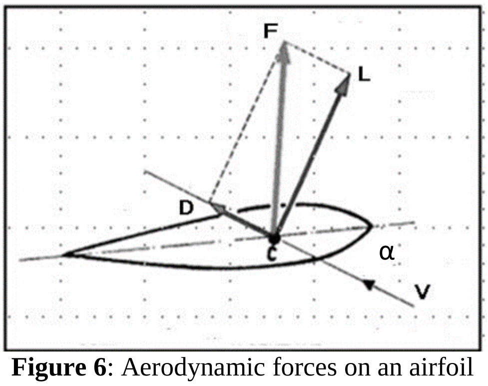

Figure 6: Aerodynamic forces on an airfoil

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.

On the other hand, the theory of airfoils applied to aircraft does not consider the atmospheric boundary layer. 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. This turbulence is generated by the friction produced when the atmosphere moves over a rough and rigid surface, that is, the Earth, or by the ascent of air parcels heated from the surface.

The pressure value Δp acting on the building's surface can be converted into the dimensionless pressure coefficient Cp, considering the air density ρ and the wind velocity V.

$$C_P = \frac{\Delta p}{\frac{1}{2}.\rho.V^2}$$

The building loads can be analyzed through wind tunnel tests.

II. METHODOLOGY

The developed methodology is based on atmospheric boundary layer wind tunnel tests. The velocity profile and turbulence conditions to which the building is exposed must be modeled. This velocity profile shows the variation of velocity depending on height. Wooden blocks with a 0.5 m spacing are placed to represent the roughness of the terrain

The velocity profile can be obtained through the Sutton´s law [3], where u1 and z1 are the velocity and height at 10 m, and α is an exponent that depends on the roughness of the terrain.

$$V(z) = v_1.\left(\frac{z}{z_1}\right)^{\alpha}$$

The boundary layer velocity profile in the model within the wind tunnel is similar to that of the prototype (real building), as shown in Figure 7.

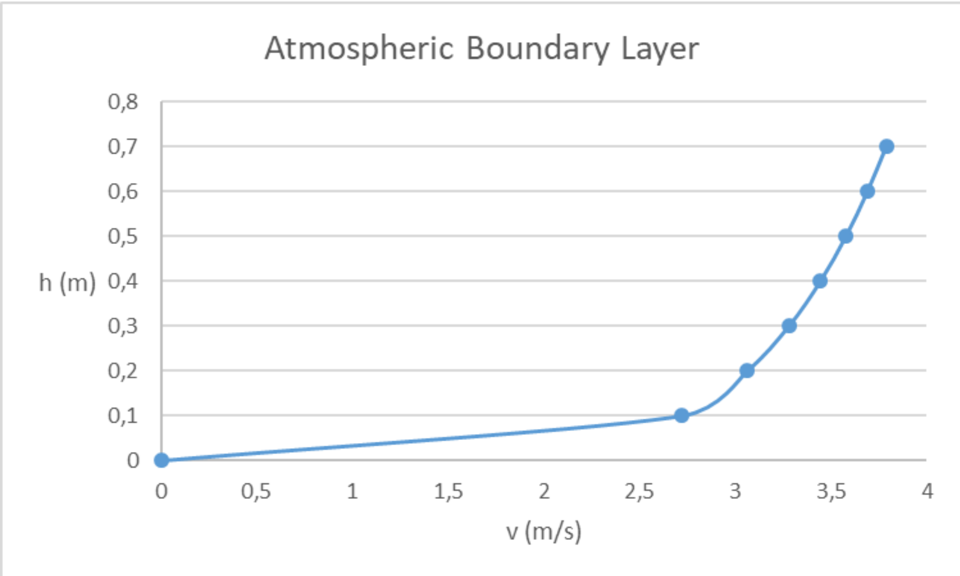

Figure 7: Atmospheric boundary layer in the wind tunnel

Two 1:250 scale models are constructed of a curved building and a rectangular building, both with the same dimensions: a length of 0.12 m, a width of 0.038 m, and a height of 0.24 m (Figure 8).

