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A COMPARISON OF "DRY POWDER" AND CHLOROBROMOMETHANE FOR FIRST-AID APPLICATION TO AIRCRAFT CRASH FIRES

by

F. E. T. Kingman and P. Nash

Summary

This report describes tests made to compare "dry powder" and chlorobromomethane as materials for first-aid application to aircraft crash fires. The tests showed chlorobromomethane to be slightly superior as an extinguishing agent on the size of fire described and under the weather conditions prevailing. Both materials suffered from the disadvantage of permitting "flashing back". With the dry powder was associated a sudden transient increase of the air temperatures in the aircraft cockpit, while under certain circumstances the atmosphere produced by the use of chlorobromomethane contained an undesirably high proportion of toxic products.

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Fire Research Station,
Boreham Wood,
Herts.

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Foreword

The work described in this report was carried out under the aegis of a panel convened by the Air Ministry. The fire tests were performed by Royal Air Force personnel under the direction of Mr. E. J. C. Williams, Chief Fire and Rescue Officer, Air Ministry, at the fire test ground, Royal Air Force Station, Kenley. The Joint Fire Research Organization of the Department of Scientific and Industrial Research and Fire Offices' Committee were responsible for the measurement of the intensity of the fires and the temperatures in the aircraft cockpit, and also for the sampling and analysis of the atmospheres in and around the cockpit during the discharge of CB on the fires. These measurements were made by two teams consisting of P. H. Thomas, R. J. French and P. L. Hinkley and E. H. Coleman, S. Tonkin and C. H. Thomas.

Introduction

At a meeting of the panel convened by Air Ministry on 1st December, 1953, it was stated that the R.A.F. Airfield Crash Rescue Unit included a light rescue vehicle (5 cwt 4 x 4 car). This vehicle having a high speed, acceleration and cross country performance, proceeds in advance of the heavier carbon dioxide and foam tenders thus enabling rescue attempts with the minimum of delay.

Experience has shown, however, that the usefulness of these rescue vehicles had on occasion been nullified by the inability to combat even minor outbreaks of fire with the limited fire extinguishing equipment carried, i.e., two 12 lb. carbon dioxide and two 2 gallon foam extinguishers. Experiments have, therefore, been carried out to determine the relative fire extinguishing merits of agents considered suitable for mounting on the light rescue vehicle with its restricted payload in sufficient quantities to effectively suppress or extinguish a serious fire in support of rescue attempts, pending the arrival of the heavier foam and carbon dioxide vehicles. These tests were carried out under Air Ministry arrangement at their Fire Test Ground at R.A.F. Kenley and from the results obtained the Air Ministry had decided that the best materials to use for this purpose were either dry powder or chlorobromomethane.

This report describes some tests which were made to decide which of these two materials was the more suitable for this purpose from the following aspects:-

(1) the ability of the material to extinguish, or to obtain a useful degree of control over, the fire, so that rescue work could proceed.

(2) the freedom of the material from noxious decomposition products.

Fire-fighting equipment

The three light rescue vehicles used for the tests were of the 5 cwt 4 x 4 type (Land Rovers) and apart from carrying a crew of two and rescue tools, had a disposable load of approximately 550 lb. which could be used for the fire-fighting equipment and material. This equipment was of the following types:-

a) Type A. Two 100 lb. dry powder extinguishers discharged through two 60 ft. long hoses by carbon dioxide under pressure. Maximum rate of discharge 172 lb./min. per nozzle. Total weight of equipment approximately 500 lb. See Plate 1.

b) Type B. Two 200 lb. dry powder extinguishers discharged through two 60 ft. hoses by carbon dioxide under pressure. Maximum rate of discharge 109 lb./min. per nozzle. Total weight of equipment approximately 640 lb. See Plate 2.

c) Type C. Two 12 gallon chlorobromomethane extinguishers, discharged through two 60 ft. hoses by carbon dioxide under pressure. Maximum rate of discharge 6 gal/min. (115 lb./min.) per nozzle. Total weight of equipment approximately 540 lb. See Plate 3.

Experimental arrangements

Eleven experiments were carried out using Spitfire aircraft from which the engines and many of the internal fittings had been removed. The undercarriages were partly retracted, and the aircraft rested on the ground on their tail wheels and radiators. In most experiments, either one or two bunds having walls of sand about 4 in. high and the areas inside them covered with a thin layer of sand, were constructed under the aircraft. Petrol was supplied to the bund on the ground under the aircraft through either one or two pipes. The experimental programme is shown in Table 1. The intensity of radiation from the fire, and the temperature at various points within the cockpit were measured during the tests. Samples of the gases in and around the cockpit were obtained at various times during the fire and the extinction period, and were subsequently analysed. Details of the experimental arrangements for these measurements are given in Appendix I.

Table 1 - Programme of tests

Test No.	Extinguishing agent used	Bunds	Petrol supply	Aircraft resting on	Condition of cockpit before test
1	Powder	One under front (see fig. 1)	One supply to centre of bund near ground (see fig. 1). Flow 3½ g.p.m.	Concrete	Skin round cockpit intact except for small aperture in floor. Cockpit cover practically intact.
2	C. B.				
3	C. B.				
4	Powder				
5	C. B.	Additional bund behind first (see fig. 2)	Additional supply to centre of second bund near ground (see fig. 2). Total flow 6½ g.p.m.		
6	Powder				
7	C. B.				
8	Powder				
9	Powder	No bund	Two supplies as in fig. 2 but front outlet 15 in. above ground. Total flow 6½ g.p.m.	Grass	6 in. diameter hole in cockpit floor. Perspex largely missing from cockpit cover.
10	C. B.				
11	C. B.	No bund	Front supply only used. Flow 3½ g.p.m.		

