

# Practical Aspects of the Low Frequency Noise Problem.

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## Low Frequency Noise

This paper describes some practical aspects of both the historical and current low frequency noise problem, proposes techniques for its specification and control, outlines some silencing methods and suggests an action plan for those interested in the subject.

## Definitions

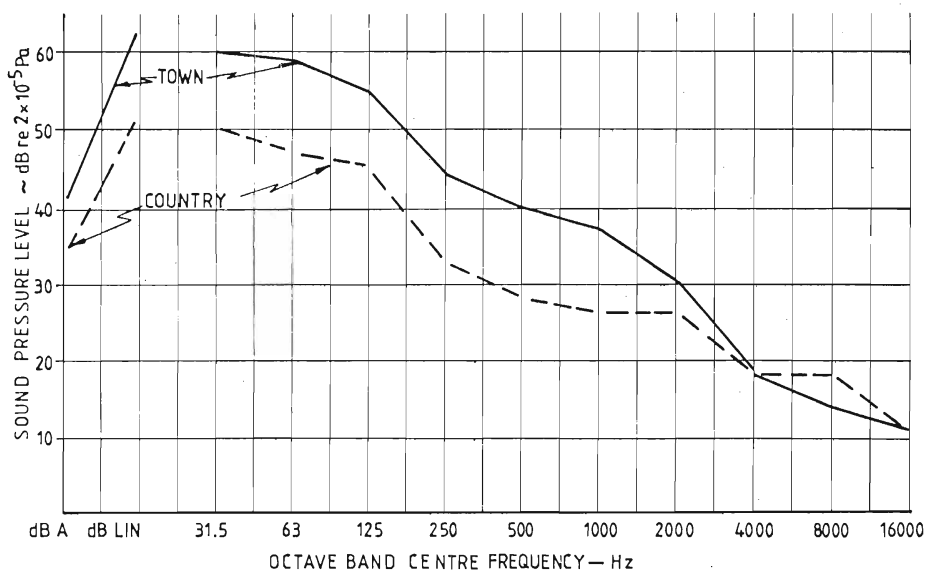
The *Low Frequency* sound referred to in this paper is arbitrarily confined to frequencies below 261 Hz.

The term *Infrasonic* refers to frequencies below the generally accepted lower limit of auditory perception of 20 Hz, although it is known that infrasound, while losing its tonal quality at frequencies below 16 Hz is in fact audible, given sufficient intensity, down to 1 Hz.

## Low Frequency Sound

Low frequency sound is omnipresent and although our ears do not readily detect it, the noise spectrum measured in even the quietest location is dominated by energy at the low end of the spectrum (Fig. 1). However, very often, and certainly much more frequently than is currently recognised, the levels of low frequency noise are enough to interfere with people to a degree sufficient to cause significant misery, distress and economic penalty.

Figure 1 Typical Ambient Noise Levels



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### Propagation of Low Frequency Sound

Because low frequency sound is subject to very little excess attenuation, its decay rate approximates to the simple Inverse Square Law. As the long wavelengths involved cause the sound to spread in a spherical manner, this type of sound can cover a wide area.

Some well documented examples include the diary of Samuel Pepys; who on 3rd June 1665, noted that people in London heard the gunfire from English and Dutch men o'war engaged in battle in the North Sea (1), and in 1883 the spectacular volcanic eruption of Krakatoa from which infrasonic waves travelled five times around the world. More recently, and with the benefit of electronic recording, infrasonic waves from the devastating explosion at the Nypro Chemical Works at Flixborough, North Lincolnshire, were clearly detected at Newbury, Berkshire, and Eskdalemuir, Dumfriesshire (2). In terms of more local phenomena, low frequency noise from industrial plant, or booms from supersonic aircraft can cause puzzling disturbance or annoyance at distances so remote that the real noise source is by no means apparent.

### What We Do Not Know

In addition to good historical data on low frequency noise propagation, cases of disturbance or even physical distress are similarly documented. For instance, Arthur Greenwood's famous novel, "Love on the Dole", published in 1933, refers to the fact that, "The thump of the presses makes the workers feel sick" (3). Somewhat surprisingly therefore, it was not until 1973 that the first international colloquium on Infrasound was held in Paris and we then had to wait until 1980 for the first international conference on Low Frequency Noise (4). Regrettably, even today there is widespread ignorance as to its quantitative and subjective effects, no convenient measurement unit to describe it, and no definitive guidelines as to the extent to which it should be controlled. These problems need to be tackled now.

### The Problem with People

Apart from the matter of acoustic fatigue in buildings and other structures, the main problem arising from excessive low frequency noise concerns people who can be disturbed, annoyed, made wretched or ill by acoustic insult to a degree which can be disruptive on a local scale and which nationally produces significant economic and social penalties.

However, just as with other forms of noise, the population at large exhibit markedly differing levels of individual sensitivity to low frequencies. Effects noted by the author in a variety of situations in several countries are:—

At the levels of low frequency noise generally encountered in everyday life, there is no observed damage to hearing.

With random (as opposed to pure tone) noise many of those exposed are not sure whether they hear it or feel it — and they refer to "the vibration". In a given population exposed to a sufficient level of low frequency noise some people can be distressed to an extreme degree while others remain quite unaffected.

Once a complaint-inducing level has been reached, there is no correlation between absolute sound pressure level and the number of complaints from a given population — people either complain or they do not.

Female (employees) tend to demonstrate earlier sensitivity than male (employees) but the author has insufficient data to make the same deduction regarding the population at large.

Once a person has displayed some sensitivity to low frequency noise, further exposure lowers the sensitivity threshold.

Any sensitivity is exacerbated by the presence of other stresses. The low frequency sensitivity syndrome includes:—

Feelings or irritation/unease/stress/undue fatigue

Headache

Nausea

Vomiting

Heart Palpitations

Disorientation

Swooning/Prostration

There is some controversy as to whether or not some or all of these symptoms are psychosomatic, but in practical terms the argument is somewhat academic as if people have, for whatever reason, stopped work because they feel ill, the result is

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lost production and the tying-up of scarce and valuable specialist effort. There is of course no sympathy for double-blind trials when production is at a standstill.

### Audibility

It has long been recognised that audibility of loudness sensation can be measured down to 1 Hz (5) and the author's experience of gas turbine installations once suggested that infrasound at about 3-5 Hz was indeed a factor to be considered, either because it appeared to be a problem in its own right or to act as an annoying modulator of low frequency sound.

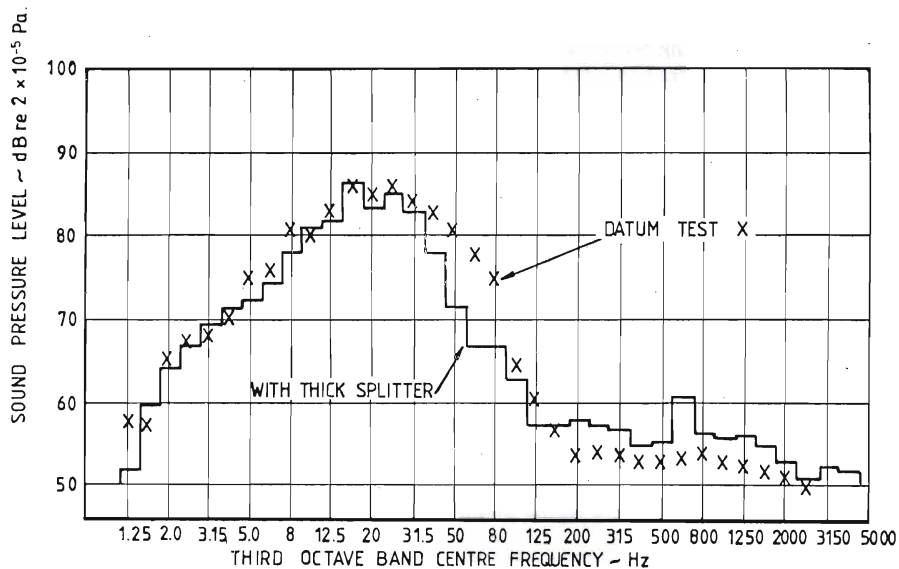
This led to considerable effort being expended in trying to directly eliminate these infrasonic disturbances, but in spite of considerable success in reducing their absolute level the subjective effect was always disappointing.

