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Prediction of circular jet streams with artificial neural networks

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Abstract

In this study, an ANN model was established by using experimental measurement values at low speed sub-audio level in an air tunnel of which length is $75cm$ and experiment room cross sections are $32cm \times 32cm$ and model results were compared to experimental values and then, the prediction was made for unmeasured jet stream values. The jet stream at value of $30m/s$ in the wind tunnel is ensured with a compressor connected to the inlet of wind tunnel experiment room. The tunnel speed values of 0, 10 and $20m/s$ is ensured with a frequency converter axial fan by making suction in same direction with jet stream. In experimental studies, the jet speed in wind tunnel and radial speed diffusion measures are obtained with a hot wire anemometer enable to make two-dimension measure in the wind tunnel experiment room. In the experiment room, measurements are made with measurement stations located in four different distances. To establish the ANN model, the tunnel speed, length rate and radial distances were taken as an input, with these data, by training the ANN model, networks were established and the radial speed diffusions corresponding to these inputs were obtained as an output. With the data obtained from that network, experimental measurement was made and speed profiles in data ranges were predicted and compared to experimental results. To verify the predicted results, these values and experimental results were compared relatively on non-dimensional speed diffusion graphics. Additionally, similar speed diffusion values and non-dimensional speed diffusion graphics were obtained for 5 and $15m/s$ tunnel speeds without experimental measurements and comparative comments were made.

Keywords: Jet stream; Artificial Neural Networks (ANN); Prediction; Hot wire anemometer; Wind tunnel
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1. Introduction

Jet streams are one of the basic stream types where the basic structure of stream can be easily examined. It has applications in many industrial areas like chemistry and medicine industry, in burns that occur in motor cylinders and laser applications. The jet stream simulations are being used in very important areas such as airway planning in connection with the wind speed predictions [1], turbulence predictions [2], air circulation and cleaning of tunnels in mining and highway sectors [3], stroke of lightning or extinguishing of electrical conduits that occur in industrial works [5]. Most of the initial researches on jet streams are related to the free jet development towards to stream around in circular jet streams [6].

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In this study, for purpose of providing data to the ANN prediction model to be firstly established, measurements related to jet and radial speed diffusion were made experimentally with hot wire anemometer. To establish the ANN Model, tunnel speed (U_t), length-diameter rate (x/D) and radial distances (y) were taken as an input and by training the network model with these data, radial speed diffusions corresponding to these inputs were obtained as an output. With the data obtained from these networks, experimental measurement was made; speed profiles in data ranges were predicted and compared to experimental results. Then, speeds at station points without experimental measurement were predicted with these trained models. To verify these predicted results, these values and experimental results were compared relatively on the non-dimensional speed diffusion graphics.

1. 1. Jet stream structure

The jet stream is one of the basic stream types that have applications in many industrial areas. The jet stream is the stream profile established by a stream coming from a nozzle towards to surrounding stream. The more the jet stream departs from the core area, the effect of shear stress resulting from neighbor fluid layers and the speed decreases. The jet stream structure in

Fig. **1** is divided into three regions with a thin boundary layer from the nozzle point. These regions are:

1. Potential core region: It is the region up to the point it is 4 or 8 times of the jet diameter in direction of x .
2. Transition region; It is the part up to the point where potential core region or mixing layer region ends and full turbulence region starts. While the turbulence force on jet axial after the core region increases, the speed begins to drop. Generally, the transient region is a short outputted part between the core region and full developed turbulence region.
3. Full developed Region: In this turbulence region, speed profiles are similar.

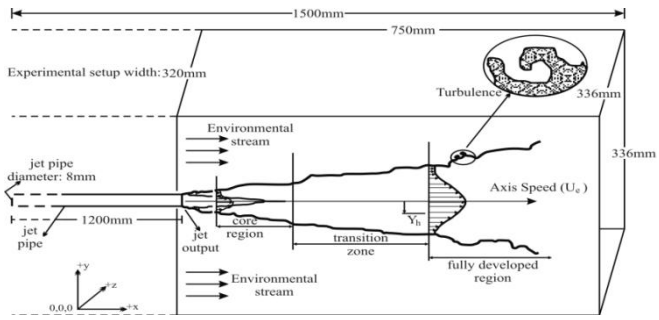

Fig. 1 Jet stream structure used in experiments.

