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Sonic booms and other aircraft noise in studios

PART I

NOISE FROM SONIC BOOMS

by

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(Research Department, BBC Engineering Division)

PART II

NOISE FROM SUBSONIC AIRCRAFT

by

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(Research Department, BBC Engineering Division)

BRITISH BROADCASTING CORPORATION

PRICE FIVE SHILLINGS

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FOREWORD

THIS is one of a series of Engineering Monographs published by the British Broadcasting Corporation. About six are produced every year, each dealing with a technical subject within the field of television and sound broadcasting. Each Monograph describes work that has been done by the Engineering Division of the BBC and includes, where appropriate, a survey of earlier work on the same subject. From time to time the series may include selected reprints of articles by BBC authors that have appeared in technical journals. Papers dealing with general engineering developments in broadcasting may also be included occasionally.

This series should be of interest and value to engineers engaged in the fields of broadcasting and of telecommunications generally.

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SONIC BOOMS AND OTHER AIRCRAFT NOISE IN STUDIOS

SUMMARY OF PARTS I AND II

Part I of this monograph gives a brief description of the causes and some of the effects of sonic booms produced by supersonic aircraft. The results of measurements made during a demonstration of sonic booms have been used to show that studio roofs having an average insulation of 70 dB are probably adequate protection against sonic booms of intensities likely to be accepted in urban areas. In some circumstances insulation provided against other aircraft noises may be adequate to exclude sonic booms and in Part II the actual levels and spectra of noise from subsonic aircraft (including helicopters), as well as the distribution of noise levels around a major airport, are considered in order to reach a specification for the sound insulation of roofs to exclude such noise.

1. Definitions

Several terms in common use to describe aircraft noise and sound insulation are defined here to assist in the reading of the following sections.

(*a*) *Mach Number*

The ratio of the speed of an aircraft to the speed of sound in the vicinity of the aircraft is known as the Mach number. At Mach numbers of unity or greater, shock waves will be generated by the motion of the aircraft.

(*b*) *'A' Weighted Sound Levels (dBA or SLA)*

Sound pressure levels filtered by means of a weighting network which is an approximation to an equal loudness contour for the ear. The particular loudness for the 'A' weighting is that having a reference value of 1 kHz pure tone of sound pressure level 40 dB relative to 2×10^{-5} N/m^2.* For certain classes of noise dBA values have been found adequate to rate the noises in order of subjective noisiness.

(*c*) *Perceived Noise Decibel (PNdB)*

A weighting function developed to place aircraft noise in order of noisiness.[1] The mathematical process to convert octave band analysis into PNdB is tedious but an electrical weighting network used on analysis has been found to give an adequate approximation; such values would be designated dBN.

(*d*) *Noise and Number Index (N.N.I.)*

An index of average annoyance derived from the sum of the average noise level in PNdB and a factor relating to the number of aircraft producing this noise level.

N.N.I. $=$ (average peak noise level, PNdB) $+$ $15(\log_{10}N) - 80$

where N $=$ number of aircraft per day producing the average noise level.

(*e*) *Sound Level Difference*

The arithmetic difference between the average sound pressure levels in the reverberant field on the source side of a barrier and those on the far side of the barrier.

(*f*) *Average Sound Level Difference*

In order to simplify general discussions and permit the use of a single figure to describe the behaviour of a construction, an average of the sound level differences between 105 and 3,200 Hz is normally taken. Since measurements in the BBC Research Department are taken at half-octave intervals in a series including 1 kHz this range is normally shortened symmetrically to be the average between 125 and 2,800 Hz.

(*g*) *Mass Law*

A homogeneous single-skin barrier is found to give sound level differences which increase at a rate of 5 dB/octave over a considerable frequency range. The particular value at a given frequency is a function of the surface density (mass/unit area) of the barrier.

PART I

NOISE FROM SONIC BOOMS

2. Introduction to Part I

The advent of supersonic airliners and the possibility that they may be flown over studio areas prompted a precautionary investigation of background noise in studios arising from sonic booms. The work was mainly directed towards finding out if the roof insulation criterion for studios recently recommended within the BBC would need to be modified to cope with sonic booms as well as the noise of present-day aircraft. To assess the likelihood of sonic booms near studios, we may note that some authorities estimate that for economic reasons supersonic airliners should attain supersonic speeds within about 160 km (100 miles) of the airport. Sonic booms over heavily populated areas of Great Britain are therefore unlikely to arise from British aircraft. Air routes between the Continent of Europe and America are, however, likely to cross the country and since the boom from a high-flying aircraft is audible over a corridor up to about 64 km (40 miles) wide, many parts of the country could be subjected to this nuisance.

* Newtons per square metre. 1 N/m^2 = 10 dynes/cm^2.

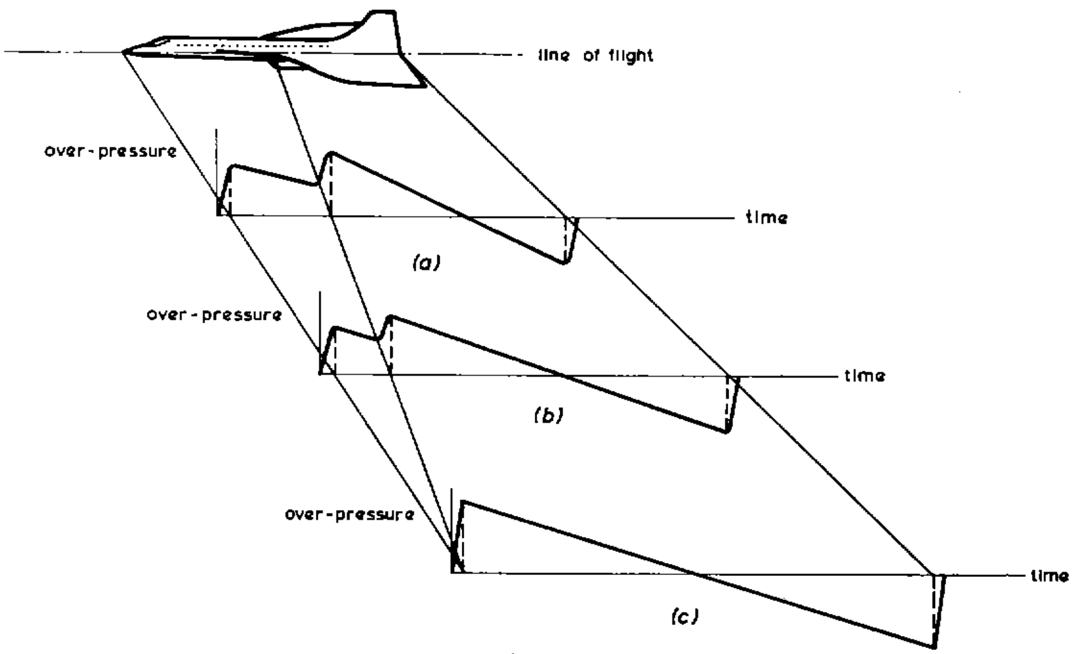

Fig. 1 — *Pressure distribution in a shock wave from a supersonic aircraft*
(*a*) Close to aircraft (*b*) About 305 m (1,000 ft) from aircraft (*c*) At a great distance from the aircraft and thereafter to ground level

3. The Cause and Effects of Sonic Booms

3.1 *The Generation of Sonic Booms*

A sonic boom is the audible feature of shock waves generated by an aircraft flying at supersonic speed. The leading and trailing edges of the aircraft give rise to disturbances comprising sharp rises in pressure, as depicted in Fig. 1 where the pressure distribution in the shock wave is shown near to the aircraft (Fig. 1(*a*)), at about 305 m from the aircraft (Fig. 1(*b*)), and at a great distance from the aircraft (Fig. 1(*c*)).[2] Ordinates represent over-pressure, i.e. the difference between the instantaneous air pressure and the ambient atmospheric pressure, while abscissae represent time.

A shock wave travels at approximately the speed of sound prevailing in the region immediately in front of it, and it must therefore lie along a line making an angle with the line of flight given by $\mu = \sin^{-1}(1/M)$, where M is the Mach number. The direction of the shock wave relative to that of the aircraft is shown in the insert to Fig. 3. As is shown by Wood,[3] pressure disturbances of large amplitude, such as exist in shock waves, propagate at speeds differing from the normal speed of sound, compressions travelling more quickly and rarefactions more slowly. Hence, the region of high pressure, occurring where the pressure jump at the leading edges of the wings is added to the overpressure following the bow shock wave (Fig. 1(*a*)), eventually catches up with the bow shock wave. Similarly the rarefaction at the tail lags farther behind. Hence the shape of the pressure wave changes as the distance from the aircraft increases, as shown in Figs. 1(*b*) and 1(*c*).

The shape of the pressure distribution in Fig. 1(*c*) resembles an 'N' and is often referred to as an 'N'-wave. It represents the basic shape of sonic boom pressure waves at ground level. Because of sundry atmospheric effects and reflections from the ground and buildings the pressure variation found in practice is seldom as simple as that shown in Fig. 1(*c*). Two examples of 'N'-waves found experimentally are shown in Fig. 2 for comparison.

