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Diffuser's Length Effects on the Aerodynamic Performances of a Flanged Diffuser

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Abstract—**Diffuser's length is between the geometric features that contribute efficiently to increase the wind velocity at the diffuser throat's section and thus to improve its aerodynamic performances. Results obtained from numerical simulations reveal that wind velocity increases as the diffuser length increases. Nevertheless, this increase is much stronger for the diffusers with a ratio (L/D_a) (diffuser length/ inlet section diameter) between 0.3 and 1.25. Beyond these values the wind velocity continues to grow up, but less strongly. So there is an optimal ratio beyond it the diffuser's length seems to be without any significant effect on increasing wind velocity.**

***Keywords*— Wind energy; Diffuser Length; Unloaded Flanged Diffuser; Numerical simulations s**

I. Introduction

To get profit from low wind, which characterized many rural and urban regions around the world, several research teams attempt to set up new technologies that artificially accelerate the wind approaching the wind-turbine plane. These are possible thanks to the physical law which states that the wind-power generation is proportional to the wind speed cubed. So, any small increase in the wind velocity can result in a large increase in the wind-energy output. One of the most tested devices to reach this goal is the Diffuser Augmented Wind Turbine (DAWT) [1]–[3], which is an association between a diffuser and wind turbine. A diffuser is a funnel-shaped structure receiving the air through its small section (inlet section) and releases it through its large section (outlet section).

In fact, a depression zone created behind the flange, allow air velocity to accelerate in the diffuser and its maximum value is attains at the throat section where a wind turbine could be installed. This acceleration can exceed 60% of the free stream velocity. The diffuser performances are depending on two factors: the section ratio between outlet and throat section $(\beta = A_o/A_{th})$, and the depression generated behind the flange. These two factors are strongly linked to the diffuser geometric features that are the length (L), the expansion angle (θ), and the flange height (H). The diffuser's length is one of the main parameters that control this mechanism. It has been the subject of several works[4]. In this study, the effect of the diffuser's lenght on the aerodynamic performance is represented and discussed.

II. PROCEDURE

In order to investigate the effect of the diffuser's length on the aerodynamic performances, we adopted an approach based on numerical simulations and experimental measurements.

During the simulation of the diffuser length, the other parameters (flange height and open angle) were kept fixed equal to their optimal values obtained in previous studies [5], [6]. Seventeen lengths of the diffuser (L) corresponding to (L/D_a) ranged from 0,21 to 3,25 were tested, which greatly exceed the diffuser length values commonly used. This choice was motivated by the need to have a clearer idea about the behavior of aerodynamic performances for both the short and long diffuser. Otherwise, since the flanged diffuser is axisymmetric, two-dimensional simulations (2D) were performed. They have concerned only the half of the diffuser. The computational domain was constructed using GAMBIT. It was meshed into about 18 000 quadrilateral cells using the structured mesh. Cells were gradually condensed toward the diffuser inlet and outlet sections where air flow dynamics is expected to be more active (Fig.1).

At the entrance of the domain (velocity inlet boundary), free stream was initialized at a mean velocity of 5 $m.s^{-1}$ that gives a Reynolds number of 66 500 (by referring to the diffuser inlet section). The other boundary conditions were chosen as follows: atmospheric pressure at the exit section (outflow boundary), a symmetry line for the bottom and the top section and no-slip boundary condition at the wall of the diffuser (Fig.2).

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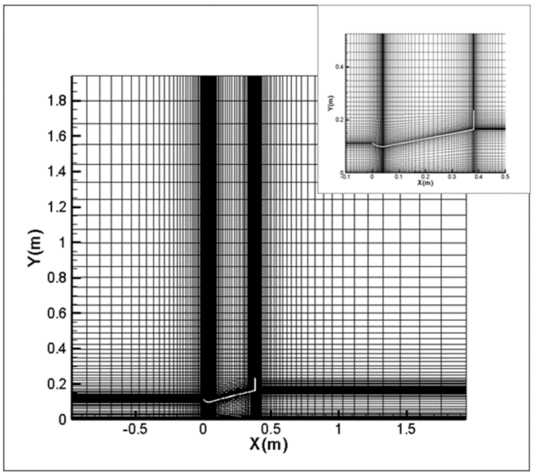

