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An Investigation of Flow Around Square Cylinders in Tandem

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ABSTRACT

Results of an experimental study of aerodynamic forces act on two square cylinders in tandem arrangement in a unifrom cross-flow are presented. A critical spacing equal to four times the width of the cylinder is found to exist, when the drag force changes sharply. For spacings less than the critical value, the downstream cylinder is subjected to a negative drag force. Velocity distributions within the spacing and in the wake of the downstream cylinders are found to be self similar.

NOMENCLATURE

b	Characteristics shear layer width defined as the distance from the centre of the cylinder to the point where the velocity becomes maximum.
C_D	Drag coefficient = $\frac{F_D}{\frac{1}{2}\rho U_o^2 D}$
Cp	Mean pressure coefficient = $\frac{P-P_o}{\frac{1}{2}\rho U_o^2}$
D	Side length of the square cylinder.
F_D	Drag force per unit length acting on the cylinder.
L	Streamwise centre to centre distance between the two square cylinders.
P	Local static pressure
P_o	Free stream static pressure
Re	Reynolds number = DU_o/ν
u	Mean axial velocity
Δu	Velocity defect ,$u-U_o$.
Δu_{max}	Maximum velocity defect, $(u-U_o)_{max}$.
U_o	Free stream velocity
X	Distance from the centre of the cylinder in the streamwise direction.
Y	Distance from the centre of the cylinder in the transverse direction.
ν	Kinematic viscosity of air.
ρ	Density of air.

INTRODUCTION

Flow past a cylinder is always associated with the separation of flow behind the cylinder incurring large energy losses. Specially in the case of flow past rectangular and square cylinders the separation of flow occurs at the corners of the frontal face and a complex wake is created behind it. Again when more than one cylinder is placed in a uniform flow, the surrounding flow phenomena becomes more complex and results in a different characteristics than in the case of a single body.

Till now extensive works have been carried out on a single cylinder and study on multiple cylinders is a very recent endeavour. An extensive review of such works can be found in Zdrakovich (1977) and Ohya et al (1990). From the flow induced vibration point of view, the square cylinder is also very interesting shape as it is subjected to both vortex resonance and galloping [Luo & Teng, 1990]. The square cylinder has also great importance in engineering as many buildings have either a square or a rectangular cross-section. The interference of the wind load on the square or rectangular cylinders may be investigated either for the cylinders in tandem or staggered arrangement. This paper reports on the interference of the pressure distribution for two equal size square cylinders placed in tandem arrangement. Other references that report on the related topics are Gowda & Sitheeq (1991), Luo & Teng (1990), Mandal & Islam (1980), Bearman & Trueman (1972), Igarashi (1982).

EXPERIMENTAL DETAILS

The expeiment is carried out in an open circuit subsonic wind tunnel in the Fluid Mechanics Laboratory of Mechanical Engineering Department, BUET, Dhaka. The test section of the wind tunel is 457 mm x 457 mm in cross section and 1.5 m long. Air enters the test section after passing through a settling chamber, a converging mouth and a honey comb. The flow is produced by a two stage contra-rotating axial flow fan. Though the fan is capable to produce a maximum velocity of about 50 m/s in the test section, the test is carried out at 7.5 m/s, 14 m/s and 19 m/s of wind speed and the turbulence intensities are estimated to be less than 0.4%.

Two square cylinders 457 mm long are mounted horizontally in tandem position in the middle of the test section (see fig. 1). The cylinders are made of 4 mm thick perspex plate and each has a 50 mm x 50 mm cross section. The aspect ratio of each cylinder is 9 and 1.0 mm dia 36 pressure tappings (9 on each side) are made in the mid span of each cylinder. The PVC tubings from the pressure taps are connected to the various ports of a selection box type FC091 (Furness Controls Ltd., UK) which are in turn connected to the micromanometer type FC-012 (make : Furness Controls Ltd., UK) with an accuracy of 0.1 mm of water column. The free stream velocity through the wind tunel is varied from 7.5 m/s to 19 m/s with the help of a damper placed downstream of the fan.

In the present paper, measurements are carried out at dimensionless streamwise spacing of $1.5 < L/D < 9$. The mean velocity in the wake of the cylinder are measured by pitot static tube connected to the micromanometer.