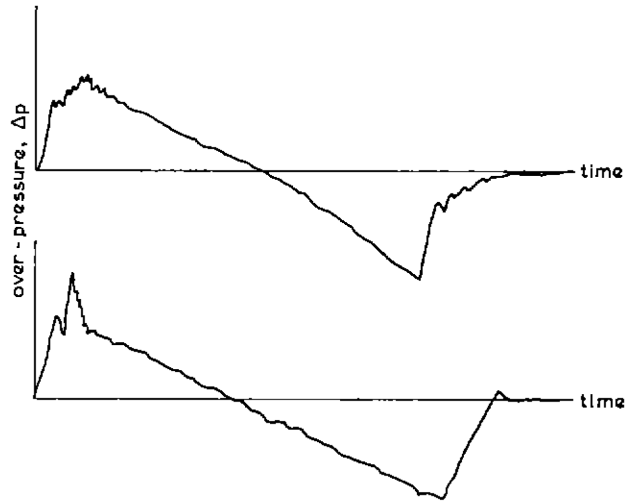

Fig. 2 — *Observed pressure waves of two sonic booms*

At any instant the leading and trailing shock waves from the aircraft lie approximately along a pair of cones each intersecting the ground area in a hyperbola as shown in Fig. 3. These hyperbolae sweep across the country, delineating the corridor within which a sonic boom will be heard.

For a given aircraft speed and height the duration of the 'N'-wave is governed chiefly by the aircraft length; for example a 16·8 m long Lightning fighter in steady level flight at Mach 1·4 and height of 9,150 m gives an 'N'-wave

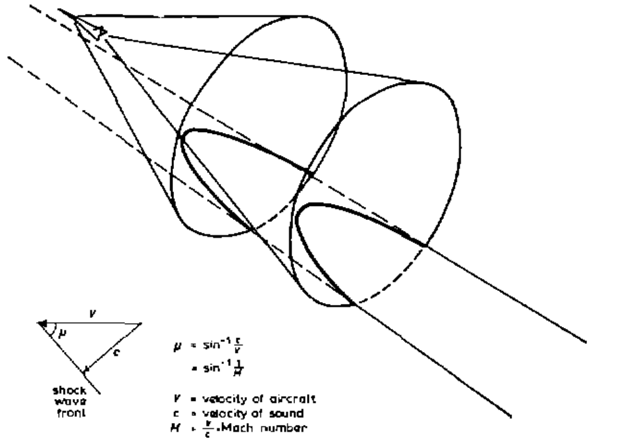

Fig. 3 — Aircraft shock waves intersect ground in hyperbolae which sweep over the ground

duration of about 120 ms while a 56·4 m long Concorde will probably give a duration of about 400 ms.

A useful measure of the strength of an 'N'-wave is the peak over-pressure. This is basically influenced by the aircraft dimensions and weight, and is further affected by propagation through the atmosphere. The over-pressure is approximately doubled at ground level due to the summation of the incident and reflected waves. The peak over-pressure may be increased at some points distant from the aircraft by focusing of the shock wave due to turning or acceleration of the aircraft or transmission of the shock wave through a non-homogeneous atmosphere having wind or temperature gradients.

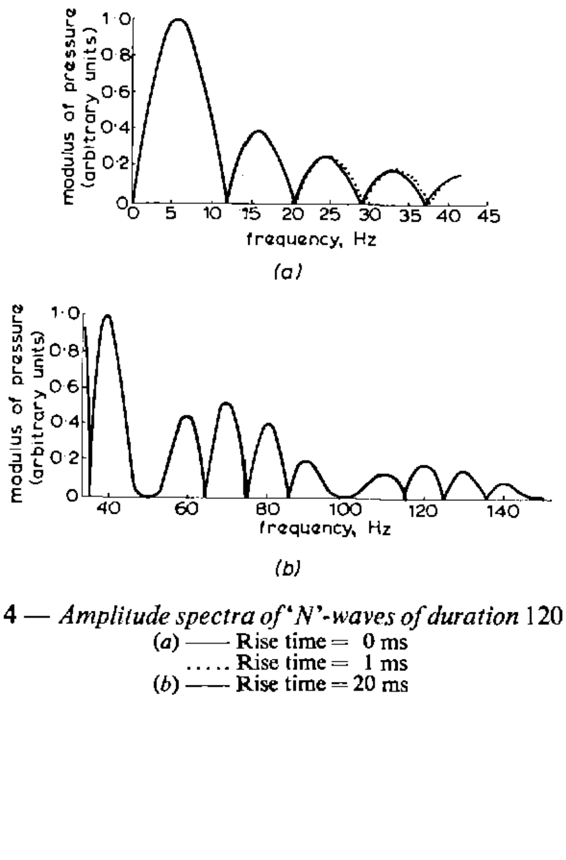

Fig. 4 — Amplitude spectra of 'N'-waves of duration 120 *ms*
(*a*) —— Rise time = 0 ms
..... Rise time = 1 ms
(*b*) —— Rise time = 20 ms

3.2 *Amplitude Spectrum of an 'N'-wave*

To investigate the frequency distribution of energy in a sonic boom a Fourier analysis was carried out on an ideal 'N'-wave. The 'N'-wave was treated as an isolated event and therefore possessed a continuous amplitude spectrum, the chief factors governing the energy distribution being the initial and final rise time and the total duration of the 'N'-wave. A computer programme was written to evaluate the amplitude spectrum and some of the results are shown graphically in Fig. 4. It can be seen that most of the energy is concentrated at sub-audio frequencies. The amplitude spectrum of an 'N'-wave with a rise time of 1 ms, a duration of 120 ms and a peak over-pressure of 95·8 N/m² (2 lb/ft²) was integrated over octave bands to give approximate sound pressure levels. The 'N'-wave parameters assumed here are typical of those for a Lightning aircraft in level flight at Mach 1·4 and about 9,150 m altitude. The computed results are shown in curve (*c*) of Fig. 5 compared with an octave band analysis of two actual booms (curves (*a*) and (*b*)) recorded at Upwood as described in Section 4.2.

3.3 *Noise, Vibration, and Damage*

The principal evidence which exists concerning the effects on a population exposed to sonic booms is derived from experiments in the U.S.A. and the results may not be directly applicable to Britain. Broadbent and Robinson,[4] working in this country, have suggested that a sonic boom with an over-pressure of 95·8 N/m² (2 lb/ft²) can be considered subjectively equivalent to aircraft noise at 110 PNdB and may be accepted without serious protest by members of the public in urban areas.

The subjective tests carried out in the U.S.A.[5] where a mid-western town was exposed to sonic booms for a six-month period, indicated a value of 102 PNdB as being equivalent to an over-pressure of 95·8 N/m² (2 lb/ft²).[6] When the series of tests began the population showed a considerable reaction based on the surprise quality of the boom and within two weeks telephone calls of inquiry or complaint were received by the local authorities at a rate of 1,700 per week. As the tests continued this number fell to a fairly steady 250 telephone calls per week and it appeared that the population had to some extent accommodated to the nuisance. The tests did not continue for a sufficient period to show whether this accommodation would continue or whether some hardening of the public attitude might build up.

Within a broadcasting organization a somewhat different attitude might be expected. In most types of programme extraneous noise, particularly if it is recognizable, is unacceptable. A particular example of this might be period drama where a noise recognizable as a sonic boom would be totally anachronistic. The investigation described in the following Sections was carried out to determine whether the boom noise levels in studios might cause disturbance, and if so, whether some increase in roof insulation might be required.

A limited amount of evidence has been gathered in this country on the effect of sonic booms on structures. It seems probable that the vibration amplitudes produced in primary structural elements are insufficient to cause damage. Even in secondary structures such as plasterwork or glass, it is unlikely that the vibration amplitudes produced by subjectively acceptable shocks will be sufficient to cause damage unless a previous weakness exists. It may be assumed therefore that within the BBC our interest will rest entirely on the subjective effects of the shock waves.

4. Measurements at the R.A.F. Station, Upwood

4.1 *General Description of the Tests*

On 21 April 1965 a demonstration of sonic booms was arranged by the Ministry of Aviation to demonstrate to Members of Parliament and other interested parties the audible effects of sonic booms, and to compare them with the noise levels produced by a jet aircraft. Arrangements were made for a Research Department team to be present at the demonstration and to make recordings. Discussions with the Administration Officer about available Station buildings with good sound insulation resulted in a medical decontamination centre being put at our disposal. For protection against air-raid damage, this building has a heavy roof and the central room in the building is protected on each side by a series of anterooms and blast doors. The dimensions of the central room are approximately 7·6 m × 7·6 m × 3·0 m.

The recordings were made in the central room and on the roof, the primary aims being to determine the effects, if any, of a sonic boom on programme microphones, and to measure the sound pressure levels resulting from the boom. A capacitor microphone (AKG Type C12) and a ribbon microphone (BBC Type PGS/1) were selected as being representative of two types of microphone in common use. In addition, a calibrated omni-directional moving coil microphone (S.T. and C. Type 4021) was placed in the room. A second calibrated moving coil microphone in a wind-shield was placed on the roof of the building. Accelerometer measurements were made of the vibration levels produced in the ceiling.

The flight programme consisted of six events, two fly-overs by a Comet jet aircraft producing 110 PNdB, and four sonic booms producing peak over-pressures of between 60 N/m² (1·25 lb/ft²) and 120 N/m² (2·5 lb/ft²). This range of over-pressures was selected as being that which covered the values likely to be acceptable to the public. The programme was performed twice during the day.

