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AN EXPERIMENTAL INVESTIGATION OF SAMPLING TIME FOR AIR JET VELOCITY MEASUREMENTS

Zou Yue and Tor G. Malmström

Department of Building Services Engineering, KTH, Stockholm, SWEDEN

ABSTRACT

In this paper, the influence of the sampling time on the evaluation of an air jet (D=41mm) performance was investigated. For an air jet with known outlet conditions, the distance from the outlet to the measurement point is an important factor affecting the accuracy of mean centerline velocity measurements.

When a short sampling time was used to evaluate jet performance, the centerline velocity decay rate could maintain the behavior $U_x \propto x^{-1}$ for a longer distance but with different values of K and x_p/D than with longer sampling time. This feature may be useful for analyzing how disturbances from the room air influence the jet disintegration.

KEYWORDS

Sampling time, Jets, Measuring techniques, Air velocity

BACKGROUND

For ventilation engineers, studies of jet behavior normally focus on the distances that supply air needs to mix with room air in order to reduce air velocities and temperature differences to acceptable levels before it enters the occupied zone. Based on such studies, a simple model was developed to describe the throw length of air jet, see Figure 1. The following formula is often used to calculate the centerline velocities of fully developed air jets or the throw for a certain distance x (see ASHRAE Handbook [1993]):

$$\frac{U_x}{U_o} = K \cdot \frac{D}{x - x_p} \qquad (1)$$

where U_x = centerline velocity at x (m/s)
U_o = outlet velocity of air jet (m/s)
K = centerline velocity decay coefficient
D = diameter of nozzle (m)
x = coordinate for distance from the outlet (m)
x_p = coordinate for the virtual origin of the jet (m)

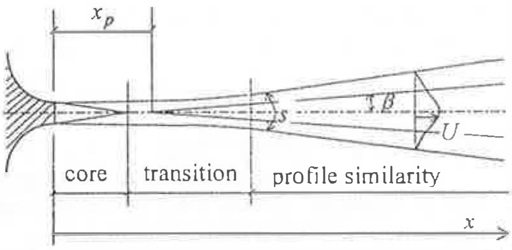

Figure 1 Symbols and denotations used in the jet model

Obviously, the K-value is an important factor for describing jet performance. K-values are usually evaluated by measuring mean velocities in different centerline positions of the air jet. In most experiments, sampling time scales of a couple of minutes are used in the whole measurement field, which may be too short for measurement points far away from the outlet, perhaps resulting in large measurement errors.

However, some research results have shown that the velocity profile of an air jet is not stable, especially for jets with low outlet velocity far away from the outlet (see Malmström et al [1992]; Nottage [1952]; Townsend [1989]). The nature of this instability, whether it is part of jet behavior or is caused by disturbances, has relevance to the measurement problem. Thus, it may be useful to study the sampling time scale for evaluating the air jet performance. In this paper, a first step is taken in the form of an experimental study of how the sampling time influences the evaluation of *K*- values.

TEST PROCEDURE

The experimental setup consists of a fan, a settling chamber, and an ASME standard long radius nozzle (D=41 mm) in a large enclosure. A fan with a bypass duct system was used to deliver the required airflow rate to the settling chamber, which was 1.2 m long and 0.8 m in diameter. Five internal fine mesh screens were used to produce a uniform velocity profile and reduce the turbulence level. The turbulence intensity of the nozzle outlet velocity was less than 0.6% for the range of the measurement. The nozzle with the settling chamber was located free in a large laboratory area.

The velocity measurements were made with a constant temperature hot-wire probe having a single, unplated tungsten sensor, 1.5 mm long and 5 μm in diameter. The probe was operated at an overheat ratio of 1.8. Data were acquired and converted by an An-2000 computerized anemometer system. Typical sampling frequency was 200 Hz.

RESULTS

Influence of sampling time on mean centerline velocity evaluation

Theoretically, the mean velocity U_m of a fixed measurement position with velocity $U(t)$ is defined as $U_m = \lim_{t\to\infty} U(t)$. However, the sampling time τ could not be indefinitely long in practice, so a measured mean velocity U_{mm} always has an error ε defined as:

$$\varepsilon^2 = \overline{(U_{mm} - U_m)^2} / U_m^2 \qquad (2)$$

Johansson and Alfredsson (1988) recommends using Eq.3 to estimate the error ε in a fully developed turbulent flow:

