DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
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AUDIBLE WARNINGS FOR FIRE APPLIANCES

by

I. C. Emson, D. Hird and R. W. Pickard

Summary

An investigation has been made of the relative effectiveness of four typical audible warning devices which may be used on fire appliances. It has been shown that the threshold levels of audibility of the devices against a background of lorry noise are not significantly different, so that the loudest warning noise will be the best for being heard by the driver of another vehicle. On this basis the warnings have been put in an order of effectiveness.

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Introduction

The highly polished brass bell is the traditional form of audible warning used on fire appliances in Great Britain. From the reports of drivers of fire appliances, however, it has become clear that difficulty is sometimes experienced in passing through traffic on the way to a fire because the drivers of some other vehicles on the roads, particularly heavy lorries, do not hear the appliance warning bell above the background noise made by their own vehicles. It is for this reason that some fire brigades have experimented with other types of audible warning.

At the request of the Joint Committee for the Design and Development of Fire Brigade Appliances and Equipment of the Central Fire Brigades Advisory Councils, an investigation has been made by the Joint Fire Research Organization to assess the relative effectiveness of four different types of audible warning devices.

Description of equipment tested

The four types of audible warning devices used in the investigation were operated from a 12 v. lead-acid accumulator of the type normally fitted to fire appliances.

Warning A (Plate 1) consisted of four electrically-operated diaphragm horns. It was stated by the manufacturers that two of the horns sounded G(390 c/s) and two sounded C(520 c/s); the four horns were coupled in pairs of the same frequency and were operated through a set of motor-driven contacts to give the sequence G.C.G.C. followed by a pause, the sequence being repeated 17 times per minute.

Warning B (Plate 2) consisted of two pneumatically-operated diaphragh horns supplied from a motor-driven air compressor. Two notes stated to be A(220 c/s) and B(247 c/s), were produced alternately 30 times per minutes without pause.

Warning C (Plate 3) was a cast brass bell, 10 in. diameter at the mouth and 8 in. high. The striking hammer is operated from a motor through a flexible shaft.

Warning D (Plate 4) which was an electrically-driven siren, produced a continuous note after an initial rise of frequency.

With the exception of the bell, all the warnings were directional.

Tape recordings and sound level measurements

A tape recording was made of the noise inside the cab of a heavy diesel lorry whilst it was being driven along an open road at a steady speed and also through traffic in a built-up area. These recordings were made with the windows both open and closed. Appendix B gives details of the sound measuring equipment and the ranges used in all the experimental work.

Tape recordings and sound level measurements were also made inside the cab of a stationary lorry in order that any attenuation of particular frequencies by the bodywork should be taken into account. Recordings of the signal due to each of the warning devices in turn from a distance of 50 ft were made with the engine switched off and the windows closed.

Further sound level measurements were made of the signals from each of the warnings at various distances from the lorry.

Laboratory tests

To determine whether any of the warnings had frequency characteristics which would make them more easily heard, the minimum sound levels at which the warning devices could be heard (i.e. the "threshold levels") against a fixed background level of lorry noise were measured.

Twelve subjects, all male, were chosen for the investigation. To account for variations in the hearing of different subjects and age groups, six were between 18 and 25 years of age, and six between 50 and 65 years. The subjects were tested individually in a room 19 ft x 12 ft which also contained an observer and an operator for the sound equipment. The arrangement of apparatus used, and the positions of the subject, operator and observer are shown in Plates 5, 6 and 7.

The sound level measurements of lorry noise varied between 85 and 95 dB irrespective of external traffic noise or whether the windows were open or closed. To provide a background of lorry noise for the experiments, a part of the tape recording was selected where the noise level was constant to within 1 dB for a period of five minutes, the duration of each test. This was amplified and played through a loudspeaker situated in one corner of the room 10 ft from the subject, so that a level of 90 dB was maintained continuously next to the subject.

Recordings of each warning device were played on a second tape recorder via a calibrated amplifier through the same loudspeaker, at various levels, and the subjects were asked to indicate, by pressing a button, whenever they heard a warning signal above the continuous background of lorry noise.

It was considered that some of the threshold levels obtained from tests in which the subjects' main concern was listening for a warning signal might be lower than those which would be obtained in the practical case where the driver of a vehicle would be preoccupied with steering, traffic conditions etc. This, it was thought, would apply particularly to those warnings producing sounds similar in nature to those due to certain parts of the engine, with which they might be confused. Accordingly, an attempt was made to simulate the effect of preoccupation by repeating the tests while the subjects performed a "paced" task; that is, one requiring their continuous attention. A description of the apparatus used for this task is given in Appendix A.

