C. P. No. 588

C. P. No. 588

MINISTRY OF AVIATION

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

Subjective Response to Sonic Bangs

By

M.J. Clarke and J.F. Wilby,

Department of Aeronautics,
University of Southampton

LONDON: HER MAJESTY'S STATIONERY OFFICE

1962

FIVE SHILLINGS NET

C.P. No.588

Subjective Response to Sonic Bangs

- By -
M. J. Clarke and J. F. Wilby,
Department of Aeronautics,
University of Southampton.

Communicated by Prof. E. J. Richards

October, 1961

SUMMARY

The response of the ear to short duration bursts of noise is discussed, and the information used in an attempt to predict human reaction to sonic bangs heard inside and outside a building.

The pressure waveform heard by an observer on the ground is assumed to be in the form of a simple N-wave. From current theory the time interval between front and rear shocks is estimated to be 0.20-0.25 seconds for a slender delta airliner flying at M 1.8 at 60,000 ft.

For a range of values of bang duration, the transmission loss based on peak levels is estimated for typical window pane sizes and thicknesses, and is found to vary between 12 and 40 dB, the higher values being for smaller, thicker window panes. Sound levels inside a building, neglecting reverberation effects, are estimated, assuming a peak pressure level for the shock wave of 1 lb/ft^2 (about 130 dB re 0.0002 micro-bar), to be between 80 and 110 dB re 0.0002 micro-bar.

For a large room it is estimated that the reverberant effect increases the apparent loudness inside by about 5 dB which with a transmission loss for that particular case of about 15 dB, results in an apparent decrease in loudness inside the room, relative to the outside, of about 10 dB. This means that, neglecting the effect of surprise, a sonic bang in this case will be less frightening when heard inside than when heard outside. A similar conclusion is reached when considering smaller rooms equivalent in size to living rooms in a house.

1. Introduction

During recent years the introduction of large jet aircraft into airline service has created renewed interest in the complex problem of subjective response to noise. The possibility of a supersonic transport poses further questions. The noise of subsonic aircraft is associated primarily with take-off and landing and is thus restricted to the vicinity of airports. The noise is of several seconds duration and, by its gradual build-up, gives the observer some warning before the

most/

Previously issued as A.R.C.23,203.

most intense levels are heard. Sonic bangs however occur underneath the aircraft throughout the supersonic period of the flight and by their very nature contain no warning of their arrival. Two new problems therefore arise; the response of the ear to very short duration noise and the problem of surprise.

A person standing in the open air may hear one, two or more bangs as a supersonic aircraft flies overhead, the number of bangs and the time between each being determined by aircraft geometry and flight and atmospheric conditions. Inside a room, however, the reverberant conditions may become very important, much more so than for continuous noises where the reverberation time is but a small fraction of the total duration. The individual bangs will be reflected by the walls and, depending on the size of the room and the surfaces of the walls, the observer may hear several bangs before the noise level is attenuated to the background level. It is probable that this repetition will increase the annoyance of the bang.

In the light of present experience, an attempt is made in this survey to estimate subjective response to sonic bangs when the observer is in the open air or in a room. It will be obvious that knowledge of subjective response to pressure pulses is very limited.

2. Shock Waves from Aircraft

2.1 Shape

The idealised far field form of a sonic bang (often heard as a double bang) from an aircraft is the well known N-wave. The initial almost instantaneous pressure rise is followed by a gradual rarefaction to below ambient with finally a second almost instantaneous pressure rise to ambient.

In the present discussions it is necessary to know the time scales of a typical sonic bang. Measurements have so far been restricted almost entirely to fighter-type aircraft and the time scales are probably smaller than those associated with supersonic airliners. Analysis of existing waveforms show that the initial pressure rise is almost instantaneous - within 2 or 3 millisecs - but the positive peak is often rounded off to give a pressure distribution of the type shown in Fig. 1. The duration Δt_1 of the flattened peak was in general within 10 milliseconds, or, with a peak to peak time T of the order of 100 milliseconds,

$$\Delta t_1 \simeq 0.1T.$$

On occasions Δt_1 was found to increase to 20 or 30 milliseconds. This phenomenon may be a property of the bang or may be caused by the response of the measuring equipment. Similarly the negative peak is shown rounded and the second pressure jump almost instantaneous.

2.2 Determination of bang time scale

The value of the peak to peak time T for bangs from supersonic airliners can be estimated from current theories.

Witham[1] has derived equations for the front and rear shocks at a large distance y from a general body of revolution and finite length. The distance between the shocks is given by

$$d = (b_1 + b_2)\, y^{\frac{1}{4}} \qquad \ldots(1)$$

where/

where b_1, b_2 are constants associated with the front and rear shocks respectively and determined by the body shape. The value of b_2 is often difficult to determine but for a slender body, pointed at both ends, b_1 and b_2 can be taken as equal.

The value of b_1 is given by

$$b_1^2 = \frac{\sqrt{2}M^4(\gamma+1)}{(M^2-1)^{\frac{3}{4}}} \int_0^{\xi_0} F(\xi)d\xi \qquad \ldots(2)$$

where M = Mach number

γ = ratio of specific heats

$$F(\xi) = \frac{1}{2\pi} \int_0^{\xi_0} \frac{S''(x)dx}{\sqrt{\xi - x}} \qquad \ldots(3)$$

and ξ_0 is the smallest positive zero of $F(\xi)$.

$S(x)$ is the cross-sectional area of the body at a distance x along the axis from the nose and

$$S''(x) = \frac{d^2S(x)}{dx^2}.$$

For a body having a parabolic profile the above relationship gives

$$b_1 = \frac{1.11\ M^2}{(M^2-1)^{\frac{3}{8}}}\ \delta\ \ell^{\frac{3}{4}}$$

where δ is the fineness ratio $\left(= \frac{\text{maximum diameter}}{\text{length}} \right)$

and ℓ is the length of the body.

Hence
$$\frac{d}{\ell} = \frac{2.22\ M^2\ \delta}{(M^2-1)^{\frac{3}{8}}}\ (y/\ell)^{\frac{1}{4}}. \qquad \ldots(4)$$

(As is pointed out by several authors the constant is 2.22, not 1.82 as given in Ref. 1.)

Equation (4) is found to give results in general agreement with measured values for fighter aircraft[2] although no allowance has been made for an unhomogeneous atmosphere. Also effects of wing-body interference and wing-lift have been neglected. These are probably small for the type of aircraft tested but may be significant for supersonic airliners.

The extension of the theory for wing-body combinations was made by Walkden in Ref. 3. The constant b_1 can be written in the form

$$b_1^2 = \frac{\sqrt{2}M^4(\gamma+1)}{(M^2-1)^{\frac{3}{4}}} \int_0^{\xi_0} G(\xi,0)d\xi \qquad \ldots(5)$$

where/

where $G(\xi,\theta)$ is a function of body cross-sectional area, wing-body interference effects, wing thickness and lift.

For the particular case of an observer below the flight path $\theta = -\pi/2$ and

$$G(\xi, -\pi/2) = \frac{1}{2\pi}\int_0^{\xi}\left(\frac{S''(t) - S_1''(t) + S_2''(t) + \sqrt{M^2-1}/2\; S_3'(t)}{(\xi-t)^{\frac{1}{2}}}\right)dt \qquad \ldots(6)$$

where $S(t)$ = body cross-sectional area

$S_1(t)$ = wing-body interference effect

$S_2(t)$ = wing thickness effect

$S_3(t)$ = lifting effect

and dashes denote differentiation with respect to t. $S_1(t)$, $S_2(t)$ and $S_3(t)$ are given by

$$\frac{dS_1}{dx}(x) = -4R(x)\frac{dZ}{dx}(x,0)$$

$$\frac{dS_2}{dx}(x) = 2\int_{-S}^{+S}\frac{\partial Z}{\partial x}(x,y)dy$$

and

$$\frac{dS_3}{dx}(x) = \int_{-S}^{+S}\frac{\Delta p(x,y)}{\frac{1}{2}\rho U^2}dy$$

where $R(x)$ is the body radius distribution

$2Z(x,y)$ is the total wing thickness for the gross wing.

and $\Delta p(x,y)$ is the local load unit area on the wing surface.

The value of b_1, the distance of the front shock from the reference point, can now be calculated for a typical supersonic airliner. For simplicity consider an aircraft of triangular planform and diamond spanwise section (Fig. 2). Let the longitudinal distribution of spanwise cross-sectional area be the same as that for a body of revolution of a parabolic arc. Then the body thickness effect and wing-body interference effect are zero.

Consider an aircraft 200 ft long, having a leading-edge sweep of 80° and a fineness ratio of 0.08. The cruise Mach number is 1.8 and cruise altitude 60,000 ft. Thickness effect alone (equation (4)) predicts a value of

$$T = 0.19 \text{ seconds.}$$

To include the effect of lift it is necessary to know the local loading of the wing. For a delta wing sweptback inside the Mach cone Walkden (Ref. 3, from Goldstein and Ward, The Aeronautical Quarterly, Vol. II, p.39, May, 1950) gives

$$\frac{\Delta p}{\frac{1}{2}\rho U^2} = \frac{4\alpha\, m_1^2}{E(k)\sqrt{m_1^2 - y^2/x^2}} \qquad \ldots(7)$$

where/

where $m_1 = 1/m = \tan\phi$, $(\pi/2-\phi)$ = angle of sweep

$E(k)$ is the complete elliptic integral of the second kind of modulus $k = \sqrt{1-m_1^2 B^2}$, and

$B^2 = M^2-1.$

In this case, the front and rear shocks are not equidistant from the reference point, i.e.,

$$b_1 \neq b_2.$$

Making the assumptions of Lilley and Spillman[4] it can be shown that the lift is given approximately by

$$L \simeq \frac{2M^2}{\sqrt{M^2-1}}\left(\frac{\gamma+1}{\gamma}\right)\frac{h^2}{(p_h p_g)^{\frac{1}{2}}}\,(\Delta p_f^2 - \Delta p_r^2)_{\theta=-\pi/2} \qquad \ldots(8)$$

where h is the aircraft altitude

p_h, p_g are the ambient pressures at altitude h and ground level respectively, and

Δp_f, Δp_r are the pressure rises of the front and rear shocks respectively.

This can be rewritten as

$$L = 2Kh\,(\Delta p_f^2-\Delta p_1^2)_{\theta=-\pi/2}$$

where K is given by equation (8).

Now $$\frac{d_f}{\Delta p_f} = Kh = \frac{d_r}{\Delta p_r}$$

where d_f, d_r are the distances of the front and rear shocks from the reference point.

$$\therefore\ d_r^2 = d_f^2 - KL/2. \qquad \ldots(9)$$

Then $$T = \frac{d}{U} = \frac{d_f+d_r}{U}$$

$\simeq$ 0.25 sec in the example considered.

Thus, for a supersonic airliner of this design, the time between the two pressure peaks of the N-wave will be of the order of 0.20 to 0.25 seconds. This is 0.10 to 0.15 seconds longer than for current fighter type aircraft. The time rise of the pressure peaks, and duration of the flattened peak may be functions of atmospheric conditions and may thus be little different for the two type of aircraft.

3. Transmission Loss through Structure

The aim of the work which is reported in this section of the paper is to try to obtain a picture of the sound field produced in a room by the passage of a sonic bang past the building.

Consideration/

Consideration of the problem leads immediately to the conclusion that the majority of the noise transmitted to the interior of a building will be provided by flexural vibrations of the windows, as these will be the least stiff members in the structure. The transmission of sound by the remainder of the structure will provide a relatively low background level; thus we deduce that the noise spectra inside will be very peaky, with the peaks occurring at the natural frequencies of vibration of the glass panes forming the windows. Of these peaks the fundamental will inevitably predominate.

