IMPACT PRESSURES IN PLUNGE BASINS DUE TO VERTICAL FALLING JETS

by

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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, i.e. 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 Froudeian scaling in model tests of plunge basins.
SYMBOLS

B Thickness of rectangular jet (short side)

B₀ Initial thickness of rectangular jet

B₁ Thickness of jet entering plunge basin

C Local volumetric air concentration

C₀ Mean volumetric air concentration (equation (15))

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

Cₚₘₚ Maximum value of Cₚ on floor of basin

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

Cₚ⁻ Pressure coefficient for minimum instantaneous dynamic pressure (Equation (34))

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

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

D₀ Initial diameter of circular jet

D₁ Diameter of jet entering plunge basin

d Mean particle size

Eₖ Kinetic energy head of jet

f Frequency

fₘ Frequency in model

fₚ Frequency in prototype

g Acceleration due to gravity

H Height of jet nozzle above floor

h Depth of water

h₁ Height of manifold above pipe exit

hₘ Static pressure head at manifold

K Coefficient in Equation (14)

k Kurtosis (Equation (36))

L Plunge length of jet in air

Lₐ Distance travelled by jet in air

L₇ Break-up length of water jet in air

Lₑ Flow-establishment length

L₉ Distance travelled by jet in water

M Momentum flux due to velocity of jet

N Number of measurements
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
\( P_{\text{max}} \)  Maximum instantaneous dynamic pressure
\( P_{\text{min}} \)  Minimum instantaneous dynamic pressure
\( P_{\text{rms}} \)  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  Energy gradient of flow
f  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
\( v_{\text{rms}} \)  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)

\( \alpha_1 \)  Semi-angle rate of contraction of high-velocity inner core of jet

\( \alpha_2 \)  Semi-angle rate of jet expansion in flow-establishment zone

\( \alpha_3 \)  Semi-angle rate of jet expansion in established-flow zone

\( \varepsilon \)  Mean turbulence intensity of velocity fluctuations (= \( \frac{v_{\text{rms}}}{V} \))

\( \varepsilon_L \)  Local turbulence intensity (= \( \frac{v_{\text{rms}}}{v} \))

\( \theta \)  Semi-angle rate of jet expansion in air

\( \theta' \)  Value of \( \theta \) in the absence of gravitational effects

\( \rho \)  Density of fluid in jet

\( \rho_0 \)  Density of fluid surrounding jet

\( \sigma \)  Standard deviation (Equation (34))
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APPENDIX A

Measurements of impact pressures
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 (e.g., 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))

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 (e.g., 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 will 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.

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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 centre 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 viscosity 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 $B_0$, and for a submerged circular jet to be equal to 6.2 times the initial jet diameter $D_0$. 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 $V_0$ by

$$\frac{v}{V_0} = \exp \left[ -42.1 \left( 0.0966 + \frac{(y - B_0/2)}{z} \right)^2 \right]$$

for $z \leq 5.2 B_0$ and $y \geq (B_0 - 0.193 z)/2$ \hspace{1cm} (1)

and in the established-flow zone by

$$\frac{v}{V_0} = 2.28 \left( \frac{B_0}{z} \right)^{1/2} \exp \left[ -42.4 \frac{y^2}{z^2} \right]$$

for $z > 5.2 B_0$ \hspace{1cm} (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 $B_0 = 0.0185$ m) discharging vertically at a height of $H = 0.82$ m above a horizontal floor (giving a ratio of $H/B_0 = 44.3$). Tests at four different flow rates ($V_0 = 1.8$ m/s to 4.8 m/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 decelerated 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 $p_m = 0.145 \rho \frac{V_o^2}{2}$. By comparison, the flow velocity on the centre-line for an unrestricted jet would according to Equation (2) have been equivalent to $p_m = 0.117 \rho \frac{V_o^2}{2}$.

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

$$\frac{V_m}{V_o} = 2.40 \left( \frac{z}{B_o} - 2.5 \right)^{-\frac{1}{2}}$$  \hspace{1cm} (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

$$p_m = 7.7 \left( \frac{B_o}{H} \right), \frac{1}{2} \rho \frac{V_o^2}{2}$$  \hspace{1cm} (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

$$\frac{p}{p_m} = \exp\left(-38.5\left(\frac{y}{H}\right)^2\right)$$  \hspace{1cm} (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

$$\frac{L_e}{D_0} = 5\left(\frac{\rho}{\rho_o}\right)^{0.345}$$  \hspace{1cm} (6)

where $D_0$ is the initial diameter of the jet, $\rho$ is the density of the jet and $\rho_o$ 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 $L_e = 50 \, D_0$ 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 $D_0 = 6, 9, 14$ and 25mm and flow velocities up to $V_o = 7\text{m/s}$. The distance $L_b$ travelled by the jet before
losing its coherence and breaking up depended on the turbulence intensity $\epsilon$ as follows.

$$L_b = 60 \, Q^{0.39}, \, \epsilon = 0.3\%$$

$$L_b = 17.4 \, Q^{0.31}, \, \epsilon = 3\%$$

$$L_b = 4.1 \, Q^{0.2}, \, \epsilon = 8\%$$

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

$$\epsilon = \frac{v_{rms}}{V}$$

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

$$L_b = 5.89 \, q^{0.319}$$

where $q$ is the unit discharge in m$^3$/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 $\theta$ of the outer edge of the jet (see Figure 1)
was found to be related to the turbulence level by

\[ \theta = \tan^{-1} (0.38 \varepsilon) \]  \hspace{1cm} (10)

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

\[ \alpha_i/\theta = 1/5 \text{ to } 1/7 \]  \hspace{1cm} (11)

According to these results, the high-velocity core of a jet with a turbulence level of \( \varepsilon = 8\% \) will disappear at a distance of about \( L_e = 100 D_0 \) from the nozzle. This compares with values of about \( L_e/D_0 = 50 \) obtained by Kraatz (Equation (6)) and by Ervine et al (1980) for the break-up length at a turbulence intensity of \( \varepsilon = 8\% \).

Ervine & Falvey (1987) also considered the behaviour of water jets travelling through water, and summarised information about the expansion angles \( \alpha_1, \alpha_2 \) and \( \alpha_3 \) in Figure 1 as follows.

<table>
<thead>
<tr>
<th>Jet condition</th>
<th>Turbulence level</th>
<th>( \alpha_1 )</th>
<th>( \alpha_2 )</th>
<th>( \alpha_3 )</th>
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<tr>
<td>submerged</td>
<td></td>
<td>4.5°</td>
<td>6°</td>
<td>11°</td>
</tr>
<tr>
<td>plunging</td>
<td>almost laminar ( \varepsilon \approx 0.3% )</td>
<td>5°</td>
<td>6°-7°</td>
<td>10°-12°</td>
</tr>
<tr>
<td>plunging</td>
<td>smooth turbulent ( \varepsilon \approx 1.2% )</td>
<td>7°-8°</td>
<td>10°-11°</td>
<td>14°</td>
</tr>
<tr>
<td>plunging</td>
<td>high turbulence ( \varepsilon \approx 5% )</td>
<td>-8°</td>
<td>13°-14°</td>
<td>14°-15°</td>
</tr>
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</table>
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 \((D_o = 25\text{mm to } 78\text{mm})\) discharging vertically downwards into air with initial velocities in the range \(V_o = 3\text{m/s to } 25\text{m/s}\). 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

\[
C_{pm} = \frac{2p_m}{\rho V_1^2}
\]  

(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

<table>
<thead>
<tr>
<th>(h/D_1)</th>
<th>(C_{pm})</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.72</td>
</tr>
<tr>
<td>6</td>
<td>0.46</td>
</tr>
<tr>
<td>8</td>
<td>0.30</td>
</tr>
<tr>
<td>10</td>
<td>0.21</td>
</tr>
<tr>
<td>12</td>
<td>0.15</td>
</tr>
<tr>
<td>16</td>
<td>0.07</td>
</tr>
<tr>
<td>20</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Measurements of the fluctuating pressures on the floor of the basin were analysed to determine the root-mean-square value, $P_{\text{rms}}$, for each test. Peak values of the corresponding pressure coefficient

$$C_p' = \frac{2P_{\text{rms}}}{\rho V^2}$$

(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 $4C_p'$; the corresponding minimum pressure fluctuation was about $3C_p'$. 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-trajecory jets entering plunge basins were fitted by Ervine & Falvey (1987) to the equation

$$C_0 = K \left( \frac{L}{D_0} \right)^{1/2} / \left[ 1 + K \left( \frac{L}{D_0} \right)^{1/2} \right]$$

(14)

where $C_0$ is the mean air concentration based on volumetric rates of air flow ($Q_a$) and water flow ($Q$),

15
\[ C_o = \frac{Q_a}{Q_a + Q} \]  

(15)

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

<table>
<thead>
<tr>
<th>Turbulence level</th>
<th>Circular jets</th>
<th>Wide rectangular jets</th>
<th>Valid range</th>
</tr>
</thead>
<tbody>
<tr>
<td>smooth turbulent</td>
<td>0.2</td>
<td>0.1</td>
<td>( L/D_o \leq 200 )</td>
</tr>
<tr>
<td>moderate turbulent</td>
<td>0.3</td>
<td>0.15</td>
<td>( L/D_o \leq 100 )</td>
</tr>
<tr>
<td>rough turbulent</td>
<td>0.4</td>
<td>0.2</td>
<td>( L/D_o \leq 50 )</td>
</tr>
</tbody>
</table>

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 \( V_o = 10 \text{m/s} \) 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 \( v_0 = 0.066 V \) and with air entrainment was \( v_m = 0.062 V_0 \).

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

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

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

$$p_m = \frac{1}{2} (1-C_0) \rho V_1^2 \left[ 16 \frac{D_1}{z} \right]^2 \quad (17)$$

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 diameter 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 0.09m³/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 -20° 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 0.09m³/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

\[
    h_m = - (1 - S_f) h_1 - \frac{V_o^2}{2g} (r - 1)
\]

(18)
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
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

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

(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;
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:

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

(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 uniformity 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: $V_o = 6.65\text{ m/s (100%)}, V_o = 4.98\text{ m/s (75%) and } V_o = 3.33\text{ m/s (50%)}$; 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 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 $V_o = 3.33\text{ m/s}$ 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, 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.

\[ v = v_m \left(\frac{y}{y_m}\right)^{0.158} \]  

(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 \( M \) of the jet due to its velocity are

\[ E_k = 1.053 \frac{V_o^2}{2g} \]  

(21)

\[ M = 1.019 \rho B_{oW} \frac{V_o^2}{V_o} \]  

(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
\[ C_p' = \frac{2p_{\text{rms}}}{\rho V_o^2} \]  

(23)

where \( p_{\text{rms}} \) 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

\[ \epsilon = \frac{v_{\text{rms}}}{V} = \frac{1}{2} C_p' \]  

(24)

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

The local turbulence intensity on the centreline of the jet

\[ \epsilon_L = \frac{v_{\text{rms}}}{V} \]  

(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-uniformity 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 $(Cv/C_o \, V_o)$ 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 \( \theta \) of the outer edge of the jet on its shorter side \( (B_o = 67\text{mm}) \) was calculated from

\[
\theta = \tan^{-1} \left[ \frac{(B - B_o)}{z} \right]
\]  

(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 \( (W_o = 200\text{mm}) \) was determined by substituting \( W \) and \( W_o \) for \( B \) and \( B_o \) in Equation (26). The values of \( \theta \) 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

\[
\theta' = \tan^{-1} \left[ \frac{B}{z} - \frac{B_o}{z} \left(1 + \frac{2g}{V_o^2} \right)^{-\frac{1}{2}} \right]
\]  

(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 \( z = 0.564\text{m} \) gives values of \( \theta' \) between 2.6° (at \( V_o = 2.45 \text{ m/s} \)) and 3.8° (at \( V_o = 4.26 \text{ m/s} \)).
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).