RESULTS AND DISCUSSIONS

The measurements are carried out at three Reynolds numbers namely 2.5×10^4, 4.7×10^4 and 6.5×10^4 for various spacings between the cylinders. Fig. 2 shows the variation of drag coefficient with dimensionless spacing L/D. The results of Takano et al (1981) and Luo & Teng (1990) are also presented in the figure. A critical spacing equal to $L/D = 4.0$ is found to exist, when C_D for both cylinders increases very sharply. For downstream cylinder (cyl. 2) negative drag exists for $L/D < 4$. However when $L/D > 4$, positive drag occurs. An explanation is given by Luo & Teng (1990) for the above observation. When $L/D < 4$ the boundary layer that separates from the upstream cylinder reattaches on to the downstream cylinder and a region of slow moving fluid is formed which is bounded by the shear layers and the two cylinders. The bounded region is at a pressure that is lower than the wake pressure of the downstream cylinder and hence the latter is subjected to a negative drag force and only the downstream cylinder is shedding vortices. This fact is suppoorted by the pressure distributions shown in figures 3 & 4 for $Re = 2.5 \times 10^4$. For $L/D > 4$, both cylinders are shedding vortices, the pressure distribution at the rear side of the downstream cylinder is lower than the front side and thus subjected to a positive drag. The effect of the downstream cylinder on the upstream cylinder can be noted from the pressure distribution shown the fig. 3. The front face of the upstream cylinder is unaffected whereas the rear face experiences the effect of the critical spacing and thus also giving a different C_D values for the upstream cylinder before and after the critical spacing $L/D = 4.0$. Since the cylinders are symmetrical, indentical pressure distributions occur at top and bottom faces resulting zero lift force. The similar behaviour of pressure distribution for other two Reynolds numbers is also observed.

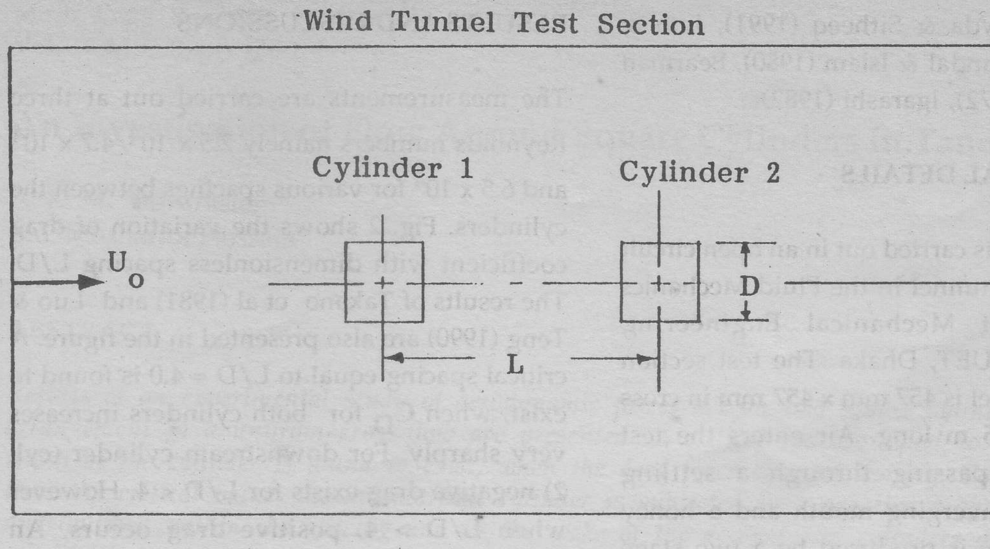

Fig. 1 : Experimental Setup.

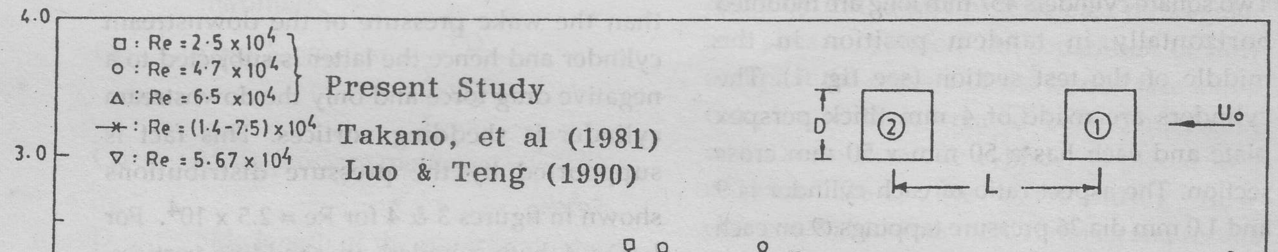

Fig. 2: Drag Coefficient as a function of dimensionless distance.