Fig.1 Computational domain and meshes

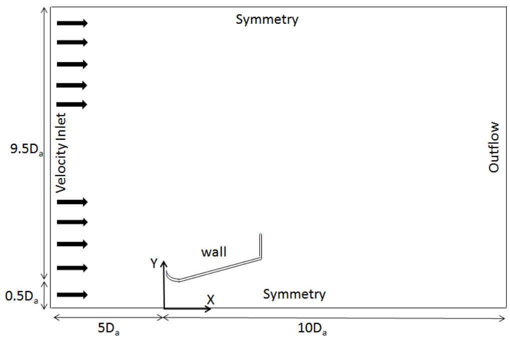

Fig.2 Boundary conditions

Numerical simulations were carried out using ***FLUENT 6.3*** which is a useful computer program for modeling fluid flow in complex geometry. The physics of air flow around and within the diffuser is governed by the incompressible Navier-Stokes equations. A first order discretization scheme was used and a 10^{-6} residual convergence criterion was chosen.

The adopted numerical model is the shear stress transport (**SST) K-**ω turbulence model. It was developed to effectively blend the robust and accurate formulation of the K-ω model in the near-wall region with the free-stream independence of the K-ε model in the far field [7]. In particular, this model developed by Menter (1993) has shown its capability to detect attached and slightly separated flows [7]. Nowadays, it is widely used for wind turbine computation.

Figure 3 represents the velocity ratio (u/U_∞) versus a dimensionless length (x/L) for the 10° open angle. The ratio (u/U_∞) was considered along the diffuser revolution axis. The points of abscissa (x/L = 0) and (x/L= 1) respectively correspond to the diffuser inlet and outlet section. The flow velocity begins to increase gradually, its maximum value (u_{max}/U_∞) is recorded just after the diffuser inlet section (at x/L = 0.37). It is exactly at this point that a wind turbine should be mounted.

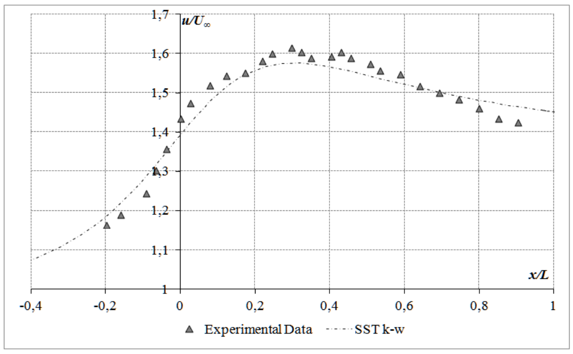

Fig.3 (u/U∞) vs. (x/L) simulations and experimental results (θ=10°)

A very satisfactory agreement between experimental measurements and numerical results was observed with an average difference of less than 12%. This is reassuring as for the quality of the results obtained by the two approaches.

The obtained ratio (u_{max}/U_∞) reaches 1.62 and 1.58 respectively for experimental and numerical results. This means an increase of 62% and 58% of the free stream velocity.

To insure that computational conditions do not significantly affect simulations results, three grid systems and three Reynolds number values were tested. Differences between the obtained maximum velocities (at the inlet section of the diffuser) have not exceeded 2%.

Experiments were performed in the wind tunnel of the Research Center and Energy Technologies (CRTEn) Borj Cedria (Tunisia). It is a closed-loop wind tunnel with a total length of 14.6 m and a width of 4.8 m. The test section has 800 mm width, 1000 mm depth and 4000 mm length.

