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Physical Characteristics of the Sonic Bangs and other Events at Exercise Westminster

By D. R. B. Webb and C. H. E. Warren

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By D. R. B. Webb and C. H. E. Warren

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Summary.
Exercise Westminster was a demonstration of sonic bangs, together with some explosive bangs and flyovers by a jet aircraft, staged for an invited audience. This Report describes how the Exercise was conducted from the operational point-of-view, and what monitoring measurements were made. An analysis of the physical characteristics of the sonic bangs and other events is made.

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1. *Introduction.*

Exercise Westminster was, primarily, a demonstration of sonic bangs held at the Royal Air Force Station, Upwood on Wednesday, 21st April, 1965. It was staged mainly for Members of Parliament, but the audience of some 250 people included also representatives of local government associations, organizations concerned with the introduction of civil supersonic aircraft, as well as guests from some foreign governments.

In addition to the sonic bang events there were some explosive bang events, consisting of the firing of pairs of explosive charges, and some flyovers by a jet aircraft. The same programme of events was staged twice, in the morning, when the audience experienced it out-of-doors, and in the afternoon, when the audience experienced it indoors. Moreover a rehearsal of the programme had been staged twice on the previous day, Tuesday, 20th April, when an audience of some 20 people had attended.

Although the exercise was primarily a demonstration to an invited audience, the opportunity was, nevertheless, taken to glean as much scientific information as was possible about sonic bangs. Extensive monitoring of the sonic bang and other events was done. Some subjective studies involving a jury were conducted. Experts observed the effects of the sonic bangs on buildings and on livestock. And an analysis was made of the public reaction and complaints arising from the Exercise. This Report describes how the Exercise was conducted from the operational point of view, and what monitoring measurements were made. An analysis of these physical measurements is made.

2. *Programme.*

The nominal programme of events is given below. It was staged four times, with only very slight departures in practice, on the Tuesday morning, Tuesday afternoon (the two rehearsal stagings), the Wednesday morning and Wednesday afternoon (the Exercise proper).

Event	*Nominal time in minutes after first event*	*Description of event*
A	0	Explosive bang of $1\frac{1}{2}$ lb/ft^2
B	3	Sonic bang of $1\frac{1}{2}$ lb/ft^2
C	5	Explosive bang of $2\frac{1}{4}$ lb/ft^2
D	8	Sonic bang of 2 lb/ft^2
E	12	Flyover by jet aircraft making 110 PNdB
F	15	Explosive bang of $1\frac{1}{2}$ lb/ft^2
G	18	Sonic bang of $1\frac{1}{2}$ lb/ft^2
H	20	Explosive bang of $2\frac{1}{4}$ lb/ft^2
J	23	Sonic bang of $2\frac{1}{4}$ lb/ft^2
K	27	Flyover by jet aircraft making 110 PNdB
L	30	Explosive bang of $2\frac{1}{4}$ lb/ft^2

As the sonic bangs were made by Lightning aircraft thay had a duration (time interval between the two shocks) of about 100 ms. The explosive bang events were made by firing pairs of explosive charges with, accordingly, a nominal 100 ms delay between them.

3. *Site and Dispositions.*

The Exercise was staged at the Royal Air Force Station, Upwood, a sketch of the relevant area of which, showing the dispositions of various parties, is shown in Fig. 1.

The main invited party were received in the Officers' Mess, and proceeded thence in the morning to the sports field, were they experienced the programme out-of-doors standing on the rugby pitch, and in the afternoon to the Secretarial Officers' Training Squadron Building, where they experienced the programme indoors disposed as they wished between the various rooms of this two-story standard R.A.F. H-block.

The sonic bangs were made by Royal Air Force Lightning aircraft from 111 Squadron Wattisham, which flew over the Station. The explosive bangs were made by the Detonation Section of the Explosives Research and Development Establishment, by firing pairs of explosive charges at a point on the airfield that was roughly 1250 ft from both the centre of the rugby pitch and from the Secretarial Officers' Training Squadron Building, a nominal 100 ms electronic delay being incorporated in the firing circuit of one of the charges. The flyovers by a jet aircraft were made by a Comet from the Aeroplane and Armament Experimental Establishment, which flew on a nominal true track angle of about 130 deg, and on a track that passed essentially directly over the rugby pitch and the Secretarial Officers' Training Squadron Building.

The sonic and explosive bangs were monitored by a team from the Structures Department Acoustics Section of the Royal Aircraft Establishment at a position between the rugby pitch and the Secretarial Officers' Training Squadron Building. The noise of the jet aircraft flyovers were monitored by a team from the Acoustics Section of the Aviation Operational Research Branch at a position near the north-west corner of the sports field[1].

The sonic bang waveforms were also recorded by a team from the Detonation Section of the Explosives Research and Development Establishment at a position on the airfield. Their particular interest was in the structure of the waveform as this affects their development of an explosive simulant.

A team from the Applied Physics Division Acoustics Section of the National Physical Laboratory were at a third position as shown in Fig. 1. The N.P.L. team, in collaboration with the Applied Psychology Research Unit of the Medical Research Council, were concerned with the subjective studies involving a jury[2], which were conducted partly out-of-doors in the vicinity of the N.P.L. monitoring position and partly indoors in Barrack Block 11.

The Exercise was controlled operationally from the Station Control Tower on the airfield by a team from the Aberporth Trials Group of the Royal Aircraft Establishment.

4. *Operational Control.*

Operational control of the Exercise was effected from Upwood Control Tower. The Lightnings were directed on to their required track by R.A.F. Neatishead Control, and the Comet by R.A.E. Bedford Control. The firing of the explosive charges was directed by Upwood Control.

Communications between Upwood Control and Neatishead Control consisted of a private tie-line. Between Upwood Control and Bedford Control a prolonged uninterrupted telephone (p.u.t.) line was established. Between Upwood Control and the R.A.E. monitoring team, the E.R.D.E. team, the N.P.L. team and the team conducting the subjective studies in Barrack Block 11 duplicated intercommunication units were installed.

5. *Lightning Flight Plans.*

The nominal flight plans for the Lightnings are shown in Fig. 2. The 34 000 ft, 27 000 ft and 25 000 ft runs were calculated to give nominally the $1\frac{1}{2}$ lb/ft^2, 2 lb/ft^2 and $2\frac{1}{4}$ lb/ft^2 sonic bangs respectively. The nominal track of the Lightnings was designed to pass over the Upwood Control Tower as indicated in Fig. 1, on a nominal true track angle of 207 deg.

The aircraft paths as flown were monitored by Neatishead Control, and also, on the Wednesday, by Bedford Control, and the results are given in Table 1. It will be noticed that there is a discrepancy between Neatishead Control and Bedford Control in regard to the lateral distance off-track of up to $2\frac{1}{2}$ nm. Now from their nearness to Upwood and other reasons Bedford Control consider that their positioning is very good, whereas Neatishead Control know that their possible error is about 2 nm. Actually Table 1 shows that a degree of agreement between the two sets of results, to within about $\frac{1}{2}$ nm, is obtained if it is assumed that the positioning of Upwood by Neatishead Control is about $1\frac{1}{2}$ nm to the right of track compared with its true position. Accordingly the best estimate of the aircraft position at the point of bang generation is probably obtained by adding '$1\frac{1}{2}$ nm right' to the Neatishead Control readings, and the values so obtained are given in the last column of Table 1.

6. *Meteorological Data.*

Surface meteorological data as recorded near the Upwood Control Tower at the times of the Exercise are given in Fig. 3a. Estimated meteorological data pertaining to the air over Upwood are given in Figs. 3b to d. Since these data were derived from routine midday soundings from the usual United Kingdom stations the picture is rather coarse.

7. *Measurements of Bang Overpressures.*

7.1. *R.A.E.*

The R.A.E. team was responsible for measuring the overpressures at the site of the demonstrations. Three microphones were used, one, Channel 1, being well above the ground on a mast so as to measure the free-air overpressures, and two, Channels 2 and 3, being mounted flush with the ground. On the Tuesday, because of very gusty wind conditions, the mast-mounted microphone was only $27\frac{3}{4}$ ft above the ground but on the Wednesday this was increased to $46\frac{1}{2}$ ft. The measuring equipment comprised Bruel and Kjaer condenser microphone cartridges type 4131, used in conjunction with a frequency modulation system in which the microphone capacity formed part of the tuned oscillator circuit stage. The frequency range of the combined measuring system was 5 c/s to 20 kc/s, both limits being imposed by microphone characteristics. Recordings were triggered by the signal from a trigger microphone situated upbang from the main microphones.

In Figs. 4 and 5 general views of the microphone positions are shown. Fig. 5a shows their positions relative to the party gathered on the rugby pitch and Fig. 4a their positions relative to the Secretarial Officers' Training Squadron Building. Fig. 5b is a close-up view of the ground-mounted microphones slightly raised.

7.2. *N.P.L.*

The N.P.L. team was concerned with the subjective studies involving a jury. Three microphones were used for measurement. One microphone, Channel G, was situated 5 ft above ground level inside a tent in which one jury group was assembled. Another microphone, Channel E, was placed at the top of a 46 ft mast at the northern end of Barrack Block 11 in which a second jury group was assembled. This was to obtain measurements of the overpressures incident upon the outside of the building. This microphone can be seen in the distance in Fig. 4b. A third microphone was placed in the room in which the second jury group was assembled. The records from this microphone are different in character from the outdoor measurements, and have not been given in this report.

7.3. *E.R.D.E.*

The E.R.D.E. team was concerned with three main aspects of the sonic bang waveform: (1) the high frequency content of the waveform as a whole, (2) the high frequency content of the bow and stern shocks, (3) the way in which the waveform of each event varied from point-to-point along the track of the aircraft. Five piezo-electric blast gauges were used, and mounted close to the ground. Gauges 4, C, 1 were laid out in a line on the airfield parallel to the nominal track, and at 270 ft spacing. Gauges 3 and 2 were laid out on either side of Gauge C, but the recording speed was increased so that the bow and stern shocks respectively were recorded on an expanded time-base.

8. *Results of the Bang Overpressure Measurements.*

The measured waveforms of the sonic bangs are shown in Figs. 7 to 22 and of the explosive bangs in Figs. 23 to 26. A summary of the vertical and horizontal scales of the oscillograms is given in Fig. 6.

Figs. 7 to 22 provide further evidence of the already known fact[3] that considerable variations in waveform from point to point can occur for one event over a relatively small area. In general the sonic bang waveform has three basic shapes, and selected examples of these traced from actual records are shown in Fig. 27. In addition to the normal N-waveforms (Fig. 27a), there occur what may be described as spiky waveforms (Fig. 27b) and rounded waveforms (Fig. 27c). In particular Fig. 17 for Event G on Wednesday morning shows that the three basic waveforms of normal, spiky and rounded were recorded by the E.R.D.E.'s three in-line measuring stations which were at 270 ft spacing.

A possible clue as to the cause of these differences in waveform is provided by R.A.E. Channel 1 in Fig. 18 for Event J on Wednesday morning. This is a record from the R.A.E. mast-mounted microphone, and it will be noted that whereas the incident bow shock (the first shock) and the incident stern shock (the third shock) are very similar, and likewise the reflected bow shock (the second shock) and the reflected stern shock (the fourth shock) are very similar, the two incident shocks are quite different from the two reflected shocks. Now the two incident shocks, bow and stern, have come from very different sources, but during the later stages of propagation they have travelled through the same portion of the medium of transmission, having come along the same ray, albeit at a spacing in time of about 100 ms. The same remarks apply to the two reflected shocks. However, considering the two bow shocks, for example, incident and reflected, we realise that they have come from almost the same source, the difference being in the portion of the medium through which they have travelled during the later stages of propagation, for they have clearly come along differnet rays, one along the incident ray, and one along a ray reflected from the ground. One is led to deduce, therefore, that the cause of the difference in shock form is associated with the nature of the path of propagation in the later stages. A natural first deduction might be that the effect is due to the ground, but it is then difficult to explain why the effect is not present in Fig. 16 for Event D which is of an event only some fifteen minutes earlier recorded with the identical microphone set-up, and, therefore, with the same piece of ground involved. It would appear, therefore, that the effect is a meteorological one, being associated with the low altitude structure of the atmosphere, which, due to turbulence, in in a state of continual motion, and that variations in a 75 ft distance, which is the distance between the incident and reflected rays in this case, are sufficiently marked to lead to the effect found.

The actual pressure rise of the bow shock has been measured on all the records for each event, and the values are shown in Table 2. Against each entry is a letter indicating the character of the waveform, whether normal (N), spiky (S) or rounded (R), two of these designations being used when the waveform exhibited the characteristics of the two. Because of the variation in waveform for a given event there is naturally considerable variation in the actual pressure rise of the bow shock. In general spiky and rounded waveforms produce pressure rises greater and less respectively than the normal N-waveform. This tends to make the actual pressure rise an unrepresentative measure of the intensity of a sonic bang. Accordingly the concept of the 'effective pressure rise' has been introduced, defined as the equivalent ideal N-wave pressure rise, and got by extending the essentially straight, sloping line between the bow and stern shocks back to the point of onset of the bow shock, as portrayed in Fig. 27. Values of effective pressure rise obtained in this manner are shown in Table 3. It will be seen that this varies much less from point to point, and is, therefore, a more representative measure of the intensity of a sonic bang of given duration, and a fairer measure of the intensity of the event as created by the aircraft in that some of the features attributable to meteorological effects are smoothed out.

Now Table 3 shows that, on average, the effective pressure rise of the reflected bow shock is equal to that for the incident shock. Moreover Table 3 also indicates that the values of the effective free-air pressure rise of the incident and reflected bow shocks are, on average, closely half the values of the effective pressure rise as measured at the ground. The evidence is, therefore, that it is realistic to allow a factor of two for the relationship between ground and free-air pressure rises.

The duration, or time interval between the bow and stern shocks; for the sonic bangs are shown in Table 4. It will be noticed that, in contrast to the pressure rise, the interval between shocks for a given event varies little from point to point over the area covered by the measurements. However there is a noticeable variation between nominally indentical events. As would be expected the interval between shocks tends to be less for the higher nominal pressure rises (lower altitudes of flight), but this variation is slight, the overall average interval being just less than 100 ms.

9. *Jet Aircraft Flyover Noise.*

The noise from the Comet was measured by two microphones along the track of the aircraft, one on the rugby pitch and the other 100 ft away. The microphones were connected to a Bruel and Kjaer sound level meter type 2203, and the noise recorded on a Nagra tape recorder. In addition the altitude of the aircraft was measured by photographing it using a Polaroid camera pointing vertically upwards, and then relating the span of the image to the true span and the focal length of the lens.

The results of the measurements are shown in Table 5, and on octave band analysis in the eight preferred frequency bands for the four flights on the Wednesday is given in Table 6. The mean difference between the noise levels on the C-scale and those in PNdB is between 8 and 9, in close agreement with previous experience. The spectrum shape, too, agrees fairly well with that previously found.

The variation of noise level with time is shown in Fig. 28 for a representative flyover, the PNdB scale being obtained by adding 11 to the reading obtained when the trace was played through an A-scale filter. The duration of the noise over 95 PNdB can be seen to be about 25 sec, which is about the average value for flyover noise during take-off at Heathrow. From a knowledge of the airspeed, altitude and time which elapsed between aircraft overhead and the time of maximum noise it was calculated that the maximum noise was radiated at an angle of 45 deg to the jet axis.

10. *Concluding Remarks.*

A summary of the best assessments of the intensity of each event that occurred during the Exercise, as experienced by the invited parties, is given in the Table opposite. They are the outdoor intensities near the ground, and therefore for the morning events experienced out-of-doors they represent the actual experience: for the afternoon events experienced indoors they represent the intensities incident upon the building in which the invited party was assembled.

For the sonic bang events the figures quoted are the bow shock pressure rises in lb/ft^2, and are based primarily on the measurements by the R.A.E., although some cognizance was taken of the measurements by the other two teams. Two figures are given, the first being the actual pressure rise, for this is what was announced to the invited parties at the time, and also, in brackets, the effective pressure rise, for this is felt in some way to represent a better measure of the intensity of a sonic bang of given duration. The durations were all round about 100 ms or just less.

