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SMOKE TRAVEL IN SHOPPING MALLS
MODEL STUDIES - PART 1 : RATES OF LATERAL SPREAD

by

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March 1971

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SUMMARY

The spread of smoke and fire in enclosed shopping malls is being studied at the Fire Research Station in full scale and model scale investigations, to obtain information from which standards of safety may be established for the occupants of shopping malls. As part of this work measurements have been made of the speed of smoke movement from a simulated fire along a model scale mall 0.56 m wide and 0.46 m high, at several combinations of fire intensity and mall length. The equipment and general procedures are described, the numerical results are presented, and comment is made on the experimental technique. Smoke speeds were in the range 0.1 to 0.6 m/s; it can be shown that these accord with speeds observed in field tests in a railway tunnel, though this and other detailed analysis of the results are reserved for a later report.

KEY WORDS: Smoke, shopping mall, spread, rate.

DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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1. INTRODUCTION

Completely enclosed shopping malls and pedestrian precincts may be expected to continue to grow in numbers and popularity. Smoke presents a particular problem in the evacuation of these extensive unbroken spaces in the event of fire, since it has been estimated[1] that in the first half minute after the release of smoke into a mall it may travel as much as a hundred metres along the mall, depending on its initial temperature. Recent and current work at the Fire Research Station, directed at obtaining information from which standards of safety for the occupants of shopping malls may be established, has included theoretical studies[1], field tests in a railway tunnel[2,3], full scale tests in a large experimental building, and the model scale studies which are discussed in the present series of reports.

In this first report are recorded the equipment and general procedures which have been used in the model-scale investigation of the mechanics of smoke movement in shopping malls, together with numerical results from the initial phase of this work concerned with the speed of smoke spread in an unventilated rectangular duct, closed at one or both ends. The independent variables were the length of the duct, and the thermal power dissipated convectively by a simulated fire at the closed end of the duct. Detailed analysis of the numerical results will be reserved for a future report; however, it may be mentioned at this point that the mean smoke speeds measured in the model mall could be successfully related by the theory of Reference 1 to those observed in the Glasgow railway tunnel experiments.

2. EXPERIMENTAL

2.1. Model Arcade. The model arcade was a rectangular duct, 0.56 m wide and 0.46 m high internally, made up of open-ended modules 2.44 m long (Figure 1). The modules were constructed of 4.8 mm hardboard on wood framing and for convenience of observation were supported above the floor of the laboratory on trestles 1.13 m high. Each module was fitted along the front with glass windows rebated into the wood framing, while the open back was closed with a downward-opening hinged flap which was retained in the closed position by hook and eye catches. Self-adhesive polyurethane foam weather stripping was used to seal the flap. The modules were butted together to form the desired length of arcade, the junctions between them being sealed with masking tape. The end of the module remote from the simulated fire was fitted with a downward-closing hinged door. Illumination was provided by twin 5 ft x 65 W fluorescent light tubes mounted externally 40 mm above narrow glass windows in the roof (Figure 1). A strip of hardboard 0.17 m high attached along the upper part of the arcade screened the lights from direct view. The exterior and interior vertical surfaces of the arcade were painted black; the floor and ceiling were white to ensure maximum illumination of smoke flowing within the arcade. Mirrors were placed above the light tubes to direct additional light through the roof windows.

2.2. Fire compartment. The fire compartment was a short wood-framed hardboard duct 0.53 m long, 0.53 m wide, and 0.46 m high (Figure 2), fitted with heavy wood flanges around its two open faces. These two flanges mated respectively with: a similar floating flange held lightly against its mating member by adjustable screws, and another flange fixed to the end of the arcade. The faces of the flanges were covered with self-adhesive polyurethane foam, and the ajustable screws joining mating pairs of flanges were tightened sufficiently to provide a light seal between the foam and a sheet metal gate which slid vertically between the flanges. The two gates were coupled by an overhead chain linkage so that they moved in unison. At the start of each experiment the gate leading to the arcade was normally in the closed position, while the other gate, which was heavily weighted, was held open by a pin. Withdrawal of the pin by a remotely controlled motor caused the two gates to move, rapidly and simultaneously, from their initial positions (e.g. open) to the opposite (shut), the complete motion taking under half a second. By this means flow within the fire compartment was suddenly transferred from the exhaust side of the compartment to the arcade. (It may be noted that precise correspondence of the flow patterns in the fire compartment before and after exchanging the gates could have been obtained only by attaching at the exhaust side a duct of the same length and dimensions as the arcade. This was not possible in the space available).

The fire compartment was supported on an angle-iron stand with its floor level with the arcade floor.

2.3. Simulated fire. The essential characteristic of a fire, for the purposes of the present study, is the convection column of hot gases which it produces. Any convenient source producing a column with similar properties may be substituted, provided the gas temperature and volume flow are coupled to each other as in a fire: that is, neither is controlled independently, both changing in concert as the thermal output of the source is changed. The 'fire' used in these experiments was a set of electric heaters (Figure 3A) fitted with aluminium fins designed to dissipate by convection over ninety per cent of the power supplied to them[4]. It will be shown in later reports in this series that in a number of important respects the heaters simulated the convection output of a real fire sufficiently well. In most experiments two heaters, design rating 750 W each at 240 V, were used. They were mounted on an asbestos-wood baseboard 13 mm thick which rested on the fillets inside the base of the fire compartment (Figure 3B). For some experiments at higher power a third heater was placed in the dotted position. The heaters were wired in parallel to a variable autotransformer with a maximum output of 270 V; the highest power available, with three heaters, was thus 2800 W (the power factor of the heaters was measured and found to be greater than 0.99). The power drawn was determined by use of an ammeter and voltmeter. Each heater was fitted near its midpoint with a chromel-alumel thermocouple clamped between two of the spacers.

