HR Wallingford

IMPACT PRESSURES IN PLUNGE BASINS DUE TO VERTICAL FALLING JETS

by

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Report SR242
January 1991

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This report describes work funded by the Department of the Environment under Research Contract No PECD 7/6/113, Hydraulic Structures and Alluvial Processes. It is published on behalf of the Department of the Environment, but any opinions expressed in this report are not necessarily those of the funding Department. The work was carried out in the River Engineering Department of Hydraulics Research, Wallingford headed by Dr W R White. The nominated project officers were Dr R P Thorogood and Mr P Woodhead for DOE and Dr W R White for HR.

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ABSTRACT

Dams with overfall crests or high-level sluices produce near-vertical water jets whose energy can be dissipated in concrete-lined plunge basins. In order to design such basins it is necessary to have information on the mean and fluctuating pressures acting on the floor slabs. This experimental study investigated how the impact pressures produced by a vertical rectangular jet vary with velocity, water depth and amount of air within the jet. The work was funded by the Construction Industry Directorate of the Department of the Environment as part of its support for research on hydraulic structures and alluvial processes.

The first stage of the study comprised a literature review and testing of a small-scale rig (see interim report by Perkins (1987)). Results from this stage assisted in the development of a larger test rig which was used for the experiments described in this report. The rig was capable of producing a rectangular jet measuring 200m x 67mm with an impact velocity of 8.5m/s. The water depth in the basin was varied from zero to 0.8m, and the jet could be arranged to discharge vertically above the basin (as a plunging jet) or below the water surface (as a submerged jet). The amount of air in the jet was varied up to a maximum concentration of 20%. Impact pressures on the floor of the basin were measured using five transducers. The results were recorded and analysed to determine the characteristics of the mean and fluctuating components of the impact pressures. A total of 35 different conditions was studied.

Analysis of the data established a correlation between the mean dynamic pressure at the centre of the rectangular jet, the jet velocity at impact with the water surface, the air concentration, the water depth and the thickness of the jet. Pressures were found to decrease rapidly with horizontal distance from the centre of the jet. Adding air to the jet decreased the mean pressures.

The turbulent pressure fluctuations were found to be fairly uniform within and immediately around the jet, and were little affected by changes in air concentration. The turbulence at the floor of the basin was strongest when the water depth was between 10 and 12 times the thickness of the jet. Correlations were established for estimating the root-mean-square and extreme values of the pressure fluctuations. The probability distributions of the turbulence were found, on average, to be more sharply peaked than a Gaussian distribution and were positively skewed, ie. the positive fluctuations tended to be larger than the negative ones. Spectral analysis showed that the turbulence energy was most concentrated at frequencies of 0-3Hz. The results of the study confirmed the validity of using Froudian scaling in model tests of plunge basins.

SYMBOLS

B Thickness of rectangular jet (short side)

B_o Initial thickness of rectangular jet

B_1 Thickness of jet entering plunge basin

C Local volumetric air concentration

C_o Mean volumetric air concentration (equation (15))

C_p Pressure coefficient for mean dynamic pressure (Equation (31))

C_{pm} Maximum value of C_p on floor of basin

C_p^+ Pressure coefficient for maximum instantaneous dynamic pressure (Equation (33))

C_p^- Pressure coefficient for minimum instantaneous dynamic pressure (Equation (34))

C_p' Pressure coefficient for root-mean-square pressure fluctuation (Equation (13))

C_p'' Pressure coefficient for root-mean-square pressure fluctuation measured by pitot tube (Equation (23))

D_o Initial diameter of circular jet

D_1 Diameter of jet entering plunge basin

d Mean particle size

E_k Kinetic energy head of jet

f Frequency

f_m Frequency in model

f_p Frequency in prototype

g Acceleration due to gravity

H Height of jet nozzle above floor

h Depth of water

h_1 Height of manifold above pipe exit

h_m Static pressure head at manifold

K Coefficient in Equation (14)

k Kurtosis (Equation (36))

L Plunge length of jet in air

L_a Distance travelled by jet in air

L_b Break-up length of water jet in air

L_e Flow-establisment length

L_w Distance travelled by jet in water

$\dot{M}$ Momentum flux due to velocity of jet

N Number of meeasurements

SYMBOLS (cont'd)

p Mean dynamic pressure due to velocity of jet

p' Pressure fluctuation from mean

p_m Mean dynamic pressure on centreline of jet

p_{max} Maximum instantaneous dynamic pressure

p_{min} Minimum instantaneous dynamic pressure

p_{rms} Root-mean-square fluctuation of dynamic pressure

Q Volumetric flow rate of water

Q_a Volumetric flow rate of air

q Volumetric flow rate of water per unit width

r Areal contraction ratio

S_f Energy gradient of flow

s Skewness (Equation (35))

T_c Time that probe is in conducting fluid

T_p Turbulent pressure intensity (Equation (36))

T_v Time that probe is in void

V Overall mean velocity of jet (discharge/area)

V_o Initial value of V for jet

V_1 Value of V for jet entering plunge basin

v Local time-mean velocity

v_m Maximum value of v

v_{rms} Root-mean-square velocity fluctuation

W Width of rectangular jet (long side)

W_o Initial width of jet

x Distance from centre of jet in direction W

y Distance from centre of jet in direction B ; distance normal to invert of channel

y_m Depth of flow measured normal to invert of channel

y_s Depth of scour below water surface

z Distance from nozzle along longitudinal centreline of jet; vertical distance below water surface

SYMBOLS (Cont'd)

α_1 Semi-angle rate of contraction of high-velocity inner core of jet

α_2 Semi-angle rate of jet expansion in flow-establishment zone

α_3 Semi-angle rate of jet expansion in established-flow zone

ϵ Mean turbulence intensity of velocity fluctuations (= v_{rms}/V)

ϵ_1 Local turbulence intensity (= v_{rms}/v)

θ Semi-angle rate of jet expension in air

θ' Value of θ in the absence of gravitational effects

ρ Density of fluid in jet

ρ_o Density of fluid surrounding jet

σ Standard deviation (Equation (34))

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1 INTRODUCTION

A wide range of methods can be used to pass flood flows over, through or around dams. One common solution in the case of concrete gravity dams is to discharge the water freely into air either over the crest of the dam or by means of short spillway chutes or jet valves positioned below the crest. The water then forms a high-energy free-trajectory jet which impacts downstream of the foot of the dam. In the case of an overflow crest, the jet lands almost vertically, whilst with a low-level valve or chute the water may have a significant horizontal velocity component at impact.

Three methods can be used to dissipate the energy of a falling jet.

(1) If suitable rock exists in the downstream channel and the jet lands far enough away from the toe of the dam, the jet may be allowed to scour out a plunge pool.

(2) If the size of an uncontrolled plunge pool might threaten the stability of the dam, a weir may be constructed downstream of the pool to raise the tailwater level and hence provide a partial water cushion which reduces the amount of scour.

(3) If the first two options are not appropriate, a concrete-lined plunge basin may be constructed with a tail weir which produces a sufficient depth of water to prevent erosion of the floor slabs.

In all three cases, the onset and extent of scour depend on the relative magnitudes of the impact pressures produced by the falling jet and the erosive resistance of the bed. A naturally-formed plunge pool deepens until the jet is cushioned sufficiently for it to be no longer able to dislodge material or transport it out of the pool. The erosive resistance of the bed depends primarily on the size and density of the material ; rock subject to jet impact tends to shatter along fault lines and forms large loose blocks. Several studies (eg Mason (1984, 1989)) have investigated the relationship between jet energy, bed material and the equilibrium depth of scour in naturally-formed plunge pools.

The design criteria for a concrete-lined plunge basin are somewhat different because it is necessary to ensure that the floor slabs can withstand the jet impact without damage. Three principal factors need to be considered:

- the trajectory of the jet through the air - this determines the location and size of the plunge basin

- air entrainment as the jet passes through the air and enters the plunge basin - this affects velocities in the jet and helps to cushion its impact

- impact pressures on the floor of the basin - these determine the size and strength of the concrete slabs needed to protect the basin

Information on jet trajectories has been obtained from theory, model tests and observations of prototype installations. Approximate estimates can be made by neglecting energy losses and assuming pressures to be atmospheric at all points in the jet; the results usually over-predict the "throw" of the jet. More accurate solutions using potential flow theory take account of internal pressures in the jet (eg Naghdi & Rubin (1981) and Hager (1983)). Martins (1977) compared several empirical methods of predicting jet lengths and recommended those due to Kawakami (1973) and Zvorykin (1975).

The problem of determining the amount of air entrainment in a free-trajectory jet is extremely difficult. Direct prototype measurements at high-head dams are virtually impossible (although high-power laser doppler anemometers might conceivably be used). Analysis of photographs of prototype jets can provide rough estimates of the amount of bulking but do not give information about the internal structure of the flow. Laboratory studies have provided some useful data on the entrainment process, but the results are likely to be subject to significant (but unknown) scale effects when extrapolated to prototype conditions. When a jet enters a plunge pool or basin, air is also entrained around the periphery of the jet where it penetrates the horizontal water surface. This additional air may not reduce peak impact pressures significantly if the high-velocity core of the jet persists to the floor of the basin.

Estimates of the pressures exerted on the floor of a plunge basin can be determined from suitable laboratory tests. Putting aside for the moment the effect of entrained air, the principal factors involved are the initial momentum of the jet (magnitude and direction), the rate of diffusion of that momentum due to viscosity and turbulence, and the relative water depth in the basin. Studies of analogous problems, such as high-energy turbulence in hydraulic-jump stilling basins, have shown that Froudian models can satisfactorily predict prototype performance in terms of mean and fluctuating pressures and their statistical distribution (eg Elder (1961) and Lopardo et al (1984) who both compared prototype and model data for stilling basins, and Schiebe (1971) who compared results from two models with a size ratio of 1:5).

The frequency of the pressure fluctuations depends on the velocity of flow and the length scales associated with the turbulence. Initially, the size of the turbulent eddies is related to a characteristic dimension of the flow (eg the depth of water, the size of jet or the height of baffle block). The turbulence then dissipates by "cascading" downwards into smaller eddies having higher frequencies. A Froudian model produces the correct relationship between flow velocity and length scale, and can therefore be expected to produce initial turbulent eddies of the appropriate size and frequency. The cascade process in the model may be somewhat truncated relative to that in the prototype (since the ultimate eddy size is independent of scale), but the amount of energy involved will usually be a small proportion of the total.

The main effect of air entrained in a body of water is to convert it from an almost incompressible liquid to a highly compressible one. This change tends to cushion the impact of the jet and reduce the peak pressures. The compressibility of the water depends on the amount of air that is present, so the cushioning effect can be expected to be reproduced correctly in a model if the volumetric air concentration is equal to that in the prototype.

The behaviour of an impacting jet clearly depends upon a variety of factors, but the above discussion indicates that the primary effects can be reproduced satisfactorily in reduced-scale models of plunge basins. Results from laboratory research can therefore be expected to provide useful data for the design of prototype installations.

Most previous studies of impact pressures have used small diameter circular jets and have measured only mean pressures. The objectives of the investigation described in this report were to:

- study rectangular water jets discharging vertically into different depths of water
- measure both mean and fluctuating pressures on the floor of the basin under the jet
- study the effect of entrained air on the impact pressures

A rectangular jet was used because this is the type which occurs most commonly in plunge basins. The jet was made as large as possible within the constraints dictated by budget and available pumping equipment. The jet was tested vertically because this arrangement produces the greatest impact pressures, and is representative of conditions which arise in a plunge basin close to the toe of a dam having either a free overfall crest or high-level sluices. (The results are not applicable to basins downstream of flip-buckets or low-level valves and sluices where the jet lands at a relatively shallow angle). Fluctuating pressures were measured because the floor of a plunge basin needs to be able to withstand the maximum positive and negative pressures imposed by a jet, and not just the mean values. As explained above, the prediction of how much air wil be entrained by a jet of water travelling through the air is difficult and can at present only be approximate. However, in terms of design, the main question is what effect does entrained air have on the impact pressures; only if it is shown to be significant, does more effort need to be spent on improving methods of predicting entrainment. In order to obtain measurements of local air concentrations, a portable void meter manufactured by Nottingham University was purchased specially for the work.

This study was funded by the Construction Industry Directorate of the Department of the Environment as part of its support for research on hydraulic structures and alluvial processes.

2 PREVIOUS STUDIES

2.1 Flow characteristics

The behaviour of a water jet discharging vertically downwards is shown schematically in Figure 1. When the jet enters air, surface disturbances around the periphery of the jet build up and begin to entrain air and dissipate some of the energy in the jet. As a result, there is a tendency for the jet to increase in width as it falls. At the same time, however, the jet is gaining in kinetic energy which tends to reduce its width. The actual rate of change of width depends upon the relative magnitudes of these opposing factors.

If the jet is initially smooth, wave-like disturbances may develop around its periphery due to the interaction between the forces due to pressure, gravity, inertia and surface tension. However, the surface disturbances are more usually the result of turbulence present within the jet. Once released from the constraint of the nozzle, a re-distribution of mean and fluctuating velocities occurs from the cente of the jet towards the periphery. As a result, the surface becomes highly disturbed and may break up into droplets. Air is entrained inwards towards the core, and the energy of the water is reduced by an exchange of momentum with the surrounding air, which is dragged downwards by the flow. The aerated outer layer of water thus increases in thickness as the jet falls and the "solid" core of high-velocity water is reduced in size. After a certain distance, the solid core disappears and the jet loses its coherence. The break-up distance depends upon the initial thickness and shape of the jet and the degree of turbulence in the flow.

The diffusion of a water jet in air occurs relatively slowly because of the large difference in density between the two fluids. In the case of a submerged jet discharging into the same fluid, the exchange of momentum is much more rapid and the break-up distance is consequently reduced (as indicated in Figure 1). The point at which the solid core disappears is used to demarcate two regions of the jet: the upper "flow-establishment" zone and the lower "established-flow" zone. The rate of expansion of the jet increases after the flow has become established. Energy dissipation within the solid core of the jet is relatively small, so a limited area of the floor of the plunge basin may be subject to almost 100% of the initial total head of the jet if it does not break up before reaching the floor.

The behaviour of a water jet in water differs depending upon whether it discharges as a submerged jet below the surface or whether it first discharges into air as a plunging jet. In the former case, the outer layer of the jet is a single-phase mixture of water from the jet and water entrained from within the basin ; although the mean velocity of the jet decreases with distance, the total discharge increases due to the entrainment process. In the second case, the outer layer is a two-phase region of water and air. As before, the liquid phase is a mixture of water from the jet and water entrained from within the pool. Part of the air is entrained into the jet during its passage through the atmosphere and part is drawn down into the basin as the jet penetrates the water surface ; the amount drawn down increases as the "roughness" of the periphery of the jet increases. The air is carried downwards by the jet to a level at which the velocity of the water becomes less than the rise velocity of the bubbles. The roughness and turbulence of a plunging jet are usually greater than those of a submerged jet, and this causes the plunging jet to diffuse more rapidly under water. Tests with submerged jets are therefore likely to produce higher impact pressures on the floor of a basin than equivalent tests with plunging jets.

2.2 Experimental results

The majority of the theoretical and experimental studies carried out in this field have been concerned with submerged jets (eg air in air or water in water). Albertson et al (1948) investigated the cases of two-dimensional rectangular jets and three-dimensional circular jets. If a jet is assumed to be fully turbulent, shear stresses due to viscocity can be neglected in comparison with the Reynolds stresses due to the velocity fluctuations. On this basis, dimensional reasoning suggests that the transverse velocity profile in the mixing region between the high-velocity core and the surrounding fluid should exhibit the same non-dimensional shape at all points along the jet. In addition, the rate of expansion of the jet should be effectively constant and not vary with distance. Albertson et al confirmed these theoretical predictions with measurements in air jets, and found that the non-dimensional velocity profiles were well-described by the Gaussian normal probability function. The length of the flow establishment zone (see Figure 1) for a submerged rectangular jet was found to be 5.2 times the initial jet thickness B_o, and for a submerged circular jet to be equal to 6.2 times the initial jet diameter D_o. In the two-dimensional case, the local velocity v at a point with co-ordinates y, z (z measured from the nozzle along the axis of the jet) is related in the flow-establishment zone to the initial mean jet velocity V_o by

$$\frac{v}{V_o} = \exp\left[-42.1 \left\{ 0.0966 + \frac{(y - B_o/2)}{z} \right\}^2 \right]$$

$$\text{for } z \leq 5.2\, B_o \text{ and } y \geq (B_o - 0.193\, z)/2 \qquad (1)$$

and in the established-flow zone by

$$\frac{v}{V_o} = 2.28 \left(\frac{B_o}{z}\right)^{1/2} \exp\left[-42.4\, y^2/z^2 \right]$$

$$\text{for } z > 5.2\, B_o \qquad (2)$$

The above results apply to submerged jets whose expansion is not restricted by the presence of solid boundaries. Cola (1965) carried out experiments with a submerged rectangular water jet (width B_o = 0.0185m) discharging vertically at a height of H = 0.82m above a horizontal floor (giving a ratio of H/B_o = 44.3). Tests at four different flow rates (V_o = 1.8m/s to 4.8m/s) gave similar profiles of mean velocity when expressed in non-dimensional form. The jet was found to develop in the same way as an unrestricted jet (ie in accordance with Equations (1) and (2)) up to a distance of z/H = 0.71 from the nozzle. Beyond that point, the jet deccelerated more rapidly as the flow approached the floor, with a consequent rise in the static pressure. The maximum mean dynamic pressure due to the impact of the jet on the floor was $p_m = 0.145\ \rho\ V_o^2/2$. By comparison, the flow velocity on the centre-line for an unrestricted jet would according to Equation (2) have been equivalent to $p_m = 0.117\ \rho\ V_o^2/2$.

Beltaos & Rajaratnam (1973) also studied plane turbulent jets impinging at right-angles on a horizontal floor. The tests were made with air discharging into air at velocities between V_o= 35m/s and 62m/s. The width of the rectangular nozzle was B_o = 2.24mm and its height above the floor was varied so as to give values of the ratio H/B_o between 14.0 and 67.4. The high-velocity core was found to persist up to a distance from the nozzle of z/B_o = 8.26. Beyond this, the flow behaved as an unrestricted jet with self-similar velocity profiles up to a distance from the nozzle of about z/H = 0.70. The maximum velocity on the centreline was given by

$$\frac{v_m}{V_o} = 2.40 \left(\frac{z}{B_o} - 2.5 \right)^{-\frac{1}{2}} \qquad (3)$$

In the impingement zone, between z/H = 0.70 and 1.0, the velocity of the jet decreased more rapidly than in an unrestricted jet and with practically no loss in total energy. The mean impact pressure on the centreline of the jet was given by

$$p_m = 7.7 \left(\frac{B_o}{H} \right) . \frac{1}{2} \rho V_o^2 \qquad (4)$$

The variation of dynamic pressure p along the wall with distance y from the centreline was found to fit a Gaussian distribution described by

$$\frac{p}{p_m} = \exp\left(- 38.5 \ (y/H)^2 \right) \qquad (5)$$

The impact pressure measured by Cola (see above) corresponds to a value for the numerical constant in Equation (4) of 6.4 instead of 7.7

The diffusion of a water jet travelling through air occurs more slowly than in water due to the difference in density of the two mediums. Kraatz (1965) suggested that the flow-establishment distance L_e for a circular jet is given by

$$\frac{L_e}{D_o} = 5 \quad (\rho/\rho_o)^{0.345} \qquad (6)$$

where D_o is the initial diameter of the jet, ρ is the density of the jet and ρ_o is the density of the surrounding fluid. For a jet of water in air at atmospheric pressure and a temperature of 10°C, Equation (6) indicates that the high-velocity core should disappear at a distance of $L_e = 50\ D_o$ from the nozzle.

Ervine et al (1980) investigated the effect of turbulence on the behaviour of near-vertical water jets in air using circular nozzles with diameters of $D_o = 6$, 9, 14 and 25mm and flow velocities up to $V_o =$ 7m/s. The distance L_b travelled by the jet before losing its coherence and breaking up depended on the turbulence intensity ϵ as follows.

$$L_b = 60 \quad Q^{0.39}, \quad \epsilon = 0.3\% \tag{7a}$$

$$L_b = 17.4 \quad Q^{0.31}, \quad \epsilon = 3\% \tag{7b}$$

$$L_b = 4.1 \quad Q^{0.2}, \quad \epsilon = 8\% \tag{7c}$$

where L_b is in m and Q is the jet discharge in m^3/s ; ϵ is defined as

$$\epsilon = v_{rms}/V \tag{8}$$

where v_{rms} is the root-mean-square velocity fluctuation and V is the overall mean velocity of the jet. Earlier, Horeni (1956) had found the break-up distance for a rectangular jet in air to be

$$L_b = 5.89 \; q^{\,0.319} \tag{9}$$

where q is the unit discharge in m^2/s ; the turbulence intensity of the flow was not stated.

Ervine & Falvey (1987) carried out detailed measurements on circular water jets in air using a laser Doppler anemometer. Nozzle diameters of 50mm and 100mm were used, and the exit velocity of the jet was varied from 3.3m/s to 29.6m/s. The expansion angle θ of the outer edge of the jet (see Figure 1) was found to be related to the turbulence level by

$$\theta = \tan^{-1}(0.38\,\epsilon) \qquad (10)$$

Measurements within the jet using a probability probe indicated that the angle of contraction α_1 of the inner high-velocity core was much smaller and of the order

$$\alpha_1/\theta = 1/5 \text{ to } 1/7 \qquad (11)$$

According to these results, the high-velocity core of a jet with a turbulence level of ϵ = 8% will disappear at a distance of about $L_e = 100\ D_o$ from the nozzle. This compares with values of about $L_e/D_o = 50$ obtained by Kraatz (Equation (6)) and by Ervine et al (1980) for the break-up length at a turbulence intensity of ϵ = 8%.

Ervine & Falvey (1987) also considered the behaviour of water jets travelling through water, and summarised information about the expansion angles α_1, α_2 and α_3 in Figure 1 as follows.

Jet condition	Turbulence level	α_1	α_2	α_3
submerged		4.5°	6°	11°
plunging	almost laminar $\epsilon \sim 0.3\%$	5°	6°-7°	10°-12°
plunging	smooth turbulent $\epsilon \sim 1.2\%$	7°-8°	10°-11°	14°
plunging	high turbulence $\epsilon \sim 5\%$	~8°	13°-14°	14°-15°

Measurements of the mean and fluctuating pressures on the floor of a plunge basin were made by Withers (1989) and Ervine & Withers (1989). The tests were carried out with circular water jets (D_o = 25mm to 78mm) discharging vertically downwards into air with initial velocities in the range V_o = 3m/s to 25m/s. The height of fall to the water surface in the plunge basin was varied up to a maximum of 2.5m. The maximum mean dynamic pressure p_m exerted on the floor of the basin was expressed in terms of a pressure coefficient C_{pm} defined as

$$C_{pm} = \frac{2\, p_m}{\rho\, V_1^2} \tag{12}$$

where V_1 is the mean velocity of the jet as it enters the plunge basin. The value of C_{pm} for a plunging jet was almost equal to unity when the water depth h in the basin was less than twice the diameter D_1 of the jet entering the basin. Increasing the water depth decreased C_{pm} as follows

h/D_1	C_{pm}
4	0.72
6	0.46
8	0.30
10	0.21
12	0.15
16	0.07
20	0.05

Measurements of the fluctuating pressures on the floor of the basin were analysed to determine the root-mean-square value, p_{rms}, for each test. Peak values of the corresponding pressure coefficient

$$C_p' = \frac{2\,p_{rms}}{\rho\,V_1^2} \tag{13}$$

were about 0.2 and occurred when the relative water depth in the basin was in the range h/D_1 = 5 to 10. The maximum positive pressure fluctuation in a test (relative to the mean) was equivalent to about 4 C_p'; the corresponding minimum pressure fluctuation was about 3 C_p'. Power spectra of the fluctuations showed that most of the turbulent energy occurred in the 3Hz to 10Hz frequency range.

Air is entrained into a plunging jet during its travel through the atmosphere and as it passes through the water surface in the basin. Measurements of the total rate of air entrainment were made by Ervine et al (1980) using the equipment described above, and by Tabushi (1969) using a nozzle of diameter 5mm discharging into a 300mm diameter cylindrical tank. Data on the amount of air entrained by free-trajectory jets entering plunge basins were fitted by Ervine & Falvey (1987) to the equation

$$C_o = K\,(L/D_o)^{1/2} \;/\; [\,1 + K\,(L/D_o)^{1/2}\,] \tag{14}$$

where C_o is the mean air concentration based on volumetric rates of air flow (Q_a) and water flow (Q), ie

$$C_o = \frac{Q_a}{Q_a + Q} \quad (15)$$

L is the plunge length through the atmosphere and values of the factor K were estimated as follows.

Turbulence level	Circular jets	Wide rectangular jets	Valid range
smooth turbulent	0.2	0.1	$L/D_o \leq 200$
moderate turbulent	0.3	0.15	$L/D_o \leq 100$
rough turbulent	0.4	0.2	$L/D_o \leq 50$

It is presumed that, in the case of wide rectangular jets, the nozzle size D_o is equivalent to the thickness B_o of the jet.

The effect of entrained air on the velocity distribution produced by a jet entering a deep cylindrical tank was studied by Chanishvili (1965). The nozzle diameter was 14.5mm and the discharge velocity ranged from V_o= 10m/s to 17.5m/s. The depth of water was varied so that the nozzle discharged either just below the surface (as a submerged jet) or just above the water surface (producing air entrainment). Comparisons of the maximum water velocity on the centreline of the jet showed that air entrainment produced no significant reduction in velocity until the jet had travelled a distance below the water surface of about z/D_o= 50 ; at this point the centreline velocity without air entrainment was $v_m = 0.066\ V_o$ and with air entrainment was $v_m = 0.062\ V_o$.

Indirect information about the effect of air entrainment is provided by a laboratory study of scour depths in plunge pools carried out by Mason (1989). Air was added to a rectangular water jet discharging at an angle of about 45° on to an erodible bed. The depth of scour y_s below the water surface was related to the other variables by

$$y_s = 3.39 \frac{q^{0.60}\ h^{0.16}}{g^{0.30}(1-C_o)^{0.30}d^{0.06}} \qquad (16)$$

where d is the mean particle size in the bed. This result is perhaps surprising at first sight because increasing the air concentration appears to increase the scour depth. However, in the experiments, adding air had the effect of increasing the velocity of the water in the jet by a factor of $(1-C_o)^{-1}$. Thus if the unit water discharge q in Equation (16) were replaced by the water velocity V and the jet thickness, it would be found that for constant V the scour depth is proportional to $(1-C_o)^{0.30}$. This point indicates that care is needed when applying Equation (16) to free-falling jets because air entrainment in the atmosphere does not increase the water velocity but tends to reduce it.

Ervine & Falvey (1987) developed several theoretical formulae describing the effect of entrained air in plunge basins, although some still await experimental verification. The formula proposed for estimating the mean dynamic pressure in an aerated jet at a depth z below the water surface was

$$p_m = \frac{1}{2} (1-C_o) \rho V_1^2 \; [16 (D_1/ z)^2] \qquad (17)$$

where V_1 is the mean velocity of the jet at impact with the water surface and D_1 is its corresponding diameter. This equation applies only in the established-flow zone which was estimated to start at about $y = 4 D_1$.

3 EXPERIMENTAL ARRANGEMENT

3.1 Small test rig

The design requirements for the test rig were that:

- it should produce a rectangular jet of water discharging vertically
- the jet should have as uniform a velocity distribution as possible
- the level at which the jet discharged should be variable
- air should be capable of being added at a known rate to the water jet prior to discharge

It was evident that the planned rig would be a relatively large construction, and that it would be difficult and expensive to modify once assembled. The inlet arrangement to the vertical discharge pipe was required to produce uniform flow conditions while being as compact as possible. Uncertainties also existed about the best method of aerating the jet.

For these reasons, it was decided to build a model of the proposed design at a scale of about 1:3.

The layout of the small rig is shown in Figures 2 and 3. Flow from two pumps entered a sealed pressure box which was used in order to prevent the formation of air-entraining vortices. Flow from the box then entered a vertical rectangular pipe, measuring 101mm x 38mm internally, and adjustable in length. An aeration system, based on designs for spillway aerators, was installed at the head of the pipe. This consisted of a small ramp around the perimeter of the pipe which contracted the flow and lowered the pressure below atmospheric. Just downstream of the pipe was a perforated box which enabled the sub-atmospheric pressure to draw air into the cavity formed by the ramp. Thus the air demand created by the high-velocity water passing the box was met without a fan having to be used to inject air into the flow.

Initial testing showed several shortcomings in the initial design of the rig. Strong swirl occurred at the entrance to the vertical pipe and tended to produce non-uniform conditions in the jet. As a result, a more symmetrical inlet arrangement was later adopted for the large rig. Initially, the aerator did not entrain air strongly enough, and difficulties were experienced in sealing the flanged joints. The air demand was increased by making the ramp larger, and reasonable flow conditions in the jet were obtained by carefully adjusting the taper downstream of the perforated box. The final design of the aerator is detailed in Figure 3, and Plate 1 shows it in operation. The experience obtained with the small rig enabled a more effective design to be successfully developed for the full-size rig, as described in Section 3.2.

3.2 Large test rig

As a result of the unsatisfactory flow conditions experienced at the entrance to the vertical pipe in the small rig, a different inlet arrangement was adopted for the full-size rig. Flow from the pump discharged into a long pipe of large diamater which was installed horizontally at a high level, with the vertical rectangular pipe connected to its invert. Due to its large diameter, the velocities in the horizontal pipe were relatively low; this design, together with a tapered transition piece, ensured good entry conditions to the vertical rectangular pipe.

The original intention had been to carry out tests with a jet measuring 300mm x 100mm with velocities up to 8m/s. Due to the cost of construction of such an arrangement, the jet was reduced in size to 200mm x 67mm, and the maximum available velocity reduced to roughly 6.5m/s (corresponding to a discharge of approximately $0.09m^3/s$). A diagrammatic layout of the final design is shown in Figure 4.

The vertical pipe was constructed using short sections of rectangular pipe with flanged joints. This enabled the length of the pipe and hence the height of the outlet point to be easily adjusted. The adjustable length of the "downpipe" allowed both the study of jets discharging into air before entering a plunge basin (ie free-falling jets), and the study of jets discharging below the water surface (ie submerged jets).

The plunge basin beneath the jet was formed by a square-shaped tank approximately 1.5m in width, with all four sides having removable boards acting as variable-height overflow weirs. The weirs allowed the depth of water in the plunge basin to be varied from approximately zero to 0.8m. Depths of water in the plunge basin were measured by means of a pressure tapping located at the mid-point of one of the sides of the basin. The bottom of the plunge basin was formed by a raised steel plate rigidly mounted on steel cross-beams. The central portion of the plate was removable and was drilled to accept the installation of transducers for measuring mean and fluctuating pressures on the floor of the basin. Details of the layout of the transducers are shown in Figure 5.

Following some early tests with one type of transducer which proved to be not entirely satisfactory (see Perkins (1987)), HR purchased six PDCR 930 transducers supplied by Druck Ltd. These transducers had the following characteristics:

(1) open-face design to allow flush mounting and prevent compressibility problems due to air collecting in tapping;
(2) waterproof casings with integral vented cable to allow compensation for changes in atmospheric pressure;
(3) very small temperature effects due to 'oil' filled isolation capsule (±0.3% of full scale for the range -2° to +30°C);
(4) full range of 500 mbar (equivalent to 5.1m head of water);
(5) high sensitivity;
(6) durable against shock and stress;
(7) long-term stability (0.1% of full scale/year).

Output signals from the transducers were conveyed via amplifiers and conditioning units to an analogue ("Teac" 7-track) tape recorder. Signals could thus be recorded continuously throughout the course of a test.

Water discharge rates were measured using initially a BS-type orifice meter and later a 203mm diameter digital bend meter developed at HR (see Deamer & May (1989)). The water flow rate was controlled by a gate valve on the delivery side of the pump whose capacity was $0.09m^3/s$.

Taking into account the problems encountered with the aeration system used in the small test rig, a new design was successfully developed for the full-size rig. This aeration system is shown diagrammatically in Figure 6. A manifold, with an internal diameter of 19mm and 18 number holes of 9.5mm diameter drilled at angles of 35° to the horizontal, was fixed into the rectangular pipe in the position shown in Figure 4. The 19mm manifold was connected to a 50mm diameter air supply pipe which extended down the side of the rig with its end open to atmosphere. The air flow rate was measured by a variable-area flow rater fitted in the 50mm pipe, and was controlled by a gate valve upstream of the flow rater. The layout of the holes in the manifold was designed to produce an even distribution of air throughout the jet. The manifold was located near the top of the rectangular pipe in order to ensure that the air/water mixture would be as uniform as possible at the point of discharge.

The aeration system worked by making use of the sub-atmospheric pressure in the water flowing past the manifold. Applying Bernoulli's equation between the manifold and the discharge point of the water jet, it can be shown that the static pressure head h_m at the manifold is given approximately by

$$h_m = -(1 - S_f)h_1 - \frac{V_o^2}{2g}(r - 1) \qquad (18)$$

where h_1 is the height of the manifold above the discharge point of the jet, S_f is the energy gradient in the rectangular jet pipe, V_o is the exit velocity of the jet and r is the ratio of the flow areas at the exit and the manifold. Assuming the minimum value of h_1= 2.2m used in the present experiments, it can be shown that the static pressure at the manifold varied from about h_m = - 3.8m at the maximum jet velocity of V_o = 6.5m/s to about h_m = - 2.5m at a 50% flow rate. These values were more than sufficient to produce the required rates of air flow in the aeration system.

4 EXPERIMENTAL PROCEDURE AND MEASUREMENTS

4.1 Velocity distribution and turbulence in jet

A number of tests was carried out to investigate the velocity distribution and turbulence level in the jets produced by the large test rig. Initial measurements of velocities and turbulence were carried out using an electromagnetic current meter connected to an analogue tape recorder (Racal 7-track). Records were digitised by means of a Farnell DTS12T digital storage oscilloscope and analysed using a software package mounted on a BBC micro-computer.

Later, velocities in the jet were measured using a total-head pitot tube, similar to that described by Arndt & Ippen (1970). The total head tube (2.0mm internal diameter) was connected via an adapter to a flush-mounted pressure transducer, which measured the instantaneous fluctuating pressures. The tube was filled with water and vacuum sealed so as to ensure that the water was retained in the tube. The small diameter of the tube and the vacuum seal prevented air bubbles becoming trapped in the tube and thus invalidating results. The output signals from the transducer were analysed to obtain values of the mean velocity and turbulence at the position in which the instrument was fixed. The probe was mounted with the tip facing vertically upwards and in the horizontal plane of the exit from the rectangular pipe.

4.2 Air concentrations

Point measurements of air concentration were made using a void-fraction meter purchased specially for this research project. The instrument was developed at Nottingham University by White & Hay (1975). The device senses the passage of air bubbles by means of a very fine wire or needle that is insulated from the main body of the probe (which must be immersed). When the tip of the probe is in water, an electrical circuit is completed between the tip and the main body of the probe. When a bubble passes over the tip, the resistance in the circuit first increases and then decreases as the tip re-enters liquid. Previous instruments of this type have used the change in mean resistance as a measure of the bubble concentration, but calibrations for such instruments are difficult to establish and subject to changes in conductivity of the liquid. White & Hay adopted a different approach in which differentiators and comparitors in the electrical circuit measure the rate of change of the signal sensed by the tip. In this way it is possible to detect the start and end of each bubble. Thus the probe acts as a simple on/off switch, "on" when the tip is in liquid and "off" when it is in a void.

