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Summary.

In July 1967 eleven supersonic flights were made over selected areas of Southern England so that the public could experience some sonic bangs. This report describes how these bangs were monitored and gives the results of the measurements.

*Replaces R.A.E. Technical Report 67 313—A.R.C. 30 164.

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1. *Introduction.*

During July 1967 a series of supersonic flights were made over three areas in Southern England under the code name Exercise Summer Sky. The object was to observe public reaction to sonic bangs, in order to build up some information of the consequences of overflying parts of the country with supersonic transport aircraft. The R.A.E. was asked to participate by measuring the sonic bang pressure waveforms at selected points in each of the three areas. One of the selected points in each area was in the nominal focus area of the flight paths, and for this purpose a ship was used as a monitoring station because the flight paths were arranged so that the focus areas occurred at sea. In this Report the recorded waveforms are shown and discussed, together with details of the aircraft tracks and relevant meteorological conditions.

2. *Programme of Flights.*

Lightning aircraft, operating from the A. & A.E.E. Boscombe Down, were used for the tests. These flew along the flight tracks shown in Fig. 1 at a nominal altitude of 43 000 ft (13 km) and at $M = 1{\cdot}4$. For these conditions the nominal sonic bang intensity is 1 lbf/ft^2 (48 N/m^2) near the ground in the open. The areas in which sonic bangs were expected to be heard are shown shaded in Fig. 1. Track 1 was primarily over Dorset, track2 over the Bristol Channel to Bristol, and track 3 over the Thames Estuary to London. The crescent-shaped regions indicate the focus areas.

The aircraft was brought onto track for the supersonic runs over the designated areas under the control of the Southern Air Traffic Control Radar Unit at Sopley. The accuracy with which an aircraft can be controlled by the Sopley radar is ± 2 naut mile (3·7 km), although the position of the aircraft can subsequently be determined with greater accuracy by analysis of the radar tracking records. Because the sonic bang intensity is not sensitive to lateral errors of ± 2 naut mile however, the heavy labour of such analysis has not been considered justified.

3. *Measuring Stations.*

For the Dorset and Bristol areas the pressure waveforms were measured at two stations on the nominal track, one being on land and the other at sea. For the Dorset area the land station was located on Bulbarrow Hill, 10 miles (16 km) west of Blandform (Map reference SY 776056). For the Bristol area it was located near Filton airfield, 5 miles (8 km) north of Bristol (Map reference ST 598795), save on one day when it was located at Frenchay Hospital (Map reference ST 639775). At these land stations measurements were taken with two pressure transducers flush with the ground. On some occasions extra measurements were taken in positions to be described later.

For the London area a further land measuring station was provided by the National Physical Laboratory in the grounds of the Royal Naval College, Greenwich (Map reference TQ 385750). They took measurements with a transducer flush with the ground. The R.A.E. measurements during this phase, however, were made on the roof of the Ministry of Defence Building Whitehall (Map reference TQ 303800), the transducers being simply laid on the roof surface.

The measuring positions at sea were chosen to be in the regions where the crescent-shaped focus areas were expected to fall, as shown in Fig. 1. For these measurements a ship, the motor vessel Cranborne, was used, on hire from John Carter and Company Ltd. of Poole, Dorset. The ship was 440 tons (4390 kN) weight, 166 ft (51 m) long, and had an open deck area of 78 ft $\times$ 27 ft (24 m $\times$ 9 m) on which the bangs were measured. The pressure transducer was simply placed on the deck surface 50 ft (15 m) forward of the ship's bridge and on the ship's centreline.

4. *Communications.*

Each of the measuring stations was in contact with ground control, and the aircraft, by means of aircraft type uhf radio sets. Apart from an acknowledgment of air-to-ground reception the radio sets were used by the stations for listening purposes only. Stop-action from the measuring stations was not required. Flight schedules were agreed on a daily basis between the R.A.E. land measuring station and the aircraft Squadron Commander. Before and after each flight various phone calls were made to a set routine. The communication pattern is set out in Table 1.

