CAD for air flow optimisation in clean room installations and other controlled environments

Dr. D.M. Deaves - Senior Engineer
Dr. Z.A. Khan - Project Engineer

Atkins Research and Development, Epsom, Surrey.

Many processes within the semi-conductor industry require ultra-clean air environments in order to minimise the risk of contamination. Such air is provided by means of high efficiency filtration, but the economical design of installations requiring clean areas often requires a knowledge of air flows both within the room, and in the plenum areas located typically above the ceiling and below the floor. This paper describes the development of a computational air flow modelling technique, and identifies applications within a clean room installations.

In addition, details are given of a validation exercise in which air flow patterns and velocities for a number of simple 2-dimensional configurations were both measured and predicted. The good agreement between measurements and predictions clearly demonstrates the usefulness of the method.

Presented at:- Conference on the Integrated Circuit Factory Design for the 1980s

on

30th and 31st January, 1984

at

Stratford-on-Avon

CAD for air flow optimisation in clean room installations and other controlled environments

Dr. D.M. Deaves - Senior Engineer
Dr. Z.A. Khan - Project Engineer

Atkins Research and Development, Epsom, Surrey.

1. Introduction

Clean rooms are being increasingly used in the nuclear and process industries for operations requiring a substantially particle-free environment. The manufacture of semi-conductor devices, for example, requires stringent controls on the air environment due to the delicate nature of their production. Design requirements in this situation generally stipulate that a laminar flow should exist in a direction parallel to all 'clean' components.

The efficiency of filtration available in clean room installations is such that any particles within the room are likely to be sub-micron. Since particles of this size follow the streamlines of the flow, the primary requirements for clean working areas should be met by ensuring that the flow patterns are acceptable. Although larger particles may be generated within the room, the attainment of acceptable flow patterns together with the purging action of a typical laminar flow system should ensure that cross-contamination is kept to a minimum. In extreme cases, a particular piece of equipment may be supplied with its own local laminar air system, designed to ensure rapid removal of contaminants from sensitive areas.

Laminar flows in clean rooms are affected by the presence of equipment, operators and sources of heat in ways which are not always easy to define. The two-dimensional version of the computer program CAFE, which has been developed by Atkins Research and Development, has been applied to such flow situations. It is the purpose of this paper to present a comparison of observed flow patterns with the corresponding computations for a vertical laminar flow room, and to give some examples of the range of application of the model.

2. Experimental arrangement

The flow measurements described in this paper were undertaken in a newly built clean room prior to its final balancing and commissioning. The room utilises a vertical laminar flow drawn in through a HEPA filter ceiling, and out, via a porous suspended floor,through an underfloor plenum. A vertical section through the room is shown in Figure 1, and the arrangement of porous flow tiles in the measurement plane is shown in Figure 2.

Measurements of air velocity and tracer gas concentrations in the clean room were obtained by use of the following techniques:-

(i) Hot-wire Anemometer - A DISA hot-wire anemometry system with single normal sensors was used for the velocity measurements. A low velocity wind tunnel was used for system calibration with particular emphasis on the 0.2-1.0 m/s velocity range, i.e. the range of velocities to be encountered in the clean room.

(ii) Vane anemometer - An Airflow Developments vane anemometer was also used for the velocity component measurements. This had a 10 cm diameter head and was held in horizontal and vertical planes to measure the predominant u and v velocity components.

(iii) Gas concentration measurement - A Century Systems flame ionisation detector was used to measure the tracer gas mixture concentrations in the flow. This instrument is capable of measuring, accurately, concentrations down to a level of 0.1% of mixture strength.

(iv) In addition, a thin trace of smoke was used for flow visualisation and this was recorded on still and cine film.

These techniques were used to assess the airflows in a variety of different configurations. These included the 'at rest' (i.e. empty room) condition, and the presence of a solid bench at a range of distances from the wall.

3. The Prediction Method

The computational prediction work was conducted using a 2D version of the program CAFE (Computer Aided Flow Evaluation). This program is designed to solve flow problems which exhibit areas of recirculation, and has been extensively used for internal air flows and related ventilation problems (see, for example, Broyd et. al (1983a)).

A detailed description of the program CAFE is not given in this paper. The following variables may be solved in either two or three dimensions:

- momentum in each dimension
- continuity
- 2 turbulence equations (unless the flow is genuinely laminar)
- concentration
- temperature

It is possible to model flow domains of any desired geometry, and internal blockages may be used to simulate work benches, items of equipment, personnel, etc. The effect of heat-emitting (or absorbing) equipment or personnel may be modelled by introducing sources (or sinks) of heat energy at appropriate positions within the model domain, (although it should be pointed out that it is difficult to simulate accurately the effects of people moving around). Likewise the shedding of particles by plant or personnel may be modelled by making the analogy between small particles and concentration of gases, since there is little loss of accuracy in assuming that particles of <10μm remain associated with individual "parcels" of air flowing through the cleanroom.

A full description of the solution technique used for CAFE may be found in Moult and Dean (1978).

The results from CAFE presented here were obtained with a finite difference grid of 31 x 25 grid nodes (in the x and y directions, respectively). Non-uniform grid spacing was used in order to cluster grid nodes in regions where steep gradients were expected; this was particularly the case in the vicinity of the work bench.

In the program CAFE, information is required along the various faces of the solution domain. The information takes the form of boundary conditions, which are shown in Figure 1.

- The north boundary corresponded to the ceiling of the room and a vertical velocity of 0.5 m/s downwards was prescribed there.
- The west boundary corresponded to a solid wall with a partial opening (below floor level) for air supply ductwork.
- The floor of the room was represented by a porosity (this is the ratio of the open area in the floor to the total floor area).
- Remaining hatched boundaries (plus the surface of the bench) are solid, with no-slip wall boundary conditions.

4. Results and Discussion

Having checked the uniformity of the flow through the ceiling filters, the first measurements were taken at a 1m height in the 'at rest' room configuration. The results in Figure 3 clearly show the effects of different porosities at different positions on the floor, and agreement between predictions and measurements is good. It should be emphasised that the slight variation of velocity across the room was due to the fact that the floor had not been 'balanced'.

The next case under consideration included a simple bench, placed close to a side wall, as shown in Figure 1. The predicted streamline pattern is shown in Figure 4, and the smoke flow visualisation is shown in Figure 5. The streamlines show that the air divides over the top of the bench, causing a stagnant region in the middle, and a large recirculation region is formed under the bench; these predictions are confirmed by the flow visualisation. Measurements and predictions of the v-velocity component for various horizontal planes are shown in Figure 6. The predictions show the same trends in the profiles as the measurements but with slightly higher values; the agreement is generally good.

The gas concentration source with a non-dimensionalised release concentration of 1.0 was placed 0.25m above the bench-top. The predicted results, Figure 7, show that the tracer flows to the front of the bench. The figure shows an enlarged view in the region of the bench with measured values, at various locations, superimposed on this plot. Although the number of measured points is scarce, the measurements and predictions are in reasonable agreement, with the higher measured values giving good agreement with the predictions. In order to obtain better agreement with the lower values, it would be necessary to take measurements on a finer matrix, and also to undertake the computations on a finer grid.

The final configuration presented here is for the same bench set against the wall. This results in a greater deflection of the streamlines, as shown in Figure 8, which was also confirmed by flow visualisations. Vertical velocity components are shown in Figure 9. Again, the trend is correctly predicted although on average there is a tendency for the program to over-estimate velocities.