Thus far we have considered the effect on instruments. Since the main object of this paper is to determine the effect on human beings, we have also to consider the response of the ear to the pressure waves produced by the vibrating window. Much of the theoretical work has been done on windows 5 ft square and $\frac{1}{4}$ in. thick, and on the assumption of simply supported edges for the panes, the fundamental frequency turns out to be 11 c/s, with overtones at 55, 100, 144 and 188 c/s as the next four in order of increasing frequency. The ear appears to be relatively insensitive to its lowest, 11 c/s, mode so that the predominant one as far as the ear is concerned would appear to be the 55 c/s mode. However, the efficiency of excitation of this mode is such that the peak pressure levels are only 2 of those due to the fundamental. The only conclusion which can be drawn from the above is that in order to estimate quantitatively the effect on the human ear the first two or three modes of the glass panes should be considered, and summed to give the total effect.

Since the approximations necessary to get any results for the internal levels in a reasonable time are such that the results can only be accepted as giving an indication of orders of magnitude, the physiological aspect of the problem has been left untouched, and work has been concentrated on determining transmission loss for the fundamental window frequency only.

The assumptions which have been found necessary in order that some results could be obtained are detailed below.

Firstly, the sonic bang has been assumed to take the form of a pure N-wave, with no lift effects or effects due to the so-called 'rise time' included. To simplify the consideration of the window response, it was also assumed that the N-wave was incident normally on the window.

Secondly, the sound field produced inside the room by the vibrating window was assumed to be a plane wave propagating normally to the window. This is a much more restrictive assumption than the previous one, and is certainly far from the truth in a practical case, but it is rendered necessary by the complex form of the exact equations for the pressure field radiated by a vibrating panel. If the windows are such that they occupy virtually the whole of one wall of the room, a condition which seems to apply more and more exactly in modern structures, the assumption of plane wave radiation is reasonable initially. However, since the pressure level varies along the wave front, the plane wave condition soon breaks down, and in fact the condition produced after one or two reflections in the room approximates more nearly to that of a reverberant field with waves travelling uniformly in all directions.

The work is given in more detail in the Appendix, but the results for the transmission loss through the window are summarised here. The 'transmission loss' was estimated assuming that the only sound inside was due to the fundamental mode of vibration of the window panes, which

were/

were assumed to be simply supported on all edges. The mean pressure immediately inside the window, as a function of time is given by

$$\frac{p}{\Delta p} = \frac{128}{\pi^4} \frac{\rho_o C}{\rho h \omega^2 l} \left[\frac{\omega T}{2} \sqrt{1 + \left(\frac{2}{\omega T} \right)^2} \cos\omega(t-\epsilon) - 1 \right]$$

$$\tan\omega\epsilon = \frac{\omega T}{2}$$

where $\rho_o C$ = characteristic impedance of air

ρ, h, f are the density, thickness and natural frequency of glass panel, and $\omega = 2\pi f$,

and T is the "passage time" of the N-wave, i.e., the time interval between the positive peak $+\Delta p$ and the negative peak $-\Delta p$ as the wave passes a stationary observer.

It will be seen that the pressure wave takes the form of a cosine wave biased to a negative mean pressure level.

The positive and negative peaks are used as indication of the transmission loss which is defined to be

$$\text{T.L.} = -20 \log_{10} \left(\frac{p}{\Delta p} \text{ peak} \right)$$

and values of this parameter are plotted in Fig. 3 for various values of T and f. This definition of transmission loss was chosen since the peak pressure for a single N-wave has a definite physical value, whereas it is difficult to define an "effective" value for such a wave.

It can be seen from Fig. 3 that for larger values of T (i.e., those appropriate to the passage overhead of a large supersonic transport as distinct from a small supersonic fighter) the transmission loss can be given by

$$\text{T.L.} = 20 \log_{10} f - 8.4 \text{ dB}.$$

Also indicated on the figure are approximate fundamental frequencies for square glass window panes, $\frac{1}{8}$ in. and $\frac{1}{4}$ in. thick and with different edge lengths. It can be seen that for large enough values of T, the transmission loss for $\frac{1}{4}$ in. thick panes at the fundamental frequency is given by:

Pane size $\frac{1}{4}$ in. thick	T.L. dB	Internal r.m.s. pressure level. Peak shock pressure 1 lb/ft² (dB re 0.0002 micro-bar)	Frequency c/s
1 ft square	40.5	84	285
2 " "	28	97	68
3 " "	21.5	103	31
4 " "	16.0	109	17
5 " "	12.5	112	11

To/

To get the corresponding pressure levels for the higher modes the following corrections are necessary:

	Mode	Correction to T.L. (dB)
Fundamental	1 : 1	+ 0
1st overtone	1 : 3	+ 13
2nd "	3 : 3	+ 38.2
3rd "	1 : 5	+ 21.9

Thus we get for the fundamental and first 3 overtones the following internal sound pressure levels for different window pane sizes:

Pane size $\frac{1}{4}$ in. thick	Freq. c/s	S.P.L. dB	Freq. c/s	S.P.L. dB	Freq. c/s	S.P.L. dB	Freq. c/s	S.P.L. dB
1 ft square	285	84	1425	71	2565	46	3705	62
2 " "	68	97	340	84	612	59	884	75
3 " "	31	103	155	90	279	65	403	91
4 " "	17	109	85	96	144	71	221	87
5 " "	11	112	55	99	99	74	143	90

For comparison the transmission loss for $\frac{1}{8}$ in. panes of various sizes, together with the internal r.m.s. pressure level for p = 1 lb/ft^2 is given here

Pane size $\frac{1}{8}$ in. thick	T.L. dB	Internal r.m.s. pressure level. Peak shock pressure 1 lb/ft^2 (dB re 0.0002 micro-bar)	Frequency c/s
1 ft square	35	90	138
2 " "	22.5	103	34
3 " "	15	110	14

The above figures for panes of both thicknesses can be interpreted in the following manner.

Firstly, for a given pane thickness, the sound pressure level immediately inside the window rises by about 13 dB for each doubling of edge length. Thus, to keep internal levels down, smaller window panes should be used if the thickness is fixed.

Secondly, one would expect conditions to be slightly better inside a dwelling with smaller, albeit thinner, panes than inside a typical office, e.g.,

	Dwelling	$\frac{1}{8}$ in. thick panes	Office	$\frac{1}{4}$ in. thick panes
	1 ft square	2 ft square	3 ft square	4 ft square
internal noise level	90	103	103	109

(Here/

(Here frequency considerations are left out since it is expected that the overall noise level will not differ appreciably from the S.P.L. of the fundamental frequency.)

The indications here are that typical houses will have sound levels inside some 6 - 13 dB lower than typical offices, for the same bang.

4. Reverberant Effects Inside Room

The other aim of the theoretical work undertaken, which was to give time histories of S.P.L. at various points, has not been so successful to date, largely because of the amount of computation required to get a reasonable picture, even over a period of time less than, say, 150 millisecs.

The complexity of the calculations arises because of the factors;

(i) The fact that the radiated wave shape changes when the wave has passed completely over the building, since the panel motion changes from forced motion, to decaying free motion.

(ii) The number of reflections to be taken into account for an average sized room is large. For example, an additional reflected wave reaches a point in the centre of a room 20 ft long every 18 milliseconds, and its effect has to be added in.

In addition to these considerations, the fact that the theory, as directly applied, assumes plane waves reflected normally from opposing walls, and also neglects (so far, at any rate) the effect of reflected waves upon the vibration of the window pane, means that the lack of applicability of the results for practical cases does not justify the expenditure of more time on this particular approach.

A further approach could be made by considering root mean square levels at any time due to any reflected wave, and summing the separate values to give the net sound field. No figures have yet come out of this method.

Finally, it is considered that in any room other than a completely empty, rectangular room, the sound field after two or more reflections from the end walls will be sufficiently diffuse owing to interfering reflections from furniture, etc., for the decay, once the shock wave has passed the building, to be exponential, with a time constant which will give the reverberation time calculated from the Sabine-Eyring formulae.

A statement of the work done on this aspect is included in the Appendix.

5. Ear Response

5.1 Loudness of single burst

Available information on the response of the ear to single and repeated short bursts of noise is inadequate but of considerable interest. Experiments have been performed[6-16] to determine subjective response to white noise and pure tones. The use of tones is complicated for the short durations considered because the 'clicks' produced by the switching on and off of the tone mask the tone itself. The statistical

reliability/

reliability of the results is open to doubt as in all cases the measurements employed only a small number of observers (10 or less).

Miller, in Ref. 6, investigated the effect of duration on the loudness of a single burst of white noise. The short burst was compared with a standard white noise of 1.55 seconds duration and each of three observers was instructed to adjust the short burst until it sounded as loud as the standard. This was repeated for various intensities of the standard noise. The results are plotted in Fig. 5. It is seen that the critical duration of the burst, above which the loudness is independent of duration, varies with intensity, decreasing from 125 milliseconds at a noise level of 30 dB to 60 milliseconds at 100 dB. Below this critical value the intensity of a noise burst must be greater than that of a continuous noise if both are to sound equally loud. This intensity difference decreases as the absolute intensity of the continuous noise increases.

The slope of the contours of equal loudness for burst durations below the critical value was found to be -8.8 dB for a tenfold increase in duration of the burst.

The mechanism producing this apparent delay in build-up of intensity in the ear is open to conjecture. It does however seem to be independent of the action of reflexes in the middle ear since similar behaviour was noted in ears lacking middle ear muscles. The time scale is also too slow for a mechanical delay, suggesting that it is some neural process.

Similar measurements were made by Garner[8,10] using a pure tone of 1,000 c.p.s., the standard tone being of 500 milliseconds duration and 40 dB or 80 dB intensity level. The results, however, were inconsistent. Three of the six observers claimed that loudness increased with duration, a conclusion in agreement with Miller's results, whilst the remaining three judged the loudness to be independent of duration. This suggests that the ears of the first group integrated the radiated energy whilst the second group measured intensity directly.

The results of other investigations employing pure tones are quoted by Wever in Ref. 15. Independent experiments by Kucharski, Békésy, Munson and Buytendijk and Meester all concluded that the loudness of a short burst increased as the duration increased up to a critical value. This value varied from experiment to experiment depending on the frequency of the tone used and its intensity, but was in the range of 125 milliseconds to greater than 200 milliseconds.

5.2 Rate of build-up of burst

The ear seems to be very sensitive to the rate of build-up of a noise burst. Turk[12] claims that the ear can detect the difference between two pure tones which reach maximum amplitude in 0.05 milliseconds and 0.25 milliseconds respectively.

5.3 Decay of noise

When a noise ceases the sensation persists in the ear for a short time and there is thus a critical decay rate such that the ear is unable to distinguish between this rate and any other faster rate. Miller[6] and Békésy, using white noise and pure tones respectively both concluded that the decay of noise perception to the auditory threshold is independent of the initial intensity of the sound, but dependent, as one would expect, on the listener. The decay time observed by Miller was

50 to 80 milliseconds to threshold, whilst Békésy observed a longer decay time of 140 milliseconds.

Indirect determination of the decay time τ by Symmes, Chapman and Halsted[13] suggested that for noise burst durations greater than about 5 milliseconds τ is approximately 120 milliseconds and is independent of intensity. However for bursts of shorter duration τ appeared to depend on intensity and duration of the noise and values of τ from 40 to 80 milliseconds were recorded.

Extending his work to determine the time delay before a second sound could be heard, Miller obtained the curves shown in Fig. 6. There is a time delay of 10 to 30 milliseconds (depending on intensity) before a second signal of equal intensity to the first can be recognised, the time delay increasing as the intensity of the second signal decreases.

