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NEAR-FIELD DISPERSION OF A BUOYANT PLUME

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ABSTRACT

Numerical models of the dispersion of a pollutant from a coast or estuary outfall require data obtained from field or laboratory measurements for calibration.

A laboratory test rig has been constructed to provide information on the initial or 'near-field' dispersion of warm water from a circular, horizontal outfall 25mm in diameter at a depth of 0.6m when it is discharged into a body of water flowing in the direction of discharge.

The outfall and all the equipment for measuring velocities, turbulence intensities and temperatures in the receiving body of water were mounted on the carriage of a current-meter rating tank and towed at various constant speeds up to 1m/s through still water. A turbulence-generating grid was attached to the carriage on the upstream side of the outfall and towed with it.

An on-board microcomputer controlled sequential sampling of all turbulence and temperature channels, converted the analogue signals to digital form and stored the data on floppy disks. After each run down the tank, the carriage was returned to the starting point and the micro connected by cable to an adjacent terminal, VDU and printer. Special software programs were written to access the data from the disks, analyse it in various ways and to print out the results.

Three 2-component e.m. current meters measured simultaneously the instantaneous components of velocity on X and Y horizontal axes, at three positions in the flume cross-section viz at the grid centre (outfall axis), at the same level near the edge of the grid, and close to the free surface. These measurements were made 0.5m, 0.75m and 1m behind the grid at carriage speeds between 0.25 and 1m/s. The interval between successive readings on the same channel was 0.05 seconds.

A vertical 2-dimensional array of 20 thermistors recorded temperatures in the heated plume at the same distances behind the grid and at the same carriage speeds. The interval between successive readings on each thermistor was 0.2 seconds.

Mean R.M.S. values of turbulence on X and Y axes were generally about 0.1m/s rising to 0.3m/s at the higher velocities. There was little systematic difference between turbulence intensities measured at the grid centre, the grid edge and near the free surface, although mean velocities at all positions were lower than the carriage towing speed. The latter is attributed to the net motion imparted to the water in the tank by the passage of the grid.

Heated discharges from the outfall were made at a constant efflux velocity of 0.5m/s at temperatures 10°C and 15°C above ambient. Dye injected with the water indicated a generally stable plume shape with a narrow angle of divergence, except in still water and at very low ambient velocities. Good 3-dimensional definition of the plumes has been obtained at all test conditions and data is available, from which diffusion coefficients can be determined.

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1 INTRODUCTION

The discharge of pollutants into coastal or estuarine waters continues to receive a great deal of attention. Of prime importance is the need to predict rates of dilution, dispersal and decay in a wide variety of practical situations, so that the outfall is both effectively designed and located and the impact of the pollutant on the environment is minimised.

The whole process of dispersion goes through a number of stages from the initial mixing of the jet in the immediate locality of the outfall to the final decay of the pollutant to a level which is undetectable in the background.

The physical processes in each stage are different, so that separate procedures are required to model the dispersion and predict the pollutant pattern in each of the stages. Dispersion problems are frequently tackled by means of numerical models and these require empirical constants, which have to be obtained either from field measurements or from laboratory tests.

This report is concerned with some laboratory tests on the initial or 'near-field' dispersion of a continuous discharge of warm water from a small, submerged, horizontal outfall in a homogeneous body of water. Tests were made with the receiving or ambient water both stationary and moving in the direction of discharge. In these circumstances the dispersion is dominated by turbulent mixing at the jet boundaries, the buoyancy of the heated water and the turbulence characteristics of the receiving body of water.

2 EXPERIMENTAL METHOD

Because of the need to conduct tests at ambient velocities up to 1m/s, it was not practical to install the outfall in a flume of large cross-section and pump water past it. Instead, the outfall was fixed below the carriage of a current-meter calibration tank and towed through a stationary body of water at various constant speeds.

To provide the necessary ambient turbulence a square grid of closely-spaced bars was also attached to the carriage in advance of the outfall.

The first part of the experimental programme was concerned with measurements of mean velocity and turbulence intensities in the wake of the grid when it was towed at various speeds up to 1m/s. These measurements were made with 2-component electromagnetic (e.m.) current meters, which were positioned 0.5m, 0.75m and 1.0m behind the grid and towed with it. In the second part of the programme water heated to 10°C above ambient was discharged from a 25mm diameter circular, horizontal outfall positioned at the centre of the grid and 70mm behind it. The exit velocity of the warm water was 0.5m/s in all tests. Temperatures in the outfall plume were measured by an array of thermistors also carried with the grid and outfall.

3 EXPERIMENTAL RIG

3.1 Tank

The current-meter calibration tank is 1.83m wide, 1.83m deep and 90m long, of which 50m is available for constant speed runs. A photograph of the tank and carriage appears in Plate 1. The carriage can be pre-set to run at any speed between 0.02 and 6.0m/s with an accuracy of ± 1 percent.

For the present tests an additional framework was constructed to hold the turbulence grid, outfall, warm water supply tank, e.m. current meters and thermistors. This framework ran on the same overhead rails as the carriage and was rigidly attached to it by a steel bar. Electrical wiring from both the e.m. current meters and the thermistors was taken forward to the main carriage where the data acquisition equipment was installed.

3.2 Turbulence grid

The turbulence grid, mounted in front of the outfall was 1.2m wide and 1.5m deep. It was constructed of 9.5mm diameter circular rods arranged in a square grid pattern with 51mm spacing between rod centres, giving a blockage ratio of approximately 35 percent. The clearance between the grid and the walls of the tank was 0.31m and between the grid and the floor of the tank 0.59m. (Fig 1).

3.3 Current meters

Three electromagnetic (e.m.) current meters were used to measure turbulence levels in the wake of the grid. (Fig 1). There are 2-component instruments measuring simultaneously the instantaneous components of velocity on the longitudinal axis of the tank (X axis) and on the transverse, horizontal axis of the tank (Y axis). The rise time (10 to 90 percent) is approximately 0.2 seconds. Before being mounted behind the grid each meter was calibrated on both axes.

3.4 Thermistors

Temperatures in the warm water plume from the outfall were measured with an array of 20 thermistors. These were arranged with the measuring tips in a radial pattern on a vertical plane with the centre thermistor on the horizontal axis of the outfall. In successive tests the whole array was positioned at different distances from the outfall to define the warm plume in 3-dimensions. (Fig 2).

Each thermistor was linearised over the range 5°C to 25°C with an accuracy within this range of ± 0.1°C. The thermistors have a characteristic rise time (10 to 90 percent) of approximately 0.5 seconds.

3.5 Data acquisition

A KEMITRON 1000E microcomputer, mounted on the main moving carriage, was used both to control sequential sampling of all e.m. current meter and thermistor channels and to record instantaneous velocities and temperatures. The micro contains analogue to digital converter modules, which allowed all the data to be stored in digital form on floppy disks. Sampling rates are variable but for the turbulence measurements the rate was set at 120 channels per second, giving an instantaneous read-out of velocity every 0.05 seconds on each X and Y axis of the three e.m. current meters. Preliminary tests with a high-speed chart recorder connected to the meter outputs had indicated that the main turbulence frequencies generated by the grid were below 4Hz. The sampling rate was thus 5 x the frequency of the phenomenon being measured.

The sampling rate for the thermistors was set at 100 channels per second, giving a temperature measurement at each of the 20 thermistors every 0.2 seconds.

No data was recorded during the acceleration or deceleration phases of the run - only when the carriage was running at the required constant speed. At the end of each run the carriage was returned to the starting point and the on-board micro connected by cable to an adjacent terminal, VDU and printer. Data stored on the disks was then read and analysed by software programs written for the purpose.

3.6 Warm water discharge

The warm water was discharged horizontally through a circular pipe 25.4mm in diameter positioned 70mm (or 1.37 mesh lengths) downstream of the turbulence grid and at its centre (0.6m below the free surface). All discharges were made at an efflux velocity of 0.5m/s and at a temperature 10°C above ambient, (with the exception of a single test at 15°C above ambient). The outfall densimetric Froude number (1) was therefore 34.1 and the outfall Reynolds number (2) 11,127 *.

(1) $F_\Delta = \frac{V}{\left[g\left(\frac{\Delta \ell}{\ell}\right).D\right]^{\frac{1}{2}}}$

(2) $R_e = \frac{VD}{\nu}$

where:

V = outfall efflux velocity
D = outfall diameter
ℓ = density of effluent
$\Delta\ell$ = density difference
ν = kinematic viscosity

The warm water was supplied from a small tank on the back of the carriage. Before each run this tank was filled with water at a temperature 10°C above ambient. Both the tank and supply pipe to the outfall were lagged to minimise heat loss. Warm water was pumped to the outfall by a small battery-powered positive displacement pump, which has a delivery rate proportional to the voltage supplied. The voltage was adjusted to give a flow rate of 0.253 l/s and an efflux velocity of 0.5m/s.

4 TEST RESULTS

4.1 Turbulence

One e.m. current meter (No 2) was positioned on the outfall axis at a depth of 0.6m. In order to detect variations in turbulence intensities away from the centre of the grid, a second meter (No 1) was placed vertically above the axis at a depth of 0.2m and a third meter (No 3) at a depth of 0.6m and 0.2m inside the edge of the grid (Fig 1). Turbulence measurements were made with these 3 meters at distances of 0.5m, 0.75m, and 1.0m behind the grid. It was assumed that at these distances (equal to or greater than 10 mesh lengths), the vortex streets, generated by individual bars in the grid, had combined to form a more or less homogeneous turbulence field. A second assumption made in the analysis was that the turbulence was isotropic, although no velocities were recorded on the vertical axis and it is known that with grid generated turbulence, intensities on the Y axis are generally about 75 percent of intensities on the X axis for an appreciable distance downstream [1].

Figs 3 to 5 show mean velocities for each of the 3 e.m. meters plotted against carriage (or towing) speed at 0.5m, 0.75m and 1.0m behind the grid. At all locations mean velocities on the X axis are lower than the actual carriage speed. This appears to be due to a net forward motion imparted to the water by the grid as it is dragged through. The reduction near the free surface (Fig 3) is between 11 and 24 percent for carriage speeds between 0.25m/s and 1m/s. At the grid centre (Fig 4) the reduction is between 25 and 32 percent and at the edge of the grid (Fig 5) between 15 and 24 percent. Also of interest is the fact that mean velocities on the transverse (Y) axis are not zero but increase slowly with carriage speed. This may be caused by slight misalignment of the meter or, more likely, is due to a progressive shift of the net flow direction away from the longitudinal axis of the tank as the speed increases. This is to be expected as the flow patterns at the meters become increasingly influenced by unobstructed flow between the edges of the grid and the wall and floor of the tank.

At carriage speeds of 0.25m/s to 0.75m/s 1200 readings of instantaneous velocity were obtained on each meter axis. At 1m/s 1000 readings were obtained. These were analysed after each run to provide average r.m.s. values of turbulence intensity (I), defined as:-

$$I = \left[(\overline{X^2}) + (\overline{Y^2})\right]^{\frac{1}{2}}$$

where $(\overline{X^2}) = \frac{\sum (x-\bar{x})^2}{n}$ and $(\overline{Y^2}) = \frac{\sum (y-\bar{y})^2}{n}$

($\bar{x}$, $\bar{y}$ are the mean velocities on X, Y axes respectively and n = number of readings).

Turbulence intensities have been plotted as a function of mean velocity on the longitudinal (X) axis at the grid centre (Meter 2) in Figs 6 to 8. Fig 6 is at a distance of 0.5m behind the grid; Fig 7 at a distance of 0.75m and Fig 8 at a distance of 1.0m. Turbulence intensities for all 3 meters are included.

There is considerable scatter on the points but the results indicate that turbulence intensities are generally of the order of 0.05 to 0.15m/s rising to 0.3m/s at the higher velocities. There is also an indication of high intensity values (up to 0.4m/s) at the lowest mean velocity (0.2m/s) but only at distances of 0.5 and 0.75m from the grid. This may be due to incomplete merging of the vortex streets generated by individual bars in the grid so that the turbulence field is non-homogeneous. There appears to be no systematic difference between the intensities measured by the 3 e.m. meters.

Because time was short, few of the turbulence runs were repeated to determine the consistency of the results nor were the reasons for the scatter in the data points investigated in greater depth. However, since the data is permanently stored on disk a more comprehensive analysis of these runs would be possible at a later date.

