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A LABORATORY RAINFALL SIMULATOR FOR PESTICIDE STUDIES

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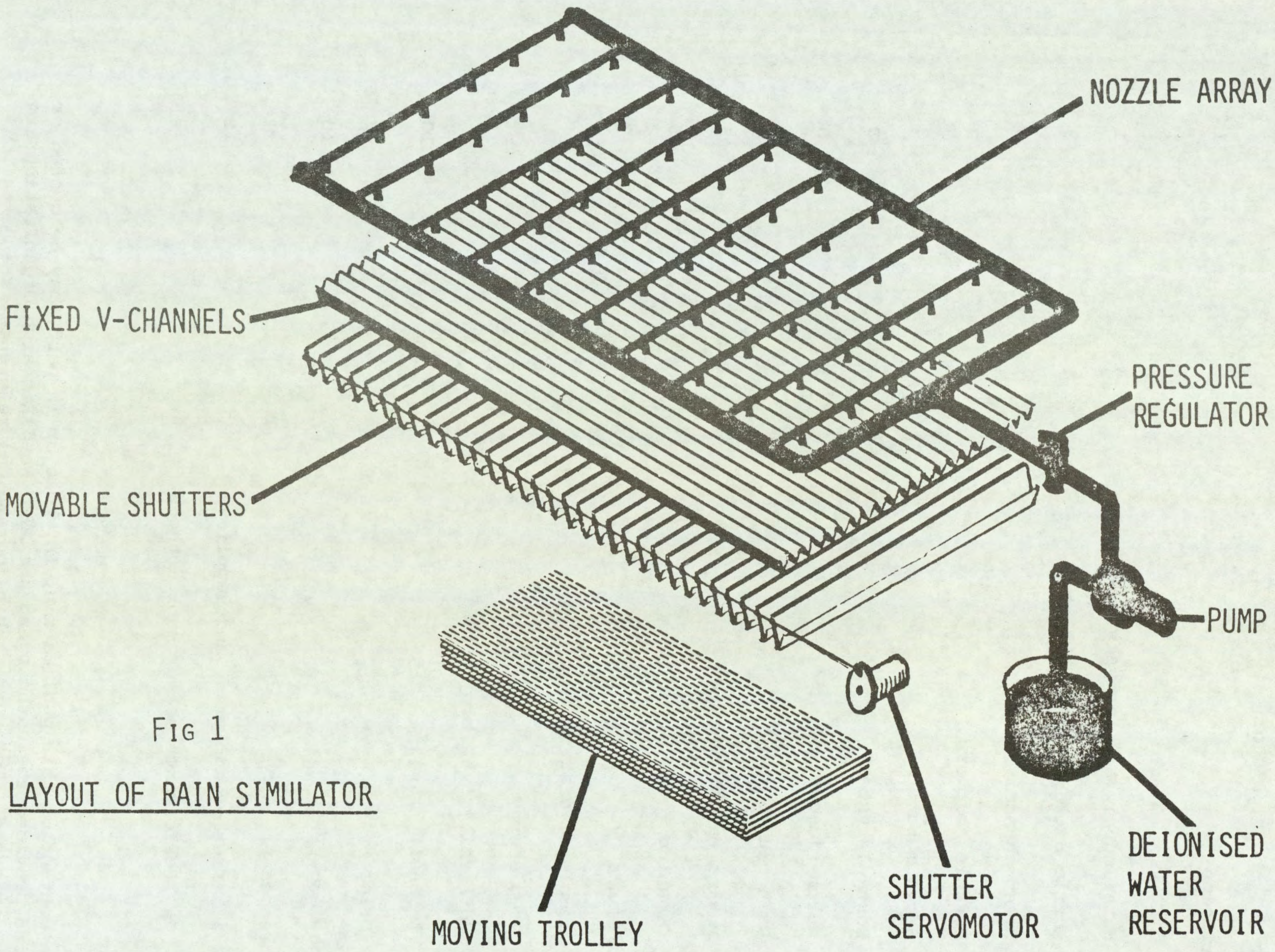

FIG 1

LAYOUT OF RAIN SIMULATOR

A LABORATORY RAINFALL SIMULATOR FOR PESTICIDE STUDIES

R.C. Simmons

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1. INTRODUCTION

We wished to investigate the effects of rainfall on herbicide performance, and required accurate simulation of drop sizes, fall velocities and intensities. The chosen design is constructed from readily available materials and is simple to operate.

2. DESIGN OF THE SIMULATOR

The factors affecting the design of a rain simulator have been discussed in a previous publication (Simmons, 1980). An existing simulator (Jacob, 1979 1,2) built by the Civil Engineering Department of Salford University, was used as the basis of the WRO unit. The nozzles used reproduced the drop size distribution of frontal rain, but the nozzle spacing which gives best uniformity delivers about 180 mm/hour. The movable shutters of Jacob's design allowed control of the intensity down to zero, but the range of intensities in which we were interested, 0.5 to 10 mm/hour, were achieved over a very limited range of shutter movement. Fixed channels (Nassif and Wilson, 1975), which removed 75% of the nozzle output, were therefore inserted above the movable ones, and perpendicular to them, as shown in Fig. 1. With these channels in place, the range is reduced to zero to 30 mm/hour with a corresponding increase in setting accuracy. A moving trolley assembly was added to allow plants to be moved in a pseudo-random manner to improve the uniformity of application, and several other modifications, detailed in the relevant parts of the text, were made to improve the performance.

3. DESCRIPTION

Site

The simulator is in a room 4.3 m high x 7 m x 3 m with a single large doorway in one side.

Water supply and recovery

Local tap water is very hard and interacts with some herbicides. It also leaves a visible deposit when it evaporates. It was not practical to collect and store rain water so deionised water is used. Elga C800 mixed bed resin cylinders are used to purify the water. This is fed via a handvalve and float valve to two 450 l tanks. A centrifugal, self-priming pump draws water from the tanks through a filter and pumps it into the nozzle network via a pressure regulating valve.

Less than 20% of the output from the nozzles reaches the target area, so efficient collection of unused water is essential for economical operation. Water intercepted by the channels, shutters and that falling onto corrugated plastic sheets outside the target area, is directed into a collection tank. This water is returned to the supply tank by a submersible pump with integral level-sensitive switch.