For the explosive bang events the figures quoted are the pressure rises in lb/ft^2, and are based entirely on the measurements by the R.A.E. The difference in pressure rise between the two bangs of each explosive bang event was not much greater in general than the difference in pressure rise between the various channels of measurements. The figures given are appropriate average values. Although the intervals between the two shocks of each explosive bang event was about 100 ms, the waveform was of course different from that of a sonic bang, the duration of the positive phase of each bang being only about 8 ms.

For the jet aircraft flyover events the figures quoted are the peak noise levels in PNdB, and are based entirely on the measurements by the A.O.R.B.

TABLE 1

Lightning Flight Path Data.

Session	Event	Altitude, ft	Mach number	True track angle at point of bang generation, deg	Lateral distance off track over Upwood, nm		
					As measured by Neatishead control	As measured by Bedford control	Neatishead measurements plus $1\frac{1}{2}$ nm right
Tuesday morning	B	34 000	1·4	207	on track		$1\frac{1}{2}$ right
	D	27 000	1·4	207	on track		$1\frac{1}{2}$ right
	G	34 000	1·4	207	$\frac{1}{2}$ right		2 right
	J	25 500	1·4	225	$\frac{1}{2}$ right		2 right
Tuesday afternoon	B	34 000	1·4	207	on track		$1\frac{1}{2}$ right
	D	27 000	1·4	207	on track		$1\frac{1}{2}$ right
	G	34 000	1·4	207	on track		$1\frac{1}{2}$ right
	J	25 000	1·4	207	on track		$1\frac{1}{2}$ right
Wednesday morning	B	34 000	1·4	207	$\frac{1}{2}$ left	1 right	1 right
	D	27 000	1·4	207	$\frac{1}{2}$ left	2 right	1 right
	G	34 000	1·4	215	$1\frac{1}{2}$ right	$3\frac{1}{2}$ right	3 right
	J	25 000	1·4	207	on track	$1\frac{1}{2}$ right	$1\frac{1}{2}$ right
Wednesday afternoon	B	34 000	1·4	211	$\frac{1}{2}$ left	on track	1 right
	D	27 000	1·4	211	$\frac{1}{2}$ right	3 right	2 right
	G	34 000	1·4	211	1 left	1 right	$\frac{1}{2}$ right
	J	25 000	1·4	207	on track	1 right	$1\frac{1}{2}$ right

Summary of Intensities.

Event	Nominal description	Intensity			
		Tuesday		Wednesday	
		Morning	Afternoon	Morning	Afternoon
A	$1\frac{1}{2}$ lb/ft^2 explosive bang	1·3	1·6	1·0	1·1
B	$1\frac{1}{2}$ lb/ft^2 sonic bang	2·0 (1·4)	3·2 (1·5)	2·4 (1·6)	1·2 (1·5)
C	$2\frac{1}{4}$ lb/ft^2 explosive bang	2·2	2·0	2·4	1·9
D	2 lb/ft^2 sonic bang	2·0 (1·6)	1·5 (1·5)	2·1 (1·9)	1·3 (1·6)
E	110 PNdB jet aircraft flyover	114	110	110	111
F	$1\frac{1}{2}$ lb/ft^2 explosive bang	1·0	1·7	1·5	1·8
G	$1\frac{1}{2}$ lb/ft^2 sonic bang	1·1 (1·1)	1·0 (1·1)	1·1 (1·2)	1·2 (1·5)
H	$2\frac{1}{4}$ lb/ft^2 explosive bang	1·9	2·5	2·1	2·2
J	$2\frac{1}{4}$ lb/ft^2 sonic bang	1·8 (1·8)	1·9 (1·7)	1·9 (1·7)	1·3 (1·7)
K	110 PNdB jet aircraft flyover	112	110	110	111
L	$2\frac{1}{4}$ lb/ft^2 explosive bang	2·1	3·3	2·6	2·2

In addition to the demonstration aspect of the Exercise much scientific information on sonic bangs and their effects was obtained, some of which has been reported separately. In this report, however, information on their physical characteristics is given. The wide variations in waveform from point to point that can occur for one event are shown, and evidence is presented which suggests that this variation is primarily an effect of the meteorological structure of the lower altitudes of the atmosphere. These variations naturally make any actual pressure rise as measured a somewhat meaningless quantity, and the concept of an effective pressure rise has been introduced as a possible better measure of the intensity of a sonic bang of given duration. Evidence is also given that it is realistic to allow a factor of two for the relationship between ground and free-air pressure rises over cropped grassland.

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TABLE 2

Sonic Bangs Bow Shock Actual Pressure Rises (lb/ft^2)

(N denotes normal N-waveform, S spiky waveform and R rounded waveform)

Event and Nominal pressure rise	Session	Pressure rises in free air				Pressure rises on the ground						
		Incident wave		Reflected wave								
		R.A.E. Channel 1	N.P.L. Channel E	R.A.E. Channel 1	N.P.L. Channel E	R.A.E. Channel 2	R.A.E. Channel 3	N.P.L. Channel G	E.R.D.E. Channel 4	E.R.D.E. Channel C	E.R.D.E. Channel 1	E.R.D.E. Channel 3
B	Tuesday morning	0·9S		1·2S		2·0SN	2·0SN					
	Tuesday afternoon	1·5S		1·8S		3·2S	3·0S		2·0N			
$1\frac{1}{2}$	Wednesday morning	1·8S	0·7RN	1·6S	0·7N	2·4S	S	1·3N	1·3R	0·9R	1·1R	
	Wednesday afternoon	0·9SR	0·8N	0·9SR	1·1SN	1·1R	1·3R	1·3N	1·7RN		2·2S	1·0
G	Tuesday morning	0·7N		0·5N		1·1N	1·1N		1·6N			
	Tuesday afternoon	0·7R		0·4R		1·0R			1·5N			
$1\frac{1}{2}$	Wednesday morning		0·6R		0·6N	1·0R	1·1R	1·1R	3·6S	1·4SN	1·3R	
	Wednesday afternoon	0·7R	1·2S	0·7N	0·5RN	1·2RN	1·2RN	1·2N	1·7SN		1·3R	0·8
D	Tuesday morning	0·9		0·9R		1·9N	2·0N			1·0R		
	Tuesday afternoon	1·0SN		0·7RN		1·4N	1·6N					
2	Wednesday morning	1·4SN	1·4N	1·1R	1·2N	2·0SN	2·2SN	1·8RN			1·5N	
	Wednesday afternoon	1·0R	0·4R	0·8R	0·7R	1·2RN	1·3RN	1·2R	1·7R		2·2S	1·3
J	Tuesday morning	1·2SN		0·8RN			1·8N			1·0R		
	Tuesday afternoon	0·9R		0·6R		1·7R	2·0R		1·3R			
$2\frac{1}{4}$	Wednesday morning	1·3S	1·2N	0·9R	1·2N	1·8S	1·9S	1·5R	1·7R	1·6SN	2·1N	1·1
	Wednesday afternoon	0·8R	0·8N	0·7R	0·9N	1·2R	1·3R	1·3N	1·7R		1·3R	0·7

TABLE 3

Sonic Bangs Bow Shock Effective Pressure Rises (lb/ft^2).

Event and Nominal pressure rise	Session	Pressure rises in free air				Pressure rises on the ground					
		Incident wave		Reflected wave							
		R.A.E. Channel 1	N.P.L. Channel E	R.A.E. Channel 1	N.P.L. Channel E	R.A.E. Channel 2	R.A.E. Channel 3	N.P.L. Channel G	E.R.D.E. Channel 4	E.R.D.E. Channel C	E.R.D.E. Channel 1
B	Tuesday morning	0·7		0·7		1·3	1·4				
	Tuesday afternoon	0·7		0·7		1·5	1·6		2·1		
1½	Wednesday morning	0·9	0·9	0·9	0·8	1·6	1·6	1·6	1·8	1·1	1·4
	Wednesday afternoon	0·8	0·9	0·8	0·9	1·3	1·5	1·8	2·0		1·7
G	Tuesday morning	0·5		0·5		1·0	1·1		1·6		
	Tuesday afternoon	0·6		0·5		1·0			1·8		
1½	Wednesday morning		0·8		0·6	1·2	1·2	1·6	1·2	1·1	1·4
	Wednesday afternoon	0·8	0·8	0·7	0·9	1·3	1·5	1·7	1·7		1·5
D	Tuesday morning	0·7		0·9		1·6	1·7			1·4	
	Tuesday afternoon	0·8		0·8		1·4	1·5				
2	Wednesday morning	1·1	1·0	1·1	1·0	1·9	2·0	1·8			1·9
	Wednesday afternoon	1·0	0·8	1·0	0·9	1·5	1·6	1·8	1·9		1·7
J	Tuesday morning	1·0		0·9			1·8			1·5	
	Tuesday afternoon	0·7		0·5		1·7	1·6		1·9		
2¼	Wednesday morning	0·9	1·1	0·9	1·1	1·5	1·7	1·9	2·4	1·3	2·2
	Wednesday afternoon	0·9	0·9	0·8	1·0	1·4	1·5	1·9	2·1		1·9

TABLE 4

Sonic Bangs Intervals Between Shocks (ms).

Event and Nominal pressure rise	Session	Intervals in free air				Intervals on the ground					
		Incident wave		Reflected wave							
		R.A.E. Channel 1	N.P.L. Channel E	R.A.E. Channel 1	N.P.L. Channel E	R.A.E. Channel 2	R.A.E. Channel 3	N.P.L. Channel G	E.R.D.E. Channel 4	E.R.D.E. Channel C	E.R.D.E. Channel 1
B	Tuesday morning	100		101		99	No results because of error in setting of trace writing speed				
	Tuesday afternoon	99		100		98			100		
$1\frac{1}{2}$	Wednesday morning	100	100	101	101	100		100	104	104	100
	Wednesday afternoon	98	98	99	98	98		98	101		98
G	Tuesday morning	100		101		100			103		
	Tuesday afternoon	101		101		100			103		
$1\frac{1}{2}$	Wednesday morning		104		104	103		104	105	107	105
	Wednesday afternoon	105	104	105	103	104		103	107		104
D	Tuesday morning	91		92		92				94	
	Tuesday afternoon	95		96		94					
2	Wednesday morning	99	100	99	100	98		98			100
	Wednesday afternoon	103	102	103	102	101		100	104		103
J	Tuesday morning	94		94						92	
	Tuesday afternoon	96		97		95			97		
$2\frac{1}{4}$	Wednesday morning	99	99	100	99	98		98	101	100	100
	Wednesday afternoon	101	99	101	100	100		100	102		100

TABLE 5

Jet Aircraft Flyovers—Measured Altitudes and Noise Levels.

Session	Event	Altitude, ft	Slant distance of aircraft from microphones, ft	Noise level in dBC		Noise level in PNdB	
				Channel 1	Channel 2	Channel 1	Channel 2
Tuesday morning	E	800	810	106	106	115	114
	K	760	810	103	104	111	113
Tuesday afternoon	E	1000	1040	102	101	111	110
	K	1070	1060	101	102	110	111
Wednesday morning	E	960	970	102	101	110	109
	K	1050	1050	102	101	110	109
Wednesday afternoon	E	1000	1010	102	102	111	110
	K	910	960	102	103	111	111

TABLE 6

Jet Aircraft Flyovers—C-Scale Octave Band Analyses.

Session	Event	Channel	Centre frequency of preferred octave band, c/s							
			63	125	250	500	1000	2000	4000	8000
Wednesday morning	E	1	85	92	95	97	96	92	82	70
		2	87	93	95	96	95	91	82	69
	K	1	86	93	95	96	97	92	83	70
		2	86	93	95	96	95	91	82	68
Wednesday afternoon	E	1	86	93	94	98	96	92	83	70
		2	85	93	95	97	96	92	83	70
	K	1	86	93	95	98	97	92	82	70
		2	85	93	97	98	98	93	83	70
Overall mean			86	93	95	97	97	92	82	70

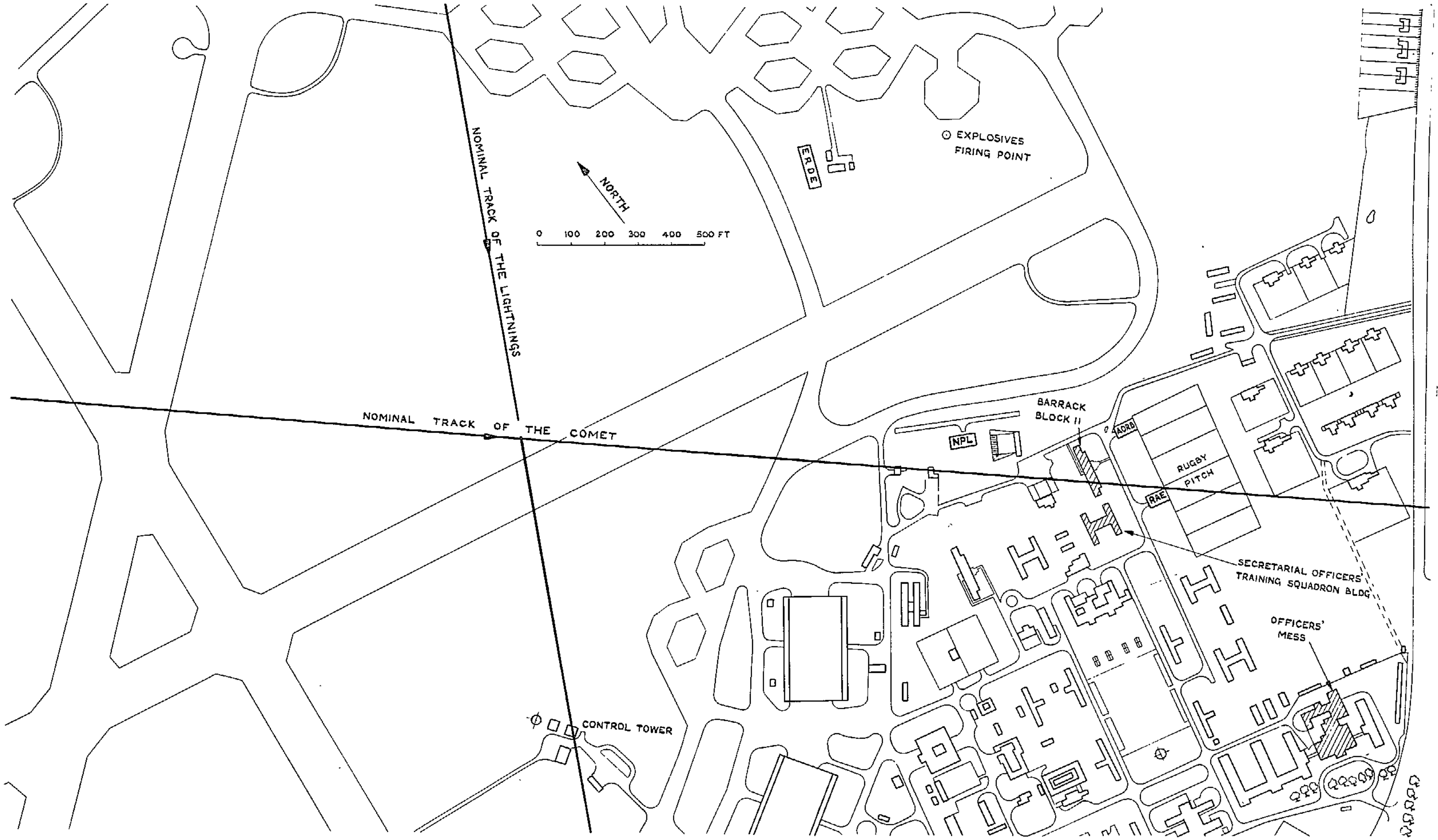


FIG. 1. Dispositions of various parties at Upwood.