4.2 Plume temperature

The e.m. current meters were removed when the turbulence measurements had been completed and replaced by the array of thermistors to measure plume temperatures. The positions of the array are described in Section 3.4 and shown in Fig 2. The inset in the figure shows the thermistor pattern and spacing, which was decided after preliminary tests with dye in the outfall discharge had shown a fairly stable plume with only a narrow angle of divergence and very little buoyancy rise. Because of the difficulty of altering the spacing once the thermistors were in the flume this pattern was adopted at all distances from the outfall and for tests at all ambient velocities.

Temperatures were measured at distances of 0.5m, 0.75m and 1.0m from the outfall and at nominal carriage speeds between 0 and 1m/s at intervals of 0.125m/s.

The heated effluent was rapidly dispersed in the flume after each run because of the residual turbulence in the water so that at the start of each test ambient temperatures were virtually constant throughout the length and cross-section of the flume. A reference ambient temperature was determined before each test and the temperature of the warm water supply adjusted to 10°C above the mean ambient temperature based on all the thermistor readings. At one distance only (0.5m from the outfall) tests were carried out with the outfall temperature at both 10°C and 15°C above ambient.

In every test the outfall discharge was 0.253 l/s and the exit velocity 0.5m/s. (Section 3.6).

The discharge from the outfall was started during the acceleration phase of each run but no temperature data was recorded until the required steady carriage speed was reached. 300 temperature readings were logged at each thermistor and these were meaned and printed out immediately after each run.

Tables 1 to 3 give the mean temperatures above background for each of the 20 thermistors at distances of 0.5m, 0.75m and 1.0m from the outfall for all the ambient velocities tested. The velocities are mean velocities on the X axis at the centre of the grid, determined for each nominal carriage speed from the calibration line in Fig 4. Table 4 gives equivalent results for a 15°C rise at the outfall but at a distance of 0.5m from the outfall only.

Although thermistor 19 was positioned at the outfall (Fig 2), it measured temperatures, which were generally below those in the outfall supply line. This was due to a degree of mixing with colder water - particularly at the higher carriage speeds.

Temperature profiles of the heated plume on the transverse, horizontal axis and on the vertical axis for all tests, in which the outfall temperature was 10°C above ambient have been plotted in Figs 9 to 17 inclusive.

The ratio of plume width to diameter of outfall on both vertical and horizontal axes at 0.5m, 0.75m and

1.0m from the outfall has been given in Table 5. In the case of the vertical profile (Table 5 (1)), the top and bottom parts of the plume have calculated separately to determine whether there is any significant asymmetry in the plume due to buoyancy. The edges of the plume have been arbitrarily defined as the points at which temperatures are 0.1°C above ambient.

The following characteristics of the plume may be seen:-

(i) The decrease in plume centre-line temperature is most rapid in the first 0.5m and becomes more marked as ambient velocity increases. For instance, in still water the drop is from 10°C to 2.9°C, while at 0.76m/s it drops from 10°C to 0.26°C.

(ii) There is a rapid increase in plume diameter (defined as the line at which the temperature falls to 0.1°C above ambient) in the first 0.5m. At ambient velocities between 0 and 0.07m/s the diameter continues to increase, but more gradually, up to 1.0m from the outfall. At velocities of 0.16m/s and above the plume diameter is constant or nearly constant at distances between 0.5m and 1.0m.

(iii) The plume is approximately symmetrical in plan about the outfall axis. Small departures from symmetry (such as at a distance of 0.75m in Fig 10) have been traced to slight misalignment of the thermistor array.

(iv) The vertical temperature profiles show generally a slight tendency for the warm water to rise but, under these test conditions, buoyancy forces do not appear to contribute significantly to the initial dispersion.

(v) Generally the plume appears to be wider on its vertical axis than on its horizontal axis, which is not wholly attributable to buoyancy since it is true for the lower half of the vertical section as well as the upper half (Table 5). It may, therefore, the result of anisotropy in the turbulence field generated by the grid.

(vi) A comparison of Table 1 and Table 4 shows that when the outfall temperature is increased from 10°C to 15°C above ambient, mean temperatures in the central section of the plume are raised by approximately 50 percent. However, temperatures immediately above the horizontal axis (thermistors 1, 2 and 8) show an average rise of 56 percent at all ambient velocities while those below the axis (thermistors 4, 5 and 6) show a rise of only 22 percent. This suggests a slight increase in the buoyancy of the plume due to the larger temperature difference.

The temperature data has been analysed in a way, which shows only its time-averaged characteristics. Sufficient data has been recorded on disk, however, to allow analysis in greater depth. For instance, a study of plume stability could be made by determining the frequency and magnitude of temperature fluctuations.

5 SUMMARY AND CONCLUSIONS

1. An experimental rig has been constructed to measure the initial or "near-field" dispersion of warm water discharging continuously from a small, submerged horizontal outfall into a large body of colder water of uniform density.

2. The circular outfall was 25mm in diameter and at a depth of 0.6m. In all tests the efflux velocity was 0.5m/s and, in the majority, the effluent temperature was 10°C above ambient. Discharges were made into still water and into water flowing at up to 0.76m/s in the direction of discharge.

3. The outfall and all data logging equipment was mounted on an overhead framework, which was towed at various steady speeds through still water behind the carriage of a current-meter calibration tank. To provide the necessary ambient turbulence in the water a grid of closely spaced bars was attached to the front of the framework and towed with the outfall.

4. A new data acquisition system, suitable for rapidly fluctuating signals, has been designed and successfully operated with this rig. An on-board microcomputer controls sequential sampling of multiple data channels at a high scan rate (120/s), converts each instantaneous analogue signal into digital form and stores it on floppy disks. At the end of each test run the micro is connected to a terminal, VDU and printer and specially written software programs access the disks, analyse the data as required and print out the results.

5. The experimental programme was in two parts. In the first part mean velocities and turbulence intensities were measured behind the grid, using two-component electromagnetic (e.m.) current meters with a high speed of response. In the second part temperatures were measured by an array of thermistors positioned in the warm water plume at distances up to 1m from the outfall.

6. Mean velocities behind the grid were always less than the carriage (or towing) speed. This is due to a net motion imparted to the water in the flume by the passage of the turbulence grid, which increased with carriage speed.

7. Mean r.m.s. values of turbulence intensity on the two horizontal planes - longitudinal and transverse to direction of motion - were of the order 0.1m/s, rising to 0.3m/s at the highest velocities. There was considerable scatter in the data but no consistent indication of decay in turbulence in the distance 0.5m to 1.0m behind the grid nor between the centre and edges of the grid.

8. Good 3-dimensional definition of the heated plume was obtained at distances up to 1.0m from the outfall. Under the limited range of test conditions buoyancy effects were very slight with the plume almost symmetrical about the outfall axis in both plan and elevation for a distance of 1.0m.

9. The plume diameter on the horizontal, transverse axis is approximately 80 percent of the diameter on the vertical axis. This may be due to anisotropy in the grid-generated turbulence field.

10. The most rapid increase in plume diameter and decrease in centre-line temperature occurs within 0.5m of the outfall. In still water and at very low ambient flows plume diameter and temperature continue to change up to 1.0m from the outfall but at ambient velocities above 0.16m/s the changes in this region are small.

11. The temperature data has been analysed and presented in a way, which shows only the time averaged characteristics of the heated plume. Also of interest would be the stability of the plume, which could be determined by a more sophisticated analysis of the existing data.

12. The experimental programme has produced data over a limited range of conditions only. Of particular value, however, has been the successful development of a multi-channel data acquisition system for investigating unsteady physical processes, which could be used to extend the investigation of buoyant plumes in the laboratory.

6 REFERENCES

1. BRADSHAW P "An Introduction to Turbulence and its Measurement" The Commonwealth and International Library. Thermodynamics and Fluid Mechanics Division. Pergamon Press, 1971.

7 ACKNOWLEDGEMENTS

The work of Mr C Beasley of the Engineering Design Department in developing the data acquisition system and of Mr R W Benson in operating the current meter calibration tank during tests is gratefully acknowledged.

TABLE 1

TEMPERATURE ABOVE AMBIENT 0.5m FROM OUTFALL

THERMISTORS

RUN NO	AMBIENT VELOCITY (MEAN) m/s	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
THM 20	0	2.91	1.65	1.66	1.66	1.41	1.80	2.03	2.10	1.74	0.27	0.18	0.33	0.12	0.18	0.28	0.42	0.27	0	0.01	8.37
11	0.07	2.41	0.89	0.96	1.09	0.83	1.05	1.35	1.69	1.01	0.01	0	0.05	0.02	0	0.02	0.10	0.02	0.03	0.01	7.68
3	0.16	1.88	1.11	0.62	0.19	0.21	0.61	0.44	0.51	0.77	0.04	0	0	0	0.01	0.01	0	0.04	0	0	7.81
4	0.26	1.09	0.89	0.48	0.17	0.18	0.49	0.35	0.40	0.71	0.10	0.03	0.02	0.01	0.04	0.02	0.03	0.12	0.01	0	9.34
5	0.36	0.67	0.57	0.38	0.19	0.14	0.33	0.28	0.33	0.54	0.08	0.04	0.01	0.01	0.05	0.02	0.04	0.15	0.01	0	9.59
6	0.48	0.44	0.48	0.31	0.14	0.09	0.20	0.22	0.31	0.44	0.09	0.04	0.01	0	0.03	0.02	0.06	0.13	0.01	0	7.03
10	0.49	0.47	0.49	0.30	0.15	0.09	0.22	0.24	0.34	0.46	0.10	0.05	0.02	0	0.03	0.03	0.06	0.14	0	0	8.62
7	0.55	0.43	0.40	0.28	0.15	0.09	0.21	0.24	0.32	0.39	0.08	0.04	0.02	0.01	0.04	0.03	0.07	0.13	0.01	0.01	8.72
8	0.65	0.34	0.30	0.25	0.13	0.08	0.16	0.20	0.28	0.32	0.05	0.04	0.02	0	0.03	0.02	0.08	0.11	0.01	0	7.67
9	0.76	0.26	0.22	0.19	0.11	0.06	0.14	0.17	0.22	0.22	0.03	0.03	0.02	0	0.02	0.03	0.07	0.07	0	0	5.77

OUTFALL TEMPERATURE ABOVE AMBIENT 10°C
DISCHARGE VELOCITY 0.5m/s

Temperatures in °C
Thermistor locations shown in Fig 2

TABLE 2

TEMPERATURE ABOVE AMBIENT· 0.75m FROM OUTFALL

THERMISTORS

RUN NO	AMBIENT VELOCITY (MEAN) m/s	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
THM 26	0	1.65	1.46	1.25	1.17	1.06	1.31	1.38	1.57	1.49	0.82	0.71	0.60	0.33	0.53	0.62	0.89	0.90	0.43	0.11	8.36
29	0.07	1.70	0.85	0.47	0.54	0.42	1.14	1.49	1.83	1.36	0.09	0.02	0	0.02	0.06	0.33	0.71	0.20	0.02	0.01	8.49
21	0.16	1.36	0.88	0.57	0.45	0.36	0.80	0.74	0.82	0.86	0.10	0	0	0	0.05	0.02	0.04	0.07	0	0.01	7.84
22	0.26	0.87	0.68	0.39	0.23	0.19	0.57	0.48	0.47	0.67	0.14	0.04	0.01	0	0.07	0.04	0.05	0.16	0	0.01	9.36
23	0.36	0.52	0.42	0.28	0.18	0.14	0.33	0.30	0.33	0.43	0.11	0.05	0.02	0	0.08	0.04	0.07	0.16	0	0.02	9.32
24	0.49	0.38	0.34	0.24	0.16	0.13	0.23	0.25	0.29	0.34	0.10	0.07	0.04	0.01	0.07	0.05	0.10	0.13	0.01	0.02	8.64
25	0.55	0.35	0.28	0.22	0.15	0.13	0.24	0.23	0.28	0.38	0.08	0.07	0.05	0.01	0.08	0.06	0.09	0.11	0.01	0.02	8.42
27	0.65	0.27	0.21	0.18	0.11	0.10	0.18	0.21	0.25	0.23	0.06	0.04	0.04	0.01	0.05	0.05	0.11	0.11	0.01	0	7.60
28	0.76	0.22	0.18	0.15	0.09	0.09	0.15	0.19	0.21	0.20	0.05	0.04	0.04	0.01	0.05	0.06	0.11	0.08	0.01	0.01	6.01