The results presented in this section have shown that the computer program CAFE can be used to predict clean room flows with reasonable accuracy. Some of the velocity over-estimates can be explained by the fact that the ceiling supports occupied about 8% of the total area, thus reducing the total inflow relative to that which was assumed in the numerical predictions.

5. Applications for the computer program CAFE

It has been shown (Broyd et al, 1983b) how the program CAFE may be used in parametric studies. It is the purpose of this section to take three rather different examples, and demonstrate the way in which results from CAFE may be used.

a) Floor balancing in a vertical flow laminar clean room

The underfloor plenum in such an installation should be large enough to be at essentially uniform pressure. In practice, structural and design considerations may result in less than ideal conditions. An example of flow within the room for a partially obstructed plenum is shown in Figure 10. The effects of the obstruction (at the left of the plenum) are clearly evident in the deflections of streamlines to the right. The effects of an attempt to balance the floor by reducing the porosity of the right-hand side from 15% to 10% are shown in Figure 11, which has a considerable improvement in flow parallelism. This modification also reduces the variability of vertical velocity across the width of the room, as is evident in Figure 12.

b) Flow through a HEPA filter ceiling

Although the relatively high resistance of a HEPA filter tends to smooth out the velocity profile through the ceiling, there can still be non-uniformities in profile owing to inlet duct position, cleanliness of filter, etc. Figure 13 gives an example of the variability of vertical velocity just below the ceiling with both these parameters. The inlet to the plenum is at the RHS, and the velocity maximum below the ceiling is laterally displaced, leaving a minimum immediately below the inlet. The dirty filter tends to accentuate this minimum, and also to increase the range of variation of velocity across the width of the room. Δp across the filter (not shown) is also higher with a dirty filter, and this has obvious implications for the energy requirements of such an installation.

c) Ventilating flow past an obstacle

The final example is for a non-clean-room application in which a relatively small jet of ventilating air is directed at the corner of an obstruction, and drawn out from the lower part of a side wall. In this case (Figure 14), a comparison is given of laminar and turbulent flow results. In this case, where the inlet only covers a small area, the turbulent case is preferable because of the large recirculations present in the laminar flow, which considerably reduces the purging action of the airflow over the face of the obstruction.

6. Conclusions

a) CAFE2D has been applied to real clean room flow situations and found to give good agreement with measured data.

b) The effects of parameter variation can be easily predicted using the computer code at the design stage without resorting to costly full-scale testing.

c) Examples have been given of the use of CAFE2D for flow optimisation in a number of different clean room and ventilating flow configurations.

7. Acknowledgement

The authors wish to express their gratitude to Mr. Howard Richards of Plessey Research Centre, Caswell for allowing the use of their facilities and for permission to publish the results.

8. References

Broyd, T.W., Moult, A., Dean R.B. & Oldfield, S.G.
The Use of a Computational Method to Assess the Safety and Quality of Ventilation in Industrial Buildings
Int. Conf. on Heat & Fluid Flow in Nuclear and Process Plant Safety, I.Mech.E., London, 1983.

Broyd, T.W., Deaves, D.M. & Oldfield, S.G.

The Use of Computational Modelling Techniques for Clean Room Design

Semicon Europa, Zurich, 1983.

Moult, A. & Dean, R.B.

CAFE - A Computer Program to Calculate the Flow Environment

CAD80, 4th Int. Conf. on Computers in Design Engineering, Brighton, 1980.