<table>
<thead>
<tr>
<th>Transducer</th>
<th>( \frac{x}{W_0} )</th>
<th>( \frac{y}{B_0} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>0.9</td>
</tr>
<tr>
<td>C</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>0.3</td>
<td>0.9</td>
</tr>
<tr>
<td>F</td>
<td>0.6</td>
<td>0</td>
</tr>
</tbody>
</table>

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 \( V_0 = 3.3, 5.0, 6.6 \text{ m/s} \)
- Jet length in water \( L_w = 0.3, 0.7 \text{ m} \)
- 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 \( V_0 = 6.6 \text{ m/s} \) 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 \( H = 1.3 \text{m} \) above the floor of the basin. The conditions investigated were:

Initial velocity \( V_o = 3.3, 5.0, 6.6 \text{m/s} \)

Jet length in air \( L_a = 1.3, 0.9, 0.5 \text{m} \)

Jet length in water \( L_w = 0, 0.4, 0.8 \text{m} \)

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

\[
C_p = \frac{2p}{\rho V_1^2} \tag{28}
\]

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

\[
V_1^2 = V_o^2 + 2g L_a \tag{29}
\]
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, $p_{\text{max}}$ and $p_{\text{min}}$, recorded during a test were defined as

$$C_{p}^{+} = \frac{2(p_{\text{max}} - p)}{\rho V_{1}^{2}}$$  \hspace{1cm} (30)$$

$$C_{p}^{-} = \frac{2(p_{\text{min}} - p)}{\rho V_{1}^{2}}$$  \hspace{1cm} (31)$$

where $p$ is the mean dynamic pressure.

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

$$C_{p}^{'} = \frac{2 p_{\text{rms}}}{\rho V_{1}^{2}}$$  \hspace{1cm} (32)$$

and the turbulent pressure intensity

$$T_{p} = \frac{p_{\text{rms}}}{p}$$  \hspace{1cm} (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 $\sigma$, 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

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

(34)

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

(35)

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

(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 $5.9 \times 10^6$ 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 \( W_0 \) 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 \( B_0 \) 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

$$B_1 = B_0 \frac{V_0}{V_1}$$

(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 dissipation) 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

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

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

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

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)

\[
C_p = 1.6 (1-C_o)^{3/4} - \frac{1}{12} (L_w/B_1) \quad (41)
\]
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

$$C_p = 1.8 (1 - C_o)^{0.09} - \frac{1}{12} (L_w/B_1) \quad (42)$$

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

$$\frac{L_a}{B_1}, \frac{V_1}{(g B_1)^{1/2}}, \frac{V_1}{(g L_a)^{1/2}} \text{ or } \frac{V_o}{(g L_a)^{1/2}}$$

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 $V_o/(g L_a)^{1/2}$. 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

Measurements 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 \( C_p^+ \), \( C_p^- \), \( C_p' \) 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 \( \pm 5.1 \text{m} \) and \( 0.0 \text{m} \) head of water (relative to atmosphere). In some instances discontinuous spikes occurred 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 $2 \times 10^{-5}$ (based on one maximum and one minimum reading out of $5 \times 32,768$ 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 $V_{o}/(g L_{a})^{1/2}$. 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

$$\frac{f_1}{f_2} = \frac{V_1}{V_2} \cdot \frac{B_2}{B_1}$$  \hspace{1cm} (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:$\lambda$ by

$$\frac{f_m}{f_p} = \lambda^{n_{Gr}}$$  \hspace{1cm} (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 $V_1/(gL_w)^{1/2}$ and $V_o/(gL_a)^{1/2}$ (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 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, except 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 $2 \times 10^{-5}$. 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.

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TABLES.
TABLE 1 Distribution of mean velocity in free jet

(a) \( y/B_o = 0 \)

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TABLE 1 (Cont'd)

(c) \( y/B_o = 0.5 \)

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<th>( V_o = 4.98 \text{ m/s} )</th>
<th>( V_o = 6.65 \text{ m/s} )</th>
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TABLE 2  Turbulence intensities in free jet

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<th>Mean jet velocity $V_o$ (m/s)</th>
<th>Rms pressure coeff for pitot tube $C_p''$ (%)</th>
<th>Mean turbulence intensity $\epsilon$ (%)</th>
<th>Local turbulence intensity $\epsilon_1$ (%)</th>
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TABLE 3 Distribution of air concentration in free jet

(a) \( y/B_0 = 0, \ V_0 = 3.33 \text{ m/s} \)

| \( x/W_0 \) | Local air concentration / Mean air concentration (\( C/C_0 \)) |  
|---|---|---|
|   | \( C_0 = 10\% \) | \( C_0 = 20\% \) | 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

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<th>Local air concentration / Mean air concentration (( C/C_o ))</th>
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<th>( C_o = 20% )</th>
<th>Average</th>
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TABLE 3 (Cont'd)

(c) \(y/B_0 = 0.5, \ V_0 = 3.33 \text{ m/s}\)

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TABLE 4. Rate of expansion of free jet in air

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* Values calculated from six measurements and not eight as for others
### TABLE 5  Distribution of mean dynamic pressure

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<td>0.467</td>
<td>0.306</td>
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</table>

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
Position of nozzle above plate.

Removable square centre section with four possible orientations.

Fig 5  Layout of pressure tappings

All dimensions in mm
Fig 6 Large test rig with aeration system
Fig 7  Profiles of mean velocity in free jet

- Average value for $V_o = 3.33, 4.98$ and $6.6$m/s
- Value for $V_o = 3.33$m/s
- $C_o = 0\%$
\[ Y/Bo = 0 \]
\[ Y/Bo = 0.25 \]
\[ Y/Bo = 0.50 \]

Fig 8 Profiles of air concentration in free jet

- Average value for \( C_o = 10\% \) and 20\% 
- Value for \( C_o = 10\% \) 
- Value for \( C_o = 20\% \)

\( V_o = 3.33m/s \)
Fig 9  Distribution of mean dynamic pressure

Co-ordinates of transducers

\[
\begin{array}{ccc}
\text{x/W}_o & \text{y/B}_o \\
A & 0 & 0 \\
B & 0 & 0.9 \\
C & 0.3 & 0 \\
D & 0.3 & 0.9 \\
F & 0.6 & 0 \\
\end{array}
\]

Key

Overall average
Average for \(C_o = 0\%\)
Average for \(C_o = 10\%\)
Average for \(C_o = 20\%\)

Lines between points are only indicative

\(W_o = 200\text{mm}\)
\(B_o = 67\text{mm}\)
Fig 10  Correlation for mean dynamic pressure ($C_o = 0\%$)
Fig 11 Correlation for mean dynamic pressure (C₀ = 10\%)

- Plunging jet
- Submerged jet
- 50 Indicates 50\% flow rate, etc
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.

Lines are only indicative.

$C_p$ vs. $V_d/(gL_d)^{1/2}$
Fig 15 Correlation for average rms dynamic pressure

$C_o = 0\%$  
$\bullet$ Plunging jet  
$\times$ Submerged jet

$C_o = 10\%$  
$\triangle$ Plunging jet  
$+$ Submerged jet

$C_o = 20\%$  
$\blacktriangle$ Plunging jet  
$\blacksquare$ Submerged jet

50 Indicates 50% flow rate

Average $C_p$ vs $L_w/B_1$
Fig 16  Correlation for average rms dynamic pressure with zero tailwater
Fig 17: Correlation for maximum rms dynamic pressure

- **$C_o = 0\%$**
  - • Plunging jet
  - × Submerged jet

- **$C_o = 10\%$**
  - ▲ Plunging jet
  - ◊ Submerged jet

- **$C_o = 20\%$**
  - ♦ Plunging jet
  - ■ Submerged jet

50 Indicates 50% flow rate

The graph shows the correlation between maximum $C_p'$ and $L_w/B_1$. The data points represent different flow rates and conditions for plunging and submerged jets.
Fig 18. Correlation between rms and mean dynamic pressures.

- $C_\alpha = 0\%$: • Plunging jet, x Submerged jet
- $C_\alpha = 10\%$: ▲ Plunging jet, + Submerged jet
- $C_\alpha = 20\%$: ◤ Plunging jet, ■ Submerged jet

50 Indicates 50% flow rate.
Fig 19 Correlation for peak dynamic pressures

- $C_o = 0\%$  
  - Plunging jet
  - Submerged jet

- $C_o = 10\%$  
  - Plunging jet
  - Submerged jet

- $C_o = 20\%$  
  - Plunging jet
  - Submerged jet

50 Indicates 50% flow rate
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

Plunging jet
No air injection
Q = 100%
Fig 23. Probability distribution for pressure fluctuations at Position A in Test 9.

Plunging jet
No air injection
$Q = 75\%$
Fig 24 Probability distribution for pressure fluctuations at Position B in Test 9
Fig 25  Spectral density for pressure fluctuations at Position A in Test 15
Fig 26  Spectral density for pressure fluctuations at Position A in Test 8

Pressures in m head of water

Plunging jet

No air injection

Q = 100%
Fig 27  Spectral density for pressure fluctuations at Position 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 \( V_0 = 2.45 \text{ m/s} \):
LONG SIDE
PLATE 2  JET DISCHARGING FROM HEIGHT OF 1.08m AT $V_0=2.45\text{m/s}$
SHORT SIDE
PLATE 3  JET DISCHARGING FROM HEIGHT OF 1.08m AT \( V_0 = 4.26 \text{m/s} \):
LONG SIDE
PLATE 4 JET DISCHARGING FROM HEIGHT OF 1.08m AT $V_0=4.26\text{m/s}$:
SHORT SIDE
PLATE 5  JET DISCHARGING FROM HEIGHT OF 2.30m AT \( V_0=2.44 \text{m/s} \):
SHORT SIDE
PLATE 6  JET DISCHARGING FROM HEIGHT OF 2.30m AT $V_0=4.29\text{m/s}$
SHORT SIDE
APPENDICES.
APPENDIX A

Measurements of impact pressures
### TEST CONDITIONS

<table>
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<tr>
<th>Page No</th>
<th>HR Test No</th>
<th>Jet type*</th>
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Note: 

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

+ $100\% \equiv 0.089 \text{ m}^3/\text{s}$  
$75\% \equiv 0.067 \text{ m}^3/\text{s}$  
$50\% \equiv 0.045 \text{ m}^3/\text{s}$  

† Exact values vary slightly for each test
| DISCHARGE (m³/s) | .00909 |
| 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) :- 6.448508
VELOCITY AT PLUNGE POOL (m/s) :- 6.448508

CALCULATED VALUES AT POSITION A

| MEAN DYNAMIC PRESSURE | :- 1.631001 |
| MAX POSITIVE PRESSURE FLUCTUATION | :- 1.26 |
| MAX NEGATIVE PRESSURE FLUCTUATION | :- -1.115 |
| PRESSURE COEFFICIENTS: |

  Tp :- .19006
  Cp :- .824688
  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 | :- -0.759 |
| PRESSURE COEFFICIENTS: |

  Tp :- .2718892
  Cp :- .3835574
  Cp' :- .1047701
  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 | :- -0.758 |
| PRESSURE COEFFICIENTS: |

  Tp :- .3030997
  Cp :- .3864886
  Cp' :- .1171446
  Cp+ :- .6980738
  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+ :- .5684530
  Cp- :- -.4694657

ALL PRESSURE MEASUREMENTS IN METRES -
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LENGTH OF JET IN AIR (m) ::

LENGTH OF JET IN WATER (m) :: 0.698

VELOCITY IN NOZZLE (m/s) :: 6.648508

VELOCITY AT PLUNGE POOL (m/s) :: 6.648508

**CALCULATED VALUES AT POSITION A**

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**PRESSURE COEFFICIENTS:**

| Tp   | 0.2061114 |
| C0   | 0.7405846 |
| Cp'  | 0.1526429 |
| C0+  | 0.5335627 |
| C0-  | -0.4695275 |