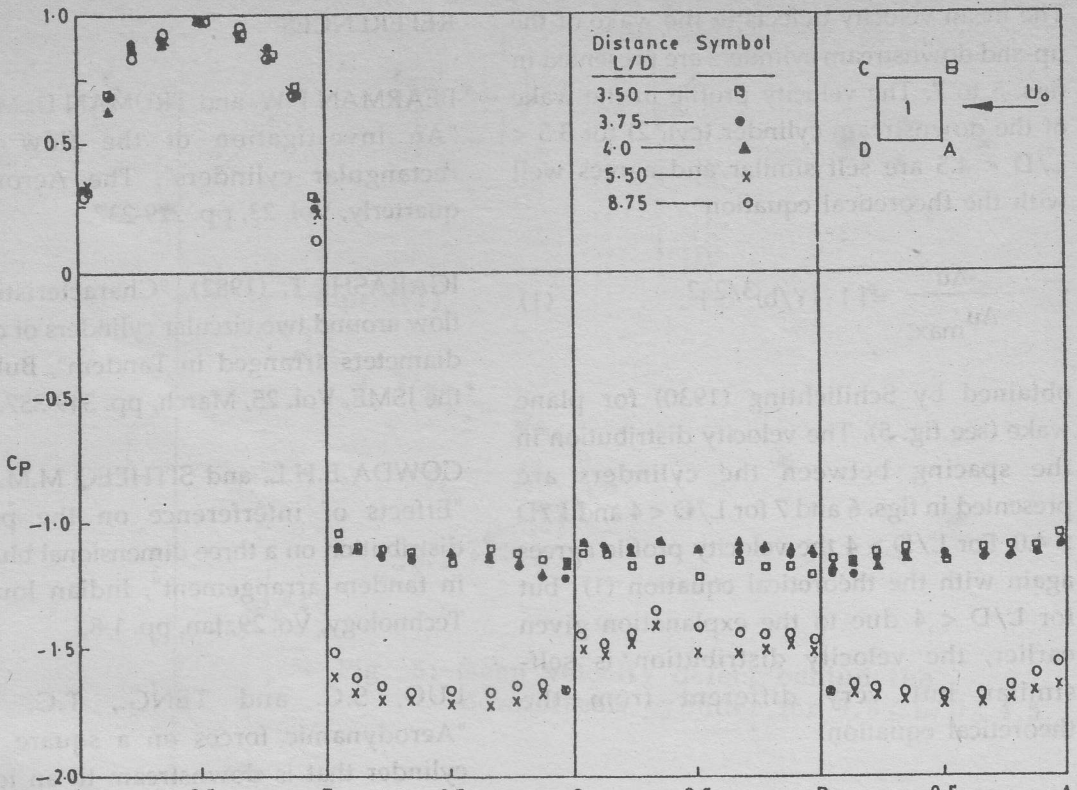

Fig. 3: Effect of L/D on C_p distribution around the upstream cylinder for Re = 2.5 X 10^4.