$$\varepsilon \approx \frac{u_{rms}}{U_m}(2\tau_0 / \tau)^{0.5} \qquad (3)$$

where $\frac{u_{rms}}{U_m}$ = turbulence intensity at the measurement point

τ_o = macro integral time scale

τ = measurement time scale

As we can see, the measurement accuracy is dependent on the macro integral time scale τ_o for the turbulent flow. Unfortunately, the theoretical solution for τ_o is not known for an air jet. If pipe flow can be used as a reference case and if the influence of disturbances from room air can be neglected, τ_o in the zone 3 of air jets may be estimated as:

$$\tau_0 = \frac{r_{tr}}{U_x} \qquad (4)$$

where r_{tr} = local radius of air jet transverse section

= $(x - x_p)\cdot\tan(s/2)$ (m)

s = total spread angle of air jet (deg)

U_x = local centerline velocity (m/s)

Substituting Eq.1 in Eq.4 gives:

$$\tau_0 = \frac{(x - x_p)^2 \cdot \tan(s/2)}{K \cdot U_n \cdot D} \qquad (5)$$

This equation implies that, for an air jet with known outlet conditions, the distance from the outlet to the measurement point is an important factor for the accuracy of mean centerline velocity measurements.

In order to study the influence of sampling time, an air jet (D=41mm, U_o =11 m/s) was investigated. Five different centerline velocities at *x/D*=16, 24, 40, 50 and 60 were measured with the total measuring period for each point of 45 minutes, which was assumed to give a real mean velocity, see Figure 2. In this case, the measuring point was *x/D* =40 and the mean velocity over 45 minutes was 1.68 m/s. Only the results evaluated from the measuring period between 40 seconds and 720 seconds are presented here. As we can see, only after a sampling time bigger than 240 seconds (4 minutes) did the mean values become relatively stable and the measurement error less than 1%.

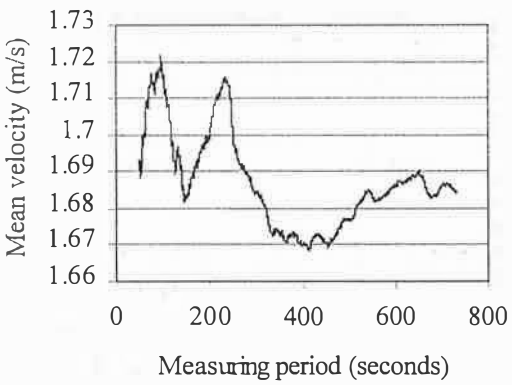

Figure 2 Mean centerline velocities evaluated for the centerline point *x/D* =40 and U_o =11 m/s. The mean velocity over 45 minutes was 1.68 m/s

Figure 3 gives data for the sampling time if we want to keep the measurement error less than 1% for different measurement points. Obviously, the sampling time should be carefully chosen for the measuring points with small air velocities or far away from the outlet. Figure 4 shows the measurement error of mean centerline velocities if 3 minutes are chosen as the sampling time in the whole measurement field. (note: this only applies in the jet studies)

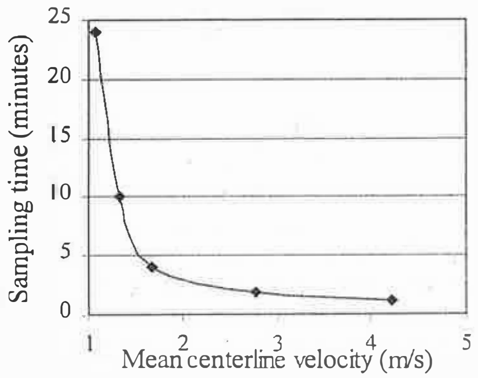

Figure 3 Sampling time needed to evaluate the mean centerline velocities with error less than 1% for air jet (D=41 mm, U_o =11 m/s)

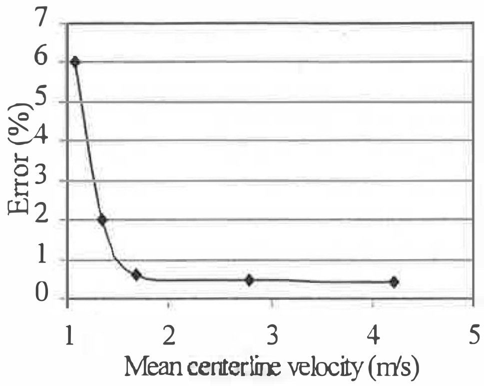

Figure 4 Error of mean centerline velocity evaluation if sampling time chosen as 3 minutes for air jet (D=41 mm, U_o =11 m/s)

However, for small air velocities or for the region far away from the nozzle, finding a suitable sampling time to get stable mean centerline velocities becomes very complicated because room air disturbances strongly influence the jet behavior. To get a velocity reading which reflects undisturbed jet behavior thus is not a matter of only sampling time. This need further studies in the future.

