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EFFECT OF LONGITUDINAL SPACING ON STATIC PRESSURE DISTRIBUTION OF RECTANGULAR CYLINDERS

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ABSTRACT

An experimental investigation of static pressure distributions on a group of rectangular cylinders for a uniform cross flow is presented. The effect of longitudinal spacing as well as the side dimension of the cylinder encountered in the investigation. The lift and drag coefficients which are calculated from the measured pressure distributions are also presented.

INTRODUCTION

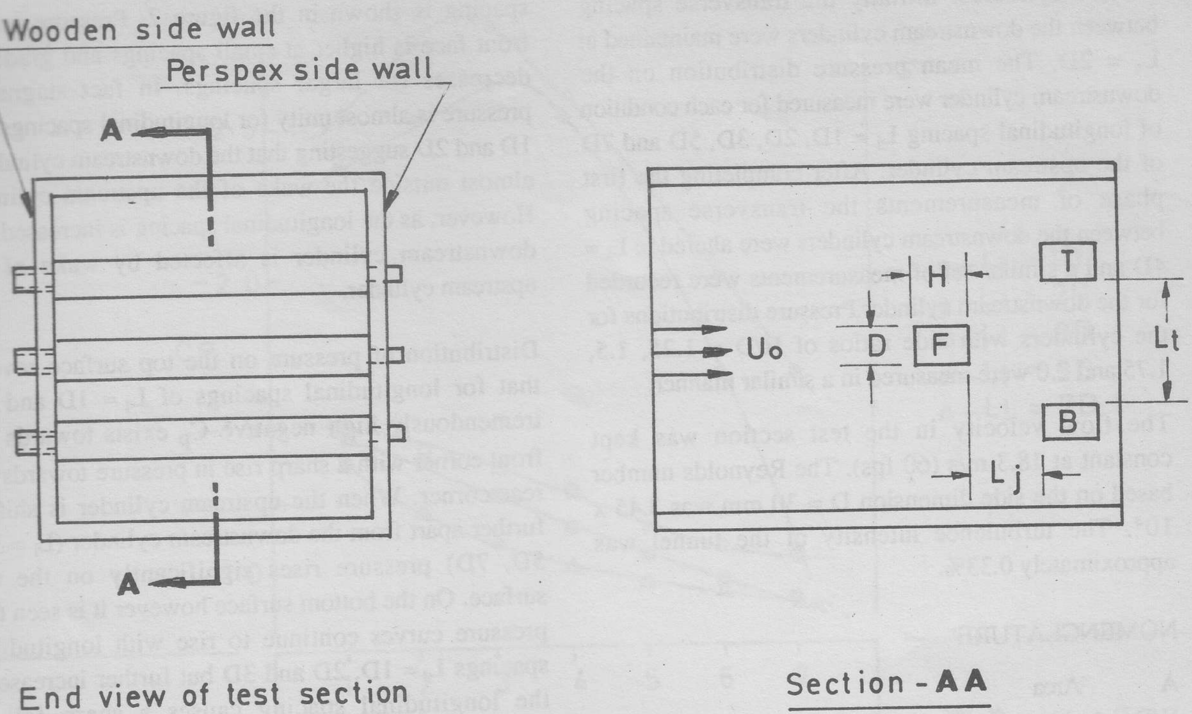
While numerous investigations have been made of the flow past single obstacles with various shapes, few studies have been made of the wake interference and vortex shedding associated with complex configurations consisting of multiple obstacles. When more than one bluff body is placed at close proximity in a uniform flow, the aerodynamic parameters like drag and lift forces, moments, pressure distributions and vortex shedding patterns are completely different from the case of a single body, because their wakes or vortex streets interfere in a complex manner, depending on the arrangement or spacing of the bodies. Practical application of a knowledge of the interference of bluff body flows are many which include engineering problems associated with groups of skyscrapers, chimneys, towers, transmission line conductors, heat exchanger tubes etc.

In the field of bluff body aerodynamics, one of the most frequently investigated objects is the circular cylinder. However, rectangular section cylinders also has great importance in engineering as many buildings have either a rectangular or square cross-section. Also the presence of a large region of separated flow and very complex structures in the wake of rectangular bodies necessitates detailed investigation of flow pattern and aerodynamic characteristics about multiple square or rectangular cylinders. Till now extensive investigation has been carried out in the area of flow past a single square cylinder.Much less has been done in the field of two or more cylinders, particularly rectangular cyliners. In the present paper the mean pressure distribution and aerodynamic forces that act on a group of rectanguar cylinders with change in side dimension as well as transverse spacing are measured and reported.

EXPERIMENTAL SET-UP

The experimental measurements were carried out in an open-loop wind tunnel about 16 m long. The test section is 1.52 m in length and has a 457.2 mm x 457.2 mm square cross-section. Four sets of rectangular section cylinders were fabricated with three identical cylinders in each set. All the twelve cylinders were made of 4 mm thick perspex plate and each measured 457.2 mm in length. The cross-section of the cylinders were width D = 30 mm for all and height H = 37.5 mm, 45 mm, 52.5 mm and 60 mm respectively for each set of cylinders. Each rectangular cylinder was tapped at midspan on two adjacent sides. The pressure tappings were connected to the limbs of a multimanometer for measurement of midspan circumferential pressure distribution. Water was used as the manometric liquid.

As shown in the figure 1, three rectangular cylinders of identical dimension were mounted horizontally in the staggered form with one cylinder placed centrally in the upstream side and the other two placed symmetrically in the downstream side with respect to the tunnel axis. Since the top downstream cylinder (T) and the bottom downstream cylinder (B) were symmetrically placed, pressure tappings of the bottom downstream cylinder were connected to the limbs of a multimanometer. The top downstream cylinder and the upstream cylinder was always used as



End view of test section

Section - AA

Figure 1: Tunnel test section showing the position of cylinders in staggered form.

passive cylinders. Initially the transverse spacing between the downstream cylinders were maintained at L_t = 2D. The mean pressure distribution on the downstream cylinder were measured for each condition of longitudinal spacing L_l = 1D, 2D, 3D, 5D and 7D of the upstream cylinder. After completing the first phase of measurements the transverse spacing between the downstream cylinders were altered to L_t = 4D and a similar set of measurements were recorded for the downstream cylinder.Pressure distributions for the cylinders with side ratios of H/D = 1.25, 1.5, 1.75 and 2.0 were measured in a similar manner.

The flow velocity in the test section was kept constant at 18.3 m/s (60 fps). The Reynolds number based on the side dimension D = 30 mm was 3.45×10^4. The turbulence intensity of the tunnel was approximately 0.33%.

NOMENCLATURE

A	Area
H/D	side ratio of cylinder
C_D	Drag coefficient
L_l	Longitudinal spacing
C_L	lift coefficient
Lt	Transverse spacing
C_p	Pressure coefficient
p	local static pressure
D	width of cylinder
P_o	Free stream static pressure
F_D	Drag force
U_o	Free stream velocity
F_L	lift force
H	Breadth of cylinder
α	Angle of attack
ρ	Density of air

RESULTS AND DISCUSSIONS

The drag and lift forces acting on the downstream cylinder at various combination of L_l and L_t are calculated by numerical integration. At first the influence of the upstream cylinder on the downstream cylinders for transverse spacing L_t = 2D is discussed. Later examination of aerodynamic forces and pressure distribution on the downstream cylinder is made for L_t = 4D.

Flow Characteristics at L_t = 2D

The variation of C_p-distribution on the downstream cylinder of side ratio H/D = 1.25 with longitudinal spacing is shown in the figure 2. Pressure on the front face is higher at small spacings and gradually decreases for larger spacings. In fact stagnation pressure is almost unity for longitudinal spacings L_l = 1D and 2D suggesting that the downstream cylinder is almost outside the wake of the upstream cylinder. However, as the longitudinal spacing is increased, the downstream cylinder is affected by wake of the upstream cylinder.