5.4 Repeated bursts - pitch

When a short burst of noise is repeated several times in quick succession an impression of pitch is noticed when the interruption rate reaches a certain frequency. Then, at higher frequencies, the interrupted noise becomes indistinguishable from a continuous noise, the transitional frequency, known as the critical flutter frequency, being determined by the intensity and sound-time fraction. The sound-time fraction is defined as the portion of the total time occupied by noise bursts. Thus, assuming constant sound-time fractions, the burst duration decreases as the interruption frequency increases.

For a constant sound-time fraction of 0.5 Miller and Taylor[7] observed the following effect of interruption frequency on bursts of white noise.

10-15 interruptions/sec:	successive bursts begin to fuse together in a manner similar to the fusion of sinusoidal waves.
40-250 interruptions/sec:	impression of definite pitch.
250-2,000 intteruptions/sec:	qualitative difference between steady and interrupted noise but no sensation of pitch.
> 2,000 interruptions/sec:	indistinguishable from steady noise (critical flutter frequency).

The approximate variation of critical flutter frequency with intensity is shown in Fig. 7 for sound-time fractions of 0.9 and 0.75. The curves are means of observations by two people; the scatter of results is small for repetition rates lower than 100/sec but is of the order of ±30% of frequency at higher interruption rates.

5.5 Repeated bursts - loudness

The loudness of repeated bursts of sound is believed to depend on the rate of interruption, but the precise relation seems to be open to question. Using pure tone stimulus Garner[9] found that, for a given intensity, the loudness increased with repetition rate for either constant burst duration or constant sound-time fraction. Results of his observations are shown in Fig. 8. In contradiction to Garner's results, Pollack's experiments[11] showed that, for noise bursts having a constant sound-time fraction of 0.45 and a constant intensity, the loudness

decreased/

decreased as the repetition rate increased (see Fig. 9), except for repetition rates below 10/sec. Both Garner and Pollack however concluded that a series of repeated sounds is always louder than a continuous similar sound when both have the same total energy.

It is perhaps interesting to note here the work of Haas[16] on the effect on speech of a single echo. If the echo was heard after a delay of 5 to 35 milliseconds after the direct sound, the sounds all appeared to come from the undelayed source. For a delay of 35 to 50 milliseconds the delayed source was recognised as being present but the direction was still located as being the same as the undelayed sound. When the delay was greater than 50 milliseconds the presence of an echo was realised. For short delays the increase in loudness was proportional to the increase in power, i.e., +3 dB for two equally loud sources. This tends to support Garner's conclusions.

5.6 The results discussed in this section can be usefully summarised below:

(i) The apparent loudness of a short burst of noise increases as the duration increases, up to a critical duration value.

(ii) Variation in build-up time of a noise burst can be detected down to values of 0.05 millisecs.

(iii) Noise persistence decay rate is independent of burst intensity; except perhaps for bursts shorter than 5 millisecs. In any case the average decay time to threshold is of the order of 80 millisecs.

(iv) Repeated bursts of noise can give a sensation of pitch when the repetition rate is within a certain frequency range determined by burst duration and intensity. At higher interruption frequencies the repeated bursts are indistinguishable from a continuous noise.

(v) The loudness of repeated bursts of noise increases with repetition rate for rates below 10/sec. At high interruption frequencies the relationship is not clear but the evidence is slightly in favour of a continued increase of loudness with repetition rate.

6. Subjective Response to Sonic Bangs

It is now possible to make some tentative assessment of subjective response to sonic bangs. There is however one important difference between short bursts of noise and sonic bangs. A noise burst is a short duration envelope of randomly varying pressure signals, whilst a shock wave is a short duration envelope of a 'steady' pressure. The latter therefore depends solely on the rate of change of the envelope for its noise characteristics whilst this is not necessarily so for a noise burst. If the pressure pulse grows and decays slowly the ear will not register a bang, simply a rise and fall of ambient pressure. It is assumed here that for the time durations considered the response of the ear is similar in both cases.

6.1 Outside

Consider first the passage of an N-wave in the open air. Assume that the first pressure pulse is maintained for 5 milliseconds and is of the order of 1 lb/ft^2 (or approximately 130 dB peak pressure level re 2×10^{-4} dynes/sq cm). These are typical values from current published

measurements/

measurements and are similar to those expected from supersonic airliners. In the case of sonic bangs root-mean-square value has little meaning but experimental results based on r.m.s. values for noise should still be valid, on a comparative basis, for peak values. Thus from Fig. 10, plotted from data in Fig. 5, the pressure pulse will sound as loud as a continuous white noise of peak amplitude 10 dB lower than that of the bang. The assumption made in this instance is that the loudness of the Fourier components of a single pressure pulse depends, within limits, on the duration of the pulse.

The second pulse of the N-wave follows the first after a time delay of 50 to 250 milliseconds. As the pulses are of similar magnitude Fig. 6 shows that they will be easily recognised as two distinct bangs although the second may sound quieter due to a brief shift of audio threshold after the first bang. The time delay is too long for the second bang to merge with the first and produce an increase in loudness. The decay rate of the first pulse is probably unimportant. It is of comparable order to the decay of audio persistence in the ear but as the rate is slow compared to the rise time of the bang it is unlikely to have noise generating characteristics. Hence the ear will not respond to changes in bang decay rate. This may be one reason why sonic bangs and explosions sound similar although their waveforms are rather different (Ref. 17) over the decaying pressure region (Fig. 11).

The survey does not indicate the effect of pressure rise time on subjective response. Observations of sonic bangs give no clearly defined limit but it has been suggested by one writer that a bang will be heard when the pressure rise rate exceeds 100 lb/ft^2/sec.

Fig. 12 illustrates the complexity of the problem. A comparison of the response of observers seems to be in contradiction to the waveforms measured.

6.2 Inside

The situation inside a room is considerably more complex. The normal modes of the walls of the building radiate noise of certain frequencies and the sound waves are reflected and attenuated by the surface in the room. The overall result is a greater proportion of higher frequency noise.

However, as a first approximation, consider the history of a single pulse in the room. The observer will hear the original pulse followed by several reflections until the pulse is lost in the general background noise. The time between reflections will depend on the distances between the observer and the walls. An observer at the centre of a room having longitudinal dimensions of the order of 25 ft will receive reflected pulses at intervals of about 25 milliseconds (i.e., at a frequency of 40/sec). This is of sufficiently high frequency for there to be a suggestion of pitch. Also the delay time is short enough for the reflected pulses to augment the loudness of the original noise. With Fig. 8 as a guide it is estimated that the repeated pulse will sound approximately 10 dB louder than a single pulse. This increase will be modified by absorption of energy at the reflecting surfaces. For example an absorption coefficient of $\alpha = 0.3$ reduces the energy of the pulse by 1.5 dB at each reflection. This could reduce the above estimated loudness increase by 3 to 5 dB.

The bang itself will be attenuated during its transmission through the structure, the estimated transmission loss being of the order of 15 dB. This suggests therefore that the reverberant pulse in the room will sound about 10 dB quieter than the original pulse outside the room.

The/

The room considered above corresponds to an average sized office but the reasoning can also be applied to the smaller rooms of houses. At the centre of a room 12 ft 6 in. square an observer will receive reflected pulses at a frequency of approximately 80 per second. This increase in repetition rate will give an apparent 3 dB increase in loudness (Fig. 8) when compared with the noise level in the office. The presence of closely spaced objects (e.g., furniture) will introduce some higher frequency noise due to an increase in repetition rate of some pulses but these reflecting surfaces will have higher absorptive properties. Hence this secondary noise will be damped out more quickly and is neglected in this comparison.

In Section 3 it is estimated that the structure of the house will provide a transmission loss 6 to 13 dB greater than that of an office building. The overall implication therefore is that a sonic bang will appear 3 to 10 dB quieter in a house than in an office of the type considered.

As is pointed out several times in this report, the effect of surprise is omitted. This should not affect the comparison of offices and houses but may be of some importance when comparing conditions inside and outside a building. The effect of surprise may be greater when one is sitting in the quiet of a living room than when one is out-of-doors.

These comparisons simplify the problem to an almost unrealistic extent but illustrate the magnitudes involved.

7. Conclusions

Existing measurements of subjective response to very short duration noise suggest that, due to neural delays in the ear, the loudness of a sonic bang may be of the order of 10 dB lower than its pressure would suggest.

Inside a room, however, the repetition of a pressure pulse due to multiple reflections from various sources will increase the loudness of an individual pulse by 5 to 10 dB, depending on the absorption present. The overall loudness will, however, be lower than outside the room due to the transmission loss experienced when the pulse is transmitted through the surrounding structure.

The structural transmission loss is assumed to be least for the windows, and consequently the internal noise is dominated by that due to the vibrating windows. It is interesting to note that the value of T.L. as defined in this report is insensitive to the "passage time" of the wave, provided this "passage time" is greater than about 0.1 sec, so that one can also deduce that the P.L. is insensitive to the shape of the tail following the first pressure peak. This observation is of value when considering the possibility of imitating sonic booms by means of explosive charges.

It should be noted that this simple approach excludes the effect of surprise on the "audience", and that this effect may well modify considerably the conclusions obtained here.

References

No.	Author(s)	Title, etc.
1	G. B. Whitham	The behaviour of supersonic flow past a body of revolution, far from the axis. Proc. Roy. Soc. (London) 201A, 1950.
2	D. J. Maglieri, H. H. Hubbard and D. L. Lansing	Ground measurements of the shock-wave noise from aeroplanes in level flight at Mach numbers up to 1.4 and at altitudes to 45,000 ft. N.A.S.A. TN D-48. 1959.
3	F. Walkden	The shock pattern of a wing-body combination, far from the flight path. Aero. Quart., Vol.9, p.164. 1958.
4	G. M. Lilley and J. J. Spillman	On the ground level disturbance from large aircraft flying at supersonic speeds. College of Aeronautics Note 103. A.R.C.21,955 May, 1960.
5	G. von Békésy	Zur Theorie des Hörens. Physik Zeits., Vol.30. 1929.
6	G. A. Miller	The perception of short bursts of noise. J.A.S.A., Vol.20, p.160. 1948.
7	G. A. Miller and W. G. Taylor	The perception of repeated bursts of noise. J.A.S.A., Vol.20, p.171. 1948.
8	W. R. Garner	Loudness and monaural loudness matching of short tones. J.A.S.A., Vol.20, p.592. 1948.
9	W. R. Garner	Loudness of repeated short tones. J.A.S.A., Vol.20, p.513. 1948.
10	W. R. Garner	Loudness of short tones. J.A.S.A., Vol.21, p.398. 1949.
11	I. Pollack	Repeated bursts of noise. J.A.S.A., Vol.23, p.646. 1951.
12	W. Turk	Duration thresholds for the perception of certain transient phenomena. J.A.S.A., Vol.13, p.65. 1941.
13	D. Symmes, L. F. Chapman and W. C. Halstead	The fusion of intermittent white noise. J.A.S.A., Vol.27, p.470. 1955.
14	E. Meyer	Definition and diffusion in rooms. J.A.S.A., Vol.26, p.630. 1954.
15	E. G. Wever	Theory of Hearing. Wiley. 1957.

16/

No.	Author(s)	Title, etc.
16	H. Haas	The influence of a single echo on the audibility of speech. Acustica, Vol. 1, p.49. 1951.
17	J. Kenneth Power	Some considerations of sonic boom. Federal Aviation Agency Office of Plans. A.R.C.23,107 May, 1961.
18	R. H. Bolt, P. E. Doak and P. J. Westervelt	Pulse statistics analysis of room acoustics. J.A.S.A., Vol. 22, p.328. 1950.
19	D. Mintzer	Transient sounds in rooms. J.A.S.A., Vol. 22, p.341. 1950.