2.4. Flow visualisation. In the model work the column of hot air rising from the heaters was the analogue of the smoke plume produced by a full-scale fire. For many experiments this hot air was made visible by adding to the air stream a small flow of a dense aerosol produced by allowing fibre insulation board to smoulder in a restricted air supply. The fibre insulation board was used in oven dried strips 38 mm wide and 13 mm thick which were broken into suitable lengths (75-100 mm) before use. Several of these pieces at a time (about 0.15 kg in all) were held in the flame of a Meker burner until their tips were glowing strongly and then placed in a sealed steel pot 0.15 m diameter and 0.25 m high, into which compressed air was bled at 10 litres/minute. Any flames on the fibre insulation board were blown out before it entered the pot. A vertical pipe led from the pot to two parallel horizontal injectors located 0.13 m apart 37 mm above the convector heaters. The bottom end of the pipe was provided with a condensate trap and drain cock to permit removal of tars which otherwise carbonised in the pipe and rapidly blocked it. The injectors were made of standard $\frac{3}{4}$ in water barrel, each drilled with twelve 3.6 mm holes at 25 mm intervals along the top. The marking aerosol issued from these holes in coherent jets which after rising 75-100 mm mixed abruptly into the layer of hot gas below the ceiling of the fire compartment and lost their identity. The hot gas marked with aerosol is referred to as 'smoke'.

2.5. Timing arrangements. A strip-chart recorder was used as an event recorder. It was connected through an appropriate resistance to a $1\frac{1}{2}$ V dry cell, the circuit to which could be completed by either of two microswitches connected in parallel in the normally open mode. The first was fitted with a spring-loaded arm and roller which pressed against the exhaust-side gate of the smoke compartment when the gate was in the open position. This switch was so located that it opened the recorder circuit when the gate had descended to within 25 mm of the closed position. The second switch was the momentary contact type and was operated by hand as the leading edge of the smoke body passed the end of each module. A chart speed of six inches per minute was normally used, though lower or higher speeds were occasionally used to reduce consumption of chart paper or to improve accuracy.

3. PROCEDURE NOTES

No readings were taken until the smoke compartment temperatures had stabilised, as indicated by constancy of the emf readings from the heater thermocouples. During the last half hour of the warming-up period the burner was started and the aerosol injection system was allowed to warm up. The flaps along the backs of the modules were left open to prevent accumulation of the small amount of warm air produced by convection at the closed arcade-side gate.

When a trial was imminent the flaps were closed and the end door on the final module was clamped shut if a closed-end trial was planned. If an open-end trial was to be run the laboratory door was locked to ensure that still-air ambient conditions would be approximated. The arcade roof lights were switched on and the event recorder drive was started. The pin holding the gates in position was withdrawn, releasing the flow of aerosol laden heated air into the previously still air in the arcade, and the momentary-contact switch of the event recorder was operated as the leading edge of the smoke body passed the end of each module.

In many cases the behaviour of the smoke body was observed visually during and after the trial. The time scale of the experiment precluded measurement of smoke depths, other than rough visual estimates, during a trial; consideration of smoke depths was therefore deferred to a later phase of the programme.

4. TESTS PERFORMED

Smoke flows with the end of the arcade open and closed were studied at arcade lengths of 6, 4 and 2 modules, and powers of 2800 (three heaters), 1500, 750 and 375 W (two heaters). Three or four trials were performed at each combination of variables. One combination (6 modules, 1500 W, open end) was taken as a reference condition and a larger number of trials was run to examine variation arising from experimental error. Additional tests were made at this condition to determine the influence of the aerosol flow rate on the speed of movement of the smoke body.

5. DESCRIPTION OF FLOW PHENOMENA

Two types of flow regime may be distinguished in the model arcade. The first occurs during the period before the smoke flow, suddenly released from the fire compartment, reaches the end of an open-ended arcade, or before it recirculates back to the fire compartment if the end is closed. This will be referred to as the transient period flow. It forms the exclusive subject of the quantitative experiments described in this report. The second regime develops slowly after the end of the transient periods; the temperature, mean velocity, and mean smoke density at any chosen point eventually cease to change with time. The physical phenomena of this steady state will be described in this report. The transient period is discussed first.

5.1. Transient period. The leading edge of the smoke mass issuing from the fire compartment after sudden removal of the gate assumes, by the time it has travelled a metre or so, the curved 'nose' outline illustrated in Figure 4. At its upper edge the nose rides up over a thin wedge of air which is not immediately expelled by the passage of the nose. A shallow dimple often observed on the surface of the nose may be an indication of incipient ripple. The surface of the nose is clearly defined, with a sharp boundary between the hot smoke-laden gas and the cold air. At its trailing edge the nose breaks up raggedly into a turbulent mass in which at irregular intervals well-formed vortices or eddies take shape. These move more slowly than the nose, and quickly break up. At times as many as three successive vortices may be seen in the rear of the nose, trailing at roughly equal spacing. Above and in the rear of the turbulent mass, extending from the fire compartment, is a shallow jet or current of smoke flowing along the roof into the nose. The gas velocity in the jet appears greater than the forward speed of the nose, which thus is continually fed by the jet. The nose does not increase in size, the quantity of smoke shed at its trailing edge being sufficient to balance that fed to it. The thickness of the nose is about twice that of the jet, and diminishes only slightly as the nose travels further from the source. Both the nose and the jet have a highly turbulent or rolling internal structure.