OUTFALL TEMPERATURE ABOVE AMBIENT 10°C
DISCHARGE VELOCITY 0.5m/s

Temperatures in °C
Thermistor locations shown in Fig 2

TABLE 3

TEMPERATURE ABOVE AMBIENT 1.0m FROM OUTFALL

THERMISTORS

RUN NO	AMBIENT VELOCITY (MEAN) m/s	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
THM 40	0	1.03	0.99	0.98	0.99	0.87	0.87	0.90	0.92	0.96	0.82	0.78	0.77	0.60	0.55	0.60	0.65	0.61	0.58	0.23	8.67
30	0.07	1.23	0.72	0.86	0.97	0.99	1.12	0.98	0.90	0.70	0.11	0.07	0.33	0.31	0.40	0.27	0.24	0.03	0	0	8.51
31	0.16	1.09	0.79	0.74	0.72	0.66	0.75	0.52	0.54	0.59	0.18	0.06	0.07	0.03	0.11	0	0.01	0.05	0	0	8.81
32	0.25	0.68	0.56	0.47	0.42	0.34	0.47	0.32	0.32	0.43	0.15	0.06	0.05	0.01	0.13	0.01	0.05	0.11	0	0	9.99
34	0.36	0.41	0.33	0.31	0.30	0.22	0.30	0.22	0.26	0.31	0.10	0.07	0.05	0.02	0.10	0.02	0.07	0.10	0	0	10.78
35	0.46	0.31	0.26	0.26	0.24	0.19	0.21	0.18	0.21	0.25	0.07	0.07	0.06	0.02	0.07	0.03	0.07	0.08	0	0	8.21
36	0.55	0.26	0.19	0.19	0.19	0.17	0.20	0.17	0.19	0.19	0.04	0.05	0.06	0.03	0.07	0.04	0.06	0.06	0	0.01	7.77
37	0.65	0.23	0.15	0.16	0.17	0.14	0.18	0.16	0.18	0.16	0.03	0.04	0.05	0.02	0.06	0.04	0.08	0.05	0	0.01	7.58
39	0.76	0.16	0.11	0.11	0.12	0.11	0.13	0.12	0.12	0.11	0.01	0.03	0.05	0.02	0.05	0.03	0.06	0.02	0	0	5.97

OUTFALL TEMPERATURE ABOVE AMBIENT 10°C
DISCHARGE VELOCITY 0.5m/s

Temperatures in °C
Thermistor locations shown in Fig 2

TABLE 4

TEMPERATURE ABOVE AMBIENT 0.5m FROM OUTFALL

THERMISTORS

RUN NO	AMBIENT VELOCITY (MEAN) m/s	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
THM 19	0	3.95	2.75	2.45	2.51	1.82	2.26	2.27	2.90	2.72	0.62	0.34	0.49	0.44	0.34	0.38	0.74	0.69	0	0.01	11.96
12	0.16	2.83	1.65	0.73	0.42	0.27	0.96	0.98	1.35	1.37	0.06	0	0	0	0.02	0	0.01	0.08	0.02	0	11.65
16	0.26	2.05	1.38	0.66	0.30	0.23	0.92	0.67	0.85	1.28	0.15	0.03	0.01	0	0.04	0.02	0.05	0.17	0.03	0	14.11
13	0.36	1.07	0.85	0.53	0.30	0.21	0.56	0.49	0.61	0.86	0.13	0.06	0.01	0.02	0.07	0.04	0.08	0.25	0.03	0.01	14.55
17	0.49	0.76	0.76	0.48	0.29	0.15	0.35	0.40	0.55	0.73	0.13	0.07	0.02	0.01	0.05	0.03	0.12	0.24	0.02	0	13.24
14	0.55	0.58	0.56	0.37	0.22	0.12	0.28	0.34	0.48	0.58	0.10	0.07	0.03	0.02	0.04	0.04	0.12	0.19	0.02	0.01	12.37
18	0.65	0.52	0.46	0.32	0.21	0.12	0.27	0.32	0.43	0.49	0.08	0.06	0.02	0.01	0.03	0.04	0.13	0.16	0.01	0.01	11.43
15	0.76	0.39	0.35	0.27	0.17	0.09	0.20	0.26	0.36	0.37	0.06	0.04	0.02	0	0.03	0.04	0.13	0.13	0	0	9.43

OUTFALL TEMPERATURE ABOVE AMBIENT 15°C
DISCHARGE VELOCITY 0.5m/s

Temperatures in °C
Thermistor locations shown in Fig 2

TABLE 5

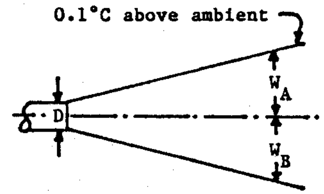
RATIO OF PLUME AND OUTFALL DIAMETERS ON TRANSVERSE AND VERTICAL AXES

MEAN AMBIENT VELOCITY (m/s)

DISTANCE FROM OUTFALL (m)	0		0.07		0.16		0.26		0.36		0.49		0.55		0.65		0.76	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
0.5	8.5	7.9	5.7	5.8	6.6	5.6	6.9	6.3	6.6	5.7	6.9	5.4	6.8	5.4	6.1	4.7	5.2	4.4
0.75	-	10.7	6.8	6.3	7.1	6.1	7.7	6.6	7.2	6.6	6.9	6.3	6.5	6.5	6.2	5.5	5.8	5.2
1.0	-	-	7.6	8.8	8.5	7.2	7.2	7.6	6.6	6.6	6.3	5.8	5.7	5.8	5.0	4.8	3.8	5.0

(1) VERTICAL SECTION

COL. A = ABOVE OUTFALL AXIS.
B = BELOW " "



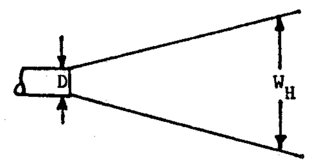
$$\text{RATIO (A)} = \frac{W_A}{D/2}$$

$$\text{RATIO (B)} = \frac{W_B}{D/2}$$

MEAN AMBIENT VELOCITY (m/s)

DISTANCE FROM OUTFALL (m)	0	0.07	0.16	0.26	0.36	0.49	0.55	0.65	0.76
0.5	-	5.8	4.3	4.2	5.2	4.5	4.6	4.2	4.3
0.75	-	5.2	5.1	4.7	4.8	5.0	5.0	4.9	4.7
1.0	-	-	5.4	5.2	5.0	4.9	4.8	4.8	3.2