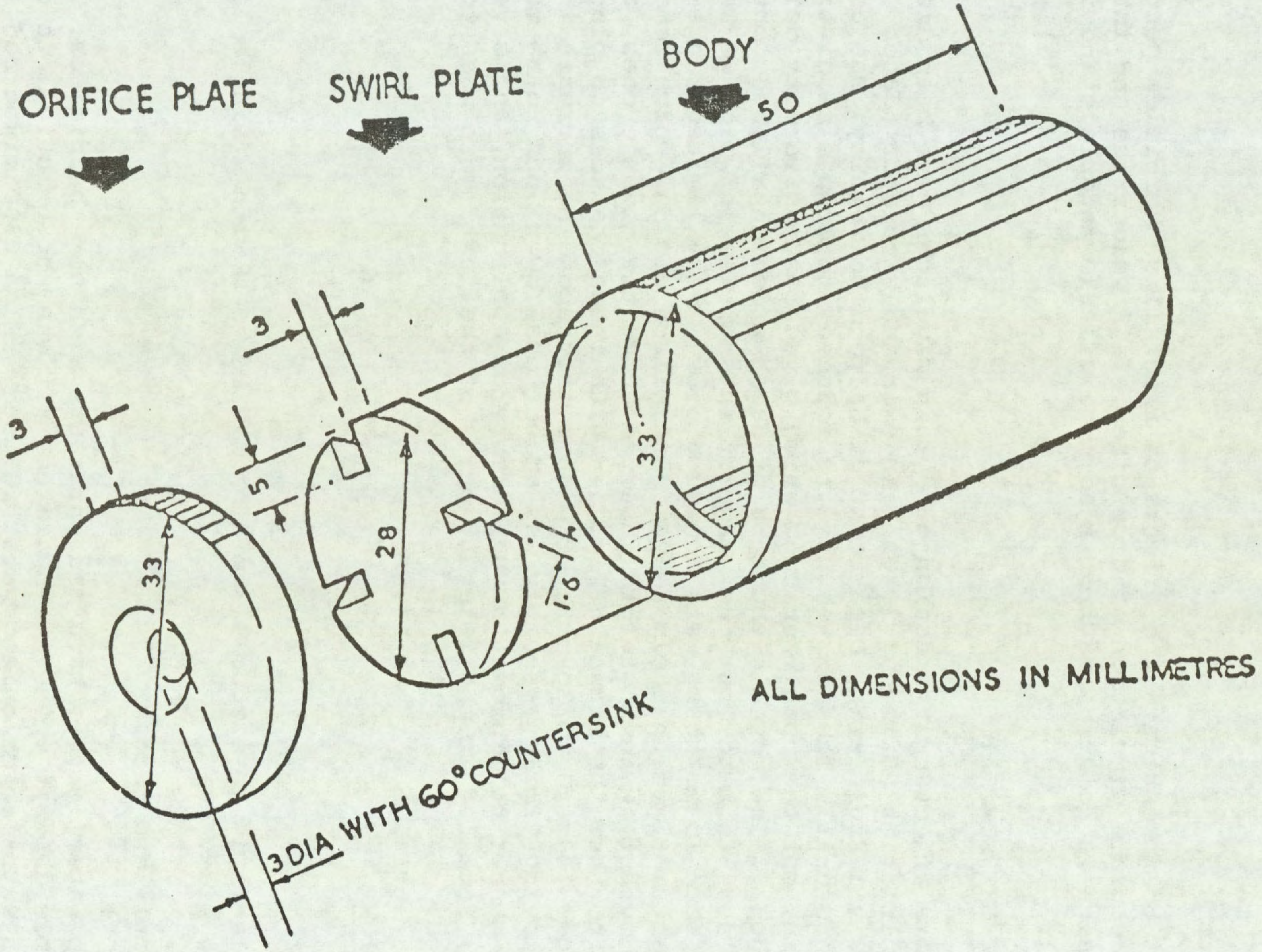


FIG 2 NOZZLE

(AFTER JACOB)

Nozzle network

This consists of 48 plastic nozzles arranged in a 8 x 6 matrix, with a spacing of 500 mm between adjacent nozzles as described by Jacob (1979, 1,2) for the Salford unit. All the nozzle parts were made from PVC water pipe or PVC sheet, and assembled using a solvent cement (Fig. 2). (Later nozzles have the orifice plate machined from brass to allow a more accurate countersink and orifice dimensions.)

The nozzles are cemented directly on to transverse supply pipes of 25 mm diameter, each end of which is fitted with a flange, which mates with a corresponding flange on a 100 mm diameter longitudinal pipe. The method of assembly allows individual transverse pipes to be removed for inspection or cleaning, and, when the pipes are all bolted in place, forms a rigid framework which is supported by a simple frame of scaffolding poles. Individual nozzles can be removed by breaking the cement join with a light twisting motion.

Fixed channels

The fixed channels are similar to those described by Nassif and Wilson (1975) and are 'v' shaped sections of thin anodised aluminium which rest in notched cross-members made of painted marine plywood. Each channel is in sections to facilitate installation and maintenance. The channels run parallel to the long axis of the simulator and have a 5% slope towards a gutter at one end. The supporting cross-members have a drip collection channel fixed to the underside.

Movable shutters

The movable shutters are similar to those described by Jacob (1979, 1,2) but additional elements (Fig. 3) have been added to catch water running down the outer surfaces, and so reduce drips. The large flange at the lower side of the shutter forms a channel to carry away water falling on the upper surface, while the small channel, formed from a separate strip glued to the main shutter, serves to remove drips from water which has splashed on the underside. The shutters are located by pegs into holes in a supporting frame of aluminium girder, and other pegs provide attachment points for the operating bar of the servo mechanism. It was not found necessary to provide bearing material, the movement of the shutters being infrequent and slow.

Servo motor

Shutter position is controlled by a commercial servomotor system. A chain reduction drive is used to give the correct ratio of shutter movement to motor rotation. The positioning signal for the servo is derived either from a control panel potentiometer, or from an automatic sequence controller. The load imposed by the weight of the shutters is not counterbalanced, so that any backlash in the chain or link rods is taken up by this load, and reproducibility of shutter position is mainly dependent on the accuracy of setting the servo positioning signal. Shutter position is indicated on a digital voltmeter scaled to read 0-100 in steps of 0.1. (The voltmeter reads a suitably scaled signal from the servo feedback potentiometer).