In a further series of experiments each of the warning signals was played at a slowly increasing level and the level at which it was first heard by each of the subjects against the background was noted.

Experimental procedure

The warning signals were played to each subject at seven sound levels of 71, 74, 77, 80, 83, 86, 89 dB; three levels were above and three levels below an approximate threshold of 80 dB which was determined by a preliminary experiment made on the operator and observer.

Before each subject was tested, the particular warning to be used was played at each level, without background noise, and the calibration of the amplifier was noted.

The subject was seated at a table upon which the paced task panel was placed. The warning was played to the subject for a short time in order that he might be able to recognise it during the experiment, and in order to accustom his ear to the conditions of the test, the background noise was also played for a few minutes. The subject was then told of the commencement of the experiment and asked to listen for the warning signal and press a button on the table each time he heard it against the background noise.

During the first minute of the experiment, the background noise was adjusted to 90 dB. The signal was then injected for a period of 10 sec. at $1\frac{1}{2}$, 2, 3, $3\frac{1}{2}$, 4, $4\frac{1}{2}$ and 5 minutes after the start, the sound levels being in random order. A record was kept of the levels which were heard by the subject so that the threshold levels could be determined. The number of false arlarms, that is, occasions when a response was obtained without a signal was also recorded.

After completing the experiment the paced task was switched on and the subject was asked to operate it for a few minutes to become accustomed to its use. The experiment was then repeated using the task and the same warning signal.

At the end of the second experiment the paced task was switched off and a further threshold level was determined by slowly increasing the level of the warning until it was just audible to the subject. The background was switched off at this point and the level of the warning signal was measured.

Immediately after the three tests, the warning signals were replayed without the background noise and a further check was made on the calibration of the amplifier.

The whole procedure was repeated for each subject and for each warning device. To eliminate any systematic error, the order in which the warning signals were played to each subject was randomized.

Field tests

To check the relative threshold levels obtained in the laboratory a number of experiments were made under practical conditions on a disused airfield. Four subjects were seated in turn in the passenger seat of a stationary diesel lorry, with the windscreen covered and the windows closed. The engine was started and its speed adjusted to give a noise level of 90 dB inside the cab. The warning devices, mounted on a moveable framework, were switched on in random order and were moved slowly towards the lorry until they became just audible. The framework was stopped, the lorry engine switched off and the signal level inside the cab was measured. This experiment was also made with the siren giving a wailing note by being switched on for 3 sec. and off for 3 sec.

Results of experiments

1. Signal level measurements

The signal levels measured inside the cab of a stationary lorry, with the engine switched off and the windows closed, from each of the four warning devices placed 50 ft away from the lorry, are given in Table I.

Fig. 1 shows the variation in signal level with distance under the same conditions.

Table I. Signal levels inside cab due to warnings 50 ft away

Warning device	Signal levels (dB)
2-horn system	90
Two-tone pneumatic horns	88
Bell	65
Siren (steady note)	81

2. Laboratory tests

Threshold levels of audibility obtained from the experiments in which the warning sounds were played at preselected levels are given in Tables II and III for the two age groups considered. A threshold level in this case was taken to be the mean of the lowest level heard by a subject and the highest level not heard by him.

Table IV shows the total number of warning signals played, the total number heard and the number of false alarms for each of the warning devices.

Table II. Threshold levels of audibility - subjects in group 1 (18-25 years)

Subject	With task (W) or Without task (W_o)	4-horn system	Two-tone pneumatic horns	Bell	Siren (steady note)
		Signal Level (dB)			
1	W	83.5	79.5	80.5	83.5
	W_o	78.0	77.0	79.0	81.5
2	W	74.5	86.5	79.5	77.5
	W_o	81.5	82.5	84.5	86.0
3	W	76.5	85.0	82.0	76.5
	W_o	77.0	73.0	84.0	82.5
4	W	79.5	75.0	81.0	82.5
	W_o	81.5	75.0	79.0	83.0
5	W	80.0	79.0	77.0	79.0
	W_o	72.5	77.5	78.0	79.0
6	W	82.5	80.0	79.0	79.0
	W_o	77.0	85.0	81.0	78.0
Mean	W	79	81	80	80
Mean	W_o	78	78	81	82

Table III. Threshold levels of audibility - subjects in group 2 (50-65 years)

