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The Solution of Low Frequency Noise Problems Associated with a Combined Heat and Power Plant

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Complaints of low frequency noise arose following installation of a CHP system in an existing boiler room. Control was by a multi-stage process, the main phases of which were: Reduction of LF noise in the boiler room: Detuning the stack: Reduction of breakout from the stack: Identifying the residual problem. The final phase enabled the correct exhaust silencer to be selected. The end result was that annoying excitation of room modes and irritating throbbing noises were reduced to below complaint level.

1. INTRODUCTION

London Power Company plc installed a CHP plant in the existing boiler house of Imperial College of Science Technology and Medicine (ICST&M) with the 51m high engine exhaust stacks in close proximity to the Royal College of Music (RCM). A major engineering challenge of this project was to build a CHP plant in a very restricted space with difficult flue locations. The main sources of energy generation were two Wartsila 18SG28 engines, which are 4-stroke 18 cylinder 'V' type, running on natural gas at a speed of 1000rpm, producing about 9MW of power.

After completion of the installation there were two separate complaints of annoyance by low frequency noise, which were attributed to the new plant. The two complaints were as follows:

- from occupants of certain rooms within ICST&M of a low frequency sound, established to be around 31.5Hz.
- from occupants of certain rooms within the RCM of a low frequency sound, established to be around 25Hz.

This paper gives the approach to the solutions of these problems and then the solution of a new, apparent very low frequency sound problem, which became audible after the initial two problems had been resolved. The combined effort of various London Power Company plc personnel, Industrial and Marine Silencers Ltd and the writers of this paper unraveled what had been a difficult combination of low frequency noise problems.

2. THE SYSTEM

Fig 1 illustrates the layout of the CHP plant. The engines run on gas and drive electrical generators. The hot exhaust gases may be sent directly to atmosphere through the stacks or diverted through the boilers when hot water is required. The boilers are also able to operate directly on gas, as an alternative to extracting heat from the engine exhaust.

The first source of sound to be considered was 31.5Hz in the boiler room, which was associated with the air intakes of boilers when burning gas. Based on the results of the sound surveys of the boilers it was observed that there was an audible tonal

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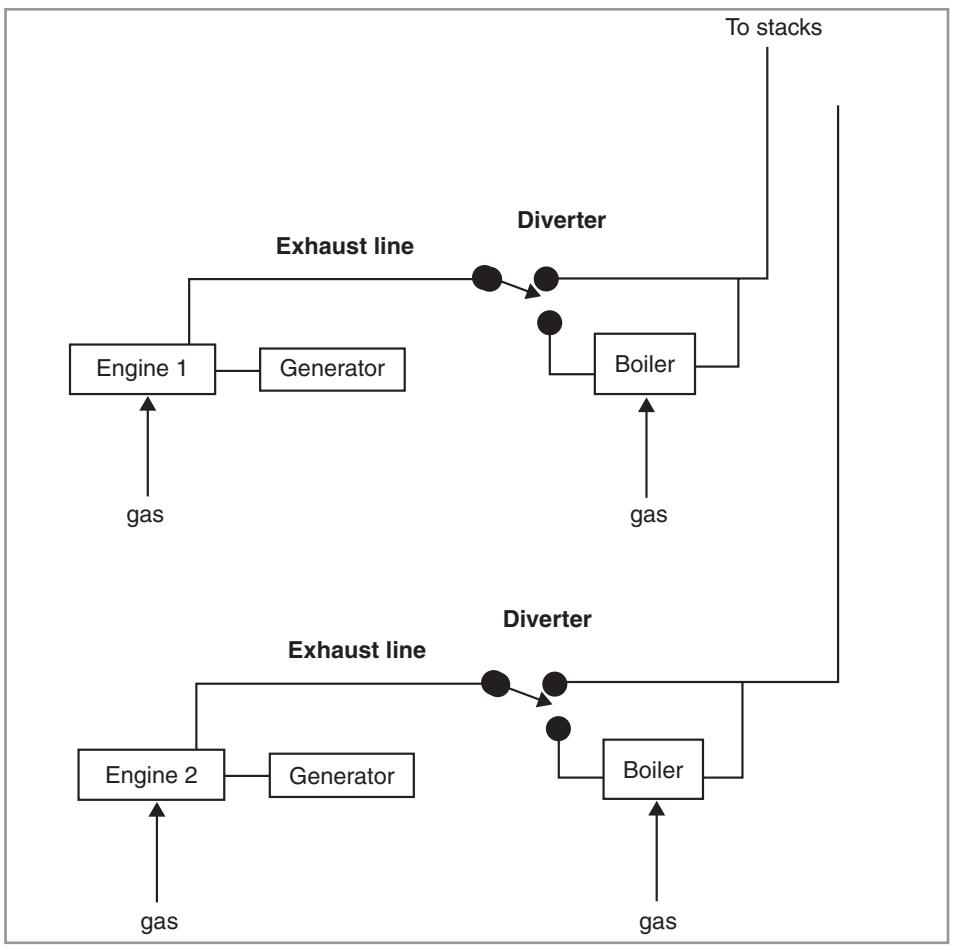