Besides, in jet stream structure examinations, jet half thickness (Y_h) must be considered. In Fig. 1, the jet half thickness region is shown. This region is defined as the region distance where it reaches to half of total of maximum speed of the jet stream in center and surrounding speeds. As the jet output speed (U_j) is constant at nozzle output, it approaches to surrounding speed (U_c) as much as it departs from the nozzle. At nozzle output, the stream profile width is almost zero. This value increases after the core region. Speed at axial (U_e) remains constant at the potential core region. The speed at bottom stream region increases the jet as long as the distance increases. From this distance, jet stream occurs in the full developed region and the

stream profiles have similar structures in sequential parts. Generally, the transient region is the short outputted area between the full developed turbulence region and core region [6].

By making the speed and distance non-dimensional, non-dimensional speed profile curves are obtained. The non-dimensional speed diffusion curves indicate whether the speed has a

steady stream direction, depending on the measured data ranges of the speed profile and whether it is similar to the studies made on jet stream. In case there is no stream speed in the tunnel, the speed is made non-dimensional by dividing mean speeds $(\bar{u})$ in axial direction at any point to maximum mean speed $(U_{\max})$ in the jet axial [7-12].

In case there is a stream speed in the tunnel, the speed is made non-dimensional by dividing the difference of speed in axial direction at any point from minimum speed $(U_{\min})$ at that distance to difference of maximum and minimum speeds at that distance. The x distance measured from jet inlet is made non-dimensional by being divided to jet diameter. The radial distance at each station is made non-dimensional with jet half thickness. The non-dimensional speed profiles are similar to each other; $\bar{u}/U_e = f(r/x)$ or $(\bar{u} - U_{min})/(U_{max} - U_{min}) = f(r/b)$. Here, U_e is axial speed, r distance from axial to radial distance and b is the radial distance corresponding to half of jet axial speed [6].

In circular jet streams, "jet beam rate" or "diffusion angle" is determined by using the "r" distance value corresponding to half of the speed in jet axial at a definite "x" distance. The data and results obtained from experiments were shown in graphics and they were analyzed. In experiments made in different categories, how the stream profile structure changes with a modification made in stream mechanism, non-dimensional speed diffusion (U_{RMS}), mean speed diffusions $(\bar{u})$ were examined by using the graphics. This experimental study is involved in subsonic speed classification [7].

For jet streams, there are different measurement types. There exists no conical addition in type A. In Table 1, measurement types for different jet stream situations are shown. In our study, an examination was made on A1, A2, A3 coded jet streams without conical addition.

Table 1. Measurement types for different jet stream situations

Code	Jet Stream	Jet Speed U_j [m/s]	Tunnel Speed U_t [m/s]
A1	Open	30	0
A2	Open	30	10
A3	Open	30	20

For measurements, 4 measurement stations were determined: $x/D = 0.3$, $x/D = 12.5$, $x/D = 31.2$ and $x/D = 50$. Measurements were made both on the bottom stream region and upper stream region. Here; x is the distance between output inlet and measurement point, D jet output inlet diameter. Experiments were made in three different groups while the maximum speed of jet stream was $30 m/s$ and tunnel speeds were 0, 10 and $20 m/s$.

2. ANN model for jet stream and results

To establish an ANN model, the tunnel speed, length rate and radial distances were taken as an input, by training the ANN model with these data, networks were established and the radial speed diffusions corresponding to these inputs were taken as an output. Experimental measurement was made with the data obtained from these networks; the speed profiles in data ranges were predicted and compared to experimental results. Then, the speeds at non-measured station points were predicted with these trained models. To verify these predicted

results, these vales and experimental results were compared relatively on non-dimensional speed diffusion graphics. Additionally, similar speed diffusion values and non-dimensional speed diffusion graphics were obtained for 5 and $15 m/s$ tunnel speeds without experimental

measurements and comparative comments were made. The block schema of the established ANN model is given in Fig. 2. In Table 2, the calculated R, MSE, MAE values are given.