Experimental procedure

The wind speed and direction were noted. Petrol was allowed to flow for two minutes before being ignited, after which the fire was allowed to burn for 75 seconds before the starting signal was given. The state of the fire in Test 1 at this stage is shown in Plate 4. On receiving the signal the two operators turned on their extinguishers and advanced towards the fire. In Tests 1-8 the first operator attacked the the fire from the front of the aircraft and the second from the windward (port) side as shown in Tests 1 and 2; in Tests 9-11 both operators attacked the fire from the front of the aircraft. The time between the signal and the application of the extinguishing agent to the fire was noted and also the total time of extinction.

If the extinguishers failed to extinguish the fire, foam was applied from a branchpipe or crash tender. The petrol soaked sand was replaced between each experiment and any foam was washed off the aircraft. A continuous film record at about seven frames per second was made of each experiment.

Experimental results

A summary of the principal experimental results is given in Table 2. All times are measured from the instant of application of extinguishing agent to the fire, which was never more than five seconds after the starting signal.

The values given for radiation are in arbitrary units scaled to a fixed distance from the fire. Examples of radiometer records are given in Figures 5 and 6 referring to Tests 5 and 6 respectively. The control point was defined as in previous experiments on trays and tanks (3) by the moment when the radiation was reduced to one-third of the value it had just before application of the extinguishing agent. The appearance of the fire at this point is shown in Plate 5 for Test 2 using chlorobromomethane and in Plate 6 for Test 1 using dry powder. These should be compared with Plate 4.

Records of cockpit temperatures during the application of the extinguishing agent are shown in Figures 7 (i) to 7 (ix). Since the flames were blown away from the cockpit hood in Tests 5-8 the gold disc radiometer readings may be regarded as being approximately the air temperature in the cockpit. All the temperatures are above ambient which was approximately 10°C.

The analysis of the atmosphere is given in Table 2, and shows that there was no phosgene present, the quantity of carbon dioxide was insignificant and there was no oxygen deficiency except in Test 10. After the extinction of the fire a smell of sulphur compounds was noticed in the cockpit. These were assumed to have been derived from flexible hose connections and electrical insulation. Sulphur dioxide is more pungent than the hydrogen halides and from the intensity of the smell it was concluded that the amounts present were within tolerable limits for short exposures. The sulphur dioxide was, therefore, not estimated separately.

Discussion of results

No large difference was evident in the performance of the different types of equipment on the first four fires fed with petrol at the lower rate, although it will be noted that the chlorobromomethane was employed on fires which were less intense than those on which dry powder was employed. In Tests 5-8 involving the higher rate of flow of petrol, there appeared to be smaller differences between the intensities of the individual fires. On these fires the chlorobromomethane equipment appeared to be superior since it extinguished one fire and reduced the other to very small proportions (see Plates 7 and 8) in spite of the fact that in the latter experiment only one extinguisher was functioning correctly. The dry powder extinguishers failed to extinguish the fires and the radiation could only be reduced to about one-quarter of the value it had at the moment before before application of the powder. The fire in Test 9 was much less intense than any other, possibly due to the petrol having soaked into the ground, but the dry powder failed to extinguish or control it, probably owing to frequent ignition from smouldering grass. The fire in Test 10 was larger than any other in the series since the ground had been thoroughly soaked with water before the experiment and did not absorb petrol. However, a useful degree of control was achieved using chlorobromomethane. Plate 9 shows that in Test 7 the fire was apparently extinguished by chlorobromomethane after 45 seconds but was reignited, presumably by hot metal, as shown in Plates 10 and 11 which were taken approximately one and two seconds respectively after Plate 9.

With both extinguishing agents the operators experienced difficulty with "flash-backs" but these were more severe with dry powder which only effected a temporary clearance of flame. As soon as the stream was directed elsewhere the petrol would reignite if any source of ignition existed. The dry powder tended to blow the flames outwards - possibly due to the high velocity of the discharge - and to cause an initial increase in the size of the fire. Plate 12 shows flames being driven by the dry powder against the wind under the entire length of the port wing in Test 4 (c.f. Plate 4). In Plate 13 the first operator is shown retreating before the flames blown towards him by the powder from the nozzle held by the second operator.

During the tests it was noticed that some of the spray of chlorobromomethane fell through the flames onto the ground or into the petrol lying on the ground. This might reduce the rate of burning of the petrol but it would not be so efficient a means of extinguishing the fire as vaporizing the chlorobromomethane in the flames. This suggests that it might be profitable to consider other designs of spray nozzle. It may be mentioned that a high discharge velocity is likely to induce too much air into the spray and this would tend to blow the flames about (e.g. dry powder). There is, therefore, likely to be an optimum design of nozzle.

(2) Temperatures in the cockpit of the aircraft

The skin temperature seldom exceeded 200°C during the application of the extinguishing agents since the flames did not generally reach the portion of the skin to which the thermocouple was attached.

The application of chlorobromomethane to the fire had no great effect on the air temperature in the cockpit but the application of dry powder usually resulted in its sudden rise (see Figures 7 (i), 7 (iv), 7 (viii) and 7 (ix)). The duration of the higher temperatures was no longer than 5-10 seconds in Tests 1, 4 and 9 but in Test 8 the air temperature prior to application of dry powder was already 100°C and for over half a minute after applying dry powder it did not fall below 200°C. The record shows transient peaks as high as 600°C indicating that the flames were being blown through one or two small apertures in the floor.

(3) Analysis of the atmosphere in the cockpit

According to Henderson & Haggard (2) the concentration (c) at which carbon monoxide becomes dangerous for a given period of exposure (t) can be calculated from the formula

$$c \times t = 1500$$

where "c" is measured in parts per million and "t" in hours.

Application of this formula indicates that the concentration of carbon monoxide observed in these tests would not create a serious toxic hazard.

The concentration of acid gases varied considerably with the conditions. Thus with a large fire not controlled by the apparatus and when the wind blew the flames back directly over the cockpit (Test 10), a concentration of 0.21 per cent was observed. With a similar fire, but with the wind blowing away from the cockpit, the concentration was very much lower (0.0006 per cent). Similarly with fires where entire extinction was achieved fairly rapidly (Tests 2 and 3) the concentration, even with the wind blowing towards the cockpit did not exceed 0·03 per cent.