The trails of smoke shed by the short lived vortices in the rear of the nose gradually stretch horizontally and, depending on whether they originated nearer to or further from the ceiling, move either in the direction of the nose or are drawn along towards the fire compartment by the action of the current of cold air which flows along the lower part of the arcade into the convector heaters. After a short time sufficient trails have formed to constitute an intermediate layer easily distinguishable from the rolling roof layer and the clearer air layer at the floor. This new layer is often smoothly striated with a streamline appearance, though merging of the striations may cause it to assume a uniform textureless appearance in which motion of any kind is difficult to discern. (The formation of striations was simulated in an ad hoc experiment in the steady state in which the aerosol marker was omitted and titanium tetrachloride smoke puffs were injected vertically from the roof of the arcade to various levels in the hot gas layer. The same behaviour was observed). At the lowest thermal power used (375 W) the vortices reach almost to the floor of the arcade, especially those formed when the nose has already traversed several modules since under all conditions the size of the vortices formed increases as the nose progresses. The trails formed by the break up of large vortices contribute to the striated layer in the manner just described, except that those trails which enter the cold air layer show less tendency to stretch out or spread, so that this layer contains numbers of isolated clumps and streamers of smoke.

The roof layer thickness, about 75-100 mm, changed little with the power of the simulated fire. Neither the roof layer nor the nose showed much change in thickness with distance travelled along the arcade. The estimated thickness of the nose was about 130 mm at 2800 W, and about 250 mm at 375 W. The length of the smooth part of the nose was $1\frac{1}{2}$-2 times its thickness. The thickness of the intermediate layer was greatest at low power. It increased with time during the transient period, at any chosen point in the arcade, and was greatest in the longer arcades (6 modules). These last two factors (i.e. low power and longer arcades) increase the time during which the layer has been forming from smoke expelled in the wake of the nose.

The most obvious effect of raising thermal power, viz the increase in the nose velocity, will be discussed separately. Almost as striking is the change in form of the turbulent rolling motion in the roof layer and nose, the eddies at the lowest powers being much larger and looser. The effect of power on the trailing vortices has been mentioned already.

None of the flow properties so far discussed shows much change when the arcade length is altered. The phenomena are generally the same for both open- and closed-end arcades up to the moment when the smoke reaches the end. Following this, in the closed-end case, it moves down the end wall, touches the floor, and rises again slightly as it begins to flow back toward the fire compartment. It then forms a somewhat turbulent layer with a diffuse leading edge overriding a shallow (30-40 mm) residual layer of clear air at the floor of the arcade. This sub-layer gradually disappears as the smoke continues to move.

5.2. Steady-state period. The general nature of the steady state flows can be inferred by extension of the previous comments on the transient flows: there is an upper rolling layer of hot gas, an intermediate uniformly dense or smoothly striated zone, and a lower turbulent layer. These zones differ little in appearance from the descriptions already given, except that in the open-end case the bottom layer contains fewer streamers of smoke, those formed earlier by the break-up of vortices behind the nose having by now drifted along to the fire compartment and circulated out in the hot gas layer. The streamers in the steady state appear to originate by entrainment into the inflowing air at the open end, where random currents in the laboratory atmosphere cause intermittent back mixing of smoke into the inflowing air. This is particularly evident at low powers. In the closed end case recirculation of the smoke through the fire compartment causes a build-up in density such that severe smoke logging develops in which the various zones can scarcely be distinguished. The time required to establish the steady state (as determined from later experiments in which temperatures were measured) is about ten times that taken for the smoke to travel to the end of the final module.

A number of interesting features could be discerned by eye. The interfaces between the intermediate and the two outer layers appeared elastic: although there was some mixing in both directions across the interface, the passage of large eddies along either of the two outer layers caused smooth displacement of the interface and the nearest 50 to 100 mm of the intermediate layer, the impression received being that of a series of waves passing along an elastic membrane. Such mixing as took place seemed to be the result of breaking behind the crests of these waves, with interchange of material in both directions across the interface. This elastic behaviour was most pronounced, and mixing least, at high powers.

Because the base of the hot gas layer was in constant irregular motion it was difficult to make any determination of the layer thickness. The layer appeared to occupy about one-sixth of the height of the arcade (about 75 mm) at 2800 W, and about one-fifth (100 mm) at 375 W. The thickness varied little along the length of the arcade. The top of the fresh air layer (open end case) was more distinct, its thickness ranging from about 75 mm (lowest power) to about 150 mm (maximum power). This also changed little along the length of the arcade, except in the final module, where the thickness appeared to increase at the expense of the intermediate layer. This may result in part from the change in flow conditions at the mouth of the arcade, since in effect it projected into free space, but is probably mostly accounted for by the gradual establishment of the striated layer in this entry section of the arcade. The length of this entrance effect, about one module, was the same for all arcade lengths.

Observation down the bore of the arcade (again in the open end case) revealed that a secondary flow resulted from cooling at the roof and walls, producing a slight downflow at the walls. This did not penetrate into the fresh air layer. It gave the smoke mass a somewhat arched cross section, the striated layer being deeper at the sides than at the centre. The arching was less pronounced at the highest and lowest powers used. Measurement of smoke depths in the model arcade, other than of the hot layer, will evidently give high values if accomplished by the casual method of looking in through the side windows; a suitably small periscope or scattered-light detector might be needed if precise information were required about smoke depths in the interior of the arcade.

6. RESULTS

6.1. Presentation. The averaged results of the timing experiments described above are presented in Table 2 as 'incremental' times, required by the smoke to traverse the length of one specified module, and 'cumulative' times, the total travel time from initiation of the smoke flow to its leaving the specified module. The corresponding incremental and cumulative mean velocities of the smoke front are also given.

