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MEASUREMENT OF A CYLINDRICAL FAR WAKE

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Abstract

The mean velocity distributions of the far wake of cylinder, with 2mm diameter d, were investigated by using the hot-wire anemometer. Measurements were made at five streamwise stations, and different free stream velocities (U_1) were used to study the effect of Reynolds number, ($U_1 d/\upsilon$, where υ is the kinematic viscosity), on the decay of the mean velocity $\overline{U}$.

The normalised mean velocity defect distributions and the streamwise variations of the maximum velocity defect U_0 and half-width L (i.e. the value of y where U_0 is reduced to half) are then used to establish the self-preservations regions of the flow (see Figure 1).

The results suggested that the mean velocity defect profiles, maximum velocity defect and the half-width get approximately self-preserving at distances greater than 150 diameters downstream of the cylinder. Within the range of Reynolds number ($Re \cong 800$ to 1,800) studied, it was found that the self-preserving mean velocity defect are independent of Re. It was also shown that the maximum velocity defect U_0 increases with the increase in Reynolds number.

1. Introduction

There are some discrepancies in the distances of self-preservation establishment of a cylindrical far wake in the literature. In an early experiment, Townsend (1949) found that the self-preservation of Reynolds shear stress can be achieved at distances from the cylinder greater than about 500 d. However, more recent investigations by other researchers have indicated that approximate self preservation can be attained at somewhat smaller distances. For example, experiments by LaRue and Libby (1974) established that self-preservation of the first four moments of temperatures can be reached at distances grater than x/d =400. More recently, Browne and Antonia (1986) obtained approximate self-preservation of the Reynolds shear stress and heat flux at x/d > 200.

The state of whether self-preservations in a wake of a flow is universal has drawn some attentions. Townsend (1949) developed the hypothesis that the structure of turbulence in all self-preserving flows is the same. These have also been widespread beliefs in the turbulent community that flows achieve a self-preservation state by becoming asymptotical independent of their initial conditions. It therefore follows that, for example, all wakes should be independent of the generators. Such an argument is a logical consequence of a belief that "turbulence forgets it origin", and can be modelled by its local properties (George, 1989).

Unfortunately, over the past two decades there has been increasing experimental evidence that such a simple picture is not correct. In fact even flows which appears to scale in similarity variables(like centreline velocity and half width) are dependent on their initial conditions. Wygnanski et al (1986) have shown that very different growth rates exist for the wakes behind cylinders and screens, even though both appear to be self-preservating. There have been considerable evidence that a memory of initial conditions persists into the region of self-preservation. This suggestion was supported by the experiments of Bevilagna and Lykoudis (1978). They have shown that two distinct self-preserving states evolved in their study of the wake of a sphere and the wake of a porous disk, with approximately the same drag.

In general, the mean velocity profiles become self-preserving first followed by the Reynolds shear-stress, then higher order turbulence moments. The concepts of a hierarchy of self-preservation has introduced by Bevilagna and Lykoudis (1978).

In the present study, measurements were made of a cylindrical far wake with three different Reynolds numbers. The primary objective is to establish the self-preservation region of the flow by the maximum velocity defect U_0 and the half-width L. The dependence of U_0 and L on the Reynolds number was also investigated.

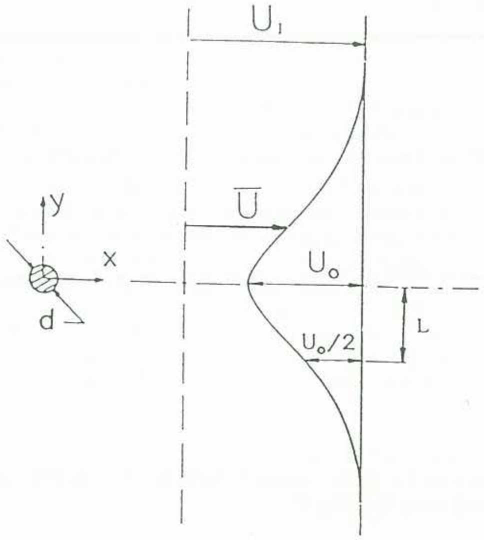

Figure 1 Schematic and definition sketch of a cylindrical far wake

2. Experimental Arrangements

An open circuit suction type wind tunnel with a test section of 400 mm x 400 mm, 2 m long was used to carry out the experiments. The tunnel consists of a settling chamber, a contraction cone, a test section, a transition section and a fan section. In the settling section is a honeycomb to straighten the flow and three mesh screens to reduce the turbulence levels. The 9 to 1 contraction cone is designed to ensure good flow quality in the test section, a transition section was used to connect the square test section and a circular fan section. The axial flow fan is driven by a 7KW AC motor and the bulk velocity in the test section can be varied from 2 m/s to 30 m/s.