(2) PLAN



$$\text{RATIO} = \frac{W_H}{D}$$

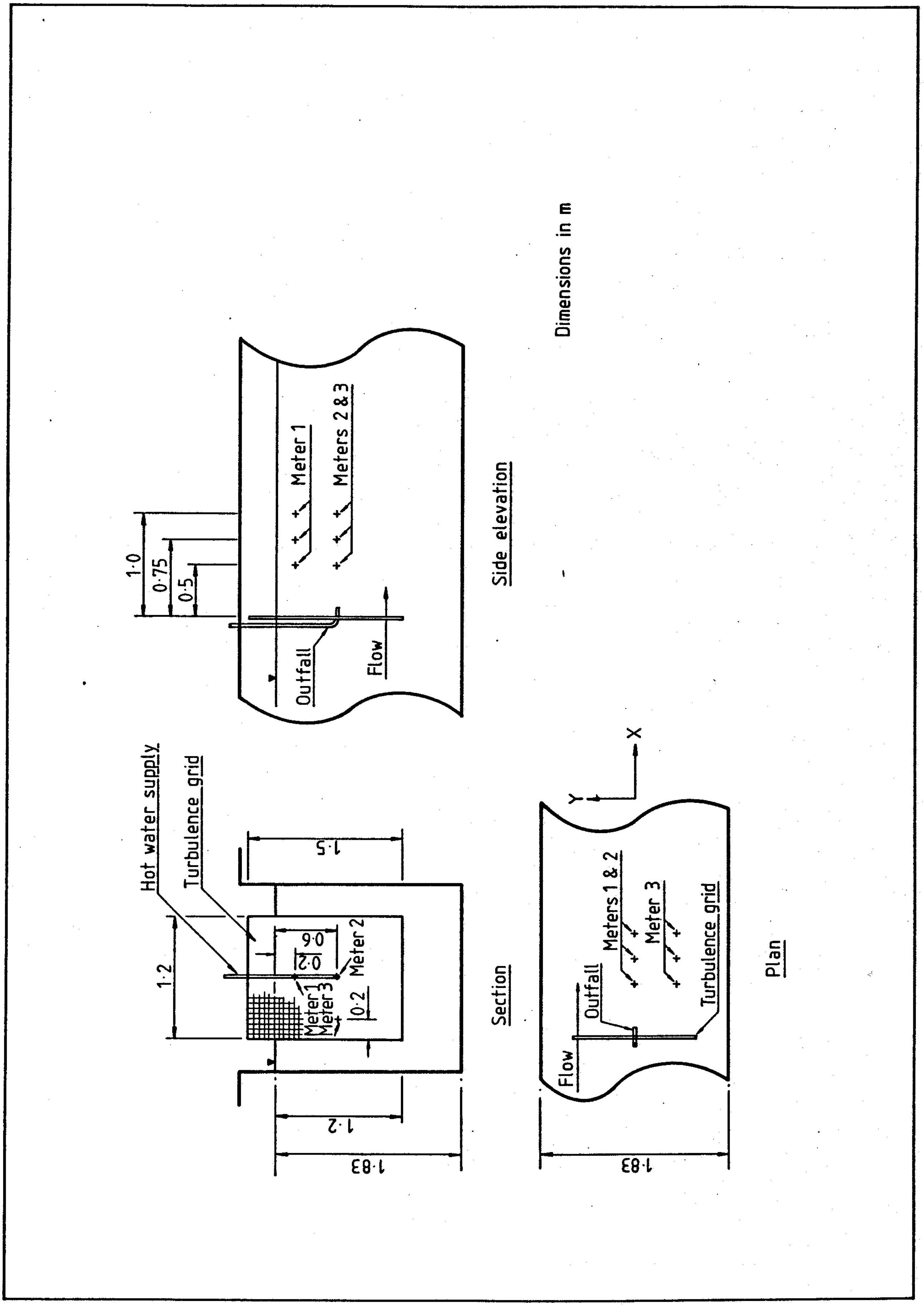


Fig. 1 Turbulence grid and location of EM current meters

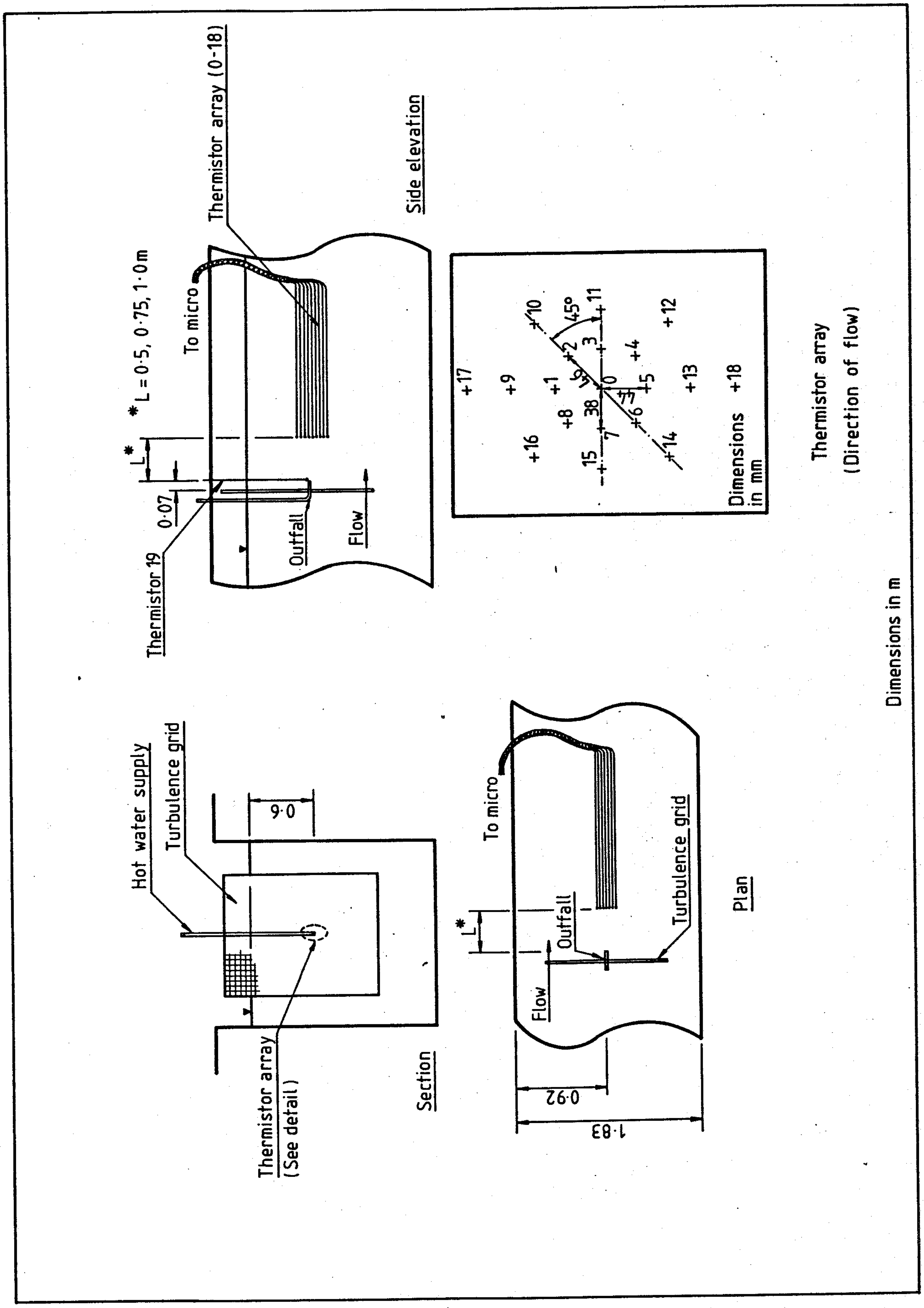


Fig 2 Outfall and thermistor array

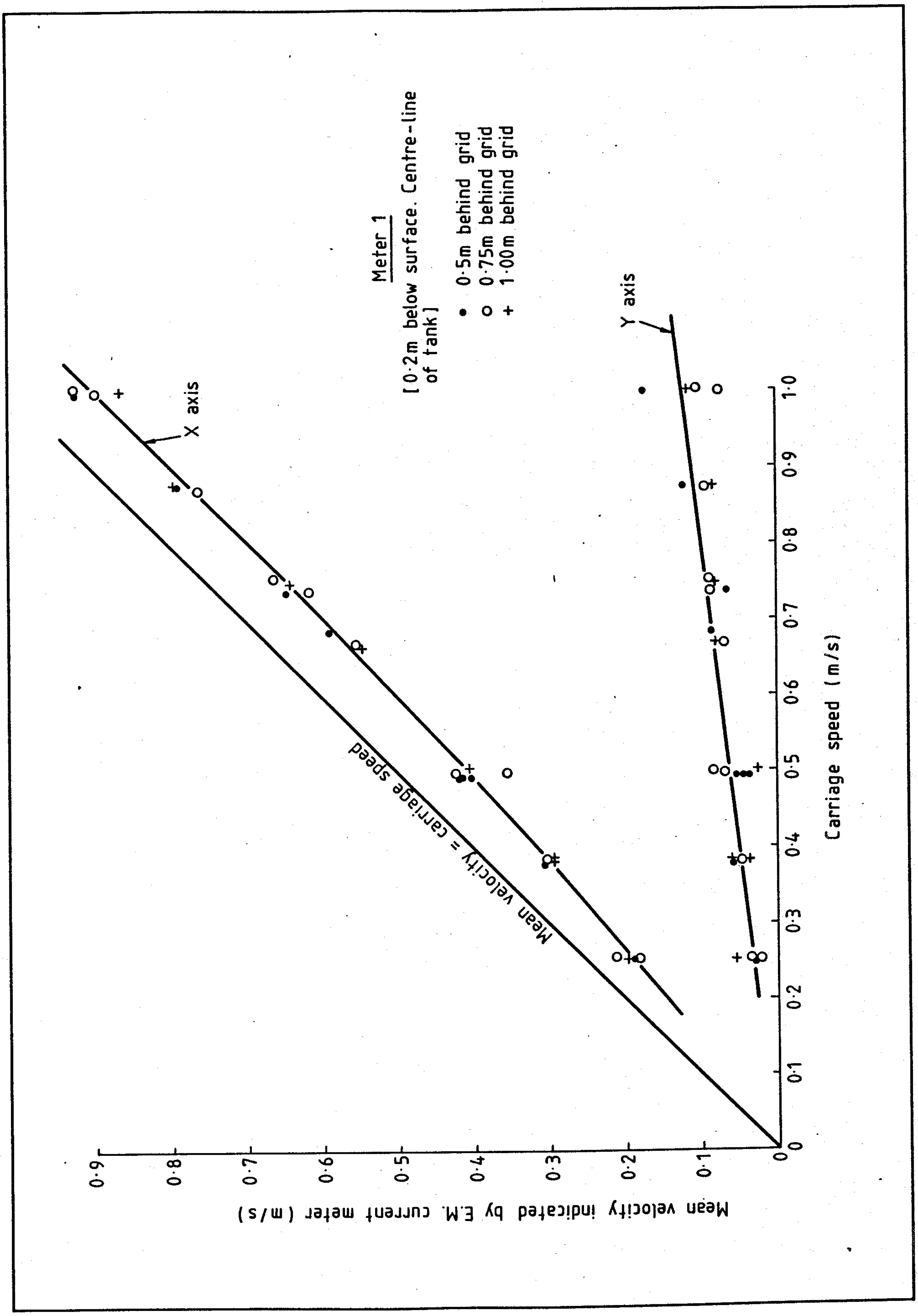


Fig. 3 Mean velocities on X and Y axes v. carriage speed