Table 1 provides a key to relate the actual experimental conditions to the code numbers used to identify results in Table 2.

Table 1

Identification of experimental conditions

Code	Number of modules	Power W	End open or closed	Number of heaters
201	2	375	Open	2
202	"	750	"	"
203	"	1500	"	"
204	"	2800	"	3
2C1	"	375	Closed	2
2C2	"	750	"	"
2C3	"	1500	"	"
2C4	"	2800	"	3
401	4	375	Open	2
402	"	750	"	"
403	"	1500	"	"
404	"	2800	"	3
4C1	"	375	Closed	2
4C2	"	750	"	"
4C3	"	1500	"	"
4C4	"	2800	"	3
601	6	375	Open	2
602	"	750	"	"
603	"	1500	"	"
603X	"	"	"	3
604	"	2800	"	"
6C1	"	375	Closed	2
6C2	"	750	"	"
6C3	"	1500	"	"
6C3X	"	"	"	3
6C4	"	2800	"	"

Table 2

Experimental smoke travel times and calculated velocities

Notes

1. In each data set:

   Row 1 gives the incremental travel time for each module, seconds
   " 2 " " cumulative travel time to the end of each module, seconds
   " 3 " " mean smoke velocity within each module, metres/second
   " 4 " " mean smoke velocity from the source to the end of each module, metres/second.

2. In the trials with only two modules, the passage of the smoke was timed over half-module increments.

3. The modules were all 2.44 m long, with the exception of the first which was 2.5 m owing to the presence of the wooden flange connecting it to the fire compartment. The running lengths are thus 2.5, 4.94, 7.38, 9.82, 12.26 and 14.70 m.

Code	Number of modules traversed					
	1	2	3	4	5	6
601	10.6	14.0	15.9	20.8	20.6	19.7
	10.6	24.6	40.5	61.2	81.8	101.5
	0.235	0.175	0.154	0.117	0.118	0.124
	0.235	0.201	0.183	0.160	0.150	0.145
602	8.0	10.9	12.5	17.3	19.1	18.4
	8.0	18.9	31.4	48.8	67.9	86.3
	0.313	0.224	0.195	0.141	0.128	0.133
	0.313	0.262	0.235	0.201	0.181	0.170
603	6.6	8.6	10.3	13.8	15.3	15.9
	6.6	15.2	25.5	39.3	54.6	70.5
	0.378	0.286	0.238	0.177	0.160	0.154
	0.378	0.326	0.290	0.250	0.225	0.209
603X	6.2	7.8	10.0	12.5	15.4	20.5
	6.2	14.0	24.1	36.6	52.0	72.4
	0.402	0.313	0.243	0.197	0.159	0.121
	0.402	0.352	0.307	0.269	0.237	0.204
604	4.8	6.1	7.6	9.1	11.0	13.3
	4.8	10.9	18.4	27.6	38.5	51.8
	0.523	0.400	0.324	0.268	0.225	0.185
	0.523	0.453	0.400	0.356	0.319	0.284

6C1	10.6 10.6 0.237 0.237	14.2 24.8 0.171 0.199	15.7 40.5 0.156 0.182	22.1 62.5 0.111 0.157	24.2 86.7 0.101 0.141	31.6 118.2 0.077 0.124
6C2	8.2 8.2 0.304 0.304	10.8 19.0 0.226 0.260	13.0 32.0 0.188 0.230	18.9 50.9 0.129 0.193	22.2 73.1 0.110 0.168	27.9 101.0 0.088 0.145
6C3	6.7 6.7 0.375 0.375	8.6 15.2 0.284 0.324	10.2 25.4 0.239 0.290	13.9 39.3 0.176 0.250	17.4 56.6 0.141 0.216	20.4 77.0 0.120 0.191
6C3X	6.4 6.4 0.394 0.394	8.0 14.4 0.304 0.344	10.0 24.4 0.244 0.303	12.6 37.0 0.195 0.266	15.4 52.3 0.160 0.235	19.9 72.3 0.123 0.204
6C4	4.6 4.6 0.545 0.545	6.2 10.8 0.392 0.457	8.1 18.9 0.302 0.390	9.7 28.5 0.253 0.344	11.9 40.5 0.204 0.303	15.5 56.0 0.158 0.263
401	10.6 10.6 0.237 0.237	13.7 24.3 0.177 0.204	16.8 41.1 0.145 0.180	19.3 60.4 0.127 0.163		
402	8.1 8.1 0.310 0.310	10.4 18.5 0.234 0.267	13.0 31.5 0.189 0.234	15.8 47.2 0.156 0.209		
403	6.2 6.2 0.404 0.404	8.0 14.2 0.307 0.349	10.0 24.2 0.245 0.305	11.8 35.9 0.210 0.274		
404	4.8 4.8 0.520 0.520	6.5 11.4 0.373 0.435	8.0 19.3 0.306 0.382	10.0 29.3 0.245 0.335		
4C1	10.6 10.6 0.235 0.235	14.0 24.6 0.175 0.201	17.2 41.8 0.142 0.177	23.3 65.1 0.105 0.151		
4C2	8.6 8.6 0.293 0.293	10.5 19.1 0.232 0.259	13.0 32.1 0.187 0.230	18.1 50.2 0.135 0.196		

