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Indoor Low Speed Air Jet Flow : Fiber Film Probe Measurements

Valentino Todde[1], Elisabet Linden[2], Mats Sandberg[3]

1. Ph.D. Student , Royal Institute of Technology, Department of Energy Technology, Division of Heating and Ventilation, Stockholm, Sweden.
2. Research Engineer, Royal Institute of Technology, Centre for Built Environment, Division of Indoor Environment Ventilation, Gävle, Sweden.
3. Professor, Royal Institute of Technology, Centre for Built Environment, Division of Indoor Environment Ventilation, Gävle, Sweden.

ABSTRACT

This paper presents results belonging to a larger investigation on low velocity indoor air jets. The experiment is undertaken in a climate room where an isothermal air jet is issued from the centre of one lateral wall. Measurements are performed with a single fiber film probe, and with Particle Streak Velocimetry system. With Particle, Streak Velocimetry has been developed a three dimensional analysis of the instantaneous velocity field. With the use of fiber film probe, the fluid-dynamics of the jet flow is explored in terms of mean longitudinal velocity, and relative turbulence intensity. This paper treats exclusively the results obtained with the fiber film probe from the measurements along the centre-line of the jet flow. The investigation deals with a number of test cases of practical value for designing supply to provide air at low speed directly to the occupied zone .

KEYWORDS

Air velocity, Full-scale experiments, Jets, Measuring technique.

INTRODUCTION

This investigation deals with low speed air jet flows in indoor climate. Particular attention is focused on the longitudinal component of air velocity of the jet, in terms of mean value and relative turbulence intensity. Figure 1 shows the geometry of the room where the experiment took place. The mean velocity at the nozzle exit has been varied between 0.3 and 1.0 m/sec. At the exit of the nozzle, the turbulence level of the jet flow was close to values of 1%. The geometry of the nozzle with its main components is shown in figure 2. Eight thermo-couples were placed in the chamber to record the mean air temperature. The temperature of the air jet flow was recorded with two thermo-couples placed in the nozzle before the honey-comb.

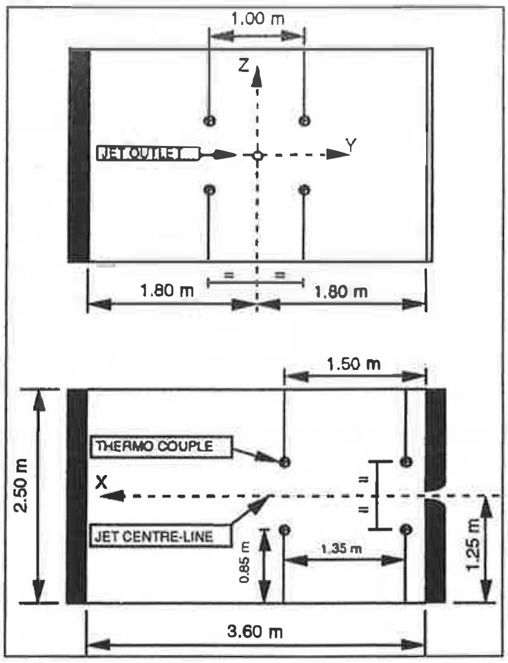

Figure 1. Lateral views of the room.

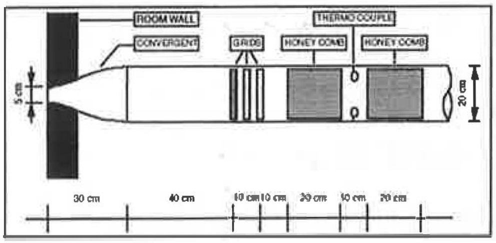

Figure 2. Nozzle design.

All the air velocity measurements were performed with a temperature compensated single probe. The sampling rate was 2000 Hz for a time length of 184 seconds. A qualitative trend of the jet flow has been analysed with smoke visualisation as well.