Fortunately Dr. Geoffrey Leventhall of Chelsea College, London, suggested that infrasonics at the levels encountered were probably less important than the low frequencies around 40-60 Hz. Accordingly an absorbent duct lining was installed to attenuate these frequencies and the result is shown in Fig. 2. Lessons in practical silencing were learnt from this installation because the attenuation achieved over a quite narrow band of low frequencies eliminated complaints about what had hitherto been regarded by the local community as a noisy installation.

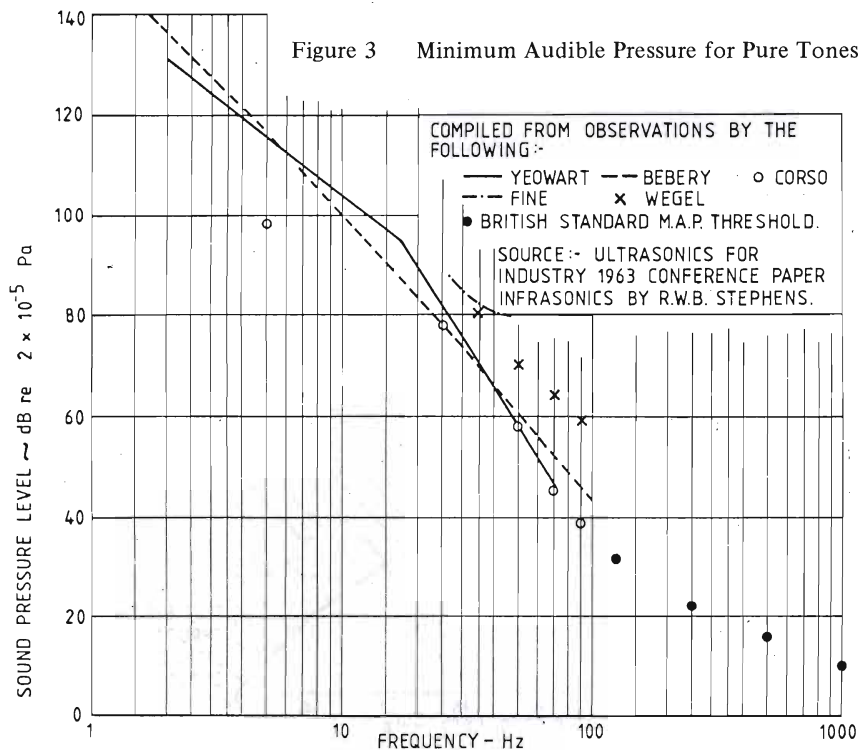
This confirmed the importance of low frequency sound relative to infrasound and suggested that before undertaking the design of expensive silencers, due regard should be paid to the absolute levels of existing sound relative to what it is known we can hear.

The hearing threshold data which has been successfully used in practical applications by the author is given in Fig. 3 (6).

Figure 2 Thick Splitter Test 55 Metres from Detuner - Max Reheat



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### Masking

As reference to Fig. 3 shows the marked increase in hearing sensitivity with increasing sound frequency, it is not unreasonable to expect that a higher frequency noise of even moderate level may effectively mask either low frequency or infrasonic noise. Practical experience shows that this is indeed so. In one case young women who had demonstrated (arguably undue) sensitivity to low frequencies from gas turbines worked apparently happily when pop music from a transistor radio actually raised their absolute noise exposure level, while masking the low frequencies.

Similarly, a test bed installation situated amid high quality housing on the edge of the Cotswolds, and which gave rise to fairly frequent noise complaints has apparently ceased to exist in acoustical terms since the opening of the nearby M5 motorway which cuts a swathe of higher frequency noise throughout the countryside.

### Unmasking – Or Can Silencing Make It Seem Worse?

There are few greater sources of din than a high speed jet discharging from a gas turbine engine and vast sums of money are spent on silencing the test beds on which their performance is checked. Now a large jet running in the free-field spreads from the exhaust nozzle at an included angle of  $15^\circ$ . Therefore if the initial jet velocity is sufficiently high (say 1000 m/s) the jet is still travelling quite fast when it has spread to a large diameter and is thus able to generate significant low frequency noise. But this low frequency is generally masked by the broad band 'roar' (Fig. 4) and complaints of low frequency noise from such jets are rare.

Fig. 4 shows noise measurements, taken at the same position relative to the final exhaust nozzle, of a jet engine under both free-field and test-bed conditions. The difference between the two curves is thus the insertion-loss of the test bed. Note however that the high frequency (jet roar) noise is reduced much more than the low frequencies around 31.5 Hz. So although this low frequency noise is reduced in absolute terms the 'silenced' spectrum is dominated by it, and subjectively the result can be distressing to some people.

### Some Practical Examples of Low Frequency Noise Problems

A variety of practical problems from the author's casebook is described below:

#### Silencing of a Gas Turbine Test Bed

Quite recently a test bed was designed, built and commissioned for testing large aero engines of the high by-pass-ratio type which develop high levels of thrust while discharging their exhaust jet at low velocity and are thus inherently quieter (approximately 15 dB) than pure jet engines giving comparable thrust.

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Figure 4 Comparison of Free Field v Test Bed Engine Noise