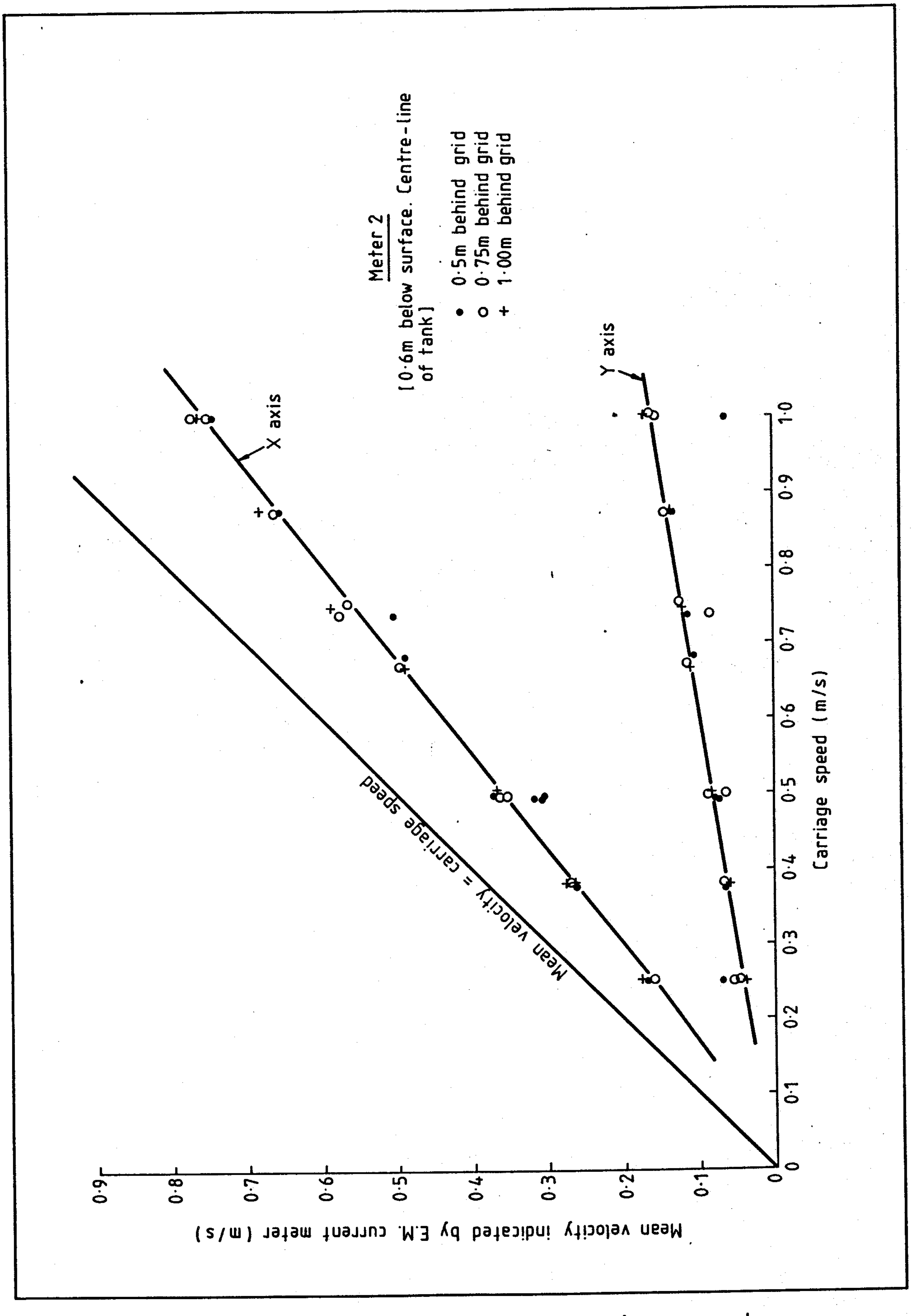


Fig. 4 Mean velocities on X and Y axes v. carriage speed

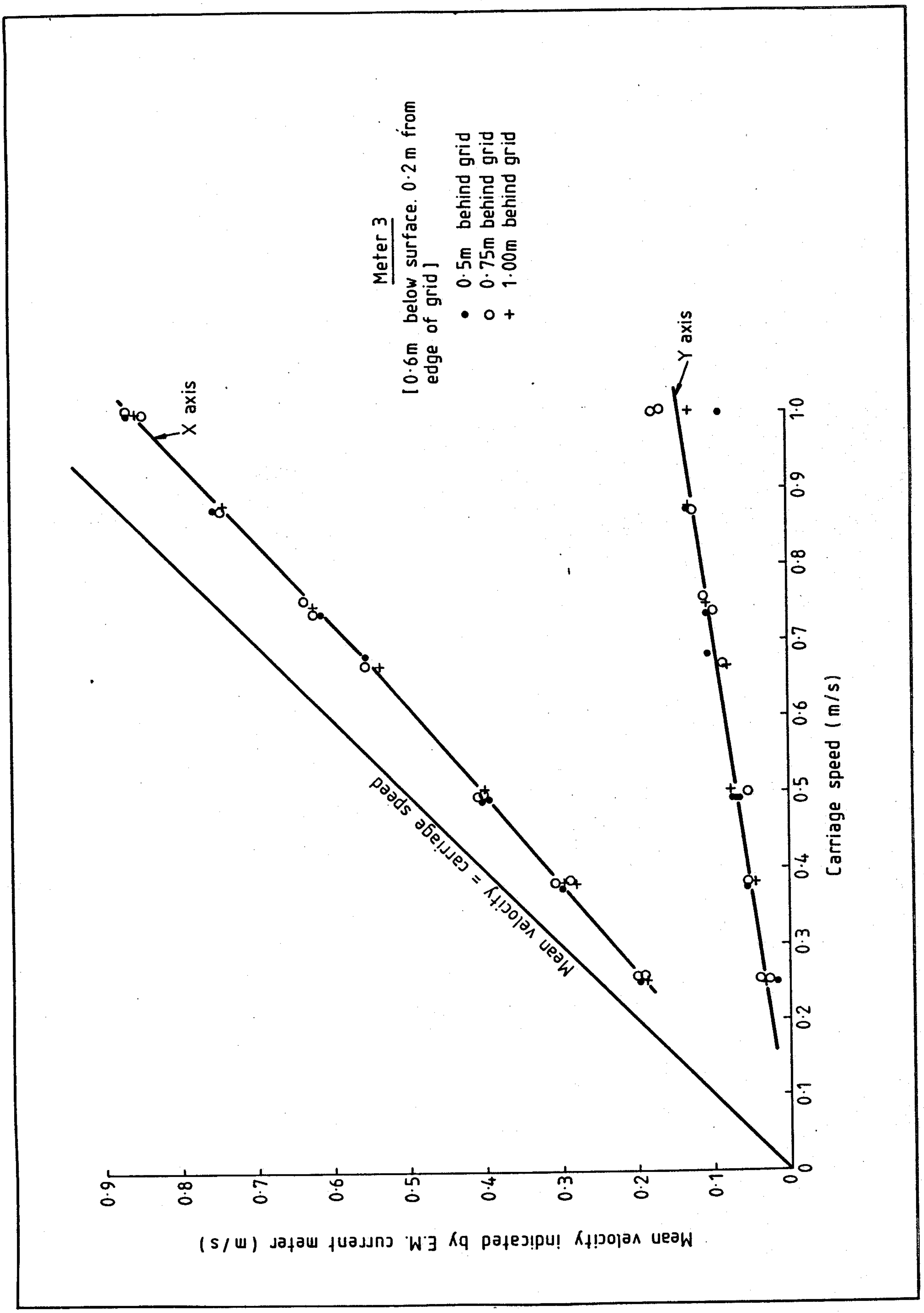


Fig. 5 Mean velocities on X and Y axes v. carriage speed

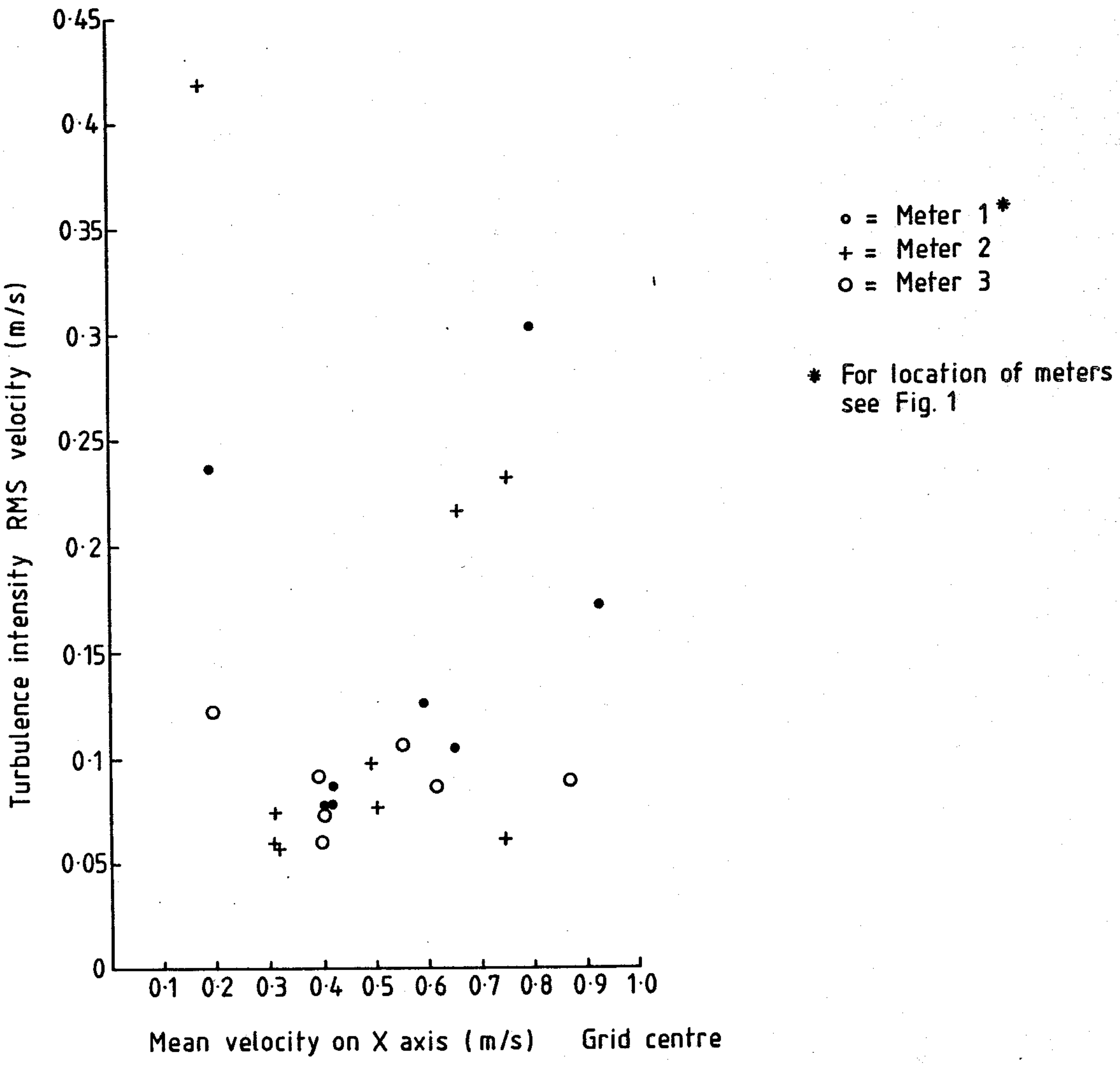


Fig. 6 Turbulence intensities 0·5m behind grid

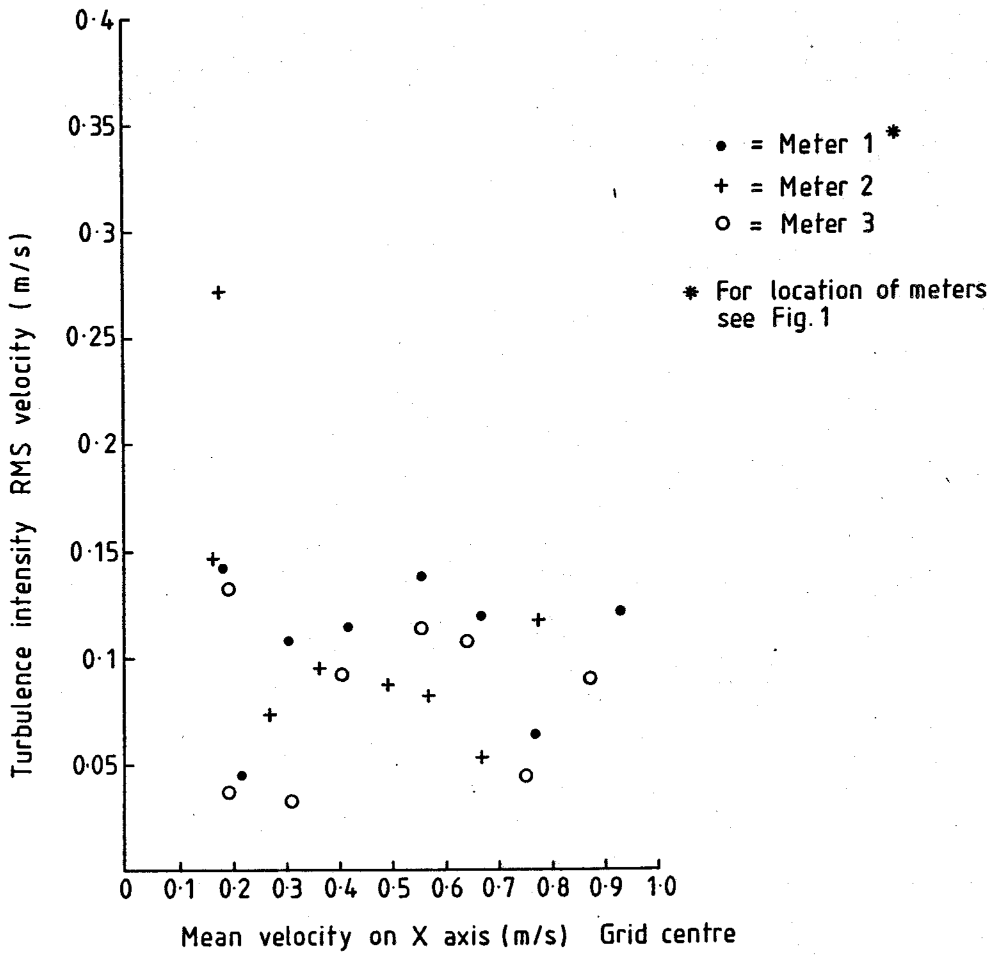


