AN INVESTIGATION OF THE QUASI-STATIC ASSUMPTION FOR A PAIR OF STAGGERED CYLINDERS IN CROSS-FLOW

by

Piotr Waclaw Sychterz B.Eng.

Department of Mechanical Engineering
McGill University
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ABSTRACT

The validity of the quasi-static assumption was tested for the case of the leeward cylinder of a pair of parallel cylinders staggered in cross-flow. Static force coefficients were used to predict dynamic force coefficients according to the quasi-static assumption. These predicted values were then compared against actual measured values.

Tests were done for non-dimensional cylinder streamwise spacing, L/d, between 2 and 5, and corresponding cross-stream spacing, T/d, between 0.17 and 1. The range of reduced velocities U/fd, which were studied, was between 15 and 250.

Three regions were identified: one where the quasi-static assumption was always true, one where the quasi-static assumption was never true, and one where the quasi-static assumption improved with increasing U/fd. The experimental data indicates that necessary conditions for the application of the quasi-static assumption are a high U/fd as well as low dC_L/dy and dC_D/dy.

SOMMAIRE

La validité de l'hypothèse "quasi-statique" a été vérifiée pour le cas d'une paire de cylindres en quinconce soumis au vent transversal. La répartition de la pression sur la surface du cylindre en amont a été mesurée quand ce cylindre était fixe et quand il était forcé à osciller dans la direction transversale à l'écoulement.

Les coefficients de force statique ont été employés pour prédire les coefficients de force dynamique selon l'hypothèse "quasi-statique". Ces valeurs calculées ont ensuite été comparées aux valeurs mesurées.

Des expériences ont été effectuées pour des valeurs d'espacement adimensionnel de cylindres longitudinal, L/d, 2 et 5, et d'espacement transversal, T/d, entre 0.17 et 1.00. La gamme des vitesses adimensionnelles U/fd, qui ont été étudiées, allait de 15 à 250.

Trois régions de comportement ont été identifiées: une où l'hypothèse "quasi-statique" était toujours valide, une autre où l'hypothèse n'était jamais valide et une troisième où l'hypothèse s'améliorait avec l'augmentation de la valeur de U/fd. Les données expérimentales indiquent que les conditions nécessaires pour l'application de l'hypothèse "quasi-statique" sont le suivantes: une valeur de U/fd élevée ainsi que valeurs basses pour dC_L/dy et dC_D/dy.

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NOMENCLATURE

a - amplitude of oscillation

C_D - coefficient of drag, $D/0.5\rho U^2$

C_L - coefficient of lift, $L/0.5\rho U^2$

C_p - coefficient of pressure

C_x - dynamic coefficient of force in the x direction

C_x^* - quasi-static coefficient of force in the x direction

C_y - dynamic coefficient of force in the y direction

C_y^* - quasi-static coefficient of force in the y direction

d - cylinder diameter

D - drag force

f - frequency in Hz

F_x - force in the x direction

F_y - force in the y direction

L - longitudinal separation between cylinder centers or lift force

L/d - non-dimensional longitudinal separation between cylinders

p - pressure

p_i - static pressure upstream

Re - Reynolds number

T - transverse separation between cylinder centers

T/d - non-dimensional transverse separation between cylinders

U - free stream velocity

U_r - relative velocity between body and fluid

U/fd - reduced velocity

V_1 - air velocity before wind tunnel contraction

V_2 - air velocity after wind tunnel contraction

V_c - body velocity

x - cartesian position coordinate

$\dot{x}$ - velocity in the x direction

y - cartesian position coordinate

$\dot{y}$ - velocity in the y direction

α - angle of attack

ρ - air density

μ - coefficient of viscosity

υ - kinematic viscosity

θ - angular orientation on cylinder surface

I INTRODUCTION

The subject of flow-induced vibration has attracted increased attention in the last few decades. Flow-induced vibrations are often observed in a number of engineering fields. Aircraft and automobiles travelling at high speeds can experience flow-induced vibrations in structural components of the vehicle. Also, flow-induced vibrations caused by wind loads have to be taken into account when designing tall buildings and towers. Flow-induced vibrations are sometimes responsible for large amplitude vibrations of electrical power cables. Offshore drilling rigs are subjected to wind and waves, which can also produce flow-induced vibrations. Internal flows in piping, jet engines, and in heat exchangers can result in flow-induced vibrations as well.

The effects of flow-induced vibrations can range from very small, sporadic vibrations at all operating frequencies, to very large, violent oscillations at specific operating conditions, which can damage the structure as a whole, or specific components, within a fraction of its expected lifetime.

Flow-induced vibrations are caused by the interaction of time dependent fluid forces with the elastic and damping forces of the structure. This interaction determines the vibration response of the structure, that is, it determines the frequency and the amplitude of the resulting vibration.

The unsteady forces exerted by the fluid on the structure can arise in a number of ways. For example, in a fluid moving at a constant free stream velocity, unsteady forces can be caused by vortex shedding from the body itself, by cavitation (if the fluid being used is a liquid), by vortex shedding from a body upstream, by turbulence within the free stream, or by vibrations of the body which were initiated by some other mechanism. Unsteady forces can of course also arise if the free stream velocity varies with time.

The effects of these unsteady forces generated by the fluid can be to initiate vibration of the body, to amplify the existing vibrations, or to dampen out the existing vibrations. The kind of response which occurs depends on a number of factors; see, for example, Blevins (1977), Fung (1955), Price (1975), Sarpkaya (1979), and Paidoussis (1979).

1.1 FLUID FORCES AND FLOW-INDUCED VIBRATION

It is generally accepted to take components of the total force exerted by the fluid on the body along and normal to the incident fluid vector and to refer to these as drag and lift respectively.

The total drag on a two dimensional body in incompressible flow is the combined effect of two mechanisms; skin friction drag, and pressure drag. Skin friction drag is caused by the friction between the surface of the body and the fluid moving past it. Pressure drag is caused by the integrated effect of different pressures acting on different parts of the surface of the body; the component of this force, taken parallel to the free stream velocity is equal to the pressure drag.

A bluff body is one which because of its shape or orientation in the flow, causes the flow to separate over a large portion of its surface, thus increasing the width of the wake produced by the body The large areas of separated flow and the wide wake result in a pressure drag which is much larger than the skin friction drag experienced by the bluff body. Examples of bluff bodies include spheres, and cylinders with circular or rectangular cross sections. Practical examples of bluff bodies in cross-flow include lamp posts, antenna masts, golf balls, and tubes in cross-flow heat exchangers. A stalled aerofoil, which encounters the flow at a large angle of attack, also becomes a bluff body, even though at small angles of attack it behaves like a streamlined body.

A streamlined body, like an aerofoil at small angles of attack, leaves a more narrow wake than a bluff body. One of the reasons for this is that the flow remains attached over most of the surface, and any flow separation which occurs, is confined to a small area of the body, when compared to the total frontal area. As a result of this, most of the drag on a streamlined body comes from skin friction drag, the friction of the fluid moving over the surface of the body, and not from pressure drag.

For lift to occur the body must exhibit some asymmetry with respect to the incident free stream vector. For instance, an overhead line conductor submitted to wind will only experience drag, whereas an iced conductor (which is non-circular in cross-section) would also have a lift force. Of course, the best known example of a lifting section is the aerofoil, and it works precisely because of the symmetry of its cross-sectional shape. Another way that lift can arise, even over a symmetrical body, is when the flow itself is asymmetric, so that the aforementioned pressure force gives rise to a lift component, as well as to drag.

Although flow-induced vibration of bluff bodies in cross-flow can be caused by a number of mechanisms, only galloping will be discussed here.

GALLOPING

Galloping is caused by the flow past any non-circular bluff body. As the body vibrates and twists in the flow, the angle of attack of the flow changes with respect to the cross-section of the body. This change in the angle of attack causes changes in the lift and drag forces which act on the body. Under some circumstances, the periodic fluctuations of the lift and drag forces can lead to increased vibration of the body. This occurs if the damping forces within the body absorb less energy than the body is able to extract from the fluid as it oscillates.

Figure 1(a) shows the lift and drag acting on a bluff body, when the body is fixed in a stream of fluid moving at a free stream velocity U. The drag, D, is parallel to the free stream velocity, and the lift, L, is perpendicular to it. Figure 1(b) shows the lift and drag forces on the same bluff body when it is moving with velocity y, in a stream of fluid flowing at a free stream velocity U. The resulting relative velocity between the body and the fluid is U_r, which is a vectorial combination of the free stream velocity U and the body velocity $\dot{y}$. The angle of attack, α, of the velocity U_r is measured from the free stream velocity vector, where $\alpha = \arctan(\dot{y}/U)$. The lift and drag forces acting on the body in this case are perpendicular and parallel to the resultant velocity vector U_r.

Changes in $\dot{y}$, the velocity of the body, will cause changes in U_r and α, and corresponding changes in the lift and drag. If the internal damping forces within the body dissipate less energy than the body extracts from the flow, then the vibration of the body will grow in amplitude. This occurs when the aerodynamic damping becomes negative, see figure 1(c), where the mechanism as elucidated by Den Hartog (1956) is outlined.

Galloping occurs in some geographical areas where the electrical power lines become covered with ice and are no longer circular. The resulting cross section is more or less elliptical in shape (Fung 1955), with the major axis perpendicular to the wind direction. This cross section is unstable in the wind, so that once the oscillations are started, they continue to build up.

1.2 QUASI-STATIC ASSUMPTION

The quasi-static assumption simplifies the experimental testing and analysis of some situations involving bodies oscillating in a fluid. As mentioned in the previous section and shown in figure 1, the forces exerted on a body by a stream of moving fluid can be represented by two perpendicular forces. The drag force, D, which is parallel to the free stream velocity U, and the lift force, L, which is perpendicular to the free stream velocity U. Also, if the body has a non-zero velocity $\underline{V}_c$, then it is necessary to calculate a resultant relative velocity U_r between the fluid and the body. In such a case, the lift and drag forces are perpendicular and parallel to the resultant relative velocity U_r, as shown in figure 1(b). Note that in figure 1(b), the velocity of the body has a component in the y direction only, while in general it is possible for $\underline{V}_c$ to have components in the x and y directions, such that $\underline{V}_c = \underline{\dot{x}} + \underline{\dot{y}}$.

As the body oscillates, its velocity, $\underline{V_c}$, changes in magnitude and sign. This causes periodic changes in the resultant relative velocity U_r, the angle of attack, α, and the directions and magnitudes of the lift and drag forces. If no simplifying assumptions are made, then it is necessary to measure lift and drag of an oscillating body at all possible values of frequency, amplitude and free stream velocity, in order to determine its behaviour. On the other hand, if the change of U_r with time is sufficiently slow, such that the flow can adjust almost instantaneously, then the quasi-static assumption can be applied. As discussed in section 6.2 the quasi-static assumption makes it possible to calculate the time-dependent lift and drag forces on an oscillating body, based on the lift and drag coefficients measured when the same object is held fixed at an angle α in a free stream of velocity U_r. This greatly reduces the amount of experimental work needed in order to be able to predict the dynamic behaviour of the body, because only static results are needed, through measurements taken when the object is held fixed in the flow.

Thus, the quasi-static assumption can be made when it can be assumed that the flow around the oscillating body adjusts instantaneously, so that at any instant in time, it resembles the flow about a similar body fixed at an angle α, in the free stream of velocity U_r. Intuitively, the flow around an oscillating body will be able to adjust to changes in U_r and α, if U_r and α change slowly. Conversely, if U_r and α change quickly, then the flow around the oscillating body will not be able to adjust sufficiently rapidly to resemble the flow around a similar body fixed in the free stream.

The ability of the flow to adjust instantaneously to changes in U_r

and α has been related to the free stream velocity U, the frequency of oscillation f, and some relevant linear dimension of the body d. For a circular cylinder in cross flow d is the cylinder diameter. For an aerofoil, d is the chord. Fung (1955) describes the reduced velocity U/fd, as a measure of non-dimensional distance (with respect to the diameter d) by which a disturbance is swept downstream by the free stream velocity U, during the time it takes for the body to complete one cycle, see figure 2. A disturbance shed from an oscillating cylinder, will move a distance of U/f (where 1/f is the period of oscillation) by the time the cylinder completes one cycle of oscillation and returns to the same position. If the distance U/f is sufficiently large, compared with d, then the velocity induced at the cylinder by the existence of the disturbance will be negligible, and the quasi-static assumption can be applied. Then the lift and drag forces acting on the oscillating cylinder can be calculated from the lift and drag coefficients measured on a stationary cylinder at the velocity corresponding to U_r and angle of attack α.

It has been found from experience that the quasi-static assumption is valid if the distance traveled during one cycle of oscillation by the disturbance shed from the body is greater than 10d, or U/fd > 10d. Therefore, the quasi-static assumption is valid if U/fd > 10, where U/fd is the reduced velocity.

There is a large amount of data to support this claim for streamlined bodies, such as aerofoils at small angles of attack. Less is known about the quasi-static assumption for bluff bodies. For bluff bodies the quasi-static assumption is used when U/fd is greater than 10, but it is not known how much greater; i.e. it is not known what the critical value of U/fd is for any given bluff body or configuration of bluff bodies. Also, not enough is known about the magnitude of errors which are introduced when the quasi-static assumption is used in cases when U/fd is greater than, but close to that critical value. The motivation for this work has been to increase the amount of experimental data available on this subject, so that some conclusions can be made about (i) the generally quoted limit U/fd > 10 for the application of the quasi-static assumption to bluff bodies, and (ii) about the errors introduced when operating close to this limit.

II LITERATURE REVIEW

This chapter will present briefly some of the previous work done on the flow past circular cylinders. It will lead up to the main topic of this thesis, an investigation of the quasi-static assumption for two parallel, staggered cylinders in cross-flow. It will begin by describing flow past a single circular cylinder, and the resulting wake: wind tunnel blockage effects and blockage corrections will also be discussed. Next, steady flow past staggered cylinders will be discussed, followed by a review of experiments in unsteady flow.

2.1 STEADY FLOW PAST A SINGLE CYLINDER

The disturbance caused by a single circular cylinder placed in a steady cross-flow has been well studied by many researchers. This disturbance, or wake, generated by the cylinder can be characterized if the Reynolds number is known for the situation.

The Reynolds number, Re, is defined as the ratio of inertia forces to viscous forces, or for a circular cylinder in cross-flow, $Re = Ud/\nu$ where U is the free stream velocity, d is the cylinder diameter, and ν is the kinematic viscosity.

The character of the wake produced by a single circular cylinder will vary depending on the value of this non-dimensional Reynolds number, but all of the flow patterns have some characteristics in common. A small portion of the oncoming fluid comes to rest at the front of the cylinder at the stagnation point. In the vicinity of the stagnation point, there is a rise in pressure equal to the dynamic pressure of the free stream. The remainder of the fluid accelerates around the front of the cylinder in order to flow past it, see figure 6. As the fluid accelerates around the front of the cylinder, there is a corresponding pressure drop in the layer of fluid in the vicinity of the cylinder (in the boundary layer). This reduction in pressure creates a favorable pressure gradient which keeps the fluid attached on the front surface of the cylinder.

The point of minimum pressure is close to the point where the cylinder cross-section begins to decrease (in the rear of the cylinder). At that point, the fluid starts to decelerate, and there is a corresponding rise in pressure in the boundary layer. The inertia of the moving fluid can overcome part of this adverse pressure gradient, but depending on the value of Re, the inertia of the fluid might not be sufficient to keep the fluid attached. As the value of Re becomes higher, it becomes more difficult for the fluid to remain attached along the back surface of the cylinder and eventually it separates and begins to recirculate behind the cylinder. These shear layers tend to roll up into vortices in the wake.

The location of the separation points will vary between 70^o and 180^o from the stagnation point, depending on the Reynolds number.

2.1.1 Wake behind a single cylinder

The major flow regimes, as described by Blevins (1977), 1984), are presented below, grouped by Reynolds number (see figure 7).

(a) $Re \leq 5$

At very low Reynolds numbers based on cylinder diameter, the flow does not separate. It is very laminar.

(b) <u>$5 \le Re \le 40$</u>

As the Reynolds number is increased, the flow separates from the back of the cylinder, and two vortices form immediately behind the cylinder.

(c) <u>$40 \le Re \le 150$</u>

As the Reynolds number is increased further, the two vortices elongate, until one of them breaks away from the cylinder, and a periodic wake and staggered vortex street are formed. Up to a Reynolds number of approximately 150, the von Karman vortex street is laminar.

(d) <u>$150 \le Re \le 300$ and $300 \le Re \le 3x10^5$</u>

Between Reynolds numbers of 150 and 300 the vortex street goes from being laminar to being turbulent. At a Reynolds number of 300 the vortex street is turbulent, and it degenerates into a fully turbulent flow at a distance of about 50 diameters downstream of the cylinder.

The range of Reynolds numbers between 300 and $3x10^5$ is called the subcritical range because it occurs just prior to the transition to turbulence in the boundary layer itself. The value of Reynolds number at which the boundary layer becomes turbulent depends on the free stream turbulence and surface roughness.

At subcritical values of Reynolds number, the vortex shedding occurs at a well defined frequency, and the vortex street is well defined. In the range of Reynolds numbers between $1x10^4$ and $3x10^5$, the value of the drag coefficient remains approximately constant at 1.2.

In the range of Reynolds numbers between $1x10^5$ and $5x10^5$ there is a sudden drop in the drag coefficient, which is caused by transition of the boundary layer from laminar to turbulent, see figure 8.

Before the transition, the separation point is at about 82^o from the stagnation point (see figure 9). After the transition, the separation point moves to about 120^o from the stagnation point.

(e) $3x10^5 \leq Re \leq 3.5x10^6$

In this critical range of the Reynolds number, the laminar boundary layer has undergone turbulent transition and the wake is narrower and disorganized. The drag on the cylinder is lower than in the previous range of Re.

(f) $3.5x10^6 \leq Re$

At this supercritical Reynolds number range, a fully turbulent vortex street is re-established. Transition to turbulence takes place in the boundary layer, ahead of the point of separation.

2.1.2 Blockage effects

The standard way of describing what happens when a body is placed in a stream of moving fluid, is to describe what would happen if the fluid is unconfined. When tests are carried out in a wind tunnel, the presence of the wind tunnel walls can influence the results. Since wind tunnels of different construction can produce different effects, it is desirable, if possible to correct the test results for wind tunnel blockage. Blockage is generally defined as the ratio of the frontal area of the model being tested to the cross section of the wind tunnel. Wind tunnel blockage corrections make it possible to compare results obtained in different wind tunnels, and to use wind tunnel results to predict the behaviour of the test body in a free stream, such as in atmospheric flows.

The presence of wind tunnel walls may cause the effective velocity at the model to be raised slightly due to the constraints of the wind tunnel walls (Duncan 1949). Another effect of the presence of the wind tunnel walls is to increase the effective incidence of a lifting surface, because of the reduction of downwash caused by surfaces of the wind tunnel walls (Duncan, Thom and Young 1981). Also, the turbulence of a stream in a wind tunnel will in general differ from the turbulence of an unconfined stream. This will affect the forces measured on the model, particularly the drag and the maximum lift, see Duncan, Thom, and Young (1981).

In this presentation, only the effects caused by the variation in velocity due to wind tunnel blockage, will be considered. The change in effective incidence will not be considered, because the tests were carried out on circular cylinders which are not generally considered as lifting surfaces. The effects of variation in turbulence will also not be considered, since the models in this experiment are not scale models of any particular object, but are hypothetical models used to investigate the quasi-static assumption. Therefore there is no actual turbulence level which could be compared to the wind tunnel turbulence; however, the turbulence intensity present in the wind tunnel, upstream of the test cylinder, is shown in figure 10, plotted as a percentage of upstream velocity. Pinnell (1987) measured the free stream turbulence in this wind tunnel at various velocities, while the wind tunnel was empty.

Duncan (1949), presented a method of wind tunnel blockage correction, which can be used to correct for the local variation in velocity due to wind tunnel blockage. This method can be applied to incompressible and compressible flows.

Allen and Vincenti (1944), developed a blockage correction which can be applied directly to the drag coefficient of a single circular cylinder. The correction is given in terms of a polynomial of blockage ratios. A blockage ratio is the ratio of frontal cross sectional area of the model to the cross sectional area of the wind tunnel. This method is used in this Thesis to correct single cylinder tests for wind tunnel blockage because of its suitability to the subcritical Reynolds numbers tested.

West and Apelt (1982) found that for blockage ratios less than 6%, the effects of blockage on pressure distribution and drag coefficient are small. For blockage ratios of 6% to 16%, there is considerable distortion of the flow, and the associated effects are complex.

Test results for staggered cylinder tests are not corrected for wind tunnel blockage; this is because no suitable method is available. This limitation may not present great problems in the present context, because the uncorrected, staggered, dynamic test results are compared against quasi-static calculations based on uncorrected, staggered, static test results. However, one can visualize situations where wind tunnel interference effects are different in static and dynamic tests, this possibility cannot be ruled out, but cannot be tested by the experiments presented in this Thesis. Therefore, in the staggered case, uncorrected results are compared against uncorrected results from the same wind tunnel, thus allowing for verification of the quasi-static assumption.

2.2 STEADY FLOW PAST A PAIR OF CYLINDERS

The definitions of side by side, tandem, and staggered arrangements for two parallel cylinders are presented in figure 3. Distance T is the center to center distance between the cylinders along a direction perpendicular to the free stream velocity. The distance L is the distance between cylinders along a direction parallel to the free stream velocity. The ratios T/d and L/d represent the non-dimensional transverse and longitudinal spacing between the cylinders, where d is the cylinder diameter.

2.2.1 Interference effects

Flow past two parallel cylinders can be similar to flow past a single cylinder if the spacing between the cylinders is sufficiently large. However, if the cylinders are within a critical distance of each other, the flow pattern becomes drastically different. Figure 11 shows the range of L/d and T/d positions at which the two cylinders have an effect on each other. Within the proximity region, where the center- to-center distance between cylinders is less than or equal to 4 cylinder diameters, the flow around the cylinders is influenced by proximity-interference. At L/d greater than 4, the wake-interference becomes most prominent, but only at values of T/d small enough so that at least part of the downstream cylinder comes close to the wake of the upstream cylinder.

During the present investigation, tests were conducted in the range of L/d between 3.5 and 5, and T/d between 0 and 1.17. This includes tandem and staggered cylinder arrangements, but not the side by side arrangement.

2.2.2 Cylinders in tandem

Zdravkovich (1977) published a review of the flow interference between two cylinders in various arrangements. Two different flow patterns are suggested by the test results; one occurs when L/d is less than 3.5, and the other when L/d is greater than 3.5.

The pressure distribution on the surface of two tandem cylinders positioned such that L/d is in the range of 1 to 3.5 is shown in figure 12. The shape of the pressure distribution on the upstream cylinder is similar to the pressure distribution on a single cylinder, the difference being that the negative base pressure at the downstream side varies with L/d spacing. The pressure on the upstream face of the downstream cylinder is negative and equal to the base pressure of the upstream cylinder. This suggests that there is no flow in the gap between the two cylinders. This idea is further reinforced by direct measurement of flow velocities in the gap.

The pressure on the downstream face of the downstream cylinder is greater than the pressure on the upstream face, but it is still negative. This results in a negative drag coefficient for the downstream cylinder. Again, the magnitude of the pressure coefficient depends on the L/d spacing.

The transition from the uniform pressure on the upstream side to the uniform pressure on the downstream side is interrupted by two maximum peaks, one on each side of the cylinder, see figure 12. These peaks move towards the front of the cylinder as L/d is increased. These two peaks are located at the points were the shear layer from the upstream cylinder attaches itself to the downstream cylinder, see figure 13.

Figure 14 shows the pressure distribution on the surface of the downstream cylinder at various values of L/d, between 1.5 and infinity. The first four curves at L/d equal to 1.5, 2.0, 2.5, 3.5, present the same information as figure 12; these four curves have similar shapes, the pressure coefficient is negative throughout. It is higher on the downstream side than on the upstream side, and there is a maximum peak on both sides of the cylinder. The three curves at L/d equal to 5.0, 7.0 and infinity, form a distinctly different class of curves. The pressure is higher on the upstream surface, and there is only one high peak, but there are two low peaks. This suggests a single stagnation point at the front of the cylinder, and two separation points on the sides.

At L/d less than infinity, but greater than 3.5, the maximum value of the pressure coefficient at the front of the stagnation point does not reach 1, as it does for a single cylinder. In fact, at L/d equal to 7, the pressure coefficient peaks at 0. This suggests that the upstream cylinder is affecting the flow about the downstream cylinder, even at this separation.

Arie, Kiya, Moriya and Mori (1983) measured the RMS values of pressure distribution on tandem cylinders, and integrated them to find the RMS lift and drag. They found that the RMS lift and drag were much larger for the downstream cylinder than for the upstream cylinder, up to the spacing of L/d equal to 7 diameters. At a spacing of L/d equal to 10 diameters, there was only a small difference from the single cylinder tests. This confirms that for longitudinal spacing of L/d less than or equal to 7, the presence of the upstream cylinder has a definite effect on both the RMS and the time averaged pressure distributions on the downstream cylinder.

Arie, Kiya, Moriya and Mori (1983) observed peak values of RMS pressure coefficient on the downstream cylinder at points corresponding to the reattachment points of the shear layer. This agrees with the results obtained by Batham (1973).

2.2.3 Staggered cylinders

Figure 15 shows the separation and reattachment points, and the shear layers present in the neighbourhood of a pair of staggered cylinders in cross flow. There is one reattachment point, and two separation points on the downstream cylinder. The downstream cylinder is located in a flow field which is no longer symmetrical. The flow on one side of the cylinder is part of the free stream, while the flow on the other side is made up of the wake of the upstream cylinder. This lack of symmetry in the flow field results in a lift force on the downstream cylinder.

Zdravkovich (1977) presented a survey of work done on staggered cylinders. Figures 16 and 17 show the lift and drag coefficients, respectively, on the downstream cylinder, plotted as contour lines against non-dimensional cylinder spacing L/d and T/d. The lift coefficient is negative at all positions (the lift vector points towards the centerline of the wake produced by the upstream cylinder).

The lift coefficient graph shows two areas where maximum values occur. These are marked by dashed lines. The so-called inner lift peak is located at T/d equal to 0.25 between L/d equal to 1 and 3.5. The so-called outer lift peak, is located along a curve in the area between T/d equal to 0.5 to 1.5, and L/d equal to 2.5 and greater.

Figure 18, taken from Zdravkovich and (1977), shows the origin of the outer lift force. The flow on the outer side of the downstream cylinder is less affected by the upstream cylinder. The flow on the inner side of the downstream cylinder is increased due to entrainment between the inner side and the fully developed wake of the upstream cylinder. The maximum negative lift coefficient occurs when the downstream cylinder displaces the streamlines and squeezes them between its inner side and the displaced wake of the upstream cylinder.

The inner peak in the lift coefficient is attributed to the existence and sudden disappearance of the gap flow between the cylinders as T/d decreases. As T/d decreases to 0.25, the increase in gap flow between the cylinders causes an increase in the lift force. When T/d falls bellow 0.25, the cylinders block the gap and the flow passes on the outside of the two cylinders, as for tandem cylinders, see figure 19. The corresponding pressure coefficient distribution on the surface of the downstream cylinder is shown in figure 20.

With L/d between 1 and 3.5 the lift coefficient reaches a peak at T/d equal to 0.25, and falls off suddenly as T/d is either increased or decreased. As a result of this, when the cylinders are located at this spacing, the flow becomes bistable, and it flips from one flow pattern to another at random intervals. This phenomenon was observed by Zdravkovich and Pridden (1977) and Pinnell (1987).

2.3 UNSTEADY FLOW PAST CYLINDERS

The previous sections have dealt with one or two cylinders held fixed in a steady cross-flow. This section will deal with steady flow past oscillating cylinders and unsteady flow past fixed cylinders.

2.3.1 Oscillating cylinders in a steady flow

Bearman and Currie (1979) measured pressure fluctuations on an oscillating circular cylinder at a point 90^{o} from the mean position of the forward stagnation point. The cylinder, which had an aspect ratio of 9.5 was forced to oscillate transverse to the flow direction in water with a free stream turbulence of 5.6%. Tests were performed at a Reynolds number of 2.4×10^{4}, at amplitudes of up to 1.33 cylinder diameters (the cylinder diameter was 57.2 mm). The reduced velocity was in the range between 3 and 18, and the frequency of oscillation was between 0 Hz and 2.35 Hz. Good agreement was found between measurements on cylinders which were free to oscillate on their own, and cylinders which were forced to oscillate at the same frequency, Reynolds number and reduced velocity. Measurements of phase difference between pressure and displacement show that the maximum out-of-phase lift force occurs at a 1/2 peak-to-peak amplitude of about d/2.

The unsteady flow and wake near an oscillating cylinder were explored by Toebes (1969). The circular test cylinder, 6 inches in diameter, was oscillated at frequencies up to 20 Hz, with a peak-to-peak amplitude of 2 inches. As many as 8 hot-wire anemometers were used to measure the fluctuating flow field around the cylinder. In the range of Reynolds numbers between 0.2×10^{5} and 1.2×10^{5} it was noted that cylinder oscillations lead to finite regions for which the ratios of

Strouhal frequency to oscillation frequency assumed values of 3.0, 2.0, 1.0, and 0.5. Also, periodic motion near the cylinder surface was strongly modulated by cylinder oscillations.

Lift forces acting on a single oscillating cylinder were studied by Tanaka and Takahara (1969) in the subcritical Reynolds number region, at Re between $4x10^4$ and $9x10^4$. The effect of increased surface roughness, or increased aspect ratio was to decrease the lift force on a stationary cylinder, while it had no effect on the lift force acting on an oscillating cylinder. Irregularity of the lift force increased as the amplitude of oscillation decreased and as the non-dimensional frequency of forced oscillation either increased or decreased away from 0.2. The absolute value of the lift force increased as the amplitude of cylinder oscillations increased, and as the non-dimensional frequency of forced oscillation approached 0.2.

Tanida, Okajima and Watanabe (1973) measured the lift and drag forces on circular cylinders in both single and tandem configurations, at Reynolds numbers between 40 and $1x10^4$. A cylinder (the downstream one in the tandem case) was made to oscillate in either the transverse or longitudinal directions. In the case of a single cylinder, its oscillation caused synchronization of the forcing and Strouhal frequencies in a frequency range around the Strouhal frequency (transverse mode) or double the Strouhal frequency (longitudinal mode). The aerodynamic damping for transverse oscillation became negative in the synchronization region. In the case of tandem cylinders, at low Reynolds numbers in the von Karman wake range, synchronization was observed to occur only when the downstream cylinder oscillated inside the vortex-formation region of the upstream cylinder, and at high

Reynolds numbers (low subcritical) synchronization occurred irrespective of the cylinder spacing in either oscillating mode. In the tandem case the transverse oscillation of the downstream cylinder became unstable in the range of synchronization.

Durgin, March and Lefebvre (1980) performed experiments to determine the lower mode response of circular cylinders in cross-flow (i.e. to search for resonance at frequencies below the fundamental frequency). The transverse amplitude response of a circular cylinder in cross-flow was determined as a function of reduced velocity for a variety of spring constants and damping coefficients. Maxima in the transverse response were at the fundamental frequency, and at 0.33 of the fundamental frequency, but not at 0.5 of the fundamental frequency. When the test cylinder was forced to oscillate at the subharmonic resonance frequency, hot wire anemometer analysis revealed that there was no lock-in region, or frequency synchronization at the subharmonic frequency. It is likely that the original spring mounted cylinder system responded subharmonically to the exciting force resulting from vortex shedding. A conceptual model, which incorporates features of both the low frequency vortex street and subharmonic response, was developed which accounted for lower mode response at a frequency of 0.33, as well as the lack of response at 0.5 of the fundamental frequency. This model showed how it is possible for every third vortex to contribute to a subharmonic frequency of 0.33 of the fundamental Strouhal frequency, while the other two vortices inhibit separation. There is no similar model which could be used to predict a subharmonic frequency of 0.5 of the fundamental frequency.

Bearman and Obasaju (1982) performed an experimental study on fixed and oscillating square-section cylinders where they measured the pressure fluctuations. Measurements were taken of the pressure fluctuations acting on a square-section cylinder, with the front face normal to the flow, with the cylinder held stationary and with it being forced to oscillate transverse to the flow. The amplitude of oscillation ranged up to 25% of the length of the side face; the range of reduced velocities investigated was between 4 and 13, which includes the vortex lock-in region. At lock-in, the amplification of the coefficient of lift was much less than that found for a circular cylinder. Also, on a square cylinder, the variation of phase angle between lift and displacement is different from that found on a circular cylinder. Vortex induced oscillations are possible only at the high reduced-velocity end of the lock-in region. For reduced velocities well below lock-in, the natural vortex shedding mode is suppressed and vortices form on the side faces of the body. At an amplitude of oscillation equal to 10% of the length of the side face, intermittent reattachment occurs over the side faces, and the time-mean drag coefficient can be reduced to 60% of the drag measured on a stationary cylinder.

Luo (1982) presented a Thesis on the steady and unsteady flow past a circular cylinder. In the steady case, pressure measurements were taken at Reynolds numbers between 1.42×10^5 and 7.2×10^5, on the surface of a circular cylinder fixed in cross-flow. These were later integrated to find the forces acting on the cylinder surface.

In the unsteady case, the cylinder was oscillated in a direction parallel to the free stream velocity. Steady and unsteady tests were conducted at the same Reynolds numbers, for combinations of two

Keulegan-Carpenter "KC" numbers, and for two frequency parameters.

The Keulegan-Carpenter number is a dimensionless period parameter $U_m t/d$, where U_m is the maximum oscillation velocity, t is the period of oscillation, and d is the cylinder diameter. Variation of average steady flow drag coefficient, and inertia coefficient depend on the Keulegan-Carpenter number.

Luo (1982) found that for unsteady tests performed at the different combinations of Reynolds number, Keulegan-Carpenter number, and frequency parameter, the flow can be considered as quasi-static. Also at each Keulegan-Carpenter-number/frequency parameter combination, the flow drag coefficient was always less than the steady flow drag coefficient.

Pinnell (1987) investigated the quasi-static assumption for single and staggered cylinder configurations. In the single cylinder case the pressure distribution around the circumference of an oscillating cylinder was measured at a Reynolds number of 6.8×10^4 and a frequency of forced oscillation of 5 Hz. The dynamic force coefficients obtained by integrating the pressure coefficient, compared favorably with its static counterpart measured on fixed cylinder. This indicates that for a single cylinder there are no significant differences between force coefficients for steady and unsteady tests. Pinnell (1987) was not able to test the validity of the quasi-static assumption for a single cylinder because the tests were conducted above the minimum reduced velocity U/fd = 10 suggested by Blevins (1977); i.e. the flow was not "unsteady" enough to produce a measurable difference for the single cylinder arrangement.

Pinnell also measured the pressure distribution on the surface of the downstream cylinder of a staggered pair for a Reynolds number of 6.8×10^4 and frequency a of 5 Hz. The non-dimensional spacing between the cylinders was $L/d = 1.5$ and T/d between 0.033 and 0.367. The unsteady pressure distribution compared well with its steady counterpart for T/d between 0.033 and 0.200, but there was a drastic difference between steady and unsteady pressure distributions for T/d between 0.311 and 0.367. As was the case with the single cylinder dynamic tests, the reduced velocity for the tandem arrangement was above the minimum $U/fd = 10$ suggested by Blevins (1977). This would indicate that the quasi-static assumption is not valid for this cylinder spacing and frequency.

2.3.2 Cylinders fixed in oscillatory flow

This section will review several papers on the forces on cylinders fixed in oscillating flow fields. This subject has gained importance with increased study of wave action on offshore structures. The experimental approach in these papers is different from the approach taken in this Thesis, because the cylinder is fixed while the flow usually has an oscillating component superimposed on a steady flow field. Some of the results presented in these papers are applicable to the present work since it is the relative motion between the body and the fluid which determines the forces involved, not the absolute definition that the cylinder or the fluid are oscillating.

Dalton and Chantranuvatana (1980) studied average pressure distributions on a circular cylinder in an oscillating flow field. The effect of Reynolds number up to 4×10^4, and Keulegan-Carpenter number on the pressure distribution were examined.

Dwyer and McCroskey (1973) performed experimental and theoretical analysis on the boundary layer of a circular cylinder in an oscillating flow at a Reynolds number of 1.06×10^5. The investigation was designed to examine the self-induced oscillations occurring in the flow. The boundary layer calculations revealed some very interesting fine-scale structures of the flow, which strongly indicated that the vanishing of the wall shear does not necessarily signal the onset of separation for unsteady flow. In general, the agreement between the theoretical calculations and the experimental results was excellent and the unsteady component of this supposedly steady flow was found to be significant.

Hatfield and Morkovin (1973) investigated the effects of a steady and an oscillating free stream on the unsteady pressure distribution around a circular cylinder. The steady free stream velocity was U_i, while the oscillating free stream velocity was $U_i(1- A \sin\omega t)$. The oscillating component of the free stream velocity was produced by rotating shutters in the downstream end of the test section. At Reynolds numbers of 1.2×10^4 to 8.0×10^4, the RMS pressure on the cylinder surface peaked at points located at 80^o from the front stagnation point, which is the location of the separation points for this Reynolds number range.

Hatfield and Morkovin (1973) also found that there was no significant coupling between the Von Karman vortex street and the free stream oscillation. This result was attributed to the fact that the free stream oscillations were symmetrical, while the Von Karman vortex street is anti-symmetrical. This argument was further reinforced when free stream oscillation was replaced by anti-symmetrical oscillation and more efficient coupling was observed between the Von Karman vortex street and the free stream oscillation.

III RESEARCH OBJECTIVES

3.1 GENERAL OBJECTIVES OF THE RESEARCH

The purpose of this thesis is to experimentally investigate what happens to the pressure distribution and resulting forces acting on the surface of the test model, when U/fd is in the neighbourhood of the generally accepted critical value of U/fd = 10. The model tested was a pair of circular cylinders of equal diameters subjected to cross-flow. The cylinders were arranged in a staggered configuration, that is, the cylinders were placed almost, but not exactly, one behind the other, see figure 3(c) when L > T. During the experiments, the surface pressure was measured on the downstream cylinder only.

During the static test the downstream cylinder was displaced from the equilibrium position, in the y direction, a direction perpendicular to the free stream velocity U. It was held there, while the surface pressure distribution was measured. Later, static lift and drag forces and the respective coefficients were calculated from these pressure distributions. This was known as the static part of the tests, because the cylinder was held fixed in the flow.

Next, the downstream cylinder (on which the measurements were taken) was oscillated in the y direction, while the surface pressure was measured continuously. This was known as the dynamic test, because the cylinder was constantly oscillating. The pressure distribution obtained from the dynamic tests was used to calculate the dynamic drag and lift forces and the respective coefficients for the downstream cylinder.

The purpose of the thesis was to discover under what conditions the quasi-static assumption could be used to calculate the dynamic lift and drag coefficients based on the corresponding static coefficients. The conditions during each test were described by four non-dimensional numbers: longitudinal separation between the cylinders, L/d, transverse separation T/d, Reynolds number $\rho Ud/\mu$, and the reduced velocity U/fd, where L is the longitudinal distance between cylinders, T is the transverse distance (see figure 3(c)), U is the free stream velocity, f is the frequency of oscillation, d is the cylinder diameter, ρ is the air density, and μ is the coefficient of viscosity of the air. Note that the amplitude of vibration, a, which could be used to form a fifth non- dimensional number was held constant during these tests.

3.2 CHOICE OF WORKING FLUID

The experiments were carried out in air flow. It was much easier to construct a shaker mechanism which would operate in a wind tunnel then it would be to construct a similar mechanism which would operate in a water tunnel. All the leaks in the wind tunnel do not have to be perfectly sealed, if it can be shown that their existence does not significantly influence the experimental results. If a water tunnel had been used, there would have been a number of places where it would have been difficult to seal the water leaks.

The downstream test cylinder, the one which was forced to oscillate, was mounted vertically in the wind tunnel, see figure 4. Steel rods (drill rods) protruded from the two ends of the test cylinder. These rods passed through circular holes cut in the top and bottom of the wind tunnel. These holes were large enough (0.1143 m diameter) to allow the cylinder to oscillate. The free ends of the drill rods were firmly held in a yoke or frame which was attached to the shaker, as shown diagrammatically in figure 5.

If a water tunnel was used, it would be absolutely necessary to seal the leaks around the moving drill rods connecting the cylinder to the shaker mechanism, in order to avoid the loss of large quantities of water.

In a water tunnel, any leakage at all would be unacceptable because the water would have ended up on the floor of the laboratory. Another place where fluid leaks would be difficult to eliminate, but could have serious effects if a water tunnel was used, would be around the pressure transducers. Since the pressure transducers were electronically activated, any moisture which came into contact with them could render them unreliable.

The disadvantage of using air as the working fluid instead of water, is that at the same velocities the resulting forces are much lower in air, due to the lower density of air as compared to water. If it was not for the problem of fluid leakage and possible electrical short circuits, it would have been easier to measure the pressure fluctuations in water than in air, because the signal to noise ratio would be better.

3.3 LIMITATIONS ON U/fd

It was the original intention to perform the experiments at values of U/fd between 5 and 200, but this was not possible due to constraints imposed by the equipment. As a result of limitations to be discussed below the experiments were carried out over a range of U/fd between 14 and 260. Some interesting phenomena were nevertheless observed even in this range of U/fd, which did not include U/fd = 10. As will be seen, breakdown of the quasi-static assumption, for the system investigated occurred at U/fd > 14; hence, there was no need to reduce U/fd any further. In the future, it might be informative to expand the range of U/fd to include values between 5 and 300, especially if other systems are investigated.

In order to achieve a high value of U/fd, high free stream velocity U, a low frequency f, and a small cylinder diameter d must be used. On the other hand, in order to achieve low values of U/fd, the reverse is true. These requirements were further combined with other considerations which placed limits on the values of U, f and d. The following paragraphs will describe the practical limits imposed on the parameters.

A configuration of staggered circular cylinders (see figure 3), with the pressure measurements made on the oscillating downstream cylinder, was chosen. This configuration was chosen because it is representative of many practical situations, such as tubes of cross-flow heat exchangers, and oil rig pylons or risers. Another reason for choosing this configuration is that Pinnell (1987). had shown that, at the velocities which could be produced in the existing wind tunnel (2 m/s to 30 m/s), the quasi-static assumption could not be tested on a single circular cylinder with a diameter of 0.1143 m (4.5 inches) and oscillating at a frequency of 1 Hz to 7 Hz. The cause for this is that even if the flow was not quasi-static, the differences would be so small that they cannot be detected experimentally.

With the tandem configuration, the downstream cylinder is subjected to a flow disturbance which is produced by the upstream cylinder. The quasi-static assumption can then be checked on this model by observing the difference in the surface pressure distributions on the downstream cylinder for the static and dynamic cases. In the static case, the downstream cylinder is stationary, and in the dynamic case, the downstream cylinder is forced to oscillate.

It was decided to keep the diameter of the two cylinders equal throughout the experiments; this is a much simpler situation than the case of two cylinders of different diameters. In any case, since little information is available on experiments done to test the limit of the quasi-static assumption for tandem bluff cylinders, it was decided to keep the setup as simple as possible. Another reason for choosing two equal diameters was that there was some information in the literature about pressure distribution on two stationary, staggered and tandem cylinders, of equal diameter, in cross-flow [Price (1975), Bokaian and Geoola (1984), Price and Paidoussis (1984), Zdravkovich (1977)]. This published information was used to verify that the apparatus was working properly, at least in the static case.

The diameter of the cylinders was influenced by a number of factors. It was set at 0.1143 m (4.5 inches) throughout all the experiments. It was desired to make the diameter large enough so that the lower range of U/fd could be reached. On the other hand, the diameter could not be too large because the tunnel blockage would then become too high and cause distortion of the results. It was desired to keep the tunnel blockage low, because it was not possible to correct the results for blockage in the case of two bluff bodies.

Another reason why the cylinder diameter was made large, is that the pressure transducer had to be mounted inside the test cylinder. See section 4.4 for discussion of why this had to be so.

The choice of free stream velocity U was influenced by a number of factors. In fact, a range of U was required as the values of U and f were changed in different experiments to achieve different values of U/fd. The minimum value of free stream velocity U which could be used in testing was 10 m/s: at velocities of 10 m/s or more, the signal to noise ratio was high enough so that the experiments were repeatable.

The maximum value of free stream velocity U was determined by the capacity of pressure transducers to measure the resulting surface pressures on the cylinder surface. This maximum U varied depending on the position of the test cylinders with respect to each other. As the free stream velocity increased, the pressure distribution on the cylinder surface exhibited larger values of maximum and minimum peak pressures. Also, if the free stream velocity remained constant, but the longitudinal spacing L, and the transverse spacing T between the cylinders were changed, the pressure distribution on the surface of the cylinders reached different maximum and minimum peaks. The maximum velocity used was 28 m/s; this was with a spacing of $T/d = 1$ and $L/d = 4$.

A variation in the frequency of the cylinder oscillation was also used to vary the value of the ratio U/fd. The frequency of oscillation was limited to a range of 1 Hz to 6 Hz. This limit was imposed by the design of the shaker mechanism. The linear bearings guiding the shaker yoke which held the oscillating test cylinder, did not have enough rigidity to withstand oscillations above 6 Hz. The low frequency limit was imposed by the fact that the motor and gear reducer combination used in the shaker mechanism did not deliver enough power at very low speeds; this caused the shaker to run at an uneven pace below 1 Hz.

IV APPARATUS

This chapter describes the apparatus used in the experimental work. Section 4.1 describes the wind tunnel and its performance characteristics. Section 4.2 describes the shaker mechanism used to oscillate the test cylinder in the wind tunnel. Section 4.3 describes the aerodynamic models, or test cylinders, used in the experiments, while section 4.4 describes the pressure transducers used, and also presents a discussion of why these transducers were chosen over all others. Section 4.5 lists the remaining equipment used during the experiments, such as: data analyzer, signal filters, and voltmeters.

4.1 WIND TUNNEL

The wind tunnel used during testing is located at McGill University, in the Mechanical Engineering Department.

It is a 40 H.P., open ended, blowdown tunnel, with a 1.83 m (6 ft.) long, 0.9 m (3 ft.) wide and 0.6 m (2 ft.) high test section. Screens, a honeycomb and a settling chamber are provided upstream of the contraction. The wind tunnel is capable of generating steady wind speeds between 10 m/s to 40 m/s.

Data on the performance of the wind tunnel has been taken from Pinnell and Mark (1983).

The growth of the boundary layer on the walls of the tunnel is shown in figures 21 to 22. It is plotted as a percent of upstream velocity versus the distance from the wall for the different positions in the working section.

The graph in figure 10 shows the amount of turbulence in the flow in the wind tunnel; the turbulence, as a percentage of upstream velocity, is plotted versus the average upstream velocity.

4.2 THE SHAKER-MECHANISM

The shaker-mechanism is used to impart sinusoidal motion to the test cylinder, in the horizontal plane. It uses a scotch yoke mechanism to transform steady rotational motion of a crankshaft into motion which is sinusoidal and reciprocating along a straight line. The maximum amplitude of the motion is 38 mm (1.5 in.) peak-to-peak, the frequency of oscillation can be varied from 1 Hz to 7 Hz.

Figures 23 and 24 show sketches of the shaker. The unit can be broken down into two main parts: the frame, and the mechanism itself.

The frame holds the mechanism in place, and provides extra weight to the unit, so that it does not slide along the floor. It can be raised or lowered on four jack screws, and it can be moved in the horizontal plane on four wheels.

The mechanism itself consists of a 2 H.P., DC motor with a variable speed controller, a 3:1 speed reducer, a flywheel, a crankshaft, three parallel sets of scotch yokes, two counter weights, and an actuator arm.

With the help of the variable speed controller, the DC motor can be operated at 175 RPM to 1750 RPM, while always being able to deliver 2 H.P. The 3:1 speed reducer brings the speed down to a range of 59 RPM to 590 RPM. Since the scotch yoke goes through one full cycle for every revolution of the crankshaft, the resulting frequency range is 1 Hz to 10 Hz. During testing, the useful range was found to be 1 Hz to 7 Hz. The limit on the upper frequency was imposed by the ability of the linear bearings, which were guiding the cylinder, to withstand the dynamic loads. When operated within this range, the shaker mechanism maintains a steady frequency. The variation in frequency between any two individual cycles is less than 5%. Average frequencies measured over 50 cycles varied by less than 1%.

The total weight of the actuating arm and test cylinder was 9.1 kg (20 lb.). Large forces are generated when oscillating a weight of this magnitude at a frequency of 1 Hz to 10 Hz with an amplitude of 38 mm (1.5 in.). In order to minimize the effects of these forces on the crankshaft and on the frame, two counter-weights, each half of the total weight of the arm and test cylinder, are provided.

This mechanism was built specifically for this set of experiments. The size of the counter-weights and of the flywheel were chosen so that the transfer of energy to and from the cylinder would cause less than 1% change in the average RPM of the shaker.

Each counter-weight has half the weight of the actuator arm and test cylinder. The two counter-weights move in the same plane, but in the opposite direction to the actuator arm. This makes the net horizontal force transmitted to the frame almost zero, so minimizing vibrations to the support frame.

The interaction between the crankshaft and the scotch yoke causes a force perpendicular to the crankshaft and in the plane of oscillation, see figure 25. The forces produced by the actuator arm, scotch yoke arm and by the counter-weights are in opposite directions, but not along the same line. They produce a bending moment on the crankshaft. If only one actuator arm and one counter-weight were present, then these opposing forces would cause large asymmetric moments in the crankshaft. In order to minimize the effects of the bending moments imposed on the crankshaft by the reciprocating weights, two counterweights are used. This distributes the bending moment evenly on both sides of the scotch yoke driving the actuator arm. To reduce the bending moment on the crankshaft even further, the distance between the scotch yoke mechanisms (the distance labelled B in figure 25) was made as small as possible.

The size of the flywheel was limited by the geometry of the mechanism, and by weight considerations. Within these limitations, the flywheel was made large enough so that the RPM of the mechanism would not vary by more than 1%.

4.3 TEST CYLINDERS

Two cylinders were used in tests on a tandem arrangement. Both cylinders were hollow aluminum cylinders with 0.1143 m (4.50 in.) outside diameters. In some tests, only one of the two cylinders was employed.

In the tandem arrangement, the upstream cylinder was permanently fixed in the wind tunnel during the tests. It extended from the floor to the ceiling of the wind tunnel test section, and had a length of 0.608 m. It was held in place by two plexiglas plates which were fitted to the ends of the cylinder and attached to the wind tunnel surfaces with wood screws. The sharp edges of the plates and the wood screws were covered with masking tape to reduce the disturbance they caused to the air stream.

The downstream cylinder was also held fixed during static tests. During dynamic tests, the downstream cylinder was forced to oscillate along a line perpendicular to the free stream velocity vector, with an amplitude of 38 mm (1.5 in.) peak-to-peak and at a forced frequency in the range of 1 Hz to 7 Hz. The length of the downstream cylinder was 0.588 m. Because the downstream cylinder had to be free to oscillate, it ended 10 mm (0.4 in.) away from both the floor and the ceiling of the wind tunnel. The cylinder was held in place by a supporting yoke.

4.4 PRESSURE TRANSDUCERS

The dynamic pressure on the surface of the cylinder was measured with an LCVR (Low Cost Variable Reluctance) pressure transducer from Celesco. This is a differential pressure transducer with a range of 0 to 5 cm of water.

This transducer was chosen because of its high sensitivity, small range, and overall small size, and because it was able to measure static, as well as low frequency dynamic pressures. Because of considerations explained below, the transducer had to fit into the oscillating cylinder which had, as previously noted, a diameter of 0.1143 m (4.50 in.). The output of this transducer can be adjusted to 14.5 V/kPa (100 V/psi). The small range of the transducer was important because some important performance characteristics of the transducer, such as hysteresis, non-linearity, and repeatability are given as a percentage of full scale reading. This makes it desirable to use a transducer in such a range that the expected readings are between 50% and 100% of the full scale reading.

Of all the transducers investigated, only this transducer was small enough to fit into the test cylinder, had high enough sensitivity, and a small range, and was able to measure static as well as low frequency dynamic pressures.

The LCVR is a differential pressure transducer. Its output is a function of the difference between the pressures supplied to the two pressure ports of the transducer. Within the transducer, the low and high pressures act on opposite sides of a steel diaphragm. The difference in pressure causes the diaphragm to deflect.

The extent to which the diaphragm has deflected within the transducer is sensed by two electromagnetic coils. One coil is energized with an electric current at 4 kHz. The second coil picks up the fluctuating magnetic field and converts it to an electrical signal. As the steel diaphragm deflects, it changes the magnetic path within the transducer. This change in the magnetic path is reflected in the signal output from the second coil.

An electronic circuit called the Low Cost Carrier Demodulator (LCCD) from Celesco draws power from a 15 V DC power supply, produces the 4 kHz signal for the first coil in the pressure transducer, and changes the AC output from the second coil into a DC voltage. Two variable resistors within the carrier demodulator circuit allow the adjustment of the sensitivity and of the zero point of the transducer.

In order to calculate the coefficient of pressure on the cylinder surface, the difference between the pressure on the surface of the cylinder and the static pressure of the flow upstream of the cylinder must be known.

The first and most obvious way to obtain this difference in pressure would be to connect a pressure port on the cylinder surface to the positive pressure port of the transducer, and to connect the negative pressure port to a static port upstream. This would involve the use of a substantial length of small diameter tubing [1.22 m (4 ft.) length of tubing with 3 mm (1/8 in.) inside diameter]. Most of this plastic tubing could be firmly attached to solid surfaces which do not flex, but there exists one place where the tubing would have to flex, namely where the tube exits from the moving cylinder.

Due to the fact that the cylinder oscillates with such a large amplitude (38 mm peak-to-peak), the flexing of the tube would most likely cause a periodic pressure signal within the tube. Even under the best circumstances, with the tube carefully mounted, the pressure signal caused by flexing the tube is of the same order of magnitude as the pressure difference being measured.

Since the direct method of using a differential pressure transducer to measure the difference in pressure will not work in this case, the two pressures had to be measured independently and then subtracted from each other. One transducer was used to measure the pressure on the surface of the cylinder, and another transducer (figure 26) was used to measure the static pressure upstream. With this arrangement, the long flexible tubing was eliminated, along with the resulting error in the pressure signal.

Even though in this tandem transducer arrangement each transducer has to measure an absolute pressure, the resolution required for the measurement remains equal to what it would have been if one differential transducer was used to measure the difference between the static and dynamic pressures. If absolute transducers, capable of measuring near-atmospheric pressures, were used, then they would not be able to provide the required accuracy. The best of the available absolute pressure transducers can provide accuracy within 1% to 0.3% of

FS (full scale). A range of 105 kPa (15 psi) would be required to make absolute measurements, because the small fluctuating pressure signal would be superimposed on the barometric pressure. For a range of 105 kPa (15 psi), an error of 0.3% FS is equal to 0.315 kPa (0.044 psi), which is of the same order of magnitude as a typical pressure difference measured in the experiment.

Instead of using absolute pressure transducers to measure the static and dynamic pressures, the LCVR differential pressure transducers were used, in order to get the high accuracy made possible by their small range. The negative pressure port of each transducer was closed off at nearly atmospheric pressure. Then the electronics were adjusted so as to zero the output of the LCVRs. From this time onwards, the signal produced by each transducer indicated the difference between the pressure applied to the positive pressure port and the atmospheric pressure present at the time of calibration. The negative port of the pressure transducer had to be connected to a known pressure because otherwise the drift in atmospheric pressure during the course of the experiment would cause a drift in pressure readings.

Originally the negative pressure ports of the LCVR pressure transducers were closed off with short pieces of tubing and plastic plugs. With this arrangement, the volume of the enclosed cavity connected to the negative pressure port was small. As the diaphragm deflected in the pressure transducer, the change in volume of this cavity was quite large compared to the total volume of the cavity. This caused the reference pressure in the enclosed cavity to vary.

To overcome this problem, two large (12 cm high and 10 cm diameter) air tight containers were built out of plexiglass one for each LCVR pressure transducer. Each of these containers has only one opening; a pressure port was connected directly to the negative port of the LCVR transducer. Now the reference pressure is enclosed within a volume which is much larger than the volume change caused by the deflection of the diaphragm.

Two parallel pressure transducer systems were built. Each system contained an LCVR pressure transducer, an LCCD carrier demodulator, and a reference pressure tank.

One transducer and its reference pressure tank was placed inside the oscillating cylinder, see figure 4. The negative pressure port of the transducer was connected to the reference pressure tank, while the positive pressure port was connected to the pressure port on the surface of the cylinder. The carrier demodulator circuit for this transducer was placed outside the wind tunnel and connected to the transducer by a three conductor wire. This transducer set is called transducer #2.

The second transducer was placed outside the wind tunnel. Its negative port was connected to its reference pressure tank. Its positive pressure port was connected to a tap on the side wall of the wind tunnel upstream of the test cylinders. This transducer was also connected to its carrier demodulator by a three conductor wire. This transducer set is called transducer #1.

The output from the two transducer setups was directed to an analog subtractor circuit. Transducer #2 (pressure on the cylinder surface) was connected to the positive input of the subtractor. Transducer #1 (static pressure upstream) was connected to the negative input of the subtractor, see figure 26. The positive and negative inputs of the subtractor circuit do not place any constraints on the polarity of the signals connected to them. They are just a convenient way of keeping track of which signal will be subtracted from the other. The signal supplied to the negative input will be subtracted from the signal supplied to the positive input. In this case the output from the subtractor was equal to the signal from transducer #2 minus the signal from transducer #1 (pressure on the surface of the cylinder minus the static pressure upstream).

The output from the analog subtractor was conditioned with a low-pass filter to remove frequencies which were much higher than the frequency of oscillation. The cutoff frequency varied with the forcing frequency of the cylinder oscillations and was typically 6 to 10 times higher than the frequency of oscillation. (See Table 1 for exact values of the cutoff frequency at different frequencies of oscillation.) This conditioned signal was then averaged and recorded using a Hewlett-Packard 5420 digital signal analyzer.

4.5 OTHER APPARATUS

Besides the equipment described above, the experimental work required a number of other pieces of equipment not described so far.

A Rockwell Filter, model 852, was used to remove high frequency noise from the signal coming from the LCVR pressure transducers.

A Hewlett-Packard 5420 Digital Signal Analyzer was used to collect the experimental data from the dynamic tests. Internally, the analyzer digitized the analog voltages coming from the Rockwell Filter, then it averaged the input over 70 cycles. The time trace of the averaged signal could then be stored on tape.

A Hewlett-Packard Digital Voltmeter, model 3438A, was used to check and reset the calibration of the pressure transducers. The voltmeter was used to measure the transducer output. With the wind tunnel shut off, the controls of the transducer circuit were used to set the output to zero.

During static tests, the difference between the pressure on the surface of the cylinder, and the static pressure upstream was measured with an inclined manometer, Type 5 from Airflow Development Ltd.

A mercury barometer, from Nova, was used to measure the atmospheric pressure in the laboratory. The thermometer mounted on the barometer was used to measure the temperature in the lab.

A Betz manometer, from Elven Precision Ltd., was used to measure the pressure drop across the wind tunnel contraction, just ahead of the working section. In the report by Pinnell and Mark (1983), this pressure drop was related to the average flow velocity in the wind tunnel.

A Frequency Counter from Hewlett-Packard, type 5345A, was used to measure the period of oscillation of the cylinder. The frequency counter was used to measure the time interval between two electrical pulses coming from a trigger mounted on the shaker mechanism. The same pulse was used to trigger the Digital Data Analyzer to start taking readings at the beginning of the cycle.

V EXPERIMENTAL PROCEDURE

5.1 STATIC TESTS

There were three reasons for doing experiments with the cylinder statically fixed in the flow, i.e. tests where the frequency of oscillation was zero. The first reason was to check if the experimental setup and procedure were free of errors. This was done by doing experiments on a single cylinder, which would later be used in the dynamic tests, and comparing the results with the published work of other researchers.

The second reason for doing static experiments was to provide input data for the quasi-static calculations, which would later be compared with the dynamic results. This second set of tests was done on the same pair of cylinders which were later used in the dynamic tests.

The third reason for doing static tests was to check the influence of a variation in Reynolds number on the pressure coefficient distribution around the downstream cylinder.

The LCVR pressure transducers were not used for static tests because only the time-averaged pressure readings were required. If the LCVR pressure transducers had been used, then a method of averaging the analog electrical signal would have had to be developed. All static tests were done using a single leg inclined manometer, described in section 4.5. Because of the inertia of the liquid in the manometer, the fluctuations in the pressure readings were very small, and the time- averaged pressure reading could be obtained directly from the manometer.

The cylinder used in the experiments had a pressure tap on its surface, half way along its length (see figure 4). The cylinder was mounted vertically in the wind tunnel. The pressure tap on the surface of the cylinder was connected to the manometer by a length of small diameter plastic tubing (3 mm inside diameter), see figure 26. The other end of the manometer was connected to a pressure tap on the wind tunnel wall just upstream of the working section; i.e., to the upstream static pressure. Thus, the manometer showed the difference between the pressure on the surface of the cylinder and the upstream static pressure.

The free-stream velocity in the wind tunnel was determined by measuring the pressure drop across the wind tunnel contraction just ahead of the working section (see figure 27). This pressure drop was measured with a Betz manometer.

At the beginning of each experiment, the atmospheric pressure and temperature were measured. Then using the incompressible equation along with Bernoulli's equation, and the fact that cross-sectional area of the wind tunnel was reduced by 6:1 in the tunnel contraction, the wind tunnel free-stream velocity was obtained from this pressure drop. The validity of this method of obtaining the free-stream velocity was checked by Pinnell and Mark (1983).

Before data was collected, the wind tunnel was operated for a period of 15 minutes to allow the motor, fan and controller to reach operating temperature. After this initial warm up period, the wind tunnel would maintain a steady speed.

5.1.1 Single cylinder experiments

Single cylinder static tests were done in order to verify the proper working of the apparatus, and to verify the experimental procedure. The single cylinder used, was mounted on the shaker mechanism; later, in the dynamic tests, this cylinder became the oscillating, downstream, test cylinder. This cylinder was chosen for static tests because it could easily be rotated about its longitudinal axis and so the pressure distribution around its circumference could be measured. In addition the cylinder could be statically displaced across the wind tunnel, and so placed anywhere along its proposed path of oscillation in the dynamic experiments.

The tests done with a single cylinder were aimed at obtaining the pressure coefficient distribution around the surface of the cylinder. This same data could also later be used to calculate the drag coefficient of the single cylinder. The pressure coefficient distribution and drag coefficient could then be compared with previously published results.

The following test procedure was used for the single cylinder tests. It was similar to the procedure for static tandem tests, with minor exceptions which will be explained in section 5.1.2.

The single static cylinder test procedure was as follows:

1. Warm up wind tunnel.

2. Measure and record the atmospheric temperature and pressure, then calculate the pressure drop across the tunnel contraction for the speed chosen for the experiment.

3. With the wind tunnel shut off, zero the Betz manometer used to measure the wind tunnel speed, and zero the manometer used to measure the difference between the static pressure and the pressure on surface

of the test cylinder.

4. Rotate the test cylinder to its starting position at 0^{o} such that the pressure tap on the cylinder surface is facing upwind.

5. With the wind tunnel running, and adjusted such that the Betz manometer indicates the desired pressure drop across the wind tunnel contraction, observe and record the pressure difference indicated by the inclined manometer. This is the pressure difference between the pressure on the cylinder surface, and the static pressure upstream of the test section.

6. Rotate the test cylinder clockwise by 10^{o}.

7. Repeat steps 5 and 6 until the entire circumference of the cylinder is covered.

5.1.2 Staggered cylinders

Staggered cylinder experiments were completed with the cylinders arranged in various configurations of L/d and T/d. The various static positions tested are shown in Table 2.

Two types of static, staggered cylinder tests were done. The goal of the first kind of test was to obtain the pressure coefficient distribution around the downstream cylinder (the pressure around the upstream cylinder was never measured). This data could then be used to calculate the lift and drag coefficients for static conditions, and was subsequently used in the quasi-static calculation to try to predict the dynamic results.

For staggered cylinder tests, the upstream cylinder was permanently mounted in the wind tunnel in a vertical position. The downstream cylinder, was mounted in the shaker yoke mechanism. In order to measure the difference in pressure between the pressure on the cylinder surface and the static pressure upstream, small diameter plastic tubing was used to connect the pressure tap on the downstream cylinder to the manometer. The other end of the manometer was connected to a pressure tap in the wall of the wind tunnel, just upstream of the working section.

The shaker mechanism was rotated by hand, until the downstream test cylinder reached the point where x/d became a minimum; x/d is the ratio of transverse cylinder separation to cylinder diameter. Then the tunnel was warmed up and the same procedure followed as described in steps 1 to 7 of section 5.1.1 until the complete pressure distribution around the cylinder was obtained.

When the seven step procedure was completed, the shaker mechanism was advanced by hand such that the cylinder moved a distance of 6.35 mm (1/4 inch) across the wind tunnel in the direction of increasing T/d. The distance of 6.35 mm is equal to 1/6 of the peak-to-peak stroke, which was later used in dynamic tests. Once the test cylinder was repositioned, steps 1 to 7 of section 5.1.1 were repeated. This sequence of advancing the cylinder by 6.35 mm (1/4 inch) and completing steps 1 through 7 was repeated until the cylinder reached the other extreme end of its stroke.

Since the peak-to-peak amplitude of forced oscillation was 38 mm (1.5 inches), and the cylinder was moved in 6.35 mm (1/4 inch) steps, there were 7 positions at which the static, tandem results were tabulated. Position 4 was always the central position, when looking upstream, position 1, was always the left most position (where x/d was at a minimum) and position 7 was always on the far right (where x/d was at a maximum), see figure 28.

The second kind of static staggered cylinder tests were done to determine the effect of Re on the pressure distribution of the downstream cylinder. The effect of Re on the pressure distribution on the cylinder surface was investigated in two ways.

The first way was to obtain a complete pressure distribution around the cylinder surface at all seven of the static positions in the cycle of oscillation. This was done by taking static, tandem tests as described in the previous paragraphs. However, because of the time required to complete each test, they were done at three velocities only, 10 m/s, 15 m/s, and at 22 m/s, which correspond to Re of 7.7×10^4, 1.16×10^5 and 1.75×10^5 respectively. Also, these tests were limited to the setup with L/d = 4 and T/d = 1.

The second way in which the effect of Re on the pressure distribution was investigated, was to vary the velocity continuously, but to limit the number of positions investigated. This was done by keeping the downstream test cylinder in one position, and by varying the free stream velocity from 10 m/s to 22.7 m/s. Only selected positions were investigated in these tests; these positions being L/d = 4 and T/d = 0.67, 1, and 1.33. At each of these three positions only four angular orientations were investigated; these being 0^o, 90^o, 180^o, and 270^o from the front stagnation point.

The procedure used to conduct these tests was similar to the seven step procedure described in section 5.1.1, except that in step 6, instead of rotating the cylinder to a new angular position, the tunnel velocity was increased in small steps from 10 m/s to 30 m/s.

5.2 DYNAMIC TESTS

Dynamic tests, where the frequency of oscillation was not equal to zero, were done only on the staggered cylinder arrangement. The cylinders were mounted in various configurations of L/d and T/d. These positions are drawn to scale in figure 29, where the dashed circles indicate positions where dynamic tests were done. The purpose of the dynamic tests was to obtain the pressure distribution around the surface of the downstream cylinder as a function of its position in the cycle of oscillation. This pressure distribution was then used to calculate pressure, drag and lift coefficients on the oscillating cylinder during different parts of the cycle. These, in turn were then compared with quasi-static calculations, which had been obtained using the static results.

During the dynamic testing, it was essential to make nearly continuous measurements of the pressure while the cylinder was oscillating. It would have been impossible to do this with a manometer. Instead, LCVR electronic pressure transducers from Celesco were used, see section 4.4 for a description of the pressure transducers. Section 4.4 also gives a description of how the pressure transducers were setup for the experiment.

The filtered signal was fed into the Hewlett-Packard 5420A Digital Signal Analyzer. The analyzer digitized the analog signal and averaged the time domain signal over 70 samples. Each sample started at the same point in the cycle, at the time when the cylinder was in position number 1 (at the point when the lowest x/d was reached during oscillation). The result was an averaged time trace of the pressure as the cylinder executed its oscillations. These time traces were stored on data tapes and recalled later for analysis.

The same cylinders were used for the dynamic tests as for the static tests. The downstream cylinder had only one pressure tap on its surface. This made it impossible to simultaneously obtain the pressure distribution over the entire cylinder surface. Therefore, in order to obtain the pressure distribution at all angular locations on circumference of the cylinder it was necessary to complete 37 tests. One test for each angular position at 10° intervals. Then, an assumption was made that the conditions remained steady while these 37 tests, covering the circumference of the cylinder were done over a period of 4 to 6 hours. This assumption was verified by repeating the initial measurement at the end of the experiment and checking that the two sets of data agreed.

Each of the 37 pressure variations with time represents the variation of pressure at some angular position on the cylinder surface, as the cylinder oscillates in the flow. Also, it should be noted that each of the 37 pressure variations, is actually an average of 70 samples. In order to obtain the "instantaneous" pressure distribution on the cylinder surface at some point in the cycle, it is necessary to take the pressure levels corresponding to that point of the cycle from each of the 37 graphs and so construct the instantaneous pressure distributions.

At any one location on the surface of the cylinder, the surface pressure fluctuated as the cylinder oscillated in the flow. These pressure fluctuations were caused by the change in the flow field as the downstream cylinder moved in the wake of the upstream cylinder. Because of the statistical nature of the turbulent flow which exists in the wake, it was very rare for any two pressure time traces to be the same for any two cycles. However if the number of samples making up the average was high enough, the average of the pressure time traces was repeatable. It was determined that an ensemble average of 70 samples produced a repeatable average of pressure time traces.

The steps taken during dynamic tests were as follows:

1. Equalize the pressure in the two reference pressure tanks provided for the two pressure transducers. This was done by temporarily disconnecting the reference pressure tanks from the negative pressure ports of the respective LCVR pressure transducers.

2. Reconnect the negative pressure ports of the transducers to their reference pressure tanks.

3. Place the LCVR pressure transducer #2 in the downstream test cylinder and connect its positive pressure port to the pressure tap on the cylinder surface.

4. Place transducer #1 outside of the wind tunnel and connect its positive pressure port to the pressure tap in the surface of the wind tunnel located just ahead of the working section.

5. Warm up the wind tunnel and the shaker mechanism for a period of 15 minutes.

6. Note and record the atmospheric pressure and temperature; calculate the pressure drop across the tunnel contraction corresponding to the velocity chosen for the experiment.

7. Shut off the wind tunnel and the shaker mechanism and rotate the test cylinder to the starting angular position, at 0°.

8. With the wind tunnel off, zero the Betz manometer which is used for measuring the tunnel velocity, and zero the output of the analog

subtractor circuit by adjusting the variable resistor in that circuit.

9. Turn on the wind tunnel and adjust its speed until the Betz manometer shows the pressure difference calculated in step 6.

10. Turn on the shaker mechanism and adjust its speed until the frequency counter shows that it is running at the frequency chosen for the experiment.

11. Start the data acquisition cvcle by pressing the RUN key on the Digital Signal Analyzer (note: the analyzer must be programmed, or set up to perform time domain measurements with 70 averages for each run).

12. While the experiment is running, note and record the atmospheric temperature and pressure. Also, if necessary, make small adjustments to the speed of the wind tunnel and to the frequency of the shaker mechanism to keep them operating at the desired values.

13. At the end of the run, save the data trace on a data tape loaded into the Digital Signal Analyzer.

14. Stop the wind tunnel and the shaker mechanism and rotate the test cylinder clockwise by 10^{o} to the next test position.

15. Repeat steps 8 through 14 until data is obtained for all 36 angular positions on the circumference of the cylinder. The first angular position, position number 1 and the last position, position number 37, are the same physical point, the point where the pressure tap on the cylinder faces directly upstream.

The data collected for static and dynamic experiments was further analyzed as described in chapter VI DATA PROCESSING.

VI DATA PROCESSING

The data collected by the procedures described in chapter V was used to calculate the pressure, lift and drag coefficients on the leeward cylinder. The static data was used to calculate the quasi-static results, which were compared against the dynamic results.

Because of the large volume of information which had to be processed and plotted, it was decided to use a digital computer to store the results, calculate the coefficients, and plot the graphs The computer used to do this, was an IBM-PC with 640 k memory, equipped with a GPIB-PC (General Purpose Interface Bus). The purpose of the GPIB-PC was to allow the IBM-PC computer to communicate with the Hewlett- Packard Digital Signal Analyzer which was used to collect data during the dynamic tests, and with the Hewlett-Packard ColorPro Plotter which was used to plot the graphs.

There were differences in the postprocessing of the static and dynamic results because the methods involved in the two types of tests were different. Section 6.1 describes the type of data postprocessing required for the static results. Section 6.2 describes the postprocessing of the dynamic results. Section 6.3, briefly describes the different computer programs which were used to handle the data. Complete listings of the computer programs are provided in Appendix A.