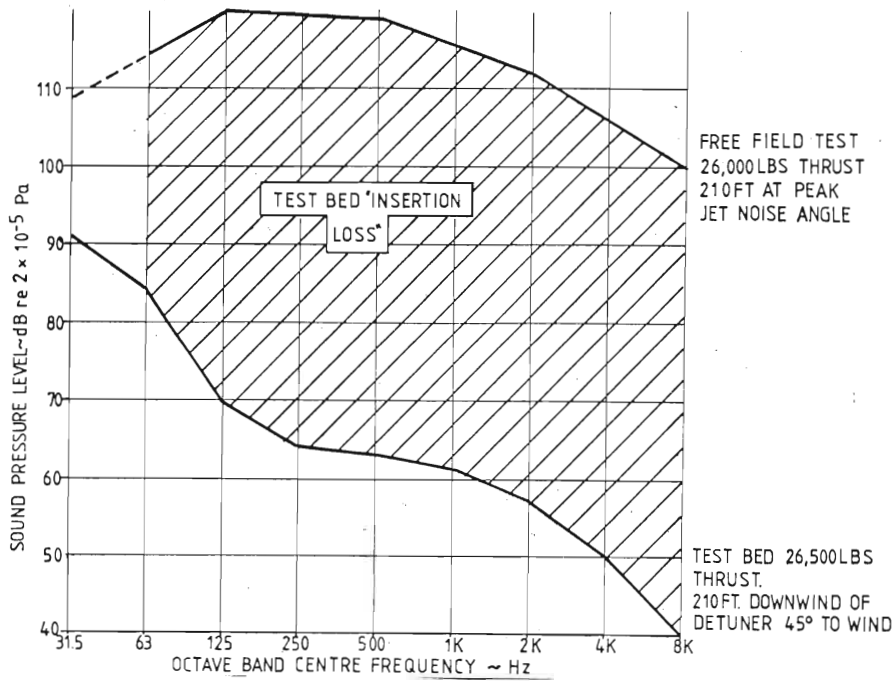
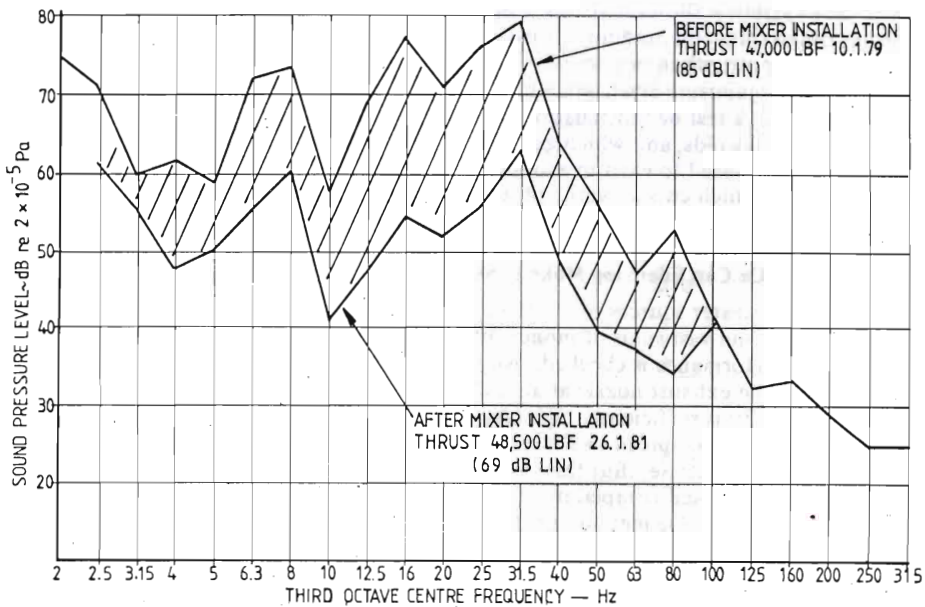


Figure 5 Effect of Detuner Mixer on L.F. Noise Levels Inside Office



As soon as engine testing commenced in earnest, severe problems arose in that employees in nearby offices were firstly annoyed and then started to demonstrate the classical low frequency sensitivity syndrome. At the same time, cracks appeared in adjacent buildings. An urgent solution was required, and as usual one of the major requirements was that any silencing modifications should not induce performance losses in the exhaust system.

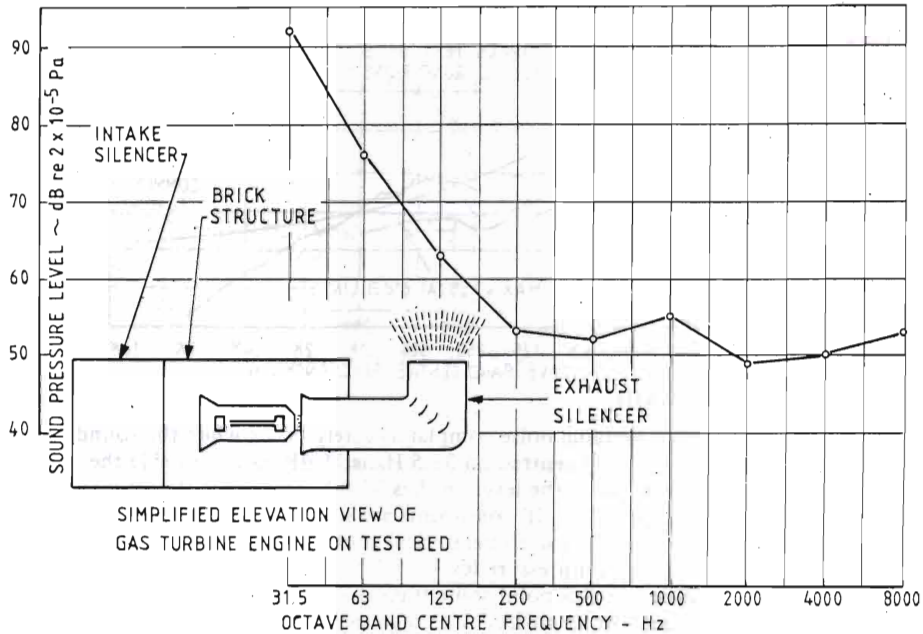
Fortunately model tests already carried out at 1/30th scale had indicated that the fitting of a fluted nozzle (as fitted to early jet aircraft such as the Comet) at the entry to the test bed exhaust duct should give the desired attenuation. A full scale mixer nozzle was made and fitted and demonstrated an overall noise attenuation of 16 dB which was sufficient to prevent further structural damage. More significantly reductions of the same order in the troublesome low frequency spectrum (Fig. 5)

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around 20 to 40 Hz produced great subjective improvement and office workers who had previously been made ill when the engine was running no longer knew whether a run was taking place.

It is now intended that this type of silencer be further developed for use in the testing of high performance reheated jet engines, for although there are standard techniques for reducing jet engine noise at source, all give greater gasflow performance losses than does this fluted nozzle.

Figure 6 Typical Noise Spectrum Measured 150ft from Intake of Gas Turbine Powered Pumping Station



### Public Exposure to Noise from Gas Turbine Installations

There are some situations where the general public may be exposed to low frequency and infrasonic noise from silenced gas turbine installations. These occur in the vicinity of certain power stations, whose prime movers are gas turbine engines or in the very rural environment near the pumping stations of the natural gas supply transmission system, which for obvious reasons, are sited away from large centres of population. There are of course a small number of places where housing is in close proximity to aero engine test beds, which in certain cases demonstrates an apparent lack of communication between environmental specialists and planners employed by local authorities. One aero engine test installation was deliberately sited two miles out of town to avoid nuisance and over the last two decades housing estates have inexorably spread to engulf the test area.

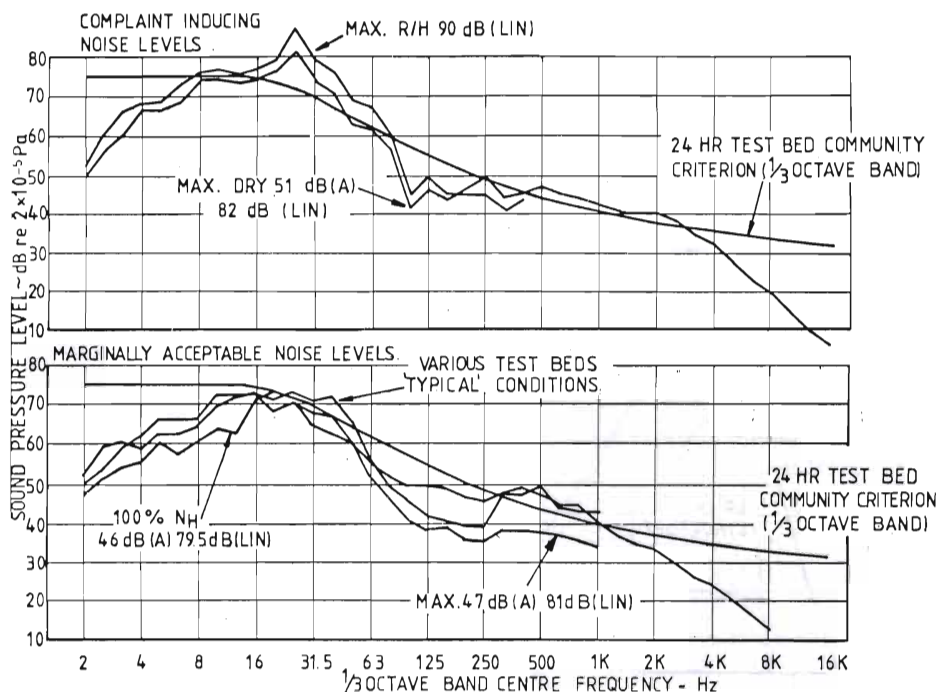
In terms of general layout and consequent noise spectrum, all those types of installations are quite similar, Fig. 6.