Influence of sampling time on the evaluation of *K*-values

For a fully developed jet flow with known outlet conditions, the *K*-value is an important factor for describing the jet performance. This part of our study focuses on the variance of *K*-values evaluated from different sampling times.

The full measuring period for every measured centerline point was 3 minutes and the positions of these points were chosen to give measurement error of mean velocities over 3 minutes less than 2% as predicted with Eq.3. 8 different sampling time scales (1s, 2s, 4s, 8s, 16s, 32s, 64s and 180s) were simulated from the available data of full 3-minutes measurement period and used to evaluate *K*-values.

For different time scales, for instance 4 seconds, the mean centerline velocity was calculated over every consecutive 4-seconds interval throughout the whole 3-minute measuring period. This results in 45 different mean velocities for every measurement point. Then the maximum 4-seconds mean value of these 45 data was chosen to evaluate the *K*-value with least square regression.

Figure 5 gives an example of the maximum mean centerline velocities variance with different time scales from 1 seconds to 180 seconds when the outlet velocity was 11m/s. As we can see, even for smaller sampling time scales, the centerline velocity decay rate still can maintain the behavior $U_c \propto x^{-1}$ which is typical for zone 3 but both *K*-values and values of x_p/D change as shown in Figure 6.

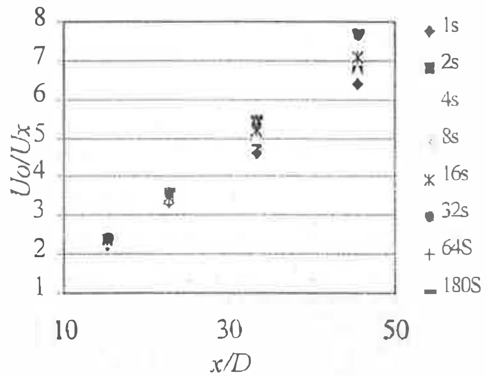

Figure 5 Jet centerline velocities in different time scales (D=41 mm, U_o =11 m/s)

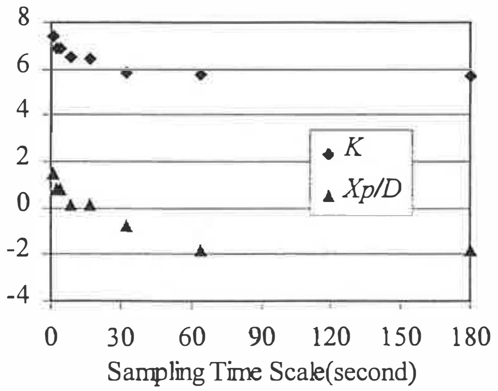

Figure 6 *K*-value and x_p/D vs. sampling time scales for an air jet (*D*=41 mm, U_o =11 m/s)

The influences of small sampling times on the evaluation of air jets with other outlet velocities were also investigated and similar trends observed, see Table 1.

Table 1 *K*- values evaluated from measuring points between 18 *D* and 30 *D*

Time Scale(s)	*K*- values vs.outlet velocities		
	8.2m/s	11.0m/s	20.5m/s
2	7.70	6.90	7.13
4	6.83	6.90	6.78
8	6.59	6.50	6.74
16	6.26	6.45	6.54
32	6.01	5.80	6.30
64	5.86	5.73	6.23
180	5.66	5.70	6.08

A possible use of different sampling times

In ventilation and air conditioning applications, jet throw length is an important factor for describing the jet performance. Normally, the throw length is divided into 4 zones. In the fourth zone, the centerline velocity decrease very fast and jet disintegration take place in a short distance, but the mechanics of jet disintegration is not well understood. In many cases, jet disintegration is caused by room air disturbances.

When small sampling time scales are used to evaluate the jet performance, the centerline velocity decay rate can maintain the behavior $U_x \propto x^{-1}$ in a longer distance but with changed values of *K* and x_p/D. This implies that when disturbances play a key role for jet disintegration, it is perhaps possible to use different sampling times to separate the influence of the disturbances from the pure jet behavior. In Figure 7, the distances where the air jet shows typical third zone centerline velocity decay rate are presented for different sampling time scales. As we can see, this distance become longer and longer when the time scale decrease. The whole measurement region appears to be in the third zone when the time scale was 2 seconds.