6.1 STATIC EXPERIMENTS

As discussed in section 5.1, the purpose of doing static experiments was threefold: i), to provide a way of comparing results obtained with the existing apparatus against other results for a single cylinder; ii), to provide input data for the quasi-static calculations for tandem cylinders; and iii), to check the influence of Re on the pressure coefficients on the downstream cylinder. In all cases the raw data was in the form of hand-written tables of cylinder location in terms of T/d, and L/d, angular cylinder orientation and the corresponding difference between pressure on the surface of the test cylinder and the free stream static pressure. Each set of data from the static experiments also included the values of atmospheric temperature and pressure at the time of the experiment and the free stream velocity at which the experiment was performed.

The results of the single cylinder tests (intended for comparison with other research work) and of the tandem cylinder tests (intended to provide input for the quasi-static calculations) were treated the same way as far as the pressure coefficients are concerned.

The pressure coefficient C_p was calculated as

$$C_p = \frac{p - p_i}{\rho U^2/2}$$

where C_p = pressure coefficient,

p = pressure on the cylinder surface,

p_i = static pressure upstream of test section,

ρ = air density,

and U = free stream velocity.

The lift and drag coefficients were calculated from the pressure coefficients by integrating them over the cylinder surface. Piecewise, numerical integration was used because the value of the pressure coefficient was known only at 36 points on the cylinder surface, at 10° intervals.

For the purposes of the force coefficient calculations, the pressure coefficient was assumed to be linear between any two consecutive points, see figure 30. The contribution of each 10^0 segment to the lift and drag coefficients was calculated by integrating the pressure times the area of the segment. The lift and drag coefficients were then obtained by summing the 36 integrals and resolving in the lift and drag directions.

$$C_D = \frac{1}{2}\sum_{i=1}^{36} \int_{\frac{\pi}{18}(i-1)}^{\frac{\pi}{18}i} \cos\theta \; C_{p_i}(\theta)d\theta$$

$$C_L = -\frac{1}{2}\sum_{i=1}^{36} \int_{\frac{\pi}{18}(i-1)}^{\frac{\pi i}{18}} \sin\theta \; C_{p_i}(\theta)d\theta$$

where $C_{p_i}(\theta)$ = pressure coefficient on the i'th segment of the circumference,

C_D = drag coefficient,

C_L = lift coefficient,

and θ is as defined in figure 30.

6.2 QUASI-STATIC CALCULATIONS

The force coefficients for the static, tandem cylinders were used to calculate quasi-static coefficients C_x^* and C_y^*, which could later be compared to dynamic force coefficients C_x and C_y measured while the downstream cylinder was oscillating.

The static force coefficients measured on the staggered cylinders were used to calculate the quasi-static force coefficients C_x^* and C_y^* as described below; these were then later compared with the dynamic force coefficients measured on the oscillating downstream cylinder.

In using the quasi-static assumption it is necessary to determine the resultant velocity vector relative to the leeward cylinder accounting for the motion of the leeward cylinder. For an isolated body this is relatively straight forward (see figure 31), but for a cylinder in the wake of a second two problems arise. Firstly, the magnitude of the local wake velocity is not known, only the magnitude of the free-stream velocity. Secondly, the orientation of the local wake velocity is not known. The second of these problems can be overcome by assuming that the wake velocity is parallel to the free-stream velocity. For $L/d \geq 4$ this has been shown to be correct by experimental measurements on staggered cylinders by Price (1976) who found that the maximum change in the orientation of the front stagnation point was less than 10° for $L/d \geq 4$. For $L/d \leq 4$ there is less justification in making this assumption but considering the other data it is still made.

Ignoring for the time being, the first problem, the resultant velocity vector diagram is as shown in figure 32. Assuming $\dot{y}$ is small compared to the local wake velocity, $\bar{U}$, and neglecting second order terms then $U_r \approx \bar{U}$

$$\text{and } \alpha = \sin^{-1}(\dot{y}/\bar{U}),$$

where α is the induced incidence.

Thus the quasi-static forces in the x and y directions may be written as

$$F_x = \frac{1}{2}\rho\bar{U}^2(\bar{C}_D + \bar{C}_L\,\dot{y}/\bar{U})$$

$$F_y = \frac{1}{2}\rho\bar{U}^2(\bar{C}_L - \bar{C}_D\,\dot{y}/\bar{U})$$

where $\bar{C}_D$ and $\bar{C}_L$ are the drag and lift coefficients respectively based on the local velocity $\bar{U}$.

If the lift and drag coefficients are based on the free stream velocity, U, rather than on $\bar{U}$, then as

$$\bar{U}^2\bar{C}_D = U^2 C_D$$

and similarly for C_L, the same expresions may be rewritten as

$$F_x = \frac{1}{2}\rho U^2 (C_D + C_L\,\dot{y}/\bar{U})$$

$$F_y = \frac{1}{2}\rho U^2 (C_L - C_D\,\dot{y}/\bar{U})$$

Thus, the quasi-steady lift and drag coefficients C_y^* and C_x^* are given by

$$C_x^* = C_D + C_L\dot{y}/\bar{U}$$

$$C_y^* = C_L + C_D\dot{y}/\bar{U}$$

The problem now remains, what to do about $\bar{U}$. One solution to this is as given by Price (1975) who assuming a constant generic drag coefficient showed that

$$C_{D*}\,\bar{U}^2 = C_D\,U^2$$

where C_{D*} is the free stream drag coefficient.

Thus $\bar{U} = bU$ where $b = (C_D/C_{D*})^{1/2}$ and the quasi-steady coefficients C_x^* and C_y^* may be written as

$$C_x^* = C_D + C_L\dot{y}/bU$$

$$C_y^{\cdot} = C_L + C_D\dot{y}/bU$$

However, bearing in mind that in the present experiments $\dot{y}/U$ is very small, the change in results obtained between using $\dot{y}/U$ and $\dot{y}/bU$ is extremely small. Thus, for the sake of simplicity the former was employed.

However, it should be appreciated that in this Thesis the quasi-static assumption is being applied to the staggered cylinders with the two assumptions included. Thus, the experiments are not strictly testing the quasi-static assumption, but the quasi-static assumption including the above two assumptions.

6.3 DYNAMIC EXPERIMENTS

The data from the dynamic tests were in the form of time-averaged pressure records indicating the surface pressure variation at some angular position on the cylinder as the cylinder was subjected to forced oscillation. Figure 33 shows some typical pressure traces produced by the 5420 Digital Signal Analyzer.

One dynamic test includes 36 traces of pressure versus time, for each angular position on the cylinder at 10^{o} intervals. Each trace of pressure versus time is described by 512 pairs of binary co-ordinates. This information was transferred from the 5420 Digital Signal Analyzer to an IBM-PC computer where it was further reduced to produce plots of C_x and C_y. The data transfer and the subsequent data reduction were carried out with the help of computer programs described in section 6.4.

Other additional data, which were recorded manually on data sheets, included the atmospheric pressure and temperature, wind tunnel speed, and frequency of oscillation.

Since the cylinder was oscillating with simple harmonic motion, it was possible to calculate its position at any point in time based on the frequency of forced oscillation. Conversely, it was possible to calculate the time elapsed between the start of the cycle and the time when the cylinder reached a particular position. The instantaneous pressure distribution on the surface of the oscillating cylinder could be obtained at any point in the cycle by reading the pressures from the 36 graphs at an appropriate offset from the start of the cycle.

Instantaneous surface pressure distributions were obtained for positions in the cycle of oscillation corresponding to the same positions where the static surface pressure distributions were measured. Then, the dynamic pressure distribution was expressed in nondimensional form in terms of its dynamic pressure coefficients.

The resulting distribution of instantaneous dynamic pressure coefficients around the surface of the oscillating cylinder was used to calculate the dynamic force coefficients C_x and C_y acting on the cylinder surface. This was done by integrating the pressure coefficients over the surface of the cylinder and resolving the resulting forces in the x and y directions.

As mentioned in the previous section, the resulting dynamic force coefficients C_x and C_y were then compared to the calculated quasi-static force coefficients C_x^* and C_y^*.

6.4 COMPUTER SOFTWARE

This section will present a brief description of the different computer programs which were prepared and used to handle the experimental data. Complete listings of programs are presented in Appendix A.

<u>CP33.BAS</u> This program was used to key-enter into the computer the data collected during static tests, both single cylinder and tandem arrangements. The program was also used to calculate the pressure coefficient on the cylinder surface.

<u>PLOTCPHP.BAS</u> This program was used to plot the pressure coefficient versus the angular position around the cylinder circumference. The resulting graphs for the single cylinder tests were then compared to

the results of other researchers. See chapter VII for discussion of results.

The pressure coefficients for the tandem arrangement were used to calculate the lift and drag coefficients, using program CDCL1.BAS. This program numerically integrates the pressures around the circumference of the cylinder in order to calculate the lift and drag coefficients from the static pressure coefficient distribution. It was also used to calculate the dynamic force coefficients C_x and C_y from the distribution of dynamic pressure coefficients.

Because pressure readings were taken at 10^o intervals, the program CDCL1.BAS assumes that the variation of pressure between any two points is linear. The magnitude of errors, inherent in this kind of numerical integration, was checked by testing the program on two test distributions of the pressure coefficient. The first test was on a hypothetical pressure coefficient distribution where the pressure coefficient was constant and equal to 1 along a 60^o arc centered on the 0^o position (upstream face of the cylinder). The pressure coefficient was equal to -1 along the 280^o arc centered on the 180^o position (downstream side of the cylinder). The change from one level of pressure coefficient to another was along two linear ramps spanning 10^o segments. The down ramp was between 30^o and 40^o, and the up ramp, was between 330^o and 340^o, see figure 34. The second test was on the pressure coefficient distribution given by inviscid flow theory, and calculated using potential flow theory.

Both examples were integrated analytically to give exact values of lift and drag coefficients. The results of the program CDCL1.BAS agreed with the analytical solutions to four decimal places. (The agreement might be even better, but it was considered sufficient to check only the first four decimal places, considering that most of the results were of the order 0.1, and a difference of the order 0.001 would not be noticeable on the graphs.)

PLOTCDC3.BAS This program plots the lift and drag coefficients which were calculated by the previous program CDCL1.BAS. These coefficients are plotted versus cylinder position.

PREDICT.BAS This program uses the quasi-static assumption to calculate the quasi-static force coefficients based on the static lift and drag coefficients, free stream velocity, amplitude and frequency of oscillation.

PLOTPRED.BAS This program plots the calculated quasi-static force coefficients and the measured force coefficients on the same graph to permit comparison. The coefficients are plotted as a function of cylinder position.

The Hewlett-Packard 5420 Digital Signal Analyzer used during dynamic tests has its own internal software for gathering and storing data. This software was not modified. The GPIB-PC (General Purpose Interface Bus) interface also has its own software which makes it possible to control the interface from the IBM-PC computer while transferring the data from the analyzer to the IBM-PC The GPIB-PC software can be interfaced with user programs in BASIC, Pascal, C, or machine language in order to accomplish the data transfer. In this case BASIC was chosen as the language to be used for control of the GPIB-PC.

HP2PC V6.BAS This program was used to transfer the experimental data from the Hewlett-Packard data tapes to a 5 1/4" diskette. A separate file was created for each data record transferred from the data tape. Each file contained a 16 number header plus 512 numbers representing the pressure time record.

VERI V6.BAS This program was used to verify that the data transferred by HP2PC V6.BAS was intact and correct.

PC2HP V6.BAS This program was used to transfer data from the IBM-PC back into the 5420 Digital Signal Analyzer if it became necessary to view it, or further analyze it by using the analyzer software.

HP2PC V3.SET The Hewlett-Packard Digital Signal Analyzer is a versatile machine which can be programmed to perform a variety of measurements. These programs or setups, can be stored on the data tapes along with data the records. The BASIC program HP2PC V3.SET was used to transfer these setup sta'.es to 5 1/4" diskettes for storage.

VERI V1.SET This program was used to verify that the setup states were transferred correctly to diskettes.

PC2HP V2.SET This program was used when it became necessary to transfer the setup states from the IBM-PC diskettes to the Hewlett-Packard Signal Analyzer.

WRITINFO.BAS This program was used to create files INFOx.DAT which contain extra information about dynamic tests, information which was not included in the data records transferred from Hewlett-Packard tapes. This information, which was manually recorded on data sheets, consists of experiment number, date of the experiment, free stream velocity, air temperature and pressure at the time of the experiment, and the frequency of forced oscillation of the cylinder.

CPDY1.BAS This program calculates the dynamic pressure coefficients as a function of angular orientation of the cylinder. It sorts through the different pressure versus time traces and picks out the appropriate data in order to calculate the dynamic pressure coefficient at various places in the cycle. It uses the technique described in section 6.3.

VII RESULTS AND DISCUSSION-STATIC TESTS

This chapter will cover the results obtained from the static experiments, i.e. tests where the cylinder was not oscillating.

7.1 SINGLE CYLINDER STATIC TESTS

The reasons for doing single cylinder static tests were twofold. Firstly, the measured drag, lift and pressure coefficients were compared to the published results of other researchers. This comparison gave an indication of how the wind tunnel flow and the test model being used compared to the equipment of other researchers, so giving an indication of the validity of the whole set of experimental results obtained.

The second reason for doing single cylinder static tests was to determine if changing the Reynolds number, within the range of 6×10^4 to 2.1×10^5, has any effect on the test results.

7.1.1 Lift and drag coefficients

Figure 35 shows a number of plots of pressure coefficient around the circumference of the cylinder, at various Reynolds numbers.

From the graph, it can be seen that there is a positive pressure on the leading surface of the cylinder for $\theta \leq 40^\circ$. The downstream half of the cylinder is subjected to a negative pressure, which is below the static pressure of the approaching free stream. There are also two cusps in the pressure coefficient curve at 80° and 280° from the front stagnation point. The base pressure coefficient at the back of the cylinder is about -0.8 in all cases.

Other researchers have found similar pressure distributions on single cylinders in cross-flow at these Reynolds numbers. The most noticeable difference between these results and the results of others, is that in the present case, the uniform, negative wake pressure, reached at the back of the cylinder is not as low as indicated by other researchers. In figure 35, the base pressure coefficient at the back of the cylinder is about -0.8. Schlichting (1979), gives a similar graph depicting work done by Flachsbart (1932) which is reproduced in figure 36. In this graph, the base pressure coefficient for Re = $1.9x10^5$ has a value of approximately -1.2. Similar curves of pressure coefficient are also given by Batham (1973) for circular cylinders in cross-flow, but the base pressure coefficient is again in the neighbourhood of -1.

Figure 37 shows the drag coefficients calculated for the present results (aspect ratio of 5.33) as a function of Reynolds number. They were calculated by integrating the pressure coefficient curves shown in figure 35. The drag coefficients, for the present case are about 0 8. This value appears to be insensitive to Reynolds number, at least in the Reynolds number range tested of $6x10^4$ to $2.1x10^5$.

The wind tunnel blockage in this case was 12.5%. A method of correction for wind tunnel blockage developed by Allen and Vincenti (1944) was used to correct the drag coefficient C_D, for a single cylinder static test.

$$C_D = C_D^*(1 - 2.472(d/H)^2 - 0.5C_D^*(d/H))$$

where: C_D = corrected drag coefficient,

C_D^* = measured drag coefficient,

(d/H) = blockage ratio.

Taking into account that the blockage ratio was 12.5%, the measured drag coefficient of 0.8, gives a corrected drag coefficient of 0.73. This is very close to the drag coefficient of 0.74 given by White for a circular cylinder with aspect ratio of 5. However, the results quoted by White are for cylinders with free ends, which are not constrained by tunnel surfaces. Work by West and Apelt (1982) is more representative of the present experiments.

West and Apelt measured pressure distributions around cylinders of varying aspect ratio and wind tunnel blockage. They used end plates fitted to the ends of their cylinders in order to eliminate the three dimensional effects of the flow. For a cylinder with an aspect ratio of 6 and wind tunnel blockage of 12.3% they obtained $C_D = 1.39$ at Re = $1.1x10^5$, however C_D decreases very suddenly when Re exceeds $1.1x10^5$. The results of West and Apelt suggest that the effect of a short aspect ratio is to increase the drag coefficient in comparison to two dimensional flow, but only for Re below $1.1x10^5$. For Re above $1.1x10^5$ the drag coefficient decreases drastically.

Pinnell (1987) used the same wind tunnel and cylinders as were used for the present experiments to also conduct tests on two parallel cylinders in cross-flow. He found that under normal operating conditions, without end-plates, and with no special seals of the wind tunnel holes, the measured C_D was lower than expected. However, the C_D increased up to 1.12, which is close to the value published by others, when he introduced end-plates at the two ends of the cylinders. The function of the end-plates was to make the flow more two dimensional by removing the boundary layer which had built up along the top and bottom of the wind tunnel, and by preventing air leakage from the wind tunnel.

The Pinnell experiment showed that the flow was not exactly two dimensional within this apparatus, thus resulting in a C_D which is lower than the published results for two dimensional flow. This experiment was not repeated during the present research since the result for the present set up are already known from Pinnell (1987).

The lower C_D obtained from the present results can be further explained by the fact that no particular effort was made to keep the cylinder surface smooth. The surface of the cylinders was that of standard grade, extruded aluminum tubing. Experiments done by Batham (1973), suggest that at Re = 1.11×10^5 to Re = 2.35×10^5, an increase in surface roughness reduced C_D from 1.17 to 0.72. Batham used 0.5 mm diameter sand particles on the cylinder surface to increase the surface roughness.

The lift coefficient, which is also shown in figure 37, was calculated from the pressure coefficient by integration, in much the same manner as the drag coefficient. The graph in figure 37 shows the lift coefficient to be -0.05, which is very close to, but not exactly, zero, as would be expected for a single circular cylinder in cross-flow. The reason for this, could be that is was impossible to mount the test cylinder exactly in the center of the wind tunnel. This was because space had to be made available so that during the staggered cylinder tests conducted later, a second cylinder could be mounted upstream and slightly to one side of the test cylinder. This resulted in the gap between the cylinder and the tunnel wall being smaller on one side of the cylinder then on the other, see figure 38. If the two gaps were exactly the same, then each one would measure 0.40 m (15.75 inches). During the static tests, the cylinder was displaced by 0.02 m

(0.75 inches) from the center line of the wind tunnel. This had the effect of forcing the air through a smaller contraction on one side than on the other, thus accelerating it to a slightly higher velocity, and producing a lower static pressure on one side of the cylinder, which resulted in non-zero lift force. As can be seen from the results presented in figure 37, the error in lift coefficient was small and was not considered to be a serious effect.

In summary, the flow field present in this experiment was not two dimensional, and the values of C_D varied from the two dimensional case, but the differences could be accounted for by a combination of effects caused by the short aspect ratio, leakage from the wind tunnel and rough surface finish. However, it should be noted that even though the numerical values of the lift and drag coefficients measured on the test model differ slightly from those of other researchers, this does not cause any problems for the present research. This is because the quasi-static theory was tested by comparing static and dynamic results obtained from exactly the same test models set up in exactly the same positions.

The shape of the pressure coefficient curve for a single cylinder indicates that the tests were done in the subcritical region ($300 < Re < 3 \times 10^5$), where the boundary layer on the upstream side of the cylinder remains laminar, and the shedding of vortices occurs at a well defined frequency.

7.1.2 Variation with Re

As stated at the beginning of this section, the second reason for doing single cylinder static tests was to determine the effect of

Reynolds number on the forces acting on the test cylinder The pressure coefficients are shown in figure 35, plotted as a function of angular position on the surface of the cylinder. Tests were done at three free stream velocities, 10 m/s, 15 m/s, and 22.7 m/s. The velocities of 10 m/s, and 22.7 m/s, are the minimum and maximum velocities which could be used in this experiment. The resulting Reynolds numbers are, 7.7×10^4, 1.16×10^5, and 1.75×10^5, respectively. As can be seen from figure 35, there was very little difference between the pressure coefficient obtained in the different Reynolds numbers, suggesting that the flow is not sensitive to Reynolds number in this range.

Figure 37, shows graphs of C_D versus Re, and C_L versus Re for the same three experiments. Once again, these graphs indicate that in the range of Re used for the experiments, Re has very little influence on the force coefficient for a single cylinder. This is in agreement with previously published results. Figure 8 shows a graph of C_D versus Re taken from Schlichting (1979). That graph indicates that the drag coefficient on a circular cylinder in cross-flow, remains almost constant in the range $1 \times 10^4 < Re < 2 \times 10^5$. Note that the drag coefficient in the present experiments was 0.8, while the graph from Schlichting shows that the drag coefficient is 1.2. The reasons for these discrepancies have been discussed earlier in this section.

7.2 STAGGERED CYLINDER STATIC TESTS

Staggered cylinder static tests were done with two cylinders in the wind tunnel, arranged as shown in figure 28. The values of L and T, the in-flow and cross-flow separation between cylinders, were varied for different experiments.

The two reasons for doing staggered cylinder static tests, were: 1), to find out how the lift and drag coefficients varied when the downstream cylinder was displaced from its nominal position indicated by T in figure 3(c), and 2), to find out if the lift and drag coefficients on staggered cylinders were influenced by changes in the Reynolds number.

The values of lift and drag measured on the fixed downstream cylinder were also required in order to carry out the quasi-static calculations, which would attempt to predict the dynamic force coefficients when the cylinder was forced to oscillate.

7.2.1 Lift and drag coefficients

To discover how the static lift and drag coefficients varied when the dowstream cylinder was displaced in the cross-flow direction from its nominal position, static tests were performed as described in section 5.1.2. Table 2 lists the different combinations of L/d and T/d which were tested. The value of T/d listed in the table is the nominal value, or in other words, the value of T/d where the downstream cylinder would be at the equilibrium of its oscillation during the dynamic testing which was done later, see chapter VIII. During the dynamic tests, the cylinder oscillated with an amplitude of y/d = 0.17. Therefore, during the static tests, the pressure coefficient was measured on the cylinder surface while the cylinder was at one of seven different positions, the equilibrium position, and three equispaced positions on either side of it, at y/d equal to plus and minus 0.06, 0.11, and 0.17. Figure 29 shows a scaled drawing of the different positions where static tests were done. The small vertical tick-marks on this drawing indicate the nominal cylinder positions given in terms of L/d and T/d. The horizontal line passing through each tick-mark indicates the locus of points over which the cylinder was displaced It corresponds to the amplitude of oscillation which could be expected in later dynamic tests. The three dashed circles indicate the positions where dynamic tests were actually done.

Figure 39 shows a graph of static pressure coefficient C_p versus angular position on the cylinder surface, for the downstream cylinder when the nominal cylinder separation was L/d = 2, T/d = 0.17. The figure also shows six other plots of pressure coefficients for positions equispaced on both side of the nominal position at y/d = ±0.6, ±0.11, and ±0.17; these correspond to T/d = 0.0, 0.6, 0.11, 0.17, 0.23, and 0.28.

Figure 40 shows similar information for a second experiment done at the same cylinder separation in order to verify repeatability of the test procedure. As can be seen, the results are in general very repeatable giving some confidence in the experimental procedure.

Figures 41 and 42 are the graphs of lift and drag coefficient respectively, (obtained from the pressure coefficients of Figures 39 and 40) versus change in cylinder position in the cross-flow direction, for two experiments at L/d = 2.

Figures 43 through 54 present the pressure, lift and drag coefficients for the downstream cylinder when it was fixed at various nominal values of L/d and T/d and at associated small displacements from these mean positions.

Figure 55 is a combined graph of all the static lift coefficients presented in the preceding graphs and figure 56 presents the static drag coefficients for the preceding graphs.

As can be seen from figures 55 and 56, the leeward cylinder position of L/d = 2 and T/d = 0.17 produces large variations of lift coefficient as the cylinder is displaced from its nominal position. The biggest change in lift coefficient occurs between positions y/d = 0.06 and 0.17. The y/d = 0.17 position is where the value of T/d reaches its maximum, and the portion of the downstream cylinder located at an orientation of 90^{o} (see figure 28) comes into contact with, and maybe even passes through, the boundary of the upstream cylinder. Negative lift, as shown in figure 55, is defined to point in the direction of negative y/d as shown in figure 28. The sudden decrease in lift experienced by the downstream cylinder, as y/d increases to the point where the downstream cylinder protrudes from the wake of the upstream cylinder, could be attributed to the sudden switch in the flow through the gap between the cylinder, as proposed by Zdravkovich (1977).

The sudden variation in the lift coefficient acting on the downstream cylinder in the neighbourhood of L/d = 2, and T/d = 0.17 was also observed by Zdravkovich and Pridden (1977). They indicate that the lift coefficient on the dowstream cylinder at Re = $6x10^{4}$ varies from about 0 to -1.0 as T/d changes from 0 to 0.15, see figure 16. This is in good agreement with the present results.

The sudden change in the lift coefficient in the neighbourhood of L/d = 2 and T/d = 0.17 represents a severe test of the quasi-static theory, because the flow pattern about the two cylinders will have to adjust to this very sudden and large change.

The second position which was later chosen for dynamic tests, is located at L/d = 5, and T/d = 0.5. At this position the variation in lift and drag coefficients is much more gradual than at L/d = 2 and T/d = 0.17. This new location, with small gradual changes in lift and drag coefficients, is a less severe test of the quasi-static theory. It is used to make sure that the quasi-static theory will work when the conditions are more favorable. If the dynamic results agree with the static results, as expected, it is also a good verification of experimental procedure.

The third static position which also was later used for dynamic tests, is located at L/d = 4 and T/d = 1. At this position, there is substantial variation in the lift and drag coefficients as the cylinder is displaced from its nominal position, but the change is much more gradual than that experienced at L/d = 2 and T/d = 0.17.

Figures 55 and 56 present plots of lift and drag coefficients for a number of other L/d and T/d positions which were not tested dynamically. At these positions there is very little variation in the force coefficients as the cylinder changes position. Therefore, the results of dynamic tests at these positions are expected to be similar to those found at L/d = 5 and T/d = 0.5, and more importantly, these tests do not provide a good test for the quasi-static assumption.

In order to determine if the static tests were repeatable, the experiment at location L/d = 2, T/d = 0.17 was performed twice. The results of both tests are included in figures 55 and 56, as well as in figures 39, 40, 41, and 42. It can be seen that the two tests produced results which were almost exactly the same, so giving the author some confidence in the experimental procedure.

One final point concerning the static staggered cylinder tests, is that an attempt was made to do static tests at the location L/d = 3 and T/d = 0.5. This attempt had to be abandoned because the flow proved to be bistable at this point. At one point in time the flow appeared to assume the characteristics of the flow found at location L/d = 2 and T/d = 0.17, but at another point in time the flow would assume the characteristics of the flow observed at L/d = 4 and T/d = 0.5. The change from one flow pattern to the other was fast and sudden, and the flow pattern remained constant for a duration of time which was random.

This bistable phenomenon was also described by Zdravkovich and Pridden (1977). They described the position of the bistable flow as L/d = 3, T/d = 0.25. Zdravkovich explains the bistable flow as a random change between two flow patterns which are sketched in figure 19. In one pattern, the shear layers separating from the upstream cylinder reattach themselves to the downstream cylinder, thus forming a cavity of recirculating flow between the two cylinders. In the other flow pattern, part of the main flow passes through the gap between the two cylinders.

Dynamic tests were not conducted at the location L/d = 3 and T/d = 0.5, where the bistable phenomenon was observed. The fact that the flow was switching between two flow patterns made it impossible to decide which of the two static results to use when comparing static and dynamic tests according to the quasi-static theory.

7.2.2 Variation with Re

As in the case of a static single cylinder, described in section 7.1, tests were done on staggered cylinders to find out if changes in

Re had any effect on the pressure distribution and force coefficients These tests were done at L/d = 4 and T/d = 1 and the associated small displacements in the cross- flow position. Tests were done at Reynolds numbers of 7.7×10^4, 1.16×10^5, and 1.75×10^5.

The resulting graphs of pressure coefficient around the cylinder circumference for different Reynolds numbers, are shown in figure 57 The stagnation pressure at the front of the cylinder remains constant over the range of Re tested. The base pressure at an orientation of 180^o from the front, increases slightly with increasing Re. This suggests that the coefficient of drag experienced by the downstream cylinder decreases with increasing Re.

The pressure coefficient at the orientation of 90^o decreases with increasing Re, while the pressure coefficient at the orientation of 270^o remains constant or increases slightly. This suggests that the lift coefficient acting on the cylinder increases with increasing Re, if lift coefficient is defined as in figure 28.

Figures 58 and 59 present graphs of lift and drag coefficients as a function of cross-flow cylinder position y/d respectively for the same cylinder position as figure 57 (L/d = 4.0). It can be seen from figure 58 that as Reynolds number increases, the lift coefficient decreases for all T/d positions in the range of T/d between 0.83 and 1.17 Figure 59 indicates that the opposite is true for the drag coefficient.

The consequence of this is that when dynamic test results will be compared with their static counterparts, at the same L/d and T/d, it will be important to make sure that Re is also the same. This places a further restriction on the experimental results in that when attempting to vary the non-dimensional velocity U/fd, it is not permissible to vary U, as this will change the Reynolds number; and thus, only f (the frequency of forced oscillation) may be varied.

VIII RESULTS AND DISCUSSION-DYNAMIC TESTS

Dynamic tests were done only on staggered cylinder configurations. The single cylinder configuration was not tested under dynamic conditions. The procedure used to perform the dynamic tests is described in section 5.2.

In section 8.1 a description is given of the influence of Re on the drag and lift coefficients of the downstream cylinder of a pair of staggered cylinders. In sections 8.2, 8.3 and 8.4 the lift and drag coefficients, C_L and C_D measured during dynamic testing are compared to the horizontal and vertical force coefficients, C_x^* and C_y^*, which were calculated from the static coefficients using the quasi- static theory. See figure 31 and section 6.2 for a definition of C_x^*, C_y^*, C_L, and C_D.

8.1 INFLUENCE OF Re ON C_D & C_L

In section 7.2.2, a description was given of how Reynolds number influences the C_L and C_D on the downstream cylinder of a pair of staggered cylinders in static tests. This section will present data which indicates a similar dependence in the dynamic case.

Figures 60 and 61 show the dynamic lift and drag coefficients for the downstream cylinder of a pair of staggered cylinders. The figures show the results of two dynamic tests done at $L/d = 4$ and $T/d = 1$. The first test, at $Re = 1.16 \times 10^5$ was done at a velocity of 15 m/s and a frequency of 3 Hz. The second test, at $Re = 1.75 \times 10^5$ was done at a velocity of 22.7 m/s and a frequency of 4.5 Hz. The value of U/fd is the same for both tests and is equal to 44.

The only two differences between the two tests are the frequency of oscillation, f, and the free stream velocity, U, such that the non-dimensional velocity U/fd remains constant. Therefore, it appears that the differences between the two sets of results are a consequence of the different Reynolds numbers.

The results of only two experiments are presented here as evidence of the dependence of C_L and C_D on Reynolds number. This is because the combined range of frequencies, f, and free stream velocities, U, which were available with the experimental set up were not broad enough to permit testing at more than two distinct Re values while keeping U/fd constant. Nevertheless, these two dynamic test results follow the pattern of behaviour established in section 7.2.2, where the dependence of static C_L and C_D on Reynolds number was discussed. The results of figures 50 and 61 also supported by data presented in section 7.2.2, is that as Re increases C_L increases but C_D decreases for the downstream cylinder of a staggered pair of cylinders.

This observation indicates that the static experimental data used in the quasi-static theory, to calculate predictions of dynamic C_D and C_L, should be taken at the same Reynolds number as the dynamic case being considered.

8.2 RESULTS FOR L/d = 2 and T/d = 0.17

As indicated in figure 29, one of the positions where dynamic tests were done was at L/d = 2 and T/d = 0.17.

The dynamic lift and drag coefficients measured on the downstream cylinder are presented in figures 62 to 71, for values of U/fd equal to 15, 22, 44, 131 and 250, respectively. The static coefficients are also plotted for comparison in each of the figures. Also, the values of the quasi-static force coefficients, C_y^* and C_x^*, are indicated in these figures by small x-marks.

As can be seen from the figures, the values of C_x^* and C_y^* predicted by the quasi-static assumption for the dynamic results are very close to the static results. This is due to the fact that the low frequency (1 to 6 Hz) and a small amplitude of oscillation (19 mm.) resulted in a cylinder velocity which was much smaller than even the lowest free stream velocity of U = 10 m/s. Therefore, the resultant velocity acting on the moving cylinder was very close to the velocity which would be acting on the cylinder if it were stationary; also, more importantly, the induced incidence is very small.

The most obvious conclusion from these results is that the dynamic results do not resemble the predicted values of C_x^* and C_y^*, this being especially so for the lift coefficient. It seems that during dynamic tests, the pressure on the surface of the cylinder was not able to adjust quickly enough to the large changes which occur when the cylinder reached positions between T/d = 0.23 and T/d = 0.34. This is the part of the oscillation cycle where the cylinder reached the highest values of T/d and obtained the largest magnitude of lift coefficient.

The dynamic lift coefficient is similar to the static lift coefficient for values of T/d from 0 to 0.23. As the cylinder enters the region of T/d from 0.23 to 0.34, the dynamic lift coefficient remains at almost the same value it had for T/d between 0 and 0.23, while the static lift coefficient indicates that there should be a sudden change. This occurs even for U/fd = 250, which is the highest value of U/fd which could be reached with the present apparatus.

At U/fd = 250 (see figure 71), the highest U/fd for this set of dynamic tests, the agreement between the dynamic drag coefficient and the predicted values of C_y^*, which were calculated with the quasi-static theory, is better than at the lowest value of U/fd = 15 (see figure 63). For the drag coefficient, the results at higher values of U/fd are closer in shape and in numerical value to the static results. In figure 71, the plot of the dynamic drag coefficient for U/fd = 250, passes close to a number of points predicted by the quasi-static theory (but the differences between the two curves in this figure are still large). In figure 63, the plots of static and dynamic drag coefficients for U/fd = 15 are much further apart.

These results lead to the conclusion that the quasi-static theory can not be applied in regions where there are very sudden changes in the force coefficients, at least for U/fd $\leq$ 250. In the case of staggered cylinders, the quasi-static theory fails at a spacing of L/d = 2 and T/d = 0.17, even at U/fd = 250.

8.3 RESULTS FOR L/d = 5 AND T/d = 0.5

Figures 72 and 73 show the dynamic lift and drag coefficients experienced by the downstream cylinder when the two cylinders are positioned such that L/d = 5and T/d = 0.5. The static coefficients for this configuration are also included, as are the predicted values of C_x^* and C_y^* calculated by quasi-static theory.

The most prominent feature of these two graphs is that the static and dynamic results fall very close to each other. The second important feature of these two graphs is that there is very little variation in the static coefficients as the cylinder is moved from a position at T/d = 0.33 to a position at T/d = 0.67. This lack of variation of static coefficients within the range of oscillation is probably responsible for the good agreement between the static and dynamic results.

As the cylinder moves back and forth from T/d = 0.33 to T/d = 0.67, the pressure on the surface of the cylinder is able to adjust to the small changes in the flow field which must be taking place.

This set of tests at L/d = 5, T/d = 0.5 indicates that the quasi-static theory can be applied if the changes in force coefficients are very small. In other words, the quasi-static assumption can be applied successfully even at reduced velocities U/fd as low as 44, provided that other conditions are satisfied. In particular, the change in static lift and drag coefficients has to be gradual across the area where the dowstream cylinder will oscillate.

This result also proves that there was no experimental flaw built into the test and analysis procedures. The static and dynamic force coefficients are nearly identical even though they have been acquired in two different ways. Refer to chapter 5. This result adds an extra measure of confidence to the surprising results obtained in section 8.2, when the quasi-static assumption failed to provide accurate results at reduced velocities of U/fd as high as 250.

8.4 RESULTS FOR L/d = 4 AND T/d = 1

The static results for staggered cylinders at a spacing of L/d = 4 and T/d = 1 show a moderate variation of C_L and C_D as the downstream cylinder is moved from a T/d of 0.83 to a T/d of 1.17 (see figures 53 and 54). The dynamic results for the same spacing, along with the corresponding static curves are presented in figures 74 to 85. Results from tests done at different Reynolds numbers are presented on different graphs in order to avoid confusion.

At low values of U/fd, the agreement between the dynamic results and the predicted values of force coefficients is poor. See figures 74 and 75 for graphs of C_L and C_D for U/fd=15, at a Reynolds number of $7.7x10^4$. At higher values of U/fd the agreement between dynamic results and predicted values is much better, see figures 76 through 85.

Figures 84 and 85 show the dynamic results for U/fd equal to 198. Surprisingly, the dynamic lift coefficients for U/fd = 198 do not agree with the static results as one would expect from the trend established on the previous graphs. The experiment at U/fd = 198 has the highest value of U/fd and it would be expected that the dynamic results would be closer to the static results, or at least as close as the case of the U/fd = 131 (figure 82). The dynamic drag coefficients for U/fd = U/fd = 198, in figure 85 are close to the static results, but the dynamic lift coefficients in figure 84 are not.

If the dynamic lift coefficient results for U/fd = 198 are left out, then the conclusion pointed to by this set of results is that as U/fd increases, the agreement improves between the dynamic force coefficients and the force coefficients predicted by the quasi-static theory. It can be seen from graphs 74 and 75, that at U/fd = 15 the quasi-static theory predicts values which in some cases are off by 100% from the measured coefficients. On the other hand, at values of U/fd equal to 44 or 131 (figures 78 through 83), the quasi-static theory predicts the final results within 50% of the measured values.

In section 8.3, where the results of tests done at L/d = 5 and T/d

= 0.5 were discussed, it was noted that the dynamic drag coefficient seemed to depend only on the position of the cylinder and not on the direction of its motion, while the dynamic lift coefficient seemed to depend on both the position of the cylinder and the direction in which the cylinder was moving. In this case, for tests done at L/d = 4 and T/d = 1, both the dynamic lift and drag coefficients appear to depend on the cylinder position and on the direction in which the cylinder is moving. In this case, as in the case of L/d = 5 and T/d = 0.5, the dynamic lift coefficient is higher when the cylinder is moving in the direction of increasing T/d, and is lower when the cylinder is moving in the opposite direction. This applies even to the case of U/fd = 15 where the quasi-static theory appears to break down.

In this case of L/d = 4 and T/d = 1 (see figures 75, 77, 79, 81, 83, and 85) the dynamic drag coefficient depends on the direction of motion of the cylinder. The drag coefficient is lower when the cylinder is moving such that T/d is increasing, and it is higher when T/d is decreasing. This behaviour is opposite to what happens to the lift coefficient at this L/d and T/d spacing.

Because the values of the dynamic lift and drag coefficients appear to depend on the direction in which the cylinder is oscillating, it seems that a transverse oscillation of the downstream cylinder will produce fluid dynamic forces which will try to sustain the transverse oscillation as well as introduce vibration parallel to the free stream velocity.

IX CONCLUSIONS

The results presented in this thesis do not answer all the questions concerning the criteria for valid application of the quasi-static theory, but they do point to a direction which should be investigated in the future. These results lead to the following conclusions.

Firstly, it became apparent that in the range of U/fd between 15 and 250, and for Reynolds numbers between 7.7×10^4 and 1.75×10^5, the force coefficients measured on the leeward cylinder of a tandem pair depend on the Reynolds number of the flow. This observation makes it necessary to use static force coefficients obtained at the same Reynolds number as the dynamic conditions which will be approximated by the quasi-static assumption.

As far as the quasi-static assumption itself is concerned, the results indicate that whether or not the quasi-static assumption is valid depends on U/fd as well as on the particular flow pattern present around the body. In particular, when the force coefficient gradients dC_L/dy and dC_D/dy are steep the limiting values of U/fd must be raised. In the present research endeavor, it was found that at a cylinder spacing of $L/d = 2$ and $T/d = 0.17$, where the force coefficient gradients are very steep, the quasi-static assumption can not be applied for $U/fd \leq 250$. This limit is well above the critical value suggested by Fung (1955) and Blevins (1977).

At a cylinder spacing where the force coefficient gradients are not as steep, such as $L/d = 4$ and $T/d = 1$, the quasi-static assumption gives a good approximation of the dynamic force coefficients for U/fd above some value which is between 44 and 131. It should also be noted that the approximation improves as U/fd increases.

When the cylinders were spaced such that L/d=5 and T/d=0.5, the dynamic force coefficients were very close to the coefficients predicted by calculations based on the quasi-static assumption. The fact that the static force coefficients did not vary much over the range of oscillation was probably responsible for the good agreement between experimental results and the quasi-static assumption. This result suggests that the quasi-static assumption can be applied successfully for reduced velocities, U/fd, as low as 44 if the geometrical configuration of the two cylinders does not impose steep gradients of static force coefficients. Secondly, this result serves to confirm the validity of the present test method, thus making it unnecessary to increase U/fd beyond 250 for the case of L/d=2, T/d=0.17 in order to obtain agreement between the experimental results and the quasi- static assumption. In the present case, such an increase could not be realized due to equipment constraints.

The final conclusion which can be made based on these results is that the criteria for valid application of the quasi-static assumption should be more than just ensuring that U/fd $\geq$ 10. If the gradients of static force coefficients are steep in the area being considered, then the critical value of U/fd will have to be determined by some other method.

APPENDIX A

This appendix contains the listing of the programs described in section 6.3. The programs are listed in the same order as they were described in that section: this is the same order in which they would be used to perform the experiments and subsequent calculations.

CP33.BAS

```
5 'THIS PROGRAM OUTPUTS THE CALCULATED CP TO PRINTER OR TO DISK
10 'CP33     JUNE 17,1986
11 'MODIFIED APRIL 8,1987
20 'THIS PROGRAM CALCULATES THE PRESSURE COEFFICIENT FOR A CYLINDER IN
   CROSS FLOW
30 CLEAR
35 CLS
40 PRINT"BEFORE RUNING THIS PROGRAM RESTART BASIS WITH THE COMMAND
45 INPUT"PRESS ENTER WHEN READY";A$
50 CLS:PRINT"THIS PROGRAM CALCULATES THE PRESSURE COEFFICIENT FOR A
   CYLINDER IN CROSS FLOW":PRINT"":PRINT
60 PRINT"THIS PROGRAM IS USED TO ENTER AND EDIT DATA TAKEN DURING THE
   STATIC TEST. IT    WILL ALSO CALCULATE THE PRESSURE COEFFICIENT."
70 PRINT"":PRINT"THE REQUIRED INPUT IS DELTA PRESSURE (P ON CYLINDER-P
   STATIC IN mm OF WATER.
80 PRINT"":PRINT"THIS DATA HAS TO BE KNOWN AT 36 POSITIONS ARROUND THE
   CYLINDER.":PRINT"":PRINT
90 PRINT"OTHER DATA REQUIRED BY THE PROGRAMS IS;"
100 PRINT"P ATM. IN INCHES OF HG":PRINT"AIR TEMP. IN DEG. C":PRINT"AIR
    VELOCITY IN M/S"
110 PRINT"":INPUT"PRESS enter";A$
120 CLS:PRINT"1 INPUT DATA":PRINT"2 LIST DATA ON SCREEN":PRINT"3 PRINT
    DATA":PRINT"4 EDIT LIST OF FILES":PRINT"5 CALCULATE & PRINT Cp":
    PRINT"6 CALCULATE Cp & SAVE TO DISK":PRINT"7 END"
130 INPUT A
140 ON A GOTO 210,910,1610,1220,2230,3000,155
150 GOTO 120
155 END
160 '****************************
170 '
180 '    INPUT DATA
190 '
200 '****************************
210 CLS:PRINT"1 START NEW FILE":PRINT"2 EDIT OLD FILE":PRINT"3 END
    INPUT"
215 INPUT A
217 ON A GOTO 260,530,120
219 GOTO 200
260 '***START NEW FILE**********
270 CLS:INPUT"INSERT DATA DISK IN DRIVE B: AND PRESS <ENTER>";A$
280 PRINT"":PRINT"NAME OF NEW FILE TO BE OPENED":INPUT NF$
290 IF LEN(NF$)>8 THEN PRINT"NAME IS TOO LONG, USE ONLY 8 CHARACTERS,
    RETYPE":GOTO 280
300 IF LEN(NF$)=0 THEN PRINT"YOU MUST ENTER 1-8 CHARS. AS THE NAME, THE
    FIRST ONE MUST BE A LETTER. RETYPE":GOTO 280
310 FOR I=1 TO LEN(NF$)
320 A$=MID$(NF$,I,1):IF A$="." OR A$=":" OR A$="/" THEN PRINT"DO NOT
    TYPE THE EXTENSION...DO  NOT USE . : /  RETYPE":GOTO280
330 NEXT I
340 A$=MID$(NF$,1,1)
```

```
350 IF (A$>CHR$(96) AND A$<CHR$(123)) OR (A$>"@" AND A$<CHR$(94)) THEN
    370 ELSE 360
360 PRINT"THE FIRST CHARACTER MUST BE A LETTER A-Z OR a-z. RETYPE":
    GOTO 280
370 NF$="B:"+NF$+".DAT"
380 OPEN "O",#1,NF$
390 PRINT"NOW YOU MAY ENTER A MESSAGE WHICH WILL BE SAVED WITH THE
    FILE":INPUT A$
400 WRITE #1,A$
410 INPUT"ATMOSPHERIC PRESSURE IN INCHES  OF HG:";AP
420 INPUT"AIR TEMPERATURE IN DEG. C:";AT
430 INPUT"AIR VELOCITY IN M/S:";AV
435 INPUT"SCALE FACTOR USED TO CONVERT MANOMETER READINGS TO mmH2O"
    ;SCALE
440 WRITE #1,AP,AT,AV,SCALE
450 PRINT"":PRINT"IF YOU WISH TO QUIT BEFORE YOU ENTER THE 36 PRESSURE
    READINGS THEN ENTER 999":PRINT""
460 PRINT"ANGLE   DELTA PRESSURE   +/-"
470 FOR AN=0 TO 360 STEP 10
480 PRINT USING"#####";AN;:PRINT"          ";:INPUT DP,VP
490 IF DP=999 THEN 520
500 WRITE #1,DP,VP
510 NEXT
520 CLOSE:GOTO 210
530 '***EDIT OLD FILE***********
540 CLS:PRINT"THE ENTRIES IN THE FILE WILL BE DISPLAYED ONE AT A TIME."
    :PRINT"":PRINT"TO KEEP THE ENTRY WITHOUT CHANGE PRESS enter."
550 PRINT"":PRINT"TO CHANGE THE SHOWN ENTRY PRESS c. THE COMPUTER WILL
    ASK FOR A  NEW ENTRY."
560 PRINT"":PRINT"TO END THE EDIT SESION PRESS q":PRINT""
565 PRINT:PRINT"INSERT DATA DISK IN DRIVE B:"
570 INPUT"NAME OF FILE TO BE EDITED";NF$:IF NF$="" THEN 570
580 NF$="B:"+NF$+".DAT"
590 OPEN"I",#1,NF$
600 OPEN"O",#2,"B:TEMPORAR.DAT"
610 INPUT#1,A1$,AP,AT,AV,SCALE:PRINTA1$:INPUTA$
620 IF A$="C" OR A$="c" THEN INPUT"ENTER NEW COMENT";A1$
630 PRINT"":PRINT"AIR PRESSURE =";AP;"in Hg":INPUT A$
640 IF A$="C" OR A$="c" THEN INPUT"ENTER NEW PRESSURE";AP
650 PRINT"AIR TEMP.=";AT;"deg C.":INPUT A$
660 IF A$="C" OR A$="c" THEN INPUT"ENTER NEW TEMP.";AT
670 PRINT"AIR VELOCITY=";AV;"m/s":INPUT A$
680 IF A$="C" OR A$="c" THEN INPUT"ENTER NEW AIR VELOCITY";AV
682 PRINT"SCALE FACTOR USED TO CONVERT MANOMETER READINGS TO mmH2O"
    ;SCALE:INPUT A$
684 IF A$="C" OR A$="c" THEN INPUT "ENTER NEW SCALE FACTOR";SCALE
690 WRITE#2,A1$,AP,AT,AV,SCALE
700 PRINT"ANGLE   DELTA PRESSURE   +/-"
710 FOR AN=0 TO 360 STEP 10
720 INPUT#1,DP,VP
730 PRINT USING"#####            ######   ###";AN,DP,VP;
740 INPUT A$
750 IF A$="C" OR A$="c" THEN PRINT"AT";AN;" DEG., ENTER NEW":INPUT
    "PRESSURE AND ERROR";DP,VP
```

```
760 WRITE#2,DP,VP
770 IF A$="Q" OR A$="q" THEN 830
780 NEXT AN
790 CLOSE:KILL NF$
800 NAME"B:TEMPORAR.DAT" AS NF$
810 GOTO 210
820 '***IF QUIT THEN COPY REST  OF FILE************************
830 IF EOF(1)=-1 THEN 790
840 INPUT#1,DP,VP:WRITE#2,DP,VP
850 GOTO 830
860 '**************************
870 '
880 '   LIST DATA ON SCREEN
890 '
900 '**************************
910 CLS:INPUT"NAME OF FILE TO BE LISTED";NF$
920 NF$="B:"+NF$+".DAT"
930 PRINT"":INPUT"INSERT DATA DISK IN DRIVE B:    PRESS enter";A$
940 OPEN"I",#1,NF$
950 INPUT#1,A$,AP,AT,AV,SCALE
960 CLS:PRINT"FILE: ";NF$:PRINT"":PRINT A$:PRINT""
970 PRINT"ATMOSPHERIC PRESSURE=";AP;"in Hg"
980 PRINT"AIR TEMPERATURE=";AT;"deg. C"
990 PRINT"AIR VELOCITY=";AV;"m/s":PRINT"SCALE FACTOR USED TO CONVERT
    MANOMETER READINGS TO mmH2O";SCALE:PRINT"":INPUT"PRESS enter";A$
1000 AN=0
1010 FOR II=1 TO 3
1020 CLS:PRINT"ANGLE   DELTA PRESSURE  +/-"
1030 FOR I=1 TO 12
1040 IF EOF(1)=-1 THEN 1150
1050 INPUT#1,DP,VP
1060 PRINT USING"##### ############### ####";AN,DP,VP
1070 AN=AN+10
1080 NEXT I
1090 IF II=3 THEN 1120
1100 INPUT"PRESS enter";A$
1110 NEXT II
1120 IF EOF(1)=-1 THEN 1150
1130 INPUT #1,DP,VP
1140 PRINT USING"##### ############### ####";AN,DP,VP
1150 INPUT"PRESS enter";A$
1160 CLOSE:GOTO 120
1170 '**************************
1180 '
1190 '   EDIT LIST OF FILES
1200 '
1210 '**************************
1220 CLS:PRINT"1 SEE LIST OF FILES":PRINT"2 CREATE NEW LIST OF FILES":
     PRINT"3 EDIT OLD LIST OF FILES":PRINT"4 END EDIT OF LIST OF FILES"
1230 INPUT A
1240 ON A GOTO 1480,1290,1450,120
1250 GOTO 1220
1280 '***EDIT NEW FILE**********
1290 CLS:PRINT"YOU MAY ENTER UP TO 7 FILE NAMES. ENTER THE ENTIRE NAME
```

```
     INCLUDDING THE EXTENSIONBUT NOT THE DRIVE DESCRIPTOR."
1300 PRINT"":PRINT"IF YOU WISH TO ENTER LESS THAN 7 FILES TYPE <END>
     TO STOP"
1310 PRINT"":PRINT"LIST THE FILES"
1320 FOR I=1 TO 7
1330 INPUT A$(I)
1340 IF A$(I)="END" THEN 1370
1350 II=I
1360 NEXT I
1370 INPUT"WHAT DO YOU WISH TO CALL THIS LIST OF FILES(DO NOT INCLUDE
     THE EXTENTION OR DRIVR DESCRIPTOR)";A$
1380 A$="B:"+A$+".DAT"
1390 OPEN"O",#1,A$
1400 FOR I=1 TO II
1410 WRITE#1,A$(I)
1420 NEXT I
1430 CLOSE:GOTO 1220
1440 '***EDIT OLD FILE**********
1450 CLS:INPUT"THIS PART OF PROGRAM IS NOT READY   PRESSenter";A
1460 COTO 1220
1470 '***SEE LIST OF FILES******
1480 CLS:INPUT"INSERT DATA DISK INTO DRIVE B:, ENTER THE NAME OF THE
     LIST WHICH YOU WISH TO SEE";A$
1490 A$="B:"+A$+".DAT"
1500 PRINT"":PRINT"FILE:";A$
1510 OPEN"I",#1,A$
1520 IF EOF(1)=-1 THEN 1540
1530 INPUT#1,A$:PRINT A$:GOTO 1520
1540 PRINT"":INPUT"PRESS enter";A$
1550 CLOSE:GOTO 1220
1560 '**************************
1570 '
1580 '   PRINT DATA
1590 '
1600 '**************************
1610 CLS:INPUT"NAmE OF LIST OF FILES TO BE LISTED";A$
1620 IF A$="" THEN 1610
1630 A$="B:"+A$+".DAT"
1640 PRINT"":INPUT"INSERT DATA DISK IN DRIVE B:, TURN PRINTER ON AND
     PRESS enter";A
1650 OPEN "I",#1,A$
1660 FOR I=1 TO 7
1670 IF EOF(1)=-1 THEN 1710
1680 INPUT#1,A$(I)
1685 A$(I)="B:"+A$(I)
1690 II=I
1700 NEXT I
1710 CLOSE #1
1720 FOR I=1 TO II
1730 OPEN"I",#I,A$(I)
1740 NEXT I
1750 LPRINT CHR$(20);CHR$(15)
1760 LPRINT TAB(8)"";
1770 FOR I=1 TO II
```

```
1780 LPRINT TAB(8+18*(I-1))A$(I);
1790 NEXT I
1800 LPRINT ""
1810 FOR I=1 TO II
1820 INPUT#I,A$
1830 NEXT I
1840 LPRINT "PRESS";TAB(8)"";
1850 FOR I=1 TO II
1860 INPUT#I,AP
1870 LPRINT TAB(8+18*(I-1))AP;" in Hg";
1880 NEXT I
1890 LPRINT ""
1900 LPRINT "TEMP";TAB(8)"";
1910 FOR I=1 TO II
1920 INPUT#I,AT
1930 LPRINT TAB(8+18*(I-1))AT;" deg. C";
1935 INPUT #I,SCALE
1940 NEXT I
1950 LPRINT ""
1960 LPRINT "SPEED";TAB(8)"";
1970 FOR I=1 TO II
1980 INPUT#I,AV
1990 LPRINT TAB(8+18*(I-1))AV;" m/s";
2000 NEXT I
2010 LPRINT ""
2020 LPRINT "ANGLE";TAB(8)"";
2030 FOR I=1 TO II
2040 LPRINT TAB(8+18*(I-1))"mm OF WATER";
2050 NEXT I
2060 LPRINT ""
2070 FOR AN=0 TO 360 STEP 10
2080 LPRINT AN;TAB(8)"";
2090 FOR I=1 TO II
2100 IF EOF(I)=-1 THEN 2140
2110 INPUT#I,DP,VP
2120 LPRINT TAB(8+18*(I-1))"";
2130 LPRINT USING"####"   "##";DP,"  +/-",VP;
2140 NEXT I
2150 LPRINT ""
2160 NEXT AN
2170 CLOSE:GOTO 120
2180 '**************************
2190 '
2200 '   CALCULATA & PRINT Cp
2210 '
2220 '**************************
2230 CLS:INPUT"NAME OF FILE TO BE USED IN CALCULATION OF Cp";NF$
2240 IF NF$="" THEN 2230
2250 F1=1/25.4 'Convert mm H2O to in H2O
2260 F2=1/12   'Convert in H2O to ft H2O
2270 F3=1/2.31 'Convert ft H2O to psi
2280 F4=6895   'Convert psi to Pascals
2290 F=F1*F2*F3*F4 'THIS IS THE CONVERSION FACTOR FOR GOING FROM mm H2O
     to Pascals
```

```
2300 NF$="B:"+NF$+".DAT"
2310 PRINT"":PRINT"READY PRINTER":PRINT"":INPUT"INSERT DATA DISC IN
     DRIVE B: AND PRESS enter";A$
2320 OPEN"I",#1,NF$
2330 LPRINT CHR$(20);CHR$(15)
2340 LPRINT TAB(8)NF$:LPRINT ""
2350 INPUT#1,A$,AP,AT,AV,SCALE
2360 II=INT(LEN(A$)/32)
2370 I1=LEN(A$)-II*32
2380 FOR I=1 TO II
2390 A1$=MID$(A$,(I-1)*32+1,32):LPRINT TAB(8)A1$
2400 NEXT I
2410 LPRINT TAB(8)MID$(A$,II*32+1,I1):LPRINT ""
2420 LPRINT TAB(8)"AIR PRESSURE=";AP;"in Hg      AIR TEMP.=";AT;"deg.
     C":LPRINT TAB(8)"AIR VELOCITY=";AV;"m/s"
2430 LPRINT ""
2440 '**************************
2450 '***CALCULATE AIR DENSITY RO
2460 AP=AP*3387 'CONVERT AIR PRESSURE FROM in Hg TO Pascals
2470 AT=AT+273.16 'CONVERT AIR TEMP. FROM CELCIUS TO KELVIN
2480 R=287 'GAS CONSTANT FOR AIR (M'2/S'2*K)
2490 RO=AP/(R*AT) 'CALCULATE AIR DENSITY RO
2500 '**************************
2510 '***CALCUALTE PART OF THE Cp EQUATION
2520 C1=SCALE*F/(.5*RO*AV'2) 'SCALE FACTOR COMES FROM THE FACT THAT ALL
     THE READINGS WERE TAKEN ON AN INCLINED MANOMETER
2530 LPRINT TAB(8)"ANGLE    PRESSURE DIFF.   COEFFICIENT OF PRESSURE"
2540 FOR AN=0 TO 360 STEP 10
2550 IF EOF(1)=-1 THEN 2600
2560 INPUT#1,DP,VP
2570 CP=C1*DP
2580 LPRINT USING"        ####        #### " "###        ###.####";AN,DP,
     "+/-",VP,CP
2590 NEXT AN
2595 LPRINT CHR$(12):REM FORM FEED TO TOP OF NEXT PAGE
2600 CLOSE:GOTO 120
3000 '**************************
3010 '
3020 '   CALCULATA Cp & SAVE TO DISK
3030 '
3040 '**************************
3050 CLS:PRINT"CALCULATE Cp AND SAVE TO DISK":PRINT" ":INPUT"NAME OF
     FILE TO BE USED IN CALCULATION OF Cp (DO NOT INCLUDE THE EXTENTION"
     ;NF$
3060 IF NF$="" THEN 3050
3070 INPUT"NAME OF OUTPUT FILE TO BE USED (DO NOT INCLUDE EXTENTION)";
     NG$
3080 IF NG$="" THEN 3070
3090 F1=1/25.4 'Convert mm H2O to in H2O
3100 F2=1/12   'Convert in H2O to ft H2O
3110 F3=1/2.31 'Convert ft H2O to psi
3120 F4=6895   'Convert psi to Pascals
3130 F=F1*F2*F3*F4 'THIS IS THE CONVERSION FACTOR FOR GOING FROM mm H2O
     to Pascals
```

```
3140 NF$="B:"+NF$+".DAT"
3150 NG$="B:"+NG$+".DAT"
3160 PRINT"":PRINT"READY PRINTER":PRINT"":INPUT"INSERT DATA DISC IN
     DRIVE B: AND PRESS enter";A$
3170 OPEN"I",#1,NF$
3180 OPEN"O",#2,NG$
3190 INPUT#1,A$,AP,AT,AV,SCALE
3200 '**************************
3210 '***CALCULATE AIR DENSITY RO
3220 AP=AP*3387 'CONVERT AIR PRESSURE FROM in Hg TO Pascals
3230 AT=AT+273.16 'CONVERT AIR TEMP. FROM CELCIUS TO KELVIN
3240 R=287 'GAS CONSTANT FOR AIR (M'2/S'2*K)
3250 RO=AP/(R*AT) 'CALCULATE AIR DENSITY RO
3260 '**************************
3270 '***CALCUALTE PART OF THE Cp EQUATION
3280 C1=SCALE*F/(.5*RO*AV'2) 'SCALE FACTOR COMES FROM THE FACT THAT ALL
     THE READINGS WERE TAKEN ON AN INCLINED MANOMETER
3290 FOR AN=0 TO 360 STEP 10
3300 IF EOF(1)=-1 THEN 3350
3310 INPUT#1,DP,VP
3320 CP=C1*DP
3330 PRINT#2,USING"####_,##.#####";AN,CP
3340 NEXT AN
3350 CLOSE
3360 GOTO 120
```

PLOTCPHP.BAS

```
10 REM PLOTCPHP.BAS
20 REM (C) FEBRUARY 10, 1987 PIOTR W. SYCHTERZ
30 REM McGILL UNIVERSITY, MONTREAL
40 REM***************************************************************
50 REM
60 REM
70 REM INITIALIZE THE GPIB-PC SOFTWARE IN THIS PROGRAM
80 REM
90 REM
100 REM**************************************************************
110 REM RESERVE MEMORY ABOVE 60650 FOR GPIB-PC SUBROUTINE CALLED IBINIT
120       CLEAR   ,60650!
130       IBINIT = 60650!
140 REM LOAD SUBROUTINE IBINIT FROM FILE BIB.M ON DRIVE A
150      BLOAD "A:BIB.M",IBINIT
160      IBSTA%=0:IBERR%=0:IBCNT%=0
170      CALL IBINIT (IBRD%,IBWRT%,IBCMD%,IBWAIT%,IBRPP%,IBONL%,IBRSC%,
         IBSIC%,IBSRE%,IBRTL%,IBRSV%,IBLPE%,IBPAD%,IBSAD%,IBIST%,IBDMA%,
         IBEOS%,IBTMO%,IBEOT%,IBGTS%,IBCAC%,IBDIAG%,IBSTA%,IBERR%,
         IBCNT%)
180 REM
190 REM BD% DENOTES THE GPIB-PC BOARD NUMBER IN SUBROUTINE CALLS
200 REM BD%=0 BECAUSE THERE IS ONLY ONE BOARD
210 BD%=0
```

```
220 REM*****************************************************************
230 REM
240 REM
250 REM INITIALIZE GPIB-PC AS THE CONTROLLER IN CHARGE OF PLOTTER
260 REM
270 REM
280 REM*****************************************************************
290 REM PUT GPIB-PC ON LINE
300 V%=1:CALL IBONL%(BD%,V%)
310 REM MAKE GPIB-PC ACTIVE SYSTEM CONTROLLER
320 CALL IBSIC%(BD%)
330 REM ASSERT REN (REMOTE ENABLE) TO PUT HP5420A IN REMOTE CONTROL
340 V%=1:CALL IBSRE%(BD%,V%)
350 REM ADDRESS GPIB-PC TO TALK "@"
360 REM ADDRESS PLOTTER TO LISTEN "%"
370 CMD$="@%":CALL IBCMD%(BD%,CMD$)
380 REM*****************************************************************
390 REM
400 REM PLOTTER IS READY TO RECEIVE INSTRUCTIONS
410 REM
420 REM*****************************************************************
430 CLS:PRINT"THIS PROGRAM PLOTS COEFFIECINETS OF PRESSURE ON THE HP
    COLOR PLOTTER."
440 PRINT" ":PRINT"AS DATA IT USES A FILE ON DRIVE B·.":PRINT"THIS FILE
    SHOULD CONTAIN 37 PAIRS OF  VALUES, FROM 0 DEGREES TO 360 DEGREES.
    IN EACH PAIR THE FIRST NUMBER IS THE ANGULAR POSITION OF THE
    CYLINDER, THE      SECOND NUMBER IS THE COEFFICIENT
450 PRINT" ":INPUT"NOW THE PLOTTER WILL DRAW THE AXIS USING PEN #1.
    INSERT PEN AND PAPER AND PRESS enter. IF YOU DO NOT WANT THE AXIS
    DRAWN (CONTINUING A PREVIOUS PLOT THEN TYPE  C";A$
451 IF A$="C" OR A$="c" THEN 452 ELSE 460
452 WRT$="SC-20,370,-2.4,1,1;".CALL IBWRT%(BD%,WRT$)
453 INPUT"HOW MANY LABELS HAVE BEEN WRITEN";A
455 XL=240:YL=.8-.1*A
458 GOTO 720
460 REM REINITIALIZE PLOTTER, SELECT PEN #1, SET SCALE
470 WRT$="IN;SP1;SC-20,370,-2.4,1,1;":CALL IBWRT%(BD%,WRT$)
475 REM INITIALIZE POSITIONS OF LINE COLOR LABELS
478 XL=240:YL=.8
480 REM DRAW AXIS
490 WRT$="PU0,1.1;PD0,-2.4;PU0,0;PD360,0;":CALL IBWRT%(BD%,WRT$)
500 REM LABEL X AXIS
510 FOR I%=0 TO 360 STEP 30
520 WRT$="PU"+STR$(I%)+",0;TL0.5,0.5;XT;PU"+STR$(I%-5)+",-0.1;LB"+STR$(
    I%)+CHR$(3):CALL IBWRT%(BD%,WRT$)
530 WRT$="PU"+STR$(I%+10)+",0;TL0.5,0;XT;":CALL IBWRT%(BD%,WRT$)
540 WRT$="PU"+STR$(I%+20)+",0;XT;":CALL IBWRT%(BD%,WRT$)
550 NEXT I%
560 REM LABEL Y AXIS
570 FOR I=0 TO 1 STEP .2
580 WRT$="PU0,"+STR$(I)+";TL0.5,0.5;YT;PU-20,"+STR$(I)+";LB"+STR$(I)+
    CHR$(3):CALL IBWRT%(BD%,WRT$)
590 WRT$="PU0,"+STR$(I+.1)+";TL0.5,0;YT;":CALL IBWRT%(BD%,WRT$)
600 NEXT I
```

```
610 FOR I=-.2 TO -2.2 STEP -.2
620 WRT$="PU0,"+STR$(I)+";TL0.5,0.5;YT;PU-20,"+STR$(I)+";LB"+STR$(I)+
    CHR$(3):CALL IBWRT%(BD%,WRT$)
630 WRT$="PU0,"+STR$(I- 1)+"TL0.5,0;YT;":CALL IBWRT%(BD%,WRT$)
640 NEXT I
650 REM PRINT TITLE
660 WRT$="PU150,1;LBCp"+CHR$(3)+"SP0;":CALL IBWRT%(BD%,WRT$)
670 REM*************************************************************
680 REM
690 REM PLOT DATA FOR Cp
700 REM
710 REM*************************************************************
720 PRINT" ":INPUT"NAME OF FILE ON DRIVE B: TO BE PLOTTED (DO NOT
    INCLUDE EXTENTION)";NG$
730 NG$="B:"+NG$+".DAT"
740 OPEN "I",#1,NG$
750 PRINT" ":INPUT "PLOT WITH PEN #"; PN
760 INPUT #1, AN,CP
765 REM ROUND OFF CP AND TURN IT INTO 0.000 FORM AS OPOSED TO 0.00E00
767 CP=INT(CP*1000)/1000
770 WRT$="SP"+STR$(PN)+";PU"+STR$(AN)+","+STR$(CP)+";PD"+STR$(AN)+","+
    STR$(CP)+";":CALL IBWRT%(BD%,WRT$)
780 FOR I%=10 TO 360 STEP 10
790 INPUT #1,AN,CP
795 CP=INT(CP*1000)/1000
800 WRT$="PD"+STR$(AN)+","+STR$(CP)+";":CALL IBWRT%(BD%,WRT$)
810 NEXT I%
815 CLOSE
820 WRT$="SP0;":CALL IBWRT%(BD%,WRT$)
830 PRINT" ":INPUT"DO YOU WANT TO LABEL THIS LINE COLOR (Y/N)";A$
840 IF A$="Y" OR A$="y" THEN 900
850 IF A$="N" OR A$="n" THEN 860
855 GOTO 830
860 PRINT" ":PRINT" ":PRINT"1 START A GRAPH ON A NEW PAGE":PRINT"2 PLOT
    ANOTHER CURVE ON THIS PAGE"
870 INPUT A
880 ON A GOTO 460,720
890 GOTO 860
900 REM LABEL LINE COLOR
910 PRINT" ":INPUT "LABEL FOR THIS LINE COLOR";A$
920 WRT$="SP"+STR$(PN)+";PU"+STR$(XL)+","+STR$(YL)+";PD"+STR$(XL+20)+",
    "+STR$(YL)+";LB"+A$+CHR$(3)+"SP0;":CALL IBWRT%(BD%,WRT$)
930 YL=YL-.1
940 GOTO 860
```

CDCL1.BAS

```
10 REM CDCL1.BAS
20 REM PIOTR SYCHTERZ, MARCH 1987
30 REM THIS PROGRAM CALCULATES THE COEFFICIENTS OF LIFT AND DRAG FROM
   THE COEFFICIENT OF PRESSURE
40 REM THE REQUIRED COMPUTER DATA INCLUDES:
```

```
50 REM  1  TWELVE OR SEVEN FILES CONTAINING THE COEFFICIENT OF PRESSURE
   DATA ARROUND THE CYLINDER AT TWELVE POINTS IN THE CYCLE
70 DIM CP(37),CD(12),CL(12)
80 REM*****************************************************************
90 REM
100 REM PRINT INTRO SCREEN
110 REM
120 REM****************************************************************
130 CLS:PRINT"This program will calculate the coefficients of lift and
    drag Cl and Cd"
140 PRINT"The program will do this for 12 dynamic positions or 7 static
    positions."
150 PRINT"To do its work the program will have to have access to the 12
    dynamic or 7      static files containing the coefficients of
    pressure arround the cylinder at    the different positions in the
    cycle."
160 PRINT" ":PRINT"The last lines in the program should contain data
    statements listing the        experiment for which the coefficient
    of drag and lift is to be calculated."
170 PRINT" ":PRINT"The list of experiments should look something like
    this
180 PRINT" ":PRINT" ":PRINT"In each case the number refers to the
    experiment number, while the letter       specifies if this is a
    static or dynamic test. The last entry in the data shouldbe the
    word END"
200 PRINT" ":PRINT" ":PRINT"Into drive B: place the disk with the files
    required by this program as input.  The output will also be writen
    to this disk."
210 PRINT" ":INPUT"Press enter when ready";Z$
220 REM****************************************************************
230 REM
240 REM GET EXPERIMENT NUMBER FROM DATA STATEMENT
250 REM
260 REM****************************************************************
270 READ Z$
280 IF Z$="END" THEN PRINT" ":PRINT" ":PRINT"***  DONE  ***":END
290 EXPNUM$=MID$(Z$,2)
300 TYPE$=MID$(Z$,1,1)
310 IF TYPE$="S" THEN NUMFILE%=7:GOTO 850
320 IF TYPE$="D" THEN NUMFILE%=12: GOTO 850
330 PRINT " ":PRINT" ":PRINT"ERROR HAS OCCURED IN PROGRAM DATA
    STATEMENT, CAN NOT DETERMINE IF EXPERIMENT IS STATIC OR DYNAMIC.":
    END
780 REM****************************************************************
790 REM
800 REM START A LOOP TO DO ALL 12 DYNAMIC, OR 7 STATIC POSITIONS OF THIS
810 REM EXPERIMENT
820 REM FOR EACH POSITION CALCULATE THE COEFFICIENT OF LIFT & DRAG
830 REM
840 REM****************************************************************
850 FOR INDEX%=1 TO NUMFILE%
860 REM****************************************************************
870 REM
880 REM OPEN FILE CONTAINING COEFFICIENT OF PRESSURE FOR THIS POSITION
```

```
890 REM
900 REM****************************************************************
910 IF TYPE$="S" THEN CPFILE$="B:CPS"+MID$(STR$(INDEX%),2)+"-"+EXPNUM$+
    ".DAT" ELSE CPFILE$="B:CPD"+MID$(STR$(INDEX%),2)+"-"+EXPNUM$+".DAT"
920 OPEN "I",#1,CPFILE$
930 REM****************************************************************
940 REM
950 REM INPUT THE 37 VALUES OF Cp
960 REM
970 REM****************************************************************
980 FOR INDEX2%=1 TO 37
990 INPUT #1,ANGLE%,CP(INDEX2%)
1000 NEXT INDEX2%
1010 CLOSE #1
1020 R=.05715:L=1:REM R=RADIUS OF CYLINDER, L=UNIT SPAN OF CYLINDER 1m
     LENGTH, BOTH ARE IN METERS
1025 S=2*L*R:REM S=PROJECTED SURFACE AREA OF CYLINDER  'WING AREA'
1030 PI=3.1415927#
1040 REM***************************************************************
1050 REM
1060 REM CALCULATE THE Cd & Cl
1070 REM
1080 REM***************************************************************
1085 CD(INDEX%)=0:CL(INDEX%)=0
1090 FOR I%= 1 TO 36
1095 QI=(I%-1)*(PI/18)
1097 QI1=I%*PI/18
1100 MI=(CP(I%)-CP(I%+1))*(-18/PI)
1110 BI=CP(I%)+(CP(I%)-CP(I%+1))*(18/PI)*QI
1120 CD(INDEX%)=CD(INDEX%)+(L*R/S)*((MI*(COS(QI1)+QI1*SIN(QI1))+BI*SIN
     (QI1))-(MI*(COS(QI)+QI*SIN(QI))+BI*SIN(QI)))
1130 CL(INDEX%)=CL(INDEX%)+(-L*R/S)*((MI*(SIN(QI1)-QI1*COS(QI1))-BI*COS
(QI1))-(MI*(SIN(QI)-QI*COS(QI))-BI*COS(QI)))
1135 PRINT"EXPERIMENT=";Z$;"  POSITION=";INDEX%;"  SEGMENT=";I%
1140 NEXT I%
1350 NEXT INDEX%
1360 REM***************************************************************
1370 REM
1380 REM IF THIS IS A STATIC TEST THEN EXTEND THE 7 POSITIONS TO 12
1390 REM POSITION #8=POSITION #6, #9=#5, #10=#4, #11=#3, #12=#2
1400 REM
1410 REM***************************************************************
1420 IF TYPE$="S" THEN 1430 ELSE 1540
1430 CD(8)=CD(6):CL(8)=CL(6)
1440 CD(9)=CD(5):CL(9)=CL(5)
1450 CD(10)=CD(4):CL(10)=CL(4)
1460 CD(11)=CD(3):CL(11)=CL(3)
1470 CD(12)=CD(2):CL(12)=CL(2)
1480 REM***************************************************************
1490 REM
1500 REM SAVE THE COEFFICIENTS OF DRAG & LIFT TO A FILE CDL?-?.DAT
1510 REM ON DRIVE A:
1520 REM
1530 REM***************************************************************
```

```
1540 IF TYPE$="S" THEN CDCLFILE$="B:CDCLS-"+EXPNUM$+".DAT" ELSE
     CDCLFILE$="B:CDCLD-"+EXPNUM$+".DAT"
1550 OPEN "O",#1,CDCLFILE$
1560 FOR INDEX%= 1 TO 12
1570 PRINT #1, USING"####.####";CD(INDEX%)
1580 NEXT INDEX%
1590 FOR INDEX%=1 TO 12
1600 PRINT #1, USING"####.####";CL(INDEX%)
1610 NEXT INDEX%
1620 CLOSE #1
1630 REM*************************************************************
1640 REM
1650 REM FINISHED WITH THIS EXPERIMENT, READY TO START FROM THE
     BEGINING,
1660 REM WORKING ON THE NEXT EXPERIMENT
1670 REM
1680 REM*************************************************************
1690 GOTO 270
1700 DATA S98,END
```