Subject	With task (W) or Without task (W_o)	Signal Level (dB)			
		4-horn system	Two-tone pneumatic horns	Bell	Siren (Steady note)
7	W	76.5	87.5	83.0	81.0
	W_o	77.0	77.5	80.0	82.0
8	W	75.5	77.5	84.0	78.5
	W_o	76.0	85.5	76.0	81.5
9	W	80.0	72.5	82.5	82.5
	W_o	82.5	79.0	84.0	87.5
10	W	85.5	82.0	81.0	82.0
	W_o	79.5	78.5	77.0	84.5
11	W	82.5	76.0	84.0	86.5
	W_o	84.5	72.0	81.5	86.5
12	W	84.0	81.0	82.5	82.5
	W_o	86.5	81.0	79.5	79.5
Mean	W	81	79	83	82
Mean	W_o	81	79	80	84

Table IV. Number of signals and false alarms

Warning	With task			Without task			Total		
	No. of signals	No. heard	No. of false alarms	No. of signals	No. heard	No. of false alarms	No. of signals	No. heard*	No. of false alarms
4-horn system	84	50	14	84	44	15	168	94	29
Two-tone pneumatic horns	84	46	12	84	48	27	168	104	39
Bell	84	42	6	84	43	13	168	85	19
Siren (steady note)	84	31	25	84	35	33	168	67	58

* The fact that different numbers of signals were heard although the thresholds of the four warnings were similar was due to variations in the calibration of the amplifier.

Threshold levels of audibility obtained by slowly increasing the warning signal are given in Tables V and VI for the two age groups.

Table V. Threshold levels by increasing warning signal - Group 1 (18-25 years)

Subject	Signal level (dB)			
	4-horn system	Two-tone pneumatic horns	Bell	Siren (steady note)
1	78	77	80	83
2	81	81	80	85
3	80	82	79	76
4	82	77	80	73
5	78	-	80	78
6	80	83	80	87
Mean	80	80	80	80

Table VI. Threshold levels by increasing warning signal - Group 2 (50-65 years)

Subject	Signal level (dB)			
	4-horn system	Two-tone pneumatic horns	Bell	Siren (steady note)
7	85	87	85	79
8	80	77	84	86
9	85	78	81	88
10	83	81	81	80
11	84	79	84	85
12	77	79	75	76
Mean	82	80	82	82

3. Field tests

Table VII gives the signal levels of the warnings measured inside the cab of a lorry when the warnings were just audible against engine noise.

Table VII

Subject	Signal level (dB)				
	4-horn system	Two-tone pneumatic horns	Bell	Siren (steady note)	Siren (wailing note)
2	76	75	>68*	82	74
8	78	78	>70*	81	74
13	74	76	-	74	77
14	77	76	-	76	72
Mean	76	76	-	78	74

* The bell was inaudible against the background of lorry noise even when the framework was touching the front of the lorry.

Discussion of results

A statistical analysis of the results of the laboratory experiments indicated that there was no significant difference between the threshold levels of audibility of any of the warning devices tested and that there was no effect on threshold levels due to the preoccupation task, although fewer false alarms were recorded when the task was being performed. The results were similar for both age groups, although the older subjects recognised the signals at slightly higher threshold levels than did the younger ones.

The field tests also showed that warnings which could be heard gave threshold levels which were similar to each other although about 4 dB less than those measured in the laboratory tests. It was not possible to obtain a threshold level for the bell in these tests as it was inaudible above the engine noise even when the moveable framework on which it was mounted was touching the front of the lorry, a distance of 5 ft from the subject.

The wailing siren gave a slightly lower threshold level than the other warnings, but more experiments would be required to show whether this difference is significant.

Since the threshold levels of all the warning devices were similar, it is concluded that the warning which produces the loudest signal is the best, giving an order of effectiveness as follows:

1. 4-horn system (130 ft);
2. Twp-tone pneumatic horns (100 ft);
3. Siren (55 ft);
4. Bell (less than 5 ft).

The figures in parentheses are taken from Fig. 1 and are the distances at which each of the warnings are just audible above a background noise of 90 dB.

Despite the fact that no differences in threshold levels of the four warnings were shown by the laboratory experiments, it was the opinion of most of the subjects taking part that a two-note system such as (1) and (2) above was more easily recognized than any other; while a few thought the bell was more distinctive. All were agreed that the steady note siren was most difficult to recognize due to the similarity of its note to some of the engine and transmission noises of the background. These opinions are borne out by the larger number of false alarms with the steady note siren (Table IV). This objection, however, may not apply to a siren giving a wailing note.