JET FLOW MEASUREMENTS

Seven test cases have been investigated. The mean air velocity, U(0), 25 mm from the outlet of the nozzle in the jet centre-line, is referred to us as the outlet velocity.

Test Case	U(0) [cm/s]	Rel. Turb. Intensity	Reynolds Number
1	31.82	1.25 %	1075
2	38.97	1.16 %	1316
3	50.61	1.00 %	1709
4	61.11	1.09 %	2064
5	69.33	1.03 %	2342
6	82.32	0.98 %	2781
7	91.93	0.96 %	3106

Table 1. Air flow properties at the outlet.

The Reynolds number, in table 1, is scaled with the outlet diameter of the nozzle (D = 50 mm), and a constant kinematic viscosity, ν, equal to 14.8 $*10^{-6}$ m^2/sec. The air velocity was measured with the fibre-film probe, DANTEC 55R76 sensor with temperature compensating. The velocity sensor was nickel film deposited on 70 μm diameter quartz fibre, overall length 3 mm, sensitive film length 1.25 mm, copper and gold plated at the ends. The film was protected by a quartz coating 0.5 μm in thickness. Temperature compensated bridge of type DANTEC 56C14 with 56C01 CTA single channel system was used. The data acquisition has been done with Lab-View System of National Instruments. The board used for data acquisition was AT-MIO-16DE-10 with 12 bites. The main characteristics of an acquisition system are the sample rate and the resolution of the signal. The highest resolution of the signal is defined by:

$$R = \frac{\Delta V}{2^n}$$

Where ΔV is the signal range and n is the number of bites of the board. In this work the signal range was maintained between the values 0 and +2 Volts, with a corresponding resolution of 0.48mV. With a thin laser pointer, it has been possible to position the velocity sensor in the centre-line of the jet with an accuracy of 0.1 mm.

RESULTS

Measurements of the u-velocity component were conducted along the jet centre-line, over a streamwise distance, ξ=0.5 to ξ=30, where ξ =X/D. The results dealing with the mean longitudinal component of air velocity are plotted from figure 3 to 5. Figure 3 shows the trend of this component for all the test cases. All the curves have a first linear slow decay till the streamwise distance of ξ = 5. Then it follows a decay . In figure 4 the mean longitudinal component is scaled with the outlet velocity, U(0). For $\xi \leq 7$, all the curves collapse onto a single curve. Figure 5 shows instead the ratio U/U(0). In this diagram it is possible to notice a linear trend for ξ >6. The decay of the centre-line velocity could be expressed as it follows:

$$\frac{U(0)}{U} = A + B \cdot \xi \qquad (1)$$

Considering the distance to the virtual origin, x_0 , we can write:

$$\frac{U(0)}{U} = \frac{1}{C}\frac{(x - x_0)}{D} \qquad (2)$$

Combining these two equations, we have:

$$C = 1/B \Leftrightarrow x_0 = -D \cdot (A/B)$$

Test Case	A	B	C	X_0 [mm]
1	-0.6822	0.2702	3.7010	+126
2	-0.5859	0.2477	4.0371	+118
3	-0.3925	0.2331	4.2900	+84
4	-0.2518	0.2274	4.3975	+55
5	-0.3387	0.2346	4.2625	+72
6	-0.2289	0.2154	4.6425	+53
7	-0.1952	0.2119	4.7192	+46
Average	-0.3821	0.2343		

Table 2. Jet centre-line velocity factors and virtual origin co-ordinate.