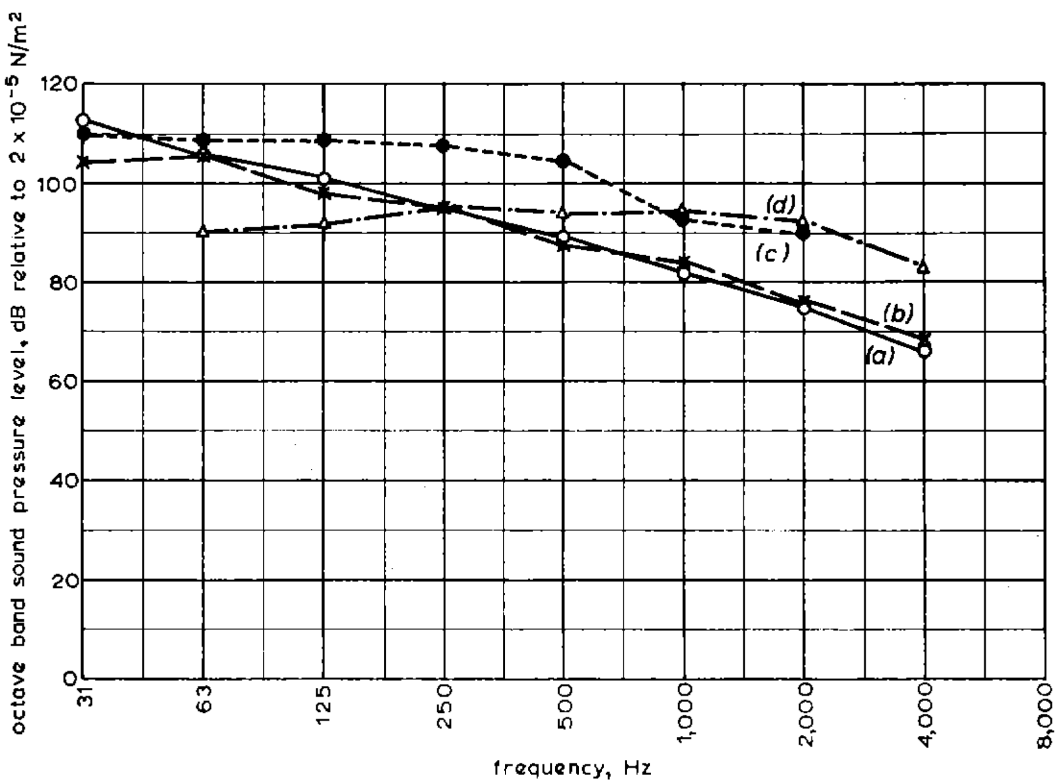

Fig. 5 — Octave band sound pressure levels

(a), (b) Two actual sonic booms of 95·8 N/m² (2 lb/ft²) peak overpressure
(c) Theoretical S.P.L.'s for a 95·8 N/m² (2 lb/ft²) 'N'-wave—duration 120 ms—rise time 1 ms
(d) Comet aircraft, 110 PN dB, measured

4.2 *Results*

No distortion due to overloading was subjectively apparent on any of the microphone outputs. The results from the ribbon and capacitor microphones were used to complement results from the moving coil microphones.

The microphone and accelerometer outputs for a representative number of the events were recorded on magnetic tape and were subsequently analysed by playing them through octave band-pass filters on to a high-speed level recorder. The tape recorders used with the microphones were of the conventional high quality audio-frequency type so that the frequency bandwidth of the broadcast programme chain was adequately covered. Special equipment for recording the whole frequency spectrum of sonic booms has been described by Taniguchi,[7] but was not considered to be necessary for the present purpose.

The octave band sound pressure levels of two sonic booms and a Comet aircraft flyover recorded on the roof are plotted in Fig. 5 for comparison with the theoretical integrated 'N'-wave spectrum. The reasonable agreement between the theoretical and experimental curves at low frequencies provides evidence that the experimental measurements were not adversely affected by the intense low frequency energy of the sonic booms. The sound pressure levels at low frequencies are primarily determined by the peak over-pressure and duration of the 'N'-wave, for both of which there was good agreement between the theoretical and experimental pressure waves. Agreement above about 100 Hz should not be expected because atmospheric and ground conditions rarely allow an ideal 'N'-wave to be observed. Rounding of the peaks and other deviations from the idealized 'N'-wave give rise to the gentle slope of the measured spectra as compared with the relatively sharp drop in the theoretical spectrum above a frequency of about 1 kHz corresponding to the rise-time of 1 ms. It is of interest to compare the $95 \cdot 8$ N/m^2 (2 lb/ft^2) sonic boom spectra with that from a Comet aircraft with a weighted sound level of 110 PNdB, although the subjective annoyance may not be directly related to the pressure spectrum. It seems probable that the higher noise levels at high frequencies from aircraft engines are subjectively balanced by the higher pressures at low frequencies from sonic booms.

The accelerometer measurements were not comprehensive but the measured accelerations did not exceed an acceptable value (about $0 \cdot 01$ m/s^2).

It has been found that measurements with a continuous noise such as that from a jet engine correspond closely to standard measurements of sound insulation and give results in good agreement with laboratory tests. Fig. 6 shows the values of sound level reduction from outside to inside the decontamination centre using the measured sound pressure levels of jet engine noise and sonic boom. Above 500 Hz the values derived from sonic boom sound pressure levels are considerably reduced. The possibility that the effective sound level reduction at frequencies of 1 kHz and above is lower for shock excitation than for continuous excitation must therefore be considered. No evidence to support this suggestion has been found heretofore, and measurements of sound insulation made with a $0 \cdot 45$ in. (11 mm) calibre revolver have agreed well with conventional measurements. It will be shown later, however, that the effect is not significant in this investigation.

5. The Relationship between the Measurements and BBC Practice

5.1 *Synthesis of Sonic Boom Sound Pressure Levels (S.P.L.'s) inside a Television Studio*

The type of studio most susceptible to interference from aircraft noise or sonic booms is that having a large area of roof not screened by surrounding buildings or natural obstacles. Consequently considerable attention has been paid to the sound level reduction required of studio roofs. The standard of studio roof insulation proposed at the time of these tests is shown in Fig. 6. A studio with a roof conforming precisely to this standard is said to have a '70 dB roof', 70 dB being approximately the average value of sound level reduction between the internationally agreed limits of 100 Hz and 3,200 Hz.

To assess the interference that a sonic boom would cause if it occurred during a drama production, especially during a quiet moment of tension, an estimate was made of the noise spectrum that might occur within a studio having a 70 dB roof. Taking the S.P.L.'s of one of the sonic booms recorded at Upwood as representative of those likely to prevail above the studio roof, the levels inside the studio (Fig. 7) were obtained by subtracting at each frequency the sound level reduction for a 70 dB roof. Fig. 7 shows that the noise inside a studio would be negligible at frequencies above about 500 Hz and this conclusion remains true even if allowance is made for uncertainty about the effective insulation at high frequencies under shock wave excitation, to which reference was made in Section 4.2 above.

The greatest noise excess above the permissible level is shown in Fig. 7 to be 11 dB in the 125 Hz octave band. This level is probably not high enough to interfere seriously with programme even if it occurs in a moment of quiet provided that it occurs infrequently, as is most likely.

5.2 *Demonstration Recording*

To facilitate communication of the essential results to interested people a recording was prepared for subjective assessment. The recording demonstrated sonic booms and a jet flyover on the one hand and on the other hand it included the noise of sonic booms attenuated as if by a roof and superimposed on an excerpt from a television play. Emphasis was laid on the programme interference caused by the sonic booms.

The procedure adopted in preparing the drama excerpt was as follows:

(*a*) A recording was obtained of a television drama production made in a studio with a background noise approximating to the appropriate characteristic curve of maximum permissible noise;

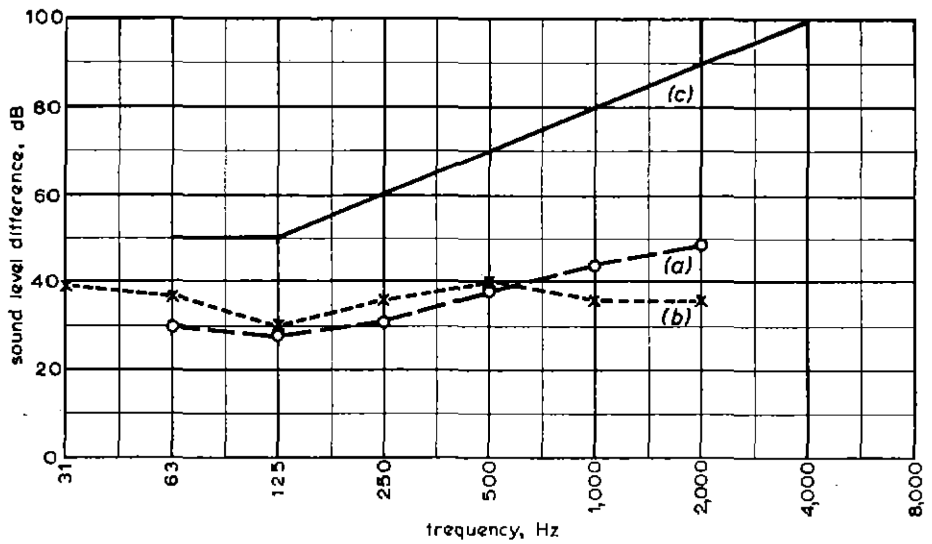

Fig. 6 — Sound level differences

(*a*) Decontamination centre, Upwood. Measured with jet engine noise
(*b*) Decontamination centre, Upwood. Measured with sonic booms
(*c*) Proposed insulation for studio roofs