5. *Measurement Procedure.*

It was necessary to know the approximate time of arrival of a bang at a measuring station in order to minimise the possibility of false triggering of the equipment in windy conditions, and to economise on the amount of recording tape required. For this purpose, in consultation with the pilots, a simple system was introduced whereby, during the aircraft run, the code words Alpha, Bravo, Charlie etc. were called out by the pilot. These code words served to define the position of the aircraft relative to the measuring station. From a knowledge of the aircraft position the time of arrival of a bang at the ground can be calculated fairly accurately, but because of possible differences in the true and nominal aircraft position and slight delays in communication it is generally safe if the measuring equipment is put into the record-mode a minute before the nominal time of arrival of a bang. The nominal positions on the tracks at which the first four call-signs were made is given in Fig. 1, and the definition of all the code words of interest and their recorded transmission times with reference to the start of the run are given in the table below together with the BST of the bang at the R.A.E. land measuring station.

Date (July 1967)	Bang time BST	Code word transmission times after Alpha (seconds)					Bang time after Alpha (seconds)
		Alpha	Bravo	Charlie	Delta	Foxtrot	
6	1419	0	12	115	177	Not called	292
7	1051	0	15	101	147		280
10	1431	0	18	96	142		591
11	1144	0	32	114	158		577
12	1432	0	41	124	165		577
13	1531	0	20	92	148		560
14	1032	0	Not noted	Not noted	151		561
17	1530	0	32	110	155	420	510
19	1058	0	Not heard	Not heard	158	Not heard	500
20	1230	0	34	125	200	405	490
21	1158	0	30	115	180	420	505

The meanings of the code words in the above table were as follows:

Alpha —Turn onto track and accelerate at 36 000 ft (11 km)

Bravo —(Alpha + 5 naut mile (9 km)) Aircraft now just sonic at 36 000 ft (11 km)

Charlie —(Alpha + 25 naut mile (45 km)). Now $M = 1{\cdot}4$ at 36 000 ft (11 km). Start climb at $M = 1{\cdot}4$.

Delta —(Alpha + 35 naut mile (54 km)). Level at 43 000 ft (14 km), $M = 1{\cdot}4$, Cruising.

Foxtrot —Overhead R.A.E. land measuring station.

6. *Measuring Equipment.*

At the R.A.E. land and sea stations the pressure waveforms were measured with Bruel and Kjaer condenser microphone cartridges type 4131 specially modified to have a long pressure-equalisation time of about six seconds so as to facilitate measurement of the low frequency components of the sonic-bang waveform. They were used in conjunction with a frequency modulation system in which the cartridge capacity formed part of a tuned oscillator circuit stage. The frequency range of the combined measuring system was 0·1 Hz to 20 kHz, both limits being imposed by the cartridge characteristics. The pressure waveforms were photographed on an oscilloscope and at the land measuring station were also recorded on tape. The N.P.L. measurements were made with equipment of different manufacture and layout from that of the R.A.E., but working on the same principles.

7. *Meteorological Data.*

Meteorological conditions from places nearest to the R.A.E. land measuring station and at times closest to the times of the sonic bangs are given in Table 2.

8. *Results.*

8.1. *General Presentation.*

The waveforms of the bangs measured during the exercise are shown in Figs. 3, 5 and 7. The positions of the transducers for the measurements are shown in Figs. 2, 4 and 6 together with the values of the pressure rises and the intervals between shocks

8.2. *Measurements on Land in the Dorset and Bristol Areas.*

As can be seen from Figs. 2 and 4 the values of the pressure rises in the Dorset and Bristol areas are scattered about the designed value of 1 lbf/ft^2 (48 N/m^2), but, in general, as can be seen from Figs. 3 and 5, the waveforms resemble the classical N-waveform. The values of the overpressures range from about 0·8 to 1·4 lbf/ft^2 (38 to 67 N/m^2) and this range for these few records is perhaps, statistically, a little large. Appreciable departures from the nominal value are usually brought about by meteorological conditions which result in either rounded or spiky waveforms. However, in the Exercise, appreciable differences in pressure rise occur between good (N) waveforms. For example the waveforms of the bangs on 6 and 7 July recorded on Channels 1 and 2 in Fig. 3 are close to classical N-waveforms, yet there is a ratio of over 1·5 between their amplitudes. The general climatic conditions were similar on the two days so it seems likely that highly local and instantaneous meteorological conditions account for such differences, as has been observed on previous exercises. The intervals between the bow and stern shocks, however, are fairly consistent being of the order of 105 ms.