4C3	6.5 6.5 0.388 0.388	8.3 14.7 0.295 0.336	10.7 25.4 0.229 0.291	13.4 38.8 0.182 0.253
4C4	5.1 5.1 0.494 0.494	6.7 11.8 0.364 0.420	8.1 19.9 0.301 0.372	10.8 30.7 0.227 0.321
	½	1	1½	2
201	4.8 4.8 0.261 0.261	6.0 10.8 0.197 0.231	6.1 16.9 0.195 0.220	6.3 23.2 0.168 0.213
202	3.9 3.9 0.318 0.318	4.4 8.3 0.286 0.300	4.9 13.2 0.252 0.282	4.9 18.1 0.249 0.273
203	2.9 2.9 0.441 0.441	3.3 6.2 0.380 0.399	3.8 10.0 0.318 0.373	4.2 14.2 0.292 0.349
204	2.2 2.2 0.562 0.562	2.4 4.6 0.530 0.545	3.2 7.7 0.387 0.481	3.2 11.0 0.379 0.451
2C1	4.7 4.7 0.264 0.264	6.4 11.1 0.197 0.225	6.4 17.5 0.195 0.213	7.2 24.7 0.168 0.200
2C2	4.0 4.0 0.319 0.319	4.5 8.5 0.284 0.245	5.4 13.9 0.227 0.267	5.3 19.2 0.232 0.257
2C3	2.7 2.7 0.472 0.472	3.7 6.4 0.342 0.396	4.2 10.6 0.292 0.353	4.3 14.9 0.281 0.332
2C4	2.3 2.3 0.554 0.554	2.9 5.2 0.439 0.483	3.3 8.4 0.375 0.441	3.5 12.0 0.345 0.413

Table 3

Module distances

Module number	Length (m)	Total distance (m)
1	2.50	2.50
2	2.44	4.94
3	2.44	7.38
4	2.44	9.82
5	2.44	12.26
6	2.44	14.70

6.2. Preliminary discussion. An inspection was made of the individual data from nine nominally identical trials at 6 modules length, 1500 W, open end, with a view to assessing experimental error. The range on incremental times (time to travel one module) was about ± 10 per cent (max. 14.3, min. 7.6) of the mean values, with the exception of the times for the final module, where the range was ± 20.4 per cent. The greater amount of error in the final module is caused by random air currents in the laboratory around the mouth of the arcade. Smoke movement approaching the open end of the arcade is susceptible to external influences because the smoke has cooled considerably by the time it reaches this region and the buoyancy forces driving it are weak.

The cumulative times showed smaller plus/minus percentage errors, ranging from 5.8 to 7.2, the figures for the first and final modules being 9.4 and 10.2 respectively. This reduction in magnitude reflects the smoothing effect of the cumulative addition of random errors, the first-module figure necessarily remaining at the previous level. The ranges of the incremental and cumulative velocities are closely similar to the figures just quoted.

In Table 4 are presented in detail the incremental times of six trials at 6 modules, 1500 W open end, to examine the effect of aerosol injection rate at the levels 5, 10, 20 litres per minute. No trend is discernible. The middle rate was found to give a satisfactory compromise between intensity of marking and convenience of operation, and was adopted as standard.

Table 4

Effect of injectant flow rate

Flow l/min	Incremental times, seconds					
	1	2	3	4	5	6
5	6.3	8.7	10.4	14.4	15.2	16.7
	6.5	9.1	10.0	13.4	14.8	15.0
10	5.7	8.9	10.6	16.5	16.7	22.1
	6.1	8.5	9.7	12.4	14.4	14.6
20	7.7	8.5	10.6	14.8	15.0	17.7
	6.1	8.1	9.5	13.0	14.2	14.4

The trials at six modules, 1500 W, open and closed end, employing both two and three heaters (Table 2, codes 603, 603X, 6C3, 6C3X) were made to discover if the behaviour of the simulated fire at a given power depends on the number of heaters used. If the heaters are quite independent of each other in their convective behaviour, then addition of the third heater, at the same total power, would be expected to result in approximately half as much again air being moved, at approximately two-thirds of the temperature rise, as with two heaters. Examination of the incremental times and velocities for codes 603/603X, 6C3/6C3X reveals little difference between the two cases. From later experiments, to be reported separately, it was found that the incremental smoke front velocities for any module are, in this laboratory model, uniquely related to the mean smoke temperature in the chosen module. The present inference is that the gas temperatures, and hence the volumetric flows, are not much changed between the two-heater and three-heater trials. This establishes that trials at the 2800 W power level (which can only be attained by use of three heaters) should be a valid extension of the lower power trials made with two heaters, and that the simulated fire behaves similarly for both cases.

The probable reason for this similarity is that access of air to the extra heater, which is at the rear of the fire compartment, is so restricted that although the heater contributes its proportionate share to the total power input it is unable to contribute significantly to the net amount of air moved. In fact, since the incremental times are a trifle lower for the three-heater trials, suggesting slightly higher gas temperatures, it appears that motion of air around the middle heater must be hindered also.

The results presented in Table 2 will be analysed in detail in a further report and possible applications discussed.

7. ACKNOWLEDGEMENTS

Mr. D. Moran, a student from Liverpool Polytechnic, assisted with the experimental work described in this report.