APPENDIX/

APPENDIX

1. Pressure-Time Relationship Assumed for N-Wave

The N-wave is assumed to be propagating horizontally, with its direction of motion making an angle θ with the normal to the panel. (See Fig. 14).

The pressure field is given by

$$t < 0 \quad p_i(x,t) \equiv 0 \qquad \ldots (1)$$

$$\begin{aligned} t \geq 0 \quad p_i(x,t) &= 0 && x < x_1 \\ &= \Delta p \left[1 + 2\left(\frac{x \sin\theta}{VT} - \frac{t}{T} \right) \right] && x_1 < x < x_2 \\ &= 0 && x_2 < x \end{aligned}$$

where $x_1 = \dfrac{V(t-T)}{\sin\theta}$ and $x_2 = \dfrac{VT}{\sin\theta}$

and V = T.A.S. of aeroplane.

Note: The incident pressure includes effects of pressure doubling or quadrupling due to ground and general building reflections.

2. Panel Response to Passage of N-Wave

The panel edge lengths are taken to be L_x (horizontal) and L_y (vertical), and the panel is assumed to be simply supported on all four edges, so that the mode shapes are given by

$$\psi_{mn} = \sin \frac{m\pi x}{L_x} \sin \frac{n\pi y}{L_y} \qquad \ldots (2)$$

where the mode $m : n$ is designated by the number of half waves in the $x : y$ directions respectively.

The Lagrange equation for the mode $m : n$ is then

$$\ddot{q}_{mn} + \omega_{mn}^2 q_{mn} = \frac{1}{\rho h M_{mn}} \int_{panel} (p_i - p_t + p_r)\, \psi_{mn}\, d^2\underline{r} \qquad \ldots (3)$$

where q_{mn} = generalised deflection in mode $m : n$

f_{mn} = natural frequency in mode $n : m$ and $\omega_{mn} = 2\pi f_{mn}$

$M_{mn} = \displaystyle\int_{panel} \psi_{mn}^2 \, d^2\underline{r} = \frac{L_x L_y}{4}$

ρ, h = density and thickness of plate

p_i, p_r, p_t = pressures in incident, reflected and transmitted waves respectively.

Note: p_r refers to 'reflected' waves due solely to panel motions; pressure doubling effects due to rigid boundaries are included in p_i.

We/

We now simplify by writing

$$\frac{1}{\rho h M_{mn}} \int (p_t - p_r)\, \psi_{mn}\, d^2\underline{r} \;=\; + 2\beta \dot{q}_{mn}$$

which can be justified by the fact that the pressure produced by a vibrating surface is proportional to the normal velocity of the surface. We then have

$$\ddot{q}_{mn} + 2\beta\dot{q}_{mn} + \omega_{mn}^2 q_{mn} = 0 \qquad n \text{ even} \qquad \ldots(4)$$

$$= \frac{16\Delta p}{\rho h m n \pi^2}\left(-\frac{L_x \sin\theta}{VT}\right) \qquad n \text{ odd, } m \text{ even}$$

$$= \frac{16\Delta p}{\rho h m n \pi^2}\left(1 - \frac{2t}{T} + \frac{L_x \sin\theta}{VT}\right) \quad n \text{ odd, } m \text{ odd.}$$

To make the problem more tractable we then assume that the wave is incident normally on the window, so that $\sin\theta = 0$, and the relation becomes

$$\ddot{q}_{mn} + 2\beta\dot{q}_{mn} + \omega_{mn}^2 q_{mn} = 0 \qquad \underline{\text{either}}\ m\ \underline{\text{or}}\ n \text{ even}$$

$$= \frac{16\Delta p}{\rho h m n \pi^2}\left(1 - \frac{2t}{T}\right) \qquad \underline{\text{both}}\ m\ \underline{\text{and}}\ n \text{ odd.}$$

$$\ldots(5)$$

Although we have chosen to use the simplified form, it should be noted that the consideration of non-normal incidence is more complex only in so far as modes with an even number of half wavelengths in the horizontal direction can be excited, in addition to those considered here. The other assumptions made in the derivation of the internal sound levels are still approximately valid, except for very small time intervals as the wave approaches and leaves the building.

The relations in the form of equation (3) are necessary if one considers the interaction between the plate motion and the reverberant field inside the building.

The solution of equation (5) is

$$q_{mn}(t) = \frac{16\Delta p}{\rho h \pi^2 m n \omega_{mn}^2}\left[\left(A_{mn} - \frac{2t}{T}\right) + P_{mn}\, e^{-\beta_{mn} t} \sin\nu_{mn}(t - \epsilon_{mn})\right]$$

$$\text{for } 0 < t < T$$

$$\ldots(6)$$

and

$$q_{mn}(t) = \frac{16\Delta p}{\rho h \pi^2 m n \omega_{mn}^2}\, R_{mn}\, e^{-\beta_{mn} t} \sin\nu_{mn}(t - \eta_{mn}) \qquad \ldots(7)$$

$$\text{for } T < t$$

where/

where $$\nu^2_{mn} = \omega^2_{mn} - \beta^2_{mn}$$

$$A_{mn} = 1 + \frac{4}{T}\frac{\beta_{mn}}{\omega^2_{mn}}$$

$$P_{mn} = \frac{1}{\nu_{mn}T}\left[(2-\beta_{mn}A_{mn}T)^2 + (\nu_{mn}A_{mn}T)^2\right]^{\frac{1}{2}}$$

$$\tan \nu_{mn}\epsilon_{mn} = \frac{\nu_{mn}A_{mn}T}{2-\beta_{mn}A_{mn}T}$$

$$R_{mn} = \left\{ \left[A_{mn} - e^{\beta_{mn}T} Q_{mn} \sin\nu_{mn}(T-\phi_{mn})\right]^2 + \left[\frac{2-\beta_{mn}A_{mn}T}{\nu_{mn}T} - e^{\beta_{mn}T} Q_{mn} \cos \nu_{mn}(T-\phi_{mn})\right]^2\right\}^{\frac{1}{2}}$$

$$\tan \nu_{mn}\eta_{mn} = \frac{A_{mn} - e^{\beta_{mn}T} Q_{mn} \sin \nu_{mn}(T-\phi_{mn})}{\frac{2-\beta_{mn}A_{mn}T}{\nu_{mn}T} - e^{\beta_{mn}T} Q_{mn} \cos \nu_{mn}(T-\phi_{mn})}$$

and $$Q_{mn} = \frac{1}{\nu_{mn}T}\left\{\left[(2-A_{mn})\nu_{mn}T\right]^2 + \left[2 + (2-A_{mn})\beta_{mn}T\right]^2\right\}^{\frac{1}{2}}$$

$$\tan \nu_{mn}\phi_{mn} = \frac{(2-A_{mn})\nu_{mn}T}{2+(2-A_{mn})\beta_{mn}T}.$$

These equations are so formidable as they stand that some simplification is necessary before they can be contemplated with equanimity. Fortunately they can be simplified somewhat, since

1. $\beta_{mn} = \delta\omega_{mn}$ where $\delta \sim 0.0025$ for square plates so that $\nu_{mn} \approx \omega_{mn}$.

2. $A_{mn} = 1 + \frac{4\delta}{\omega_{mn}T} \approx 1.$

3. $P_{mn} \approx \left[\left(\frac{2}{\omega_{mn}T} - \delta\right)^2 + 1\right]^{\frac{1}{2}} \approx 1.$

4. $\tan \nu_{mn}\epsilon_{mn} \approx \frac{\omega_{mn}T}{2-\delta\omega_{mn}T} \approx \frac{\omega_{mn}T}{2}.$

5./

5. $$\tan \nu_{mn} \phi_{mn} \approx \frac{\omega_{mn}T}{2 + \delta\omega_{mn}T} \approx \frac{\omega_{mn}T}{2} \approx \tan \nu_{mn} \epsilon_{mn}$$

6. $$Q_{mn} \approx \left[1 + \left(\frac{2}{\omega_{mn}T} + \delta\right)^2\right]^{\frac{1}{2}} \approx 1.$$

7. $$\tan \nu_{mn} \eta'_{mn} \approx \frac{1 - e^{\delta\omega_{mn}T} \sin \omega_{mn}(T-\phi_{mn})}{\left(\frac{2}{\omega_{mn}T} - \delta\right) - e^{\delta\omega_{mn}T} \cos \omega_{mn}(T-\phi_{mn})}$$

8. $$R'_{mn} \approx \{[1 - e^{\delta\omega_{mn}T} \sin \omega_{mn}(T-\phi_{mn})]^2 + [e^{\delta\omega_{mn}T} \cos \omega_{mn}(T-\phi_{mn})]^2\}^{\frac{1}{2}}$$

giving

$$q_{mn}(t) \approx \frac{16\Delta p}{\rho h\pi^2 mn\omega_{mn}^2} \left[\left(1 - \frac{2t}{T}\right) + e^{-\delta\omega_{mn}t} \sin \omega_{mn}(t-\epsilon_{mn})\right] \qquad 0 < t < T \qquad \ldots(8)$$

$$q_{mn}(t) \approx \frac{16\Delta p}{\rho h\pi^2 mn\omega_{mn}^2} R'_{mn}\, e^{-\delta\omega_{mn}t} \sin \omega_{mn}(t-\eta'_{mn}) \qquad \ldots(9)$$

$$T < t.$$

In the case where damping is neglected, so that $\beta = 0$, equations (6) and (7) give

$$q_{mn}(t) = \frac{16\Delta p}{\rho h\pi^2 mn\omega_{mn}^2} \left[\left(1 - \frac{2t}{T}\right) + \sqrt{1 + \left(\frac{2}{\omega_{mn}T}\right)^2} \sin \omega_{mn}(t-\epsilon_{mn})\right] \qquad 0 < t < T \qquad \ldots(10)$$

$$q_{mn}(t) = \frac{32\Delta p}{\rho h\pi^2 mn\omega_{mn}^2} \left[\frac{2}{\omega_{mn}T} \sin \frac{\omega_{mn}T}{2} - \cos \frac{\omega_{mn}T}{2}\right] \cos \omega_{mn}\left(t - \frac{T}{2}\right) \qquad T < t. \qquad \ldots(11)$$

3. Transmission Loss through Window

The crucial assumption made here is that the vibrating window radiates plane waves of sound, which propagate normally to the window. This is certainly true near the window, but since the wave fronts have a non-uniform lateral pressure distribution, velocity components in the plane of the wave front appear which change the direction of the wave front locally, so that the plane wave characteristic is lost as the wave travels further from the window.

This gives the local pressure near the window as

$$p(x,y,t) = \rho_0 c\, \dot{q}_{mn}(t)\, \psi_{mn}(x,y) \qquad \ldots(12)$$

and/

and if we use the average pressure over the wave front, this becomes

$$\overline{p(t)} = \frac{4\rho_o c}{mn\pi^2}\dot{q}_{mn}(t). \qquad \ldots(13)$$

From this relation, using equation (10), has been derived the transmission loss formula quoted in the body of the report:

$$\text{T.L.} = +\ 20 \log_{10} f - 8.4 \text{ dB} \qquad \ldots(14)$$

for <u>modes 1 : 1</u>

or

$$\text{T.L.} = +\ 20 \log_{10} \frac{f}{mn} - 8.4 \text{ dB} \qquad \ldots(15)$$

for <u>modes m : n</u>.