Figure 1 Arrangement of boiler room

component, peaking at a third octave frequency of 31.5Hz. The spectra are given in Figs 2 and 3 for boiler 1 and boiler 2 respectively.

The sound pressure levels at 31.5 Hz at 1m from the air intake were:

Boiler No.1-118 dB,

Boiler No.2-108 dB.

The flue intake pipes were of suitable length to resonate at 31.5Hz. The first proposal was to increase the lengths of the air intake ducts to a half wavelength at 31.5Hz, but this was not possible as other plant was in the way.

However, there was the unusual situation of spare capacity in the fan assisted airflow to the boiler and the air flow was reduced using a baffle plate, which resulted in an acceptable sound reduction.

3. STACKS

The second low frequency sound problem was associated with the exhaust stacks, which were of height 51m and nominal diameter 0.9m. An annoying tonal sound at 25Hz was produced in rooms in the adjacent Royal College of Music. Fig 4 shows the sound pressure level measured at a distance of 10m from the exhaust stack at a point around 25m from ground level, with the exhaust system on by-pass i.e. the exhaust gases are not being used to heat water. The one-third octave sound pressure at 25Hz was nearly 130dB.

The situation occurring here was similar to the boiler intake ducts, but on a much larger scale. The gas columns in the stacks were creating high sound levels at 25Hz. due to resonance. There were absorptive attenuators in the stacks but no reactive attenuation was included, as it was believed that there was not sufficient space to include attenuators which would be effective at 25Hz.

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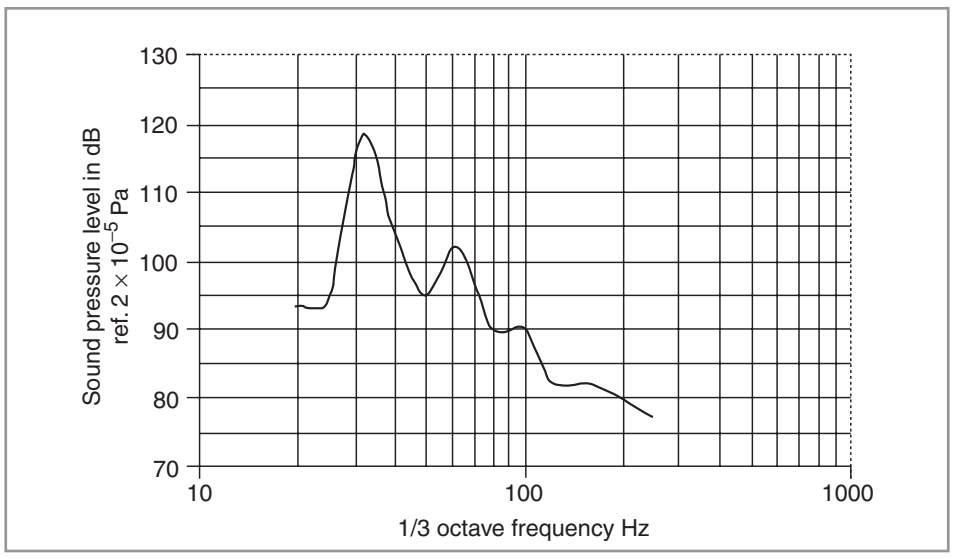