**CALCULATED VALUES AT POSITION D**

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**PRESSURE COEFFICIENTS:**

| Tp   | 0.341112 |
| C0   | 0.2840745 |
| C0+  | 9.717673E-02 |
| C0-  | 0.5726546 |
| C0-  | -0.2715624 |

**CALCULATED VALUES AT POSITION B**

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**PRESSURE COEFFICIENTS:**

| Tp   | 0.3132713 |
| C0   | 0.2875369 |
| C0'  | 9.007066E-02 |
| C0+  | 0.5675299 |
| C0-  | -0.3265848 |

**CALCULATED VALUES AT POSITION F**

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**PRESSURE COEFFICIENTS:**

| Tp   | 0.2478549 |
| C0   | 0.4654725 |
| C0'  | 0.1153696 |
| C0+  | 0.5826167 |
| C0-  | -0.3447778 |

**CALCULATED VALUES AT POSITION C**

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**PRESSURE COEFFICIENTS:**

| Tp   | 0.1994917 |
| C0   | 0.6984305 |
| C0'  | 0.139331 |
| C0+  | 0.7707851 |
| C0-  | -0.4481667 |

**ALL PRESSURE MEASUREMENTS IN METRES**
### DISCHARGE (m³/s)

6.67600E-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

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#### ALL PRESSURE MEASUREMENTS IN METRES

---

A.4
DISCHARGE (m3/s) 0.04466
NUMBER OF BOARDS 4
HEIGHT OF OUTLET (m) 0.698
PLUNGE POOL LEVEL (m) 0.802
WATER TEMPERATURE (C) 9.100001

LENGTH OF JET IN AIR (m) 1.9
LENGTH OF JET IN WATER (m) 0.698
VELOCITY IN NOZZLE (m/s) 3.332836
VELOCITY AT PLUNGE POOL (m/s) 3.332836

CALculated VALUES AT POSITION A

MEAN DYNAMIC PRESSURE : -0.3890007
MAX POSITIVE PRESSURE FLUCTUATION : 0.352
MAX NEGATIVE PRESSURE FLUCTUATION : -0.302
PRESSURE COEFFICIENTS:

Tp : -0.2287914
Cp : -0.6868929
Cp' : -0.1571532
Cp+ : -0.6215576
Cp- : -0.5332681

CALculated VALUES AT POSITION B

MEAN DYNAMIC PRESSURE : -0.1790007
MAX POSITIVE PRESSURE FLUCTUATION : 0.378
MAX NEGATIVE PRESSURE FLUCTUATION : -0.201
PRESSURE COEFFICIENTS:

Tp : -0.3631271
Cp : -0.3160774
Cp' : -0.1147763
Cp+ : -0.667468
Cp- : -0.5349236

CALculated VALUES AT POSITION F

MEAN DYNAMIC PRESSURE : -0.2620007
MAX POSITIVE PRESSURE FLUCTUATION : 0.354
MAX NEGATIVE PRESSURE FLUCTUATION : -0.277
PRESSURE COEFFICIENTS:

Tp : -0.263581
Cp : -0.626378
Cp' : -0.121894
Cp+ : -0.629891
Cp- : -0.4891235

CALculated VALUES AT POSITION C

MEAN DYNAMIC PRESSURE : -0.4270007
MAX POSITIVE PRESSURE FLUCTUATION : -0.375
MAX NEGATIVE PRESSURE FLUCTUATION : -0.366
PRESSURE COEFFICIENTS:

Tp : -0.2068887
Cp : -0.7599929
Cp' : -0.1553894
Cp+ : -0.6621707
Cp- : -0.6462786

ALL PRESSURE MEASUREMENTS IN METRES

A.5
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 := 5.131663E-02
Cp := 1.314327
Cp' := 6.744666E-02
Cp+ := .2382827
Cp- := -.3603083

ALL PRESSURE MEASUREMENTS IN N/m²
<table>
<thead>
<tr>
<th>DISCHARGE (m³/s)</th>
<th>6.676001E-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUMBER OF BOARDS</td>
<td>2</td>
</tr>
<tr>
<td>HEIGHT OF OUTLET (m)</td>
<td>.283</td>
</tr>
<tr>
<td>PLUNGE POOL LEVEL (m)</td>
<td>.405</td>
</tr>
<tr>
<td>WATER TEMPERATURE (°C)</td>
<td>9.7</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
<th>:= 1.636</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
<td>:= .3590002</td>
</tr>
<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION</td>
<td>:= -.3539999</td>
</tr>
</tbody>
</table>

PRESSURE COEFFICIENTS:

\[
\begin{align*}
T_p & := 5.012225E-02 \\
C_p & := 1.292786 \\
C_{p'} & := 6.479735E-02 \\
C_{p^+} & := .2836861 \\
C_{p^-} & := -.2797348
\end{align*}
\]

### CALCULATED VALUES AT POSITION B

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
<th>:= .4790004</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
<td>:= .336</td>
</tr>
<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION</td>
<td>:= -.29</td>
</tr>
</tbody>
</table>

PRESSURE COEFFICIENTS:

\[
\begin{align*}
T_p & := .1503131 \\
C_p & := .3785116 \\
C_{p'} & := 5.689523E-02 \\
C_{p^+} & := .2655111 \\
C_{p^-} & := -.2291614
\end{align*}
\]

### CALCULATED VALUES AT POSITION C

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
<th>:= 1.668</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
<td>:= .3770001</td>
</tr>
<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION</td>
<td>:= -.5489999</td>
</tr>
</tbody>
</table>

PRESSURE COEFFICIENTS:

\[
\begin{align*}
T_p & := 5.635491E-02 \\
C_p & := 1.318073 \\
C_{p'} & := 7.427989E-02 \\
C_{p^+} & := .2979098 \\
C_{p^-} & := -.4338261
\end{align*}
\]

### CALCULATED VALUES AT POSITION D

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
<th>:= .4550004</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
<td>:= .533</td>
</tr>
<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION</td>
<td>:= -.365</td>
</tr>
</tbody>
</table>

PRESSURE COEFFICIENTS:

\[
\begin{align*}
T_p & := .1934085 \\
C_p & := .3595466 \\
C_{p'} & := 6.953662E-02 \\
C_{p^+} & := .4211828 \\
C_{p^-} & := -.2884272
\end{align*}
\]

### CALCULATED VALUES AT POSITION F

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
<th>:= .7000003</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
<td>:= .646</td>
</tr>
<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION</td>
<td>:= -.454</td>
</tr>
</tbody>
</table>

PRESSURE COEFFICIENTS:

\[
\begin{align*}
T_p & := .1692307 \\
C_p & := .6163653 \\
C_{p'} & := .1043079 \\
C_{p^+} & := .5104767 \\
C_{p^-} & := -.358756
\end{align*}
\]

ALL PRESSURE MEASUREMENTS IN METRES
DISCHARGE (m³/s): 0.04466

NUMBER OF BOARDS: 2

HEIGHT OF OUTLET (m): 0.283

PLUNGE POOL LEVEL (m): 0.4

WATER TEMPERATURE (°C): 9.8

LENGTH OF JET IN AIR (m): 0.263

LENGTH OF JET IN WATER (m): 0.283

VELOCITY IN NOZZLE (m/s): 3.332836

VELOCITY AT PLUNGE POOL (m/s): 3.332836

### Calculated Values at Position A

**Mean Dynamic Pressure:** 0.6970003

**Max Positive Pressure Fluctuation:** 0.161

**Max Negative Pressure Fluctuation:** -0.176

**Pressure Coefficients:**

\[
\begin{align*}
T_p & = 5.308637E-02 \\
C_p & = 1.250755 \\
C_p' & = 6.533418E-02 \\
C_p^+ & = 0.284292 \\
C_p^- & = -0.310786
\end{align*}
\]

### Calculated Values at Position B

**Mean Dynamic Pressure:** 0.1830003

**Max Positive Pressure Fluctuation:** 0.19

**Max Negative Pressure Fluctuation:** -0.111

**Pressure Coefficients:**

\[
\begin{align*}
T_p & = 0.185792 \\
C_p & = 0.323399 \\
C_p' & = 6.003681E-02 \\
C_p^+ & = 0.355499 \\
C_p^- & = -0.1960025
\end{align*}
\]

### Calculated Values at Position C

**Mean Dynamic Pressure:** 0.7350003

**Max Positive Pressure Fluctuation:** 0.166

**Max Negative Pressure Fluctuation:** -0.212

**Pressure Coefficients:**

\[
\begin{align*}
T_p & = 5.714283E-02 \\
C_p & = 1.297855 \\
C_p' & = 7.416312E-02 \\
C_p^+ & = 0.2931209 \\
C_p^- & = -0.3743472
\end{align*}
\]

### Calculated Values at Position D

**Mean Dynamic Pressure:** 0.1790003

**Max Positive Pressure Fluctuation:** 0.02

**Max Negative Pressure Fluctuation:** -0.144

**Pressure Coefficients:**

\[
\begin{align*}
T_p & = 0.201117 \\
C_p & = 0.3160767 \\
C_p' & = 6.356838E-02 \\
C_p^+ & = -0.3531577 \\
C_p^- & = -0.2542735
\end{align*}
\]

### Calculated Values at Position F

**Mean Dynamic Pressure:** 0.3400003

**Max Positive Pressure Fluctuation:** 0.077

**Max Negative Pressure Fluctuation:** -0.212

**Pressure Coefficients:**

\[
\begin{align*}
T_p & = 0.1676469 \\
C_p & = 0.6005687 \\
C_p' & = 0.1006499 \\
C_p^+ & = 0.4891234 \\
C_p^- & = -0.3743472
\end{align*}
\]

**All Pressure Measurements in Metres**

---

A.8
### Calculated Values at Position A

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Dynamic Pressure</td>
<td>1.645001</td>
</tr>
<tr>
<td>Max Positive Pressure Fluctuation</td>
<td>2.313</td>
</tr>
<tr>
<td>Max Negative Pressure Fluctuation</td>
<td>-1.554</td>
</tr>
</tbody>
</table>

**Pressure Coefficients:**

- $T_p = 0.3191488$
- $C_p = 0.5915938$
- $C_p' = 0.1888065$
- $C_{p+} = 0.8316273$
- $C_{p-} = -0.5588671$

### Calculated Values at Position B

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Dynamic Pressure</td>
<td>1.137001</td>
</tr>
<tr>
<td>Max Positive Pressure Fluctuation</td>
<td>2.369</td>
</tr>
<tr>
<td>Max Negative Pressure Fluctuation</td>
<td>-1.198</td>
</tr>
</tbody>
</table>

**Pressure Coefficients:**

- $T_p = 0.4019347$
- $C_p = 0.4089011$
- $C_p' = 0.1643515$
- $C_{p+} = 0.8519665$
- $C_{p-} = -0.4308384$

### Calculated Values at Position C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Dynamic Pressure</td>
<td>2.005001</td>
</tr>
<tr>
<td>Max Positive Pressure Fluctuation</td>
<td>4.164</td>
</tr>
<tr>
<td>Max Negative Pressure Fluctuation</td>
<td>-2.797</td>
</tr>
</tbody>
</table>

**Pressure Coefficients:**

- $T_p = 0.3265101$
- $C_p = 0.7203418$
- $C_p' = 0.2351989$
- $C_{p+} = 1.497505$
- $C_{p-} = -1.005889$

### Calculated Values at Position D

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Dynamic Pressure</td>
<td>1.366001</td>
</tr>
<tr>
<td>Max Positive Pressure Fluctuation</td>
<td>2.271</td>
</tr>
<tr>
<td>Max Negative Pressure Fluctuation</td>
<td>-1.339</td>
</tr>
</tbody>
</table>

**Pressure Coefficients:**

- $T_p = 0.3887261$
- $C_p = 0.4912566$
- $C_p' = 0.1909643$
- $C_{p+} = 0.8167228$
- $C_{p-} = -0.4015464$

### Calculated Values at Position F

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Dynamic Pressure</td>
<td>1.166001</td>
</tr>
<tr>
<td>Max Positive Pressure Fluctuation</td>
<td>1.951</td>
</tr>
<tr>
<td>Max Negative Pressure Fluctuation</td>
<td>-1.083</td>
</tr>
</tbody>
</table>

**Pressure Coefficients:**

- $T_p = 0.3396225$
- $C_p = 0.4193304$
- $C_p' = 0.142414$
- $C_{p+} = 0.7016408$
- $C_{p-} = -0.3894807$