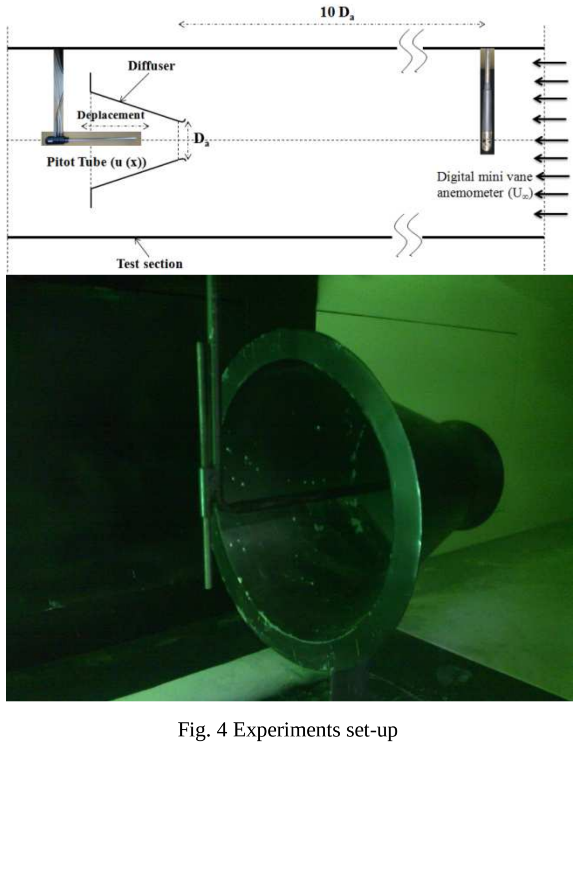

Fig. 4 Experiments set-up

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The wind velocity inside the wind tunnel can vary from 0 to about 30 m/s. The free stream velocity was measured via a digital mini-vane anemometer (Testo 435) positioned at $10\times D_a$ upstream of the diffuser. While measurements of wind velocity, at several points along the diffusers centerline, were carried out with a second Pitot tube (Fig.4). The accuracy of this device is about 1%. The air temperature variations were considered negligible during tests.

III. RESULTS

Due to the so-called Kelvin-Helmholtz instabilities induced by the shear-layer boundary effect, two contra-rotating vortices are generated behind the flange. They produce a low-pressure region that accelerates the airflow in the diffuser throat (Fig.5). This result is expected since it was also found hardly in all previous studies including simulations and wind tunnel experiments [4], [5], [8].

To study the effect of the diffuser's length on the aerodynamic performance, the ratio (u_{max}/U_∞) vs. (L/D_a) is represented in figure 6.

From this figure, it can be noted that the ratio (u/U_∞) increase as (L/D_a) increases. This confirms the results obtained from previous works, which stipulate that over the diffuser is longer the wind acceleration is important [4], [9]. The (u/U_∞) values vary from 1.33 for the smallest diffuser with $((L/D_a)= 0.21)$ and 1.72 for the longer one $((L/D_a) = 3.25)$. These values are of the same order of magnitude as those reported in the literature [4] (Fig. 7).

Despite the relatively good alignment of the curve points in figure 6, the trend line does not pass systematically by the vast majority of the points. The gap is most pronounced for small values of the ratio (L/D_a), and for those included in the interval [1; 1.6]. For a better representation of this curve, it was necessary to split the data into two branches (Fig. 8). With this new format, the points have become perfectly aligned and the correlation reached almost the value of 1 ($R^2 = 0.99$) on the first curve and slightly deteriorated with ($R^2 = 0.93$) on the second tranche.

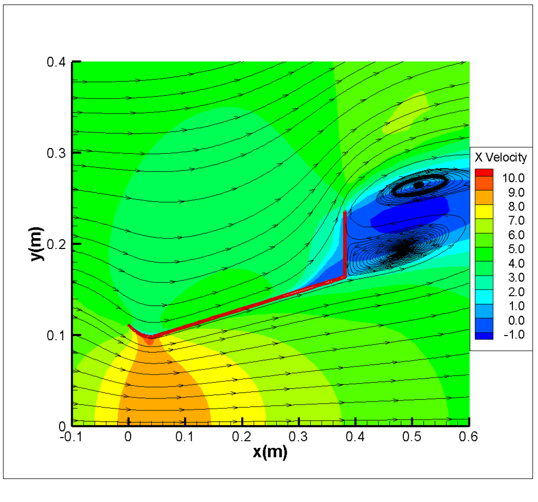

Fig.5 Velocity contours obtained from numerical simulations

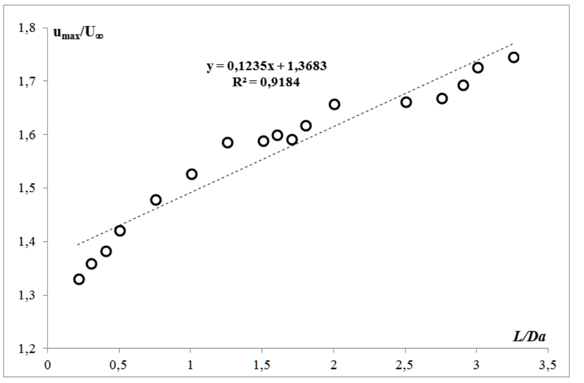

Fig 6 The ratio (u_{max}/U_∞) vs. the ratio (L/D_a).