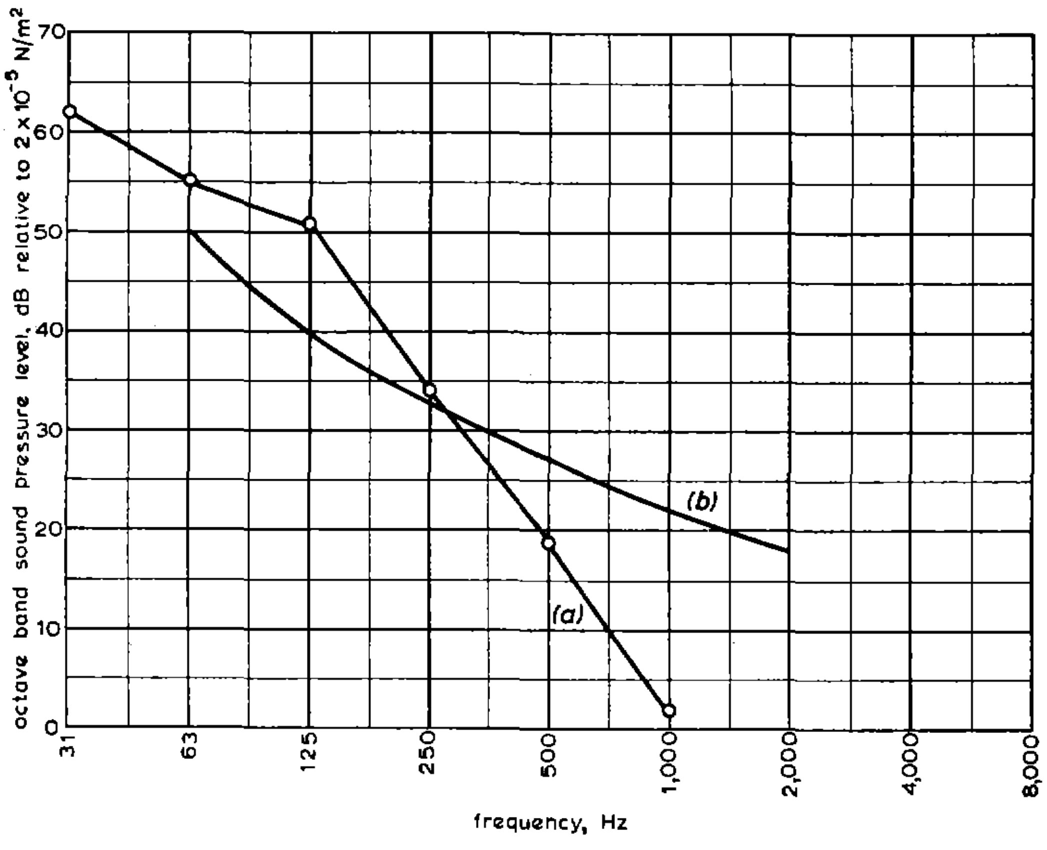

Fig. 7 — Octave band sound pressure levels

(*a*) Estimated S.P.L. of 95·8 N/m^2 (2 lb/ft^2) sonic boom inside a television studio
(*b*) Permissible background noise inside a television studio

(*b*) It was felt that the listener would probably be annoyed to the greatest extent when a sonic boom occurred during a tense dramatic sequence. Excerpts were accordingly chosen to represent this type of sequence.

(*c*) The recording of a sonic boom made inside the building at Upwood was played through a variable filter unit to make its spectrum approximately that of a boom as heard inside a studio with a 70 dB roof (see Fig. 7).

(*d*) The modified boom recording was dubbed on to the drama excerpt at appropriate moments. The ratio of the boom level to the background noise level in the drama excerpt was arranged to be the same as the ratio of a 95·8 N/m^2 (2 lb/ft^2) boom level, attenuated by a 70 dB roof, to the maximum permissible background noise level for television studios (see Fig. 7).

In order to enhance the realism of the demonstration care was taken when the final recording was replayed to make the audible sound pressure levels in the listening room, for the sonic boom and jet aircraft flyover, approximately equal to the ground level open-air values. Conventional high quality audio-frequency reproduction equipment was used and consequently, although the full subjective effects of the boom and flyover were not reproduced, a large enough frequency band was represented for assessing the effects on broadcasts. The television drama excerpts were replayed at about the mean listening level adopted by BBC engineers.[8]

The final recording was demonstrated to the interested parties within the BBC. The general reaction was that the interference with programme caused by a 95·8 N/m^2 (2 lb/ft^2) sonic boom is not serious when the studio has a 70 dB roof, and that no special precautions need be taken against sonic booms at the moment so far as studios are concerned.

6. Conclusions

(*a*) If commercial supersonic flight becomes general, sonic booms will probably be experienced in most parts of the country, mainly from air routes between North America and the Continent of Europe.

(*b*) Legislation is likely to impose an upper limit of 95·8 N/m^2 (2 lb/ft^2) on the permitted over-pressure at ground level from such aircraft.[6]

(*c*) If the above two conclusions are borne out in practice, a mean roof insulation of 70 dB should be adequate to avoid interference on programmes, provided the upper limit of over-pressure is strictly observed.

7. Acknowledgments

The BBC wishes to express appreciation of the help given by the Ministry of Aviation, R.A.E. Farnborough, and R.A.F. Upwood.

PART II
NOISE FROM SUBSONIC AIRCRAFT

8. Introduction to Part II

8.1 *General*

During recent years the noise from aircraft has increased in loudness with the increasing use of jet propulsion and the greater size and weight of aircraft. The use of jet aircraft on domestic routes has meant a corresponding rise in the number of such aircraft using all airports and a much more widespread distribution of the noise over the country. The length of runway required to accommodate fast jet aircraft has meant extensions to existing airports or the construction of new airports close to major cities. As a result of the increase of noise level, interference with programme has occurred in some studios and, in common with most broadcasting authorities, the BBC found it necessary to specify the sound insulation required to exclude such noise.

A specification and design for a studio roof adequate to protect programmes from the noise of jet aircraft was first produced by Research Department in conjunction with Building Department at the time of the construction of a new television studio at Glasgow.

In normal wind conditions, the instrument approach path to Renfrew Airport lay directly over Broadcasting House, Glasgow, and landing aircraft passed over at a height of about 300 m. Our limited range of measurements at that time together with published figures and an allowance for future increases in noise levels suggested that at this height aircraft might, in due course, produce sound pressure levels up to 100 dB in many octaves. Taken in conjunction with the acceptable noise levels for studios then in force, these values led to the conclusion that a roof having sound level differences giving an average value of 70 dB would be required to render the jet noise acceptable inside the studio. In order to illustrate this recommendation a demonstration was arranged in a television studio. Aircraft noise was reproduced over loudspeakers at the levels to be expected in a studio having an average roof insulation of 60 or 70 dB. It was felt at that time that a 70 dB roof was necessary and on this recommendation a double-skin roof was constructed for the Glasgow television studio.

8.2 *1966 Demonstration Recordings*

Recently, during a period of financial stringency, roof insulation requirements for new studios were brought under review. A further demonstration tape was produced in which aircraft noise, as heard inside a studio, was superimposed on an extract of television drama. The drama recordings were made in the BBC Television Centre, Studio 1, a studio having ventilation noise levels following very closely the curve (*b*) in Fig. 8 specified as acceptable in television studios.

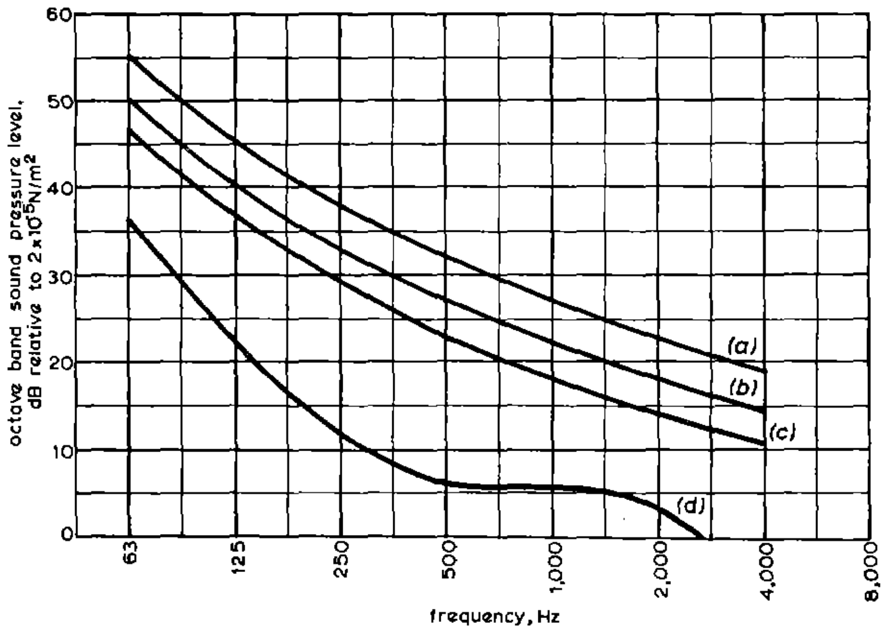

Fig. 8 — Permissible background noise in studios from all sources
(*a*) Sound studios for Light Entertainment (*b*) Sound studios (except drama). All Television studios
(*c*) Sound drama studios (*d*) Threshold of hearing for continuous spectrum noise

The aircraft noise levels assumed for this demonstration were once again those believed to occur beneath aircraft at 300 m altitude. The octave band sound pressure levels are shown in Fig. 9 together with the sound pressure levels for a sonic boom which was also included in this demonstration.