There is little information available for the effects of very short exposures to hydrochloric acid and none have been found for hydrobromic acid. Henderson and Haggard state that 0·1 to 0·2 per cent hydrochloric acid is dangerous for short exposures, and according to Jacobs (3) concentrations of 0·13 to 0·2 per cent hydrochloric acid are lethal for exposures of a few minutes, although 0·005 per cent for 1 minute is regarded as dangerous by Imperial Chemical Industries.

Assuming that the toxicity of hydrogen bromide is of the same order as that of hydrogen chloride, it is possible to make some assessment of the toxic hazard due to the acid gases formed by the decomposition of chlorobromomethane in these tests. If we use the figures given by Jacobs, and Henderson and Haggard, the lethal concentration was only obtained or approached in Test 10. In all the other tests the concentrations of acid gases were considerably less, though probably sufficient to cause at least toxic manifestations of varying degree.

Conclusions

The following conclusions have been drawn from the results of the tests described in this report. They should be regarded as applying to fires of approximately the same size and intensity as in the experiments under wind and weather conditions similar to those prevailing. It is for the Panel to decide what is the practical significance of the temperature and toxicity conditions reported in (4) and (5).

(1) There is some evidence that chlorobromomethane was more effective than dry powder in reducing or extinguishing the larger of the fires. With the smaller fires there was no significant difference in the effectiveness of the two materials. The larger of the fires was of almost the limiting size that could effectively be controlled by the apparatus.

(2.) "Flashing back" was troublesome with both materials, but was apparently rather more likely with dry powder than with chlorobromomethane.

(3.) With the dry powder, there was a marked tendency for flames to be blown about, and to spread from the original seat of the fire. The effect was not noticed with chlorobromomethane.

(4.) On the application of dry powder, there was a marked but transitory increase in the temperatures in the cockpit. It is not possible to say how much this was due to the driving of the flames, and how much to other causes.

(5.) If the lethal concentrations quoted from Jacobs and Henderson and Haggard are accepted it could be concluded that the atmosphere was not lethal in these tests where extinction was rapid, or the fire was blown away from the cockpit. Much higher concentrations near or above the lethal limit could occur when the fire is too large to be controlled by the extinguishing agent, especially if the wind is blowing flames directly into the cockpit.

(6.) It is possible that the effectiveness of the chlorobromomethane could be improved by use of a better nozzle.

References

(1.) Report of Dry Chemical, Carbon dioxide, Foam and Chlorobromomethane demonstrations held at Kenley, 6th May, 1953. Air Ministry Fire and Rescue Service Paper B/F. 16/0.9.

(2.) FRENCH, R. J., HINKLEY, P. L. and FRY, J. F. The surface application of foam to petrol fires. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization. F.R. Note No. 21/1952.

(3.) HENDERSON, Y and HAGGARD, H. W. Noxious Gases, 2nd Edn. Rheinhold Publishing Corporation, New York, 1943.

(4.) JACOBS, M. B. The analytical chemistry of industrial poisons hazards and solvents. p.396. 2nd Edn. Interscience Publishers Ltd, New York, 1949.

Appendix I

Details of Experimental Arrangements

Four radiometers were placed 4 ft. 6 in. above the ground at the corners of a square having its centre at the bulkhead in front of the cockpit: the diagonal measured 50 ft. in the first four experiments and 80 ft. in all other experiments. The radiometers were connected in series to a D.C. amplifier the output of which operated a pen recorder. This arrangement of radiometers was similar to that used in experiments on the application of foam to petrol fires (2).

Cockpit temperatures were measured by three thermocouples (see fig.3).

These were:-

(1) A 22 S.W.G. chromel-alumel couple silver soldered to a copper disc 0.012 in. thick which was attached to the inside surface of the skin on the starboard side of the aircraft in line with and 6 in. below the forward edge of the cockpit opening.

(2) A 40 S.W.G. chromel-alumel couple to obtain an indication of the air temperature 3 in. above the gunsight mounting inside the cockpit cover.

(3) A 40 S.W.G. chromel-alumel couple to obtain an indication of the air temperature 6 in. above the floor of the cockpit.

In experiments 5-8 couple number 3 was replaced by a gold disc radiometer mounted horizontally facing upwards 1 in. below the level of the cockpit opening.

A second D.C. amplifier and pen recorder was switched automatically to the output from each thermocouple in turn every two seconds. An investigation of the decomposition products from the pyrolysis of halogen containing extinguishing agents had been made previously by the Joint Fire Research Organization, and the results showed that the principal toxic constituents would be the hydrogen halides. For chlorobromomethane, these would be hydrogen chloride and bromide, and from the work carried out at the Joint Fire Research Organization it appears that these would be produced in approximately equal amounts.

It was, therefore, considered that the toxicity of the atmosphere could be assessed sufficiently reliably by estimating the total halogen acids. Nevertheless, since the chlorobromomethane could be in contact with hot metal there was a possibility that carbonyl halides such as phosgene would be produced and the gases were examined for these.

The presence of carbon monoxide and carbon dioxide and the deficiency of oxygen are dangers common to all fires, and these three gases also were estimated.

The gas samples were collected in evacuated 5-litre flasks which were opened by an electrical device during the fire, and the flasks were removed as soon as possible afterwards. The samples were analysed subsequently by standard gas analysis methods. Carbonyl halides were estimated at the time of the tests, since they decompose in the presence of moisture. Air from the cockpit was drawn at 25 l/min through steel and lead tubing over drying agents and into 10-litre bottles. After obtaining the sample the contents were drawn slowly at $\frac{1}{2}$ l/min through absorption tubes and estimated by a modification of the standard D.S.I.R. method. (Methods for the detection of toxic gases in Industry Leaflet No.8. D.S.I.R. H.M.S.O. 1939).