8.3. *Measurements on Land in the London Area.*

In contrast with the rather classical waveforms recorded at ground level in Dorset and Bristol, the waveforms of the bangs measured in London were unusual, as can be seen from Fig. 7. They are characterised by possessing two sharp peaks, the second one being partly positive, and with little negative phase evident. The extreme case is seen on Channels 1 and 2 for the bang on July 21. This waveform is rather similar to that resulting from two point explosive charges having a time delay between them.

If measurements had been taken on the roof of the M.O.D. Building only it would have been suspected that the unusual shapes of the waveforms were the result of some sort of interference by the building. However it can be seen in Fig. 7, Channel 4, that the measurements by the N.P.L. in an open area at the Royal Naval College, Greenwich were rather similar, although perhaps not so extreme in their departure from an N-waveform. In total, the waveforms measured in London were appreciably different from those measured on previous exercises, and this may be due to the greater possibility of multiple ray paths existing in a highly built-up area. The fact that relatively few measurements were taken in the London area, however, precludes a definite conclusion, and it may be safer at this stage to regard these 'unusual' waveforms as simply further examples of variations from the classical N-waveform. It is of interest to note that the intervals between shocks is significantly greater than those of the more classic waveforms recorded in Dorset and Bristol, particularly those measured by the N.P.L. Presumably the explanation for this will be associated with explanations of the waveforms.

8.4. *Measurements at Sea.*

The measurements at sea were undertaken to provide information about the level of the bangs in areas of focus, shown as crescents on Fig. 1. The difficulties of doing this with one transducer and relatively poor data on aircraft position was recognised at the outset, but at the worst it was felt that the measurements would serve as a guide to the bang level in an open area when measurements in confined spaces such as at London might be strongly affected by interference from buildings.

For the first three bangs recorded (that on July 6 being missed), the ship was nominally positioned at the centre of the crescent-shaped areas shown on tracks 1 and 2 of Fig. 1. However, the levels of the recorded bangs were close to the designed value of 1 lbf/ft^2 (48 N/m^2), and so apparently a focused bang was not being measured. Accordingly for some of the subsequent bangs the ship's position was adjusted, in an arbitrary way, relative to the nominal focus areas. This decision tacitly assumed that the aircraft flight plan remained reasonably constant in relation to the size of the assumed focus area. The subsequently estimated position of the ship and the aircraft, and the observations made are summarised in the following Table.

Date July (1967)	Estimated position of ship uptrack of centre of nominal focus area naut mile (km)	Estimated error in aircraft's position positive uptrack naut mile (km)	Deduced position of ship uptrack of estimated centre of actual focus area naut mile (km)	Observation
6	Not recorded	−3 (−5·6)	?	Bang heard but not recorded
7	Nominally in centre	+2 (3·7)	−2 (−3·7)	Pressure rise measured to be near designed value of 1 lbf/ft^2 (48 N/m^2)
10	−1·5 (−2·8)	+3 (5·6)	−4·5 (8·4)	
11	−0·75 (−1·4)	+1 (1·9)	−1·75 (3.3)	
12	+3 (5·6)	+1 (1·9)	+2 (3·7)	No bang heard
13	At centre	+2 (3·7)	−2 (−3·7)	Pressure rise 1·0 lbf/ft^2 (48 N/m^2)
14	+8 (14·8) Off track, south of nominal Delta position	+3 (5·6)	Outside the focus region	Bang heard but not recorded
17	−0·15 (0·3)	+2 (3·7)	−2·15 (−4·0)	Pressure rise 1·0 lbf/ft^2 (48 N/m^2)
19	+1 (1·9)	+3 (5·6)	−2 (−3·7)	Bang heard but not recorded
20	+0·75 (1·4)	0	+0·75 (1·4)	No bang heard
21	−0·25 (0·5)	0	−0·25 (−0·5)	High intensity bang recorded 2·2 lbf/ft^2 (105 M/m^2)

The above Table suggests that the region of high intensity associated with the focus is less than that drawn on the map in Fig. 1. It can be seen that a bang was heard at all positions down track of the estimated centre of the actual focus area (negative distances in the fourth column), and so no bang was heard at the two positions uptrack of the estimated centre. This observation can be narrowed further by noting the results of the measurements on July 20 and 21 which indicate a focus depth of less than 1 naut mile (1·9 km). Because of the paucity of information, however, this observation should be regarded as tentative, although it confirms American data.