PLOTCDC3.BAS

```
10 REM PLOTCDC3.BAS
20 REM (C) FEBRUARY 27, 1987 PIOTR W. SYCHTERZ
30 REM McGILL UNIVERSITY, MONTREAL
40 REM***************************************************************
50 REM
60 REM
70 REM INITIALIZE THE GPIB-PC SOFTWARE IN THIS PROGRAM
80 REM
90 REM
100 REM**************************************************************
110 REM RESERVE MEMORY ABOVE 60650 FOR GPIB-PC SUBROUTINE CALLED IBINIT
120        CLEAR   ,60650!
130        IBINIT = 60650!
140 REM LOAD SUBROUTINE IBINIT FROM FILE BIB.M ON DRIVE A
150       BLOAD "A:BIB.M",IBINIT
160       IBSTA%=0:IBERR%=0:IBCNT%=0
170       CALL IBINIT (IBRD%,IBWRT%,IBCMD%,IBWAIT%,IBRPP%,IBONL%,IBRSC%,
          IBSIC%,IBSRE%,IBRTL%,IBRSV%,IBLPE%,IBPAD%,IBSAD%,IBIST%,IBDMA%,
          IBEOS%,IBTMO%,IBEOT%,IBGTS%,IBCAC%,IBDIAG%,IBSTA%,IBERR%,
          IBCNT%)
180 REM
190 REM BD% DENOTES THE GPIB-PC BOARD NUMBER IN SUBROUTINE CALLS
200 REM BD%=0 BECAUSE THERE IS ONLY ONE BOARD
210 BD%=0
220 REM**************************************************************
230 REM
240 REM
250 REM INITIALIZE GPIB-PC AS THE CONTROLLER IN CHARGE OF PLOTTER
260 REM
270 REM
```

```
280 REM*****************************************************************
290 REM PUT GPIB-PC ON LINE
300 V%=1:CALL IBONL%(BD%,V%)
310 REM MAKE GPIB-PC ACTIVE SYSTEM CONTROLLER
320 CALL IBSIC%(BD%)
330 REM ASSERT REN (REMOTE ENABLE) TO PUT HP5420A IN REMOTE CONTROL
340 V%=1:CALL IBSRE%(BD%,V%)
350 REM ADDRESS GPIB-PC TO TALK "@"
360 REM ADDRESS PLOTTER TO LISTEN "%"
370 CMD$="@%":CALL IBCMD%(BD%,CMD$)
380 REM*****************************************************************
390 REM
400 REM PLOTTER IS READY TO RECEIVE INSTRUCTIONS
410 REM
420 REM*****************************************************************
430 CLS:PRINT"This program will plot Cd & Cl (coefficient of drag &
    coefficient of pressure onan HP Plotter. The last lines in the
    program should contain a list of           experiments for which
    this plotting will take place."
440 PRINT" ":PRINT" ":PRINT"The experiments should be listed in the
    following format.":PRINT" ":PRINT" "
450 PRINT"10000 DATA S3,1,Static"
460 PRINT"10001 DATA S4,1,NON"
470 PRINT"10002 DATA D4,2,U/fd=131"
480 PRINT"10003 DATA D5,2,NON"
490 PRINT" ":PRINT" ":PRINT"The letter S denotes a static test, the
    letter D denotes a dynamic test. The    number after the letter
    denotes the experiment number. The string at the end of the line
    will become a label for the pen color."
500 PRINT"If the string is equal to NON then there will be no label for
    this line."
510 PRINT" ":INPUT"Insert disk with data files into drive B: , load
    plotter, specify CD or CL, and press ENTER when    ready";A$
520 IF A$="CD" THEN 550
530 IF A$="CL" THEN 1430
540 GOTO 510
550 PRINT"NOW PLOTTING Cd"
560 REM*****************************************************************
570 REM
580 REM INITIALIZE PLOTTER AND DRAW AXIS FOR PLOTTING Cd
590 REM
600 REM*****************************************************************
610 REM
620 REM
630 REM
640 XMIN=1:XMAX=12:REM NEVER CHANGES
650 YMIN=-.5:YMAX=.3:REM ADJUST TO SUIT GRAPH
660 REM
670 REM
680 REM
690 IF XMIN<0 THEN XMININT=INT(XMIN-1) ELSE XMININT=INT(XMIN)
700 IF XMAX<0 THEN XMAXINT=INT(XMAX) ELSE XMAXINT=INT(XMAX+1)
710 IF YMIN<0 THEN YMININT=INT(YMIN-1) ELSE YMININT=INT(YMIN)
720 IF YMAX<0 THEN YMAXINT=INT(YMAX) ELSE YMAXINT=INT(YMAX+1)
```

```
730 P1Y%=INT(((2-.25)-5*(YMIN-YMININT)/(YMAX-YMIN))*1016)
740 P2Y%=P1Y%+INT(((YMAXINT-YMININT)*5/(YMAX-YMIN))*1016)
750 P1X%=INT(((2.25-.495)-7.25*(XMIN-XMININT)/(XMAX-XMIN))*1016)
760 P2X%=P1X%+INT(((XMAXINT-XMININT)*7.25/(XMAX-XMIN))*1016)
770 XLEGEND=XMIN-(1.4/7.25)*(XMAX-XMIN)
780 YLEGEND=YMIN+(2/5)*(YMAX-YMIN)
790 WRT$="IN;IP "+STR$(P1X%)+","+STR$(P1Y%)+","+STR$(P2X%)+","+STR$
    (P2Y%)+";":CALL IBWRT%(BD%,WRT$)
800 WRT$="SC "+STR$(XMININT)+","+STR$(XMAXINT)+","+STR$(YMININT)+","+
    STR$(YMAXINT)+";SP1;PU "+STR$(XMIN)+","+STR$(YMIN)+";":CALL IBWRT%
    (BD%,WRT$)
810 WRT$="PD"+STR$(XMAX)+","+STR$(YMIN)+","+STR$(XMAX)+","+STR$(YMAX)+
    ","+STR$(XMIN)+","+STR$(YMAX)+","+STR$(XMIN)+","+STR$(YMIN)+";":
    CALL IBWRT%(BD%,WRT$)
820 REM NEXT 5 LINES LABEL THE X AXIS DIVISIONS, THIS NEVER CHANGES AND
    IS WRITTEN IN TERMS OF VARIABLE WHICH DO NOT CHANGE WHEN YOU CHANGE
    XMIN, XMAX, YMIN, YMAX (THESE 5 LINES WOULD BE INCORECT IF YOU
    CHANGED XMIN, XMAX)
830 REM IN ORDER FOR THE NEXT 5 LINES TO BE CORRECT XMIN=1, XMAX=12,
    YMIN<0, YMAX>0
840     WRT$="PU 1,0;PD12,0;SI 0.14,0.5;":CALL IBWRT%(BD%,WRT$)
850     FOR PS%=2 TO 12
860     PS$=STR$(PS%)
870     WRT$="PU"+PS$+",0;XT;PR-0.24,"+STR$((-1.5*.01)*(YMAXINT-YMININT
        ))+";PA;LB"+PS$+CHR$(3):CALL IBWRT%(BD%,WRT$)
880     NEXT PS%
890 REM THE NEXT PIECE OF CODE LABELS THE DIVISIONS ON THE Y AXIS. THIS
    PART OF THE PROGRAM IS WITTEN SO THAT IT ADJUSTS TO CHANGING YMIN &
    YMAX
900 RANGE=YMAX-YMIN
910 IF RANGE=>5 THEN INTER=1:GOTO 990
920 IF RANGE=>2.5 THEN INTER=.5:GOTO 990
930 IF RANGE=>1 THEN INTER=.25:GOTO 990
940 IF RANGE=>.5 THEN INTER=.1:GOTO 990
950 IF RANGE=>.25 THEN INTER=.05:GOTO 990
960 IF RANGE=>.1 THEN INTER=.025:GOTO 990
970 IF RANGE=>.05 THEN INTER=.01:GOTO 990
980 PRINT"YMAX-YMIN=RANGE=";RANGE;" CAN NOT BE HANDLED BY THIS PROGRAM.
    PLEASE CORRECT.":STOP
990 REM
1000 FOR COEF%= 0 TO YMAX*100 STEP INTER*100
1010 COEF$=STR$(COEF%/100)
1020 WRT$="PU 1,"+COEF$+";YT;PR"+STR$((-7*.007)*(XMAXINT-XMININT))+","+
     STR$((-.5*.01)*(YMAXINT-YMININT))+";PA;LB"+COEF$+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
1030 NEXT COEF%
1040 FOR COEF%=-INTER*100 TO YMIN*100 STEP -INTER*100
1050 COEF$=STR$(COEF%/100)
1060 WRT$="PU 1,"+COEF$+";YT;PR"+STR$((-7*.007)*(XMAXINT-XMININT))+","+
     STR$((-.5*.01)*(YMAXINT-YMININT))+";PA;LB"+COEF$+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
1070 NEXT COEF%
1080 REM***************************************************************
1090 REM
```

```
1100 REM LABEL GRAPH FOR PLOTTING Cd
1110 REM
1120 REM**************************************************************
1130 WRT$="PU "+STR$(XMIN+(1.5/7.25)*(XMAX-XMIN))+","+STR$(YMAX+(.125/5)
     *(YMAX-YMIN))+";LBCoefficient of drag"+CHR$(3):CALL IBWRT%(BD%,
     WRT$)
1140 WRT$="LB  VS  Cylinder position"+CHR$(3):CALL IBWRT%(BD%,WRT$)
1150 WRT$=CHR$(3)+"PU "+STR$(XMIN-(.75/7.25)*(XMAX-XMIN))+","+STR$(YMAX
     -(1/5)*(YMAX-YMIN))+";LBCd"+CHR$(3):CALL IBWRT%(BD%,WRT$)
1160 WRT$="PU "+STR$(XMIN+(2/7.25)*(XMAX-XMIN))+","+STR$(YMIN-(.5/5)*(
     YMAX-YMIN))+";LBPosition"+CHR$(3):CALL IBWRT%(BD%,WRT$)
1170 WRT$="SI 0.15,0.3;":CALL IBWRT%(BD%,WRT$):REM SET SMALL CHARACTER
     SIZE FOR LINE LABELS
1180 REM**************************************************************
1190 REM
1200 REM LOAD DATA AND PLOT Cd FOR SPECIFIED EXPERIMENTS
1210 REM
1220 REM**************************************************************
1230 READ EXPERIMENT$,PENCOL$,LABEL$
1240 IF EXPERIMENT$="END" THEN 1430
1250 EXPNUM$=MID$(EXPERIMENT$,2)
1260 TYPE$=MID$(EXPERIMENT$,1,1)
1270 FILENAME$="B:CDCL"+TYPE$+"-"+EXPNUM$+".DAT"
1280 OPEN "I",#1,FILENAME$
1290 WRT$="SP"+PENCOL$+";":CALL IBWRT%(BD%,WRT$)
1300 INPUT #1,CD$
1310 WRT$="PU 1,"+CD$+";":CALL IBWRT%(BD%,WRT$)
1320 FOR PS%= 2 TO 12
1330 PS$=STR$(PS%)
1340 INPUT #1,CD$
1350 WRT$="PD "+PS$+","+CD$+";":CALL IBWRT%(BD%,WRT$)
1360 NEXT PS%
1370 CLOSE #1
1380 IF LABEL$="NON" THEN 1410
1390 WRT$="PU"+STR$(XLEGEND)+","+STR$(YLEGEND)+";PD"+STR$(XLEGEND+(.125
     /7.25)*(XMAX-XMIN))+","+STR$(YLEGEND)+";LB"+LABEL$+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
1400 YLEGEND=YLEGEND-(YMAX-YMIN)*(.17/5)
1410 WRT$="SP0;":CALL IBWRT%(BD%,WRT$)
1420 GOTO 1230
1430 REM**************************************************************
1440 REM
1450 REM DRAW AXIS FOR PLOTTING COEFFICIENT OF LIFT
1460 REM
1470 REM**************************************************************
1480 RESTORE
1490 PRINT" ":INPUT"Insert new page for the Cl graph, and press ENTER";
     A$
1500 REM
1510 REM
1520 REM
1530 XMIN=1:XMAX=12:REM NVER CHANGES, THESE ARE THE POSTIONS OF THE
     CYLINDER
1540 YMIN=-1.3:YMAX=.3:REM ADJUST TO SUIT GRAPH
```

```
1550 REM
1560 REM
1570 REM
1580 IF XMIN<0 THEN XMININT=INT(XMIN-1) ELSE XMININT=INT(XMIN)
1590 IF XMAX<0 THEN XMAXINT=INT(XMAX) ELSE XMAXINT=INT(XMAX+1)
1600 IF YMIN<0 THEN YMININT=INT(YMIN-1) ELSE YMININT=INT(YMIN)
1610 IF YMAX<0 THEN YMAXINT=INT(YMAX) ELSE YMAXINT=INT(YMAX+1)
1620 P1Y%=INT(((2-.25)-5*(YMIN-YMININT)/(YMAX-YMIN))*1016)
1630 P2Y%=P1Y%+INT(((YMAXINT-YMININT)*5/(YMAX-YMIN))*1016)
1640 P1X%=INT(((2.25-.495)-7.25*(XMIN-XMININT)/(XMAX-XMIN))*1016)
1650 P2X%=P1X%+INT(((XMAXINT-XMININT)*7.25/(XMAX-XMIN))*1016)
1660 XLEGEND=XMIN-(1.4/7.25)*(XMAX-XMIN)
1670 YLEGEND=YMIN+(2/5)*(YMAX-YMIX)
1680 WRT$="IN;IP "+STR$(P1X%)+","+STR$(P1Y%)+","+STR$(P2X%)+","+STR$
     (P2Y%)+";":CALL IBWRT%(BD%,WRT$)
1690 WRT$="SC "+STR$(XMININT)+","+STR$(XMAXINT)+","+STR$(YMININT)+","+
     STR$(YMAXINT)+";SP1;PU "+STR$(XMIN)+","+STR$(YMIN)+";":CALL IBWRT%
     (BD%,WRT$)
1700 WRT$="PD"+STR$(XMAX)+","+STR$(YMIN)+","+STR$(XMAX)+","+STR$(YMAX)+
     ","+STR$(XMIN)+","+STR$(YMAX)+","+STR$(XMIN)+","+STR$(YMIN)+";":
     CALL IBWRT%(BD%,WRT$)
1710 REM NEXT 5 LINES LABEL THE X AXIS DIVISIONS, THIS NEVER CHANGES AND
     IS WRITTEN IN TERMS OF VARIABLES WHICH DO NOT CHANGE WHEN YOU
     CHANGE XMIN, XMAX, YMIN, YMAX (THESE 5 LINES WILL BE INCORRECT IF
     YOU CHANGE XMIN, XMAX)
1720 REM IN ORDER FOR THE NEXT 5 LINES TO BE CORRECT XMIN=1, XMAX=12,
     YMIN<0, YMAX>0
1730      WRT$="PU 1,0;PD 12,0;SI 0.14,0.5;":CALL IBWRT%(BD%,WRT$)
1740      FOR PS%=2 TO 12
1750      PS$=STR$(PS%)
1760      WRT$="PU"+PS$+",0;XT;PR-0.24,"+STR$((-2!*.01)*(YMAXINT-
          YMININT))+";PA;LB"+PS$+CHR$(3):CALL IBWRT%(BD%,WRT$)
1770      NEXT PS%
1780 REM THE NEXT PIECE OF CODE LABELS THE DIVISIONS ON THE Y AXIS. THIS
     PART OF THE PROGRAM IS WRITTEN SO THAT IT ADJUSTS TO CHANGING YMIN
     & YMAX
1790 RANGE=YMAX-YMIN
1800 IF RANGE=>5 THEN INTER=1:GOTO 1880
1810 IF RANGE=>2.5 THEN INTER=.5:GOTO 1880
1820 IF RANGE=>1 THEN INTER=.25:GOTO 1880
1830 IF RANGE=>.5 THEN INTER=.1:GOTO 1880
1840 IF RANGE=>.25 THEN INTER=.05:GOTO 1880
1850 IF RANGE=>.1 THEN INTER 0.025:GOTO 1880
1860 IF RANGE=>.05 THEN INTER=.01:GOTO 1880
1870 PRINT"YMAX-YMIN=RANGE=";RANGE;" CAN NOT BE HANDLED BY THIS PROGRAM
     . PLEASE CORRECT.":STOP
1880 REM
1890 FOR COEF%=0 TO YMAX*100 STEP INTER*100
1900 COEF$=STR$(COEF%/100)
1910 WRT$="PU 1,"+COEF$+";YT;PR"+STR$((-7*.007)*(XMAXINT-XMININT))+","+
     STR$((-.5*.01)*(YMAXINT-YMININT))+";PA;":CALL IBWRT%(BD%,WRT$)
1920 WRT$="LB"+COEF$+CHR$(3):CALL IBWRT%(BD%,WRT$)
1930 NEXT COEF%
1940 FOR COEF%=-INTER*100 TO YMIN*100 STEP -INTER*100
```

```
1950 COEF$=STR$(COEF%/100)
1960 WRT$="PU 1,"+COEF$+";YT;PR"+STR$((-7*.007)*(XMAXINT-XMININT))+","+
     STR$((-.5*.01)*(YMAXINT-YMININT))+";PA;LB"+COEF$+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
1970 NEXT COEF%
1980 REM*************************************************************
1990 REM
2000 REM LABEL GRAPH FOR PLOTTING Cl
2010 REM
2020 REM*************************************************************
2030 WRT$="PU "+STR$(XMIN+(1.5/7.25)*(XMAX-XMIN))+","+STR$(YMAX+(.125/
     5)*(YMAX-YMIN))+";":CALL IBWRT%(BD%,WRT$)
2040 WRT$="LBCoefficient of lift"+CHR$(3):CALL IBWRT%(BD%,WRT$)
2050 WRT$="LB  VS  Cylinder position"+CHR$(3):CALL IBWRT%(BD%,WRT$)
2060 WRT$=CHR$(3)+"PU "+STR$(XMIN-(.75/7.25)*(XMAX-XMIN))+","+STR$
     (.0001*INT(10000*(YMAX-(1/5)*(YMAX-YMIN))))+";LBCl"+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
2080 WRT$="PU "+STR$(XMIN+(2/7.25)*(XMAX-XMIN))+","+STR$(YMIN-(.5/5)*
     (YMAX-YMIN))+";LBPosition"+CHR$(3):CALL IBWRT%(BD%,WRT$)
2090 WRT$="SI 0.15,0.3;":CALL IBWRT%(BD%,WRT$)
2100 REM*************************************************************
2110 REM
2120 REM LOAD DATA AND PLOT Cl FOR SPECIFIED EXPERIMENTS
2130 REM
2140 REM*************************************************************
2150 READ EXPERIMENT$,PENCOL$,LABEL$
2160 IF EXPERIMENT$="END" THEN END
2170 EXPNUM$=MID$(EXPERIMENT$,2)
2180 TYPE$=MID$(EXPERIMENT$,1,1)
2190 FILENAME$="B:CDCL"+TYPE$+"-"+FXPNUM$+".DAT"
2200 OPEN "I",#1,FILENAME$
2210 FOR PS%=1 TO 12:INPUT #1,CL$:NEXT PS%
2220 WRT$="SP"+PENCOL$+";":CALL IBWRT%(BD%,WRT$)
2230 INPUT #1,CL$
2240 WRT$="PU 1,"+CL$+";":CALL IBWRT%(BD%,WRT$)
2250 FOR PS%= 2 TO 12
2260 PS$=STR$(PS%)
2270 INPUT #1,CL$
2280 WRT$="PD "+PS$+","+CL$+";":CALL IBWRT%(BD%,WRT$)
2290 NEXT PS%
2300 CLOSE #1
2310 IF LABEL$="NON" THEN 2340
2320 WRT$="PU"+STR$(XLEGEND)+","+STR$(YLEGEND)+";PD"+STR$(XLEGEND+(.125
     /7.25)*(XMAX-XMIN))+","+STR$(YLEGEND)+";LB"+LABEL$+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
2330 YLEGEND=YLEGEND-(YMAX-YMIN)*(.17/5)
2340 WRT$="SP0;":CALL IBWRT%(BD%,WRT$)
2350 GOTO 2150
2360 REM*************************************************************
2370 REM
2380 REM DATA
2390 REM
2400 REM*************************************************************
2410 DATA S3,1,Static
```

```
2420 DATA S4,1,NON
2430 DATA D9,1,U/fd=250
2440 DATA D4,1,U/fd=131
2450 DATA D5,1,NON
2460 DATA D6,1,U/fd=44
2470 DATA D7,1,U/fd=22
2480 DATA D8,1,U/fd=15
2490 DATA END,END,END
```

PREDICT.BAS

```
10 REM PREDICT.BAS
20 REM PIOTR SYCHTERZ, MARCH 1987
30 REM THIS PROGRAM CALCULATES A PREDICTION OF Cd & Cl (COEFFICIENTS OF
   DRAG AND LIFT), FOR DYNAMIC SITUATIONS BY USING THE Cd & Cl FROM
   STATIC TESTS
40 REM THIS IS DONE AT 12 POSITIONS IN THE CYCLE OF OSCILLATION.
50 REM THE REQUIRED INPUT IS :
60 REM      A FILE CONTAINING THE 12 Cd AND Cl
70 REM      FREQUENCY OF OSCILLATION, IN Hz (IT SHOULD BE LISTED IN THE
   DATA)
75 DIM CD(12),CL(12),CY(12),CX(12)
80 CLS:PRINT"This program calculates a prediction for Cd & Cl
   (Coefficients of drag and lift)for dynamic situations by using the
   Cd & Cl from static tests."
90 PRINT"This is done for 12 positions in the cycle.  The required data
   includes:"
100 PRINT"    A file containing the 12 Cd & Cl for the static cases
110 PRINT"    Frequency of oscillation, in Hz (it should be listed in
    the data statements,    for which Cd & Cl will be calculated,
    together with its related air velocity"
120 PRINT" ":PRINT" ":PRINT"Into drive B: insert the disk with the files
    containing the Cd & Cl,           and press ENTER";:INPUT A$
130 PI=3.1415927#:AMP=.01905:REM AMP is the amplitude of oscillation in
    meters
140 READ REPNUM%
142 FOR INDEX%=1 TO 12
143   CD(INDEX%)=0
144   CL(INDEX%)=0
145 NEXT INDEX%
150 FOR INDEX%= 1 TO REPNUM%
160   READ FILENAME$
170   OPEN "I",#1,FILENAME$
180   FOR INDEX2%= 1 TO 12
190     INPUT #1, CD
200     CD(INDEX2%)=CD(INDEX2%)+CD
210   NEXT INDEX2%
220   FOR INDEX2%=1 TO 12
230     INPUT #1,CL
240     CL(INDEX2%)=CL(INDEX2%)+CL
250   NEXT INDEX2%
255   CLOSE #1
```

```
260 NEXT INDEX%
270 FOR INDEX%=1 TO 12
280   CL(INDEX%)=CL(INDEX%)/REPNUM%
290   CD(INDEX%)=CD(INDEX%)/REPNUM%
300 NEXT INDEX%
310 READ FILENAME$,HZ,AIRVELOCITY
315 FREQ=HZ
320 IF FILENAME$="DONE" THEN PRINT FILENAME$:END
325 FOR INDEX%=1 TO 12
326   IF INDEX%<=7 THEN X1=1 ELSE X1=-1
327   IF INDEX%<=7 THEN XX=-1+INDEX%*.25 ELSE XX=2.5-INDEX%*.25
328   GOSUB 10980:REM THE SUBROUTINE TO FIND THE TIME FROM START OF
      CYCLE
330   CYLINDERVELOCITY=AMP*2*PI*HZ*COS(T*(HZ*2*PI)-PI/2)
340   ALPHA=ATN(CYLINDERVELOCITY/AIRVELOCITY)
345   RESULTANTVELOCITYSQRD=(AIRVELOCITY'2)+(CYLINDERVELOCITY'2)
350   CY(INDEX%)=(RESULTANTVELOCITYSQRD/(AIRVELOCITY'2))*(CL(INDEX%)*COS
      (ALPHA)-CD(INDEX%)*SIN(ALPHA))
360   CX(INDEX%)=(RESULTANTVELOCITYSQRD/(AIRVELOCITY'2))*(CL(INDEX%)*SIN
      (ALPHA)+CD(INDEX%)*COS(ALPHA))
370 NEXT INDEX%
380 OPEN "O",#1,FILENAME$
390 FOR INDEX%=1 TO 12
395   REM STORE CX=PREDICTED COEFFICIENT OF DRAG FIRST
400   PRINT #1,USING"####.####";CX(INDEX%)
410 NEXT INDEX%
420 FOR INDEX%=1 TO 12
425   REM STORE CY=PREDICTED COEFFICIENT OF LIFT SECOND
430   PRINT #1,USING"####.####";CY(INDEX%)
440 NEXT INDEX%
450 CLOSE #1
460 GOTO 310
500 DATA 2,"B:CDCLS-3.DAT","B:CDCLS-4.DAT"
510 DATA "B:PRED-4.DAT",1,15
520 DATA "B:PRED-6.DAT",3.0273,15
530 DATA "B:PRED-7.DAT",6.054,15
540 DATA "B:PRED-8.DAT",6.054,10
550 DATA "B:PRED-9.DAT",1.0254,29.4
10980 REM ***********************************************************
10990 REM SUBROUTINE TO FIND TIME T AT WHICH CYLINDER IS AT PARTICULAR
      LOCATION XX
11000 REM INPUT VARIABLES:
11010 REM   XX=DISTANCE FROM CENTER POSITION IN INCHES
11020 REM   X1=1 IF XX IS INCREASING
11030 REM     =-1IF XX ID DECREASING
11040 REM FREQ=FREQUENCY OF OSCILATION OF CYLINDER
11050 REM OUTPUT VARIABLES:
11060 REM   T =TIME IN SECONDS REQUIRED TO TRAVEL FROM XX=-0.75 TO GIVEN
      XX AT FREQUENCY FREQ AND AMPLITUDE OF 0.75 INCHES
11070 REM VARIABLES USED INTERNALY:
11080 REM   A =AMPLITUDE OF OSCILATION 0.75
11090 REM   PI=PIE 3.1415927
11100 REM   S =SINE OF ANGLE XX/A
11110 REM   X =
```

```
11120 REM   Z =
11130 REM   W =ARCSIN OF S IN RADIANS
11140 REM   Y =ARCSIN OF S IN DEGREES
11150 A=.75
11160 PI=3.1415927#
11170 IF X1=1 THEN 11200
11180 IF X1=-1 THEN 11240
11190 PRINT"ERROR IN GET-TIME SUBROUTINE":STOP
11200 S=XX/A:GOSUB 11280:REM GET ARCSIN(S)
11210 T=(W/(2*PI))+.25:T=T/FREQ
11220 RETURN:REM RETURN TO MAIN PROGRAM WITH TIME T
11230 REM FOR XX=.5 TO -.75 STEP -.25 ....I THINK THIS IS A DUD
11240 S=XX/A:GOSUB 11280:REM GET ARCSIN(S)
11250 T=1-((W/(2*PI))+.25):T=T/FREQ
11260 RETURN:REM RETURN TO MAIN MPROGRAM WITH TIME T
11270 REM************************************************************
11280 REM SEE "GETTING STARTED WITH COLOR BASIC", PAGE 289
11290 REM *ARCSIN SUBROUTINE* INPUT S, OUTPUT Y,W
11300 REM Y IS IN DEGREES, W IS IN RADIANS
11310 REM ALSO USES VARIABLES X,Z INTERNALLY
11320 X=S:IF ABS(S)<=.707107 THEN 11390
11330 X=1-S*S: IF X<0 THEN PRINT S;"IS OUT OF RANGE":STOP
11340 IF X=0 THEN W=90/57.29577951#:IF S<0 THEN W=-W
11350 IF X=0 THEN 11420
11360 W=X/2: Z=0
11370 Y=(X/W-W)/2:IF (ABS(Y)<1E-09)AND(Y=Z) THEN X=W:GOTO 11390
11380 W=W+Y:Z=Y:GOTO 11370
11390 Y=X+X*X*X/6+X*X*X*X*X*.075+X*X*X*X*X*X*X*4.464286E-02
11400 W=Y+X*X*X*X*X*X*X*X*X*3.038194E-02
11410 IF ABS(S)>.707107 THEN W=1.570796-W
11420 Y=W*57.29577951#:RETURN:REM RETURN TO THE GET-TIME SUBROUTINE.
```

PLOTPRED.BAS

```
10 REM PLOTPRED.BAS
20 REM (C) MARCH 27, 1987 PIOTR W. SYCHTERZ
30 REM McGILL UNIVERSITY, MONTREAL
40 REM************************************************************
50 REM
60 REM
70 REM INITIALIZE THE GPIB-PC SOFTWARE IN THIS PROGRAM
80 REM
90 REM
100 REM************************************************************
110 REM RESERVE MEMORY ABOVE 60650 FOR GPIB-PC SUBROUTINE CALLED IBINIT
120       CLEAR   ,60650!
130       IBINIT = 60650!
140 REM LOAD SUBROUTINE IBINIT FROM FILE BIB.M ON DRIVE A
150       BLOAD "A:BIB.M",IBINIT
160       IBSTA%=0:IBERR%=0:IBCNT%=0
170       CALL IBINIT (IBRD%,IBWRT%,IBCMD%,IBWAIT%,IBRPP%,IBONL%,IBRSC%,
          IBSIC%,IBSRE%,IBRTL%,IBRSV%,IBLPE%,IBPAD%,IBSAD%,IBIST%,IBDMA%,
```

```
          IBEOS%,IBTMO%,IBEOT%,IBGTS%,IBCAC%,IBDIAG%,IBSTA%,IBERR%,
          IBCNT%)
180 REM
190 REM BD% DENOTES THE GPIB-PC BOARD NUMBER IN SUBROUTINE CALLS
200 REM BD%=0 BECAUSE THERE IS ONLY ONE BOARD
210 BD%=0
220 REM*****************************************************************
230 REM
240 REM
250 REM INITIALIZE GPIB-PC AS THE CONTROLLER IN CHARGE OF PLOTTER
260 REM
270 REM
280 REM*****************************************************************
290 REM PUT GPIB-PC ON LINE
300 V%=1:CALL IBONL%(BD%,V%)
310 REM MAKE GPIB-PC ACTIVE SYSTEM CONTROLLER
320 CALL IBSIC%(BD%)
330 REM ASSERT REN (REMOTE ENABLE) TO PUT HP5420A IN REMOTE CONTROL
340 V%=1:CALL IBSRE%(BD%,V%)
350 REM ADDRESS GPIB-PC TO TALK "@"
360 REM ADDRESS PLOTTER TO LISTEN "%"
370 CMD$="@%":CALL IBCMD%(BD%,CMD$)
380 REM*****************************************************************
390 REM
400 REM PLOTTER IS READY TO RECEIVE INSTRUCTIONS
410 REM
420 REM*****************************************************************
430 CLS:PRINT"This program will plot Cd & Cl (coefficient of drag &
     coefficient of pressure onan HP Plotter. The last lines in the
     program should contain a list of           experiments for which
     this plotting will take place."
440 PRINT" ":PRINT" ":PRINT"The experiments should be listed in the
    following format.":PRINT" ":PRINT" "
450 PRINT"10000 DATA S3,1,Static"
460 PRINT"10001 DATA S4,1,NON"
470 PRINT"10002 DATA D4,2,U/fd=131"
480 PRINT"10003 DATA D5,2,NON"
490 PRINT" "·PRINT" ":PRINT"The letter S denotes a static test, the
    letter D denotes a dynamic test. The    number after the letter
    denotes the experiment number. The string at the end of the line
    will become a label for the pen color."
500 PRINT"If the string is equal to NON then there will be no label for
    this line."
510 PRINT" ":INPUT"Insert disk with data files into drive B: , load
    plotter, specify CD or CL, and press ENTER when   ready";A$
520 IF A$="CD" THEN 550
530 IF A$="CL" THEN 1580
540 GOTO 510
550 PRINT"NOW PLOTTING Cd"
560 REM*****************************************************************
570 REM
580 REM INITIALIZE PLOTTER AND DRAW AXIS FOR PLOTTING Cd
590 REM
600 REM*****************************************************************
```

```
610 REM
620 REM
630 REM
640 XMIN=1:XMAX=12:REM NEVER CHANGES
650 YMIN=-1.3:YMAX=.3:REM ADJUST TO SUIT GRAPH
660 REM
670 REM
680 REM
690 IF XMIN<0 THEN XMININT=INT(XMIN-1) ELSE XMININT=INT(XMIN)
700 IF XMAX<0 THEN XMAXINT=INT(XMAX) ELSE XMAXINT=INT(XMAX+1)
710 IF YMIN<0 THEN YMININT=INT(YMIN-1) ELSE YMININT=INT(YMIN)
720 IF YMAX<0 THEN YMAXINT=INT(YMAX) ELSE YMAXINT=INT(YMAX+1)
730 P1Y%=INT(((2-.25)-5*(YMIN-YMININT)/(YMAX-YMIN))*1016)
740 P2Y%=P1Y%+INT(((YMAXINT-YMININT)*5/(YMAX-YMIN))*1016)
750 P1X%=INT(((2.25-.495)-7.25*(XMIN-XMININT)/(XMAX-XMIN))*1016)
760 P2X%=P1X%+INT(((XMAXINT-XMININT)*7.25/(XMAX-XMIN))*1016)
770 XLEGEND=XMIN-(1.4/7.25)*(XMAX-XMIN)
780 YLEGEND=YMIN+(2/5)*(YMAX-YMIN)
790 WRT$="IN;IP "+STR$(P1X%)+","+STR$(P1Y%)+","+STR$(P2X%)+","+STR$
    (P2Y%)+";":CALL IBWRT%(BD%,WRT$)
800 WRT$="SC "+STR$(XMININT)+","+STR$(XMAXINT)+","+STR$(YMININT)+","+
    STR$(YMAXINT)+";SP1;PU "+STR$(XMIN)+","+STR$(YMIN)+";":CALL IBWRT%
   (BD%,WRT$)
810 WRT$="PD"+STR$(XMAX)+","+STR$(YMIN)+","+STR$(XMAX)+","+STR$(YMAX)+
    ","+STR$(XMIN)+","+STR$(YMAX)+","+STR$(XMIN)+","+STR$(YMIN)+";":CALL
    IBWRT%(BD%,WRT$)
820 REM NEXT 5 LINES LABEL THE X AXIS DIVISIONS. THIS NEVER CHANGES AND
    IS WRITTEN IN TERMS OF VARIABLE WHICH DO NOT CHANGE WHEN YOU CHANGE
    XMIN, XMAX, YMIN, YMAX (THESE 5 LINES WOULD BE INCORECT IF YOU
    CHANGED XMIN, XMAX)
830 REM IN ORDER FOR THE NEXT 5 LINES TO BE CORRECT XMIN=1, XMAX=12,
    YMIN<0, YMAX>0
840      WRT$="PU 1,0;PD12,0;SI 0.14,0.5;":CALL IBWRT%(BD%,WRT$)
850      FOR PS%=2 TO 12
860      PS$=STR$(PS%)
870      WRT$="PU"+PS$+",0;XT;PR-0.24,"+STR$((-1.5*.01)*(YMAXINT-
         YMININT))+";PA;LB"+PS$+CHR$(3):CALL IBWRT%(BD%,WRT$)
880      NEXT PS%
890 REM THE NEXT PIECE OF CODE LABELS THE DIVISIONS ON THE Y AXIS. THIS
    PART OF THE PROGRAM IS WITTEN SO THAT IT ADJUSTS TO CHANGING YMIN &
    YMAX
900 RANGE=YMAX-YMIN
910 IF RANGE=>5 THEN INTER=1:GOTO 990
920 IF RANGE=>2.5 THEN INTER=.5:GOTO 990
930 IF RANGE=>1 THEN INTER=.25:GOTO 990
940 IF RANGE=>.5 THEN INTER=.1:GOTO 990
950 IF RANGE=>.25 THEN INTER=.05:GOTO 990
960 IF RANGE=>.1 THEN INTER=.025:GOTO 990
970 IF RANGE=>.05 THEN INTER=.01:GOTO 990
980 PRINT"YMAX-YMIN=RANGE=";RANGE;" CAN NOT BE HANDLED BY THIS PROGRAM.
    PLEASE CORRECT.":STOP
990 REM
1000 FOR COEF%= 0 TO YMAX*100 STEP INTER*100
1010 COEF$=STR$(COEF%/100)
```

```
1020 WRT$="PU 1,"+COEF$+";YT;PR"+STR$((-7*.007)*(XMAXINT-XMININT))+","+
     STR$((-.5*.01)*(YMAXINT-YMININT))+";PA;LB"+COEF$+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
1030 NEXT COEF%
1040 FOR COEF%=-INTER*100 TO YMIN*100 STEP -INTER*100
1050 COEF$=STR$(COEF%/100)
1060 WRT$="PU 1,"+COEF$+",YT;PR"+STR$((-7*.007)*(XMAXINT-XMININT))+","+
     STR$((-.5* 01)*(YMAXINT-YMININT))+";PA;LB"+COEF$+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
1070 NEXT COEF%
1080 REM*************************************************************
1090 REM
1100 REM LABEL GRAPH FOR PLOTTING Cd
1110 REM
1120 REM*************************************************************
1130 WRT$="PU "+STR$(XMIN+(1.5/7.25)*(XMAX-XMIN))+","+STR$(YMAX+(.125/
     5)*(YMAX-YMIN))+";LBCoefficient of drag"+CHR$(3):CALL IBWRT%(BD%,
     WRT$)
1140 WRT$="LB  VS  Cylinder position"+CHR$(3):CALL IBWRT%(BD%,WRT$)
1150 WRT$=CHR$(3)+"PU "+STR$(XMIN-(.75/7.25)*(XMAX-XMIN))+","+STR$(YMAX-
     (1/5)*(YMAX-YMIN))+";LBCd"+CHR$(3):CALL IBWRT%(BD%,WRT$)
1160 WRT$="PU "+STR$(XMIN+(2/7.25)*(XMAX-XMIN))+","+STR$(YMIN-(.5/5)*
     (YMAX-YMIN))+";LBPosition"+CHR$(3):CALL IBWRT%(BD%,WRT$)
1170 WRT$="SI 0.15,0 3;":CALL IBWRT%(BD%,WRT$):REM SET SMALL CHARACTER
     SIZE FOR LINE LABELS
1180 REM*************************************************************
1190 REM
1200 REM LOAD DATA AND PLOT Cd FOR SPECIFIED EXPERIMENTS
1210 REM
1220 REM*************************************************************
1230 READ EXPERIMENT$,PENCOL$,LABEL$
1240 IF EXPERIMENT$="END" THEN 1580
1250 EXPNUM$=MID$(EXPERIMENT$,2)
1260 TYPE$=MID$(EXPERIMENT$,1,1)
1270 FILENAME$="B:CDCL"+TYPE$+"-"+EXPNUM$+".DAT"
1280 OPEN "I",#1,FILENAME$
1290 WRT$="SP"+PENCOL$+";":CALL IBWRT%(BD%,WRT$)
1300 INPUT #1,CD$
1310 WRT$="PU 1,"+CD$+";":CALL IBWRT%(BD%,WRT$)
1320 FOR PS%= 2 TO 12
1330 PS$=STR$(PS%)
1340 INPUT #1,CD$
1350 WRT$="PD "+PS$+","+CD$+";":CALL IBWRT%(BD%,WRT$)
1360 NEXT PS%
1370 CLOSE #1
1380 IF LABEL$="NON" THEN 1410
1390 WRT$="PU"+STR$(XLEGEND)+","+STR$(YLEGEND)+";PD"+STR$(XLEGEND+(.125/
     7 25)*(XMAX-XMIN))+","+STR$(YLEGEND)+";LB"+LABEL$+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
1400 YLEGEND=YLEGEND-(YMAX-YMIN)*(.17/5)
1410 IF LABEL$="NON" OR LABEL$="Static" THEN 1560
1420 XOFF=(.25/7 25)*(XMAX-XMIN)
1430 XOFF$=STR$(XOFF):XOFF2$=STR$(2*XOFF)
1440 YOFF=(.25/5)*(YMAX-YMIN)
```

```
1450 YOFF$=STR$(YOFF):YOFF2$=STR$(2*YOFF)
1460 FILENAME$="B:PRED-"+EXPNUM$+".DAT"
1470 OPEN"I",#1,FILENAME$
1480 FOR PS%=1 TO 12
1490   PS$=STR$(PS%)
1500   INPUT#1,CD$
1510   WRT$="PU"+PS$+","+CD$+";LBx"+CHR$(3):CALL IBWRT%(BD%,WRT$)
1520   REM WRT$="PU"+PS$+","+CD$+";PR;PU-"+XOFF$+","+YOFF$+";PD"+XOFF2$+
       ",-"+YOFF2$+";":CALL IBWRT%(BD%,WRT$)
1530   REM WRT$="PU 0,"+YOFF2$+";PD -"+XOFF2$+",-"+YOFF2$+";PA;":CALL
       IBWRT%(BD%,WRT$)
1540 NEXT PS%
1550 CLOSE #1
1560 WRT$="SP0;":CALL IBWRT%(BD%,WRT$)
1570 GOTO 1230
1580 REM***************************************************************
1590 REM
1600 REM DRAW AXIS FOR PLOTTING COEFFICIENT OF LIFT
1610 REM
1620 REM***************************************************************
1630 RESTORE
1640 PRINT" ':INPUT"Insert new page for the Cl graph, and press ENTER";
     A$
1650 REM
1660 REM
1670 REM
1680 XMIN=1:XMAX=12:REM NVER CHANGES, THESE ARE THE POSTIONS OF THE
     CYLINDER
1690 YMIN=-1.3:YMAX=.3:REM ADJUST TO SUIT GRAPH
1700 REM
1710 REM
1720 REM
1730 IF XMIN<0 THEN XMININT=INT(XMIN-1) ELSE XMININT=INT(XMIN)
1740 IF XMAX<0 THEN XMAXINT=INT(XMAX) ELSE XMAXINT=INT(XMAX+1)
1750 IF YMIN<0 THEN YMININT=INT(YMIN-1) ELSE YMININT=INT(YMIN)
1760 IF YMAX<0 THEN YMAXINT=INT(YMAX) ELSE YMAXINT=INT(YMAX+1)
1770 P1Y%=INT(((2-.25)-5*(YMIN-YMININT)/(YMAX-YMIN))*1016)
1780 P2Y%=P1Y%+INT(((YMAXINT-YMININT)*5/(YMAX-YMIN))*1016)
1790 P1X%=INT(((2.25-.495)-7.25*(XMIN-XMININT)/(XMAX-XMIN))*1016)
1800 P2X%=P1X%+INT(((XMAXINT-XMININT)*7 25/(XMAX-XMIN))*1016)
1810 XLEGEND=XMIN-(1.4/7.25)*(XMAX-XMIN)
1820 YLEGEND=YMIN+(2/5)*(YMAX-YMIX)
1830 WRT$="IN;IP "+STR$(P1X%)+","+STR$(P1Y%)+","+STR$(P2X%)+","+STR$
     (P2Y%)+";":CALL IBWRT%(BD%,WRT$)
1840 WRT$="SC "+STR$(XMININT)+","+STR$(XMAXINT)+","+STR$(YMININT)+","+
     STR$(YMAXINT)+";SP1;PU "+STR$(XMIN)+","+STR$(YMIN)+";":CALL IBWRT%
     (BD%,WRT$)
1850 WRT$="PD"+STR$(XMAX)+","+STR$(YMIN)+","+STR$(XMAX)+","+STR$(YMAX)+
     " '+STR$(XMIN)+","+STR$(YMAX)+","+STR$(XMIN)+","+STR$(YMIN)+";":
     CALL IBWRT%(BD%,WRT$)
1860 REM NEXT 5 LINES LABEL THE X AXIS DIVISIONS, THIS NEVER CHANGES AND
     IS WRITTEN IN TERMS OF VARIABLES WHICH DO NOT CHANGE WHEN YOU
     CHANGE XMIN, XMAX, YMIN, YMAX (THESE 5 LINES WILL BE INCORRECT IF
     YOU CHANGE XMIN, XMAX)
```

```
1870 REM IN ORDER FOR THE NEXT 5 LINES TO BE CORRECT XMIN=1, XMAX=12,
     YMIN<0, YMAX>0
1880      WRT$="PU 1,0;PD 12,0;SI 0.14,0.5;":CALL IBWRT%(BD%,WRT$)
1890      FOR PS%=2 TO 12
1900      PS$=STR$(PS%)
1910      WRT$="PU"+PS$+",0;XT;PR-0.24,"+STR$((-2!*.01)*(YMAXINT-
          YMININT))+";PA;LB"+PS$+CHR$(3):CALL IBWRT%(BD%,WRT$)
1920      NEXT PS%
1930 REM THE NEXT PIECE OF CODE LABELS THE DIVISIONS ON THE Y AXIS. THIS
     PART OF THE PROGRAM IS WRITTEN SO THAT IT ADJUSTS TO CHANGING YMIN
     & YMAX
1940 RANGE=YMAX-YMIN
1950 IF RANGE=>5 THEN INTER=1:GOTO 2030
1960 IF RANGE=>2.5 THEN INTER=.5:GOTO 2030
1970 IF RANGE=>1 THEN INTER=.25:GOTO 2030
1980 IF RANGE=>.5 THEN INTER=.1:GOTO 2030
1990 IF RANGE=>.25 THEN INTER=.05:GOTO 2030
2000 IF RANGE=>.1 THEN INTER 0.025:GOTO 2030
2010 IF RANGE=>.05 THEN INTER=.01:GOTO 2030
2020 PRINT"YMAX-YMIN=RANGE=";RANGE;" CAN NOT BE HANDLED BY THIS PROGRAM
     . PLEASE CORRECT.":STOP
2030 REM
2040 FOR COEF%=0 TO YMAX*100 STEP INTER*100
2050 COEF$=STR$(COEF%/100)
2060 WRT$="PU 1,"+COEF$+";YT;PR"+STR$((-7*.007)*(XMAXINT-XMININT))+","+
     STR$((-.5*.01)*(YMAXINT-YMININT))+";PA;":CALL IBWRT%(BD%,WRT$)
2070 WRT$="LB"+COEF$+CHR$(3):CALL IBWRT%(BD%,WRT$)
2080 NEXT COEF%
2090 FOR COEF%=-INTER*100 TO YMIN*100 STEP -INTER*100
2100 COEF$=STR$(COEF%/100)
2110 WRT$="PU 1,"+COEF$+";YT;PR"+STR$((-7*.007)*(XMAXINT-XMININT))+","+
     STR$((-.5*.01)*(YMAXINT-YMININT))+";PA;LB"+COEF$+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
2120 NEXT COEF%
2130 REM***************************************************************
2140 REM
2150 REM LABEL GRAPH FOR PLOTTING C1
2160 REM
2170 REM***************************************************************
2180 WRT$="PU "+STR$(XMIN+(1.5/7.25)*(XMAX-XMIN))+","+STR$(YMAX+(.125/
     5)*(YMAX-YMIN))+";":CALL IBWRT%(BD%,WRT$)
2190 WRT$="LBCoefficient of lift"+CHR$(3):CALL IBWRT%(BD%,WRT$)
2200 WRT$="LB  VS  Cylinder position"+CHR$(3):CALL IBWRT%(BD%,WRT$)
2210 WRT$=CHR$(3)+"PU "+STR$(XMIN-(.75/7.25)*(XMAX-XMIN))+","+STR$
     (.0001*INT(10000*(YMAX-(1/5)*(YMAX-YMIN))))+";LBC1"+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
2220 WRT$="PU "+STR$(XMIN+(2/7.25)*(XMAX-XMIN))+","+STR$(YMIN-(.5/5)*
     (YMAX-YMIN))+";LBPosition"+CHR$(3):CALL IBWRT%(BD%,WRT$)
2230 WRT$="SI 0.15,0.3;":CALL IBWRT%(BD%,WRT$)
2240 REM***************************************************************
2250 REM
2260 REM LOAD DATA AND PLOT C1 FOR SPECIFIED EXPERIMENTS
2270 REM
2280 REM***************************************************************
```

```
2290 READ EXPERIMENT$,PENCOL$,LABEL$
2300 IF EXPERIMENT$="END" THEN END
2310 EXPNUM$=MID$(EXPERIMENT$,2)
2320 TYPE$=MID$(EXPERIMENT$,1,1)
2330 FILENAME$="B:CDCL"+TYPE$+"-"+EXPNUM$+".DAT"
2340 OPEN "I",#1,FILENAME$
2350 FOR PS%=1 TO 12:INPUT #1,CL$:NEXT PS%
2360 WRT$="SP"+PENCOL$+";":CALL IBWRT%(BD%,WRT$)
2370 INPUT #1,CL$
2380 WRT$="PU 1,"+CL$+";":CALL IBWRT%(BD%,WRT$)
2390 FOR PS%= 2 TO 12
2400 PS$=STR$(PS%)
2410 INPUT #1,CL$
2420 WRT$="PD "+PS$+","+CL$+";":CALL IBWRT%(BD%,WRT$)
2430 NEXT PS%
2440 CLOSE #1
2450 IF LABEL$="NON" THEN 2480
2460 WRT$="PU"+STR$(XLEGEND)+","+STR$(YLEGEND)+";PD"+STR$(XLEGEND+(.125/
     7.25)*(XMAX-XMIN))+","+STR$(YLEGEND)+";LB"+LABEL$+CHR$(3):CALL
     IBWRT%(BD%,WRT$)
2470 YLEGEND=YLEGEND-(YMAX-YMIN)*(.17/5)
2480 IF LABEL$="NON" OR LABEL$="Static" THEN 2570
2490 FILENAME$="B:PRED-"+EXPNUM$+".DAT"
2500 OPEN "I",#1,FILENAME$
2505 FOR PS%=1 TO 12:INPUT #1,CD:NEXT PS%
2510 FOR PS%=1 TO 12
2520   PS$=STR$(PS%)
2530   INPUT #1,CL$
2540   WRT$="PU"+PS$+","+CL$+";LBx"+CHR$(3):CALL IBWRT%(BD%,WRT$)
2550 NEXT PS%
2560 CLOSE #1
2570 WRT$="SP0;":CALL IBWRT%(BD%,WRT$)
2580 GOTO 2290
2590 REM*************************************************************
2600 REM
2610 REM DATA
2620 REM
2630 REM*************************************************************
2640 DATA S3,1,Static
2650 DATA S4,1,NON
2660 DATA D9,2,U/fd=250
2670 DATA D4,3,U/fd=131
2680 DATA D5,3,NON
2690 DATA D6,4,U/fd=44
2700 DATA D7,5,U/fd=22
2710 DATA D8,6,U/fd=15
2720 DATA END,END,END
```

HP2PC V6.BAS

```
10 REM HP2PC_V6.BAS
20 REM (C) DECEMBER 22, 1986 PIOTR W. SYCHTERZ
```

```
30 REM McGILL UNIVERSITY, MONTREAL
40 REM*****************************************************************
50 REM
52 REM
53 REM INITIALIZE THE GPIB-PC SOFTWARE IN THIS PROGRAM
54 REM
55 REM
56 REM*****************************************************************
60 REM RESERVE MEMORY ABOVE 60650 FOR GPIB-PC SUBROUTINE CALLED IBINIT
70       CLEAR   ,60650!
80       IBINIT = 60650!
90 REM LOAD SUBROUTINE IBINIT FROM FILE BIB.M ON DRIVE A
100      BLOAD "A:BIB.M",IBINIT
110      IBSTA%=0:IBERR%=0:IBCNT%=0
120      CALL IBINIT (IBRD%,IBWRT%,IBCMD%,IBWAIT%,IBRPP%,IBONL%,IBRSC%,
         IBSIC%,IBSRE%,IBRTL%,IBRSV%,IBLPE%,IBPAD%,IBSAD%,IBIST%,IBDMA%,
         IBEOS%,IBTMO%,IBEOT%,IBGTS%,IBCAC%,IBDIAG%,IBSTA%,IBERR%,
         IBCNT%)
130 REM
140 REM BD% DENOTES THE GPIB-PC BOARD NUMBER IN SUBROUTINE CALLS
150 REM BD%=0 BECAUSE THERE IS ONLY ONE BOARD
160 BD%=0
165 REM*****************************************************************
170 REM
172 REM
180 REM PRINT INTRODUCTION ON SCREEN
182 REM
184 REM
185 REM*****************************************************************
190 CLS:PRINT"     This program transfers files between the HP5420A and
    the IBM-PC."
200 LOCATE 3,1:PRINT"     The hardware necessary for this data transfer
    includes;"
210 LOCATE 4,10:PRINT"IBM-PC"
220 LOCATE 5,10:PRINT"GPIB-PC interface & software supplied with it"
230 LOCATE 6,10:PRINT"HP5420A data anlyzer"
240 LOCATE 7,10:PRINT"HP data tape #98200A"
250 LOCATE 8,10:PRINT"5 1/2 diskette"
260 LOCATE 20,10:PRINT"(C) SEPTEMBER 1986, PIOTR SYCHTERZ, McGILL
    UNIVERSITY, MONTREAL"
270 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
280 REM PRINT INSTRUCTIONS
290 CLS:PRINT"     To run the program the following steps must be
    taken;"
300 PRINT TAB(10)"Set HP5420A data analyzer to ADDRESSABLE with switch
    S3 on back panel"
310 PRINT TAB(10)"Conect the GPIB-PC interface cable to HP-IB10920A
    interface on HP5420A"
320 PRINT TAB(10)"Power up the HP5420A"
330 PRINT TAB(10)"Insert an HP data tape into the HP5420A"
340 PRINT TAB(10)"Boot IBM-PC with the GPIB-PC system disk in drive A"
350 PRINT TAB(10)"Enter the basic editor, load & run HP2PC.BAS"
360 PRINT TAB(10)"Insert the data diskette in drive B"
370 LOCATE 11,1:PRINT"NOTE: You may want to write-protect the diskette
```

```
   or tape if you will not      transfer data to it.  This will
   prevent accidental errasure."
380 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
400 REM*****************************************************************
402 REM
404 REM
406 REM CHOOSE AUTOMATIC OR MANUAL TRANSFER
408 REM
410 REM
412 REM*****************************************************************
500 HEAD$="1  Transfer data block & header in ASCII, remove quotes &
    spaces and save it as        single precision number converted to
    string using MKS$."
610 CLS:PRINT HEAD$:INPUT "AUTOMATIC OR MANUAL TRANSFER  A/M";AUT$
615 INPUT"Press the VIEW button on the HP until the data screen is
    shown.                  Then press   ENTER   on the IBM-PC.";A$
620 IF AUT$="A" OR AUT$="a" OR AUT$="M" OR AUT$="m" THEN 630 ELSE 610
630 IF AUT$="M" OR AUT$="m" THEN 760 ELSE 640
632 REM*****************************************************************
633 REM
634 REM
635 REM AUTOMATIC TRANSFER
636 REM
637 REM
638 REM*****************************************************************
640 PRINT"The last line of the program should contain a data statement
    listing the records to be transfered.  The data statements in the
    program should refer only to the files which will be transfered."
650 INPUT"Is this condition satisfied y/n";BA$
660 IF BA$="Y" OR BA$="y" THEN 670 ELSE STOP
670 INPUT "Insert data disk in drive B and data tape in HP. READY? Y/N";
    BA$
680 IF BA$="N" OR BA$="n" THEN 670
690 IF BA$="Y" OR BA$="y" THEN 700 ELSE 670
700 INPUT "Data tape #";TAPENO$
710 READ RECORDNO$
720 IF RECORDNO$="END" THEN STOP
730 RECORD$="B:REC"+RECORDNO$+".T"+TAPENO$
740 PRINT "TRANSFERING ...";RECORD$
750 GOTO 960
752 REM*****************************************************************
753 REM
754 REM
755 REM MANUAL TRANSFER
756 REM
757 REM
758 REM*****************************************************************
760 CLS:PRINT HEAD$
770 LOCATE 3,1:INPUT"HP tape #";TAPENO$
780 INPUT"Data record #";RECORDNO$
790 RECORD$="B:REC"+RECORDNO$+".T"+TAPENO$
800 LOCATE 6,1:PRINT"Data block & header from: tape #";TAPENO$
810 PRINT TAB(25)"record #";RECORDNO$
820 LOCATE 9,1:PRINT"will be saved on disk in drive B in the file ";
```

```
    RECORD$
830 LOCATE 11,1:PRINT"Do you wish to change the file name (Y/N)"
840 A$=INKEY$:IF A$="" THEN 840
850 IF A$="N" OR A$="n" OR A$="Y" OR A$="y" THEN GOTO 860 ELSE GOTO 840
860 IF A$="Y" OR A$="y" THEN GOSUB 1930
870 REM GO ON WITH THE TRANSFER PROCEDURE
880 CLS:PRINT HEAD$
890 LOCATE 3,1:PRINT"From tape #";TAPENO$
900 PRINT"   record #";RECORDNO$
910 LOCATE 7,1:PRINT"To drive B, file ";RECORD$
920 LOCATE 9,1:PRINT"Insert proper tape & diskette.  Abort or continue
    (A/C)"
930 A$=INKEY$:IF A$="" THEN GOTO 930
940 IF A$="A" OR A$="a" OR A$="C" OR A$="c" THEN 950 ELSE 930
950 IF A$="A" OR A$="a" THEN 480
952 REM************************************************************
953 REM
954 REM
955 REM LOAD DATA INTO HP FROM TAPE&INITIATE TRANSFER PROCEDURE FROM HP
    TO PC
956 REM
957 REM
958 REM**************************************************************
960 REM PUT GPIB-PC ON LINE
970 V%=1:CALL IBONL%(BD%,V%)
980 IF IBSTA%<0 THEN PERROR%=1:GOTO 2090:REM ERROR HAS OCCURED
990 REM MAKE GPIB-PC ACTIVE SYSTEM CONTROLLER
1000 CALL IBSIC%(BD%)
1010 IF IBSTA%<0 THEN PERROR%=2:GOTO 2090:REM ERROR HAS OCCURED
1020 REM ASSERT REN (REMOTE ENABLE) TO PUT HP5420A IN REMOTE CONTROL
1030 V%=1:CALL IBSRE%(BD%,V%)
1040 IF IBSTA%<0 THEN PERROR%=3:GOTO 2090:REM ERROR HAS OCCURED
1050 REM ADDRESS GPIB-PC TO TALK "@"
1060 REM ADDRESS HP5420A TO LISTEN "$"
1070 CMD$="$@":CALL IBCMD%(BD%,CMD$)
1080 IF IBSTA%<0 THEN PERROR%=4:GOTO 2090:REM ERROR HAS OCCURED
1090 REM INSTRUCT HP5420A TO LOAD DATA RECORD FROM TAPE
1100 WRT$=RECORDNO$+"RA"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1110 IF IBSTA%<0 THEN PERROR=5:GOTO 2090:REM ERROR HAS OCCURED
1120 REM INITIATE SAVE TO IBM-PC OF DATA BLOCK & HEADER IN ASCII
1130 WRT$="501SA"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1140 IF IBSTA%<0 THEN PERROR%=6:GOTO 2090:REM ERROR HAS OCCURED
1150 A%=IBSTA% AND 4096
1160 IF A%=4096 THEN 1180 ELSE 1170
1170 PRINT"ERROR: NO SRQ PRESENT AFTER 501 SAVE INSTRUCTION":STOP
1180 REM RESET FLAG2=0 TO SHOW THAT HP5420A HAS NOT YET TRIED TO SEND
     DATA & HEADER IN ASCII
1190 FLAG2=0
1195 REM************************************************************
1196 REM
1197 REM
1200 REM DO SERIAL POLL
1201 REM
1202 REM
```

```
1203 REM*****************************************************************
1210 REM UNADDRESS LISTENER & TALKER, SEND SPE (SERIAL POLL ENABLE,
     OCTAL 30)
1220 REM ADDERSS GPIB-PC TO LISTEN " "
1230 REM ADDRESS HP5420A TO TALK "D"
1240 CMD$="?_"+CHR$(24)+"D ":CALL IBCMD%(BD%,CMD$)
1250 REM READ STATUS BYTE FROM HP5420A
1260 RD$=SPACE$(1):CALL IBRD%(BD%,RD$)
1270 PRINT"STATUS BYTE:";RD$
1280 REM IF RD$=" "AND FLAG2=1 THEN THERE ARE NO SRQ LEFT & WE HAVE
     FINISHE
1290 REM IF RD$=" " AND FLAG2=0 THEN THE HP5420A IS NOT TRYING TO
     TRANSMIT DATA AND HEADER THEREFORE THERE IS AN ERROR
1300 IF RD$=" " AND FLAG2=1 THEN 1340
1310 IF RD$=" " AND FLAG2=0 THEN PRINT"ERROR: HP5420A IS NOT TRYING TO
     SEND DATA & HEADER IN ASCII AFTER 501 SAVE":STOP
1320 IF RD$=CHR$(96) THEN FLAG2=1
1322 CMD$=CHR$(25):CALL IBCMD%(BD%,CMD$)
1325 GOTO 1240
1330 REM SEND SPD (SERIAL POLL DISABLE,OCTAL 31)
1340 CMD$=CHR$(25):CALL IBCMD%(BD%,CMD$)
1350 REM DO WAIT FOR SRQ OR TMO (20480 MASK)
1380 MASK%=20480:CALL IBWAIT%(BD%,MASK%)
1390 REM CHECK IF THERE ARE ANY SRQ LEFT
1400 A%=IBSTA% AND 4096:IF A%=4096 THEN 1240 ELSE 1490
1420 REM ***END OF SERIAL POLL***
1430 REM ****************************************************
1432 REM
1434 REM
1435 REM TRANSFER DATA FROM HP TO PC
1436 REM
1437 REM
1438 REM*****************************************************************
1440 REM HP5420A IS READY TO SEND DATA & HEADER IN ASCII FORMAT
1450 REM FIRST MUST READ 16 WORDS OF 16 BITS EACH IN ASCII
1460 REM THESE CHARACTERS WILL BE SAVED TO FILE RECORD$ IN DRIVE B:
1470 REM WORD#3 / 2  IS THE NUMBER OF VARIBLES SENT IN THE DATA BLOCK
1480 REM OPEN FILES RECORD$ ON DRIVE B
1490 OPEN "R",#1,RECORD$,4
1500 FIELD #1,4 AS RDS$
1510 REM UNADDRESS LISTENER & TALKER AND
1520 REM ADDRESS GPIB-PC TO LISTEN " "
1530 REM ADDRESS HP5420A TO TALK "D"
1540 CMD$="?_D ":CALL IBCMD%(BD%,CMD$)
1550 FOR I%=1 TO 16
1560 RD$=SPACE$(16):CALL IBRD%(BD%,RD$)
1570 REM DECODE WORD INTO A NUMBER
1580 RD$=LEFT$(RD$,14):REM TAKE THE FIRST 14 CHAR., DROP THE LAST TWO
     (CR & LF)
1590 REM THE WORD IS IN THE FORM BBB1.024000EB3 CR LF
1600 RD=VAL(RD$)
1610 IF I%=3 THEN II%=RD/2
1620 LSET RDS$=MKS$(RD)
1630 PUT #1
```

```
1640 NEXT I%
1650 REM READ DATA FROM HP5420A AND SAVE IT TO FILE #1 (RECORD$)
1660 REM NUMBER OF VARIABLES READ IS II%
1670 FOR COUNT%=1 TO II%
1680 RD$=SPACE$(16):CALL IBRD%(BD%,RD$)
1690 RD$=LEFT$(RD$,14):RD=VAL(RD$)
1700 LSET RDS$=MKS$(RD)
1710 PUT #1
1720 NEXT COUNT%
1730 CLOSE #1
1740 REM FINISHED TRANSFER OF DATA & HEADER IN ASCII FROM SPECIFIED
     RECORD
1750 REM RETURN TO MENUE FOR SAVE TO IBM-PC DATA BLOCK & HEADER IN
     ASCII
1760 IF AUT$="M" OR AUT$="m" THEN 760
1770 IF AUT$="A" OR AUT$="a" THEN 710
1910 REM***********************************************************
1911 REM***********************************************************
1912 REM***********************************************************
1913 REM
1920 REM
1930 REM SUBROUTINE TO ENTER NEW FILE NAME AND CHECK IF IT IS A GOOD
     FILE NAME
1932 REM
1933 REM
1934 REM***********************************************************
1940 PRINT"Enter new file name including extension but not including
     the drive descriptor"
1950 INPUT"New file name   ";RECORD$
1960 AAA%=LEN(RECORD$)
1970 IF AAA%>11 THEN PRINT"New file name is too long":GOTO 1940
1980 IF AAA%=0 THEN GOTO 1940
1990 FLAG1=0:REM FLAG1 IS 0 IF NO EXTENSION FOUND
2000 FOR I%=1 TO AAA%
2010 A$=MID$(RECORD$,I%,1)
2020 IF A$=":" THEN PRINT"Do not include drive descriptor <:>":
     GOTO 1940
2030 IF A$="." AND (AAA%-I%)=0 THEN PRINT"Extension is a null string":
     GOTO 1940
2040 IF A$="." AND (AAA%-I%)>3 THEN PRINT"Extension is too long":
     GOTO 1940
2050 IF A$="." THEN FLAG1=1
2060 NEXT I%
2070 IF FLAG1=0 THEN PRINT"You must include an extension with a <.>":
     GOTO 1940
2080 RETURN
2082 REM***********************************************************
2083 REM
2084 REM
2085 REM SUBROUTINE TO REPORT ERRORS
2086 REM
2087 REM
2088 REM***********************************************************
2090 REM ERROR REPORTING ROUTINE
```

```
2100 PRINT"at point PERROR=";PERROR%
2110 PRINT "An error has occured in the execution on GPIB-PC software"
2120 STOP
2124 REM*****************************************************************
2125 REM
2126 REM
2127 REM DATA
2128 REM
2129 REM
2130 REM*****************************************************************
2135 REM THE FOLOWING IS A LIST OF THE RECORDS TO BE TRANSFFRED FROM
     THE HP TO THE IBM-PC
2140 DATA 1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,
     25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,
     47,48,49,50,51,52,53,54,55,56,57,58,59,91,92,93,94,95,96,97,98,99,
     100,101,102,103,104,105,106,107,108
2150 DATA 109,110,111,112,113,114,115,116,117,118,119,120,END
```