Table 2 shows the results for every test-case. In all the test cases, the virtual origin has a positive co-ordinate, in front of the outlet section. As the mean air velocity U(0) increases the virtual origin moves towards the nozzle, and the slope of the lines, in figure 5, decreases. Discrepancies appear for the test-case 5, which are probably due to instabilities of the fan and duct system providing the air. The average of the coefficients in table 2 could be used for a practical estimation of the mean centre-line velocity as it follows:

$$U = \frac{U(0)}{0.2343 \cdot \xi - 0.3821} \quad (3)$$

This expression, could provide an acceptable accuracy for the whole Reynolds number range investigated, from the longitudinal co-ordinate $\xi = 6.5$. The curve of eq. 3 is compared with the results from measurements in figure 4, referred as mean curve. Figure 6 shows a dimensionless distribution of the turbulence intensity of the U-velocity component versus the streamwise distance ξ. The local mean velocity U on the jet axis is chosen as the scaling velocity. We can distinguish two general trends. The first one holds for the lower velocity test-cases: U(0) up till around 50 cm/sec. For these cases, the curves show an initial increase in the intensity which ends in a peak followed by a subsequent decrease down to a more or less constant plateau. The peak is located at the abscissa of ten diameters. For the test case 1, the plateau is more irregular. All these curves have an evident inflection at the abscissa of around 4 diameters which rise up to higher values as the mean outlet velocity increases. The second trend, holding for the other test-cases, has a first peak located at the abscissa of around 4-5 diameters, followed by a decrease down till a minimum at the abscissa of 6 diameters. Then we have an increase in intensity ending with a second peak located at the abscissa of 9-10 diameters, followed by a new decrease down and a subsequent plateau. With the exception of the test case 1, all the experiments show a maximum of relative turbulence intensity between 25-26%, at the abscissa of 9-10 diameters.

In figure 7 is plotted the standard deviation of the mean velocity U versus the dimensionless streamwise distance ξ. Also in this diagram it is possible to distinguish two trends. For the first three test cases the standard deviation has a maximum at the exact abscissa of 8 diameters and then it decays. On the other hand, in the other test cases the maximum is located at an abscissa of around 4 diameters. At the abscissa of 8 diameters there is a second peak of lower intensity, and then we have a decay trend similar to the previous lowest velocity test-cases. Scaling the standard deviation with the standard deviation at the abscissa of ξ = 8, we obtain the curves in figure 8. It is possible to notice that all the curves collapse quite closely for $\xi > 8$. The inverse of this ratio is shown in figure 9. We can provide a simple equation holding for all test cases to estimate the standard deviation for $\xi > 8$. The average relative turbulence intensity over all the test cases at the abscissa $\xi = 8$ is 23.32%, then from eq. 3 we can write :

$$St_{\xi=8} = 0.1563 \cdot U(0) \quad (4)$$

From the results shown in diagram 9, we can estimate the decay of the centre-line standard deviation of axial velocity, in the domain $\xi>8$, as it follows:

$$\frac{St.Dev.(8)}{St,Dev.} = A + B \cdot \xi \tag{5}$$

Test Case	A	B
1	-0.3583	0.1615
2	-0.3926	0.1646
3	-0.3581	0.1703
4	-0.3537	0.1674
5	-0.3721	0.1663
6	-0.3581	0.1604
7	-0.3330	0.1582
Average	-0.3608	0.1641

Table 3. Coefficients of equation 5.

In table 3 are shown the coefficients obtained in each test case. From an average of these coefficients, and combining eq. 4 with 5, we can write a general equation to predict the standard deviation of the longitudinal velocity, for $\xi > 8$:

$$St.Dev._{\xi>8} = \frac{U(0)}{1.0499 \cdot \xi - 2.3084} \tag{6}$$

The ratio between eq. 6 and 3 will provide the relative turbulence intensity of the longitudinal velocity in the centre-line from the co-ordinate $\xi = 8$.