Distribution of pressure on the top surface reveals that for longitudinal spacings of L_l = 1D and 2D tremendously high negative C_p exists towards the front corner with a sharp rise in pressure towards the rear corner. When the upstream cylinder is shifted further apart from the downstream cylinder (L_l = 3D, 5D, 7D) pressure rises significantly on the top surface. On the bottom surface however it is seen that pressure curves continue to rise with longitudinal spacings L_l = 1D, 2D and 3D but further increase in the longitudinal spacing causes a sharp fall in pressure near the front corner probably due to influence of wake.

On the back surface of the cylinder it is seen that the C_p-values increases with increase in longitudinal spacing.

The pressure distribution around the rectangular cylinders with side ratios of H/D = 1.5 and 1.75 are shown in figure 3 and 4 respectively. The nature of pressure distribution around these cylinders are more or less similar to those for H/D = 1.25. However, at the bottom surface considerably low pressure exists near the front corner and pressure recovery takes place towards the rear for spacings L_l = 3D, 5D and 7D. For the cylinder with side ratio H/D = 1.75 significantly large negative C_p-value occurs near the front corner at longitudinal spacing of L_l = 2D and also lowest pressure on the back surface is observed.

When the side ratio of the cylinder is H/D = 2 it can be seen from the figure 5 that the pressure curves on the front face are close to unity for all longitudinal spacings suggesting that the cylinder is relatively less influenced by wake of the upstream cylinder. On the top surface large suction pressure occur for longtudinal spacing L_l = 1D only. Also when L_l = 2D the C_p-curve is more or less uniform for both top and bottom surface of the cylinder.

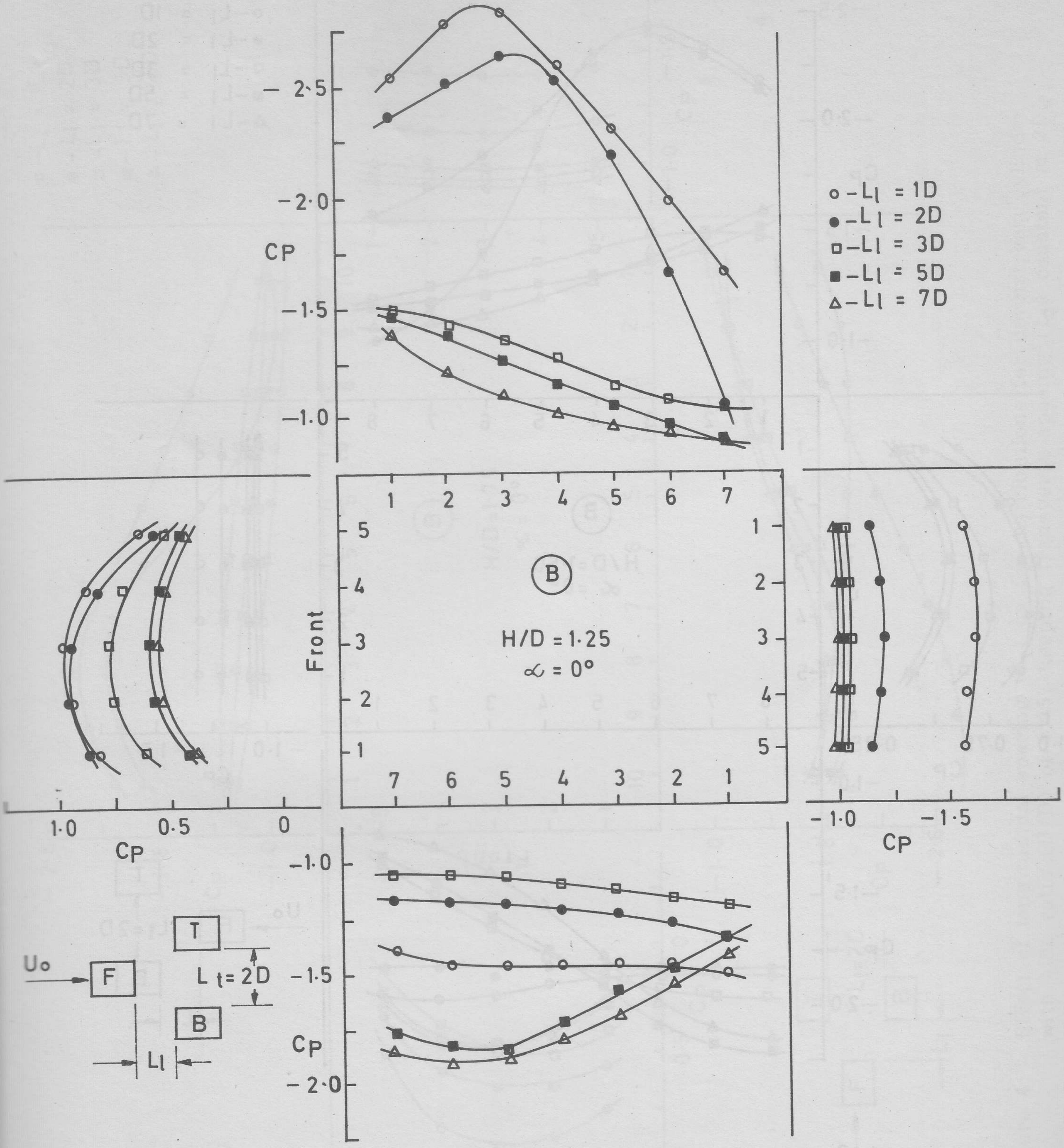


Figure 2: Effect of longitudinal spacing (L_l) on Cp-distribution for downstream cylinders with side ratio (H/D) of 1.25, keeping transverse spacing (L_t) constand at 2D.