The concentration is determined by integrating the signal using a Schmitt trigger to find the total lengths of time, T_c and T_v that the tip has been in the conducting fluid and in the non-conducting voids. The average concentration of the voids is given by

$$C = \frac{T_v}{T_c + T_v} \tag{19}$$

It is assumed here that the voids move at the same velocity as the liquid. In the large test rig, the location of the air supply manifold at the top of the vertical rectangular pipe enabled the air and water to become well mixed prior to discharge.

4.3 Impact pressures

Pressure measurements on the floor of the plunge basin were made using non-aerated and aerated jets for a range of flow rates and water levels in the basin.

The tests with the non-aerated jets were carried out first, without the manifold for the air supply system installed in the rectangular pipe. The following five measurements were made when studying the non-aerated jets:

(1) flow rate of water in jet;
(2) height of outlet above floor level in the plunge basin;
(3) depth of tailwater in plunge basin;

(4) water temperature;

(5) pressure fluctuations on the floor of the plunge basin at various positions beneath the jet.

The first two items in the list above were fixed at the beginning of each test; the other three were monitored during the course of each test.

For the second set of tests with aerated jets, the air supply manifold was installed, and the following additional measurements recorded:

(6) total flow rate of air added to the jet;

(7) air temperature;

(8) air pressure.

The required air flow rate was set at the start of each test with an aerated jet. The air temperature was monitored during the course of the test and the air pressure was recorded on a daily basis.

Each test with an aerated or non-aerated jet lasted approximately 40-45 minutes. An initial period of roughly 30 minutes was allowed for conditions to stabilise before measurements were begun. Analogue recordings of the output signals from the pressure transducers were obtained using the 7-track recorder. Each of these recordings was approximately 10 minutes in length ; shorter recordings of calibration signals were also taken at regular intervals throughout the test programme. The analogue readings were then digitised and analysed using the DATS software package to determine the statistical and spectral characteristics of the pressure fluctuations.

5 TEST RESULTS AND ANALYSIS

5.1 Characteristics of free jet

The unformity of the jet produced by the vertical rectangular pipe in the large test rig was investigated using the small diameter pitot tube described in Section 4.1. The tests were carried out with the pipe discharging freely into air at three different mean velocities: V_o = 6.65 m/s (100%), V_o = 4.98 m/s (75%) and V_o= 3.33 m/s (50%); these same flow rates were also used in the tests described later to measure impact pressures.

Figure 7 shows how the time-mean velocity v varied along three sections parallel to the longitudinal centreline of the jet (on the centreline at y = 0, at the edge of of the jet at y = $B_o/2$ and at the mid-point y = $B_o/4$); values are listed in Table 1. The tests were carried out with the air supply manifold installed (see Figure 4) but with no air being entrained, and the measurements were made in the horizontal plane immediately below the exit from the pipe. The first test at V_o = 3.33 m/s demonstrated that the velocity distribution was almost fully symmetrical about the mid-point of the pipe. The tests at higher flow rates showed similar profiles, but with a tendency for the distribution to become slightly more uniform with increasing velocity. The measurements labelled A and C in Table 1 correspond to the points which were vertically above the pressure transducers A and C in the floor of the plunge basin (see Figure 5). The average values of time-mean velocity in the vicinity of A ($x = 0$, $y = 0$) and C ($x = 0.3\ W_o$, $y = 0$) were $v = 1.188\ V_o$ and $v = 1.132\ V_o$ respectively.

The velocity distribution in turbulent flow is predicted theoretically by appropriate forms of the log-velocity law, but can be described by simple power-law relationships over most of the depth range. Cain & Wood (1981) found that high-turbulence flows in a rectangular spillway fitted the following vertical distribution of mean velocity.

$$v = v_m \quad (y/y_m)^{0.158} \tag{20}$$

where v_m is the maximum velocity at the surface $y = y_m$. Integration of Equation (20) to obtain the depth-averaged velocity V_o shows that $v_m = 1.158\ V_o$ and that $v = 1.038\ V_o$ at $y/y_m = 0.5$. These values are in reasonable agreement with the data in Table 1; clearly Equation (20) is not valid at the edge of the jet ($y = 0$) which, in any case, is difficult to define precisely when it enters air. Taking Equation (20) as the basis, it can be shown that the kinetic energy head E_k and the momentum flux $\dot{M}$ of the jet due to its velocity are

$$E_k = 1.053 \quad V_o^2/2g \tag{21}$$

$$\dot{M} = 1.019 \quad \rho\ B_o W_o V_o^2 \tag{22}$$

Pressure fluctuations in the jet at its point of exit from the vertical pipe were measured using the total-head pitot tube described in Section 4.1. The measurements were used to calculate values of the pressure coefficient

$$C''_p = \frac{2p_{rms}}{\rho V_o^2} \qquad (23)$$

where p_{rms} is the root-mean-square pressure fluctuation on the centreline of the jet and V_o is the mean exit velocity of the jet (= discharge/flow area). Values of C''_p were found to be in the range 11.6% to 11.0% for jet velocities between 4.9 m/s and 6.6 m/s (see Table 2).

The above results can be used to estimate the approximate intensity of the velocity fluctuations in the jet if it is assumed that the instantaneous kinetic energy of the fluid is converted into dynamic pressure at the pitot without loss of energy (ie in accordance with Bernoulli's equation). The precise relationship depends on how much the turbulence varies with direction (e.g. whether it is isotropic) and on the shape of its probability distribution (eg whether it is Gaussian). If the turbulence level is relatively low, then to a first approximation the turbulence intensity is given by

$$\epsilon = \frac{v_{rms}}{V} = \frac{1}{2} C''_p \qquad (24)$$

where v_{rms} is the root-mean-square velocity fluctuation on the centreline of the jet. The measurements from the pitot tube indicate approximate values of ϵ in the range 5.8% to 5.5 % (see Table 2). The local turbulence intensity on the centreline of the jet

$$\epsilon_1 = \frac{v_{rms}}{v} \qquad (25)$$

was also calculated assuming the centreline velocity to be $v = 1.188\ V_o$, as given by Table 1.

The distribution of entrained air within the jet produced by operation of the air supply system was measured using the void meter described in Section 4.2. The method of measurement was similar to that used for the velocity profiles, with the jet discharging freely and with the probe mounted just below the exit plane of the pipe. The tests were carried out at the 50% flow rate (V_o = 3.33 m/s) and at two mean air concentrations C_o = 10% and C_o = 20% (with C_o defined as in Equation (15)). The concentration profiles measured along the same three longitudinal sections as before are plotted in Figure 8 and listed in Table 3. It can be seen that the air distribution was reasonably uniform across most of the thickness of the jet, but that each profile was not perfectly symmetrical about the mid-point. This non-unformity occurred because the inlet manifold was supplied from one side only; as a result more air emerged at the far end of the manifold where the static pressure within the perforated pipe was higher.

As explained in Section 4.2, the void meter was self-calibrating. However, its accuracy was checked independently by calculating, for each measuring point in the pipe, the product of C/C_o from Table 3 and the corresponding velocity ratio v/V_o from Table 1. Assuming no slip between the air and water and no change in velocity profile due to the addition of the air, one would expect the value of the product, averaged over the cross-section of the jet, to be equal to unity. The average values of the quantity (Cv/C_oV_o) were in fact calculated to be 0.86 for the test with C_o = 10% and 0.94 for the test with C_o = 20%. This degree of agreement is considered satisfactory given the nature of the measurements and assumptions, and confirms the usefulness of the void meter. Photographs of the jet discharging freely into air were taken in order to study its development and rate of expansion; a representative selection is presented in Plates 1-6. The rate of expansion θ of the outer edge of the jet on its shorter side (B_o = 67mm) was calculated from

$$\theta = \tan^{-1} [(B-B_o)/z] \qquad (26)$$

where B is the mean thickness of the jet at a level z below the pipe outlet. The corresponding angle for the long side (W_o = 200mm) was determined by substituting W and W_o for B and B_o in Equation (26). The values of θ obtained from the photographs are given in Table 4. In the absence of diffusion effects, the falling jet would contract as its velocity increases with distance below the pipe exit. An approximate estimate of the rate at which a two-dimensional jet would expand in the absence of gravitational effects can be found from

$$\theta' = \tan^{-1} \left[\frac{B}{z} - \frac{B_o}{z} (1 + 2gz/V_o^2)^{-\frac{1}{2}} \right] \qquad (27)$$

which assumes that the flow is uniform and that potential energy is converted without loss into kinetic energy. Using the data in Table 4 for the short side of the jet at z = 0.564m gives values of θ' between 2.6° (at V_o = 2.45 m/s) and 3.8° (at V_o = 4.26 m/s).

5.2 Test conditions for impact tests

Pressures on the floor of the plunge basin in the area of jet impact were measured for a range of velocities, water depths and air concentrations. Five pressure transducers were located with the following co-ordinates relative to the extrapolated centreline of the jet pipe (see Figure 5).

Transducer	x/W_o	y/B_o
A	0	0
B	0	0.9
C	0.3	0
D	0.3	0.9
F	0.6	0

Transducers A and C were therefore within the jet and B, D and F outside.

Tests were carried out with the jet pipe either discharging about 0.12m below the water surface in the plunge basin or discharging freely into air to produce a plunging jet. The conditions investigated with the submerged jet were:

Initial velocity V_o = 3.3, 5.0, 6.6m/s

Jet length in water L_w = 0.3, 0.7m

Air concentration C_o = 0, 10, 20%

All combinations of these values were tested except that it was not possible to achieve the maximum velocity of V_o = 6.6m/s at C_o = 10% and 20%.

In the case of the tests with the plunging jet, the exit of the pipe was located at a height of H = 1.3m above the floor of the basin. The conditions investigated were:

Initial velocity V_o = 3.3, 5.0, 6.6m/s

Jet length in air L_a = 1.3, 0.9, 0.5m

Jet length in water L_w = 0, 0.4, 0.8m

Air concentration C_o = 0, 10, 20%

All combinations were tested except that firstly the maximum velocity could not be achieved when air was added, and secondly the relationship between L_a and L_w was fixed by the geometry of the rig ($L_a = H - L_w$). A value of $L_w = 0$ indicates that the jet impinged directly on to the floor of the basin without any imposed tailwater.

The dynamic pressure due to the impact of the jet was obtained by subtracting from the transducer reading the hydrostatic pressure corresponding to the measured water depth h. The mean dynamic pressure p was expressed in terms of the dimensionless coefficient

$$C_p = \frac{2p}{\rho V_1^2} \qquad (28)$$

where V_1 is the velocity of the water entering the plunge basin. In the case of the submerged jet, V_1 was equal to the exit velocity V_o. In the case of the plunging jet, the water velocity increased before impact so for the purposes of the analysis it was assumed that

$$V_1^2 = V_o^2 + 2g L_a \qquad (29)$$

This is a simplification but secondary effects due to the non-uniform velocity distribution, diffusion and energy dissipation are difficult to quantify.

Equivalent coefficients for the maximum and minimum dynamic pressures, p_{max} and p_{min}, recorded during a test were defined as

$$C_p^+ = \frac{2(p_{max} - p)}{\rho V_1^2} \tag{30}$$

$$C_p^- = \frac{2(p_{min} - p)}{\rho V_1^2} \tag{31}$$

where p is the mean dynamic pressure.

Two alternative coefficients for describing the root-mean-square fluctuation in dynamic pressure, p_{rms}, were considered:

$$C_p' = \frac{2\, p_{rms}}{\rho V_1^2} \tag{32}$$

and the turbulent pressure intensity

$$T_p = \frac{p_{rms}}{p} \tag{33}$$

Statistical and spectral analyses of the pressure fluctuations in selected tests were also carried out. The characteristics of a random process can be described in statistical terms by parameters such as the mean, standard deviation σ, skewness s and kurtosis k. If N measurements are made of the pressure fluctuation p' relative to the mean, then these parameters are defined to be

$$\sigma = \left[\frac{\sum (p')^2}{N} \right]^{1/2} \quad (34)$$

$$s = \frac{\sum (p')^3}{N \sigma^3} \quad (35)$$

$$k = \frac{\sum (p')^4}{N \sigma^4} \quad (36)$$

A positive value of skewness indicates that the distribution of the fluctuations is not symmetrical about the mean and that the median value of the distribution (i.e the value with a cumulative probability of 0.5) occurs on the negative side of the mean. The value of kurtosis increases as the distribution becomes more sharply peaked about the mean ; for a Gaussian normal distribution k = 3. The statistical analysis was carried out on digitised data files, each containing 2^{15} ($\equiv$ 32.8 k) values recorded at a sampling rate of 100 Hz ; the duration of each file was therefore approximately 5.5 minutes. The same files were analysed using the Fast Fourier Transform technique to determine the frequency spectra of the fluctuations ; smoothing of the Fourier components was carried out so as to result in 52 spectral values at frequency intervals of approximately 0.98 Hz up to a maximum frequency of 50 Hz.

5.3 Mean impact pressures

Impact pressures were recorded as described in Section 5.2 for a total of 35 test conditions plus one repeat. The number of measured values was therefore 36 tests x 5 transducers x 32,768 measurements per transducer per test = total of 5.9 x 10^6 values. The computed results for each test are given in Appendix A.

Attention will be concentrated in this Section on how the values of mean dynamic pressure on the floor of the plunge basin are influenced by jet type, jet velocity, water depth and air concentration. Jet type can either be submerged (rectangular pipe discharging under water) or plunging (discharging first into air). It should be noted for the submerged case that the length L_w of the jet in water (measured vertically from the pipe exit to the floor of the basin) is less than the water depth h; for the case of a plunging jet L_w = h. Values of mean impact pressure will be considered in terms of the pressure coefficient C_p (Equation (28)) calculated using the mean velocity V_1 of the jet entering water (Equation (29)).

The variation of mean impact pressure with positions in the jet is illustrated in Figure 9, based on the values given in Table 5. The values were obtained by dividing the pressures at transducer positions B,C,D and F by the corresponding pressure measured for that test at position A, the centre of the jet. Turbulence in the flow inevitably resulted in some variations in these pressure ratios, but several clear trends are evident. Jet velocity generally had little effect on the values of the ratios, so Table 5 gives an average for each combination of jet type, water depth and air concentration. (Individual values for each test can be determined from the data in Appendix A).

Along the centreline of the jet (ACF), the pressure distributions were similar for both submerged and plunging jets and were little affected by changes in water depth. Outside the jet, along the parallel line BD, increases in water depth caused an increase in pressure relative to that at A. Introduction of air into the jet tended to reduce pressures relative to that at A.

Two main conclusions can be drawn from Figure 9. Firstly, the experimental set-up produced reasonably uniform two-dimensional conditions in the vicinity of the jet (compare the overall pressure ratios for A and C and for B and D). Secondly, mean impact pressures decrease rapidly outwards from the jet. At point F, which is 0.1 W_o from the edge of the jet, the value of C_p is typically about 54% of that within the jet. Similarly at points B and D , which are 0.4 B_o from the side of the jet, the ratio is typically about 37%. The values of mean impact pressure which are most important for design are therefore those which occur within the jet. Attention will thus now be concentrated on the values of C_p at points A and C. Maximum pressures tended to occur at point C in the tests without air injection and at point A in the tests with air injection. Since the differences were relatively small (see Table 5), average values for C_p at A and C are considered in the following comparisons.

Figure 10 shows for the case of no air injection a correlation between the coefficient C_p of mean dynamic pressure and the ratio L_w/B_1, where L_w is the length of the jet in water and B_1 is estimated from

$$B_1 = B_o \frac{V_o}{V_1} \qquad (37)$$

The data for the submerged jets show that the values of C_p are almost independent of flow velocity. Similarly good agreement will be seen later for other parameters of the submerged jets. This is encouraging because it indicates that the results are not affected by scale effects due to variations in Reynolds number. Alternatively, this can be viewed as evidence that the jets were fully turbulent and therefore not influenced by viscosity.

It is noteworthy that the value of C_p can exceed unity at short jet lengths. Evidence from earlier studies (see Section 2.2) suggests that the high velocity core of a rectangular submerged jet will persist for a distance L_w between about 5.2 B_1 (Alberston et al (1948)) and 8.3 B_1 (Beltaos & Rajaratnam (1973)). The latter value corresponds closely to the point where C_p = 1.0 in the present tests. C_p can exceed unity because it is calculated using the mean jet velocity V_1. The measurements of velocity distribution within the jet (see Section 5.1) showed that at the point of discharge the velocity on the centreline was about 1.16 times the mean velocity. Thus the maximum value of C_p to be expected is 1.16^2 = 1.35: the largest value measured in these tests was 1.32. The effect of a non-uniform velocity distribution within a jet does not appear to have been considered in previous studies.

The data for the plunging jets show a similar trend but with rather more scatter than in the case of the submerged jets. Part of this may be due to greater turbulence in the plunging jets. Also, the plotting position of a data point is affected by the value of B_1, which is estimated only approximately by equation (37). Nevertheless, there is clearly some dependence of C_p on flow rate at lower values of L_w/B_1. This is to be expected because the effect of a plunging jet is likely to be partly dependent on a Froude-type parameter such as $V_1/(gL_w)^{1/2}$.

The results for zero tailwater ($L_w/B_1 = 0$) lie below the trend of the other points, and need to be considered separately because of the different behaviour of the flow. Less recovery of pressure head (and therefore more energy dissipitation) than expected occurs when there is no tailwater. In fact, the plotting position of L_w/B_1 is not strictly correct because the impacting jet does produce a thin water cushion on the floor of the basin.

Figure 10 also shows a plot of Equation (4) which Beltaos & Rajaratnam (1973) obtained for air jets in air for values of L_w/B_1 between 14.0 and 67.4. The agreement is good considering the differences in nature and scale between the two studies. Neglecting the data for zero tailwater, the other results in Figure 10 for plunging and submerged jets can be described rather more simply and accurately by the linear equation

$$C_o = 0\% \quad : \quad C_p = 1.613 - 8.224\text{x}10^{-2}(L_w/B_1) \quad (38)$$

which has a correlation coefficient of $r = -0.943$. The estimated maximum value of $C_p = 1.35$ (see above) occurs for $L_w/B_1 \leq 3.2$. The impact pressures in Figure 10 are higher than those recorded by Withers (1989) for circular plunging jets (see Section 2.2).

Corresponding results for values of C_p with injected air concentrations of $C_o = 20\%$ are shown in Figures 11 and 12 respectively. The addition of air reduces the mean impact pressures for both the submerged and plunging jets. In the case of zero tailwater, the change from 10% to 20% air concentration produced larger reductions in C_p than occurred with finite tailwater depths.

Neglecting data for $L_w/B_1 = 0$, the other results in Figures 11 and 12 can be described quite well by linear relationships similar to Equation (38). The following best-fit equations were obtained.

$$C_o = 10\% : \quad C_p = 1.447 - 8.528 \times 10^{-2} (L_w/B_1) \qquad (39)$$

$$C_o = 20\% : \quad C_p = 1.361 - 8.474 \times 10^{-2} (L_w/B_1) \qquad (40)$$

The correlation coefficients were $r = -0.970$ and -0.963 respectively.

Comparison of Equations (38), (39) and (40) shows that the best-fit lines have almost equal slopes and that the intercepts at $L_w/B_1=0$ vary smoothly with C_o. All the data for submerged and plunging jets (except those for zero tailwater) can therefore be described by the following best-fit equation (with rounded coefficients)

$$C_p = 1.6 \, (1-C_o)^{3/4} - \frac{1}{12} \, (L_w/B_1) \qquad (41)$$

A comparison between the measured values of C_p and those predicted by Equation (41) is shown in Figure 13. An equivalent result that gives conservative (ie. high) values of C_p relative to all the test data from the present study is

$$C_p = 1.8\ (1 - C_o)^{0.9} - \frac{1}{12}\ (L_w/B_1) \qquad (42)$$

This equation could be suitable for design purposes, but in some cases it does overpredict considerably relative to the measured values of mean dynamic pressure.

Equations (41) and (42) do not apply to the case of zero tailwater. The amount of data obtained for this condition is not sufficient to establish with certainty an equivalent type of correlation relating C_p to the dimensions and energy of the jet. Possible parameters which might influence C_p are

$$\frac{L_a}{B_1}\ ,\quad \frac{V_1}{(g\ B_1)^{½}}\ ,\quad \frac{V_1}{(g\ L_a)^{½}}\ \text{or}\ \frac{V_o}{(g\ L_a)^{½}}$$

where L_a is the length of the jet in air. Values of the first two parameters did not vary greatly in the tests so are unlikely to account for the significant variations in C_p which were observed. The second two parameters are relevant to the evolution of the jet in its fall through the air. Figure 14 shows the values of C_p for zero tailwater plotted against $V_o/(gL_a)^{½}$. The validity of using L_a in the parameter cannot be confirmed from the present data because it was not varied in the tests. More results are therefore needed to establish whether Figure 14 is a useful method of correlation. However, in terms of applications, the case of zero tailwater is less important because a reasonable depth of water will normally be available in plunge basins for high-head dams.

5.4 Fluctuating impact pressures

Measumements relating to the characteristics of the turbulent pressure fluctuations on the floor of the impact basin are listed in Appendix A. For each test and transducer position, values are given of the maximum positive and negative pressure fluctuations and of the root-mean-square (rms) values. These values are also expressed in terms of the non-dimensional pressure coefficients C_p', T_p, C_p^+ and C_p^- defined by Equations (32), (36), (30) and (31) respectively.

In a limited number of cases, the recorded pressures occasionally reached the measurement limits of the transducers of about + 5.1m and 0.0m head of water (relative to atmosphere). In some instances discontinuous spikes ocurred in the signals. These are believed to have been caused by electrical interference, and were therefore removed from the records before the statistical analysis was carried out. The other instances were considered to have been genuine fluctuations which were truncated because the mean pressure was too close to one of the measurement limits. The majority of the records were not subject to any such problems. In those that were, the "error" rate did not exceed about 1 in 1000 and was typically 1 or 2 in 10000. The effects on the values of the root-mean-square fluctuations were therefore negligible. The truncation of a fluctuation would, however, have caused the maximum or minimum value of pressure in a test to be underestimated. Cases where this occurred are marked in Appendix A by an asterisk next to the relevant value of C_p^+ or C_p^-.

Study of the values of the pressure coefficients C_p', C_p^+ and C_p^- shows that the amount of turbulence in a particular test was fairly constant at all five measuring positions. The largest values of C_p' occurred at A, C or F on the centreline of the jet, but positions B and D sometimes experienced the largest values of C_p^+ or C_p^-. This contrasts with the behaviour of the mean dynamic pressure, maximum values of which always occurred at A or C within the jet (see Section 5.3).

Figure 15 shows the correlation between the average value of C_p' for all five gauges and the parameter L_w/B_1 described in Section 5.3. Results for all the tests, with and without air injection, are plotted. The data for the submerged jets and the plunging jets are separately consistent, and define two distinct curves as indicated in Figure 15.

Considering the plunging jets first, the value of C_p' (neglecting two aerated tests at low velocity) is approximately constant between $L_w/B_1 = 0$ and 7; this region corresponds to the "flow-establishment" zone (see Section 2.1 and Figure 1) where the high-velocity core is still coherent. The range of $C_p' = 0.09$ to

0.12 is very similar to the root-mean-square figure of $C_p' = 0.11$ to 0.12 measured in the free jet using the pitot tube (see Table 2). As the core of the jet begins to break up beyond $L_w/B_1 = 7$, flow energy is converted into turbulence energy. The value of C_p' therefore rises to a peak of about 0.20 at $L_w/B_1 = 12$. Beyond this point, the turbulence energy appears to decay or diffuse more rapidly than the rate at which it is generated by further break-up of the high-velocity core. The results in Figure 15 compare quite closely with the measurements made by Withers (1989) for circular plunging jets (see Section 2.2)

Turbulence in the submerged jets was lower than in the plunging jets but appears to follow a similar pattern. The good consistency of the results obtained at different flow rates indicates that the submerged jets were fully turbulent and had self-similar velocity distributions.

Figure 15 shows that the amount of air in the jet had little effect on C_p', except in the special case of zero tailwater. The data for this condition are re-plotted in Figure 16 versus the parameter $V_o/(g\,L_a)^{1/2}$ discussed in Section 5.3. Although the validity of this parameter cannot definitely be established from the limited number of measurements, it does help identify a pattern in the results. Below a value of $V_o/(g\,L_a)^{1/2} = 1.5$, addition of air promotes the break up of the jet and increases the level of turbulence.

Figure 17 is similar in type to Figure 15 but shows for each test the maximum value of C_p' recorded at any of the five measuring positions. The results follow a similar pattern to that in Figure 15, with an estimated peak value of $C_p' = 0.27$ occurring at about $L_w/B_1 = 11.5$.

An alternative view of the data is obtained by plotting in Figure 18 the average root-mean-square pressure coefficient against the mean dynamic pressure coefficient (i.e average C_p' versus C_p). The results for submerged and plunging jets are again separately consistent and are little affected by the amount of injected air. In the case of plunging jets, the turbulence is a maximum when the mean dynamic pressure coefficient is approximately $C_p = 0.65$; for the submerged jets, the corresponding condition occurs at about $C_p = 0.8$.

Data on the largest positive and negative pressure fluctuations recorded in each test by any of the five transducers are presented in Figure 19. Values of the coefficients C_p^+ and C_p^- are plotted against the parameter L_w/B_1 and show similar trends to those seen in Figures 14 and 15. For plunging jets, the maximum value of C_p^+ is estimated to be about 2.0 and occurs when $L_w/B_1 = 10.5$. The negative fluctuations about the mean are smaller with a maximum of about $C_p^- = -0.8$ at $L_w/B_1 = 7.5$. Turbulence levels were lower in the jets, and the extreme fluctuations were therefore also less with peak figures of about $C_p^+ = 0.9$ and $C_p^- = -0.6$. The probability of each of the points plotted in Figure 19 is estimated to be of the order of $2x10^{-5}$ (based on one maximum and one minimum reading out of 5 x 32,768 values, and assuming fairly uniform turbulence at all five measuring positions).

The results for zero tailwater in Figure 19 show considerable scatter, and are therefore re-plotted in Figure 20 versus the parameter $V_o/(g\ L_a)^{½}$. As in the case of Figure 16, this method of correlation indicates that the amount of air in the jet begins to affect the turbulence level when $V_o/(g\ L_a)^{1/2}$ is less than 1.5. Further data are needed to confirm the relevance of L_a in this parameter.

Statistical and spectral analyses were carried out on the recorded pressure fluctuations. Figures 21 to 24 show plots of the non-dimensional probability density (pd) distributions for pressures recorded at transducer A (centre of jet) and transducer B (outside jet, see Figure 5) in Tests 8 and 9 (plunging jets with no air injection, see sheets A.9 and A.10 in Appendix A). These are reasonably typical of the results obtained in other tests. The distributions in Figures 21 to 24 are positively skewed so each median value lies on the negative side of the mean. When considering possible damage to stilling basins due to extreme pressure fluctuations, Lopardo et al (1984) suggested use of an exceedance probability of 0.1%. In the present tests, this limit corresponds very approximately to 2.5 standard deviations for negative fluctuations and 4 standard deviations for positive fluctuations. The pd distributions are generally more peaked than the Gaussian distribution, which is also shown plotted in Figures 21 to 24.

Considering all the tests carried out, 89% of the 180 distributions were positively skewed. The average value of skewness (see Equation (35)) was about $s = 0.6$, with extremes of -1.5 and $+4.3$. All but one of the distributions with negative skewness occurred at positions A and C within the jet and were most common in the case of zero tailwater. The average value of kurtosis (see Equation (36)) for all the tests was about $k = 5$, which compares with $k = 3$ for a

Gaussian distribution. Addition of air to the plunging jets caused the peakedness of the distributions to increase, typically from k = 4 to k = 6 ; the maximum value recorded with a plunging jet was k = 17 (though we have some doubts about the accuracy of the DATS analysis package when dealing with such sharply peaked distributions).

Representative results obtained from spectral analysis of the pressure fluctuations are shown in Figures 25 to 28. All the plots are for transducer A in the centre of the jet and illustrate the following test conditions:

Figure 25 - submerged jet with no air injection
(Test 15, Sheet A.2)

Figure 26 - plunging jet with no air injection
(Test 8, Sheet A.9)

Figure 27 - submerged jet with C_o = 20%
(Test 22, Sheet A.28)

Figure 28 - plunging jet with C_o = 20%
(Test 34, Sheet A.32)

All the plots show that the turbulence energy is most concentrated at the lowest frequencies. The spectra do not exhibit any well-defined peaks so it is not possible to relate a "characteristic" frequency to the particular flow conditions in the jet. Instead the energy decreases fairly steadily with increasing frequency and in most cases becomes relatively insignificant beyond 25Hz.

The frequencies in Figures 25 to 29 are those measured in the present tests, so it is necessary to consider how they are related to turbulence frequencies in prototype jets. As discussed in Section 1, the primary factors likely to determine fluctuation frequencies are the dimensions of the jet and its velocity (note gravity is not a dominant factor here). Also, results presented above have demonstrated that the jets were fully turbulent with self-similar flow characteristics. On this basis, it is expected that frequencies measured in these tests can be related to frequencies in prototype jets by the relation

$$\frac{f_1}{f_2} = \frac{V_1}{V_2} \cdot \frac{B_2}{B_1} \qquad (43)$$

If a prototype plunge basin is studied using a Froudian model, with the jet thickness and water depth scaled correctly, then the model and prototype frequencies (f_m, f_p) will be related to the geometric scale of 1:λ by

$$\frac{f_m}{f_p} = \lambda^{0.5} \qquad (44)$$

Froudian scaling is necessary in such a model because mean impact pressures and the evolution of the jet in air are influenced by the parameters $V_1/(gL_w)^{\frac{1}{2}}$ and $V_o/(gL_a)^{\frac{1}{2}}$ (see Section 5.3).

6 CONCLUSIONS

1. This study has investigated the mean and fluctuating pressures imposed on the horizontal floor of a plunge basin by a vertical rectangular jet of high-velocity water. The characteristics of two types of jet have been considered : submerged jets discharging under water into the plunge basin ; and plunging jets discharging

vertically into air before entering the plunge basin. Factors which were studied included jet velocity, depth of water in the plunge basin and amount of air in the jet.

2. Measurements of velocity and pressure distributions showed that the aspect ratio of the the jet pipe used in the tests (width = 3 x breadth) was sufficient to produce two-dimensional flow conditions in the central region of the jet. The results also demonstrated that the jets were fully turbulent with self-similar flow characteristics. The turbulence intensity ϵ at the point of discharge from the jet pipe was about 5-6%.

3. The pressure acting on the floor of a plunge basin consists of three components : the hydrostatic pressure due to the depth of tailwater in the basin ; the mean dynamic pressure produced by the impact of the jet ; and fluctuations about the mean due to turbulence.

4. The mean dynamic pressure was found to be dependent on the ratio between the jet length in water and the thickness of the jet at impact with the water surface. Increasing the amount of air in the jet decreased the impact pressures. The best-fit correlation for the mean dynamic pressure beneath the centreline of the jet (either plunging or submerged) is given by Equation (41). An alternative correlation which provides conservative (ie high) estimates of mean pressure relative to all the measurements is described by Equation (42). Outside the jet, pressures were found to decrease rapidly with horizontal distance from the centre.

5. Mean impact pressures on the jet centreline are presented in Figure 14 for the special case of zero tailwater in the plunge basin. More data are needed to investigate the effect of the jet length in air.

6. The characteristics of the fluctuating impact pressures due to turbulence in the basin were measured in terms of root-mean-square (rms) values, extreme maximum and minimum pressures, statistical properties and spectral density distributions.

7. The rms pressure fluctuations were found to decrease much less rapidly with distance from the centre of the jet than in the case of the mean dynamic pressure. Also, adding air to the jet had little effect on the level of turbulence, expect when there was zero tailwater. The measurements of the average rms pressure are shown by the correlation in Figure 15. This shows that the turbulence initially increases as the jet breaks up and reaches a maximum when the depth of water in the plunge basin is about 10 to 12 times the transverse thickness of the rectangular jet at impact with the water surface. The results for the special case of zero tailwater are given in Figure 16.

8. The values of the extreme maximum and minimum pressure fluctuations recorded in each test at any of the five measuring positions (two inside the jet, three outside) are plotted in Figure 19, and Figure 20 shows the results for the case of zero tailwater. The probability of occurrence of each data point is estimated to be of the order of $2x10^{-5}$. For design purposes, extreme pressures are sometimes calculated on the basis

of an exceedance probability of 0.1%. In this study, such a probability was found to correspond approximately to 2.5 times the rms value for negative fluctuations and 4 times the rms value for positive fluctuations.

9. Spectral analysis of the fluctuations showed that the turbulence energy was most concentrated at frequencies of 0-3Hz with a fairly gradual decrease to low energies beyond a frequency of about 25Hz.

10. The results of the study confirmed (within the experimental range) the validity of using Froudian scaling for model tests of plunge basins.

11. Further work is recommended to investigate over a larger range how the fall height of the jet in air and its initial level of turbulence influence the impact pressures on the floor of the basin.

7. ACKNOWLEDGEMENTS

The experimental measurements and processing of the data were carried out by Mr. I.R Willoughby. The project was supervised by Mr. J.A Perkins and Mr. R.W.P May in the River Engineering Department headed by Dr W.R White.

8. REFERENCES

ALBERTSON M.L. et al (1948). Diffusion of submerged jets. Proc ASCE, Vol 74, December, pp 639-663.

ARNDT R.E.A. & IPPEN A.T. (1970). Turbulence measurements in liquids using an improved total pressure probe. Jnl Hydraulic Research, Vol 2, pp 131-158.

BELTAOS S. & RAJARATNAM N. (1973). Plane turbulent impinging jets. Jnl Hydraulic Research, Vol 11, No.1, pp 29-59.

CAIN P. & WOOD I.R. (1981). Instrumentation for aerated flow on spillways. Proc ASCE, Jnl Hydraulic Div, Vol 107, HY11, November, pp 1407-1424.

CHANISHVILI A.G. (1965). Experimental researches on the influence of aeration on the intensity of kinetic energy dissipation. Proc XIth IAHR Congress, Leningrad, Vol 1, Paper 1.43.

COLA R. (1965). Energy dissipation of a high-velocity vertical jet entering a basin. Proc XIth IAHR Congress, Leningrad, Vol 1, Paper 1.52.

DEAMER A.P. & MAY R.W.P. (1989). A digital bend meter for measuring flow in pipes. Hydraulics Research, Wallingford, Report IT 339.

ELDER R.A. (1961). Model-prototype turbulence scaling. Proc XIth IAHR Convention, Dubrovnik, Yugoslavia, pp 24-31.

ERVINE D.A. et al (1980). Effect of turbulence intensity on the rate of air entrainment by plunging water jets. Proc ICE, Part 2, Vol 69, June, pp 425-445.

ERVINE D.A. & FALVEY H.T. (1987). Behaviour of turbulent water jets in the atmosphere and in plunge pools. Proc ICE, Part 2, Vol 83, March, pp 295-314.

ERVINE D.A. & WITHERS W.J. (1989). Turbulence and pressure fluctuations in plunge pools. Proc XXIIIrd IAHR Congress, Ottawa, Canada, Tech Session A, pp 215-222.

HAGER W.H. (1983). Hydraulics of plane free overfall. Proc ASCE, Jnl Hydraulics Div, Vol 109, HY12, December, pp 1683-1697.

HORENI P. (1956). Disintegration of a free jet of water in air. Byzkumny ustav vodohospodarsky prace a studie, Sesit 93, Praha-Podbaba.

KAWAKAMI K. (1973). A study on the computation of horizontal distance of jet issued from ski-jump spillway. Trans. Japanese Society of Civil Engineers, Vol 5.