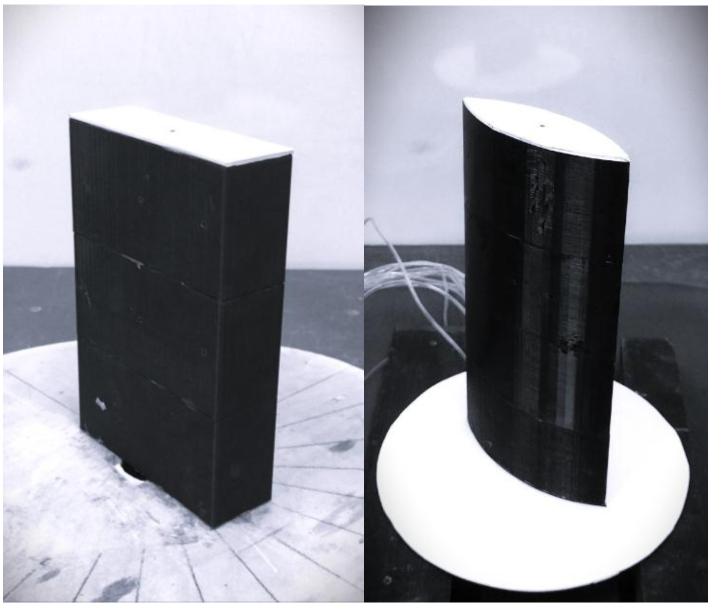

Figure 8: Rectangular building model (left). Curved building model (right)

The scale tests were carried out in the wind tunnel of the Environmental Fluid Dynamics Laboratory (LaDiFA) of the Faculty of Engineering of Universidad Nacional del Comahue. It is 7.40 m long with a test section of 0.90 m x 0.90 m, it is open (atmospheric boundary layer type) with a 6 CV electric motor, with speed regulator/stabilizer. The models are tested at angles of attack of 0°, 15°, 30°, 45°, 60°, 75°, 90°, at a wind velocity of 7.5 m/s.

The models have static taps connected to piezoelectric sensors that measure pressures. There are eight taps on the right face, the windward side (lower face), and six on the left face, the leeward side (upper face), numbered as shown in Figure 9.

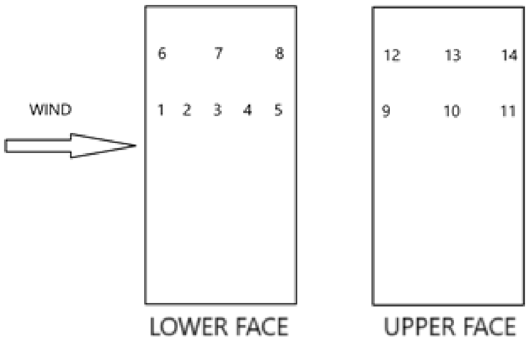

Figure 9: Taps in building scale models

III. RESULTS

The pressure values at each tap are converted to the dimensionless parameter called the pressure coefficient Cp in order to compare the two types of buildings. Graphs of the mean Cp value as a function of the angle of attack are created for each tap for the curved building (blue) and the rectangular building (red), as seen in Figure 10 (lower face) and Figure 11 (upper face).