Fig. 7 Turbulence intensities 0·75m behind grid

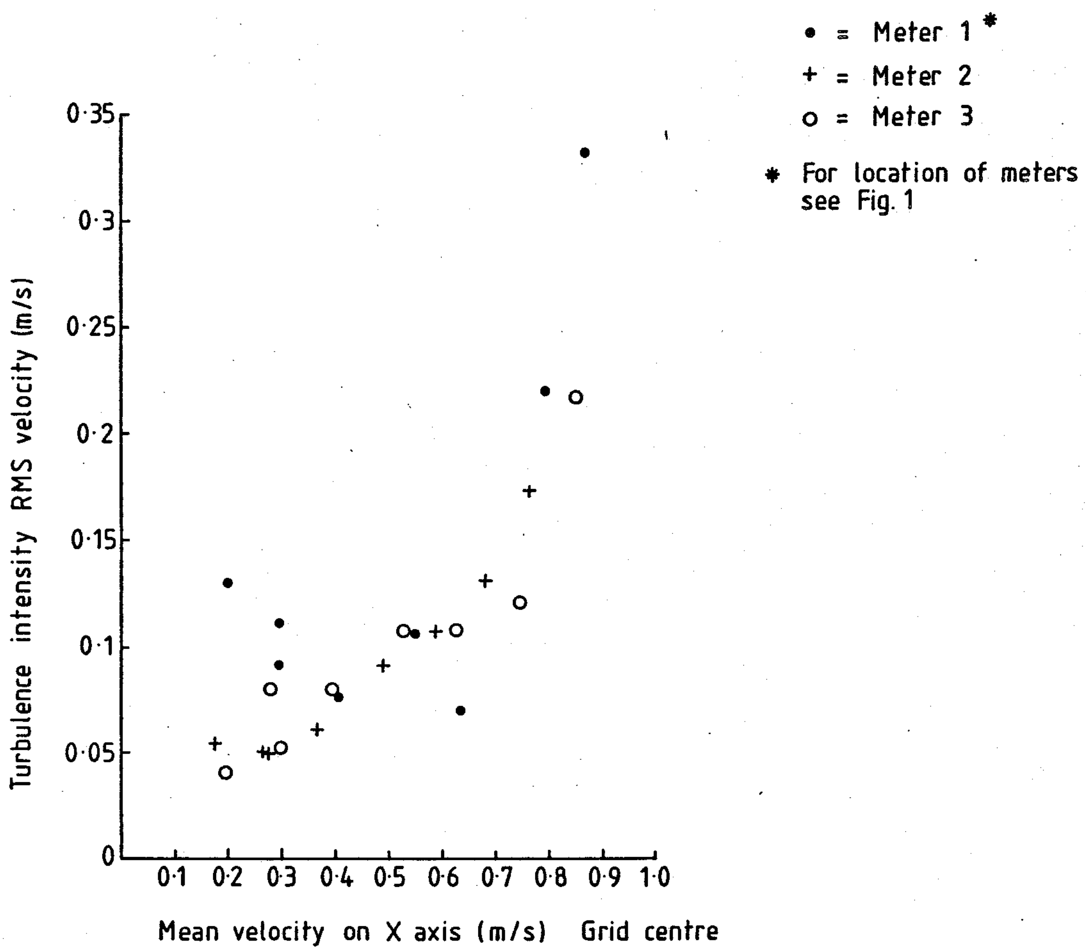


Fig. 8 Turbulence intensities 1·0 m behind grid

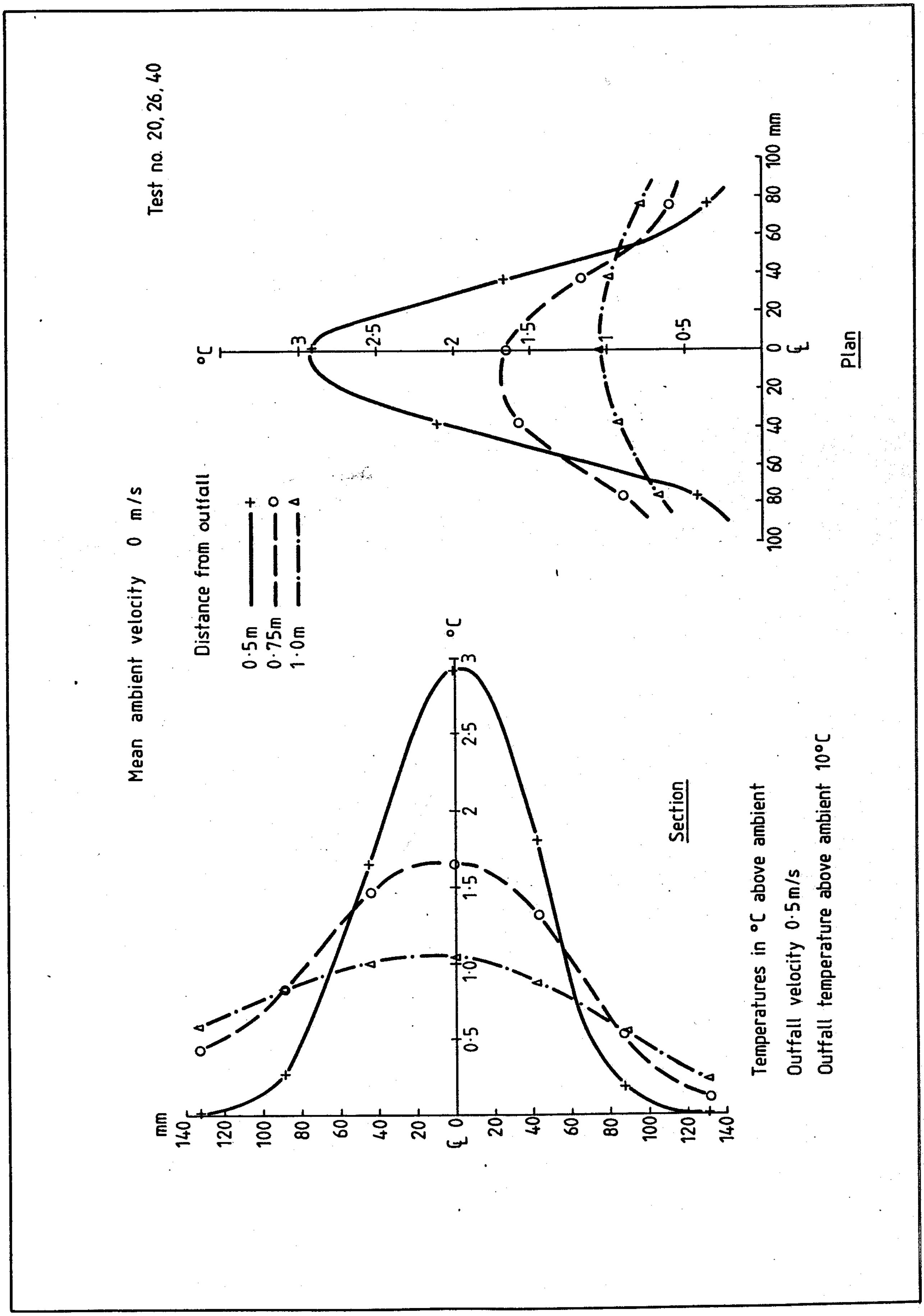


Fig. 9 Plan and section of outfall plume

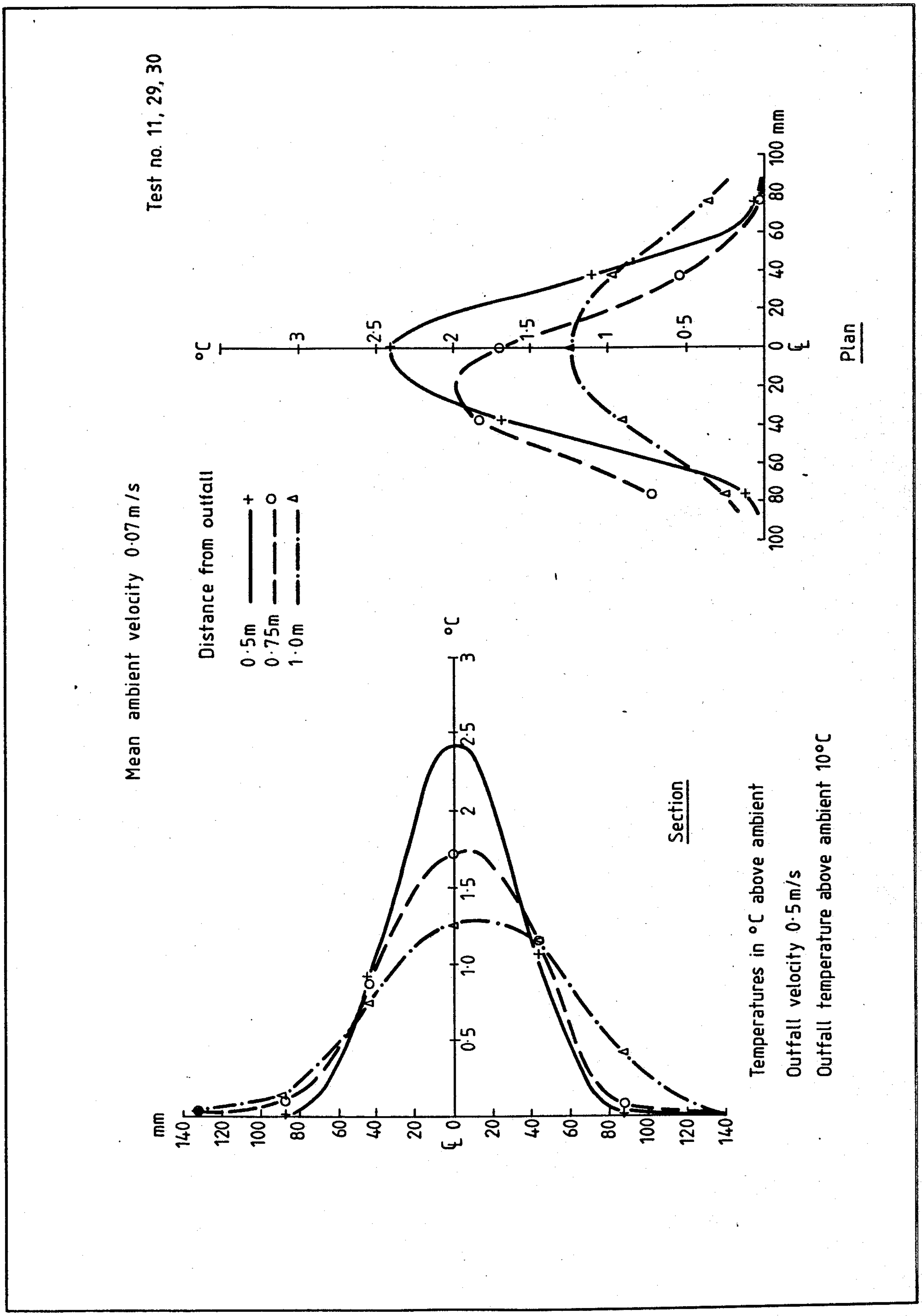


Fig. 10 Plan and section of outfall plume

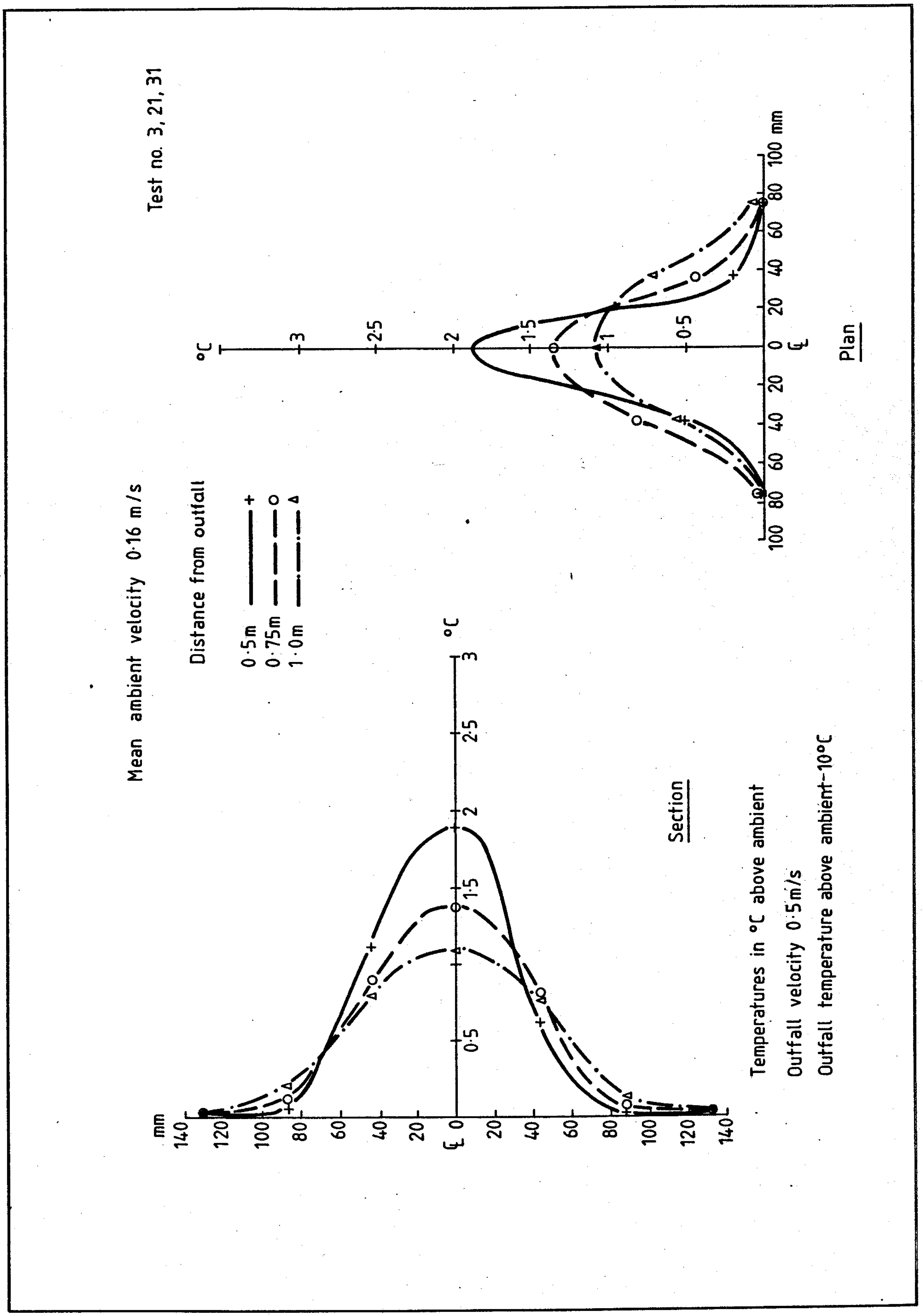