Conclusions

The results of the investigation indicate that none of the four warning devices tested has any characteristic which would make it more easily heard than another by the driver of a heavy vehicle.

The warning which produces the loudest noise is therefore the best, and on this basis their order of effectivess is as follows:

1. 4-horn system.
2. Two-tone pneumatic horns.
3. Siren with steady note.
4. Bell.

Measurements made during the investigation show that the driver of a heavy diesel lorry is unlikely to have any audible warning of the approach of a fire appliance fitted with the bell tested.

Acknowledgments

Thanks are due to Mr. Copeland of the National Physical Laboratory for much helpful advice on sound measurement techniques and their interpretation; to the Building Research Station and the Road Research Laboratory of the Department of Scientific and Industrial Research for the loan of equipment; to Mr. D. Landeg for assistance with the experimental work; and to the twelve members of the Joint Fire Research Organization who acted as subjects for the tests and were subjected to a rather higher noise level than usual.

Appendix A

Paced task apparatus

In order to simulate a condition of preoccupation during some of the laboratory experiments, a paced task machine was constructed which each subject participating in the investigation was asked to operate, and which required his continuous attention.

At a table in front of the subject was placed a panel to which were fixed five irregularly spaced red indicator lamps. Close to each lamp was a push-button which, when pressed, would extinguish the light from its associated lamp. Lights were switched on, one at a time, in a preselected random order every $1\frac{1}{2}$ seconds for a period of $\frac{3}{4}$ of a second and the subject was required to press the appropriate button to cancel the light before the light was switched off. Failure to do so resulted in a white light at the rear of the panel being switched on for $\frac{3}{4}$ of a second and a score being made on a counter on a control panel. By observing the score at the end of the experiment it was possible to check the degree of attention given to the task.

The control panel situated on a table near to the subject consisted of a counter, uniselector, relays and associated wiring all mounted on a hollow metal box to give a "sounding board" effect. The noise produced by the switching operations provided an aural distraction, although not at a sufficiently high noise level to affect the threshold levels of the warning devices.

To switch the lights on the subject's panel two banks of uniselector outlets were wired to give a preselected random order which was repeated after every 50 operations. It was considered unlikely that there would be any significant learning factor in the relatively short time the apparatus was in use.

Appendix B

Noise level measurements

All noise level measurements were made on a Dawe model 1400 D sound level meter. Due to the presence of low frequencies (30-50 c/s), engine noise measurements were made using the 'B' weighting network. The warning noises were measured using the C flat network.