KRAATZ W. (1965). Flow characteristics of a free circular water jet. Proc XIth IAHR Congress, Leningrad, USSR, Vol 1, Paper 1.44.

LOPARDO R.A. et al (1984). Model-prototype comparisons on pressure fluctuations in hydraulic jump energy dissipators. Symp on Scale Effects in Modelling Hydraulic Structures, IAHR/DVWK, Esslingen, Germany, Paper 5.7.

MARTINS R. (1977). Kinematics of the free jet in the field of hydraulic structures. Ministerio das Obras Publicas, Memoria No 486, (in Portuguese).

MASON P.J. (1984). Erosion of plunge pools downstream of dams due to the action of free-trajectory jets. Proc ICE, Part 1, Vol 76, May, pp 523-537.

MASON P.J. (1989). Effects of air entrainment on plunge pool scour. Jnl Hydraulic Engng, ASCE, Vol 115, No 3, pp 385-399.

NAGHDI P.M & RUBIN M.B. (1981). On inviscid flow in a waterfall. Jnl Fluid Mechanics, Vol 103, February, pp 375-388.

PERKINS J.A. (1987). Impact pressures in falling-jet energy dissipators: Literature review and preliminary experiments. Hydraulics Research, Wallingford, Report SR 124.

SCHIEBE. F. (1971). The stochastic characteristics of pressure fluctuations on a channel bed due to the turbulence in a hydraulic jump. PhD thesis for University of Minnesota, USA.

TABUSHI K. (1969). Air entrainment and pressure distribution in a circular tank by plunging liquid jet. XIIIth IAHR Congress, Kyoto, Japan, Vol 2, Paper B.9, pp 81-89.

WHITE P.R.S. & HAY N. (1975). A portable air concentration meter. Proc XVIth IAHR Congress, Sao Paulo, Vol 3, pp 541-548.

WITHERS W.J. (1989). Pressure fluctuations downstream of concrete arch spillway dams. Paper for Scottish branch of ICE.

TABLES.

TABLE 1 Distribution of mean velocity in free jet

(a) $y/B_o = 0$

	Local velocity / Mean velocity (v/V_o)			
x/W_o	V_o= 3.33 m/s	V_o= 4.98 m/s	V_o = 6.65 m/s	Average
- 0.48	0.749			
- 0.45	0.918			
- 0.40	1.049			
- 0.35	1.096			
- 0.30	1.164			
- 0.25	1.186			
- 0.20	1.186			
- 0.15	1.197			
- 0.10	1.197			
- 0.05	1.207			
0	1.207	1.196	1.175	1.193
0.05	1.207	1.191	1.178	1.192
0.10	1.197	1.191	1.178	1.189
0.15	1.186	1.186	1.173	1.182
0.20	1.186	1.177	1.167	1.177
0.25	1.164	1.167	1.153	1.161
0.30	1.153	1.142	1.134	1.143
0.35	1.119	1.101	1.090	1.103
0.40	1.061	1.037	1.020	1.039
0.45	0.946	0.939	0.907	0.931
0.48	0.783	0.793	0.730	0.769

TABLE 1 (Cont'd)

(b) $y/B_o = 0.25$

	Local velocity / Mean velocity (v/V_o)			
x/W_o	V_o= 3.33 m/s	V_o= 4.98 m/s	V_o = 6.65 m/s	Average
- 0.48	0.678			
- 0.45	0.946			
- 0.40	1.024			
- 0.35	1.084			
- 0.30	1.108			
- 0.25	1.119			
- 0.20	1.131			
- 0.15	1.131			
- 0.10	1.131			
- 0.05	1.142			
0	1.142	1.064	1.063	1.090
0.05	1.142	1.064	1.072	1.093
0.10	1.131	1.064	1.075	1.090
0.15	1.108	1.048	1.075	1.077
0.20	1.108	1.048	1.069	1.075
0.25	1.096	1.037	1.051	1.061
0.30	1.073	1.015	1.036	1.041
0.35	1.049	1.003	1.023	1.025
0.40	1.024	1.975	0.991	0.997
0.45	0.932	0.945	0.948	0.942
0.48	0.750	0.771	0.801	0.774

TABLE 1 (Cont'd)

(c) $y/B_o = 0.5$

	Local velocity / Mean velocity (v/V_o)			
x/W_o	V_o= 3.33 m/s	V_o= 4.98 m/s	V_o = 6.65 m/s	Average
- 0.48	0.576			
- 0.45	0.678			
- 0.40	0.783			
- 0.35	0.815			
- 0.30	0.861			
- 0.25	0.861			
- 0.20	0.890			
- 0.15	0.905			
- 0.10	0.918			
- 0.05	0.918			
0	0.932	0.908	0.871	0.904
0.05	0.918	0.914	0.878	0.903
0.10	0.932	0.914	0.878	0.908
0.15	0.905	0.889	0.885	0.893
0.20	0.890	0.882	0.874	0.882
0.25	0.861	0.863	0.863	0.862
0.30	0.846	0.842	0.837	0.842
0.35	0.831	0.829	0.817	0.826
0.40	0.831	0.808	0.829	0.823
0.45	0.783	0.771	0.794	0.783
0.48	0.697	0.702	0.726	0.708

TABLE 2 Turbulence intensities in free jet

Mean jet velocity V_o (m/s)	Rms pressure coeff for pitot tube C_p'' (%)	Mean turbulence intensity ϵ (%)	Local turbulence intensity ϵ_1 (%)
6.65	11.0	5.5	4.6
6.16	11.9	5.9	5.0
4.87	11.6	5.8	4.9

TABLE 3 Distribution of air concentration in free jet

(a) $y/B_o = 0$, $V_o = 3.33$ m/s

x/W_o	Local air concentration / Mean air concentration (C/C_o)		
	$C_o = 10\%$	$C_o = 20\%$	Average
-0.48	0.42	0.58	0.50
-0.45	0.67	0.79	0.73
-0.40	0.75	0.81	0.78
-0.35	0.75	0.85	0.80
-0.30	0.83	0.88	0.85
-0.25	0.86	0.89	0.87
-0.20	0.89	0.89	0.89
-0.15	0.92	0.89	0.90
-0.10	0.98	0.94	0.96
-0.05	1.00	0.99	0.99
0	1.05	1.00	1.03
0.05	1.07	1.02	1.05
0.10	1.10	1.05	1.08
0.15	1.15	1.09	1.12
0.20	1.10	1.11	1.11
0.25	1.10	1.15	1.13
0.30	1.10	1.15	1.13
0.35	1.08	1.15	1.12
0.40	1.07	1.15	1.11
0.45	1.02	1.14	1.08
0.48	0.48	0.57	0.53

TABLE 3 (Cont'd)

(b) $y/B_o = 0.25$, $V_o = 3.33$ m/s

x/W_o	Local air concentration / Mean air concentration (C/C_o)		
	$C_o = 10\%$	$C_o = 20\%$	Average
-0.48	0.37	0.48	0.43
-0.45	0.71	0.79	0.75
-0.40	0.74	0.84	0.79
-0.35	0.74	0.86	0.80
-0.30	0.77	0.87	0.82
-0.25	0.80	0.89	0.84
-0.20	0.83	0.90	0.86
-0.15	0.87	0.92	0.90
-0.10	0.92	0.96	0.94
-0.05	0.96	0.99	0.97
0	1.06	1.01	1.04
0.05	1.08	1.04	1.06
0.10	1.07	1.06	1.07
0.15	1.10	1.12	1.11
0.20	1.14	1.12	1.13
0.25	1.11	1.16	1.14
0.30	1.10	1.17	1.14
0.35	1.14	1.17	1.16
0.40	1.18	1.17	1.18
0.45	1.07	1.14	1.11
0.48	0.35	0.54	0.45

TABLE 3 (Cont'd)

(c) $y/B_o = 0.5$, $V_o = 3.33$ m/s

x/W_o	Local air concentration / Mean air concentration (C/C_o)		
	C_o = 10%	C_o = 20%	Average
-0.48	0.60	0.91	
-0.45	0.34	0.75	
-0.40	0.39	0.70	
-0.35	0.36	0.72	
-0.30	0.41	0.77	
-0.25	0.47	0.79	
-0.20	0.61	0.80	
-0.15	0.35	0.81	
-0.10	0.35	0.82	
-0.05	0.32	0.89	
0	0.41	0.67	
0.05	0.42	0.62	
0.10	0.26	0.55	
0.15	0.27	0.54	
0.20	0.29	0.59	
0.25	0.37	0.57	
0.30	0.31	0.86	
0.35	0.44	0.87	
0.40	0.48	0.89	
0.45	0.80	0.90	
0.48	0.37	0.51	

TABLE 4. Rate of expansion of free jet in air

Initial jet velocity V_o (m/s)	Distance below jet exit z (m)	Expansion rate θ (degrees)			
		Long side		Short side	
		av	st dev	av	st dev
2.45	0.104	3.3*	0.7*	2.3	0.8
2.45	0.564	1.1*	0.2*	-0.2	0.2
3.15	0.104	5.0	1.0	4.1	0.8
3.15	0.564	2.1	0.3	1.0	0.3
4.26	0.104	6.5	0.8	4.9	0.9
4.26	0.564	3.7	0.1	2.4	0.5

* Values calculated from six measurements and not eight as for others

TABLE 5 Distribution of mean dynamic pressure

Position	Water depth h (m)	Jet Type	Value of C_p relative to value at A: Air concentration C_o 0%	10%	20%	Average
C	0.8	S	1.008	0.901	0.926	0.961
		P	1.064	0.973	0.898	0.991
	0.4	S	1.029	0.910	0.916	0.963
		P	1.127	0.894	0.839	0.978
	0	P	1.060	0.999	0.917	1.002
	Average		1.054	0.935	0.899	0.978
F	0.8	S	0.653	0.497	0.529	0.583
		P	0.665	0.550	0.386	0.552
	0.4	S	0.484	0.426	0.444	0.456
		P	0.542	0.504	0.453	0.506
	0	P	0.592	0.606	0.617	0.603
	Average		0.591	0.517	0.486	0.541
B	0.8	S	0.451	0.375	0.374	0.413
		P	0.716	0.501	0.411	0.567
	0.4	S	0.288	0.286	0.278	0.285
		P	0.320	0.244	0.194	0.262
	0	P	0.297	0.188	0.300	0.267
	Average		0.417	0.319	0.311	0.360
D	0.8	S	0.473	0.308	0.350	0.401
		P	0.754	0.484	0.376	0.569
	0.4	S	0.275	0.233	0.244	0.254
		P	0.450	0.305	0.235	0.347
	0	P	0.339	0.199	0.299	0.279
	Average		0.467	0.306	0.301	0.374

Note : S = Submerged jet discharging under water
P = Plunging jet discharging first into air

FIGURES

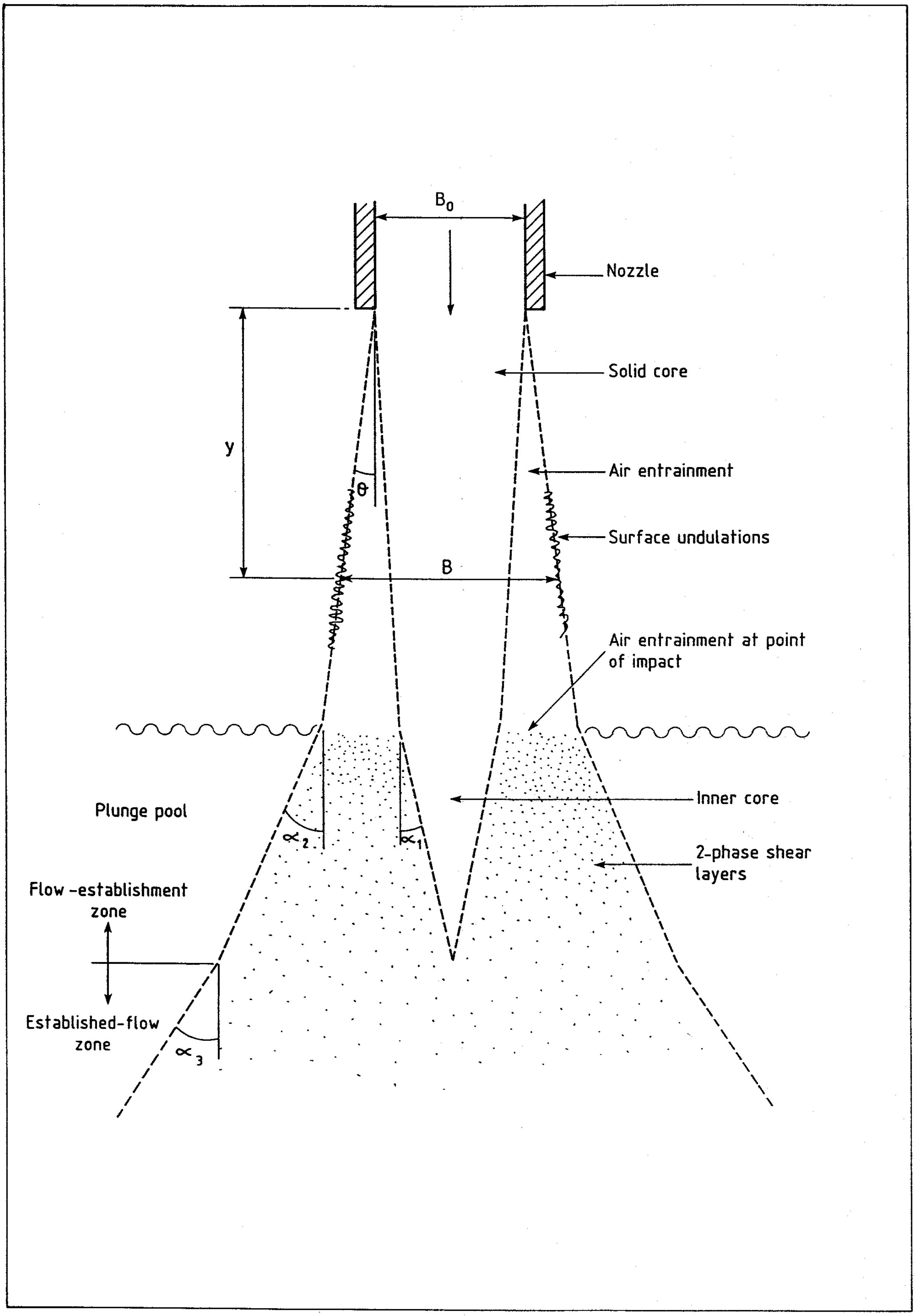


Fig 1 Schematic diagram of jet falling through atmosphere into plunge pool (after Ervine)

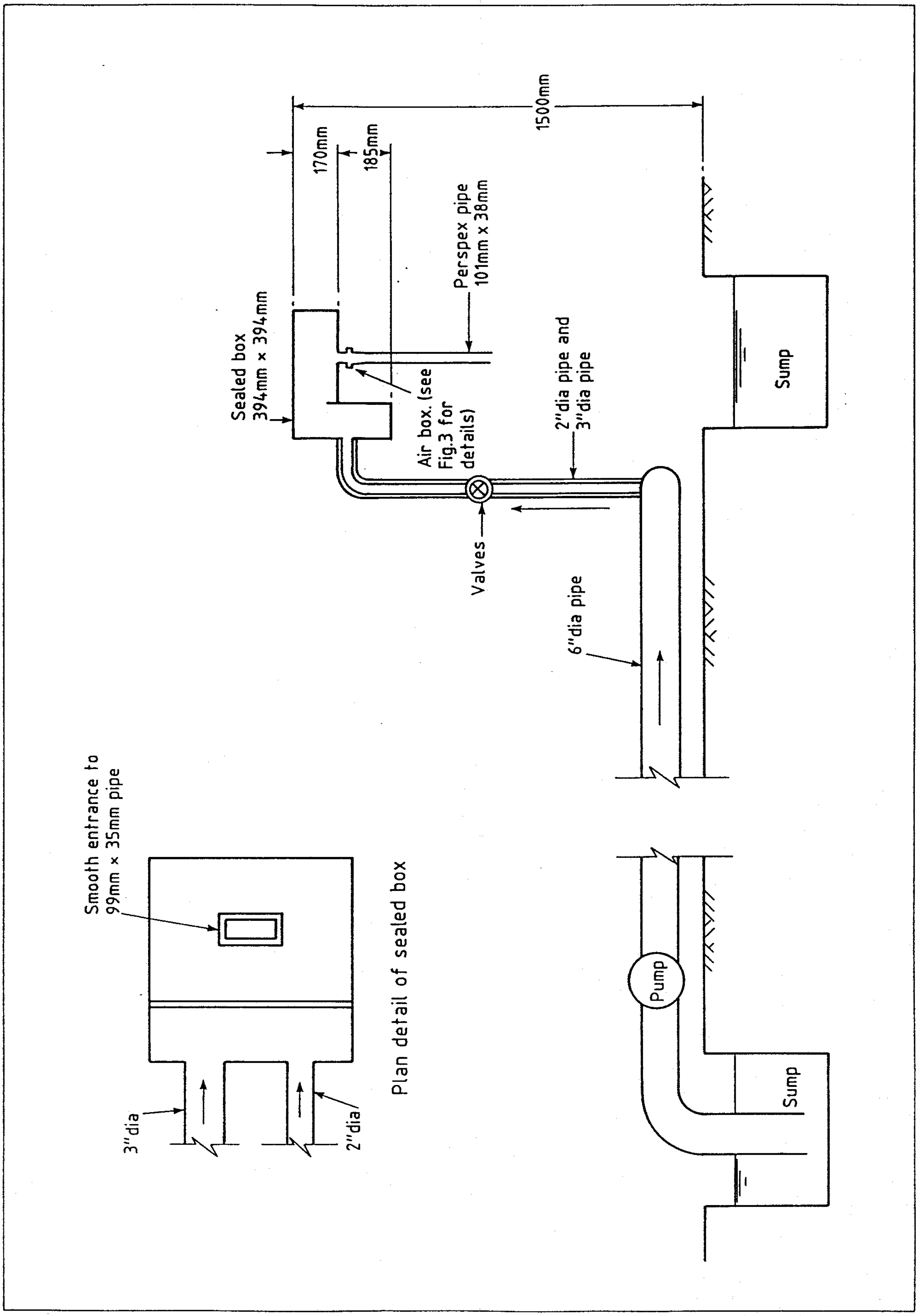


Fig 2 General layout of small test rig

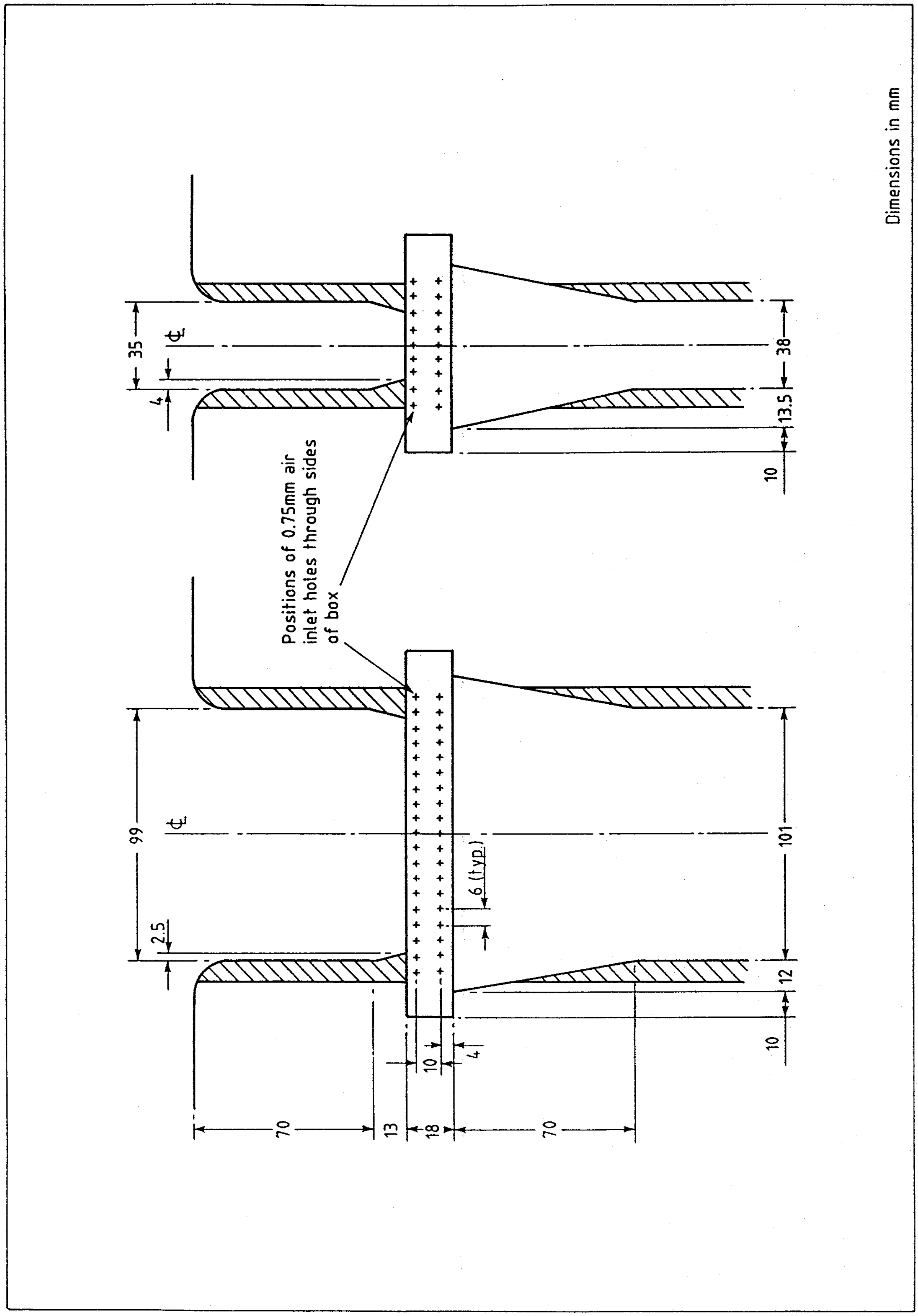


Fig 3 Aeration system for small test rig (after modifications)

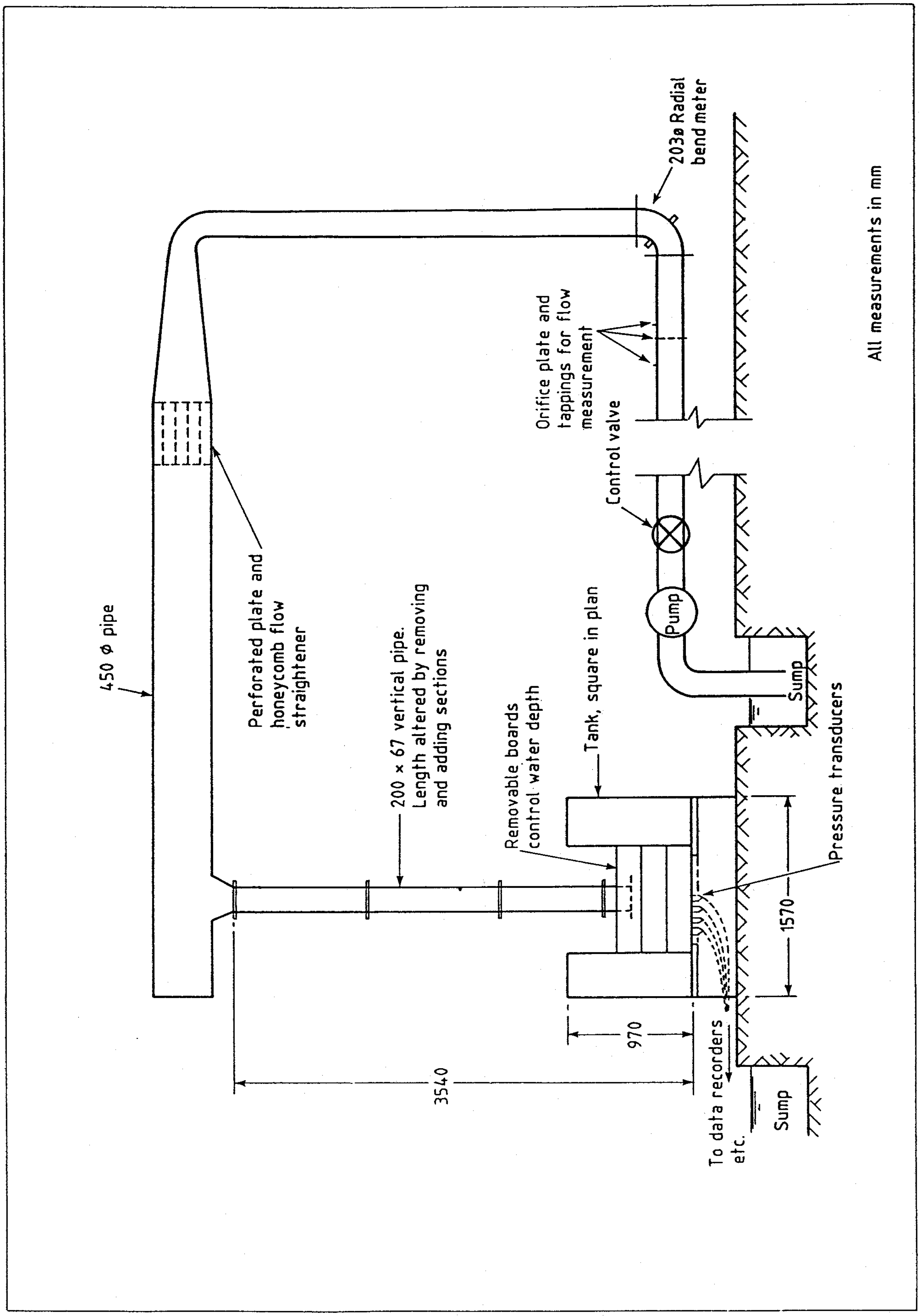
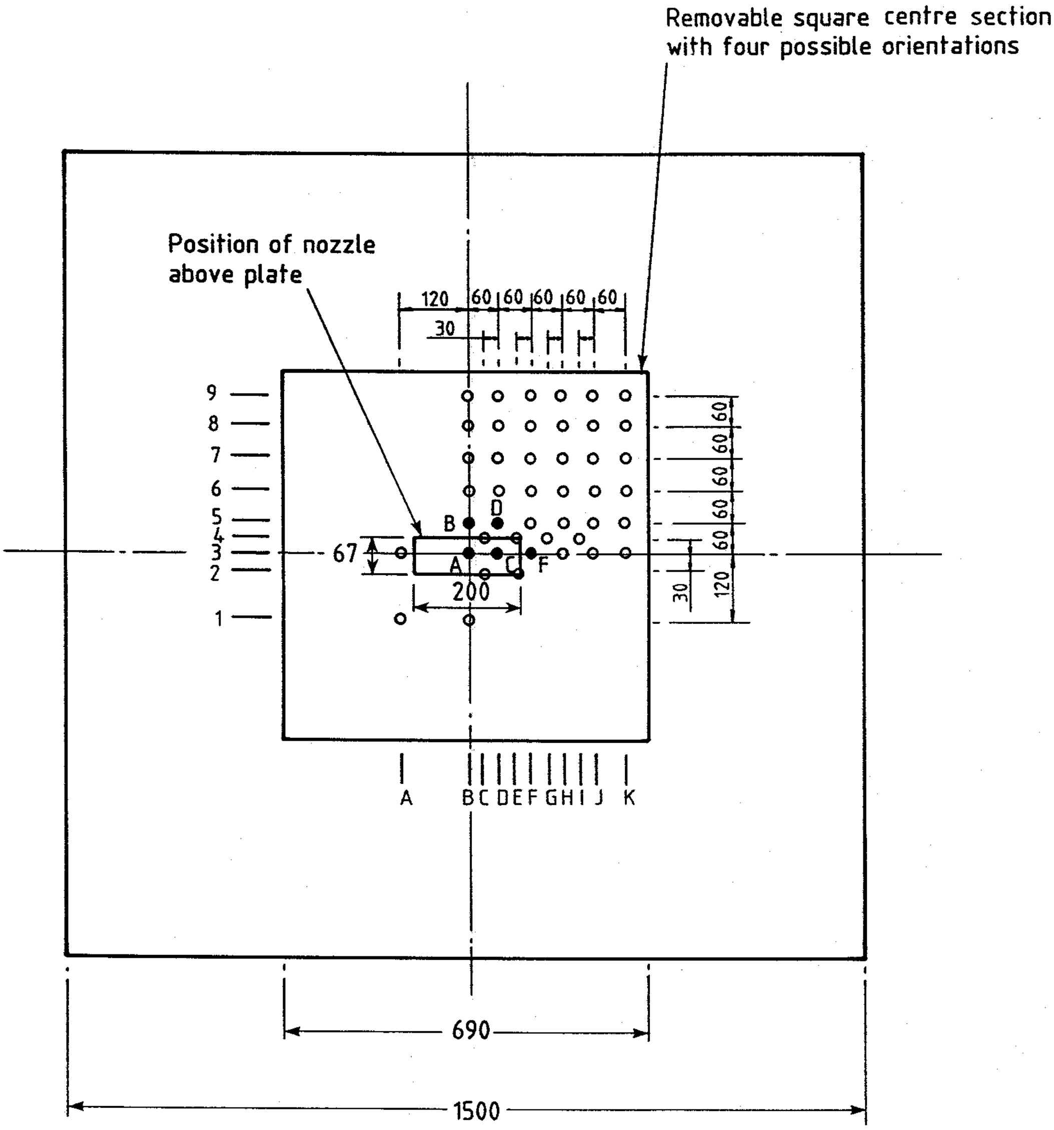