4. <u>Sound Field in Room</u>

The question of reflections within the room raises immediate difficulties since the transient nature of the excitation and consequent sound field means that the usual absorption coefficient, which is measured for a reverberant sound field, is not directly applicable. The quantity which is of most use here is the specific normal impedance of the appropriate surface material, which, if given in the form

$$Z = R + iX \qquad \ldots(16)$$

gives

$$\alpha = \frac{p_{reflected}}{p_{incident}} = \frac{\{[(\rho^2-1) + \sigma^2]^2 + 4\sigma^2\}^{\frac{1}{2}}}{(\rho+1)^2 + \sigma^2} \qquad \ldots(17)$$

with phase shift ϕ on reflection given by

$$\tan\phi = \frac{2\sigma}{(\rho^2-1) + \sigma^2} \qquad \ldots(18)$$

where

$$\rho + i\sigma = \frac{Z}{\rho_o c}. \qquad \ldots(19)$$

However, a rapid search of the literature produced only a few figures for different acoustic treatments, and none at all for normal structural materials.

Thus, the assumptions were made that

$$\alpha = (1-\bar{\alpha})^{\frac{1}{2}} \qquad \ldots(20)$$

where $\bar{\alpha}$ = absorption coefficient and $\phi = 0$.

An attempt was made, on the basis of the above assumptions, to calculate time histories of pressure for points in the room. It was found immediately that a large amount of computation would be required, since for the room considered, which was 20 ft from window to opposite wall, a new reflected wave had to be considered, on the average, every 18 milliseconds.

The/

The point chosen in the room corresponded approximately to the position of the microphone in the laboratory for the firework tests, in the hope that some correspondence might be found between the approximate theory and the test traces obtained. There was none, so the attempt was abandoned.

It is thought that some indication of the way the sound field decays may be obtainable from the use of equations (13), (8) and (9) by the following approach.

The root-mean-square levels at a point distant Z from the window, at time t are given approximately by

$$\frac{64}{\pi^4}\Delta p\frac{\rho_0 c}{\rho h(mn\omega_{mn})^2}\left[\frac{-\omega_{mn}^2\, e^{-2\delta\omega_{mn}(t-Z/c)}}{2}+\frac{4}{T^2}\right]^{-\frac{1}{2}} \quad 0 < t-\frac{Z}{c} < T$$

and

$$\frac{64}{\pi^4}\Delta p\frac{\rho_0 c}{\rho h(mn\omega_{mn})^2}\;\frac{R'_{mn}\, e^{-\delta\omega_{mn}(t-Z/c)}}{\sqrt{2}} \qquad T < t-\frac{Z}{c}.$$

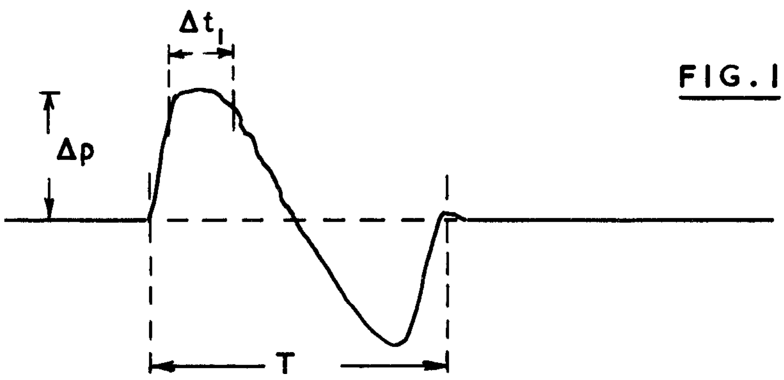
Then, by including all images of the radiating panel which could influence the pressure at point Z at time t, the r.m.s. pressure can be found by direct summation, and a time history can be constructed.

It must be realised, when carrying out this process, that the plane wave assumption tacitly assumes a rectangular room which is completely empty. The presence of furniture, etc., which introduces extra reflections will tend to set up a diffuse sound field, for which the time history is difficult to determine, and, in fact, statistical methods have to be used. This leads naturally to the use of the Sabine-Eyring formulae for reverberation time.

ES

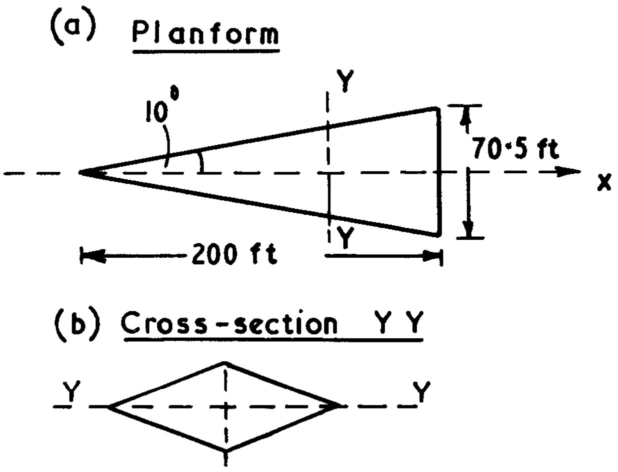
FIGS. 1 & 2

FIG. 1



Typical measured shape of the far-field pressure wave from a supersonic aircraft.

FIG. 2



Cruise altitude 60,000 ft.
Cruise Mach № 1·8

Cross-sectional area distribution :-

$$\frac{S(x)}{S(x)_{max}} = 16\,x^2\,(1-x)^2$$

Simple form of supersonic airliner.

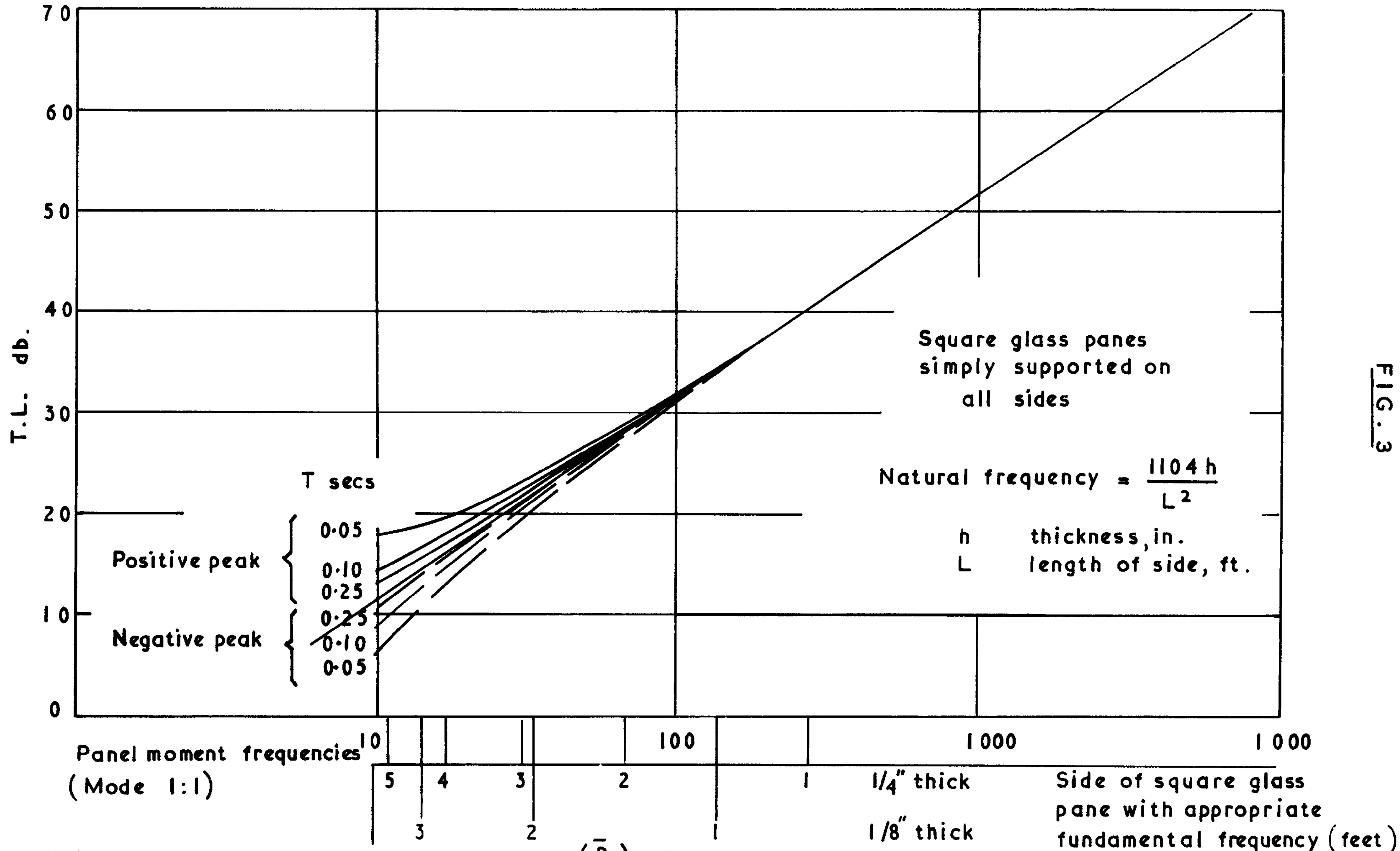


FIG. 3

Minimum transmission loss - db. $T.L. = -20 \log_{10}\left(\frac{\bar{p}}{\Delta p}\right)$. $\bar{p}$ = peak pressure inside room. Δp = peak pressure in N-wave

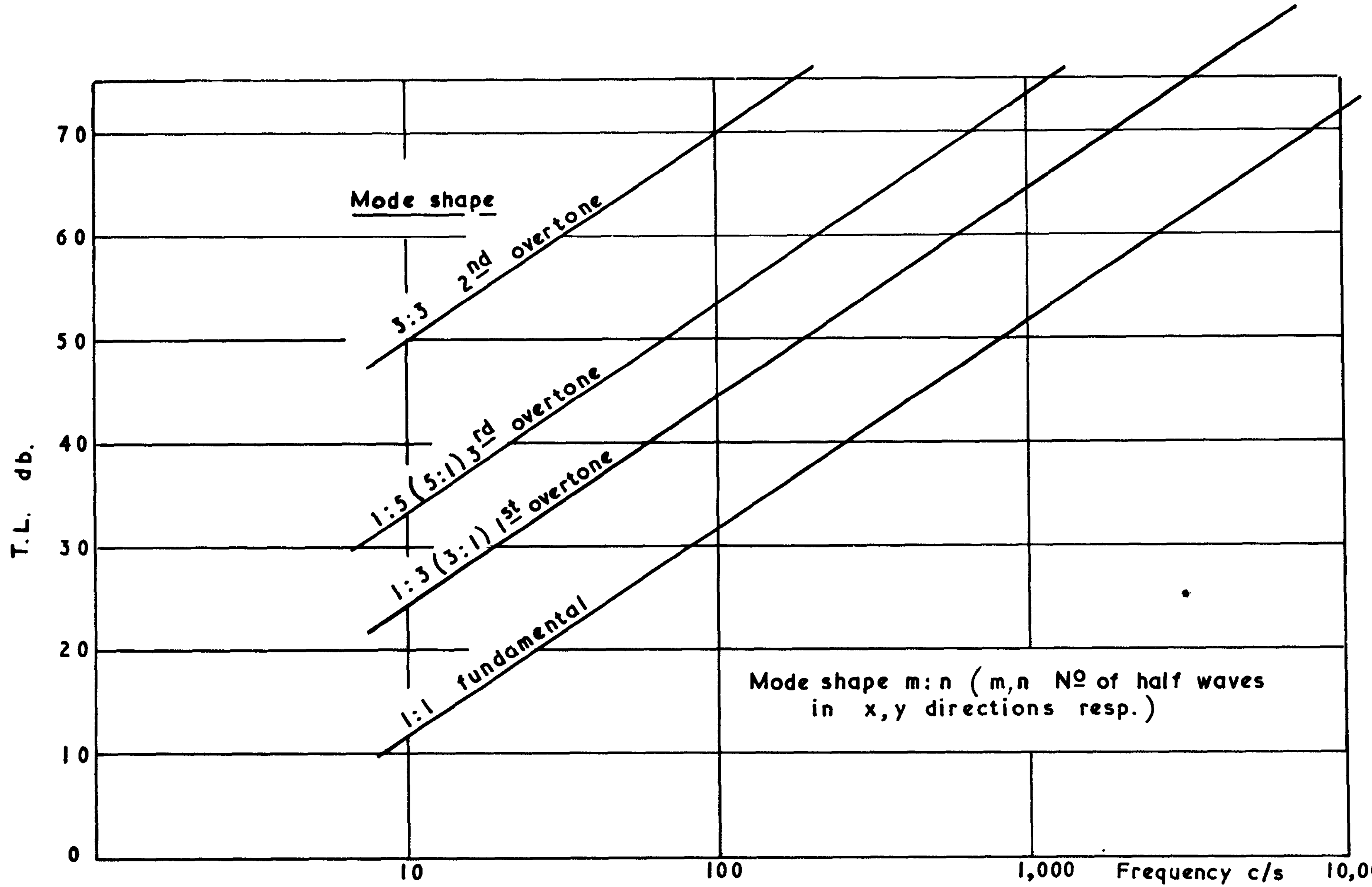


FIG. 4

Relative values of T.L. for different mode shapes (large values of T).