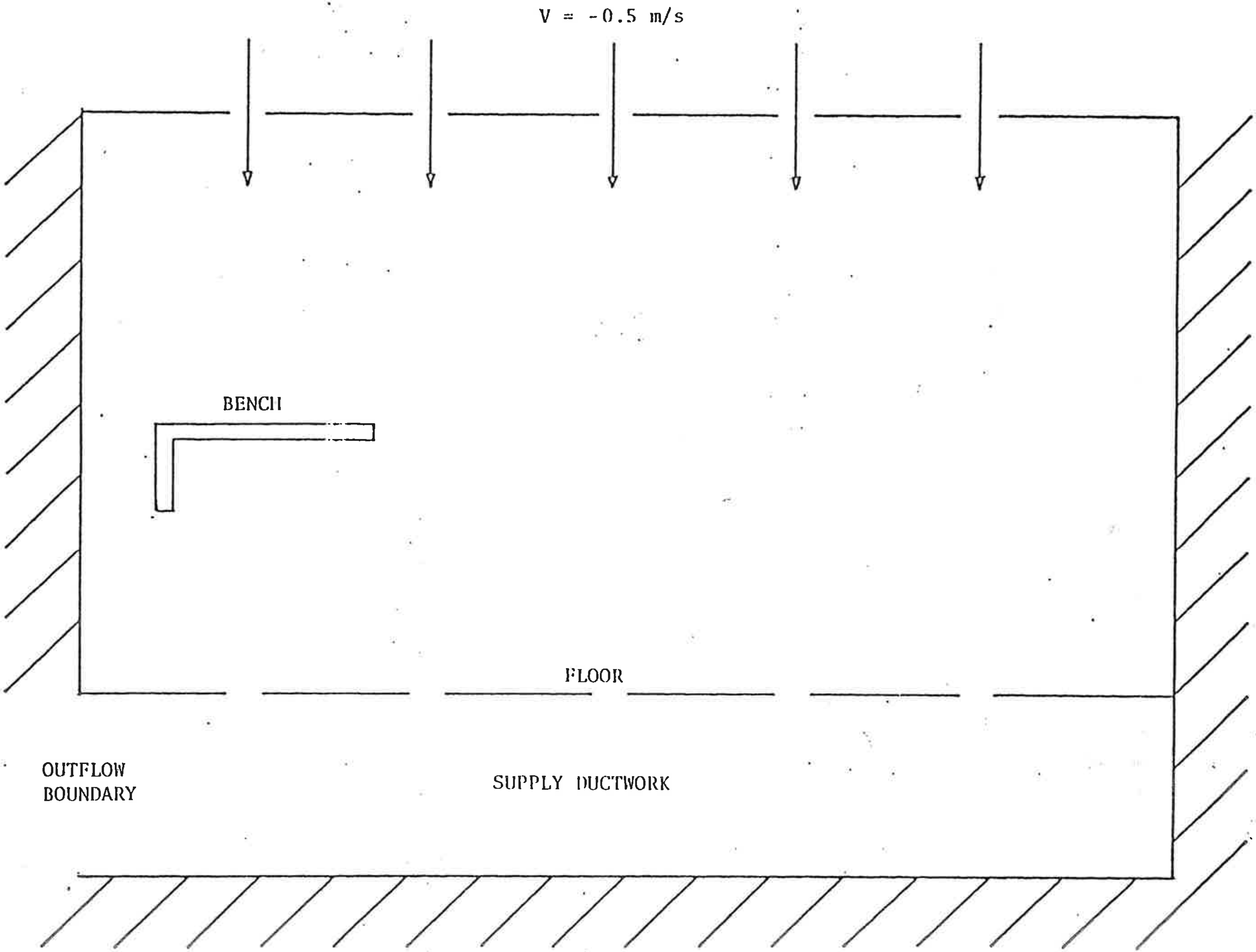


Figure 1: Schematic of clean room

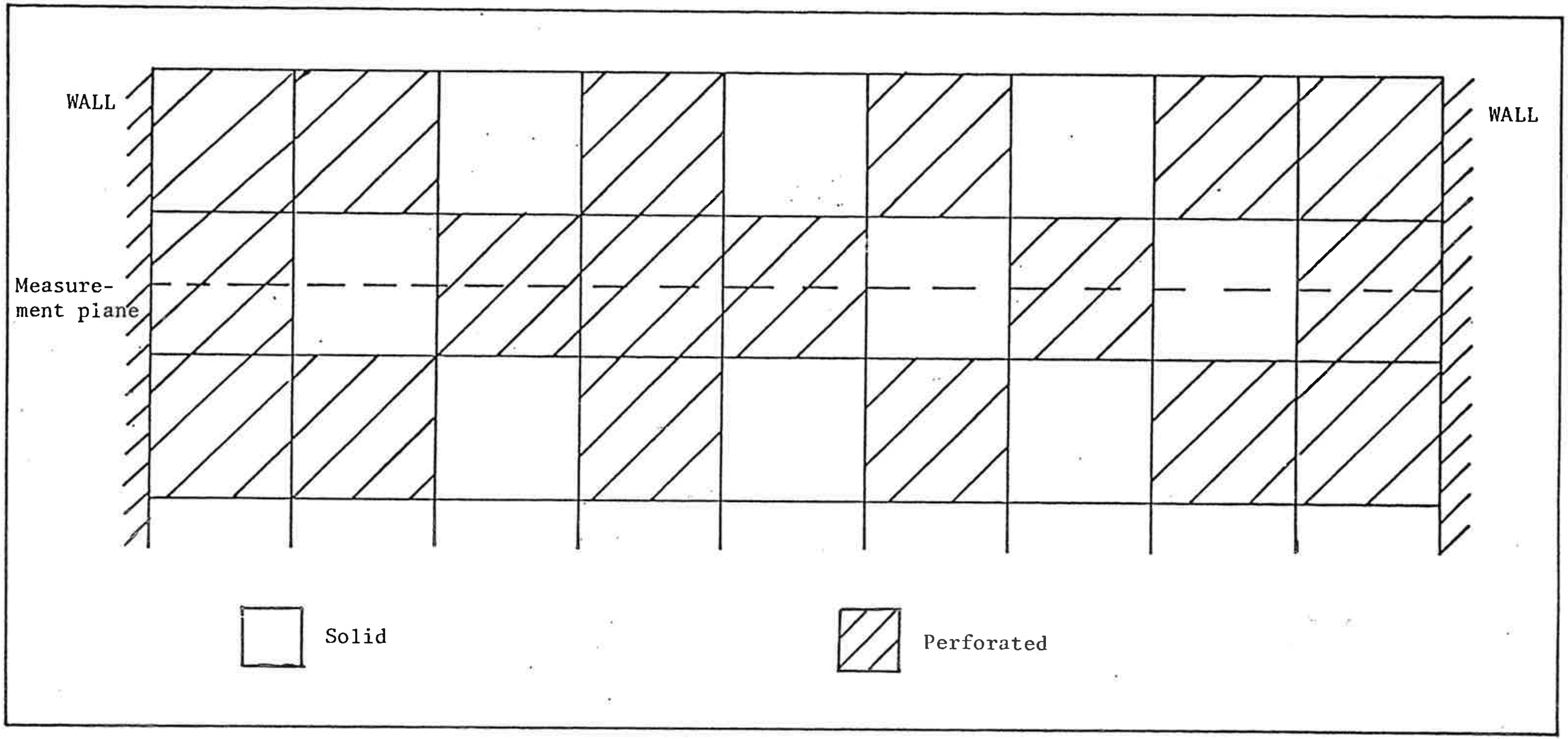


Figure 2: Arrangement of perforated tiles on floor