DISCUSSION

A mathematical model for predicting low speed isothermal air jet flows with outlet velocity lower than 1m/sec is of practical value for designing outlets of air supply in ventilated rooms. Thermal comfort and draught risk require quite often a level of air mean velocity in the occupied zone lower than 30 cm/sec. Low air velocity from the supply system is also required to reduce the noise level. Even though, it has not been found any reference about results from experimental investigation on jet flows at this low velocity domain. Theory for turbulent jets, ref. [1]-[3], and investigations of jets at high velocity, give decay laws of air mean velocity in the centre-line different than the one obtained in this work. In figure 10, eq. 3 is compared with the results of the lower outlet velocity test cases of Ref [5]. Only one of the curves fits with our equation. We have no reference to compare the results dealing with turbulence intensity. The results seem to agree with Ref. [1] which indicates a level of 23% in the fully developed zone as the most reliable. According to the results of this work, as the outlet velocity, U(0), increases the decay coefficient, C, of the air mean centre-line velocity increases, and, the virtual origin moves towards the nozzle. An analysis of the fluid-dynamics of the entire jet, needs a three dimensional investigation. At this low velocity level anemometry has tremendous problems to detect the air velocity direction and is insensitive to reversal flow. Visualisation methods, ref. [4], are indispensable to implement the results from anemometry.

ACKNOWLEDGEMENTS

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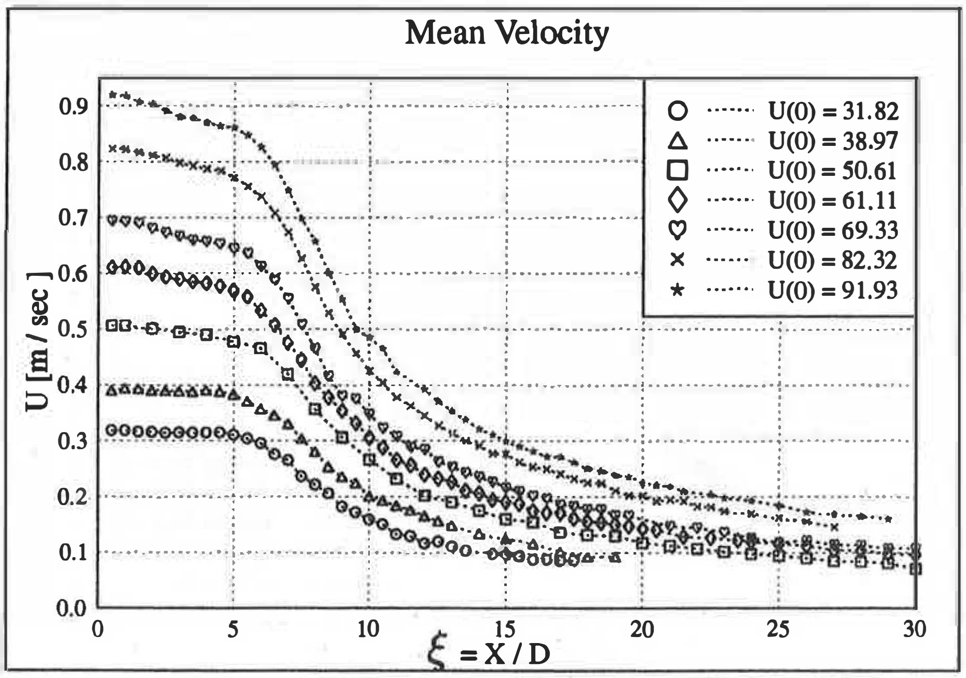

Figure 3. Air mean velocity in the centre-line of the jet.