Fig 4 General layout of large test rig



All dimensions in mm

Fig 5 Layout of pressure tappings

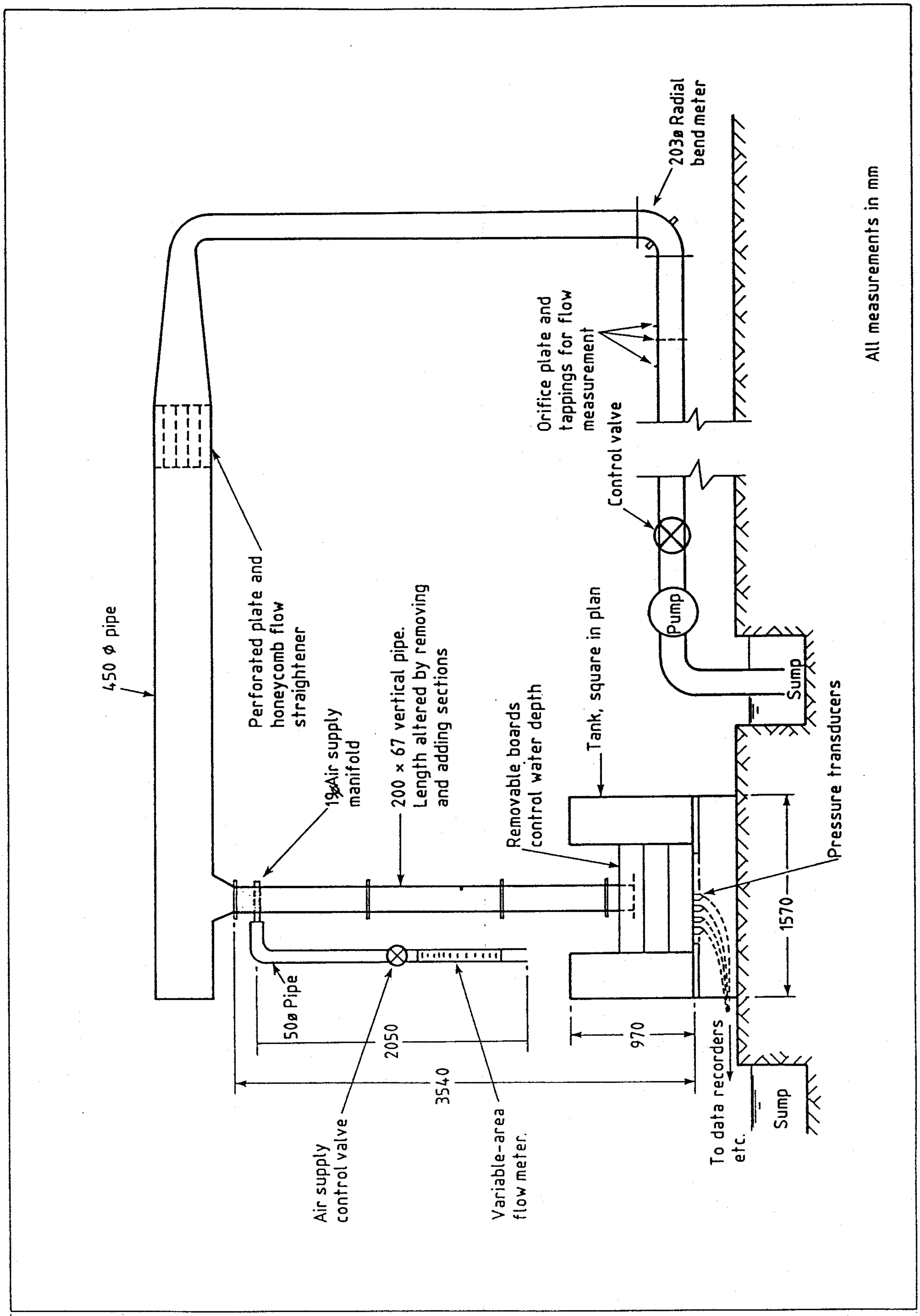


Fig 6   Large test rig with aeration system

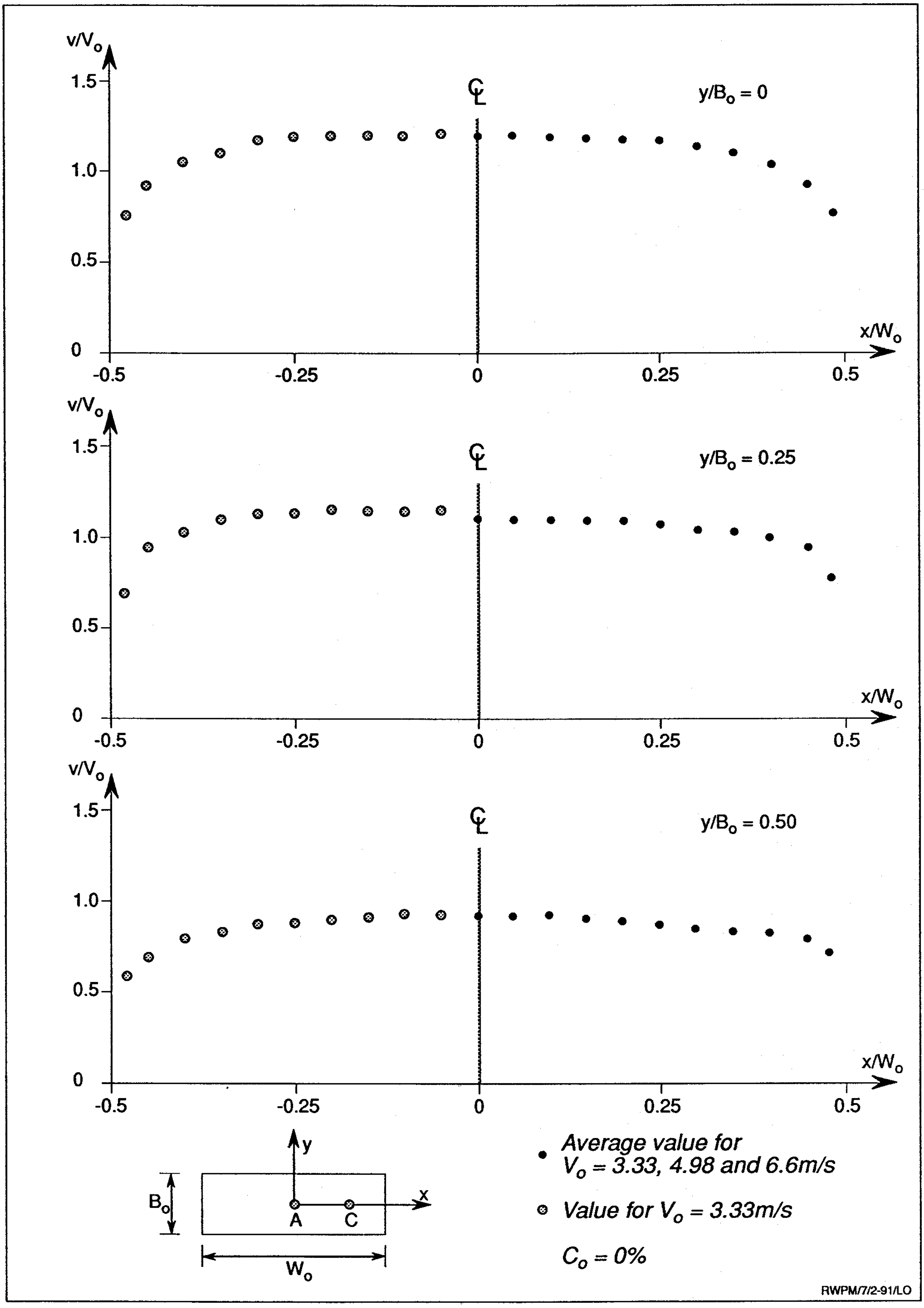


Fig 7 Profiles of mean velocity in free jet

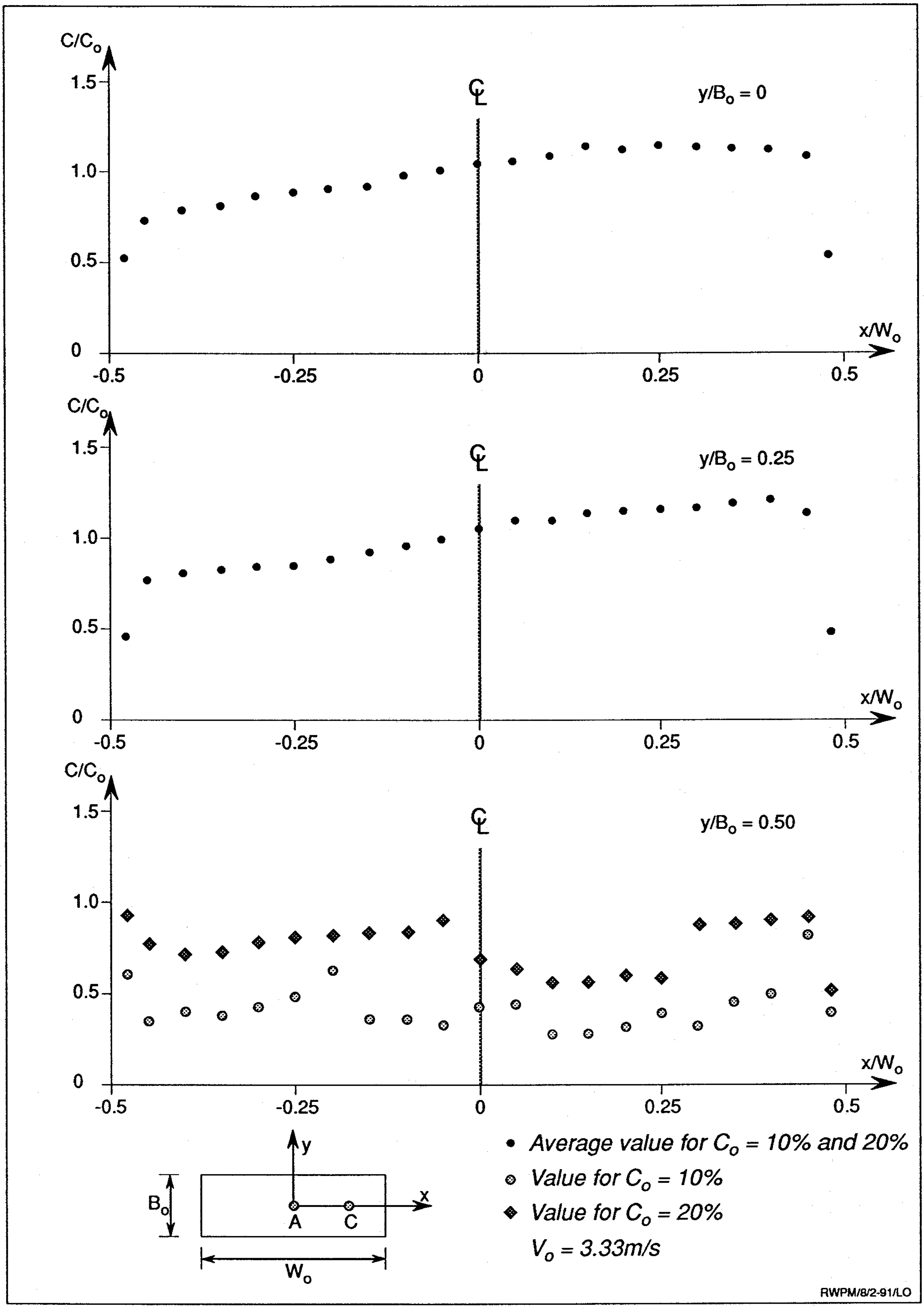


Fig 8 Profiles of air concentration in free jet

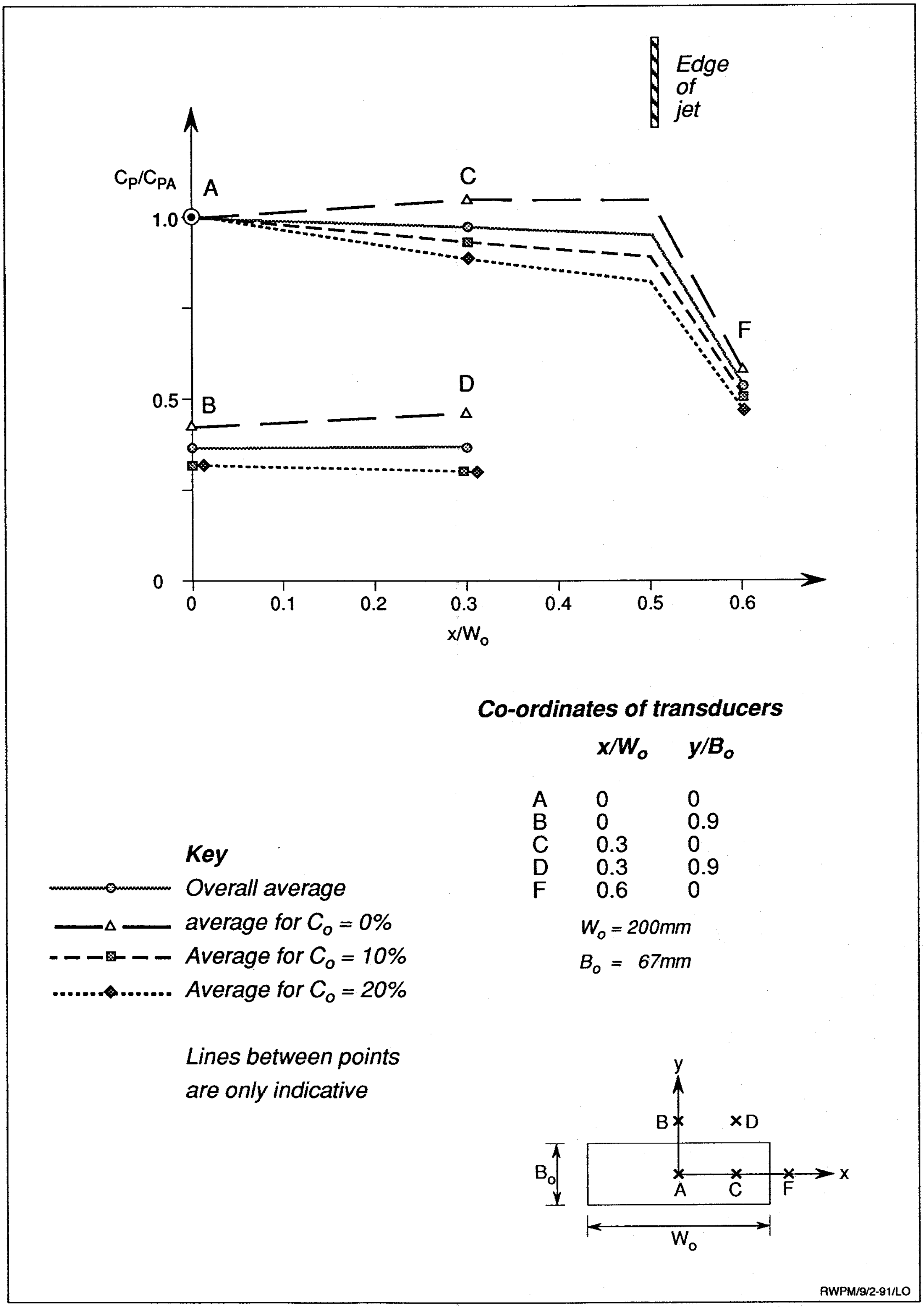


Fig 9 Distribution of mean dynamic pressure

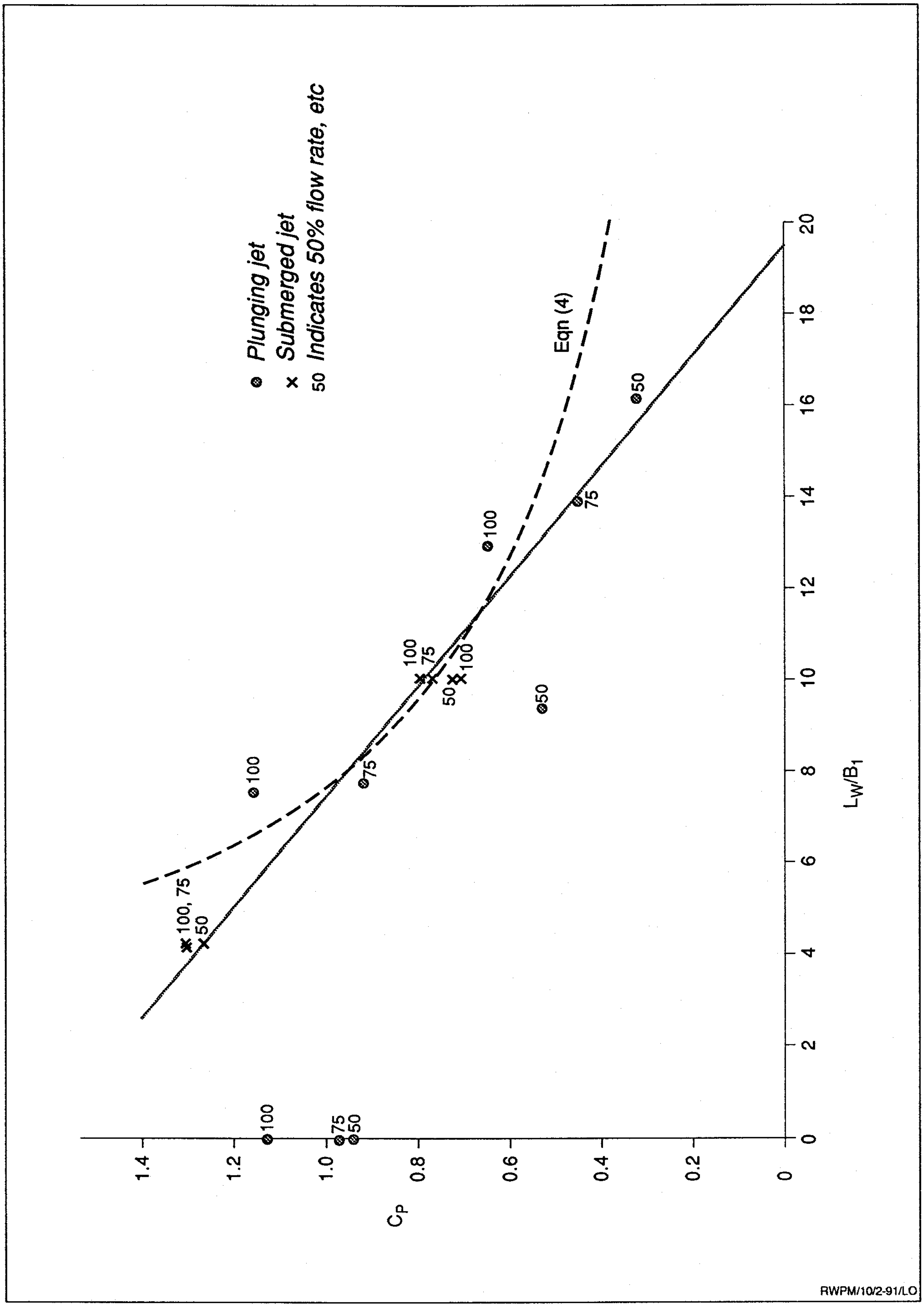


Fig 10 Correlation for mean dynamic pressure (C_o = 0%)

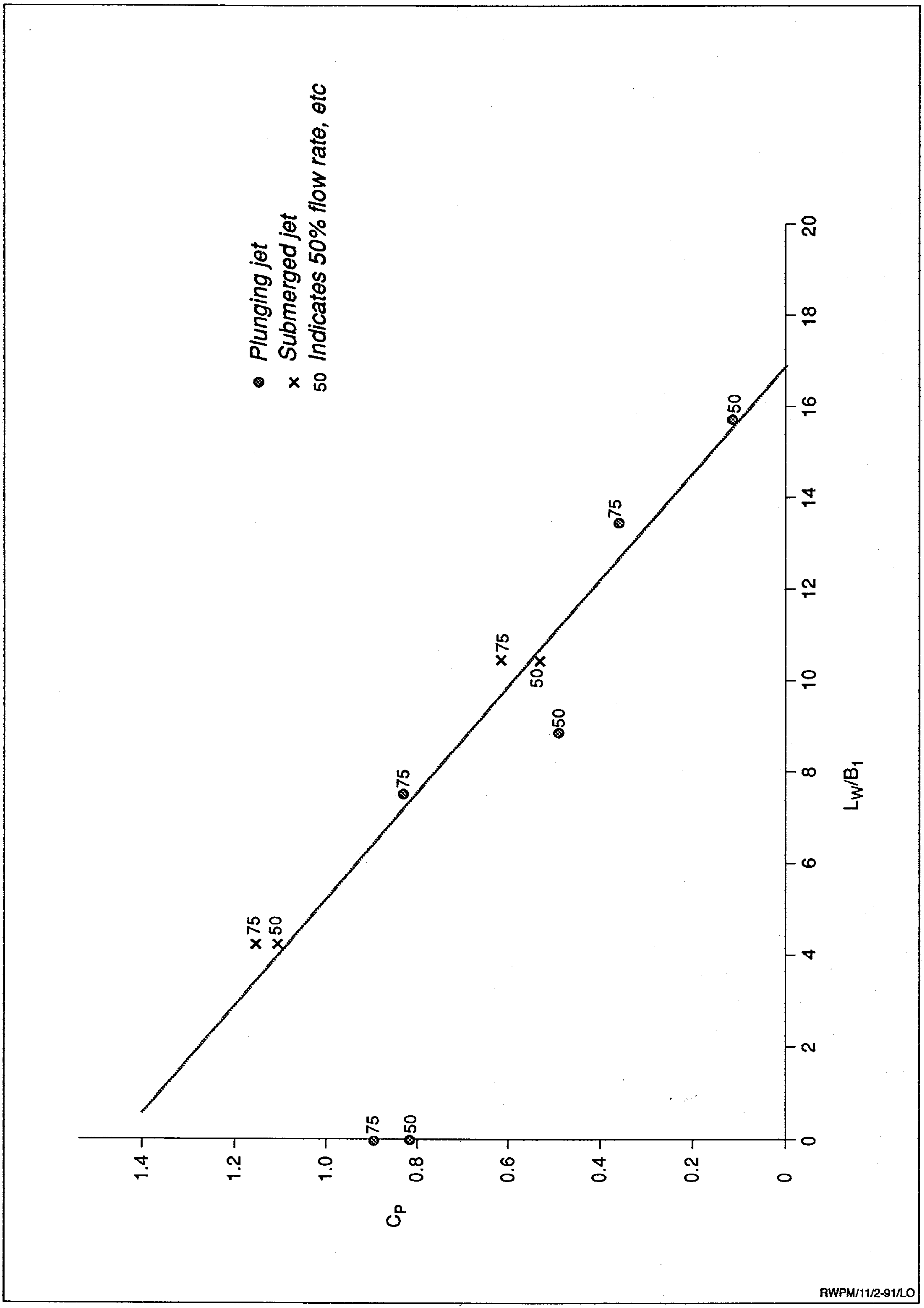


Fig 11 Correlation for mean dynamic pressure (C_o = 10%)

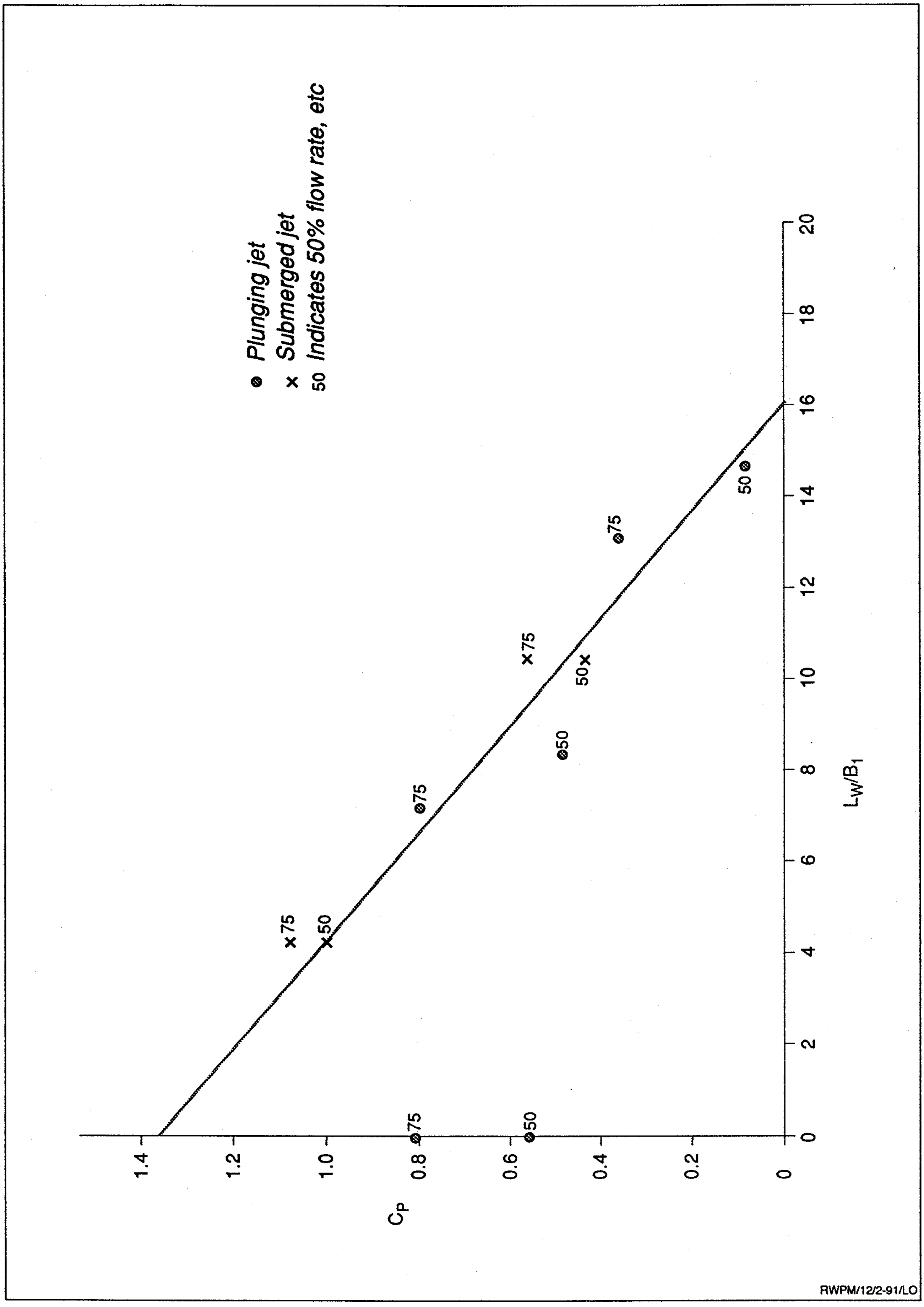


Fig 12 Correlation for mean dynamic pressure (C_o = 20%)