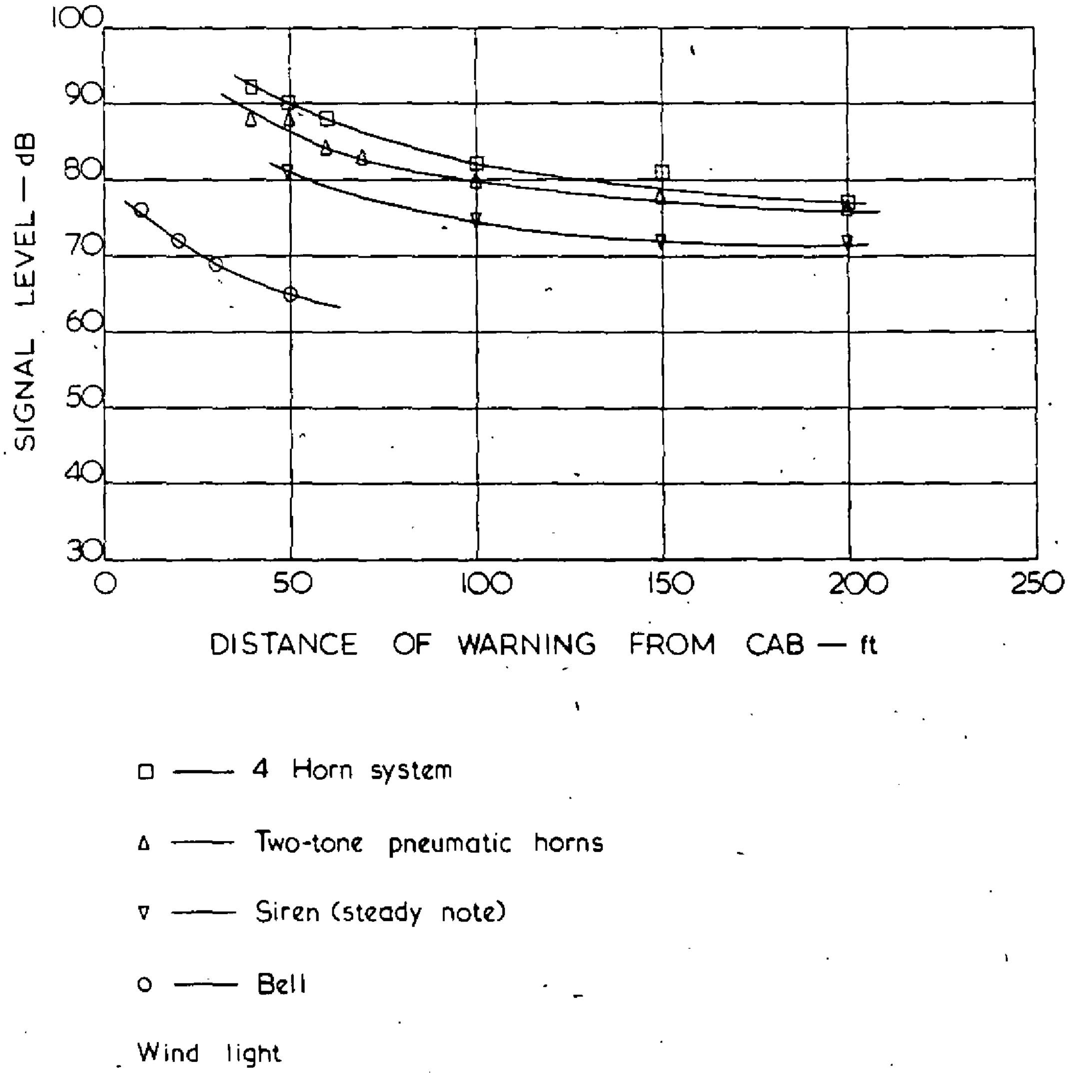

FIG. 1. VARIATION OF SIGNAL LEVEL WITH DISTANCE

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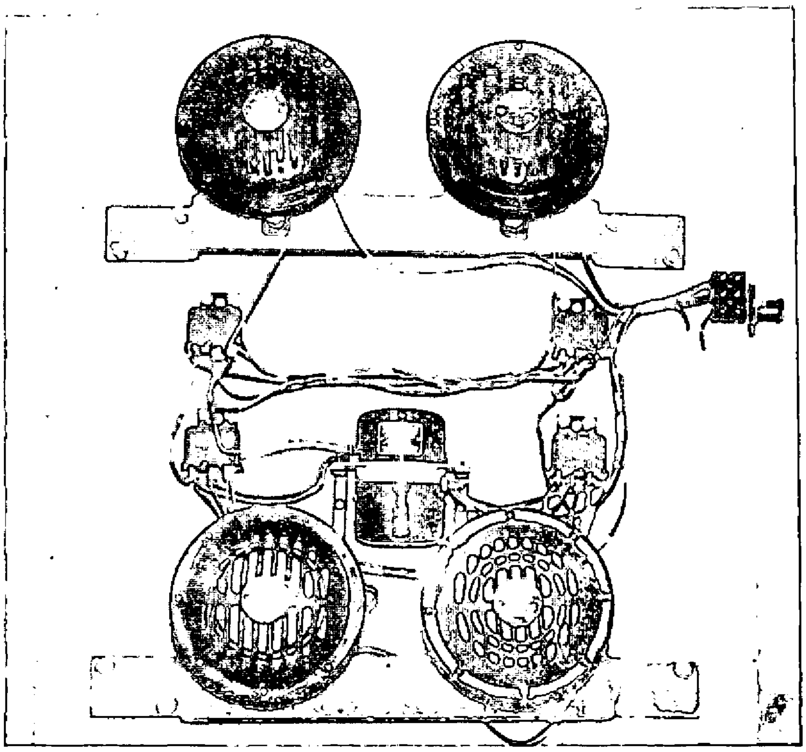

