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TURBULENCE SCALING FOR THREE-DIMENSIONAL WALL JETS ON CONVEX CYLINDRICAL SURFACES

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ABSTRACT

The turbulent kinetic energy is utilised to scale turbulence quantities measured in three-dimensional wall jets on convex cylindrical surfaces. The scaling is quite satisfactory in the case normal stresses. However, a better scaling is observed in the case of shear stresses, when the product ($\tilde{u}\,\tilde{v}$) is used as the scaling parameter.

INTRODUCTION

There are a number of fields of engineering applications where wall jets occur such as boundary layer control of airfoils, effective film cooling of turbine blades, in the design of air vents for ventilation purposes and in the area of fluidics. In many of the practical applications of wall jets cited above, curvature effects (particularly convex curvature) occur. Hence, it would be essential to understand the effect of curvature both on mean and turbulence characteristics of wall jets developing on such surfaces. In all the investigations dealing with the study of curvature effects, there are basically two types of approaches, 1. the radius of curvature of the surface is kept constant (Wilson and Goldstein, 1976; Alcaraz et al., 1977; Dakos et al., 1984; Fujisawa and Shirai, 1987), 2. the curvature parameter (b/R; b is the half-width and R, the radius of curvature) is maintained constant along the length of the curved surface (Giles et al., 1966; Kamemoto, 1974; Guitton and Newman, 1977). In the latter case, taking into account the rate of growth of the half width b, the condition of having constant curvature parameter along the length of the surface leads to logarithmic spiral surfaces (the radius of curvature has to vary continuously along the length to obtain the required curvature parameter). In the former case, the surfaces will be cylindrical surfaces. There are advantages and disadvantages in both approaches. In the second case, the influence of a particular curvature parameter on the properties of the wall jet can be seen, whereas in the first case, the properties on a cylindrical surface with a particular radius of curvature are obtained; the curvature parameter will be varying along the length of the cylindrical surface. In practical situations, rarely does one come across a situation where the radius of curvature is changing continuously along the flow direction resulting in a surface with constant curvature parameter. Even if there are changes in the radius of curvature, one could expect long stretches where it will remain constant. Hence, from among the two approaches adopted to study the influence of curvature, the former seems to be nearer to practical situations. This is the approach that has been adopted in the present study.

EXPERIMENTAL METHOD

Investigations have been carried out to determine both mean and turbulence characteristics of three-dimensional wall jets developing on convex surfaces with constant radius of curvature using a circular orifice geometry (10 mm diameter). Studies are made on three such cylindrical surfaces (Fig.1): 1. Surface with a large radius of curvature (referred to as cylindrical surface 1 or CYS 1) which gives low values of local curvature parameter (b/R varying from 0.01 to 0.03); 2. Cylindrical surface 2 (CYS 2), where the radius of curvature is such that a range of medium local curvature parameters is obtained (b/R varying from 0.025 to 0.12) and 3. A cylindrical surface with a small radius of curvature (CYS 3) which gives high values of local curvature parameter (b/R varying from 0.12 to 1.114). Measurements have been carried out on a plane surface also for obtaining corresponding comparison . Usually, in a wall jet, the maximum velocity U_m is utilised as the scaling parameter for the turbulence quantities measured at various stations. In this paper, the turbulent kinetic energy q^2 has been utilised to scale the turbulence quantities and the results presented.

All the measurements reported in this study have been carried out using the jet tunnel facility (Padmanabham and Gowda, 1991a and b) and hot-wire anemometer. The test set up is shown in Fig.2. The plates are aligned so that the leading edge of each abuts with the surface of the orifice plate. The various components of the normal stresses i.e., $\tilde{u}$, $\tilde{v}$, and , $\tilde{w}$ and the turbulent shear stresses $\overline{uv}$ and $\overline{uw}$

are measured by using a X-wire probe. The constant temperature hot-wire anemometer system DANTEC 56 C with CTA bridges 56C17, linearisers (56N21), signal conditioners (56N20), digital voltmeter (56N10), RMS voltmeter (56N11) and analog processor unit (56N22) are made use of. The cross-wire probe used is DISA miniature -wire probe 55P61 with a wire length of 1.25 mm and a wire separation of 2mm. The linearisation and calibration of the probes are carried out in two velocity ranges (i) 80 m/s to 8 m/s and (ii) 8 m/s to 0.5 m/s. The jet exit Reynolds number based on the diameter of the orifice is 5.48×10^4 . Further details of the text set up are given in Durbha, 1996.