VERI V6.BAS

```
10 REM VERI_V6.BAS
20 REM (C) DECEMBER 22, 1986 PIOTR W. SYCHTERZ
30 REM McGILL UNIVERSITY, MONTREAL
40 REM********************************************************************
50 REM
52 REM
53 REM INITIALIZE THE GPIB-PC SOFTWARE IN THIS PROGRAM
54 REM
55 REM
56 REM********************************************************************
60 REM RESERVE MEMORY ABOVE 60650 FOR GPIB-PC SUBROUTINE CALLED IBINIT
70        CLEAR   ,60650!
80        IBINIT = 60650!
90 REM LOAD SUBROUTINE IBINIT FROM FILE BIB.M ON DRIVE A
100       BLOAD "A:BIB.M",IBINIT
110       IBSTA%=0:IBERR%=0:IBCNT%=0
120       CALL IBINIT (IBRD%,IBWRT%,IBCMD%,IBWAIT%,IBRPP%,IBONL%,IBRSC%,
          IBSIC%,IBSRE%,IBRTL%,IBRSV%,IBLPE%,IBPAD%,IBSAD%,IBIST%,IBDMA%,
          IBEOS%,IBTMO%,IBEOT%,IBGTS%,IBCAC%,IBDIAG%,IBSTA%,IBERR%,
          IBCNT%)
130 REM
140 REM BD% DENOTES THE GPIB-PC BOARD NUMBER IN SUBROUTINE CALLS
150 REM BD%=0 BECAUSE THERE IS ONLY ONE BOARD
160 BD%=0
165 REM********************************************************************
170 REM
172 REM
180 REM PRINT INTRODUCTION ON SCREEN
182 REM
184 REM
185 REM********************************************************************
190 CLS:PRINT"     This program compares DATA files stored on HP5420A
```

```
    and the IBM-PC."
200 LOCATE 3,1:PRINT"     The hardware necessary for this data transfer
    includes;"
210 LOCATE 4,10:PRINT"IBM-PC"
220 LOCATE 5,10:PRINT"GPIB-PC interface & software supplied with it"
230 LOCATE 6,10:PRINT"HP5420A data anlyzer"
240 LOCATE 7,10:PRINT"HP data tape #98200A"
250 LOCATE 8,10:PRINT"5 1/2 diskette"
260 LOCATE 20,10:PRINT"(C) SEPTEMBER 1986, PIOTR SYCHTERZ, McGILL
    UNIVERSITY, MONTREAL"
270 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
280 REM PRINT INSTRUCTIONS
290 CLS:PRINT"     To run the program the following steps must be
    taken;"
300 PRINT TAB(10)"Set HP5420A data analyzer to ADDRESSABLE with switch
    S3 on back panel"
310 PRINT TAB(10)"Conect the GPIB-PC interface cable to HP-IB10920A
    interface on HP5420A"
320 PRINT TAB(10)"Power up the HP5420A"
330 PRINT TAB(10)"Insert an HP data tape into the HP5420A"
340 PRINT TAB(10)"Boot IBM-PC with the GPIB-PC system disk in drive A"
350 PRINT TAB(10)"Enter the basic editor, load & run VERI_V?.BAS
360 PRINT TAB(10)"Insert the data diskette in drive B"
370 LOCATE 11,1:PRINT"NOTE: You may want to write-protect the diskette
    or tape if you will not        transfer data to it.  This will
    prevent accidental errasure."
380 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
400 REM*************************************************************
402 REM
404 REM
406 REM CHOOSE AUTOMATIC OR MANUAL TRANSFER
408 REM
410 REM
412 REM*************************************************************
500 HEAD$="1   Compare DATA block & header in ASCII, stored on HP &
    IBM-PC in drive B:"
610 CLS:PRINT HEAD$:INPUT "AUTOMATIC OR MANUAL TRANSFER  A/M";AUT$
615 INPUT"Press the VIEW button on the HP until the data screen is
    shown.               Then press   ENTER   on the IBM-PC.";A$
620 IF AUT$="A" OR AUT$="a" OR AUT$="M" OR AUT$="m" THEN 630 ELSE 610
630 IF AUT$="M" OR AUT$="m" THEN 760 ELSE 640
632 REM*************************************************************
633 REM
634 REM
635 REM AUTOMATIC TRANSFER
636 REM
637 REM
638 REM*************************************************************
640 PRINT"The last line of the program should contain a data statement
    listing the records to be compared.  The data statements in the
    program should refer only to the files which will be compared."
650 INPUT"Is this condition satisfied y/n";BA$
660 IF BA$="Y" OR BA$="y" THEN 670 ELSE STOP
670 INPUT "Insert data disk in drive B and data tape in HP. READY? Y/N";
```

```
    BA$
680 IF BA$="N" OR BA$="n" THEN 670
690 IF BA$="Y" OR BA$="y" THEN 700 ELSE 670
700 INPUT "Data tape #";TAPENO$
710 READ RECORDNO$
720 IF RECORDNO$="END" THEN STOP
730 RECORD$="B:REC"+RECORDNO$+".T"+TAPENO$
740 PRINT "COMPARING...";RECORD$
750 GOTO 960
752 REM*****************************************************************
753 REM
754 REM
755 REM MANUAL TRANSFER
756 REM
757 REM
758 REM*****************************************************************
760 CLS:PRINT HEAD$
770 LOCATE 3,1:INPUT"HP tape #";TAPENO$
780 INPUT"Data record #";RECORDNO$
790 RECORD$="B:REC"+RECORDNO$+".T"+TAPENO$
800 LOCATE 6,1:PRINT"Data block & header from: tape #";TAPENO$
810 PRINT TAB(25)"record #";RECORDNO$
820 LOCATE 9,1:PRINT"will be compared to data on disk in drive B in the
    file ";RECORD$
830 LOCATE 11,1:PRINT"Do you wish to change the disk file name (Y/N)"
840 A$=INKEY$:IF A$="" THEN 840
850 IF A$="N" OR A$="n" OR A$="Y" OR A$="y" THEN GOTO 860 ELSE GOTO 840
860 IF A$="Y" OR A$="y" THEN GOSUB 1930
862 PRINT"Do you wish to change the tape set up # (Y/N)"
863 A$=INKEY$:IF A$="" THEN 863
864 IF A$="N" OR A$="n" OR A$="Y" OR A$="y" THEN 865 ELSE 862
865 IF A$="Y" OR A$="y" THEN 760
870 REM GO ON WITH THE TRANSFER PROCEDURE
880 CLS:PRINT HEAD$
890 LOCATE 3,1:PRINT"From tape #";TAPENO$
900 PRINT"    record #";RECORDNO$
910 LOCATE 7,1:PRINT"To drive B, file ";RECORD$
920 LOCATE 9,1:PRINT"Insert proper tape & diskette.  Abort or continue
    (A/C)"
930 A$=INKEY$:IF A$="" THEN GOTO 930
940 IF A$="A" OR A$="a" OR A$="C" OR A$="c" THEN 950 ELSE 930
950 IF A$="A" OR A$="a" THEN 480
952 REM*****************************************************************
953 REM
954 REM
955 REM LOAD DATA INTO HP FROM TAPE&INITIATE TRANSFER PROCEDURE FROM HP
    TO PC
956 REM
957 REM
958 REM*****************************************************************
960 REM PUT GPIB-PC ON LINE
970 V%=1:CALL IBONL%(BD%,V%)
980 IF IBSTA%<0 THEN PERROR%=1:GOTO 2090:REM ERROR HAS OCCURED
990 REM MAKE GPIB-PC ACTIVE SYSTEM CONTROLLER
```

```
1000 CALL IBSIC%(BD%)
1010 IF IBSTA%<0 THEN PERROR%=2:GOTO 2090:REM ERROR HAS OCCURED
1020 REM ASSERT REN (REMOTE ENABLE) TO PUT HP5420A IN REMOTE CONTROL
1030 V%=1:CALL IBSRE%(BD%,V%)
1040 IF IBSTA%<0 THEN PERROR%=3:GOTO 2090:REM ERROR HAS OCCURED
1050 REM ADDRESS GPIB-PC TO TALK "@"
1060 REM ADDRESS HP5420A TO LISTEN "$"
1070 CMD$="$@":CALL IBCMD%(BD%,CMD$)
1080 IF IBSTA%<0 THEN PERROR%=4:GOTO 2090:REM ERROR HAS OCCURED
1090 REM INSTRUCT HP5420A TO LOAD DATA RECORD FROM TAPE
1100 WRT$=RECORDNO$+"RA"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1110 IF IBSTA%<0 THEN PERROR=5:GOTO 2090:REM ERROR HAS OCCURED
1112 REM WAIT UNTIL HP SENDS SRQ (ASSUME THAT THE FIRST SRQ IS A
     NOTIFICATION OF END OF TAPE ACTION)
1114 MASK%=4096:CALL IBWAIT%(BD%,MASK%)
1120 REM INITIATE SAVE TO IBM-PC OF DATA BLOCK & HEADER IN ASCII
1130 WRT$="501SA"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1140 IF IBSTA%<0 THEN PERROR%=6:GOTO 2090:REM ERROR HAS OCCURED
1150 A%=IBSTA% AND 4096
1160 IF A%=4096 THEN 1180 ELSE 1170
1170 PRINT"ERROR: NO SRQ PRESENT AFTER 501 SAVE INSTRUCTION":STOP
1180 REM RESET FLAG2=0 TO SHOW THAT HP5420A HAS NOT YET TRIED TO SEND
     DATA & HEADER IN ASCII
1190 FLAG2=0
1195 REM*****************************************************************
1196 REM
1197 REM
1200 REM DO SERIAL POLL
1201 REM
1202 REM
1203 REM*****************************************************************
1210 REM UNADDRESS LISTENER & TALKER, SEND SPE (SERIAL POLL ENABLE,
     OCTAL 30)
1220 REM ADDERSS GPIB-PC TO LISTEN " "
1230 REM ADDRESS HP5420A TO TALK "D"
1240 CMD$="?_"+CHR$(24)+"D ":CALL IBCMD%(BD%,CMD$)
1250 REM READ STATUS BYTE FROM HP5420A
1260 RD$=SPACE$(1):CALL IBRD%(BD%,RD$)
1270 PRINT"STATUS BYTE:";RD$
1280 REM IF RD$=" "AND FLAG2=1 THEN THERE ARE NO SRQ LEFT & WE HAVE
     FINISHED
1290 REM IF RD$=" " AND FLAG2=0 THEN THE HP5420A IS NOT TRYING TO
     TRANSMIT DATA AND HEADER THEREFORE THERE IS AN ERROR
1300 IF RD$=" " AND FLAG2=1 THEN 1340
1310 IF RD$=" " AND FLAG2=0 THEN PRINT"ERROR: HP5420A IS NOT TRYING TO
     SEND DATA & HEADER IN ASCII AFTER 501 SAVE":STOP
1320 IF RD$=CHR$(96) THEN FLAG2=1
1322 CMD$=CHR$(25):CALL IBCMD%(BD%,CMD$)
1325 GOTO 1240
1330 REM SEND SPD (SERIAL POLL DISABLE,OCTAL 31)
1340 CMD$=CHR$(25):CALL IBCMD%(BD%,CMD$)
1350 REM DO WAIT FOR SRQ OR TMO (20480 MASK)
1380 MASK%=20480:CALL IBWAIT%(BD%,MASK%)
1390 REM CHECK IF THERE ARE ANY SRQ LEFT
```

```
1400 A%=IBSTA% AND 4096:IF A%=4096 THEN 1240 ELSE 1490
1420 REM ***END OF SERIAL POLL***
1430 REM **************************************************
1432 REM
1434 REM
1435 REM TRANSFER DATA FROM HP TO PC THEN COMPARE TO DATA STORED ON DISK
1436 REM
1437 REM
1438 REM************************************************************
1440 REM HP5420A IS READY TO SEND DATA & HEADER IN ASCII FORMAT
1450 REM FIRST MUST READ 16 WORDS OF 16 BITS EACH IN ASCII
1460 REM THESE CHARACTERS WILL BE SAVED TO FILE RECORD$ IN DRIVE B:
1470 REM WORD#3 / 2  IS THE NUMBER OF VARIBLES SENT IN THE DATA BLOCK
1480 REM OPEN FILES RECORD$ ON DRIVE B
1490 OPEN "R",#1,RECORD$,4
1500 FIELD #1,4 AS RDS$
1510 REM UNADDRESS LISTENER & TALKER AND
1520 REM ADDRESS GPIB-PC TO LISTEN " "
1530 REM ADDRESS HP5420A TO TALK "D"
1540 CMD$="?_D ":CALL IBCMD%(BD%,CMD$)
1550 FOR I%=1 TO 16
1560 RD$=SPACE$(16):CALL IBRD%(BD%,RD$)
1570 REM DECODE WORD INTO A NUMBER
1580 RD$=LEFT$(RD$,14) REM TAKE THE FIRST 14 CHAR., DROP THE LAST TWO
     (CR & LF)
1590 REM THE WORD IS IN THE FORM BBB1.024000EB3 CR LF
1600 RD=VAL(RD$)
1610 IF I%=3 THEN II%=RD/2
1620 GET #1
1624 RDN=CVS(RDS$)
1626 IF RDN<> RD THEN PRINT "In the header item #";I%;" differs RDN=";
     RDN;"  RD=";RD:BEEP:INPUT "CONTINUE";A$
1640 NEXT I%
1650 REM READ DATA FROM HP5420A AND SAVE IT TO FILE #1 (RECORD$)
1660 REM NUMBER OF VARIABLES READ IS II%
1670 FOR COUNT%=1 TO II%
1680 RD$=SPACE$(16):CALL IBRD%(BD%,RD$)
1690 RD$=LEFT$(RD$,14):RD=VAL(RD$)
1700 GET #1
1704 RDN=CVS(RDS$)
1708 IF RDN<>RD THEN PRINT "In the data item #";II%;" differs RDN=";
     RDN;"  RD=";RD:BEEP:INPUT"CONTINUE";A$
1720 NEXT COUNT%
1730 CLOSE #1
1740 REM FINISHED COMPARING DATA & HEADER FROM SPECIFIED RECORD WITH
     DATA SAVED ON DISK WITH THAT RECORD NUMBER
1750 PRINT "Record #";RECORDNO$;" from tape #";TAPENO$;" is saved
     correctly in"
1755 PRINT "file  ";RECORD$
1756 IF AUT$="A" OR AUT$="a" THEN 1760
1757 INPUT"Press  ENTER  to go on";A$
1760 IF AUT$="M" OR AUT$="m" THEN 760
1770 IF AUT$="A" OR AUT$="a" THEN 710
1910 REM************************************************************
```

```
1911 REM*******************************************************************
1912 REM*******************************************************************
1913 REM
1920 REM
1930 REM SUBROUTINE TO ENTER NEW FILE NAME AND CHECK IF IT IS A GOOD
     FILE NAME
1932 REM
1933 REM
1934 REM*******************************************************************
1940 PRINT"Enter new file name including extension but not including
     the drive descriptor"
1950 INPUT"New file name   ";RECORD$
1960 AAA%=LEN(RECORD$)
1970 IF AAA%>11 THEN PRINT"New file name is too long":GOTO 1940
1980 IF AAA%=0 THEN GOTO 1940
1990 FLAG1=0:REM FLAG1 IS 0 IF NO EXTENSION FOUND
2000 FOR I%=1 TO AAA%
2010 A$=MID$(RECORD$,I%,1)
2020 IF A$=":" THEN PRINT"Do not include drive descriptor <:>":
     GOTO 1940
2030 IF A$="." AND (AAA%-I%)=0 THEN PRINT"Extension is a null string":
     GOTO 1940
2040 IF A$="." AND (AAA%-I%)>3 THEN PRINT"Extension is too long":
     GOTO 1940
2050 IF A$="." THEN FLAG1=1
2060 NEXT I%
2070 IF FLAG1=0 THEN PRINT"You must include an extension with a <.>":
     GOTO 1940
2080 RETURN
2082 REM*******************************************************************
2083 REM
2084 REM
2085 REM SUBROUTINE TO REPORT ERRORS
2086 REM
2087 REM
2088 REM******************************************************************
2090 REM ERROR REPORTING ROUTINE
2100 PRINT"at point PERROR=";PERROR%
2110 PRINT "An error has occured in the execution on GPIB-PC software"
2120 STOP
2124 REM*****************************************************************
2125 REM
2126 REM
2127 REM DATA
2128 REM
2129 REM
2130 REM*******************************************************************
2135 REM THE FOLOWING IS A LIST OF FILES TO BE COMPARED BETWEEN THE HP
     AND THE IBM-PC
2140 DATA 1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,
     25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,
     47,48,49,50,51,52,53,54,55,56,57,58,59,91,92,93,94,95,96,97,98,99,
     100,101,102,104,105,106,107,108,109
2150 DATA 110,111,112,113,114,115,116,117,118,119,120,END
```

PC2HP V6.BAS

```
10 REM PC2HP_V6.BAS
20 REM (C) DECEMBER 22, 1986 PIOTR W. SYCHTERZ
30 REM McGILL UNIVERSITY, MONTREAL
40 REM******************************************************************
50 REM
52 REM
53 REM INITIALIZE THE GPIB-PC SOFTWARE IN THIS PROGRAM
54 REM
55 REM
56 REM******************************************************************
60 REM RESERVE MEMORY ABOVE 60650 FOR GPIB-PC SUBROUTINE CALLED IBINIT
70      CLEAR   ,60650!
80      IBINIT = 60650!
90 REM LOAD SUBROUTINE IBINIT FROM FILE BIB.M ON DRIVE A
100     BLOAD "A:BIB.M",IBINIT
110     IBSTA%=0:IBERR%=0:IBCNT%=0
120     CALL IBINIT (IBRD%,IBWRT%,IBCMD%,IBWAIT%,IBRPP%,IBONL%,IBRSC%,
        IBSIC%,IBSRE%,IBRTL%,IBRSV%,IBLPE%,IBPAD%,IBSAD%,IBIST%,IBDMA%,
        IBEOS%,IBTMO%,IBEOT%,IBGTS%,IBCAC%,IBDIAG%,IBSTA%,IBERR%,
        IBCNT%)
130 REM
140 REM BD% DENOTES THE GPIP-PC BOARD NUMBER IN SUBROUTINE CALLS
150 REM BD%=0 BECAUSE THERE IS ONLY ONE BOARD
160 BD%=0
165 REM******************************************************************
170 REM
172 REM
180 REM PRINT INTRODUCTION ON SCREEN
182 REM
184 REM
185 REM******************************************************************
190 CLS:PRINT"     This program transfers files between the HP5420A and
    the IBM-PC."
200 LOCATE 3,1:PRINT"     The hardware necessary for this data transfer
    includes;"
210 LOCATE 4,10:PRINT"IBM-PC"
220 LOCATE 5,10:PRINT"GPIB-PC interface & software supplied with it"
230 LOCATE 6,10:PRINT"HP5420A data anlyzer"
240 LOCATE 7,10:PRINT"HP data tape #98200A"
250 LOCATE 8,10:PRINT"5 1/2 diskette"
260 LOCATE 20,10:PRINT"(C) SEPTEMBER 1986, PIOTR SYCHTERZ, McGILL
    UNIVERSITY, MONTREAL"
270 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
280 REM PRINT INSTRUCTIONS
290 CLS:PRINT"     To run the program the following steps must be
    taken;"
300 PRINT TAB(10)"Set HP5420A data analyzer to ADDRESSABLE with switch
    S3 on back panel"
310 PRINT TAB(10)"Conect the GPIB-PC interface cable to HP-IB10920A
```

```
    interface on HP5420A"
320 PRINT TAB(10)"Power up the HP5420A"
330 PRINT TAB(10)"Insert an HP data tape into the HP5420A"
340 PRINT TAB(10)"Boot IBM-PC with the GPIB-PC system disk in drive A"
350 PRINT TAB(10)"Enter the basic editor, load & run PC2HP_V?.BAS"
360 PRINT TAB(10)"Insert the data diskette in drive B"
370 LOCATE 11,1:PRINT"NOTE: You may want to write-protect the diskette
    or tape if you will not        transfer data to it.  This will
    prevent accidental errasure."
380 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
400 REM*****************************************************************
402 REM
404 REM
406 REM CHOOSE AUTOMATIC OR MANUAL TRANSFER
408 REM
410 REM
412 REM*****************************************************************
500 HEAD$="1 Transfer data block & header in ASCII, from IBM-PC to HP.
    Get data from file where the data is stored as 4byte strings (single
    presision)."
610 CLS:PRINT HEAD$:INPUT "AUTOMATIC OR MANUAL TRANSFER  A/M";AUT$
615 INPUT"Press the VIEW button on the HP until the data screen is
    shown.                  Then press   ENTER   on the IBM-PC.";A$
620 IF AUT$="A" OR AUT$="a" OR AUT$="M" OR AUT$="m" THEN 630 ELSE 610
630 IF AUT$="M" OR AUT$="m" THEN 760 ELSE 640
632 REM*****************************************************************
633 REM
634 REM
635 REM AUTOMATIC TRANSFER
636 REM
637 REM
638 REM*****************************************************************
640 PRINT"The last line of the program should contain a data statement
    listing the records to be transfered.  The data statements in the
    program should refer only to the files which will be transfered."
650 INPUT"Is this condition satisfied y/n";BA$
660 IF BA$="Y" OR BA$="y" THEN 670 ELSE STOP
670 INPUT "Insert data disk in drive B and data tape in HP. READY? Y/N";
    BA$
680 IF BA$="N" OR BA$="n" THEN 670
690 IF BA$="Y" OR BA$="y" THEN 700 ELSE 670
700 INPUT "Data tape #";TAPENO$
710 READ RECORDNO$
720 IF RECORDNO$="END" THEN STOP
730 RECORD$="B:REC"+RECORDNO$+".T"+TAPENO$
740 PRINT "TRANSFERING ...";RECORD$
750 GOTO 960
752 REM*****************************************************************
753 REM
754 REM
755 REM MANUAL TRANSFER
756 REM
757 REM
758 REM*****************************************************************
```

```
760 CLS:PRINT HEAD$
770 LOCATE 3,1:INPUT"HP tape #";TAPENO$
780 INPUT"Data record #";RECORDNO$
790 RECORD$="B:REC"+RECORDNO$+".T"+TAPENO$
800 LOCATE 6,1:PRINT"Data block & header to: tape #";TAPENO$
810 PRINT TAB(25)"record #";RECORDNO$
820 LOCATE 9,1:PRINT"will come from disk in drive B in the file ";
    RECORD$
830 LOCATE 11,1:PRINT"Do you wish to change the file name (Y/N)"
840 A$=INKEY$:IF A$="' THEN 840
850 IF A$="N" OR A$="n" OR A$="Y" OR A$="y" THEN GOTO 860 ELSE GOTO 840
860 IF A$="Y" OR A$="y" THEN GOSUB 1930
870 REM GO ON WITH THE TRANSFER PROCEDURE
880 CLS:PRINT HEAD$
890 LOCATE 3,1:PRINT"To tape #";TAPENO$
900 PRINT" record #";RECORDNO$
910 LOCATE 7,1:PRINT"To drive B, file ";RECORD$
920 LOCATE 9,1:PRINT"Insert proper tape & diskette.  Abort or continue
    (A/C)"
930 A$=INKEY$:IF A$="" THEN GOTO 930
940 IF A$="A" OR A$="a" OR A$="C" OR A$="c" THEN 950 ELSE 930
950 IF A$="A" OR A$="a" THEN 480
952 REM*****************************************************************
953 REM
954 REM
955 REM INITIATE TRANSFER PROCEDURE FROM PC TO HP
956 REM
957 REM
958 REM*****************************************************************
960 REM PUT GPIB-PC ON LINE
970 V%=1:CALL IBONL%(BD%,V%)
980 IF IBSTA%<0 THEN PERROR%=1:GOTO 2090:REM ERROR HAS OCCURED
990 REM MAKE GPIB-PC ACTIVE SYSTEM CONTROLLER
1000 CALL IBSIC%(BD%)
1010 IF IBSTA%<0 THEN PERROR%=2:GOTO 2090:REM ERROR HAS OCCURED
1020 REM ASSERT REN (REMOTE ENABLE) TO PUT HP5420A IN REMOTE CONTROL
1030 V%=1:CALL IBSRE%(BD%,V%)
1040 IF IBSTA%<0 THEN PERROR%=3:GOTO 2090:REM ERROR HAS OCCURED
1050 REM ADDRESS GPIB-PC TO TALK "@"
1060 REM ADDRESS HP5420A TO LISTEN "$"
1070 CMD$="$@":CALL IBCMD%(BD%,CMD$)
1080 IF IBSTA%<0 THEN PERROR%=4:GOTO 2090:REM ERROR HAS OCCURED
1120 REM INITIATE RECALL FROM IBM-PC OF DATA BLOCK & HEADER IN ASCII
1130 WRT$="501RA"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1135 REM WAIT TO GIVE HP A CHANCE TO SEND SRQ
1136 REM WAIT FOR SRQ OR TMO (20480 MASK)
1137 MASK%=20480:CALL IBWAIT%(BD%,MASK%)
1140 IF IBSTA%<0 THEN PERROR%=6:GOTO 2090:REM ERROR HAS OCCURED
1150 A%=IBSTA% AND 4096
1160 IF A%=4096 THEN 1180 ELSE 1170
1170 PRINT"ERROR: NO SRQ PRESENT AFTER 501 SAVE INSTRUCTION":STOP
1180 REM RESET FLAG2=0 TO SHOW THAT HP5420A HAS NOT YET TRIED TO RECEIVE
     DATA & HEADER IN ASCII
1190 FLAG2=0
```

```
1195 REM****************************************************************
1196 REM
1197 REM
1200 REM DO SERIAL POLL
1201 REM
1202 REM
1203 REM****************************************************************
1210 REM UNADDRESS LISTENER & TALKER, SEND SPE (SERIAL POLL ENABLE,
     OCTAL 30)
1220 REM ADDERSS GPIB-PC TO LISTEN " "
1230 REM ADDRESS HP5420A TO TALK "D"
1240 CMD$="?_"+CHR$(24)+"D ":CALL IBCMD%(BD%,CMD$)
1250 REM READ STATUS BYTE FROM HP5420A
1260 RD$=SPACE$(1):CALL IBRD%(BD%,RD$)
1270 PRINT"STATUS BYTE:";RD$
1280 REM IF RD$=" "AND FLAG2=1 THEN THERE ARE NO SRQ LEFT & WE HAVE
     FINISHE
1290 REM IF RD$=" " AND FLAG2=0 THEN THE HP5420A IS NOT TRYING TO
     TRANSMIT DATA AND HEADER THEREFORE THERE IS AN ERROR
1300 IF RD$=" " AND FLAG2=1 THEN 1340
1305 IF RD$="0" AND FLAG2=1 THEN 1340
1310 IF RD$=" " AND FLAG2=0 THEN PRINT"ERROR: HP5420A IS NOT TRYING TO
     SEND DATA & HEADER IN ASCII AFTER 501 SAVE":STOP
1320 IF RD$=CHR$(112) THEN FLAG2=1
1322 CMD$=CHR$(25):CALL IBCMD%(BD%,CMD$)
1325 GOTO 1240
1330 REM SEND SPD (SERIAL POLL DISABLE,OCTAL 31)
1340 CMD$=CHR$(25):CALL IBCMD%(BD%,CMD$)
1350 REM DO WAIT FOR SRQ OR TMO (20480 MASK)
1380 MASK%=20480:CALL IBWAIT%(BD%,MASK%)
1390 REM CHECK IF THERE ARE ANY SRQ LEFT
1400 A%=IBSTA% AND 4096:IF A%=4096 THEN 1240 ELSE 1490
1420 REM ***END OF SERIAL POLL***
1430 REM **************************************************
1432 REM
1434 REM
1435 REM TRANSFER DATA FROM PC TO HP
1436 REM
1437 REM
1438 REM****************************************************************
1440 REM HP5420A IS READY TO RECEIVE DATA & HEADER IN ASCII FORMAT
1450 REM FIRST MUST READ 16 WORDS OF 16 BITS EACH IN ASCII
1460 REM THESE CHARACTERS WILL COME FROM FILE RECORD$ IN DRIVE B:
1470 REM WORD#3 / 2  IS THE NUMBER OF VARIBLES SENT IN THE DATA BLOCK
1480 REM OPEN FILES RECORD$ ON DRIVE B
1490 OPEN "R",#1,RECORD$,4
1500 FIELD #1,4 AS RDS$
1510 REM UNADDRESS LISTENER & TALKER AND
1520 REM ADDRESS GPIB-PC TO TALK "@"
1530 REM ADDRESS HP5420A TO LISTEN "$"
1540 CMD$="?_$@":CALL IBCMD%(BD%,CMD$)
1545 REM RETURN ALL DEVICES TO LOCAL MODE
1547 V%=0:CALL IBSRE%(BD%,V%)
1550 FOR I%=1 TO 16
```

```
1560 GET #1
1565 RDS=CVS(RDS$)
1567 IF I%=3 THEN II%=RDS/2:REM THE THIRD/2=THE NUMBER OF DATA WORDS
     (16 BYTES) THAT WILL FOLOW THE 16 WORD HEADER
1570 RD$=STR$(RDS)+CHR$(13)+CHR$(10)
1580 IF LEN(RD$)>16 THEN PRINT"RD$ IS TOO LONG":STOP
1590 IF LEN(RD$)<16 THEN RD$=" "+RD$ :GOTO 1590
1600 WRT$=RD$:CALL IBWRT%(BD%,WRT$)
1640 NEXT I%
1650 REM READ DATA FROM DISK AND SAVE IT TO HP
1660 REM NUMBER OF VARIABLES READ IS II%
1670 FOR COUNT%=1 TO II%
1680 GET #1
1690 RDS=CVS(RDS$)
1700 RD$=STR$(RDS)+CHR$(13)+CHR$(10)
1710 IF LEN(RD$)>16 THEN PRINT"RD$ IS TOO LONG":STOP
1720 IF LEN(RD$)<16 THEN RD$=" "+RD$ :GOTO 1720
1725 WRT$=RD$:CALL IBWRT%(BD%,WRT$)
1727 NEXT COUNT%
1730 CLOSE #1
1740 REM FINISHED TRANSFER OF DATA & HEADER IN ASCII FROM SPECIFIED
     RECORD
1741 REM SAVE DATA TO HP DATA-TAPE
1742 WRT$=RECORDNO$+"SA"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1744 REM DO WAIT FOR SRQ  (MASK%=4096), THIS WILL BE THE END OF TAPE
     ACTION SRQ
1746 MASK%=4096:CALL IBWAIT%(BD%,MASK%)
1760 IF AUT$="M" OR AUT$="m" THEN 760
1770 IF AUT$="A" OR AUT$="a" THEN 710
1910 REM***************************************************************
1911 REM***************************************************************
1912 REM***************************************************************
1913 REM
1920 REM
1930 REM SUBROUTINE TO ENTER NEW FILE NAME AND CHECK IF IT IS A GOOD
     FILE NAME
1932 REM
1933 REM
1934 REM***************************************************************
1940 PRINT"Enter new file name including extension but not including
     the drive descriptor"
1950 INPUT"New file name   ";RECORD$
1960 AAA%=LEN(RECORD$)
1970 IF AAA%>11 THEN PRINT"New file name is too long":GOTO 1940
1980 IF AAA%=0 THEN GOTO 1940
1990 FLAG1=0:REM FLAG1 IS 0 IF NO EXTENSION FOUND
2000 FOR I%=1 TO AAA%
2010 A$=MID$(RECORD$,I%,1)
2020 IF A$=":" THEN PRINT"Do not include drive descriptor <:>":GOTO 1940
2030 IF A$="." AND (AAA%-I%)=0 THEN PRINT"Extension is a null string":
     GOTO 1940
2040 IF A$="." AND (AAA%-I%)>3 THEN PRINT"Extension is too long":
     GOTO 1940
2050 IF A$="." THEN FLAG1=1
```

```
2060 NEXT I%
2070 IF FLAG1=0 THEN PRINT"You must include an extension with a <.>":
     GOTO 1940
2080 RETURN
2082 REM*****************************************************************
2083 REM
2084 REM
2085 REM SUBROUTINE TO REPORT ERRORS
2086 REM
2087 REM
2088 REM*****************************************************************
2090 REM ERROR REPORTING ROUTINE
2100 PRINT"at point PERROR=";PERROR%
2110 PRINT "An error has occured in the execution on GPIB-PC software"
2120 STOP
2124 REM*****************************************************************
2125 REM
2126 REM
2127 REM DATA
2128 REM
2129 REM
2130 REM*****************************************************************
2135 REM THE FOLOWING IS A LIST OF FILES TO BE TRANSFERED FROM THE
     IBM-PC TO THE HP
2140 DATA 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,END
```

HP2PC V3.SET

```
10 REM HP2PC_V3.SET
20 REM (C) SEPTEMBER 1986 PIOTR W. SYCHTERZ
30 REM McGILL UNIVERSITY, MONTREAL
35 REM*******************************************************************
40 REM
50 REM
52 REM INITIALIZE THE GPIB-PC SOFTWARE IN THIS PROGRAM
53 REM
54 REM
55 REM*******************************************************************
60 REM RESERVE MEMORY ABOVE 60650 FOR GPIB-PC SUBROUTINE CALLED IBINIT
70       CLEAR   ,60650!
80       IBINIT = 60650!
90 REM LOAD SUBROUTINE IBINIT FROM FILE BIB.M ON DRIVE A
100      BLOAD "A:BIB.M",IBINIT
110      IBSTA%=0:IBERR%=0:IBCNT%=0
120      CALL IBINIT (IBRD%,IBWRT%,IBCMD%,IBWAIT%,IBRPP%,IBONL%,IBRSC%,
         IBSIC%,IBSRE%,IBRTL%,IBRSV%,IBLPE%,IBPAD%,IBSAD%,IBIST%,IBDMA%,
         IBEOS%,IBTMO%,IBEOT%,IBGTS%,IBCAC%,IBDIAG%,IBSTA%,IBERR%,
         IBCNT%)
130 REM
140 REM BD% DENOTES THE GPIB-PC BOARD NUMBER IN SUBROUTINE CALLS
150 REM BD%=0 BECAUSE THERE IS ONLY ONE BOARD
160 BD%=0
```

```
165 REM***************************************************************
170 REM
172 REM
180 REM PRINT INTRODUCTION ON SCREEN
182 REM
184 REM
186 REM***************************************************************
190 CLS:PRINT"     This program transfers SETUPS between the HP5420A and
    the IBM-PC."
200 LOCATE 3,1:PRINT"     The hardware necessary for this data transfer
    includes;"
210 LOCATE 4,10:PRINT"IBM-PC"
220 LOCATE 5,10:PRINT"GPIB-PC interface & software supplied with it"
230 LOCATE 6,10:PRINT"HP5420A data anlyzer"
240 LOCATE 7,10:PRINT"HP data tape #98200A"
250 LOCATE 8,10:PRINT"5 1/2 diskette"
260 LOCATE 20,10:PRINT"(C) SEPTEMBER 1986, PIOTR SYCHTERZ, McGILL
    UNIVERSITY, MONTREAL"
270 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
280 REM PRINT INSTRUCTIONS
290 CLS:PRINT"     To run the program the following steps must be
    taken;"
300 PRINT TAB(10)"Set HP5420A data analyzer to ADDRESSABLE with switch
    S3 on back panel"
310 PRINT TAB(10)"Conect the GPIB-PC interface cable to HP-IB10920A
    interface on HP5420A"
320 PRINT TAB(10)"Power up the HP5420A"
330 PRINT TAB(10)"Insert an HP data tape into the HP5420A"
340 PRINT TAB(10)"Boot IBM-PC with the GPIB-PC system disk in drive A"
350 PRINT TAB(10)"Enter the basic editor, load & run HP2PC_V?.SET
360 PRINT TAB(10)"Insert the data diskette in drive B"
370 LOCATE 11,1:PRINT"NOTE: You may want to write-protect the diskette
    or tape if you will not        transfer data to it.  This will
    prevent accidental errasure."
380 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
400 REM***************************************************************
402 REM
404 REM
406 REM CHOOSE AUTOMATIC OR MANUAL TRANSFER
408 REM
410 REM
412 REM***************************************************************
500 HEAD$="1  Transfer SETUPS in binary from HP to IBM PC and store
    then in binary to disk in drive B."
610 CLS:PRINT HEAD$:INPUT "AUTOMATIC OR MANUAL TRANSFER  A/M";AUT$
615 PRINT"Press the view button on the HP until the setup window can be
    seen."
616 INPUT"Press enter when ready....";A$
620 IF AUT$="A" OR AUT$="a" OR AUT$="M" OR AUT$="m" THEN 630 ELSE 610
630 IF AUT$="M" OR AUT$="m" THEN 760 ELSE 640
632 REM***************************************************************
633 REM
634 REM
635 REM AUTOMATIC TRANSFER
```

```
636 REM
637 REM
638 REM*****************************************************************
640 PRINT"The last line of the program should contain a data statement
    listing the SETUPS to be transfered.  The data statements in the
    program should refer only to the SETUPS which will be transfered."
650 INPUT"Is this condition satisfied y/n";BA$
660 IF BA$="Y" OR BA$="y" THEN 670 ELSE STOP
670 INPUT "Insert data disk in drive B and data tape in HP. READY? Y/N";
    BA$
680 IF BA$="N" OR BA$="n" THEN 670
690 IF BA$="Y" OR BA$="y" THEN 700 ELSE 670
700 INPUT "Data tape #";TAPENO$
702 REM
703 REM
704 REM RECURSIVE LOOP OF AUTOMATIC CONTROL STARTS IN THE NEXT LINE
705 REM
706 REM
710 READ RECORDNO$
720 IF RECORDNO$="END" THEN STOP
730 RECORD$="B:SETUP"+RECORDNO$+".T"+TAPENO$
740 PRINT "TRANSFERING ...";RECORD$
750 GOTO 960
752 REM*****************************************************************
753 REM
754 REM
755 REM MANUAL TRANSFER
756 REM
757 REM
758 REM*****************************************************************
760 CLS:PRINT HEAD$
770 LOCATE 3,1:INPUT"HP tape #";TAPENO$
780 INPUT"SETUP #";RECORDNO$
790 RECORD$="B:SETUP"+RECORDNO$+".T"+TAPENO$
800 LOCATE 6,1:PRINT"Setup from: tape #";TAPENO$
810 PRINT TAB(25)"setup #";RECORDNO$
820 LOCATE 9,1:PRINT"will be saved on disk in drive B in the file ";
    RECORD$
830 LOCATE 11,1:PRINT"Do you wish to change the file name (Y/N)"
840 A$=INKEY$:IF A$="" THEN 840
850 IF A$="N" OR A$="n" OR A$="Y" OR A$="y" THEN GOTO 860 ELSE GOTO 840
860 IF A$="Y" OR A$="y" THEN GOSUB 1930
870 REM GO ON WITH THE TRANSFER PROCEDURE
880 CLS:PRINT HEAD$
890 LOCATE 3,1:PRINT"From tape #";TAPENO$
900 PRINT"   setup #";RECORDNO$
910 LOCATE 7,1:PRINT"To drive B, file ";RECORD$
920 LOCATE 9,1:PRINT"Insert proper tape & diskette.  Abort or continue
    (A/C)"
930 A$=INKEY$:IF A$="" THEN GOTO 930
940 IF A$="A" OR A$="a" OR A$="C" OR A$="c" THEN 950 ELSE 930
950 IF A$="A" OR A$="a" THEN STOP
952 REM*****************************************************************
953 REM
```

```
954 REM
955 REM LOAD SETUP INTO HP FROM TAPE&INITIATE TRANSFER PROCEDURE FROM HP
    TO PC
956 REM
957 REM
958 REM***************************************************************
960 REM PUT GPIB-PC ON LINE
970 V%=1:CALL IBONL%(BD%,V%)
980 IF IBSTA%<0 THEN PERROR%=1:GOTO 2090:REM ERROR HAS OCCURED
990 REM MAKE GPIB-PC ACTIVE SYSTEM CONTROLLER
1000 CALL IBSIC%(BD%)
1010 IF IBSTA%<0 THEN PERROR%=2:GOTO 2090:REM ERROR HAS OCCURED
1020 REM ASSERT REN (REMOTE ENABLE) TO PUT HP5420A IN REMOTE CONTROL
1030 V%=1:CALL IBSRE%(BD%,V%)
1040 IF IBSTA%<0 THEN PERROR%=3:GOTO 2090:REM ERROR HAS OCCURED
1050 REM ADDRESS GPIB-PC TO TALK "@"
1060 REM ADDRESS HP5420A TO LISTEN "$"
1070 CMD$="$@":CALL IBCMD%(BD%,CMD$)
1080 IF IBSTA%<0 THEN PERROR%=4:GOTO 2090:REM ERROR HAS OCCURED
1090 REM INSTRUCT HP5420A TO LOAD SETUP RECORD FROM TAPE
1100 WRT$=RECORDNO$+"RO"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1110 IF IBSTA%<0 THEN PERROR=5:GOTO 2090:REM ERROR HAS OCCURED
1120 REM INITIATE STORE OF HEADER TO IBM PC IN BINARY
1130 WRT$="500SO"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1140 IF IBSTA%<0 THEN PERROR%=6:GOTO 2090:REM ERROR HAS OCCURED
1150 A%=IBSTA% AND 4096
1160 IF A%=4096 THEN 1180 ELSE 1170
1170 PRINT"ERROR: NO SRQ PRESENT AFTER 500 STORE INSTRUCTION":STOP
1180 REM RESET FLAG2=0 TO SHOW THAT HP5420A HAS NOT YET TRIED TO STORE
     SETUP IN ASCII
1190 FLAG2=0
1192 REM***************************************************************
1194 REM
1196 REM
1200 REM DO SERIAL POLL
1202 REM
1204 REM
1206 REM***************************************************************
1210 REM UNADDRESS LISTENER & TALKER, SEND SPE (SERIAL POLL ENABLE,
     OCTAL 30)
1220 REM ADDERSS GPIB-PC TO LISTEN " "
1230 REM ADDRESS HP5420A TO TALK "D"
1240 CMD$="?_"+CHR$(24)+"D ":CALL IBCMD%(BD%,CMD$)
1250 REM READ STATUS BYTE FROM HP5420A
1260 RD$=SPACE$(1):CALL IBRD%(BD%,RD$)
1262 FOR STB%=0 TO 256
1263 IF CHR$(STB%)=RD$ THEN 1270
1264 NEXT STB%
1270 PRINT"STATUS BYTE:";RD$,STB%
1280 REM IF RD$=" "AND FLAG2=1 THEN THERE ARE NO SRQ LEFT & WE HAVE
     FINISHE
1290 REM IF RD$=" " AND FLAG2=0 THEN THE HP5420A IS NOT TRYING TO
     TRANSMIT DATA AND HEADER THEREFORE THERE IS AN ERROR
1295 IF RD$="c" THEN 1440
```

```
1300 IF RD$-" " AND FLAG2-1 THEN 1440
1310 IF RD$-" " AND FLAG2-0 THEN PRINT"ERROR: HP5420A IS NOT TRYING TO
     SEND SETUP IN BINARY AFTER 500 STORE":STOP
1320 IF RD$-CHR$(96) THEN FLAG2-1
1330 REM SEND SPD (SERIAL POLL DISABLE,OCTAL 31)
1340 CMD$-CHR$(25):CALL IBCMD%(BD%,CMD$)
1350 REM DO WAIT FOR SRQ OR TMO (20480 MASK), THEN
1360 REM ADDRESS GPIB-PC TO TALK "@"
1370 REM ADDRESS HP5420A TO LISTEN "$"
1380 MASK%-20480:CALL IBWAIT%(BD%,MASK%)
1390 CMD$-"$@":CALL IBCMD%(BD%,CMD$)
1400 REM LOOP BACK TO XXXX TO SEE IF ANY SRQ LEFT TO READ
1410 GOTO 1200
1420 REM ***END OF SERIAL POLL***
1430 REM ****************************************************
1432 REM
1433 REM
1434 REM TRANSFER SETUP FROM HP TO PC
1435 REM
1436 REM
1438 REM*************************************************************
1440 REM HP5420A IS READY TO STORE SETUP IN BINARY FORMAT
1450 REM THERE WILL BE 118 BYTES OF 8 BITS EACH.
1460 REM THESE VALUES WILL BE SAVED TO FILE RECORD$ IN DRIVE B:
1480 REM OPEN FILES RECORD$ ON DRIVE B
1490 OPEN "R",#1,RECORD$,1
1500 FIELD #1,1 AS RDS$
1510 REM UNADDRESS LISTENER & TALKER AND
1520 REM ADDRESS GPIB-PC TO LISTEN " "
1530 REM ADDRESS HP5420A TO TALK "D"
1540 CMD$-"D ":CALL IBCMD%(BD%,CMD$)
1550 FOR I%-1 TO 118
1560 RD$-SPACE$(1):CALL IBRD%(BD%,RD$)
1591 REM
1592 FOR SSS%-0 TO 255:IF CHR$(SSS%)-RD$ THEN 1594 ELSE NEXT SSS%
1593 REM
1594 PRINT I%,SSS%,RD$
1596 REM
1597 REM
1598 REM
1620 LSET RDS$-RD$
1630 PUT #1
1640 NEXT I%
1730 CLOSE #1
1740 REM FINISHED TRANSFER OF DATA & HEADER IN ASCII FROM SPECIFIED
     RECORD
1750 REM RETURN TO MENUE FOR SAVE TO IBM-PC DATA BLOCK & HEADER IN ASCII
1760 IF AUT$-"M" OR AUT$-"m" THEN 760
1770 IF AUT$-"A" OR AUT$-"a" THEN 710
1920 REM*************************************************************
1922 REM*************************************************************
1923 REM*************************************************************
1924 REM
1925 REM
```

```
1930 REM SUBROUTINE TO ENTER NEW FILE NAME AND CHECK IF IT IS A GOOD
     FILE NAME
1932 REM
1934 REM
1935 REM***************************************************************
1940 PRINT"Enter new file name including extension but not including the
     drive descriptor"
1950 INPUT"New file name   ";RECORD$
1960 AAA%=LEN(RECORD$)
1970 IF AAA%>11 THEN PRINT"New file name is too long":GOTO 1940
1980 IF AAA%=0 THEN GOTO 1940
1990 FLAG1=0:REM FLAG1 IS 0 IF NO EXTENSION FOUND
2000 FOR I%=1 TO AAA%
2010 A$=MID$(RECORD$,I%,1)
2020 IF A$=":" THEN PRINT"Do not include drive descriptor <:>":GOTO 1940
2030 IF A$="." AND (AAA%-I%)=0 THEN PRINT"Extension is a null string":
     GOTO 1940
2040 IF A$="." AND (AAA%-I%)>3 THEN PRINT"Extension is too long":
     GOTO 1940
2050 IF A$="." THEN FLAG1=1
2060 NEXT I%
2070 IF FLAG1=0 THEN PRINT"You must include an extension with a <.>":
     GOTO 1940
2080 RETURN
2082 REM***************************************************************
2083 REM
2084 REM
2085 REM SUBROUTINE TO REPORT ERRORS
2086 REM
2087 REM
2088 REM***************************************************************
2090 REM ERROR REPORTING ROUTINE
2100 PRINT"at point PERROR=";PERROR%
2110 PRINT "An error has occured in the execution on GPIB-PC software"
2120 STOP
2124 REM***************************************************************
2125 REM
2126 REM
2127 REM DATA
2128 REM
2129 REM
2130 REM TEH FOLOWING IS A LIST OF SETUPS TO BE TRANSFERED FROM THE HP
     TO THE IBM-PC
2140 DATA
```

VERI V1.SET

```
10 REM VERI_V1.SET
20 REM (C) DECEMBER 1986 PIOTR W. SYCHTERZ
30 REM McGILL UNIVERSITY, MONTREAL
35 REM*****************************************************************
40 REM
```

```
50 REM
52 REM INITIALIZE THE GPIB-PC SOFTWARE IN THIS PROGRAM
53 REM
54 REM
55 REM*****************************************************************
60 REM RESERVE MEMORY ABOVE 60650 FOR GPIB-PC SUBROUTINE CALLED IBINIT
70       CLEAR   ,60650!
80       IBINIT = 60650!
90 REM LOAD SUBROUTINE IBINIT FROM FILE BIB.M ON DRIVE A
100      BLOAD "A:BIB.M",IBINIT
110      IBSTA%=0:IBERR%=0:IBCNT%=0
120      CALL IBINIT (IBRD%,IBWRT%,IBCMD%,IBWAIT%,IBRPP%,IBONL%,IBRSC%,
         IBSIC%,IBSRE%,IBRTL%,IBRSV%,IBLPE%,IBPAD%,IBSAD%,IBIST%,IBDMA%,
         IBEOS%,IBTMO%,IBEOT%,IBGTS%,IBCAC%,IBDIAG%,IBSTA%,IBERR%,
         IBCNT%)
130 REM
140 REM BD% DENOTES THE GPIB-PC BOARD NUMBER IN SUBROUTINE CALLS
150 REM BD%=0 BECAUSE THERE IS ONLY ONE BOARD
160 BD%=0
165 REM****************************************************************
170 REM
172 REM
180 REM PRINT INTRODUCTION ON SCREEN
182 REM
184 REM
186 REM****************************************************************
190 CLS:PRINT"     This program compares SETUPS stored on HP5420A and
    the IBM-PC."
200 LOCATE 3,1:PRINT"     The hardware necessary for this data transfer
    includes;"
210 LOCATE 4,10:PRINT"IBM-PC"
220 LOCATE 5,10:PRINT"GPIB-PC interface & software supplied with it"
230 LOCATE 6,10:PRINT"HP5420A data anlyzer"
240 LOCATE 7,10:PRINT"HP data tape #98200A"
250 LOCATE 8,10:PRINT"5 1/2 diskette"
260 LOCATE 20,10:PRINT"(C) DECEMBER 1986, PIOTR SYCHTERZ, McGILL
    UNIVERSITY, MONTREAL"
270 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
280 REM PRINT INSTRUCTIONS
290 CLS:PRINT"     To run the program the following steps must be
    taken;"
300 PRINT TAB(10)"Set HP5420A data analyzer to ADDRESSABLE with switch
    S3 on back panel"
310 PRINT TAB(10)"Conect the GPIB-PC interface cable to HP-IB10920A
    interface on HP5420A"
320 PRINT TAB(10)"Power up the HP5420A"
330 PRINT TAB(10)"Insert an HP data tape into the HP5420A"
340 PRINT TAB(10)"Boot IBM-PC with the GPIB-PC system disk in drive A"
350 PRINT TAB(10)"Enter the basic editor, load & run HP2PC_V?.SET
360 PRINT TAB(10)"Insert the data diskette in drive B"
370 LOCATE 11,1:PRINT"NOTE: You may want to write-protect the diskette
    or tape if you will not        transfer data to it.  This will
    prevent accidental errasure."
380 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
```

```
400 REM*****************************************************************
402 REM
404 REM
406 REM CHOOSE AUTOMATIC OR MANUAL COMPARISON
408 REM
410 REM
412 REM*****************************************************************
500 HEAD$="1   Compare SETUPS stored on HP data tape and IBM PC in
    drive B."
610 CLS:PRINT HEAD$:INPUT "AUTOMATIC OR MANUAL TRANSFER  A/M";AUT$
615 PRINT"Press the view button on the HP until the setup window can be
    seen."
616 INPUT"Press enter when ready....";A$
620 IF AUT$="A" OR AUT$="a" OR AUT$="M" OR AUT$="m" THEN 630 ELSE 610
630 IF AUT$="M" OR AUT$="m" THEN 760 ELSE 640
632 REM*****************************************************************
633 REM
634 REM
635 REM AUTOMATIC COMPARISON
636 REM
637 REM
638 REM*****************************************************************
640 PRINT"The last line of the program should contain a data statement
    listing the SETUPS to be compared.  The data statements in the
    program should refer only to the SETUPS which will be transfered."
650 INPUT"Is this condition satisfied y/n";BA$
660 IF BA$="Y" OR BA$="y" THEN 670 ELSE STOP
670 INPUT "Insert data disk in drive B and data tape in HP. READY? Y/N";
    BA$
680 IF BA$="N" OR BA$="n" THEN 670
690 IF BA$="Y" OR BA$="y" THEN 700 ELSE 670
700 INPUT "Data tape #";TAPENO$
702 REM
703 REM
704 REM RECURSIVE LOOP OF AUTOMATIC CONTROL STARTS IN THE NEXT LINE
705 REM
706 REM
710 READ RECORDNO$
720 IF RECORDNO$="END" THEN STOP
730 RECORD$="B:SETUP"+RECORDNO$+".T"+TAPENO$
740 PRINT "COMPARING ...";RECORD$
750 GOTO 960
752 REM*****************************************************************
753 REM
754 REM
755 REM MANUAL COMPARISON
756 REM
757 REM
758 REM*****************************************************************
760 CLS:PRINT HEAD$
770 LOCATE 3,1:INPUT"HP tape #";TAPENO$
780 INPUT"SETUP #";RECORDNO$
790 RECORD$="B:SETUP"+RECORDNO$+".T"+TAPENO$
800 LOCATE 6,1:PRINT"Setup from: tape #";TAPENO$
```

```
810 PRINT TAB(25)"setup #";RECORDNO$
820 LOCATE 9,1:PRINT"will be compared to setup on disk in drive B in the
    file ";RECORD$
830 LOCATE 11,1:PRINT"Do you wish to change the disk file name (Y/N)"
840 A$=INKEY$:IF A$="" THEN 840
850 IF A$="N" OR A$="n" OR A$="Y" OR A$="y" THEN GOTO 860 ELSE GOTO 840
860 IF A$="Y" OR A$="y" THEN GOSUB 1930
862 PRINT"Do you wish to change the tape setup # (Y/N)"
863 A$=INKEY$:IF A$="" THEN 863
864 IF A$="N" OR A$="n" OR A$="Y" OR A$="y" THEN 865 ELSE 863
865 IF A$="Y" OR A$="y" THEN 760
870 REM GO ON WITH THE TRANSFER PROCEDURE
880 CLS:PRINT HEAD$
885 PRINT"Compare setups...."
890 LOCATE 3,1:PRINT"From tape #";TAPENO$
900 PRINT"   setup #";RECORDNO$
910 LOCATE 7,1:PRINT"To drive B, file ";RECORD$
920 LOCATE 9,1:PRINT"Insert proper tape & diskette.  Abort or continue
    (A/C)"
930 A$=INKEY$:IF A$="" THEN GOTO 930
940 IF A$="A" OR A$="a" OR A$="C" OR A$="c" THEN 950 ELSE 930
950 IF A$="A" OR A$="a" THEN STOP
952 REM*************************************************************
953 REM
954 REM
955 REM LOAD SETUP INTO HP FROM TAPE&INITIATE COMPARISON
956 REM
957 REM
958 REM*************************************************************
960 REM PUT GPIB-PC ON LINE
970 V%=1:CALL IBONL%(BD%,V%)
980 IF IBSTA%<0 THEN PERROR%=1:GOTO 2090:REM ERROR HAS OCCURED
990 REM MAKE GPIB-PC ACTIVE SYSTEM CONTROLLER
1000 CALL IBSIC%(BD%)
1010 IF IBSTA%<0 THEN PERROR%=2:GOTO 2090:REM ERROR HAS OCCURED
1020 REM ASSERT REN (REMOTE ENABLE) TO PUT HP5420A IN REMOTE CONTROL
1030 V%=1:CALL IBSRE%(BD%,V%)
1040 IF IBSTA%<0 THEN PERROR%=3:GOTO 2090:REM ERROR HAS OCCURED
1050 REM ADDRESS GPIB-PC TO TALK "@"
1060 REM ADDRESS HP5420A TO LISTEN "$"
1070 CMD$="$@":CALL IBCMD%(BD%,CMD$)
1080 IF IBSTA%<0 THEN PERROR%=4:GOTO 2090:REM ERROR HAS OCCURED
1090 REM INSTRUCT HP5420A TO LOAD SETUP RECORD FROM TAPE
1100 WRT$=RECORDNO$+"RO"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1110 IF IBSTA%<0 THEN PERROR=5:GOTO 2090:REM ERROR HAS OCCURED
1120 REM INITIATE STORE OF HEADER TO IBM PC IN BINARY
1130 WRT$="500SO"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1140 IF IBSTA%<0 THEN PERROR%=6:GOTO 2090:REM ERROR HAS OCCURED
1150 A%=IBSTA% AND 4096
1160 IF A%=4096 THEN 1180 ELSE 1170
1170 PRINT"ERROR: NO SRQ PRESENT AFTER 500 STORE INSTRUCTION":STOP
1180 REM RESET FLAG2=0 TO SHOW THAT HP5420A HAS NOT YET TRIED TO STORE
     SETUP IN ASCII
1190 FLAG2=0
```

```
1192 REM**************************************************************
1194 REM
1196 REM
1200 REM DO SERIAL POLL
1202 REM
1204 REM
1206 REM**************************************************************
1210 REM UNADDRESS LISTENER & TALKER, SEND SPE (SERIAL POLL ENABLE,
     OCTAL 30)
1220 REM ADDERSS GPIB-PC TO LISTEN " "
1230 REM ADDRESS HP5420A TO TALK "D"
1240 CMD$="?_"+CHR$(24)+"D ":CALL IBCMD%(BD%,CMD$)
1250 REM READ STATUS BYTE FROM HP5420A
1260 RD$=SPACE$(1):CALL IBRD%(BD%,RD$)
1262 FOR STB%=0 TO 256
1263 IF CHR$(STB%)=RD$ THEN 1270
1264 NEXT STB%
1270 PRINT"STATUS BYTE:";RD$,STB%
1280 REM IF RD$=" "AND FLAG2=1 THEN THERE ARE NO SRQ LEFT & WE HAVE
     FINISHE
1290 REM IF RD$=" " AND FLAG2=0 THEN THE HP5420A IS NOT TRYING TO
     TRANSMIT DATA AND HEADER THEREFORE THERE IS AN ERROR
1295 IF RD$="c" THEN 1440
1300 IF RD$=" " AND FLAG2=1 THEN 1440
1310 IF RD$=" " AND FLAG2=0 THEN PRINT"ERROR: HP5420A IS NOT TRYING TO
     SEND SETUP IN BINARY AFTER 500 STORE":STOP
1320 IF RD$=CHR$(96) THEN FLAG2=1
1330 REM SEND SPD (SERIAL POLL DISABLE,OCTAL 31)
1340 CMD$=CHR$(25):CALL IBCMD%(BD%,CMD$)
1350 REM DO WAIT FOR SRQ OR TMO (20480 MASK), THEN
1360 REM ADDRESS GPIB-PC TO TALK "@"
1370 REM ADDRESS HP5420A TO LISTEN "$"
1380 MASK%=20480:CALL IBWAIT%(BD%,MASK%)
1390 CMD$="$@":CALL IBCMD%(BD%,CMD$)
1400 REM LOOP BACK TO XXXX TO SEE IF ANY SRQ LEFT TO READ
1410 GOTO 1200
1420 REM ***END OF SERIAL POLL***
1430 REM ************************************************
1432 REM
1433 REM
1434 REM TRANSFER SETUP FROM HP TO PC THEN COMPARE TO SETUP STORED ON
     DISK
1435 REM
1436 REM
1438 REM**************************************************************
1440 REM HP5420A IS READY TO STORE SETUP IN BINARY FORMAT
1450 REM THERE WILL BE 118 BYTES OF 8 BITS EACH.
1460 REM THESE VALUES WILL BE COMPARED TO FILE RECORD$ IN DRIVE B:
1480 REM OPEN FILES RECORD$ ON DRIVE B
1490 OPEN "R",#1,RECORD$,1
1500 FIELD #1,1 AS RDS$
1510 REM UNADDRESS LISTENER & TALKER AND
1520 REM ADDRESS GPIB-PC TO LISTEN " "
1530 REM ADDRESS HP5420A TO TALK "D"
```

```
1540 CMD$="D ":CALL IBCMD%(BD%,CMD$)
1550 FOR I%=1 TO 118
1560 RD$=SPACE$(1):CALL IBRD%(BD%,RD$)
1570 GET #1
1590 IF RDS$=RD$ THEN 1640
1600 PRINT "DIFFERENCE IN ITEM #";I%
1640 NEXT I%
1730 CLOSE #1
1735 PRINT"NO OTHER DIFFERENCES EXIST IN FILE ";RECORD$
1740 REM FINISHED TRANSFER OF DATA & HEADER IN ASCII FROM SPECIFIED
     RECORD
1750 REM RETURN TO MENUE FOR SAVE TO IBM-PC DATA BLOCK & HEADER IN ASCII
1760 IF AUT$="M" OR AUT$="m" THEN 760
1770 IF AUT$="A" OR AUT$="a" THEN 710
1920 REM*************************************************************
1922 REM*************************************************************
1923 REM*************************************************************
1924 REM
1925 REM
1930 REM SUBROUTINE TO ENTER NEW FILE NAME AND CHECK IF IT IS A GOOD
     FILE NAME
1932 REM
1934 REM
1935 REM*************************************************************
1940 PRINT"Enter new file name including extension but not including the
     drive descriptor"
1950 INPUT"New file name   ";RECORD$
1960 AAA%=LEN(RECORD$)
1970 IF AAA%>11 THEN PRINT"New file name is too long":GOTO 1940
1980 IF AAA%=0 THEN GOTO 1940
1990 FLAG1=0:REM FLAG1 IS 0 IF NO EXTENSION FOUND
2000 FOR I%=1 TO AAA%
2010 A$=MID$(RECORD$,I%,1)
2020 IF A$=":" THEN PRINT"Do not include drive descriptor <:>":GOTO 1940
2030 IF A$="." AND (AAA%-I%)=0 THEN PRINT"Extension is a null string":
     GOTO 1940
2040 IF A$="." AND (AAA%-I%)>3 THEN PRINT"Extension is too long":
     GOTO 1940
2050 IF A$="." THEN FLAG1=1
2060 NEXT I%
2070 IF FLAG1=0 THEN PRINT"You must include an extension with a <.>":
     GOTO 1940
2080 RETURN
2082 REM*************************************************************
2083 REM
2084 REM
2085 REM SUBROUTINE TO REPORT ERRORS
2086 REM
2087 REM
2088 REM*************************************************************
2090 REM ERROR REPORTING ROUTINE
2100 PRINT"at point PERROR=";PERROR%
2110 PRINT "An error has occured in the execution on GPIB-PC software"
2120 STOP
```

```
2124 REM*****************************************************************
2125 REM
2126 REM
2127 REM DATA
2128 REM
2129 REM
2130 REM THE FOLOWING IS A LIST OF FILES TO BE COMPARED BETWEEN THE
     IBM-PC AND  THE HP
2140 DATA
```

PC2HP V3.SET

```
10 REM PC2HP_V3.SET
20 REM (C) DECEMBER 1986 PIOTR W. SYCHTERZ
30 REM McGILL UNIVERSITY, MONTREAL
35 REM*****************************************************************
40 REM
50 REM
52 REM INITIALIZE THE GPIB-PC SOFTWARE IN THIS PROGRAM
53 REM
54 REM
55 REM*****************************************************************
60 REM RESERVE MEMORY ABOVE 60650 FOR GPIB-PC SUBROUTINE CALLED IBINIT
70       CLEAR   ,60650!
80       IBINIT = 60650!
90 REM LOAD SUBROUTINE IBINIT FROM FILE BIB.M ON DRIVE A
100      BLOAD "A:BIB.M",IBINIT
110      IBSTA%=0:IBERR%=0:IBCNT%=0
120      CALL IBINIT (IBRD%,IBWRT%,IBCMD%,IBWAIT%,IBRPP%,IBONL%,IBRSC%,
         IBSIC%,IBSRE%,IBRTL%,IBRSV%,IBLPE%,IBPAD%,IBSAD%,IBIST%,IBDMA%,
         IBEOS%,IBTMO%,IBEOT%,IBGTS%,IBCAC%,IBDIAG%,IBSTA%,IBERR%,
         IBCNT%)
130 REM
140 REM BD% DENOTES THE GPIB-PC BOARD NUMBER IN SUBROUTINE CALLS
150 REM BD%=0 BECAUSE THERE IS ONLY ONE BOARD
160 BD%=0
165 REM*****************************************************************
170 REM
172 REM
180 REM PRINT INTRODUCTION ON SCREEN
182 REM
184 REM
186 REM*****************************************************************
190 CLS:PRINT"     This program transfers SETUPS between the IBM-PC and
    the HP5420A"
200 LOCATE 3,1:PRINT"     The hardware necessary for this data transfer
    includes;"
210 LOCATE 4,10:PRINT"IBM-PC"
220 LOCATE 5,10:PRINT"GPIB-PC interface & software supplied with it"
230 LOCATE 6,10:PRINT"HP5420A data anlyzer"
240 LOCATE 7,10:PRINT"HP data tape #98200A"
250 LOCATE 8,10:PRINT"5 1/2 diskette"
```

```
260 LOCATE 20,10:PRINT"(C) DECEMBER 1986, PIOTR SYCHTERZ, McGILL
    UNIVERSITY, MONTREAL"
270 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
280 REM PRINT INSTRUCTIONS
290 CLS:PRINT"     To run the program the following steps must be
    taken;"
300 PRINT TAB(10)"Set HP5420A data analyzer to ADDRESSABLE with switch
    S3 on back panel"
310 PRINT TAB(10)"Conect the GPIB-PC interface cable to HP-IB10920A
    interface on HP5420A"
320 PRINT TAB(10)"Power up the HP5420A"
330 PRINT TAB(10)"Insert an HP data tape into the HP5420A"
340 PRINT TAB(10)"Boot IBM-PC with the GPIB-PC system disk in drive A"
350 PRINT TAB(10)"Enter the basic editor, load & run PC2HP_V?.SET
360 PRINT TAB(10)"Insert the data diskette in drive B"
370 LOCATE 11,1:PRINT"NOTE: You may want to write-protect the diskette
    or tape if you will not        transfer data to it.  This will
    prevent accidental errasure."
380 LOCATE 23,10:INPUT"Tap ENTER to continue",A$
400 REM***************************************************************
402 REM
404 REM
406 REM CHOOSE AUTOMATIC OR MANUAL TRANSFER
408 REM
410 REM
412 REM***************************************************************
500 HEAD$="   Transfer SETUPS in binary from IBM PC to HP and store
    them on tape in the HP."
610 CLS:PRINT HEAD$:INPUT "AUTOMATIC OR MANUAL TRANSFER  A/M";AUT$
615 PRINT"Press the view button on the HP until the setup window can be
    seen."
616 INPUT"Press enter when ready....";A$
620 IF AUT$="A" OR AUT$="a" OR AUT$="M" OR AUT$="m" THEN 630 ELSE 610
630 IF AUT$="M" OR AUT$="m" THEN 760 ELSE 640
632 REM***************************************************************
633 REM
634 REM
635 REM AUTOMATIC TRANSFER
636 REM
637 REM
638 REM***************************************************************
640 PRINT"The last line of the program should contain a data statement
    listing the  SETUPS to be transfered.  The data statements in the
    program should refer only  to the SETUPS which will be transfered."
650 INPUT"Is this condition satisfied y/n";BA$
660 IF BA$="Y" OR BA$="y" THEN 670 ELSE STOP
670 INPUT "Insert data disk in drive B and data tape in HP. READY? Y/N";
    BA$
680 IF BA$="N" OR BA$="n" THEN 670
690 IF BA$="Y" OR BA$="y" THEN 700 ELSE 670
700 INPUT "Data tape #";TAPENO$
702 REM
703 REM
704 REM RECURSIVE LOOP OF AUTOMATIC CONTROL STARTS IN THE NEXT LINE
```

```
705 REM
706 REM
710 READ RECORDNO$
720 IF RECORDNO$="END" THEN STOP
730 RECORD$="B:SETUP"+RECORDNO$+".T"+TAPENO$
740 PRINT "TRANSFERING ...";RECORD$
750 GOTO 960
752 REM*******************************************************************
753 REM
754 REM
755 REM MANUAL TRANSFER
756 REM
757 REM
758 REM*******************************************************************
760 CLS:PRINT HEAD$
770 INPUT "Insert data disk in drive B: and press ENTER";A$
780 FILES "B·
790 INPUT"Name of file to be transfered to HP..(INCLUDE DRIVE AND EXT.)
    ";RECORD$
800 INPUT"This information is to be saved in record #";RECORDNO$
870 REM GO ON WITH THE TRANSFER PROCEDURE
880 CLS:PRINT HEAD$
890 PRINT"From disk file... ";RECORD$
900 PRINT"To record #";RECORDNO$
920 LOCATE 9,1:PRINT"Insert proper tape & diskette.  Abort or continue
    (A/C)"
930 A$=INKEY$:IF A$="" THEN GOTO 930
940 IF A$="A" OR A$="a" OR A$="C" OR A$="c" THEN 950 ELSE 930
950 IF A$="A" OR A$="a" THEN STOP
952 REM*******************************************************************
953 REM
954 REM
955 REM INITIATE TRANSFER PROCEDURE FROM PC TO HP
956 REM
957 REM
958 REM*******************************************************************
960 REM PUT GPIB-PC ON LINE
970 V%=1:CALL IBONL%(BD%,V%)
980 IF IBSTA%<0 THEN PERROR%=1:GOTO 2090:REM ERROR HAS OCCURED
990 REM MAKE GPIB-PC ACTIVE SYSTEM CONTROLLER
1000 CALL IBSIC%(BD%)
1010 IF IBSTA%<0 THEN PERROR%=2:GOTO 2090:REM ERROR HAS OCCURED
1020 REM ASSERT REN (REMOTE ENABLE) TO PUT HP5420A IN REMOTE CONTROL
1030 V%=1:CALL IBSRE%(BD%,V%)
1040 IF IBSTA%<0 THEN PERROR%=3:GOTO 2090:REM ERROR HAS OCCURED
1050 REM ADDRESS GPIB-PC TO TALK "@"
1060 REM ADDRESS HP5420A TO LISTEN "$"
1070 CMD$="$@":CALL IBCMD%(BD%,CMD$)
1080 IF IBSTA%<0 THEN PERROR%=4:GOTO 2090:REM ERROR HAS OCCURED
1090 REM INSTRUCT HP5420A TO LOAD SETUP RECORD FROM GPIB-PC
1100 WRT$="500RO"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1135 REM WAIT TO GIVE HP A CHANCE TO SEND SRQ
1136 REM WAIT FOR SRQ OR TMO (MASK%=20480)
1137 MASK%=20480:CALL IBWAIT%(BD%,MASK%)
```

```
1140 IF IBSTA%<0 THEN PERROR%=6:GOTO 2090:REM ERROR HAS OCCURED
1150 A%=IBSTA% AND 4096
1160 IF A%=4096 THEN 1180 ELSE 1170
1170 PRINT"ERROR: NO SRQ PRESENT AFTER 500 RESTORE INSTRUCTION":STOP
1180 REM RESET FLAG2=0 TO SHOW THAT HP5420A HAS NOT YET TRIED TO RESTORE
     SETUP IN BINARY
1190 FLAG2=0
1192 REM**************************************************************
1194 REM
1196 REM
1200 REM DO SERIAL POLL
1202 REM
1204 REM
1206 REM**************************************************************
1207 REM RESET FLAG2
1208 FLAG2=0:REM AS LONG AS FLAG2=0, THE HP HAS NOT ASKED TO RECEIVE THE
     SETUP
1210 REM UNADDRESS LISTENER & TALKER, SEND SPE (SERIAL POLL ENABLE,
     OCTAL 30)
1220 REM ADDERSS GPIB-PC TO LISTEN " "
1230 REM ADDRESS HP5420A TO TALK "D"
1240 CMD$="?_"+CHR$(24)+"D ":CALL IBCMD%(BD%,CMD$)
1250 REM READ STATUS BYTE FROM HP5420A
1260 RD$=SPACE$(1):CALL IBRD%(BD%,RD$)
1270 PRINT"STATUS BYTE:";RD$
1280 REM IF RD$=" "AND FLAG2=1 THEN THERE ARE NO SRQ LEFT & WE HAVE
     FINISHED
1290 REM IF RD$=" " AND FLAG2=0 THEN THE HP5420A IS NOT TRYING TO
     TRANSMIT SETUP IN BINARY,THERE IS AN ERROR
1300 IF RD$=" " AND FLAG2=1 THEN 1340
1305 IF RD$="3" AND FLAG2=1 THEN 1340
1310 IF RD$=" " AND FLAG2=0 THEN PRINT"ERROR: HP5420A IS NOT TRYING TO
     RECEIVE SETUP IN BINARY AFTER 500 RESTORE":STOP
1320 IF RD$=CHR$(115) THEN FLAG2=1
1322 CMD$=CHR$(25):CALL IBCMD%(BD%,CMD$)
1325 GOTO 1240
1330 REM SEND SPD (SERIAL POLL DISABLE,OCTAL 31)
1340 CMD$=CHR$(25):CALL IBCMD%(BD%,CMD$)
1350 REM DO WAIT FOR SRQ OR TMO (20480 MASK)
1380 MASK%=20480:CALL IBWAIT%(BD%,MASK%)
1390 REM CHECK IF THERE ARE ANY SRQ LEFT
1400 A%=IBSTA% AND 4096:IF A%=4096 THEN 1240 ELSE 1490
1420 REM ***END OF SERIAL POLL***
1430 REM ***************************************************
1432 REM
1433 REM
1434 REM TRANSFER SETUP FROM PC TO HP
1435 REM
1436 REM
1438 REM**************************************************************
1440 REM HP5420A IS READY TO RESTORE SETUP IN BINARY FORMAT FROM PC
1450 REM THERE WILL BE 118 BYTES OF 8 BITS EACH.
1460 REM THESE VALUES WILL COME FROM A FILE RECORD$ IN DRIVE B:
1480 REM OPEN FILES RECORD$ ON DRIVE B
```

```
1490 OPEN "R",#1,RECORD$,1
1500 FIELD #1,1 AS RDS$
1510 REM UNADDRESS LISTENER & TALKER AND
1520 REM ADDRESS GPIB-PC TO TALK "@"
1530 REM ADDRESS HP5420A TO LISTEN "$"
1540 CMD$="?_@$":CALL IBCMD%(BD%,CMD$)
1545 REM RETURN ALL DEVICES TO LOCAL MODE
1547 V%=0:CALL IBSRE%(BD%,V%)
1550 FOR I%=1 TO 118
1560 GET#1
1570 WRT$=RDS$:CALL IBWRT%(BD%,WRT$):REM SEND CHARACTER TO HP
1640 NEXT I%
1730 CLOSE #1
1740 REM FINISHED TRANSFER OF SETUP IN BINATY FROM SPECIFIED FILE
1741 REM SAVE SETUP TO HP-DATA TAPE
1742 WRT$=RECORDNO$+"SO"+CHR$(10):CALL IBWRT%(BD%,WRT$)
1744 REM WAIT FOR TAPE TO FINISH
1746 MASK%=4096:CALL IBWAIT%(BD%,MASK%)
1750 REM LOOP BACK TO CONTINUE
1760 IF AUT$="M" OR AUT$="m" THEN 760
1770 IF AUT$="A" OR AUT$="a" THEN 710
1920 REM******************************************************
1922 REM******************************************************
2082 REM******************************************************
2083 REM
2084 REM
2085 REM SUBROUTINE TO REPORT ERRORS
2086 REM
2087 REM
2088 REM******************************************************
2090 REM ERROR REPORTING ROUTINE
2100 PRINT"at point PERROR=";PERROR%
2110 PRINT "An error has occured in the execution on GPIB-PC software"
2120 STOP
2124 REM******************************************************
2125 REM
2126 REM
2127 REM DATA
2128 REM
2129 REM
2130 REM THE FOLOWING IS A LIST OF SETUPS TO BE TRANSFERD FROM THE
     IBM-PC THE THE HP
2140 DATA
```