Fig. 11 Plan and section of outfall plume

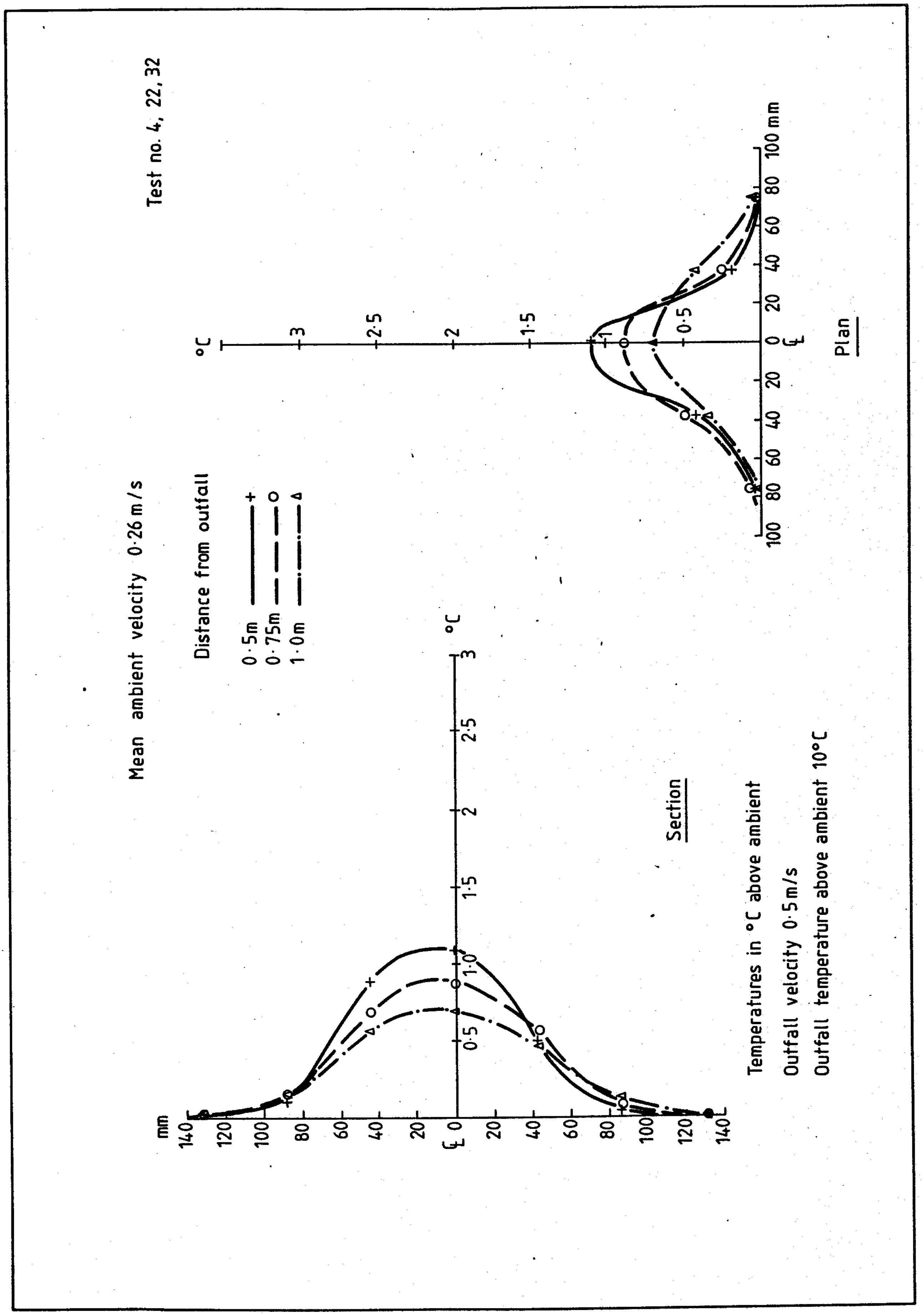


Fig. 12 Plan and section of outfall plume

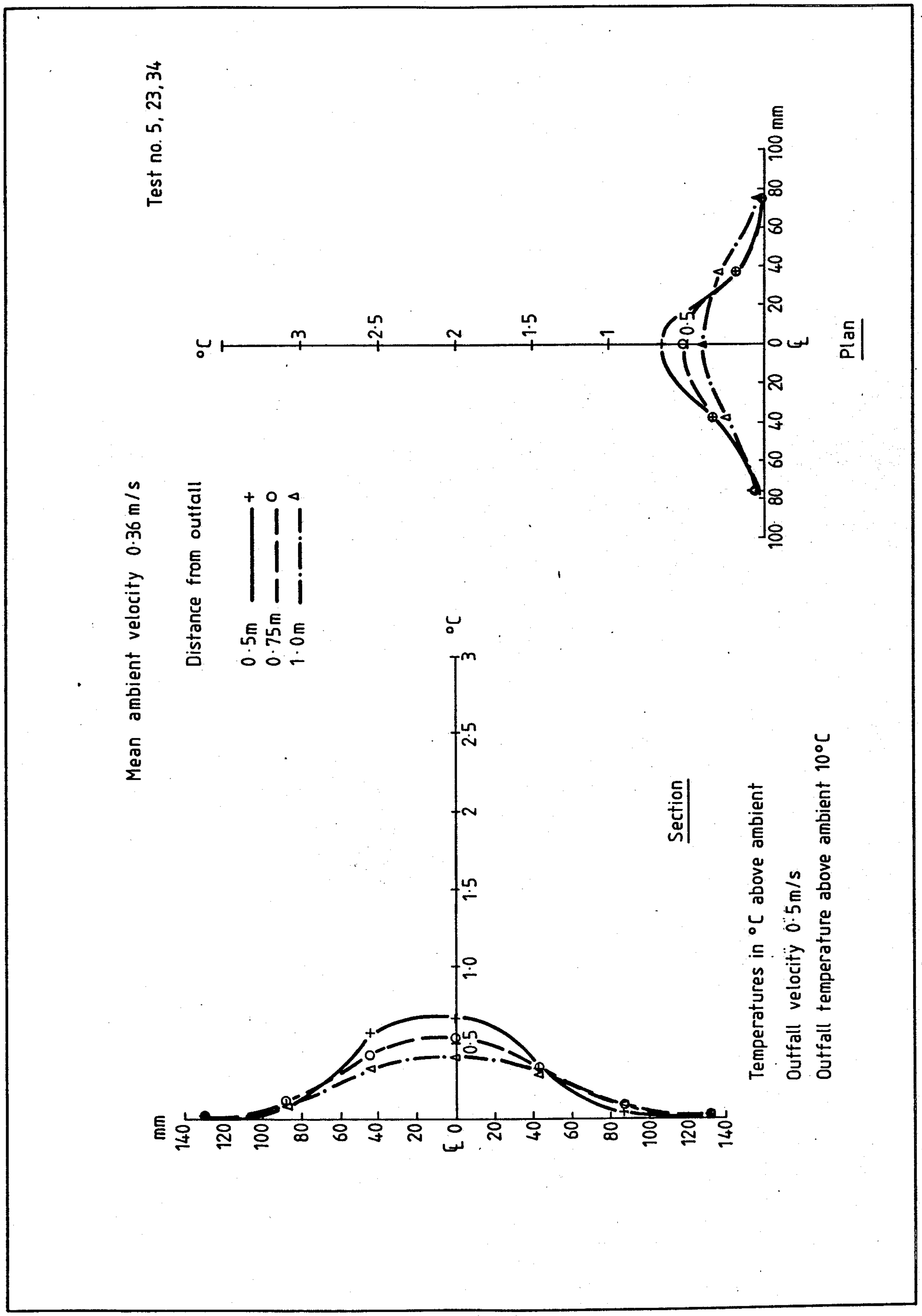


Fig. 13 Plan and section of outfall plume

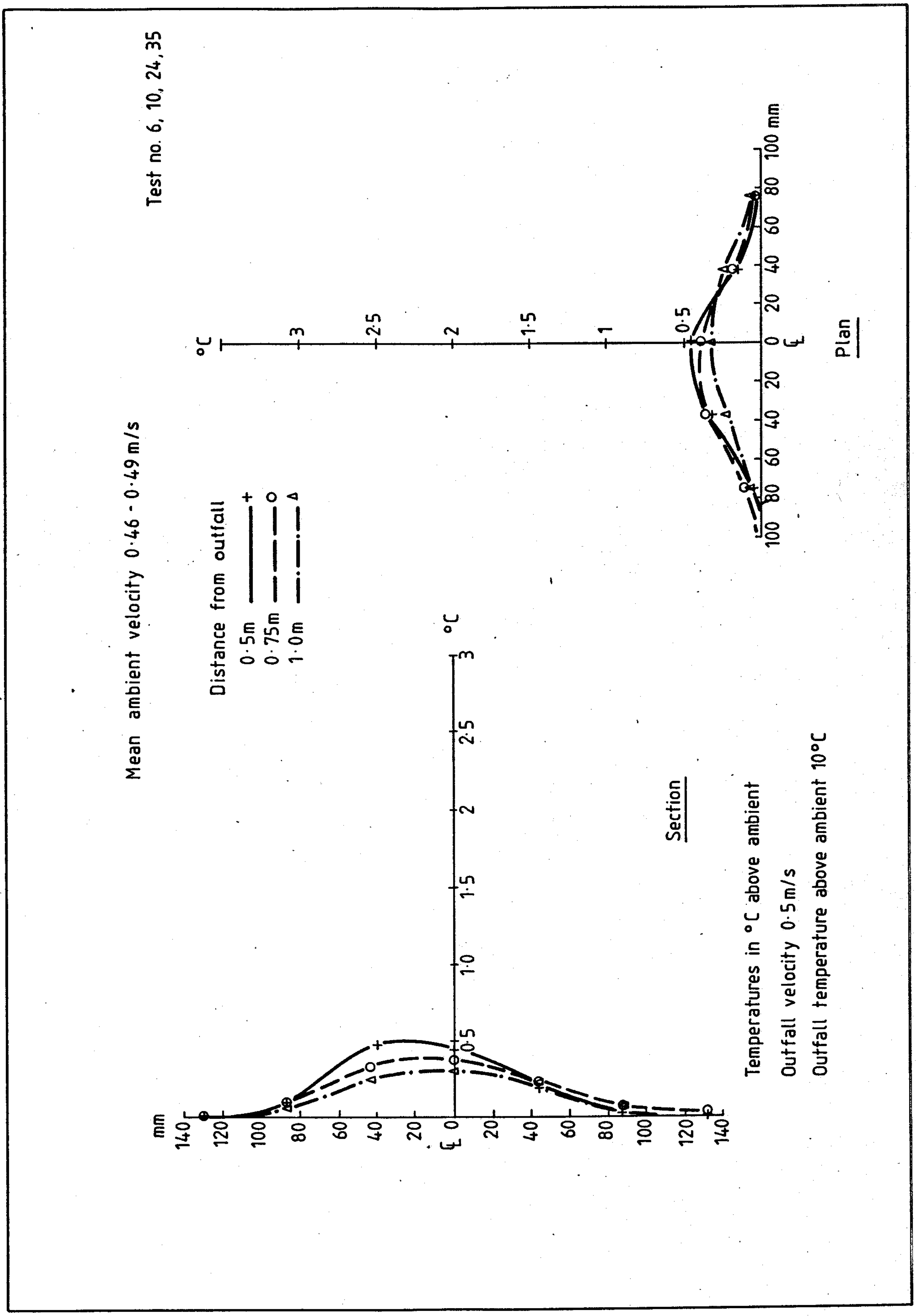


Fig. 14 Plan and section of outfall plume