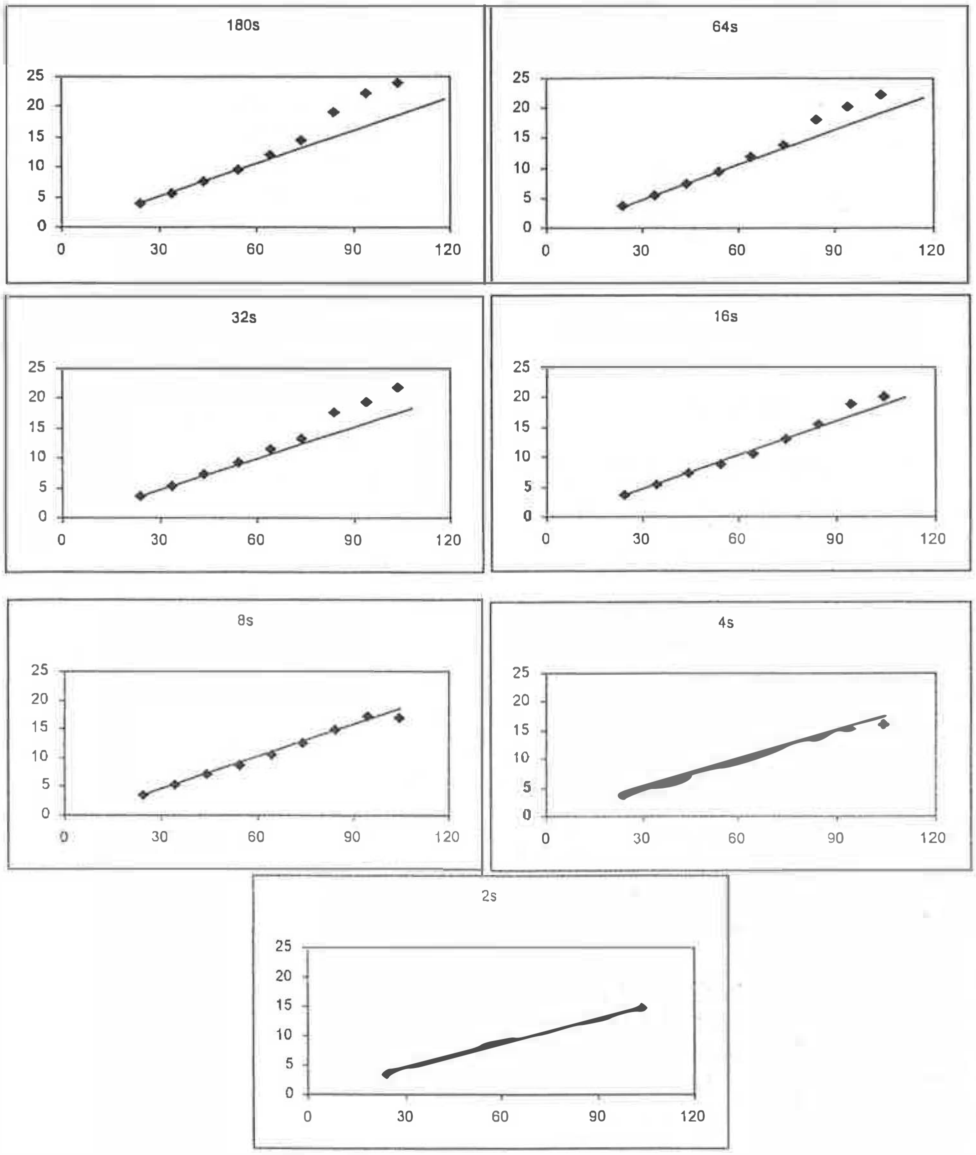

Figure 7 One air jet performance$(D=41mm,\ U_o=10\ m/s)$ in different sampling time scale. For all diagrams, x-axis is x/D and y-axis is U_o / U_x

CONCLUSIONS

It is important to choose the appropriate sampling time for evaluating the air jet performance in the fully developed zone. For an air jet with known outlet conditions, the distance from the outlet to the measurement point is an important factor affecting the accuracy of mean centerline velocity measurement and the sampling time.

When a small sampling time is used to evaluate jet performance, the centerline velocity can still maintain a decay rate $U_x \propto x^{-1}$ but both K-value and x_p/D are changed.

ACKNOWLEDGEMENTS

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