A circular cylinder of diameter 2mm made of stainless steel was used as a wake generating body. The cylinder spans horizontally across the mid-plane of the wind tunnel, about 230 mm after the end of the wind tunnel contraction. The two ends of the cylinder was inserted to the two perspex pieces to minimise leakage of the flow. The measurements were made at 3 different free stream velocities, i.e. 6.4, 9.5 and 14.5 m/s, and the corresponding Reynolds numbers are 800, 1,190 and 1,800. The mean velocity was measured by using a single hot-wire probe (5µm diameter Pt- 10% RhWollaston wire, length ≅ 1.0 mm) which was mounted on a height gauge (resolution 0.01 mm). The hot-wire was operated at a resistance ratio of 1.6. The hot-wire was calibrated before and after each series of measurements at the free stream of the test section, using a pitot tube connected to a twin-wire resistance-probe water manometer (Liu et al ,1986) with a resolution of 0.01 mm water. For each point of measurement, three readings for the anemometer output voltage were recorded. The sampling time for each reading is 10 seconds. The average value of these three readings were then used to convert to the mean velocity. The wire calibration constants were determined by a least squares method. This method circumvents the use of the " linearlizer" in the constant temperature anemometer circuit.

3. Results and Discussion

Figure 2 displays the normalised mean velocity defect profiles, $f(\eta)$ plotted as a function of η, for all the three Reynolds numbers studied. The values of $f(\eta)$ is found by normalising the mean velocity defect $(U_1 - \overline{U})$ using U_o as the velocity scale, while the value of η is determined by normalising y using L as the length scale. The least square best fit curve from the results of Browne and Antonia (1986) was also plotted in the figure for comparison. For each of the Reynolds number investigated, it can be seen that all the three sets of profile, conform reasonably well with self-preservation, i.e $f(\eta)$ collapse onto a curve. Although the mean velocity defect profiles have shown that self-preservation is satisfied, the shape of the normalised velocity profile is not a sensitive indicator for self-preservation (Wygnanski and Fiedler, 1969, and Chevray and Tutu, 1978). This is because the mean velocity defect distribution is the easiest to attain self-preservation. Therefore the more sensitive indicators for self-preservation, the centre-line variations of U_o and L with x/d , were used.

Within the framework of self-preservation, where the equation for the conservation of momentum is satisfied on a local and integral basis, if

$$L \sim x^{1/2} \text{ and } U_o \sim x^{-1/2}$$

for a circular cylindrical wake (Hinze, 1975).

The results obtained for the streamwise variations of U_o and L are shown in Figure 3 for the three Reynolds numbers investigated. Measurements were made only for $x/d > 150$, since it is unlikely that self-preservation would be attained before this point, although Freymuth and Uberoi (1971) suggested that self-preservations starts at $x/d > 114$ by mean and rms temperatures.

The experimental distributions of these figures represent the least square best fits to experimental data of $(U_1/U_o)^2$ and $(L/d)^2$ over the range of $157 < x/d < 654$. In all cases, the variations of $(L/d)^2$ and $(U_1/U_o)^2$ with x/d are approximately linear for $x > 157d$. Results also indicated that approximate self-preservation of the wake has been achieved. The variations of C_1, C_2 and virtual origin with Reynolds number are listed in Table I below.