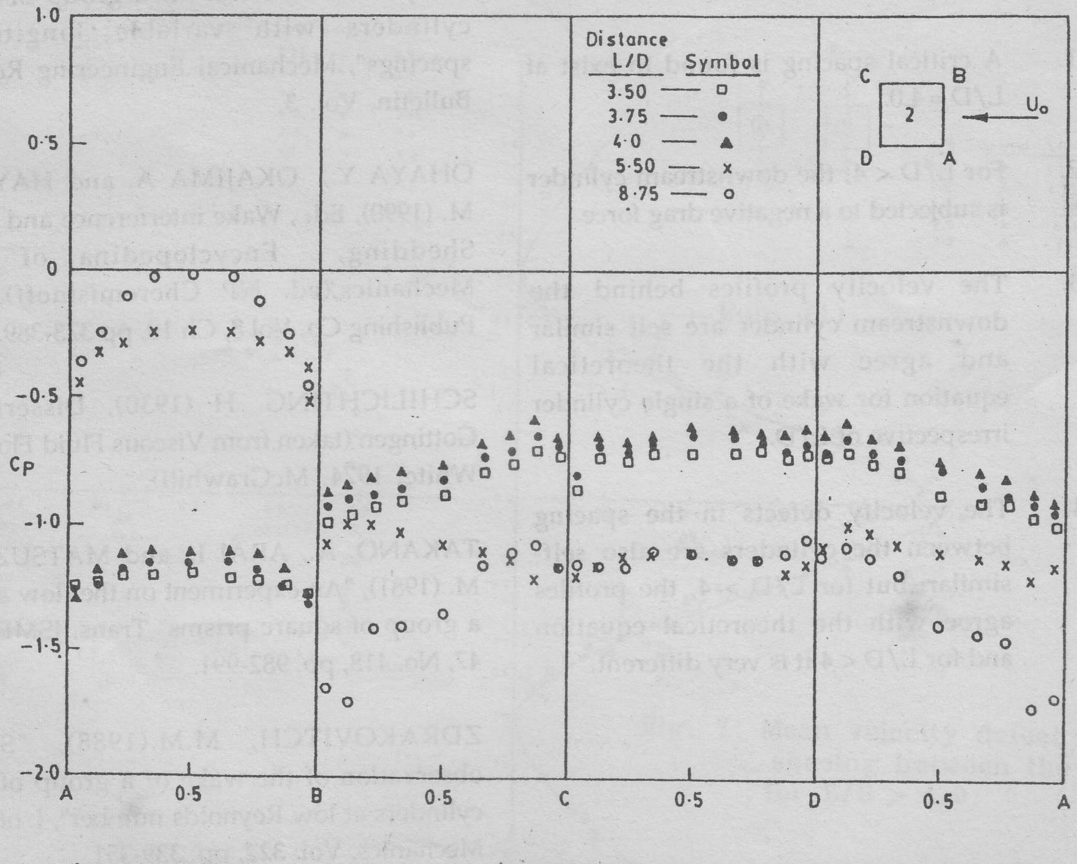

Fig. 4: Effect of L/D on C_p distribution around the downstream cylinder for Re = 2.5 X 10^4.

The mean velocity defects in the wake of the up-and downstream cylinders are presented in figs. 5 to 7. The velocity profile in the wake of the downstream cylinder (cyl. 2) for $3.5 < L/D < 4.5$ are self similar and agrees well with the theoretical equation

$$\frac{\Delta u}{\Delta u_{max}} = [1 - (Y/b)^{3/2}]^2 \qquad (1)$$

obtained by Schilichting (1930) for plane wake (see fig. 5). The velocity distribution in the spacing between the cylinders are presented in figs. 6 and 7 for $L/D < 4$ and $L/D > 4.0$. For $L/D > 4$ the velocity profile agrees again with the theoretical equation (1) but for $L/D < 4$ due to the explanation given earlier, the velocity distribution is self-similar but very different from the theoretical equation.

CONCLUSIONS

From the results presented and discussed for two square cylinders in tandem arrangment the following conclusions are drawn :

1. A critical spacing is found to exist at $L/D = 4.0$.
2. For $L/D < 4$, the downstream cylinder is subjected to a negative drag force.
3. The velocity profiles behind the downstream cylinder are self similar and agree with the theoretical equation for wake of a single cylinder irrespective of L/D.
4. The velocity defects in the spacing between the cylinders are also self-similar, but for $L/D > 4$, the profiles agree with the theoretical equation and for $L/D < 4$ it is very different.

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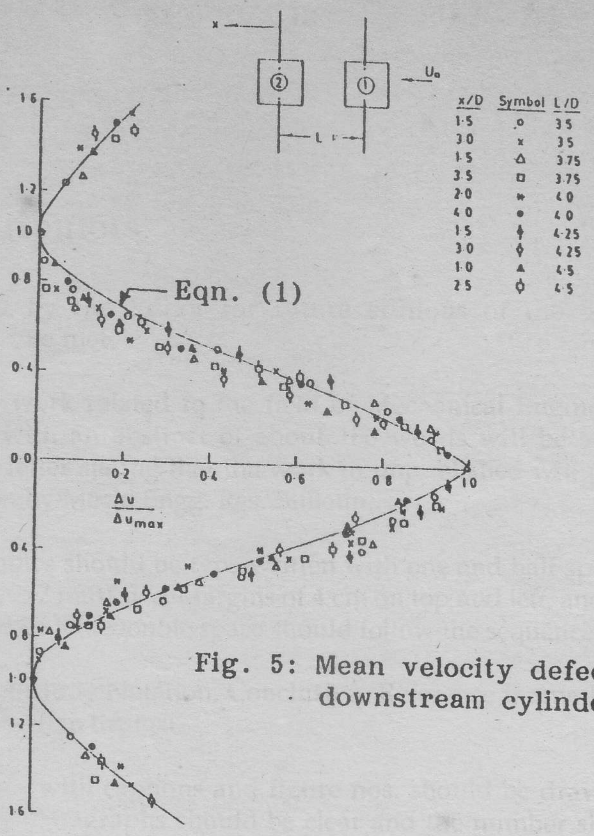

Fig. 5: Mean velocity defect behind the downstream cylinder for 3.5 ≤ L/D ≤ 4.5.