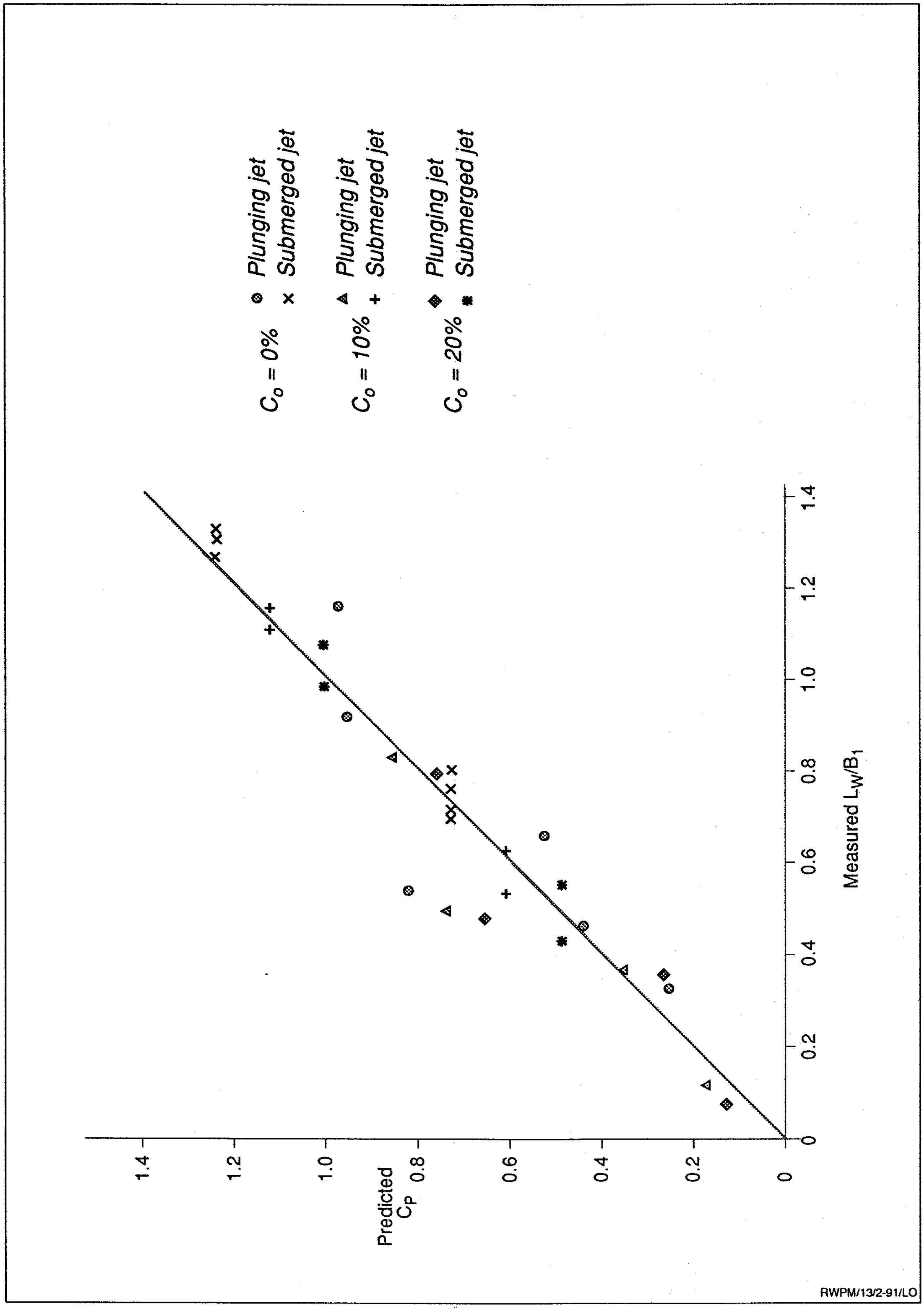


Fig 13 Comparison of predicted and measured values of C_P

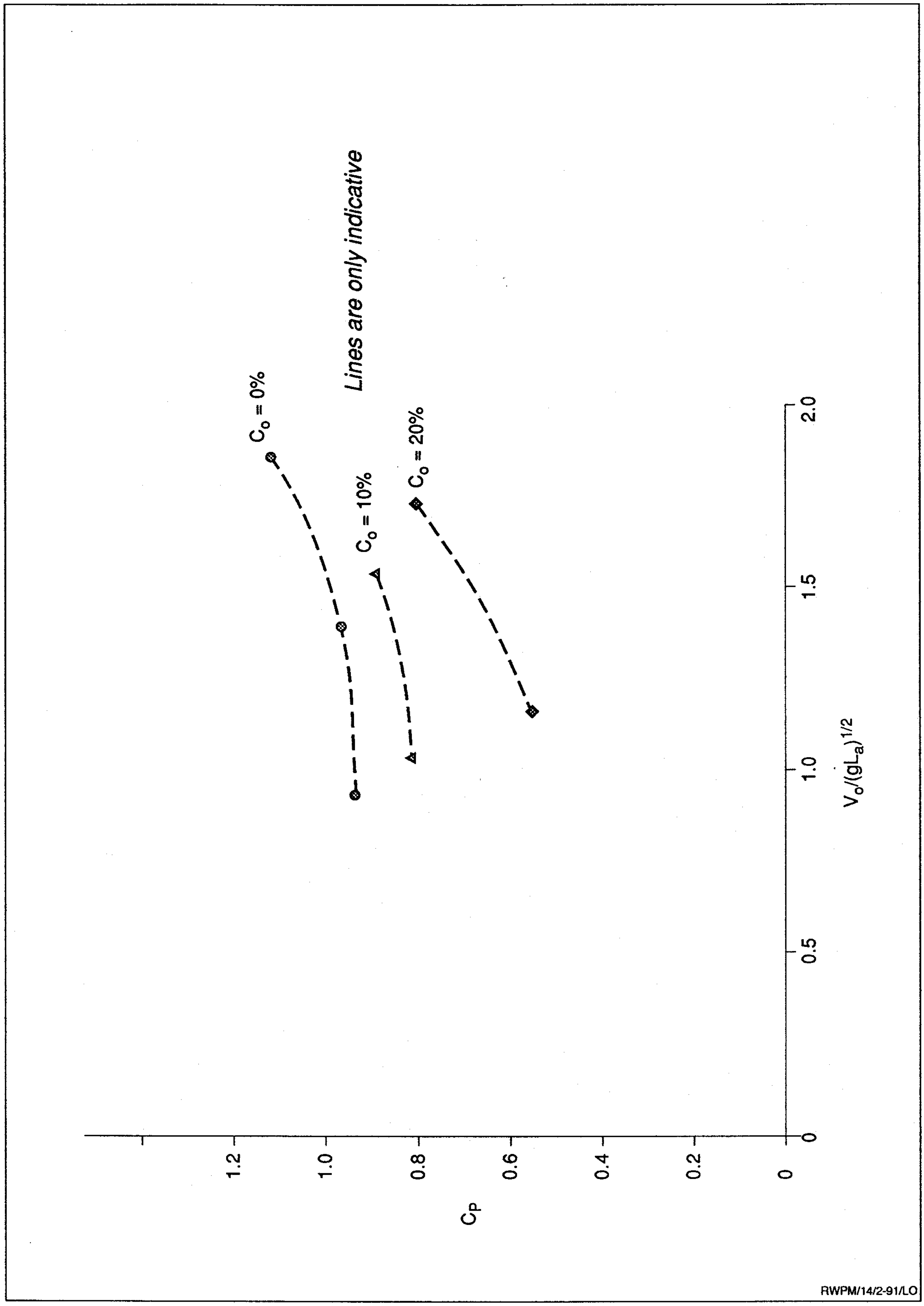


Fig 14 Correlation for mean dynamic pressure with zero tailwater

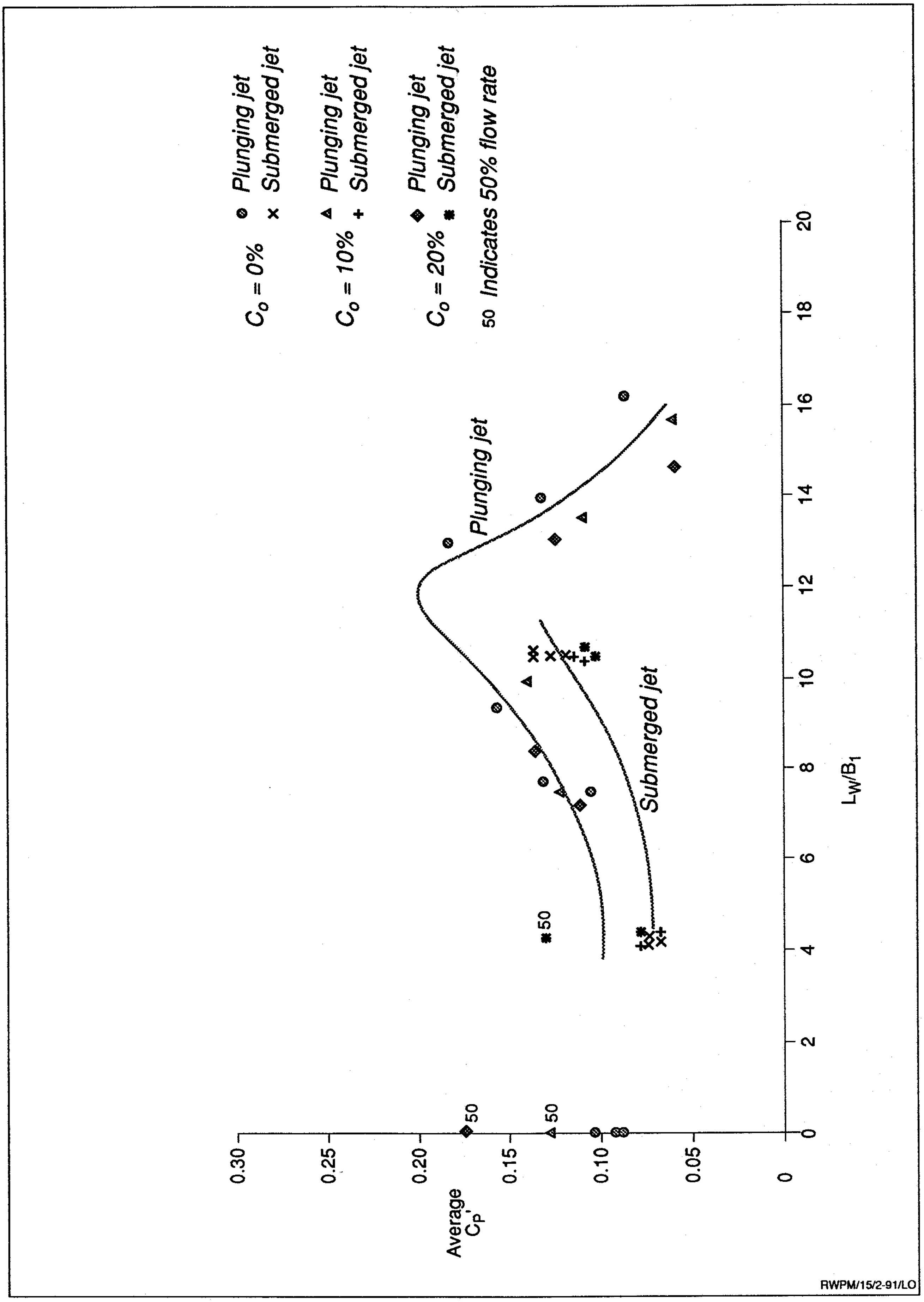


Fig 15 Correlation for average rms dynamic pressure

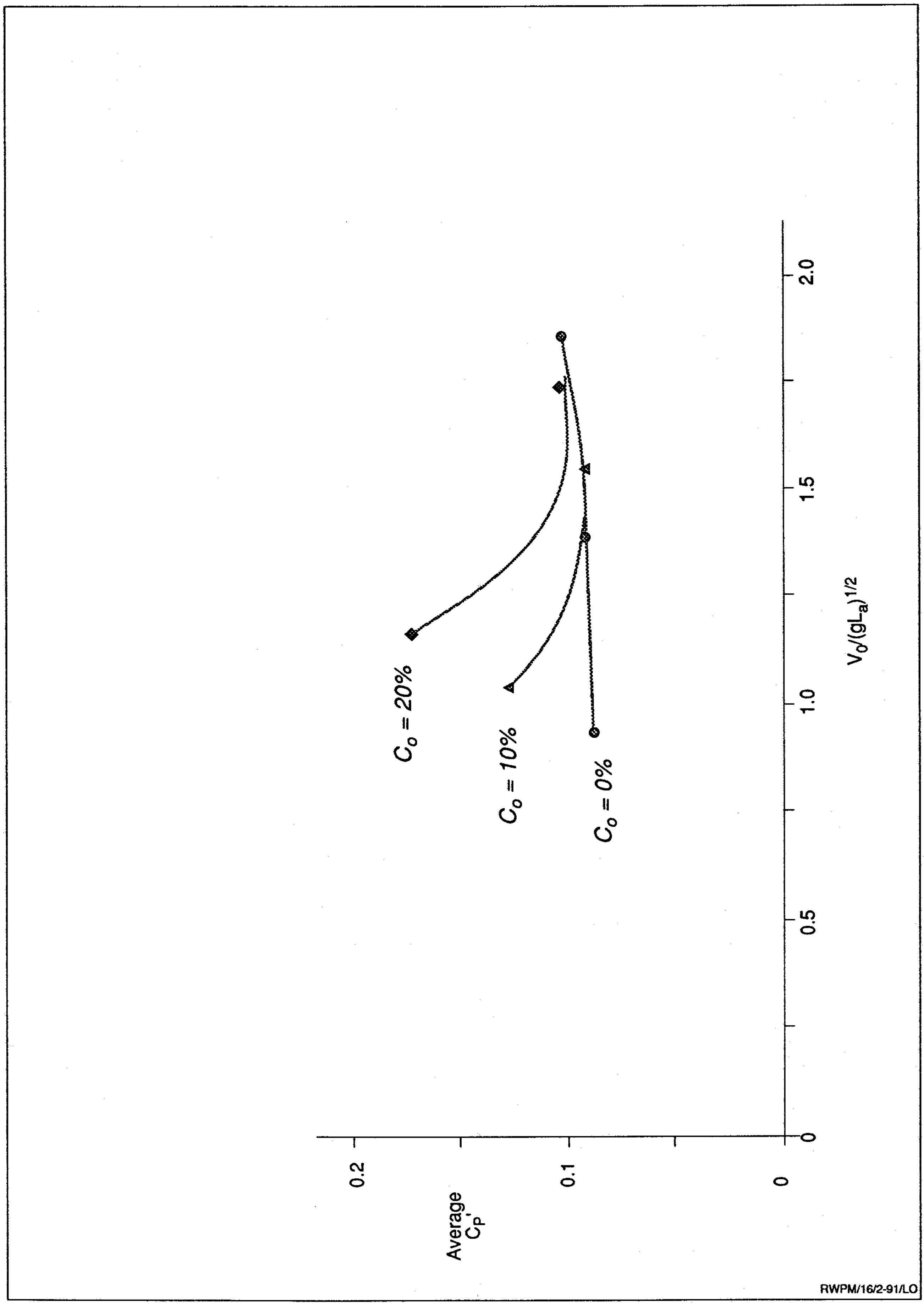


Fig 16 Correlation for average rms dynamic pressure with zero tailwater

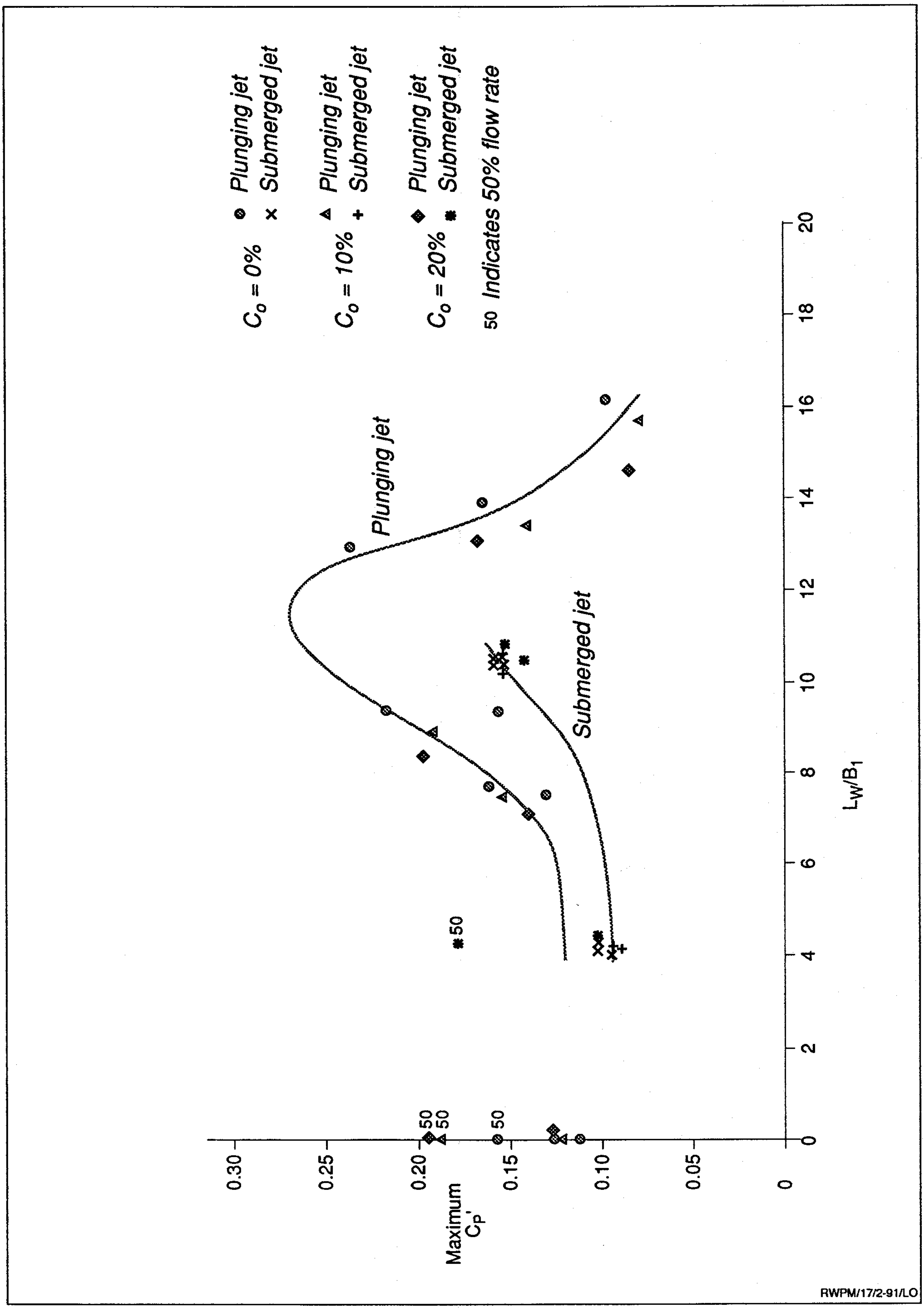


Fig 17 Correlation for maximum rms dynamic pressure

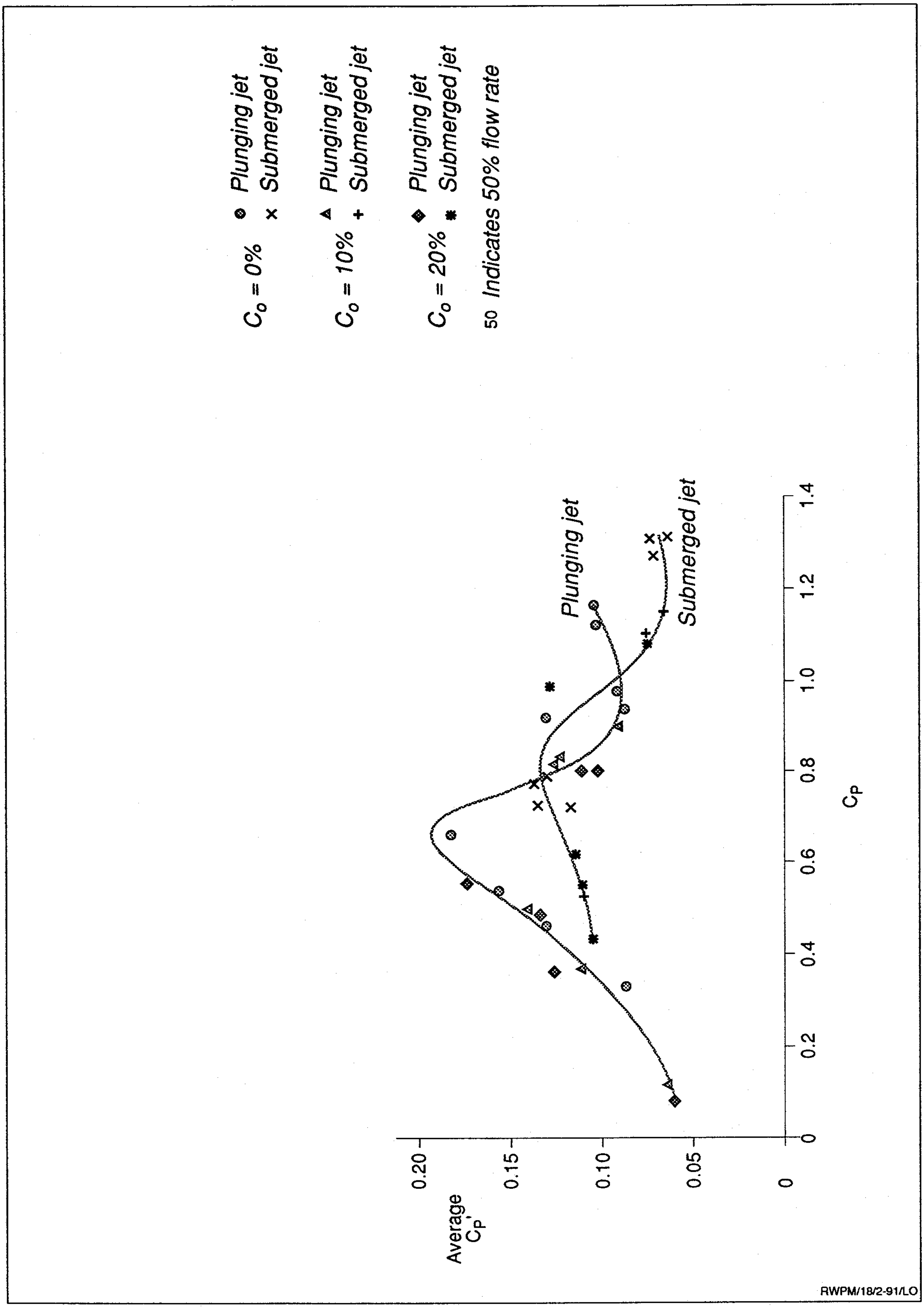


Fig 18 Correlation between rms and mean dynamic pressures

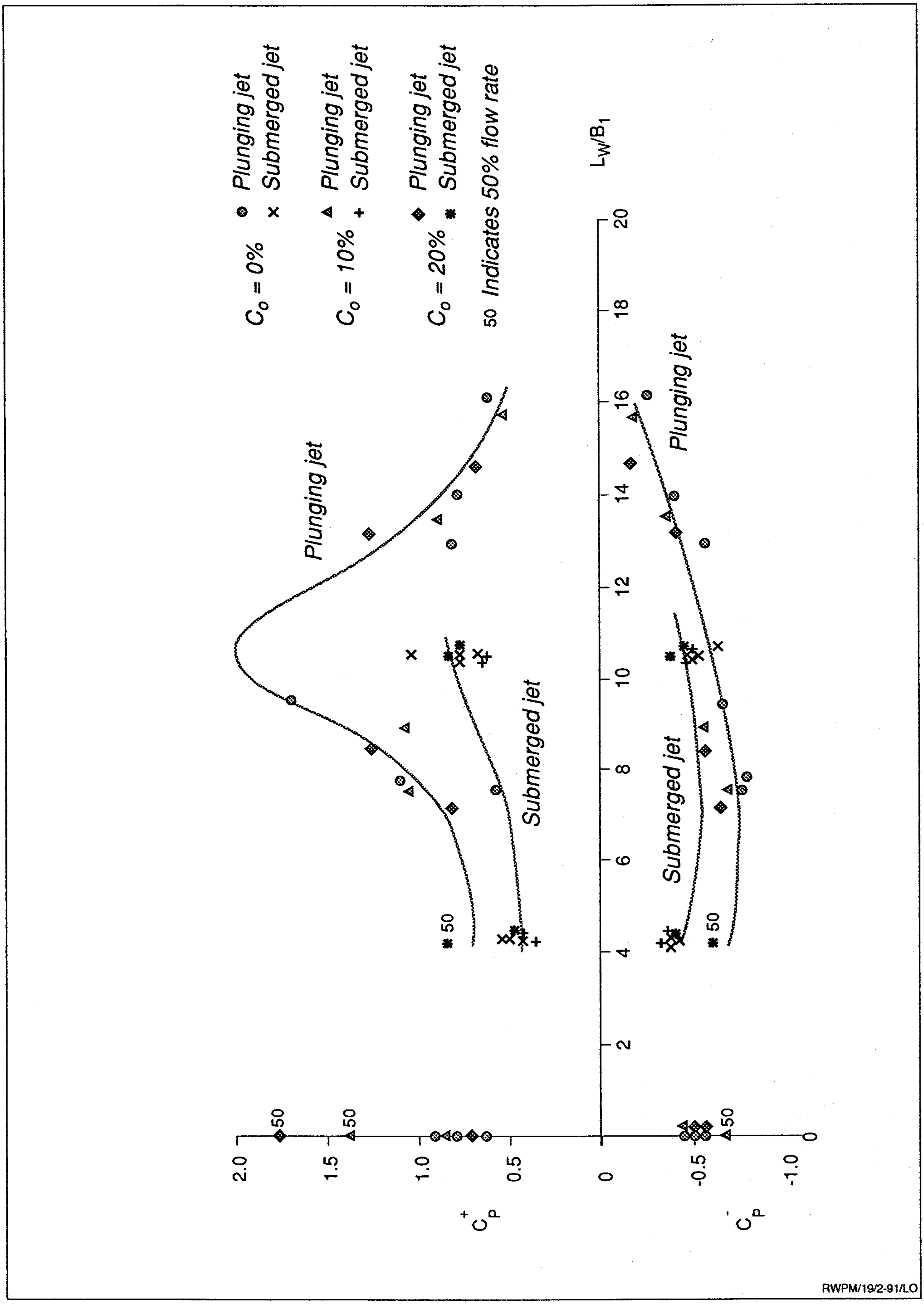


Fig 19 Correlation for peak dynamic pressures

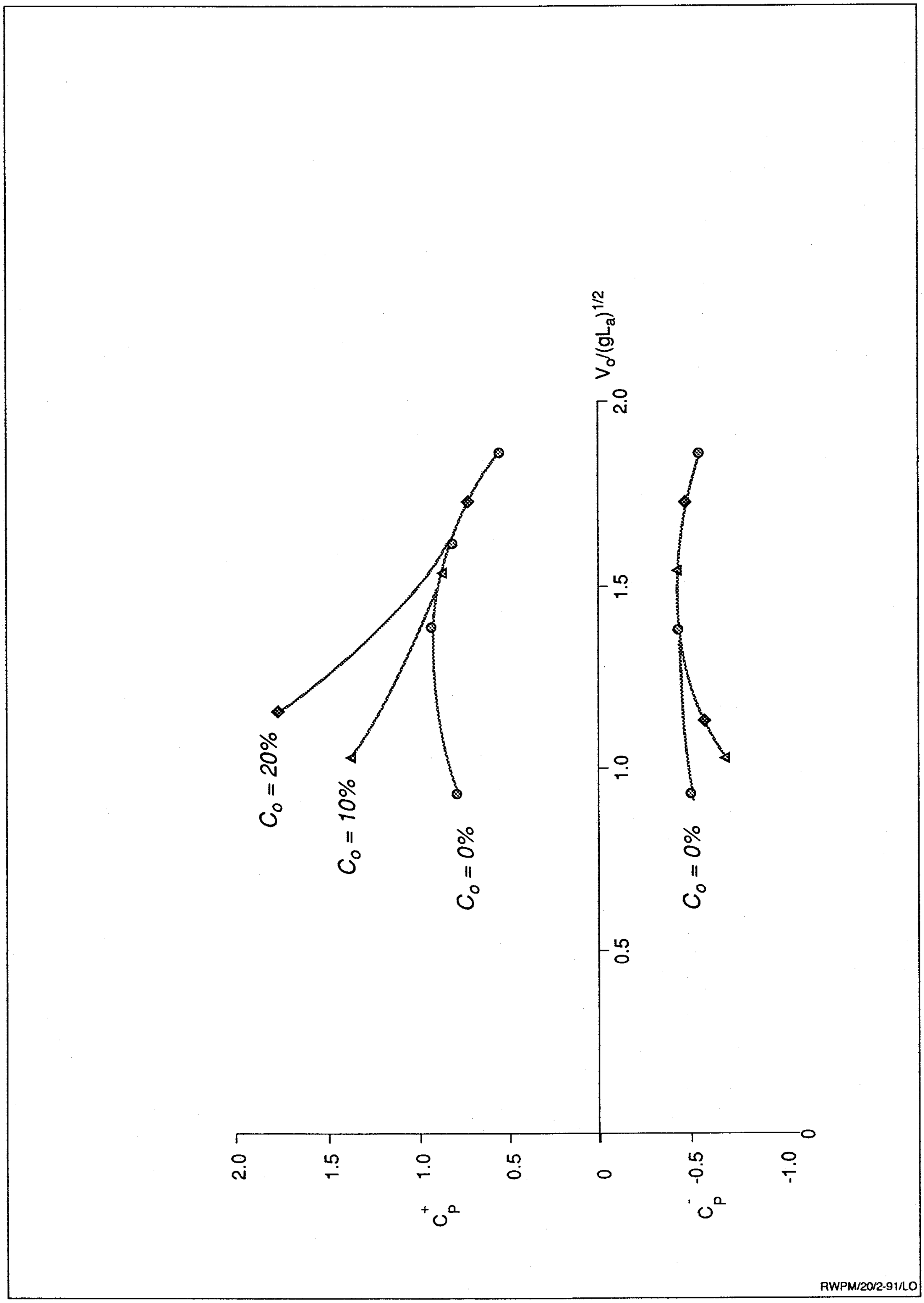


Fig 20 Correlation for peak dynamic pressures with zero tailwater

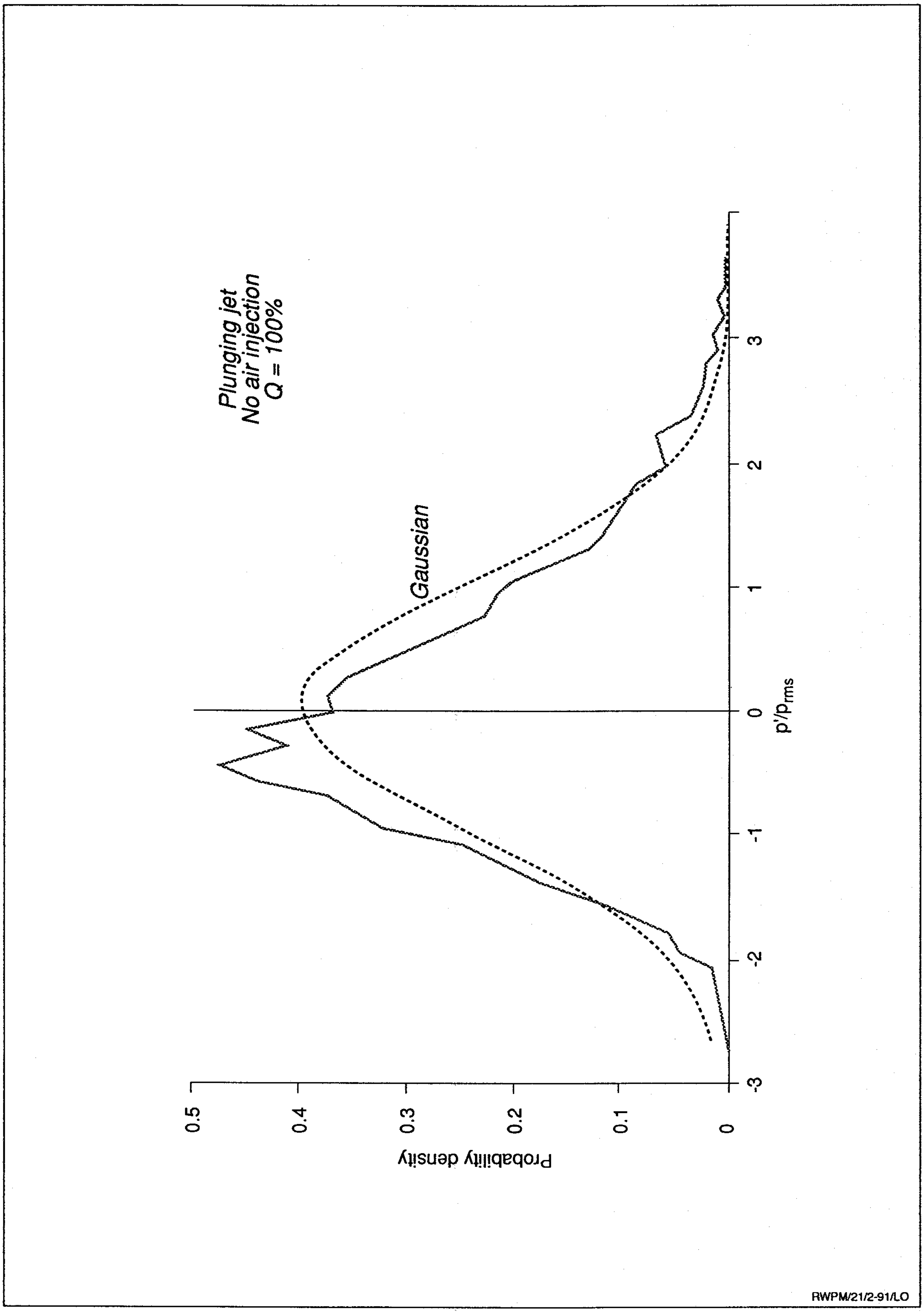


Fig 21 Probability distribution for pressure fluctuations at Position A in Test 8

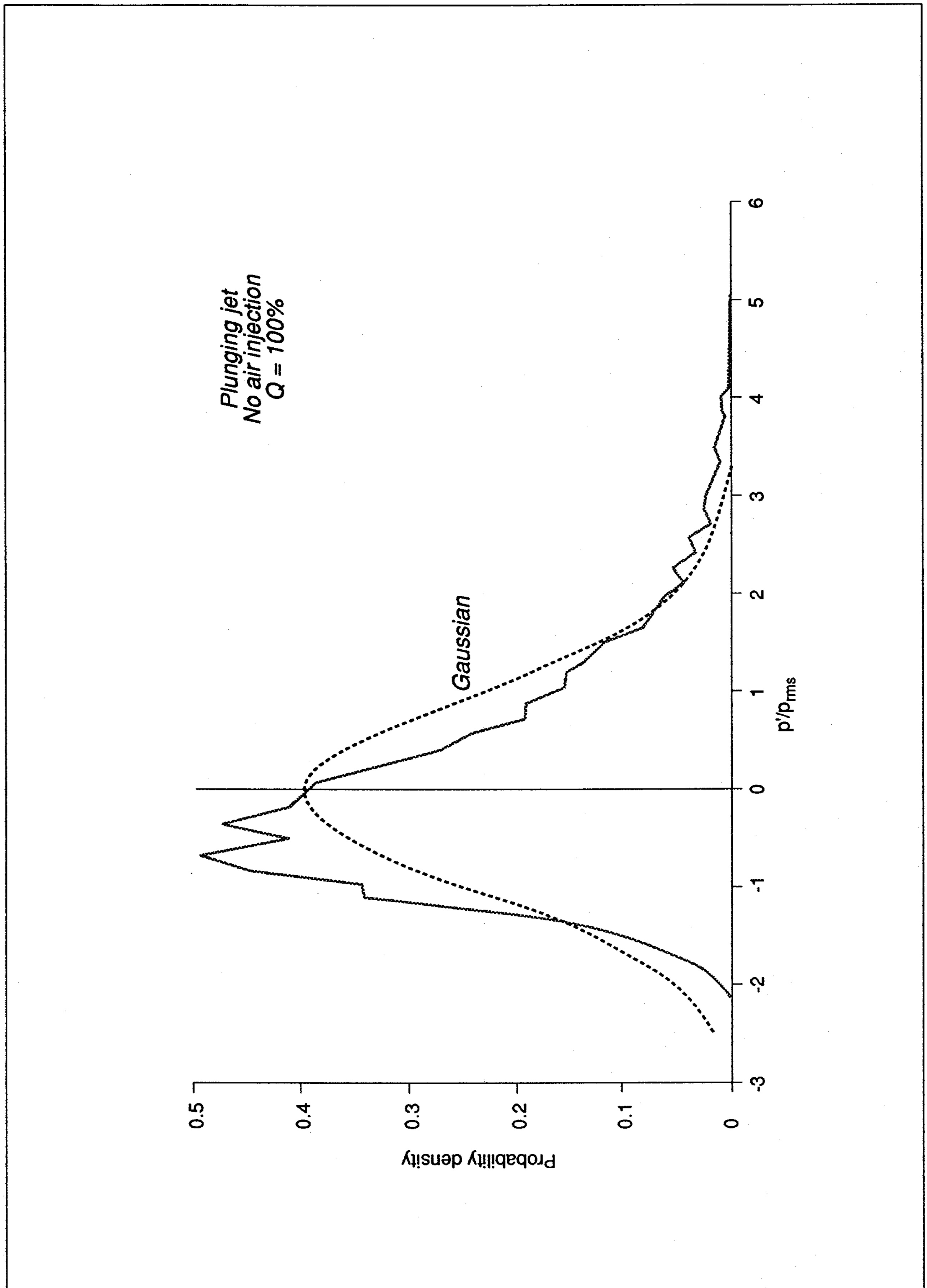


Fig 22 Probability distribution for pressure fluctuations at Position B in Test 8

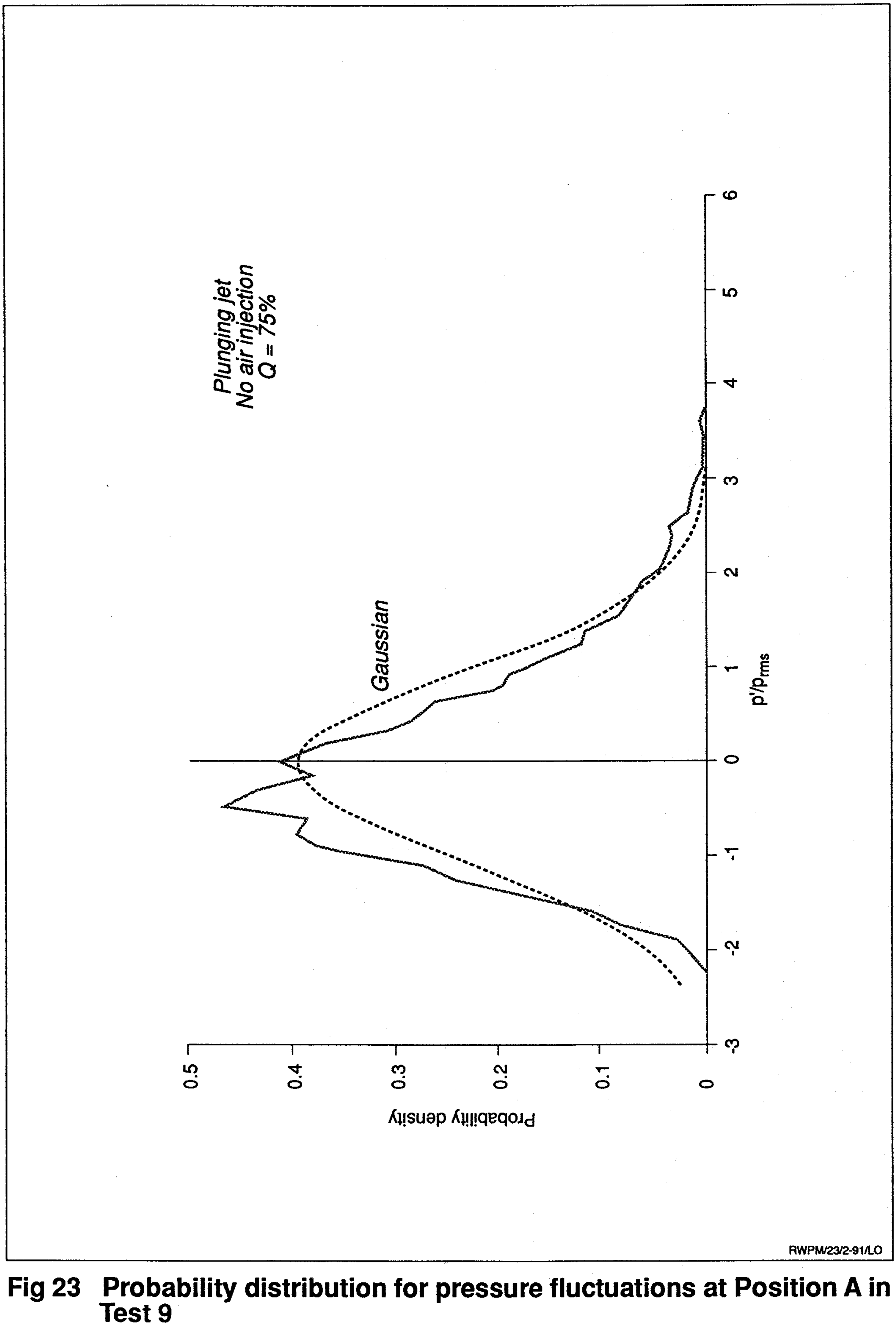


Fig 23 Probability distribution for pressure fluctuations at Position A in Test 9

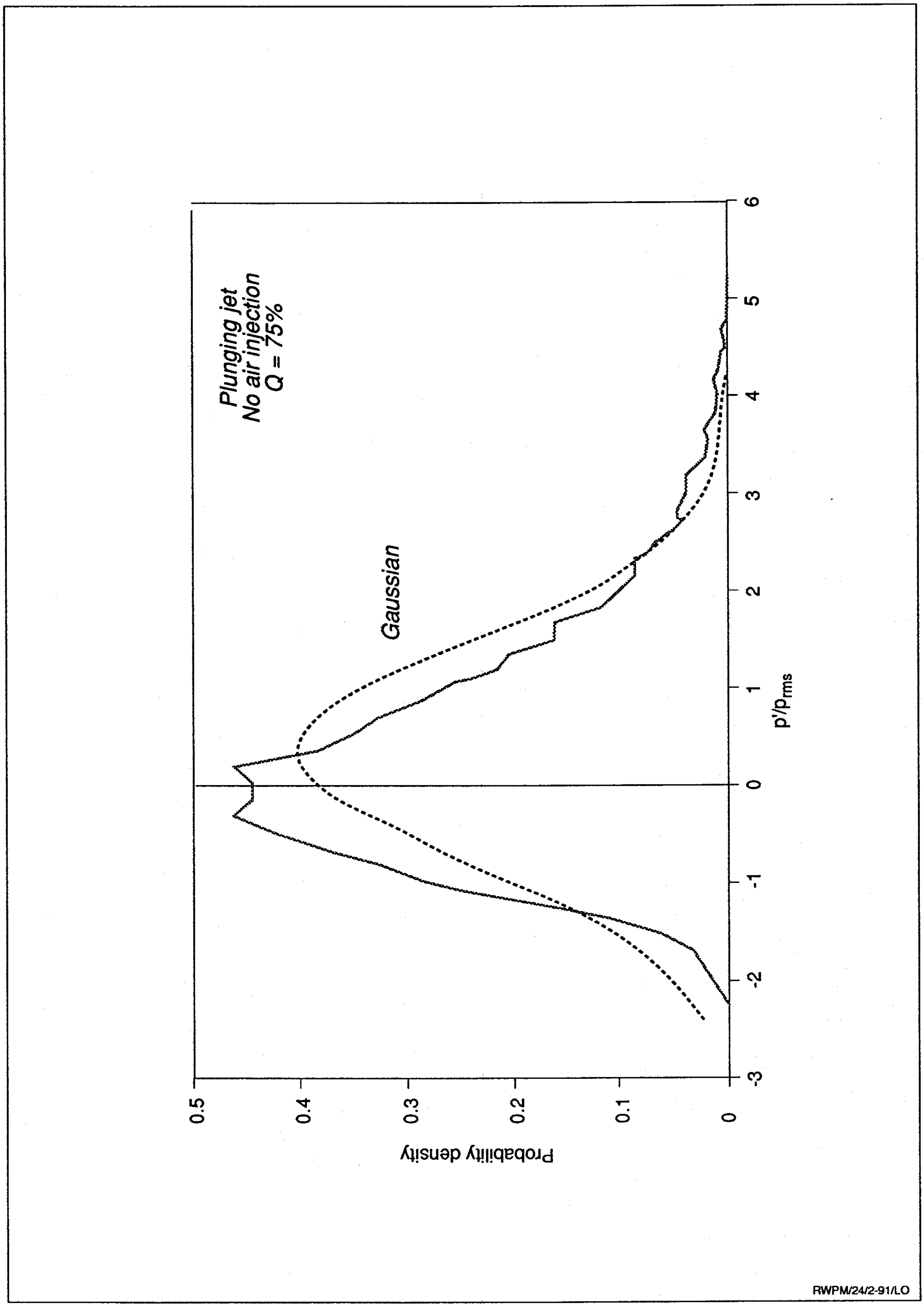


Fig 24 Probability distribution for pressure fluctuations at Position B in Test 9