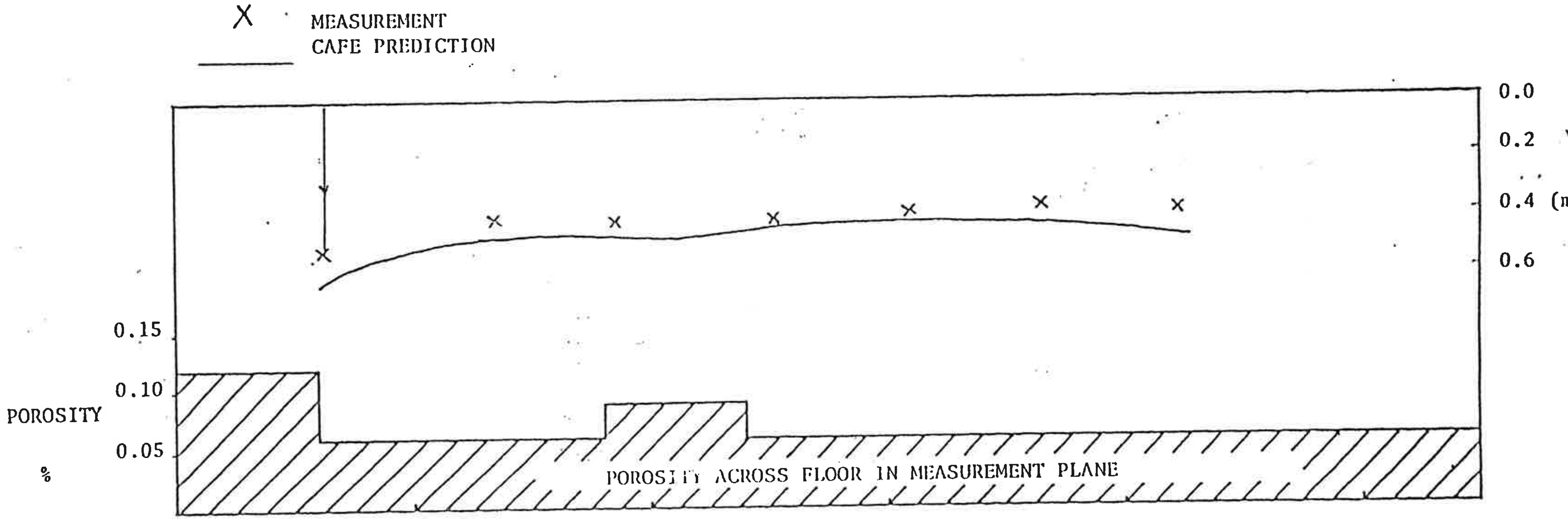


Figure 3: Velocity predictions for 'at rest' condition

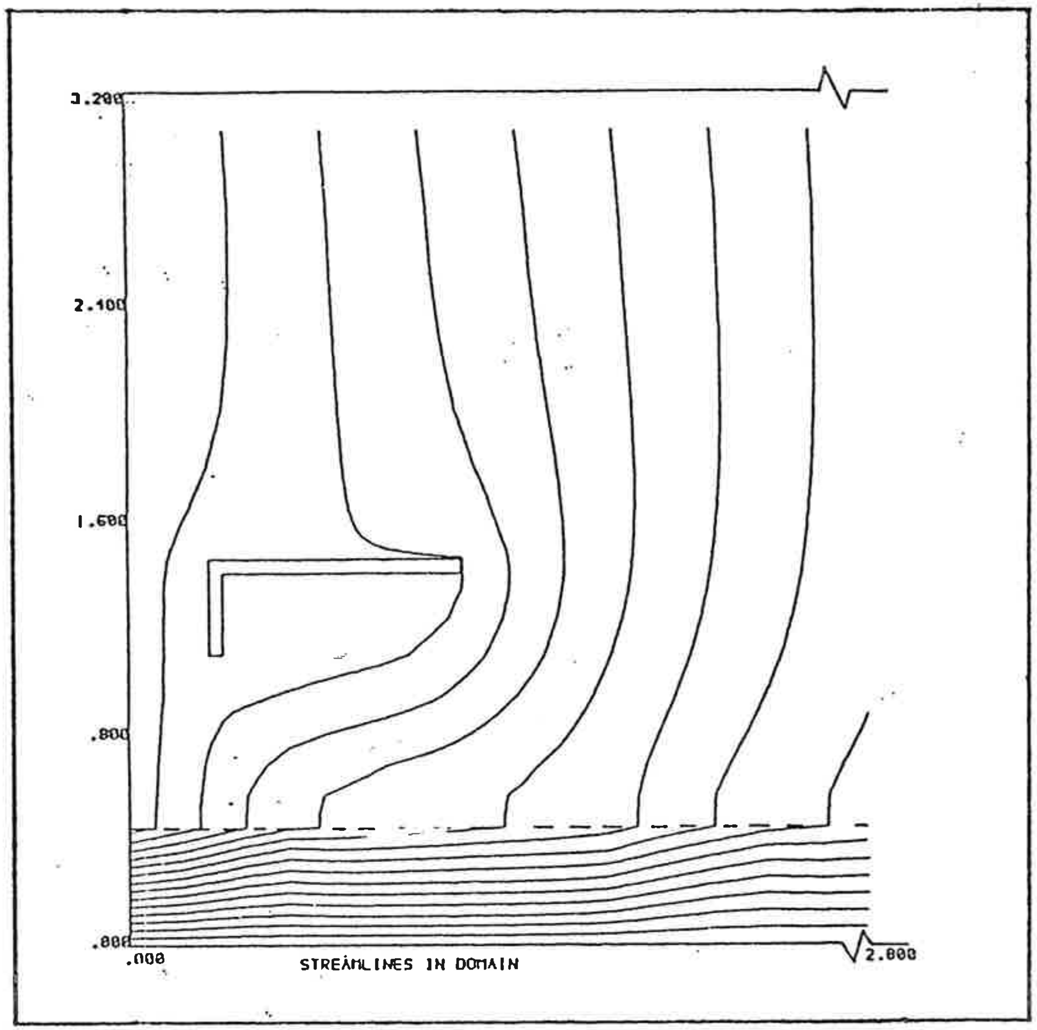
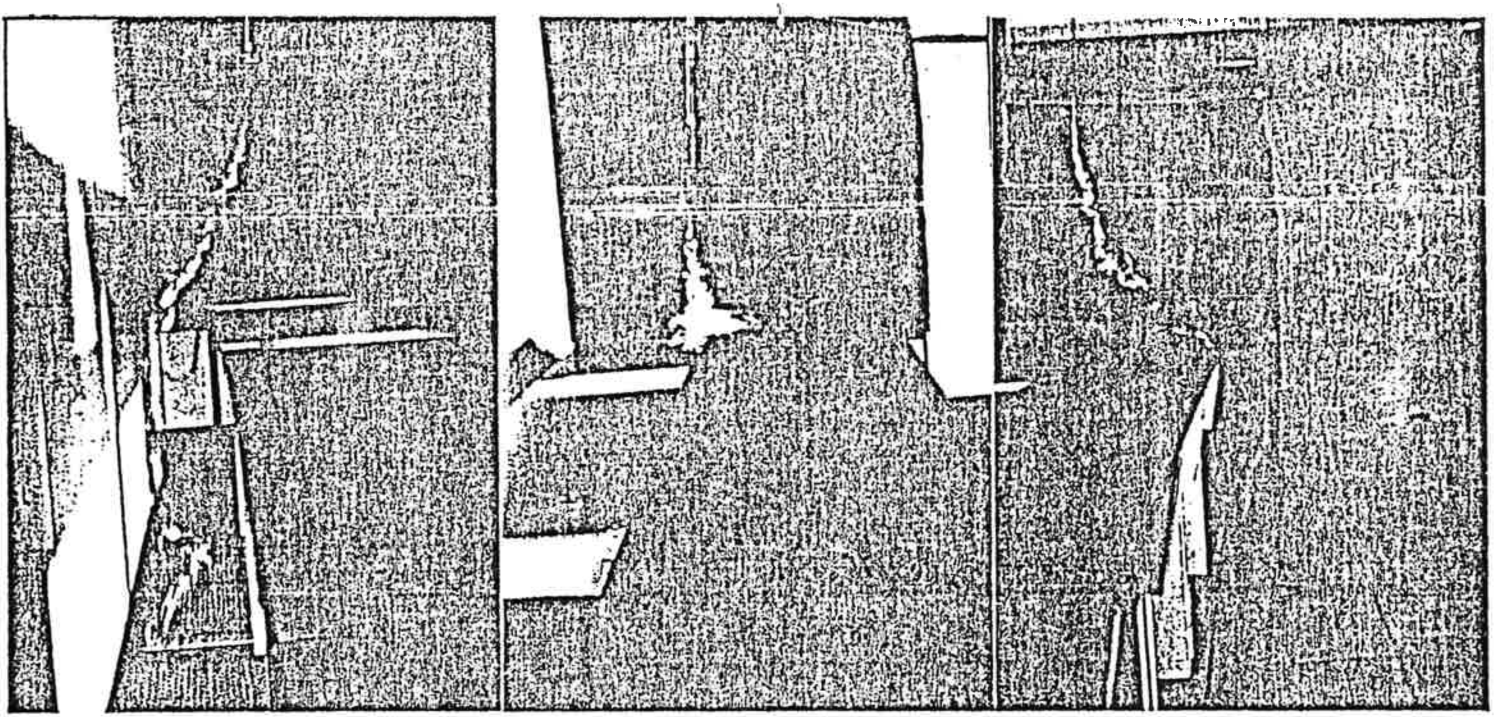