Four roof insulations, 60, 64, 67, and 70 dB, were simulated and the idealized curves which would give these average sound level differences are shown in Fig. 10. A fuller description of the practical considerations leading to these curves is given in Section 12. The noise levels expected inside a studio having each of these insulations were calculated by subtracting the sound level difference for each octave from the appropriate octave band sound pressure level. Recordings of aircraft noise and sonic booms were filtered and adjusted in level until they achieved the appropriate value relative to the background noise level on the drama recording and a composite recording of dramatic excerpt and aircraft noise was then produced.

On the basis of this demonstration most observers agreed once more that a roof having a 70 dB average sound level difference was desirable. We were requested, however, to determine over what area the noise levels assumed for jet aircraft might be found in practice.

9. Aircraft Noise Spectra and Weighted Noise Levels

The results of measurements made by Research Department and information supplied by the Ministry of Aviation Operational Research Branch[9,10] were used to determine spectra of noise level for aircraft landing and taking off. These values were averaged for several types of aircraft producing similar weighted noise levels; Fig. 11 shows the results obtained, (*A*) being for aircraft taking off and (*B*) for landing aircraft. The spectra used in the demonstration recordings are shown for comparison.

It will be noted that at frequencies below 1 kHz, aircraft taking off produce significantly higher sound pressure levels than those landing. The idealized spectrum used for demonstration purposes was for aircraft taking off and it will be shown in Section 12.2 that the greatest excess of noise level over acceptable values arises from such a spectrum.

The weighted noise values (PNdB) for the spectra are indicated in the key to Fig. 11. It will be seen that this type of weighting attaches greater importance to high than to low frequencies, due to the increased subjective effect of the high frequencies. Thus, in Fig. 11(*A*) the BBC results are greater than the Ministry of Aviation values at low frequencies, yet produce lower perceived noise levels due to the more rapid fall-off at high frequencies. The PNdB value is not by itself an accurate indication of the pressure levels to be expected in individual octave bands.

However, for a known spectrum shape, the weighted sound level will enable octave band levels to be deduced, the accuracy of the deduction depending on the completeness of the knowledge of the shape of the spectrum. Fig. 12 will illustrate this. Fig. 12(*A*) shows the idealized spectrum as used for the 1966 demonstration (Section 8.2) and the same spectrum shifted downwards by 5 dB and 10 dB respectively. The PNdB values are also reduced by the same amounts. Fig. 12(*B*) on the other hand shows measured spectra from aircraft, all Boeings type 707/400. Each curve is the mean spectrum of two or three aircraft producing the weighted noise value shown for the curve. The differences in these values correspond roughly to the mean shifts in the spectra but the actual shifts differ for different octave bands.

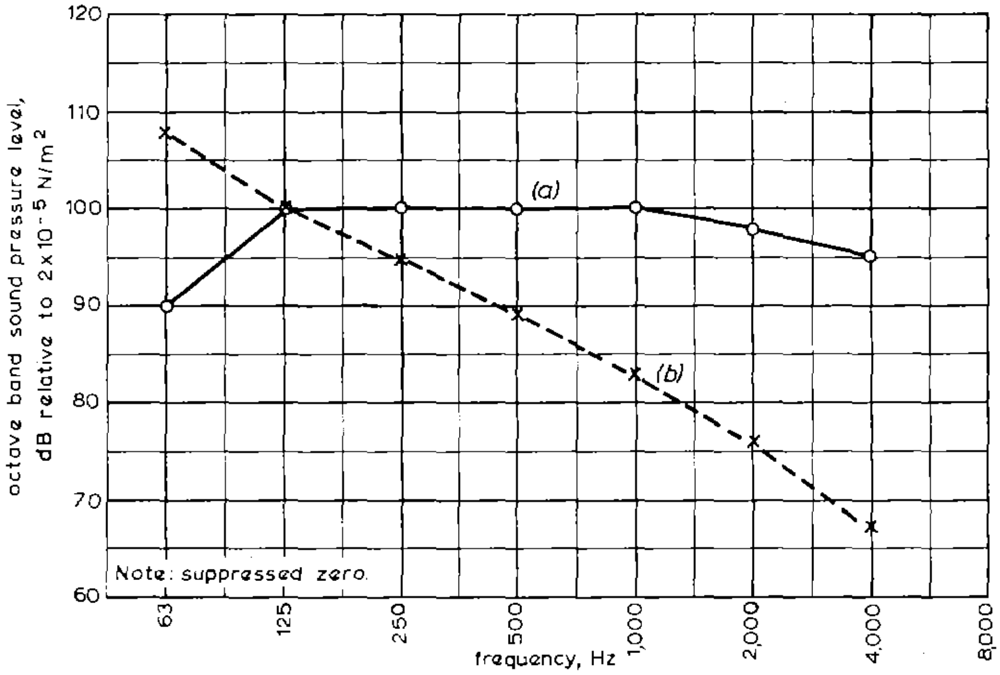

Fig. 9 — Noise spectra used in 1966 roof insulation demonstration recordings
(*a*) Aircraft noise (*b*) Sonic boom (mean of curves (*a*) and (*b*) of Fig. 5 in Part I)

10. Noise Levels around London (Heathrow) Airport

10.1 *Ministry of Aviation Survey 1962*

Measurements of noise levels in the vicinity of London Airport were carried out in 1962 by the Ministry of Aviation on behalf of the Committee on the Problem of Noise. In the report of the Committee[11] the results of this survey were summarized as Noise and Number Indices, a combination of noise levels and numbers of aircraft which correlated well with people's subjective reactions of annoyance.

When our interest is in interference with a programme such an index is not acceptable since an individual aircraft producing high noise levels at the wrong moment is sufficient to ruin a production. We were fortunate in arranging with the Ministry of Aviation Operational Research Branch to see the noise level contours from which the index was derived. These were, of course, long-term averages and considerable deviation from the results must be expected. These average values indicated that the greatest distance at which 115 PNdB might be expected was 3·2 km from the periphery of the airport in the direction of take-off under the usual wind conditions.

A set of measurements close to the end of the runway under take-off conditions indicates that 10 per cent of the aircraft will exceed a value 3 PNdB higher than the average and the absolute range found was ± 9 PNdB. The range found under landing conditions is somewhat more restricted and amounts to ± 5 PNdB.

A further result of measurements carried out by the Ministry of Aviation was embodied in a transparency showing peak perceived noise level contours for large turbo-jet aircraft. For a position immediately beneath the flight path an average value of 115 PNdB might be expected at a distance of approximately 2·4 km from the airport periphery for landing aircraft or 3·2 km from the periphery for aircraft taking off. On the basis of the spread of noise levels suggested above, 10 per cent of aircraft at these distances would exceed 118 PNdB and would produce the noise levels used in the demonstration recordings. Occasional aircraft would exceed 120 PNdB.

Fig. 13 shows a plot of weighted sound level against distance from airport perimeter in six different directions. The level at each distance depends on the proximity of the chosen direction to a flight path.

10.2 *Research Department Survey 1966*

A survey of limited extent and duration was undertaken by Research Department to supplement and bring up to date the Ministry of Aviation figures.

Six sites were chosen, three on the landing flight path at distances of approximately 1 km, 3 km, and 10 km from the airport periphery and three on the take-off path at distances of 2 km, 3 km, and 5 km from the airport periphery. Recordings at each site were made for periods of up to two hours during which at least twelve aircraft passed.

Fig. 14 shows as a noise spectrum for each distance the maximum levels found in each octave band. In general the results are within the range quoted by the Ministry of Aviation.