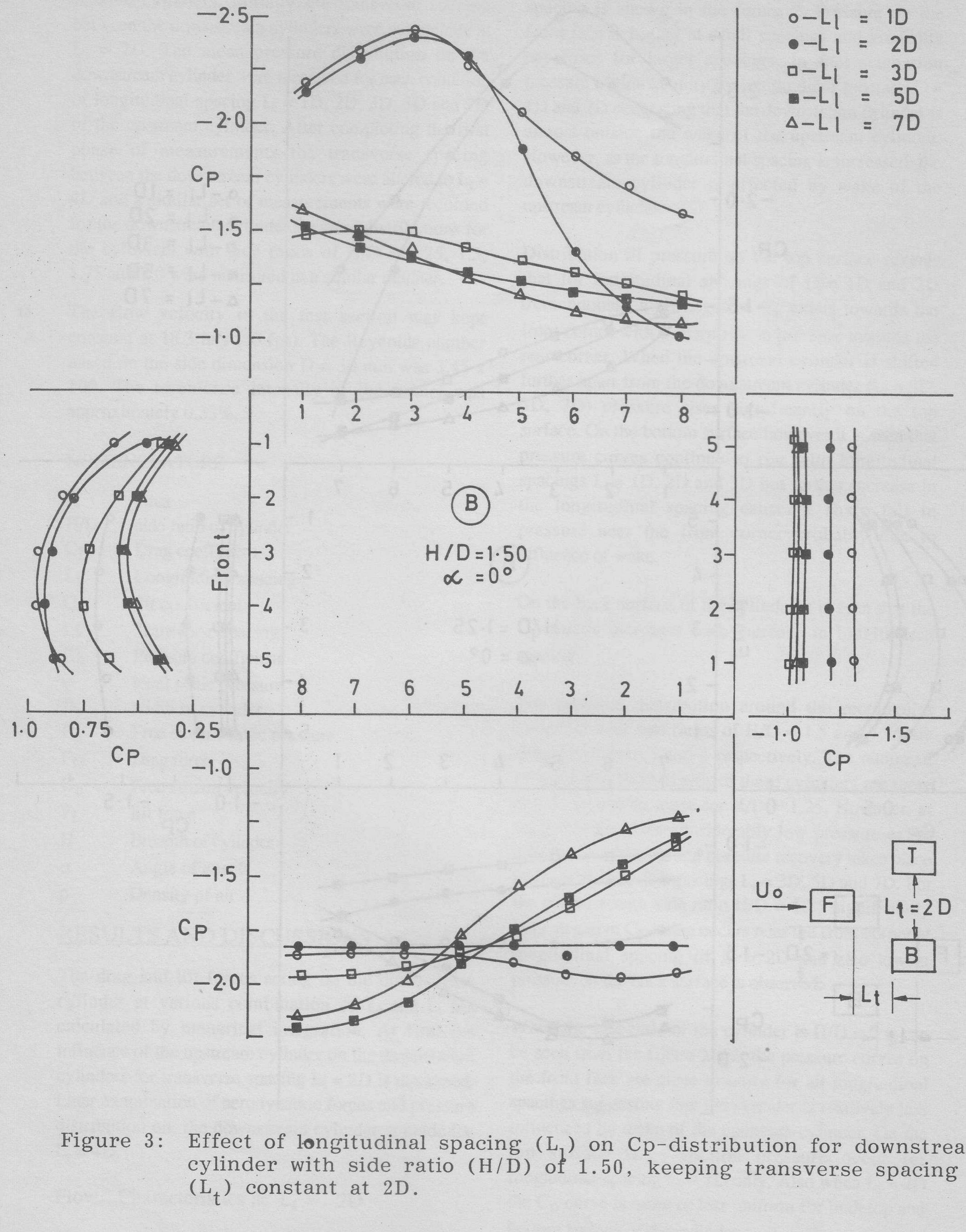


Figure 3: Effect of longitudinal spacing (L_l) on Cp-distribution for downstream cylinder with side ratio (H/D) of 1.50, keeping transverse spacing (L_t) constant at 2D.

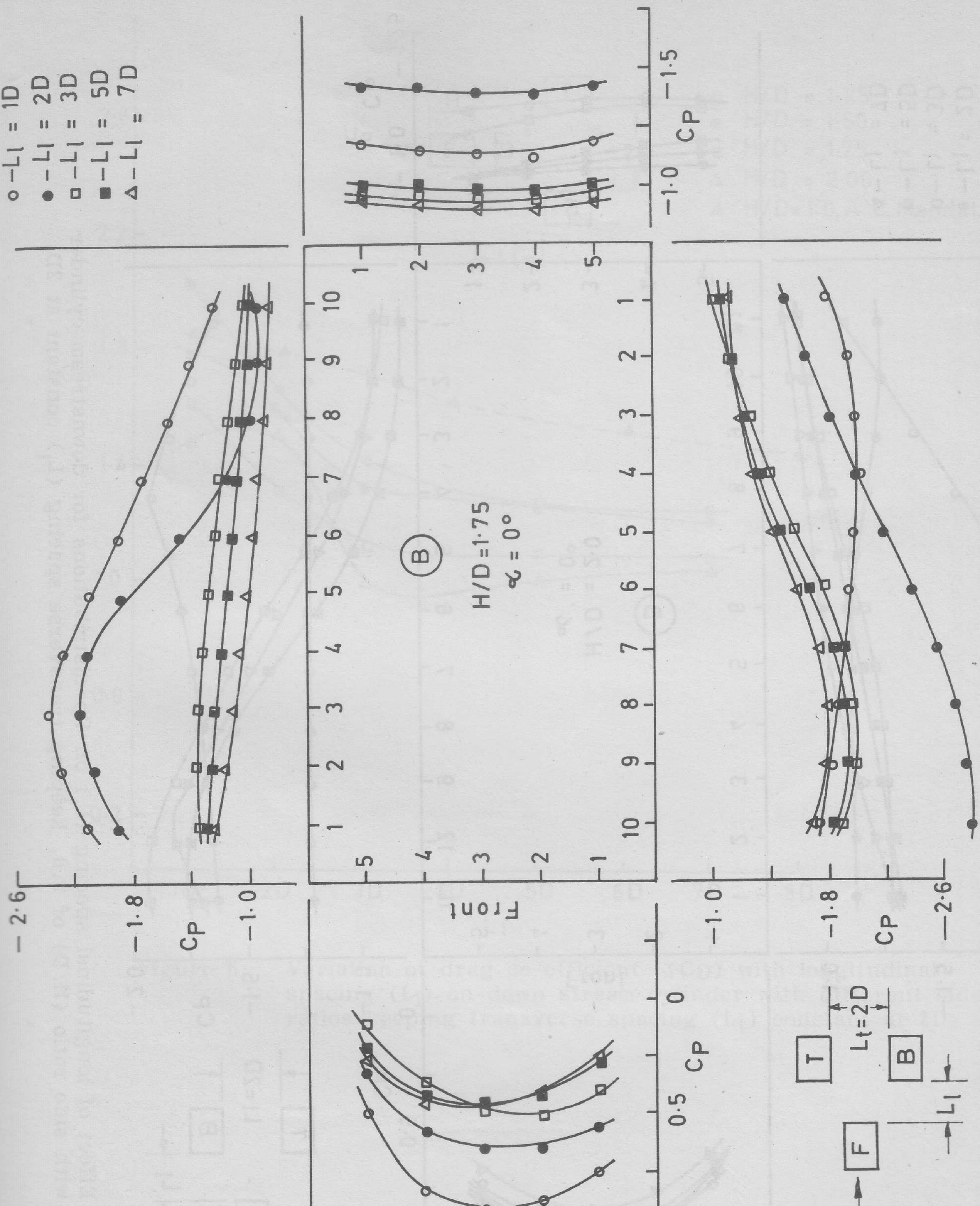


Figure 4: Effect of longitudinal spacing (L_l) on Cp-distributions for downstream cylinder with side ratio (H/D) of 1.75, keeping transverse spacing (L_t) constant at 2D.