Figure 4: Predicted streamlines around bench



FLOW BEHIND BENCH

FLOW OVER CENTRE OF BENCH

FLOW TO THE FRONT OF BENCH

Figure 5: Smoke visualisation around bench

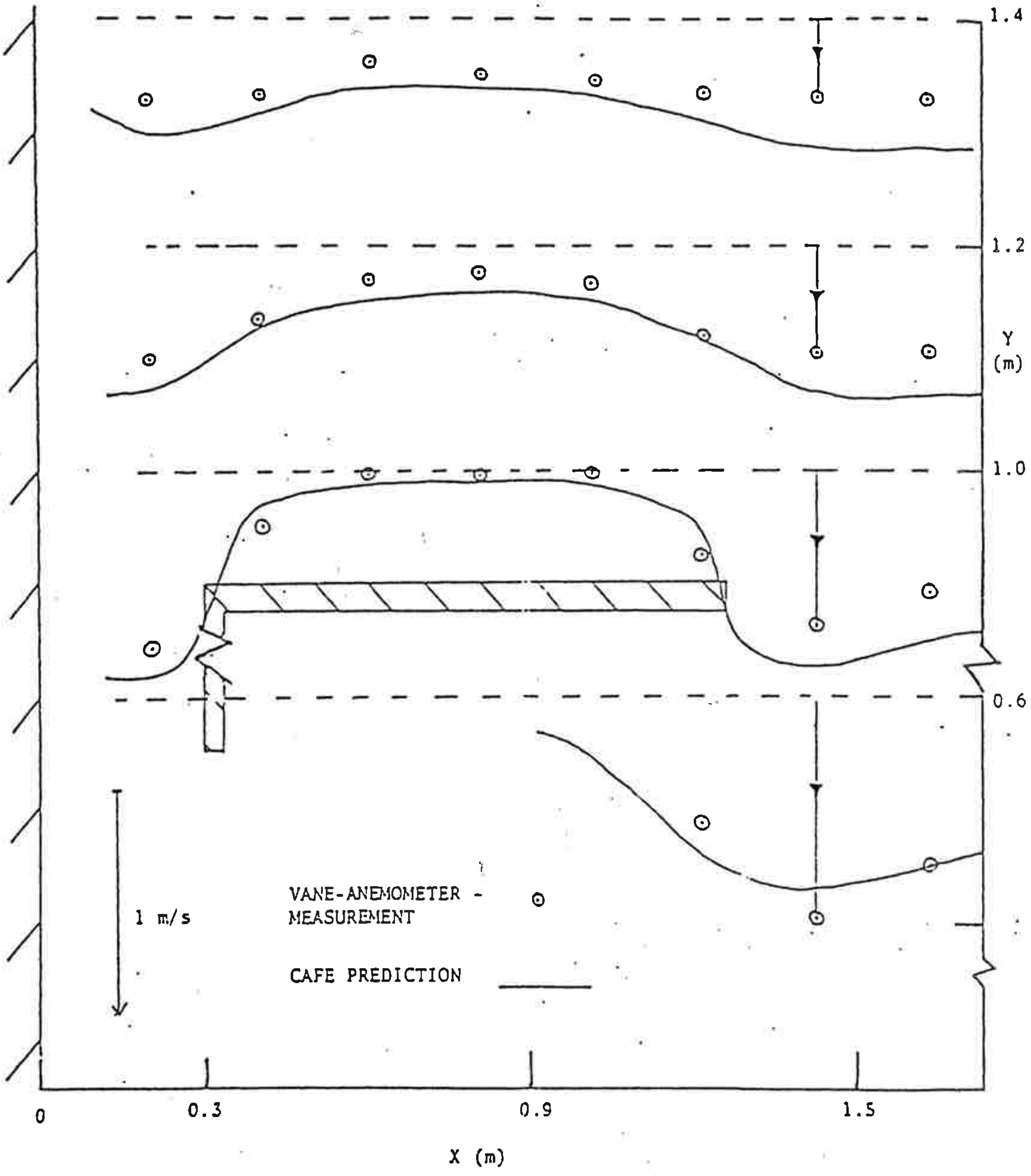


Figure 6: Comparison of predicted and measured velocities over bench

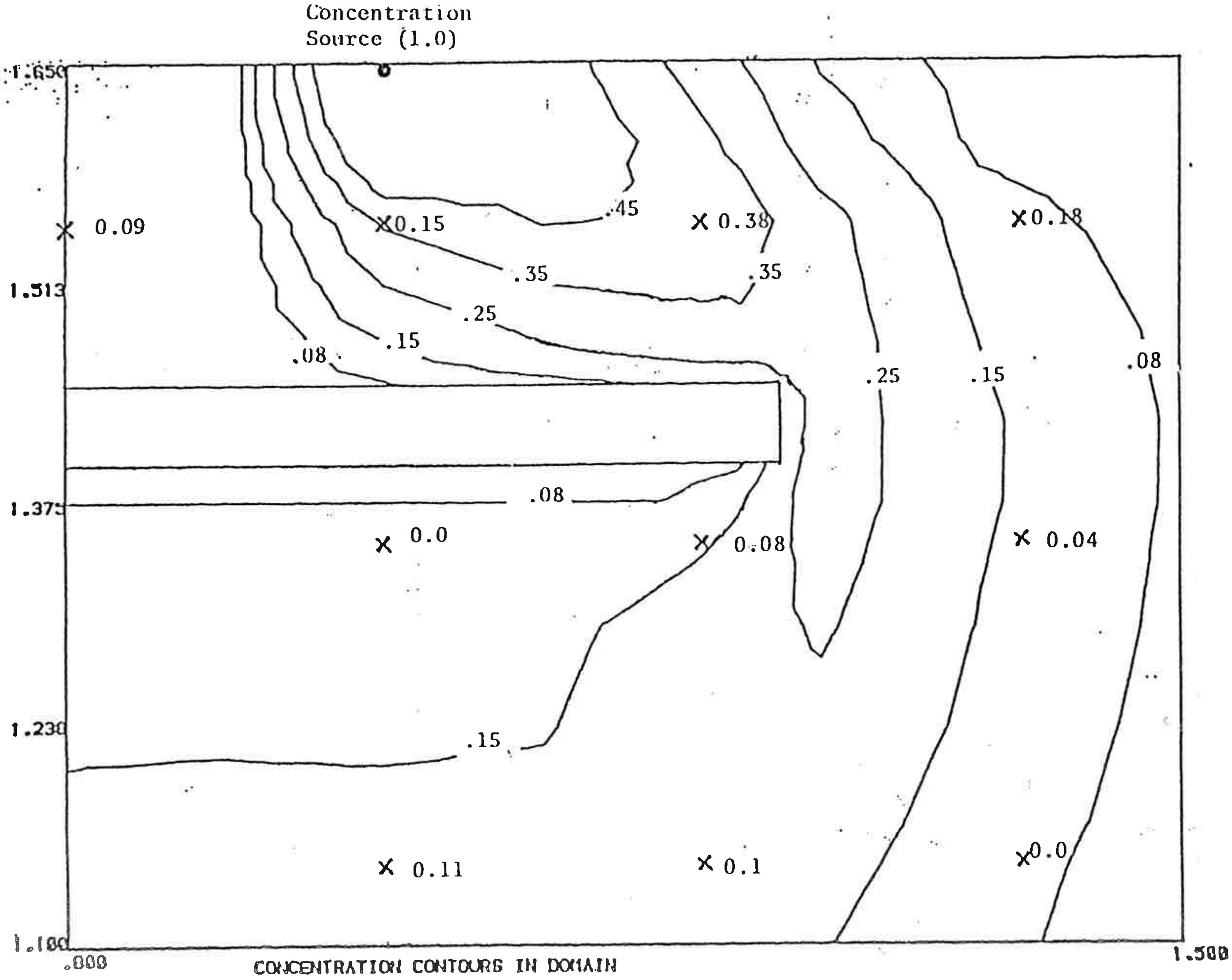


Figure 7: Tracer gas concentrations