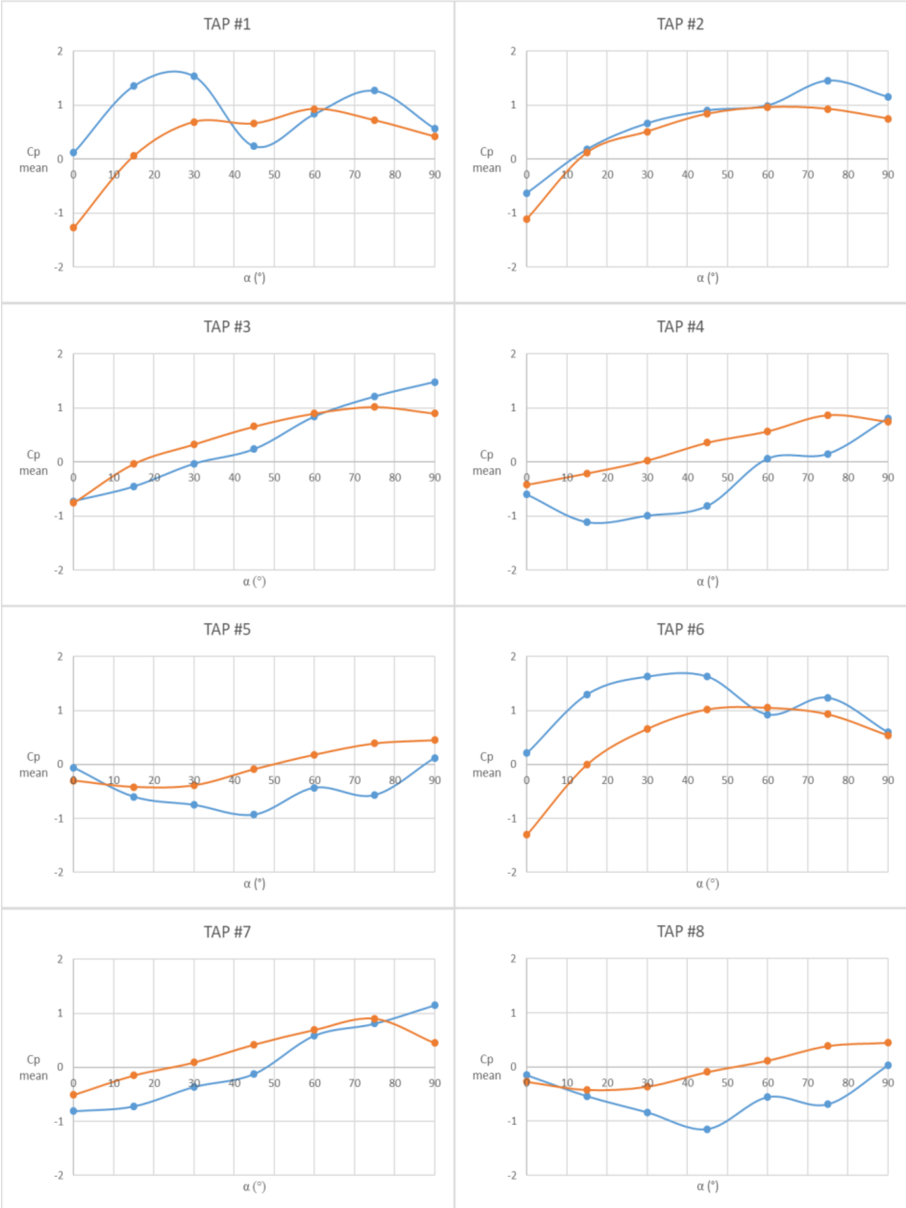

Figure 10: Cp (mean) vs angle of attack (α), in each tap, for curved building (blue) and rectangular building (red), lower face