RESULTS

The turbulent quantities, in some situations, are found to exhibit similarity when scaled with another turbulent quantity (Wilson and Goldstein, 1976; Dakos et al., 1984). In the present study an attempt has been made to look into such a possibility and the scaling parameter chosen for this purpose is q^2. The quantities $\overline{u^2}$, $\overline{v^2}$, $\overline{w^2}$ are normalised with q^2 and the results are shown at three typical stations, x/d = 60, 100 and 130 in Fig.3. The scaling is very encouraging, particularly for $\overline{v^2}$ and $\overline{w^2}$. Interestingly, including $\overline{u^2}$, the scaling is satisfactory for $y/b \leq 1.2$. Further, the results also indicate the approximate distribution for the total turbulent kinetic energy among the three components $\tilde{u}$, $\tilde{v}$, and $\tilde{w}$; it is about 60% , 20% and 20% respectively.

However, the scaling with q^2 is not satisfactory in the case of the turbulent shear stress $\overline{uv}$ as seen in Fig.4. When the shear stress is normalised with ($\tilde{u}\ \tilde{v}$), a better correlation is seen as shown in Fig.5. Here also, the correlation appears to become unsatisfactory when the curvature parameter is very high (Fig.5c; CYS 3). The shear correlation coefficient ($\overline{uv}/\tilde{u}\ \tilde{v}$) tends to an asymptotic value at large downstream distances on plane surfaces (Padmanabham and Gowda, 1991b). This appears to be the case for convex surfces also except in the case of very high curvature parameter.

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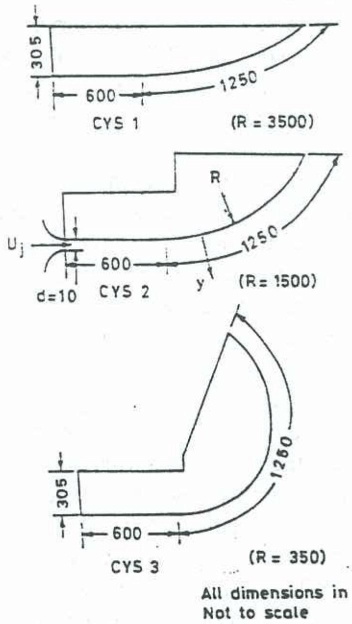