KC.

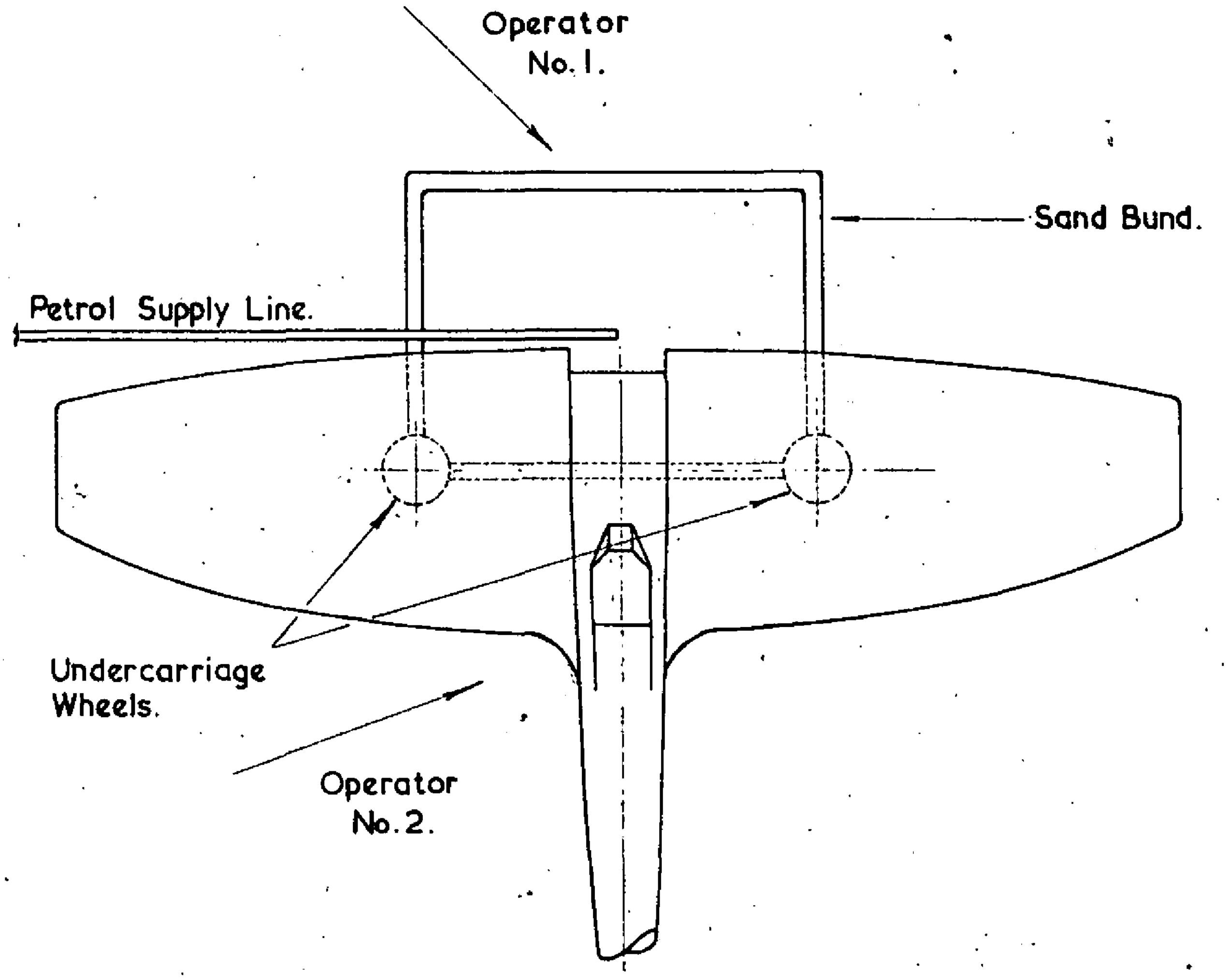

FIG. 1. ARRANGEMENT FOR TESTS 1 – 4.

