Mapping Of Turbulent Round Jet Developing Region Using a Constant Temperature Anemometer (CTA)

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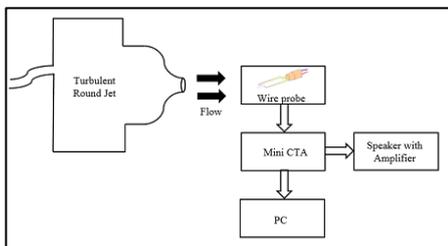[c] Intarsia Optics, Sønderskovvej 3, Birkerød, Denmark

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Graphical abstract

Abstract

A turbulent round jet comprises not only different regions spanning the downstream direction viz. developing and fully developed, but also different layers spanning the radial direction viz. the jet center (surrounding the jet centerline), shear layer region and the outer region. Free shear layer flows such as this is a classical turbulent flow of special interest for fundamental investigation (Hinze, 1975). The fully developed jet has been extensively studied (Hussein, Capp, & George, 1994), whereas the developing regions is much less understood. The high shear and turbulence intensities in the most interesting parts the developing region make them inaccessible to common measurement techniques such as Constant Temperature Anemometry (CTA) due to the high demands on the measurement techniques for accuracy of the measurements. Turbulence measurements are therefore planned using our in-house Laser Doppler Anemometer (LDA) system (Preben Buchhave & Velte, 2017) based on its capability to provide accurate measurements with the ability to properly distinguish velocity components. A rigorous measurement with the intended LDA system however demands impractical processing time, so knowing the critical points at which measurement are to be taken will save valuable time. This information is herein acquired significantly faster and more practically with single-wire CTA. A high-resolution measurement was done using a computer-controlled single-wire CTA with the wire probe mounted perpendicular to the incoming flow from the jet orifice. The measurement covered several points in radial direction along x=10D, x=15D, x=20D and x=30D downstream with resolution ranging from 1 to 3 mm between the points, depending on how far the measurement was from the jet centerline. A proper alignment was also done prior to measurement so that the same points can be reached again for LDA measurement on the same jet afterwards. The radial profiles of mean velocity and turbulence intensity at each downstream position are presented to show the statistics of the air flow inside and outside the jet. As expected from theory, the mean profiles display a nearly Gaussian shape, spread out and taper along the downstream direction. The highest velocities are located at the centerline.

Keywords: hot wire; turbulent round jet, turbulence

INTRODUCTION

The flow field of a turbulent round jet is not only divided into delevoped and fully developed region in the streamwise direction (Mossa & Serio, 2016), but also in the variations along the radial direction which comprises three different layers viz. centreline layer, shear layer region and outer region (Ball, Fellouah, & Pollard, 2012). These regions and layers are clearly illustrated in Fig.1 and Fig.2. LDA is capable of resolving velocity measurement non-intrusively (i.e. without disturbing the flow) (Preben Buchhave, George, & Lumley, 1979)and are also able to accurately distinguish the spatial velocity components, even at high turbulence intensities (Hussein et al., 1994).

However, our in-house LDA system (Clara M Velte, Buchhave, & Hodzic, 2017) demands much longer computation time compared to computer-controlled CTA which is faster and easier to use especially with automated calibration (Jørgensen, 1996). Having to obtain the mean velocity and turbulence intensity profiles quickly from CTA measurement in our under-investigation turbulent round jet, will be time-efficient and the results will be useful for the upcoming high-resolution LDA measurement in mapping the developing region of the same jet using the same flow conditions. The result is aimed to help us in finding the boundary between the jet and the surrounding air, and also the shear layer for different downstream positions, which is one of the regions of highest interest currently- in turbulence research.
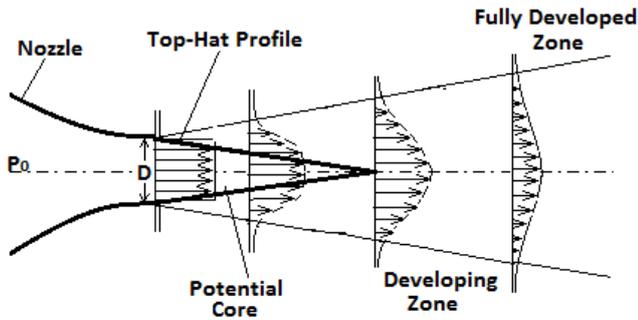
Fig.1 Development region of turbulent round jet in streamwise direction (Kaushik, Kumar, & Humrutha, 2015).
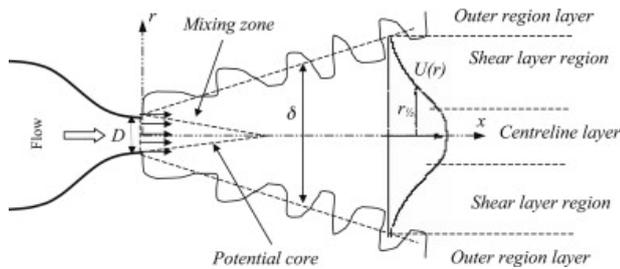

Fig.2 Different layers of turbulent round jet in radial direction (Fellouah, Ball, & Pollard, 2009).