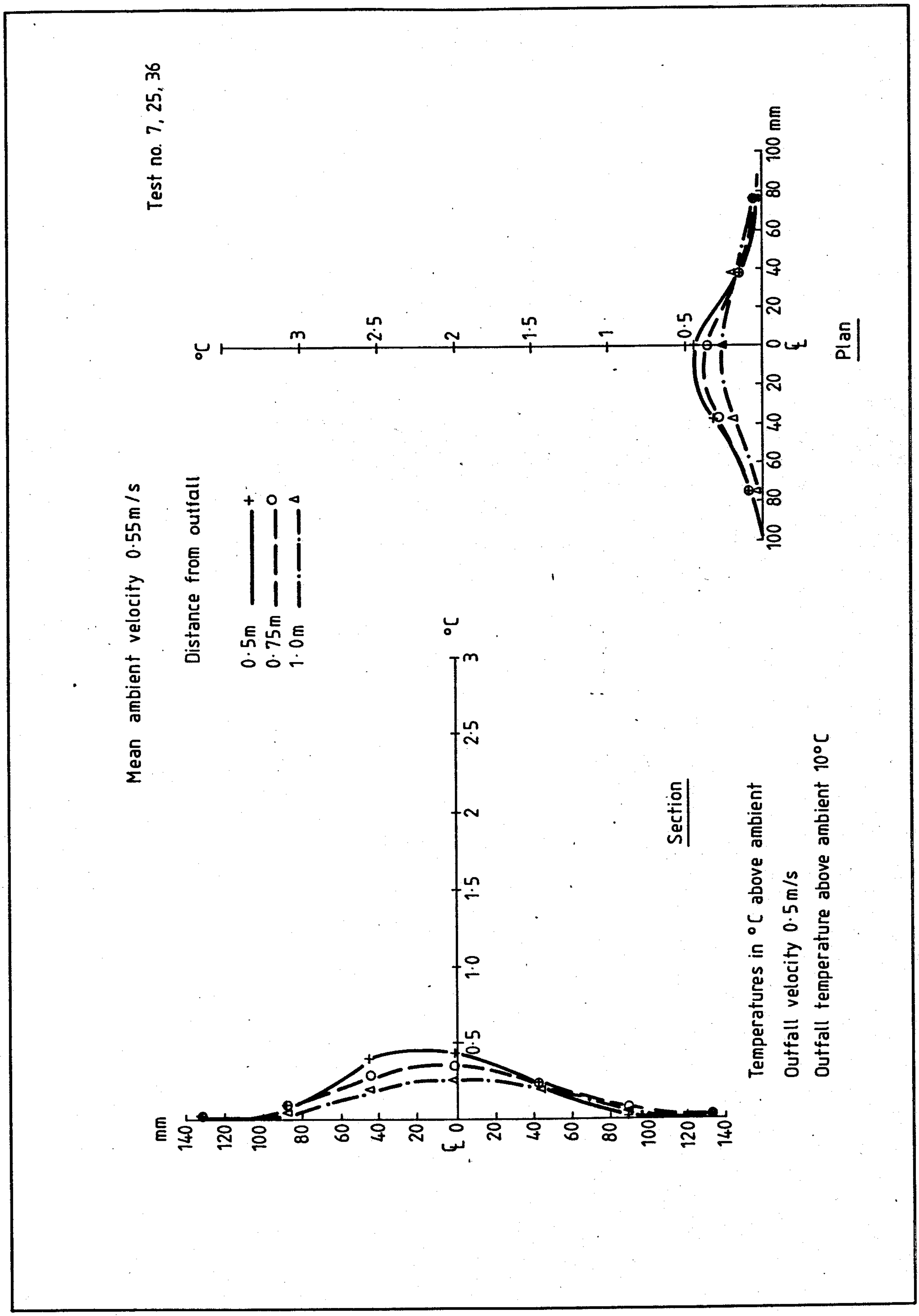


Fig. 15 Plan and section of outfall plume

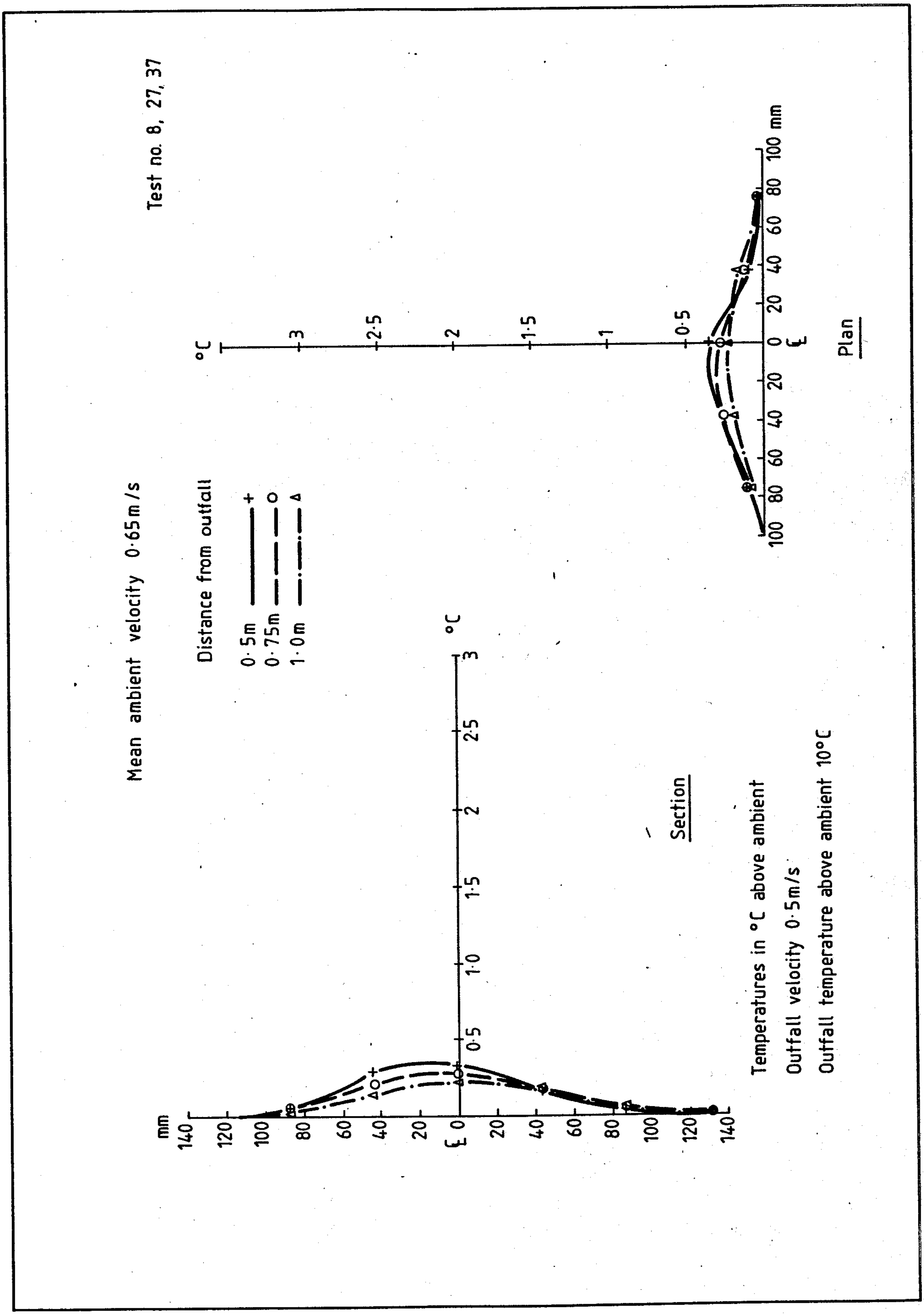


Fig. 16 Plan and section of outfall plume

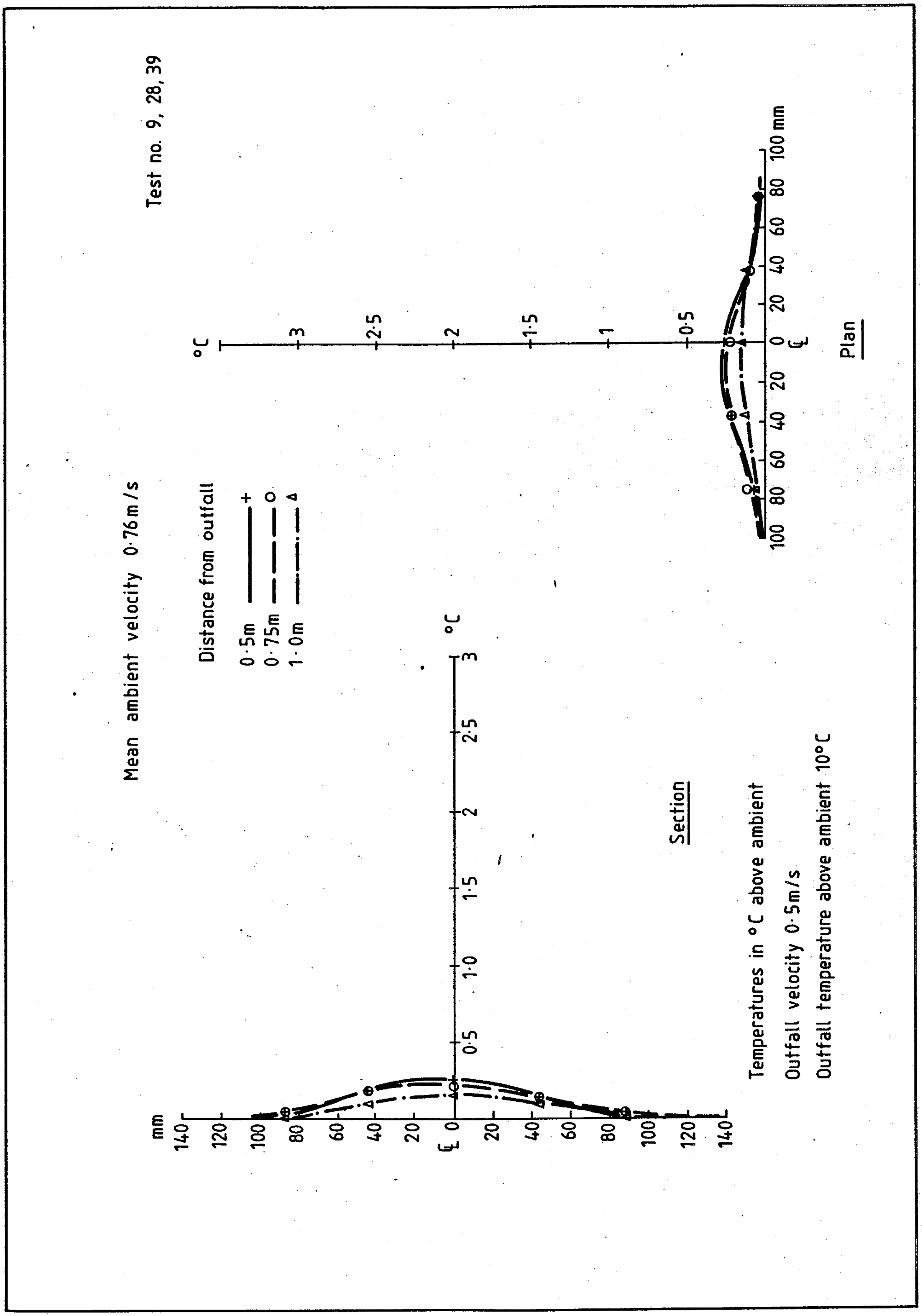


Fig. 17 Plan and section of outfall plume

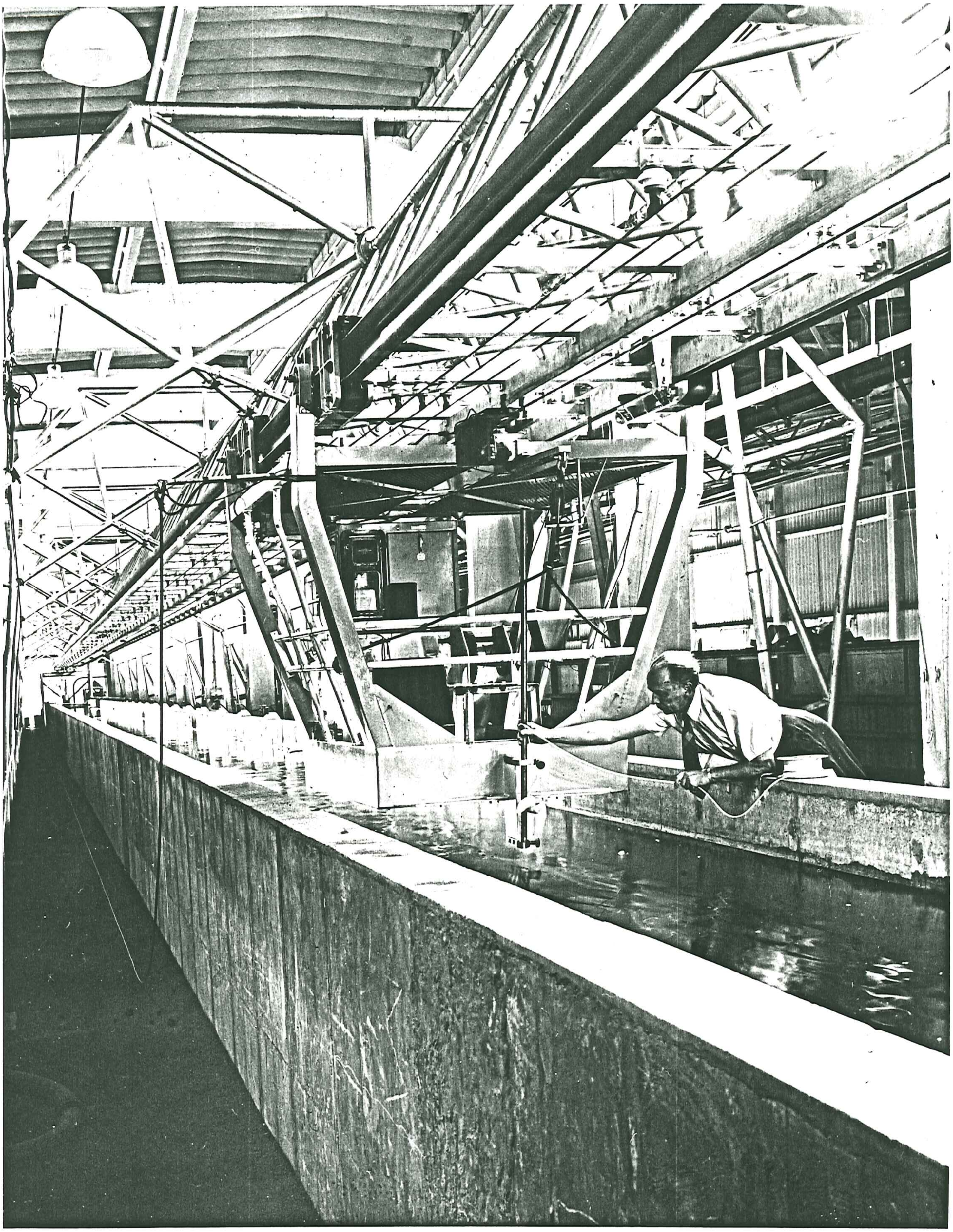


PLATE 1. Current meter calibration tank and carriage