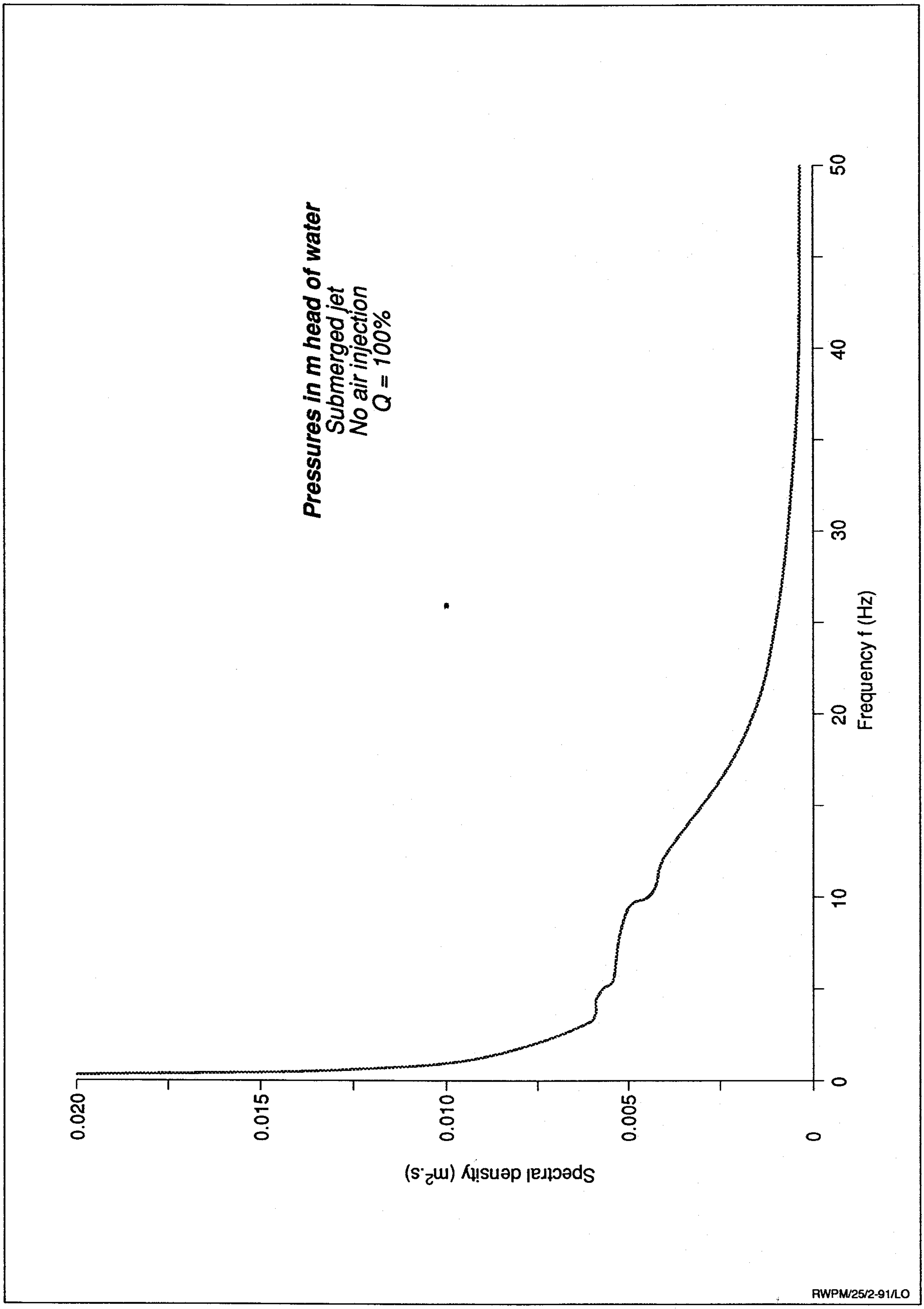


Fig 25 Spectral density for pressure fluctuations at Postion A in Test 15

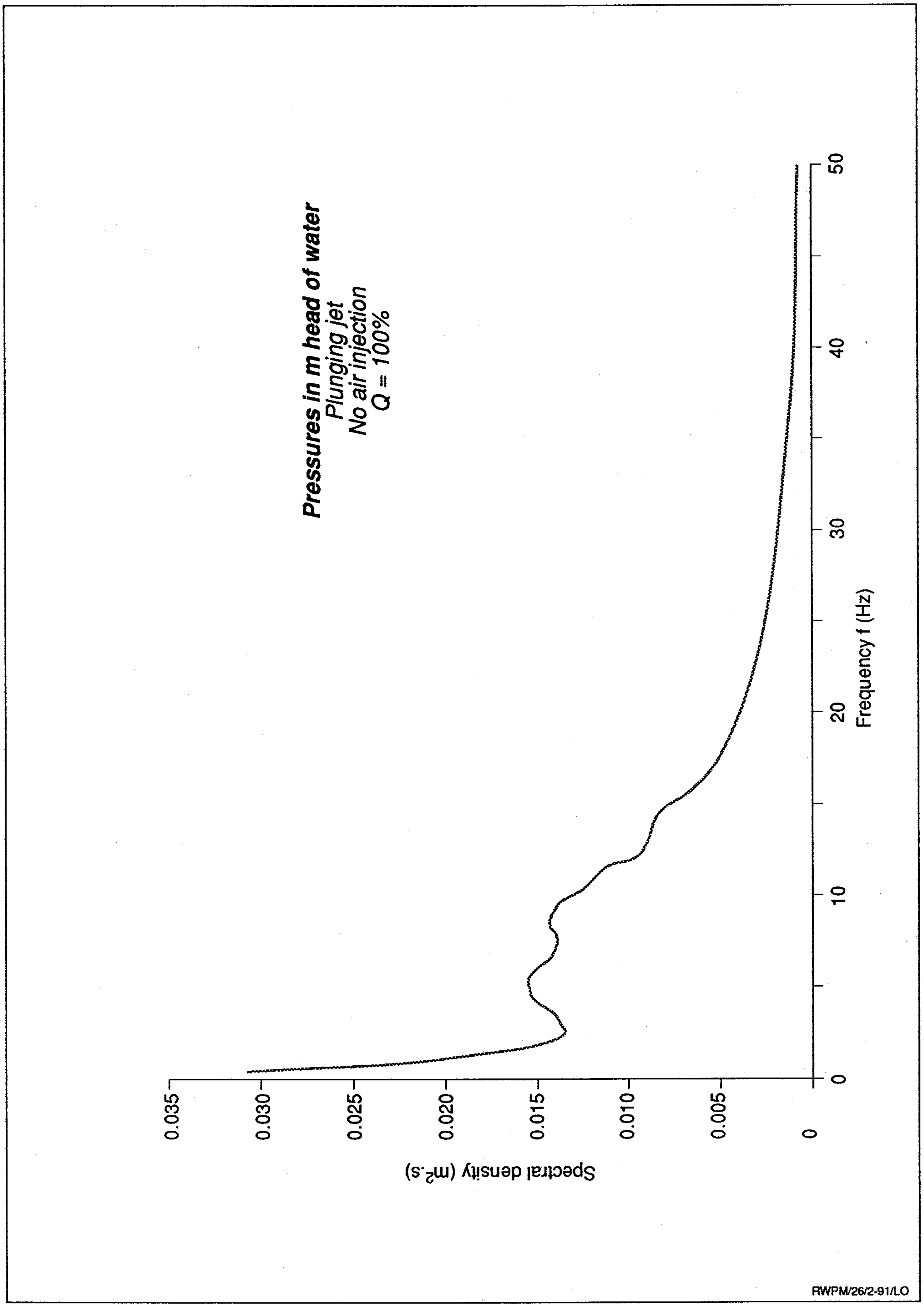


Fig 26 Spectral density for pressure fluctuations at Postion A in Test 8

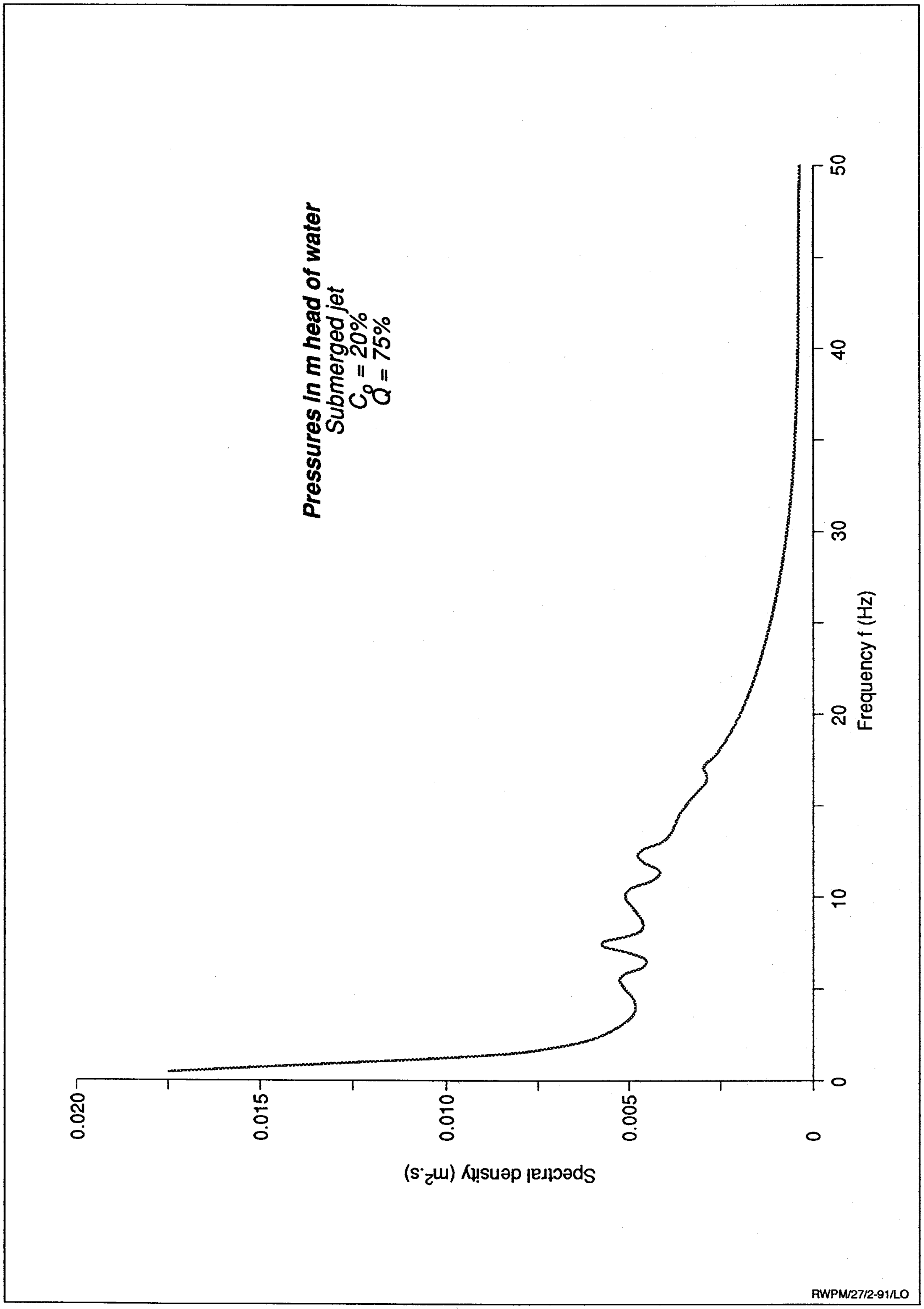


Fig 27 Spectral density for pressure fluctuations at Postion A in Test 22

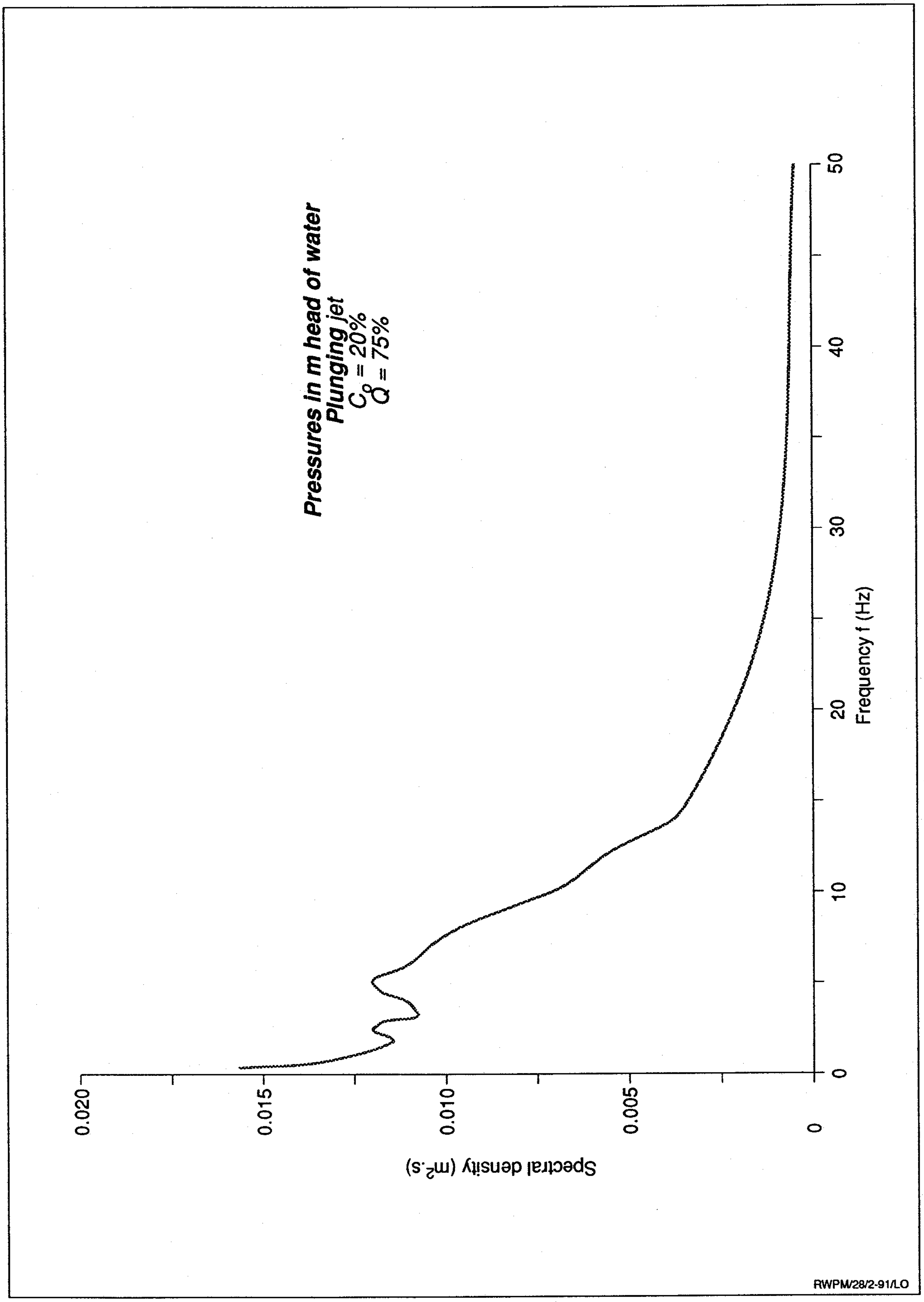


Fig 28 Spectral density for pressure fluctuations at Postion A in Test 34

PLATES.

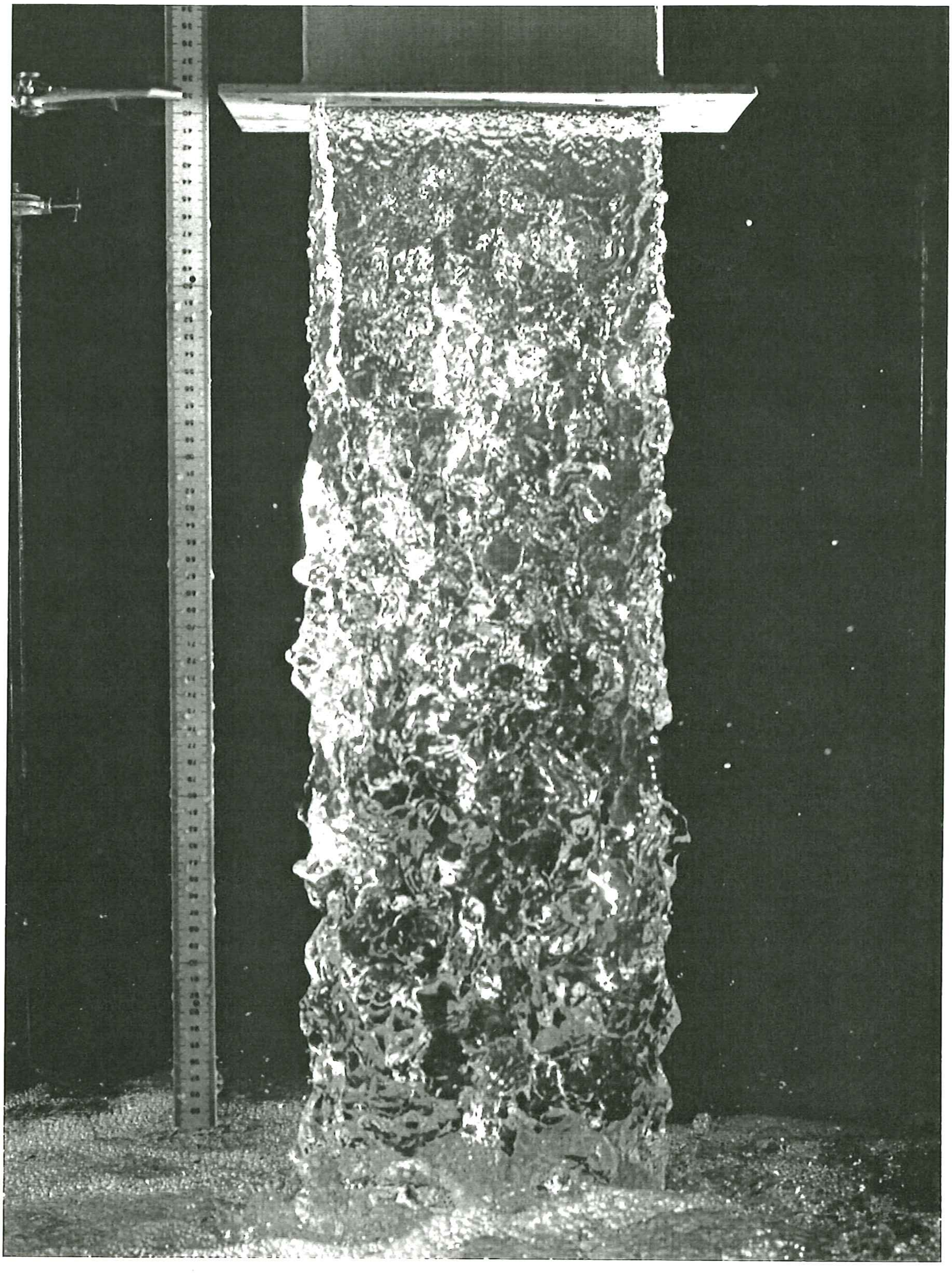


PLATE 1 JET DISCHARGING FROM HEIGHT OF 1.08m AT V_0=2.45m/s : LONG SIDE

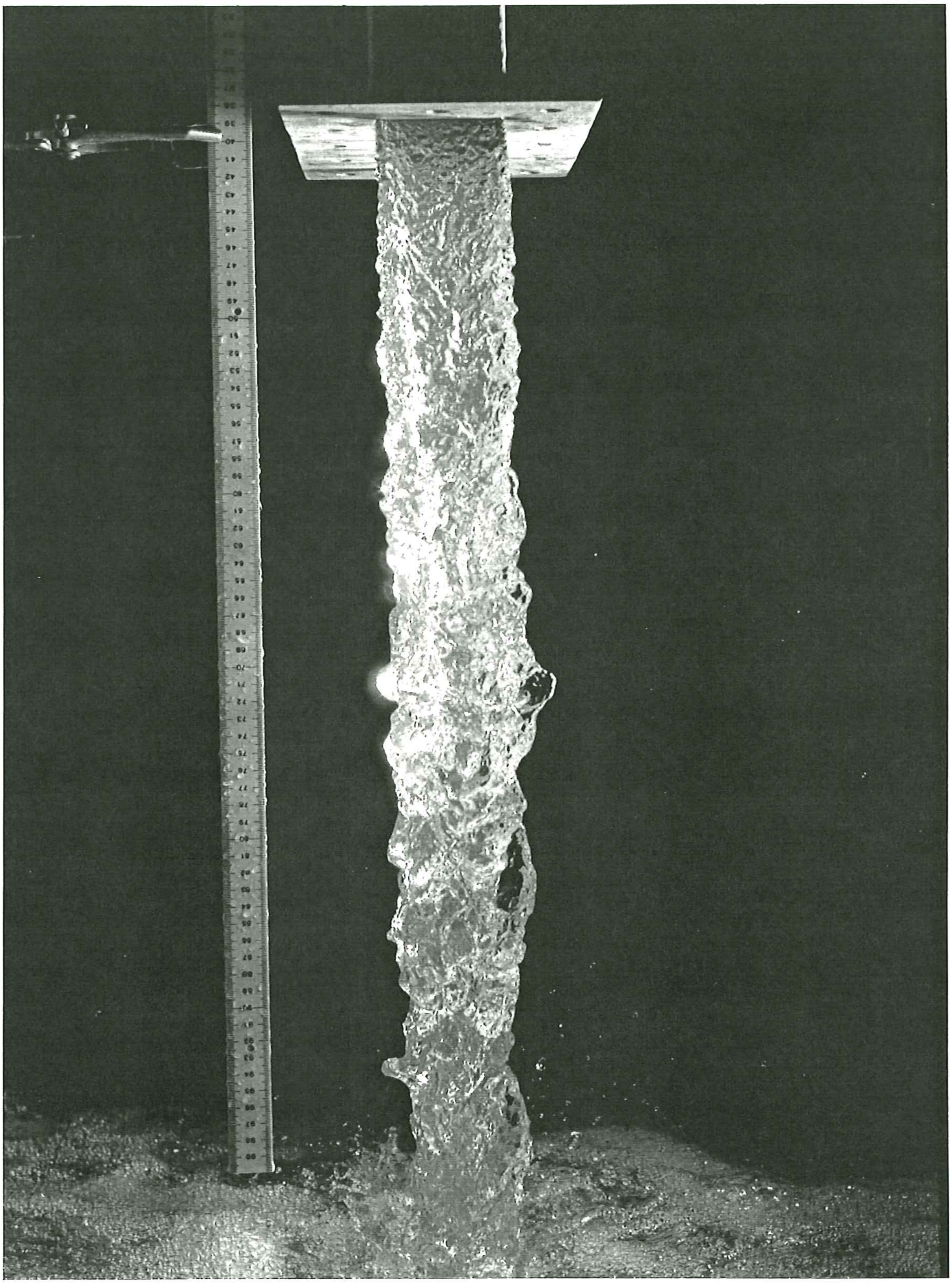


PLATE 2 JET DISCHARGING FROM HEIGHT OF 1.08m AT V_0=2.45m/s : SHORT SIDE

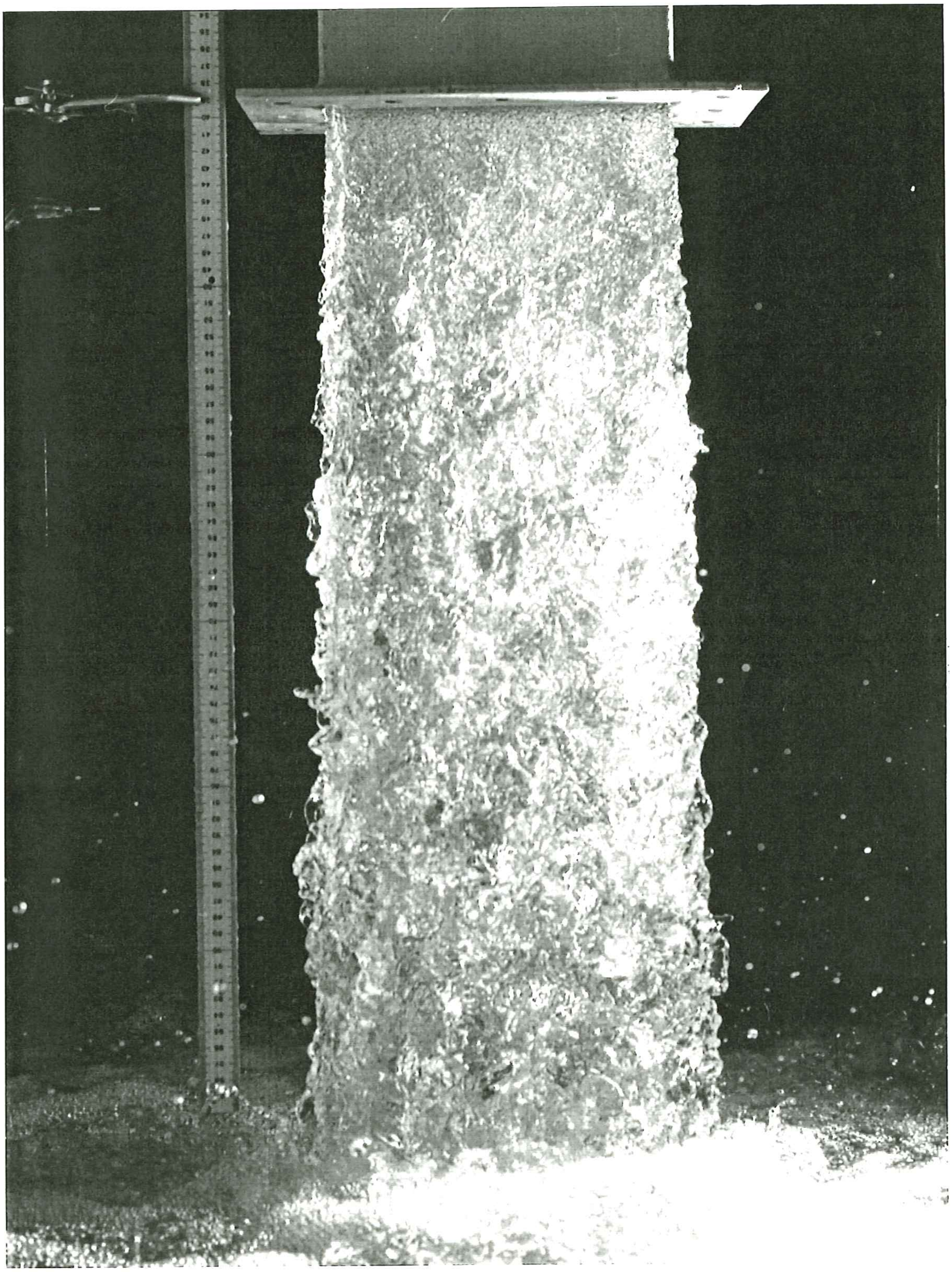


PLATE 3 JET DISCHARGING FROM HEIGHT OF 1.08m AT V_o=4.26m/s : LONG SIDE

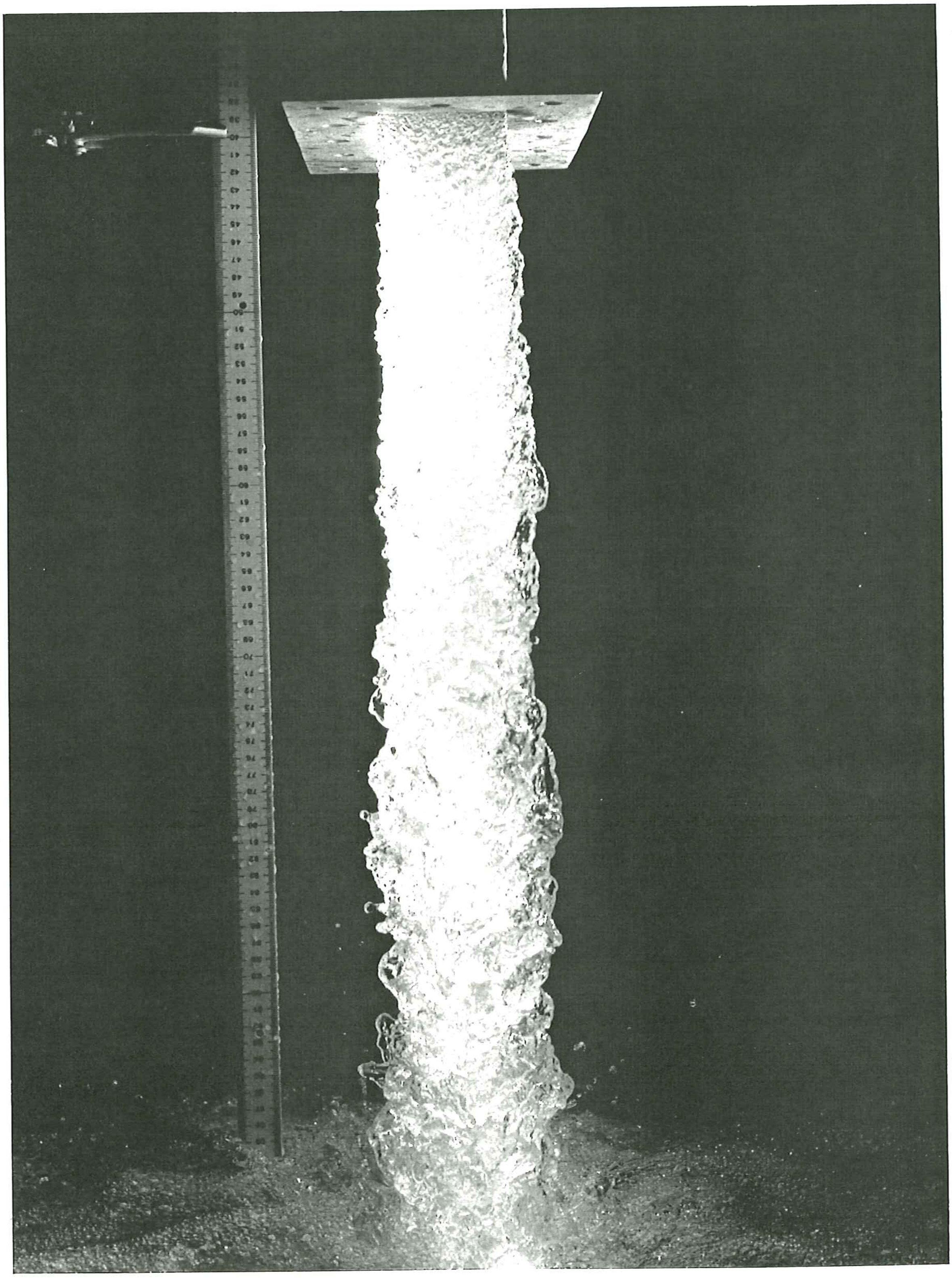


PLATE 4 JET DISCHARGING FROM HEIGHT OF 1.08m AT V_o=4.26m/s : SHORT SIDE

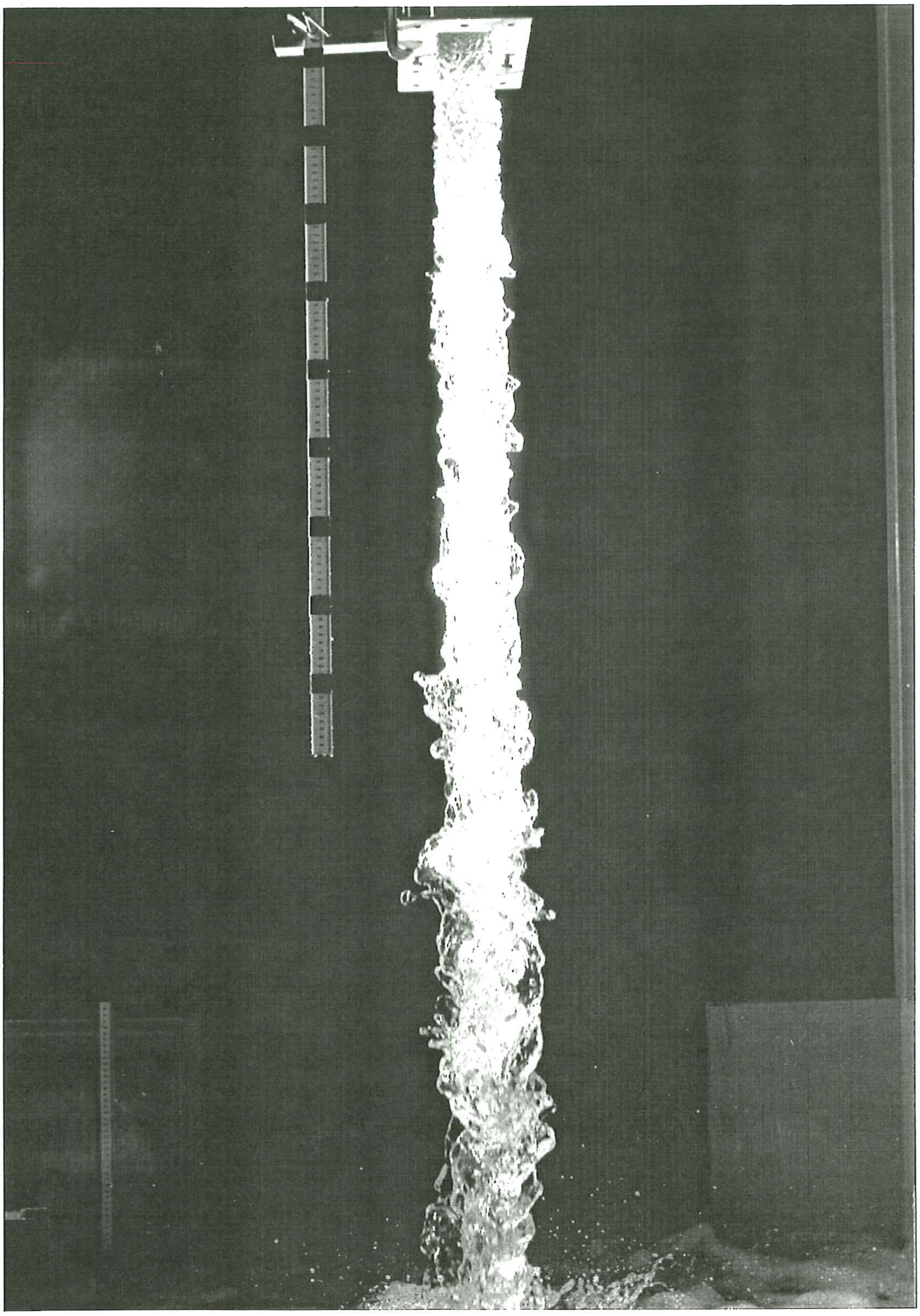


PLATE 5 JET DISCHARGING FROM HEIGHT OF 2.30m AT V_0=2.44m/s : SHORT SIDE

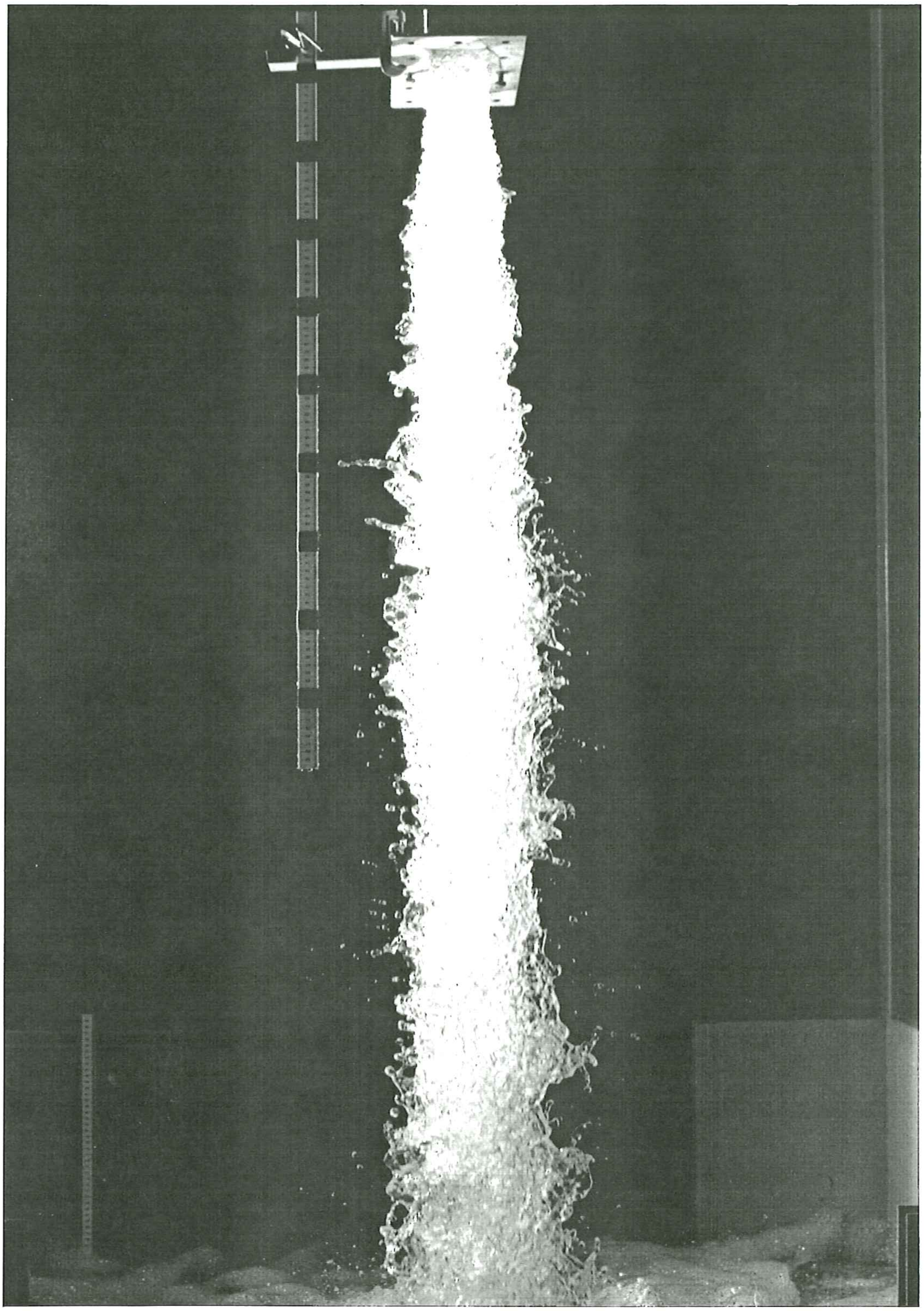


PLATE 6 JET DISCHARGING FROM HEIGHT OF 2.30m AT V_o=4.29m/s : SHORT SIDE

APPENDICES.