8. REFERENCES

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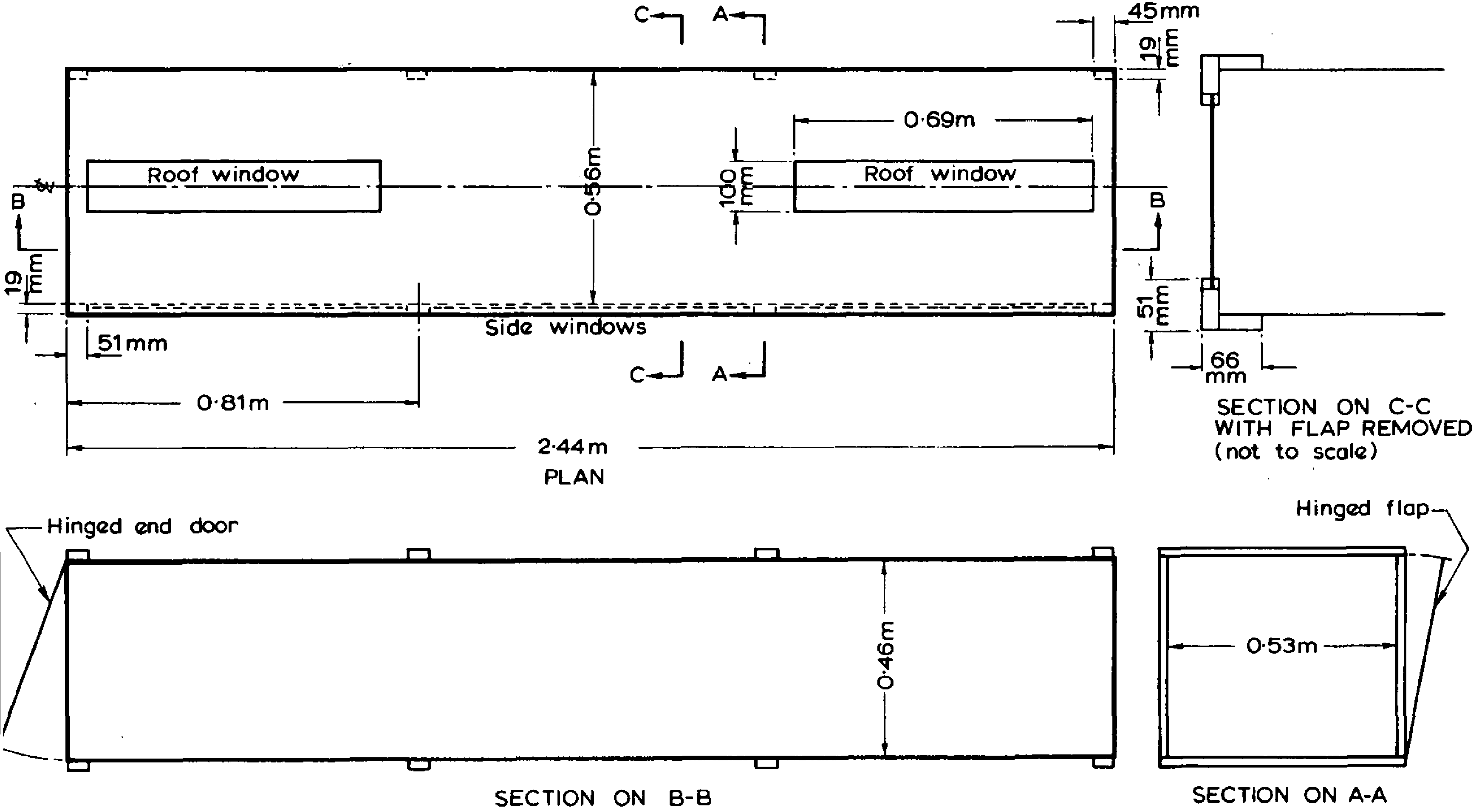

FIG. 1. DIMENSIONS OF MODULE

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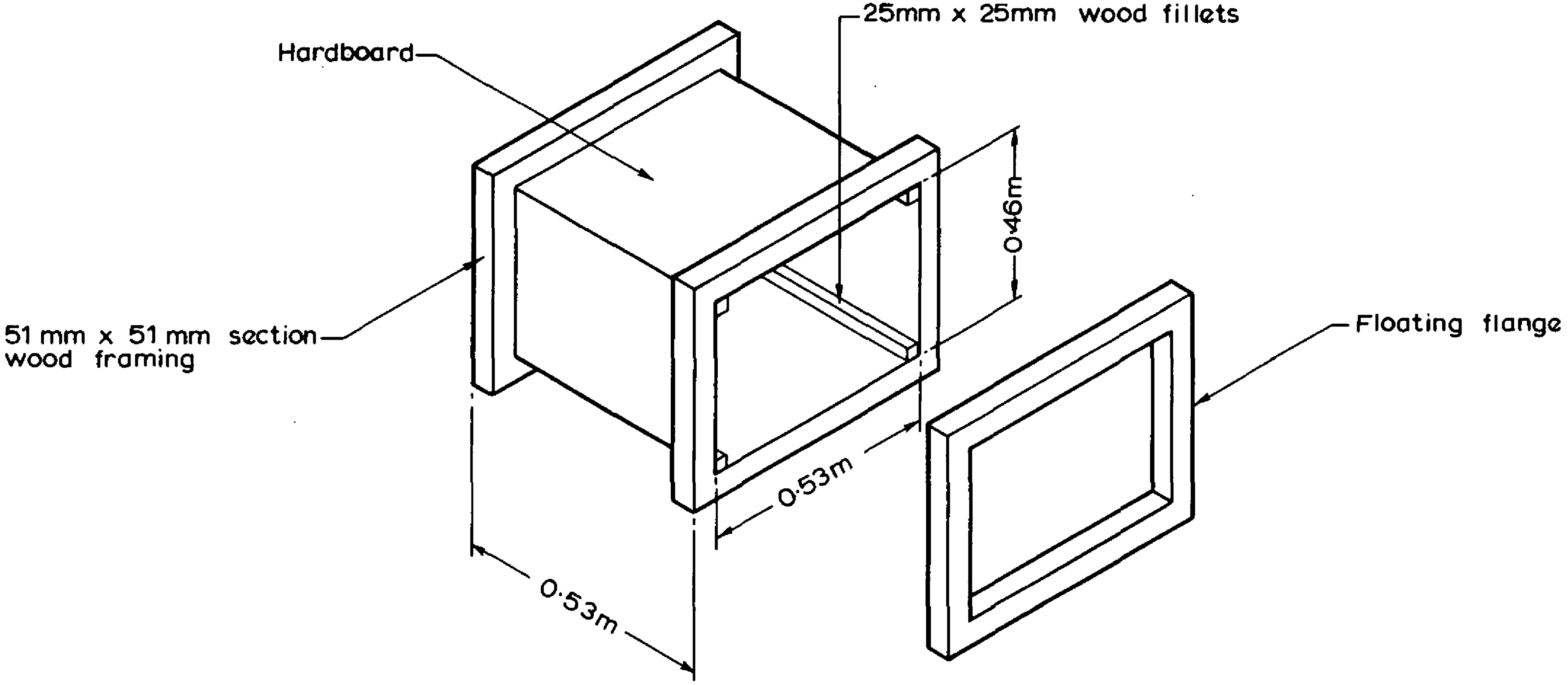