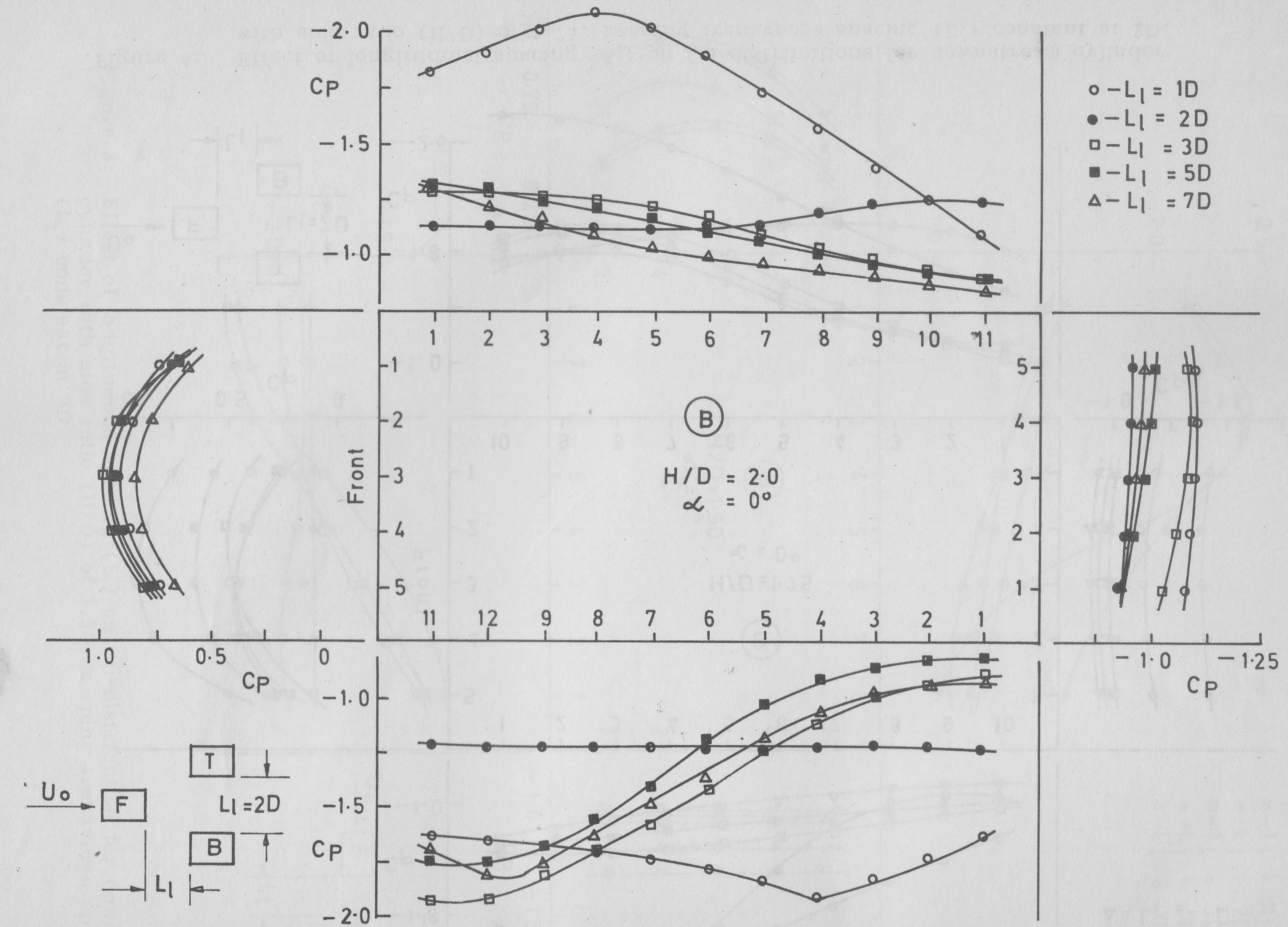


Figure 5: Effect of longitudinal spacing (L_1) on Cp-distributions for downstream cylinder with side ratio (H/D) of 2.0, keeping transverse spacing (L_1) constant at 2D.

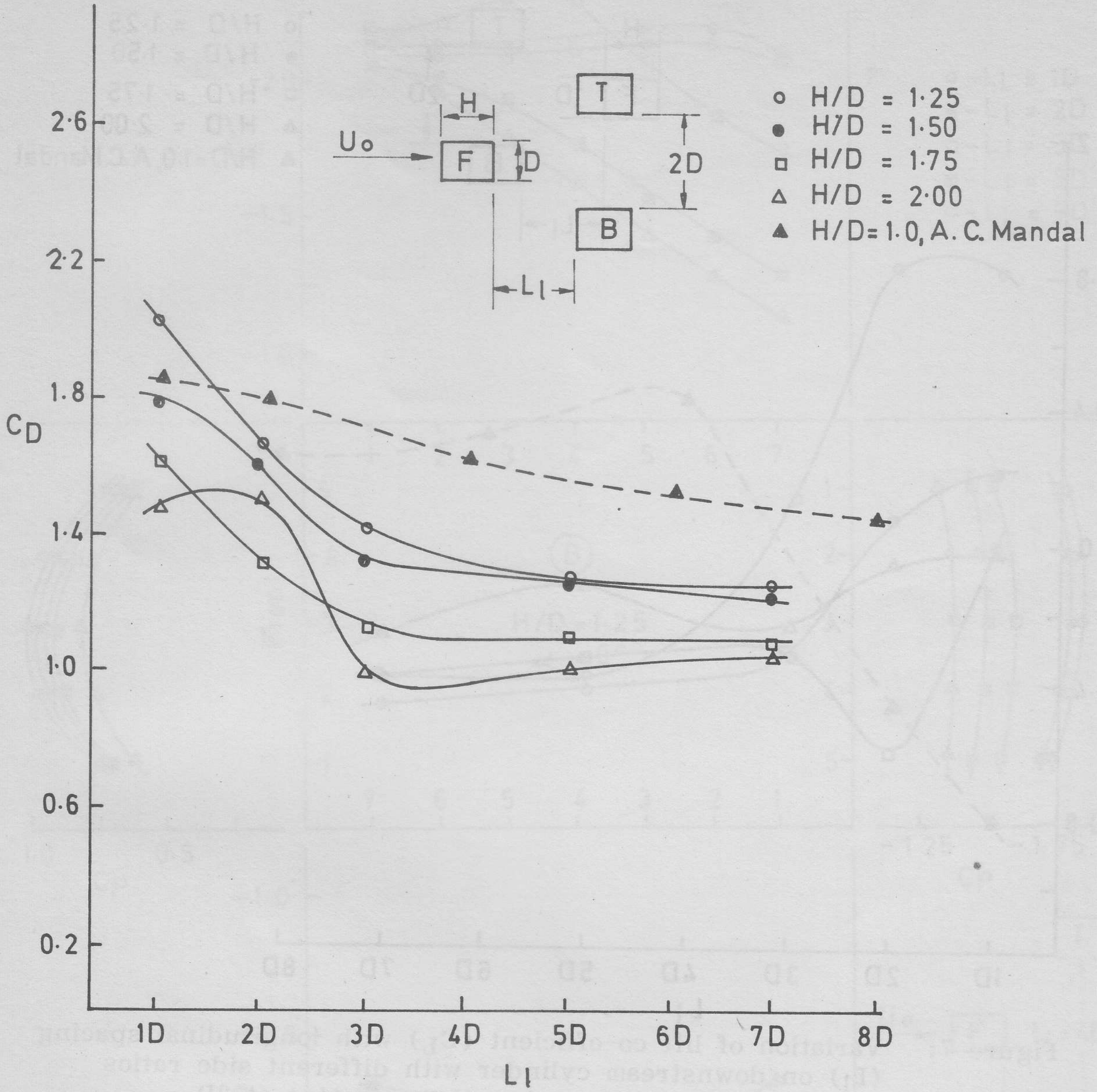


Figure 6: Variation of drag co-efficient (C_D) with longitudinal spacing (L_l) on down stream cylinder with different side ratios keeping transverse spacing (L_t) constant at 2D.