PLATE 1. 4-HORN SYSTEM

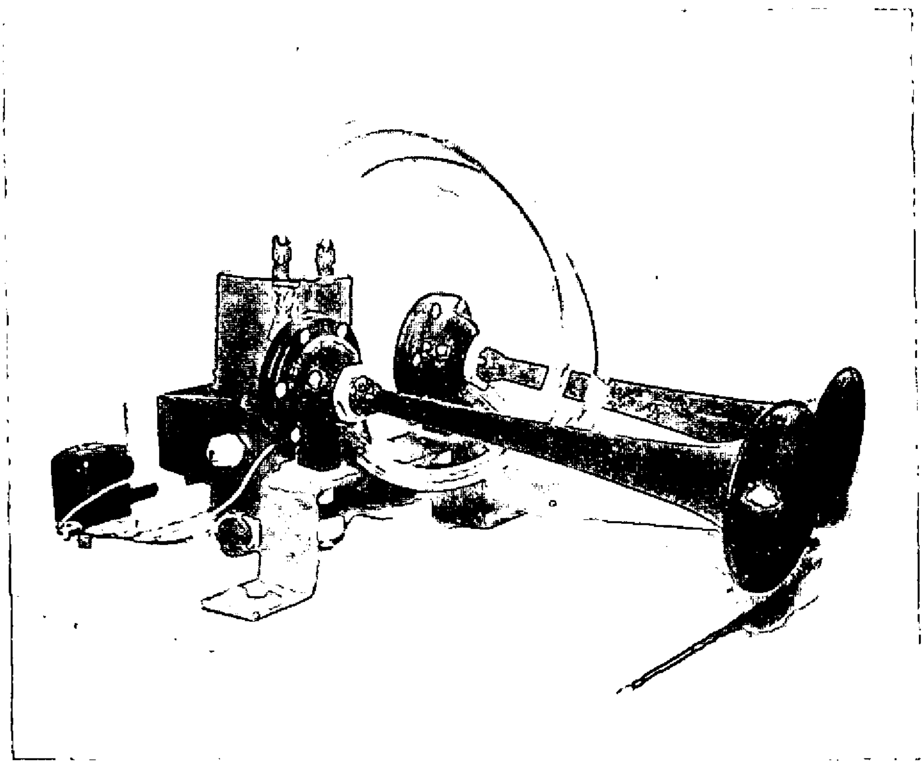

PLATE 2. TWO-TONE PNEUMATICALLY OPERATED HORNS

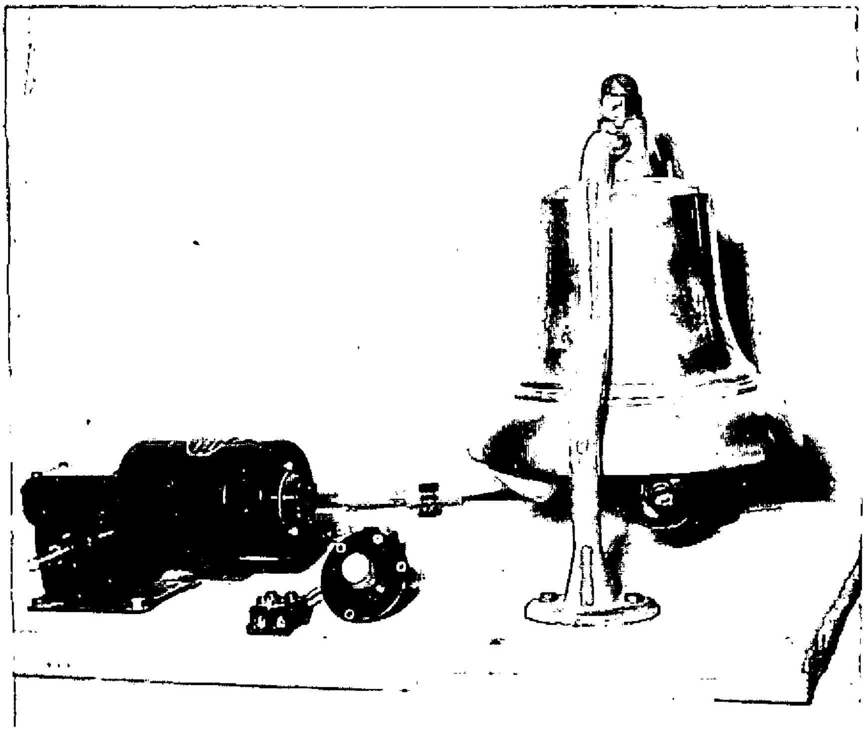

PLATE 3. BRASS BELL