---

**ALL PRESSURE MEASUREMENTS IN METRES**

---

A.9
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge (m³/s)</td>
<td>6.67600E-02</td>
</tr>
<tr>
<td>Number of boards</td>
<td>4</td>
</tr>
<tr>
<td>Height of outlet (m)</td>
<td>1.307</td>
</tr>
<tr>
<td>Plunge pool level (m)</td>
<td>0.785</td>
</tr>
<tr>
<td>Water temperature (°C)</td>
<td>0</td>
</tr>
<tr>
<td>Length of jet in air (m)</td>
<td>0.522</td>
</tr>
<tr>
<td>Length of jet in water (m)</td>
<td>0.785</td>
</tr>
<tr>
<td>Velocity in nozzle (m/s)</td>
<td>4.90209</td>
</tr>
<tr>
<td>Velocity at plunge pool (m/s)</td>
<td>5.921126</td>
</tr>
</tbody>
</table>

**Calculated Values at Position A**

- Mean dynamic pressure: 0.7850006
- Max positive pressure fluctuation: 1.311
- Max negative pressure fluctuation: -0.5700001

Pressure Coefficients:

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tp</td>
<td>0.305732</td>
</tr>
<tr>
<td>Cp</td>
<td>0.4391653</td>
</tr>
<tr>
<td>Cp'</td>
<td>0.134267</td>
</tr>
<tr>
<td>Cp+</td>
<td>0.7354335</td>
</tr>
<tr>
<td>Cp-</td>
<td>-0.323597</td>
</tr>
</tbody>
</table>

**Calculated Values at Position B**

- Mean dynamic pressure: 0.5850006
- Max positive pressure fluctuation: 1.063
- Max negative pressure fluctuation: -0.527

Pressure Coefficients:

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tp</td>
<td>0.3623928</td>
</tr>
<tr>
<td>Cp</td>
<td>0.3272761</td>
</tr>
<tr>
<td>Cp'</td>
<td>0.1186025</td>
</tr>
<tr>
<td>Cp+</td>
<td>0.594691</td>
</tr>
<tr>
<td>Cp-</td>
<td>-0.294828</td>
</tr>
</tbody>
</table>

**Calculated Values at Position C**

- Mean dynamic pressure: 0.8500006
- Max positive pressure fluctuation: 1.347
- Max negative pressure fluctuation: -0.711

Pressure Coefficients:

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tp</td>
<td>0.3458821</td>
</tr>
<tr>
<td>Cp</td>
<td>0.4755292</td>
</tr>
<tr>
<td>Cp'</td>
<td>0.1644171</td>
</tr>
<tr>
<td>Cp+</td>
<td>0.7535736</td>
</tr>
<tr>
<td>Cp-</td>
<td>-0.3977659</td>
</tr>
</tbody>
</table>

**Calculated Values at Position D**

- Mean dynamic pressure: 0.6170005
- Max positive pressure fluctuation: 1.219
- Max negative pressure fluctuation: -1.42

Pressure Coefficients:

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tp</td>
<td>0.3987031</td>
</tr>
<tr>
<td>Cp</td>
<td>0.3451783</td>
</tr>
<tr>
<td>Cp'</td>
<td>0.1376237</td>
</tr>
<tr>
<td>Cp+</td>
<td>0.6819645</td>
</tr>
<tr>
<td>Cp-</td>
<td>-0.794413</td>
</tr>
</tbody>
</table>

**Calculated Values at Position F**

- Mean dynamic pressure: 0.5360006
- Max positive pressure fluctuation: 0.952
- Max negative pressure fluctuation: -0.462

Pressure Coefficients:

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tp</td>
<td>0.3600743</td>
</tr>
<tr>
<td>Cp</td>
<td>0.2998633</td>
</tr>
<tr>
<td>Cp'</td>
<td>0.107973</td>
</tr>
<tr>
<td>Cp+</td>
<td>0.5325925</td>
</tr>
<tr>
<td>Cp-</td>
<td>-0.2584639</td>
</tr>
</tbody>
</table>

**All Pressure Measurements in Metres**
### Calculated Values at Position A

- **Mean Dynamic Pressure**: 0.377006
- **Max Positive Pressure Fluctuation**: 0.459001
- **Max Negative Pressure Fluctuation**: -1.192
- **Pressure Coefficients**:
  - \( T_p \): 0.281167
  - \( C_p \): 0.344822
  - \( C_p' \): 8.39251E-02
  - \( C_p^+ \): 0.419822
  - \( C_p^- \): -1.090258

### Calculated Values at Position B

- **Mean Dynamic Pressure**: 0.268006
- **Max Positive Pressure Fluctuation**: 0.535
- **Max Negative Pressure Fluctuation**: -0.276
- **Pressure Coefficients**:
  - \( T_p \): 0.3470142
  - \( C_p \): 0.2451258
  - \( C_p' \): 8.50211E-02
  - \( C_p^+ \): 0.4893558
  - \( C_p^- \): -0.2524423

### Calculated Values at Position C

- **Mean Dynamic Pressure**: 0.336007
- **Max Positive Pressure Fluctuation**: 0.4929999
- **Max Negative Pressure Fluctuation**: -0.2480001
- **Pressure Coefficients**:
  - \( T_p \): 0.3124994
  - \( C_p \): 0.3073218
  - \( C_p' \): 9.603786E-02
  - \( C_p^+ \): 0.4509206
  - \( C_p^- \): -0.2268324

---

### Calculated Values at Position D

- **Mean Dynamic Pressure**: 0.2430006
- **Max Positive Pressure Fluctuation**: 0.666
- **Max Negative Pressure Fluctuation**: -0.226
- **Pressure Coefficients**:
  - \( T_p \): 0.307151
  - \( C_p \): 0.2222596
  - \( C_p' \): 8.50211E-02
  - \( C_p^+ \): 0.6091545
  - \( C_p^- \): -0.207101

### Calculated Values at Position F

- **Mean Dynamic Pressure**: 0.2270006
- **Max Positive Pressure Fluctuation**: 0.4450001
- **Max Negative Pressure Fluctuation**: -0.225
- **Pressure Coefficients**:
  - \( T_p \): 0.3612326
  - \( C_p \): 0.2076253
  - \( C_p' \): 0.075001
  - \( C_p^+ \): 0.4070177
  - \( C_p^- \): -0.2057954

---

**All pressure measurements in metres**
DISCHARGE (m³/s) 0.08909
NUMBER OF BOARDS 2
HEIGHT OF OUTLET (m) 1.307
PLUNGE POOL LEVEL (m) 0.425
WATER TEMPERATURE (°C) 0

LENGTH OF JET IN AIR (m) 0.882
LENGTH OF JET IN WATER (m) 0.425
VELOCITY IN NOZZLE (m/s) 6.648508
VELOCITY AT PLUNGE POOL (m/s) 7.842334

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE 3.545
MAX POSITIVE PRESSURE FLUCTUATION 0.993
MAX NEGATIVE PRESSURE FLUCTUATION -2.388
PRESSURE COEFFICIENTS:
Tp = 8.693190E-02
Cp = 1.129919
Cp' = 9.822604E-02
Cp+ = 0.166833
Cp- = -0.761508

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE 1.605
MAX POSITIVE PRESSURE FLUCTUATION 1.804
MAX NEGATIVE PRESSURE FLUCTUATION -1.434
PRESSURE COEFFICIENTS:
Tp = 0.252074
Cp = 0.511222
Cp' = 0.120842
Cp+ = 0.575324
Cp- = -0.4573252

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE 3.710001
MAX POSITIVE PRESSURE FLUCTUATION 0.987
MAX NEGATIVE PRESSURE FLUCTUATION -2.391
PRESSURE COEFFICIENTS:
Tp = 8.113266E-02
Cp = 1.183178
Cp' = 9.599363E-02
Cp+ = 0.3147698
Cp- = -0.7625276

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE 1.554
MAX POSITIVE PRESSURE FLUCTUATION 1.007
MAX NEGATIVE PRESSURE FLUCTUATION -1.322
PRESSURE COEFFICIENTS:
Tp = 0.2406692
Cp = 0.4955952
Cp' = 0.1197745
Cp+ = 0.5762807
Cp- = -0.4216066

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE 1.213
MAX POSITIVE PRESSURE FLUCTUATION 1.81
MAX NEGATIVE PRESSURE FLUCTUATION -0.968
PRESSURE COEFFICIENTS:
Tp = 0.273413
Cp = 0.3868449
Cp' = 6.426166E-02
Cp+ = 0.577275
Cp- = -0.3087104

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) := 4.90209

### VELOCITY AT PLUNGE POOL (m/s) := 6.538227

**CALCULATED VALUES AT POSITION A**

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
<th>1.892</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
<td>1.106</td>
</tr>
<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION</td>
<td>-1.538</td>
</tr>
</tbody>
</table>

**PRESSURE COEFFICIENTS:**

- $T_p := .1707188$
- $C_p := .68096$
- $C_p' := .1482003$
- $C_p^+ := .5074598$
- $C_p^- := -.705672$

**CALCULATED VALUES AT POSITION B**

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
<th>.3950003</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
<td>1.32</td>
</tr>
<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION</td>
<td>-1.602</td>
</tr>
</tbody>
</table>

**PRESSURE COEFFICIENTS:**

- $T_p := .4329111$
- $C_p := .1812356$
- $C_p' := 7.845898E-02$
- $C_p^+ := .6056483$
- $C_p^- := -.2762123$

**CALCULATED VALUES AT POSITION C**

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
<th>2.117</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
<td>2.392</td>
</tr>
<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION</td>
<td>-1.747</td>
</tr>
</tbody>
</table>

**PRESSURE COEFFICIENTS:**

- $T_p := .1606046$
- $C_p := .9713215$
- $C_p' := .1560005$
- $C_p^+ := 1.097508$
- $C_p^- := -.8015663$

**CALCULATED VALUES AT POSITION D**

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
<th>.6170003</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
<td>1.453</td>
</tr>
<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION</td>
<td>-1.042</td>
</tr>
</tbody>
</table>

**PRESSURE COEFFICIENTS:**

- $T_p := .3987033$
- $C_p := .2830948$
- $C_p' := .1128708$
- $C_p^+ := .666672$
- $C_p^- := -.478095$

**CALCULATED VALUES AT POSITION F**

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
<th>1.163</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
<td>1.197</td>
</tr>
<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION</td>
<td>-1.573</td>
</tr>
</tbody>
</table>

**PRESSURE COEFFICIENTS:**

- $T_p := .3000859$
- $C_p := .533643$
- $C_p' := .1601297$
- $C_p^+ := .5492129$
- $C_p^- := -.7217508$

*ALL PRESSURE MEASUREMENTS IN METRES*
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Position A</th>
<th>Position B</th>
<th>Position C</th>
<th>Position D</th>
<th>Position F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Discharge (m³/s)</strong></td>
<td>0.04466</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Number of boards</strong></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Height of outlet (m)</strong></td>
<td>1.307</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Plunge pool level (m)</strong></td>
<td>0.388</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Water temperature (°C)</strong></td>
<td>6.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Length of jet in air (m)</strong></td>
<td>0.919</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Length of jet in water (m)</strong></td>
<td>0.388</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Velocity in nozzle (m/s)</strong></td>
<td>3.32836</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Velocity at plunge pool (m/s)</strong></td>
<td>5.397506</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Calculated Values at Position A**

- **Mean Dynamic Pressure**: 0.7180005
- **Max Positive Pressure Fluctuation**: 1.067
- **Max Negative Pressure Fluctuation**: -0.781

**Pressure Coefficients**

- \( T_p \): 0.5774372
- \( C_p \): 0.4835081
- \( C_{p'} \): 0.1824526
- \( C_{p^+} \): 0.7183645
- \( C_{p^-} \): -0.5258131

**Calculated Values at Position B**

- **Mean Dynamic Pressure**: 0.2150003
- **Max Positive Pressure Fluctuation**: 0.955
- **Max Negative Pressure Fluctuation**: -0.498

**Pressure Coefficients**

- \( T_p \): 0.679069
- \( C_p \): 0.1447503
- \( C_{p'} \): 9.829541E-02
- \( C_{p^+} \): 0.6429596
- \( C_{p^-} \): -0.3352816