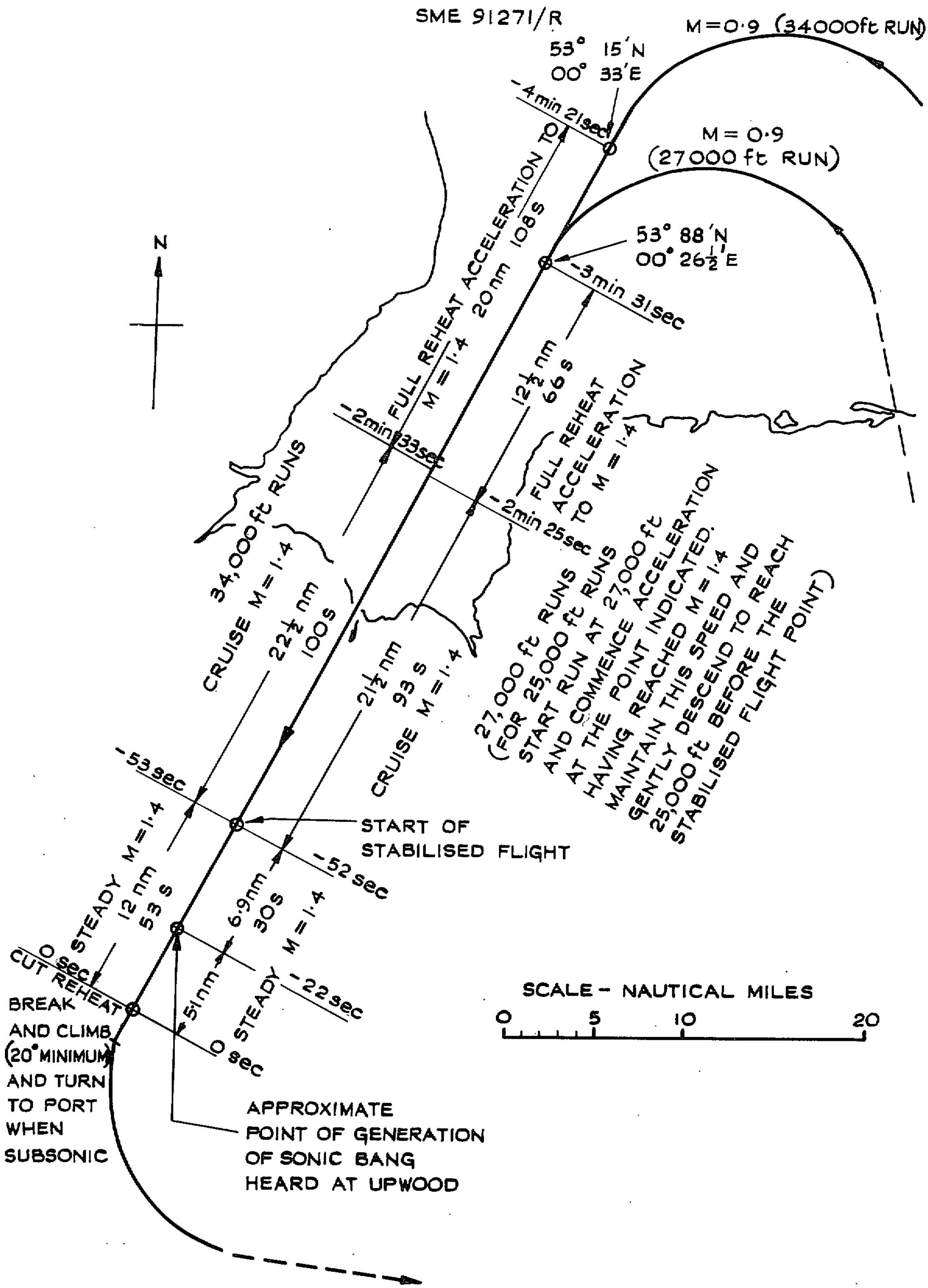
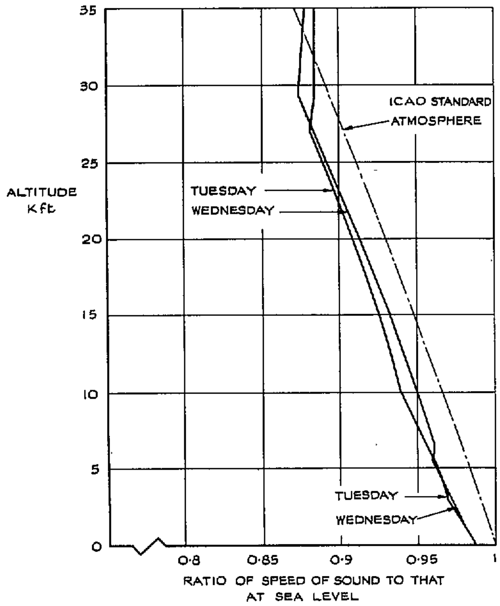


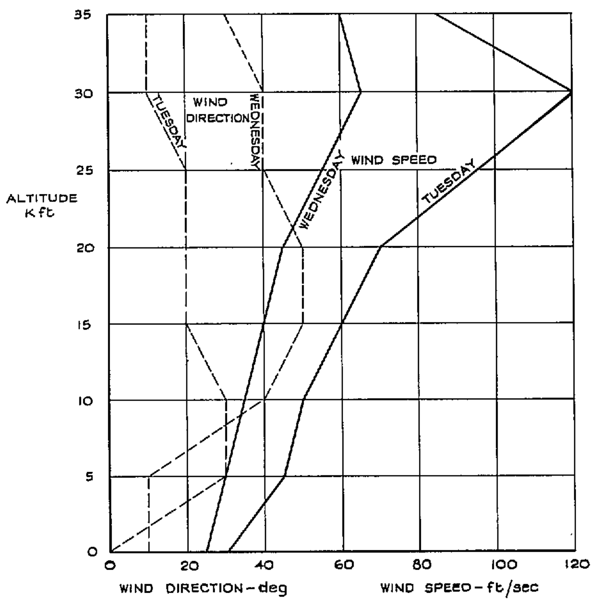
FIG. 2. Lightning flight plans.

		TUESDAY		WEDNESDAY	
		1200 bst	1400 bst	1200 bst	1400 bst
WIND SPEED	ft/sec	30	35	25	25
WIND DIRECTION	deg	360	010	010	010
PRESSURE	mb	1011·4	1012·2	1015·7	1015·1
TEMPERATURE	°C	7·4	8·6	7·6	7·6
RELATIVE HUMIDITY		0·76	0·75	0·73	0·66
WEATHER		CLOUDY	CLOUDY	CLOUDY SLIGHT RAIN SHOWER	CLOUDY
CLOUD AMOUNT		8/8	7/8	7/8 2/8	7/8
CLOUD BASE	ft	2000	2000	2500 1000	2500
VISIBILITY	mile	8	10	10	10

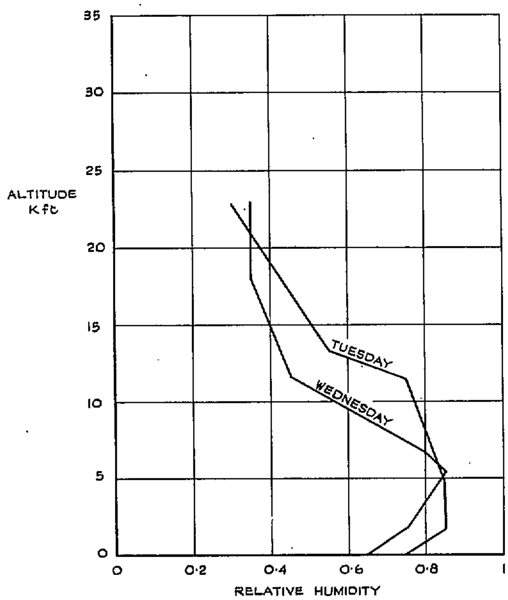
(a) SURFACE DATA



(b) ESTIMATED SPEEDS OF SOUND



(c) ESTIMATED WINDS



(d) ESTIMATED HUMIDITIES

FIG. 3a to d. Meteorological data.

Fig. 4a.

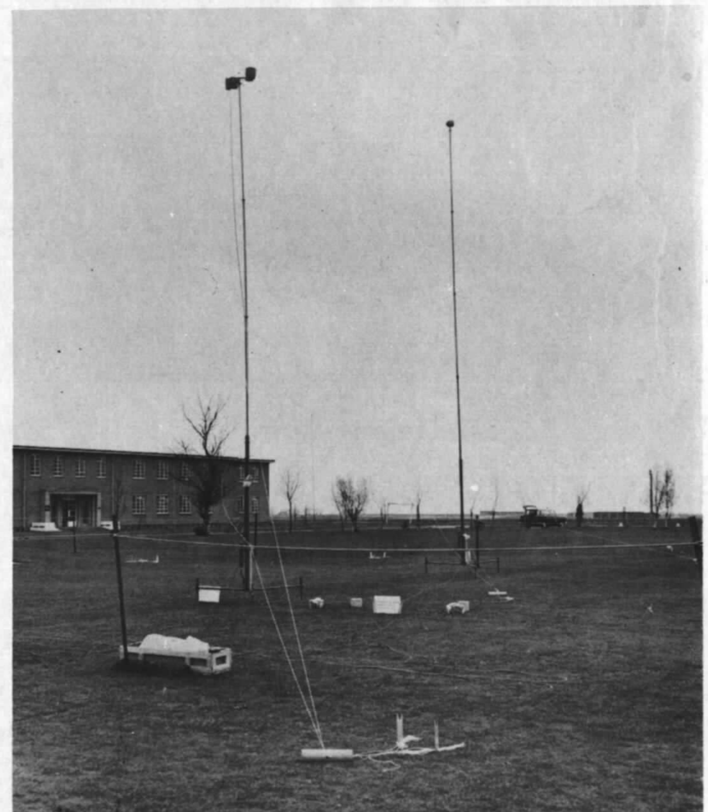


Fig. 4b.

FIG. 4. Microphone positions.

Fig. 5a.

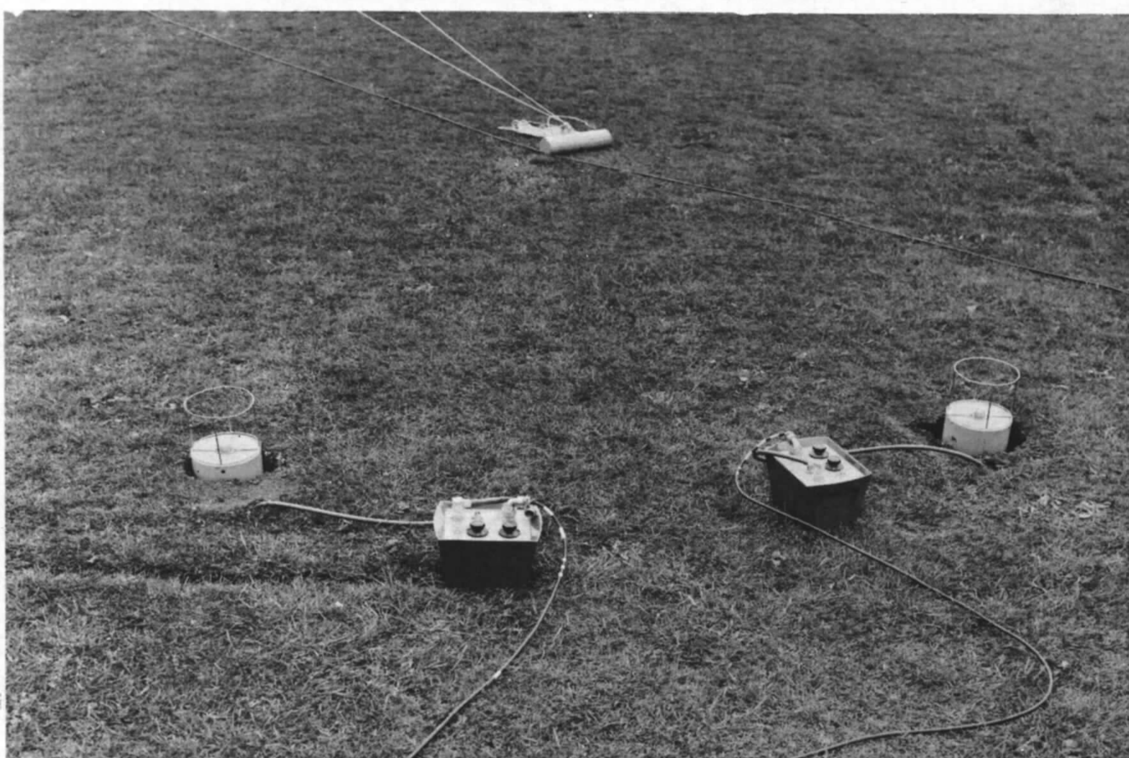


Fig. 5b.

FIG. 5. Microphone positions.

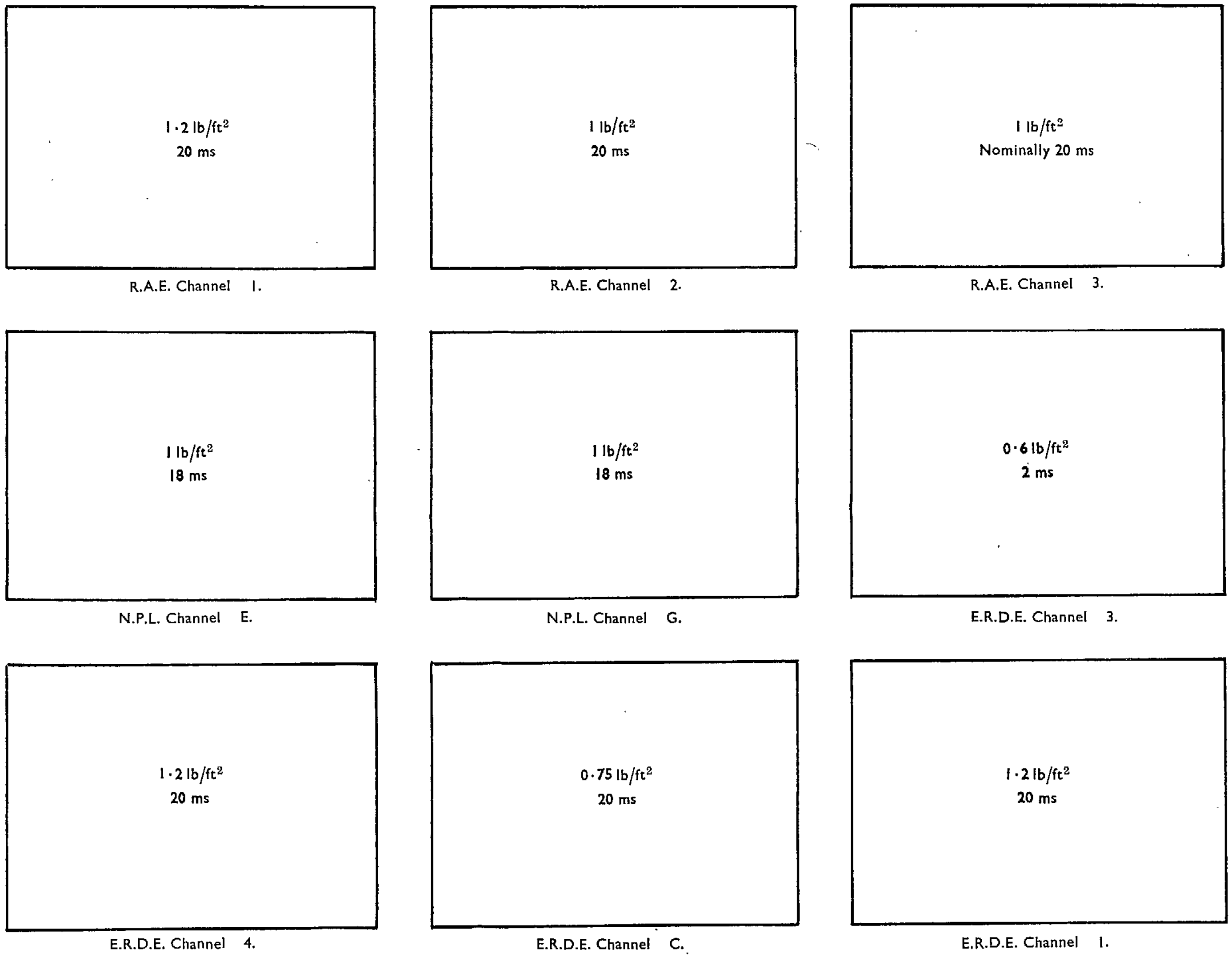
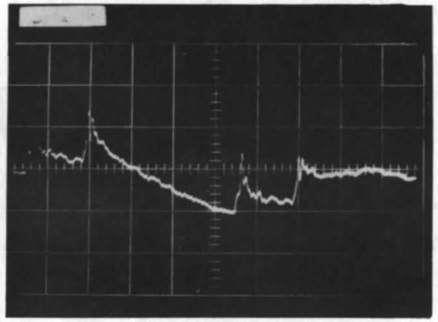
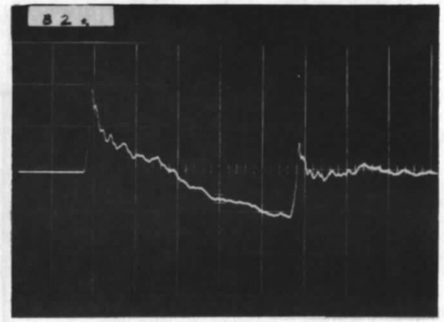


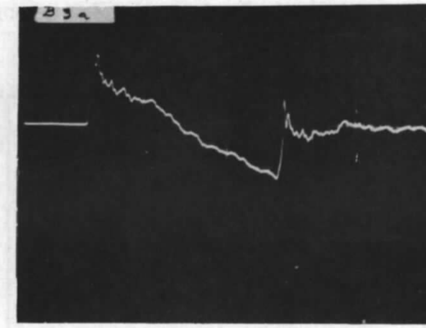
FIG. 6. Summary of vertical and horizontal scales, per division, used in Figures 7 to 26.