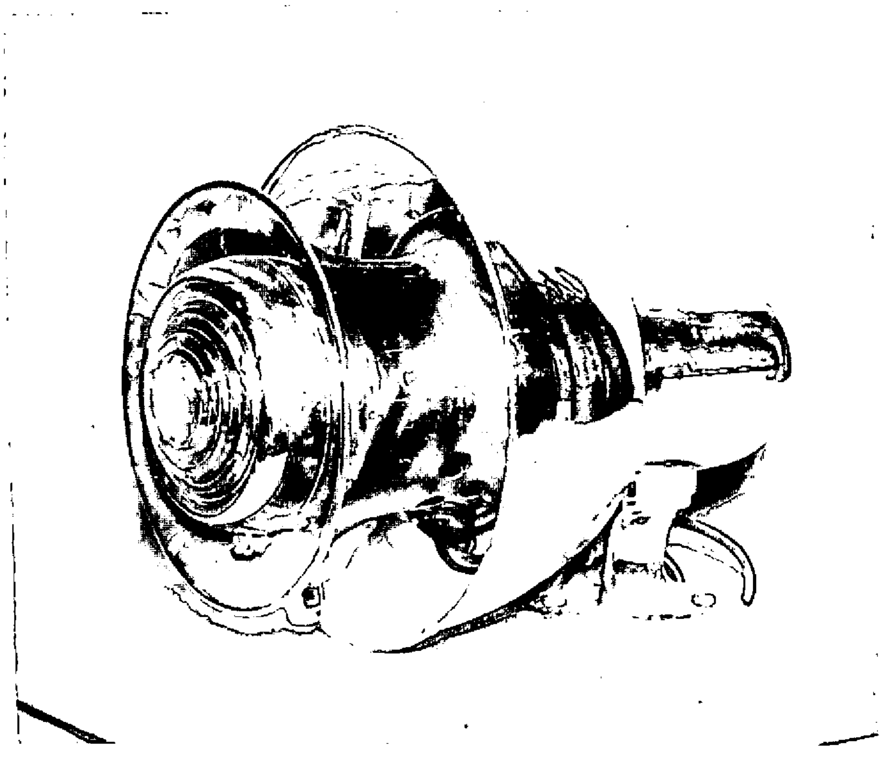

PLATE 4. COMBINED SIREN AND FLASHING LIGHT

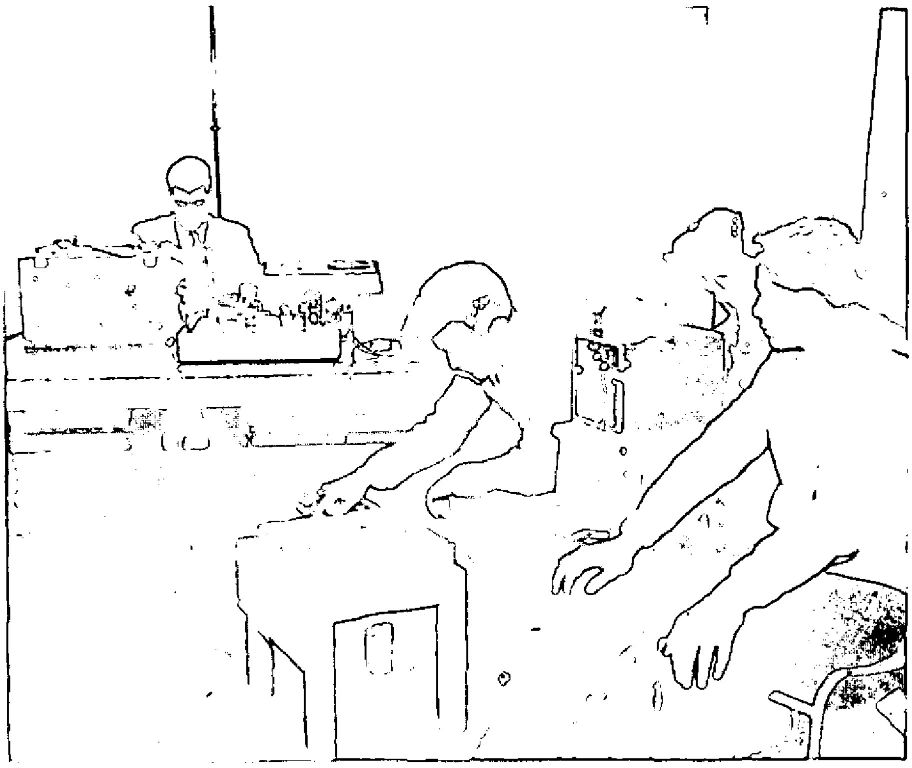

PLATE 5. ARRANGEMENT OF OPERATORS AND SUBJECT (CENTRE)