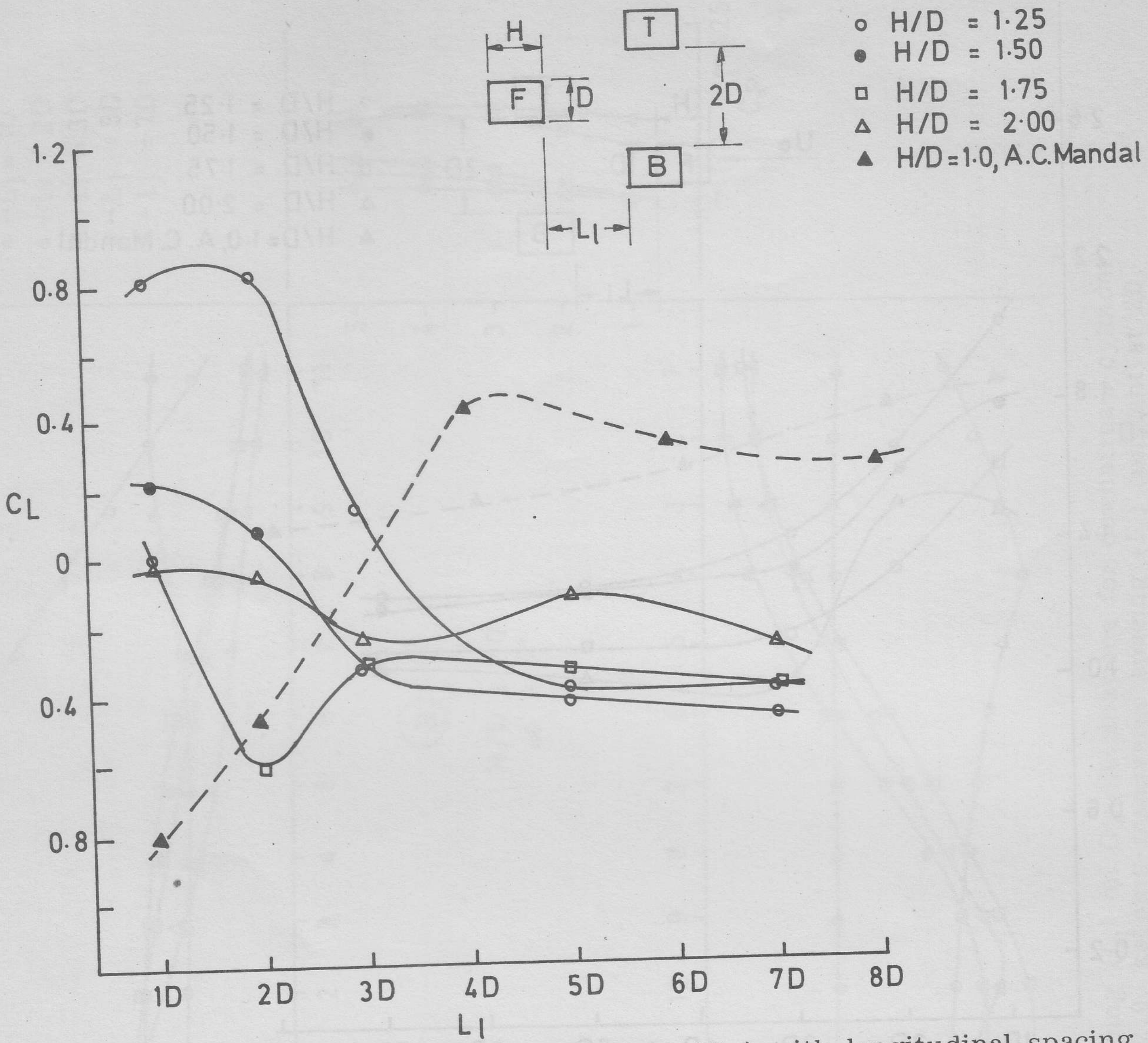


Figure 7: Variation of lift co-efficient (C_L) with longitudinal spacing (L_l) on downstream cylinder with different side ratios keeping transverse spacing (L_t) constánt at 2D.

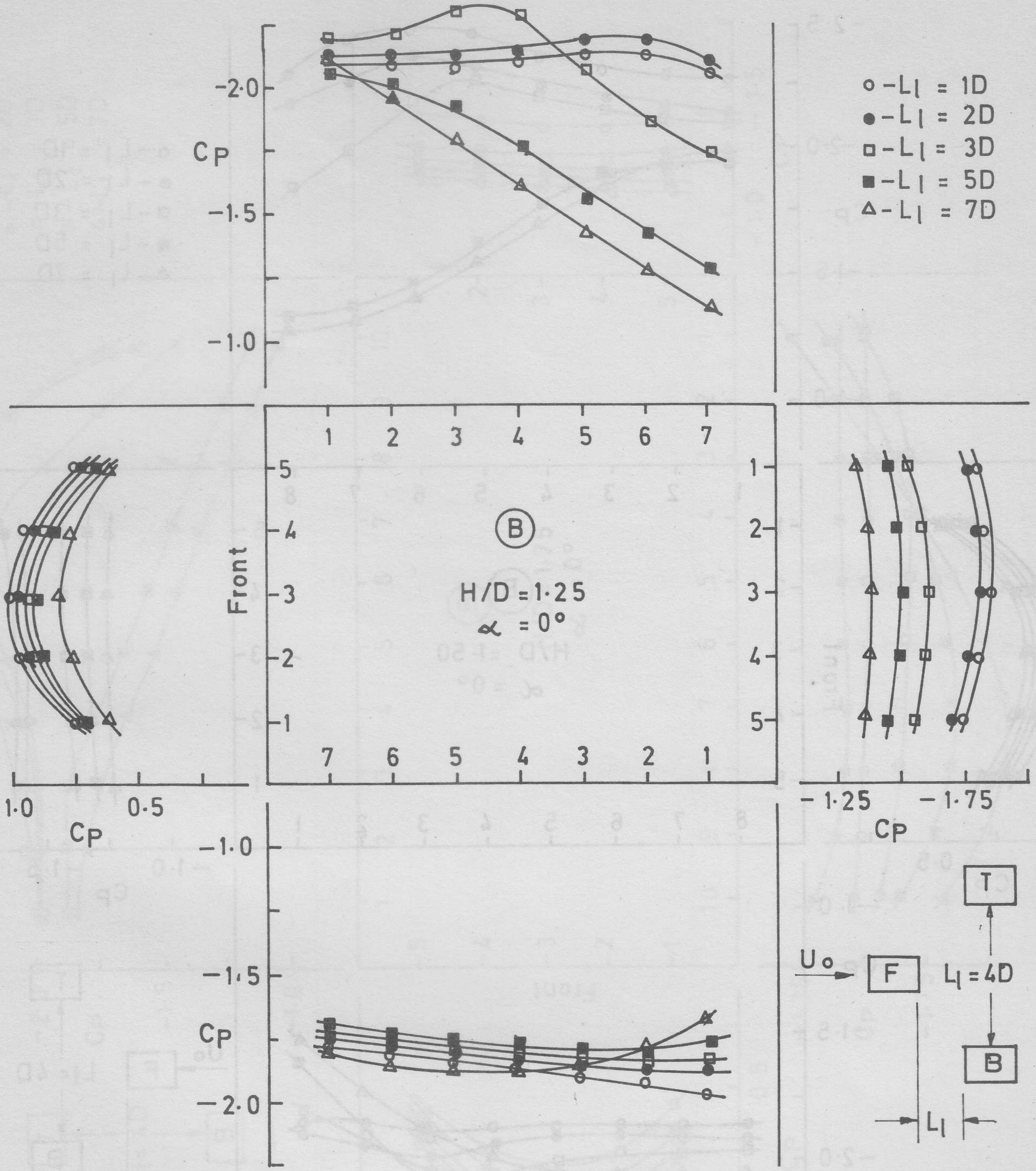


Figure 8: Effect of longitudinal spacing (L_l) on Cp-distribution for downstream cylinder with side ratio (H/D) of 1.25, keeping transverse spacing (L_t) constant at 4D.