They give rise to noise complaints for two reasons:

- 1) The primary noise, (low frequency or infrasonic) radiated from source and entering houses either through their structure, which affords little attenuation, or through open windows.
- 2) Secondary noise, such as rattling windows, doors and handles on drawers. This secondary noise either causes disturbance in its own right or quite often wakes people up and they then become conscious of the low frequency pulsation.

In either case, social and political problems can arise if either the gas turbine plant noise specification is say, framed in dBA — which is irrelevant so far as low frequencies are concerned — or framed in octave band levels which only go down to 63 Hz. Social problems occur because lack of defined low frequency criteria quite often result in too much of this type of noise. Resultant community reaction leads to the political arguments about who pays for any additional silencing work which may be expensive.

Figure 7 Comparison of 'Acceptable' & 'Unacceptable' Noise Spectra



**Complaint – Inducing Levels**

In the author's experience genuine noise complaints rarely occur when the sound pressure level in the octave band centred on 31.5 Hz is 75 dB or less outside the nearest house\*. Conversely when the level reaches 85 dB complaints almost invariably occur, but between 75 and 85 dB complaints are sporadic, random and unpredictable. It therefore follows that a useful empirical guideline to avoid most problems is to limit the octave band sound pressure level at 31.5 Hz below 75 dB whatever the noise source. To illustrate this point some typical noise spectra which almost invariably caused complaint are compared with marginally 'acceptable' spectra in Fig. 7.

Interestingly enough the subjective impression from the noise emitted by these gas turbine installations is of a very low frequency thumping, with a randomly varying repetition rate of 5 Hz or less. However, this appears to be a trap for any unwary acoustician because as mentioned earlier most of the annoyance seems to be caused by frequencies around 40 Hz. Needless to say the gas turbine and power generation industries are devoting a great deal of effort into improved silencing techniques, and the public can expect a quieter future.

**Telex Room**

A number of ladies worked all day in a fairly spartan telex transmission and receiving room where the clatter of machines, ringing of telephones, constant interruptions and queries, plus the urgency and importance of the work, produced a quite stressful environment.

When some new plant was commissioned, it raised the sound pressure level in the telex room by 14 dB at frequencies around 17 Hz.

The effects were quite dramatic in that the occupants of the room immediately displayed symptoms including headache, loss of concentration, sickness and vomiting, heart palpitations, extreme fatigue at the end of the day, unsteadiness to a degree sufficient to make them lose confidence in crossing a road with motor traffic and finally attacks of a syncopal nature.

Urgent engineering action was taken to reduce the low frequency and infra-sonic noise by about 14 dB within one week, but by then the telex operators had apparently become sensitised to a remarkable degree and so the symptoms persisted.

The problem was eventually solved by moving the telex installation to a new location, made quieter in terms of external noise by much improved masonry and glazing, and internally made quieter and more aesthetically pleasing by the extensive use of acoustic absorbent tiles and carpeting. The 'before' and 'after' noise spectra are shown in Fig. 8.

Happily the cure appears permanent and there has been no further incident during the last eight years.

\* One exception is quoted later – see Domestic Boilers

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Figure 8 Telex Room — Silencing by Improved Transmission Loss & Room Characteristics

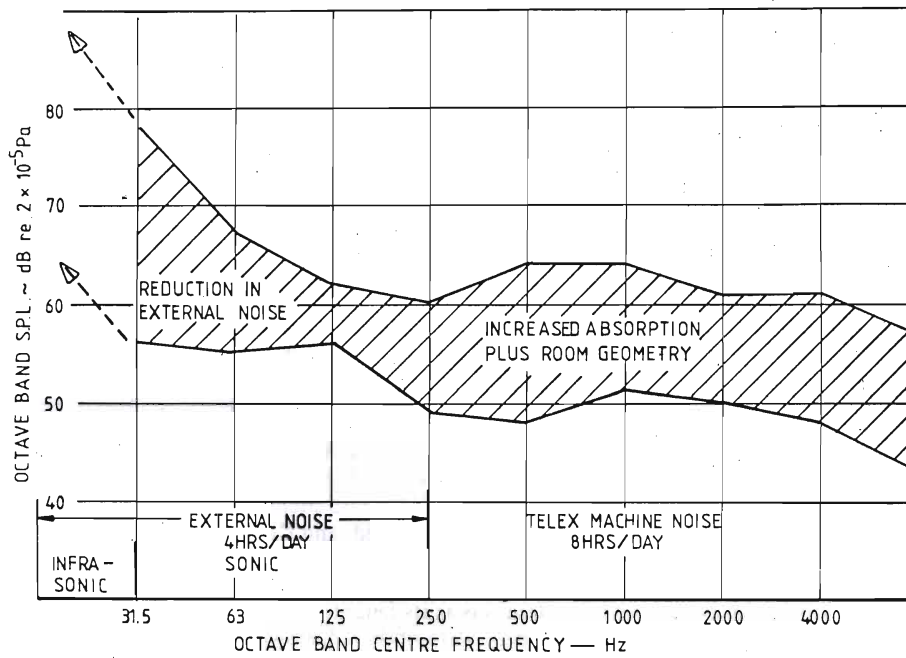
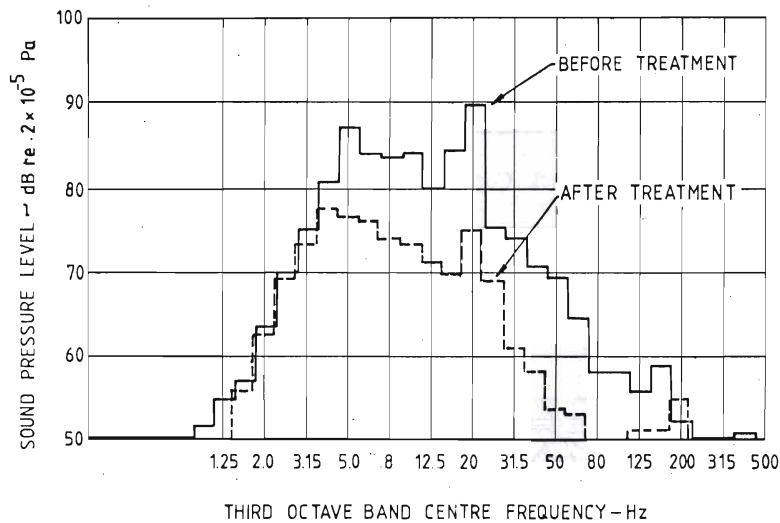


Figure 9 Ventilation Fan Noise in Disc Cleaning Room



### Ventilating Fan Noise

One very common source of low frequency noise is concerned with ventilation and air conditioning systems in large buildings. In such cases the air mover is a large fan, often feeding into a plenum-chamber from which supply ducts run off to various parts of the building. Typical of the problems encountered was the case of a new computer installation, housed in a prestige block with full air conditioning, double glazing, a great deal of added acoustic absorption and hence a generally hushed ambience. However, when the people moved in and the air conditioning was switched on the result was chaos.

High levels of low frequency noise affected certain vital rooms in the building and within the first day complaints and cases of sickness were reported. Noise measurements in these rooms showed a spectrum with most of the sound energy distributed between 2 Hz and 50 Hz, and dominated by a tone at 20 Hz (Fig. 9).