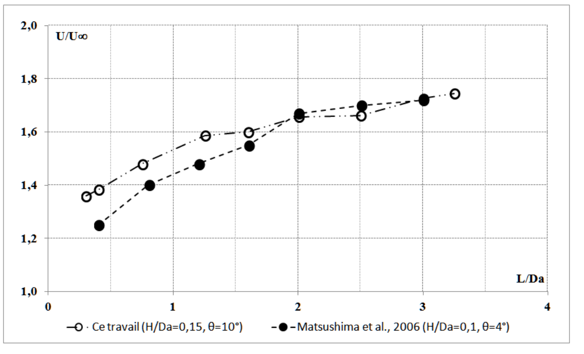

Fig. 7 (u_{max}/U_∞) vs (L/D_a) (only some length value was used in this figure, which are very close to those tested by Matsushima et al., (2006)).

It is also easy to notice that the slope of the first branch is much pronounced, with a value of 0.242 which is more than three times higher than that of second one with a slope of only 0.078.

This means that increasing (u_{max}/U_∞) is more important for diffuser with (L/D_a) between 0.3 and 1.25. Beyond these values, the ratio (u_{max}/U_∞) continues to grow, but less strongly with an average growth rate of less than 10%. It is specified that for values of (L/D_a) about 1.25, the increase of the wind speed was found to be 1.62.

In practice, this result means that for (L/D_a) superior to (1.25-1.50), the diffuser gets larger but it is not more powerful. Indeed, when the diffuser is twice as long, the ratio (u_{max}/U_∞) changes from 1.62 to 1.73 with an increase of only 8%. The additional power recovered wouldn't be justified both economically and practically. In other words, additional expenses may be induced by the diffuser extension to a relatively small increase in wind velocity. More importantly, the large size of the diffuser can cause serious practical problems with respect to load-bearing structures due to the fluid-structure interaction that would result. Thus, the length for which the ratio (L/D_a = 1.25 to 1.50) can be considered optimal length.

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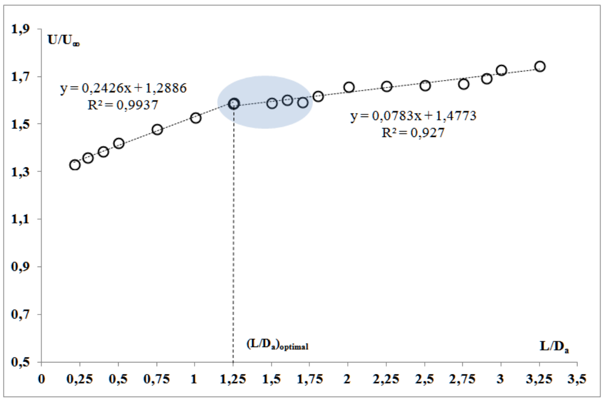

Fig. 8 (u_{max}/U_∞) vs. (L/D_a) whith new format.

IV. Conclusions

Numerical simulation was used in this paper to investigate on the effect of the diffuser's length on the aerodynamic performances of a flanged diffuser. The results so obtained show that:

- With a very satisfactory agreement to the experimental measurements, the shear stress transport **(SST) K-**ω numerical model was adopted.
- A low-pressure region generated behind the flange, accelerates the airflow in the diffuser throat. This behavior is expected since it was also found previous studies.
- The velocity ratio (u_{max}/U_∞) increases as the diffuser's length increases. This confirms the results obtained from previous works.
- The ratio (u_{max}/U_∞) is more important for diffuser with (L/D_a) between 0.3 and 1.25. Beyond these values, the ratio (u_{max}/U_∞) continues to grow, but less strongly.
- When the diffuser is twice as long, the increase of the ratio (u_{max}/U_∞) is of about only 8%.
- The additional power recovered wouldn't be justified both economically and practically.
- The length for which the ratio (L/D_a = 1.25 to 1.50) can be considered optimal length.

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