Control system

Controls for the simulator are very simple. Switches are provided to operate the pump and travel unit. These have 'auto', 'on' and 'off' positions. In the 'auto' position control is from an automatic sequence controller. The shutter servo system has a similar switch, with auto, on and manual positions. The 'off' position is connected to move the shutters to the closed position, in the 'manual' position the shutters are positioned according to the voltage set on a 10 turn potentiometer on the control panel, while in the 'auto' mode the

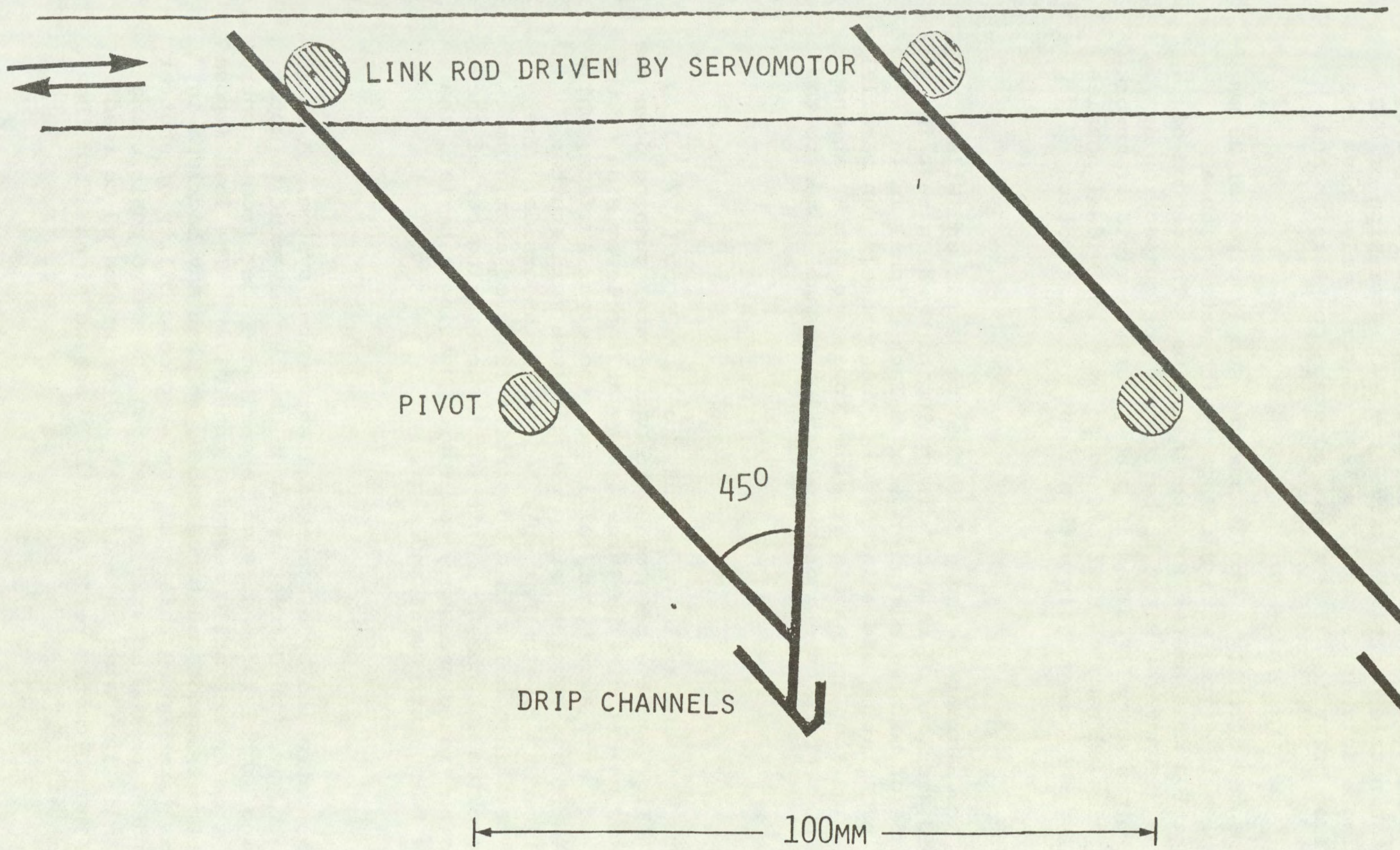


FIG 3 CROSS-SECTION OF SHUTTER

control voltage is generated by the automatic controller. A low water level indicator is also incorporated in the control panel.

Automatic controller

A commercial process controller is used for automatic operation of the rain simulator. The unit has an analogue output signal, which is used to control the servo position. It also has seven switch outputs, of which four operate the main pump, moving target, audible alarm and rain gauge counter, while the other three are available at terminals to switch ancillary equipment such as chart recorders.

Instructions to the controller's microcomputer define timed 'segments' during which the analogue signal changes from one value to another, and at the junctions of which switching of any of the seven switch outputs can occur. Thus a program can be entered which will start the unit at a predetermined time, perform a sequence of different intensities, and stop. This sequence may be repeated exactly at will, or may be modified by the operator. Combinations of automatic and manual control are possible, for example manual start and stop, with automatic shutter sequencing.

Rain gauge

A tipping bucket gauge is used to check the rain intensity. To allow as accurate as possible determination in a reasonable time, even at low intensities, a gauge which tips every 0.2 mm is used. This resolution is achieved by the use of a standard 1 mm bucket (15 ml/tip) with an oversize gauge head having a collection area of 750 cm^2. Although this would not be considered good practice in a meteorological station, due to evaporation errors causing underestimates of cumulative totals, in the rain simulator an equilibrium is achieved and the gauge appears to read consistently against a standard 'Snowdon' pattern M.O. gauge.

Measurement of rainfall intensities $<$ 1 mm/hour is time-consuming and can take over an hour because the first tip of the bucket is discarded as the gauge takes some time to come to equilibrium. Alternative types of gauge have been considered and a weighing unit is under investigation.

Moving target assembly

This consists of a large trolley which can move back and forth within the target area. Upon this is mounted another trolley which can move from side to side. Both units are moved by hydraulic rams, and operate at different speeds so that a pseudo-random motion results. The amplitude of movement of both trolleys is 500 mm, a value chosen to yield a useful increase in uniformity while maintaining an adequate target area. Figure 4 shows the arrangement of the trolley system. The large trolley takes about 5 minutes to complete one cycle of movement, while the smaller trolley has a period of about 33 seconds.

A hydraulic power unit was chosen because it provided smooth motion, was available in materials suitable for use in wet conditions, and needed minimal electrical controls. Electrical limit switches operate reversing valves at each end of the trolley travel and the smaller trolley has additional switches which operate restrictor valves to slow it down during changes of direction, to minimise vibration of the plants. All electrical components within the target area operate at low voltage to ensure operator safety.