Fig.1 Details of the curved plates

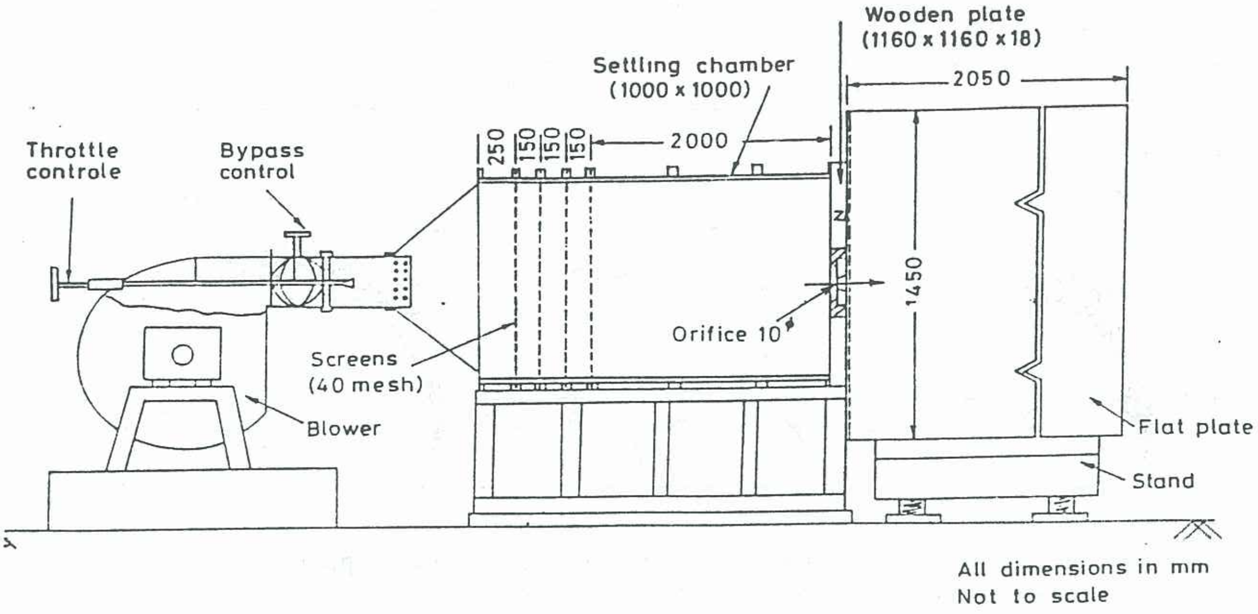

Fig.2 Experimental set-up

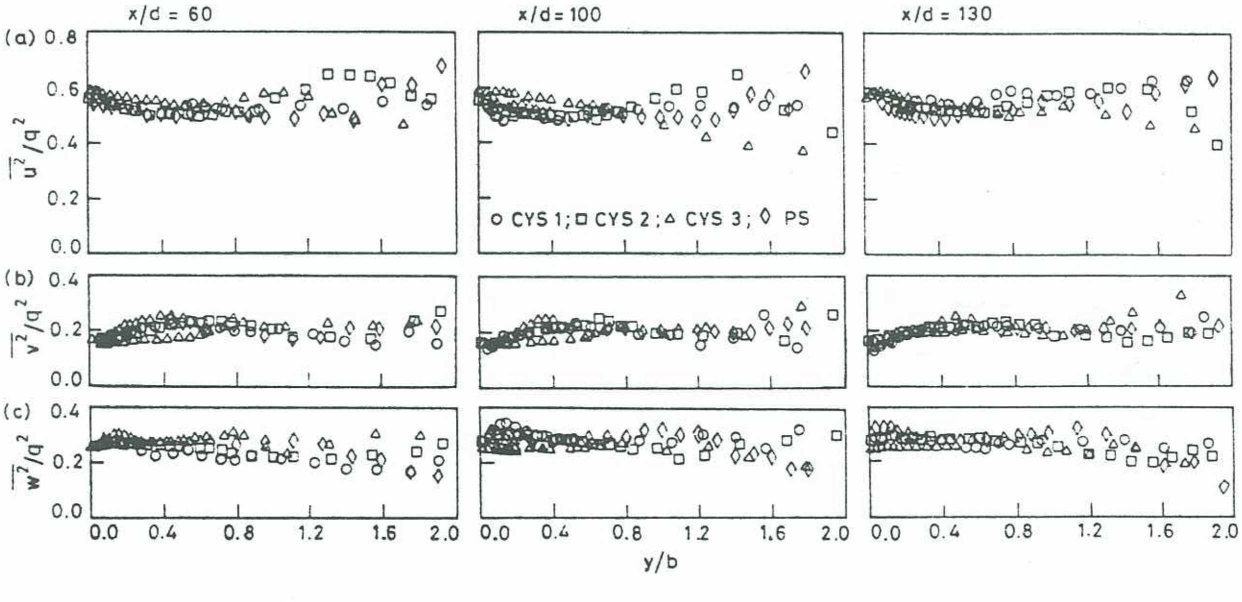

Fig.3 Variation of $\overline{u^2}$, $\overline{v^2}$ and $\overline{w^2}$ normalised with q^2 at three typical axial stations on CYS1, CYS2 and CYS3