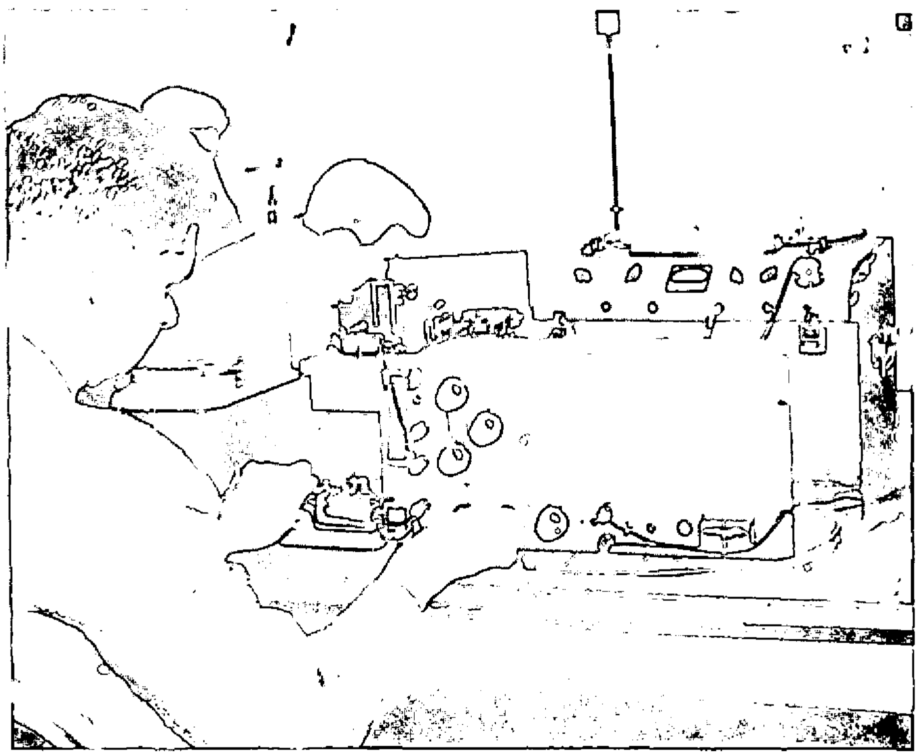

PLATE 6. OPERATOR'S POSITION

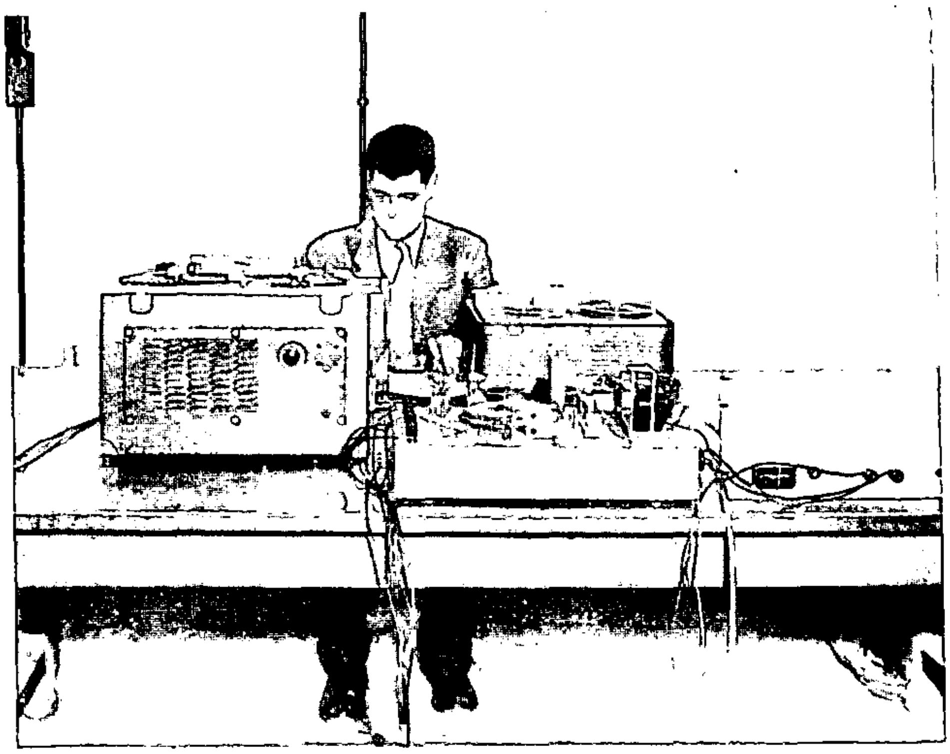

PLATE 7. TAPE RECORDERS AND PACED TASK CONTROL PANEL