WRITINFO.BAS

```
10 REM WRITINFO.BAS
20 REM (C) PIOTR SYCHTERZ , FEBRUARY 12, 1987
30 CLS:PRINT"1 INPUT DATA"
40 PRINT"2 PRINT DATA TO PRINTER":PRINT"3 END"
50 INPUT A
60 ON A GOTO 90,500,80
```

```
70 GOTO 30
80 END
90 CLS:PRINT"This program is used to enter the auxilliary data needed
   to calculate the      dynamic coefficient of pressure."
100 PRINT" ":PRINT"The program will ask for the following data:"
110 PRINT"1 The historical number of this experiment"
120 PRINT"2 The date of this experiment (It will be saved as a literal
    string)"
130 PRINT"3 Data for angular positions of the cylinder from 0 deg. to
    360 deg. (37 sets):"
140 PRINT"   a. ANGLE is the angular position of the cylinder"
150 PRINT"   b. RECORD is the record number of the data on an HP data
    tape"
160 PRINT"   c. TAPE is the tape number on which the information is
    stored"
170 PRINT"   d. VELOCITY is the upstream air velocity in m/s"
180 PRINT"   e. TEMP is the air temperature in degrees Celcius"
190 PRINT"   f. PRESS is the barometric air pressure in in.Hg"
200 PRINT"   g. FREQ is the frequency at which the cylinder is being
    oscilated"
210 PRINT" ":PRINT"The program will automatically save the information
    entered to a file INFO#.DAT where # coresponds to the experiment
    number."
220 PRINT" ":PRINT"Insert disk into drive B:":PRINT"Ready ?";
230 A$=INKEY$:IF A$="" THEN 230
240 IF A$="Y" OR A$="y" THEN 260
250 GOTO 230
260 CLS
270 INPUT"EXPERIMENT #";A$
280 A=VAL(A$)
290 IF " "+A$=STR$(A) THEN 300 ELSE PRINT"REDO..?":GOTO 270
300 OPEN "O",#1,"B:INFO"+A$+".DAT"
310 PRINT" "
320 INPUT "Date of experiment ";EXPDATE$
330 WRITE #1,"EXPERIMENT #"+A$,EXPDATE$
340 REM START LOOP TO ENTER THE 37 SETS OF DATA VALUES
350 FOR ANGLE%=0 TO 360 STEP 10
355 PRINT" ":PRINT"*******************************************************
360 PRINT"Entering data for angle ";ANGLE%
370 INPUT"RECORD NUMBER ";RECORD$
380 A=VAL(RECORD$):IF " "+RECORD$=STR$(A) THEN 390 ELSE PRINT"REDO..?":
    GOTO 370
390 INPUT"TAPE NUMBER ";TAPE$
400 A=VAL(TAPE$):IF " "+TAPE$=STR$(A) THEN 410 ELSE PRINT"REDO..?",A,
    TAPE$:GOTO 390
410 INPUT"VELOCITY (m/s) ",VELOCITY
420 INPUT"TEMPERATURE (C) ",TEMP
430 INPUT"AIR PRESSURE   ",PRESS
440 INPUT"FREQUENCY      ",FREQ
450 WRITE #1, ANGLE%,RECORD$,TAPE$,VELOCITY,TEMP,PRESS,FREQ
460 NEXT
470 CLOSE #1
480 PRINT"DONE":PRINT" "
490 GOTO 30
```

```
495 REM***************************************************************
497 REM
500 REM LIST DATA TO PRINTER
501 REM
502 REM***************************************************************
510 CLS:PRINT"This program will list auxiliary data to the printer."
520 PRINT" ":PRINT"Insert data disk in drive B:":PRINT" ":INPUT"
    Experiment number ";A$
530 A=VAL(A$):IF " "+A$=STR$(A) THEN 540 ELSE PRINT "REDO..?":GOTO 520
540 OPEN "I",#1,"B:INFO"+A$+".DAT"
550 PRINT"Is printer ready";
560 B$=INKEY$:IF B$="" THEN 560
570 IF B$="Y" OR B$="y" THEN 580 ELSE 560
580 INPUT#1,NUMEXP$,EXPDATE$
590 LPRINT NUMEXP$,EXPDATE$
595 LPRINT" ":LPRINT"  ANGLE  RECORD   TAPE    VELOCITY TEMPERATURE
    PRESSURE     FREQUENCY"
600 FOR ANGLE%=0 TO 360 STEP 10
610 INPUT#1, ANGLE%,RECORD$,TAPE$,VELOCITY,TEMP,PRESS,FREQ
620 LPRINT USING"  ####     "    "    "    " ####.#     ###.#     ###.##
     ##.#########";ANGLE%;RECORD$;TAPE$;VELOCITY;TEMP;PRESS;FREQ
630 NEXT ANGLE%
640 CLOSE #1
650 GOTO 30
```

CPDY1.BAS

```
10 REM CPDY1.BAS
20 REM (C) PIOTR SYCHTERZ, FEBRUARY 12, 1987
21 REM SP=RDS=> SAMPLE SPACING IN THE TIME DOMAIN
22 REM IP=POSNUM%=> POSITION NUMBER OF THE CYLINDER 1 TO 12
30 CLS:PRINT"This program calculates the dynamic coefficient of pressure
   on the surface of a cylinder. It uses the data files from HP
   analyzer, stored in files RECxx.Ty,   where xx stands for the record
   number and y stands for the tape number."
40 PRINT" ":PRINT"The program also uses a file INFOe.DAT where e stands
   for the experiment number. This file contains auxiliary data such as:
   the experiment number, the date of"
50 PRINT"the experiment, and 37 sets of angle, record number, tape
   number, air velocity, air temperature, barometric pressure, and
   frequency of oscillation of the      cylinder."
60 PRINT" ":INPUT"Put the disk with the HP data records into drive A:
   and the disk with auxiliary data file into drive B: and type in the
   experiment number";NUMEXP$
70 A=VAL(NUMEXP$):IF " "+NUMEXP$=STR$(A) THEN 80 ELSE PRINT"REDO..?":
   GOTO 60
80 OPEN"I",#13,"B:INFO"+NUMEXP$+".DAT"
90 PRINT" ":PRINT" ":PRINT" ":INPUT"The results will be stored to disk
   drive B:.Should the results also be printed  on the printer (Y/N)";
   FLPRINT$
100 IF FLPRINT$="Y" OR FLPRINT$="y" OR FLPRINT$="N" OR FLPRINT$="n"
    THEN 110 ELSE 90
110 INPUT#13,NEXP$,EXPDATE$
```

```
115 IF FLPRINT$="Y" OR FLPRINT$="y" THEN LPRINT CHR$(27)+"Q"+CHR$(132)+
    CHR$(15)
120 NEXP$=MID$(NEXP$,13):IF NEXP$<>NUMEXP$ THEN PRINT"THIS FILE CONTAINS
    INFORMATION FORM EXPERIMENT #";NEXP$;" NOT EXPERIMENT #";NUMEXP$:
    STOP
130 FOR POSNUM%=1 TO 12
140 OPEN "O",#POSNUM%,"B:CPD"+MID$(STR$(POSNUM%),2)+"-"+NEXP$+".DAT"
150 NEXT POSNUM%
155 FOR ANG%=0 TO 360 STEP 10
157 IF FLPRINT$="Y" OR FLPRINT$="y" THEN LPRINT USING"  ####";ANG%;
158 PRINT USING " ####";ANG%
160 INPUT#13,ANGLE%,RECORD$,TAPE$,VELOCITY,TEMP,PRESS,FREQ
165 PRESS=PRESS*3387:REM CONVERT AIR PRESSURE FROM inHg TO PASCALS
167 TEMP=TEMP+273.16:REM CONVERT AIR TEMPERATURE FROM CELCIUS TO KELVIN
170 OPEN "R",#14,"A:REC"+RECORD$+".T"+TAPE$,4
180 REM GET THE ELEVENTH VALUE IN THE HP DATA FILE, THIS IS THE SAMPLE
    SPACING IN THE TIME DOMAIN
190 FIELD #14,4 AS RDS$
200 GET #14,11
210 SP=CVS(RDS$):REM CONVERTS THE 4 BIT CODED STRING INTO A SINGLE
    PRESSISION NUMBER
215 FOR POSNUM%=1 TO 12
220 REM*************************************************************
230 REM
240 REM CALCUALATE WHICH RECORDS IN THE FILE #14 CORESPOND TO THE
    POSITION BEING INVESTIGATED
250 REM
260 REM*************************************************************
280 IP=POSNUM%
285 REM IF IP<=7 TEH XX IS INCREASING OTHERWISE IT IS DECREASING
290 IF IP<=7 THEN X1=1 ELSE X1=-1
295 IF IP<=7 THEN XX=(IP*.25)+(-1) ELSE XX=.5-(.25)*(IP-8)
300 GOSUB 10980:REM GET TIME T IN SECONDS WHEN CYLINDER IS AT GIVEN
    DISPLACEMENT XX
320 GOSUB 11440:REM CONVERT TIME T  INTO TI(..), THE NUMBER OF DATA
    RECORD IN FILE #14 CORESPONDING TO TIME T
330 REM AVERAGE OUT THE THREE POSIBLE VALUES OF DP (DELATA PRESSURE)
340 REM DP= DELATA PRESSURE
350 REM CC= NUMBER OF VALUES USED TO CALCULATE DP
360 DP=0:CC=0
370 GET #14,TI(1)
380 D=CVS(RDS$)
390 DP=DP+D:CC=CC+1
400 IF TI(2)<0 THEN 440
410 GET #14,TI(2)
420 D=CVS(RDS$)
430 DP=DP+D:CC=CC+1
440 IF TI(3)<0 THEN 480
450 GET #14,TI(3)
460 D=CVS(RDS$)
470 DP=DP+D:CC=CC+1
480 DP=DP/CC:REM NOW DP IS THE AVERAGE DELTA PRESSURE IN psi
485 DP=DP*6895:REM CONVERT DELTA PRESSURE FROM psi TO PASCALS
490 REM*************************************************************
```

```
500 REM
510 REM CALCULATE Cp
520 REM
530 REM*************************************************************
540 REM CALCULATE AIR DENSITY RO
570 R=287:REM GAS CONSTANT FOR AIR ..UNITS (M'2/(S'2*K))
580 RO=PRESS/(R*TEMP):REM CALCULATE AIR DENSITY
590 CP=DP/( 5*RO*VELOCITY*VELOCITY):REM CALCULATE COEFFICIENT OF
    PRESSURE
600 PRINT #POSNUM%,USING "####_,##.####";ANGLE%;CP
610 IF FLPRINT$="Y" OR FLPRINT$="y" THEN LPRINT USING"  ##.###";CP;
620 PRINT USING"  ##.###";CP;
800 NEXT POSNUM%
810 IF FLPRINT$="Y" OR FLPRINT$="y" THEN LPRINT" "
820 CLOSE #14
830 PRINT  " "
900 NEXT ANG%
910 CLOSE
920 END
10980 REM ***********************************************************
10990 REM SUBROUTINE TO FIND TIME T AT WHICH CYLINDER IS AT PARTICULAR
      LOCATION XX
11000 REM INPUT VARIABLES:
11010 REM   XX=DISTANCE FROM CENTER POSITION IN INCHES
11020 REM   X1=1 IF XX IS INCREASING
11030 REM      =-1IF XX ID DECREASING
11040 REM FREQ=FREQUENCY OF OSCILATION OF CYLINDER
11050 REM OUTPUT VARIABLES:
11060 REM   T =TIME IN SECONDS REQUIRED TO TRAVEL FROM XX=-0.75 TO
      GIVEN XX AT FREQUENCY FREQ AND AMPLITUDE OF 0.75 INCHES
11070 REM VARIABLES USED INTERNALY:
11080 REM   A =AMPLITUDE OF OSCILATION 0.75
11090 REM   PI=PIE 3.1415927
11100 REM   S =SINE OF ANGLE XX/A
11110 REM   X =
11120 REM   Z =
11130 REM   W =ARCSIN OF S IN RADIANS
11140 REM   Y =ARCSIN OF S IN DEGREES
11150 A=.75
11160 PI=3.1415927#
11170 IF X1=1 THEN 11200
11180 IF X1=-1 THEN 11240
11190 PRINT"ERROR IN GET-TIME SUBROUTINE":STOP
11200 S=XX/A:GOSUB 11280:REM GET ARCSIN(S)
11210 T=(W/(2*PI))+.25:T=T/FREQ
11220 RETURN:REM RETURN TO MAIN PROGRAM WITH TIME T
11230 REM FOR XX=.5 TO -.75 STEP -.25 ....I THINK THIS IS A DUD
11240 S=XX/A:GOSUB 11280:REM GET ARCSIN(S)
11250 T=1-((W/(2*PI))+.25):T=T/FREQ
11260 RETURN:REM RETURN TO MAIN MPROGRAM WITH TIME T
11270 REM************************************************************
11280 REM SEE "GETTING STARTED WITH COLOR BASIC", PAGE 289
11290 REM *ARCSIN SUBROUTINE* INPUT S, OUTPUT Y,W
11300 REM Y IS IN DEGREES, W IS IN RADIANS
```

```
11310 REM ALSO USES VARIABLES X,Z INTERNALLY
11320 X=S:IF ABS(S)<=.707107 THEN 11390
11330 X=1-S*S: IF X<0 THEN PRINT S;"IS OUT OF RANGE":STOP
11340 IF X=0 THEN W=90/57.29577951#:IF S<0 THEN W=-W
11350 IF X=0 THEN 11420
11360 W=X/2: Z=0
11370 Y=(X/W-W)/2:IF (ABS(Y)<1E-09)AND(Y=Z) THEN X=W:GOTO 11390
11380 W=W+Y:Z=Y:GOTO 11370
11390 Y=X+X*X*X/6+X*X*X*X*X*.075+X*X*X*X*X*X*X*4.464286E-02
11400 W=Y+X*X*X*X*X*X*X*X*X*3.038194E-02
11410 IF ABS(S)>.707107 THEN W=1.570796-W
11420 Y=W*57.29577951#:RETURN:REM RETURN TO THE GET-TIME SUBROUTINE.
11430 REM*************************************************************
11440 REM THIS SUBROUTINE CALCULATES THE NUMBER OF THE DATA RECORD WHICH
      CORESPONDS TO A GIVEN TIME T
11450 REM INPUT VARIABLES:
11460 REM   T -TIME IN SECONDS FROM START OF CYCLE
11470 REM   SP=SAMPLE SPACING IN THE TIME DOMAIN IN SECONDS
11480 REM OUTPUT VARIABLES:
11490 REM   T(3)=THE NUMBER OF DATA RECORD THE 3 REPRESENTS 3 POSIBLE
      REPETITION
11500 REM VARIABLES USED INTERNALY:
11510 REM
11520 IF ((T/SP)-FIX(T/SP))>.5 THEN TI(1)=17+1+FIX(T/SP) ELSE TI(1)=17+
      FIX(T/SP)
11530 REM CALCULATE TI(2)
11540 PT=T+1/FREQ
11550 IF ((PT/SP)-FIX(PT/SP))>.5 THEN TI(2)=17+1+FIX(PT/SP) ELSE TI(2)=
      17+FIX(PT/SP)
11560 IF TI(2)>512+16 THEN TI(2)=-1
11570 REM ANGULAR ORIENTATION (Y-1)*10
11580 PT=T+2/FREQ
11590 IF ((PT/SP)-FIX(PT/SP))>.5 THEN TI(3)=17+1+FIX(PT/SP) ELSE TI(3)=
      17+FIX(PT/SP)
11600 IF TI(3)>512+16 THEN TI(3)=-1
11610 RETURN:REM RETURN TO MAIN PROGRAM
```

APPENDIX B
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TABLE 1

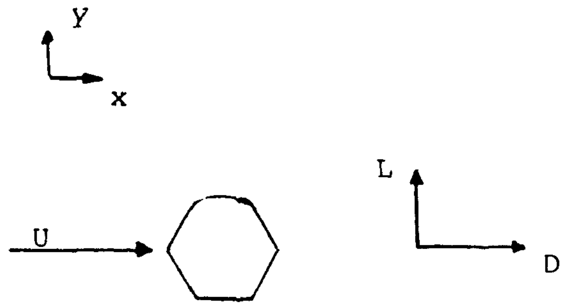
CUT-OFF FREQUENCY FOR ANALOG FILTER
FOR VARIOUS DYNAMIC EXPERIMENTS

L/d	T/d	Re	U/fd	f(cylinder frequency) Hz	filter cut-off frequency Hz
2	0.17	1.16×10^5	131	1	10
2	0.17	1.16×10^5	44	3	20
2	0.17	1.16×10^5	22	6	40
2	0.17	7.7×10^4	15	6	40
2	0.17	2.16×10^5	250	1	10
5	0.5	1.16×10^5	44	3	20
5	0.5	1.16×10^5	131	1	10
4	1	7.7×10^4	15	6	40
4	1	1.75×10^5	198	1	10
4	1	1.16×10^5	131	1	10
4	1	1.16×10^5	44	3	20
4	1	1.75×10^5	44	4.5	27
4	1	1.16×10^5	22	6	40

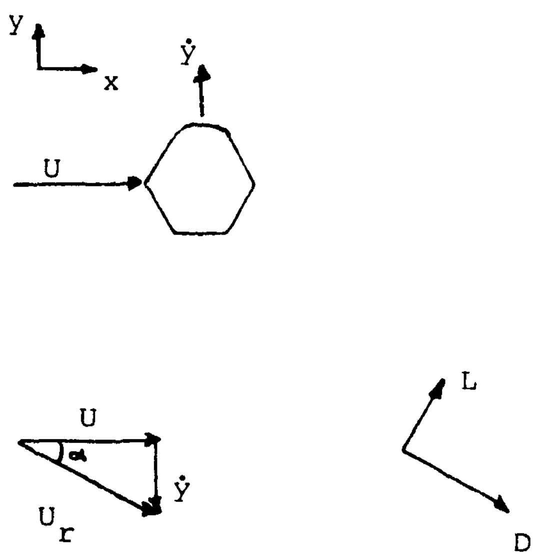
TABLE 2

L/d AND T/d POSITIONS TESTED UNDER STATIC AND DYNAMIC CONDITIONS

L/d	T/d	Re	f(cylinder frequency) Hz	U/fd
2	0.17	7.7×10^4	static	
2	0.17	7.7×10^4	6	15
2	0.17	1.16×10^5	6	22
2	0.17	1.16×10^5	3	44
2	0.17	1.16×10^5	1	131
2	0.17	2.16×10^5	1	250
3	0.5	1.16×10^5	static	
4	0.5	1.16×10^5	static	
4	1	7.7×10^4	static	
4	1	1.16×10^5	static	
4	1	7.7×10^5	6	15
4	1	1.16×10^5	6	22
4	1	1.16×10^5	3	44
4	1	1.75×10^5	4.5	44
4	1	1.16×10^5	1	131
4	1	1.75×10^5	1	198
5	0.17	1.16×10^5	static	
5	0.5	1.16×10^5	static	
5	0.5	1.16×10^5	3	44
5	0.5	1.16×10^5	1	131

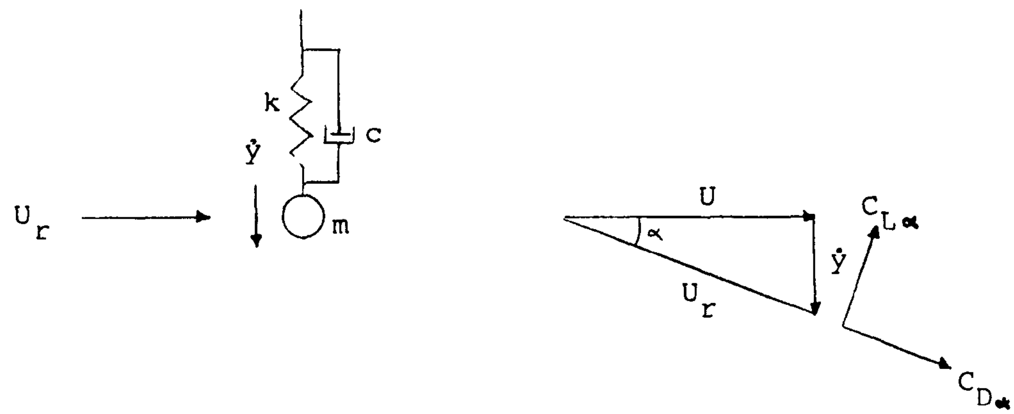


a Lift L, and drag D acting on a body fixed in a free stream of velocity U.



b Lift L, and drag D acting on a body moving with velocity $\dot{y}$, in a free stream of velocity U. U_r is the relative velocity between the fluid and the body.

Figure 1. Lift and drag forces acting on a body in cross-flow.



$$m\ddot{y} + c\dot{y} + ky = F_y$$

$$F_y = -\tfrac{1}{2}\rho U_r^2 \, dl \, (C_L \cos\alpha + C_D \sin\alpha)$$

$$\cos\alpha \simeq 1, \quad \sin\alpha \simeq \alpha \simeq \dot{y}/U, \quad U_r \simeq U$$

$$F_y = -\tfrac{1}{2}\rho U^2 \, dl \, (C_L + C_D \dot{y}/U)$$

$$C_L = C_{L0} + \alpha C_{L\alpha}, \quad \alpha = \dot{y}/U$$

collecting all terms in $\dot{y}$

$$\dot{y}\left\{c + \tfrac{1}{2}\rho U^2 \, dl \left(\frac{C_D}{U} + \frac{C_{L\alpha}}{U}\right)\right\}$$

galloping occures when the damping is negative

for negative damping $C_{L\alpha}$ must be negative

and $|C_{L\alpha}| \geq C_D$

Figure 1c. Aerodynamic conditions for galloping.

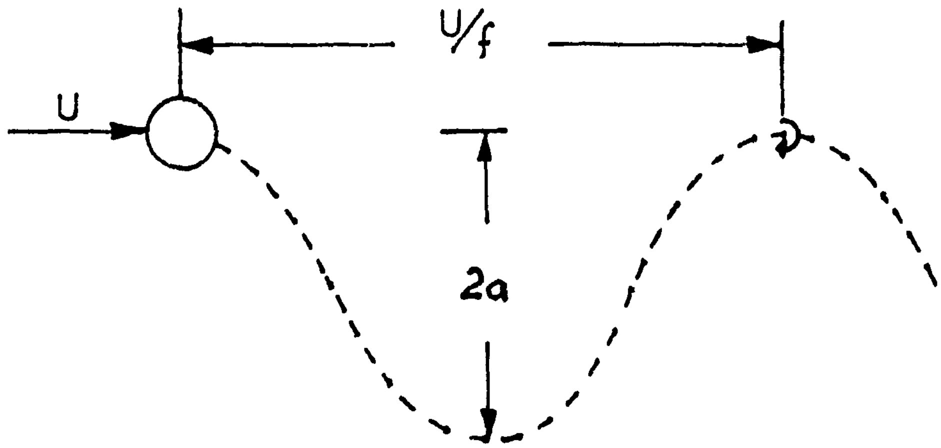


Figure 2. Schematic explanation for the distance a disturbance is swept downstream behind a cylinder.

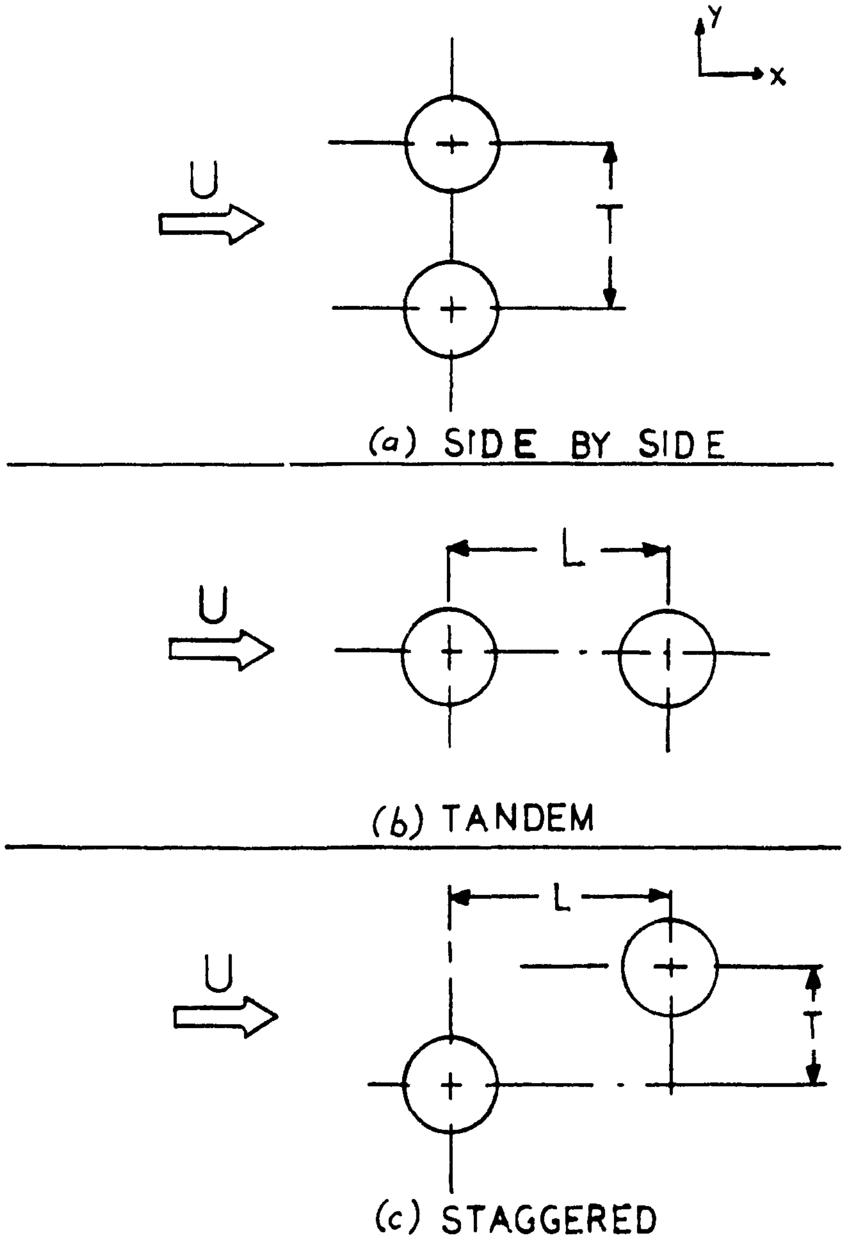
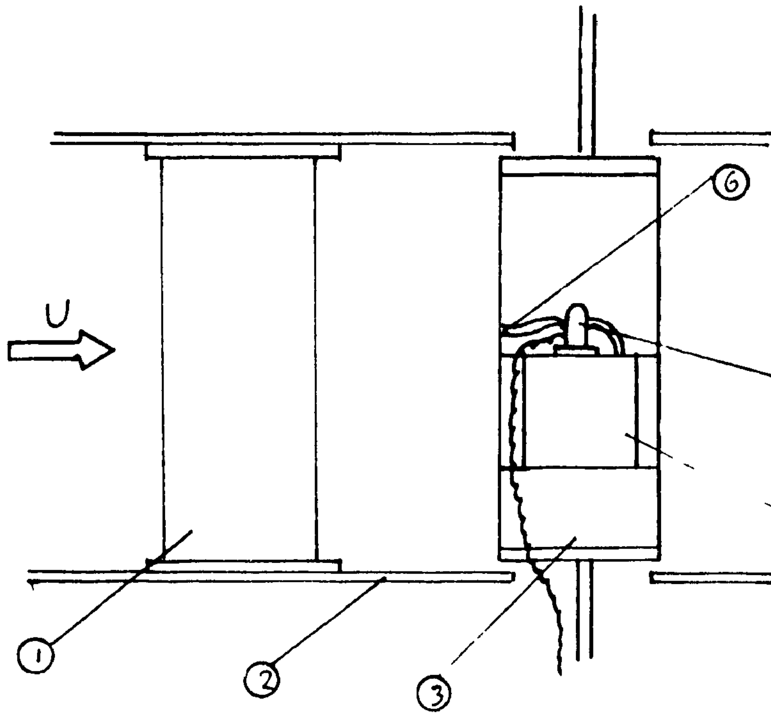


Figure 3. Three possible arrangements of two cylinders in cross-flow; side by side, tandem, and staggered.



1 UPSTREAM CYLINDER
2 WIND TUNNEL
3 DOWNSTREAM CYLINDER
4 REFERENCE PRESSURE TANK
5 TRANSDUCER
6 PRESSURE TAP

Figure 4. Schematic diagram of the test cylinders.

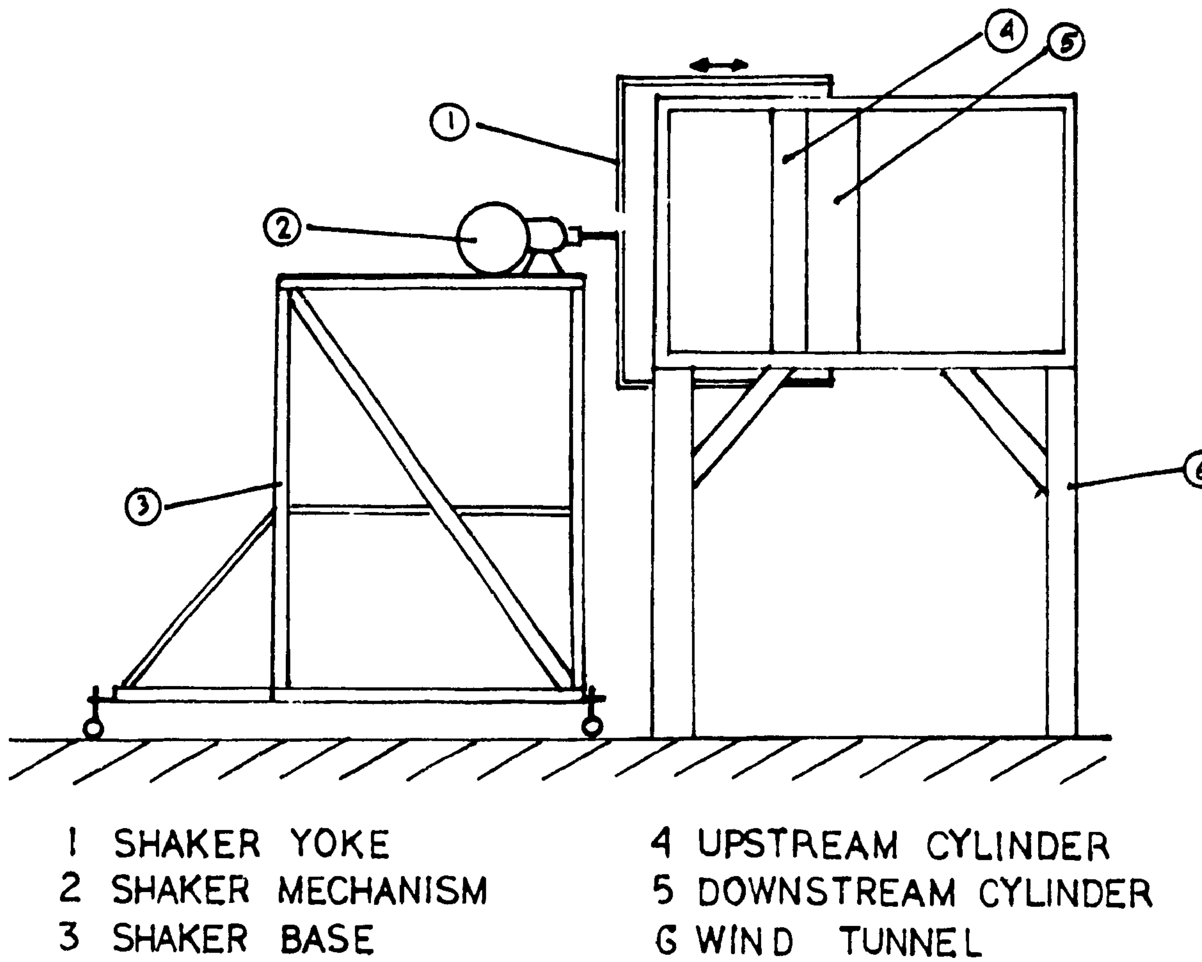


Figure 5. Schematic diagram of the skotch yoke mechanism and the cylinder support yoke.

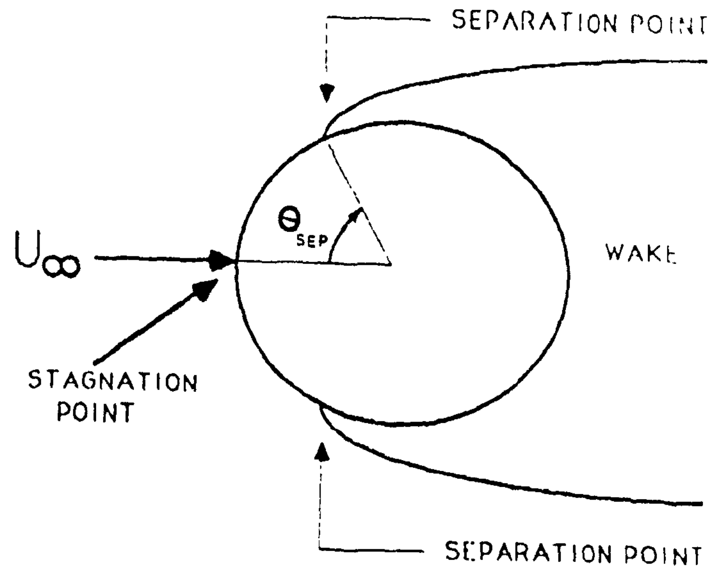


Figure 6. Flow past a single stationary cylinder. (Pinnell 1987).

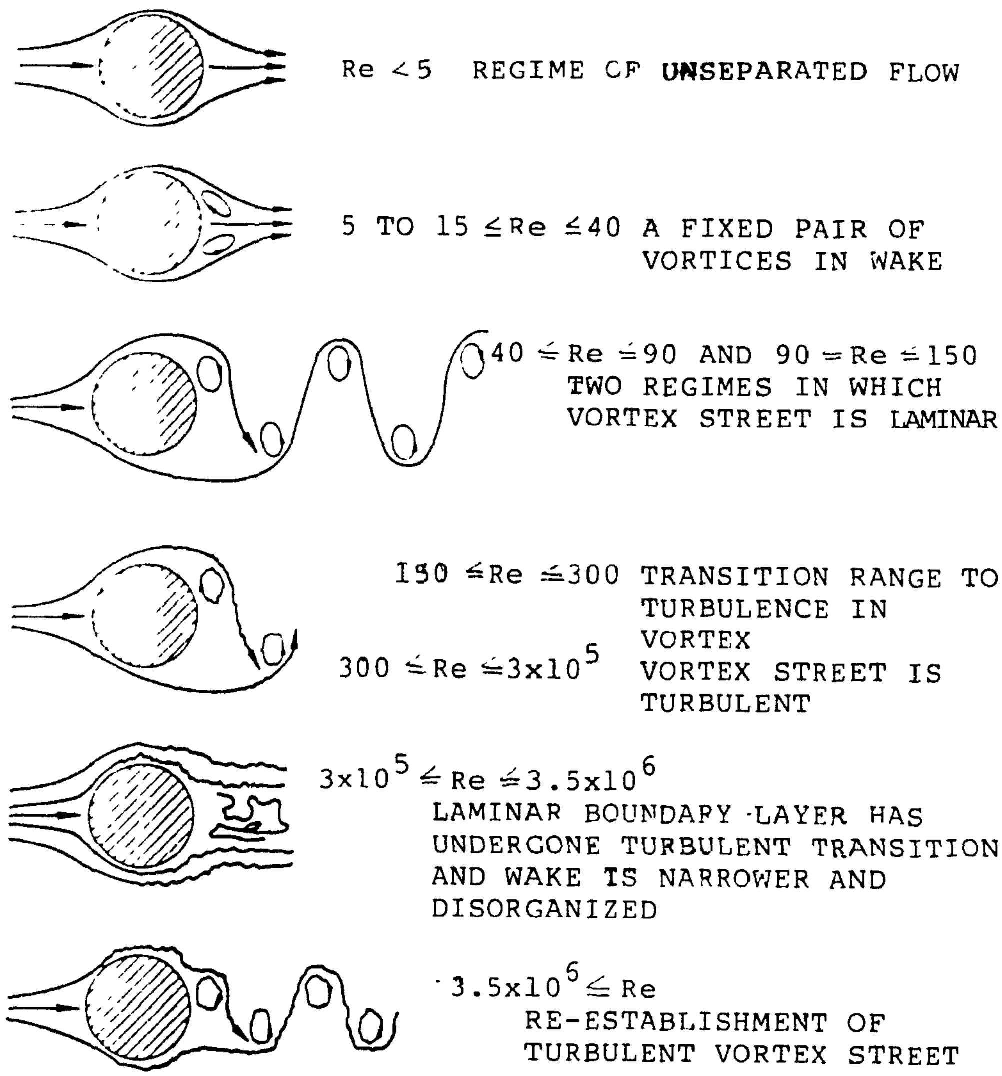


Figure 7. Major flow regimes for flow past a single stationary cylinder. (Blevins 1984).

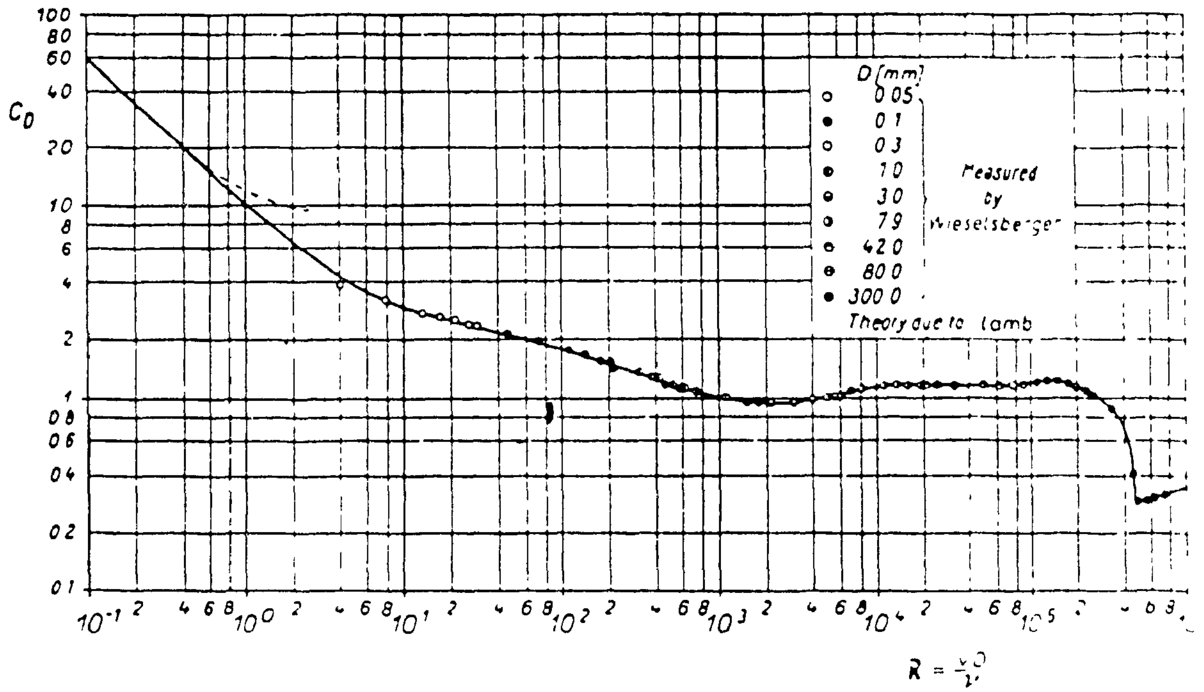


Figure 8. Drag coefficient for circular cylinder as a function of Reynolds number. (Schlichting 1979).

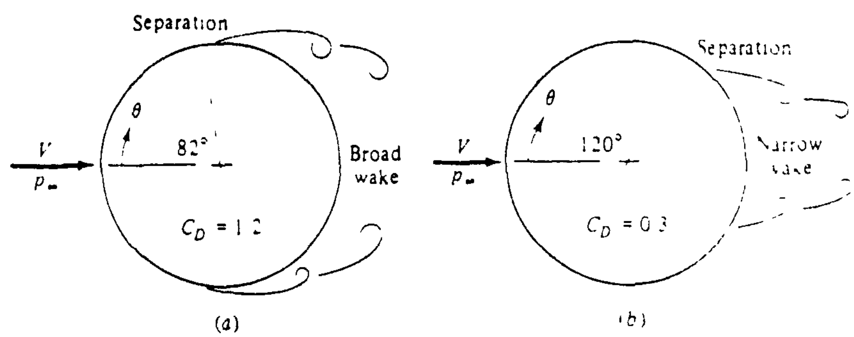


Figure 9. Flow past a circular cylinder: (a) laminar separation; (b) turbulent separation. (White 1979)

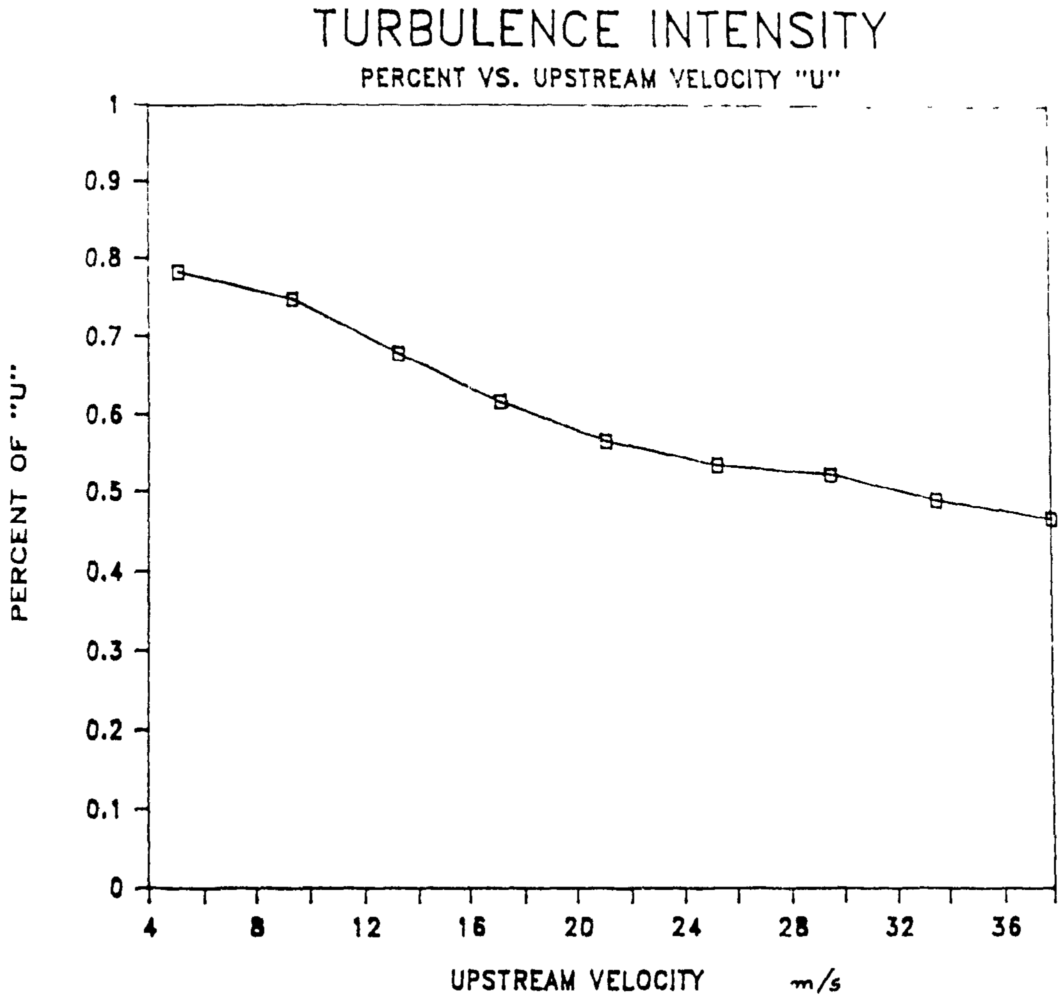


Figure 10. Calibration curve of turbulence intensity versus upstream velocity in the wind tunnel (Pinnell 1987).

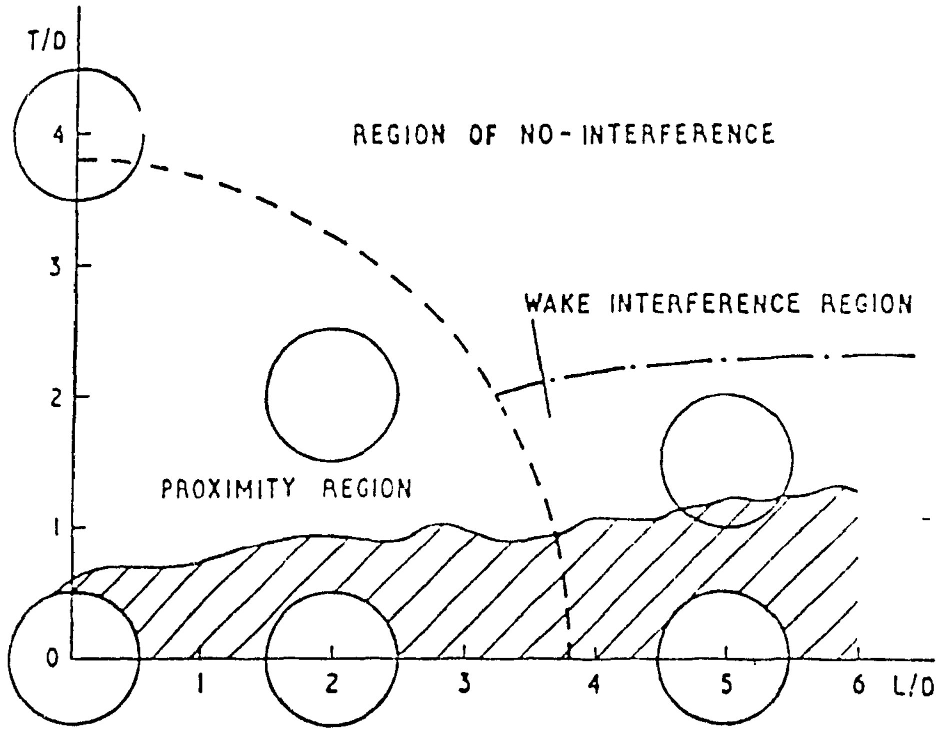


Figure 11. Clasification of interference regions (Blevins 1984).

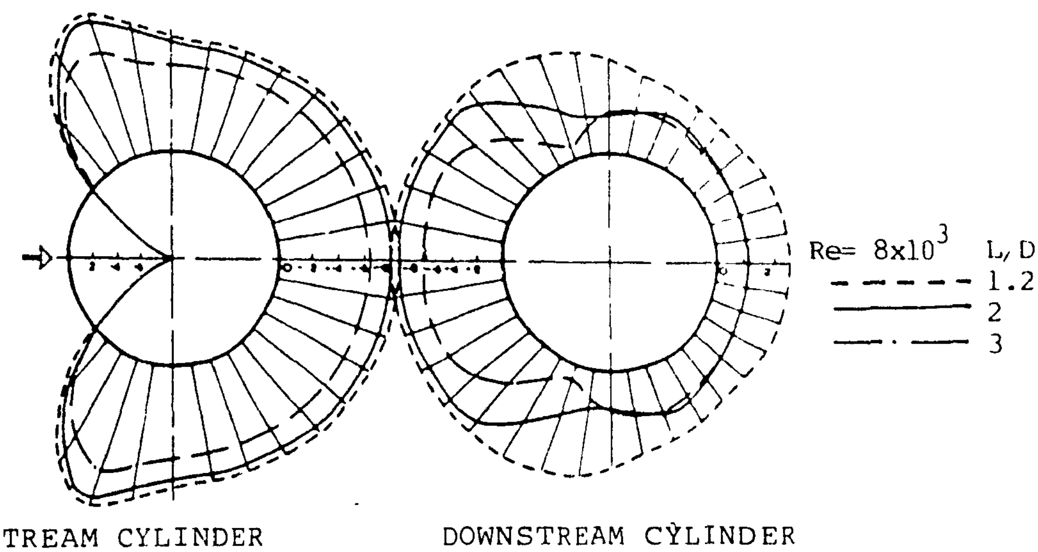


Figure 12. Pressure distribution around two cylinders in tandem arrangement (Zdravkovich 1977).

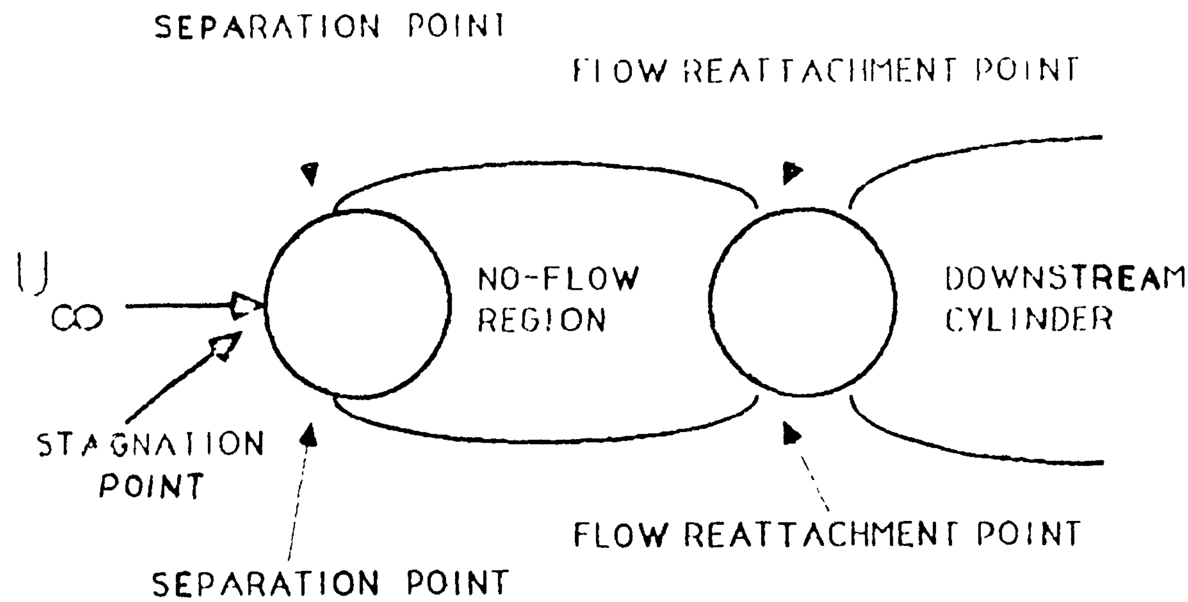


Figure 13. Flow past two stationary circular cylinders in a tandem arrangement (Pinnell 1987).

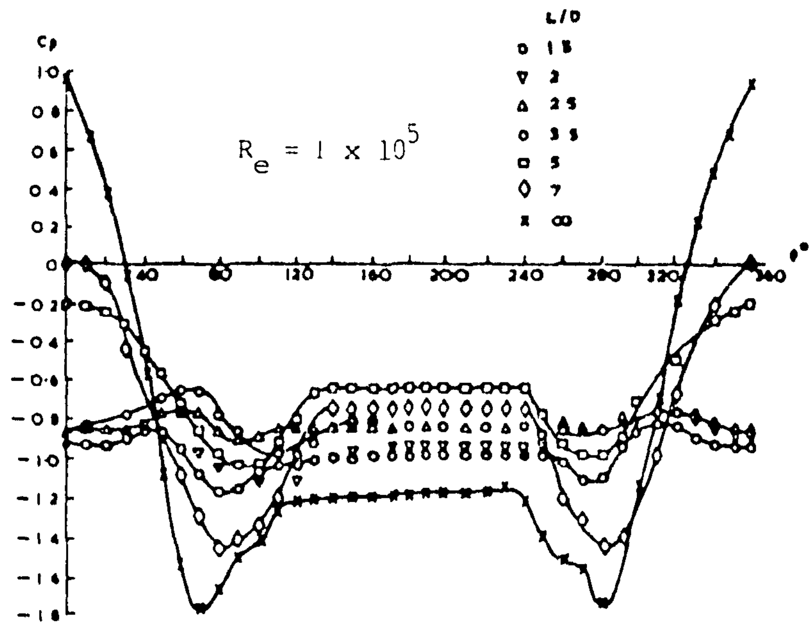


Figure 14. Pressure distribution around downstream cylinder in various tandem arrangements (Zdravkovich 1977).

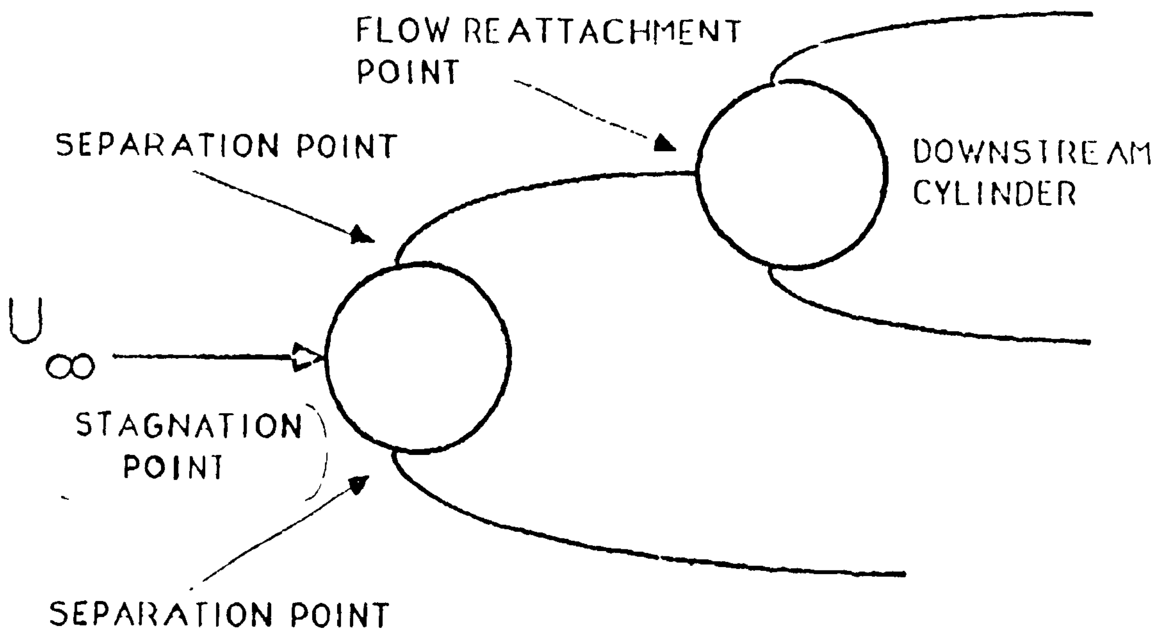


Figure 15. Flow past stationary circular cylinders in a staggered arrangement (Pinnell 1987).

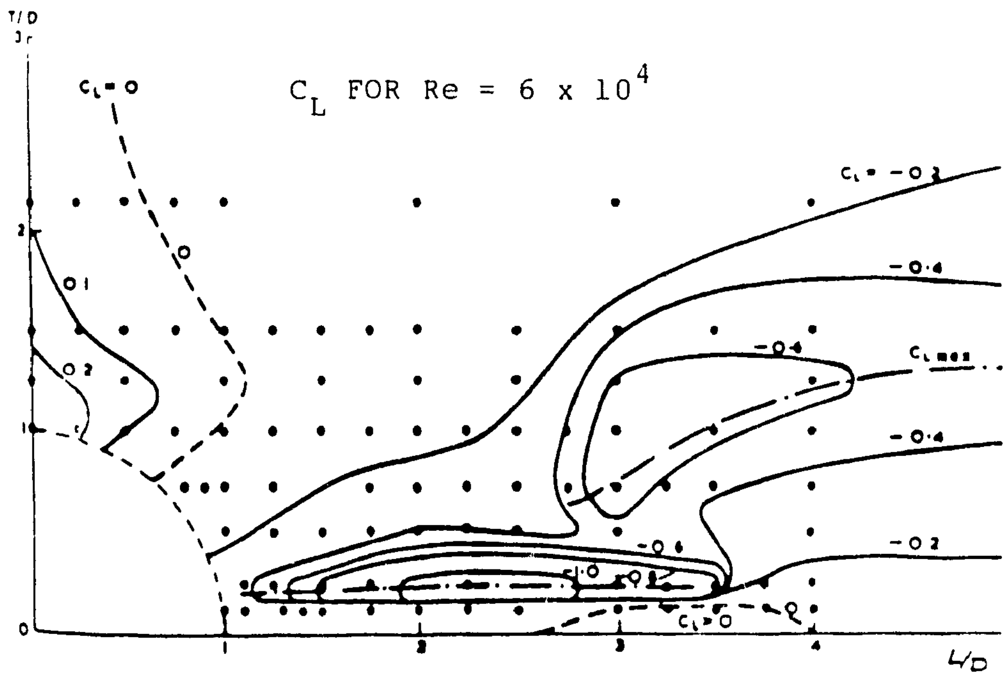


Figure 16. Lift force coefficient for downstream cylinder at Re = 6.1 x 10^4 (Zdravkovich 1977).

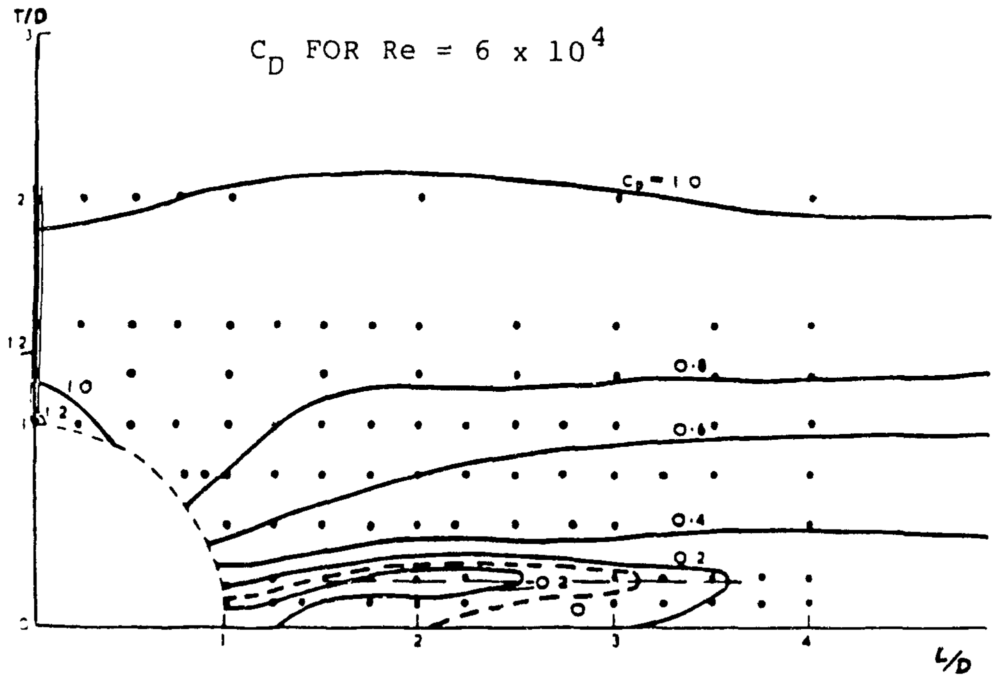


Figure 17. Drag coefficient for dowstream cylinder at Re = 6.1 x 10^4 (Zdravkovich 1977).

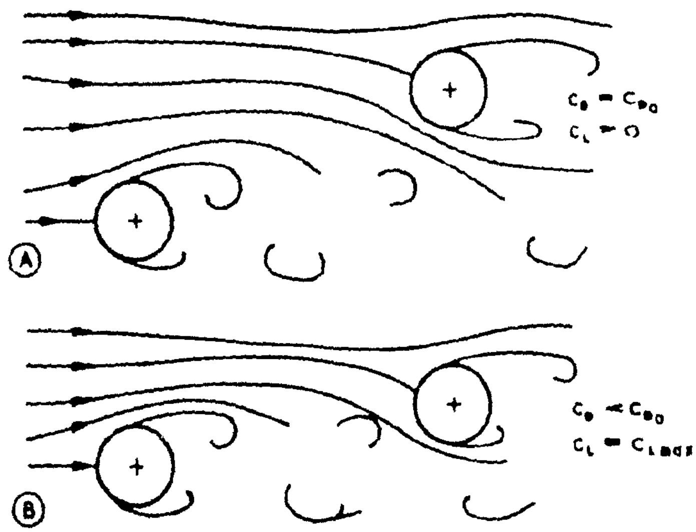
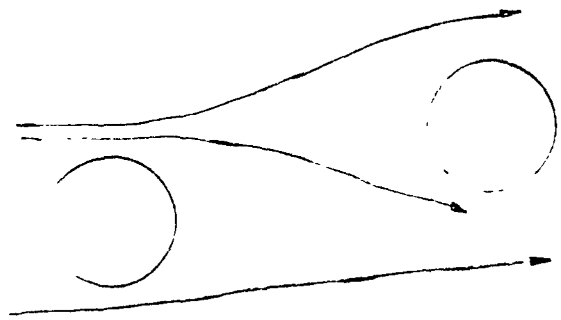
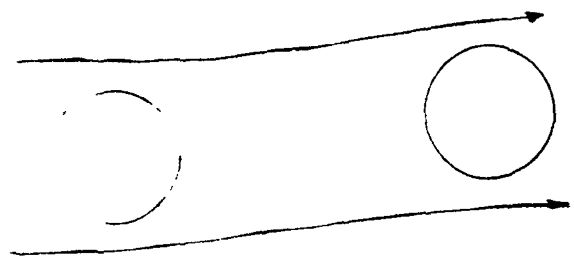


Figure 18. Sketch of flow patterns in staggered arrangement (Zdravkovich 1977).



Gap Flow Present



Gap Flow Not Present

Figure 19. Sketch of flow patterns in staggered arrangement causing inner lift peak.

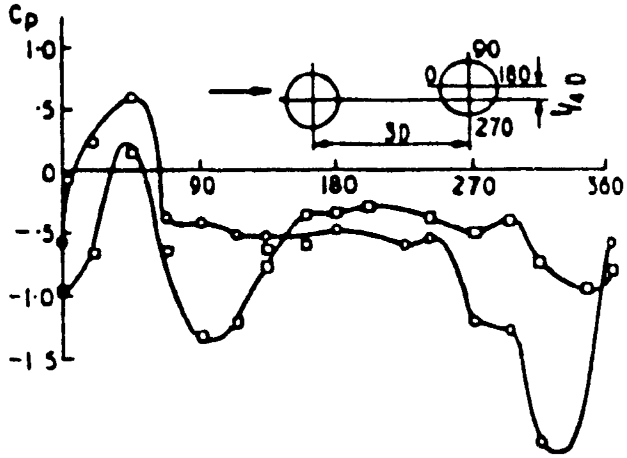


Figure 20. Pressure coefficient distribution for L/d=3 and T/d=1/4 (R_e=6.1x10^4) according to Zdravkovich and Pridden (1977).

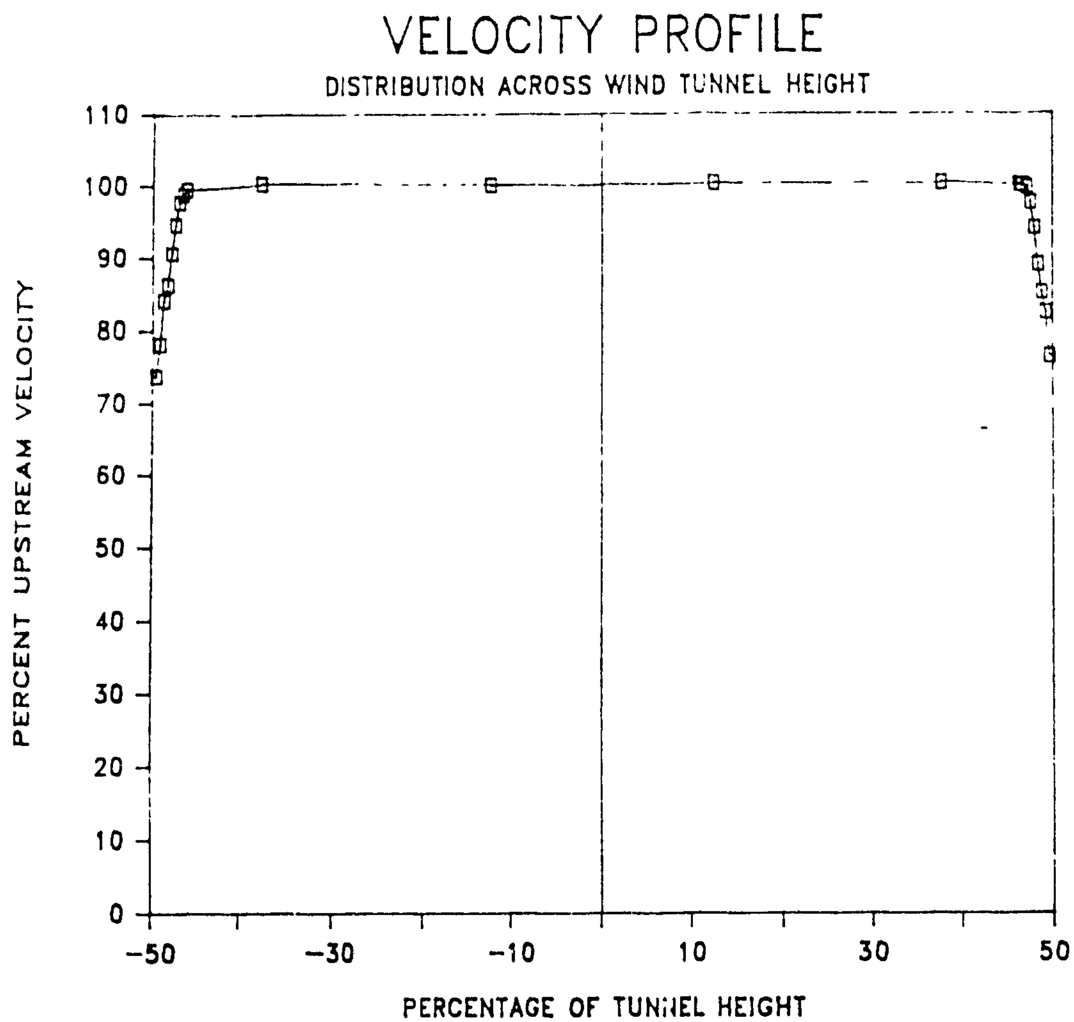


Figure 21. Velocity distribution across the wind tunnel height measured by Pinnell (1987).

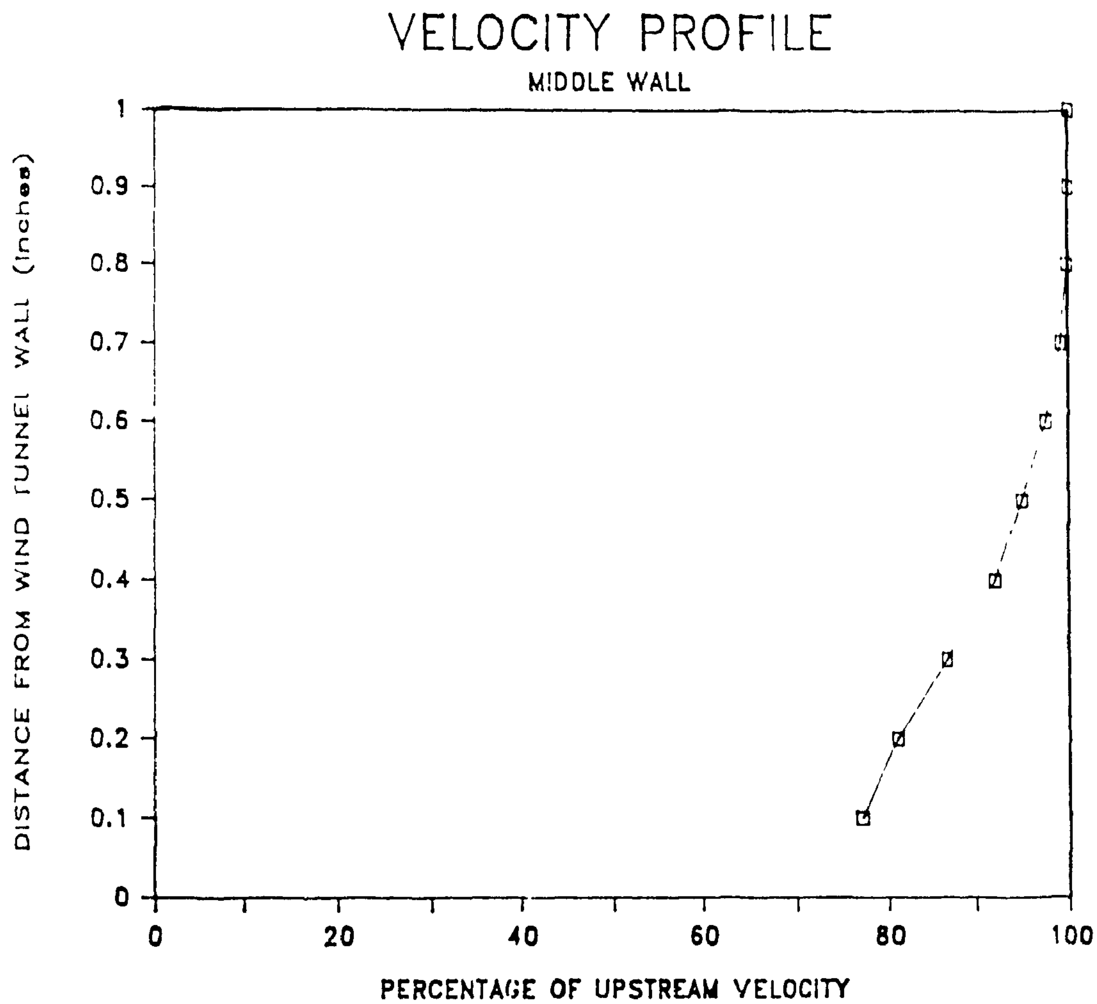
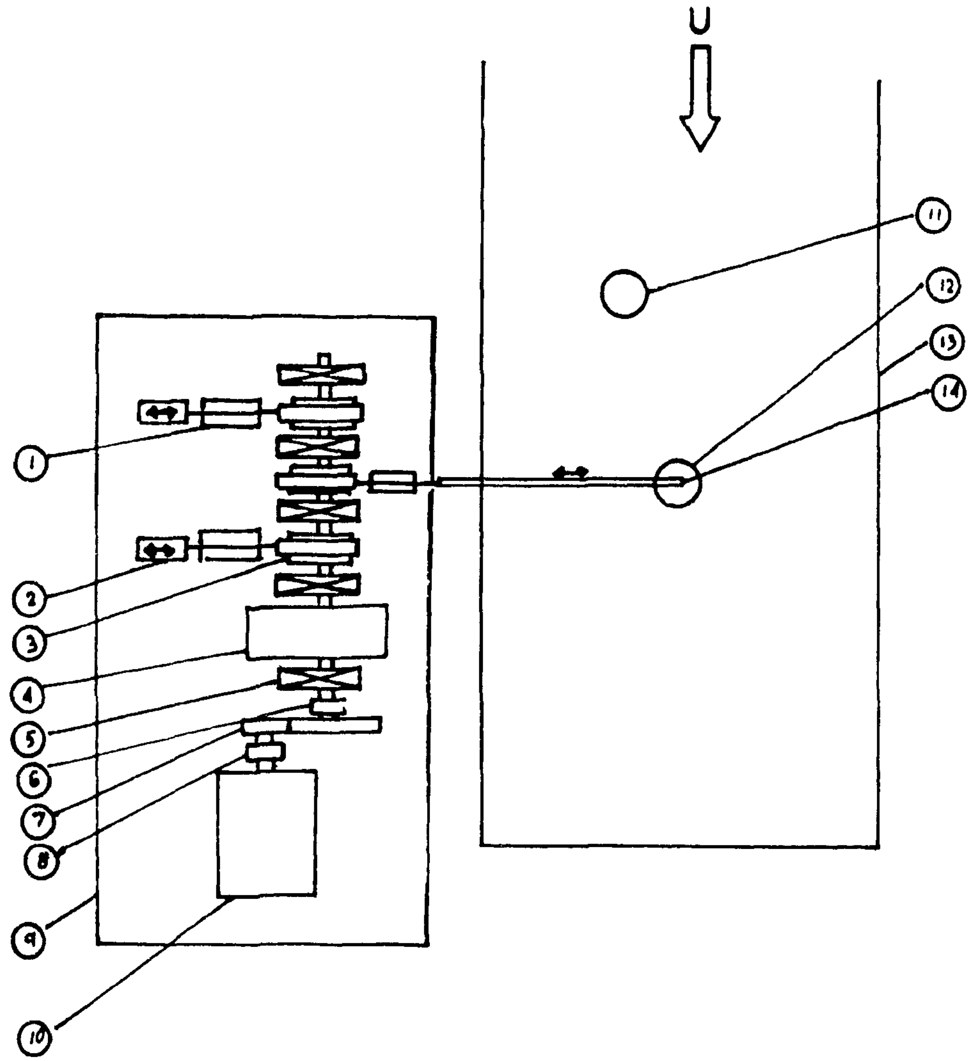
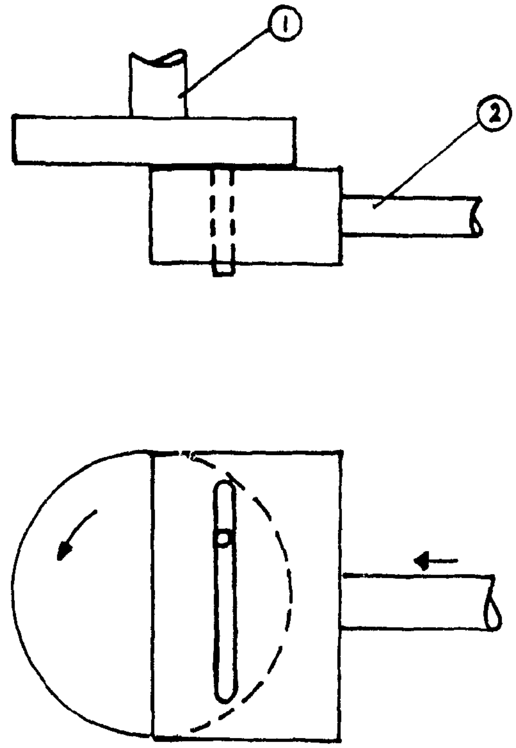


Figure 22. Calibration curve of the distance from the wind tunnel wall versus the percentage of upstream velocity as measured by Pinnell (1987).



1	LINEAR BEARING	8	FLEXIBLE COUPLING
2	COUNTERWEIGHT	9	SHAKER BASE
3	SCOTCH YOKE	10	MOTOR
4	FLYWHEEL	11	UPSTREAM CYLINDER
5	BALL BEARING	12	DOWNSTREAM CYLINDER
6	FLEXIBLE COUPLING	13	WIND TUNNEL
7	GEAR REDUCER	14	SHAKER YOKE

Figure 23. Schematic diagram of shaker mechanism.