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This was somewhat surprising since in fan noise spectra, the dominant tone occurs commonly at blade passing frequency (Number of fan blades X Rotor revolutions per second) which in this case would have given a tone frequency of over 200 Hz. It was quickly discovered that the dominant 20 Hz tone coincided with the fan rotor fundamental frequency (1 X Rotor revolutions per second) and was almost certainly due to an aerodynamic imbalance. It was then that the real arguments started, because the fan manufacturer considered that the fan was moving the specified amount of air while consuming the specified electrical power. The acoustical contractor who had supplied the air-duct silencers did not want to be involved because he had been given a noise specification based on one of the internationally recognised NR curves (NR 35) which specified sound pressure levels in octave bands only down to a centre frequency of 63 Hz. As this specification had been met, the low frequency noise was irrelevant to him, although by now the building was unusable.

Meanwhile with an expensive computer standing idle the managers wanted an instant solution.

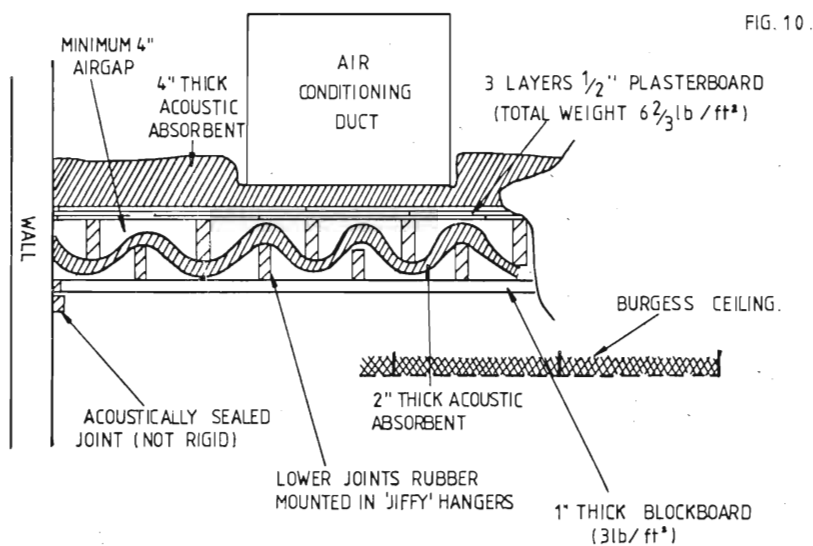
Measurement showed that most of the low frequency energy was being radiated through the exposed sides of the sheet metal air distribution ducts rather than through the air distribution nozzles in each room. So although it was recognised as not the ideal solution, the acousticians were prevailed upon to silence the offending ducts rather than deal with the noise at source. By simple application of the mass-law plus the use of acoustic absorption, adequate silencing was achieved (Fig. 9). Within one week, computer work restarted, and the building has now been in use without noise complaints for 6 years. The silencing treatment which was employed is shown in Fig. 10.

Incidentally, while the problem was at its height, measurements in one of the rooms where no ill effects to people were observed showed a 1/3rd octave sound pressure level of 74 dB at 20 Hz and this, together with previous experience of the community accepting 75 dB in the 31.5 Hz octave band, suggested, with obvious success, a target level of 75 dB for the low frequency sound.

The total irrelevance of the dBA scale in low frequency work is shown by the following comparison of dBA and overall sound pressure levels dB(Lin) measured in the disc cleaning room:

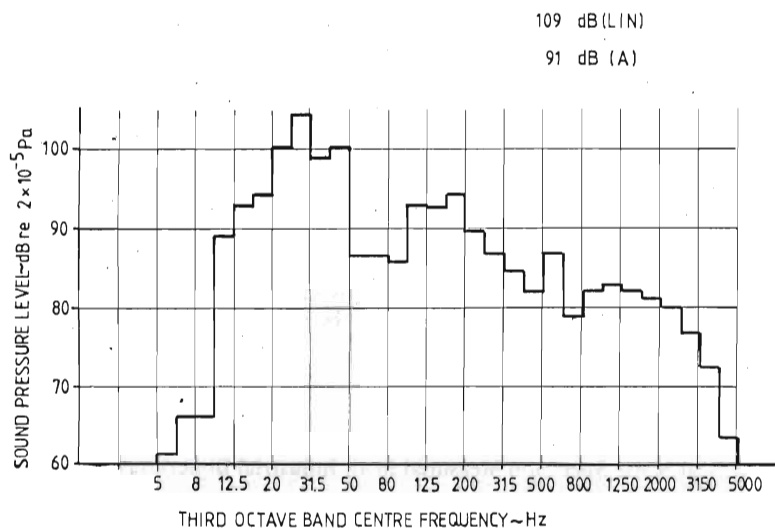
	dB(A)	dB(Lin)	Effect
Before Treatment	54	98	People Ill
After Treatment	48	85	People unaffected

Figure 10 New Computer Block. Construction of Acoustic Ceiling



NOTE:  
THE STANDARD BURGESS CEILING WAS RE-INSTALLED BELOW  
THE ACOUSTIC CEILING SHOWN ABOVE

Figure 11 Reciprocating Air Compressor 1ft from Intake (On Load)



**Reciprocating Type Air Compressors**

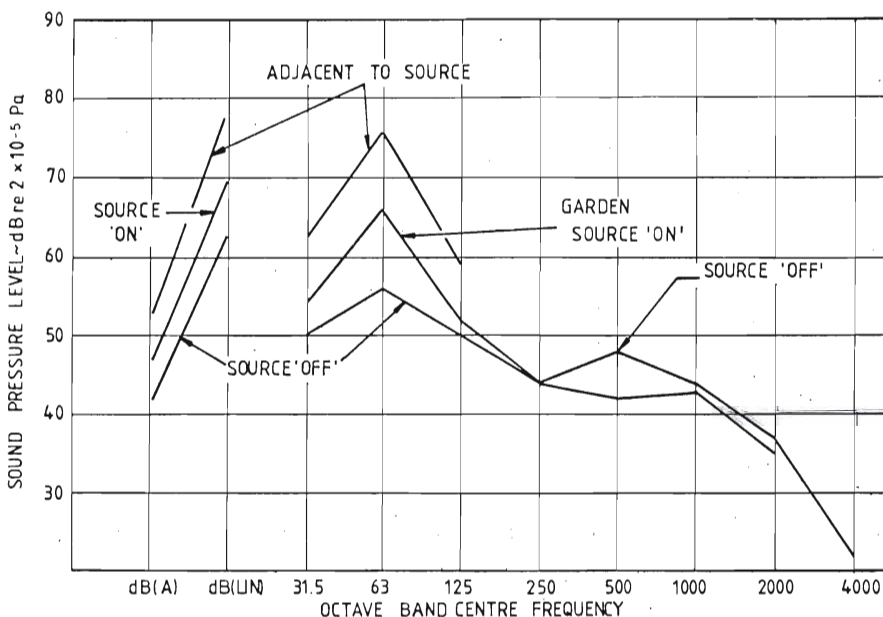
Reciprocating type air compressors are extensively used throughout industry and are a source of much annoyance. Moreover when they are used to maintain pressure in a pneumatic system with variable demand, such as a compressed air supply for a whole factory they continuously go on and off load. As the resultant noise level varies intermittently it is more annoying for a given level than a steady noise.

Fig. 11 shows the low frequency spectrum measured at the air inlet to a compressor which is typical of the breed. This particular noise proved stressful to people in nearby offices, but it also affected an adjacent surgery and worse still the very low frequencies were audible inside an audiometry booth which was itself situated in a masonry structure designed to be virtually bomb-proof during the 1939-45 war.