R.A.E. Channel 1.



R.A.E. Channel 2.



R.A.E. Channel 3.

FIG. 7. Sonic bang waveforms. Tuesday morning Event B.

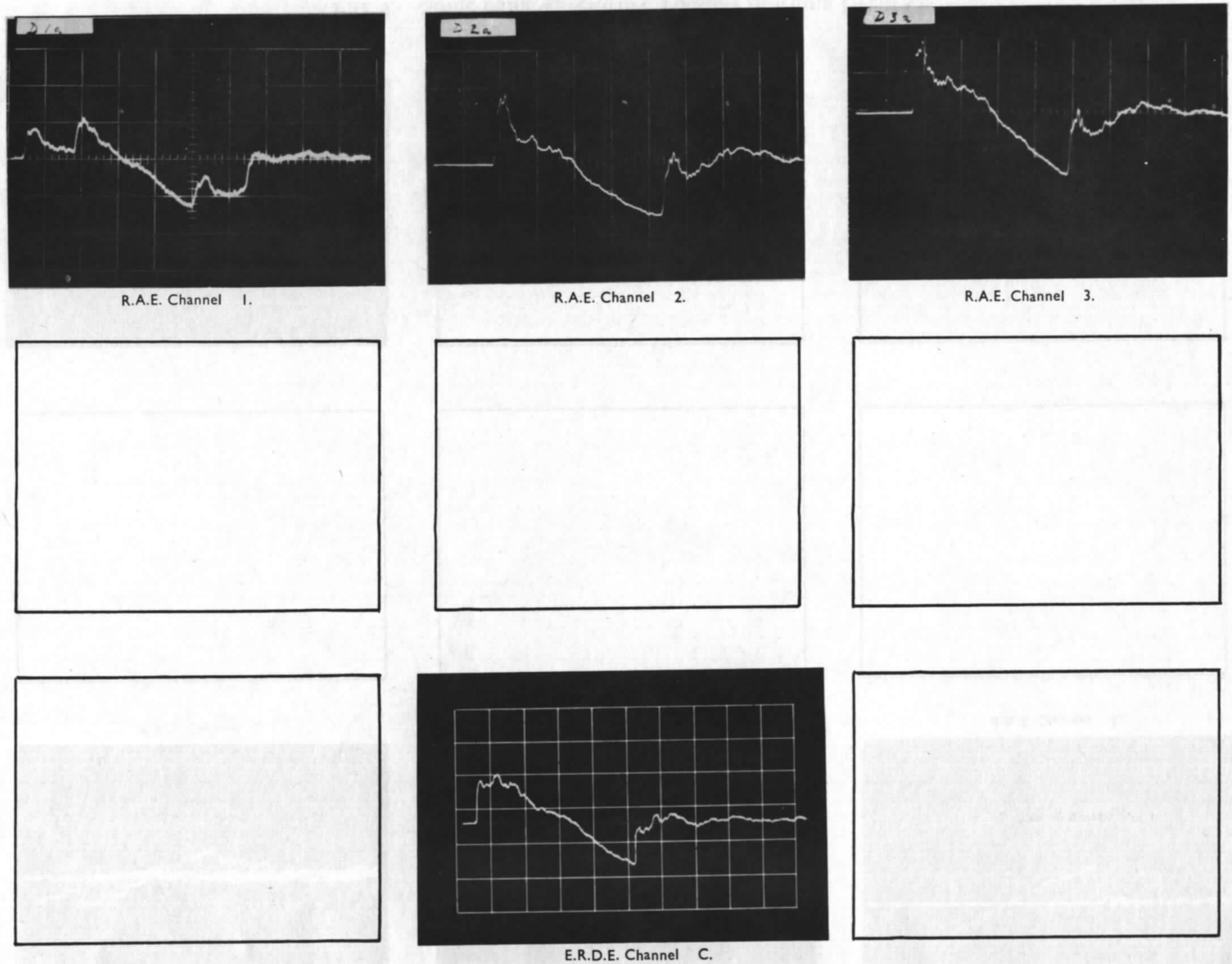


FIG. 8. Sonic bang waveforms. Tuesday morning Event D.

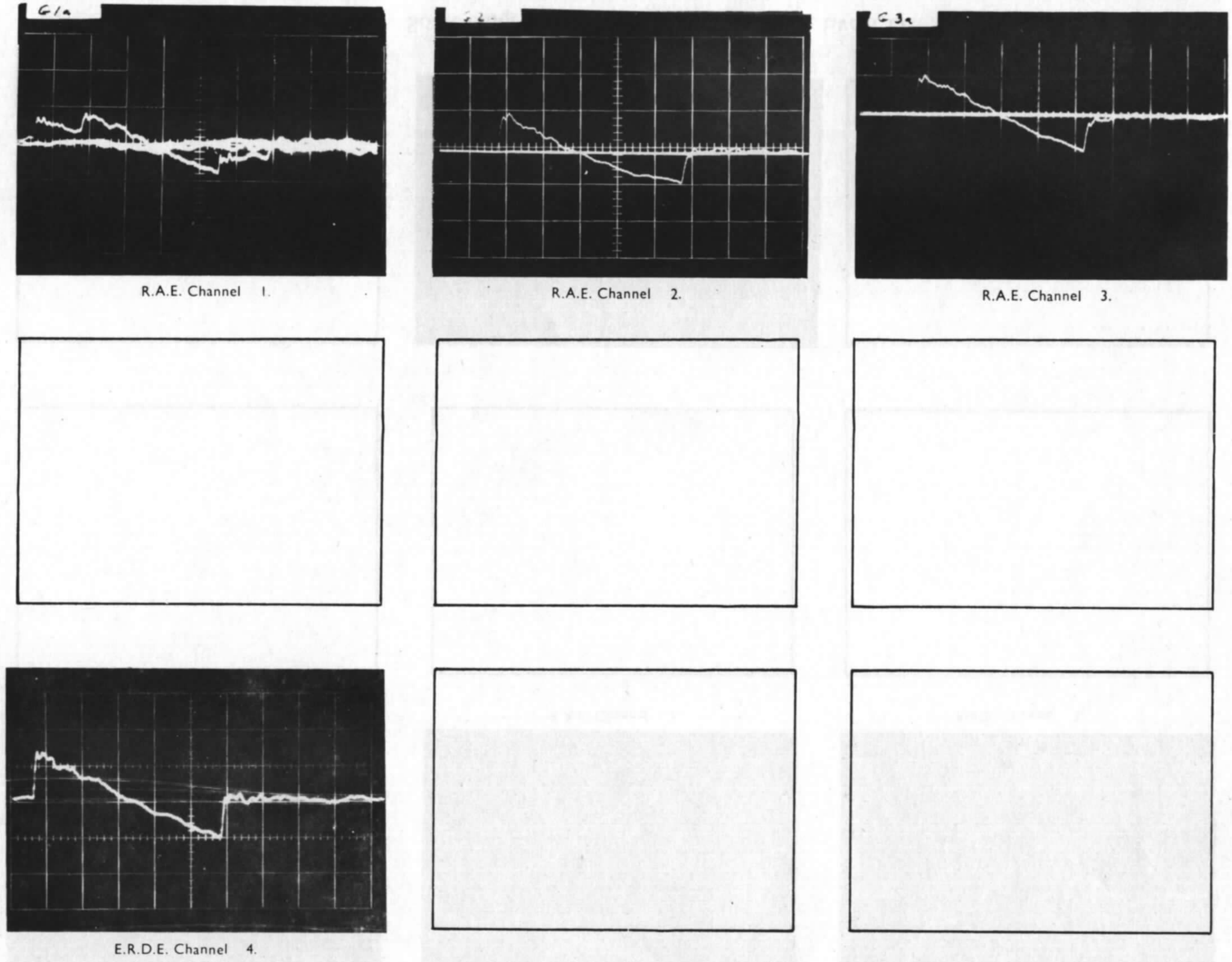


FIG. 9. Sonic bang waveforms. Tuesday morning Event G.

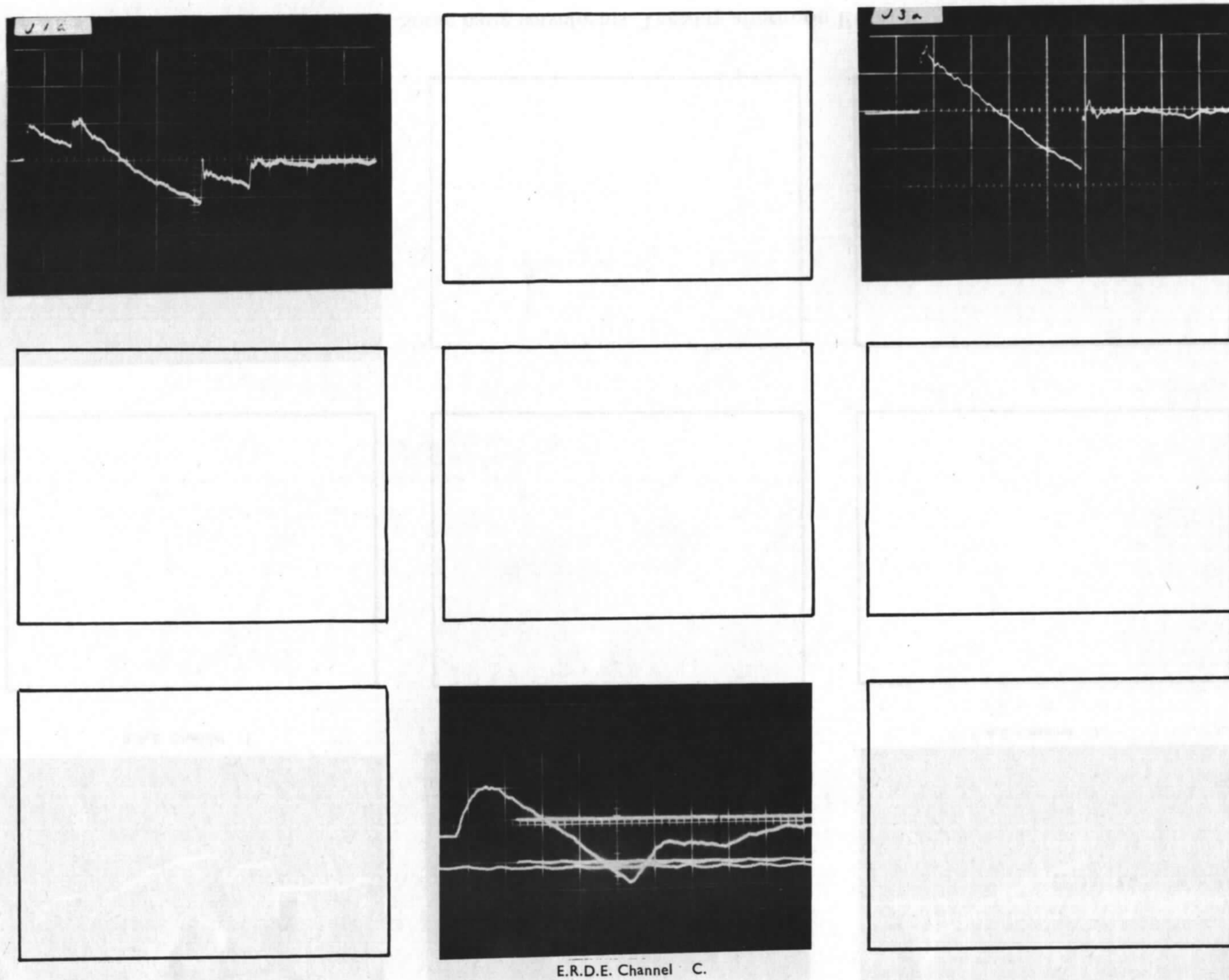


FIG. 10. Sonic bang waveforms. Tuesday morning Event J.

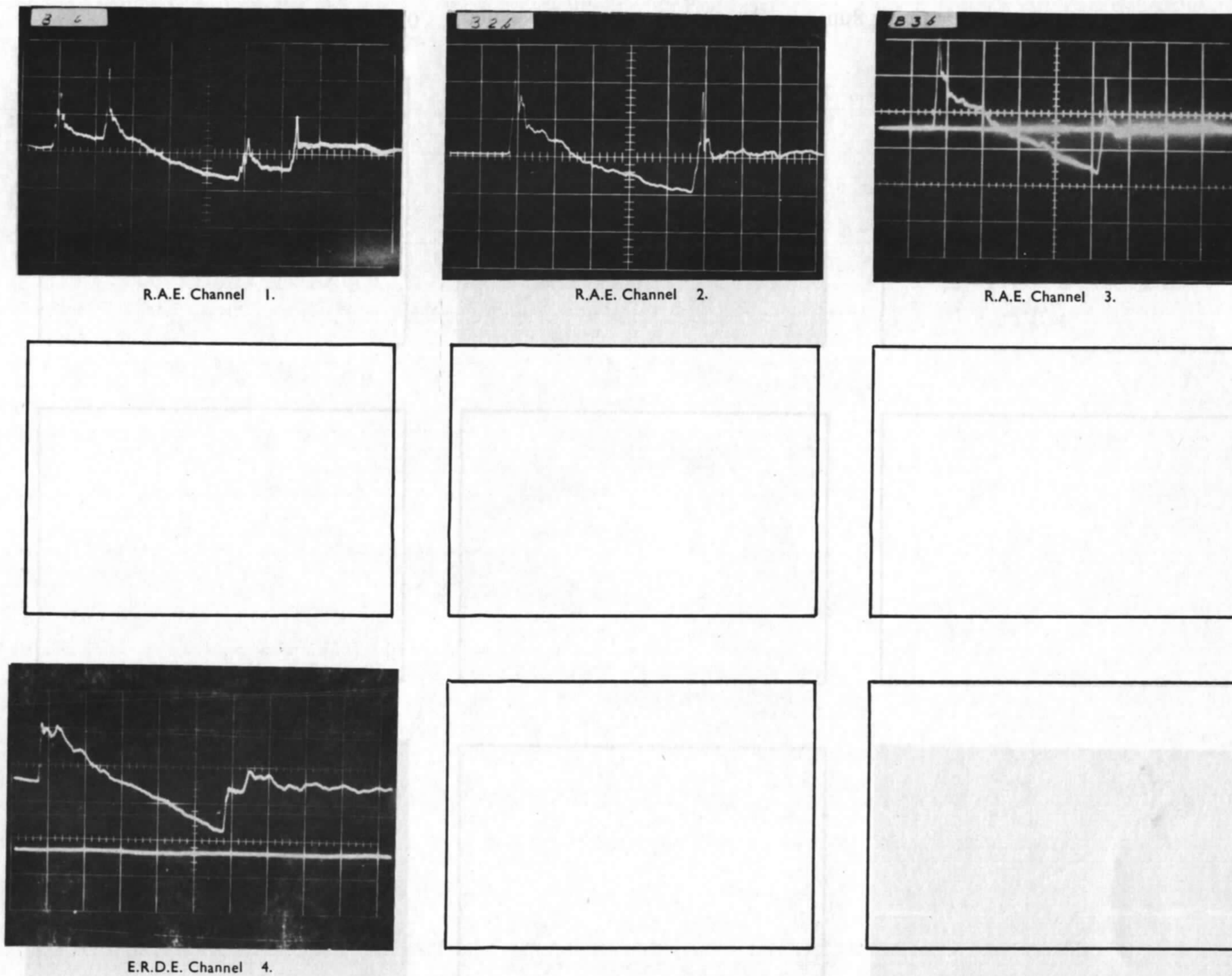


FIG. 11. Sonic bang waveforms. Tuesday afternoon Event B.