**Calculated Values at Position C**

- **Mean Dynamic Pressure**: 0.8720002
- **Max Positive Pressure Fluctuation**: 2.504
- **Max Negative Pressure Fluctuation**: -0.985

**Pressure Coefficients**

- \( T_p \): 0.3658256
- \( C_p \): 0.5870796
- \( C_{p'} \): 0.2147688
- \( C_{p^+} \): 1.66718
- \( C_{p^-} \): -0.6631574

**Calculated Values at Position D**

- **Mean Dynamic Pressure**: 0.4200003
- **Max Positive Pressure Fluctuation**: 1.053
- **Max Negative Pressure Fluctuation**: -0.579

**Pressure Coefficients**

- \( T_p \): 0.5142853
- \( C_p \): 0.2827678
- \( C_{p'} \): 0.1454233
- \( C_{p^+} \): 0.7089388
- \( C_{p^-} \): -0.3890153

**Calculated Values at Position F**

- **Mean Dynamic Pressure**: 0.4790003
- **Max Positive Pressure Fluctuation**: 1.062
- **Max Negative Pressure Fluctuation**: -0.539

**Pressure Coefficients**

- \( T_p \): 0.4405008
- \( C_p \): 0.3224899
- \( C_{p'} \): 0.1420571
- \( C_{p^+} \): 0.7145981
- \( C_{p^-} \): -0.3628851

**All Pressure Measurements in Metres**
<table>
<thead>
<tr>
<th>Transaction</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transaction 1</td>
<td>$123.45</td>
</tr>
<tr>
<td>Transaction 2</td>
<td>$67.89</td>
</tr>
<tr>
<td>Transaction 3</td>
<td>$90.12</td>
</tr>
</tbody>
</table>

**CALculated VALUES AT POSITION A**

- Mean Dynamic Pressure: 3.906
- Max Positive Pressure Fluctuation: 1.092
- Max Negative Pressure Fluctuation: -3.908

**Pressure Coefficients:**

- $T_p = 8.294931E-02$
- $C_p = 1.096999$
- $C_p' = 9.099531E-02$
- $C_p" = 0.806888$
- $C_p"' = -1.097561$

**CALculated VALUES AT POSITION B**

- Mean Dynamic Pressure: 2.345
- Max Positive Pressure Fluctuation: 1.973
- Max Negative Pressure Fluctuation: -2.362

**Pressure Coefficients:**

- $T_p = 0.1641791$
- $C_p = 0.6585926$
- $C_p' = 0.1081271$
- $C_p" = 0.5541166$
- $C_p"' = -0.6635671$

**CALculated VALUES AT POSITION C**

- Mean Dynamic Pressure: 4.068
- Max Positive Pressure Fluctuation: 1.054
- Max Negative Pressure Fluctuation: -1.966

**Pressure Coefficients:**

- $T_p = 9.046215E-02$
- $C_p = 1.142497$
- $C_p' = 0.1033527$
- $C_p" = 0.2960157$
- $C_p"' = -0.5521505$

**CALculated VALUES AT POSITION D**

- Mean Dynamic Pressure: 2.117
- Max Positive Pressure Fluctuation: 1.806
- Max Negative Pressure Fluctuation: -1.483

**Pressure Coefficients:**

- $T_p = 0.1719414$
- $C_p = 0.5945509$
- $C_p' = 0.1022993$
- $C_p" = 0.5072146$
- $C_p"' = -0.4165002$

**CALculated VALUES AT POSITION F**

- Mean Dynamic Pressure: 1.749
- Max Positive Pressure Fluctuation: 2.176
- Max Negative Pressure Fluctuation: -1.194

**Pressure Coefficients:**

- $T_p = 0.2264151$
- $C_p = 0.4912062$
- $C_p' = 0.1112165$
- $C_p" = 0.611129$
- $C_p"' = -0.3353346$

**All Pressure Measurements in Meters**

---

A.15
DISCHARGE (m³/s) 6.67600E-02

NUMBER OF BORDS 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) 4.90209

VELOCITY AT PLUNGE POOL (m/s) 7.103289

CALCULATED VALUES AT POSITION A

MEAN DYNAMIC PRESSURE 2.409
MAX POSITIVE PRESSURE FLUCTUATION .9990002
MAX NEGATIVE PRESSURE FLUCTUATION 1.166

PRESSURE COEFFICIENTS:
Tp : .1008717
Cp : .5364495
Cp' : 9.446129E-02
Cp^ : .5335553
Cp^- : -.4532587

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE 0
MAX POSITIVE PRESSURE FLUCTUATION 0
MAX NEGATIVE PRESSURE FLUCTUATION 0

PRESSURE COEFFICIENTS:
Tp : 1.70412E+38
Cp : 0
Cp' : 0
Cp^ : 0
Cp^- : 0

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 : .1559369
Cp' : 4.353722E-02
Cp^ : .4287687
Cp^- : -.1570242

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' : 1.243935
Cp^ : .4761938
Cp^- : -.4450954

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 : 1.0000201
Cp' : 9.951478E-02
Cp^ : 9.100016
Cp^- : -.4361546

ALL PRESSURE MEASUREMENTS IN METRES
Discharge (m³/s) = 0.0446
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 = 0.741
Max Negative Pressure Fluctuation = -0.831
Pressure Coefficients:

- $T_p = 0.1183746$
- $C_p = 0.9064129$
- $C_p' = 0.1072646$
- $C_p^+ = 0.3955548$
- $C_p^- = -0.4453979$

**Calculated Values at Position B**

Mean Dynamic Pressure = 0.215
Max Positive Pressure Fluctuation = 0.389
Max Negative Pressure Fluctuation = -0.337
Pressure Coefficients:

- $T_p = 0.3255814$
- $C_p = 0.1147696$
- $C_p' = 3.736685E-02$
- $C_p^+ = 0.2076529$
- $C_p^- = -0.1799476$

**Calculated Values at Position C**

Mean Dynamic Pressure = 1.817
Max Positive Pressure Fluctuation = 0.715001
Max Negative Pressure Fluctuation = -0.939
Pressure Coefficients:

- $T_p = 0.1012658$
- $C_p = 0.9693646$
- $C_p' = 9.822143E-02$
- $C_p^+ = 0.3816757$
- $C_p^- = -0.5012496$

**Calculated Values at Position D**

Mean Dynamic Pressure = 0.23
Max Positive Pressure Fluctuation = 0.531
Max Negative Pressure Fluctuation = -0.33
Pressure Coefficients:

- $T_p = 0.3130435$
- $C_p = 0.1227768$
- $C_p' = 3.843447E-02$
- $C_p^+ = 0.2834524$
- $C_p^- = -0.176158$

**Calculated Values at Position F**

Mean Dynamic Pressure = 1.036
Max Positive Pressure Fluctuation = 1.458
Max Negative Pressure Fluctuation = -0.879
Pressure Coefficients:

- $T_p = 0.2028186$
- $C_p = 0.530294$
- $C_p' = 0.156407$
- $C_p^+ = 0.778298$
- $C_p^- = -0.4692209$

All Pressure Measurements in Metres
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge (m³/s)</td>
<td>6.676001E-02</td>
</tr>
<tr>
<td>True Air Concentration %</td>
<td>9.835805</td>
</tr>
<tr>
<td>Number of Booms</td>
<td>4</td>
</tr>
<tr>
<td>Height of Outlet (m)</td>
<td>0.698</td>
</tr>
<tr>
<td>Plunge Pool Level (m)</td>
<td>0.815</td>
</tr>
<tr>
<td>Water Temperature (°C)</td>
<td>9.399999</td>
</tr>
<tr>
<td>Air Temperature (°C)</td>
<td>0.7</td>
</tr>
<tr>
<td>Air Pressure (mBars)</td>
<td>1028</td>
</tr>
<tr>
<td>Length of Jet in Air (m)</td>
<td></td>
</tr>
<tr>
<td>Length of Jet in Water (m)</td>
<td>0.698</td>
</tr>
<tr>
<td>Velocity in Nozzle (m/s)</td>
<td>5.525575</td>
</tr>
<tr>
<td>Velocity at Plunge Pool (m/s)</td>
<td>5.525575</td>
</tr>
</tbody>
</table>

**Calculated Values at Position A**

| Mean Dynamic Pressure                    | 1.019001           |
| Max Positive Pressure Fluctuation        | 0.870999           |
| Max Negative Pressure Fluctuation        | 0.716              |
| Pressure Coefficients:                   |                    |
|  \( T_p \)                              | 0.2345435          |
|  \( C_p \)                              | 0.6546153          |
|  \( C_p' \)                             | 0.153538           |
|  \( C_p^+ \)                            | 0.5595383          |
|  \( C_p^- \)                            | -0.4599649         |

**Calculated Values at Position B**

| Mean Dynamic Pressure                    | 0.3820007          |
| Max Positive Pressure Fluctuation        | 0.9990001          |
| Max Negative Pressure Fluctuation        | -0.439             |
| Pressure Coefficients:                   |                    |
|  \( T_p \)                              | 0.3769627          |
|  \( C_p \)                              | 0.2454007          |
|  \( C_p' \)                             | 0.0925069          |
|  \( C_p^+ \)                            | 0.6417667          |
|  \( C_p^- \)                            | -0.2820176         |

**Calculated Values at Position C**

| Mean Dynamic Pressure                    | 0.8980007          |
| Max Positive Pressure Fluctuation        | 0.9040001          |
| Max Negative Pressure Fluctuation        | -0.6880001         |
| Pressure Coefficients:                   |                    |
|  \( T_p \)                              | 0.2449867          |
|  \( C_p \)                              | 0.5768038          |
|  \( C_p' \)                             | 0.14133            |
|  \( C_p^+ \)                            | 0.5807378          |
|  \( C_p^- \)                            | -0.4419775         |

**Calculated Values at Position D**

| Mean Dynamic Pressure                    | 0.3010007          |
| Max Positive Pressure Fluctuation        | 0.967              |
| Max Negative Pressure Fluctuation        | -0.3850001         |
| Pressure Coefficients:                   |                    |
|  \( T_p \)                              | 0.4318927          |
|  \( C_p \)                              | 0.1953656          |
|  \( C_p' \)                             | 0.351317E-02       |
|  \( C_p^+ \)                            | 0.5559686          |
|  \( C_p^- \)                            | -0.2473275         |

**Calculated Values at Position E**

| Mean Dynamic Pressure                    | 0.5110007          |
| Max Positive Pressure Fluctuation        | 0.728              |
| Max Negative Pressure Fluctuation        | -0.548             |
| Pressure Coefficients:                   |                    |
|  \( T_p \)                              | 0.317025           |
|  \( C_p \)                              | 0.3282714          |
|  \( C_p' \)                             | 0.1040703          |
|  \( C_p^+ \)                            | -0.4612497         |
|  \( C_p^- \)                            | -0.3520402         |

**All Pressure Measurements in Metres**
DISCHARGE (m3/s)  .04466

TRUE AIR CONCENTRATION %  9.853143

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  := .2061532
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- := -.3947118

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 (m^3/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 | :- -.4800001 |

PRESSURE COEFFICIENTS:

\[
\begin{align*}
T_p & :- 5.651237E-02 \\
C_p & :- 1.195128 \\
C_p' & :- 6.742646E-02 \\
C_p\pi & :- .2825491 \\
C_p\pi' & :- -.3135726 \\
\end{align*}
\]

CALCULATED VALUES AT POSITION B

| MEAN DYNAMIC PRESSURE | :- .5530003 |
| MAX POSITIVE PRESSURE FLUCTUATION | :- .45 |
| MAX NEGATIVE PRESSURE FLUCTUATION | :- -.3 |

PRESSURE COEFFICIENTS:

\[
\begin{align*}
T_p & :- .148282 \\
C_p & :- .355113 \\
C_p' & :- 5.265687E-02 \\
C_p\pi & :- .2889706 \\
C_p\pi' & :- -.1926471 \\
\end{align*}
\]

CALCULATED VALUES AT POSITION C

| MEAN DYNAMIC PRESSURE | :- 1.72 |
| MAX POSITIVE PRESSURE FLUCTUATION | :- .457 |
| MAX NEGATIVE PRESSURE FLUCTUATION | :- -.5240001 |