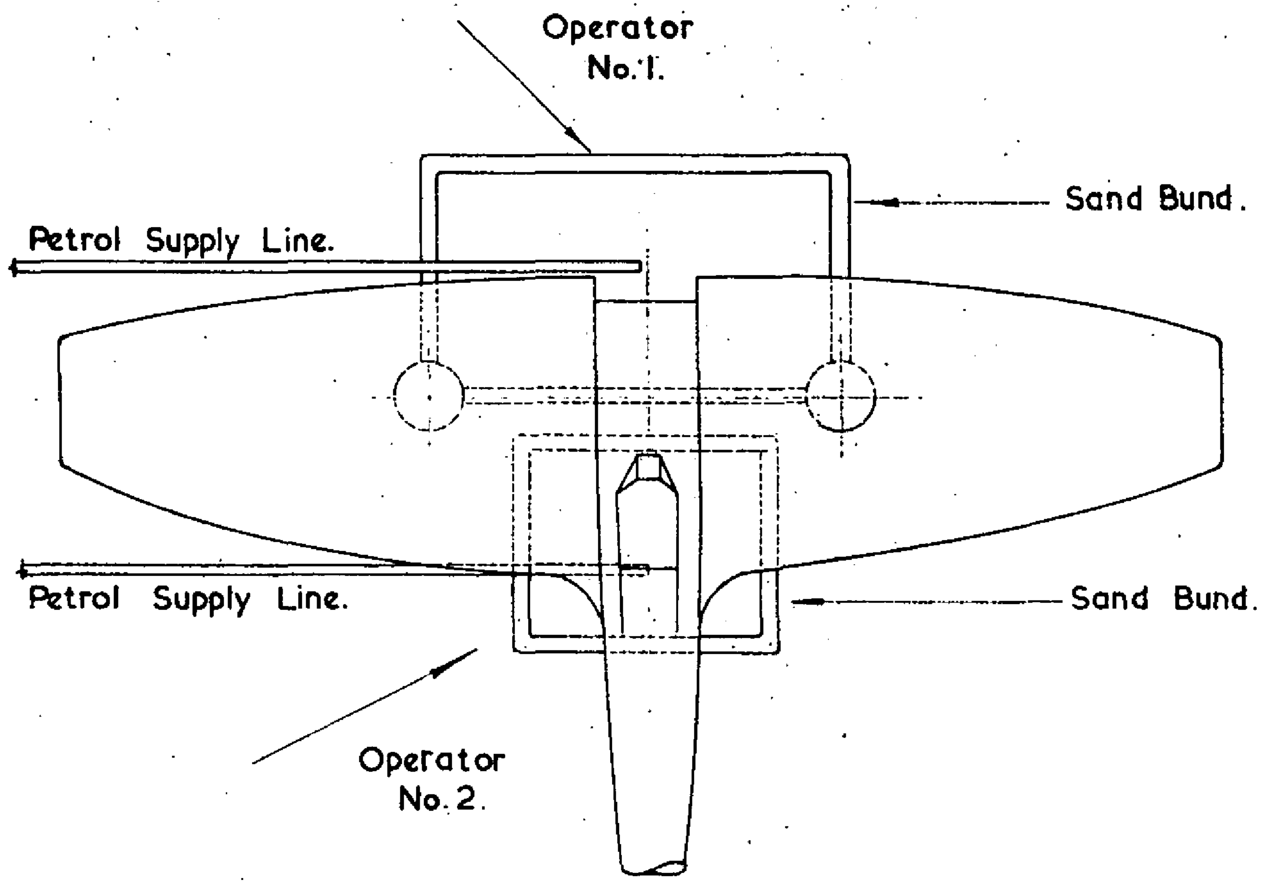

FIG. 2. ARRANGEMENT FOR TESTS 5 – 8.

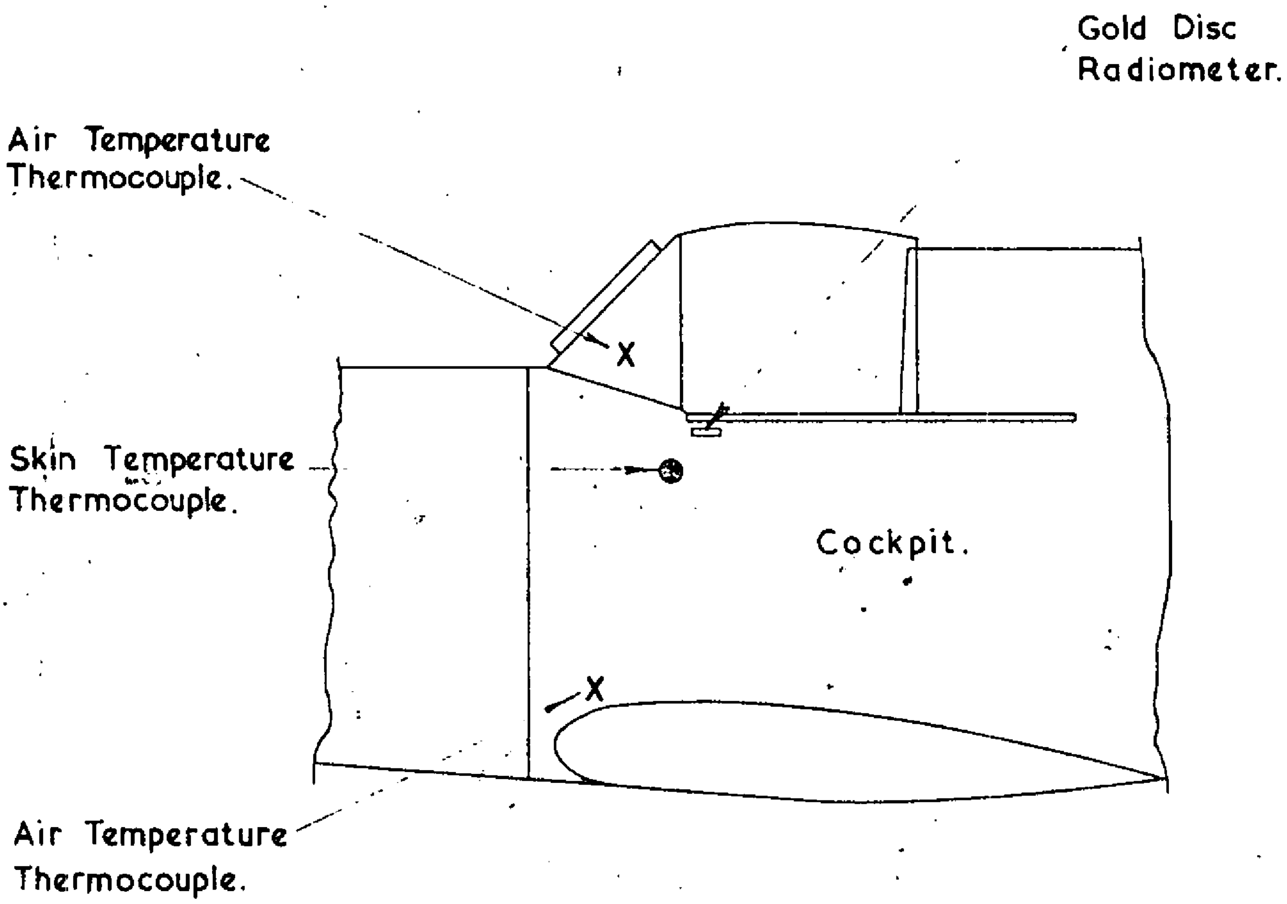

FIG. 3. POSITIONS OF THERMOCOUPLES.