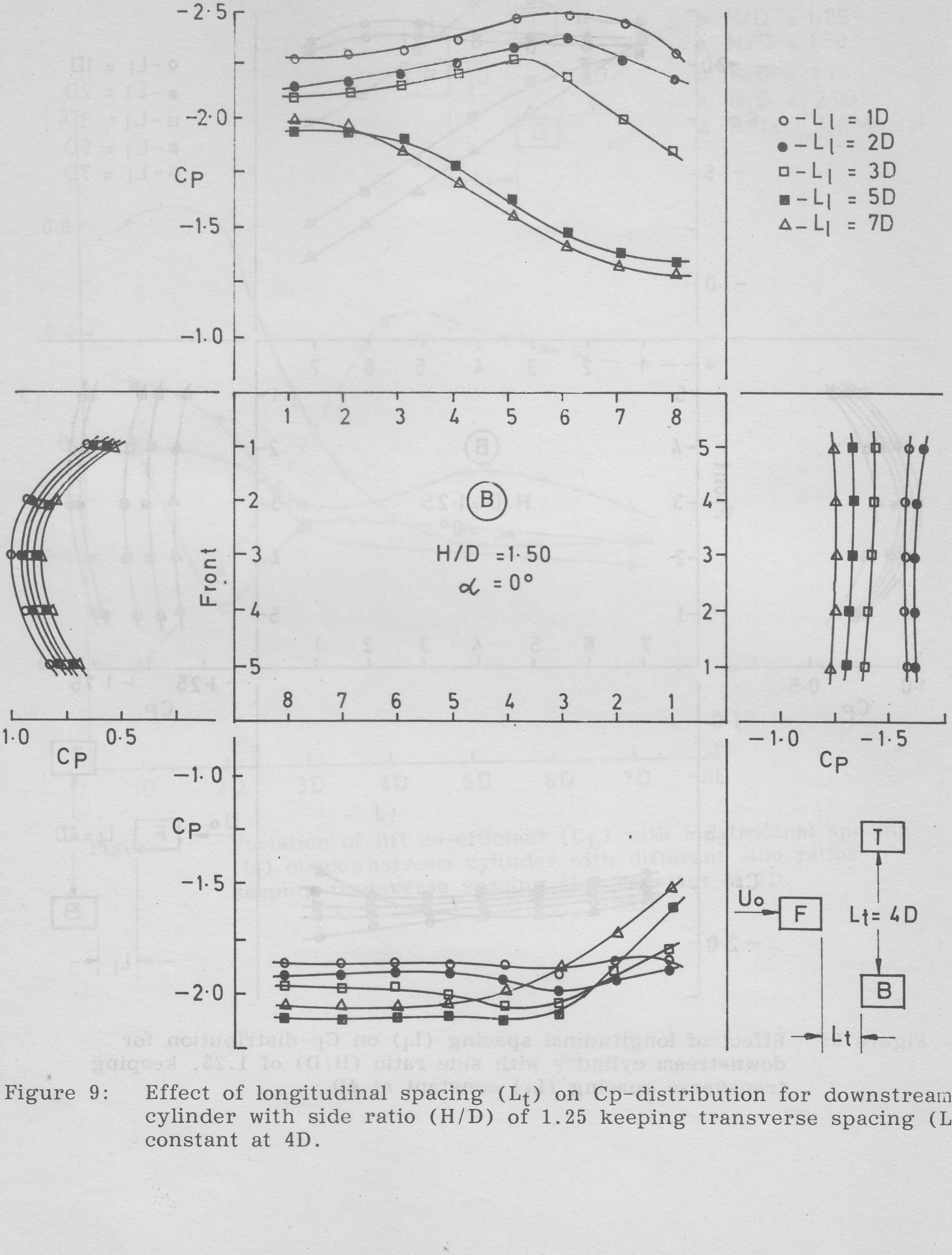


Figure 9: Effect of longitudinal spacing (L_t) on Cp-distribution for downstream cylinder with side ratio (H/D) of 1.25 keeping transverse spacing (L_t) constant at 4D.

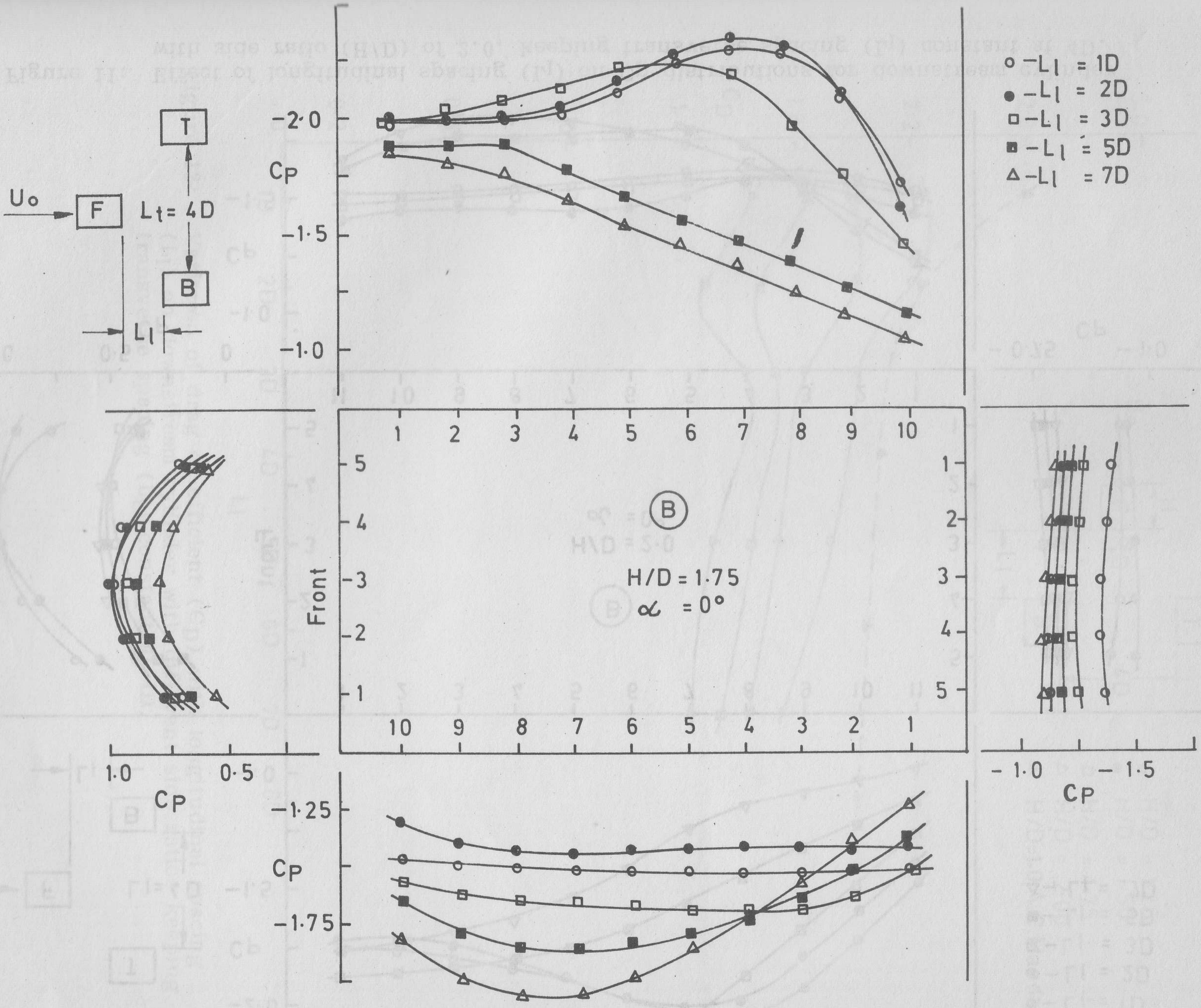


Figure 10: Effect of longitudinal spacing (L_l) on Cp-distribution for downstream cylinder with side ratio (H/D) of 1.75 keeping transverse spacing (L_t) constant at 4D.