PRESSURE COEFFICIENTS:

\[
\begin{align*}
T_p & :- .062093 \\
C_p & :- 1.10451 \\
C_p' & :- 6.81078E-02 \\
C_p\pi & :- .2934657 \\
C_p\pi' & :- -.3364982 \\
\end{align*}
\]

CALCULATED VALUES AT POSITION D

| MEAN DYNAMIC PRESSURE | :- .4600004 |
| MAX POSITIVE PRESSURE FLUCTUATION | :- .5000001 |
| MAX NEGATIVE PRESSURE FLUCTUATION | :- -.276 |

PRESSURE COEFFICIENTS:

\[
\begin{align*}
T_p & :- .1826086 \\
C_p & :- .2953924 \\
C_p' & :- 5.394118E-02 \\
C_p\pi & :- .3262157 \\
C_p\pi' & :- -.1772353 \\
\end{align*}
\]

CALCULATED VALUES AT POSITION F

| MEAN DYNAMIC PRESSURE | :- .8100004 |
| MAX POSITIVE PRESSURE FLUCTUATION | :- .565 |
| MAX NEGATIVE PRESSURE FLUCTUATION | :- -.5160001 |

PRESSURE COEFFICIENTS:

\[
\begin{align*}
T_p & :- .1703703 \\
C_p & :- .5201473 \\
C_p' & :- 8.861764E-02 \\
C_p\pi & :- .3628136 \\
C_p\pi' & :- -.331353 \\
\end{align*}
\]

ALL PRESSURE MEASUREMENTS IN METRES
### Calculated Values at Position A

**Mean Dynamic Pressure:** .8120003

**Max Positive Pressure Fluctuation:** .258

**Max Negative Pressure Fluctuation:** -.22

**Pressure Coefficients:**
- $T_p = 0.0689655$
- $C_p = 1.165145$
- $C_p' = 8.055489E-02$
- $C_{p+} = 0.3702062$
- $C_{p-} = -0.3156797$

### Calculated Values at Position B

**Mean Dynamic Pressure:** .2220003

**Max Positive Pressure Fluctuation:** .246

**Max Negative Pressure Fluctuation:** -.152

**Pressure Coefficients:**
- $T_p = 0.2117114$
- $C_p = 0.31855$
- $C_p' = 6.744666E-02$
- $C_{p+} = 0.381854$
- $C_{p-} = -0.218006$

### Calculated Values at Position C

**Mean Dynamic Pressure:** .7250003

**Max Positive Pressure Fluctuation:** .2570001

**Max Negative Pressure Fluctuation:** -.269

**Pressure Coefficients:**
- $T_p = 8.275859E-02$
- $C_p = 1.040309$
- $C_p' = 8.694466E-02$
- $C_{p+} = 0.368714$
- $C_{p-} = -0.385992$

---

**All Pressure Measurements in Metres**

A.21
| DISCHARGE (m³/s) | 6.67600E-02 |
| TRUE AIR CONCENTRATION | 9.87913 |
| NUMBER OF BOARDS | 4 |
| HEIGHT OF OUTLET (a) | 1.307 |
| PLUNGE POOL LEVEL (a) | .78 |
| WATER TEMPERATURE (°C) | 9.100001 |
| AIR TEMPERATURE (°C) | 8.3 |
| AIR PRESSURE (mBars) | 1018 |

LENGTH OF JET IN AIR (H) := .5270001
LENGTH OF JET IN WATER (H) := .78
VELOCITY IN NOZZLE (m/s) := 5.52705
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 := .3568402
  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' := .1072641
  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 E

MEAN DYNAMIC PRESSURE := .4840007
MAX POSITIVE PRESSURE FLUCTUATION := 1.184
MAX NEGATIVE PRESSURE FLUCTUATION := -.5450001
PRESSURE COEFFICIENTS:
  Tp := .4000259
  Cp := .2321433
  Cp' := 9.304904E-02
  Cp* := .5678669
  Cp- := -.2614007

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE := .4900008
MAX POSITIVE PRESSURE FLUCTUATION := 1.204
MAX NEGATIVE PRESSURE FLUCTUATION := -.5320001
PRESSURE COEFFICIENTS:
  Tp := .4220239
  Cp := .2201243
  Cp' := .9.304904E-02
  Cp* := .5678669
  Cp- := -.2614007

ALL PRESSURE MEASUREMENTS IN METRES
**DISCHARGE (m³/s)**: 0.04466

**TRUE AIR CONCENTRATION %**: 9.858001

**NUMBER OF BOARDS**: 4

**HEIGHT OF OUTLET (m)**: 1.307

**PLUNGE POOL LEVEL (m)**: 0.8

**WATER TEMPERATURE (°C)**: 9

**AIR TEMPERATURE (°C)**: 7.4

**AIR PRESSURE (mBars)**: 1018

---

**LENGTH OF JET IN AIR (H)**: 0.5070001

**LENGTH OF JET IN WATER (H)**: 0.8

**VELOCITY IN NOZZLE (m/s)**: 3.697317

**VELOCITY AT PLUNGE POOL (m/s)**: 4.859471

---

**CALCULATED VALUES AT POSITION A**

**MEAN DYNAMIC PRESSURE**: -0.1380007

**MAX POSITIVE PRESSURE FLUCTUATION**: -0.629

**MAX NEGATIVE PRESSURE FLUCTUATION**: -0.227

**PRESSURE COEFFICIENTS**: 

- $T_p = -0.6739096$
- $C_p = -0.1146225$
- $C_p' = -7.724322E-02$
- $C_p\# = -0.5224435$
- $C_p- = -0.1883448$

---

**CALCULATED VALUES AT POSITION B**

**MEAN DYNAMIC PRESSURE**: 6.000066E-02

**MAX POSITIVE PRESSURE FLUCTUATION**: -0.225

**MAX NEGATIVE PRESSURE FLUCTUATION**: -2.190001

**PRESSURE COEFFICIENTS**: 

- $T_p = -1.266453$
- $C_p = -4.902441E-02$
- $C_p' = -6.312512E-02$
- $C_p\# = -0.4717772$
- $C_p- = -0.1819001$

---

**CALCULATED VALUES AT POSITION C**

**MEAN DYNAMIC PRESSURE**: -0.1400006

**MAX POSITIVE PRESSURE FLUCTUATION**: -0.401

**MAX NEGATIVE PRESSURE FLUCTUATION**: -0.197

**PRESSURE COEFFICIENTS**: 

- $T_p = -0.3857116$
- $C_p = -0.1162837$
- $C_p' = -6.810809E-02$
- $C_p\# = -0.4991869$
- $C_p- = -0.163427$

---

**CALCULATED VALUES AT POSITION D**

**MEAN DYNAMIC PRESSURE**: 5.600066E-02

**MAX POSITIVE PRESSURE FLUCTUATION**: -0.4790001

**MAX NEGATIVE PRESSURE FLUCTUATION**: -0.158

**PRESSURE COEFFICIENTS**: 

- $T_p = -1.160701$
- $C_p = -4.651319E-02$
- $C_p' = -5.390859E-02$
- $C_p\# = -0.3978544$
- $C_p- = -0.1312338$

---

**CALCULATED VALUES AT POSITION F**

**MEAN DYNAMIC PRESSURE**: 6.200066E-02

**MAX POSITIVE PRESSURE FLUCTUATION**: -0.39

**MAX NEGATIVE PRESSURE FLUCTUATION**: -0.153

**PRESSURE COEFFICIENTS**: 

- $T_p = -0.9677321$
- $C_p = -5.149734E-02$
- $C_p' = -4.983562E-02$
- $C_p\# = -0.3239316$
- $C_p- = -0.1270808$

---

**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 :: .2104
MAX POSITIVE PRESSURE FLUCTUATION :: .9030001
MAX NEGATIVE PRESSURE FLUCTUATION :: -1.654
PRESSURE COEFFICIENTS:
Tp :: .154945
Cp :: .852309
Cₚ' :: -.132059
Cₚ+ :: .365792
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' :: 7.939741E-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 :: .1883102
Cp :: .8045005
Cₚ' :: -.1515036
Cₚ+ :: 1.047562
Cₚ- :: -.7028388

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' :: .1463274
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) | 8.89999 |
| AIR TEMPERATURE (°C) | 7.7 |
| AIR PRESSURE (mBar) | 1010 |

LENGTH OF JET IN AIR (m) | .917000 |
LENGTH OF JET IN WATER (m) | .79 |
VELOCITY IN NOZZLE (m/s) | 5.698954 |
VELOCITY AT PLUNGE POOL (m/s) | 5.627459 |

**CALCULATED VALUES AT POSITION A**

| MEAN DYNAMIC PRESSURE | .8630003 |
| MAX POSITIVE PRESSURE FLUCTUATION | .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+ | 1.07644 |
| Cp- | -.4630992 |

**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+ | .720328 |
| 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 | 9.882596 |
| NUMBER OF BOARDS | 0 |
| HEIGHT OF OUTLET (m) | 1.307 |
| WATER TEMPERATURE (°C) | 9.100001 |
| AIR TEMPERATURE (°C) | 8.899999 |
| AIR PRESSURE (mBar) | 1018 |

LENGTH OF JET IN AIR (m) := 1.367
LENGTH OF JET IN WATER (m) := 0
VELOCITY IN NOZZLE (m/s) := 5.528432
VELOCITY AT PLUNGING POOL (m/s) := 7.46681

### Calculated Values at Position A

**Mean Dynamic Pressure:** 2.581
**Max Positive Pressure Fluctuation:** 1.094
**Max Negative Pressure Fluctuation:** -1.26

**Pressure Coefficients:**
- \( T_p := .10577 \)
- \( C_p := .9087945 \)
- \( C_p' := 9.527949E-02 \)
- \( C_{p+} := .5818168 \)
- \( C_{p-} := -.4397525 \)

### Calculated Values at Position B

**Mean Dynamic Pressure:** 0.535
**Max Positive Pressure Fluctuation:** 1.815
**Max Negative Pressure Fluctuation:** -0.5080001

**Pressure Coefficients:**
- \( T_p := .3372103 \)
- \( C_p := .867203 \)
- \( C_p' := 6.212376E-02 \)
- \( C_{p+} := .634528 \)
- \( C_{p-} := -.77297 \)

### Calculated Values at Position C

**Mean Dynamic Pressure:** 2.328
**Max Positive Pressure Fluctuation:** 2.456
**Max Negative Pressure Fluctuation:** -1.162

**Pressure Coefficients:**
- \( T_p := .1162975 \)
- \( C_p := .882297 \)
- \( C_p' := .1026089 \)
- \( C_{p+} := .5871682 \)
- \( C_{p-} := -.4055495 \)

### Calculated Values at Position D

**Mean Dynamic Pressure:** 0.569
**Max Positive Pressure Fluctuation:** 1.605
**Max Negative Pressure Fluctuation:** -0.614

**Pressure Coefficients:**
- \( T_p := .3725035 \)
- \( C_p := .1985866 \)
- \( C_p' := .0739901 \)
- \( C_{p+} := .5601609 \)
- \( C_{p-} := -.2149901 \)

### Calculated Values at Position F

**Mean Dynamic Pressure:** 1.684
**Max Positive Pressure Fluctuation:** 1.553
**Max Negative Pressure Fluctuation:** -1.266

**Pressure Coefficients:**
- \( T_p := .2864323 \)
- \( C_p := .5879326 \)
- \( C_p' := .1225025 \)
- \( C_{p+} := .5420123 \)
- \( C_{p-} := -.4418465 \)

---

_ALL PRESSURE MEASUREMENTS IN METRES_
DISCHARGE (m³/s) : 0.04466

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 (Bars) : 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:

\[ T_p = 0.1766849 \]
\[ C_p = 0.8217134 \]
\[ C_p' = 0.1451043 \]
\[ C_p\beta = 0.5682645 \]
\[ C_p\alpha = -0.6720380 \]

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE : 0.278
MAX POSITIVE PRESSURE FLUCTUATION : 1.884
MAX NEGATIVE PRESSURE FLUCTUATION : -0.43