1 CRANKSHAFT
2 CONNECTING ROD TO SHAKER YOKE

Figure 24. Scotch yoke mechanism.

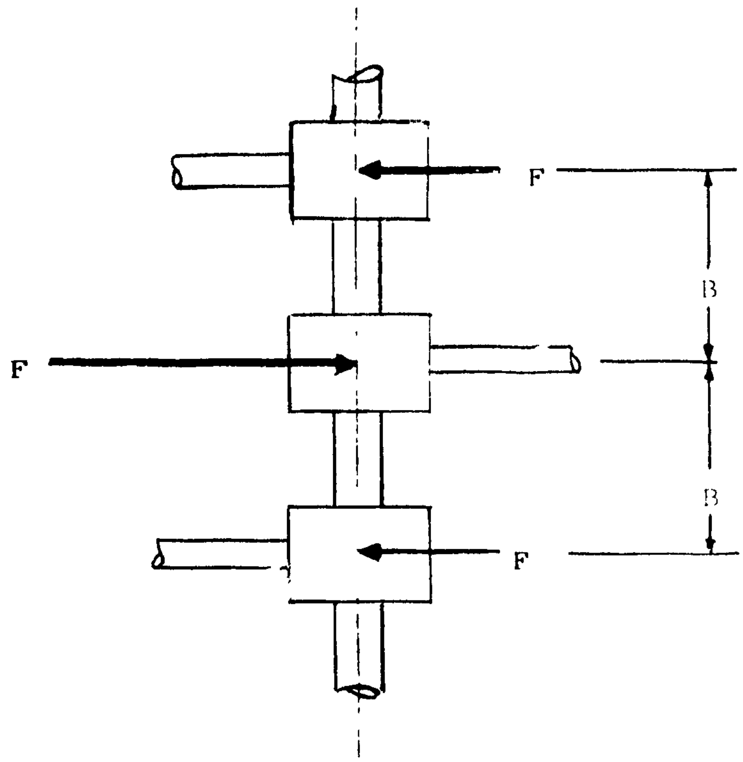


Figure 25. Forces acting between scotch yoke mechanism and crankshaft.

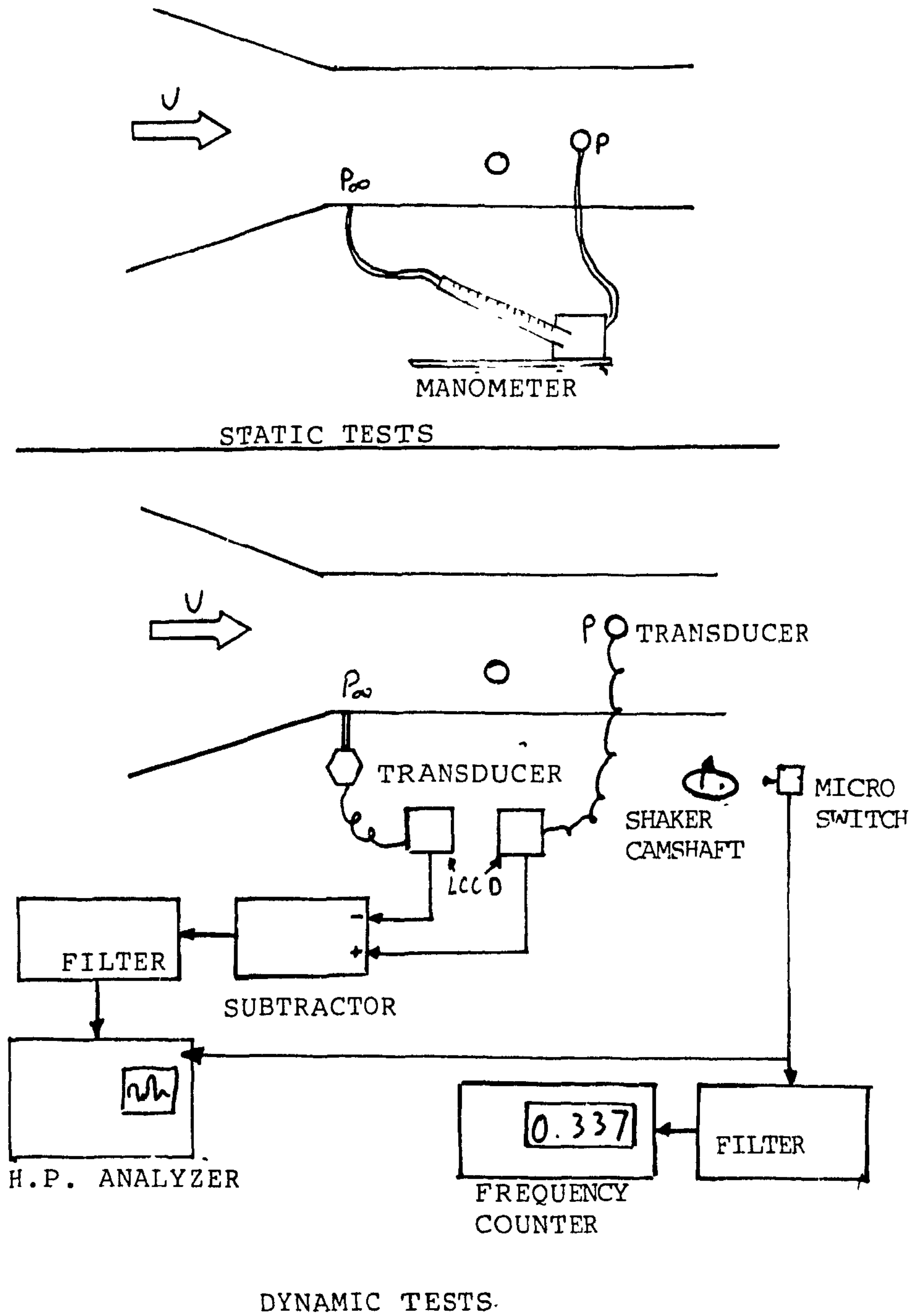


Figure 26. Schematic of instrumentation setup.

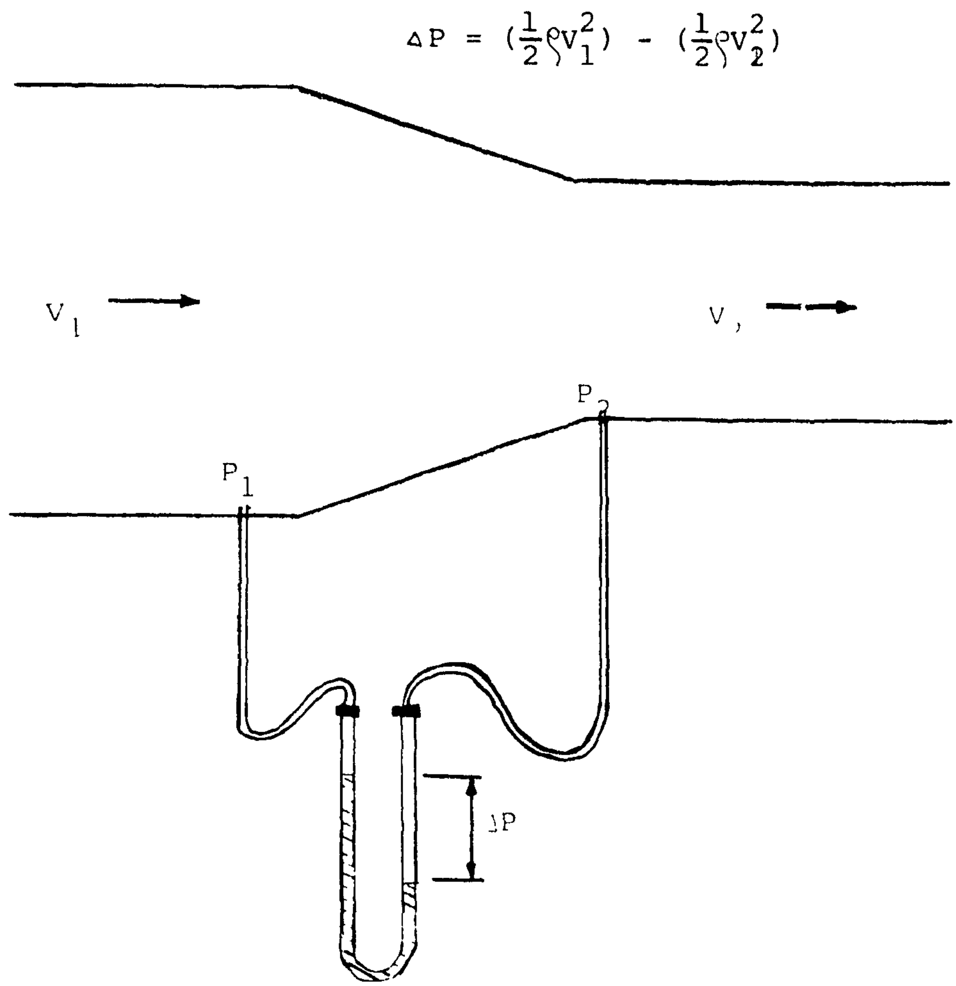


Figure 27. Schematic of wind tunnel speed measurement.

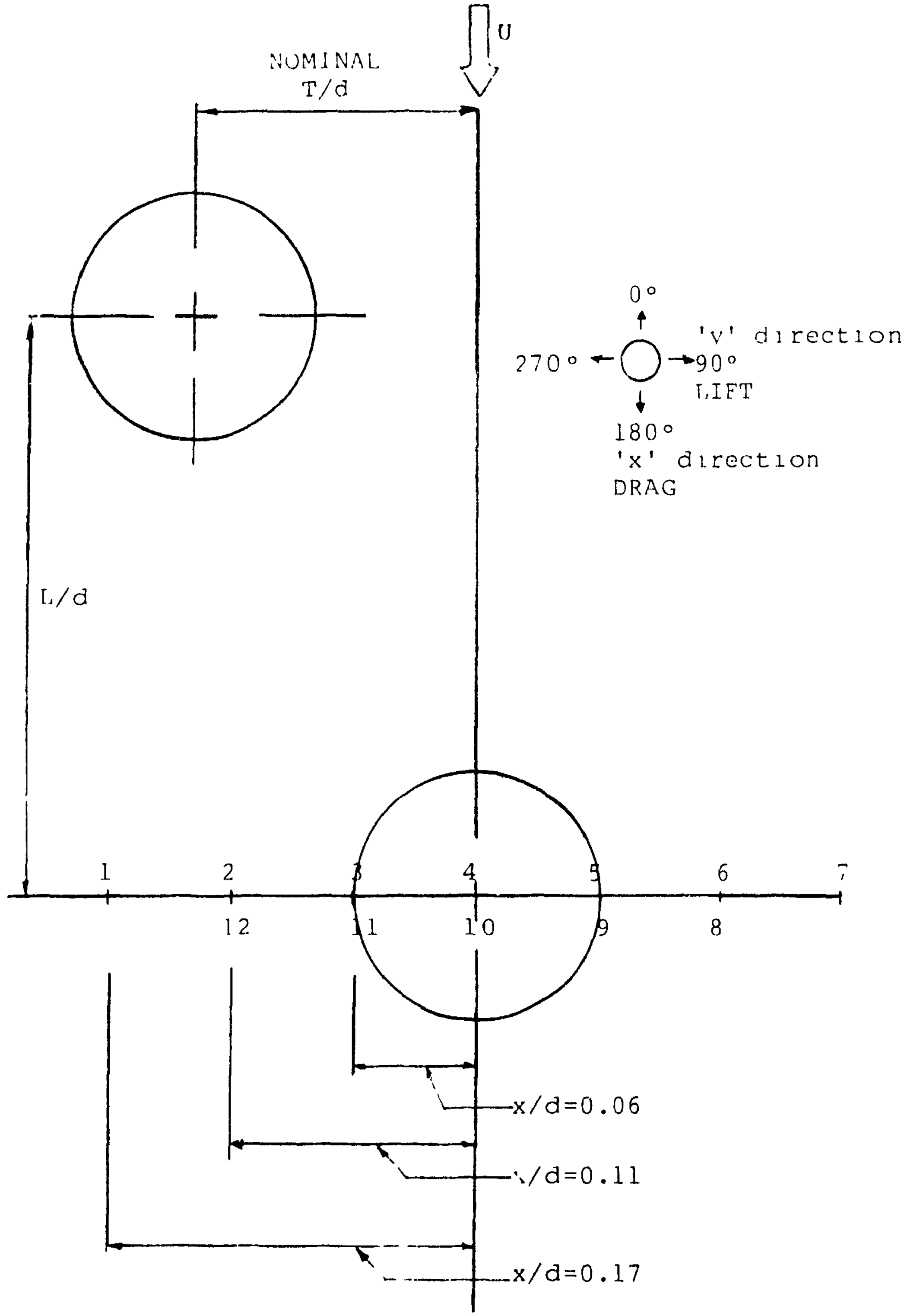


Figure 28. Schematic showing the 7 general positions where static tests were done.

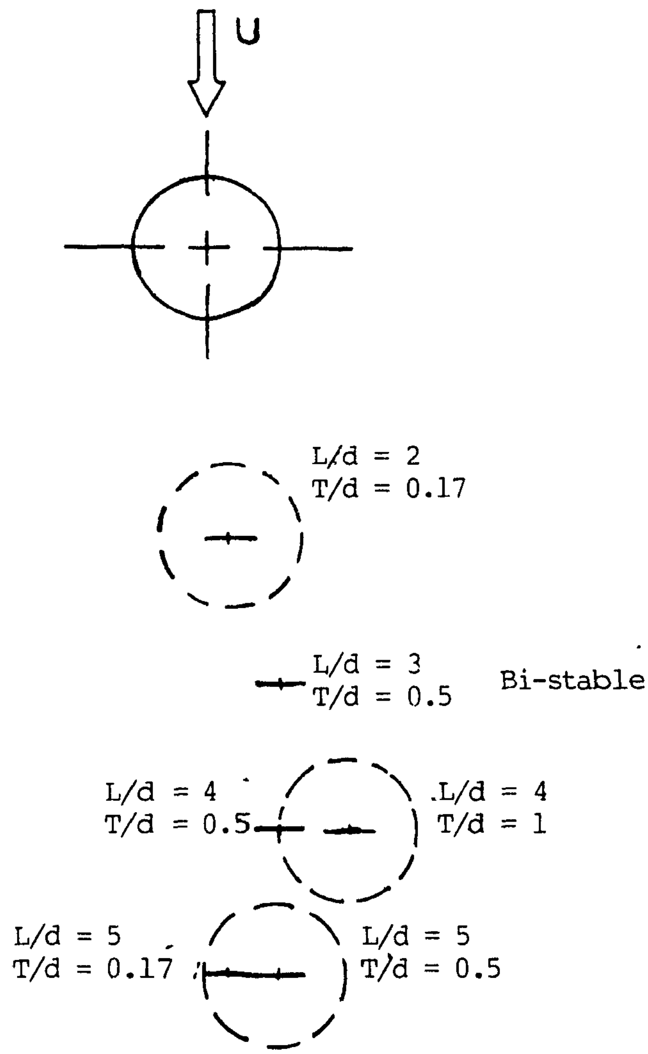


Figure 29. Schematic of L/d and T/d locations where dynamic tests were done.

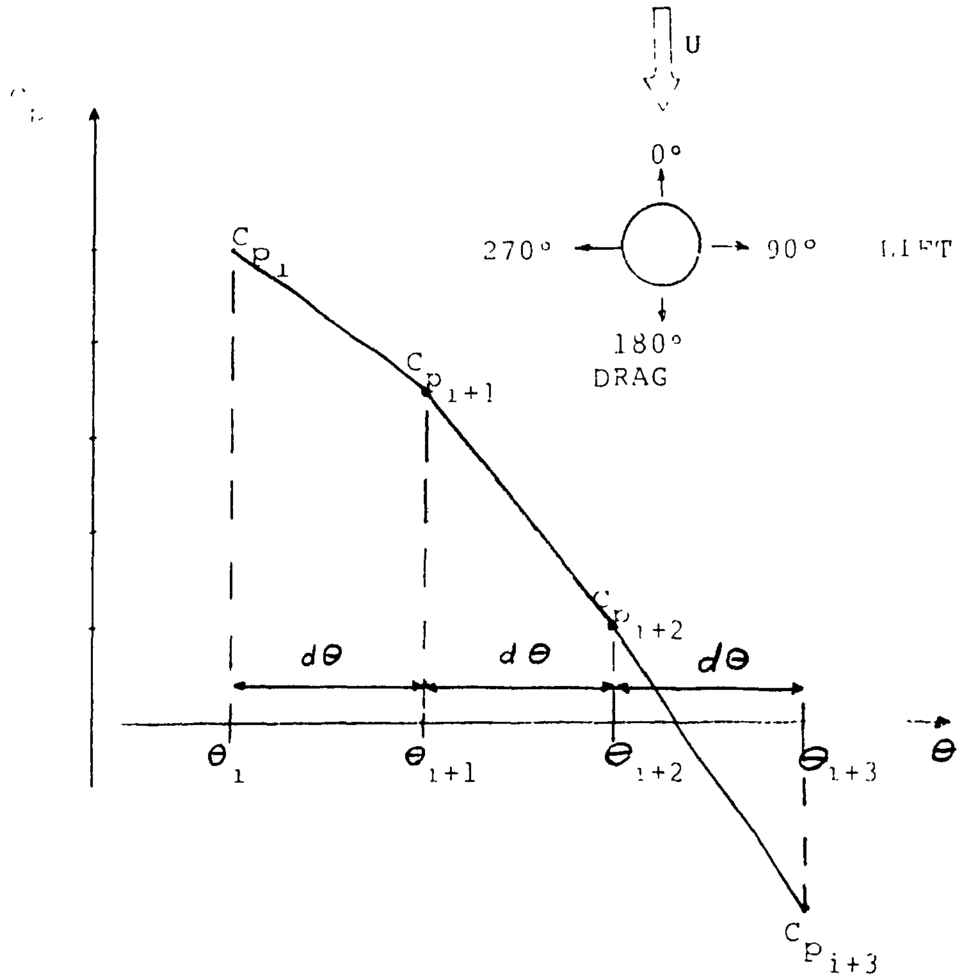
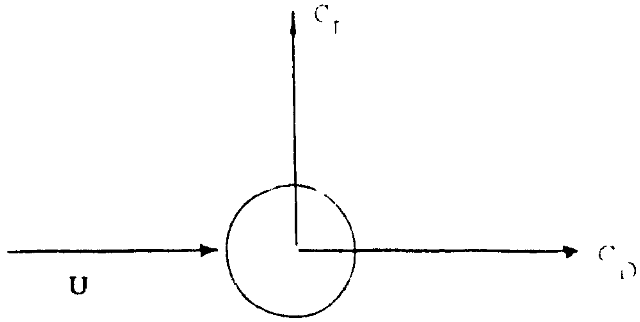
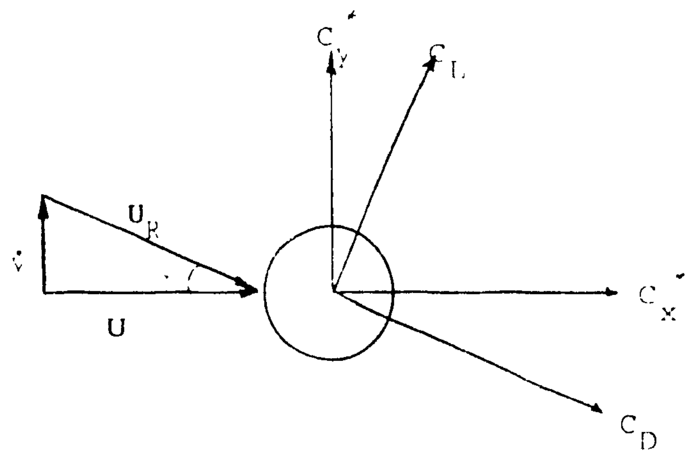


Figure 30. Graphic relationship between drag and lift coefficients and the pressure coefficient.



Lift coefficient C_L and drag coefficient C_D for a static cylinder.



Lift coefficient C_L and drag coefficient C_D produced by resultant velocity $\mathbf{U}_R$ acting on a cylinder moving with velocity $\dot{y}$.

$$C_x^* = (U_R^2 \ / \ U^2)\ (C_D \cos\alpha + C_L \sin\alpha)$$

$$C_y^* = (U_R^2 \ / \ U^2)\ (C_L \cos\alpha - C_D \sin\alpha)$$

Figure 31. Relationship between static and quasi-static force coefficients.

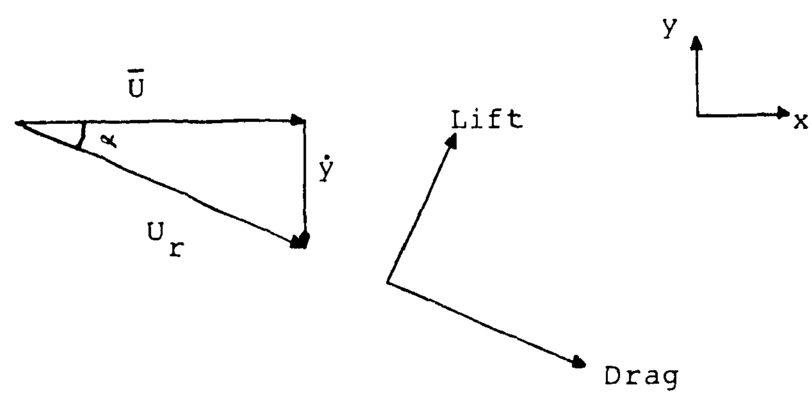


Figure 32. Lift and drag forces acting on a body as a result of local wake velocity $\bar{U}$.

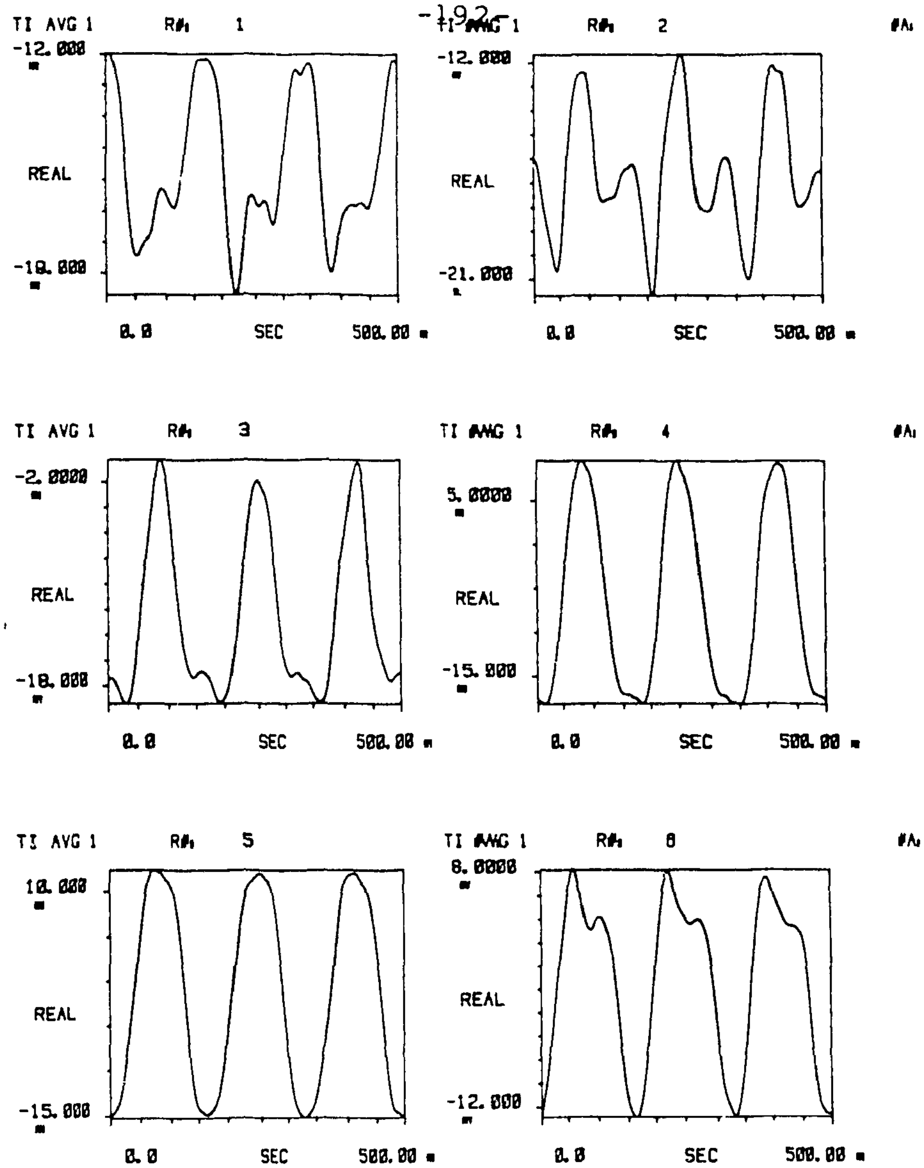


Figure 33. Typical pressure traces recorded by 5420 Digital Signal Analyzer for six points on an oscillating cylinder. V = 15m/s, L/d = 2, T/d = 0.17, and $\Theta = 0^{\circ}$ to 60°.

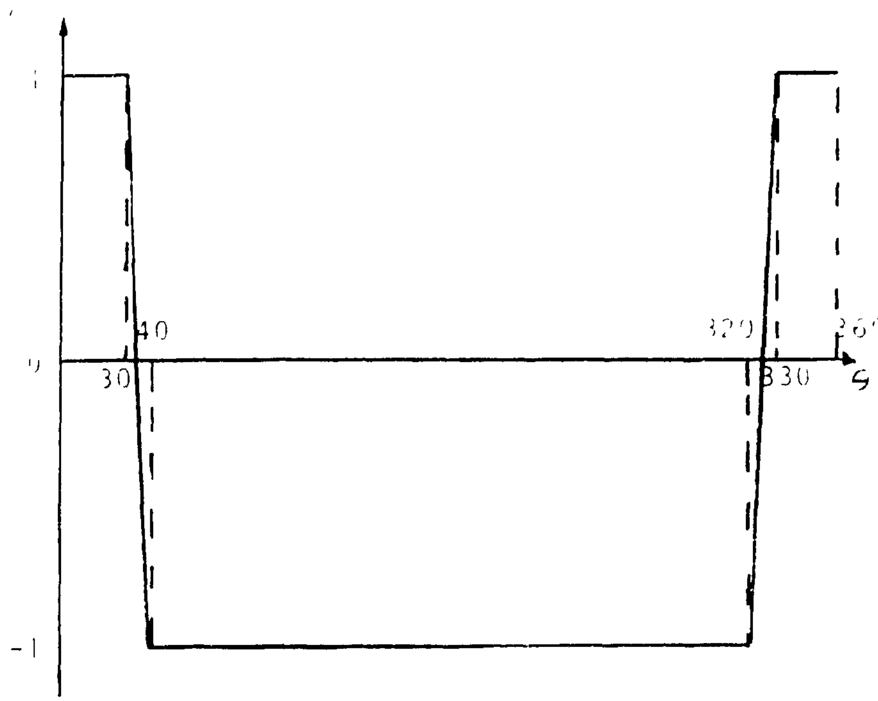


Figure 34. Idealized pressure distribution on a cylinder surface, used to check program CDCL1.BAS.

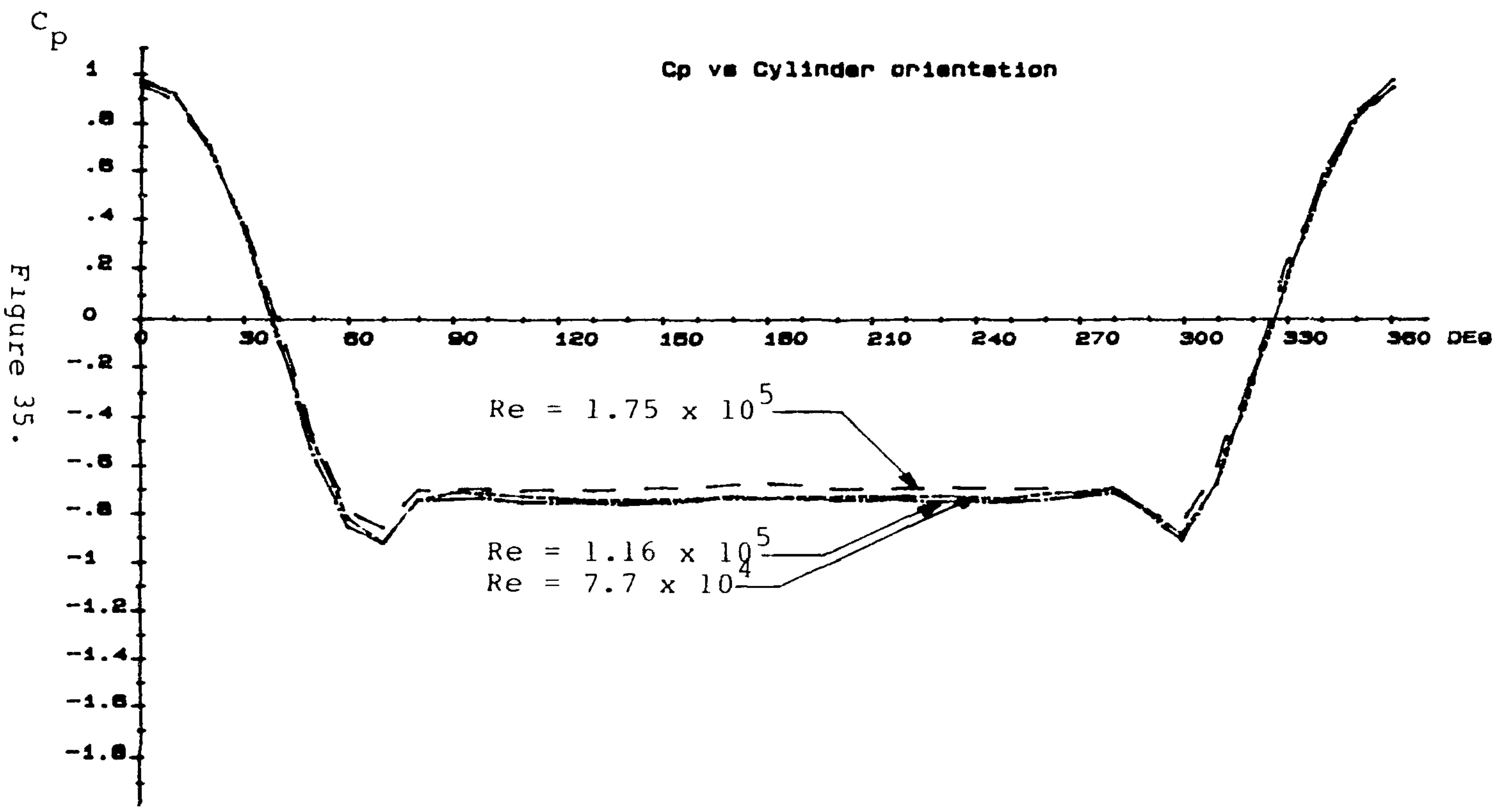


Figure 35.

Pressure coefficient versus cylinder position for single static cylinder at various Re.

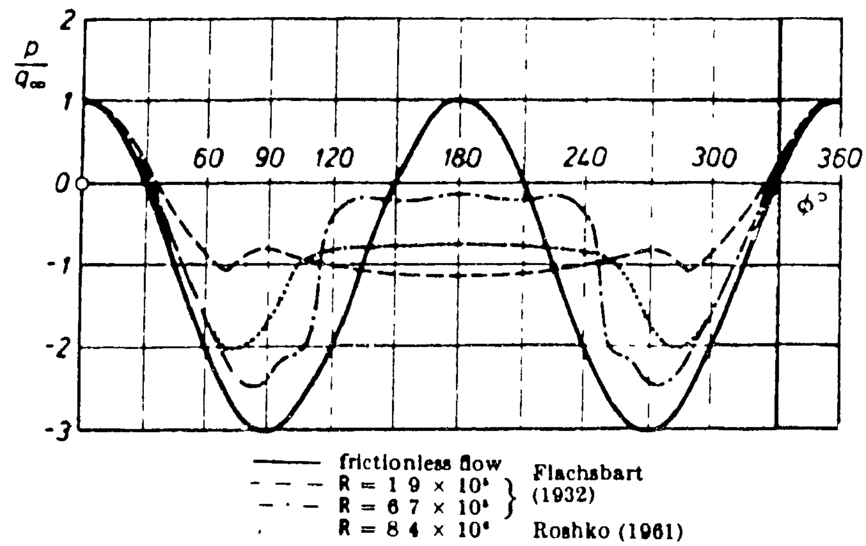
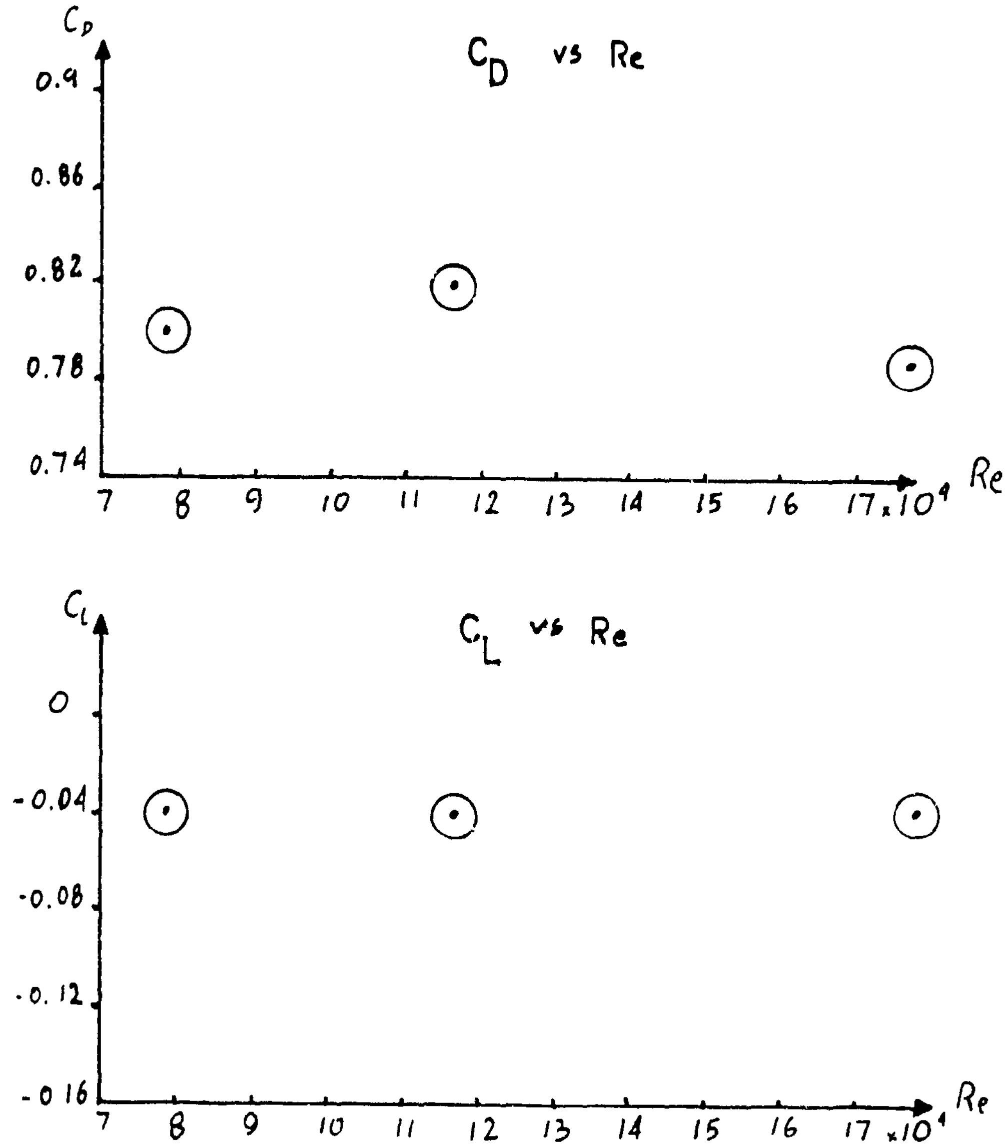
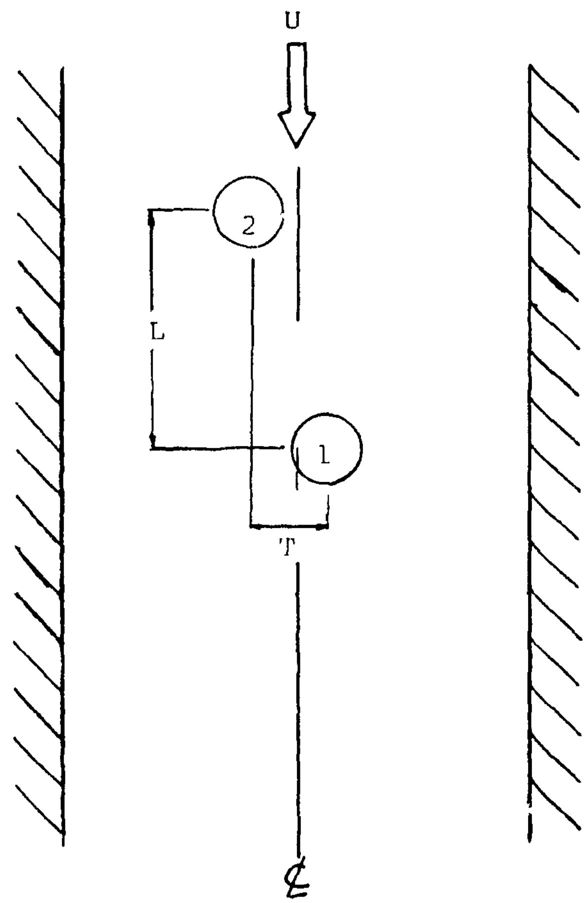


Figure 36. Pressure distribution on a circular cylinder in the subcritical range of Reynolds numbers. Ref: Schlichting (1979).



Drag coefficient versus Re, and lift coefficient versus Re.
Single cylinder, static tests.

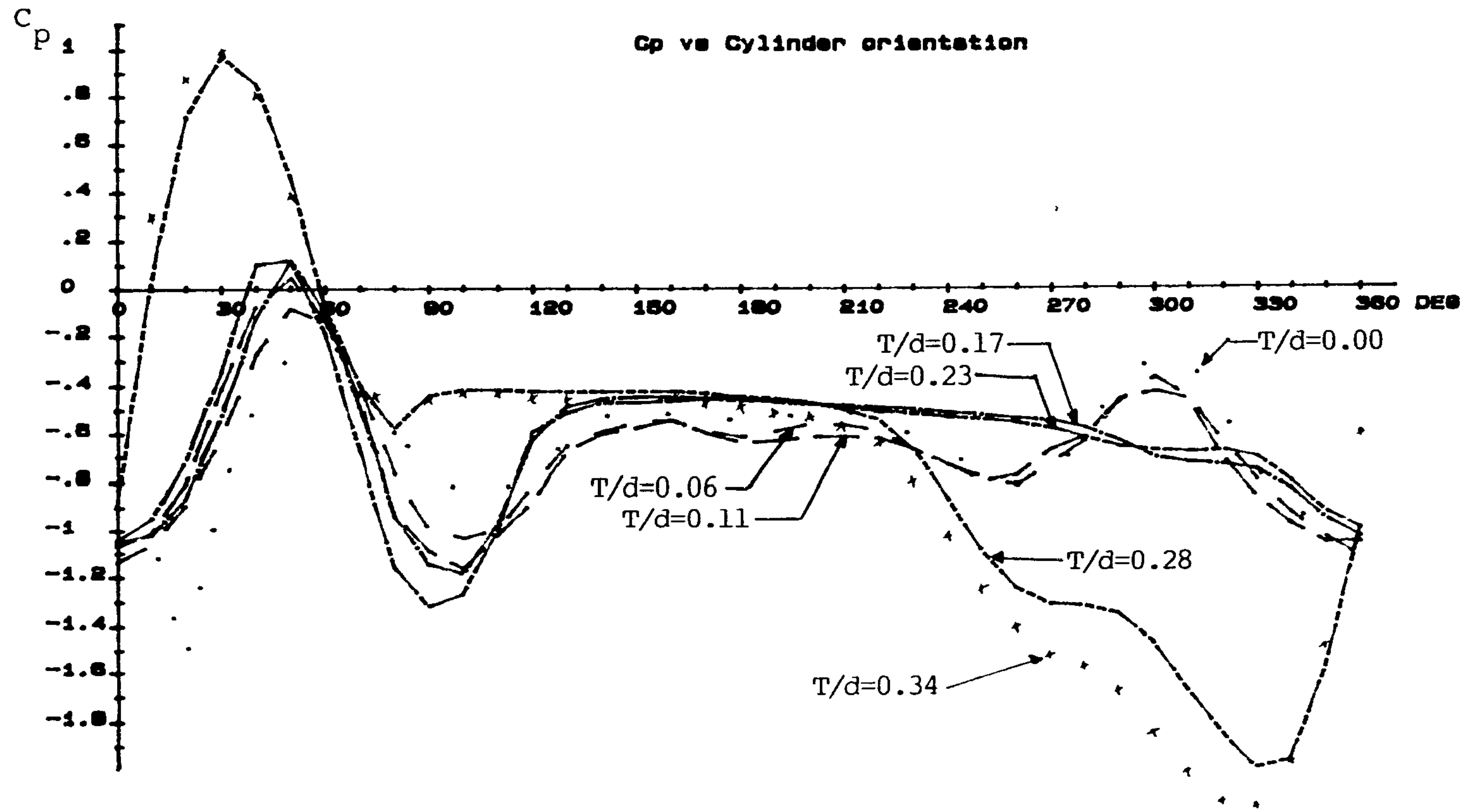
Figure 37.



Only cylinder 1 was present in the wind tunnel for single cylinder tests.
Cylinder 2 was added for tests on staggered cylinders.

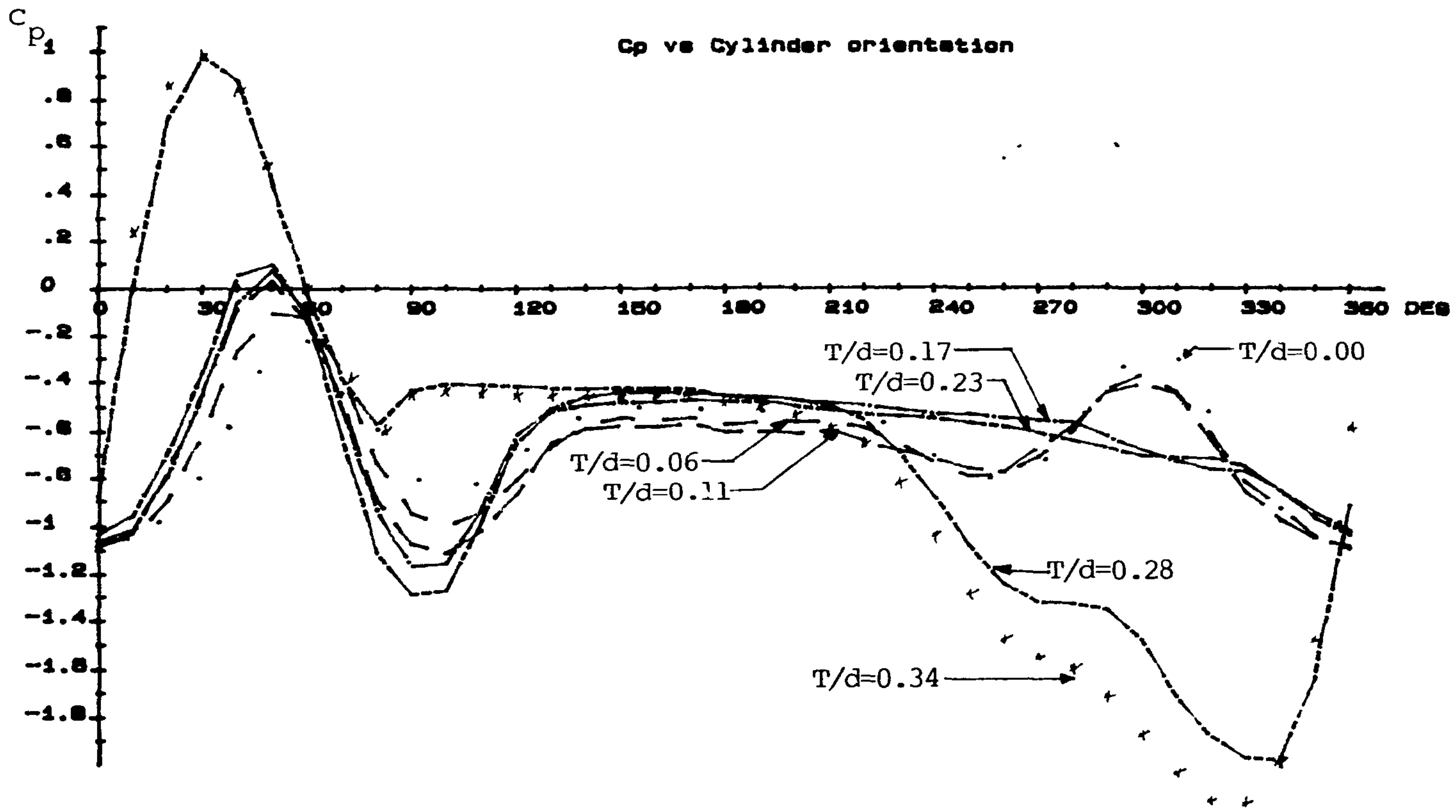
Figure 38. Cylinder arrangement - Top view.

Figure 39.

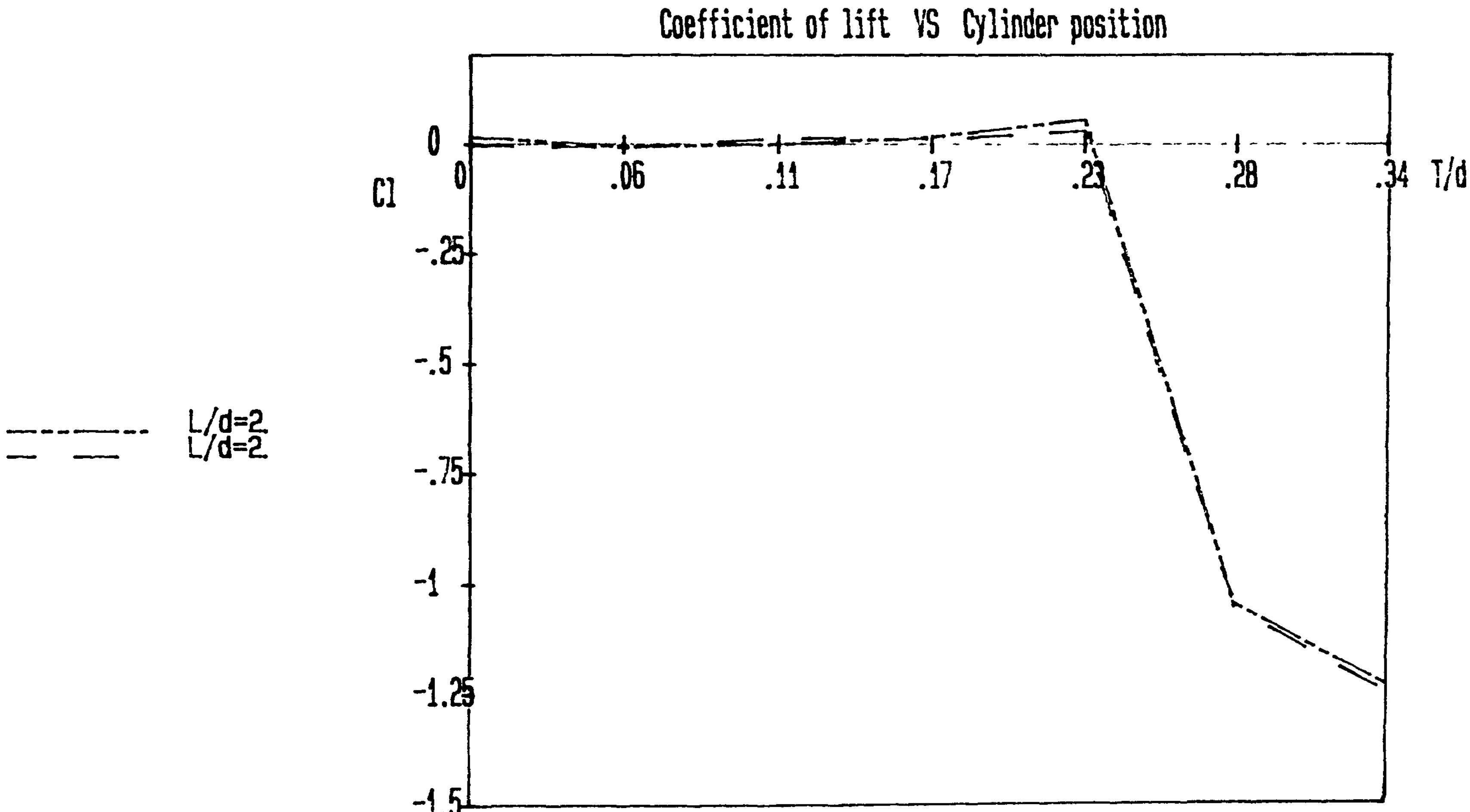


Pressure coefficient versus angular position on cylinder surface.
Staggered cylinders at L/d=2.

Figure 40.

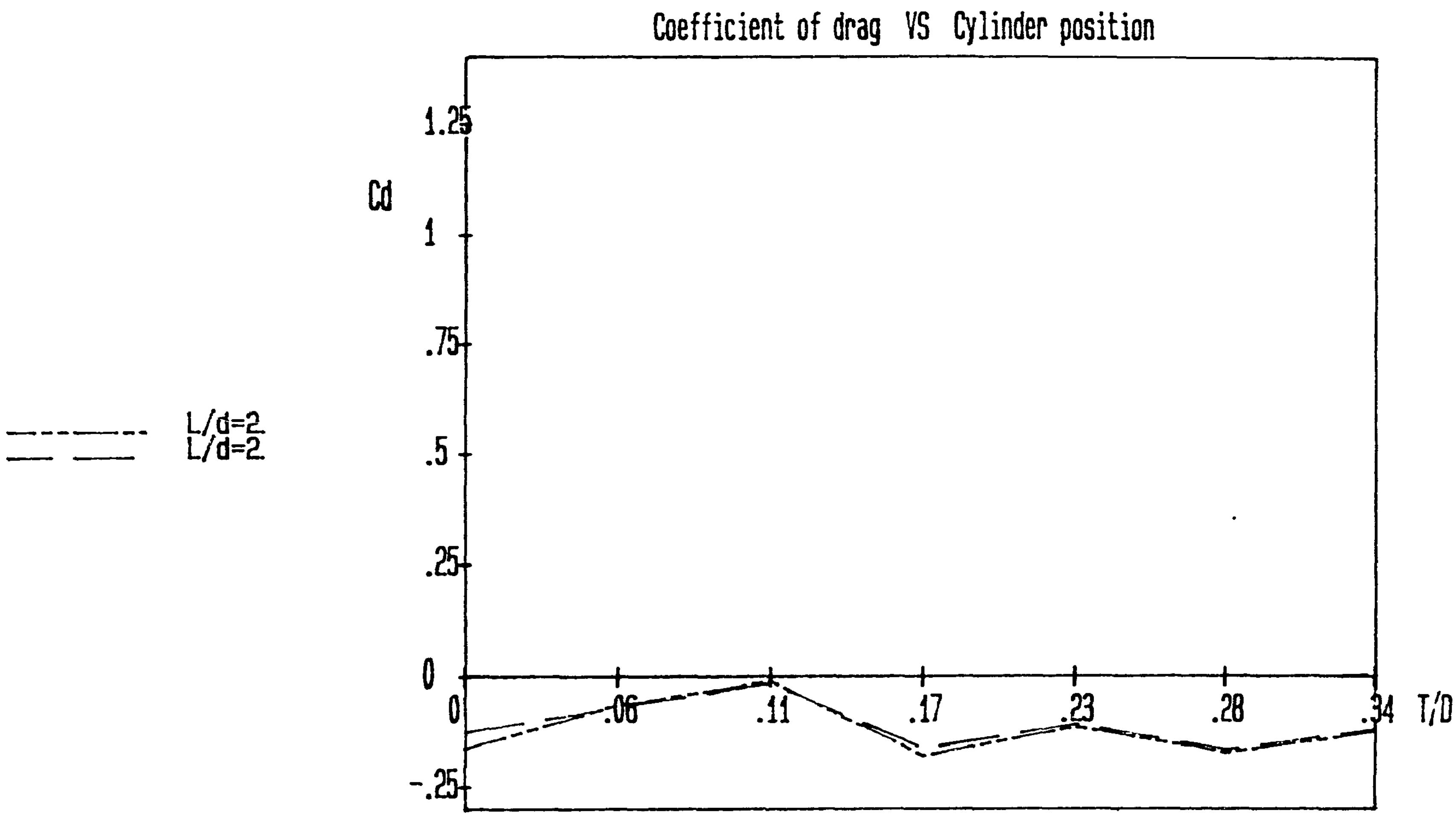


Pressure coeffient versus angular position on cylinder surface. Staggered cylinders at L/d=2. This experiment was identical to the one shown in figure 38. It was repeated to verify repeatability of results.



Coefficient of lift versus cylinder position. Two static tests at L/d=2.

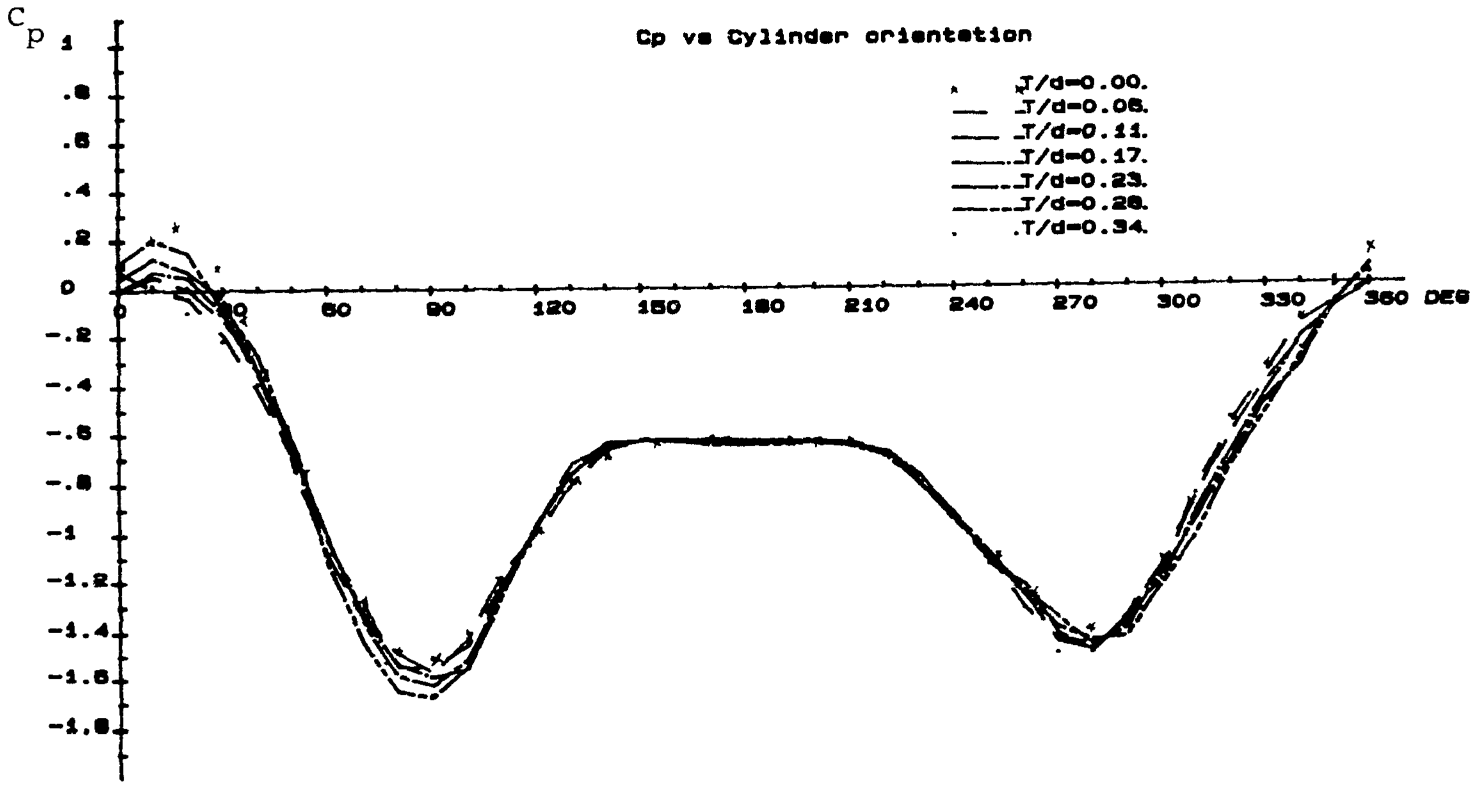
Figure 41.



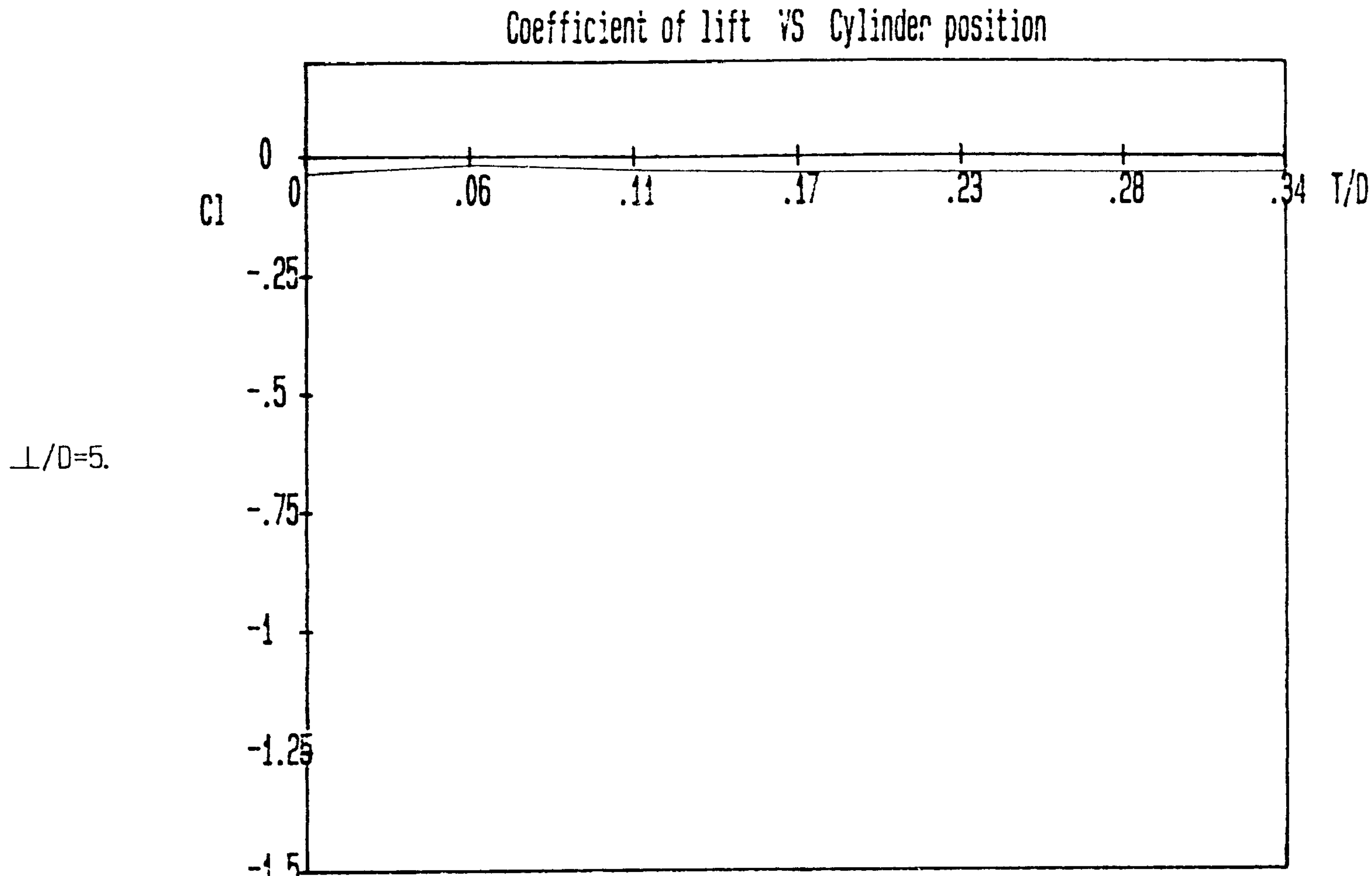
Coefficient of drag versus cylinder position. Two static tests at L/d=2.

Figure 42.

Figure 43.

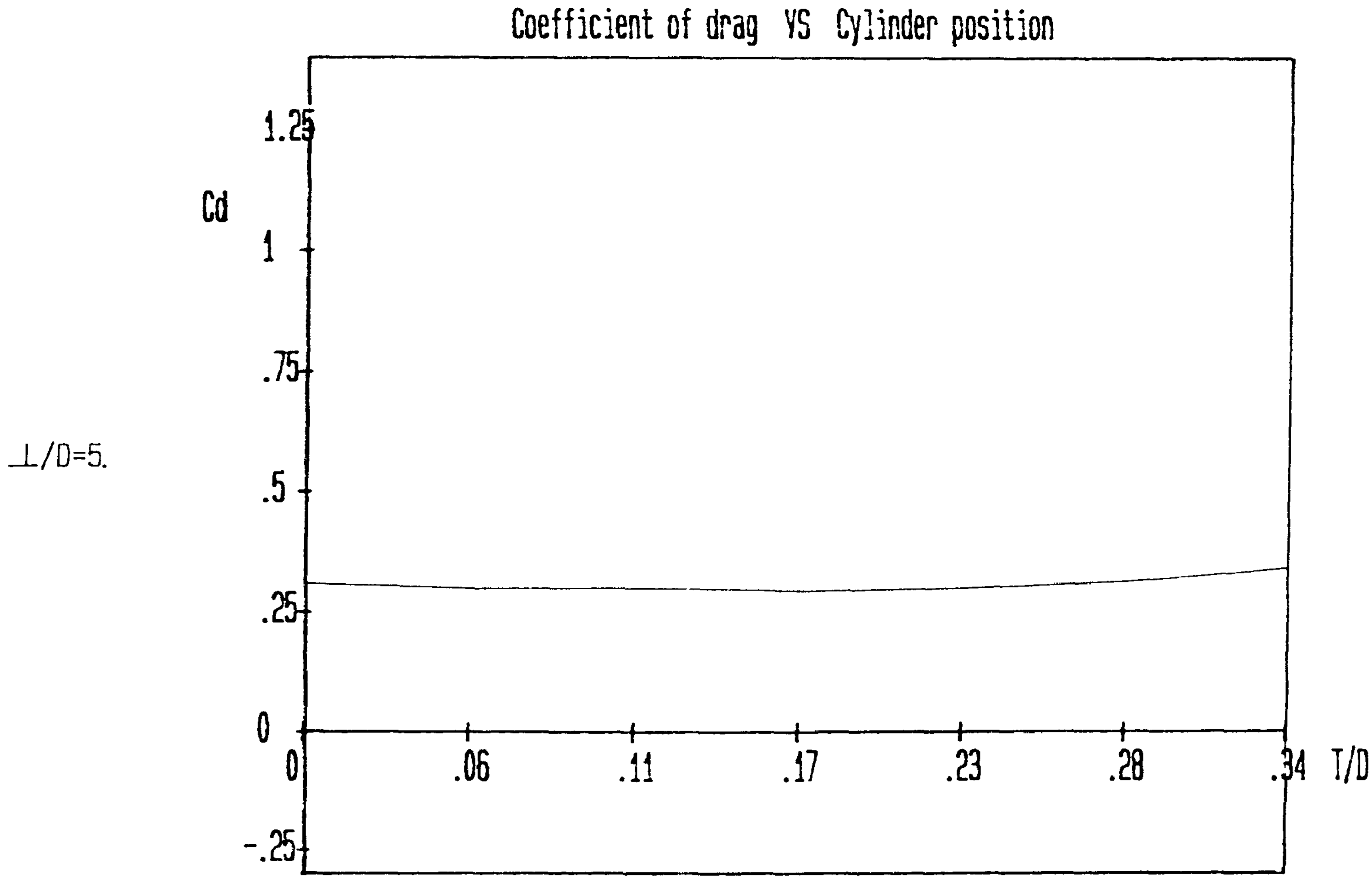


Pressure coefficient versus angular position on the leeward cylinder at L/d=5.



Coefficient of lift versus cylinder position. Static tests at L/D=5.

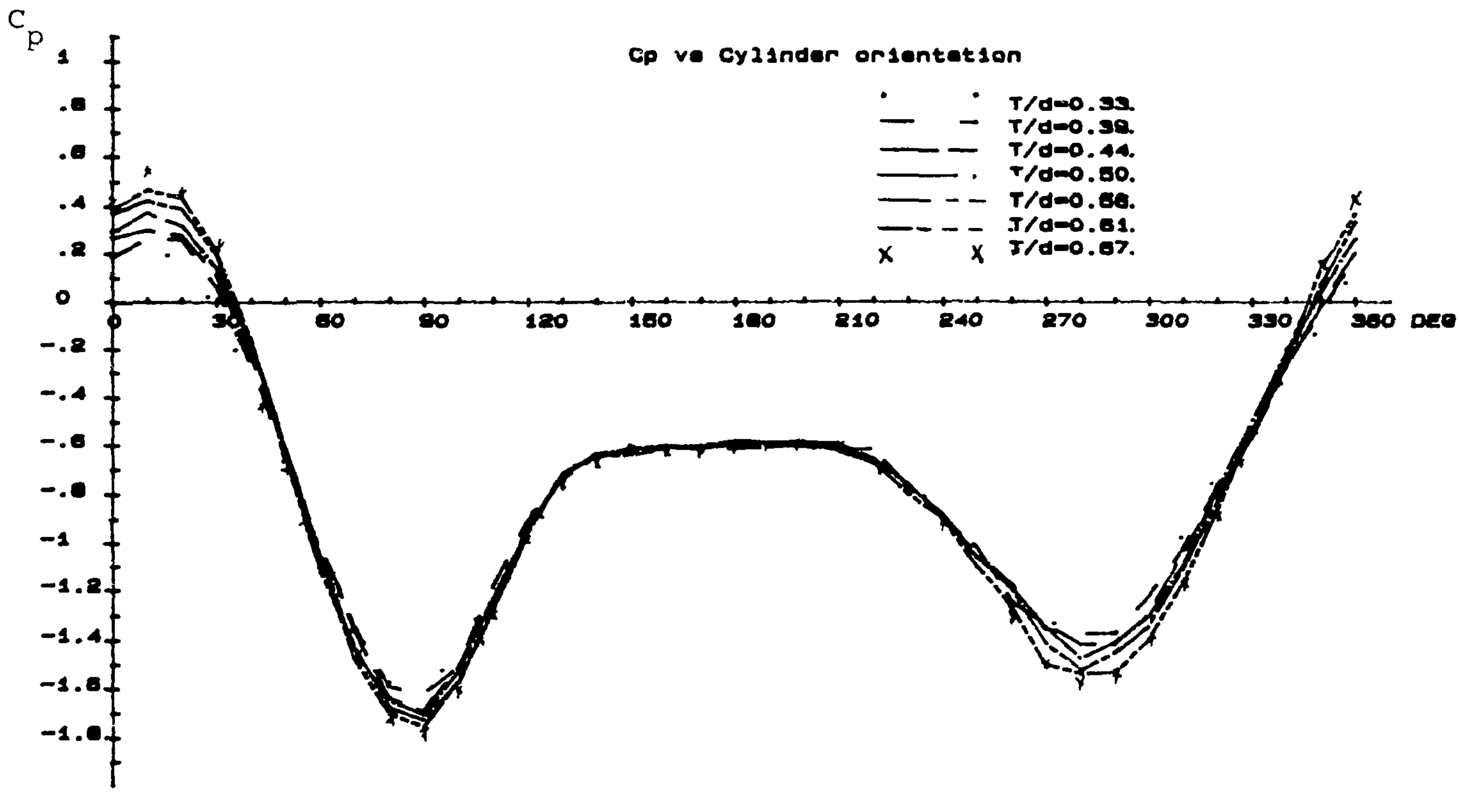
Figure 44.



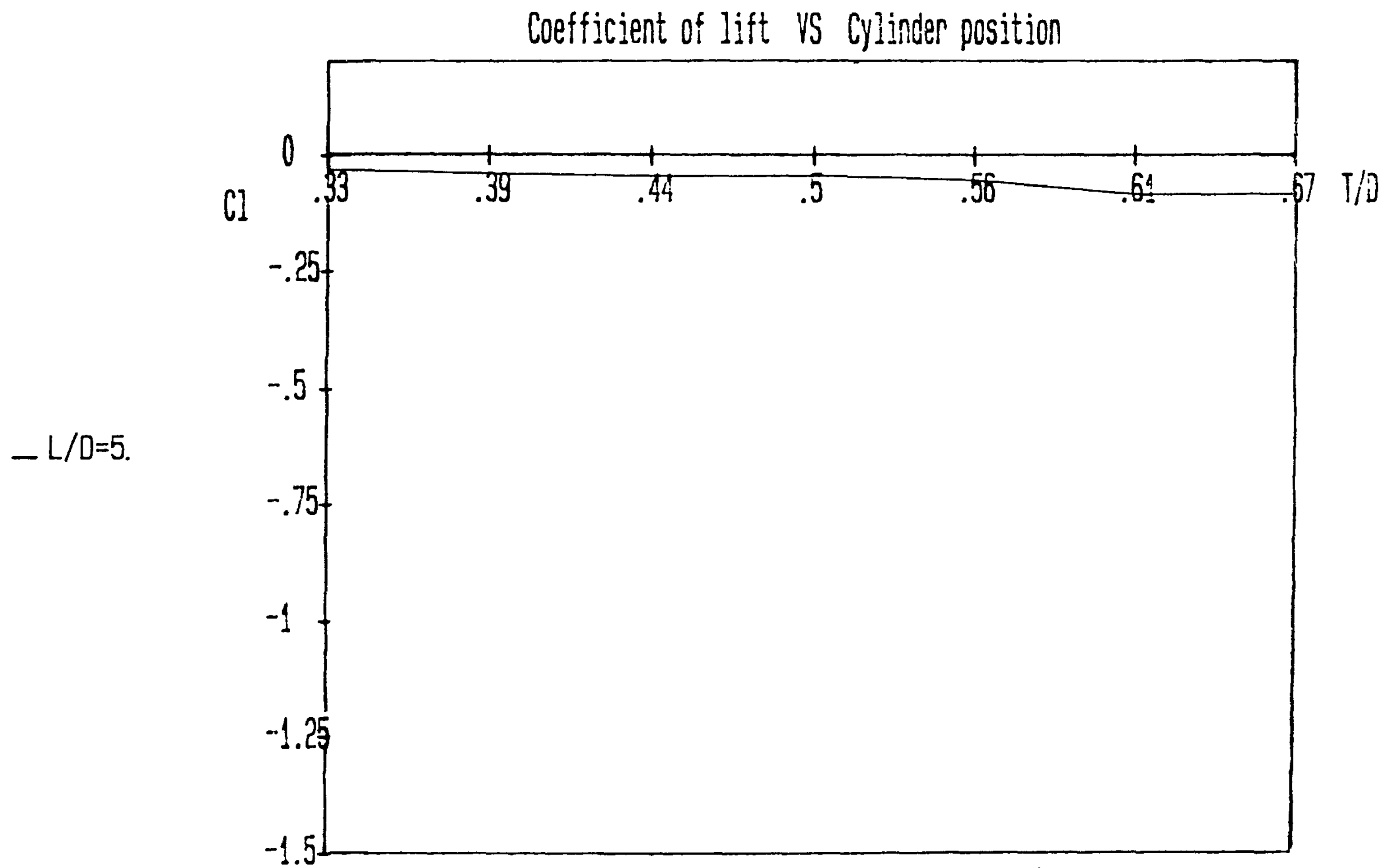
Coefficient of drag versus cylinder position. Static tests at L/D=5.

Figure 45.

Figure 46.