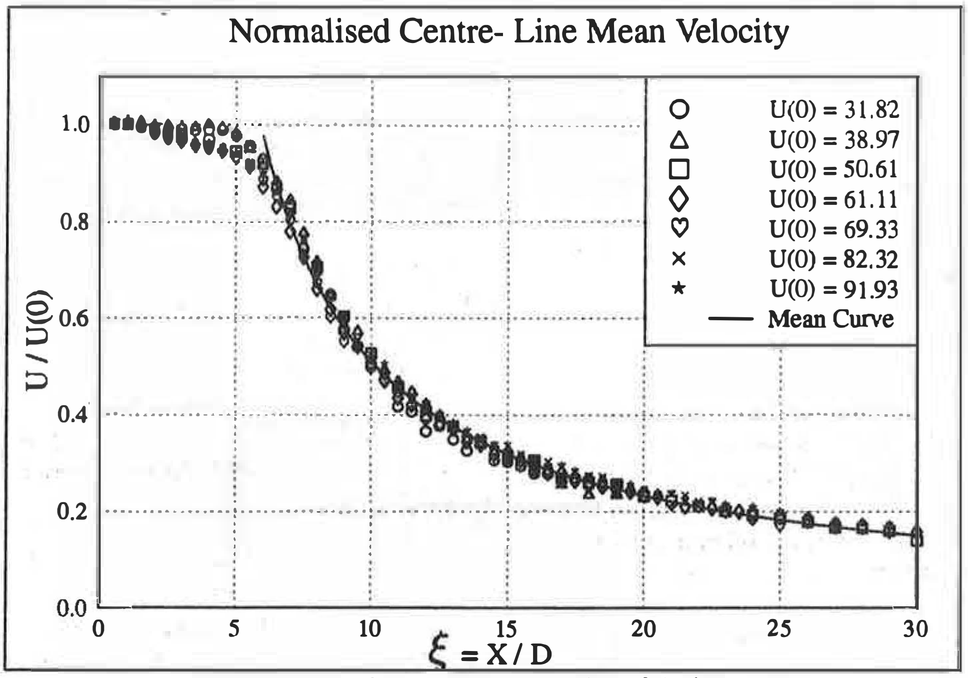

Figure 4. Normalised air mean velocity in the centre-line of the jet.

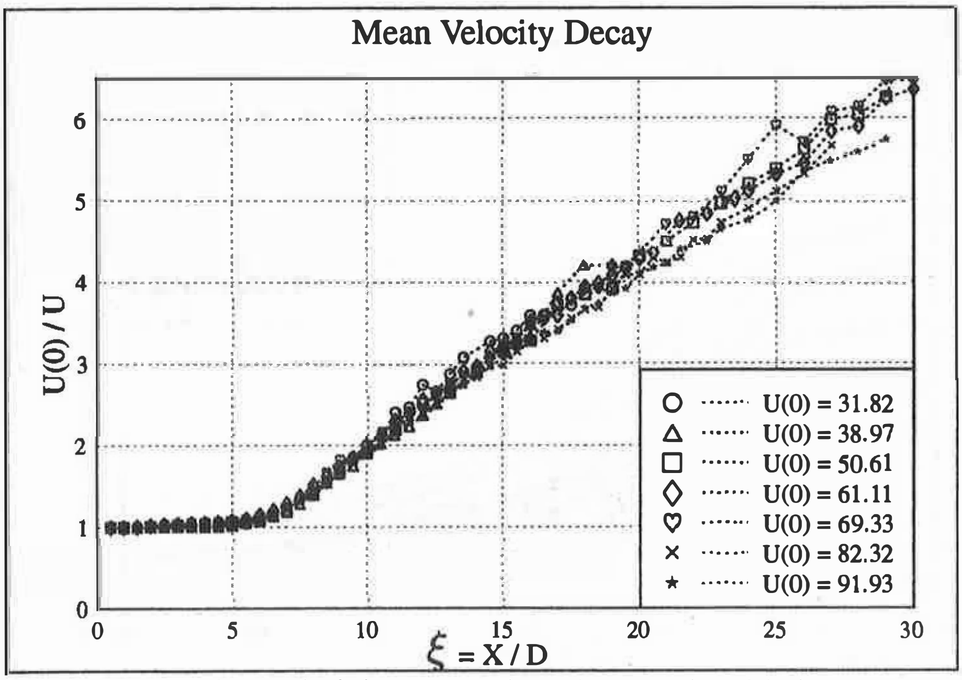

Figure 5. Inverse of normalised air mean velocity in the centre-line of the jet.