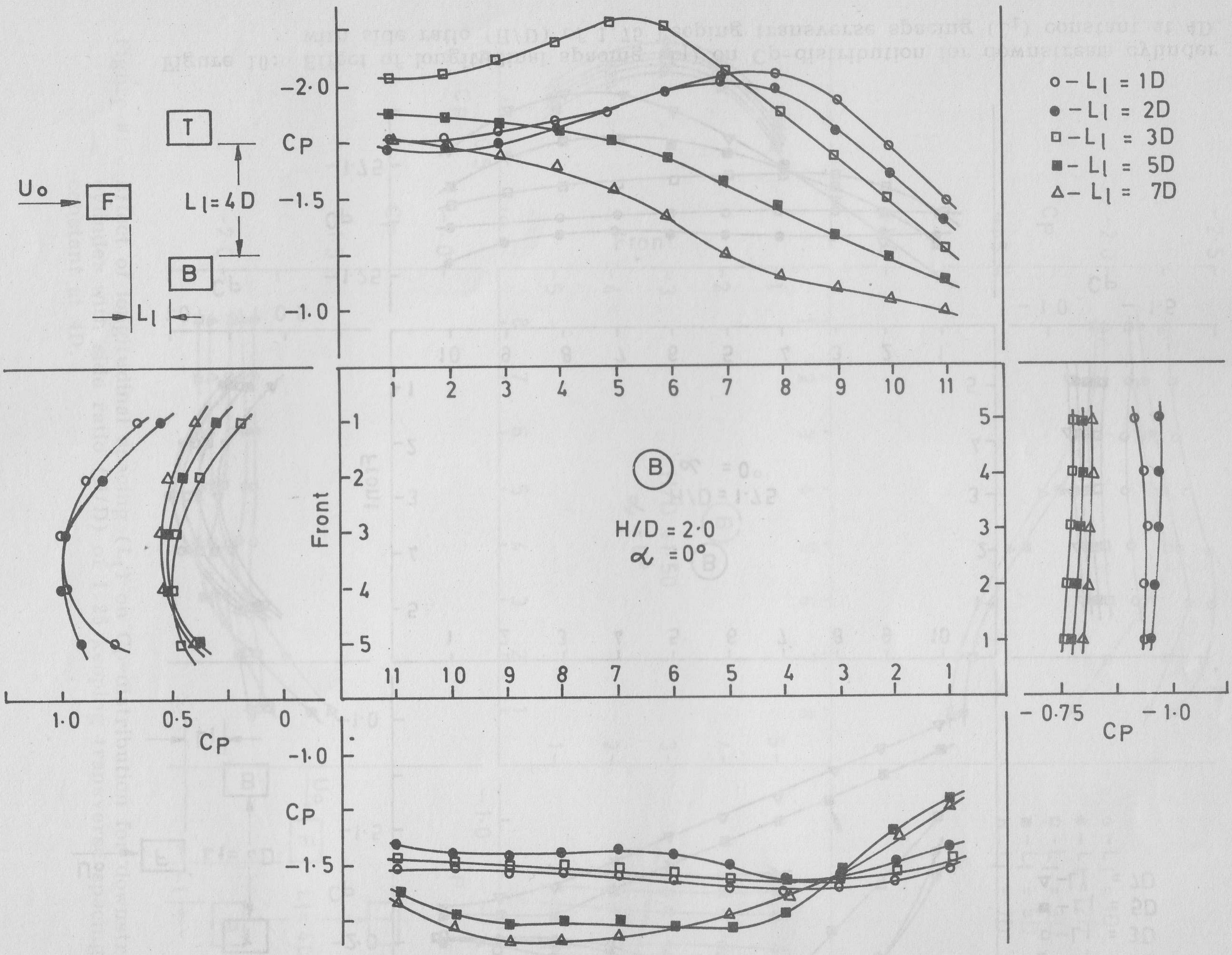


Figure 11: Effect of longitudinal spacing (L_l) on Cp-distributions for downstream cylinder with side ratio (H/D) of 2.0, keeping transverse spacing (L_l) constant at 4D.

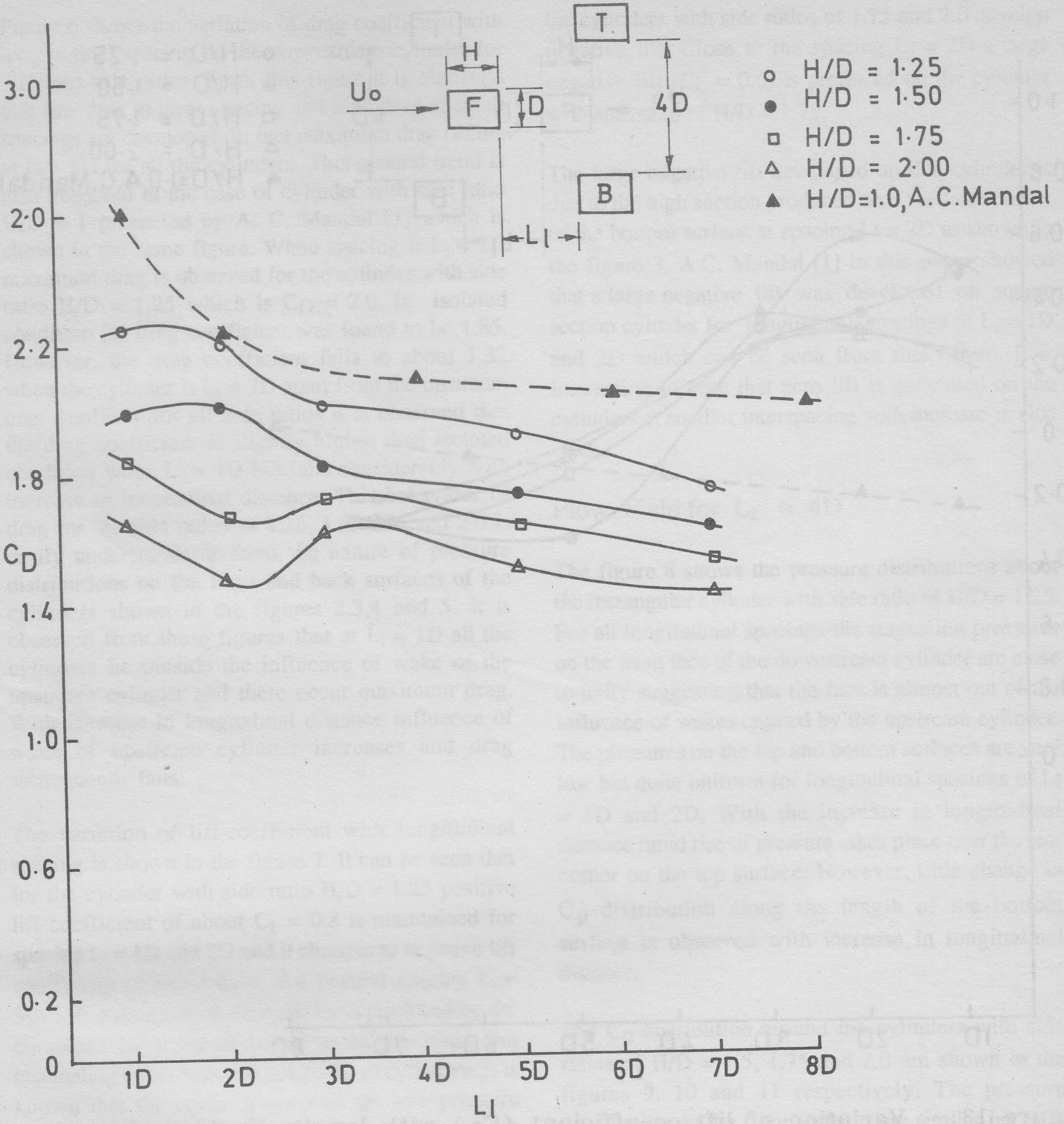


Figure 12: Variation of drag co-efficient (C_D) with longitudinal spacing (L_l) on downstream cylinder with different side ratios keeping transverse spacing (L_t) constant at 4D.