Predictions ——
Measurements X

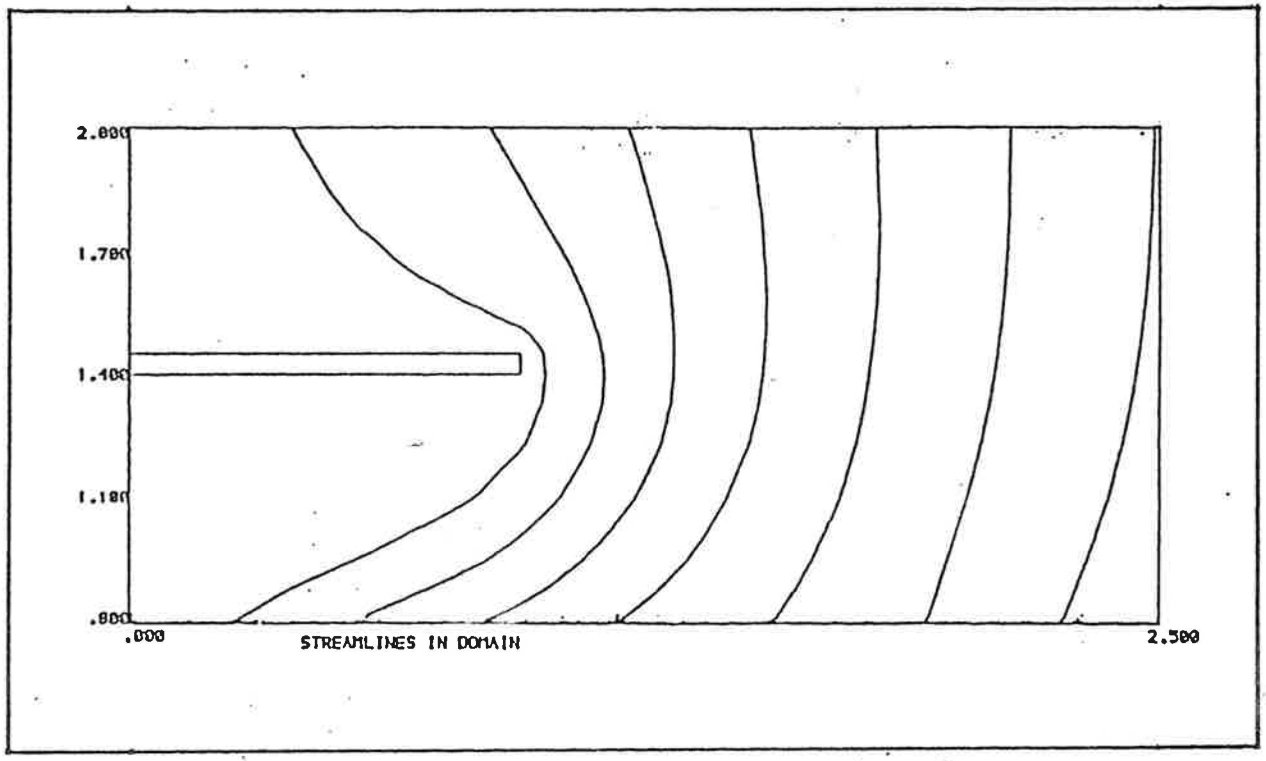


Figure 8: Predicted streamlines around bench against wall

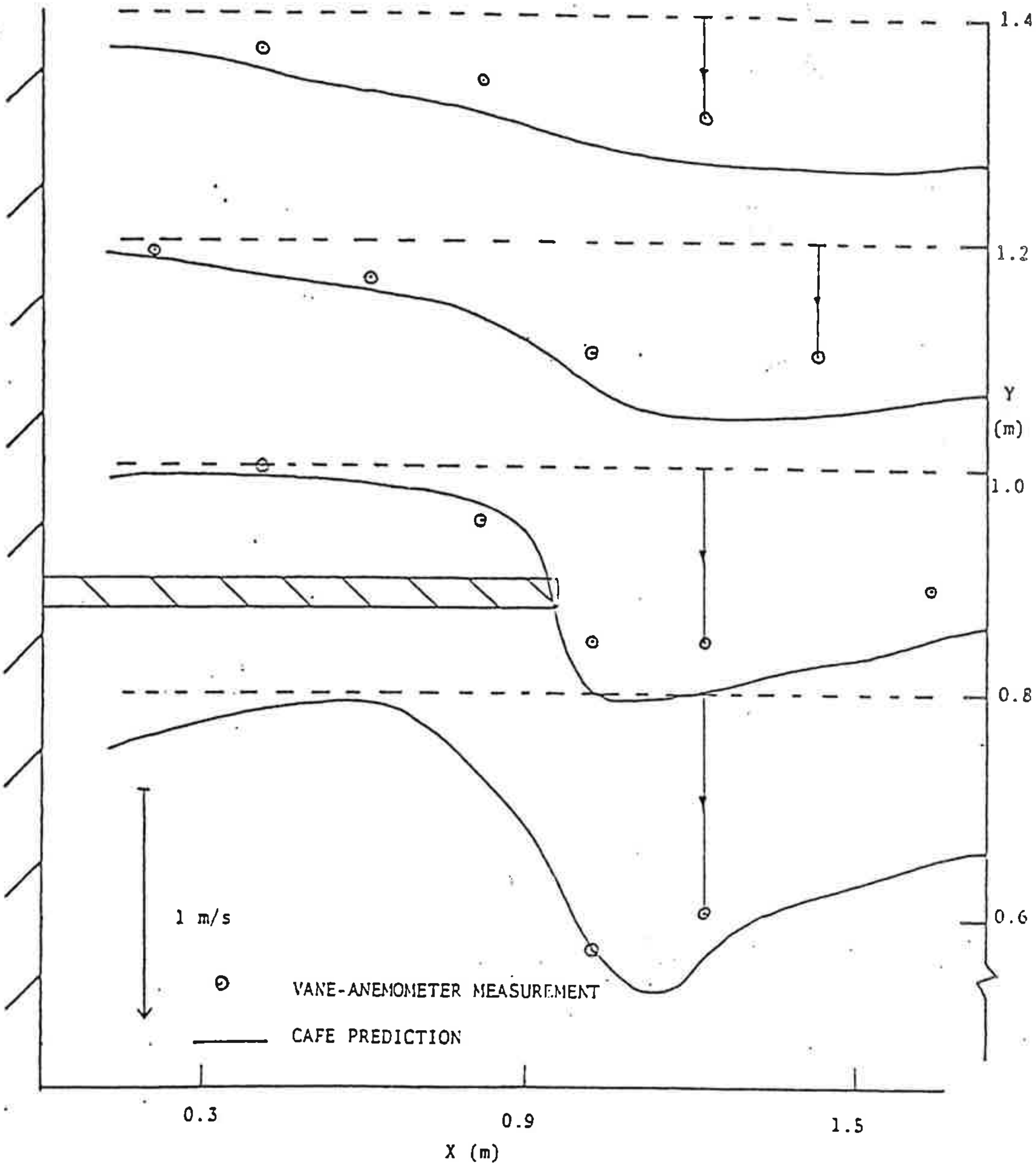


Figure 9: Comparison of predicted and measured velocities for bench against wall

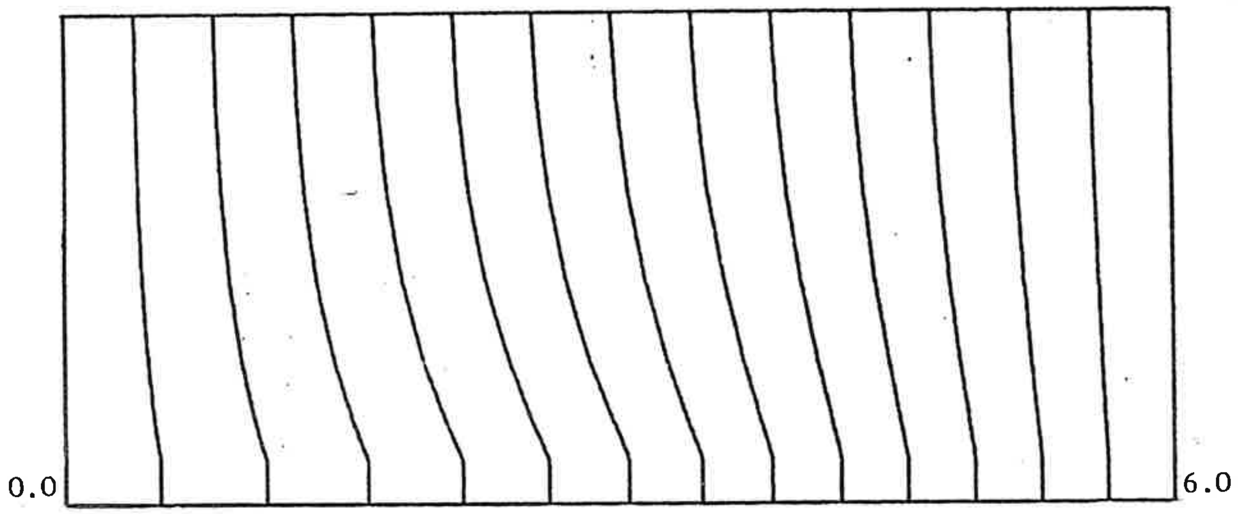


Figure 10: STREAMLINES FOR UNBALANCED FLOOR (15% POROSITY)