APPENDIX A

Measurements of impact pressures

TEST CONDITIONS

Page No	HR Test No	Jet type*	Water discharge + (%)	Approx water depth ‡ (m)	Approx air concentration ‡ (%)
A.2	15	S	100	0.8	0
A.3	21	S	100	0.8	0
A.4	16	S	75	0.8	0
A.5	17	S	50	0.8	0
A.6	20	S	100	0.4	0
A.7	19	S	75	0.4	0
A.8	18	S	50	0.4	0
A.9	8	P	100	0.8	0
A.10	9	P	75	0.8	0
A.11	10	P	50	0.8	0
A.12	6	P	100	0.4	0
A.13	11	P	75	0.4	0
A.14	12	P	50	0.4	0
A.15	7	P	100	0	0
A.16	13	P	75	0	0
A.17	14	P	50	0	0
A.18	23	S	75	0.8	10
A.19	25	S	50	0.8	10
A.20	27	S	75	0.4	10
A.21	29	S	50	0.4	10
A.22	35	P	75	0.8	10
A.23	37	P	50	0.8	10
A.24	31	P	75	0.4	10
A.25	33	P	50	0.4	10
A.26	39	P	75	0	10
A.27	41	P	50	0	10
A.28	22	S	75	0.8	20
A.29	24	S	50	0.8	20
A.30	26	S	75	0.4	20
A.31	28	S	50	0.4	20
A.32	34	P	75	0.8	20
A.33	36	P	50	0.8	20
A.34	30	P	75	0.4	20
A.35	32	P	50	0.4	20
A.36	38	P	75	0	20
A.37	40	P	50	0	20

Note : * S = Submerged jet discharging under water
P = Plunging jet discharging first into air

\+ 100% $\equiv$ 0.089 m^3/s

75% $\equiv$ 0.067 m^3/s

50% $\equiv$ 0.045 m^3/s

‡ Exact values vary slightly for each test

DISCHARGE (m3/s)	.08909
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	.698
PLUNGE POOL LEVEL (m)	.825
WATER TEMPERATURE (C)	8.600001

LENGTH OF JET IN AIR (M) :-

LENGTH OF JET IN WATER (M) :- .698

VELOCITY IN NOZZLE (M/S) :- 6.648508

VELOCITY AT PLUNGE POOL (M/S) :- 6.648508

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 1.831001
MAX POSITIVE PRESSURE FLUCTUATION :- 1.26
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.115
PRESSURE COEFFICIENTS:

Tp :- .19006
Cp :- .8124688
Cp' :- .1544178
Cp+ :- .559099
Cp- :- -.4947582

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .8680006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.408
MAX NEGATIVE PRESSURE FLUCTUATION :- -.759
PRESSURE COEFFICIENTS:

Tp :- .2718892
Cp :- .3851574
Cp' :- .1047201
Cp+ :- .624771
Cp- :- -.3367906

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 1.777001
MAX POSITIVE PRESSURE FLUCTUATION :- 2.317
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.131
PRESSURE COEFFICIENTS:

Tp :- .1862689
Cp :- .7885074
Cp' :- .1468744
Cp+ :- 1.028121
Cp- :- -.501858

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .8710006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.575
MAX NEGATIVE PRESSURE FLUCTUATION :- -.758
PRESSURE COEFFICIENTS:

Tp :- .3030997
Cp :- .3864886
Cp' :- .1171446
Cp+ :- .6988738
Cp- :- -.3363468

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.189001
MAX POSITIVE PRESSURE FLUCTUATION :- 1.263
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.058
PRESSURE COEFFICIENTS:

Tp :- .2220352
Cp :- .5275945
Cp' :- .1171446
Cp+ :- .5604303
Cp- :- -.4694657

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.08909
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	.698
PLUNGE POOL LEVEL (m)	.87
WATER TEMPERATURE (C)	9.600001

LENGTH OF JET IN AIR (M) :-

LENGTH OF JET IN WATER (M) :- .698

VELOCITY IN NOZZLE (M/S) :- 6.648508

VELOCITY AT PLUNGE POOL (M/S) :- 6.648508

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 1.669001
MAX POSITIVE PRESSURE FLUCTUATION :- 1.202
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.096
PRESSURE COEFFICIENTS:
Tp :- .2061114
Cp :- .7405846
Cp' :- .1526429
Cp+ :- .5333627
Cp- :- -.4863275

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .6480007
MAX POSITIVE PRESSURE FLUCTUATION :- 1.279
MAX NEGATIVE PRESSURE FLUCTUATION :- -.736
PRESSURE COEFFICIENTS:
Tp :- .3132713
Cp :- .2875369
Cp' :- 9.007706E-02
Cp+ :- .5675299
Cp- :- -.3265848

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 1.574001
MAX POSITIVE PRESSURE FLUCTUATION :- 1.737
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.01
PRESSURE COEFFICIENTS:
Tp :- .1994917
Cp :- .6984303
Cp' :- .139331
Cp+ :- .7707581
Cp- :- -.4481667

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .6420006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.291
MAX NEGATIVE PRESSURE FLUCTUATION :- -.612
PRESSURE COEFFICIENTS:
Tp :- .3411212
Cp :- .2848745
Cp' :- 9.717673E-02
Cp+ :- .5728546
Cp- :- -.2715624

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.049001
MAX POSITIVE PRESSURE FLUCTUATION :- 1.313
MAX NEGATIVE PRESSURE FLUCTUATION :- -.7770001
PRESSURE COEFFICIENTS:
Tp :- .2478549
Cp :- .4654725
Cp' :- .1153696
Cp+ :- .5826167
Cp- :- -.3447778

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	.698
PLUNGE POOL LEVEL (m)	.816
WATER TEMPERATURE (C)	8.8

LENGTH OF JET IN AIR (M) :-

LENGTH OF JET IN WATER (M) :- .698

VELOCITY IN NOZZLE (M/S) :- 4.98209

VELOCITY AT PLUNGE POOL (M/S) :- 4.98209

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .9670007
MAX POSITIVE PRESSURE FLUCTUATION :- .773
MAX NEGATIVE PRESSURE FLUCTUATION :- -.667
PRESSURE COEFFICIENTS:

Tp :- .2068251
Cp :- .7641351
Cp' :- .1580423
Cp+ :- .6108335
Cp- :- -.5270711

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .4650007
MAX POSITIVE PRESSURE FLUCTUATION :- .844
MAX NEGATIVE PRESSURE FLUCTUATION :- -.4320001
PRESSURE COEFFICIENTS:

Tp :- .313978
Cp :- .3674489
Cp' :- .1153709
Cp+ :- .6669386
Cp- :- -.3413715

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .9860007
MAX POSITIVE PRESSURE FLUCTUATION :- .7579999
MAX NEGATIVE PRESSURE FLUCTUATION :- -.694
PRESSURE COEFFICIENTS:

Tp :- .199797
Cp :- .7791492
Cp' :- .1556717
Cp+ :- .5989803
Cp- :- -.5484068

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .4960007
MAX POSITIVE PRESSURE FLUCTUATION :- .8150001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.4960001
PRESSURE COEFFICIENTS:

Tp :- .3306447
Cp :- .3919455
Cp' :- .1295947
Cp+ :- .6440225
Cp- :- -.391945

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .6380007
MAX POSITIVE PRESSURE FLUCTUATION :- .8470001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.564
PRESSURE COEFFICIENTS:

Tp :- .2413791
Cp :- .5041556
Cp' :- .1216926
Cp+ :- .6693093
Cp- :- -.4456794

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466	
NUMBER OF BOARDS	4	
HEIGHT OF OUTLET (m)	.698	
PLUNGE POOL LEVEL (m)	.802	
WATER TEMPERATURE (C)	9.100001	

LENGTH OF JET IN AIR (M) :-

LENGTH OF JET IN WATER (M) :- .698

VELOCITY IN NOZZLE (M/S) :- 3.332836

VELOCITY AT PLUNGE POOL (M/S) :- 3.332836

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .3890007
MAX POSITIVE PRESSURE FLUCTUATION :- .352
MAX NEGATIVE PRESSURE FLUCTUATION :- -.302
PRESSURE COEFFICIENTS:
Tp :- .2287914
Cp :- .6868929
Cp' :- .1571552
Cp+ :- .6215576
Cp- :- -.5332681

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .1790007
MAX POSITIVE PRESSURE FLUCTUATION :- .378
MAX NEGATIVE PRESSURE FLUCTUATION :- -.201
PRESSURE COEFFICIENTS:
Tp :- .3631271
Cp :- .3160774
Cp' :- .1147763
Cp+ :- .667468
Cp- :- -.3549236

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .4270007
MAX POSITIVE PRESSURE FLUCTUATION :- .375
MAX NEGATIVE PRESSURE FLUCTUATION :- -.366
PRESSURE COEFFICIENTS:
Tp :- .2060887
Cp :- .7539929
Cp' :- .1553894
Cp+ :- .6621707
Cp- :- -.6462786

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .2020006
MAX POSITIVE PRESSURE FLUCTUATION :- .4360001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.1909999
PRESSURE COEFFICIENTS:
Tp :- .371286
Cp :- .3566904
Cp' :- .1324342
Cp+ :- .769884
Cp- :- -.3372655

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .2620007
MAX POSITIVE PRESSURE FLUCTUATION :- .354
MAX NEGATIVE PRESSURE FLUCTUATION :- -.277
PRESSURE COEFFICIENTS:
Tp :- .2633581
Cp :- .4626378
Cp' :- .1218394
Cp+ :- .6250891
Cp- :- -.4891235

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.08909
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	.283
PLUNGE POOL LEVEL (m)	.42
WATER TEMPERATURE (C)	9.5

LENGTH OF JET IN AIR (M) :-

LENGTH OF JET IN WATER (M) :- .283

VELOCITY IN NOZZLE (M/S) :- 6.648508

VELOCITY AT PLUNGE POOL (M/S) :- 6.648508

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 2.924001
MAX POSITIVE PRESSURE FLUCTUATION :- .57
MAX NEGATIVE PRESSURE FLUCTUATION :- -.6340001
PRESSURE COEFFICIENTS:
Tp :- 4.890561E-02
Cp :- 1.297465
Cp' :- .0634533
Cp+ :- .2529257
Cp- :- -.2813245

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .8960003
MAX POSITIVE PRESSURE FLUCTUATION :- .5550001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.428
PRESSURE COEFFICIENTS:
Tp :- .1316964
Cp :- .3975817
Cp' :- 5.236007E-02
Cp+ :- .2462698
Cp- :- -.1899162

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 2.962
MAX POSITIVE PRESSURE FLUCTUATION :- .537
MAX NEGATIVE PRESSURE FLUCTUATION :- -.8120001
PRESSURE COEFFICIENTS:
Tp :- 5.131667E-02
Cp :- 1.314327
Cp' :- 6.744686E-02
Cp+ :- .2382827
Cp- :- -.3603083

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .8490004
MAX POSITIVE PRESSURE FLUCTUATION :- .9349999
MAX NEGATIVE PRESSURE FLUCTUATION :- -.4610001
PRESSURE COEFFICIENTS:
Tp :- .1684334
Cp :- .3767264
Cp' :- .0634533
Cp+ :- .414887
Cp- :- -.2045593

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.426
MAX POSITIVE PRESSURE FLUCTUATION :- .878
MAX NEGATIVE PRESSURE FLUCTUATION :- -.697
PRESSURE COEFFICIENTS:
Tp :- .1451613
Cp :- .6327583
Cp' :- 9.185198E-02
Cp+ :- .3895944
Cp- :- -.3092793

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	.283
PLUNGE POOL LEVEL (m)	.405
WATER TEMPERATURE (C)	9.7

LENGTH OF JET IN AIR (M) :-

LENGTH OF JET IN WATER (M) :- .283

VELOCITY IN NOZZLE (M/S) :- 4.98209

VELOCITY AT PLUNGE POOL (M/S) :- 4.98209

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 1.636
MAX POSITIVE PRESSURE FLUCTUATION :- .3590002
MAX NEGATIVE PRESSURE FLUCTUATION :- -.3539999
PRESSURE COEFFICIENTS:

Tp :- 5.012225E-02
Cp :- 1.292786
Cp' :- 6.479735E-02
Cp+ :- .2836861
Cp- :- -.2797348

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .4790004
MAX POSITIVE PRESSURE FLUCTUATION :- .336
MAX NEGATIVE PRESSURE FLUCTUATION :- -.29
PRESSURE COEFFICIENTS:

Tp :- .1503131
Cp :- .3785116
Cp' :- 5.689523E-02
Cp+ :- .2655111
Cp- :- -.2291614

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 1.668
MAX POSITIVE PRESSURE FLUCTUATION :- .3770001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.5489999
PRESSURE COEFFICIENTS:

Tp :- 5.635491E-02
Cp :- 1.318073
Cp' :- 7.427989E-02
Cp+ :- .2979098
Cp- :- -.4338261

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .4550004
MAX POSITIVE PRESSURE FLUCTUATION :- .533
MAX NEGATIVE PRESSURE FLUCTUATION :- -.365
PRESSURE COEFFICIENTS:

Tp :- .1934065
Cp :- .3595466
Cp' :- 6.953862E-02
Cp+ :- .4211828
Cp- :- -.2884272

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .7800003
MAX POSITIVE PRESSURE FLUCTUATION :- .646
MAX NEGATIVE PRESSURE FLUCTUATION :- -.454
PRESSURE COEFFICIENTS:

Tp :- .1692307
Cp :- .6163653
Cp' :- .1043079
Cp+ :- .5104767
Cp- :- -.358756

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	.283
PLUNGE POOL LEVEL (m)	.4
WATER TEMPERATURE (C)	9.8

LENGTH OF JET IN AIR (M) :-

LENGTH OF JET IN WATER (M) :- .283

VELOCITY IN NOZZLE (M/S) :- 3.332836

VELOCITY AT PLUNGE POOL (M/S) :- 3.332836

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .6970003
MAX POSITIVE PRESSURE FLUCTUATION :- .161
MAX NEGATIVE PRESSURE FLUCTUATION :- -.176
PRESSURE COEFFICIENTS:

Tp :- 5.308463E-02
Cp :- 1.230755
Cp' :- 6.533418E-02
Cp+ :- .284292
Cp- :- -.3107788

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .1830003
MAX POSITIVE PRESSURE FLUCTUATION :- .19
MAX NEGATIVE PRESSURE FLUCTUATION :- -.111
PRESSURE COEFFICIENTS:

Tp :- .185792
Cp :- .3231399
Cp' :- 6.003681E-02
Cp+ :- .3354998
Cp- :- -.1960025

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .7350003
MAX POSITIVE PRESSURE FLUCTUATION :- .166
MAX NEGATIVE PRESSURE FLUCTUATION :- -.212
PRESSURE COEFFICIENTS:

Tp :- 5.714283E-02
Cp :- 1.297855
Cp' :- 7.416312E-02
Cp+ :- .2931209
Cp- :- -.3743472

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .1790003
MAX POSITIVE PRESSURE FLUCTUATION :- .2
MAX NEGATIVE PRESSURE FLUCTUATION :- -.144
PRESSURE COEFFICIENTS:

Tp :- .201117
Cp :- .3160767
Cp' :- 6.356838E-02
Cp+ :- .3531577
Cp- :- -.2542735

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .3400003
MAX POSITIVE PRESSURE FLUCTUATION :- .277
MAX NEGATIVE PRESSURE FLUCTUATION :- -.212
PRESSURE COEFFICIENTS:

Tp :- .1676469
Cp :- .6003687
Cp' :- .1006499
Cp+ :- .4891234
Cp- :- -.3743472

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.08909
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.78
WATER TEMPERATURE (C)	0

LENGTH OF JET IN AIR (M) :- .5270001

LENGTH OF JET IN WATER (M) :- .78

VELOCITY IN NOZZLE (M/S) :- 6.648508

VELOCITY AT PLUNGE POOL (M/S) :- 7.385068

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 1.645001
MAX POSITIVE PRESSURE FLUCTUATION :- 2.313
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.554
PRESSURE COEFFICIENTS:

Tp :- .3191488
Cp :- .5915938
Cp' :- .1888065
Cp+ :- .8318273
Cp- :- -.5588671

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- 1.137001
MAX POSITIVE PRESSURE FLUCTUATION :- 2.369
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.198
PRESSURE COEFFICIENTS:

Tp :- .4019347
Cp :- .4089011
Cp' :- .1643515
Cp+ :- .8519665
Cp- :- -.4308384

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 2.003001
MAX POSITIVE PRESSURE FLUCTUATION :- 4.164
MAX NEGATIVE PRESSURE FLUCTUATION :- -2.797
PRESSURE COEFFICIENTS:

Tp :- .3265101
Cp :- .7203418
Cp' :- .2351989
Cp+ :- 1.497505 *
Cp- :- -1.005889 *

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- 1.366001
MAX POSITIVE PRESSURE FLUCTUATION :- 2.271
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.339
PRESSURE COEFFICIENTS:

Tp :- .3887261
Cp :- .4912566
Cp' :- .1909643
Cp+ :- .8167228
Cp- :- -.4815464

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.166001
MAX POSITIVE PRESSURE FLUCTUATION :- 1.951
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.083
PRESSURE COEFFICIENTS:

Tp :- .3396225
Cp :- .4193304
Cp' :- .142414
Cp+ :- .7016408
Cp- :- -.3894807

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.785
WATER TEMPERATURE (C)	0

LENGTH OF JET IN AIR (M) :- .522

LENGTH OF JET IN WATER (M) :- .785

VELOCITY IN NOZZLE (M/S) :- 4.98209

VELOCITY AT PLUNGE POOL (M/S) :- 5.921126

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .7850006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.311
MAX NEGATIVE PRESSURE FLUCTUATION :- -.5780001
PRESSURE COEFFICIENTS:
Tp :- .3057322
Cp :- .4391653
Cp' :- .134267
Cp+ :- .7334335
Cp- :- -.3233597

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .5850006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.063
MAX NEGATIVE PRESSURE FLUCTUATION :- -.527
PRESSURE COEFFICIENTS:
Tp :- .3623928
Cp :- .3272761
Cp' :- .1186025
Cp+ :- .594691
Cp- :- -.294828

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .8500006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.347
MAX NEGATIVE PRESSURE FLUCTUATION :- -.711
PRESSURE COEFFICIENTS:
Tp :- .3458821
Cp :- .4755292
Cp' :- .1644771
Cp+ :- .7535736
Cp- :- -.3977659

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .6170005
MAX POSITIVE PRESSURE FLUCTUATION :- 1.219
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.42
PRESSURE COEFFICIENTS:
Tp :- .3987031
Cp :- .3451783
Cp' :- .1376237
Cp+ :- .6819645
Cp- :- -.794413 *

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .5360006
MAX POSITIVE PRESSURE FLUCTUATION :- .952
MAX NEGATIVE PRESSURE FLUCTUATION :- -.462
PRESSURE COEFFICIENTS:
Tp :- .3600743
Cp :- .2998633
Cp' :- .107973
Cp+ :- .5325925
Cp- :- -.2584639

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m^3/s)	.04466
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.78
WATER TEMPERATURE (C)	0

LENGTH OF JET IN AIR (M) :- .5270001

LENGTH OF JET IN WATER (M) :- .78

VELOCITY IN NOZZLE (M/S) :- 3.332836

VELOCITY AT PLUNGE POOL (M/S) :- 4.630807

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .3770006
MAX POSITIVE PRESSURE FLUCTUATION :- .4590001
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.192
PRESSURE COEFFICIENTS:
Tp :- .2811667
Cp :- .3448222
Cp' :- 9.695251E-02
Cp+ :- .4198228
Cp- :- -1.090258 *

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .2680006
MAX POSITIVE PRESSURE FLUCTUATION :- .535
MAX NEGATIVE PRESSURE FLUCTUATION :- -.276
PRESSURE COEFFICIENTS:
Tp :- .3470142
Cp :- .2451258
Cp' :- 8.506211E-02
Cp+ :- .4893358
Cp- :- -.2524423

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .3360007
MAX POSITIVE PRESSURE FLUCTUATION :- .4929999
MAX NEGATIVE PRESSURE FLUCTUATION :- -.2480001
PRESSURE COEFFICIENTS:
Tp :- .3124994
Cp :- .3073218
Cp' :- 9.603786E-02
Cp+ :- .4509206
Cp- :- -.2268324

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .2430006
MAX POSITIVE PRESSURE FLUCTUATION :- .666
MAX NEGATIVE PRESSURE FLUCTUATION :- -.226
PRESSURE COEFFICIENTS:
Tp :- .3827151
Cp :- .2222596
Cp' :- 8.506211E-02
Cp+ :- .6091545
Cp- :- -.2067101

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .2270006
MAX POSITIVE PRESSURE FLUCTUATION :- .4450001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.225
PRESSURE COEFFICIENTS:
Tp :- .3612326
Cp :- .2076253
Cp' :- .075001
Cp+ :- .4070177
Cp- :- -.2057954

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.08909
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.425
WATER TEMPERATURE (C)	0

LENGTH OF JET IN AIR (M) :- .882

LENGTH OF JET IN WATER (M) :- .425

VELOCITY IN NOZZLE (M/S) :- 6.648508

VELOCITY AT PLUNGE POOL (M/S) :- 7.842334

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 3.543
MAX POSITIVE PRESSURE FLUCTUATION :- .993
MAX NEGATIVE PRESSURE FLUCTUATION :- -2.388
PRESSURE COEFFICIENTS:

Tp :- 8.693198E-02
Cp :- 1.129919
Cp' :- 9.822604E-02
Cp+ :- .3166833
Cp- :- -.7615708

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- 1.603
MAX POSITIVE PRESSURE FLUCTUATION :- 1.804
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.434
PRESSURE COEFFICIENTS:

Tp :- .2520274
Cp :- .511222
Cp' :- .128842
Cp+ :- .575324
Cp- :- -.4573252

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 3.710001
MAX POSITIVE PRESSURE FLUCTUATION :- .987
MAX NEGATIVE PRESSURE FLUCTUATION :- -2.391
PRESSURE COEFFICIENTS:

Tp :- 8.113206E-02
Cp :- 1.183178
Cp' :- 9.599363E-02
Cp+ :- .3147698 *
Cp- :- -.7625276

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- 1.554
MAX POSITIVE PRESSURE FLUCTUATION :- 1.807
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.322
PRESSURE COEFFICIENTS:

Tp :- .2406692
Cp :- .4955952
Cp' :- .1192745
Cp+ :- .5762807
Cp- :- -.4216066

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.213
MAX POSITIVE PRESSURE FLUCTUATION :- 1.81
MAX NEGATIVE PRESSURE FLUCTUATION :- -.968
PRESSURE COEFFICIENTS:

Tp :- .223413
Cp :- .3868449
Cp' :- 8.642616E-02
Cp+ :- .5772375
Cp- :- -.3087104

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.393
WATER TEMPERATURE (C)	6.6

LENGTH OF JET IN AIR (M) :- .9140001

LENGTH OF JET IN WATER (M) :- .393

VELOCITY IN NOZZLE (M/S) :- 4.98209

VELOCITY AT PLUNGE POOL (M/S) :- 6.538227

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 1.892
MAX POSITIVE PRESSURE FLUCTUATION :- 1.106
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.538
PRESSURE COEFFICIENTS:

Tp :- .1707188
Cp :- .868096
Cp' :- .1482003
Cp+ :- .5074598
Cp- :- -.705672

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .3950003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.32
MAX NEGATIVE PRESSURE FLUCTUATION :- -.602
PRESSURE COEFFICIENTS:

Tp :- .4329111
Cp :- .1812358
Cp' :- 7.845898E-02
Cp+ :- .6056483
Cp- :- -.2762123

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 2.117
MAX POSITIVE PRESSURE FLUCTUATION :- 2.392
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.747
PRESSURE COEFFICIENTS:

Tp :- .1606046
Cp :- .9713315
Cp' :- .1560003
Cp+ :- 1.097508
Cp- :- -.8015663

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .6170003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.453
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.042
PRESSURE COEFFICIENTS:

Tp :- .3987033
Cp :- .2830948
Cp' :- .1128708
Cp+ :- .666672
Cp- :- -.478095 *

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.163
MAX POSITIVE PRESSURE FLUCTUATION :- 1.197
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.573
PRESSURE COEFFICIENTS:

Tp :- .3000859
Cp :- .533613
Cp' :- .1601297
Cp+ :- .5492129
Cp- :- -.7217308 *

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.388
WATER TEMPERATURE (C)	6.7

LENGTH OF JET IN AIR (M) :- .919

LENGTH OF JET IN WATER (M) :- .388

VELOCITY IN NOZZLE (M/S) :- 3.332836

VELOCITY AT PLUNGE POOL (M/S) :- 5.397506

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .7180003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.067
MAX NEGATIVE PRESSURE FLUCTUATION :- -.781
PRESSURE COEFFICIENTS:

Tp :- .3774372
Cp :- .4833981
Cp' :- .1824524
Cp+ :- .7183645
Cp- :- -.5258131

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .2150003
MAX POSITIVE PRESSURE FLUCTUATION :- .955
MAX NEGATIVE PRESSURE FLUCTUATION :- -.498
PRESSURE COEFFICIENTS:

Tp :- .679069
Cp :- .1447503
Cp' :- 9.829541E-02
Cp+ :- .6429596
Cp- :- -.3352816

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .8720002
MAX POSITIVE PRESSURE FLUCTUATION :- 2.506
MAX NEGATIVE PRESSURE FLUCTUATION :- -.985
PRESSURE COEFFICIENTS:

Tp :- .3658256
Cp :- .5870796
Cp' :- .2147688
Cp+ :- 1.68718
Cp- :- -.6631574

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .4200003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.053
MAX NEGATIVE PRESSURE FLUCTUATION :- -.579
PRESSURE COEFFICIENTS:

Tp :- .5142853
Cp :- .2827678
Cp' :- .1454233
Cp+ :- .7089388
Cp- :- -.3898153

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .4790003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.062
MAX NEGATIVE PRESSURE FLUCTUATION :- -.539
PRESSURE COEFFICIENTS:

Tp :- .4405008
Cp :- .3224899
Cp' :- .1420571
Cp+ :- .7149981
Cp- :- -.3628851

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.08909
NUMBER OF BOARDS	0
HEIGHT OF OUTLET (m)	1.307
WATER TEMPERATURE (C)	0

LENGTH OF JET IN AIR (M) :- 1.307

LENGTH OF JET IN WATER (M) :- 0

VELOCITY IN NOZZLE (M/S) :- 6.648508

VELOCITY AT PLUNGE POOL (M/S) :- 8.35692

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 3.906
MAX POSITIVE PRESSURE FLUCTUATION :- 1.092
MAX NEGATIVE PRESSURE FLUCTUATION :- -3.908
PRESSURE COEFFICIENTS:

Tp :- 8.294931E-02
Cp :- 1.096999
Cp' :- 9.099531E-02
Cp+ :- .306688
Cp- :- -1.097561 *

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- 2.345
MAX POSITIVE PRESSURE FLUCTUATION :- 1.973
MAX NEGATIVE PRESSURE FLUCTUATION :- -2.362
PRESSURE COEFFICIENTS:

Tp :- .1641791
Cp :- .6585926
Cp' :- .1081271
Cp+ :- .5541165
Cp- :- -.6633671 *

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 4.068
MAX POSITIVE PRESSURE FLUCTUATION :- 1.054
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.966
PRESSURE COEFFICIENTS:

Tp :- 9.046215E-02
Cp :- 1.142497
Cp' :- .1033527
Cp+ :- .2960157 *
Cp- :- -.5521505

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- 2.117
MAX POSITIVE PRESSURE FLUCTUATION :- 1.806
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.483
PRESSURE COEFFICIENTS:

Tp :- .1719414
Cp :- .5945589
Cp' :- .1022293
Cp+ :- .5072146
Cp- :- -.4165002

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.749
MAX POSITIVE PRESSURE FLUCTUATION :- 2.176
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.194
PRESSURE COEFFICIENTS:

Tp :- .2264151
Cp :- .4912062
Cp' :- .1112165
Cp+ :- .611129
Cp- :- -.3353346

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02	
NUMBER OF BOARDS	0	
HEIGHT OF OUTLET (m)	1.307	
WATER TEMPERATURE (C)	7	

LENGTH OF JET IN AIR (M) :- 1.307

LENGTH OF JET IN WATER (M) :- 0

VELOCITY IN NOZZLE (M/S) :- 4.98209

VELOCITY AT PLUNGE POOL (M/S) :- 7.103289

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 2.409
MAX POSITIVE PRESSURE FLUCTUATION :- .9090002
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.166
PRESSURE COEFFICIENTS:

Tp :- .1008717
Cp :- .9364495
Cp' :- 9.446129E-02
Cp+ :- .3533553
Cp- :- -.4532587

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .396
MAX POSITIVE PRESSURE FLUCTUATION :- 1.103
MAX NEGATIVE PRESSURE FLUCTUATION :- -.406
PRESSURE COEFFICIENTS:

Tp :- .2828283
Cp :- .1539369
Cp' :- 4.353772E-02
Cp+ :- .4287687
Cp- :- -.1578242 *

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 2.573
MAX POSITIVE PRESSURE FLUCTUATION :- 2.341
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.122
PRESSURE COEFFICIENTS:

Tp :- 9.949476E-02
Cp :- 1.000201
Cp' :- 9.951478E-02
Cp+ :- .910016
Cp- :- -.4361546

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- 0
MAX POSITIVE PRESSURE FLUCTUATION :- 0
MAX NEGATIVE PRESSURE FLUCTUATION :- 0
PRESSURE COEFFICIENTS:

Tp :- 1.701412E+38
Cp :- 0
Cp' :- 0
Cp+ :- 0
Cp- :- 0

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.734
MAX POSITIVE PRESSURE FLUCTUATION :- 1.225
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.145
PRESSURE COEFFICIENTS:

Tp :- .1845444
Cp :- .6740571
Cp' :- .1243935
Cp+ :- .4761938
Cp- :- -.4450954

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
NUMBER OF BOARDS	0
HEIGHT OF OUTLET (m)	1.307
WATER TEMPERATURE (C)	7.1

LENGTH OF JET IN AIR (M) :- 1.307

LENGTH OF JET IN WATER (M) :- 0

VELOCITY IN NOZZLE (M/S) :- 3.332836

VELOCITY AT PLUNGE POOL (M/S) :- 6.061625

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 1.698
MAX POSITIVE PRESSURE FLUCTUATION :- .741
MAX NEGATIVE PRESSURE FLUCTUATION :- -.831
PRESSURE COEFFICIENTS:
Tp :- .1183746
Cp :- .9064129
Cp' :- .1072962
Cp+ :- .3955548
Cp- :- -.4435979

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .215
MAX POSITIVE PRESSURE FLUCTUATION :- .389
MAX NEGATIVE PRESSURE FLUCTUATION :- -.337
PRESSURE COEFFICIENTS:
Tp :- .3255814
Cp :- .1147696
Cp' :- 3.736685E-02
Cp+ :- .2076529
Cp- :- -.1798947 *

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 1.817
MAX POSITIVE PRESSURE FLUCTUATION :- .7150001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.939
PRESSURE COEFFICIENTS:
Tp :- .1012658
Cp :- .9699366
Cp' :- 9.822143E-02
Cp+ :- .3816757
Cp- :- -.5012496

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .23
MAX POSITIVE PRESSURE FLUCTUATION :- .531
MAX NEGATIVE PRESSURE FLUCTUATION :- -.33
PRESSURE COEFFICIENTS:
Tp :- .3130435
Cp :- .1227768
Cp' :- 3.843447E-02
Cp+ :- .2834542
Cp- :- -.176158 *

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.036
MAX POSITIVE PRESSURE FLUCTUATION :- 1.458
MAX NEGATIVE PRESSURE FLUCTUATION :- -.879
PRESSURE COEFFICIENTS:
Tp :- .2828186
Cp :- .5530294
Cp' :- .156407
Cp+ :- .778298
Cp- :- -.4692209

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
TRUE AIR CONCENTRATION %	9.835805
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	.698
PLUNGE POOL LEVEL (m)	.815
WATER TEMPERATURE (C)	9.399999
AIR TEMPERATURE (C)	8.7
AIR PRESSURE (mBars)	1028

LENGTH OF JET IN AIR (M) :-
LENGTH OF JET IN WATER (M) :- .698
VELOCITY IN NOZZLE (M/S) :- 5.525575
VELOCITY AT PLUNGE POOL (M/S) :- 5.525575

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 1.019001
MAX POSITIVE PRESSURE FLUCTUATION :- .8709999
MAX NEGATIVE PRESSURE FLUCTUATION :- -.716
PRESSURE COEFFICIENTS:

Tp :- .2345435
Cp :- .6546153
Cp' :- .1535358
Cp+ :- .5595383
Cp- :- -.4599649

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .3820007
MAX POSITIVE PRESSURE FLUCTUATION :- .9990001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.439
PRESSURE COEFFICIENTS:

Tp :- .3769627
Cp :- .2454007
Cp' :- .0925069
Cp+ :- .6417667
Cp- :- -.2820176

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .8980007
MAX POSITIVE PRESSURE FLUCTUATION :- .9040001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.6880001
PRESSURE COEFFICIENTS:

Tp :- .2449887
Cp :- .5768838
Cp' :- .14133
Cp+ :- .5807378
Cp- :- -.4419775

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .3010007
MAX POSITIVE PRESSURE FLUCTUATION :- .867
MAX NEGATIVE PRESSURE FLUCTUATION :- -.3850001
PRESSURE COEFFICIENTS:

Tp :- .4318927
Cp :- .1933656
Cp' :- 8.351317E-02
Cp+ :- .5569686
Cp- :- -.2473275

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .5110007
MAX POSITIVE PRESSURE FLUCTUATION :- .718
MAX NEGATIVE PRESSURE FLUCTUATION :- -.548
PRESSURE COEFFICIENTS:

Tp :- .317025
Cp :- .3282714
Cp' :- .1040703
Cp+ :- .4612497
Cp- :- -.3520402

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
TRUE AIR CONCENTRATION %	9.835143
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	.698
PLUNGE POOL LEVEL (m)	.795
WATER TEMPERATURE (C)	9.600001
AIR TEMPERATURE (C)	8.7
AIR PRESSURE (mBars)	1028

LENGTH OF JET IN AIR (M) :-
LENGTH OF JET IN WATER (M) :- .698
VELOCITY IN NOZZLE (M/S) :- 3.69638
VELOCITY AT PLUNGE POOL (M/S) :- 3.69638

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .3870006
MAX POSITIVE PRESSURE FLUCTUATION :- .415
MAX NEGATIVE PRESSURE FLUCTUATION :- -.3760001
PRESSURE COEFFICIENTS:

Tp :- .2713174
Cp :- .5555524
Cp' :- .150731
Cp+ :- .5957463
Cp- :- -.5397606

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .1450006
MAX POSITIVE PRESSURE FLUCTUATION :- .412
MAX NEGATIVE PRESSURE FLUCTUATION :- -.226
PRESSURE COEFFICIENTS:

Tp :- .4551706
Cp :- .2081532
Cp' :- 9.474521E-02
Cp+ :- .5914398
Cp- :- -.3244306

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .3560006
MAX POSITIVE PRESSURE FLUCTUATION :- .435
MAX NEGATIVE PRESSURE FLUCTUATION :- -.275
PRESSURE COEFFICIENTS:

Tp :- .2499996
Cp :- .5110508
Cp' :- .1277625
Cp+ :- .624457
Cp- :- -.3947718

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .1240006
MAX POSITIVE PRESSURE FLUCTUATION :- .342
MAX NEGATIVE PRESSURE FLUCTUATION :- -.185
PRESSURE COEFFICIENTS:

Tp :- .4999976
Cp :- .178007
Cp' :- 8.900307E-02
Cp+ :- .4909525
Cp- :- -.2655737

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .1900006
MAX POSITIVE PRESSURE FLUCTUATION :- .37
MAX NEGATIVE PRESSURE FLUCTUATION :- -.22
PRESSURE COEFFICIENTS:

Tp :- .3368411
Cp :- .2727522
Cp' :- 9.187414E-02
Cp+ :- .5311474
Cp- :- -.3158174

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
TRUE AIR CONCENTRATION %	9.853499
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	.283
PLUNGE POOL LEVEL (m)	.405
WATER TEMPERATURE (C)	9.7
AIR TEMPERATURE (C)	9
AIR PRESSURE (mBars)	1025

LENGTH OF JET IN AIR (M) :-
LENGTH OF JET IN WATER (M) :- .283
VELOCITY IN NOZZLE (M/S) :- 5.52666
VELOCITY AT PLUNGE POOL (M/S) :- 5.52666

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 1.858
MAX POSITIVE PRESSURE FLUCTUATION :- .4400001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.4880001
PRESSURE COEFFICIENTS:
Tp :- 5.651237E-02
Cp :- 1.193128
Cp' :- 6.742646E-02
Cp+ :- .2825491
Cp- :- -.3133726

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .5530003
MAX POSITIVE PRESSURE FLUCTUATION :- .45
MAX NEGATIVE PRESSURE FLUCTUATION :- -.3
PRESSURE COEFFICIENTS:
Tp :- .148282
Cp :- .355113
Cp' :- 5.265687E-02
Cp+ :- .2889706
Cp- :- -.1926471