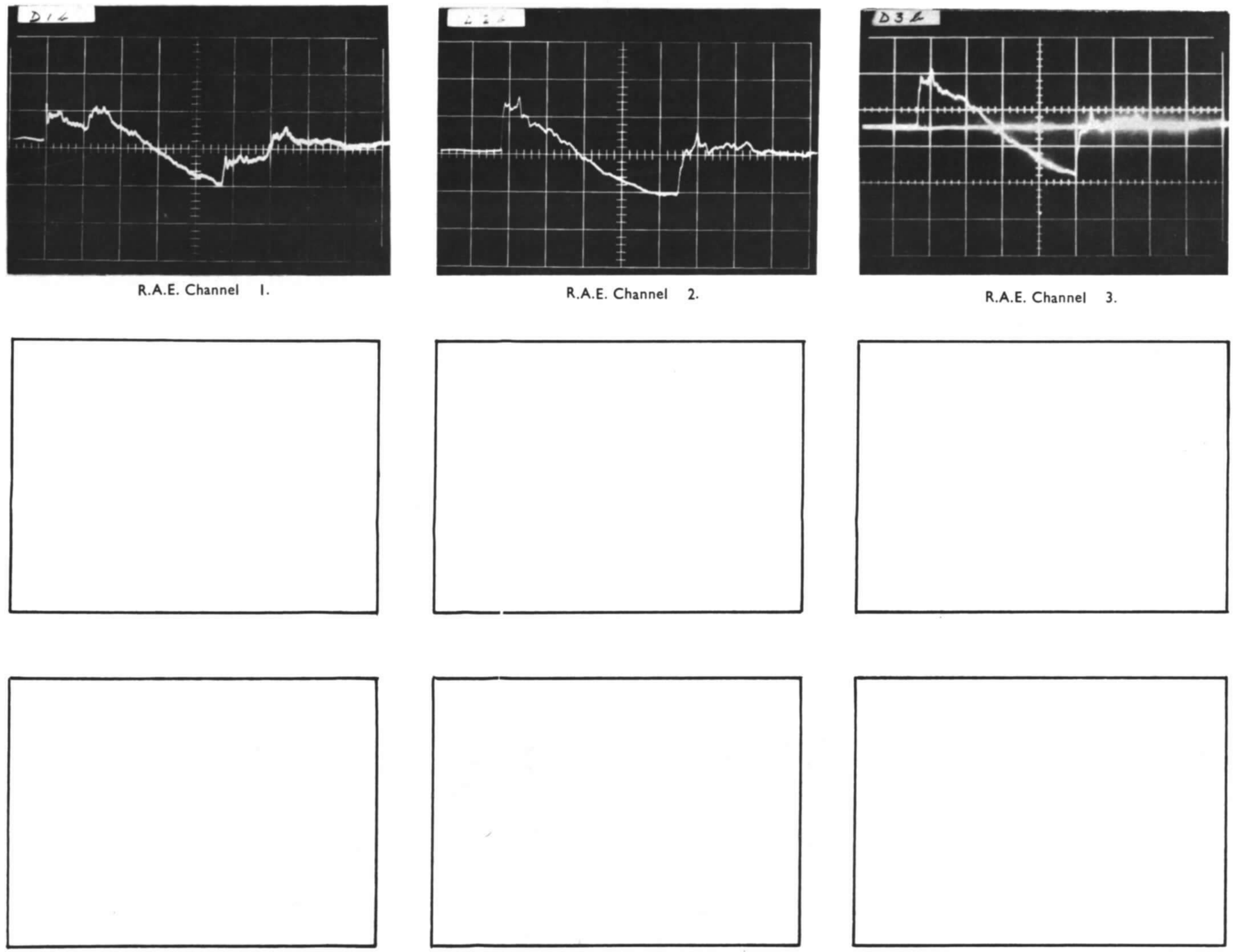


FIG. 12. Sonic bang waveforms. Tuesday afternoon Event D.

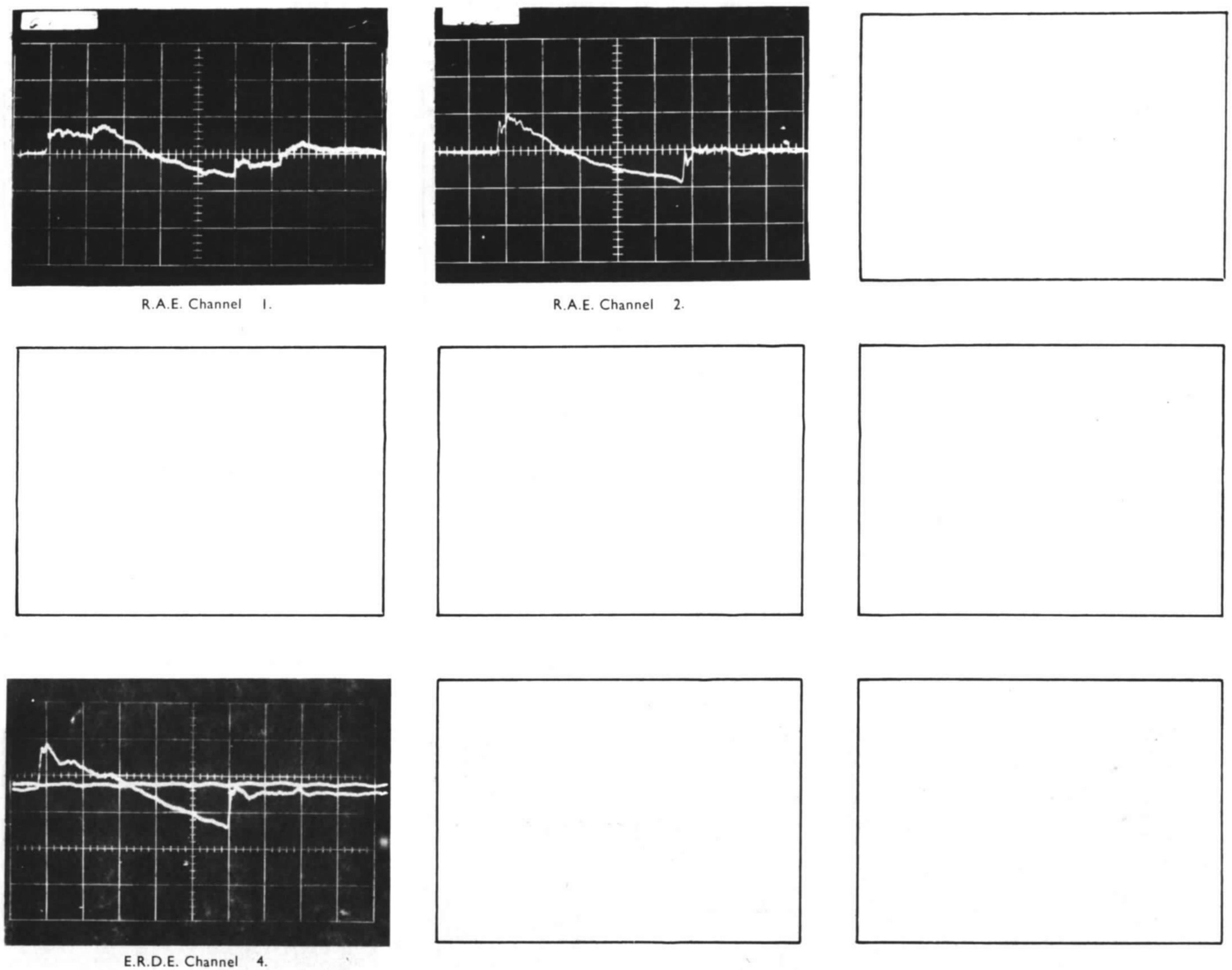


FIG. 13. Sonic bang waveforms. Tuesday afternoon Event G.

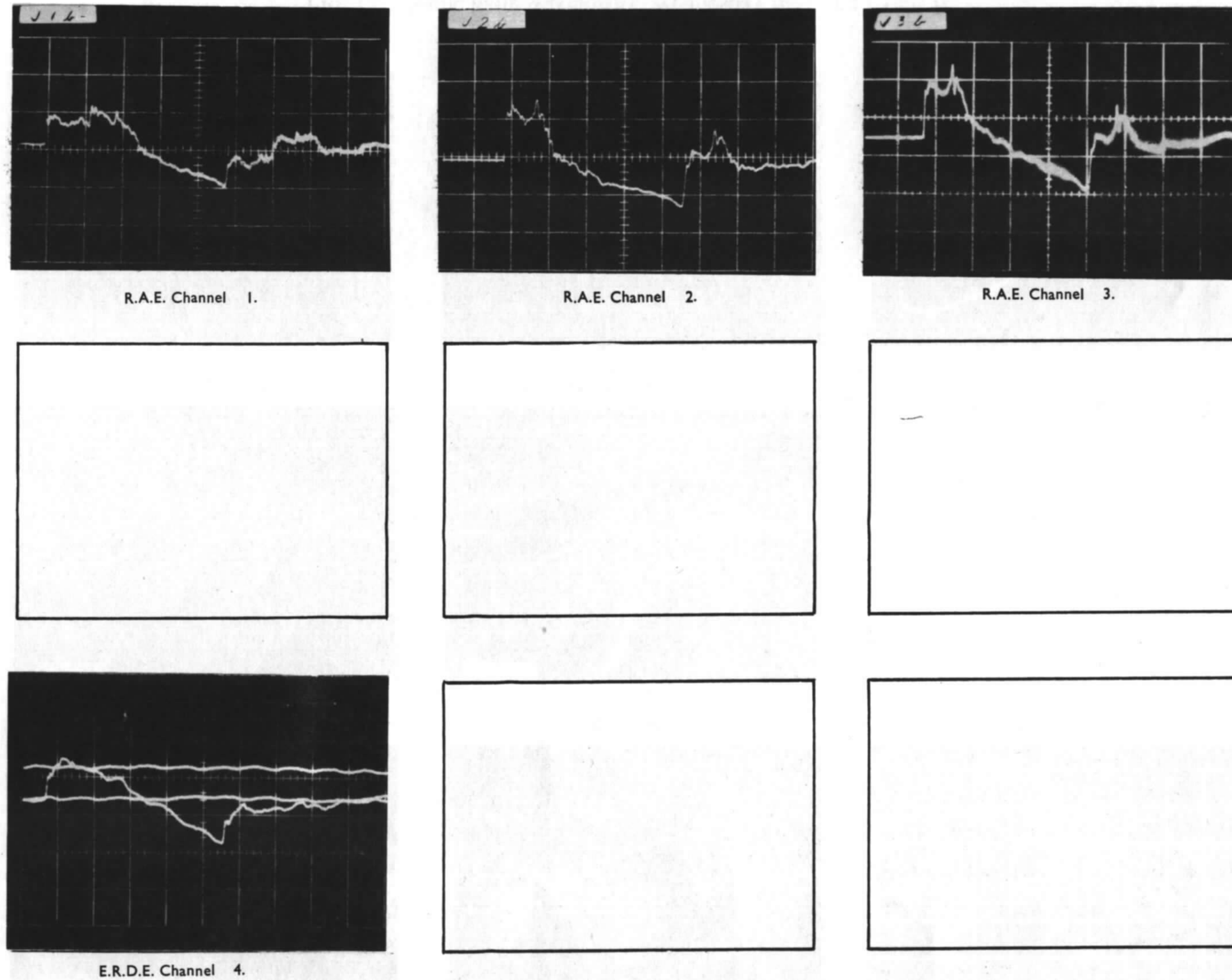


FIG. 14. Sonic bang waveforms. Tuesday afternoon Event J.

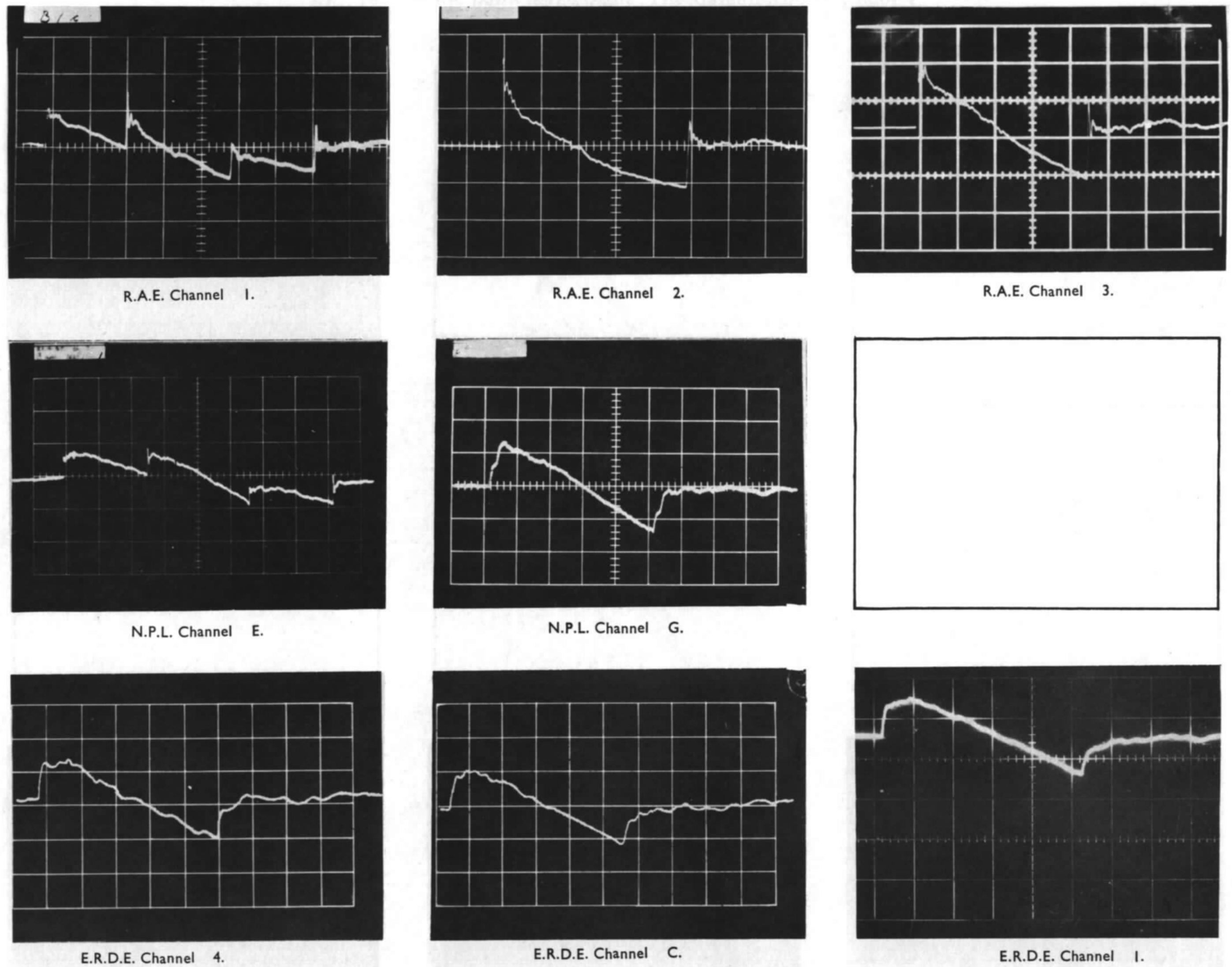


FIG. 15. Sonic bang waveforms. Wednesday morning Event B.