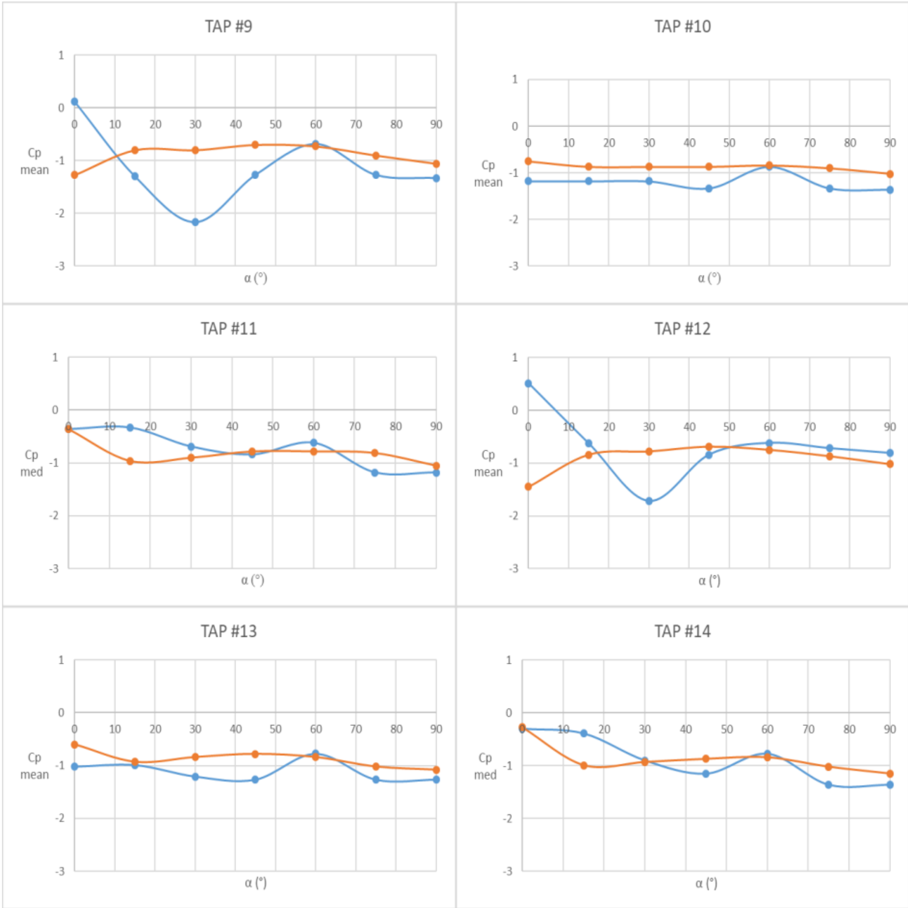

Figure 11: Cp (mean) vs angle of attack (α), in each tap, for curved building (blue) and rectangular building (red), upper face.

On the other hand, the resultant wind force (F) on each building is calculated for a unit area of 1 m² (A), according to the equation, where Δp is the pressure difference :

$$F = \Delta p \cdot A$$

In the Figure 12, the resultant wind force for the central taps can be observed, specifically between tap #3 and tap #10, and between tap #7 and tap #13.

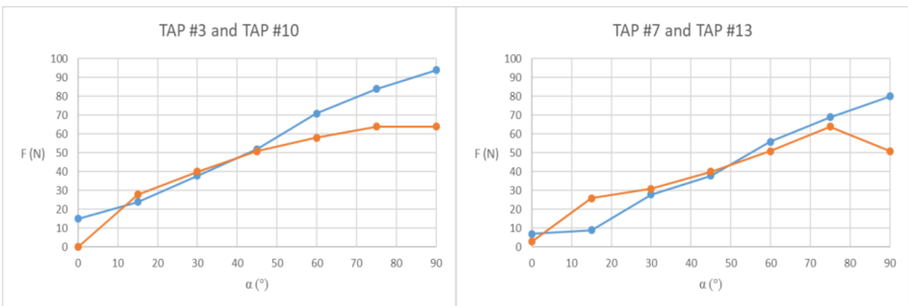

Figure 12: Wind force (F) vs angle of attack (α), for curved building (blue) and rectangular building (red)

IV. CONCLUSION

The pressure coefficient values differ depending on the type of building, whether curved building or rectangular building. This is mainly due to the shape of each building. As previously mentioned, in the curved building, having an aerodynamic profile, the airflow adheres to the surface and separates further back, leading to the formation of vortices; whereas in the rectangular building, the separation occurs at the sharp edge. In general, it is observed that the pressure at the taps is higher in the curved building than in the rectangular building, with the greatest difference on the lower face (tap #1 to tap #8, Figure 10). This may be due to the fact that in the rectangular building, the wind mainly impacts the front face, generating weaker vortices on the side faces, while in the curved building, the wind directly impacts the left side (lower face), especially at the initial angles of attack. On the upper face, downstream of the wind direction, the pressure difference is smaller. When analyzing the resultant wind force in Figure 12, for the central taps, tap #3 and tap #10, tap #7 and tap #13, it is generally observed that the values do not differ much for the different angles of attack, but a greater difference is noted for the curved building at extreme angles. From an angle of attack of 45°, the force begins to be greater on the rectangular building. This is related to aerodynamic shape of curved building compared to the rectangular building.

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