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 1.72
MAX POSITIVE PRESSURE FLUCTUATION :- .457
MAX NEGATIVE PRESSURE FLUCTUATION :- -.5240001
PRESSURE COEFFICIENTS:
Tp :- .0622093
Cp :- 1.10451
Cp' :- 6.871078E-02
Cp+ :- .2934657
Cp- :- -.3364902

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .4600004
MAX POSITIVE PRESSURE FLUCTUATION :- .5080001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.276
PRESSURE COEFFICIENTS:
Tp :- .1826086
Cp :- .2953924
Cp' :- 5.394118E-02
Cp+ :- .3262157
Cp- :- -.1772353

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .8100004
MAX POSITIVE PRESSURE FLUCTUATION :- .565
MAX NEGATIVE PRESSURE FLUCTUATION :- -.5160001
PRESSURE COEFFICIENTS:
Tp :- .1703703
Cp :- .5201473
Cp' :- 8.861764E-02
Cp+ :- .3628186
Cp- :- -.331353

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
TRUE AIR CONCENTRATION %	9.854799
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	.283
PLUNGE POOL LEVEL (m)	.412
WATER TEMPERATURE (C)	9.2
AIR TEMPERATURE (C)	9.399999
AIR PRESSURE (mBars)	1026

LENGTH OF JET IN AIR (M) :-
LENGTH OF JET IN WATER (M) :- .283
VELOCITY IN NOZZLE (M/S) :- 3.697186
VELOCITY AT PLUNGE POOL (M/S) :- 3.697186

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .8120003
MAX POSITIVE PRESSURE FLUCTUATION :- .258
MAX NEGATIVE PRESSURE FLUCTUATION :- -.22
PRESSURE COEFFICIENTS:

Tp :- .0689655
Cp :- 1.165145
Cp' :- 8.035483E-02
Cp+ :- .3702062
Cp- :- -.3156797

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .2220003
MAX POSITIVE PRESSURE FLUCTUATION :- .266
MAX NEGATIVE PRESSURE FLUCTUATION :- -.152
PRESSURE COEFFICIENTS:

Tp :- .2117114
Cp :- .31855
Cp' :- 6.744066E-02
Cp+ :- .3816854
Cp- :- -.218106

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .7250003
MAX POSITIVE PRESSURE FLUCTUATION :- .2570001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.269
PRESSURE COEFFICIENTS:

Tp :- 8.275859E-02
Cp :- 1.040309
Cp' :- 8.609446E-02
Cp+ :- .3687714
Cp- :- -.3859902

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .1770003
MAX POSITIVE PRESSURE FLUCTUATION :- .217
MAX NEGATIVE PRESSURE FLUCTUATION :- -.134
PRESSURE COEFFICIENTS:

Tp :- .2259883
Cp :- .2539791
Cp' :- 5.739631E-02
Cp+ :- .311375
Cp- :- -.1922776

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .3370004
MAX POSITIVE PRESSURE FLUCTUATION :- .2980001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.243
PRESSURE COEFFICIENTS:

Tp :- .1899108
Cp :- .4835644
Cp' :- .0918341
Cp+ :- .4276026
Cp- :- -.3486826

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
TRUE AIR CONCENTRATION %	9.872913
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.78
WATER TEMPERATURE (C)	9.100001
AIR TEMPERATURE (C)	8.3
AIR PRESSURE (mBars)	1018

LENGTH OF JET IN AIR (M) :- .5270001
LENGTH OF JET IN WATER (M) :- .78
VELOCITY IN NOZZLE (M/S) :- 5.52785
VELOCITY AT PLUNGE POOL (M/S) :- 6.394818

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .7440007
MAX POSITIVE PRESSURE FLUCTUATION :- 1.57
MAX NEGATIVE PRESSURE FLUCTUATION :- -.7400001
PRESSURE COEFFICIENTS:

Tp :- .3911287
Cp :- .3568482
Cp' :- .1395736
Cp+ :- .7530258
Cp- :- -.3549294

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .4210006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.547
MAX NEGATIVE PRESSURE FLUCTUATION :- -.507
PRESSURE COEFFICIENTS:

Tp :- .5083128
Cp :- .2019263
Cp' :- .1026417
Cp+ :- .7419941
Cp- :- -.2431746

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .6940006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.841
MAX NEGATIVE PRESSURE FLUCTUATION :- -.588
PRESSURE COEFFICIENTS:

Tp :- .3659939
Cp :- .3328665
Cp' :- .1218271
Cp+ :- .8830066
Cp- :- -.2820249

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .4180006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.595
MAX NEGATIVE PRESSURE FLUCTUATION :- -.524
PRESSURE COEFFICIENTS:

Tp :- .4641142
Cp :- .2004874
Cp' :- 9.304904E-02
Cp+ :- .7650166
Cp- :- -.2513283

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .4840007
MAX POSITIVE PRESSURE FLUCTUATION :- 1.184
MAX NEGATIVE PRESSURE FLUCTUATION :- -.5450001
PRESSURE COEFFICIENTS:

Tp :- .4008259
Cp :- .2321433
Cp' :- 9.304904E-02
Cp+ :- .5678869
Cp- :- -.2614007

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
TRUE AIR CONCENTRATION %	9.858001
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.8
WATER TEMPERATURE (C)	9
AIR TEMPERATURE (C)	7.4
AIR PRESSURE (mBars)	1018

LENGTH OF JET IN AIR (M) :- .5070001
LENGTH OF JET IN WATER (M) :- .8
VELOCITY IN NOZZLE (M/S) :- 3.697317
VELOCITY AT PLUNGE POOL (M/S) :- 4.859471

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .1380007
MAX POSITIVE PRESSURE FLUCTUATION :- .629
MAX NEGATIVE PRESSURE FLUCTUATION :- -.227
PRESSURE COEFFICIENTS:

Tp :- .6739098
Cp :- .1146225
Cp' :- 7.724522E-02
Cp+ :- .5224435
Cp- :- -.1885448

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- 6.000066E-02
MAX POSITIVE PRESSURE FLUCTUATION :- .568
MAX NEGATIVE PRESSURE FLUCTUATION :- -.2190001
PRESSURE COEFFICIENTS:

Tp :- 1.266653
Cp :- 4.983617E-02
Cp' :- 6.312512E-02
Cp+ :- .4717772
Cp- :- -.1819001

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .1400006
MAX POSITIVE PRESSURE FLUCTUATION :- .601
MAX NEGATIVE PRESSURE FLUCTUATION :- -.197
PRESSURE COEFFICIENTS:

Tp :- .5857116
Cp :- .1162837
Cp' :- 6.810869E-02
Cp+ :- .4991869
Cp- :- -.163627

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- 5.600065E-02
MAX POSITIVE PRESSURE FLUCTUATION :- .4790001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.158
PRESSURE COEFFICIENTS:

Tp :- 1.160701
Cp :- 4.651379E-02
Cp' :- 5.398859E-02
Cp+ :- .3978544
Cp- :- -.1312338

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 6.200063E-02
MAX POSITIVE PRESSURE FLUCTUATION :- .39
MAX NEGATIVE PRESSURE FLUCTUATION :- -.153
PRESSURE COEFFICIENTS:

Tp :- .9677321
Cp :- 5.149734E-02
Cp' :- 4.983562E-02
Cp+ :- .3239316
Cp- :- -.1270808

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
TRUE AIR CONCENTRATION %	9.892185
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.397
WATER TEMPERATURE (C)	8.600001
AIR TEMPERATURE (C)	7.3
AIR PRESSURE (mBars)	1010

LENGTH OF JET IN AIR (M) :- .91
LENGTH OF JET IN WATER (M) :- .397
VELOCITY IN NOZZLE (M/S) :- 5.529032
VELOCITY AT PLUNGE POOL (M/S) :- 6.958371

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 2.104
MAX POSITIVE PRESSURE FLUCTUATION :- .9030001
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.654
PRESSURE COEFFICIENTS:

Tp :- .154943
Cp :- .852309
Cp' :- .1320593
Cp+ :- .3657962
Cp- :- -.6700186

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .4270003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.137
MAX NEGATIVE PRESSURE FLUCTUATION :- -.665
PRESSURE COEFFICIENTS:

Tp :- .4590161
Cp :- .1729735
Cp' :- 7.939761E-02
Cp+ :- .4605871
Cp- :- -.2693848

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 1.986
MAX POSITIVE PRESSURE FLUCTUATION :- 2.586
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.735
PRESSURE COEFFICIENTS:

Tp :- .1883182
Cp :- .8045085
Cp' :- .1515036
Cp+ :- 1.047562
Cp- :- -.7028308

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .6210003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.37
MAX NEGATIVE PRESSURE FLUCTUATION :- -.764
PRESSURE COEFFICIENTS:

Tp :- .4251206
Cp :- .2515609
Cp' :- .1069437
Cp+ :- .5549731
Cp- :- -.3094886

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.134
MAX POSITIVE PRESSURE FLUCTUATION :- 1.425
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.179
PRESSURE COEFFICIENTS:

Tp :- .3183421
Cp :- .459372
Cp' :- .1462374
Cp+ :- .5772531
Cp- :- -.4776009

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
TRUE AIR CONCENTRATION %	9.897878
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.39
WATER TEMPERATURE (C)	8.899999
AIR TEMPERATURE (C)	7.7
AIR PRESSURE (mBars)	1010

LENGTH OF JET IN AIR (M) :- .9170001
LENGTH OF JET IN WATER (M) :- .39
VELOCITY IN NOZZLE (M/S) :- 3.698954
VELOCITY AT PLUNGE POOL (M/S) :- 5.627459

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .8630003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.098
MAX NEGATIVE PRESSURE FLUCTUATION :- -.9140001
PRESSURE COEFFICIENTS:

Tp :- .3568944
Cp :- .5345063
Cp' :- .1907623
Cp+ :- .6800553
Cp- :- -.5660933

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .2450003
MAX POSITIVE PRESSURE FLUCTUATION :- .9450001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.405
PRESSURE COEFFICIENTS:

Tp :- .6734686
Cp :- .1517429
Cp' :- .1021941
Cp+ :- .5852935
Cp- :- -.25084

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .7270003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.738
MAX NEGATIVE PRESSURE FLUCTUATION :- -.749
PRESSURE COEFFICIENTS:

Tp :- .3865198
Cp :- .4502736
Cp' :- .1740396
Cp+ :- 1.076444
Cp- :- -.4638992

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .2720003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.164
MAX NEGATIVE PRESSURE FLUCTUATION :- -.515
PRESSURE COEFFICIENTS:

Tp :- .6360286
Cp :- .1684656
Cp' :- .107149
Cp+ :- .7209328
Cp- :- -.3189694

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .4050003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.021
MAX NEGATIVE PRESSURE FLUCTUATION :- -.5990001
PRESSURE COEFFICIENTS:

Tp :- .4987651
Cp :- .2508403
Cp' :- .1251103
Cp+ :- .6323646
Cp- :- -.3709955

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02	
TRUE AIR CONCENTRATION %	9.882396	
NUMBER OF BOARDS	0	
HEIGHT OF OUTLET (m)	1.307	
WATER TEMPERATURE (C)	9.100001	
AIR TEMPERATURE (C)	8.899999	
AIR PRESSURE (mBars)	1018	

LENGTH OF JET IN AIR (M) :- 1.307
LENGTH OF JET IN WATER (M) :- 0
VELOCITY IN NOZZLE (M/S) :- 5.528432
VELOCITY AT PLUNGE POOL (M/S) :- 7.496601

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 2.581
MAX POSITIVE PRESSURE FLUCTUATION :- 1.094
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.26
PRESSURE COEFFICIENTS:

Tp :- .105773
Cp :- .9007945
Cp' :- 9.527969E-02
Cp+ :- .3818168
Cp- :- -.4397525

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .535
MAX POSITIVE PRESSURE FLUCTUATION :- 1.815
MAX NEGATIVE PRESSURE FLUCTUATION :- -.5080001
PRESSURE COEFFICIENTS:

Tp :- .3327103
Cp :- .1867203
Cp' :- 6.212376E-02
Cp+ :- .6334528
Cp- :- -.177297

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 2.528
MAX POSITIVE PRESSURE FLUCTUATION :- 2.456
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.162
PRESSURE COEFFICIENTS:

Tp :- .1162975
Cp :- .882297
Cp' :- .1026089
Cp+ :- .8571682
Cp- :- -.4055495

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .569
MAX POSITIVE PRESSURE FLUCTUATION :- 1.605
MAX NEGATIVE PRESSURE FLUCTUATION :- -.616
PRESSURE COEFFICIENTS:

Tp :- .3725835
Cp :- .1985866
Cp' :- .0739901
Cp+ :- .5601609
Cp- :- -.2149901 *

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.684
MAX POSITIVE PRESSURE FLUCTUATION :- 1.553
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.266
PRESSURE COEFFICIENTS:

Tp :- .2084323
Cp :- .5877326
Cp' :- .1225025
Cp+ :- .5420123
Cp- :- -.4418465

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
TRUE AIR CONCENTRATION %	9.883311
NUMBER OF BOARDS	0
HEIGHT OF OUTLET (m)	1.307
WATER TEMPERATURE (C)	9.3
AIR TEMPERATURE (C)	9
AIR PRESSURE (mBars)	1018

LENGTH OF JET IN AIR (M) :- 1.307
LENGTH OF JET IN WATER (M) :- 0
VELOCITY IN NOZZLE (M/S) :- 3.698356
VELOCITY AT PLUNGE POOL (M/S) :- 6.270034

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 1.647
MAX POSITIVE PRESSURE FLUCTUATION :- 1.139
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.347
PRESSURE COEFFICIENTS:

Tp :- .1766849
Cp :- .8217134
Cp' :- .1451843
Cp+ :- .5682645
Cp- :- -.6720388

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .278
MAX POSITIVE PRESSURE FLUCTUATION :- 1.884
MAX NEGATIVE PRESSURE FLUCTUATION :- -.43
PRESSURE COEFFICIENTS:

Tp :- .5755396
Cp :- .1386984
Cp' :- 7.982644E-02
Cp+ :- .9399562
Cp- :- -.2145336 *

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 1.606
MAX POSITIVE PRESSURE FLUCTUATION :- 2.743
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.373
PRESSURE COEFFICIENTS:

Tp :- .1793275
Cp :- .8012579
Cp' :- .1436876
Cp+ :- 1.368524
Cp- :- -.6850106

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .292
MAX POSITIVE PRESSURE FLUCTUATION :- 1.424
MAX NEGATIVE PRESSURE FLUCTUATION :- -.382
PRESSURE COEFFICIENTS:

Tp :- .5479452
Cp :- .1456833
Cp' :- 7.982644E-02
Cp+ :- .7104553
Cp- :- -.1905856 *

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .921
MAX POSITIVE PRESSURE FLUCTUATION :- 1.693
MAX NEGATIVE PRESSURE FLUCTUATION :- -.968
PRESSURE COEFFICIENTS:

Tp :- .4060804
Cp :- .459501
Cp' :- .1865943
Cp+ :- .8446635
Cp- :- -.48295 *

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
TRUE AIR CONCENTRATION %	19.70147
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	.698
PLUNGE POOL LEVEL (m)	.795
WATER TEMPERATURE (C)	9.3
AIR TEMPERATURE (C)	8.5
AIR PRESSURE (mBars)	1028

LENGTH OF JET IN AIR (M) :-
LENGTH OF JET IN WATER (M) :- .698
VELOCITY IN NOZZLE (M/S) :- 6.20446
VELOCITY AT PLUNGE POOL (M/S) :- 6.20446

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 1.138001
MAX POSITIVE PRESSURE FLUCTUATION :- 1.138
MAX NEGATIVE PRESSURE FLUCTUATION :- -.8639999
PRESSURE COEFFICIENTS:

Tp :- .2592266
Cp :- .5798305
Cp' :- .1503075
Cp+ :- .5798303
Cp- :- -.4402226

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .4360006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.392
MAX NEGATIVE PRESSURE FLUCTUATION :- -.466
PRESSURE COEFFICIENTS:

Tp :- .394495
Cp :- .2221497
Cp' :- 8.763691E-02
Cp+ :- .7092475
Cp- :- -.2374349

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 1.034001
MAX POSITIVE PRESSURE FLUCTUATION :- 1.514
MAX NEGATIVE PRESSURE FLUCTUATION :- -.7660001
PRESSURE COEFFICIENTS:

Tp :- .2485492
Cp :- .5268408
Cp' :- .1309459
Cp+ :- .7714086
Cp- :- -.39029

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .4350006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.2
MAX NEGATIVE PRESSURE FLUCTUATION :- -.494
PRESSURE COEFFICIENTS:

Tp :- .4160914
Cp :- .2216402
Cp' :- 9.222256E-02
Cp+ :- .6114203
Cp- :- -.2517014

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .6040006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.017
MAX NEGATIVE PRESSURE FLUCTUATION :- -.5600001
PRESSURE COEFFICIENTS:

Tp :- .2897348
Cp :- .3077485
Cp' :- 8.916546E-02
Cp+ :- .5181787
Cp- :- -.2853295

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
TRUE AIR CONCENTRATION %	19.70709
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	.698
PLUNGE POOL LEVEL (m)	.785
WATER TEMPERATURE (C)	9.399999
AIR TEMPERATURE (C)	8.7
AIR PRESSURE (mBars)	1028

LENGTH OF JET IN AIR (M) :-
LENGTH OF JET IN WATER (M) :- .698
VELOCITY IN NOZZLE (M/S) :- 4.150847
VELOCITY AT PLUNGE POOL (M/S) :- 4.150847

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .3840006
MAX POSITIVE PRESSURE FLUCTUATION :- .626
MAX NEGATIVE PRESSURE FLUCTUATION :- -.327
PRESSURE COEFFICIENTS:

Tp :- .3255203
Cp :- .4371445
Cp' :- .1422994
Cp+ :- .7126353
Cp- :- -.3722553

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .1400006
MAX POSITIVE PRESSURE FLUCTUATION :- .53
MAX NEGATIVE PRESSURE FLUCTUATION :- -.209
PRESSURE COEFFICIENTS:

Tp :- .5285693
Cp :- .159376
Cp' :- 8.424125E-02
Cp+ :- .6033495
Cp- :- -.2379246

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .3620005
MAX POSITIVE PRESSURE FLUCTUATION :- .712
MAX NEGATIVE PRESSURE FLUCTUATION :- -.2739999
PRESSURE COEFFICIENTS:

Tp :- .3066294
Cp :- .4120997
Cp' :- .1263619
Cp+ :- .8105374
Cp- :- -.3119202

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .1220006
MAX POSITIVE PRESSURE FLUCTUATION :- .518
MAX NEGATIVE PRESSURE FLUCTUATION :- -.181
PRESSURE COEFFICIENTS:

Tp :- .5573745
Cp :- .1388849
Cp' :- 7.741088E-02
Cp+ :- .5896887
Cp- :- -.2060495

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .2020006
MAX POSITIVE PRESSURE FLUCTUATION :- .5830001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.232
PRESSURE COEFFICIENTS:

Tp :- .4108899
Cp :- .2299565
Cp' :- .0944868
Cp+ :- .6636845
Cp- :- -.2641077

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
TRUE AIR CONCENTRATION %	19.73866
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	.283
PLUNGE POOL LEVEL (m)	.39
WATER TEMPERATURE (C)	9.600001
AIR TEMPERATURE (C)	9
AIR PRESSURE (mBars)	1025

LENGTH OF JET IN AIR (M) :-
LENGTH OF JET IN WATER (M) :- .283
VELOCITY IN NOZZLE (M/S) :- 6.207335
VELOCITY AT PLUNGE POOL (M/S) :- 6.207335

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 2.218001
MAX POSITIVE PRESSURE FLUCTUATION :- .649
MAX NEGATIVE PRESSURE FLUCTUATION :- -.625
PRESSURE COEFFICIENTS:

Tp :- 7.213705E-02
Cp :- 1.129062
Cp' :- 8.144721E-02
Cp+ :- .3303702
Cp- :- -.3181532

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .6450003
MAX POSITIVE PRESSURE FLUCTUATION :- .694
MAX NEGATIVE PRESSURE FLUCTUATION :- -.382
PRESSURE COEFFICIENTS:

Tp :- .1689922
Cp :- .3283342
Cp' :- 5.548591E-02
Cp+ :- .3532773
Cp- :- -.1944552

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 1.994
MAX POSITIVE PRESSURE FLUCTUATION :- .748
MAX NEGATIVE PRESSURE FLUCTUATION :- -.7730001
PRESSURE COEFFICIENTS:

Tp :- 8.375123E-02
Cp :- 1.015036
Cp' :- 8.501052E-02
Cp+ :- .3807657
Cp- :- -.3934919

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .5410003
MAX POSITIVE PRESSURE FLUCTUATION :- .6160001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.334
PRESSURE COEFFICIENTS:

Tp :- .1996302
Cp :- .2753935
Cp' :- 5.497687E-02
Cp+ :- .3135718
Cp- :- -.170021

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1
MAX POSITIVE PRESSURE FLUCTUATION :- .9180001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.676
PRESSURE COEFFICIENTS:

Tp :- .198
Cp :- .5090452
Cp' :- .1007909
Cp+ :- .4673034
Cp- :- -.3441145

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
TRUE AIR CONCENTRATION %	19.7583
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	.283
PLUNGE POOL LEVEL (m)	.41
WATER TEMPERATURE (C)	9
AIR TEMPERATURE (C)	9.7
AIR PRESSURE (mBars)	1025

LENGTH OF JET IN AIR (M) :-
LENGTH OF JET IN WATER (M) :- .283
VELOCITY IN NOZZLE (M/S) :- 4.153496
VELOCITY AT PLUNGE POOL (M/S) :- 4.153496

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .8970004
MAX POSITIVE PRESSURE FLUCTUATION :- .561
MAX NEGATIVE PRESSURE FLUCTUATION :- -.4550001
PRESSURE COEFFICIENTS:

Tp :- .1282051
Cp :- 1.019839
Cp' :- .1307485
Cp+ :- .6378253
Cp- :- -.5173093

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .2380003
MAX POSITIVE PRESSURE FLUCTUATION :- .425
MAX NEGATIVE PRESSURE FLUCTUATION :- -.284
PRESSURE COEFFICIENTS:

Tp :- .2815122
Cp :- .2705929
Cp' :- 7.617521E-02
Cp+ :- .4832009
Cp- :- -.322892

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .8370003
MAX POSITIVE PRESSURE FLUCTUATION :- .742
MAX NEGATIVE PRESSURE FLUCTUATION :- -.539
PRESSURE COEFFICIENTS:

Tp :- .1875746
Cp :- .951622
Cp' :- .1785001
Cp+ :- .843612
Cp- :- -.6128125

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- 0
MAX POSITIVE PRESSURE FLUCTUATION :- 0
MAX NEGATIVE PRESSURE FLUCTUATION :- 0
PRESSURE COEFFICIENTS:

Tp :- 0
Cp :- 0
Cp' :- 0
Cp+ :- 0
Cp- :- 0

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .3920003
MAX POSITIVE PRESSURE FLUCTUATION :- .665
MAX NEGATIVE PRESSURE FLUCTUATION :- -.35
PRESSURE COEFFICIENTS:

Tp :- .3035712
Cp :- .4456822
Cp' :- .1352963
Cp+ :- .7560674
Cp- :- -.3979302

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
TRUE AIR CONCENTRATION %	19.76763
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.777
WATER TEMPERATURE (C)	9
AIR TEMPERATURE (C)	8.100001
AIR PRESSURE (mBars)	1018

LENGTH OF JET IN AIR (M) :- .53
LENGTH OF JET IN WATER (M) :- .777
VELOCITY IN NOZZLE (M/S) :- 6.209576
VELOCITY AT PLUNGE POOL (M/S) :- 6.996732

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .9470006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.812
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.043
PRESSURE COEFFICIENTS:

Tp :- .4392817
Cp :- .3794253
Cp' :- .1666746
Cp+ :- .7259961
Cp- :- -.4178885

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .4510007
MAX POSITIVE PRESSURE FLUCTUATION :- 1.741
MAX NEGATIVE PRESSURE FLUCTUATION :- -.6660001
PRESSURE COEFFICIENTS:

Tp :- .63858
Cp :- .180698
Cp' :- .1153901
Cp+ :- .6975493
Cp- :- -.2668396

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .8420006
MAX POSITIVE PRESSURE FLUCTUATION :- 3.123
MAX NEGATIVE PRESSURE FLUCTUATION :- -.858
PRESSURE COEFFICIENTS:

Tp :- .4216149
Cp :- .337356
Cp' :- .1422343
Cp+ :- 1.251262
Cp- :- -.3437663

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .4560007
MAX POSITIVE PRESSURE FLUCTUATION :- 1.715
MAX NEGATIVE PRESSURE FLUCTUATION :- -.6290001
PRESSURE COEFFICIENTS:

Tp :- .5745606
Cp :- .1827013
Cp' :- .1049729
Cp+ :- .687132
Cp- :- -.2520152

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .5350006
MAX POSITIVE PRESSURE FLUCTUATION :- 1.466
MAX NEGATIVE PRESSURE FLUCTUATION :- -.7320001
PRESSURE COEFFICIENTS:

Tp :- .4504668
Cp :- .2143534
Cp' :- 9.655908E-02
Cp+ :- .5873677
Cp- :- -.2932832

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
TRUE AIR CONCENTRATION %	19.76199
NUMBER OF BOARDS	4
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.777
WATER TEMPERATURE (C)	9.100001
AIR TEMPERATURE (C)	7.9
AIR PRESSURE (mBars)	1018

LENGTH OF JET IN AIR (M) :- .53
LENGTH OF JET IN WATER (M) :- .777
VELOCITY IN NOZZLE (M/S) :- 4.153687
VELOCITY AT PLUNGE POOL (M/S) :- 5.258188

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .1080006
MAX POSITIVE PRESSURE FLUCTUATION :- .951
MAX NEGATIVE PRESSURE FLUCTUATION :- -.243
PRESSURE COEFFICIENTS:

Tp :- 1.092587
Cp :- 7.661618E-02
Cp' :- 8.370983E-02
Cp+ :- .6746445
Cp- :- -.1723855

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .0370006
MAX POSITIVE PRESSURE FLUCTUATION :- .797
MAX NEGATIVE PRESSURE FLUCTUATION :- -.205
PRESSURE COEFFICIENTS:

Tp :- 2.351313
Cp :- 2.624842E-02
Cp' :- 6.171827E-02
Cp+ :- .565396
Cp- :- -.1454281

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .0970006
MAX POSITIVE PRESSURE FLUCTUATION :- .9230001
MAX NEGATIVE PRESSURE FLUCTUATION :- -.208
PRESSURE COEFFICIENTS:

Tp :- .9484478
Cp :- 6.881275E-02
Cp' :- 6.526529E-02
Cp+ :- .6547812
Cp- :- -.1475563

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- 2.900058E-02
MAX POSITIVE PRESSURE FLUCTUATION :- .739
MAX NEGATIVE PRESSURE FLUCTUATION :- -.214
PRESSURE COEFFICIENTS:

Tp :- 2.482709
Cp :- 2.057317E-02
Cp' :- 5.107718E-02
Cp+ :- .5242505
Cp- :- -.1518127

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 2.200061E-02
MAX POSITIVE PRESSURE FLUCTUATION :- .534
MAX NEGATIVE PRESSURE FLUCTUATION :- -.2000001
PRESSURE COEFFICIENTS:

Tp :- 2.681744
Cp :- 1.560735E-02
Cp' :- 4.185492E-02
Cp+ :- .3788224
Cp- :- -.1418811

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
TRUE AIR CONCENTRATION %	19.79345
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.393
WATER TEMPERATURE (C)	8.399999
AIR TEMPERATURE (C)	6.8
AIR PRESSURE (mBars)	1010

LENGTH OF JET IN AIR (M) :- .9140001
LENGTH OF JET IN WATER (M) :- .393
VELOCITY IN NOZZLE (M/S) :- 6.211576
VELOCITY AT PLUNGE POOL (M/S) :- 7.51737

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 2.415001
MAX POSITIVE PRESSURE FLUCTUATION :- 1.16
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.88
PRESSURE COEFFICIENTS:

Tp :- .1358178
Cp :- .8382081
Cp' :- .1138436
Cp+ :- .4026174
Cp- :- -.6525181

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .4810003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.59
MAX NEGATIVE PRESSURE FLUCTUATION :- -.742
PRESSURE COEFFICIENTS:

Tp :- .4345112
Cp :- .1669475
Cp' :- 7.254057E-02
Cp+ :- .5518636
Cp- :- -.2575364

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 2.181
MAX POSITIVE PRESSURE FLUCTUATION :- 2.395
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.753
PRESSURE COEFFICIENTS:

Tp :- .178817
Cp :- .7569904
Cp' :- .1353628
Cp+ :- .8312663
Cp- :- -.6084383

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .6610003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.677
MAX NEGATIVE PRESSURE FLUCTUATION :- -.7380001
PRESSURE COEFFICIENTS:

Tp :- .4251133
Cp :- .2294227
Cp' :- 9.753061E-02
Cp+ :- .58206
Cp- :- -.2561481

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.258
MAX POSITIVE PRESSURE FLUCTUATION :- 1.349
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.282
PRESSURE COEFFICIENTS:

Tp :- .3147853
Cp :- .4366319
Cp' :- .1374453
Cp+ :- .4682164
Cp- :- -.4449618

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
TRUE AIR CONCENTRATION %	19.81612
NUMBER OF BOARDS	2
HEIGHT OF OUTLET (m)	1.307
PLUNGE POOL LEVEL (m)	.392
WATER TEMPERATURE (C)	8.7
AIR TEMPERATURE (C)	7.6
AIR PRESSURE (mBars)	1010

LENGTH OF JET IN AIR (M) :- .9150001
LENGTH OF JET IN WATER (M) :- .392
VELOCITY IN NOZZLE (M/S) :- 4.156491
VELOCITY AT PLUNGE POOL (M/S) :- 5.934917

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- .9730003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.238
MAX NEGATIVE PRESSURE FLUCTUATION :- -.994
PRESSURE COEFFICIENTS:

Tp :- .3627954
Cp :- .5418141
Cp' :- .1965676
Cp+ :- .6893788
Cp- :- -.5535078

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .1840003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.226
MAX NEGATIVE PRESSURE FLUCTUATION :- -.415
PRESSURE COEFFICIENTS:

Tp :- .9184768
Cp :- .1024603
Cp' :- 9.410745E-02
Cp+ :- .6826967
Cp- :- -.2310923

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- .7500003
MAX POSITIVE PRESSURE FLUCTUATION :- 2.261
MAX NEGATIVE PRESSURE FLUCTUATION :- -.809
PRESSURE COEFFICIENTS:

Tp :- .4253332
Cp :- .4176368
Cp' :- .1776348
Cp+ :- 1.259035
Cp- :- -.4504907

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .1900003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.119
MAX NEGATIVE PRESSURE FLUCTUATION :- -.368
PRESSURE COEFFICIENTS:

Tp :- .8421038
Cp :- .1058015
Cp' :- 8.909581E-02
Cp+ :- .6231138
Cp- :- -.2049204

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .3740003
MAX POSITIVE PRESSURE FLUCTUATION :- 1.082
MAX NEGATIVE PRESSURE FLUCTUATION :- -.499
PRESSURE COEFFICIENTS:

Tp :- .5775397
Cp :- .2082616
Cp' :- .1202794
Cp+ :- .6025105
Cp- :- -.2778676

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	6.676001E-02
TRUE AIR CONCENTRATION %	19.77891
NUMBER OF BOARDS	0
HEIGHT OF OUTLET (m)	1.307
WATER TEMPERATURE (C)	9
AIR TEMPERATURE (C)	8.5
AIR PRESSURE (mBars)	1018

LENGTH OF JET IN AIR (M) :- 1.307
LENGTH OF JET IN WATER (M) :- 0
VELOCITY IN NOZZLE (M/S) :- 6.210449
VELOCITY AT PLUNGE POOL (M/S) :- 8.012812

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 2.696
MAX POSITIVE PRESSURE FLUCTUATION :- 1.469
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.475
PRESSURE COEFFICIENTS:

Tp :- .134273
Cp :- .8236004
Cp' :- .1105873
Cp+ :- .4487644
Cp- :- -.4505974

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .669
MAX POSITIVE PRESSURE FLUCTUATION :- 2.233
MAX NEGATIVE PRESSURE FLUCTUATION :- -.7470001
PRESSURE COEFFICIENTS:

Tp :- .3901345
Cp :- .2043726
Cp' :- 7.973282E-02
Cp+ :- .6821585
Cp- :- -.2282009 *

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 2.543
MAX POSITIVE PRESSURE FLUCTUATION :- 2.371
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.507
PRESSURE COEFFICIENTS:

Tp :- .1498231
Cp :- .7768604
Cp' :- .1163916
Cp+ :- .7243162
Cp- :- -.460373

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .693
MAX POSITIVE PRESSURE FLUCTUATION :- 2.115
MAX NEGATIVE PRESSURE FLUCTUATION :- -.658
PRESSURE COEFFICIENTS:

Tp :- .4256854
Cp :- .2117044
Cp' :- 9.011947E-02
Cp+ :- .6461108
Cp- :- -.2010122

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- 1.672
MAX POSITIVE PRESSURE FLUCTUATION :- 1.607
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.506
PRESSURE COEFFICIENTS:

Tp :- .2446172
Cp :- .5107789
Cp' :- .1249453
Cp+ :- .490922
Cp- :- -.4600676

ALL PRESSURE MEASUREMENTS IN METRES

DISCHARGE (m3/s)	.04466
TRUE AIR CONCENTRATION %	19.79299
NUMBER OF BOARDS	0
HEIGHT OF OUTLET (m)	1.307
WATER TEMPERATURE (C)	9.3
AIR TEMPERATURE (C)	9
AIR PRESSURE (mBars)	1018

LENGTH OF JET IN AIR (M) :- 1.307
LENGTH OF JET IN WATER (M) :- 0
VELOCITY IN NOZZLE (M/S) :- 4.155293
VELOCITY AT PLUNGE POOL (M/S) :- 6.549958

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE :- 1.286
MAX POSITIVE PRESSURE FLUCTUATION :- 1.673
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.252
PRESSURE COEFFICIENTS:

Tp :- .3211509
Cp :- .5879366
Cp' :- .1888163
Cp+ :- .7648663
Cp- :- -.5723924

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE :- .451
MAX POSITIVE PRESSURE FLUCTUATION :- 1.982
MAX NEGATIVE PRESSURE FLUCTUATION :- -.549
PRESSURE COEFFICIENTS:

Tp :- .7361419
Cp :- .2061893
Cp' :- .1517846
Cp+ :- .9061356
Cp- :- -.2509932 *

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE :- 1.132
MAX POSITIVE PRESSURE FLUCTUATION :- 3.845
MAX NEGATIVE PRESSURE FLUCTUATION :- -1.079
PRESSURE COEFFICIENTS:

Tp :- .3754417
Cp :- .5175305
Cp' :- .1943025
Cp+ :- 1.757867
Cp- :- -.4932999

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE :- .439
MAX POSITIVE PRESSURE FLUCTUATION :- 1.932
MAX NEGATIVE PRESSURE FLUCTUATION :- -.5530001
PRESSURE COEFFICIENTS:

Tp :- .7448746
Cp :- .2007031
Cp' :- .1494986
Cp+ :- .8832764
Cp- :- -.2528219 *

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE :- .789
MAX POSITIVE PRESSURE FLUCTUATION :- 1.727
MAX NEGATIVE PRESSURE FLUCTUATION :- -.867
PRESSURE COEFFICIENTS:

Tp :- .5145754
Cp :- .3607169
Cp' :- .1856161
Cp+ :- .7895541
Cp- :- -.3963772 *

ALL PRESSURE MEASUREMENTS IN METRES