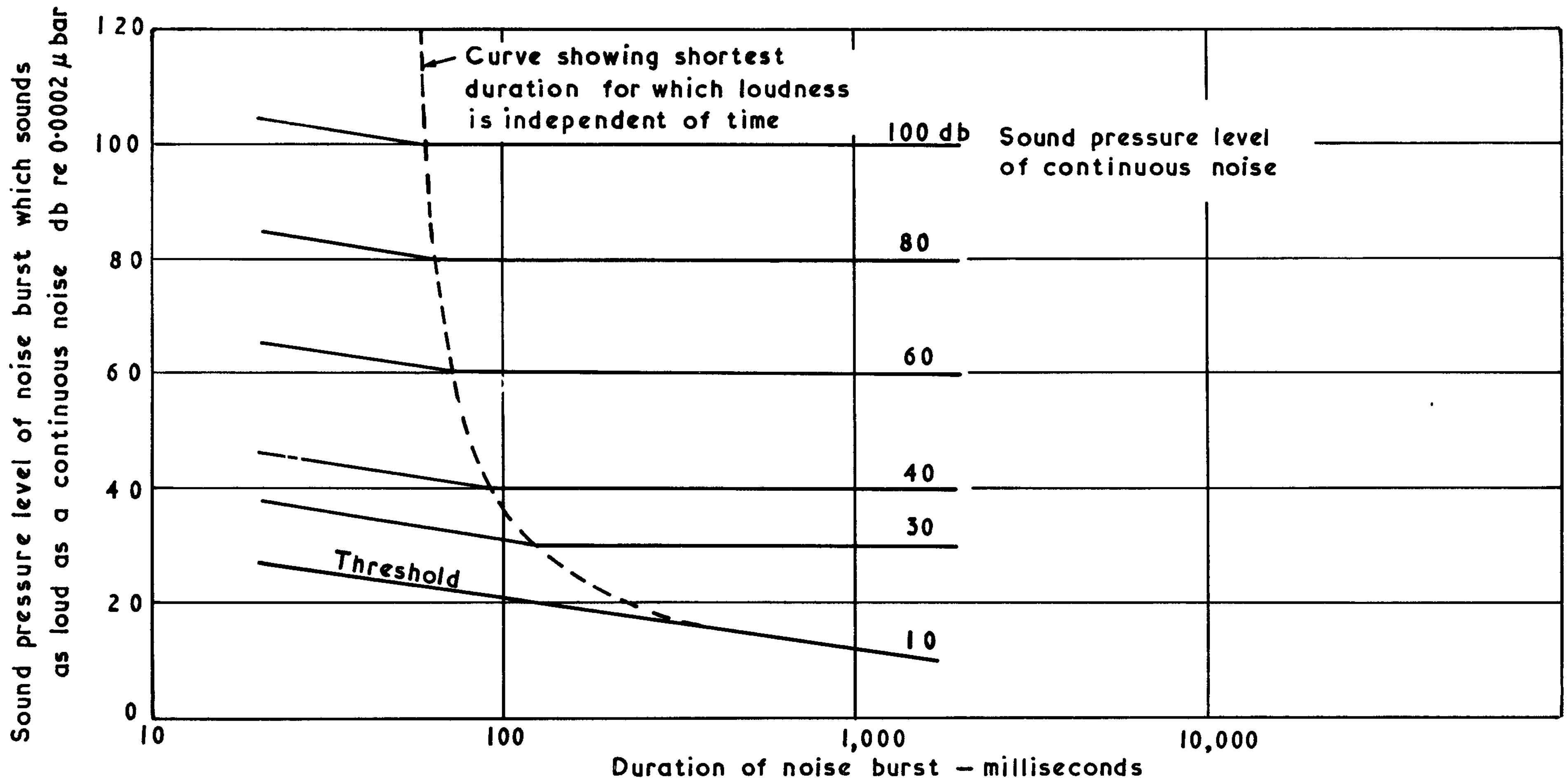
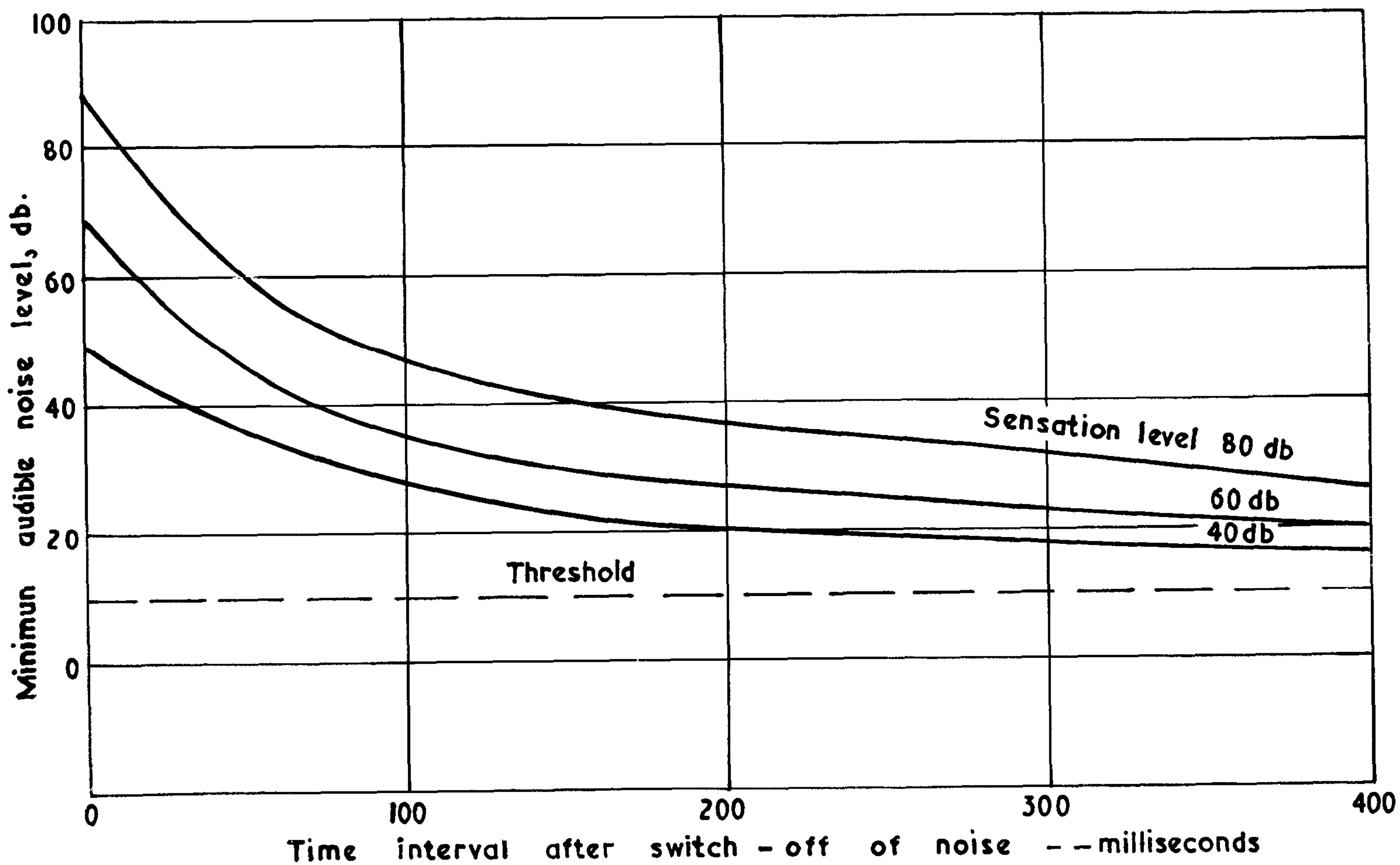


FIG. 5

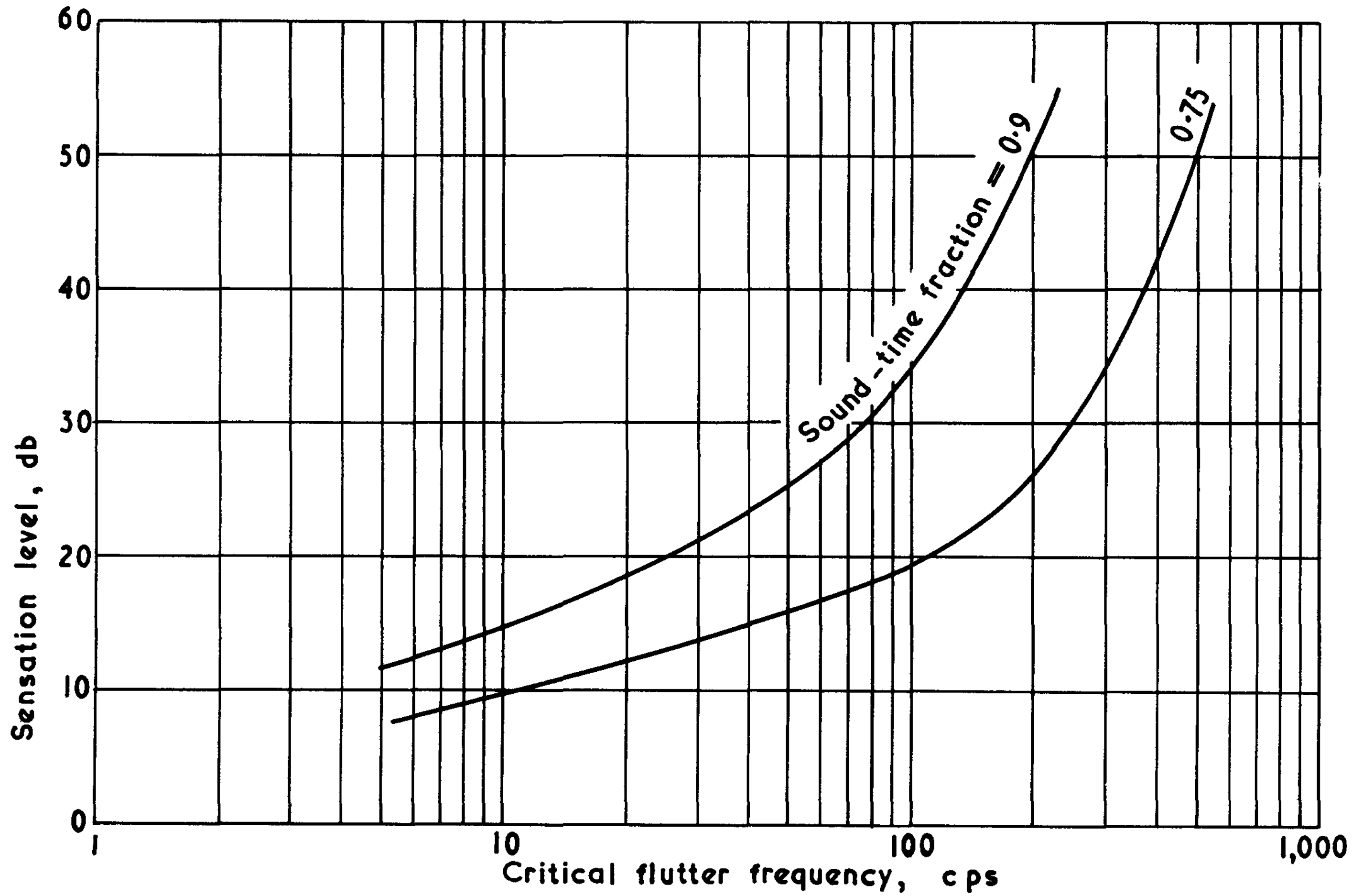
Equal loudness contours for noise bursts as a function of duration. (Ref. 6)



Audio persistence (Ref. 6.)