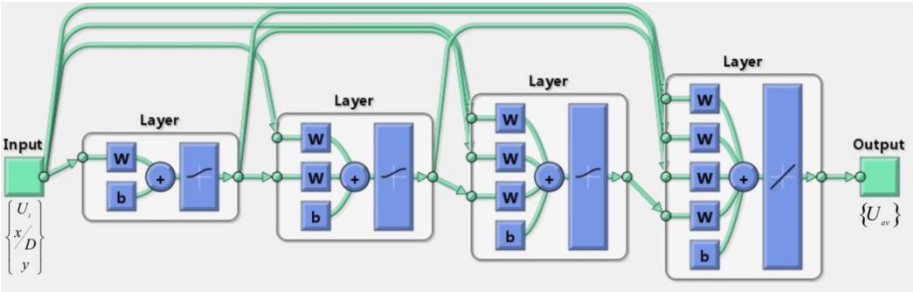

Fig. 2 ANN structure.

Table 2. Error indicators of ANN model

	Iteration	MSE	MAE	R
ANN	10,000	0.1214	0.268	0.99881

In Fig. 3, comparisons of (TD) data predicted with experimental data (GD) for A1, A2 and A3 streams given in Table 1 are shown. For both three situations, the accuracy of jet stream predicted with non-dimensional speed diffusion was tested. It was determined that the values predicted for A1 stream were close to experimental values when compared, as the R value increased above 99%. In A2 and A3 streams, as much as the radial distance rate increases for values of which x/D rate is greater than 31.2, the predicted mean speed (U_{av}) values do not comply with the experimental values.

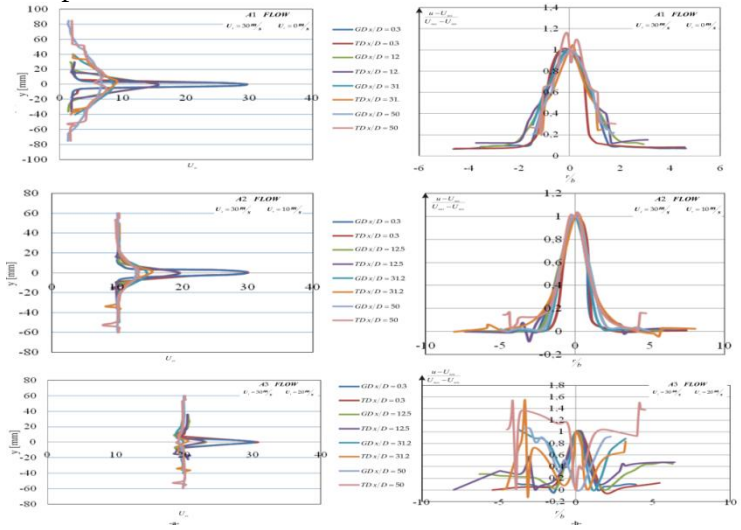

Fig. 3 a) $\boldsymbol{U_{av} - y}$, b) non-dimensional speed diffusion graphics of A1, A2, A3 jet streams.

In

Fig. **4**, ANN results and real system (TD) data for A1, A2 and A3 streams are compared. Here, it is clearly seen that ANN training performance is very good, as the R value is above %99.

3. Determination of non-experimental data with ANN

In this section, by using the developed ANN model, the mean speeds (U_{av}) when the tunnel speeds (U_t) are 5 and $15 m/s$ were predicted. The obtained results are shown in Table 3.

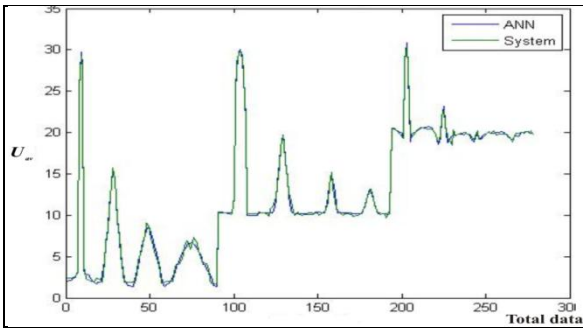

Fig. 4 Comparison of ANN outputs and test data.

Though the fault values in different iteration numbers were low (MSE, MAE, R), a structure not compatible with the jet stream structure appeared. For this reason, the iteration number was selected as 10,000.