PRESSURE COEFFICIENTS:

\[ T_p = 0.5755396 \]
\[ C_p = 0.1386784 \]
\[ C_p' = 7.982644E-02 \]
\[ C_p\beta = 0.9399562 \]
\[ C_p\alpha = -0.2145356 \]

CALCULATED VALUES AT POSITION C

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

PRESSURE COEFFICIENTS:

\[ T_p = 0.1793275 \]
\[ C_p = 0.8012579 \]
\[ C_p' = 0.1436876 \]
\[ C_p\beta = 1.368524 \]
\[ C_p\alpha = -0.6850106 \]

ALL PRESSURE MEASUREMENTS IN METRES
LENGTH OF JET IN AIR (m) = 0
LENGTH OF JET IN WATER (m) = 0.698
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 = -0.8659999
PRESSURE COEFFICIENTS:
Tp = 0.2592266
Cp = 0.5798305
C'p = 0.753075
Cp+ = 0.5798303
Cp- = -0.4402226

CALCULATED VALUES AT POSITION B

MEAN DYNAMIC PRESSURE = 0.4360006
MAX POSITIVE PRESSURE FLUCTUATION = 1.392
MAX NEGATIVE PRESSURE FLUCTUATION = -1.466
PRESSURE COEFFICIENTS:
Tp = 0.394495
Cp = 0.2221497
C'p = -0.765891E-02
Cp+ = 0.7092475
Cp- = -0.2374349

CALCULATED VALUES AT POSITION C

MEAN DYNAMIC PRESSURE = 1.034001
MAX POSITIVE PRESSURE FLUCTUATION = 1.514
MAX NEGATIVE PRESSURE FLUCTUATION = -1.7660001
PRESSURE COEFFICIENTS:
Tp = 0.2405492
Cp = 0.5268408
C'p = 0.1309459
Cp+ = 0.7741086
Cp- = -0.39029

CALCULATED VALUES AT POSITION D

MEAN DYNAMIC PRESSURE = 0.4350006
MAX POSITIVE PRESSURE FLUCTUATION = 1.2
MAX NEGATIVE PRESSURE FLUCTUATION = -0.494
PRESSURE COEFFICIENTS:
Tp = 0.4160914
Cp = 0.2216402
C'p = -9.222256E-02
Cp+ = 0.6114203
Cp- = -0.2517014

CALCULATED VALUES AT POSITION F

MEAN DYNAMIC PRESSURE = 0.6040006
MAX POSITIVE PRESSURE FLUCTUATION = 1.017
MAX NEGATIVE PRESSURE FLUCTUATION = -0.5600001
PRESSURE COEFFICIENTS:
Tp = -0.2897348
Cp = 0.3071405
C'p = -0.9165446E-02
Cp+ = 0.5181787
Cp- = -0.2855295

ALL PRESSURE MEASUREMENTS IN METRES
### Calculated Values at Position A

<table>
<thead>
<tr>
<th>Mean Dynamic Pressure</th>
<th>0.3840006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Positive Pressure Fluctuation</td>
<td>0.626</td>
</tr>
<tr>
<td>Max Negative Pressure Fluctuation</td>
<td>-0.327</td>
</tr>
</tbody>
</table>

**Pressure Coefficients:**

- \( T_p \): 0.3255203
- \( C_p \): 0.4571445
- \( C_{p'} \): 0.1422994
- \( C_{p^+} \): 0.7126353
- \( C_{p^-} \): 0.3722555

### Calculated Values at Position B

<table>
<thead>
<tr>
<th>Mean Dynamic Pressure</th>
<th>0.1400006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Positive Pressure Fluctuation</td>
<td>0.53</td>
</tr>
<tr>
<td>Max Negative Pressure Fluctuation</td>
<td>-0.209</td>
</tr>
</tbody>
</table>

**Pressure Coefficients:**

- \( T_p \): 0.5208693
- \( C_p \): 0.159376
- \( C_{p'} \): 0.424125E-02
- \( C_{p^+} \): 0.6035495
- \( C_{p^-} \): 0.2379246

### Calculated Values at Position C

<table>
<thead>
<tr>
<th>Mean Dynamic Pressure</th>
<th>0.3620005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Positive Pressure Fluctuation</td>
<td>0.712</td>
</tr>
<tr>
<td>Max Negative Pressure Fluctuation</td>
<td>-0.2739999</td>
</tr>
</tbody>
</table>

**Pressure Coefficients:**

- \( T_p \): 0.3066294
- \( C_p \): 0.4120997
- \( C_{p'} \): 0.1263619
- \( C_{p^+} \): 0.8105374
- \( C_{p^-} \): 0.3119202

---

<table>
<thead>
<tr>
<th>Calculated Values at Position D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Dynamic Pressure</td>
</tr>
<tr>
<td>Max Positive Pressure Fluctuation</td>
</tr>
<tr>
<td>Max Negative Pressure Fluctuation</td>
</tr>
</tbody>
</table>

**Pressure Coefficients:**

- \( T_p \): 0.5575745
- \( C_p \): 0.1388049
- \( C_{p'} \): 7.741008E-02
- \( C_{p^+} \): 0.5896887
- \( C_{p^-} \): -0.2060495

<table>
<thead>
<tr>
<th>Calculated Values at Position F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Dynamic Pressure</td>
</tr>
<tr>
<td>Max Positive Pressure Fluctuation</td>
</tr>
<tr>
<td>Max Negative Pressure Fluctuation</td>
</tr>
</tbody>
</table>

**Pressure Coefficients:**

- \( T_p \): 0.4108899
- \( C_p \): 0.2299965
- \( C_{p'} \): 0.0945468
- \( C_{p^+} \): 0.6636845
- \( C_{p^-} \): -0.2641077

---

**All Pressure Measurements in Metres**

---

A. 29
### CALCULATED VALUES AT POSITION A

**Mean Dynamic Pressure:** 2.218001
**Max Positive Pressure Fluctuation:** .649
**Max Negative Pressure Fluctuation:** -.625

<table>
<thead>
<tr>
<th>Pressure Coefficients</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_p$</td>
<td>7.213705E-02</td>
</tr>
<tr>
<td>$C_p$</td>
<td>1.129062</td>
</tr>
<tr>
<td>$C_p'$</td>
<td>8.144721E-02</td>
</tr>
<tr>
<td>$C_p^+$</td>
<td>.3503762</td>
</tr>
<tr>
<td>$C_p^-$</td>
<td>-.3181532</td>
</tr>
</tbody>
</table>

### CALCULATED VALUES AT POSITION B

**Mean Dynamic Pressure:** .6450003
**Max Positive Pressure Fluctuation:** .694
**Max Negative Pressure Fluctuation:** -.302

<table>
<thead>
<tr>
<th>Pressure Coefficients</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_p$</td>
<td>.168992</td>
</tr>
<tr>
<td>$C_p$</td>
<td>.3283342</td>
</tr>
<tr>
<td>$C_p'$</td>
<td>5.548591E-02</td>
</tr>
<tr>
<td>$C_p^+$</td>
<td>.353273</td>
</tr>
<tr>
<td>$C_p^-$</td>
<td>-.1944552</td>
</tr>
</tbody>
</table>

### CALCULATED VALUES AT POSITION C

**Mean Dynamic Pressure:** 1.994
**Max Positive Pressure Fluctuation:** .748
**Max Negative Pressure Fluctuation:** -.7730001

<table>
<thead>
<tr>
<th>Pressure Coefficients</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>$T_p$</td>
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<tr>
<td>$C_p$</td>
<td>1.015016</td>
</tr>
<tr>
<td>$C_p'$</td>
<td>8.501057E-02</td>
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<tr>
<td>$C_p^+$</td>
<td>.3807657</td>
</tr>
<tr>
<td>$C_p^-$</td>
<td>-.3924919</td>
</tr>
</tbody>
</table>

### ALL PRESSURE MEASUREMENTS IN METRES
### Calculated Values at Position A

**Mean Dynamic Pressure:** 0.8970004

**Max Positive Pressure Fluctuation:** 0.561

**Max Negative Pressure Fluctuation:** -0.4550001

**Pressure Coefficients:**
- $T_p = 0.1282051$
- $C_p = 1.019859$
- $C_p' = 0.1307485$
- $C_p^+ = 0.6378253$
- $C_p^- = 0.11736793$

### Calculated Values at Position B

**Mean Dynamic Pressure:** 0.2380003

**Max Positive Pressure Fluctuation:** 0.425

**Max Negative Pressure Fluctuation:** -0.284

**Pressure Coefficients:**
- $T_p = 0.2815122$
- $C_p = 0.2705929$
- $C_p' = 0.4157216-02$
- $C_p^+ = 0.4832009$
- $C_p^- = 0.322892$

### Calculated Values at Position C

**Mean Dynamic Pressure:** 0.8370003

**Max Positive Pressure Fluctuation:** 0.742

**Max Negative Pressure Fluctuation:** -0.539

**Pressure Coefficients:**
- $T_p = 0.1875746$
- $C_p = 0.951622$
- $C_p' = 0.1785001$
- $C_p^+ = 0.843612$
- $C_p^- = 0.6128125$

### Calculated Values at Position D

**Mean Dynamic Pressure:** 0

**Max Positive Pressure Fluctuation:** 0

**Max Negative Pressure Fluctuation:** 0

**Pressure Coefficients:**
- $T_p = 0$
- $C_p = 0$
- $C_p' = 0$
- $C_p^+ = 0$
- $C_p^- = 0$

### Calculated Values at Position F

**Mean Dynamic Pressure:** 0.3920003

**Max Positive Pressure Fluctuation:** 0.665

**Max Negative Pressure Fluctuation:** -0.35

**Pressure Coefficients:**
- $T_p = 0.3035712$
- $C_p = 0.4456822$
- $C_p' = 0.1532963$
- $C_p^+ = 0.7560674$
- $C_p^- = 0.3979502$

### All Pressure Measurements in Metres

---

A.31
<table>
<thead>
<tr>
<th>DISCHARGE (m³/s)</th>
<th>6.676001E-02</th>
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<tbody>
<tr>
<td>TRUE AIR CONCENTRATION %</td>
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<td>HEIGHT OF OUTLET (m)</td>
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<tr>
<td>PLUNGE POOL LEVEL (m)</td>
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</tr>
<tr>
<td>WATER TEMPERATURE (°C)</td>
<td>9</td>
</tr>
<tr>
<td>AIR TEMPERATURE (°C)</td>
<td>8.100001</td>
</tr>
<tr>
<td>AIR PRESSURE (mBar)</td>
<td>1018</td>
</tr>
</tbody>
</table>

LENGTH OF JET IN AIR (m) : 0.53
LENGTH OF JET IN WATER (m) : 0.777
VELOCITY IN NOZZLE (m/s) : 6.209576
VELOCITY AT PLUNGE POOL (m/s) : 6.996732

**CALCULATED VALUES AT POSITION A**

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
<th>: - 0.9470006</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION : 1.082</td>
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<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION : -1.043</td>
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<td>PRESSURE COEFFICIENTS:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td>Tp</td>
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<td>Cp</td>
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<td>Cp'</td>
<td>: - 0.1666746</td>
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<tr>
<td>Cpt</td>
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<tr>
<td>Cp-</td>
<td>: - 0.4178885</td>
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**CALCULATED VALUES AT POSITION B**

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
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<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION : 1.741</td>
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</tr>
<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION : -0.6640001</td>
<td></td>
</tr>
<tr>
<td>PRESSURE COEFFICIENTS:</td>
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<tr>
<td></td>
<td></td>
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<tr>
<td>Tp</td>
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<tr>
<td>Cp</td>
<td>: - 0.108698</td>
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<td>Cpt</td>
<td>: - 0.1153901</td>
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<td>Cpt'</td>
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<td>Cp-</td>
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**CALCULATED VALUES AT POSITION C**

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
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<td>MAX POSITIVE PRESSURE FLUCTUATION : 3.123</td>
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<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION : -0.858</td>
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<td>PRESSURE COEFFICIENTS:</td>
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<tr>
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<td>Cpt</td>
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<td>Cpt'</td>
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<td>Cp-</td>
<td>: - 0.3437663</td>
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**CALCULATED VALUES AT POSITION D**