Cleaning

Although deionised water is used, scale is eventually deposited on the orifice plates of nozzles and on the underside of shutters and channels. These deposits may result from corrosion of the aluminium parts of the simulator, and

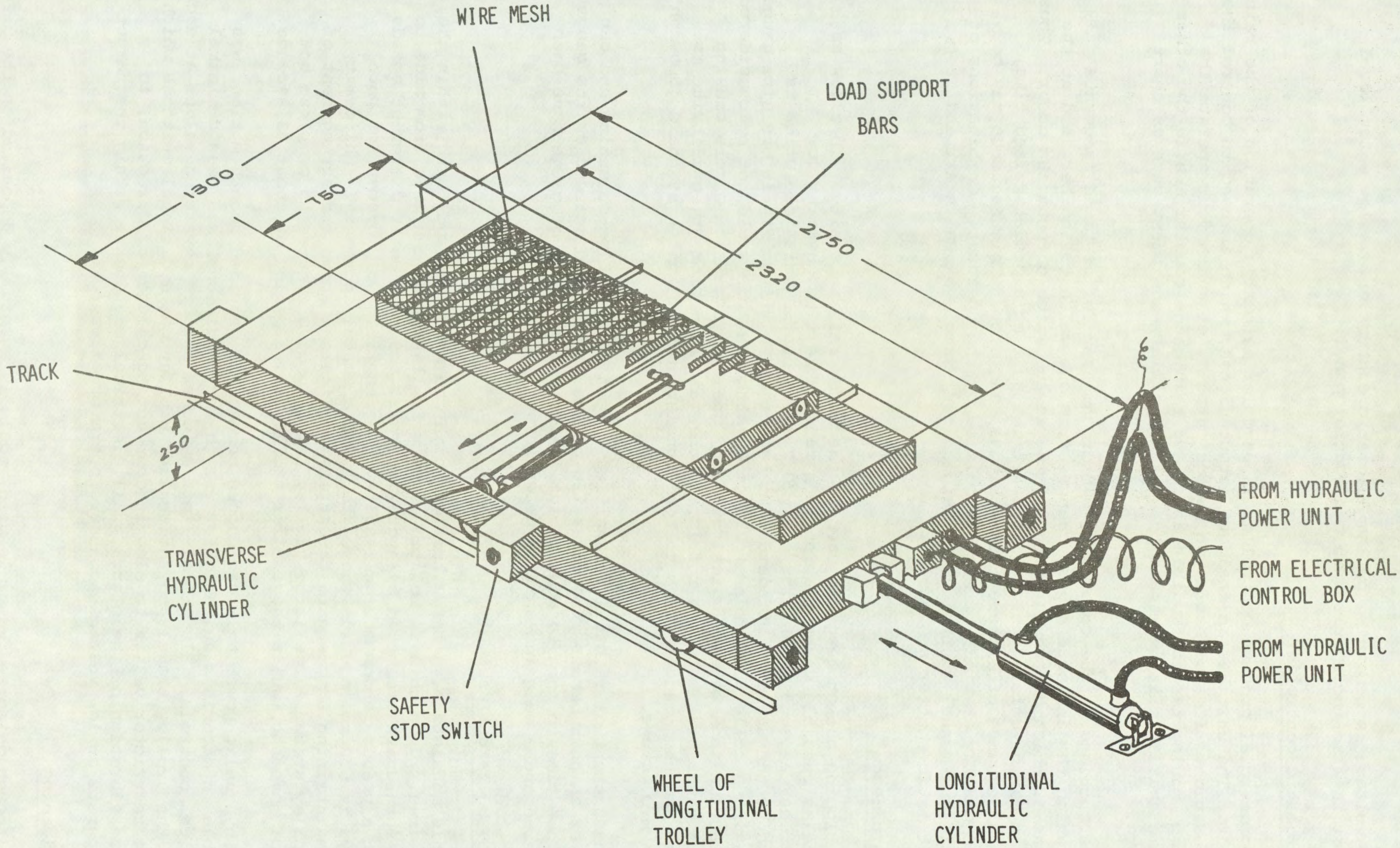


FIG 4 MOVING TROLLEY

from airborne contaminants which enter the water during its journey around the unit.

From time to time the affected parts are cleaned with a 5% solution of citric acid in water to which a trace of 'Teepol' detergent is added. This solution is pumped through the nozzles, and wiped over the shutters. Deionised water is then pumped through the system to remove the remaining acid.

4. PERFORMANCE

Drop size distribution

Several workers, including Laws and Parsons (1943), Marshall and Palmer (1948), Best (1960), and Mason and Andrews (1960) have investigated the size distribution of raindrops. The authors generally agree on the range of distributions found in rains of different intensities and origins. It was decided for the purposes of our research to concentrate on simulating the frontal rain showers which are the most common rain type in the British Isles. Tests were made on commercial and specially designed nozzles (Simmons, 1980) and a suitable nozzle chosen. The nozzle characteristics were originally measured using the stain method (Hall, 1970). Later the smaller drops emitted by the completed simulator were sized using a Particle Measuring Systems analyser type PDPS-11C fitted with a probe capable of measuring objects up to 0.6 mm diameter, and simultaneously the stain method was used for the larger drop sizes.

The results are shown in graph 1, which shows a composite graph of the simulator drop size distributions by both methods. A more detailed description of the methods is given in appendix 2.

Some drops with diameters of about 2.5 to 2.7 were detected. These are probably drips falling from the shutters or v-channels, as very few drops of this size are produced by the nozzles. Altering the intensity by opening or closing the shutters did not have a detectable effect on the size distribution. Reducing the operating pressure by 30% caused a slight change in distribution (Graph 2). The measurements indicate that the simulator has a drop size distribution similar to that of light frontal rain. The slope of the distribution can be varied slightly by changing the operating pressure.

Drop energy

The impact energy of a rain drop depends on its speed. Natural raindrops have always reached their maximum speed (the terminal velocity) by the time they reach the ground. This speed, and the free fall needed to achieve it, vary with drop size (Smith and Wichsmeier, 1962).