It should be noted that the spectrum shown in Fig. 11 does not represent a continuous noise, but shows the sound pressure distribution during each repetitive 'chug' of the compressor which occurred about 6 times per second.

Standard methods of silencing would be to mount the compressor on anti-vibration pads, to put an acoustically absorbent duct section in front of the air intake and to put flexible sections in all pipes connected to the unit. However this type of installation can be effectively silenced by a side-branch resonator in the air-inlet-duct.

Figure 12 Domestic Boiler Noise



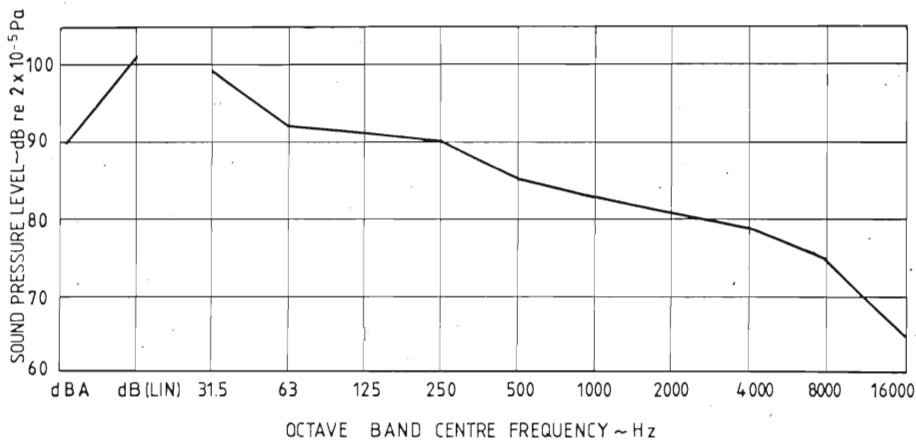
**Domestic Boilers**

Domestic and industrial boilers, whether fired by oil or gas can give rise to disturbing levels of low frequency noise, although complaints quite often refer to 'vibration problems'.

On one occasion an Environmental Health Officer of Bristol Corporation contacted the author because a householder had complained that noise from gas turbine test beds was bouncing off cloud, with which the city of Bristol is afflicted, and drenching a certain road with low frequency noise. In such cases it is useless to simply assert that the complainant is wrong, because he is then likely to feel that he has been fobbed off by a large organisation. It is infinitely preferable to pinpoint the source and get the complainant to agree, as was done in this case. Fig. 12 shows octave band noise spectra measured in the complainant's garden and adjacent to the balanced flue of a small gas fired boiler in a nearby house, which the complainant readily agreed was the offending noise source.

The obvious limitation of trying to define either low frequency noise level or noise nuisance in terms of dBA units is again demonstrated in Fig. 12, for a level of 46 dBA measured at the complainant's house with the source 'ON' is reasonable by any currently accepted standards.

Figure 13 Typical Noise Spectrum Measured in an Industrial Boilerhouse



**Industrial Boiler Plant**

Because in industrial plant the energy release is much greater than in the case of domestic boilers, and the scale of the process is of course larger, much more low frequency noise is generated. This can give rise to problems in adjacent offices and workshops as well as in the surrounding community.

A typical sound pressure spectrum measured at the control desk in a boiler hall is shown in Fig. 13. It is not surprising that boilermen who are exposed for long periods complain of tiredness and irritability at the end of the working shift.

So far as the local community are concerned they are likely to be afflicted with a disturbingly intermittent low frequency rumble. In urban areas the problem is less marked than in quiet rural locations where for instance the combustion roar from oil fired heating boilers in horticultural nurseries can prove intrusive over a wide area.

There appears to be little that can be done to ensure inherently quiet combustion, but fortunately there is scope for putting acoustically absorbent sections in the exhaust duct to attenuate the low frequency noise.

This is helpful so far as the surrounding community is concerned but of course does nothing for the boilerman. It is now common practice to erect some sort of quiet refuge either in or adjacent to the boiler house so that the operator is not needlessly exposed to noise over long periods.

Some industrial boilers have a fan-assisted air supply which is another frequent source of complaint. However, silencing of fan ducts is a fairly simple procedure, and standard bolt-on silencers are readily available.

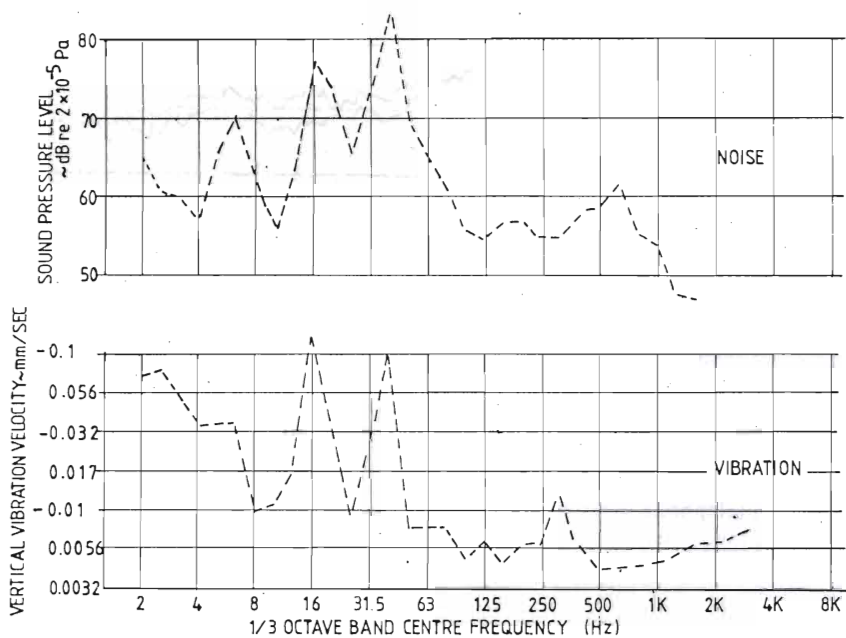
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### Diesel Powered Transport

The diesel engine, with its low firing rate and often immense power, is a prolific source of disturbing low frequency noise and the literature abounds with reference to ill effects noted in, for instance, submarine crews and locomotive drivers.

Powerful diesels used for ship propulsion produce both noise and vibration which, travelling as airborne and structure-borne waves, cause annoyance and physiological reactions in passengers and crew. Results from an investigation carried out on the cabin deck of a cross-channel car ferry (7) demonstrate peaks of noise and vibration in the infrasonic and low frequency bands, which make the ship both uncomfortable and unpopular (Fig. 14). In such cases effective silencing can be extremely complex and expensive. Far better to specify reasonable acoustic criteria at the design stage. In the case of diesel powered locomotives and lorries, high level exposure to low frequency noise is generally confined to the occupants of the driving compartment.

Figure 14 Noise & Vibration on Cabin Deck of Diesel Powered Ship



### Dynamic Noise Suppression for Diesel Engines

Apart from conventional silencing techniques the facilities afforded by the microchip have resurrected interest in dynamic silencing. It is possible to detect a sound wave by a microphone, reverse its phase by 180° and feed it back at the same level as the source, thus completely cancelling the noise.

In the case of ducts carrying discrete sound pulses, as for instance diesel exhausts, the silencing effect can be quite spectacular, but in the free field it is often less so.