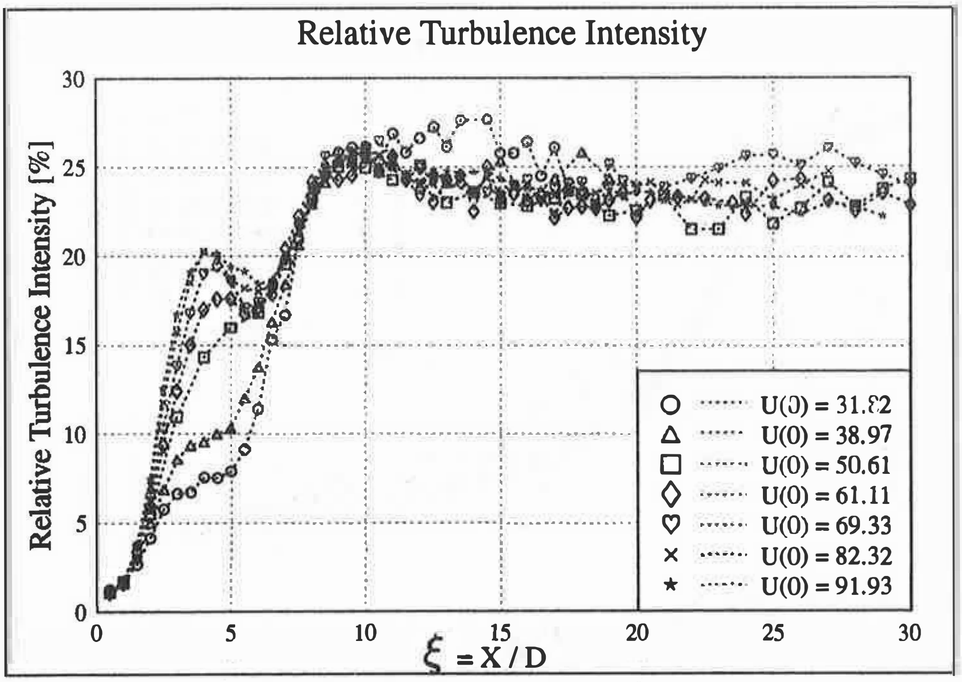

Figure 6. Relative turbulence intensity of the u-component of air velocity in the centre-line.