The levels found 1 km from the landing point of the aircraft are relatively low, possibly because the position was not directly below the flight path. This is also true of measurements taken 5 km from take-off, although in this case an additional complication arises as the power is cut

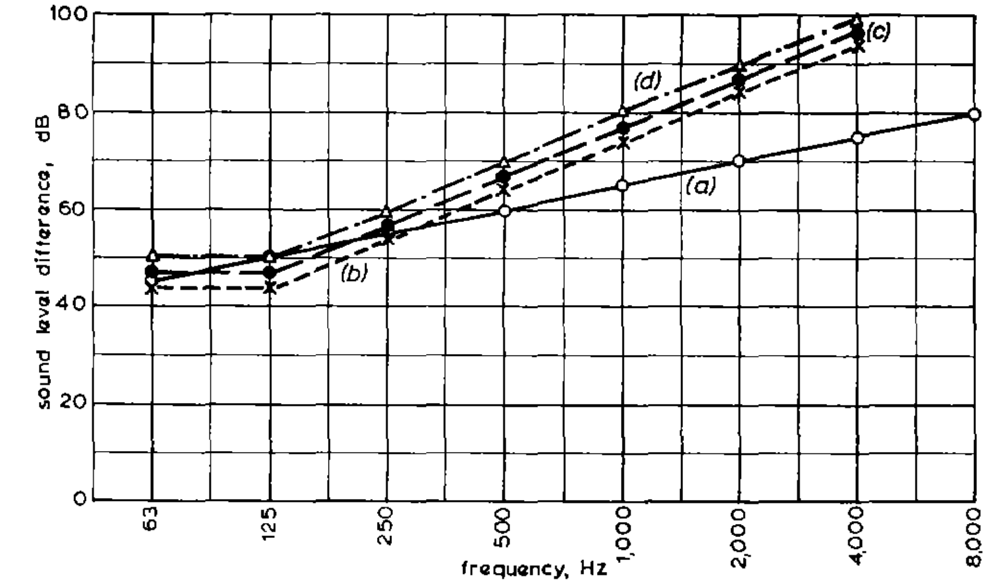

Fig. 10 — *Sound level differences of roof construction*

(*a*) 60 dB 5 dB/octave slope (*b*) 64 dB, (*c*) 67 dB, (*d*) 70 dB 10 dB/octave slope

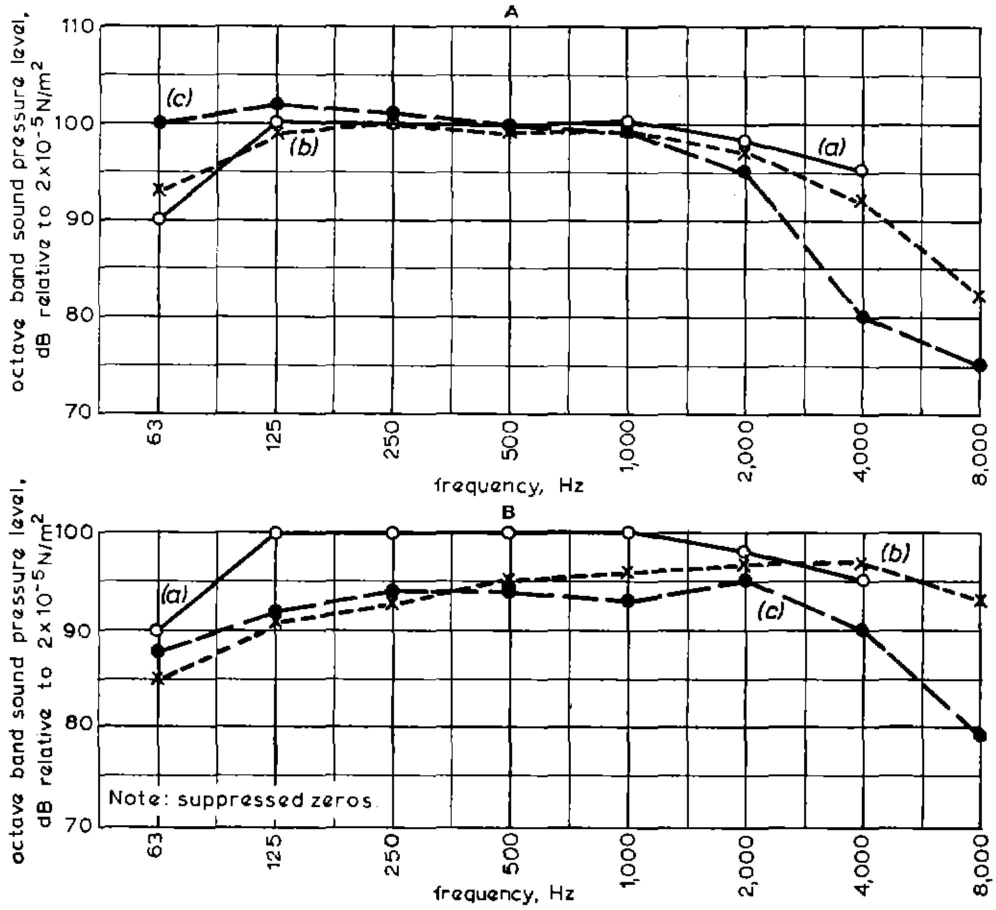

Fig. 11 — *Aircraft noise spectra*

A—Noise produced on take off
(*a*) Demonstration recording noise levels (117 PNdB)
(*b*) Ministry of Aviation figures (118 PNdB)
(*c*) BBC results (115 PNdB)

B—Noise produced on landing
(*a*) Demonstration recording noise levels (117 PNdB)
(*b*) Ministry of Aviation figures (118 PNdB)
(*c*) BBC results (114 PNdB)

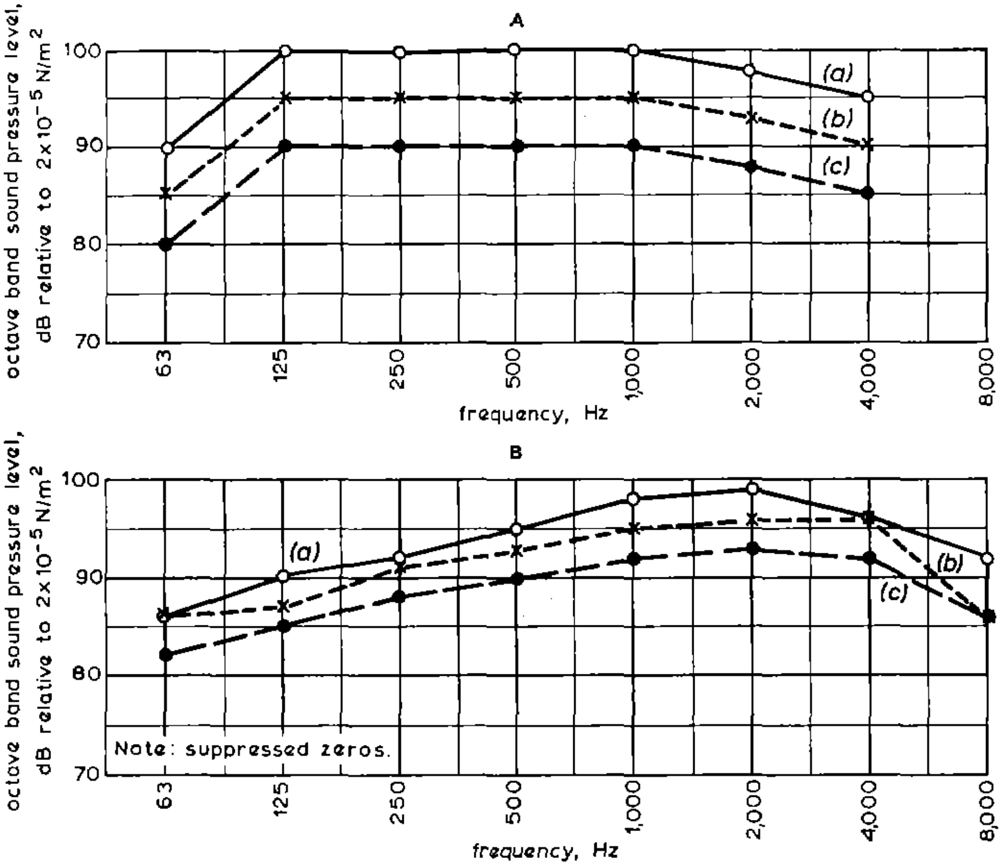

Fig. 12 — *Effect on a weighted sound level of transposing a spectrum*

A—Idealized spectra	*B*—Actual spectra of landing Boeing 707
(*a*) 117 PNdB	(*a*) 118 PNdB
(*b*) 112 PNdB	(*b*) 115 PNdB
(*c*) 107 PNdB	(*c*) 113 PNdB

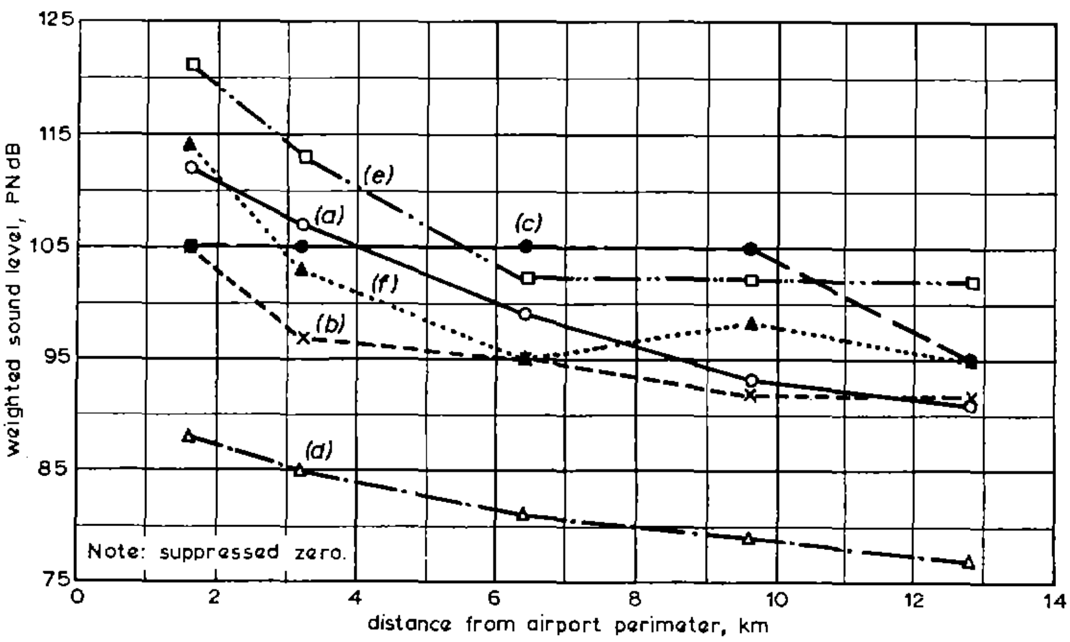

Fig. 13 — *Weighted noise levels as a function of distance from the perimeter of London* (*Heathrow*) *Airport*
(*a*) East (*b*) East-north-east (*c*) North-east (*d*) North (*e*) West (*f*) West

back at this distance and the rate of climb reduced in order to limit the noise levels produced.