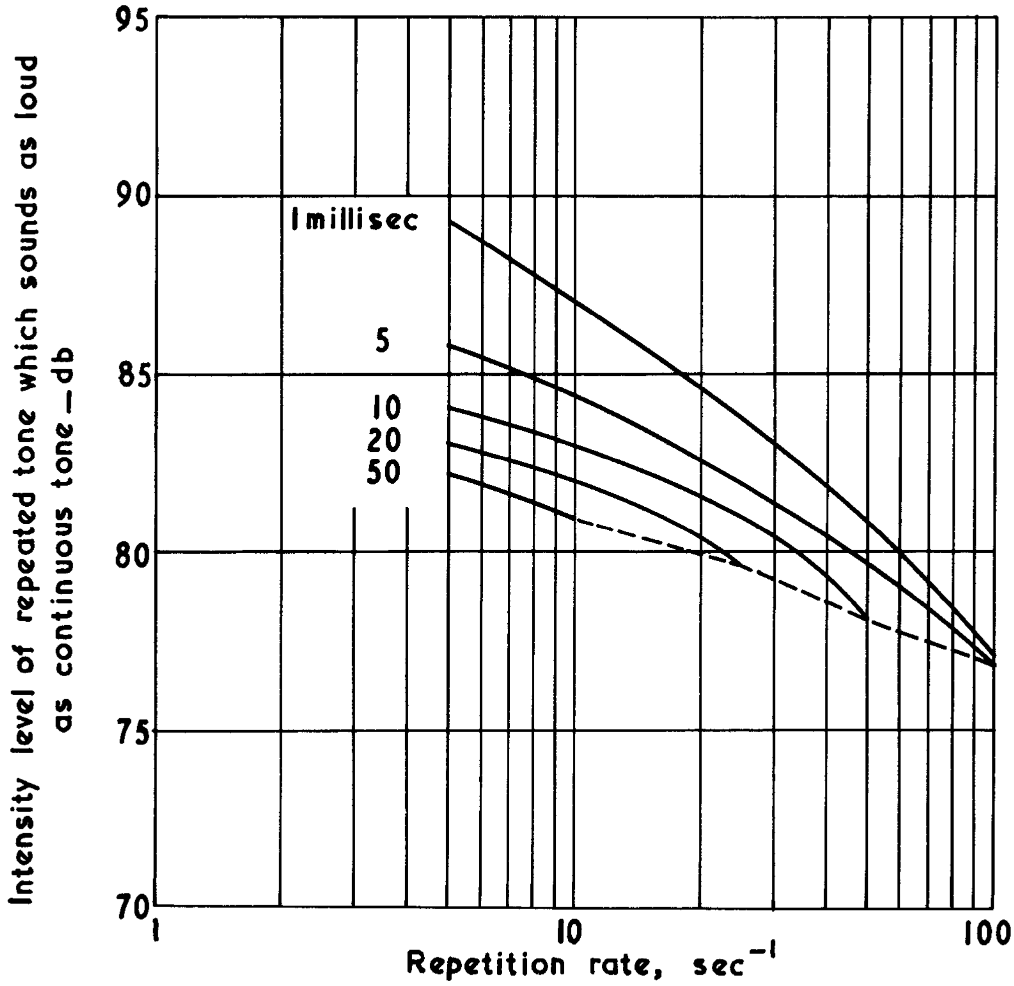
FIG. 6.

FIG. 7



Sensation level at which repeated burst of noise could not be distinguished from a continuous noise

FIG. 8

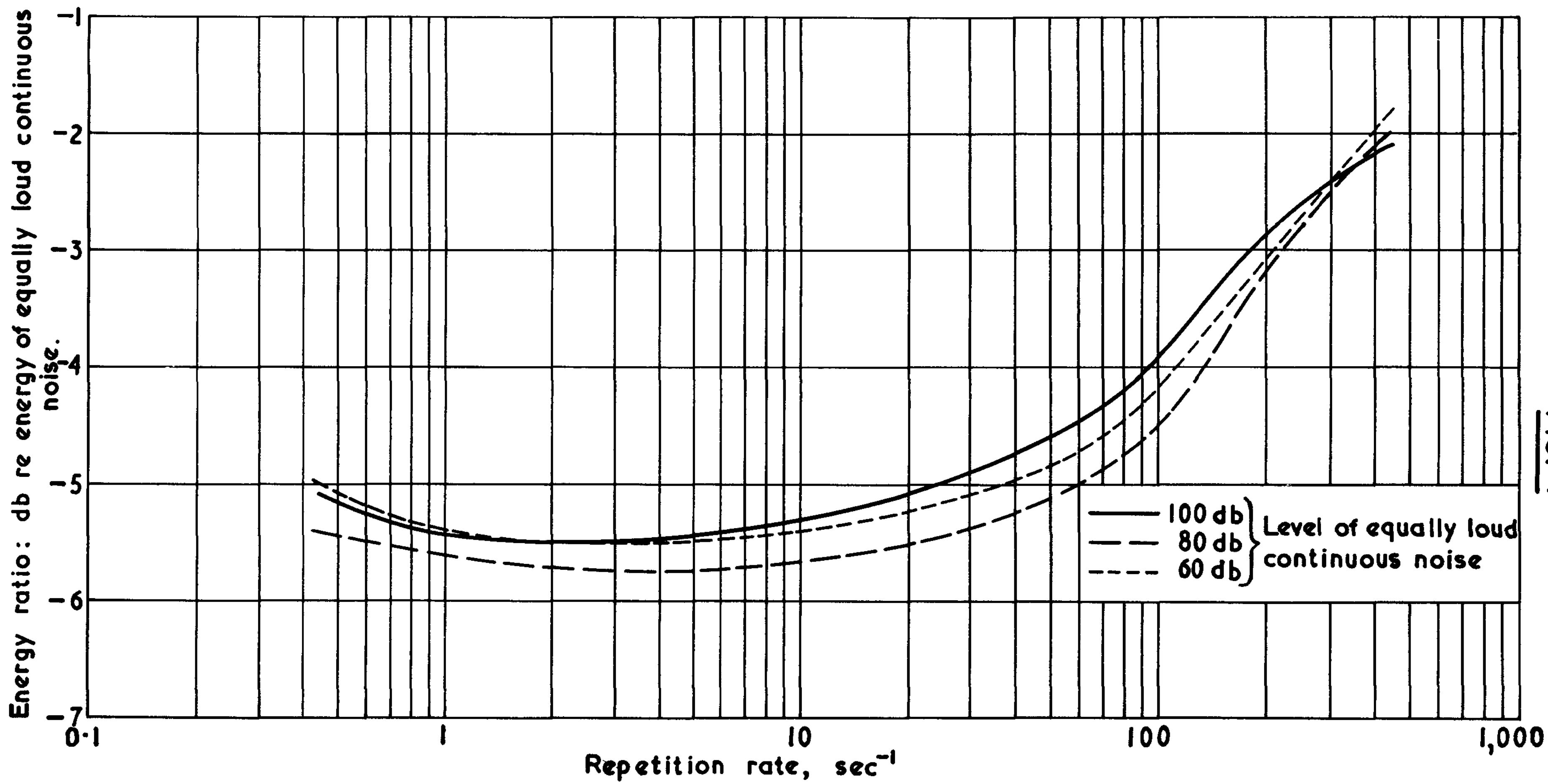


Continuous tone: 1,000 cps 80db

---- Line joining points which would have equal total energy if at the same intensity

Loudness contours for repeated tones. (Ref. 9)

FIG. 9



Loudness contours for repeated bursts of white noise. (Ref. 11)