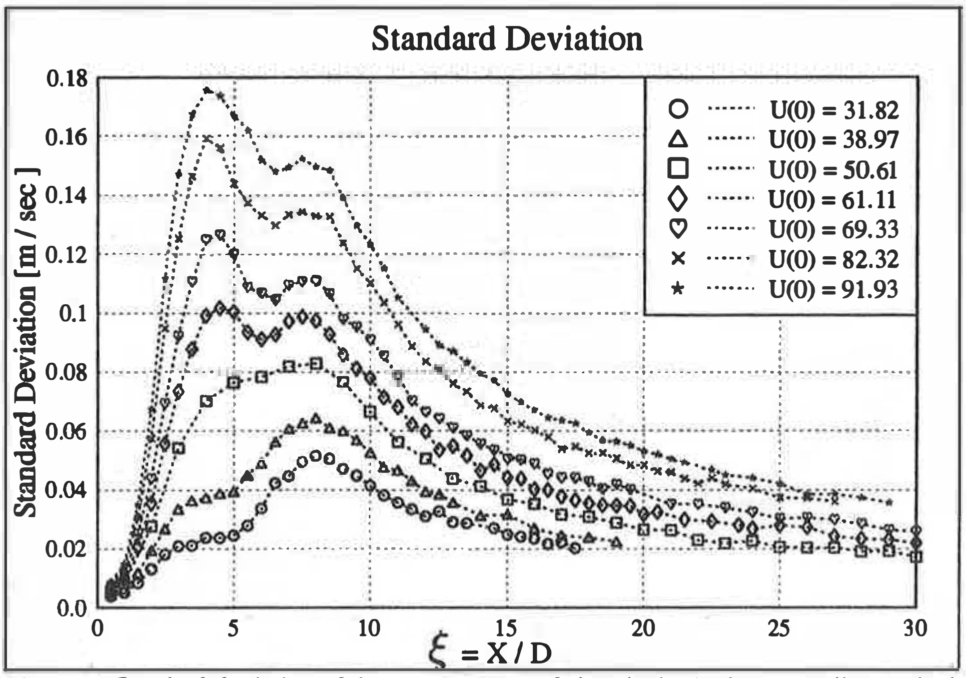

Figure 7. Standard deviation of the u-component of air velocity in the centre-line of the jet.

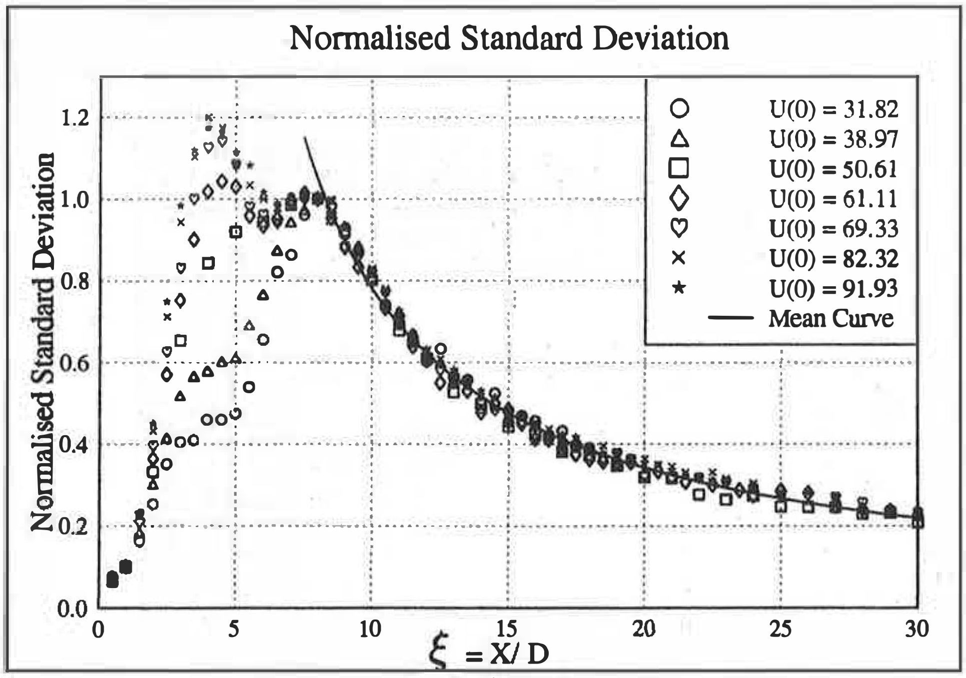

Figure 8. Normalised standard deviation of air velocity in the centre-line of the jet.