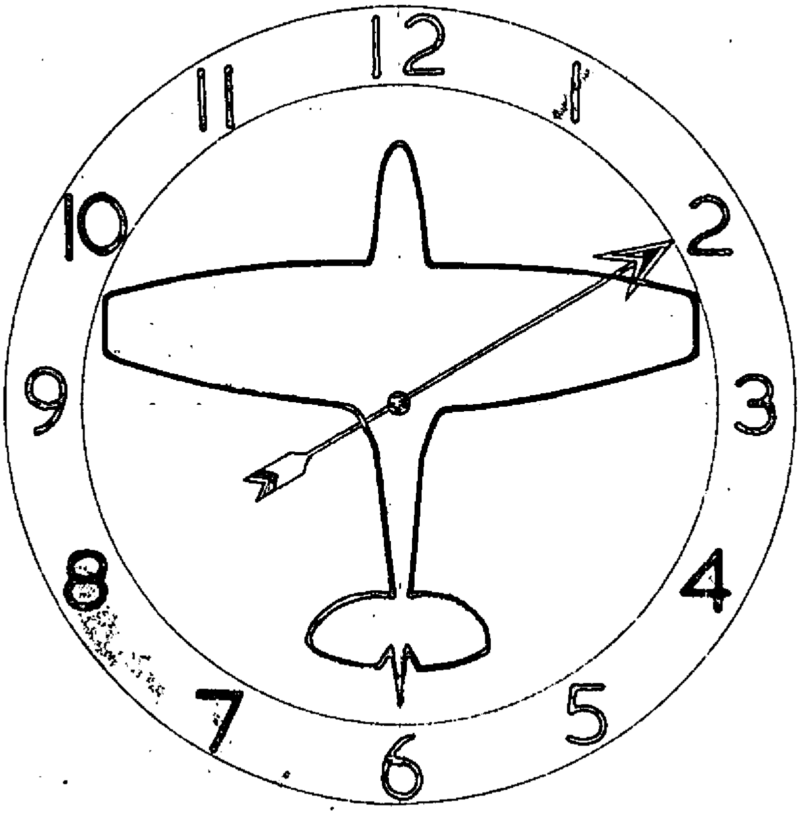

FIG. 4. WIND DIRECTION CHART.