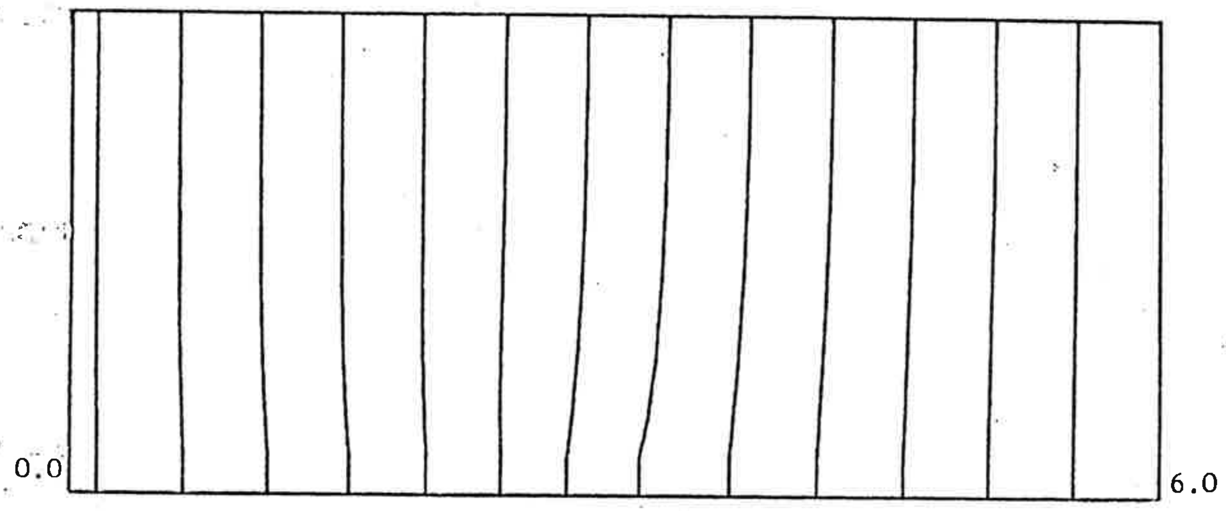


Figure 11: STREAMLINES FOR BALANCED FLOOR (15%/10%)