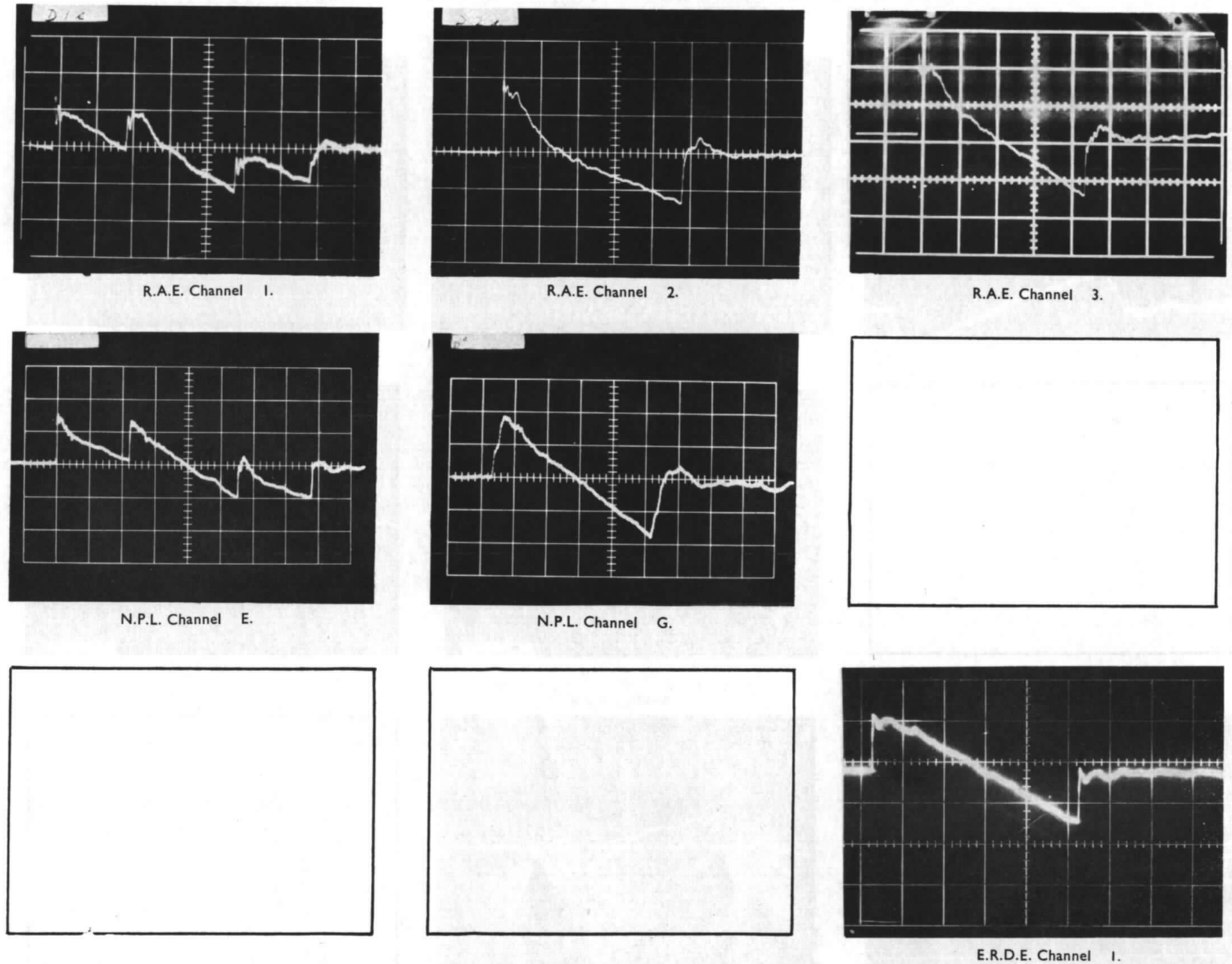


FIG. 16. Sonic bang waveforms. Wednesday morning Event D.

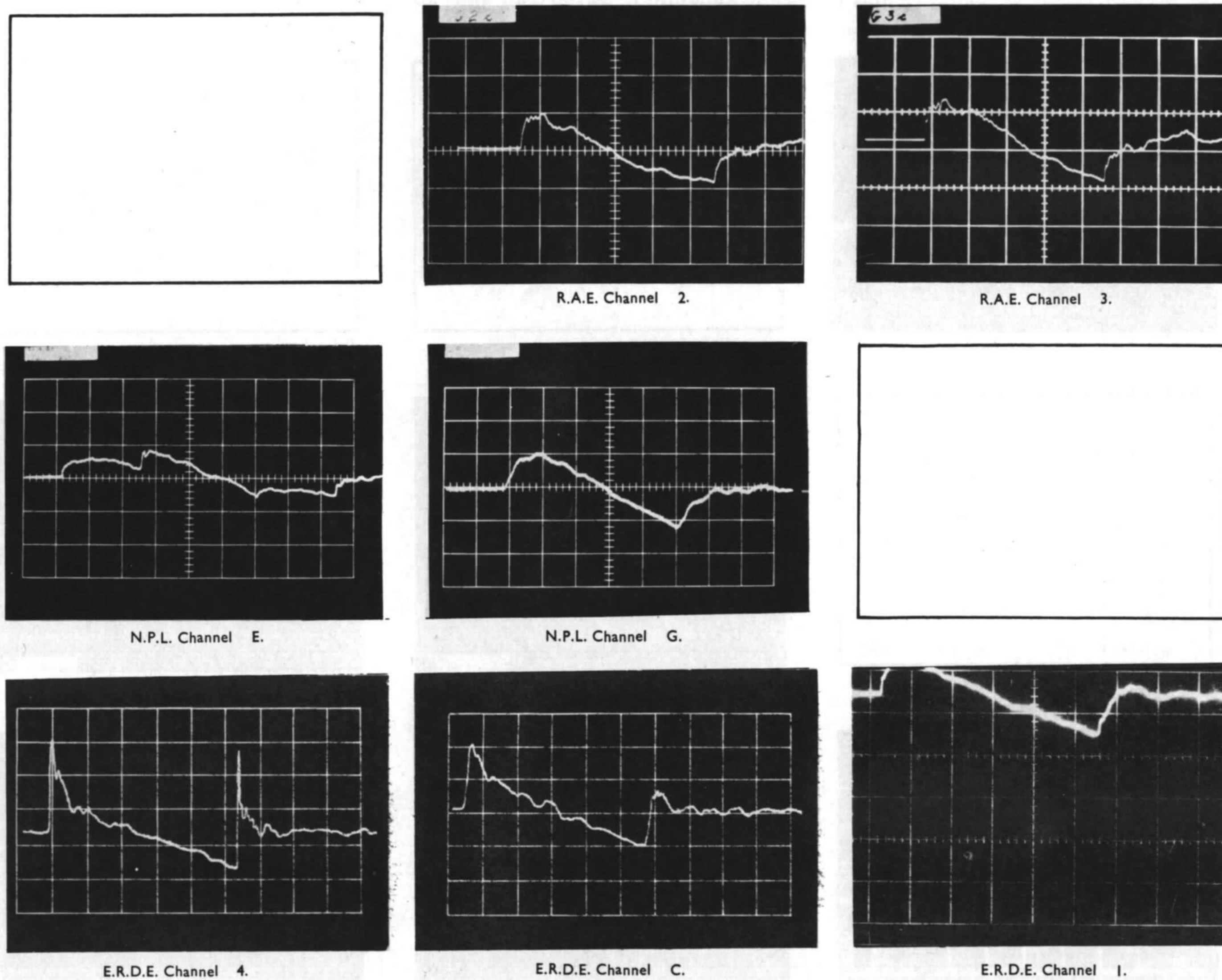


FIG. 17. Sonic bang waveforms. Wednesday morning Event G.

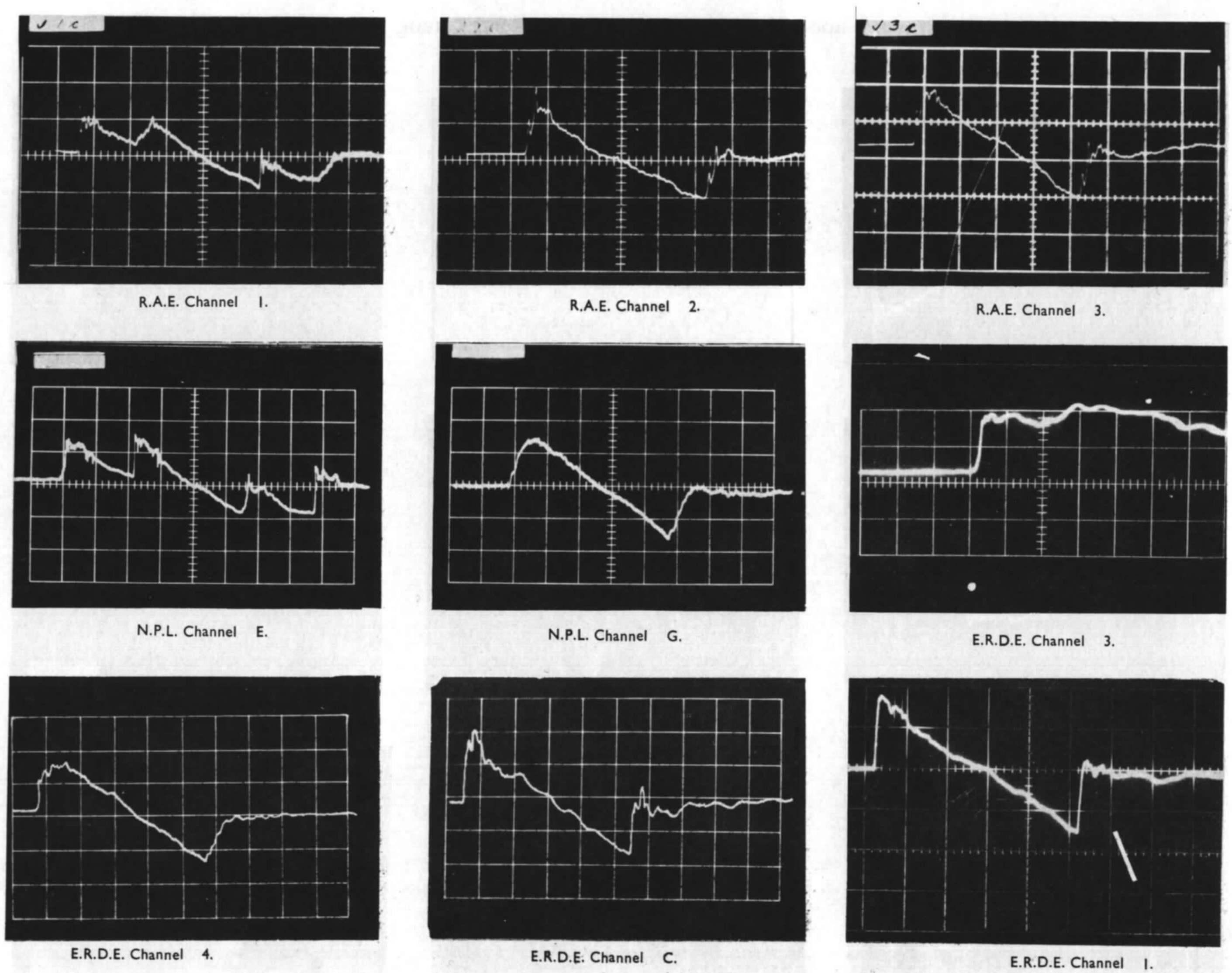


FIG. 18. Sonic bang waveforms. Wednesday morning Event J.

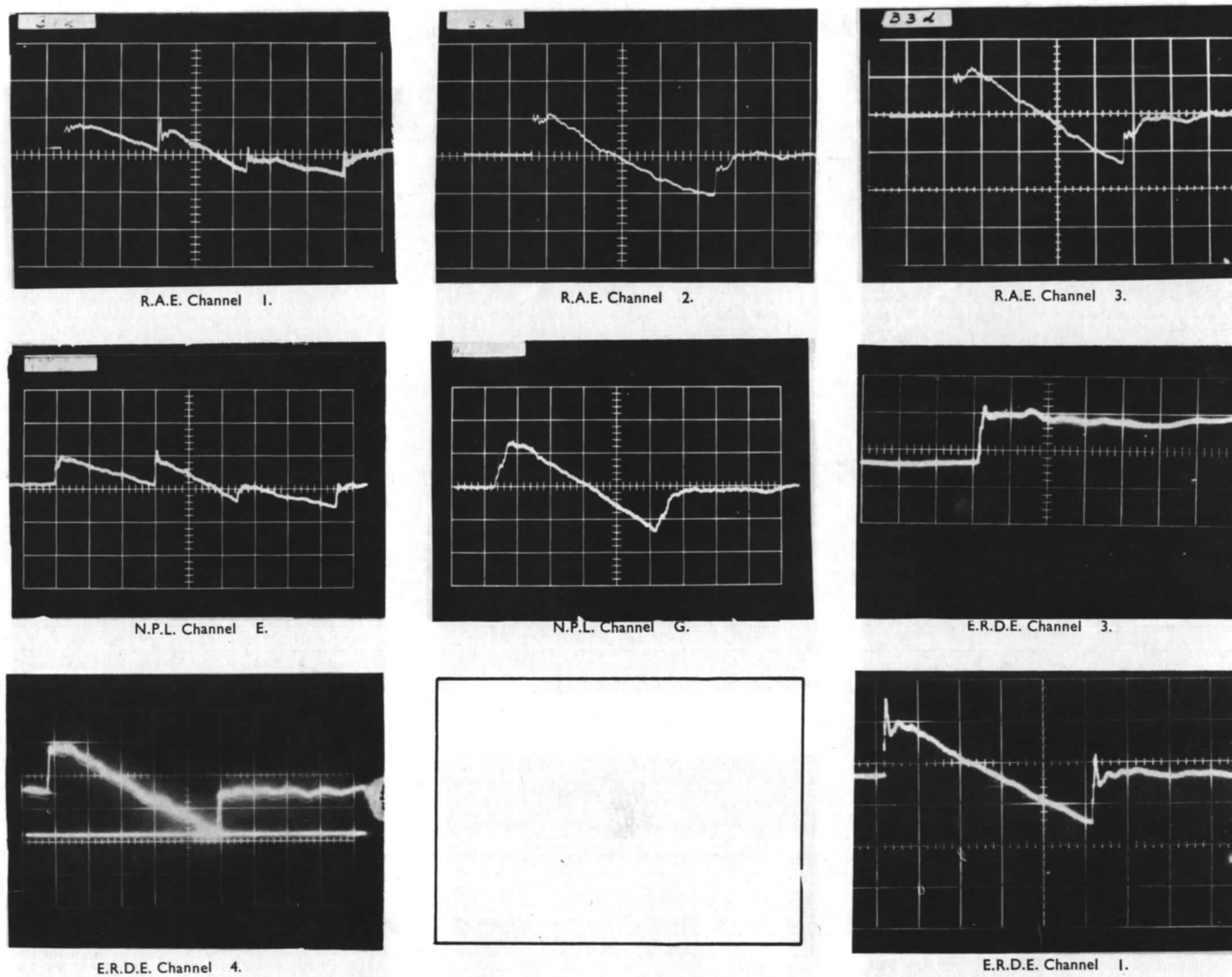


FIG. 19. Sonic bang waveforms. Wednesday afternoon Event B.