The waveforms of all six bangs recorded at sea were similar although their shapes were not of such good N-waveform as those recorded on land in the Dorset and Bristol areas. Their shapes are consistent, however, and are likely to be due to interference by the ship.

The duration of the bangs measured at sea tended to be longer than those on land. This is expected from the lower Mach number at which the aircraft would be flying near the focus area. The duration was particularly long for the high intensity bang recorded on July 21. (*See* Fig. 6).

9. *Conclusions.*

The average sonic bang intensity during the Exercise was close to the designed value of 1 lbf/ft^2 (48 N/m^2). More than double this value was measured in the focus area on one occasion and from the very limited evidence obtained during the Exercise it seems possible that the extent of the high intensity region is quite small, being possibly less than 1 naut mile (1·9 km) along the direction of flight. The waveforms of the bangs measured in the London area, and particularly those on the roof of the M.O.D. Building, showed big departures from the classical N-shape.

Acknowledgement.

Acknowledgement is made of the four traces described in the report as Channel 4 in Fig. 7, which were provided by Dr. M. E. Delaney of the Acoustics Section of the National Physical Laboratory.

TABLE 1

Communication Pattern.

Sequence	Time	Object
	PRE-FLIGHT	
1	Day before trial	Inform ship of expected time of flight
2	0·930 BST	Phone Boscombe Down to confirm flight time
3	0949 BST	Inform ship of confirmed flight time
4	0945 BST	Inform Ministry of Agriculture, Fisheries and Food of flight time
5	Flight time minus 30 min	Check on flight time with Boscombe Down
6	Flight time minus 25 min	Confirm flight time with ship
7	—	If necessary recontact Ministry of Agriculture, Fisheries and Food
	DURING FLIGHT	
1	—	Listen out on Boscombe Down approach frequency of 260·9 Mc/s for 1 *minute only* after stated time of take-off
2	—	Switch to Sopley Southern Radar frequency of 293·7 Mc/s for remainder of flight. Note time of code calls
	POST-FLIGHT	
1	—	Call ship to obtain pressure measurements
2	—	Phone St. Giles Court to report on measurements at ground and sea stations
3	—	Phone Boscombe Down (a) to obtain corrected co-ordinates of the code call points (b) to discuss time of flight for following day

TABLE 2

Meteorological Conditions.

Meteorological Station and date (July 1967)	Time BST	Ground conditions				Cloud conditions	
		Air Tempera-ture (°C)	Relative humidity (%)	Wind direction (°)	Speed (knots)	Eighths type	Altitude (ft)
Hurn							
6	1300	20·9	54	180	5	1/8 Cu	2000
						5/8 Ci	20 000
7	1000	18·1	73	180	5	1/8 Ac	9000
						5/8 Ci	20 000
Filton							
10	1300	19·1	69	250	11	Nil	
	1600	22·1	64	250	8	1/8 Cu	3200
11	1000	17·3	86	Calm		2/8 Cu	1100
	1300	23·8	61	220	2	2/8 Cu	3000
12	1300	24·9	54	060	9	1/8 Cu	3200
						3/8 Ci	25 000
	1600	26·5	49	120	5	4/8 Cu	3500
13	1300	17·5	87	050	8	6/8 St	900
						8/8 St	1200
	1600	22·8	69	070	3	1/8 Ac	15 000
14	1000	17·4	67	260	15	7/8 Cu	1800
Kew							
17	1500	28·0	45	170	14	—	
	1600	28·7	43	170	14	1/8 Cu	4000
19	1000	19·9	64	230	8	3/8 Cu	3000
						7/8 Sc	4500
	1100	20·9	68	230	10	—	
20	1200	20·6	52	240	9	—	
	1300	20·7	48	240	10	2/8 Cu	3000
21	1200	20·2	49	270	3	—	
	1300	21·0	42	240	3	3/8 Cu	3500
						3/8 Sc	4300