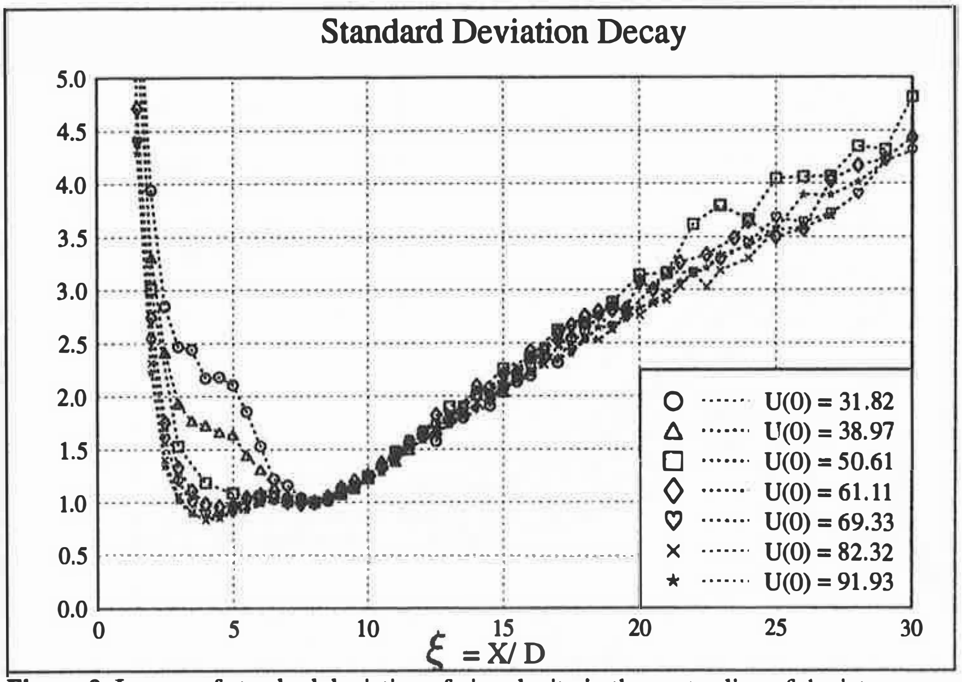

Figure 9. Inverse of standard deviation of air velocity in the centre-line of the jet.

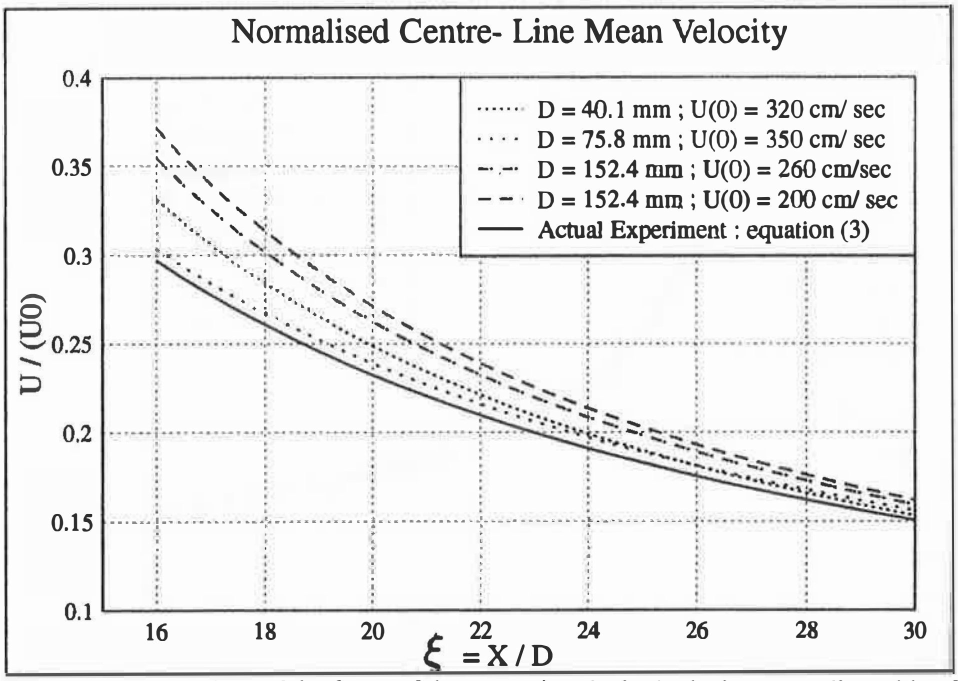

Figure 10. Comparison of the decay of the mean air velocity in the jet centre-line with ref. [4].