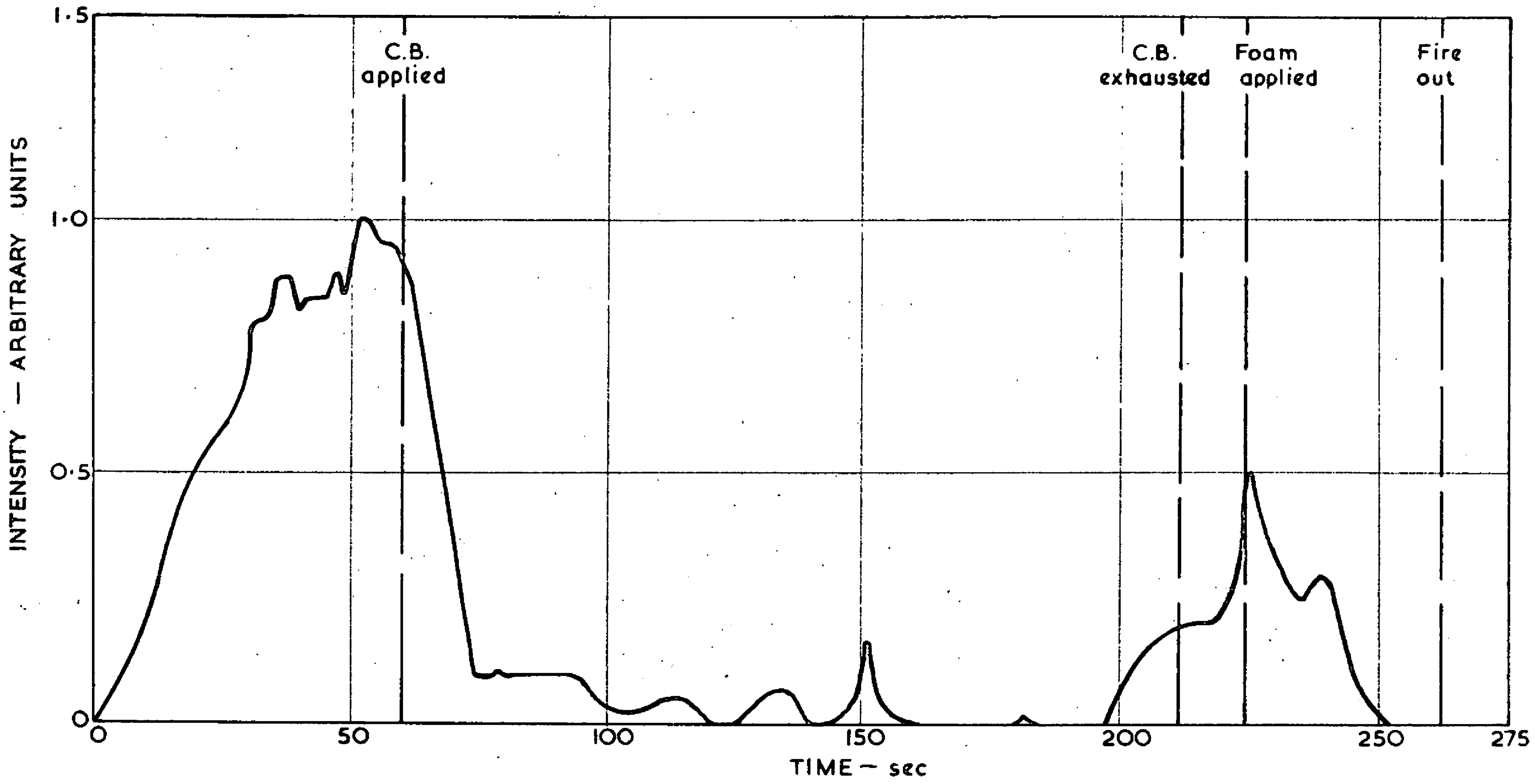

FIG. 5. RADIANT INTENSITY DURING TEST 5

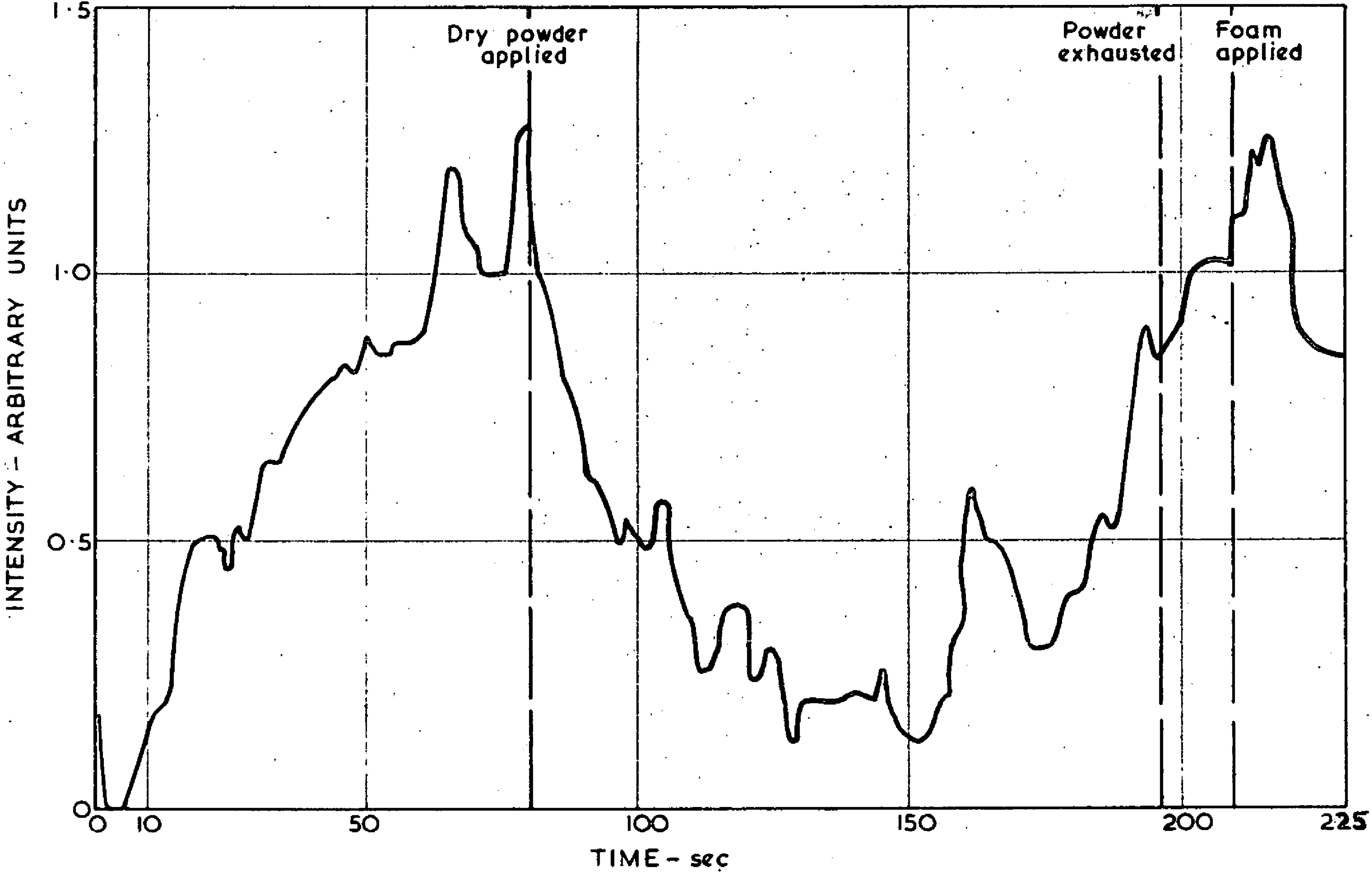

FIG.6. RADIANT INTENSITY DURING TEST 6