10.3 *Noise Levels at Television Centre*

As has been pointed out above, the ventilation noise levels in Television Centre Studio 1 correspond closely to those considered acceptable in a television studio. It is known from previous measurements in Television Centre Studio 5 that the insulation of the roof construction is no greater than 60 dB. If, therefore, noise levels approximating those used in the demonstration recordings existed above Television Centre, complaints of interference with programme should have occurred. Since no such complaints have, in fact, been recorded, it was suggested that we should determine the actual noise levels to which these studios are subjected.

Recordings of aircraft noise were made with a microphone on the roof of the office block at Television Centre during one entire week. Comments from personnel occupying the office in which the recording equipment was sited indicated that subjectively the noise levels were not as high during this period as at some previous time when a different runway was in use.

Fig. 15 shows the maximum sound pressure levels in each octave band found during this period. The levels at frequencies between 250 Hz and 1 kHz are somewhat higher than average values expected on the basis of the distance of 11 km from London (Heathrow) Airport. These levels were, however, only approached by about five aircraft during approximately 60 hours of recording and they are within the extremes expected.

11. Noise Levels over a Studio Centre

11.1 *Jet Aircraft Noise*

In general, airports are at a distance of 8 km or greater from the centre of a city. The only exception to this rule is Southampton where presumably only light aircraft operate. For the larger airports, such as Heathrow, the distances are appropriately greater.

In general, BBC studio centres are at a distance not greater than 5 km from the centre of a city since ease of access is a major consideration in their planning.

Thus the chances of a studio centre being 3 km or less from an airport are very small. The closest approach at present is to the Liverpool studios which lie 6 km from the airport. The maximum noise levels to be expected over a studio centre distant 6 km from a major airport seem at present likely to lie in a region from 90 to 95 dB in each octave band up to 1 kHz.

Although an increase in the power available from aircraft is likely to continue, it seems possible that in line with the recommendations of the Wilson Committee the operation of the aircraft will be controlled so that the noise levels over built-up areas do not exceed 110 PNdB. This limitation, if successful, would prevent noise levels rising significantly above 95 dB in any octave band up to 1 kHz. The noise levels against which a studio roof might have to provide protection are shown in the table. If the limitation of noise levels is not successful the values of 100 dB proposed previously may be reached within five to ten years.

11.2 *Helicopter Noise*

It has been suggested that the noise of helicopters may present a problem in view of the restricted height at which they operate. Fig. 16 shows the noise levels from an S61N helicopter at a distance of 120 m. Even with a 60 dB roof these noise levels are always at least 5 dB below an acceptable criterion curve. The recognizable characteristics of helicopter noise (blade slap) seem unlikely therefore to be audible inside a studio.

Higher noise levels would undoubtedly be found from a helicopter such as a Rotodyne with jet-driven rotor, but its operation over a built-up area is thought unlikely for the reason of the increased noise. A recent Japanese publication[12] quoted pressure levels found on the ground beneath a helicopter landing or taking off. Until the establishment of a heliport on the roof of a studio centre in this country these levels are only of theoretical interest.

11.3 *Comparison with Sonic Boom*

The octave band sound pressure levels shown in Fig. 9(*b*) are the mean of two sets of results which are shown in curves (*a*) and (*b*) of Fig. 5 in Part I. They correspond to a boom arising from a pressure jump of 95·8 N/m² (2 lb/ft²) which is presently believed to be the maximum value likely to be accepted by an urban community.

12. Roof Insulation

12.1 *Sound Insulation of Roof Constructions*

In order to calculate the noise levels produced by aircraft inside a studio it was necessary to assume typical values for roof insulation; these were shown in Fig. 10. The simplest form of roof construction would be a single homogeneous skin of, say, reinforced concrete. Such a single skin would follow a 'mass law' behaviour over a considerable frequency range, and would therefore have a sound insulation characteristic rising with frequency at a rate of 5 dB per octave. The 60 dB average sound level difference, curve (*a*) shown in Fig. 10, is of this type, and the mass necessary to provide an average value of 60 dB would be 635 kg/m² (130 lb/ft²). Such a roof would require approximately 250 mm of reinforced concrete.

To increase the average insulation by a further 5 dB would require twice this thickness, and such roof weight would be unacceptable in view of the large walls and foundations required to support it. Insulations in excess of 60 dB will normally have to be provided by a double skin type of construction. If an adequate air space is provided and no serious mechanical coupling exists between the two skins, then a higher insulation for a given weight can be obtained from such a construction. As an example of this increase in possible insulation, the roof of the new television studio in Glasgow, has a total mass very little in excess of that proposed for the 60 dB roof mentioned above. For reasons unassociated with the acoustical effect

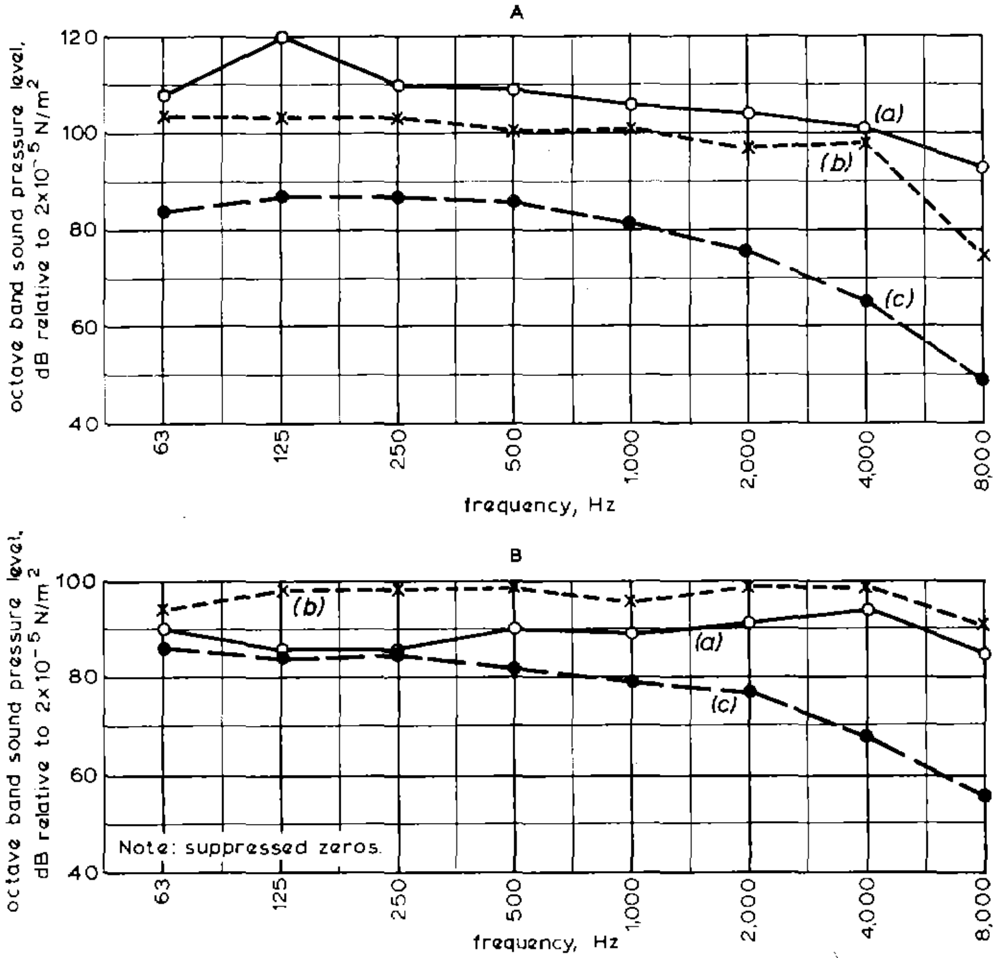

Fig. 14 — *Measured aircraft noise spectra at different distances from an airport periphery*