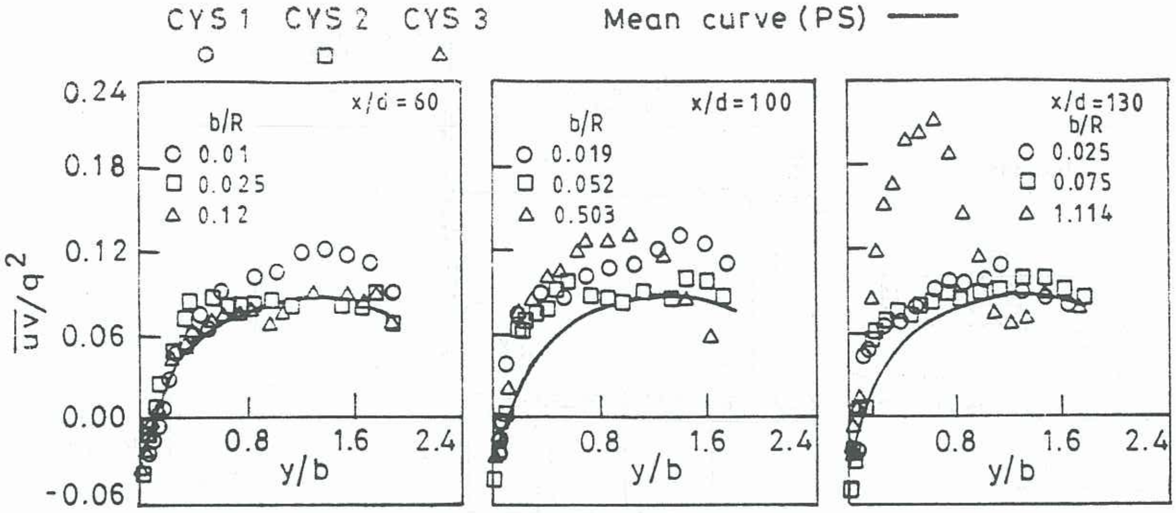

Fig.4 Variation of $\overline{uv}$ normalised with q^2 at three typical axial stations on CYS1, CYS2 and CYS3

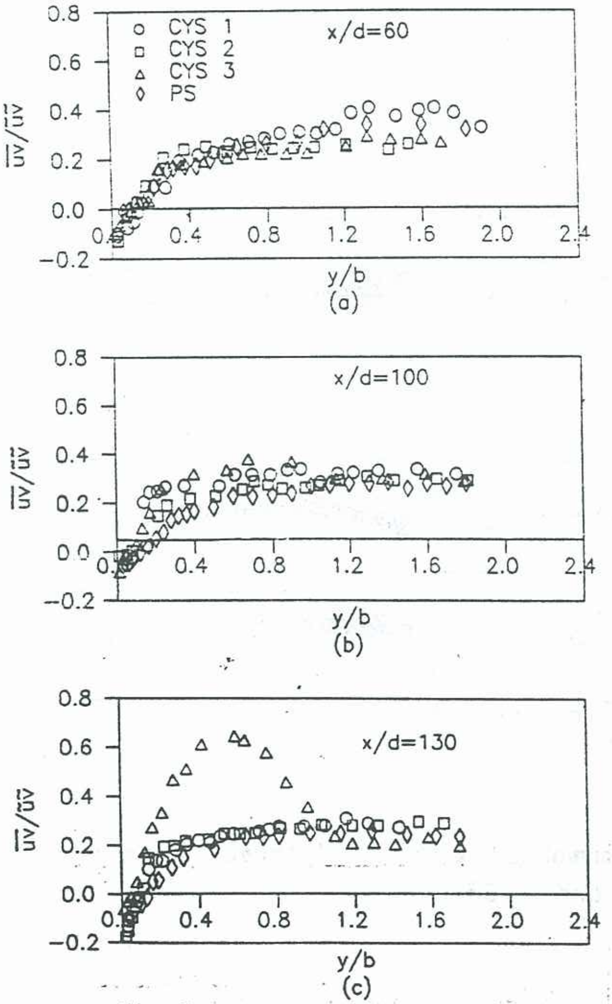

Fig.5 Variation of correlation coefficient at three typical axial stations