FIG. 2. SMOKE COMPARTMENT

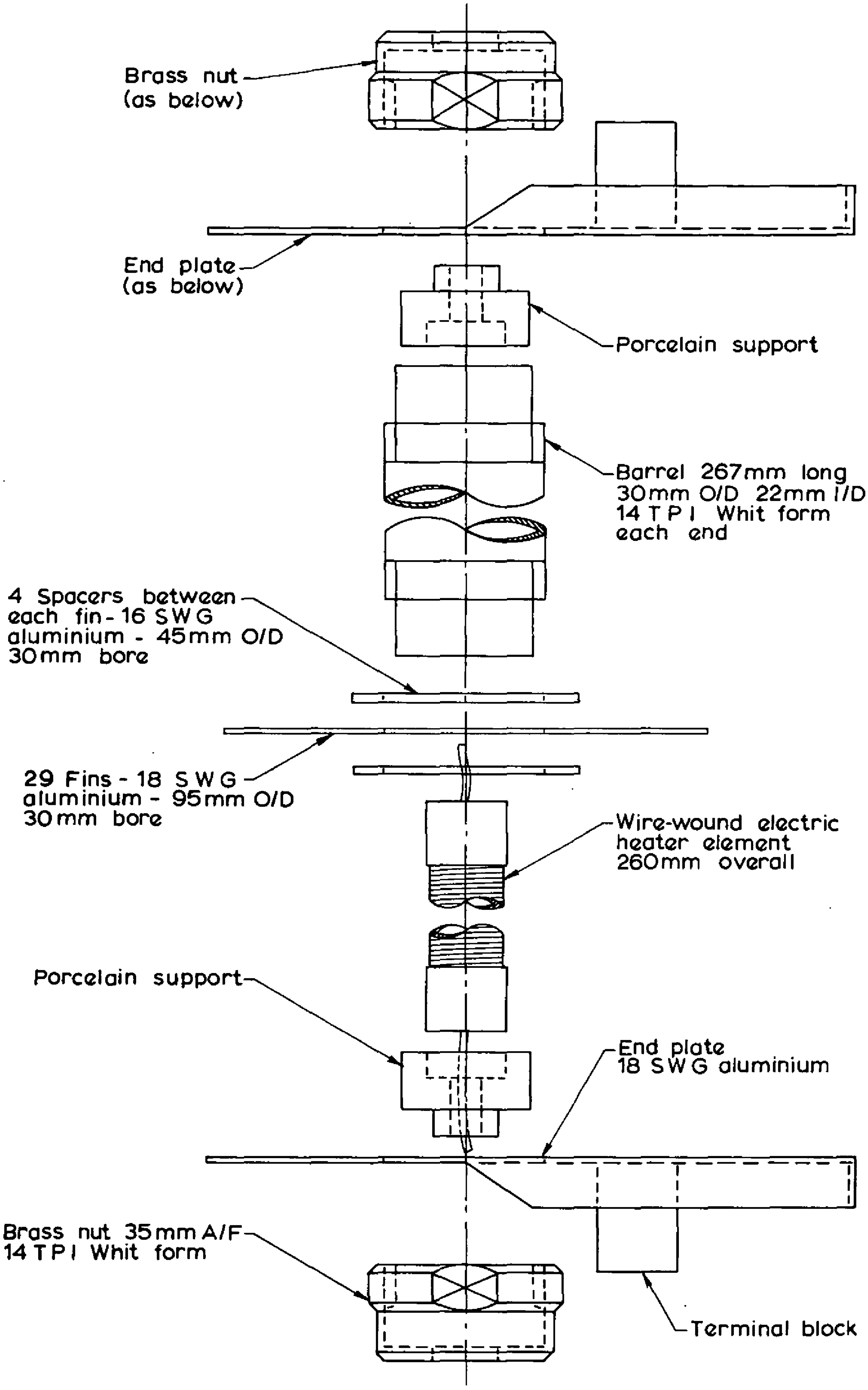

FIG. 3A. EXPLODED VIEW OF CONVECTOR HEATER (286 MM LONG)

