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Experimental study in the effect of nozzle dimensions on the flow uniformity and turbulence intensity

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ABSTRACT

In order to decrease construction cost of vertical wind tunnel, it is necessary to reduce the wind tunnel nozzle length. In this regard, it is adequate to reduce the ratio of inlet to outlet diameters of the nozzle and ratio of nozzle length to its inlet diameter. In addition, shifting of the inflection point of the nozzle curves to the flow upstream and reduction of the exit section of the nozzle can result in reduction in nozzle length. These modifications may cause change in the flow quality at the nozzle exit, which has to be studied. In this experimental study, by using hot wire, velocity distribution and turbulence intensity at the nozzle exit have been investigated. The ratio of inlet to outlet turbulence intensity increases from 0.2 to 0.4, when the ratio of inlet to outlet area of the nozzle reduces from 12 to 6.25. Using the results, the nozzle length can be reduced by about 62% so that air quality in the short nozzle output is acceptable.

KEYWORDS:

Nozzle, Velocity distribution, Turbulence intensity, hot-wire anemometry.

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1- INTRODUCTION

Nozzle is an important component of fluid systems such as wind tunnels [1]. Many researchers have worked on the design of nozzles [2, 3]. Important factors such as reverse pressure gradient near the inlet and outlet of the nozzle and flow separation at the boundary layer affect the design process, especially for wind tunnel applications. The nozzle configuration and length will be important factors. In the design of wind tunnels, as the ratio of inlet to outlet cross section increases, the flow quality improves. For large wind tunnels, we have to reduce the length of nozzle. In order to reduce the nozzle length the following considerations have been used:

- reduction of the A_i/A_o ratio
- reduction of L/D_i ratio,
- truncation of the nozzle cone at outlet

The main difference between the present work and preview works is the study of turbulence intensity and uniform distributism of velocity at the outlet of the nozzle. Application of the results of this research can be used for the design of nozzle of much lower height in vertical wind funnel.

2- EXPERIMENTAL PROCEDURE

Experiments on the nozzle types have been carried out in an open circuit wind tunnel. Based on the results of numerical analysis, three nozzle models, identified as N1, N2, N3, have been selected for further investigation (see Table 1).

Table 1. Specifications of the nozzles

Nozzle ID	A_o/A_i	L/D_i	X/L	Geometry
N1	12	1.2	0.3	Square
N2	6.25	0.9	0.3	Octagonal
N3	6.25	0.9	0.175	Octagonal

Flow velocity and turbulence intensity were measured using a one-dimensional probe hot wire anemometer (HWA). Flow was measured at inlet and outlet of the nozzles. In order to provide for the controlled placement of the measuring probe, a traverse mechanism with 0.1 mm accuracy has been used.

3- RESULTS AND DISCUSSION

The non-dimensional mean velocity contour at the nozzle N1 inlet $\overline{U}(x,y)/\overline{U}_a$ is shown in Figure 1. Similarly, Figure 2 shows the non-dimensional mean velocity contour at the nozzle outlet. In order to study the velocity fluctuation, the turbulence intensity is considered by:

$$T_u(x,y) = \sqrt{\overline{(u'(x,y))^2}} \Big/ \overline{U}(x,y) \times 100$$

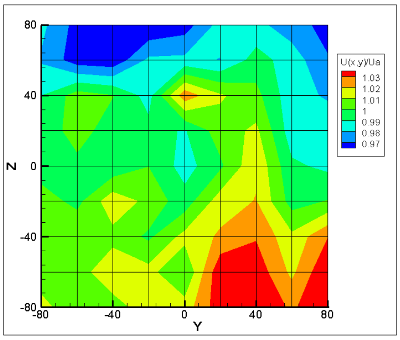

Figure 1. The non-dimensional mean velocity contour at the nozzle N1 inlet (U = 22.5 m/s)

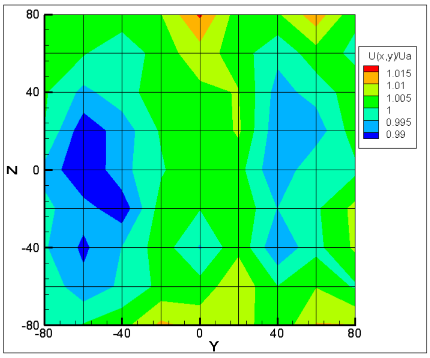

Figure 2. The non-dimensional mean velocity contour at the nozzle N1 outlet (U = 22.5 m/s)

Figure 3 shows the turbulence intensity contour ($\overline{T}_u(x,y)$) at the nozzle N1 inlet. Similarly, Figure 4 shows the turbulence intensity contour at the nozzle N1 outlet. The above figures, which indicate the variations in the velocity and turbulence at the nozzle inlet and outlet, show the positive effects of the nozzle on the flow characteristics.