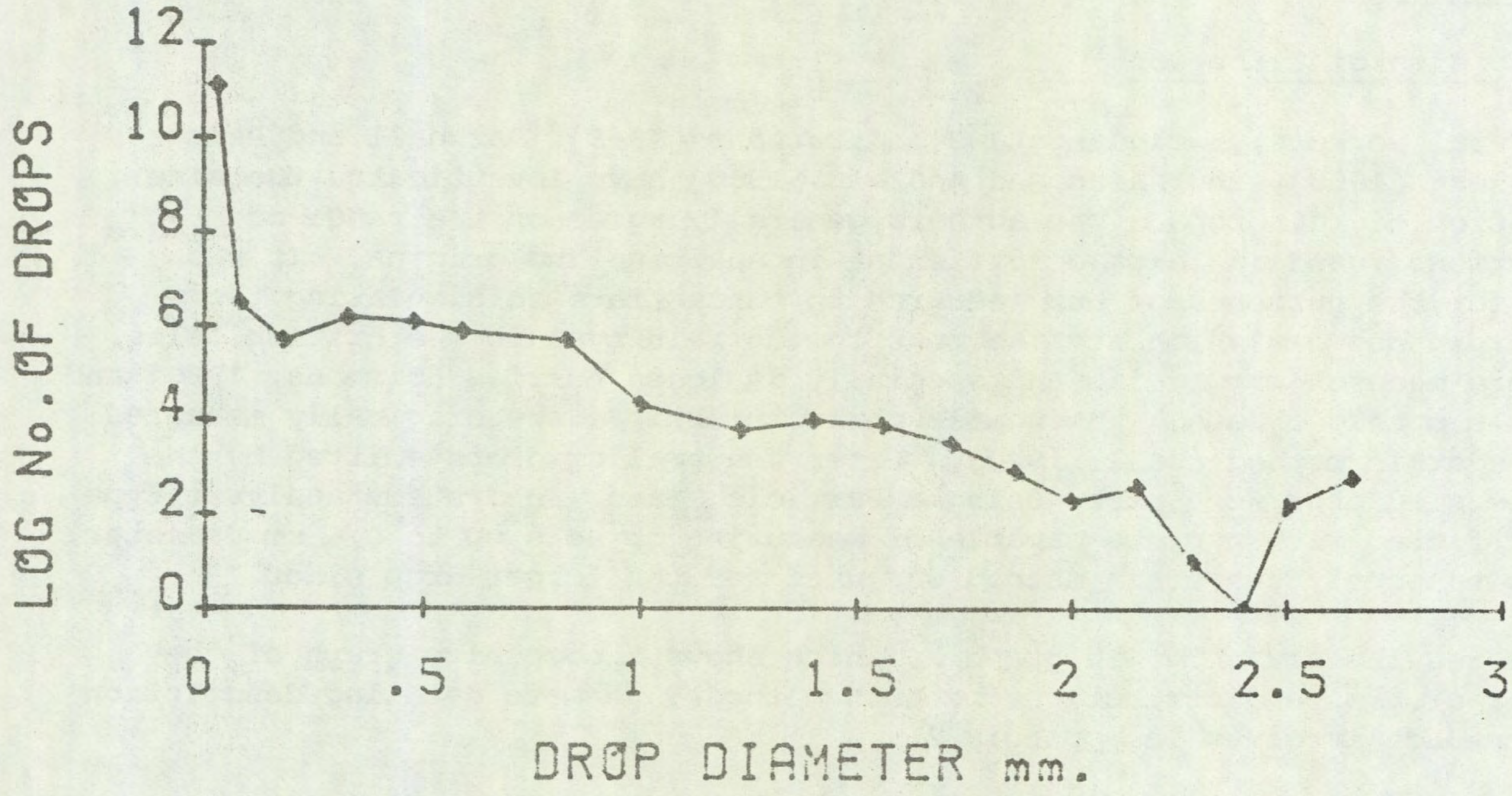
The combination of initial ejection velocity and gravitational acceleration caused all the drops measured by the PMS analyser to have reached 95% of their terminal velocities as they passed through the measuring beam 1 m above the target floor. There was no convenient method of measuring the velocities of drops too large to measure with the PMS apparatus.

Uniformity over target area

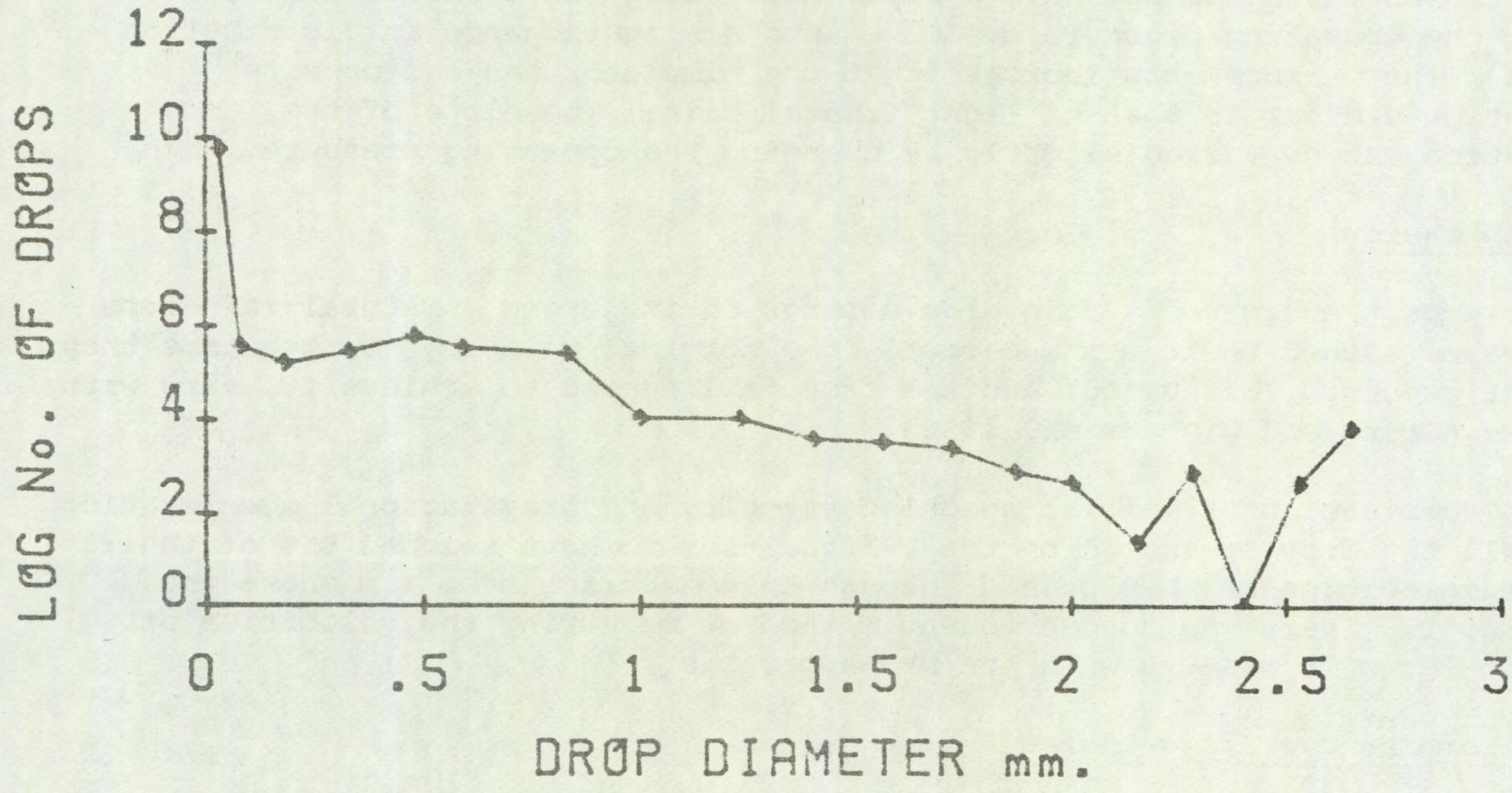
The nozzles used in the simulator have a characteristic pattern of intensity, and, when combined in a large array of identical equally spaced nozzles, the result is a recurring pattern of predictable form. However differences in the individual nozzle patterns do cause variations in the measured rainfall in different places on the target area.