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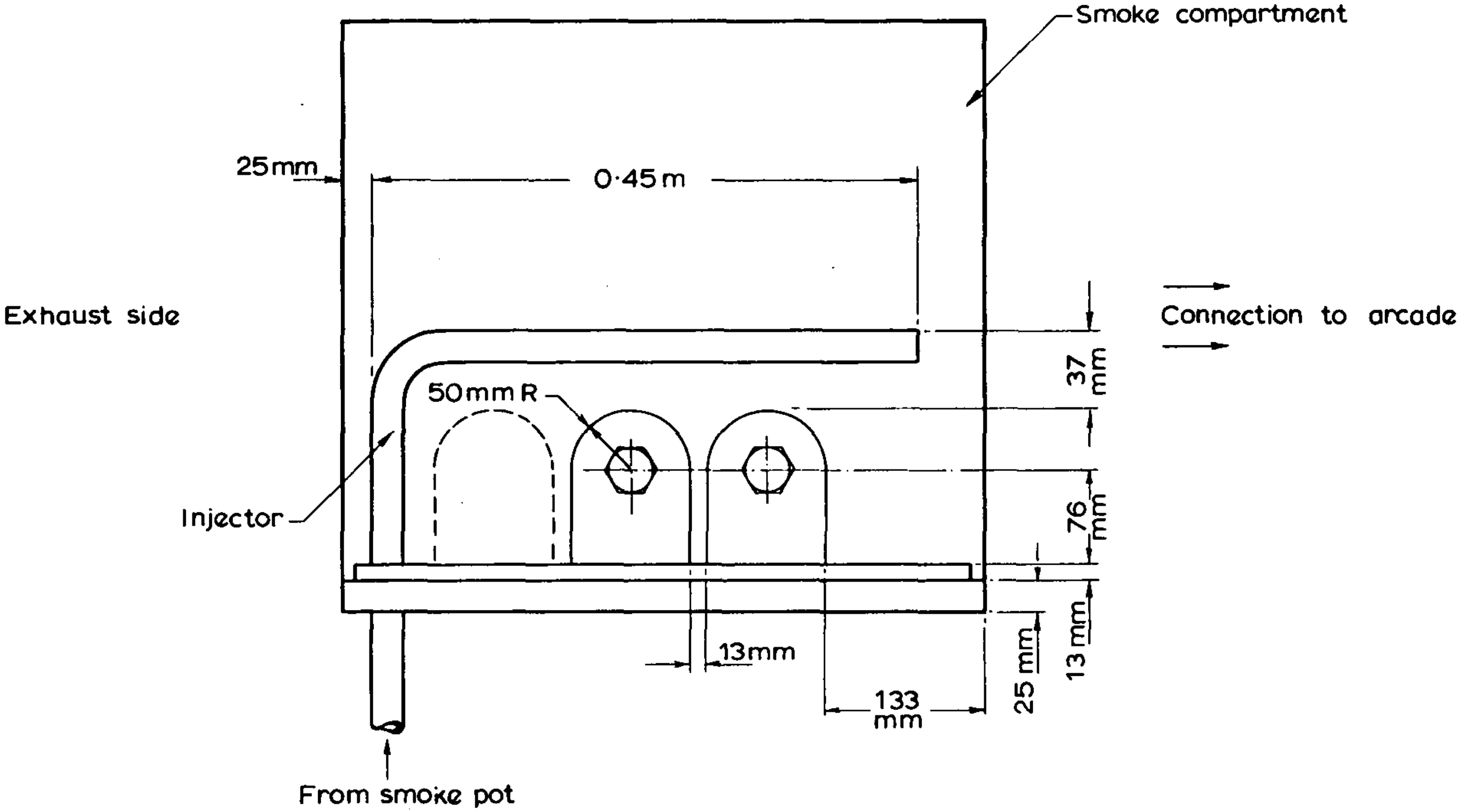
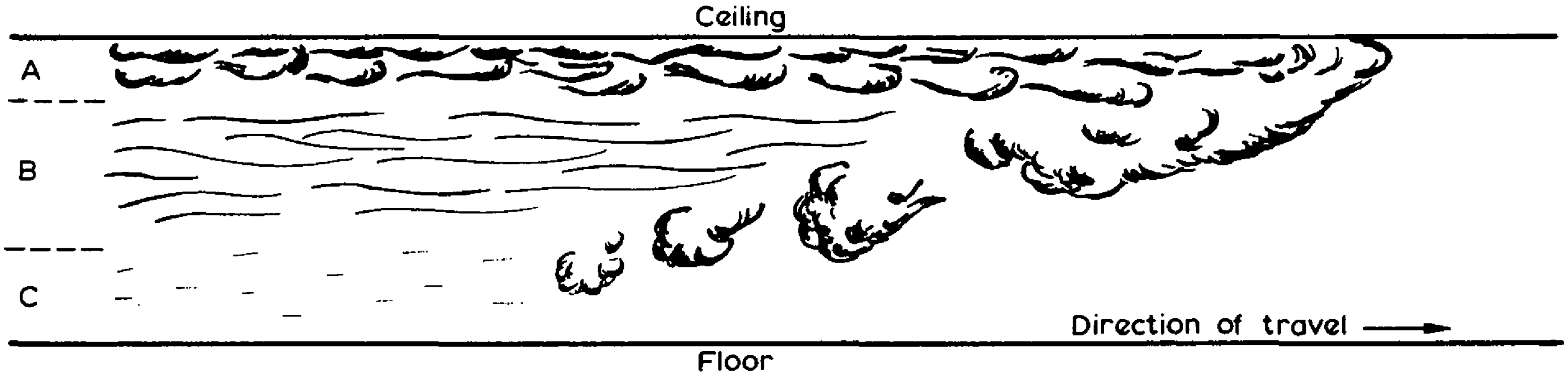


FIG. 3B. SIDE VIEW OF SMOKE COMPARTMENT INTERNALS



A = Roof layer
B = Intermediate layer
C = Clear air layer

FIG. 4. STRUCTURE OF TRANSIENT FLOW