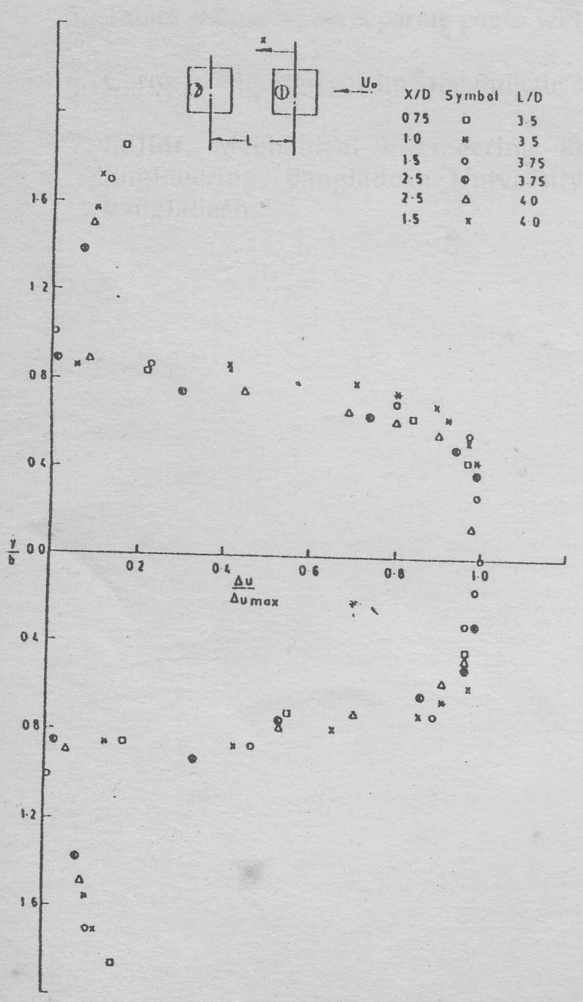

Fig. 6: Mean velocity defect in the spacing between the cylinders for L/D ≤ 4.0.

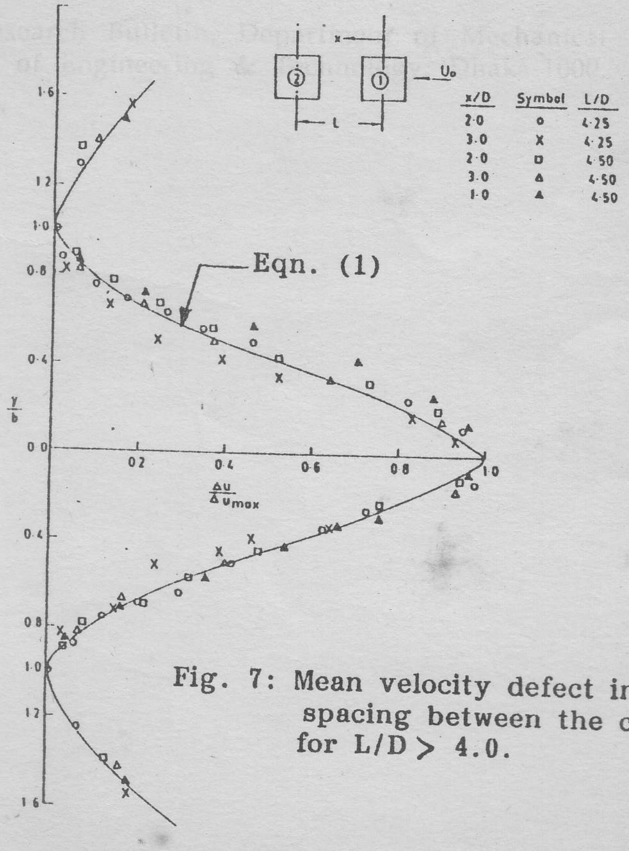

Fig. 7: Mean velocity defect in the spacing between the cylinders for L/D > 4.0.