The degree of movement of the moving target assembly is designed to reduce the effective spatial variation to an acceptable level. The maps show the distribution of rainfall on the moving target, summed over several cycles of

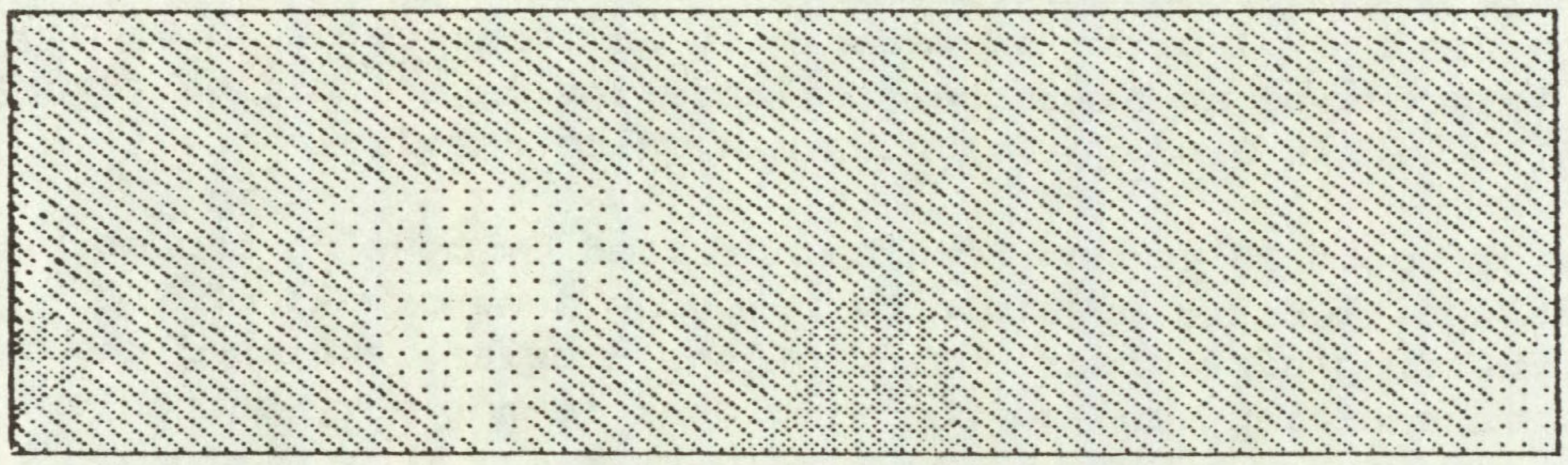
DROP SIZE DISTRIBUTIONS



Graph 1. NØRMAL (31kPa)

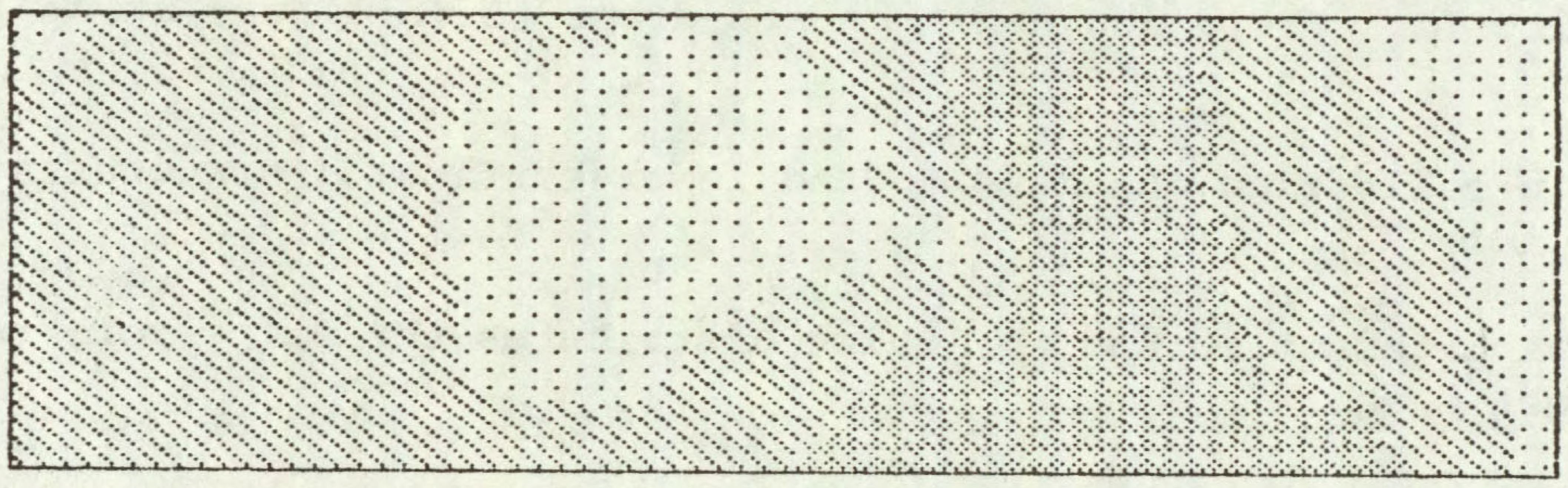


Graph 2. LØW PRESSURE (22kPa)



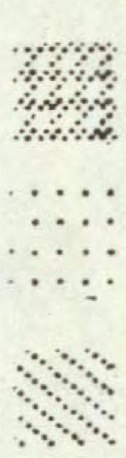
MAP 1. 20 mm/hour

Uniformity Coefficient 0.97



MAP 2. 1 mm/hour

Uniformity Coefficient 0.94



All of map 1 is within 10% of mean

94% of map 2 is within 10% of mean

movement. Uniformity coefficients, calculated by the method of Christiansen (1941) are included, so that the performance may be compared with that of other designs.