EXPERIMENTAL METHOD

CTA provides velocity time-history information in one measurement position. Based on the convective heat transfer principle (Jørgensen, 2004), the passing air will cause temperature change on the heated wire placed within the flow. The anemometer is keeping the wire at a constant temperature by adjusting the voltage passing through the wire as depicted in Fig. 3.
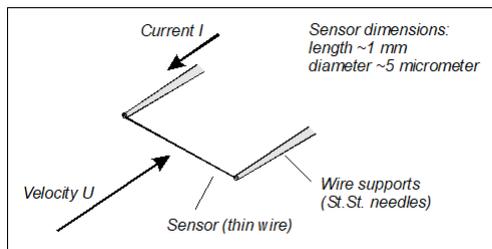

Fig. 3 Close-up of support and wire-sensor with a velocity, U, and current, I in the wire (F. Gökhan Ergin, 2016).

The jet box used for these investigations was made of aluminum with dimensions 58 x 58.5 x 59 cm and fitted with an outer nozzle which was designed to condition the flow to follow as closely as possible a laminar top-hat profile at the jet exit with diameter D =10 mm. The turbulent round jet itself was a replica of the one used by (Clara Marika Velte, George, & Buchhave, 2014), from which further details can be found. The jet input pressure was set to 1 bar, corresponding to a jet exit velocity ≈ 30 m/s and Re ≈ 20,000.

Prior to the measurements, the system was first calibrated using an automatic calibration system from Dantec Dynamics. This was separately done by increasing the air flow in accordance with pressure difference inside a well conditioned wind tunnel and then fitting a 4th-order polynomial to a relation between output voltage and velocity. The experimental settings listed in Table 1 were considered during the calibration.

Table 1 Experiment setting

Sampling frequency	10 kHz
Sampling time	10s
Number of samples	100 kS
Temperature	≈ 21.5°C
Atmospheric pressure	≈ 1015hPa

The measurements were conducted using a uni-directional single sensor probe where the thin wire was placed perpendicular to the incoming flow from the jet orifice. The probe was mounted on a support (see Fig. 4) and connected to the CTA anemometer and computer installed with Dantec Dynamics MiniCTA software (see Fig. 5), from which a single time series data was reduced to a series of fluctuating velocity of the streamwise component, leading to the calculation of mean and rms velocity for each measurement point.
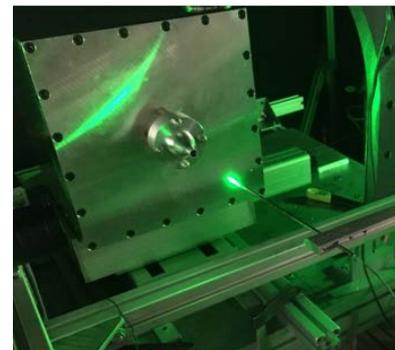

Fig. 4 CTA experiment showing jet orifice and the support mounted wire probe.
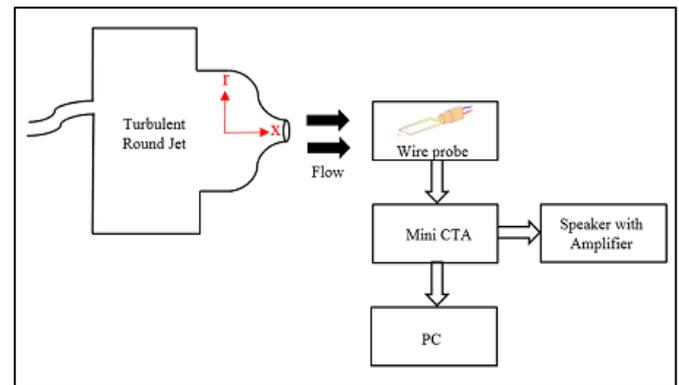

Fig. 5 Overall experimental setup. A speaker with amplifier was also installed to produce noise from the turbulence to help locating regions of various turbulence intensity such as the highest shear layer.

The measurement covered several points in the radial (*r*-direction) along 10D, 15D, 20D and 30D downstream (*x*-direction) where D is the jet exit diameter, with resolution ranging from 1 to 3 mm between the points, depending on how far the measurements were from the jet centreline. The jet box was mounted on a 3-axis traversing system so that it can be easily manoeuvred to the desired points correspondingly when performing the LDA measurement.