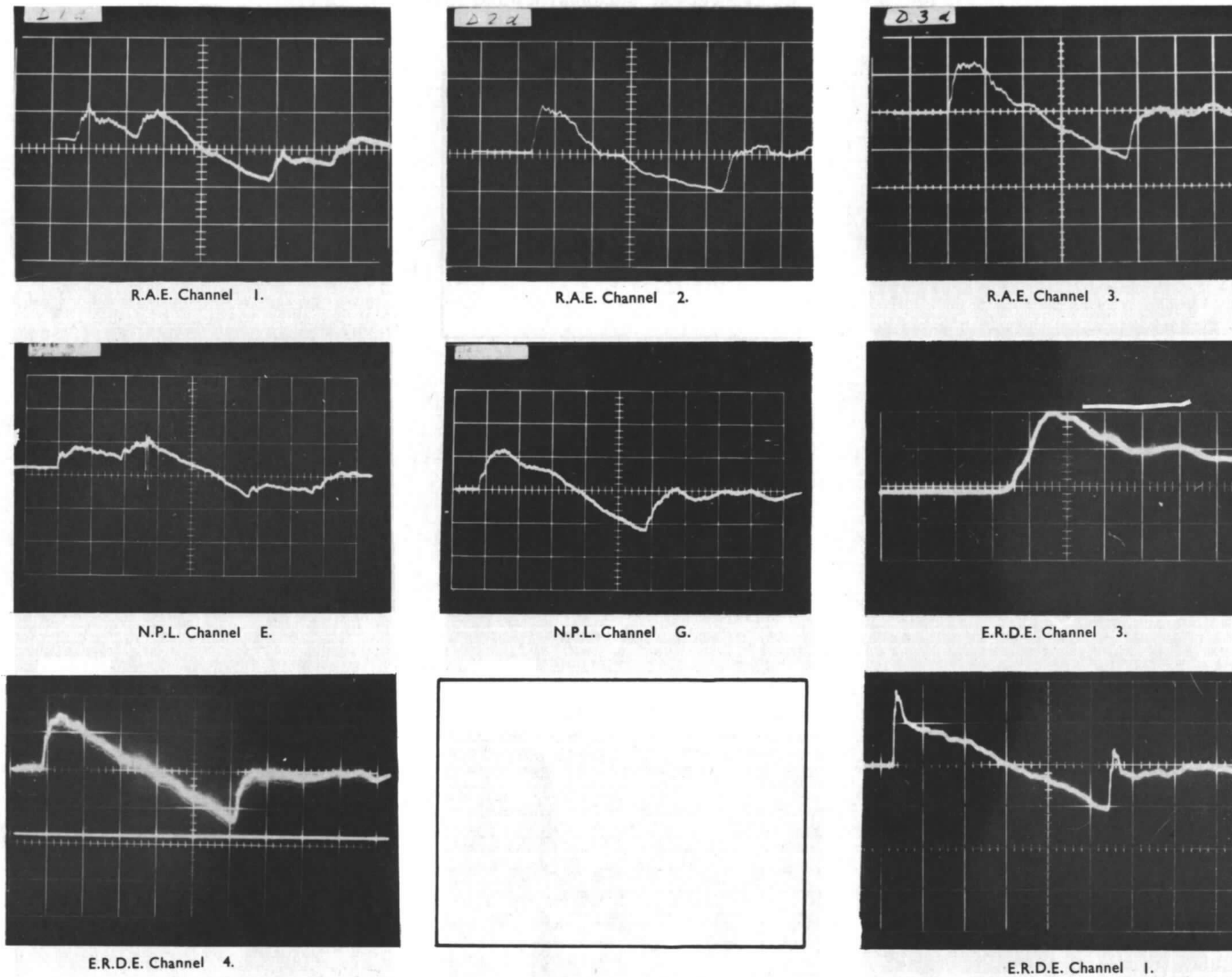


FIG. 20. Sonic bang waveforms. Wednesday afternoon Event D.

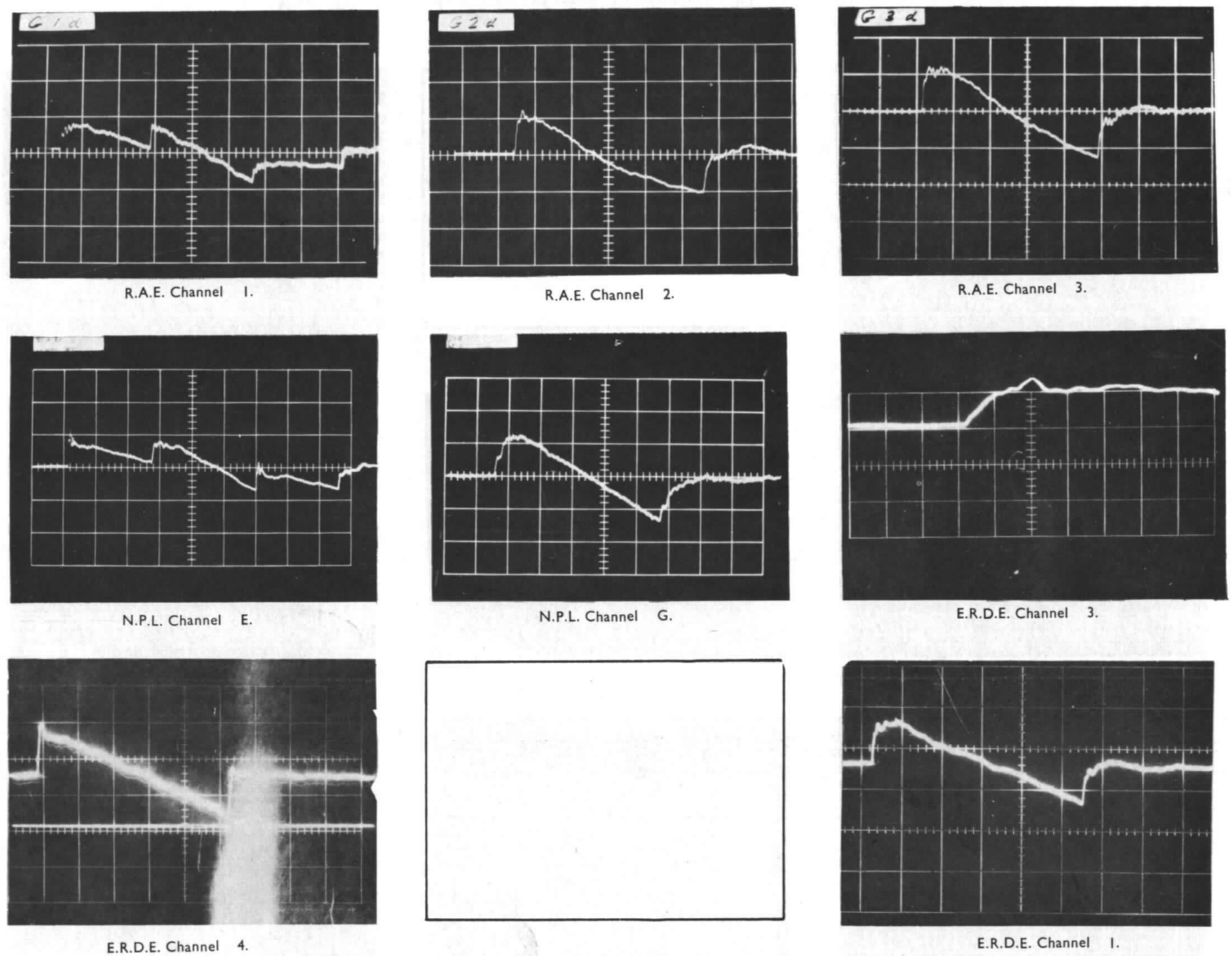
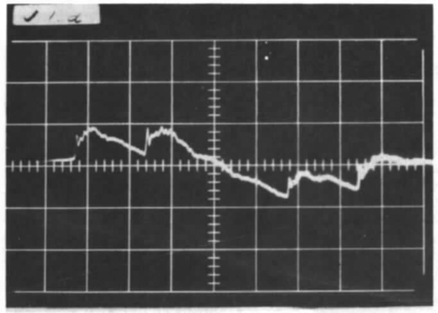
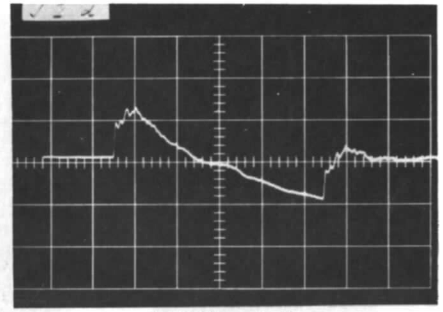


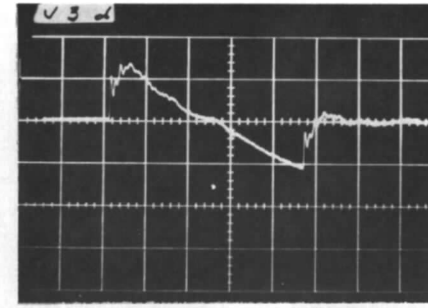
FIG. 21. Sonic bang waveforms. Wednesday afternoon Event G.



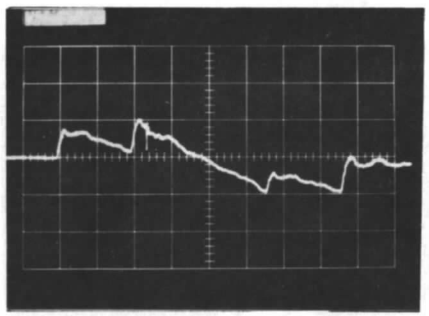
R.A.E. Channel 1.



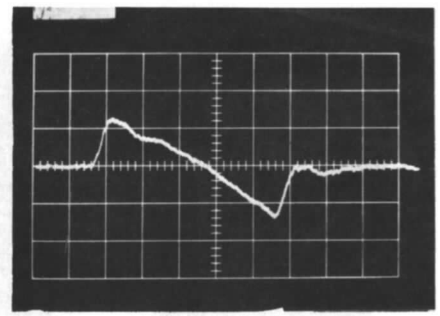
R.A.E. Channel 2.



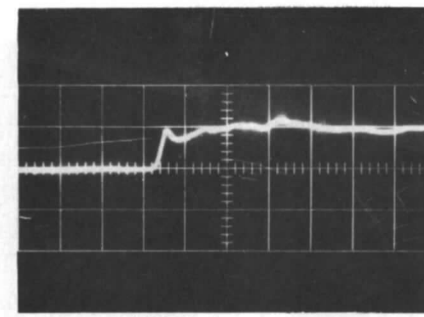
R.A.E. Channel 3.



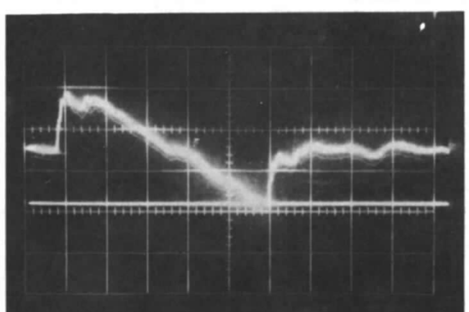
N.P.L. Channel E.



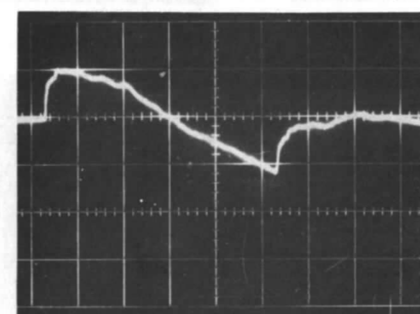
N.P.L. Channel G.



E.R.D.E. Channel 3.



E.R.D.E. Channel 4.



E.R.D.E. Channel 1.

FIG. 22. Sonic bang waveforms. Wednesday afternoon Event J.

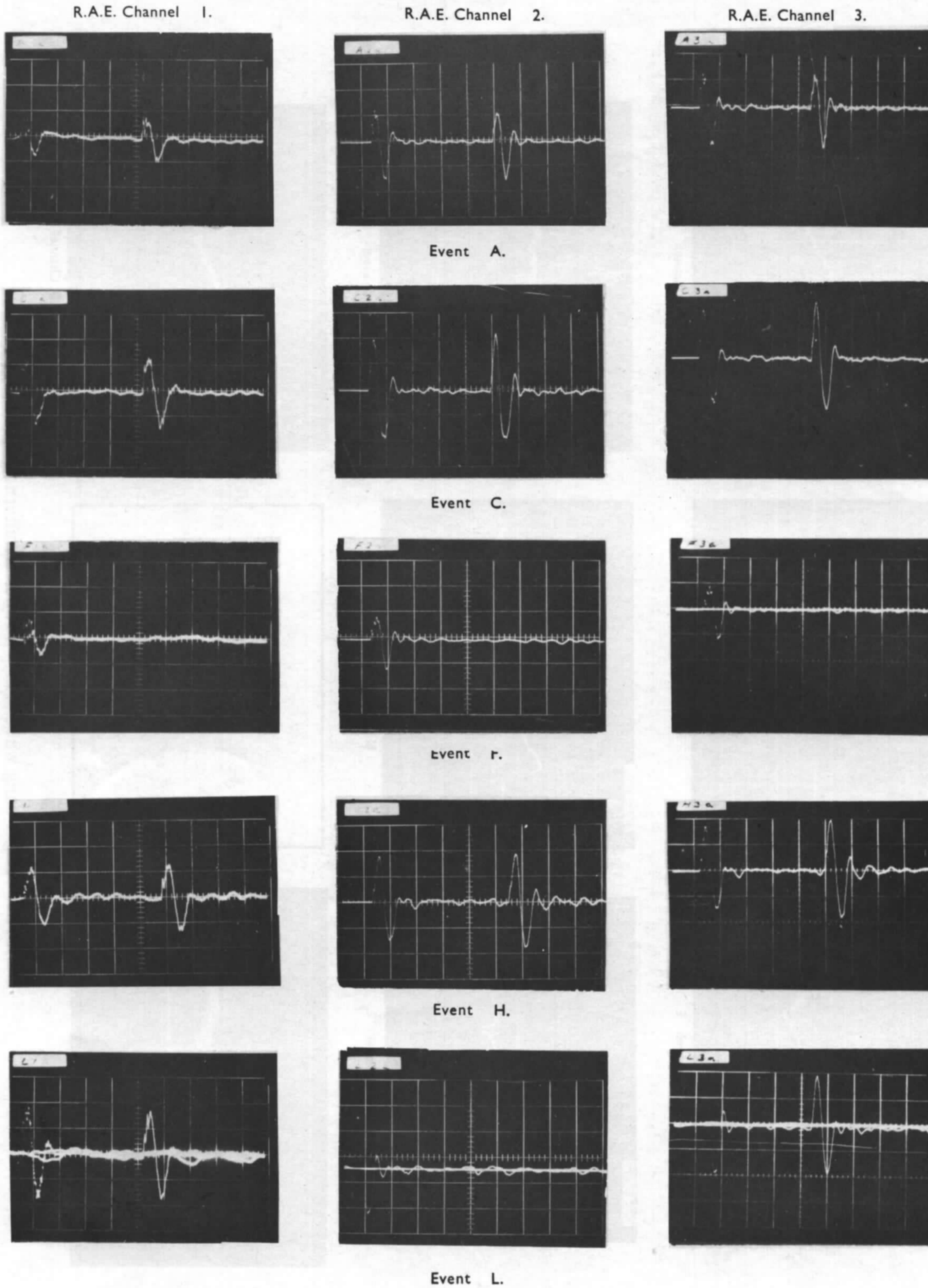


FIG. 23. Explosive bang waveforms. Tuesday morning.