Intensity range

The lower limit of intensity is determined by the accuracy and repeatability with which the simulator can be set. There are two problems in setting low intensities. One is that a small change in the position of the shutters produces a large percentage change in intensity, hence the mechanical and electrical performance of the servo system is most critical at low intensities. The other problem is that of measuring the rainfall. At an intensity of 0.5 mm/hour, a standard 5" rain gauge collects only 6.3 ml of water per hour. In order to set up the intensity in a reasonable time, it is desirable to obtain a measurement of intensity within 5 minutes, which implies being able to measure 0.5 ml or so of water with an accuracy of ±0.05 ml). A method has been tried using an electronic balance inside a modified rain gauge. This can be read to within 0.02 g(i.e. 0.02 ml) quite easily.

Intensities of up to 28 mm/hour can be obtained by opening the shutters fully. Higher intensities are possible by removing some or all of the v-channels, but the drop size distribution of the nozzles is biased towards representing low intensities, and so the simulator is not very suitable for high intensities.

Drips

Because the simulator has an extensive system of channels and shutters beneath the nozzles, it has a tendency to produce drips. This problem was minimised by:-

a) Coating the lower surfaces of shutters and channels with a plastic which has little affinity for water, and hence causes drops to fall away at smaller diameters.

b) Attaching drip-collecting channels to the lower surface of structures wherever possible.

c) Using the moving target mechanism, which distributes the drips more randomly over the target area.

5. ACKNOWLEDGEMENTS

The original design and construction of the simulator was done by members of the Civil Engineering Department of Salford University under the direction of Professor E.M. Wilson. The Department also provided test facilities and prototype modificaions during the development of the WRO version, and installed the WRO unit.

Testing and subsequent modification of the simulator was carried out by the author with the valuable assistance of Miss S. Norris, Mr D. Ogden, Miss K. Proudfoot, Mrs C.M. Bond and Mr D. Deasey. Dr D. Coupland developed the special rain gauge with electronic balance inside.

Statistical and computing services were provided by Mr B.O. Bartlett and Mr W. Jenkins of the Joint Biometrics Department.

The moving target assembly was constructed by Mr N. Heath of the Research Instrumentation Services Department at WRO. Other members of that department assisted with the design and construction of the servo drive and water flow systems.

I would like to thank all of these people, and also Dr J.C. Caseley for his continued encouragement.

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APPENDIX 1

List of equipment and suppliers

Nozzles and pipework	Made from 'Durapipe' pvc pipe and fittings (available from plumbers' merchants).
Main pump	Goodenough self priming centrifugal pump. Goodenough Ltd., Moss Industrial Estate, Leigh, Lancs., WN7 3PZ.
Scavenge pump	'Sumpak', type AU. Ingersoll-Rand Ltd., Queensway, Team Valley Trading Estate, Gateshead, Tyne and Wear NE11 0QB.
Servo motor and amplifier	McLennan RM 3432 motor, PM 121 servo amplifier, McLennan Servo Supplies Ltd., Yorktown Industrial Estate, Doman Road, Camberley, Surrey.
Automatic controller	'Data Trak' 73211 process controller, Westlairds Ltd., North Green, Datchet, Slough, Bucks SL3 9JH.
Rain gauge	'Artech' MK3 with small base and 750 cm^2 collector, Artech Meteorological Ltd., Blackwater Trading Estate, Camberley, Surrey.

Lamps, switches, relays, plugs and sockets were obtained from:

R.S. Components Ltd., PO Box 427,
13-17 Epworth St., London EC2P 2HA.

Suitable items are stocked by many other wholesale and retail component suppliers. Splash resistant plugs and sockets used for connection of rain gauge:-

Bulgin L1349 range supplied by:
Farnell Electronic Components Ltd.,
Canal Road, Leeds LS2 2TU.

Deioniser	Elga Products Ltd., Lane End, High Wycombe, Bucks.
Plastic coated metal parts	Alcan Building Materials, Blackpole Trading Estate, Worcs.
Hydraulic pump and rams	Smiths Industries, Burford Road, Witney, Oxon.

APPENDIX 2

Performance measurement methods

Drop size distribution.

The drop size distribution was estimated using two methods:-

Drops from 0 to 0.5 mm diameter were measured using a Particle Measuring Systems PDPS-11C particle size analyser equipped with a standard 2D probe. It works by measuring the size of shadow cast by the drop on a linear array of photocells. Drops from 0.5 to 2.7 mm were estimated using the Stain method (Hall, 1970).

The PMS probe was mounted vertically on the moving target trolley, so that its measuring element was 1.2 m above the target surface. The analyser was set up using a program from the National Institute of Agricultural Engineering which was intended for pesticide sprayer measurements. It rejects images which are not sufficiently in focus, those falling on either end element of the photodiode array, and those which failed the bulk area ratio test. (This is a test of 'roundness' since the sizer assumes when calculating drop diameters that the image is of an approximately spherical object). The handbook for the PDP-11C contains descriptions of these tests and their mathematical basis.

The probability of detecting a drop close to the maximum size of the detector's capability is very small, so sample times of up to 4 hours had to be used. The manual advises against accepting data for size classes greater than 0.55 mm (the detector's maximum is 0.62 mm) since these data represent a very small sample multiplied by a very large correction factor.

The stain method uses the relationship between the diameter of stain made by a drop absorbed on an absorbent medium, and the diameter of the drop. This relationship has been determined experimentally by a number of workers using Whatman No. 1 filter paper. The quoted coefficients vary from author to author, so we chose values in the middle of the range.

$$d = \left(\frac{D}{3.3}\right)^{0.66}$$

where d = drop diameter, D = stain diameter.

About 50 filter papers were briefly exposed to the rain by uncovering a tray containing the papers, beneath the simulator array. The papers were prepared by drying in a desiccator, then dusting with powdered Brom-cresol green. This is brownish-yellow when dry, but changes to blue when wet. The resulting stains were classified into size groups using a particle sizing program on an Optomax image analyser. Stains made by drops <0.6 mm in diameter were not reliably counted, as they were irregular in shape and not deeply coloured enough to be detected. Drops greater than about 2.75 mm diameter tended to splash, producing irregular stains with poor outlines. These effects defined the limits over which measurements could be made.