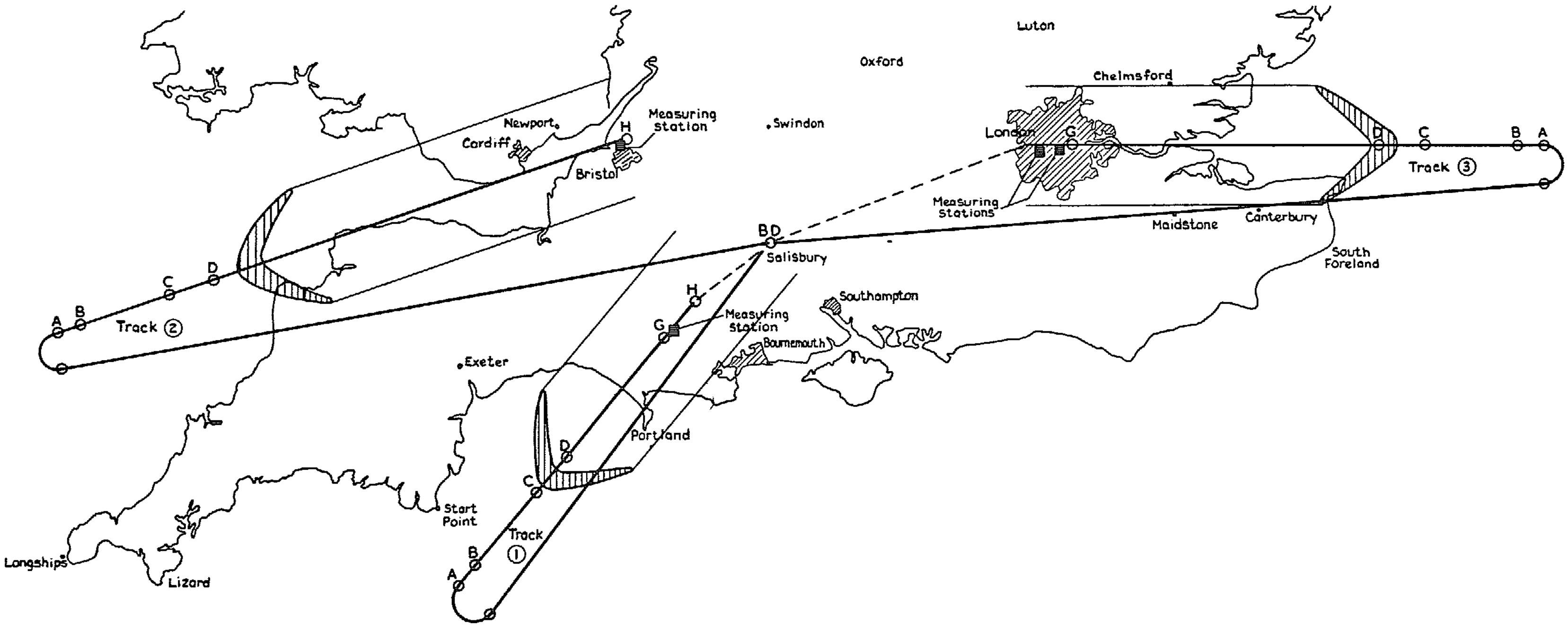

FIG. 1. Flight tracks of Lightning aircraft over Southern England.

Date (July 1967)	Channel No.	Position of transducer	Bow shock pressure rise lbf/ft^2 (N/m^2)	Time interval between shocks ms
6	1	Flush with ground in the open	1·3 (62)	106
7			0·9 (43)	106
6	2	Flush with ground in the open 50 ft (15 m) down track of Channel 1	1·4 (67)	106
7			1·0 (48)	106
6	3	145 ft (46 m) above ground	0·87 (42) (incident shock)	106 (incident) 105 (reflected)
7		180 ft (55 m) above ground	0·57 (27) (incident shock)	107 (incident) 106 (reflected)
7	5	*At Sea* Lying on fore hatch cover of ship, nominally in centre of focus area	0·9 (43)	117

FIG. 2. Details of measurements in the Dorset area.