Having in mind that the results will map the points or region of interest for the incoming LDA measurement, the probe was first carefully aligned (see Fig. 6) so that the thin wire was placed at the pinhole of a photodetector (Yaacob, Schlander, Buchhave, & Velte, 2018), at which the jet centreline and measurement volume of LDA has been identified to overlap beforehand, without moving or changing the position of the photodetector. This location of the probe was fixed while traversing only the jet throughout the CTA measurement. The same points can therefore consequently be reached again for LDA measurement.
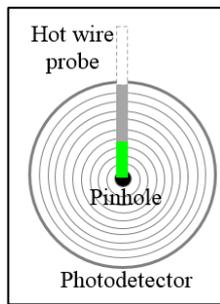
Fig. 6 View through a photodetector showing probe alignment with the pinhole.

RESULTS AND DISCUSSION

In the figures presented herein, the data have not been normalized or fitted to any order polynomial, in order to display the direct flow results. Fig. 7 shows the radial profiles of mean velocity at various downstream positions throughout the developing region, namely x/D = 10, 15, 20 & 30. As expected from theory, the profiles seem to follow a nearly Gaussian shape, spread out and tapered with downstream position. The highest average velocities are spotted at the centreline while the points where average velocity is very close to zero indicate that the measurement was somewhere near the boundary between the jet and the surrounding air, which should be noted when conducting the LDA measurement.
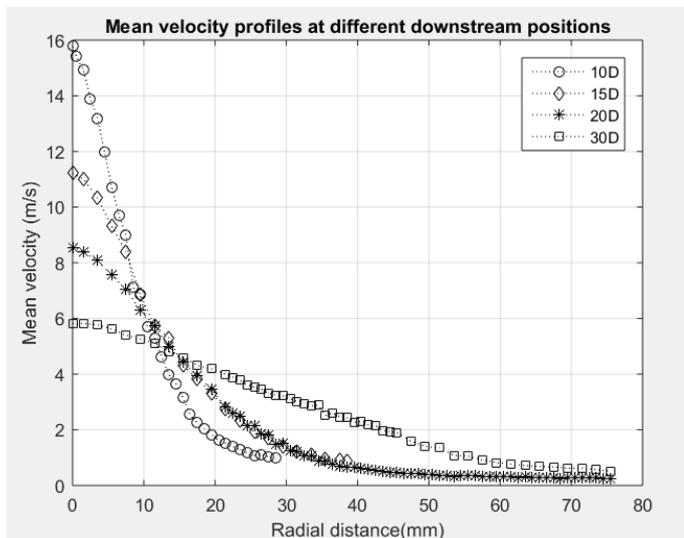

Fig. 7 Radial profiles of mean velocity at different downstream positions x/D = 10, 15, 20 & 30 where D is the jet exit diameter.

Fig. 8 shows radial profiles of turbulence intensity at different downstream positions. Turbulence intensity was first determined using Equation (1)

$$turbulence\ intensity = \sqrt{\frac{\overline{u'^2}}{\overline{u}^2}} \qquad (1)$$

where $\bar{u}$ is the mean velocity and u' is the rms velocity.

When the measurements progress away from the centerline, turbulence intensity increases in the region where the shear layer is located. In these regions, the high levels of fluctuations will require an appropriate frequency shift to measure accurately with the LDA system (P. Buchhave, 1984). Again, keep in mind that the profiles obtained are just an approximation (and intended only to aid the latter LDA measurement) and does not accurately describe turbulence especially in the region where fluctuations are large compared to the streamwise convection. However the approximation is more acceptable when

turbulence intensity is low as the streamwise convection dominates over the fluctuations.
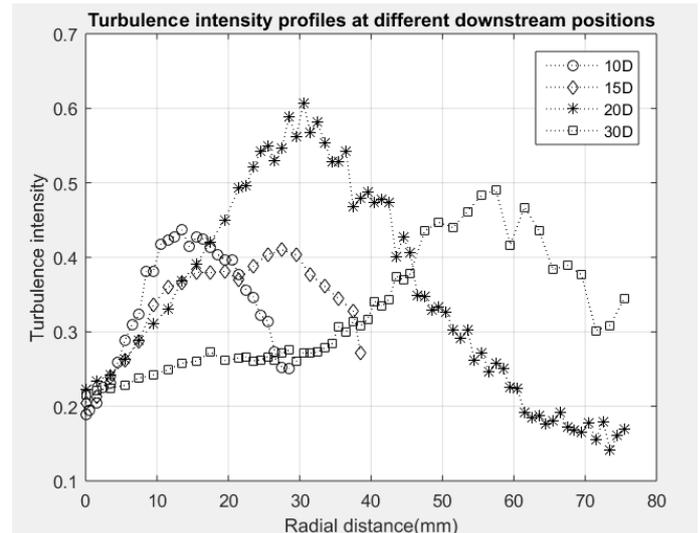

Fig. 8 Radial profiles of streamwise turbulence intensity at different downstream positions x/D = 10, 15, 20 & 30 where D is the jet exit diameter.

CONCLUSION

A CTA measurement was successfully performed to provide a measurement scheme and to identify the spatial extent of regions of interest for future, more rigorous LDA turbulence measurement. The outcome of the planned LDA measurements will be published in a separate scientific article.

ACKNOWLEDGEMENT

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