Figure 5 shows the ratio of the average turbulence intensity at outlet and inlet (T_{u_o}/T_{u_i}), on basis of flow velocity. As shown, the turbulence intensity for N1 decreases with increase in velocity. The rate of decrease in turbulence intensity is high for up to 17 m/s, and then after it remains constant with velocity, attaining a value of 0.2. As shown in Figure 5, the trend for (T_{u_o}/T_{u_i}) in nozzle N2 is similar to that of nozzle N1, where the slope is steep up to about 15 m/s, and then after it remains nearly constant at 0.33. This value is higher than the corresponding value for N1, mainly due to the decrease in A_i/A_o for this nozzle. The quantity T_{u_o}/T_{u_i} for N3 in Figure 5 shows a similar trend as that of N2, reaching a value of 0.33, which is close to values obtained from the above relations. Referring to Figure 5, it may be concluded that shifting of inflection point, with respect to the nozzle inlet, from 0.3 to 0.175, and also reduction of L/D_i from 1.2 to 0.9, have little effects on the turbulence intensity. Therefore, in order to reduce the nozzle length, the inflection point can be shifted towards the nozzle inlet.

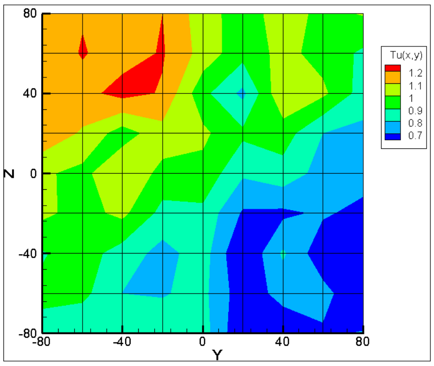

Figure 3. The turbulence intensity contour at the nozzle inlet (U = 22.5 m/s)

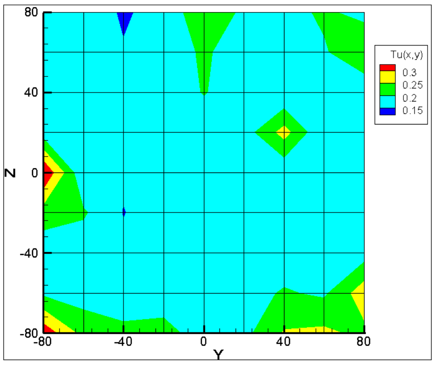

Figure 4. The turbulence intensity contour at the nozzle outlet (U = 22.5 m/s)

Referring to Figures 1 and 2, the spatial non-dimensional standard deviations (*σ(u)*) at the nozzle inlet and outlet have been calculated for U=22.5 m/s. To demonstrate the effects of nozzle on the uniformity of flow, the non-dimensional spatial standard deviation of average velocity has been considered. As shown, values of the standard deviation ratio ($\sigma(U_o)/\sigma(U_i)$) for nozzles N1, N2 and N3 are 0.22, 0.29 and 0.30, respectively. As shown, (A_i/A_o) ratio has greater effect on the uniformity of flow than the (L/D_i) ratio.

4- CONCLUSIONS

The following results have been observed in the present study:

• Reduction in A_i/A_o ratios from 12 to 6.25 results in increase in turbulence intensity (up to 50%), which is confirmed by results of other researchers [4, 5]. As a result, the nozzle length can be decreased by about 28%, which is very significant in big vertical wind tunnel applications.

• Reduction in turbulence intensity by the nozzle depends on the velocity at the nozzle outlet, and at lower velocities, the nozzle is less effective in the reduction of turbulence intensity.

• Reduction in (L/D_i) ratio from 1.2 to 0.9 does not increase the turbulence intensity significantly, but it can result in reduction in the nozzle length (about 25%).

• Due to the shifting of the intersection point of the two curves (inflection point) to the upstream, variation in cross section close to the nozzle outlet is reduced. This helps in truncation of the nozzle at the section with nearly constant profile, resulting in reduced nozzle length. In addition, although change of X_i/L from 0.3 to 0.175 has little effect on the turbulence intensity, it can lead to significant reduction in the nozzle length (about 10%).

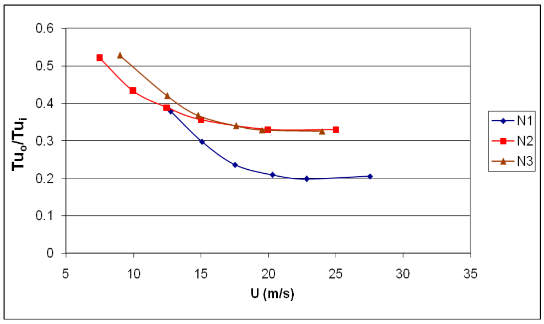

Figure 5. The ratio of turbulence intensities at the nozzle inlet and outlet on the basis of flow velocity

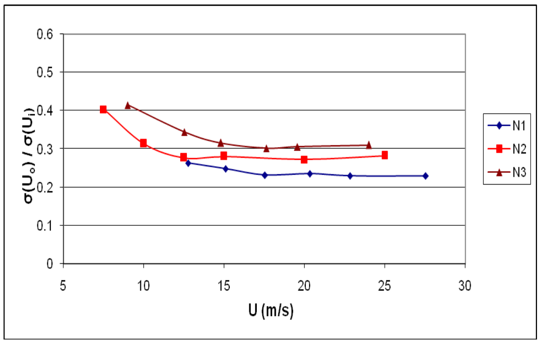

Figure 6. The non-dimensional spatial standard deviation of average velocity

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