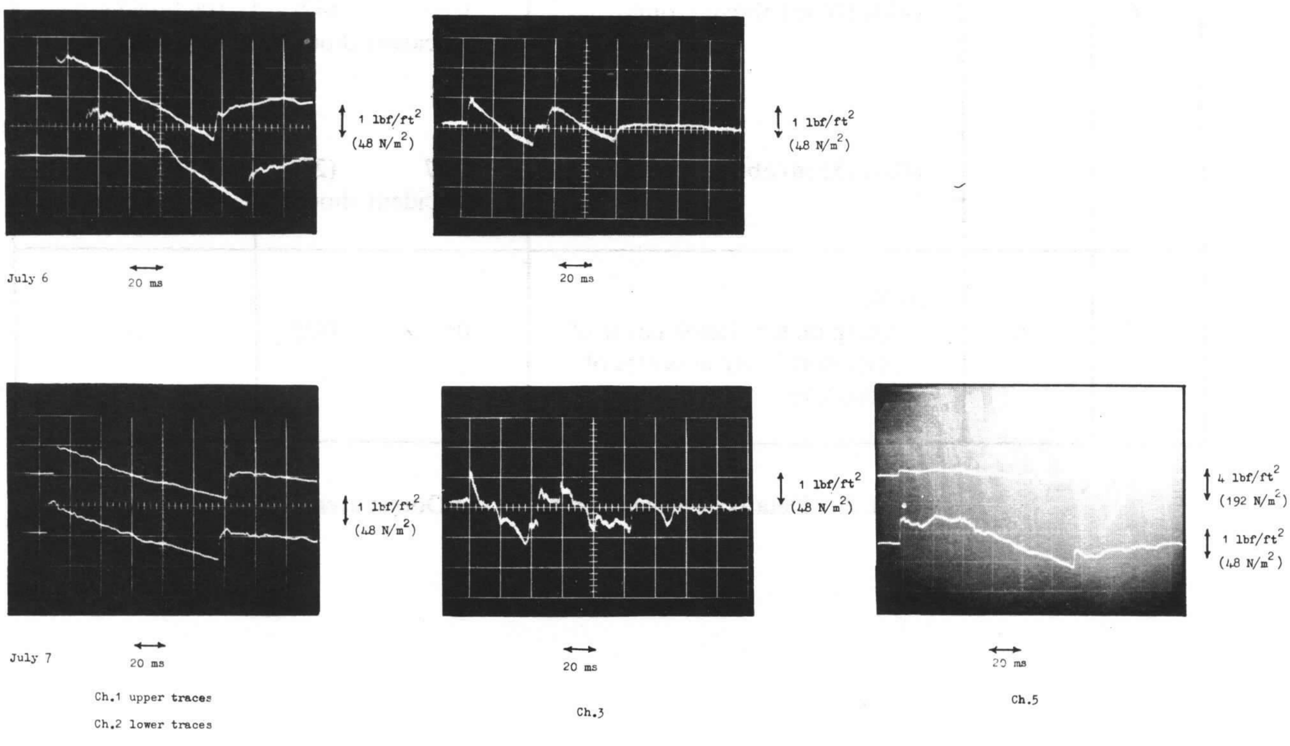

FIG. 3. Waveforms of Sonic Bangs in the Dorset area.

Date (July 1967)	Channel No.	Position of transducer	Bow shock pressure rise lbf/ft^2 (N/m^2)		Time interval between shocks ms
10	1		0·8	(38)	106
11		Flush with ground in the open (Filton)	1·0	(48)	103
12			0·9	(43)	103
13		Flush with ground in the open (Frenchay)	0·8	(38)	105
14		Flush with ground in the open (Filton)	0·7	(34)	95
10	2	Close to Channel 1	0·8	(38)	106
11		100 ft (31 m) from Channel 1, across track	1·0	(48)	102
12		50 ft (15 m) from Channel 1, across track	1·0	(47)	Not measurable
13		Close to Channel 1	0·8	(38)	104
14		Close to Channel 1	0·8	(38)	95
13	3	On bench top in Pathological Lab. of Frenchay Hospital	0·9	(43)	Not applicable
		At Sea			
10	5	Ship nominally in centre of focus region	0·9	(43)	112
11		Ship nominally in centre of focus	1·1	(53)	108
12		Ship 3 naut mile (4·8 km) up track focus	1·0	(48)	108

FIG. 4. Details of measurements made in the Bristol area.