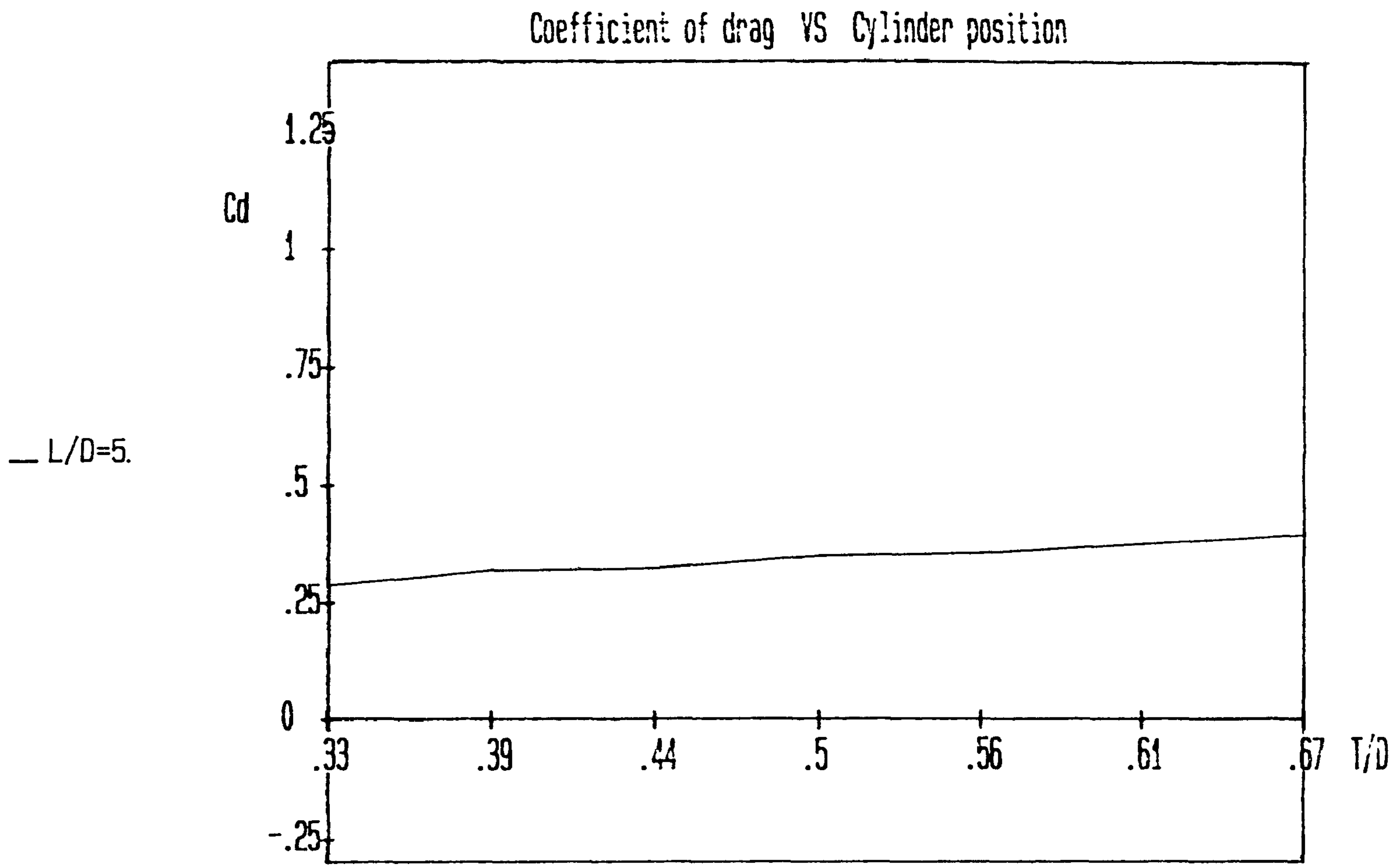


Pressure coefficient versus angular position on the leeward cylinder at L/d=5.



Coefficient of lift versus cylinder position. Static tests at L/D=5.

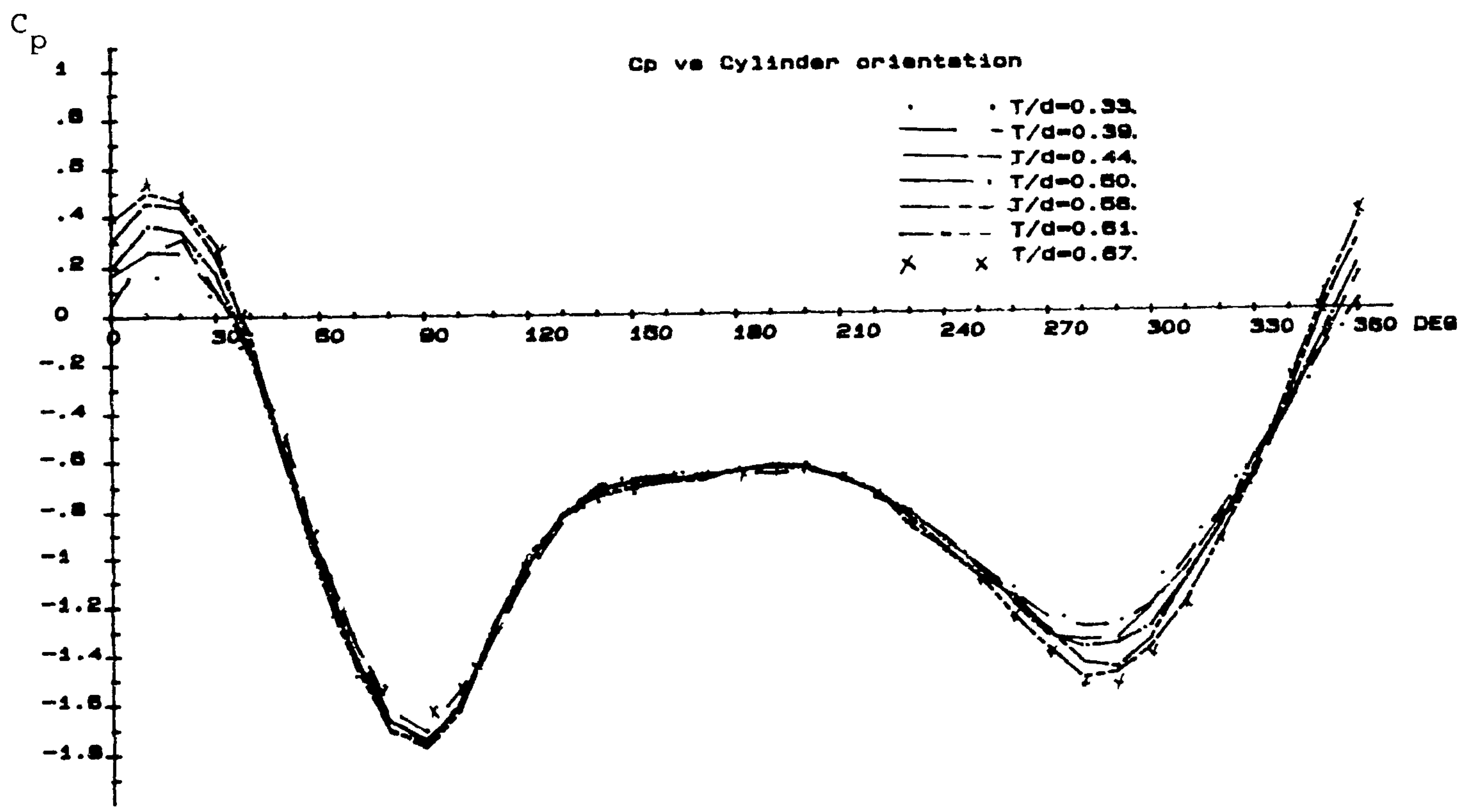
Figure 47.



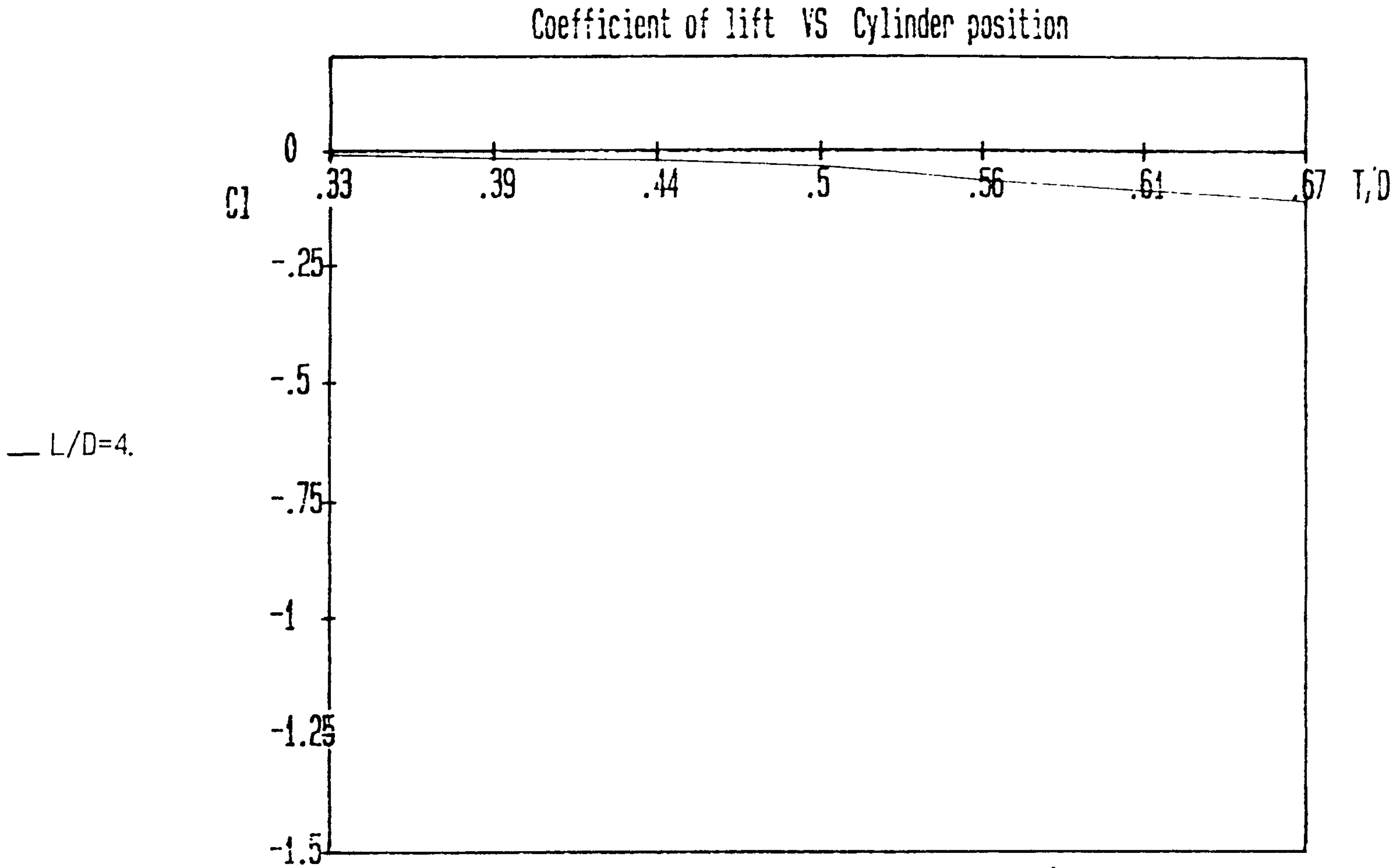
Coefficient of drag versus cylinder position. Static tests at L/D=5.

Figure 48.

Figure 49.

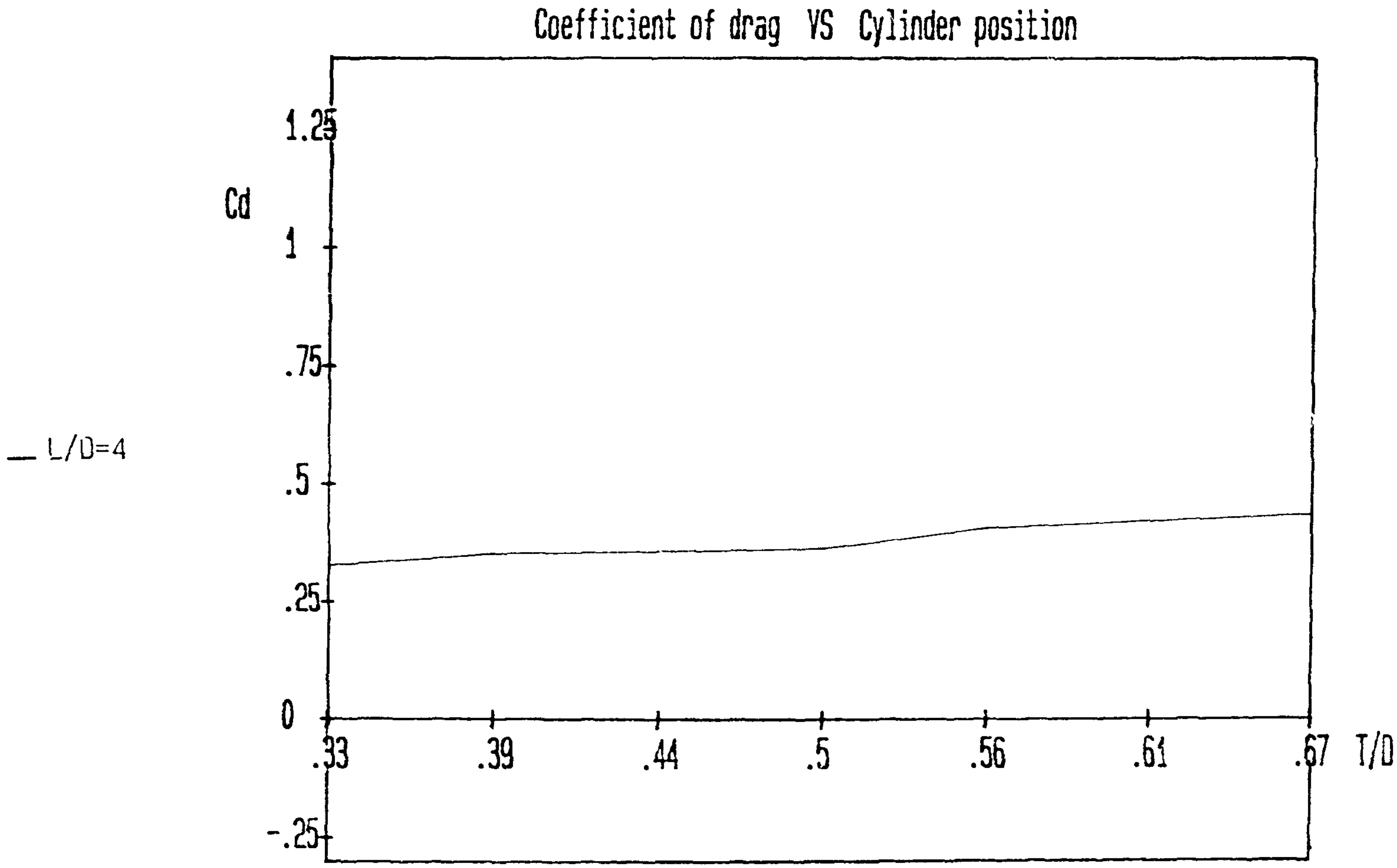


Pressure coefficient versus angular position on the leeward cylinder at L/d=4.



Coefficient of lift versus cylinder position. Static tests at L/D=4.

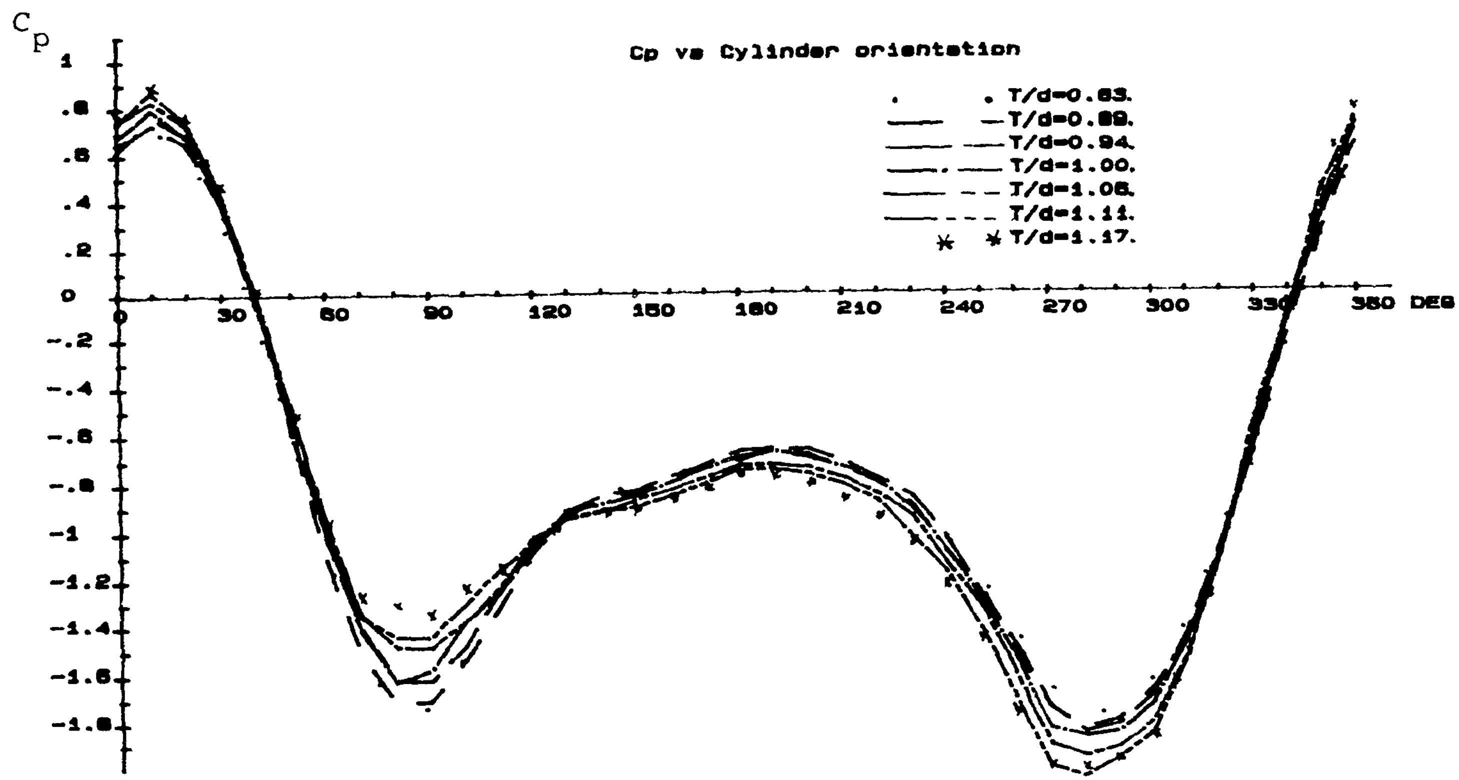
Figure 50.



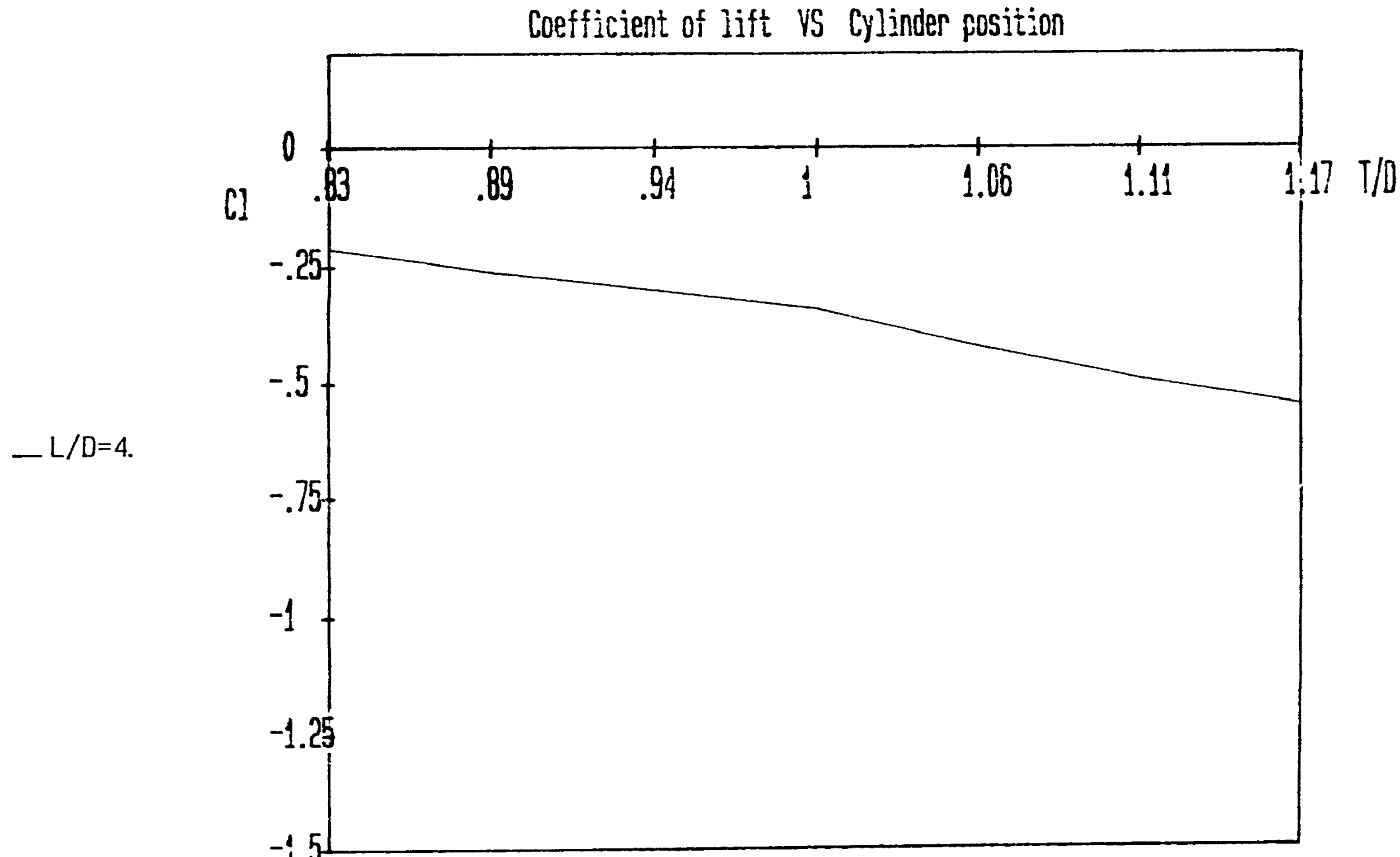
Coefficient of drag versus cylinder position. Static tests at L/D=4.

Figure 51.

Figure 52.

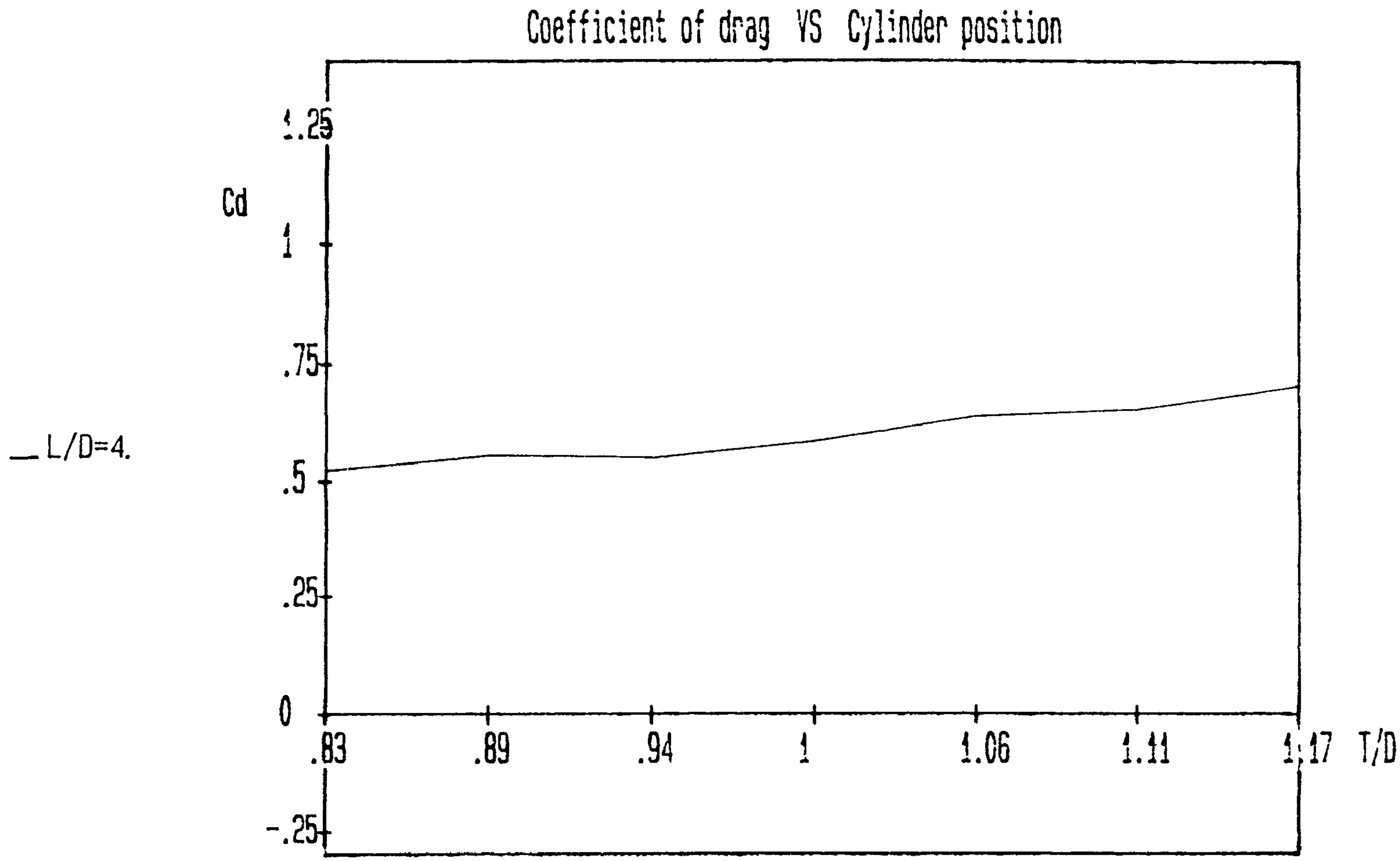


Pressure coefficient versus angular position on the leeward cylinder at L/d=4.



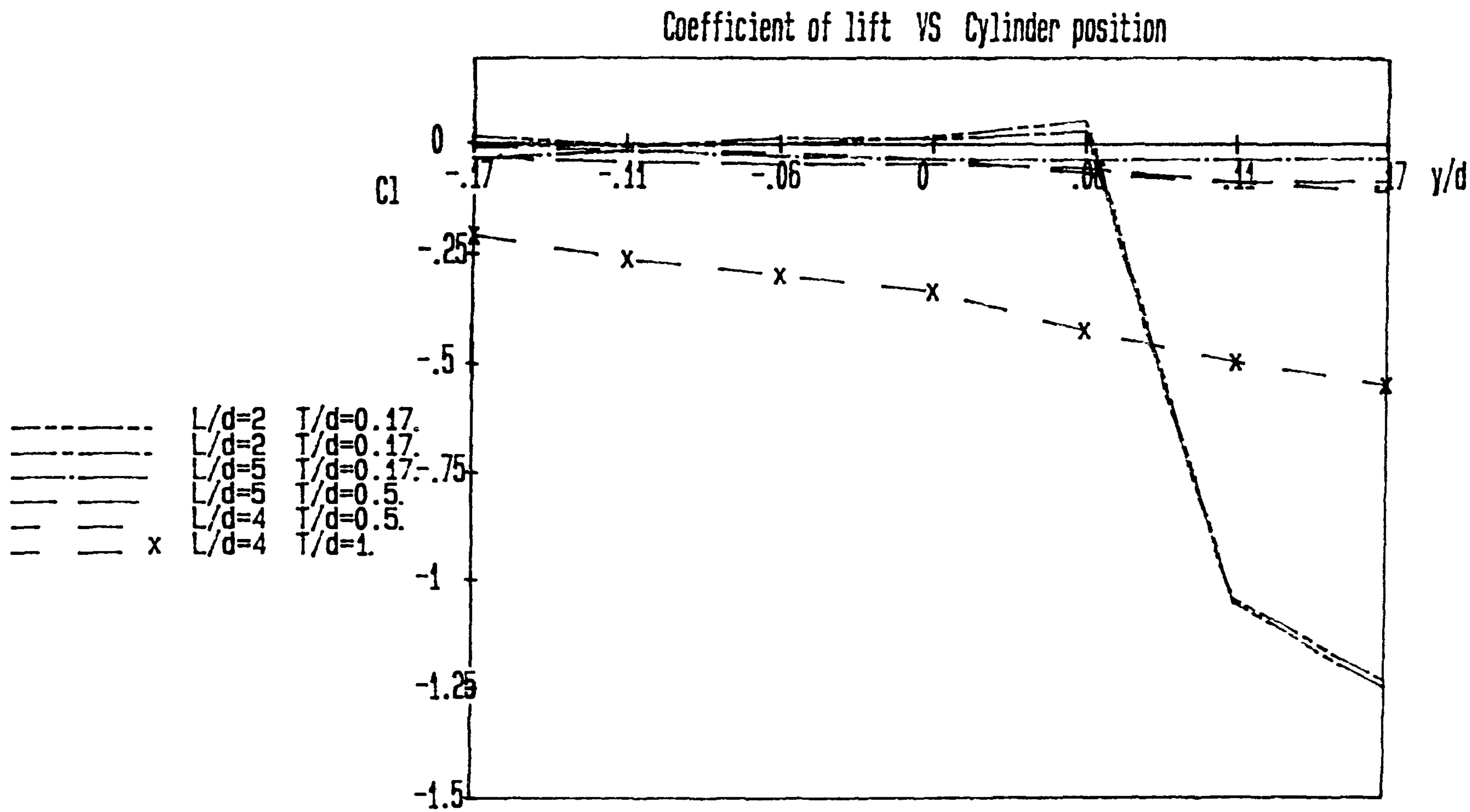
Coefficient of lift versus cylinder position. Static tests at L/D=4.

Figure 53.



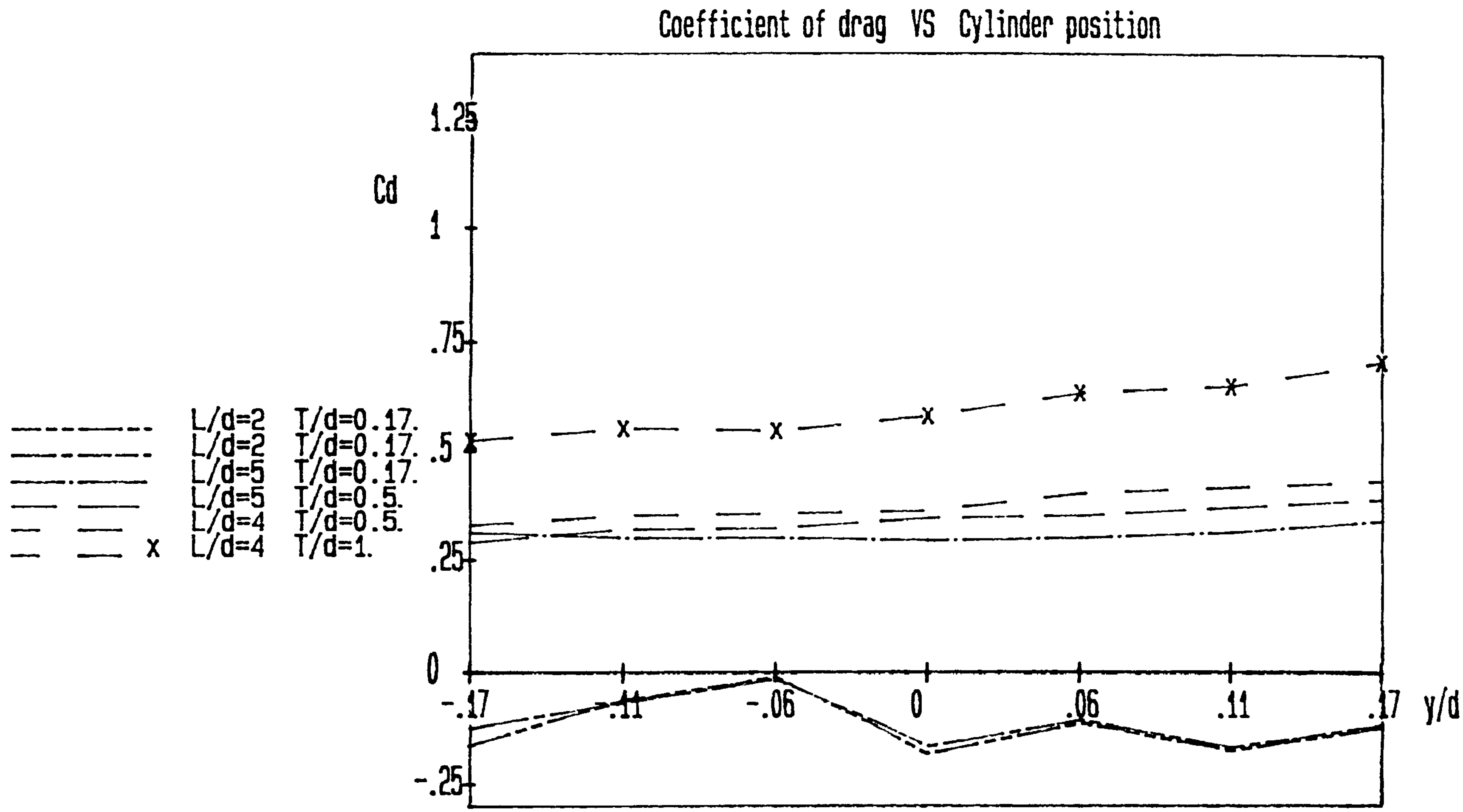
Coefficient of drag versus cylinder position. Static tests at L/D=4.

Figure 54.



Coefficient of lift versus cylinder position. Results of all static tests are included for comparison. The horizontal axis represents delta change in y/d from the equilibrium value of T/d.

Figure 55.



Coefficient of drag versus cylinder position. Results of all tests are included for comparison. The horizontal axis represents delta change in y/d from equilibrium value of T/d.

Figure 56.

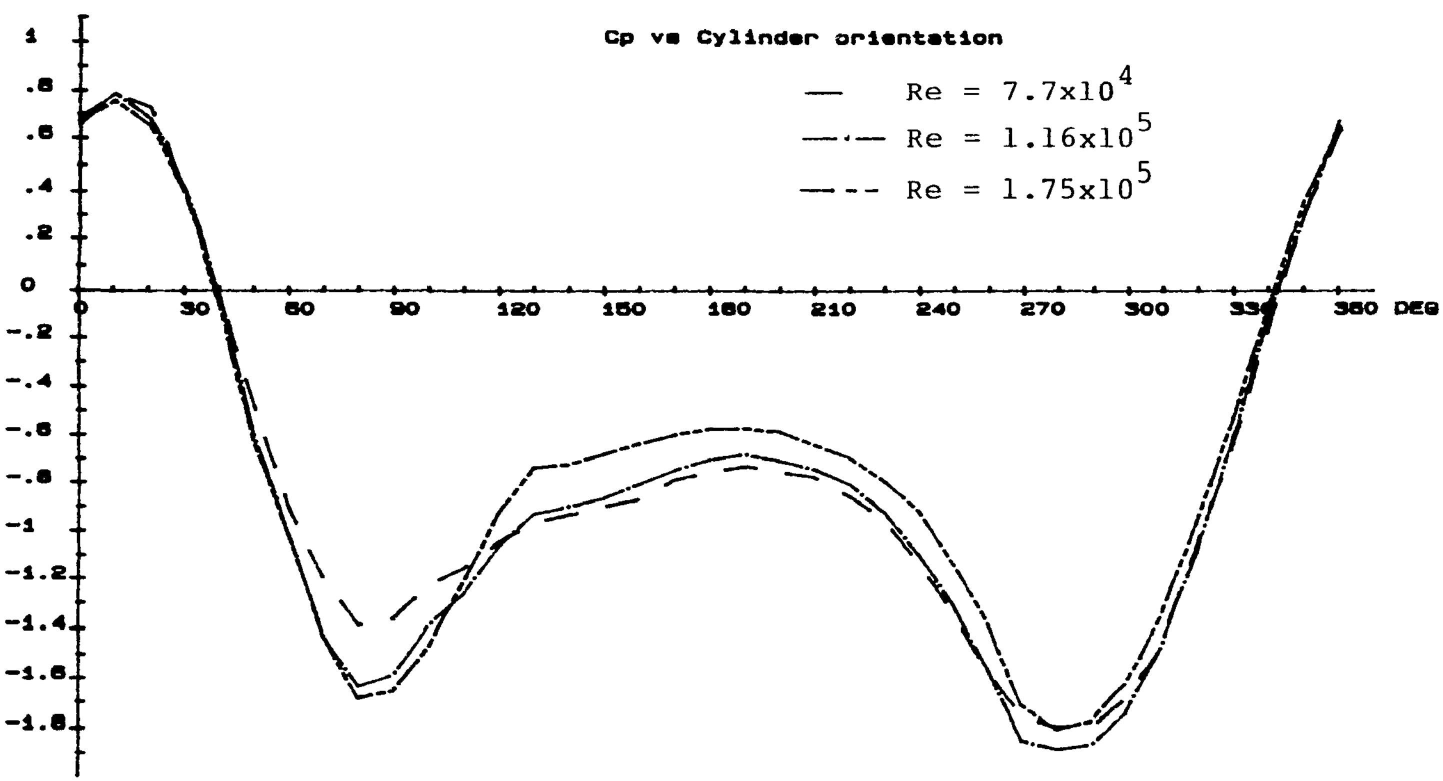
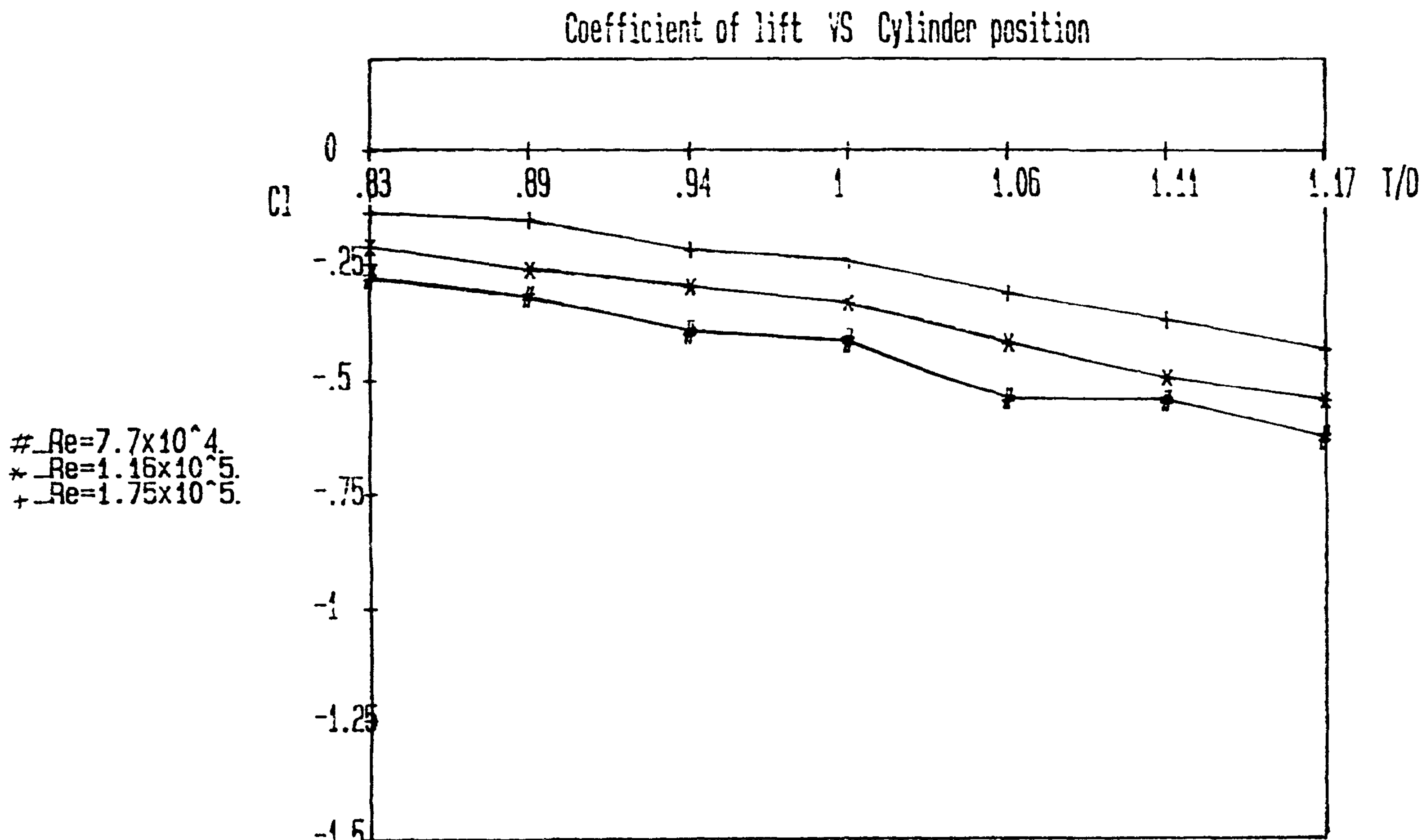


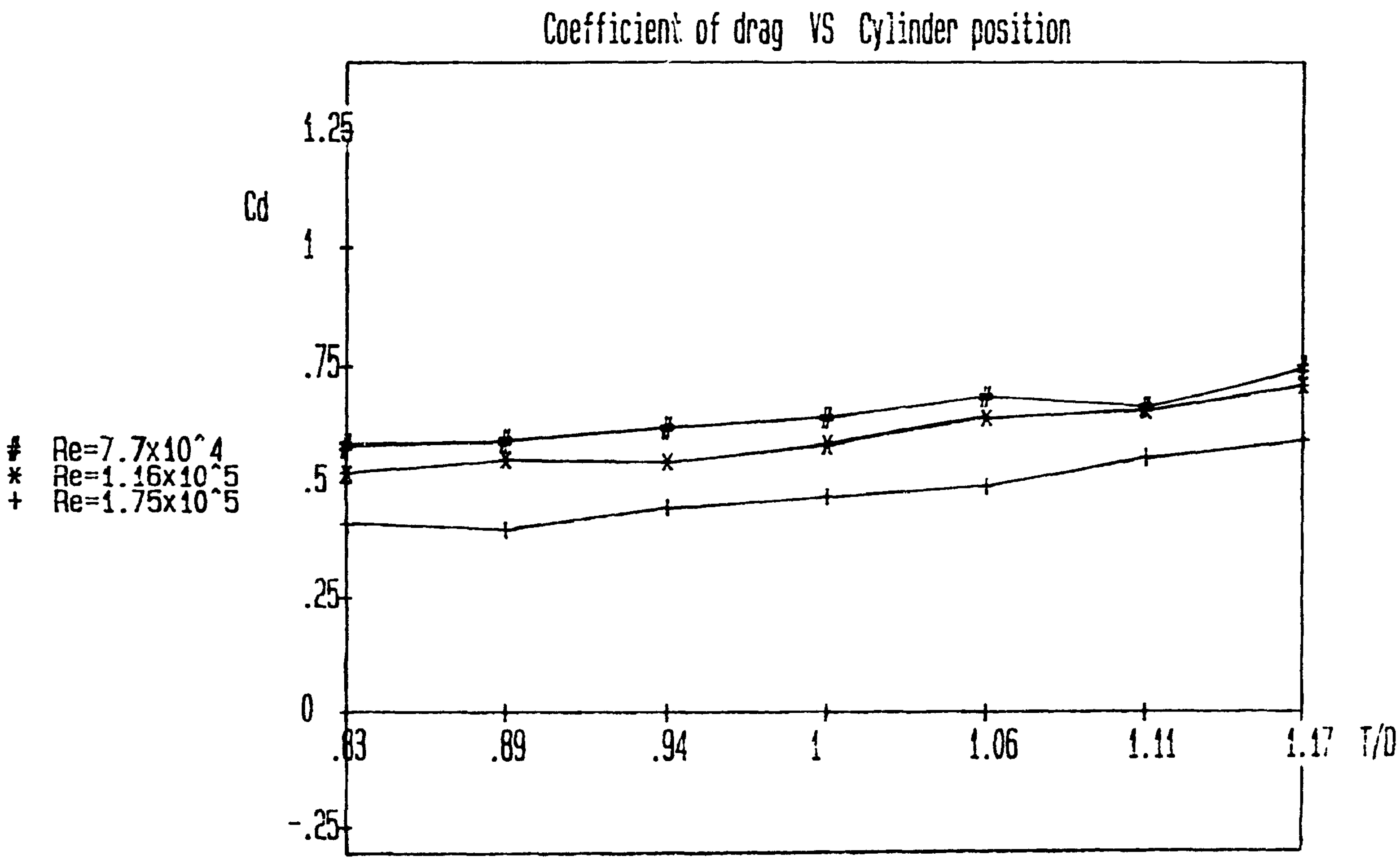
Figure 57.

Pressure coefficient versus cylinder orientation for staggered static cylinders at various Re. L/d=4 T/d=1.



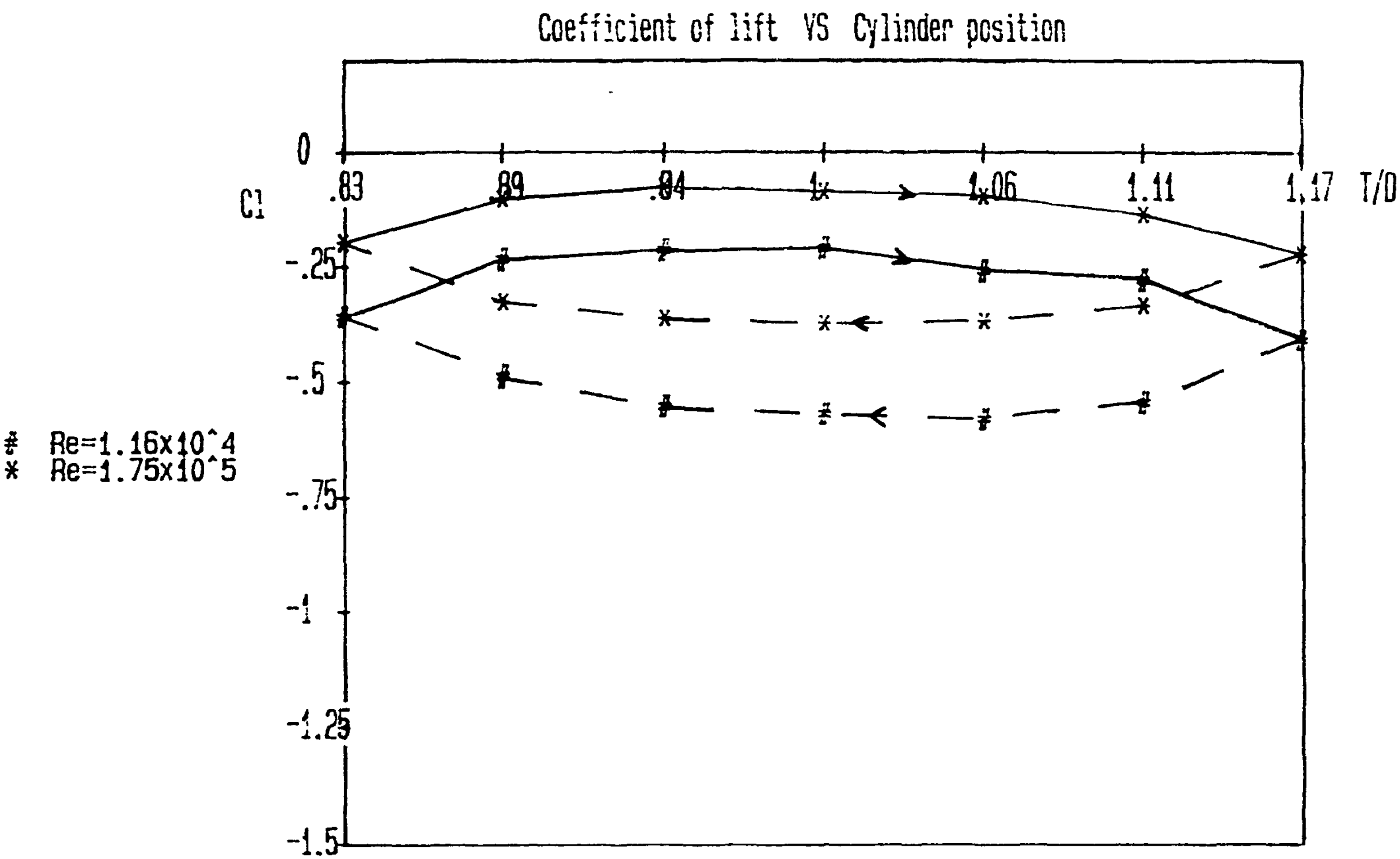
Lift coefficient versus cylinder position for static staggered cylinders at various Re.
L/D=4.

Figure 58.



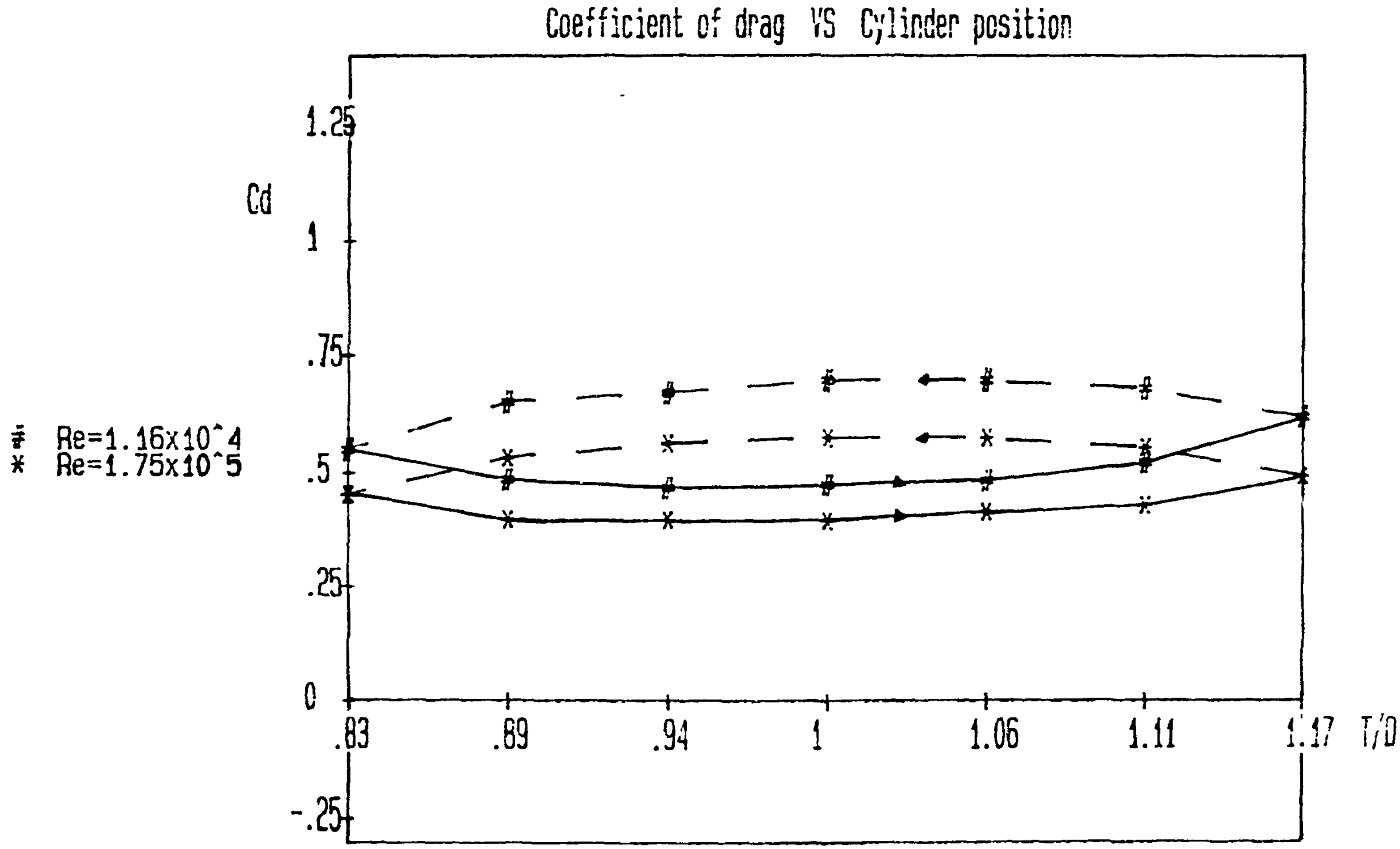
Drag coefficient versus cylinder position for static staggered cylinders at various Re.
L/D=4.

Figure 59.



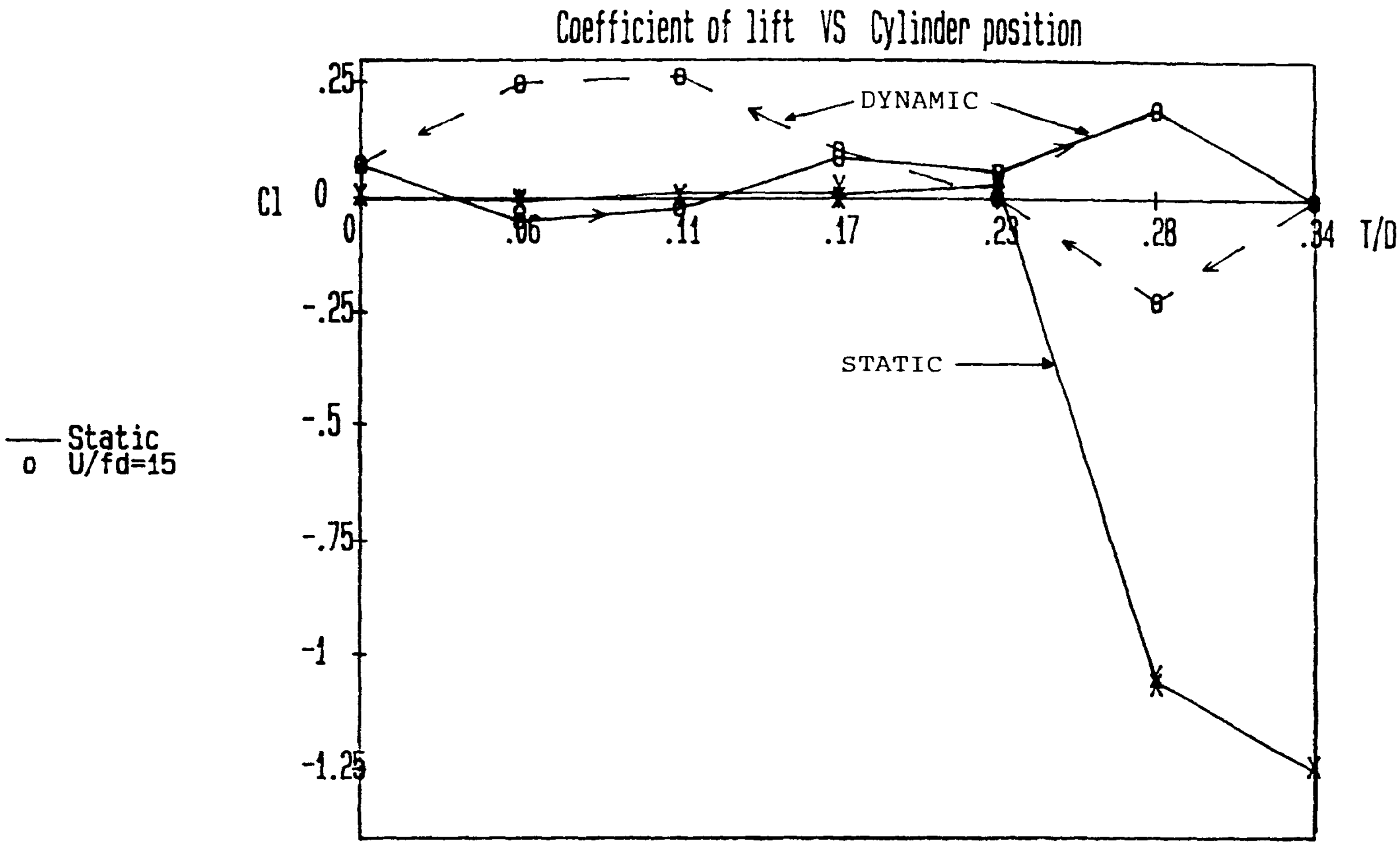
Lift coefficient versus cylinder position. Two dynamic tests at different Re. U/fd=44 and L/D=4 for both tests.

Figure 60.



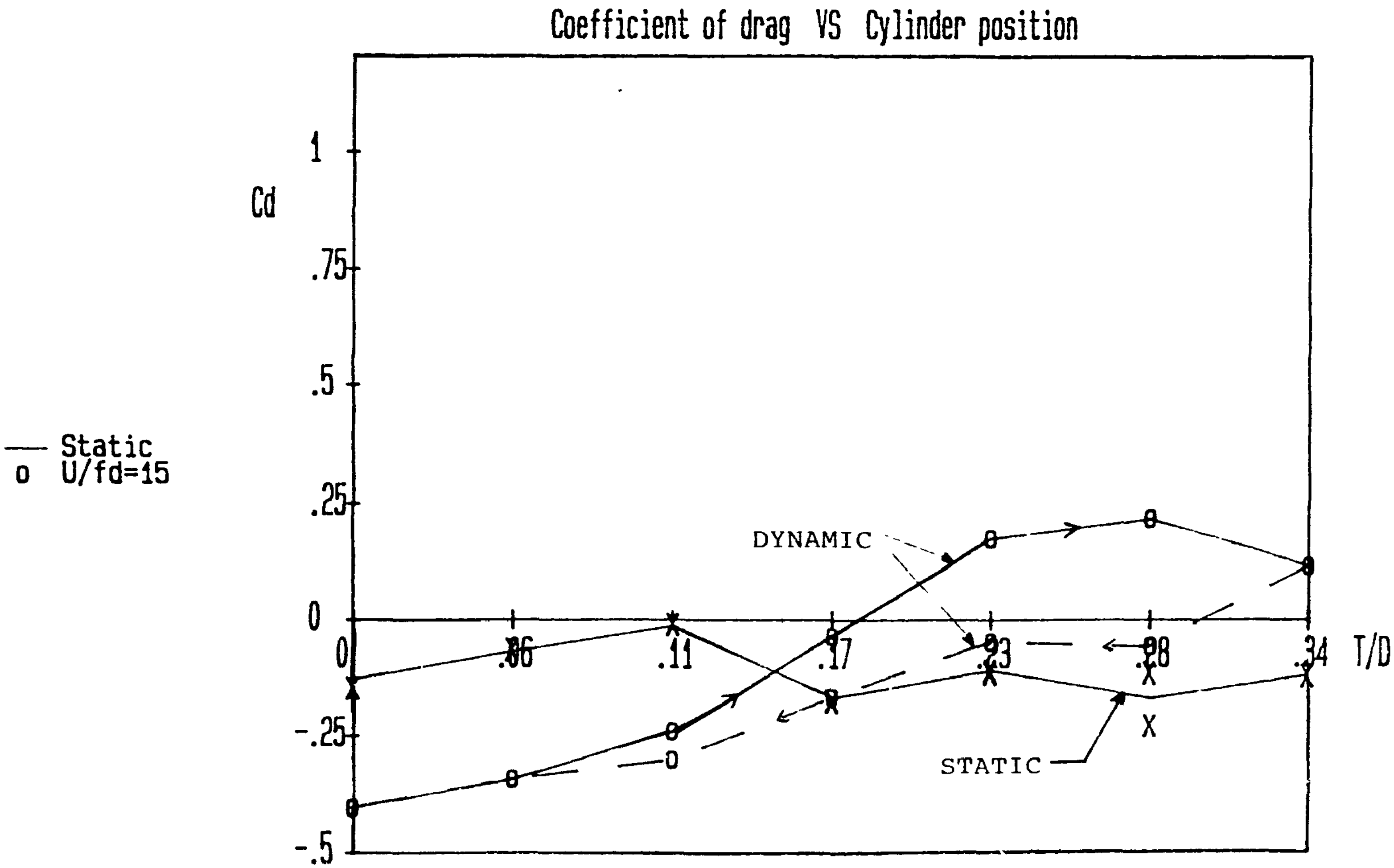
Drag coefficient versus cylinder position. Two dynamic tests at different Re. U/fd=44 and L/D=4 for both tests.

Figure 61.



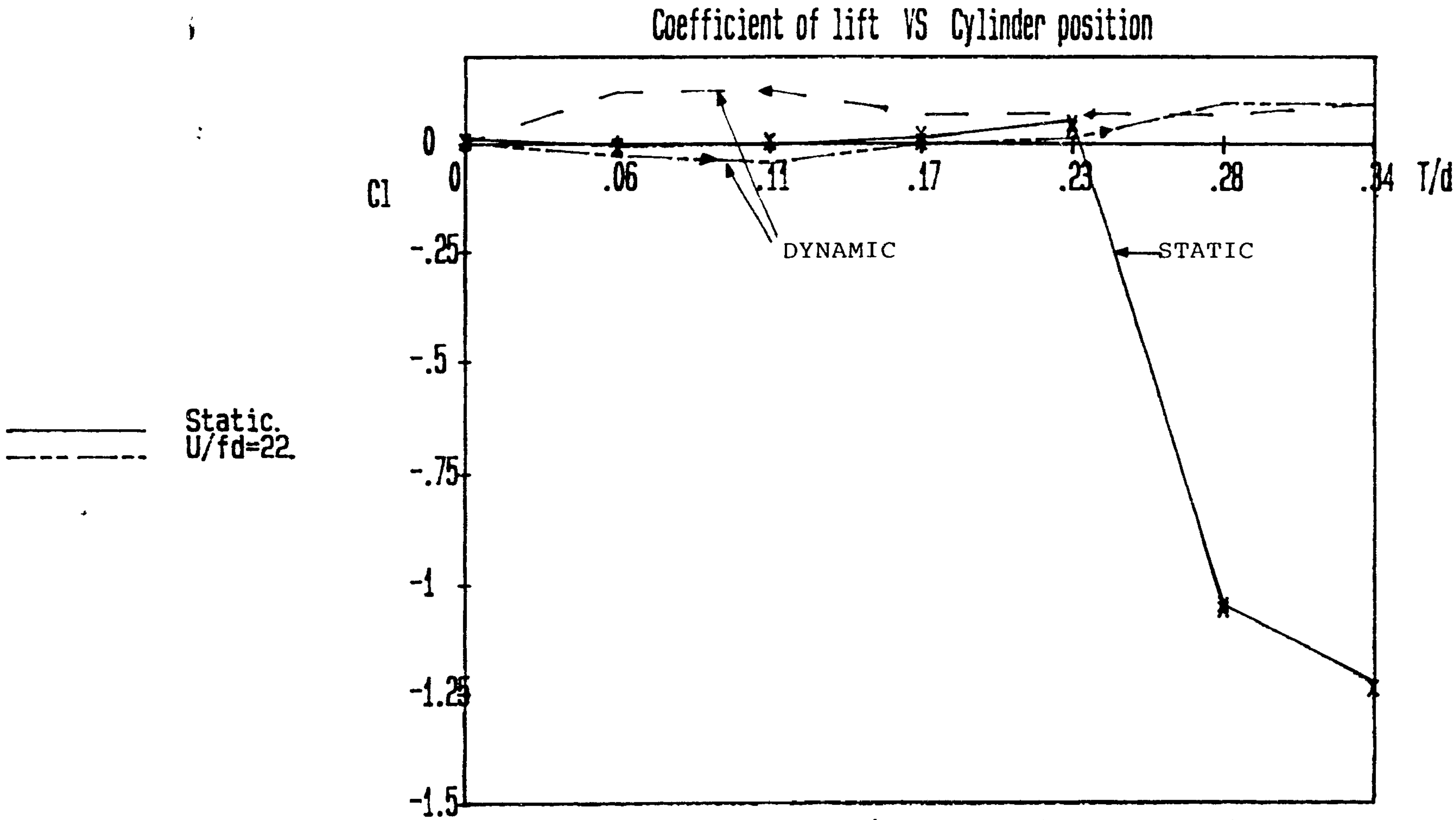
Lift coefficient versus cylinder position.
X-marks indicate Cl predicted by quasi-static assumption.
L/D=2 Re=7.7x10^4

Figure 62.



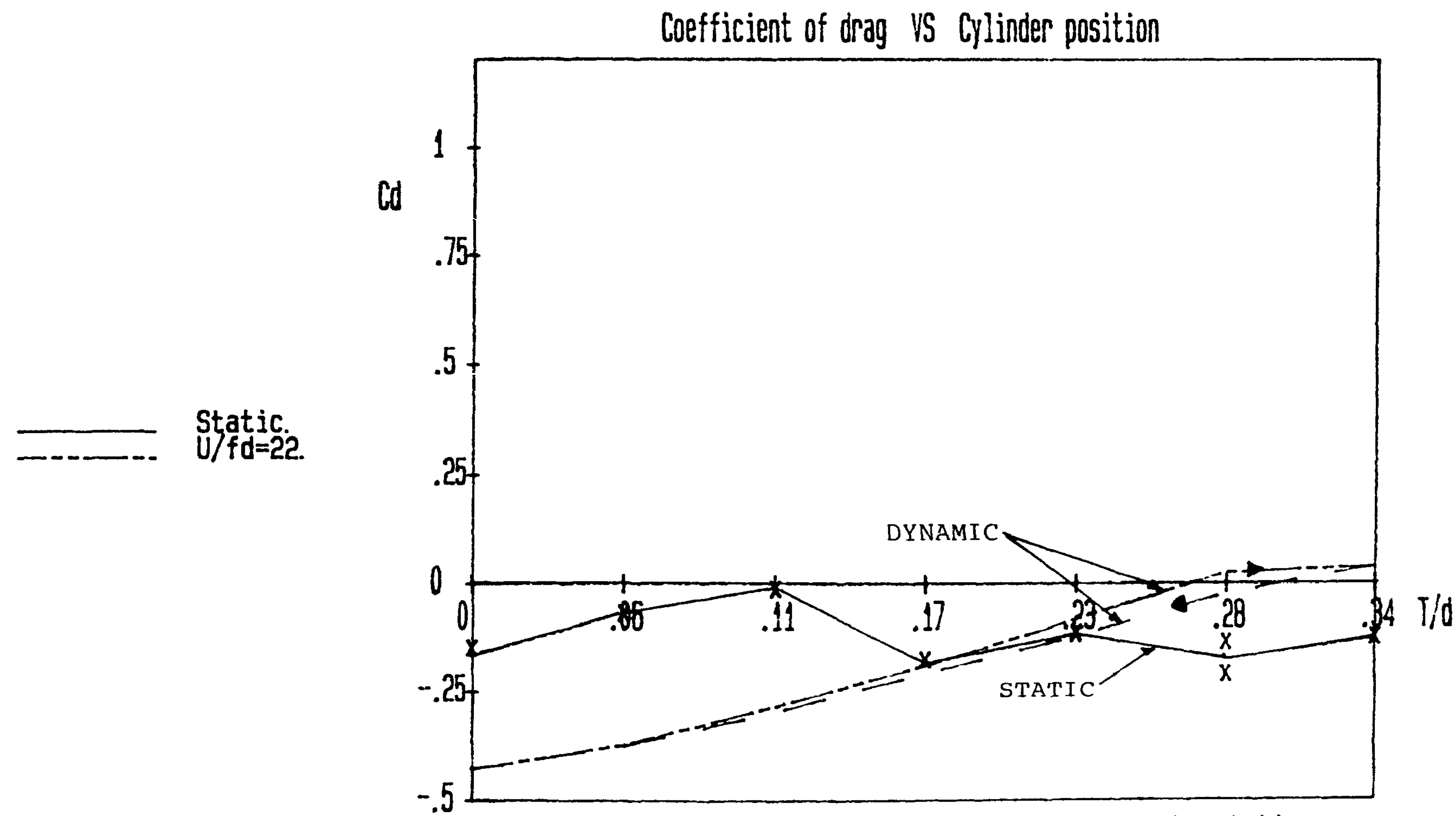
Drag coefficient versus cylinder position.
X-marks indicate Cd predicted by quasi-static assumption.
L/D=2 Re=7.7x10^4

Figure 63.



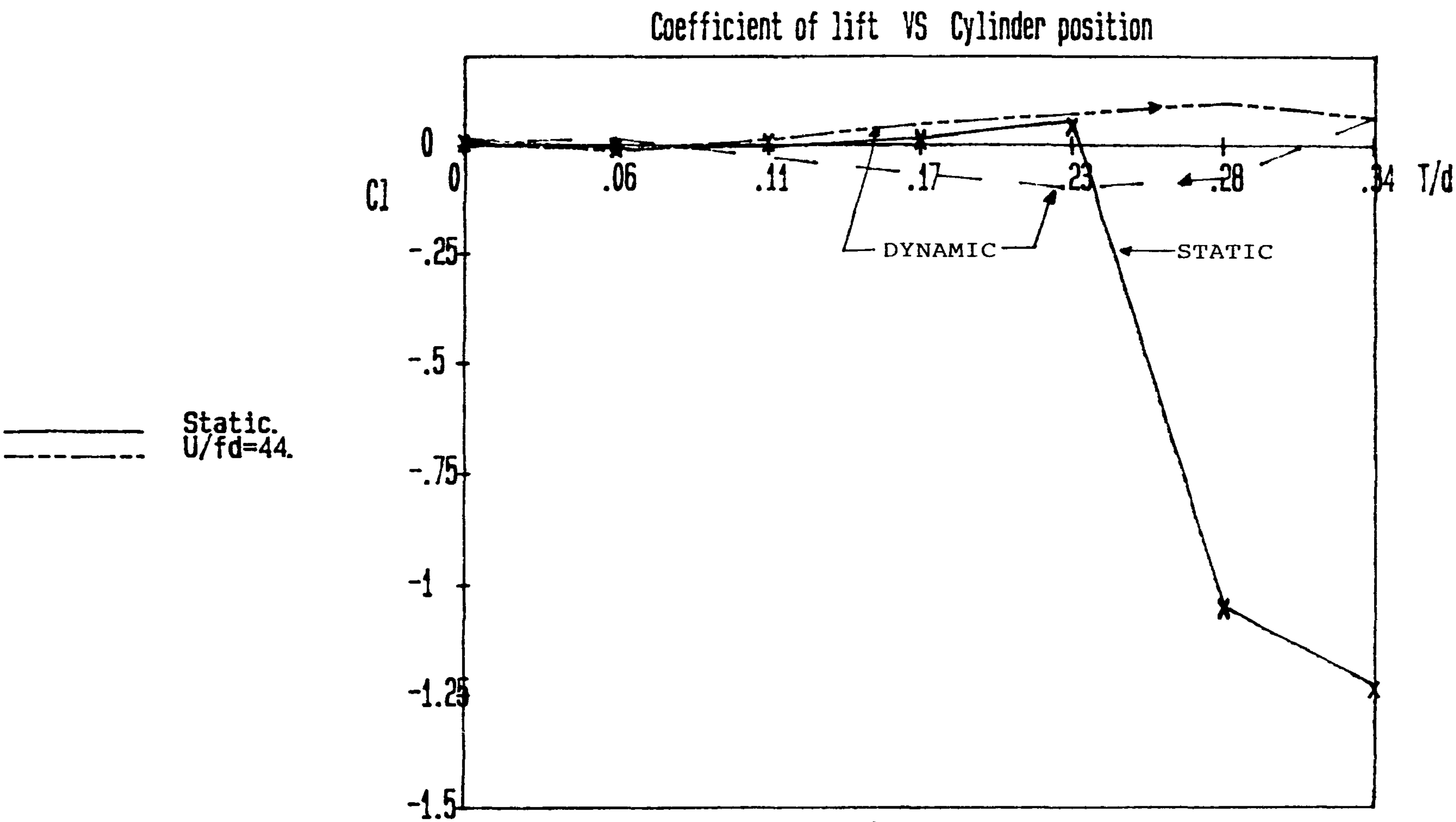
Coefficient of lift versus cylinder position at L/d=2. Solid line represents static tests. Dashed line represents dynamic tests. X-marks represnt quasi-static predictions.

Figure 64.