Presentation of results

Combination of the two methods results depends on subjective estimation, as there is little overlap, and no absolute reference to relate the two sets of results, because neither method allows a straightforward calculation of numbers of drops per unit area per unit time. Converting the numbers to logarithms does allow us to plot the results on one graph since the intercept on the 'log number of drops' axis is an arbitrary scale factor which can be varied so that the two sets of points are aligned at their junction. Since the distribution of drops by size is likely to be a continuous function, the slope of the curves either side of the junction should be similar. If they were not, an error in one of the methods might be indicated. There was considerable uncertainty attached to the values at the larger end of the PMS range, for reasons given already, and so groups of 15 size classes were averaged to get a more reliable estimate of the mean slope. Where the slope changed more rapidly but consistently from one size class to another, means of five adjacent classes were plotted. It is difficult to get an estimate of the accuracy of the PMS analyser results, as there is only one estimate for each size class and its accuracy depends on both the number of drops sampled and the square root of the factor applied to correct for effective sample volume. NIAE regard unexpected discontinuities in the slope of a size distribution with suspicion unless they appear on a number of repeated runs, but do no formal statistics, since it is fairly obvious from the look of the graph whether it is a good estimate of the distribution. It is possible however to devise some kind of standard error for the groups of five and 15 adjacent size classes mentioned above, by treating the curve as being linear over these short size ranges, and each value as a contributor to a mean estimate of $\log_e$ (no. of drops) against diameter. With the stain method, replication of the entire sample several times is the only way of obtaining information about the variability of the estimate. In this series of tests there was not enough time or materials to replicate runs, but some assumptions may be made by comparing runs made with different settings, but which gave similar results. Thus, for example, the unexpected peak at 2.5 to 2.7 mm appeared in all the runs, and is therefore very unlikely to be due to chance.

Uniformity

Uniformity of distribution was tested by collecting the rain in 100 mm diameter plastic containers at 70 equally spaced positions over the target area. The volume of water in each was measured and the measurements used to prepare a map.

The maps display the areas which differ more than 5% from the mean value.

Christiansen's uniformity coefficient is expressed for evenly spaced samples as

$$Cu = \frac{1-\Sigma|x-\bar{x}|}{\Sigma x}$$

where $x_1 \ldots {}_n$ are the individual observations and Σx is the sum of these observations. It tends towards 1 for uniform distributions.

ABBREVIATIONS

ångström	Å	freezing point	f.p.
Abstract	Abs.	from summary	F.s.
acid equivalent*	a.e.	gallon	gal
acre	ac	gallons per hour	gal/h
active ingredient*	a.i.	gallons per acre	gal/ac
approximately equal to*	$\simeq$	gas liquid chromatography	GLC
aqueous concentrate	a.c.	gramme	g
bibliography	bibl.	hectare	ha
boiling point	b.p.	hectokilogram	hkg
bushel	bu	high volume	HV
centigrade	C	horse power	hp
centimetre*	cm	hour	h
concentrated	concd	hundredweight*	cwt
concentration	concn	hydrogen ion concentration*	pH
concentration x time product	ct	inch	in.
concentration required to kill 50% test animals	LC50	infra red	i.r.
		kilogramme	kg
cubic centimetre*	cm^3	kilo ($x10^3$)	k
cubic foot*	ft^3	less than	$<$
cubic inch*	in^3	litre	l.
cubic metre*	m^3	low volume	LV
cubic yard*	yd^3	maximum	max.
cultivar(s)	cv.	median lethal dose	LD50
curie*	Ci	medium volume	MV
degree Celsius*	^oC	melting point	m.p.
degree centigrade	^oC	metre	m
degree Fahrenheit*	^oF	micro ($x10^{-6}$)	μ
diameter	diam.	microgramme*	μg
diameter at breast height	d.b.h.	micromicro (pico: $x10^{-12}$)*	μμ
divided by*	÷ or /	micrometre (micron)*	μm (or μ)
dry matter	d.m.	micron (micrometre)* †	μm (or μ)
emulsifiable concentrate	e.c.	miles per hour*	mile/h
		milli ($x10^{-3}$)	m
equal to*	=	milliequivalent*	m.equiv.
fluid	fl.	milligramme	mg
foot	ft	millilitre	ml

† The name micrometre is preferred to micron and μm is preferred to μ.

millimetre*	mm
millimicro* (nano: $x10^{-9}$)	n or mμ
minimum	min.
minus	-
minute	min
molar concentration*	M (small cap)
molecule, molecular	mol.
more than	>
multiplied by*	x
normal concentration*	N (small cap)
not dated	n.d.
oil miscible concentrate	o.m.c. (tables only)
organic matter	o.m.
ounce	oz
ounces per gallon	oz/gal
page	p.
pages	pp.
parts per million	ppm
parts per million by volume	ppmv
parts per million by weight	ppmw
percent(age)	%
pico (micromicro: $x10^{-12}$)	p or μμ
pint	pint
pints per acre	pints/ac
plus or minus*	±
post-emergence	post-em
pound	lb
pound per acre*	lb/ac
pounds per minute	lb/min
pound per square inch*	lb/in^2
powder for dry application	p. (tables only)
power take off	p.t.o.
precipitate (noun)	ppt.

pre-emergence	pre-em.
quart	quart
relative humidity	r.h.
revolution per minute*	rev/min
second	s
soluble concentrate	s.c.
soluble powder	s.p.
solution	soln
species (singular)	sp.
species (plural)	spp.
specific gravity	sp. gr.
square foot*	ft^2
square inch	in^2
square metre*	m^2
square root of*	$\sqrt{\ }$
sub-species*	ssp.
summary	s.
temperature	temp.
ton	ton
tonne	t
ultra-low volume	ULV
ultra violet	u.v.
vapour density	v.d.
vapour pressure	v.p.
varietas	var.
volt	V
volume	vol.
volume per volume	v/v
water soluble powder	w.s.p. (tables only)
watt	W
weight	wt
weight per volume*	w/v
weight per weight*	w/w
wettable powder	w.p.
yard	yd
yards per minute	yd/min

* Those marked * should normally be used in the text as well as in tables etc.

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TECHNICAL REPORTS

(Price includes surface mail; airmail £2.00 extra)

(* denotes Reports now out of print)

6. The botany, ecology, agronomy and control of Poa trivialis L. rough-stalked meadow-grass. November 1966. G P Allen. Price - £0.25

7. Flame cultivation experiments 1965. October 1966. G W Ivens. Price - £0.25

8. The development of selective herbicides for kale in the United Kingdom. 2. The methylthiotriazines. Price - £0.25

10. The liverwort, Marchantia polymorpha L. as a weed problem in horticulture; its extent and control. July 1968. I E Henson. Price - £0.25

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