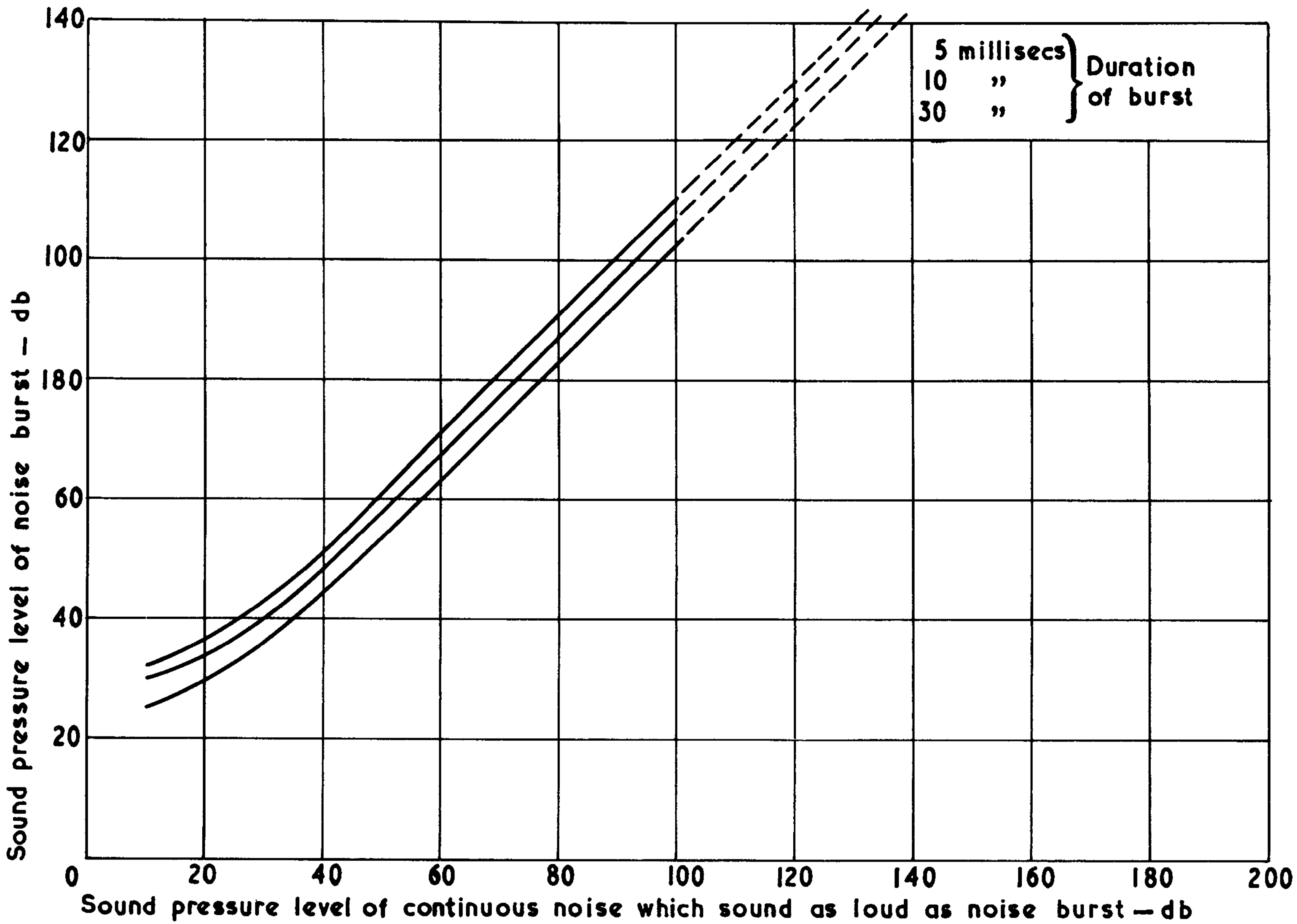
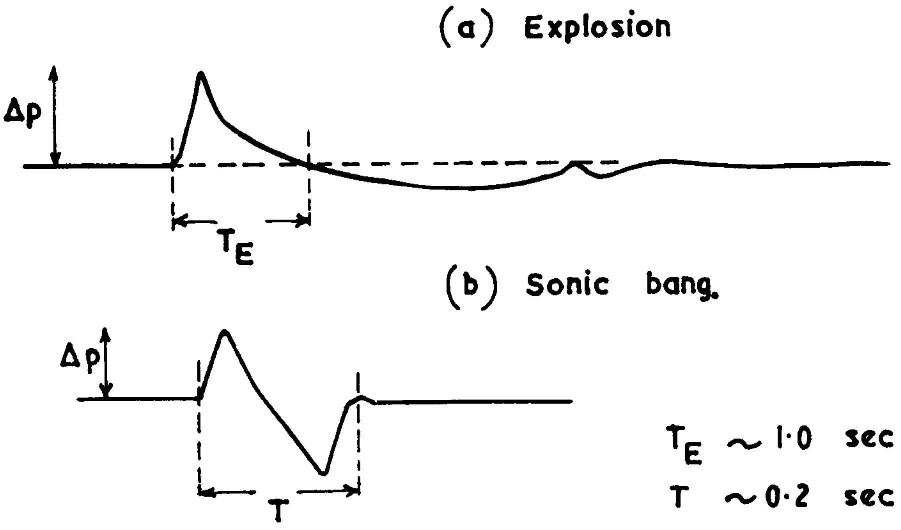


FIG. 10

Noise level of continuous sound which appears as loud as a noise burst of given duration (From Fig.5)

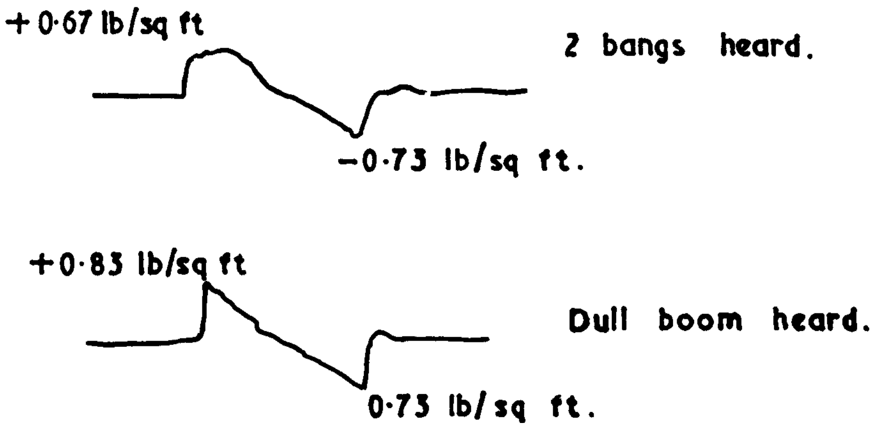
FIGS. 11, & 12.

FIG. 11.



Comparison of waveforms of explosive charge and a sonic bang.

FIG. 12.

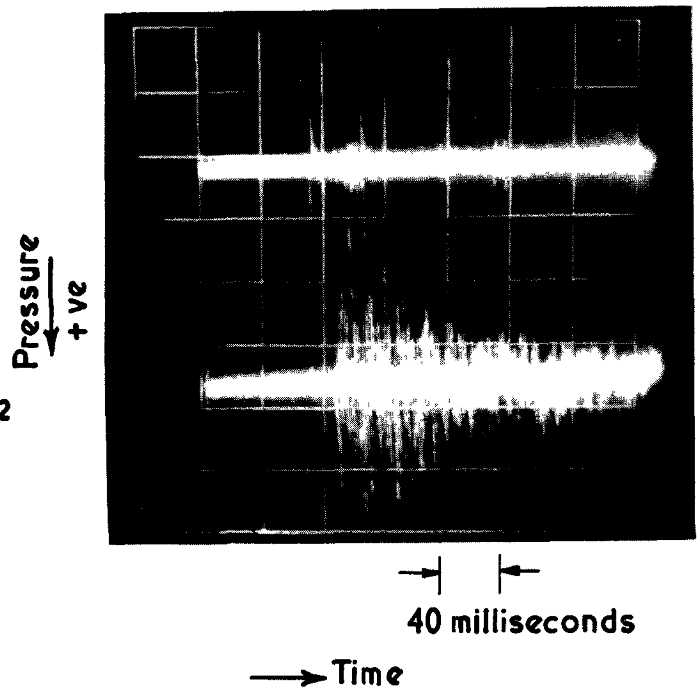


Example of discrepancies between measured pressure waveform and observers reactions.

FIG. 13

Channel 1 Δp_1

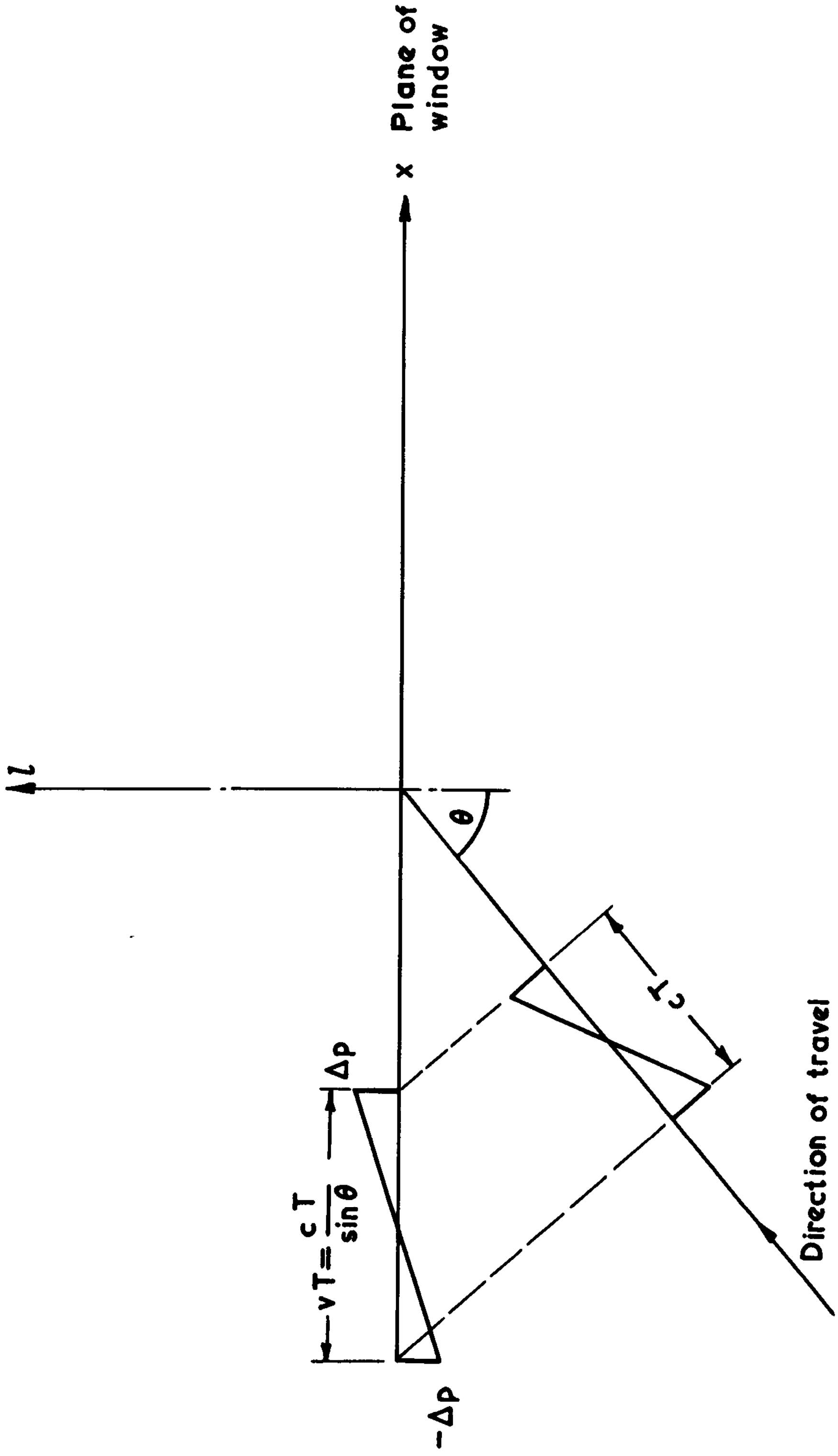
Channel 2 Δp_2



N.B. Δp_2 is magnified relative to Δp_1

Typical waveforms outside and inside a room when a firework is exploded outside

FIG. 14



x
Plane of window
l
θ
cT
Direction of travel of N. wave
Δp
$vT = \frac{cT}{\sin\theta}$
−Δp

A.R.C. C.P. No. 588
October, 1961
Clarke, M. J. and Wilby, J. F. University of Southampton

SUBJECTIVE RESPONSE TO SONIC BANGS

The response of the ear to short duration bursts of noise is discussed, and the information used in an attempt to predict human reaction to sonic bangs heard inside and outside a building. The increase of apparent loudness due to the reverberant effect has to be offset against the decrease in loudness within the rooms, as compared with outside, due to transmission loss.

A.R.C. C.P. No. 588
October, 1961
Clarke, M. J. and Wilby, J. F. University of Southampton

SUBJECTIVE RESPONSE TO SONIC BANGS

The response of the ear to short duration bursts of noise is discussed, and the information used in an attempt to predict human reaction to sonic bangs heard inside and outside a building. The increase of apparent loudness due to the reverberant effect has to be offset against the decrease in loudness within the rooms, as compared with outside, due to transmission loss.

A.R.C. C.P. No. 588
October, 1961
Clarke, M. J. and Wilby, J. F. University of Southampton

SUBJECTIVE RESPONSE TO SONIC BANGS

The response of the ear to short duration bursts of noise is discussed, and the information used in an attempt to predict human reaction to sonic bangs heard inside and outside a building. The increase of apparent loudness due to the reverberant effect has to be offset against the decrease in loudness within the rooms, as compared with outside, due to transmission loss.

C.P.No.588

Printed and published by
HER MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, London, W.C.2
423 Oxford Street, London W.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
80 Chichester Street, Belfast 1
or through any bookseller

Printed in England

S.O. Code No. 23-9012-88

C. P. No. 588