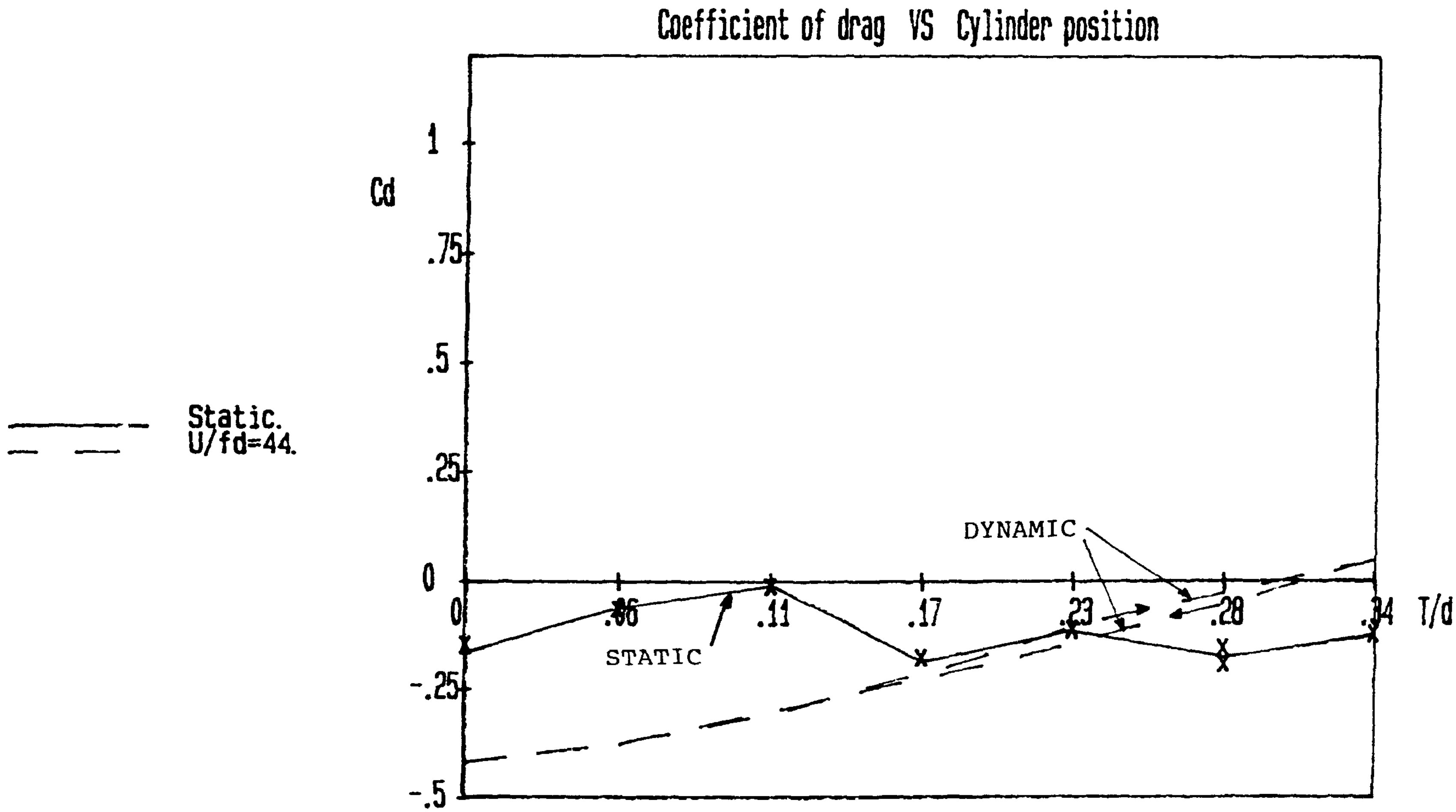
Coefficient of drag versus cylinder position L/d=2. Solid line represents static tests. Dashed line represents dynamic tests. X-marks represent quasi-static predictions.

Figure 65.



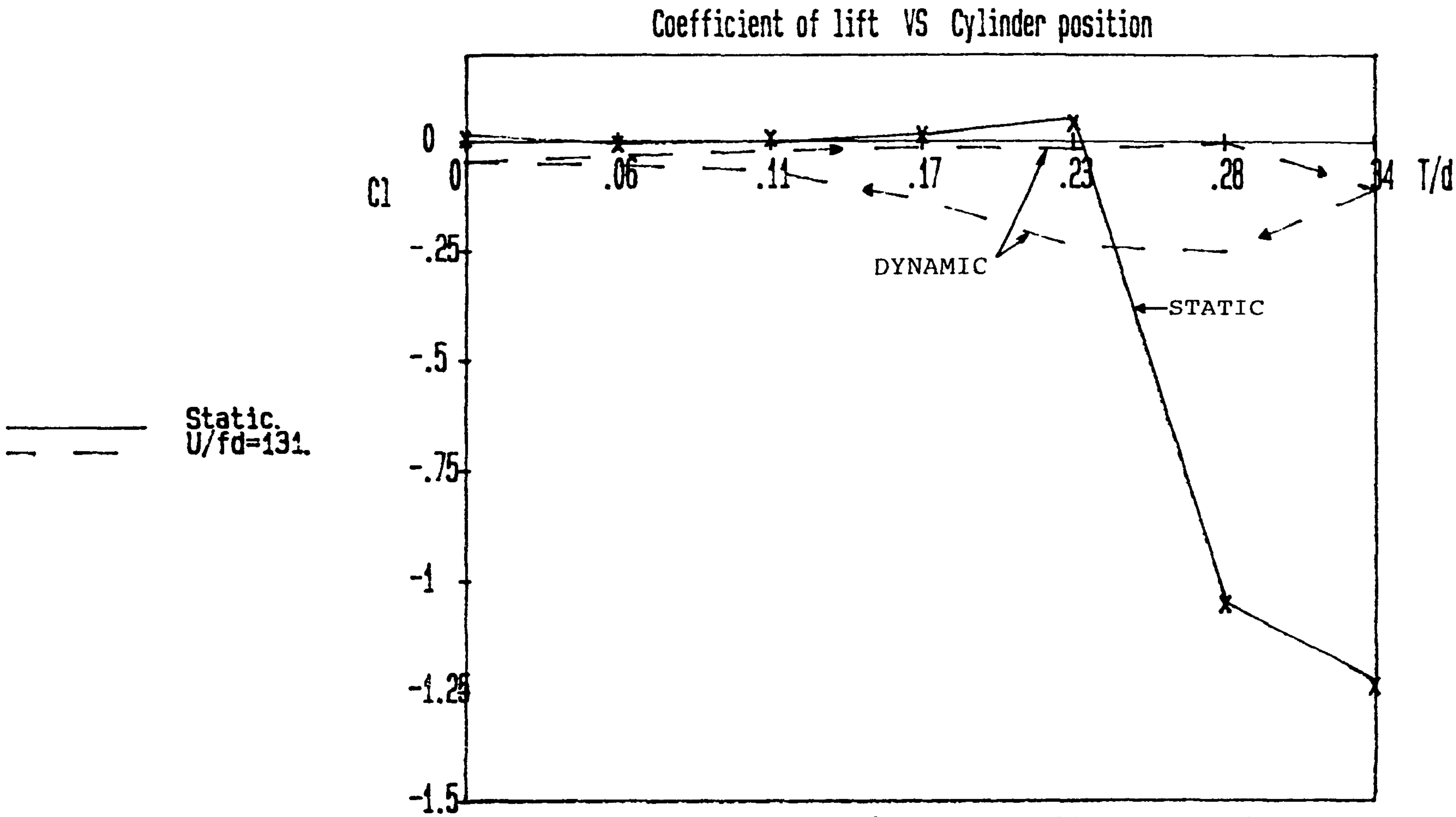
Coefficient of lift versus cylinder position at L/d=2. Solid line represents static tests. Dashed line represents dynamic tests. X-marks represent quasi-static predictions.

Figure 66.



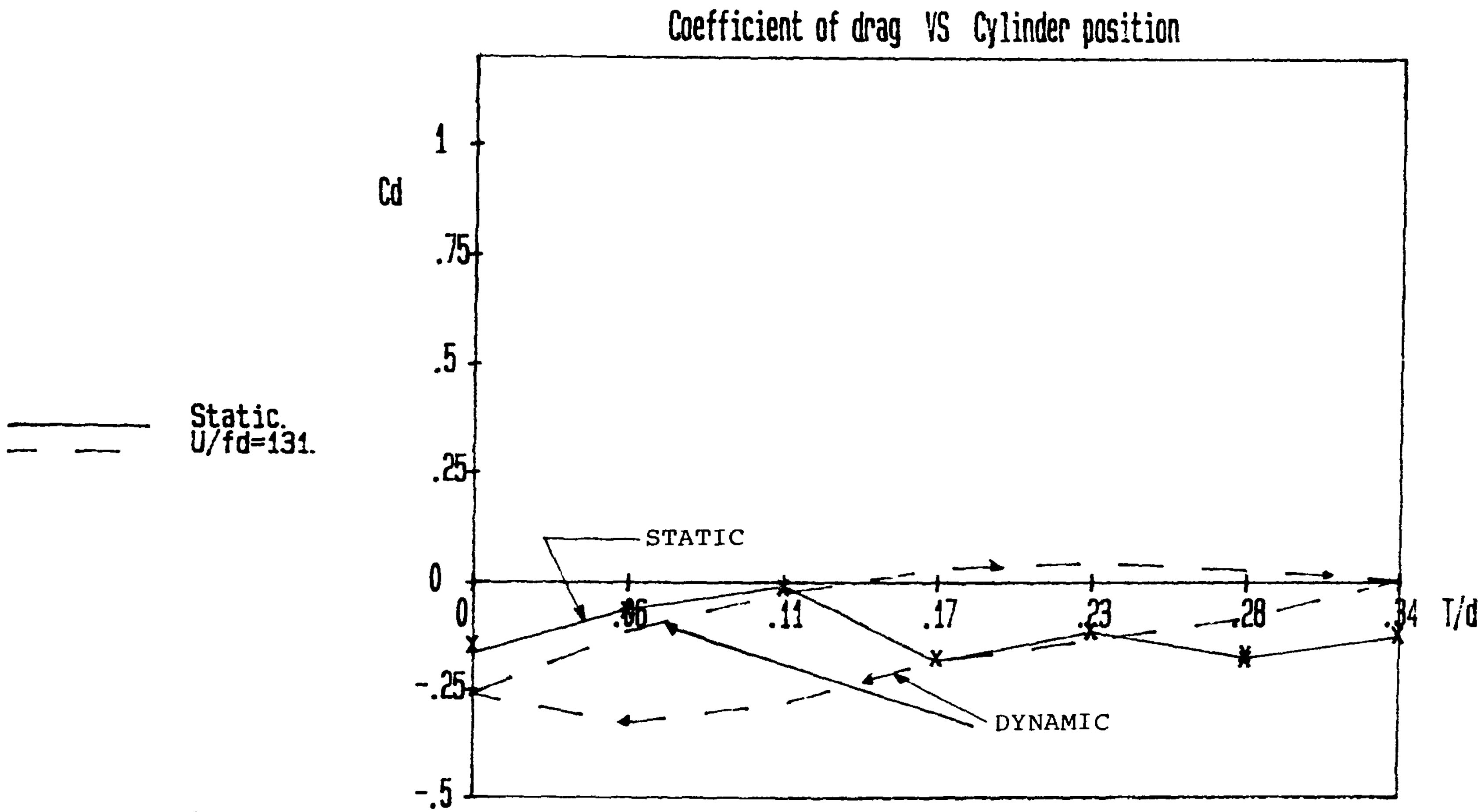
Coefficient of drag versus cylinder position at L/d=2. Solid line represents static tests. Dashed line represents dynamic tests. X-marks represent quasi-static predictions.

Figure 67.



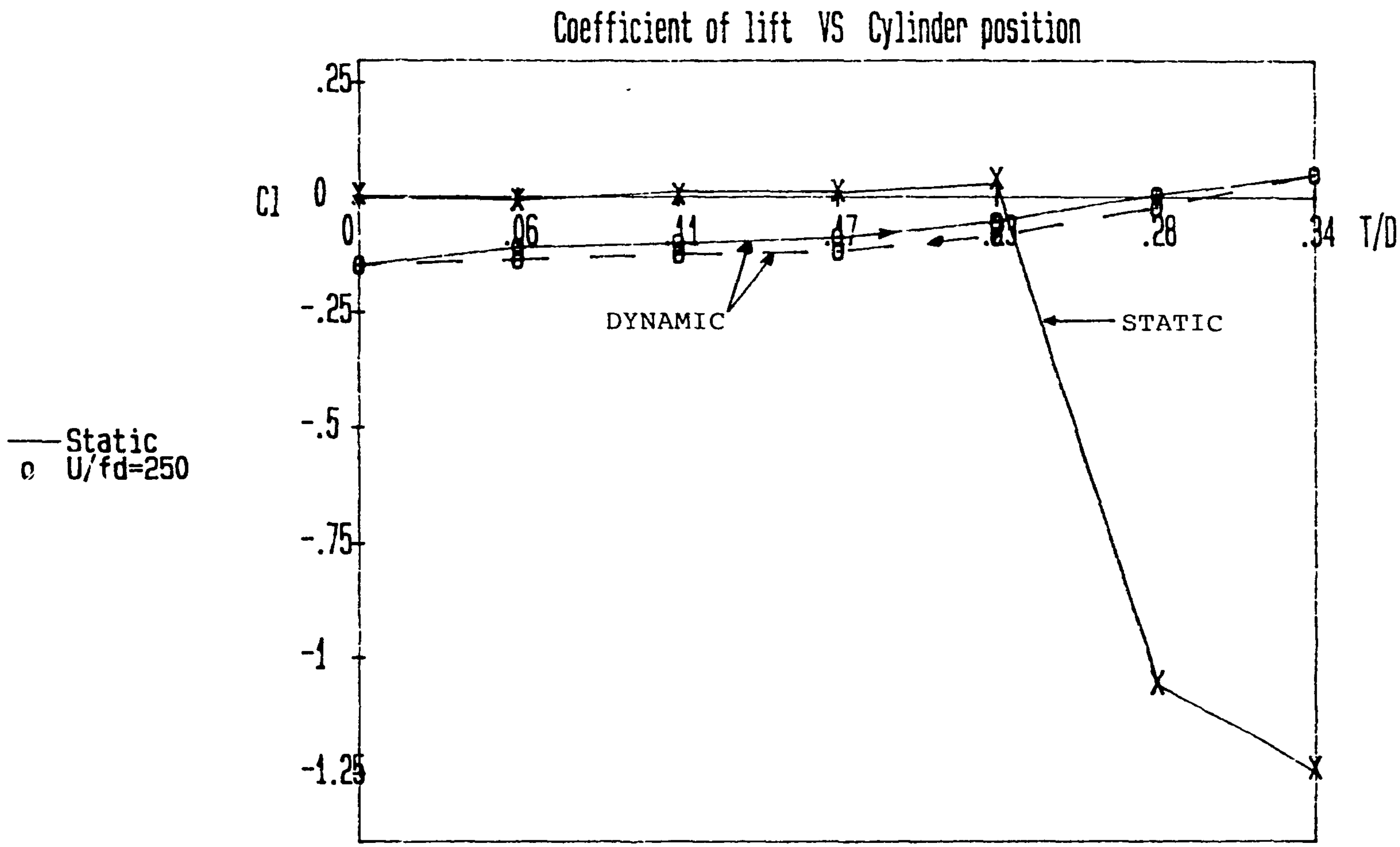
Coefficient of lift versus cylinder position at L/d=2. Solid line represents static tests. Dashed line represents dynamic tests. X-marks represent quasi-static predictions.

Figure 68.



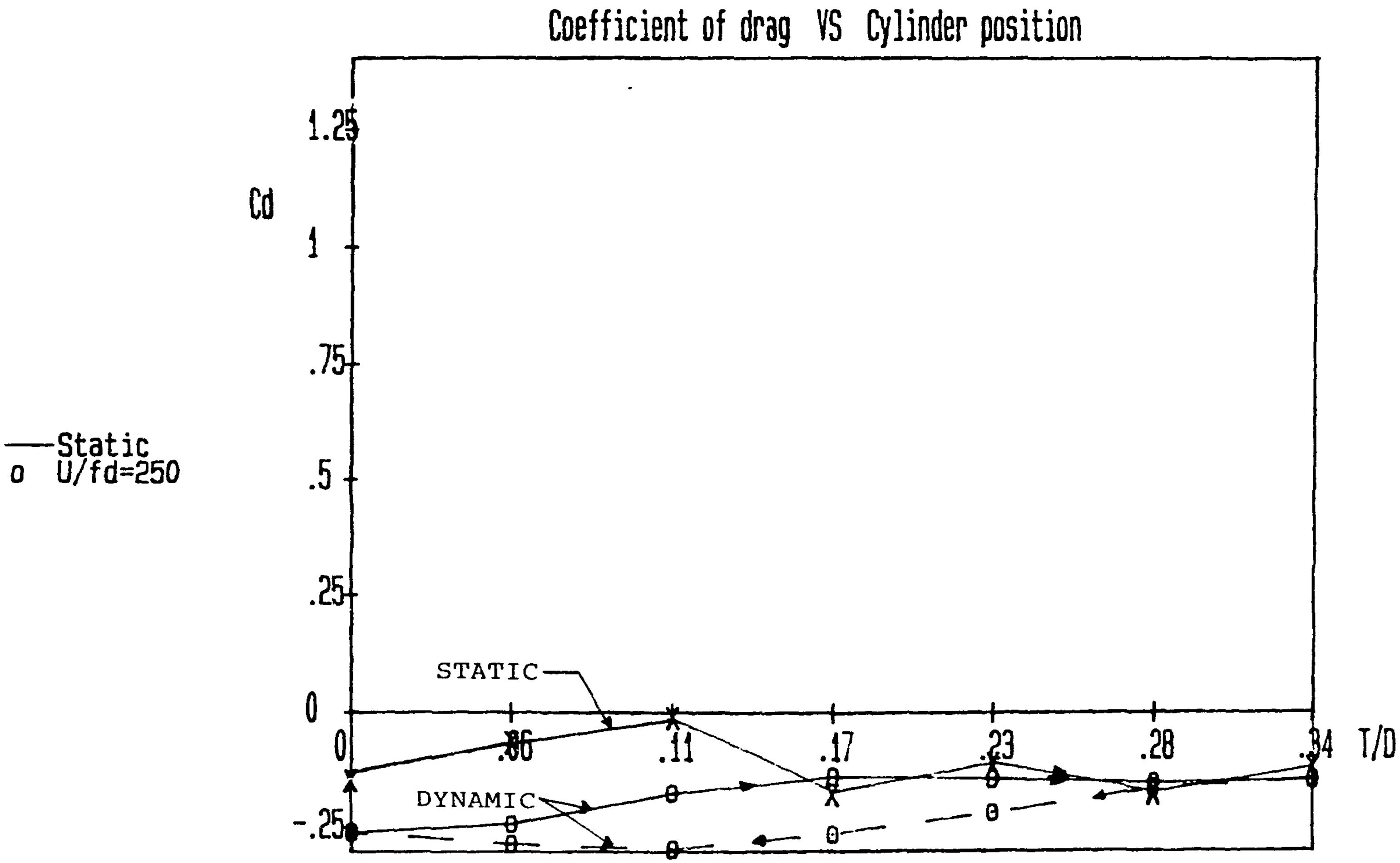
Coefficient of drag versus cylinder position at L/d=2. Solid line represents static tests. Dashed line represents dynamic tests. X-marks represent quasi-static predictions.

Figure 69.



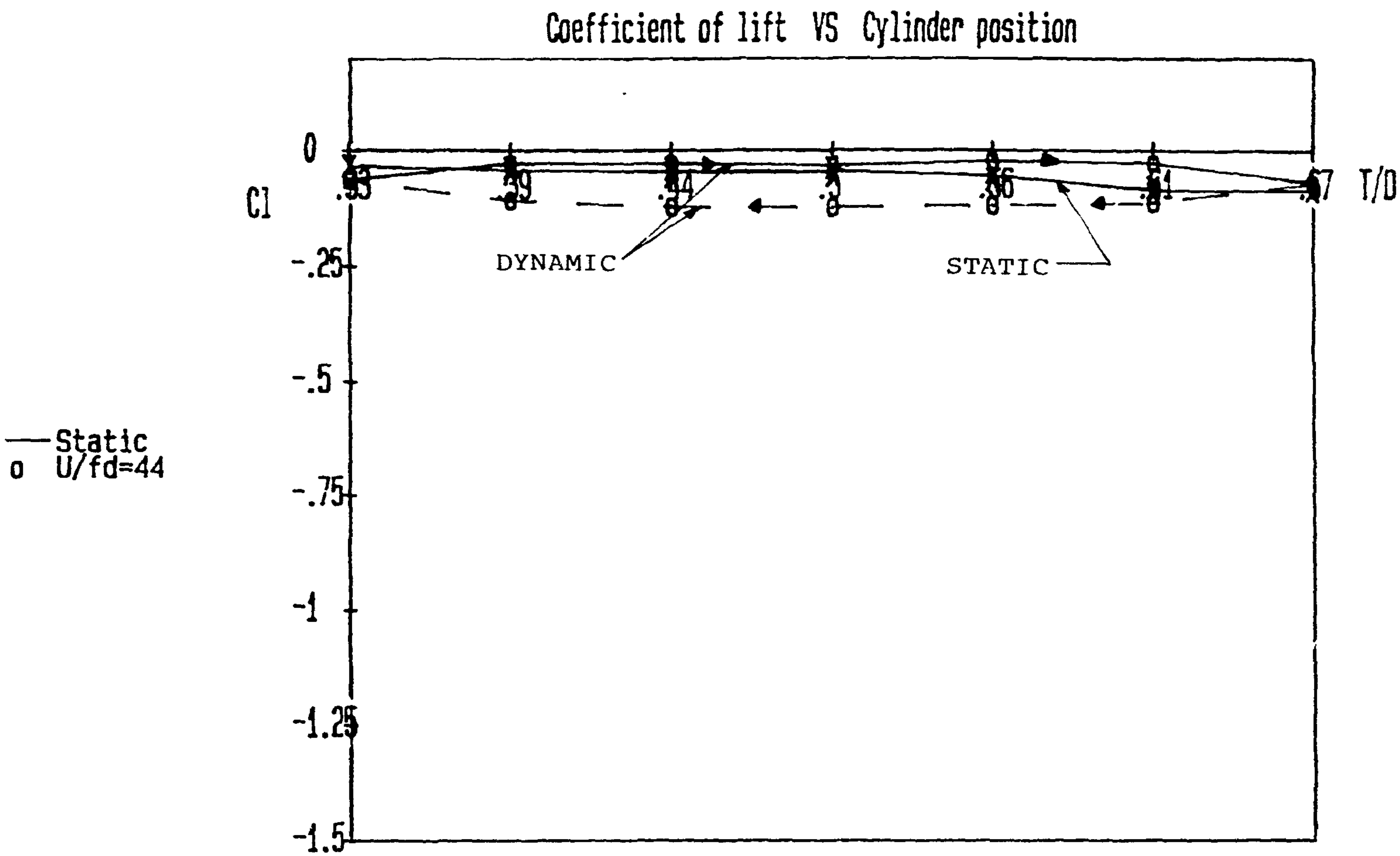
Lift coefficient versus cylinder position.
X-marks indicate Cl predicted by quasi-static assumption.
L/D=2 Re=2.16x10^5

Figure 70.



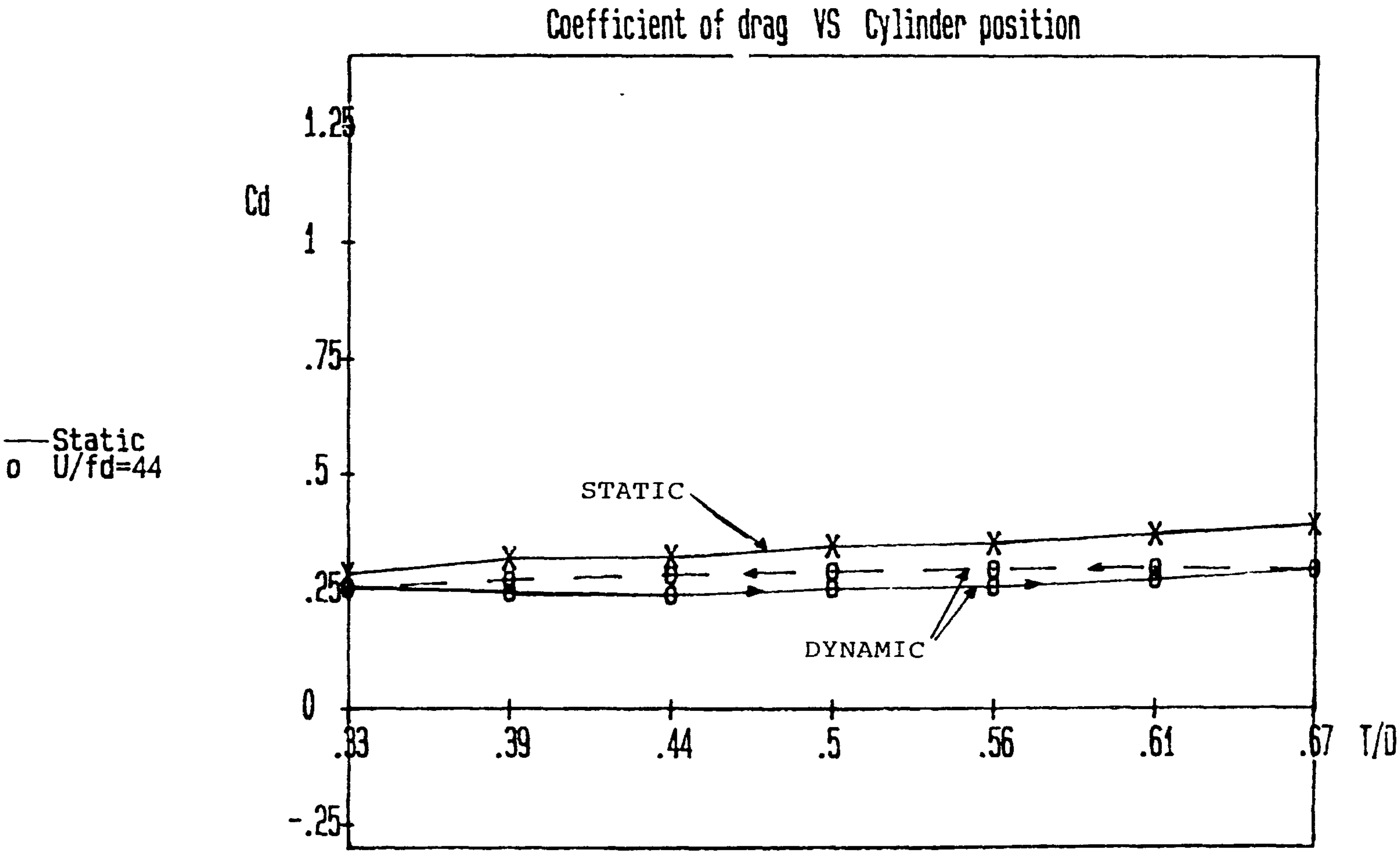
Drag coefficient versus cylinder position.
X-marks indicate Cd predicted by quasi-static assumption.
L/D=2 Re=2.16x10^5

Figure 71.



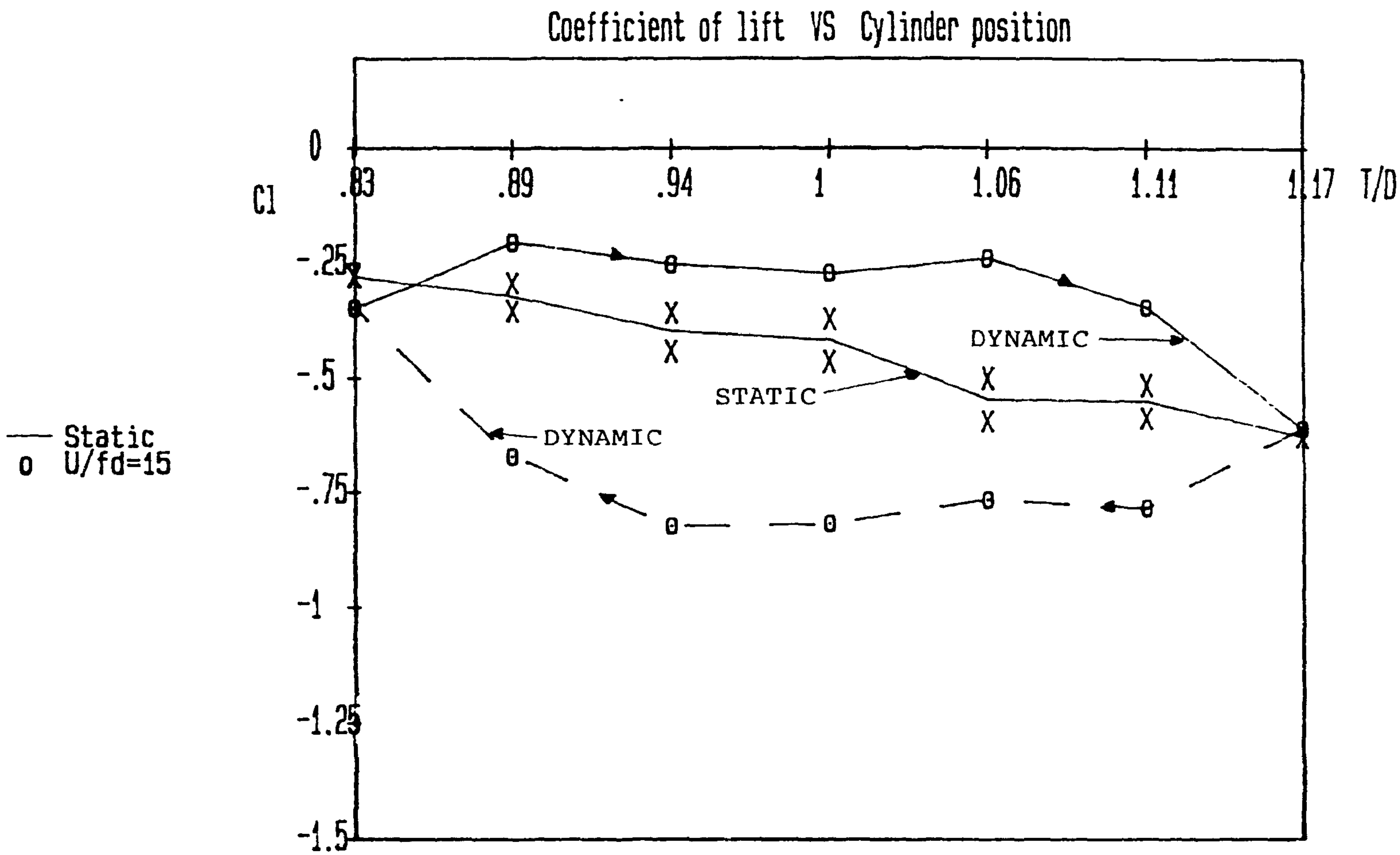
Lift coefficient versus cylinder position.
X-marks indicate Cl predicted by quasi-static assumption.
L/D=5   Re=1.16x10^5

Figure 72.



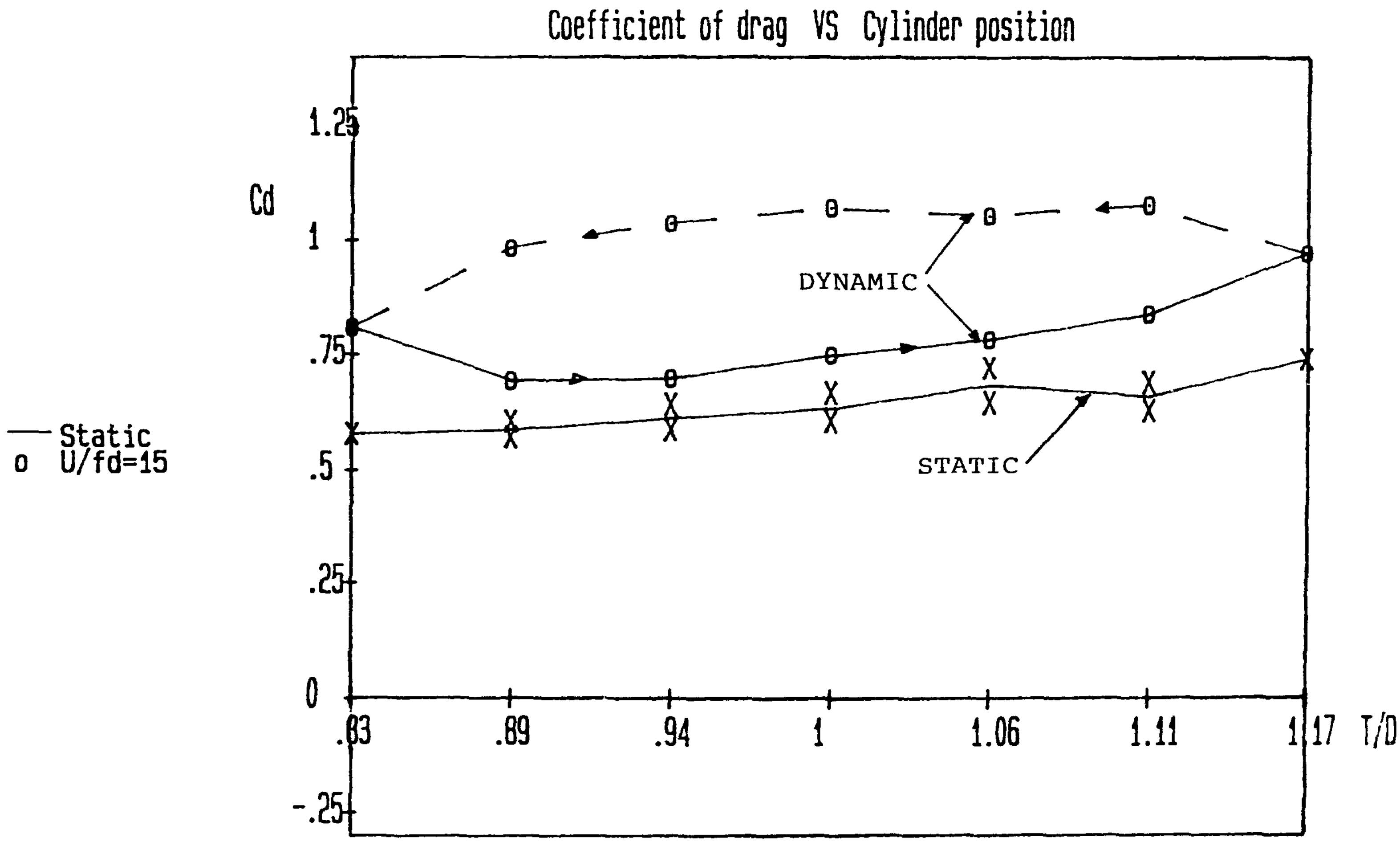
Drag coefficient versus cylinder position.
X-marks indicate Cd predicted by quasi-static assumption.
L/D=5   Re=1.16x10^5

Figure 73.



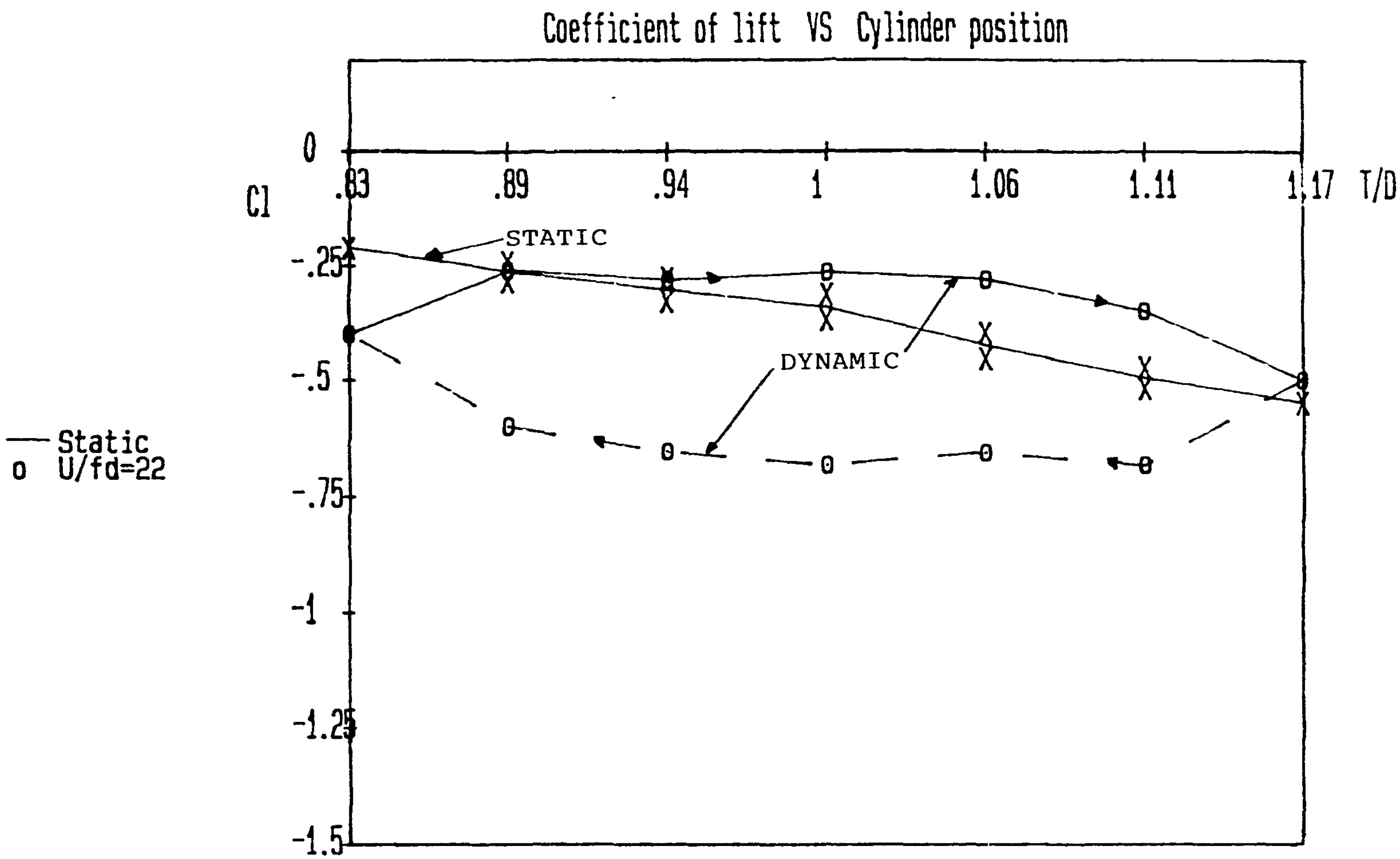
Lift coefficient versus cylinder position.
X-marks indicate Cl predicted by quasi-static assumption.
L/D=4   Re=7.7x10^4

Figure 74.



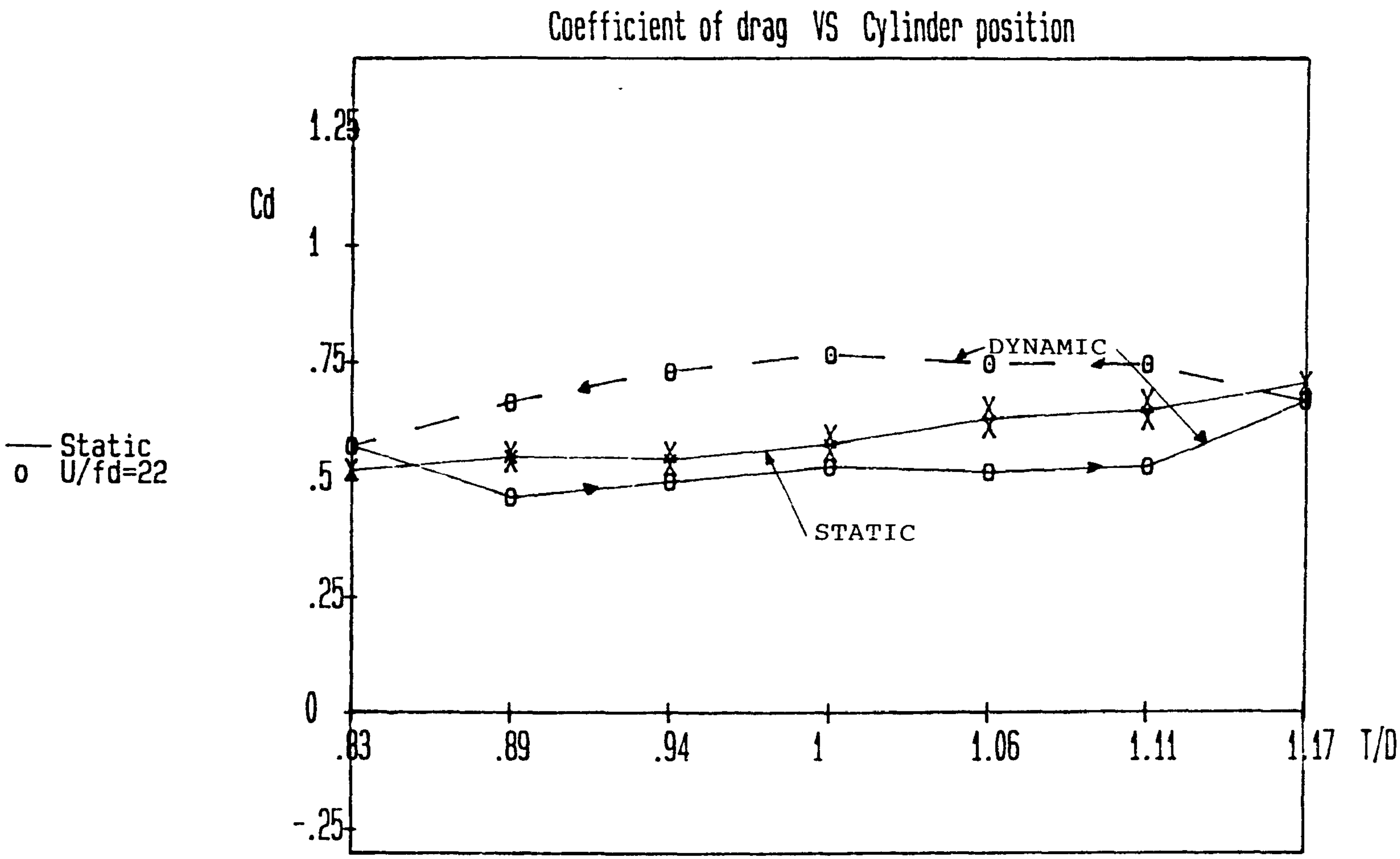
Drag coefficient versus cylinder position.
X-marks indicate Cd predicted by quasi-static assumption.
L/D=4 Re=7.7x10^4

Figure 75.



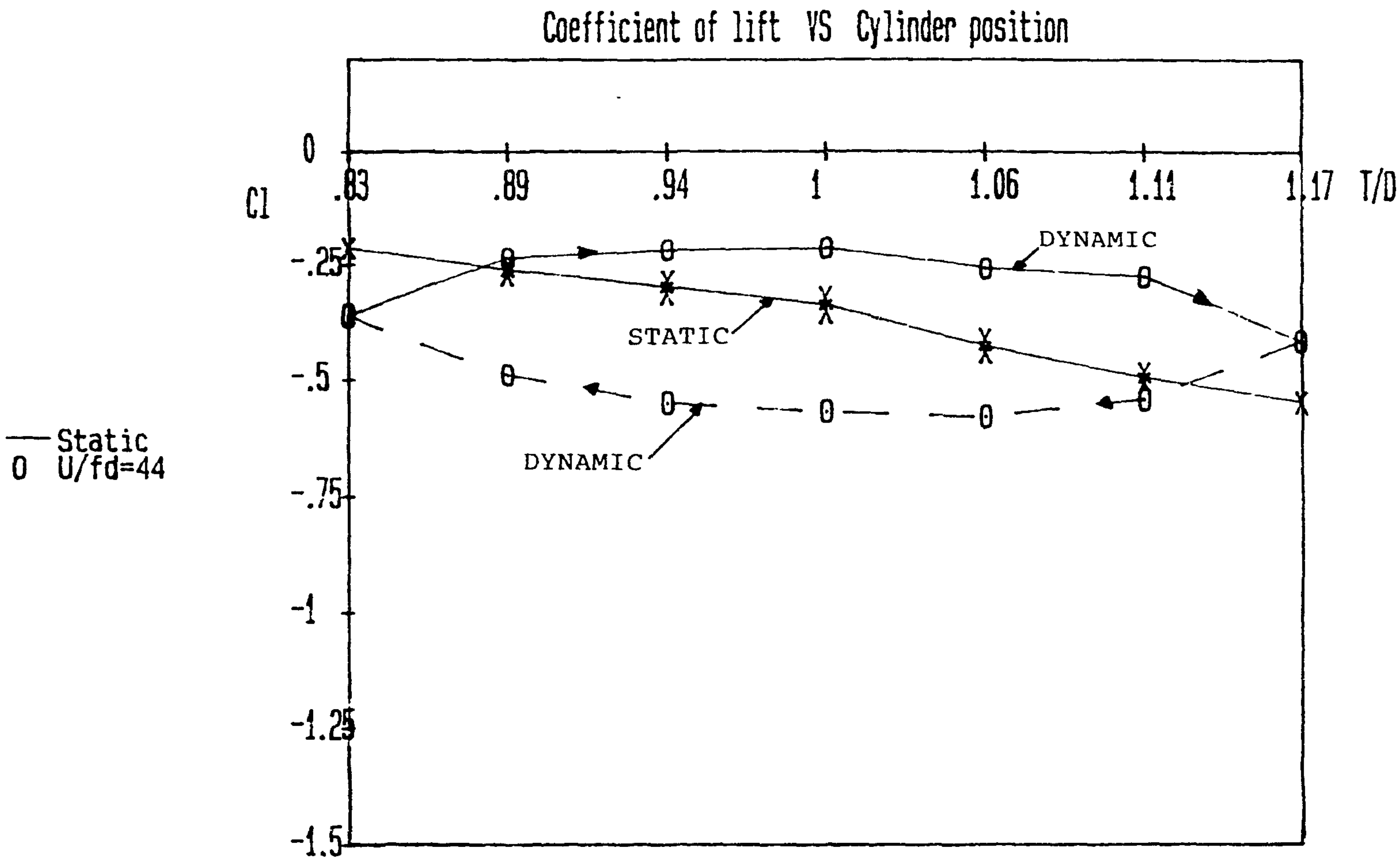
Lift coefficient versus cylinder position.
X-marks indicate Cl predicted by quasi-static assumption.
L/D=4 Re=1.16x10^5

Figure 76.



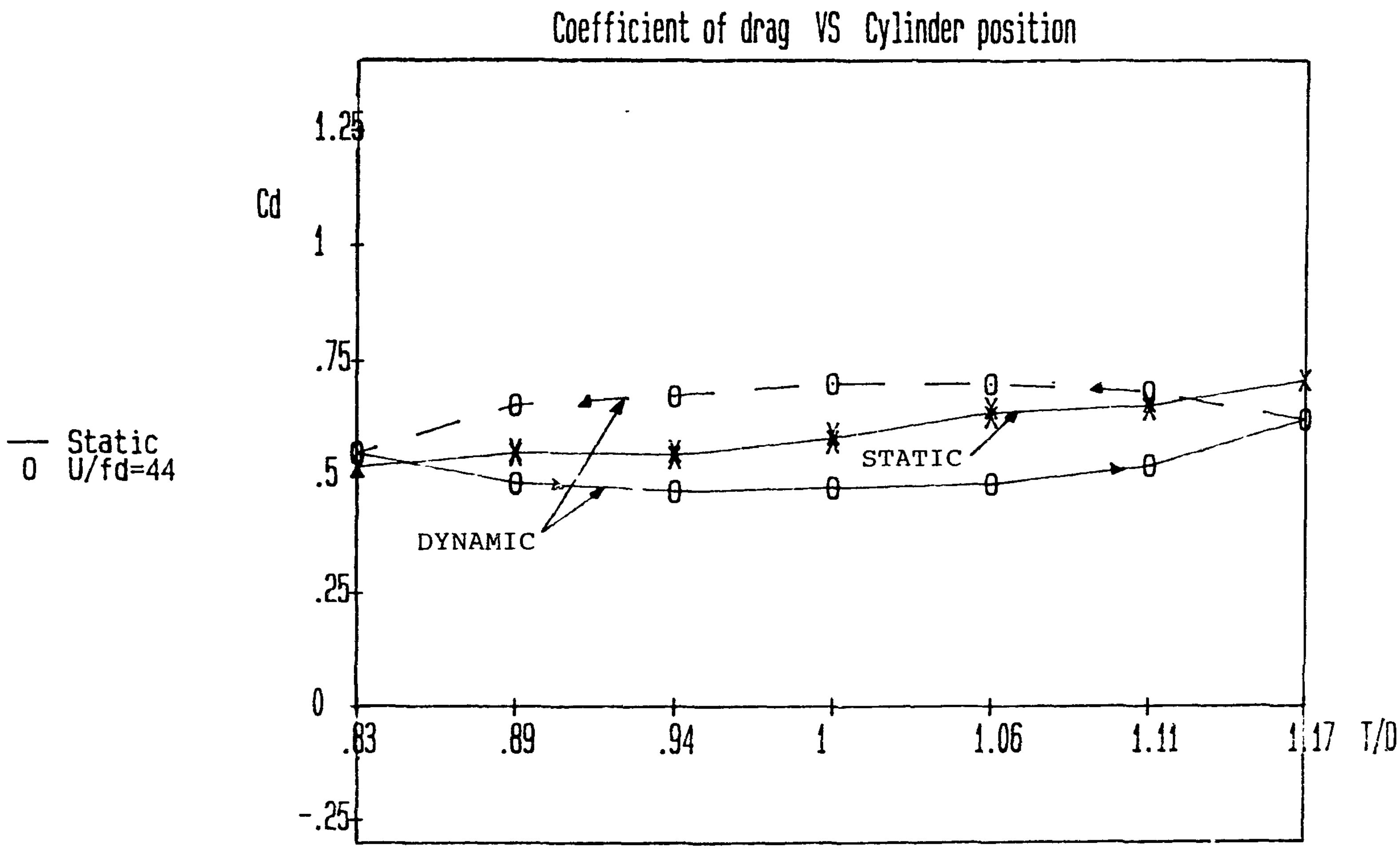
Drag coefficient versus cylinder position.
X-marks indicate Cd predicted by quasi-static assumption.
L/D=4   Re=1.16x10^5

Figure 77.



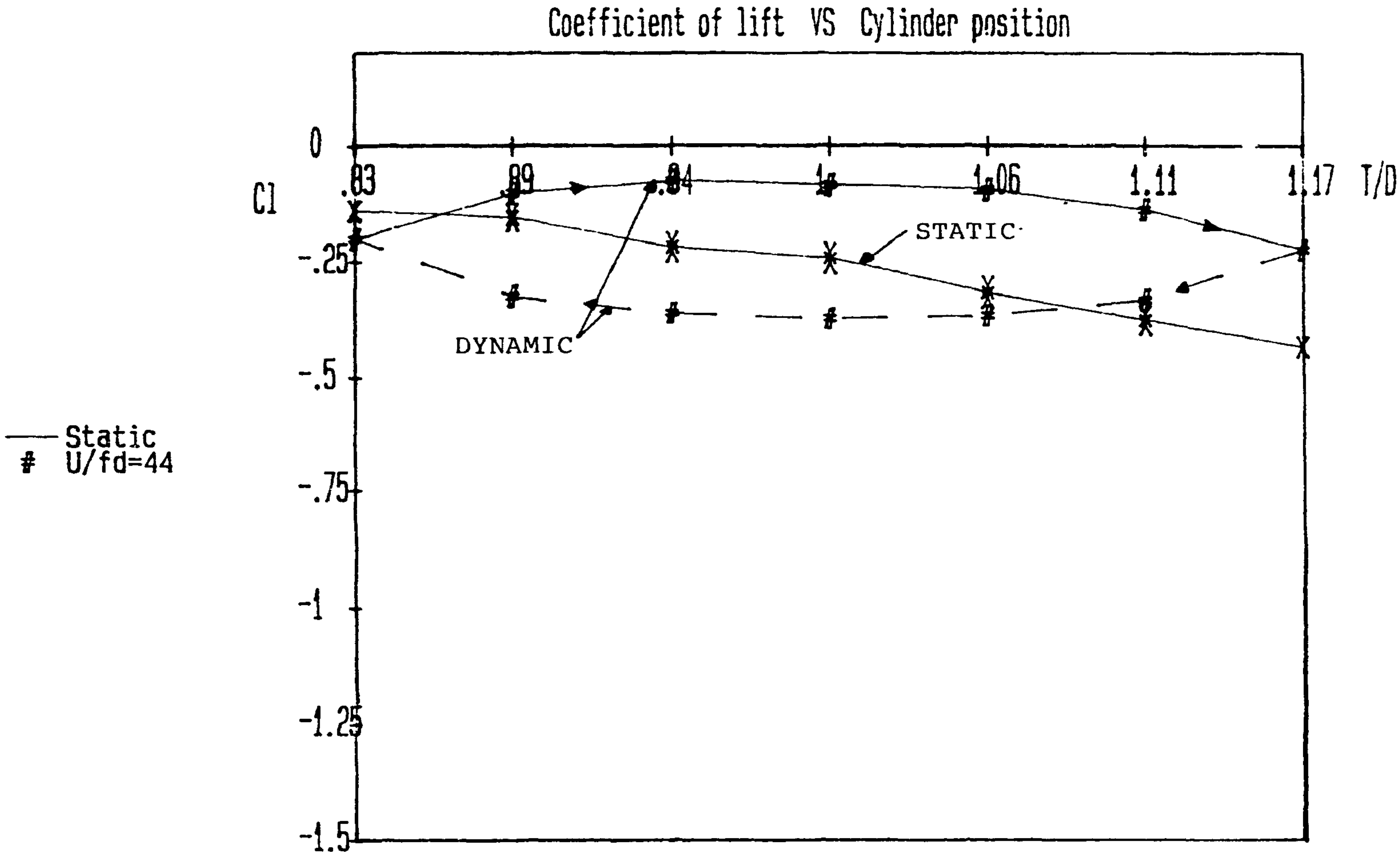
Lift coefficient versus cylinder position.
X-marks indicate Cl predicted by quasi-static assumption.
L/D=4 Re=1.16X10^5

Figure 78.



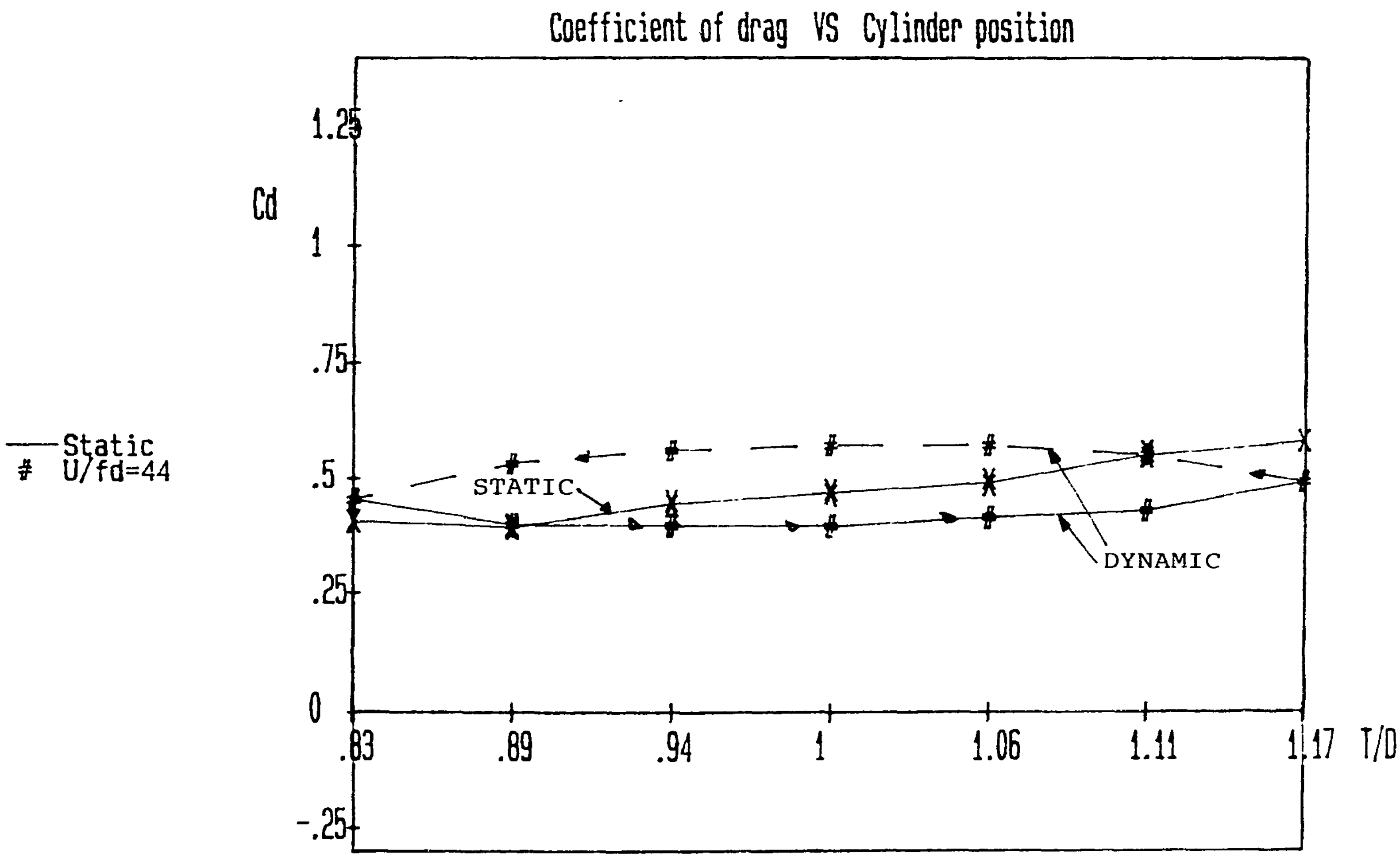
Drag coefficient versus cylinder position.
X-marks indicate Cd predicted by quasi-static assumption.
L/D=4 Re=1.16X10^5

Figure 79.



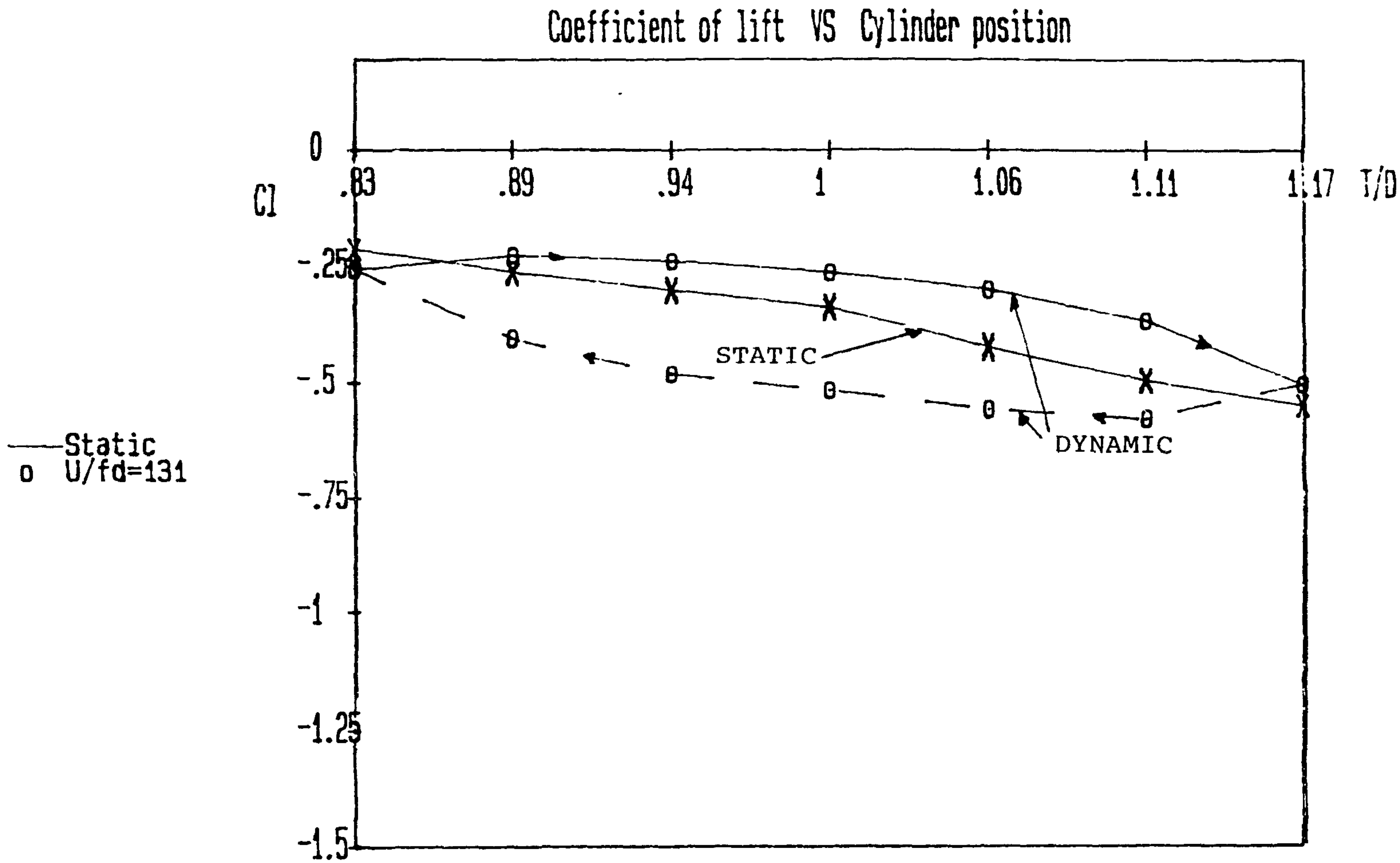
Lift coefficient versus cylinder position.
X-marks indicate Cl predicted by quasi-static assumption.
L/D=4   Re=1.75X10^5

Figure 80.



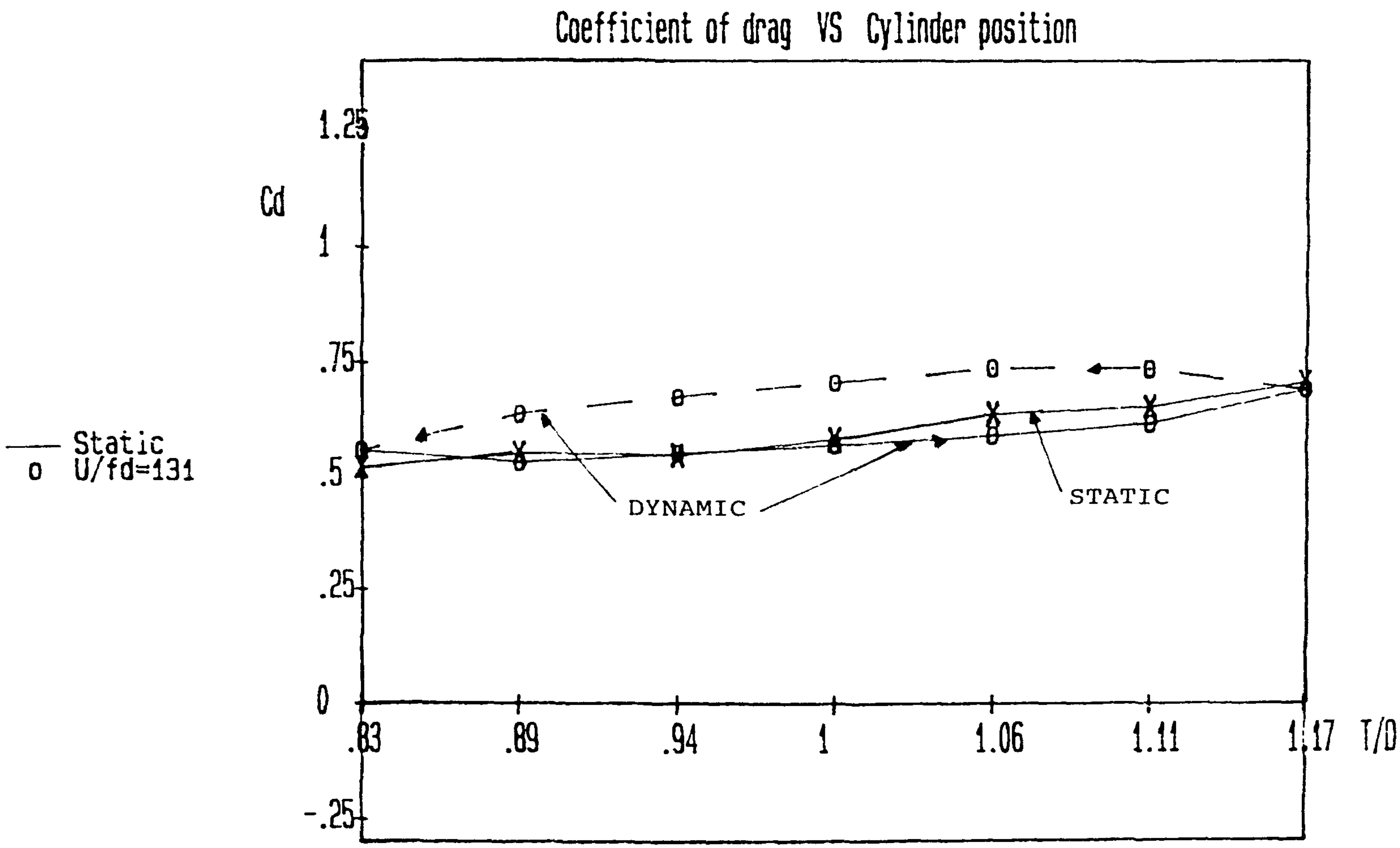
Drag coefficient versus cylinder position.
X-marks indicate Cd predicted by quasi-static assumption.
L/D=4 Re=1.75X10^5

Figure 81.



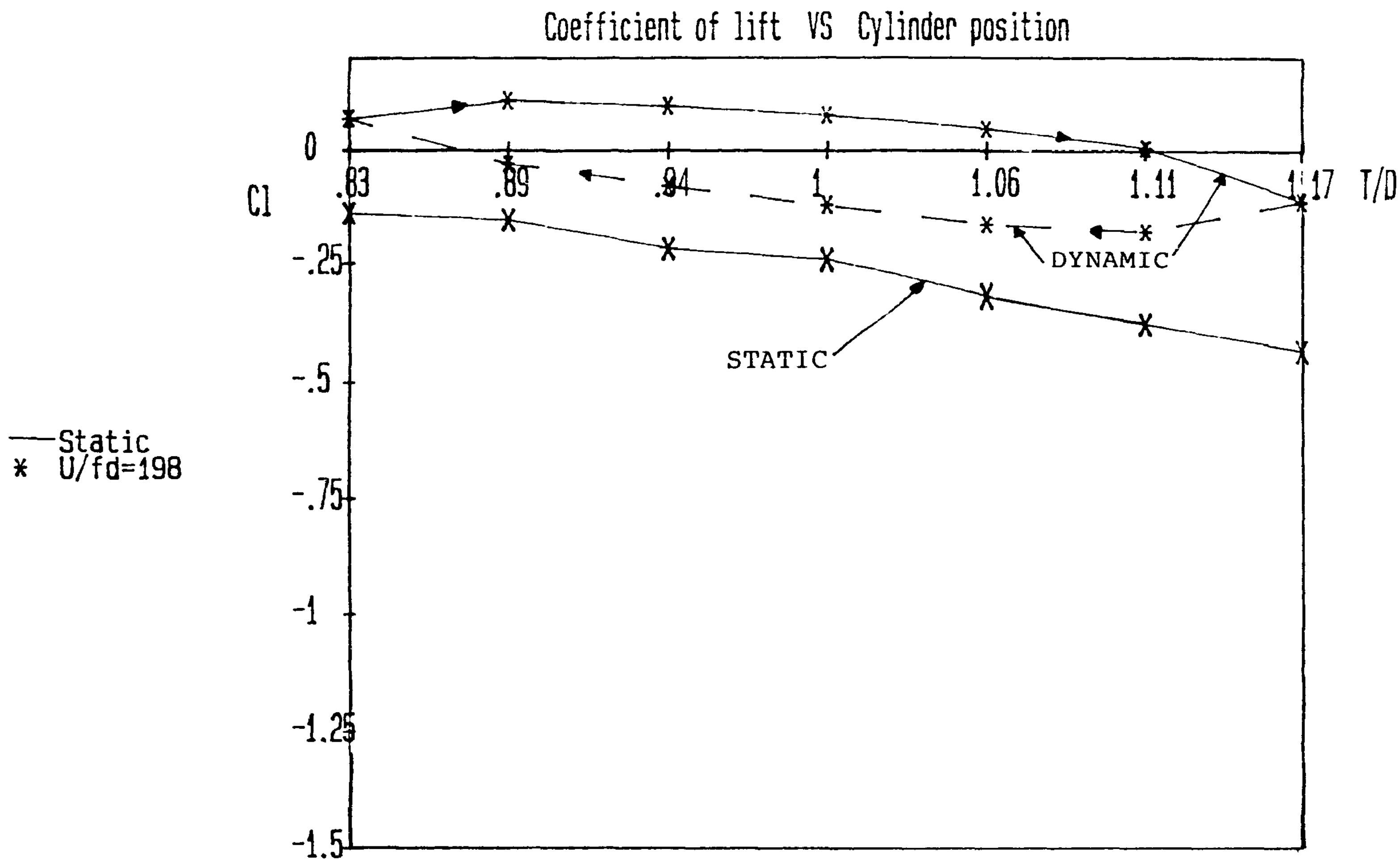
Lift coefficient versus cylinder position.
X-marks indicate Cl predicted by quasi-static assumption.
L/D=4 Re=1.16X10^5

Figure 82.



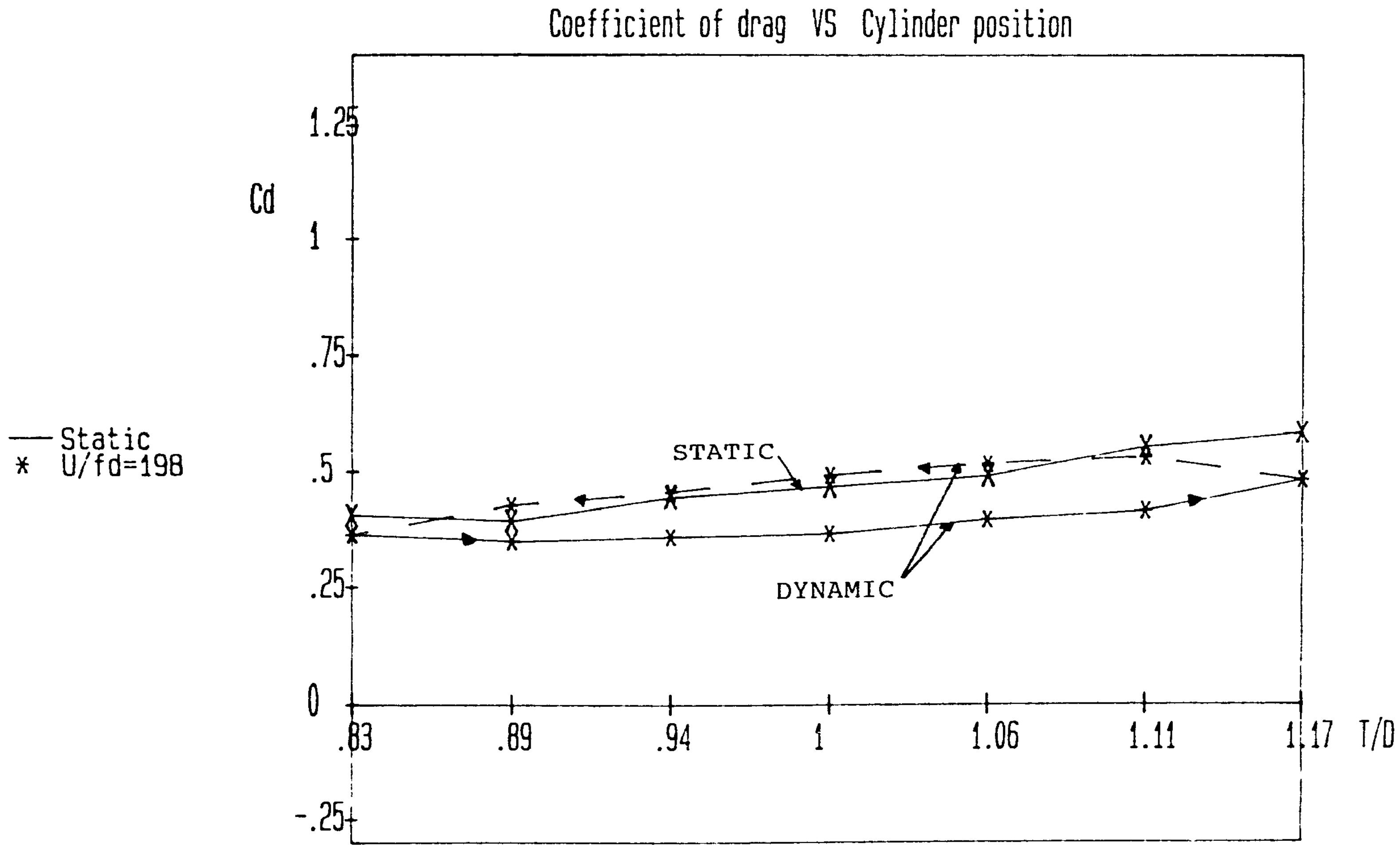
Drag coefficient versus cylinder position.
X-marks indicate Cd predicted by quasi-static assumption.
L/D=4 Re=1.16X10^5

Figure 83.



Lift coefficient versus cylinder position.
X-marks indicate Cl predicted by quasi-static assumption.
L/D=4 Re=1.75X10^5

Figure 84.



Drag coefficient versus cylinder position.
X-marks indicate Cd predicted by quasi-static assumption.
L/D=4   Re=1.75X10^5

Figure 85.