Table I

Re	C_1	C_2	x_o (for L)	x_o (for U_o)
800	0.18	1.03	-105d	-45d
1,190	0.19	1.04	-70d	-95d
1,800	0.20	0.95	-50d	-30d

Note :

$$(L/d)^2 = C_1{}^2 \,[(x - x_o)/d] \qquad (1)$$

$$(U_1/U_o)^2 = C_2{}^{-2} \,[(x - x_o)/d] \qquad (2)$$

The values of C_1 were found to be almost constant, ranging from 0.18 to 0.20. These results are in good agreement with the investigation by Browne and Antonia (1986) who found C_1 to be 0.20 for Re= 1,190. Results of C_2 obtained show that its values ranges from 0.95 to 1.04. This is lower than as compared to 1.28 as obtained by Browne and Antonia (1986). These low values of C_2 found can be attributed to the lower U_o values obtained, causing the gradient of the graph to be steeper than the literature (note that C_2 is the inverse of the square-root of the gradient). A unique value of virtual origin, which is required in equations (1) and (2), cannot be obtained even for small Reynolds number as shown in Table I. This is due to the motor of the wind tunnel cannot maintain a constant speed during the experiment, resulted in a slight variation of the free stream velocity, U_1. As x_o reflects on possible effects of Reynolds numbers and initial conditions, it will be interesting to see the variation of x_o within the range of Reynolds numbers studied while the initial conditions in the present experiment are being kept constant. A feed back control of the motor is suggested and and is going to be installed. Careful measurement should be made to have the characteristics of x_o investigated.

From the results shown in Table II, it is evident that the maximum velocity defects U_o increases with the increasing Reynolds number for all the x/d stations. However, the velocity defect half-width L is not found to have any consistent trend with increasing Reynolds number from the results indicated in Table II. Nevertheless, their differences in magnitudes are not significant. It is therefore no conclusive relation between the half-width L and the Reynolds number. Further experiments also required to investigate the effect of Re on the development of self-preserving flow.

Table II

Re \ x/d		157	305	453	554	654
800	U_o (m/s)	0.44	0.362	0.299	0.274	0.236
	L (mm)	5.8	7.5	8.2	9.2	10.0
1,190	U_o (m/s)	0.623	0.488	0.429	0.376	0.364
	L (mm)	5.6	7.5	8.4	9.3	10.2
1,800	U_o (m/s)	0.965	0.717	0.625	0.567	0.5
	L (mm)	6.2	7.4	8.4	9.7	10.9

4. Conclusion

All the results suggested that the mean velocity defect profiles, maximum velocity defect U_o and the half-width L get approximately self-preserving at distance greater than 150 diameters downstream of the cylinder. It was found that the self-preserving mean velocity defect profiles are independent of Reynolds number. Within the range Re $\cong$ 800 to 1,800 studied, It was also shown that the maximum velocity defect U_o, increases with the increase in Reynolds number. However, there is no conclusive relation between the half-width, L and Re, furthermore, the virtual origin obtained is not unique. The reasons may be due to experimental uncertainties encountered during the measurements. Further detailed experiments are required in order to establish the effect of Re on the variation of half-width and x_o.

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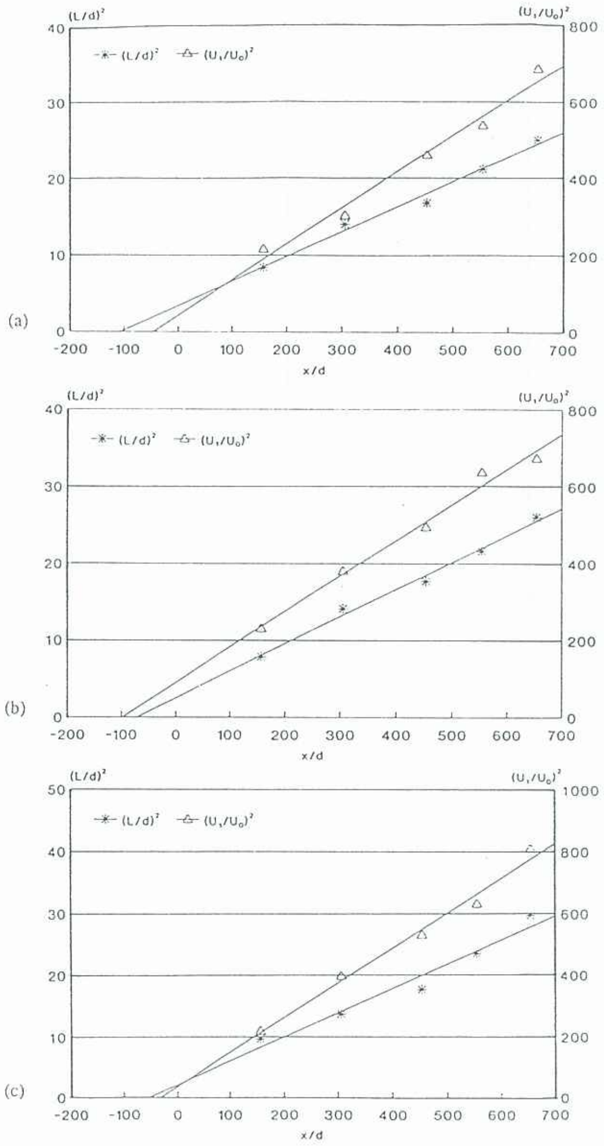