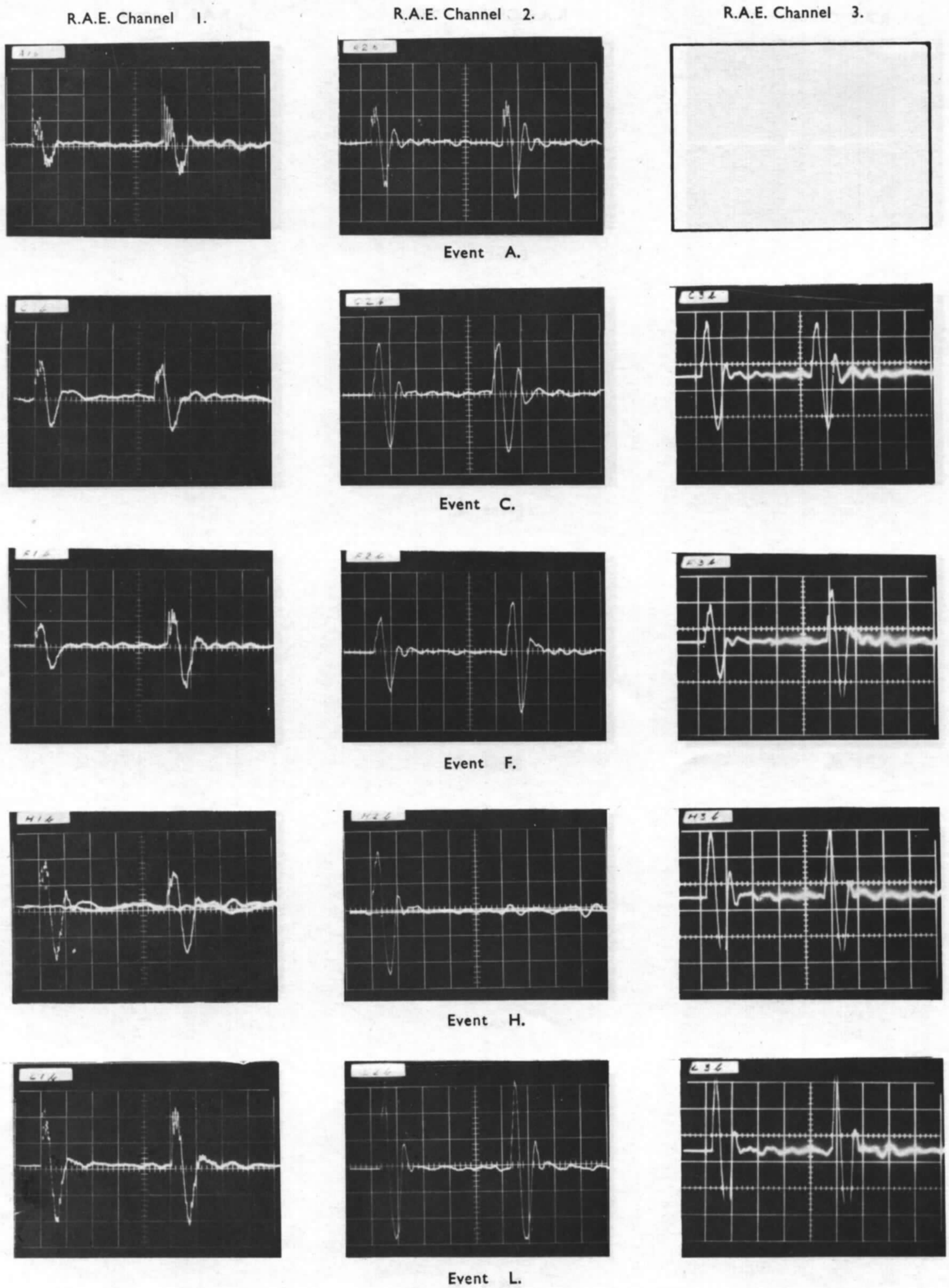


FIG. 24. Explosive bang waveforms. Tuesday afternoon.

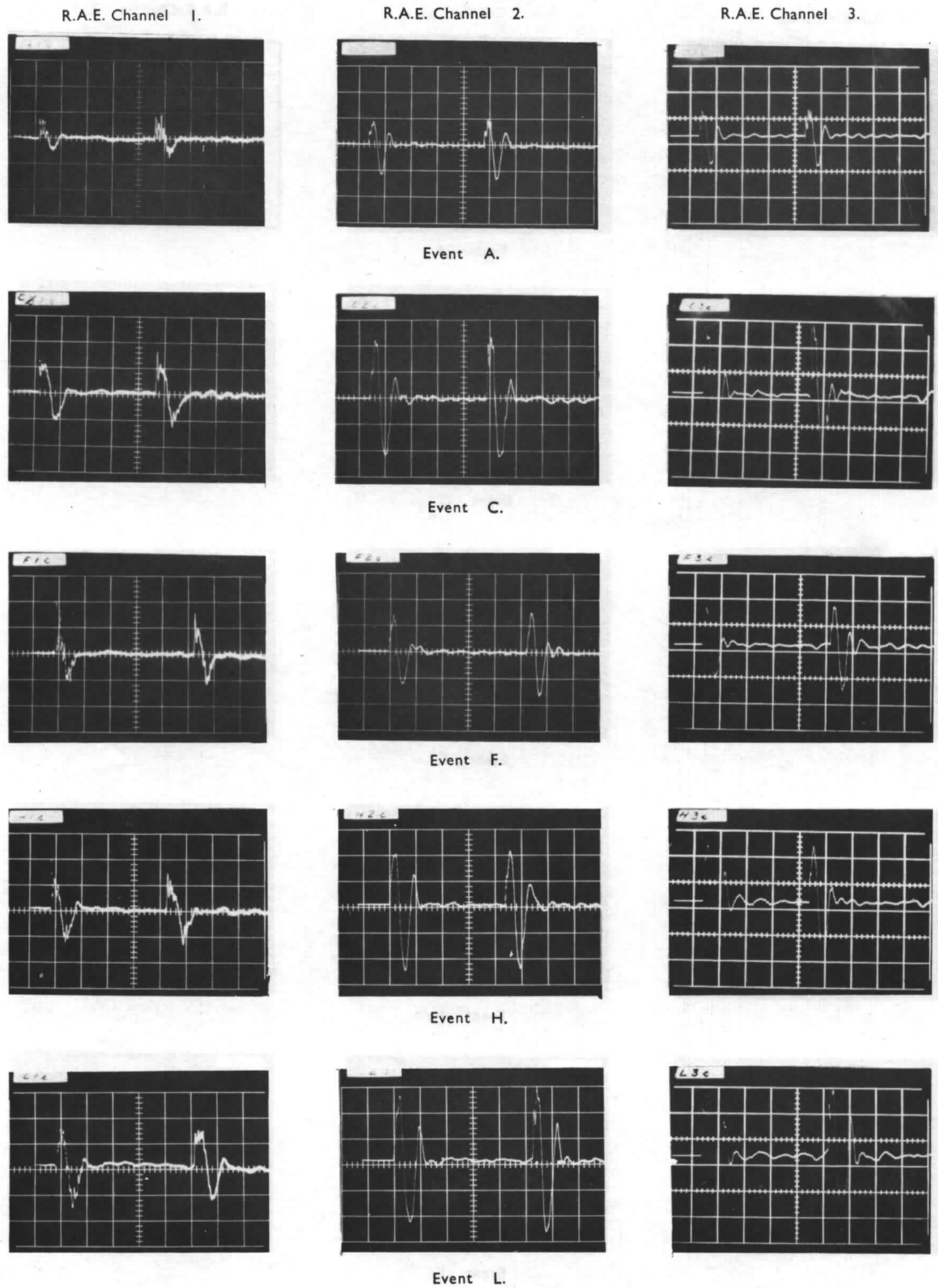


FIG. 25. Explosive bang waveforms. Wednesday morning.

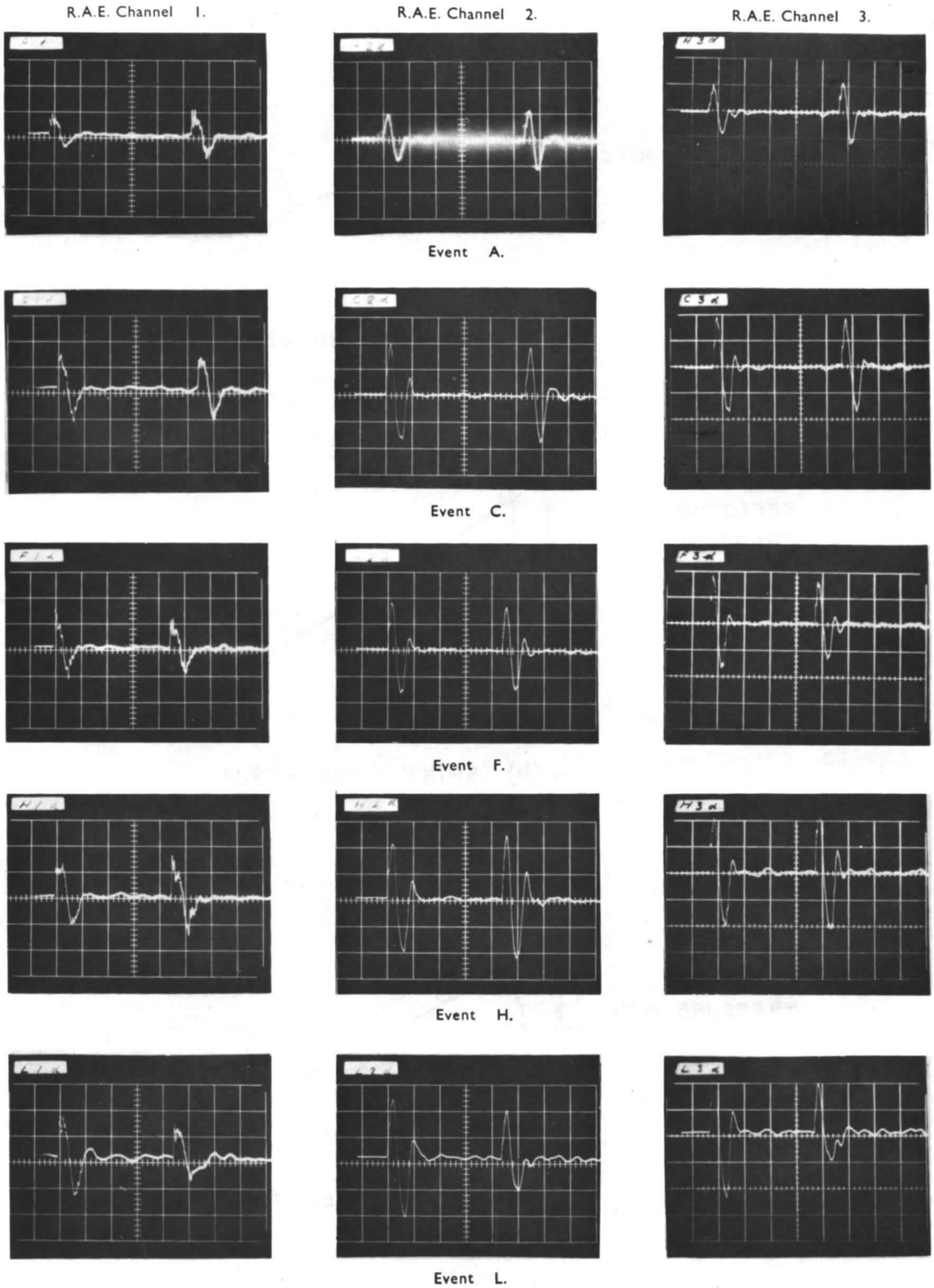


FIG. 26. Explosive bang waveforms. Wednesday afternoon.

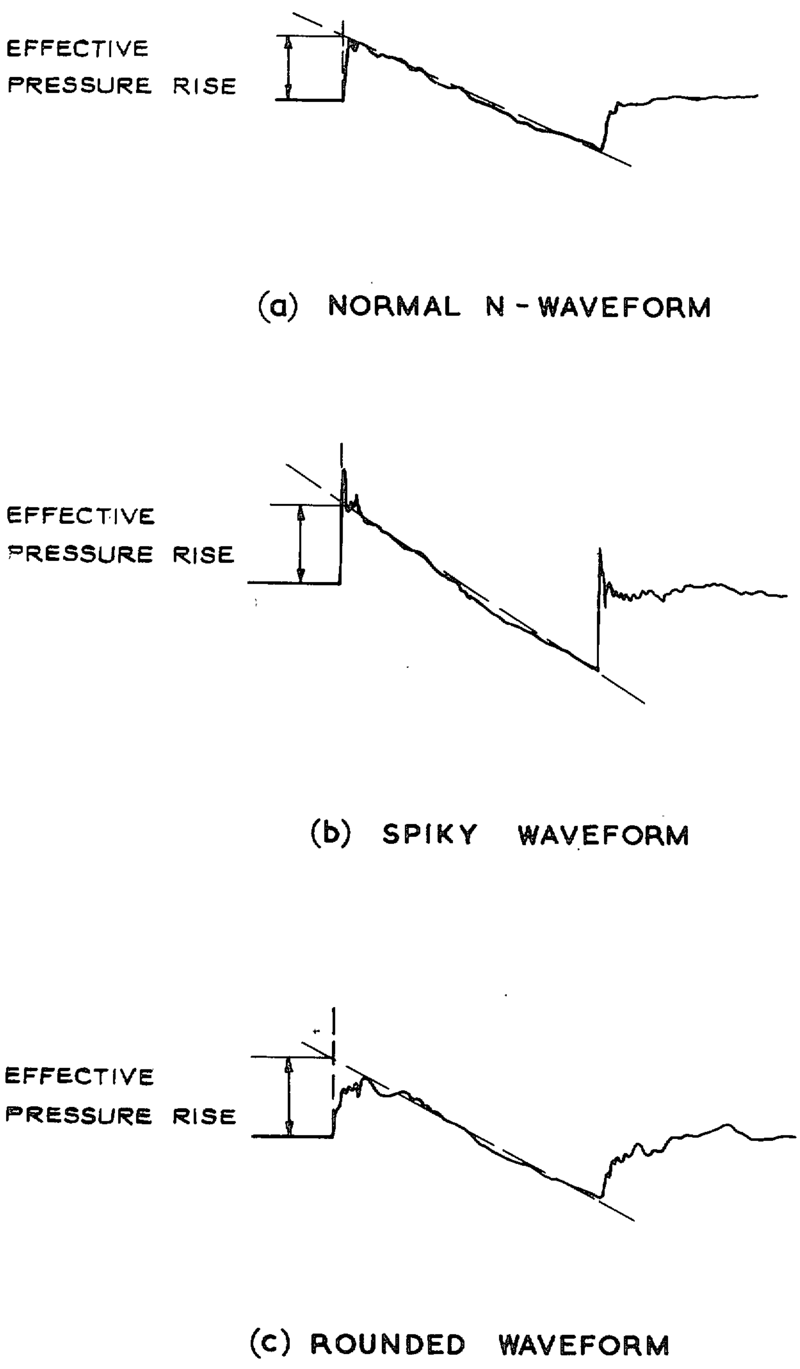


FIG. 27a to c. Three basic types of sonic bang waveform.

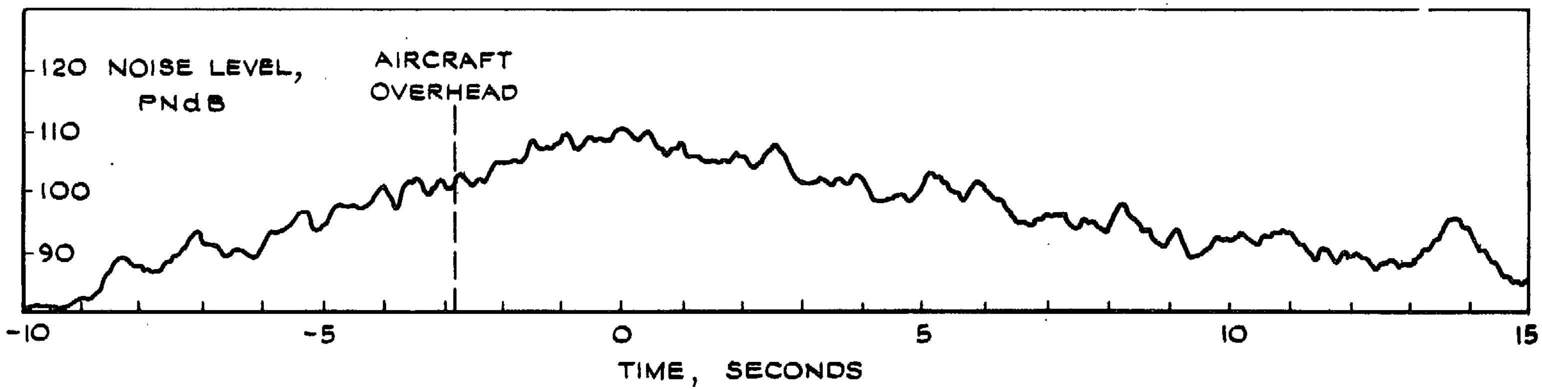


FIG. 28. Time variation of jet aircraft flyover noise level.

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