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</thead>
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<td>MAX POSITIVE PRESSURE FLUCTUATION : 1.715</td>
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<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION : -0.6290001</td>
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<tr>
<td>PRESSURE COEFFICIENTS:</td>
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<tr>
<td></td>
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<tr>
<td>Tp</td>
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<tr>
<td>Cp</td>
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<td>Cpt</td>
<td>: - 0.1049729</td>
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<td>Cpt'</td>
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<td>Cp-</td>
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**CALCULATED VALUES AT POSITION E**

<table>
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</thead>
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<td>MAX POSITIVE PRESSURE FLUCTUATION : 1.466</td>
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<tr>
<td>MAX NEGATIVE PRESSURE FLUCTUATION : -0.7320001</td>
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<tr>
<td>PRESSURE COEFFICIENTS:</td>
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<td>Cp</td>
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<td>Cpt</td>
<td>: - 9.655908E-02</td>
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<td>Cpt'</td>
<td>: - 0.5873677</td>
</tr>
<tr>
<td>Cp-</td>
<td>: - 0.2932832</td>
</tr>
</tbody>
</table>

ALL PRESSURE MEASUREMENTS IN METRES
| DISCHARGE (m³/s) | 0.0466 |
| True Air Concentration | 19.76199 |
| Number of boards | 4 |
| Height of outlet (m) | 1.307 |
| Plunge pool level (m) | 0.777 |
| Water temperature (°C) | 9.100001 |
| Air temperature (°C) | 7.9 |
| Air pressure (Bars) | 10.18 |

**Length of Jet in Air (m)**: 0.53  
**Length of Jet in Water (m)**: 0.777  
**Velocity in Nozzle (m/s)**: 4.153687  
**Velocity at Plunge Pool (m/s)**: 5.285188

**Calculated Values at Position A**

- **Mean Dynamic Pressure**: 0.108006  
- **Max Positive Pressure Fluctuation**: 0.351  
- **Max Negative Pressure Fluctuation**: -0.253  

**Pressure Coefficients:**
- \( T_p \): 1.092587  
- \( C_p \): 7.661618E-02  
- \( C_p' \): 8.370983E-02  
- \( C_{p+} \): 0.6746445  
- \( C_{p-} \): -0.173855

**Calculated Values at Position B**

- **Mean Dynamic Pressure**: 0.037006  
- **Max Positive Pressure Fluctuation**: 0.797  
- **Max Negative Pressure Fluctuation**: -0.205  

**Pressure Coefficients:**
- \( T_p \): 2.351313  
- \( C_p \): 2.624042E-02  
- \( C_p' \): 6.171027E-02  
- \( C_{p+} \): 0.565396  
- \( C_{p-} \): -0.1454281

**Calculated Values at Position C**

- **Mean Dynamic Pressure**: 0.097006  
- **Max Positive Pressure Fluctuation**: 0.9230001  
- **Max Negative Pressure Fluctuation**: -0.208  

**Pressure Coefficients:**
- \( T_p \): 0.9484478  
- \( C_p \): 6.881275E-02  
- \( C_p' \): 6.526529E-02  
- \( C_{p+} \): 0.6547812  
- \( C_{p-} \): -0.1475563

**Calculated Values at Position D**

- **Mean Dynamic Pressure**: 2.90006E-02  
- **Max Positive Pressure Fluctuation**: -0.739  
- **Max Negative Pressure Fluctuation**: -0.214  

**Pressure Coefficients:**
- \( T_p \): 2.482709  
- \( C_p \): 2.057317E-02  
- \( C_p' \): 5.107108E-02  
- \( C_{p+} \): 0.5242505  
- \( C_{p-} \): -0.1518127

**Calculated Values at Position F**

- **Mean Dynamic Pressure**: 2.20661E-02  
- **Max Positive Pressure Fluctuation**: -0.534  
- **Max Negative Pressure Fluctuation**: -2.000001

**Pressure Coefficients:**
- \( T_p \): 2.681744  
- \( C_p \): 1.560735E-02  
- \( C_p' \): 4.105492E-02  
- \( C_{p+} \): 0.378224  
- \( C_{p-} \): -0.1418811

---

**All Pressure Measurements in Metres**

A.33
### Calculated Values at Position A

- **Mean Dynamic Pressure**: 2.415001
- **Max Positive Pressure Fluctuation**: 1.16
- **Max Negative Pressure Fluctuation**: -1.88

**Pressure Coefficients**:

- $T_p$: 0.3350178
- $C_p$: 0.6382201
- $C_p'$: 0.138436
- $C_p^+$: 0.402674
- $C_p^-$: -0.6525181

### Calculated Values at Position B

- **Mean Dynamic Pressure**: 0.4810003
- **Max Positive Pressure Fluctuation**: 1.59
- **Max Negative Pressure Fluctuation**: -0.742

**Pressure Coefficients**:

- $T_p$: 0.4345112
- $C_p$: 0.1468475
- $C_p'$: 0.2540529
- $C_p^+$: 0.557856
- $C_p^-$: -0.257354

### Calculated Values at Position C

- **Mean Dynamic Pressure**: 2.181
- **Max Positive Pressure Fluctuation**: 2.391
- **Max Negative Pressure Fluctuation**: -1.753

**Pressure Coefficients**:

- $T_p$: 0.178817
- $C_p$: 0.7659904
- $C_p'$: 0.353858
- $C_p^+$: 0.831263
- $C_p^-$: -0.608428

### Calculated Values at Position D

- **Mean Dynamic Pressure**: 0.6410003
- **Max Positive Pressure Fluctuation**: 1.677
- **Max Negative Pressure Fluctuation**: -0.7380001

**Pressure Coefficients**:

- $T_p$: 0.4251133
- $C_p$: 0.2394227
- $C_p'$: 0.753961
- $C_p^+$: 0.58206
- $C_p^-$: -0.2561481

### Calculated Values at Position F

- **Mean Dynamic Pressure**: 1.250
- **Max Positive Pressure Fluctuation**: 1.349
- **Max Negative Pressure Fluctuation**: -1.282

**Pressure Coefficients**:

- $T_p$: 0.3147853
- $C_p$: 0.4368319
- $C_p'$: 0.1374453
- $C_p^+$: 0.4682164
- $C_p^-$: -0.4449618

---

**All Pressure Measurements in Metres**

---

**A.34**
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<tr>
<th>DISCHARGE (m³/s)</th>
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<tbody>
<tr>
<td>TRUE AIR CONCENTRATION (g)</td>
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<td>NUMBER OF BOARDS</td>
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<tr>
<td>HEIGHT OF OUTLET (m)</td>
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<tr>
<td>PLUNGE POOL LEVEL (m)</td>
<td>.392</td>
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<tr>
<td>WATER TEMPERATURE (°C)</td>
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<td>AIR TEMPERATURE (°C)</td>
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<tr>
<td>AIR PRESSURE (mBars)</td>
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</table>

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

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<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
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</thead>
<tbody>
<tr>
<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
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<td>PRESSURE COEFFICIENTS:</td>
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<td>Tp</td>
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<td>Cp</td>
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<td>Cp'</td>
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<tr>
<td>Cp+</td>
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<td>Cp-</td>
<td>-.5535078</td>
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CALCULATED VALUES AT POSITION B

<table>
<thead>
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<th>MEAN DYNAMIC PRESSURE</th>
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</tr>
</thead>
<tbody>
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<td>MAX POSITIVE PRESSURE FLUCTUATION</td>
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<td>MAX NEGATIVE PRESSURE FLUCTUATION</td>
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<td>Cp+</td>
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<tr>
<td>Cp-</td>
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CALCULATED VALUES AT POSITION C

<table>
<thead>
<tr>
<th>MEAN DYNAMIC PRESSURE</th>
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<tbody>
<tr>
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CALCULATED VALUES AT POSITION D

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CALCULATED VALUES AT POSITION F

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ALL PRESSURE MEASUREMENTS IN METRES

A. 35
<table>
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<tr>
<th>DISCHARGE (m³/s)</th>
<th>6.676001E-02</th>
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<tbody>
<tr>
<td>TRUE AIR CONCENTRATION</td>
<td>19.77891</td>
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<tr>
<td>NUMBER OF BOARDS</td>
<td>0</td>
</tr>
<tr>
<td>HEIGHT OF OUTLET (m)</td>
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<tr>
<td>WATER TEMPERATURE (°C)</td>
<td>9</td>
</tr>
<tr>
<td>AIR TEMPERATURE (°C)</td>
<td>8.5</td>
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<td>AIR PRESSURE (atm)</td>
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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 | -0.134273 |
| Cp | -0.8236004 |
| Cp' | -0.1105873 |
| Cp± | -0.4487544 |
| Cp- | -0.4505574 |

**CALCULATED VALUES AT POSITION B**

| MEAN DYNAMIC PRESSURE | 0.669 |
| MAX POSITIVE PRESSURE FLUCTUATION | 2.233 |
| MAX NEGATIVE PRESSURE FLUCTUATION | -2.7470001 |
| PRESSURE COEFFICIENTS: |
| Tp | -0.3901345 |
| Cp | -0.2043726 |
| Cp' | -0.797322E-02 |
| Cp± | -0.6821585 |
| Cp- | -0.2282009 |

**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 | -0.1498251 |
| Cp | -0.7768604 |
| Cp' | -0.1163916 |
| Cp± | -0.7243162 |
| Cp- | -0.460373 |

**CALCULATED VALUES AT POSITION D**

| MEAN DYNAMIC PRESSURE | 0.693 |
| MAX POSITIVE PRESSURE FLUCTUATION | 2.115 |
| MAX NEGATIVE PRESSURE FLUCTUATION | -0.658 |
| PRESSURE COEFFICIENTS: |
| Tp | -0.4256854 |
| Cp | -0.2117044 |
| Cp' | -9.011947E-02 |
| Cp± | -0.6461108 |
| Cp- | -0.2010122 |

**CALCULATED VALUES AT POSITION E**

| MEAN DYNAMIC PRESSURE | 1.672 |
| MAX POSITIVE PRESSURE FLUCTUATION | 1.607 |
| MAX NEGATIVE PRESSURE FLUCTUATION | -1.506 |
| PRESSURE COEFFICIENTS: |
| Tp | -0.2446172 |
| Cp | -0.5107789 |
| Cp' | -0.1249453 |
| Cp± | -0.450922 |
| Cp- | -0.4600676 |

**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 | -0.2446172 |
| Cp | -0.5107789 |
| Cp' | -0.1249453 |
| Cp± | -0.450922 |
| Cp- | -0.4600676 |

**ALL PRESSURE MEASUREMENTS IN METRES**
### MEAN DYNAMIC PRESSURE

**Position A:**
- Mean: 1.286
- Max Positive: 1.673
- Max Negative: -1.252

Pressure Coefficients:
- \( T_P \): .3211599
- \( C_P \): .5879166
- \( C_P' \): .18808163
- \( C_P'' \): -.7648663
- \( C_P''' \): .5723924

**Position B:**
- Mean: .451
- Max Positive: 1.982
- Max Negative: -.549

Pressure Coefficients:
- \( T_P \): .7361419
- \( C_P \): .2061893
- \( C_P' \): .1517846
- \( C_P'' \): .9061356
- \( C_P''' \): -.2509932

**Position C:**
- Mean: 1.132
- Max Positive: 3.845
- Max Negative: -1.079

Pressure Coefficients:
- \( T_P \): .3754417
- \( C_P \): .5175305
- \( C_P' \): .1943025
- \( C_P'' \): 1.757867
- \( C_P''' \): -.4922999

### MAX POSITIVE PRESSURE FLUCTUATION

**Position A:**
- 1.673

**Position B:**
- 1.982

**Position C:**
- 3.845

### MAX NEGATIVE PRESSURE FLUCTUATION

**Position A:**
- -1.252

**Position B:**
- -.549

**Position C:**
- -1.079

### PRESSURE COEFFICIENTS

- \( T_P \)
- \( C_P \)
- \( C_P' \)
- \( C_P'' \)
- \( C_P''' \)

### ALL PRESSURE MEASUREMENTS IN METRES