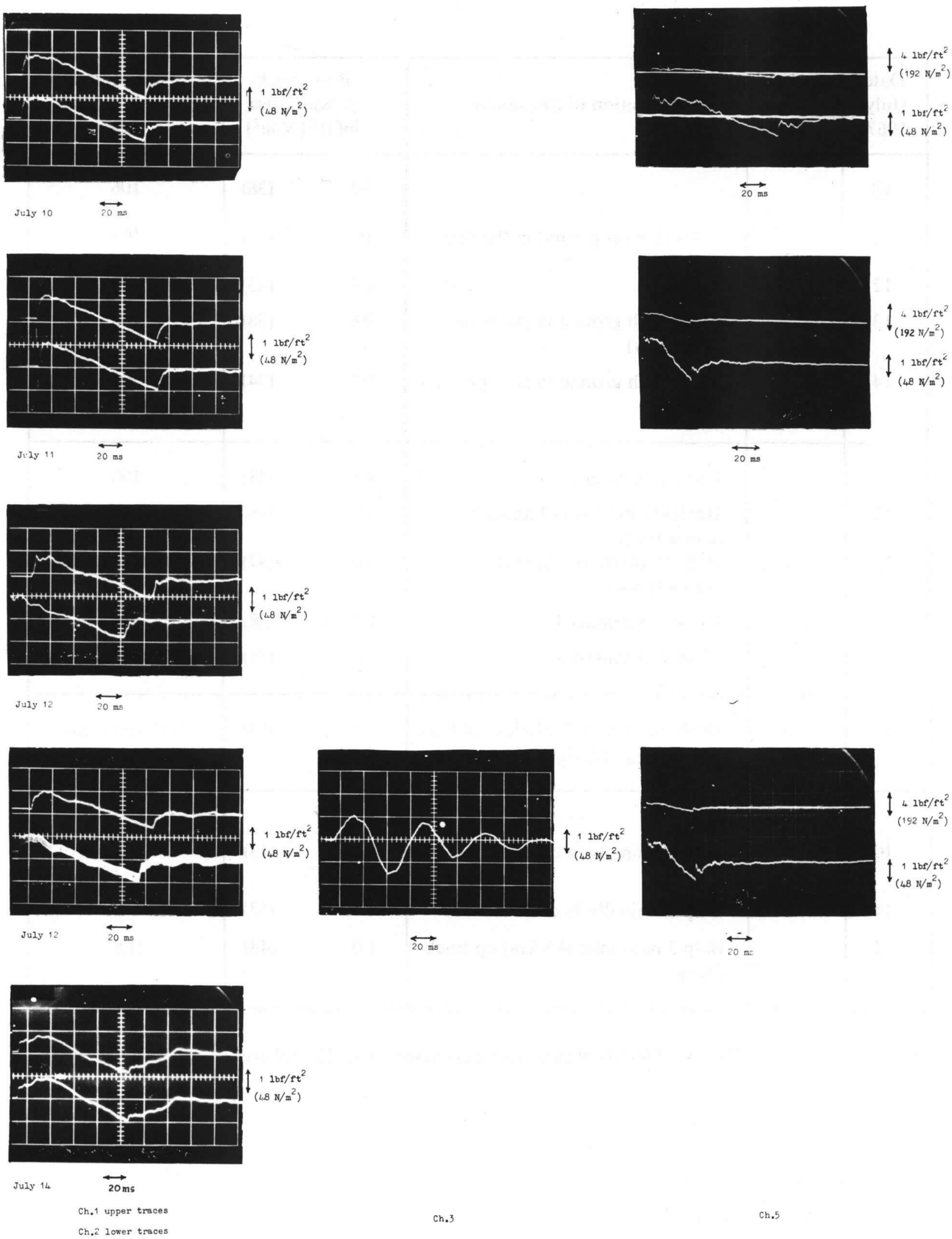

FIG. 5. Waveforms of Sonic Bangs in the Bristol area.

Date (July 1967)	Channel No.	Position of transducer	Bow shock pressure rise lbf/ft² (N/m^2)	Time interval between shocks ms
17 } 19 }		Lying on roof of Spine 4	2·0 (96) 1·5 (72)	117 118
20		13 ft (4 m) above roof of Spine 4	0·7 (34) (incident shock)	112
21	1	Attached to wooden fence 5 ft (1·5 m) above local roof level on on roof garden adjacent to Defence Council Suite	1·2 (58)	116
17 } 19 } 20 }		Lying on roof of Spine 4	2·3 (110) 1·5 (72) 0·6 (29)	117 118 112
21	2	Attached to wooden fence 5 ft (1·5 m) above floor of roof garden adjacent to Defence Council Suite	1·3 (62)	116
17 } 19 } 20 }	4	Flush with ground in the open (Greenwich)	0·9 (43) 0·7 (34) 1·0 (48)	125 129 114
21			1·7 (81)	118
17	5	*At Sea* Ship 0·75 naut mile (1·4 km) uptrack of nominal focus	1·0 (48)	118
21		Ship 0·25 naut mile (0·5 km) downtrack of nominal focus	2·2 (105)	136

FIG. 6. Details of measurements in the London area.