Figure 3 Centre-line variations of the maximum velocity defect U_0, and the half-width L, for (a) Re ≅ 800, (b) Re ≅ 1,190 and (c) Re ≅ 1,800

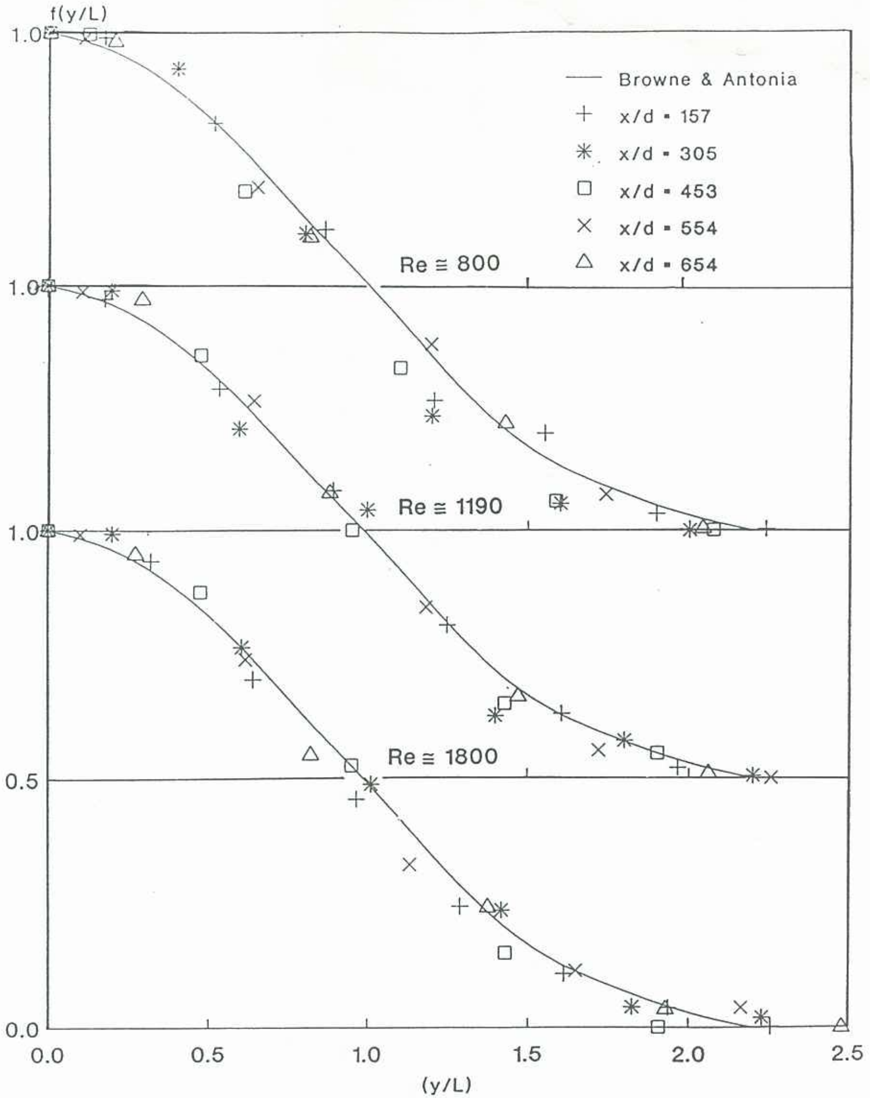

Figure 2 Mean Velocity distributions using self-preserving scales for Reynolds numbers 800, 1,190 and 1,800