Figure 2 *Spectrum near to boiler No.1*

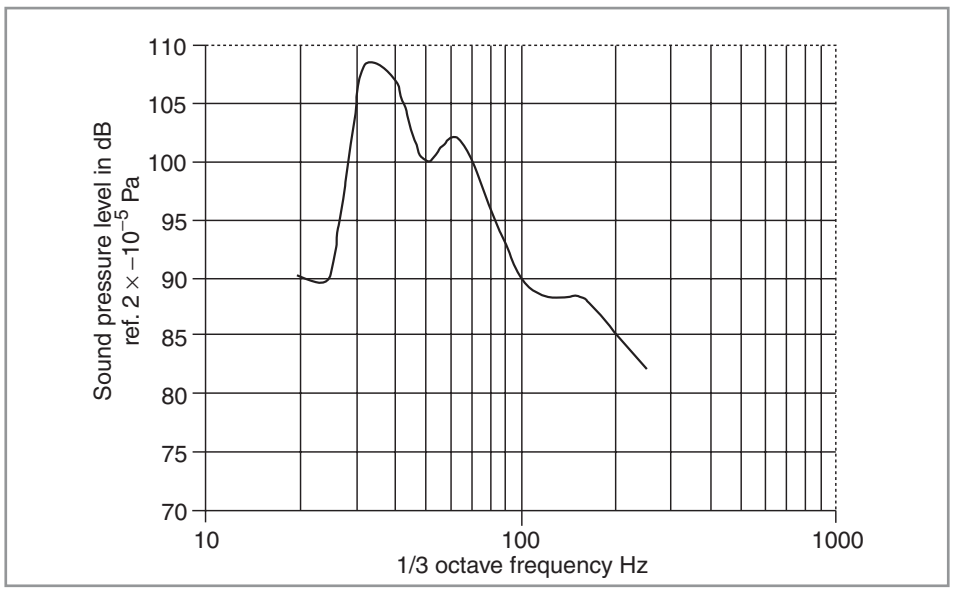

Figure 3 *Spectrum near to boiler No.2*

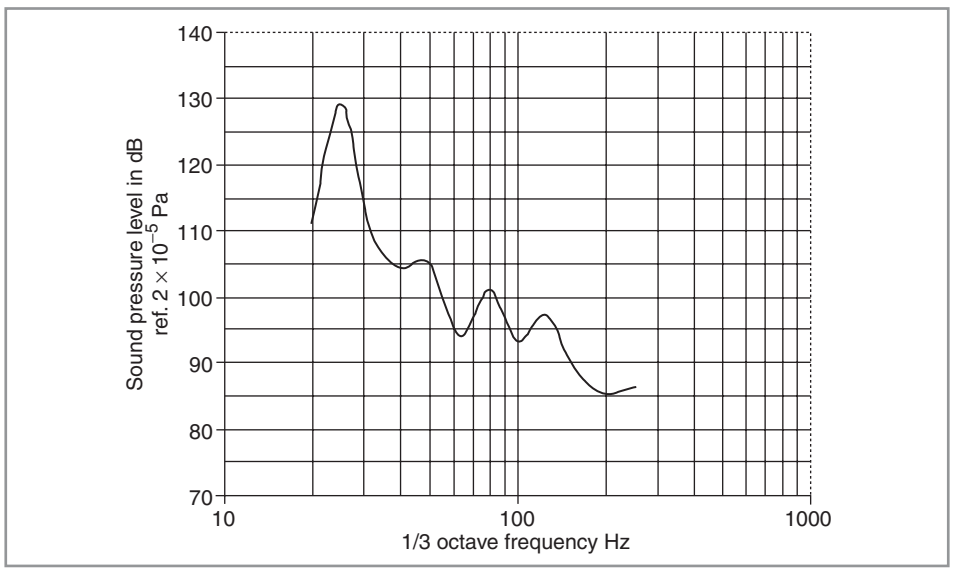

Figure 4 *Noise 10m from exhaust stack*

NOISE & HEALTH

Chronic noise exposure may increase your risk of heart attack, according to German researchers who interviewed more than 4,000 heart attack patients admitted to Berlin hospitals between 1998 and 2001. The researchers looked at to what extent the patients had been bothered by annoying noises from sources like traffic, industrial sites, or construction zones. Participants were asked about the noises, their sources, and how vexing the sounds had been. The researchers also considered traffic around the patients' home and calculated how much noise they had been exposed to at work over a 10-year period. For women, environmental noises were a health hazard. Those who reported annoying environmental noises were 50 percent more likely to have had a heart attack than those who didn't report them. Men weren't affected by environmental noises, but noisy workplaces made them 30 percent more likely to have a heart attack. Workplace noise didn't seem to bother a woman's heart. Studies have suggested chronic noise exposure causes stress, which leads to increases in blood pressure and changes in cholesterol. These changes can contribute to the development of heart disease. The work was presented at the European society of Cardiology's Congress, 28 August – 1 September.

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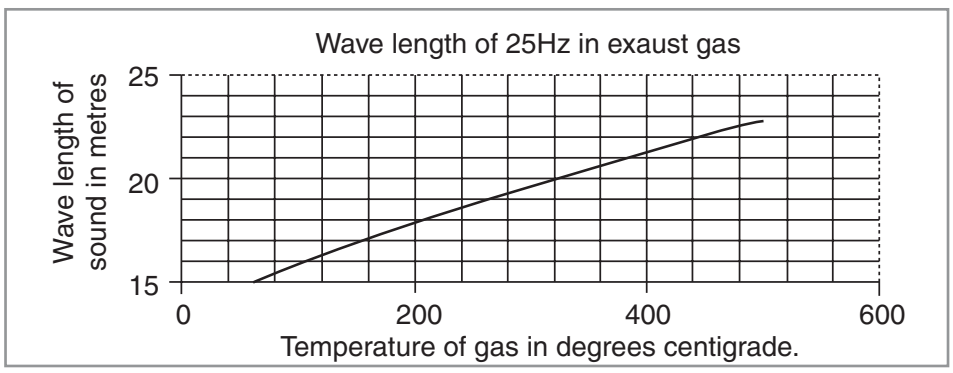

Figure 5 Wavelength of 25Hz in exhaust gas

At the time of taking these measurements a relatively faint, much lower frequency sound, could be discerned which was similar to 'piston slap' and was initially estimated to have a frequency around 5Hz.