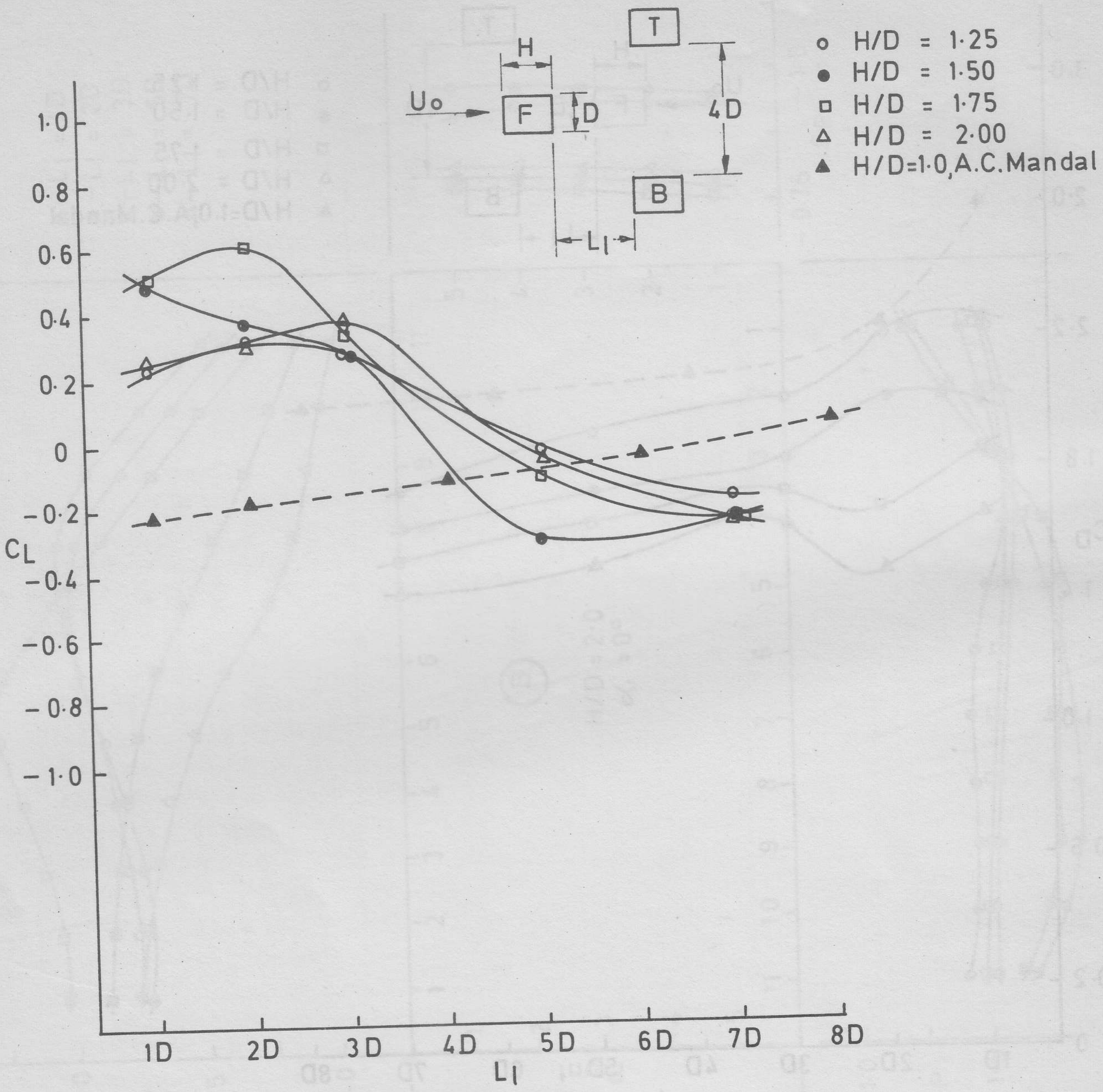


Figure 13: Variation of lift co-efficient (C_L) with longitudinal spacing (L_l) on downstream cylinder with different side ratios keeping transverse spacing (L_t) constant at 4D.

Figure 6 shows the variation of drag coefficient with longitudinal spacing on the downstream cylinder for different side ratios. From this figure it is observed that low drag at large spacing and high drag at small spacings are developed. In fact maximum drag occurs at $L_l = 1D$ for all the cylinders. This general trend is also observed in the case of cylinder with side ratio $H/D = 1$ presented by A. C. Mandal [1] which is shown in the same figure. When spacing is $L_l = 1D$ maximum drag is observed for the cylinder with side ratio $H/D = 1.25$ which is $C_D = 2.0$. In isolated condition [2] drag coefficient was found to be 1.85. However, the drag coefficient falls to about 1.32 when the cylinder is $L_l = 7D$ apart from the upstream one. Similarly for all side ratios it is observed that the drag coefficient is slightly higher than isolated condition when $L_l = 1D$ but falls considerably with increase in longtudinal distance. This behaviour of drag for the side ratios of 1.25, 1.5, 1.75 and 2.0 is easily understandable from the nature of pressure distributions on the front and back surfaces of the cylinders shown in the figures 2,3,4 and 5. It is observed from these figures that at $L_l = 1D$ all the cylinders lie outside the influence of wake of the upstream cylinder and there occur maximum drag. With increase in longtudinal distance influence of wake of upstream cylinder increases and drag subsequently falls.

The variation of lift-coefficient with longitudinal spacing is shown in the figure 7. It can be seen that for the cylinder with side ratio $H/D = 1.25$ positive lift coefficient of about $C_L = 0.8$ is maintained for spacing $L_l = 1D$ and 2D and it changes to negative lift coefficient of about $C_l = -0.4$ beyond spacing $L_l = 5D$. Lift generation on the cylinder is produced by the combined influence of vortex street proximity and channeling effect between the group of cylinders. It is known that the cores of vortices are low pressure regions in a flow field. At spacing $L_l = 1D$ and 2D the downstream cylinder is just outside the wake of the upstream cylinder. But it seems that the top surface is close to the mean locus of cores of vortices shed by the upstream cylinder as a result of which very high suction pressure is developed on the top surface as shown in the figure 2. As a result a positive lift is generated. However, beyond $L_l = 5D$ it can be seen from the figure 2 that the bottom surface experience low pressure due to influence of wake of upstream cylinder and a negative lift is generated. It can be noted that the cylinder with side ratio $H/D = 1.5$ also experience positive lift in the lower range of longitudinal spacings. However, for the same range the cylinders with side ratios of 1.75 and 2.0 develop negative lift. Close to the spacing $L_l = 2D$ a large negative lift ($C_L = 0.6$) is produced on the cylinder with side ratio of $H/D = 1.75$.

The large negative lift developed on this cylinder is due to the high suction produced near the front corner of the bottom surface at spacing $L_l = 2D$ as shown in the figure 3. A.C. Mandal [1] in this paper showed that a large negative lift was developed on square section cylinder for longtudinal spacings of $L_l = 1D$ and 2D which can be seen from this figure. It is interesting to note that zero lift is generated on the cylinders at smaller interspacing with increase in side ratio.

Flow Field for $L_t = 4D$:

The figure 8 shows the pressure distributions about the rectangular cylinder with side ratio of $H/D = 1.25$. For all longitudinal spacings the stagnation pressures on the front face of the downstream cylinder are close to unity suggesting that the face is almost out of the influence of wakes created by the upstream cylinder. The pressures on the top and bottom surfaces are very low but quite uniform for longitudinal spacings of $L_l = 1D$ and 2D. With the increase in longitudinal distance rapid rise of pressure takes place near the rear corner on the top surface. However, little change in C_p-distribution along the length of the bottom surface is observed with increase in longitudinal distance.

The C_p-distribution around the cylinders with side ratios of $H/D = 1.5$, 1.75 and 2.0 are shown in the figures 9, 10 and 11 respectively. The pressure distribution on the front surfaces are similar but with the side ratio of $H/D = 2$ the pressures are comparatively lower for larger longitudinal spacing suggesting relatively higher influence of wake produced by upstream cylinder. On the top surface of each cylinder low pressure exists near the front corner at all longitudinal spacings. However, rise in pressure towards the rear corner at all longitudinal spacings is observed only for the cylinders with side ratio of $H/D = 1.75$ and 2.0 on the bottom surface reattachment tendency is observed with higher side ratios. The back surface pressure increase with the increase in longitudinal distance in case of all the cylinders.

Drag :

The variation of drag coefficient with longitudinal spacing is shown in figure 12. It is observed from this figure that the drag in general drops, as the longitudinal spacing increases. Also for all longitudinal spacings drag is lower for larger side ratios. At $L_l = 1D$ the drag coefficient is $C_D = 2.25$ for $H/D = 1.25$ and $C_D = 1.65$ for $H/D = 2$. These values are higher compared to the corresponding values of C_D for transverse spacing $L_t = 2D$.

Lift :

The figure 13 reveals the variation of lift coefficient with longitudinal spacing. It is observed from this figure that positive lift is developed on all the cylinders at small spacings ($L_l = 1D, 2D, 3D$) whereas negative lift is produced at larger spacings. The reason is easily understandable from the figures 8, 9, 10 and 11. Contrary to the present finding A.C. Mandal [1] showed that square section cylinder experienced negative lift for almost all longtudinal spacings which can be observed from the same figure.

CONCLUSIONS

1. In general drag is higher on the cylinders when transverse spacing is $L_t = 4D$ compared to the cylinder at spacing $L_t = 2D$.

2. For both transverse spacings, downstream cylinders are almost outside the influence of wake of upstream cylinder for short distances ($L_l = 1D, 2D$).

3. Negative lift is experienced by the cylinders with side ratios $H/D = 1.75$ and 2.0 for all longitudinal spacings when transverse spacing is $L_t = 4D$.

4. At transverse spacing $L_t = 4D$, positive lift is developed on all the cylinders at spacings $L_l =$ 1D, 2D and 3D. For the same longitudinal spacing positive lift is also developed on the cylinders with side ratio $H/D = 1.25$ and 1.5 when transverse spacing is $L_t = 2D$.

5. Negative lift is developed on all the cylinders beyond longtudinal spacing $L_l = 3D$ when transverse spacing is $L_t = 4D$.

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