### Low Frequency Noise and Wind Throb in Cars

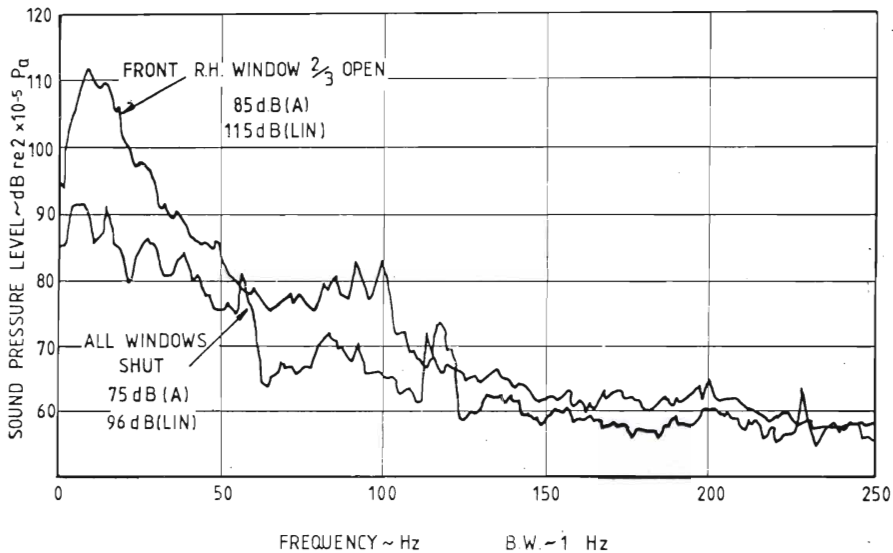
The very common phenomenon of car sickness may in certain cases be related to low frequency noise. Because of the relative insensitivity of ears to low frequency and infrasonic noise most people do not realise the levels to which they can be exposed during a car journey. Furthermore, opening a window at speed induces a wind throb effect in which the car body acting as a classical Helmholtz resonator, induces greatly increased sound pressure.

A detailed examination of the phenomena is given by Aspinwall (8) but a simple example of the effect of opening the driver's window of the author's car when travelling at 60 miles per hour on a motorway is shown in Fig. 15.

There are arguments about the significance of this effect – which some believe to be quite sinister – but one thing that is readily demonstrated at a practical level is the surprising feeling of freshness after a long drive on a motorway while wearing resilient plastic or glass down ear inserts.

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Figure 15 Vehicle Wind Throb – Window Open/Closed Saloon Car ~ 60 m.p.h.



### Buildings in the Wind

When a solid body such as a telephone cable is exposed to the wind it produces a distinctive humming sound. The frequency can be predicted from the simple Strouhal Number equation

$$\frac{\text{Sound Frequency} \times \text{Body Diameter}}{\text{Wind Velocity}} = 0.18 - (\text{a constant})$$

Now as with telephone wires, so it is with high rise buildings, only in this case the frequency is low (usually infrasonic).

There can be no doubt that humans are susceptible to fluctuations in atmospheric pressure even at very low frequencies, and any infant school teacher will confirm that young children, particularly in the mass, are unmanageable on a windy day. It follows therefore that infrasonic and low frequency noise due to high winds round buildings can cause problems.

As an example, data have been published which show that at the top of a 16 storey hospital in Denmark people exhibited the low frequency sickness syndrome during high winds when the infrasonic noise increased by about 10 dB above the ambient level (9).

Is it possible that some of the depression symptoms exhibited by dwellers in high rise buildings are noise-induced?

### Distant Guns

An irritant to sensitive people in the Bristol area is the dull thud of gunfire from Army activities on Salisbury Plain. The phenomenon, apparent on hot and humid days, causes irritation and comment and is just one more stress factor.

### The Bristol Hum

In the field of low frequency noise control an exercise which attracted world-wide publicity has recently been completed.

Complaints of low frequency noise are endemic and certainly in the gas turbine industry are handled as a matter of routine. However, for some time residents of the City of Bristol had complained of a persistent and widespread problem. Eventually the local authority decided to mount a major campaign to trace the source of what rapidly became known as the Bristol Hum.

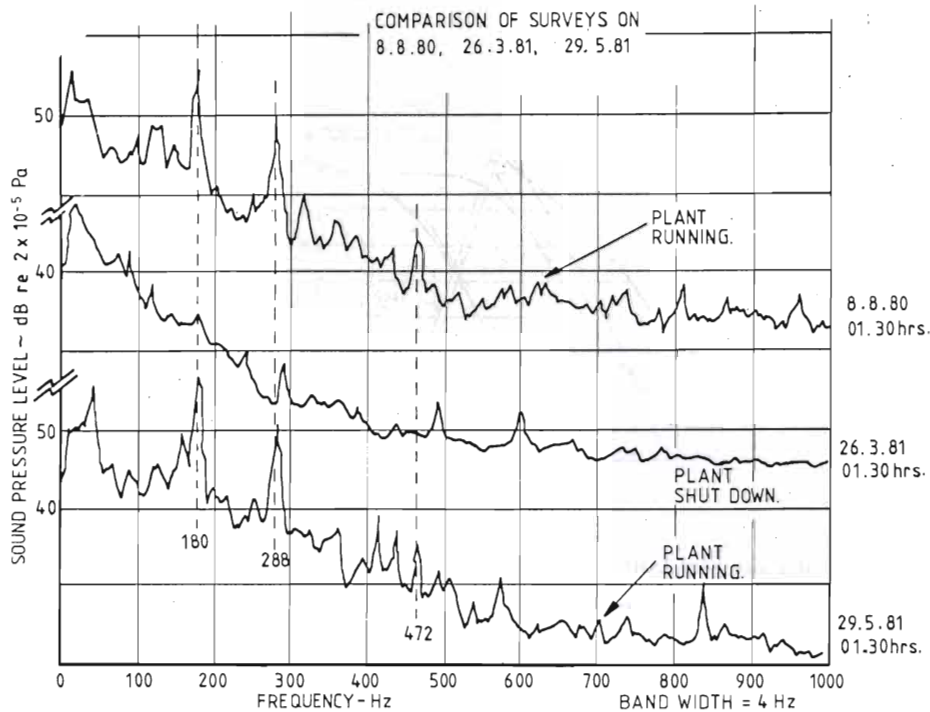
As might have been expected, and in spite of widespread rumour and speculation, the joint local-authority/industry exercise established that there was no omnipresent hum throughout the city, but that in common with any other urban environment there was a multiplicity of noise sources, some of which persisted at night when the general ambient levels had fallen by about 8 dB from their daytime level. Therefore these noises could become quite intrusive. So, on the Eastern

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side of the city the hum was in fact the motorway, near the city centre it was industrial plant, and on the western side it was tonal in character, of fairly low level, quite annoying to sensitive ears and emanated from a bank of large fans in an industrial complex. Having unambiguously located this particular noise source the local authority are taking steps to have it silenced, but this will do nothing for those in other areas of Bristol, Dorset, Norfolk, The United States, Australia, or New Zealand who wrote to say that they were themselves afflicted!

The genuine 'Bristol Hum' with its characteristic tonal quality consisting of true Low Frequency noise is shown in Fig. 16 where it is compared with an ambient spectrum measured at the same location. It should be noted that the ambient spectrum is itself dominated by infrasonic energy although the subjective effect was one of absolute quiet! One should therefore never be mesmerised by the numbers game, but should remember that ears are indispensable tools in assessing the subjective effect of any noise.

Figure 16 Bristol Hum Investigation



### Practical Difficulties of Low Frequency Noise Suppression

Although some specific silencing techniques have been described above, there are some very important aspects of the general case which should be noted.