A—Aircraft taking off
(*a*) 2 km
(*b*) 3 km
(*c*) 5 km

B—Aircraft landing
(*a*) 1 km
(*b*) 3 km
(*c*) 10 km

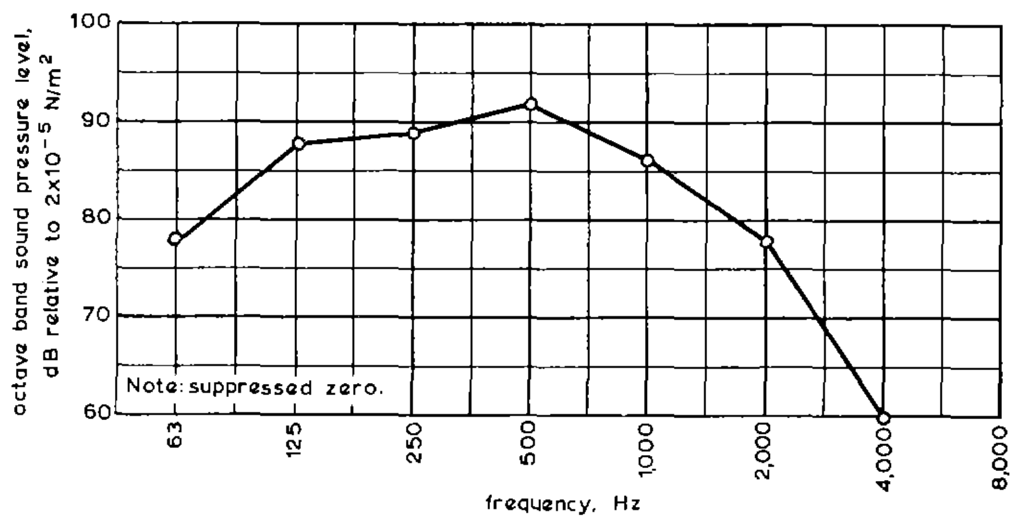

Fig. 15 — *Aircraft noise levels measured at BBC Television Centre* 21–25 *March* 1966

TABLE

Possible Octave Band Noise Levels over a Studio Centre

Octave band centre frequency Hz	63	125	250	500	1,000	2,000	4,000
Octave band noise level dB rel. 2×10^{-5} N/m²	95	95	95	95	95	93	90

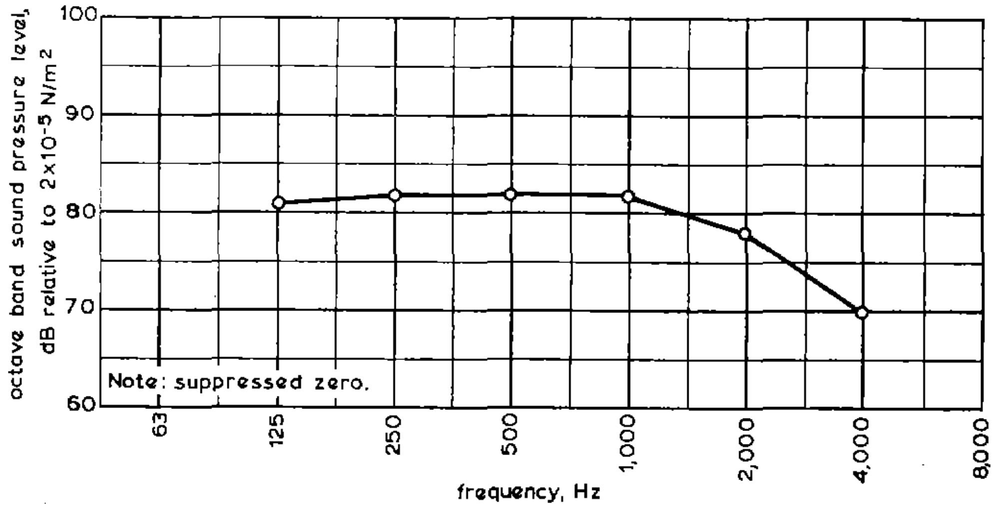

Fig. 16 — *Noise levels produced by S61N helicopter distant* 120 *m*

a large air space (about 1·6 m) was left between the two skins and the resulting average insulation increased to approximately 85 dB. Such a large air space is not normally available.

The curve (*d*), having the average sound level difference of 70 dB shown in Fig. 10, assumes sufficient isolation between the two skins for the insulation to rise at 10 dB per octave over most of the frequency range. Any resonance of the two skins with the air space between them will occur at a low frequency and this has been shown in a typical form by the flattening of the curves below 125 Hz. The curves (*c*) and (*b*) for 67 and 64 dB average sound level difference were obtained by transposing the 70 dB curve downwards in two steps of 3 dB each. It will be assumed that each of these curves is obtained by a progressive lightening of the construction.

As a result of the lower mass involved in the 64 and 67 dB curves and the resonance which will exist between the skins, the insulation at about 125 Hz is significantly lower than for the single skin 60 dB curve. This produces audible and apparently anomalous differences in the demonstration recordings. If these curves can be taken as typical of these forms of construction, there would seem to be no advantage in aiming at less than a 70 dB roof insulation from a double skin construction, particularly since the mass involved is little greater than that required for a single skin 60 dB roof.

12.2 *Sound Insulation Required for Protection of Studios*

It is possible for each noise spectrum which we have discussed to calculate the sound level differences between the octave band noise level and a permissible background noise criterion. Fig. 17 shows such sound level differences for the aircraft noise spectrum assumed in the 1966 demonstration recording, for the spectrum proposed in Section 11.1 above and for sonic booms. For comparison, Fig. 17 also shows the sound level difference curves for 60 and 70 dB roofs. The subjective evaluation described in Section 8.2 provided substantial agreement with deductions from this figure since 70 dB was found sufficient to protect a dramatic production from the noise levels assumed at that time to arise from jet aircraft.

If it is now assumed that the lower levels proposed above represent a reasonable estimate of the noise levels to be found above a studio roof, then it seems probable that a roof providing 65 dB average sound level difference and having a slope of 10 dB per octave will be acceptable. As has been shown above such a roof must be of a double skin construction and the thickness of the individual skins will be set by practical constructional considerations. The reduction of overall sound insulation may permit a reduction in the air space or the introduction of some degree of coupling between the skins. For sonic booms both 60 and 70 dB roofs gave comparable subjective effects since the majority of the energy is at low frequencies. A reduction in insulation obtained from lighter skins or a closer spacing of the skins will render the booms heard in the studio more audible. However, in view of the probable infrequency of such booms this may be acceptable.

13. Conclusions

The noise levels which were used in the demonstration of roof insulation are higher by about 5 dB than any which might at present be found over the roof of a studio centre. The levels were obtained for aircraft at 300 m altitude on

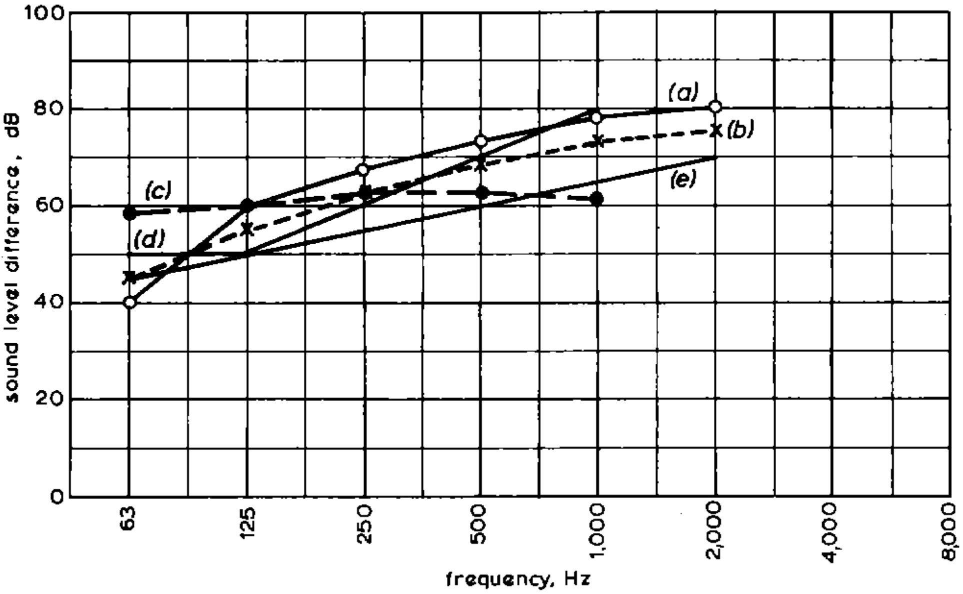

Fig. 17 — Sound level differences between aircraft noise levels and permissible background noise levels
(*a*) Jet noise spectrum used in 1966 demonstration recording (*b*) Jet noise spectrum suggested in this report
(*c*) Sonic boom (*d*) 70 dB roof insulation (*e*) 60 dB roof insulation

take-off and since it was envisaged that noise levels might continue to increase, an allowance (about 5 dB) was made for this increase.

Some increase of noise from individual aircraft may have occurred in the period 1962–6 and the number of aircraft producing these high levels will have increased greatly. In the absence of any overriding control the levels used in the demonstration tape might be reached in five to ten years, which is well within the life expectation of any studio at present under construction.

Some degree of control will exist if public opinion is expressed sufficiently strongly to force the implementation of the recommendations of the report[11] mentioned in Section 10.1.

Even if such a control limits the maximum noise levels found over a studio centre to the 95 dB figure suggested above, it remains apparent that a roof insulation of at least 65 dB would be required to reduce such a noise to a level acceptable inside a television studio. Such a roof insulation must still come from a double-skin construction.

14. Acknowledgments

The BBC wishes to express appreciation of the help given by the Ministry of Aviation Operational Research Branch and the Building Research Station.

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