Table 3. Predicted speed values

Code	Jet stream	Jet speed, U_j (m/s)	Tunnel speed Ut (m/s)
B1	Open	30	5
B2	Open	30	15

In

Fig. **5**, the non-dimensional speed diffusion graphic of mean speed data predicted with ANN for $U_t = 5 m/s$ and $U_t = 15 m/s$ speeds and jet axial speed and jet beam rate for these speed values are given respectively. As it can be seen, when $U_t = 5 m/s$, U_{av} value on radial axial is steady. When $U_t = 15 m/s$, the speed diffusion in $-20 \le y \le 20$ range on radial axial is steady but as much as it is departed from this range, the speed diffusions become unsteady with the effect of turbulence. The jet axial speeds are at approximate value at $x/D = 0.3$ it is seen that the axial speeds of predicted values of $U_t = 5 m/s$ and $U_t = 15 m/s$ are in proportional ranges. In Fig. 6, comparative graphic is given for jet axial speeds.

The comparative graphic of beam rates of predicted tunnel speeds $U_t = 5 m/s$ and $U_t = 15 m/s$ to the experimentally measured beam rate in speed of $10 m/s$ is given in Fig. **7**. It is seen that the prediction of beam rate in low tunnel speed gives better result. In predictions made for high speeds, there occur more deviations in experimental values. The reason of it is the turbulence in the experiment room because of increase in the tunnel speed.

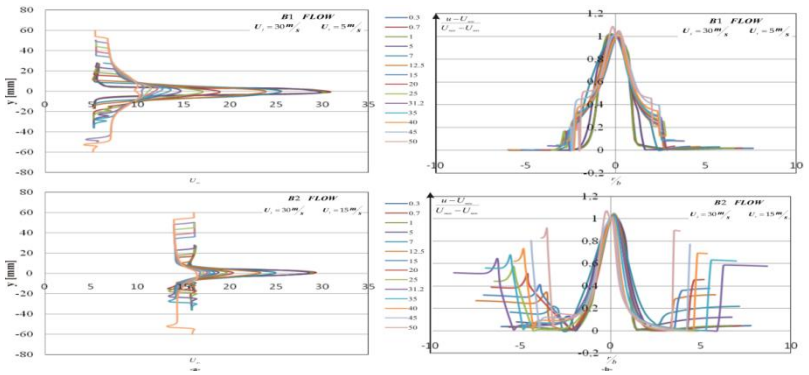

Fig. 5 a) $\boldsymbol{U_{av} - y}$, b) non-dimensional speed diffusion graphics of B1 and B2 jet streams (prediction results of ANN).

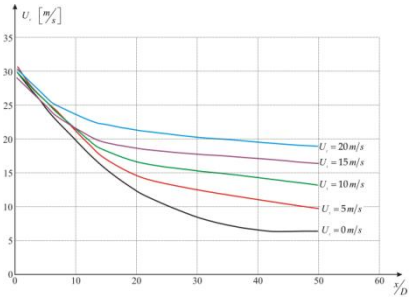

Fig. 6. Comparative graphic for jet axial speeds between experimental results and predicted values in $0.3 \le x/D \le 50$.

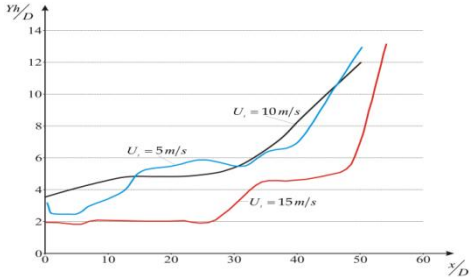

Fig. 7. Beam rate graphics for 5, 10 and $15 m/s$ tunnel speeds.

4. Comparison of results, discussion and conclusion

In this study, it is aimed to predict jet streams at non-measured points by using an ANN model trained with experimental data. Though the dynamic and complex structure of jet streams, the regression value of ANN model reached to a very high value as 99.881% (R = 0.99881). For purpose of comparison, graphics of the axial speeds and jet beam rates obtained from the ANN model and experimental results were shown on the same coordinate axial. As a result of the prediction made with ANN, the lowest fault rate was found as 12.4%. Because of insufficient number of data, as much as it is departed from the jet output direction, it is seen that the fault rate increases when the predicted data are compared to real data. As the x/D rate increases, normally turbulence was established in the tunnel. The establishment points of turbulence were determined as $x/D \ge 31.2$ region for 10, 15 and $20 m/s$ values of tunnel speeds. As the mean speed values on the axial plane were close to each other because of the effect of turbulence, a full symmetric stream could not been predicted. The regression value obtained in the study reveals that the prediction value that especially demonstrated a good performance in predictions before turbulence, gives a successful result.

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