The physical principles of noise reduction apply equally at all frequencies but in the case of low frequencies the engineering task is made much more difficult than it is for high frequencies. Effective silencing of any source can only be achieved by:—

- Reduction in generated acoustic power
- Suppression of the noise after generation
- Prevention of any residual noise getting to an unwilling receiver.

In practice successful silencing usually depends on a combination of these.

The special difficulties in low frequency silencing arise from the fact that:—

- Many of the source processes are inherently noisy (viz. combustion, turbulent gas flow, etc.) and those sources which effectively generate great amounts of acoustic power at low frequency are themselves comparatively huge. So the scale of the engineering is often large and expensive.
- Suppression of noise depends usually on a combination of transmission loss plus acoustic absorption to deal with any reverberant noise in either the source or receiving enclosures, or in any ducts along which the noise must travel. But because of the large wavelength involved and the quarter-wavelength law for efficient absorption, effective absorbers are usually impractical. Adequate transmission loss by enclosure is also difficult to achieve. For example, whatever the transmission loss of a structure at a medium

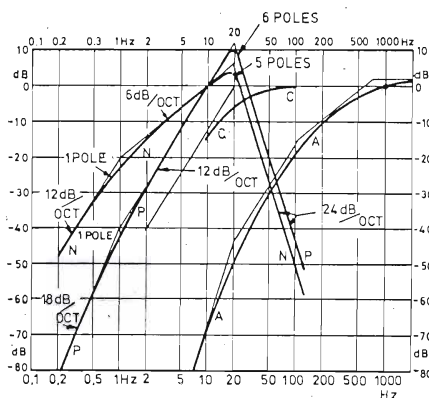
## PRACTICAL ASPECTS OF LOW FREQUENCY NOISE

frequency, say 1,000 Hz, it is likely to be 25 dB less at a typical low frequency of say 32 Hz.

To reduce the propagation of residual noise from source to receiver depends usually on a combination of distance and shielding. But as has already been stated, low frequencies travel well over great distances, the long wavelength makes them spread spherically and they easily refract over most practical barriers.

These difficulties, plus the fact that there are no accepted criteria for low frequency noise has meant that throughout industry, the problem has been largely ignored.

Figure 17 International Standardisation for Low Frequency Noise Measurement – Weighting Curves for Discussion. (After Bruel Ref. 10)



### A New Measurement Unit

There exist well established techniques for measuring low frequency noise, but for control to be applied in a scientific and cost-effective manner, low frequency and infrasound must be described in simple units and it is imperative that some standardisation is established. For an acoustician, the noise can be adequately described by enumerating the sound pressure levels in given frequency bands, as indeed has been done throughout this paper. But if these data are to be used in a wider context of defining permissible limits and describing a noise simply, they must be turned into one number such as is given by the A weighting curve when defining higher frequency noise.

As has been shown, the A weighting curve is by definition unsuitable for describing low frequencies or infrasound because it is designed specifically to exclude them. Therefore a curve which approximates to the hearing threshold (designated as the P weighting) and which falls off by 12 dB per octave towards the low frequencies (Fig. 17) is being studied by the International Standards Organisation (Ref. 10). But it has been assumed that international labour protection agencies would not favour this curve as it tolerates very high sound pressures between 2 Hz and 4 Hz.

It is therefore also proposed to introduce another curve (designated 'N') which falls off at 6 dB per octave – Fig. 17.

Once these curves and their tolerances have been defined by the International Standards Organisation each country will be free to prescribe its own limits for both low frequency and infrasound.

Definition of these parameters and the consequent introduction of meters capable of measuring them directly will prove scientifically useful. However, a number of local authorities are concerned that they may have to invest money in yet more noise measuring equipment.

### Limiting Levels and What Damages Us

It is not clear to the author what level of low frequency noise is physically damaging to people, and only in a few extreme cases has a relationship between damage and exposure to infrasound been established on a firm scientific basis (Ref. 10).

## PRACTICAL ASPECTS OF LOW FREQUENCY NOISE

Sweden and Norway have however established limits for the maximum permissible levels of infrasound and the current situation is as follows:

Country:	Frequency:	Level:	Time:
Sweden	2 Hz–20 Hz	110 dB	8 hour working day
Norway	Regulation has been postponed due to increasing criticism – Possibly awaiting action by International Standards Organisation (ISO)		

United Kingdom limits are not yet defined and interested parties should contribute to the debate while there is still time.

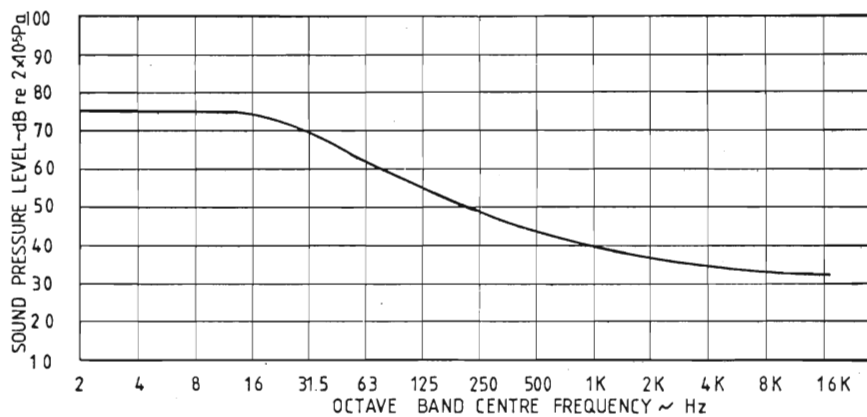
### An Empirical Criterion to Avoid Nuisance

In order to minimise reaction from the local community while not going to an unreasonable extent on the law of diminishing returns which characterises all silencing work, the author has found that the empirically derived criterion, shown in Fig. 18, is useful. For convenience, the data are presented in both graphical and tabular form.

Figure 18 Community Noise Criterion

$\frac{1}{3}$  Octave Band ~ Measured at the Nearest House

Sound Pressure Level dB re $2 \times 10^{-5}$ Pa	$\frac{1}{3}$ Octave Band Centre Freq. ~ Hz	Sound Pressure Level dB re $2 \times 10^{-5}$ Pa	$\frac{1}{3}$ Octave Band Centre Freq. ~ Hz	Sound Pressure Level dB re $2 \times 10^{-5}$ Pa	$\frac{1}{3}$ Octave Band Centre Freq. ~ Hz	Sound Pressure Level dB re $2 \times 10^{-5}$ Pa	$\frac{1}{3}$ Octave Band Centre Freq. ~ Hz
75	2	73.2	20	50.8	200	37.2	2K
75	2.5	71.8	25	49	250	36.4	2.5K
75	3.15	70	31.5	47	315	35.8	3.15K
75	4	67	40	45.5	400	35	4K
75	5	64.5	50	44	500	34.2	5K
75	6.3	62	63	42.5	630	34	6.3K
75	8	59.5	80	41.2	800	33.2	8K
75	10	57.2	100	40	1K	32.8	10K
75	12.5	55	125	39	1.25K	32.2	12.5K
74.5	16	52.8	160	38	1.6K	32	16K



### Conclusions and Action Plan

Low frequency noise and infrasound currently pose a significant, but not paramount, pollution problem in industrialised society. Their ill-effects are becoming more widely known and increasing public awareness will generate social pressure for adequate control of any hazard. This will inevitably lead to legislation and both before and after that legislation is framed the author suggests that those with an interest in the subject should:

Encourage wider awareness by ensuring that proven facts on the subject are promulgated to those having a need to know;

Make their own views known in a clear and authoritative manner;

And finally, do what they can to draw together the relevant local authorities, industries, professions and agencies to act as a truly multidisciplinary team to free us, so far as is reasonably practicable from the curious rumblings of low frequency noise.



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