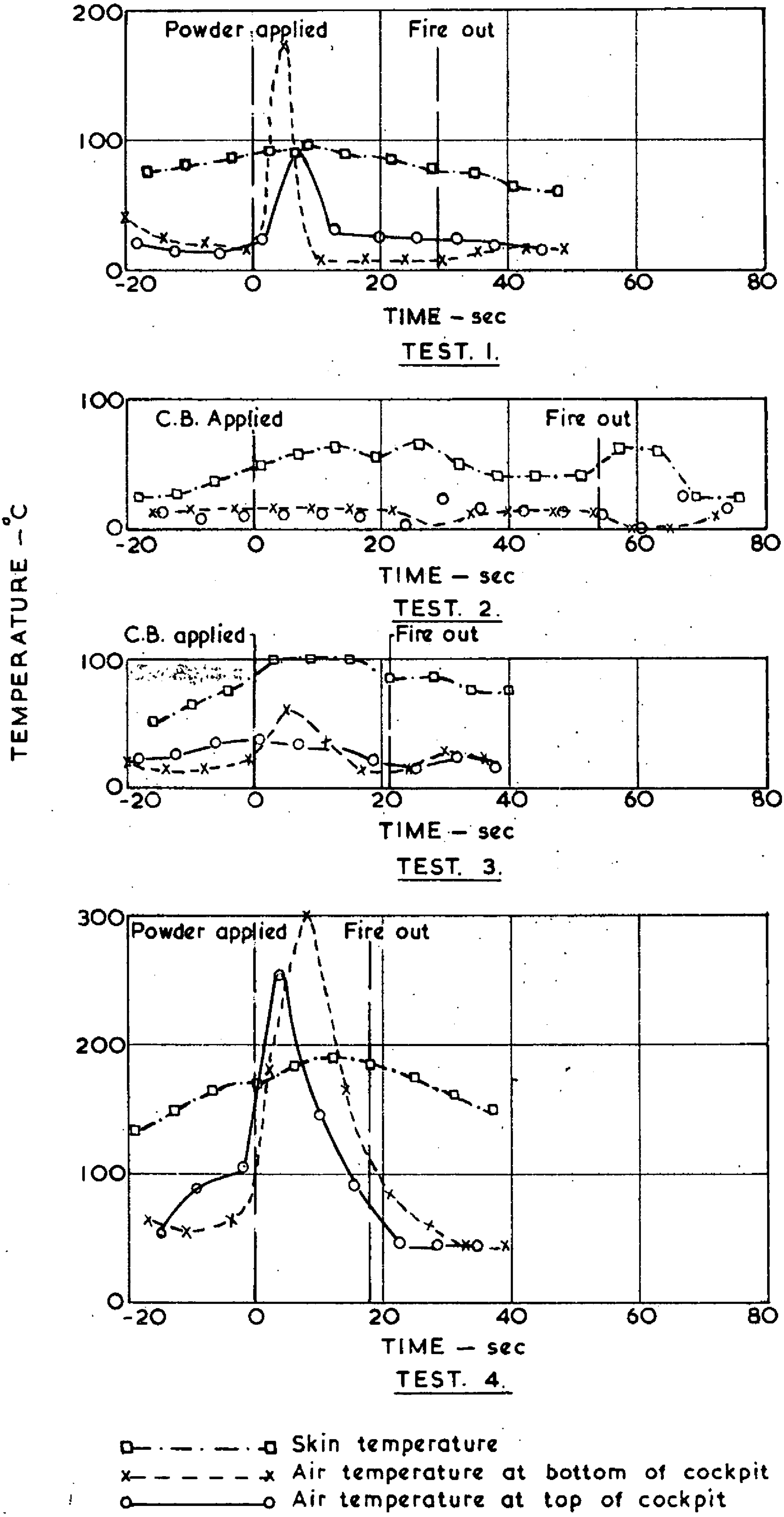

FIG. 7. COCKPIT TEMPERATURE RECORDS

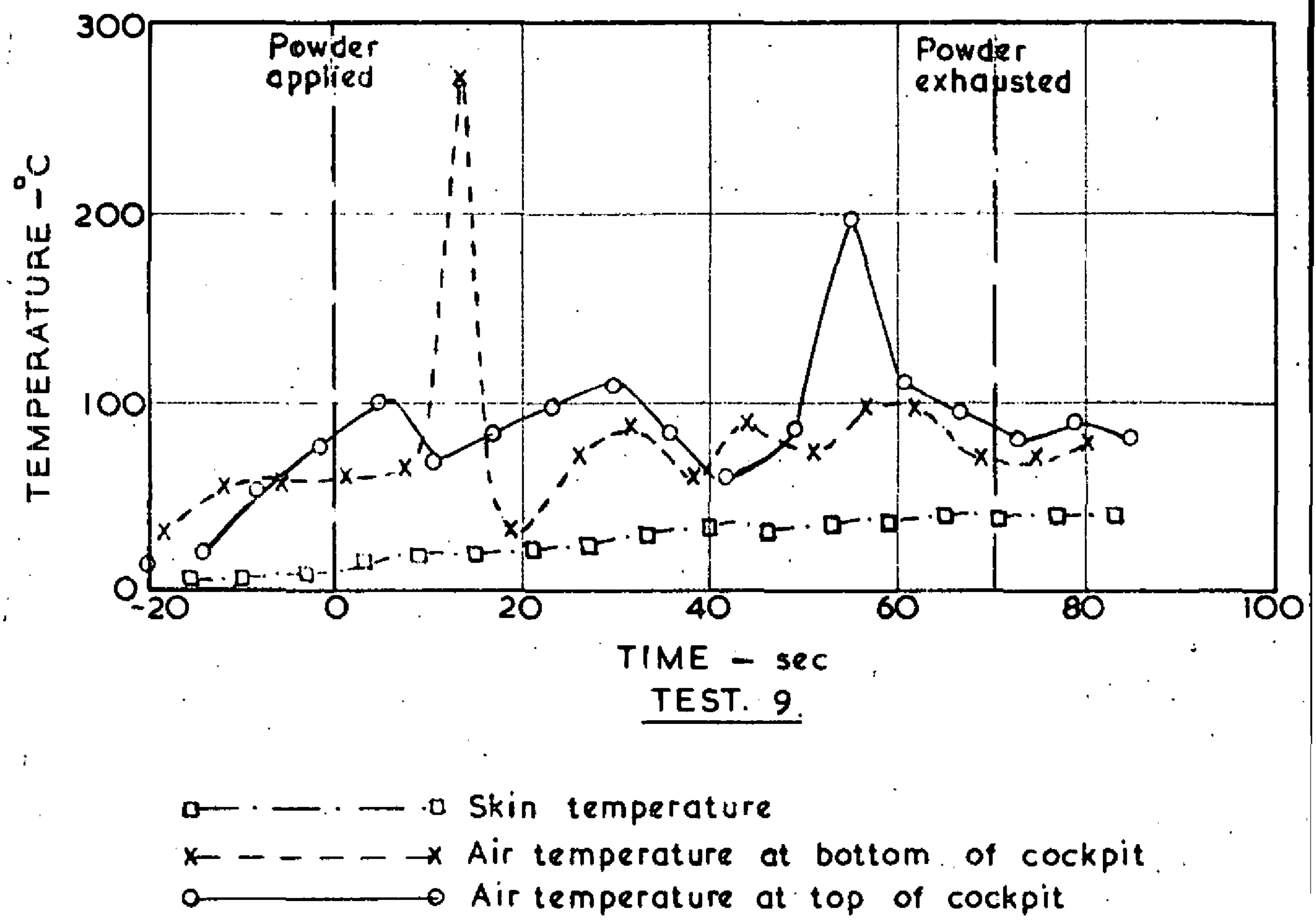

FIG.7. (CONTD.) COCKPIT TEMPERATURE RECORDS