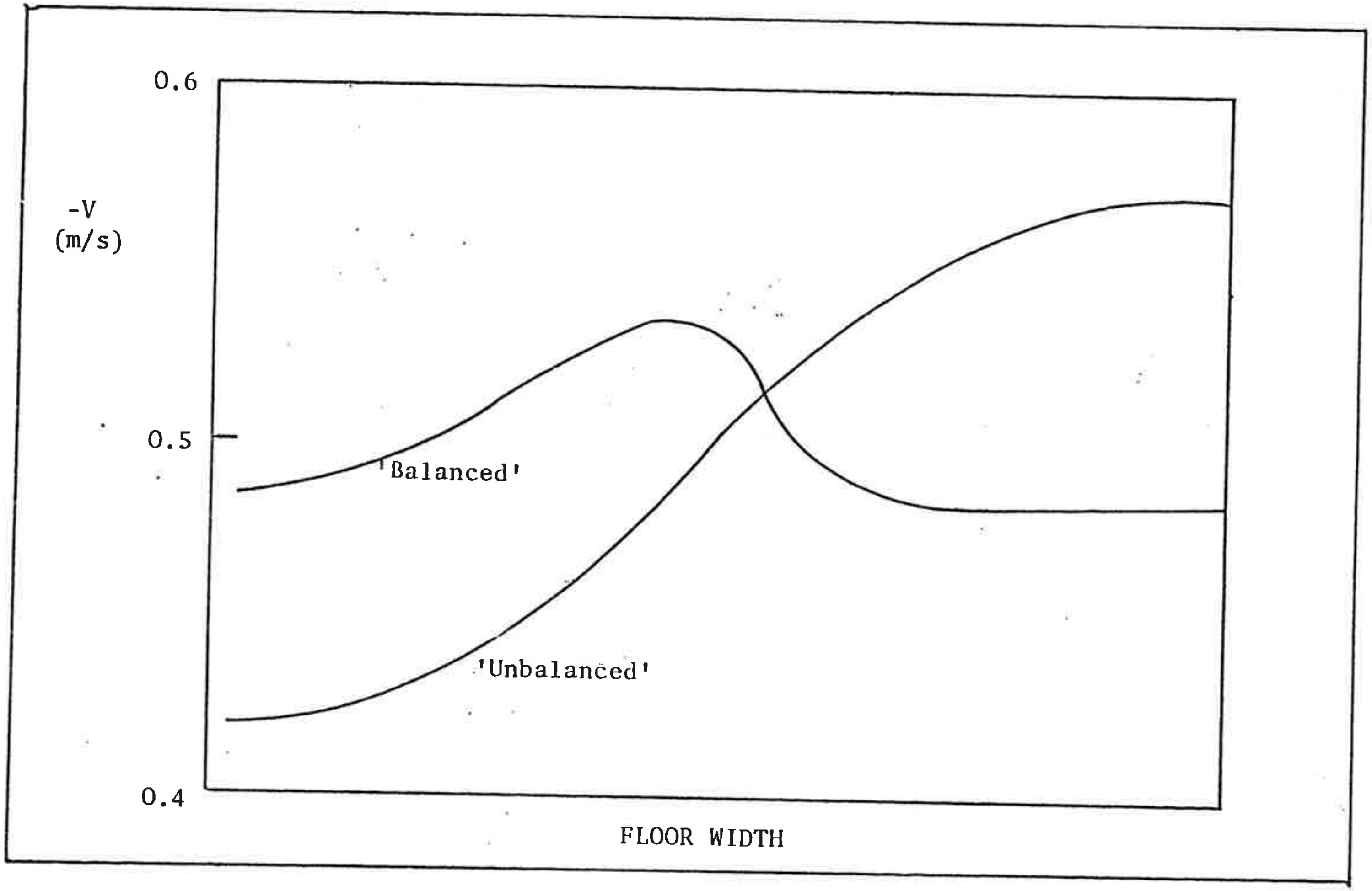


Figure 12: Vertical velocity profile across room, 2 foot above floor level

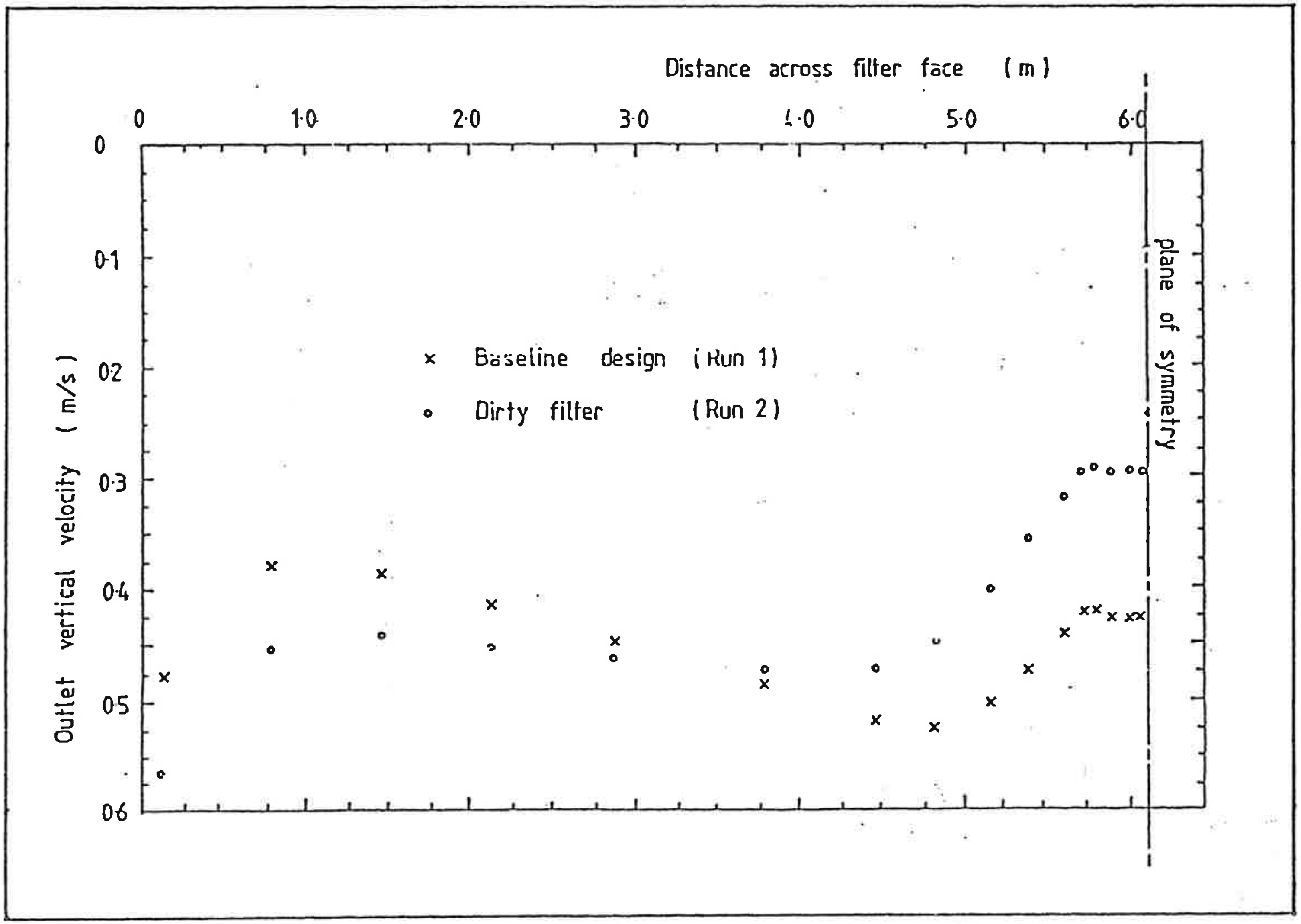
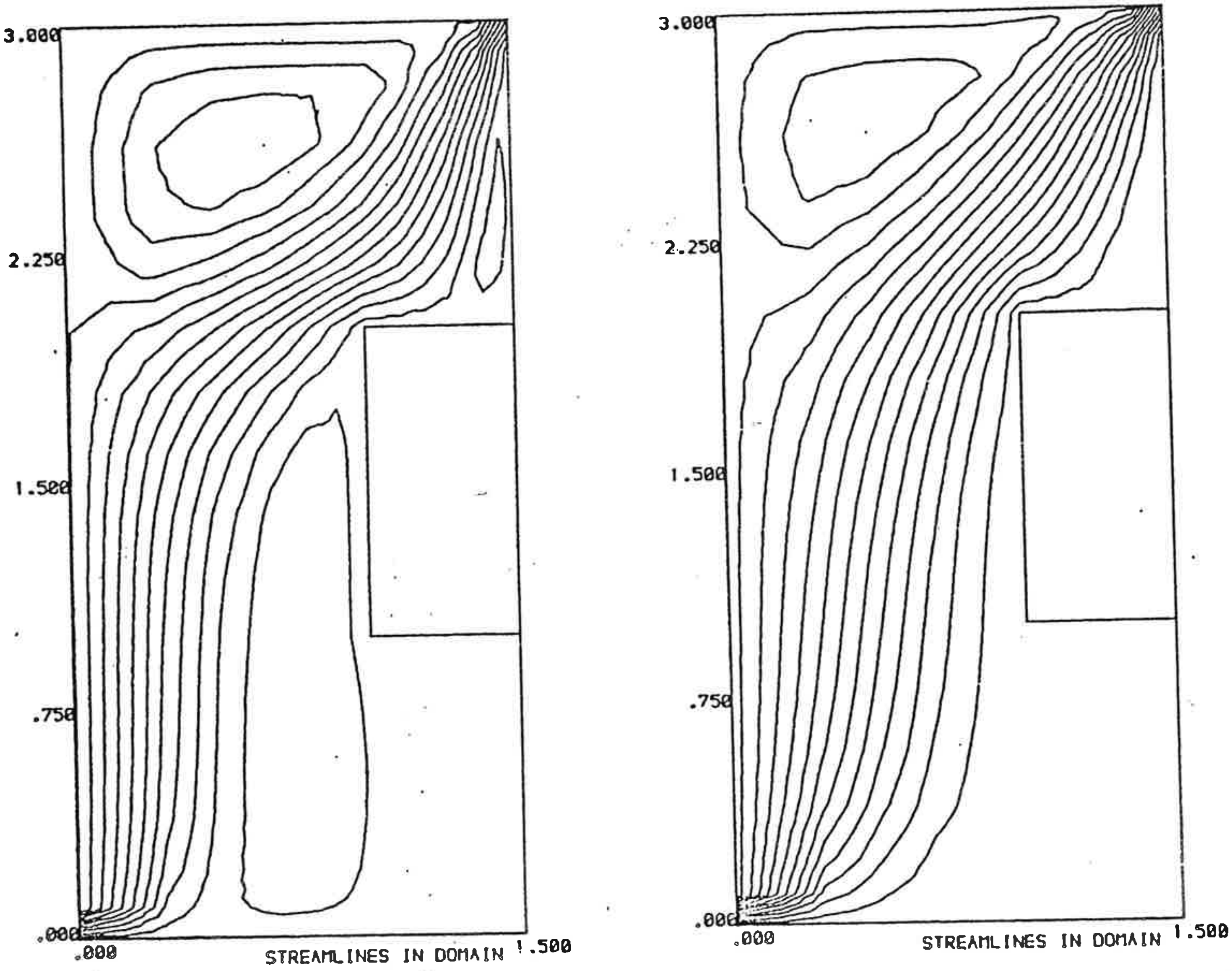


Figure 13: Velocities through clean and dirty HEPA filters



a) LAMINAR

b) TURBULENT

Figure 14: Ventilation flow past an obstruction