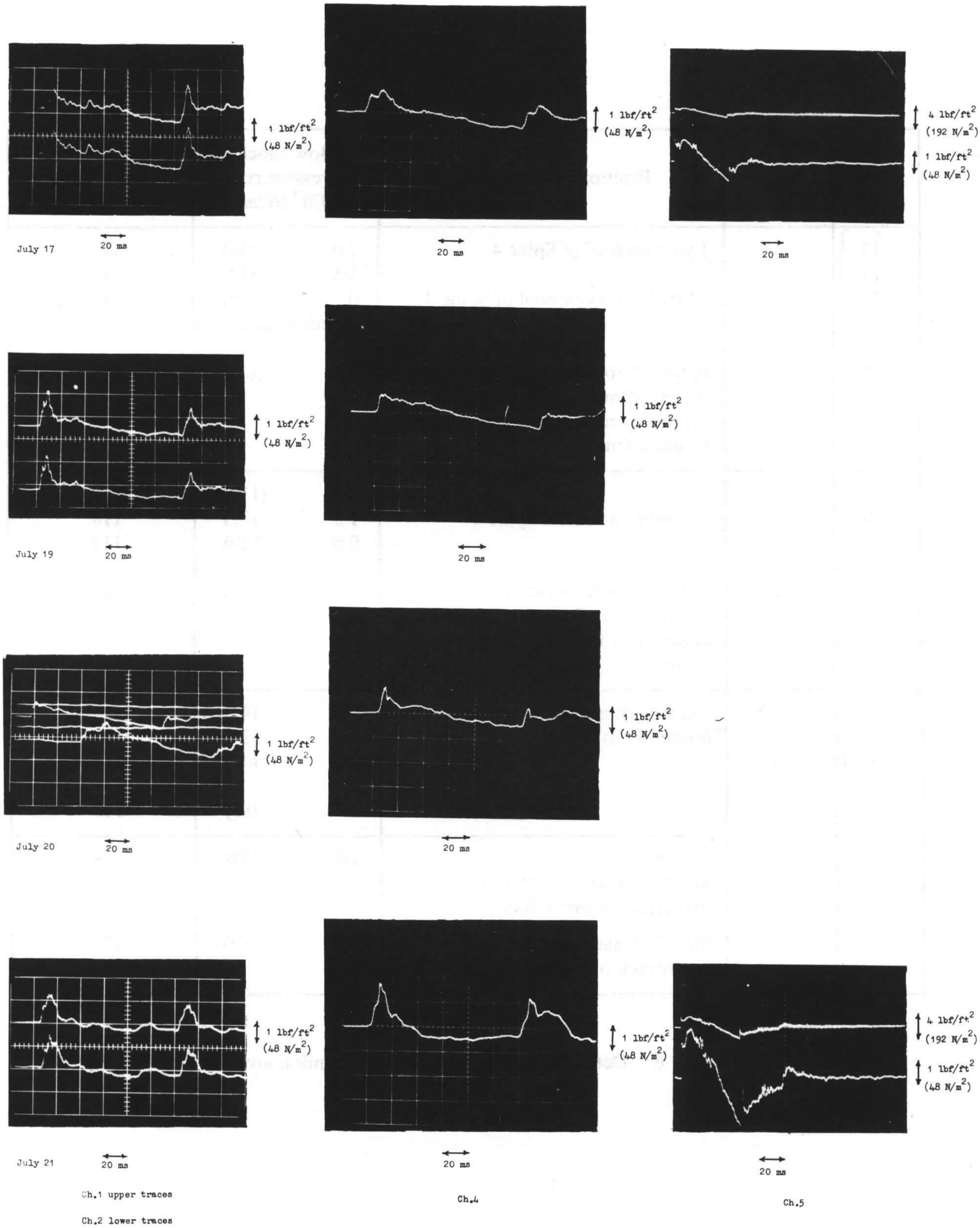

FIG. 7. Waveforms of Sonic Bangs in the London area.

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