Due to the space restriction, the exhaust ducts changed shape from circular to rectangular section when passing through the plant room wall and then back to circular section. This created large flat panels that could resonate at low frequencies and were susceptible to break-out. The solution was to stiffen the rectangular ducts in-situ by ribs fitted inside the duct.

Reduction at 25Hz was achieved by detuning the stacks by the insertion of a hole in the stacks to change the resonant frequency of the gas columns. This is similar to opening a hole on a wind instrument, but on a larger scale. However, the exhaust stacks ran at two different temperatures, one on by-pass and one when the exhaust gases were directed through the boilers. The two temperatures were nominally 400°C and 200°C. Both conditions gave rise to a peak at 25Hz, although there was a level difference between the two conditions, as the boilers gave some, but insufficient, attenuation.

Therefore both conditions had to be considered when locating the detuning hole, as the wavelength of the exhaust gases will depend on temperature. (See Fig 5).

The information available included:

- 25Hz Measured frequency.
- 150Hz engine firing frequency.
- As these are 'V' type engines there is usually a half firing frequency of 75Hz.
- Also the firing rate of each cylinder was 150/18 = 8.33Hz.
- Height of stack, approx 50m

25Hz is the third harmonic of 8.33Hz

The resonant frequencies in a closed–open pipe of length h are given by

$$f = \frac{(2n - 1)}{4} \frac{c}{h} \text{ Hz} \qquad (1)$$

where c is the velocity of sound and n an integer.

Assuming constant temperature along the pipe. Table I gives relations between the quantities for h = 50m.

Inserting a hole, which operated for both temperatures, near the top of the stack could be effective, but in practice there are:

- Uncertainties in the temperature of the gas.
- An end correction for the stacks.
- Uncertainty as to the exact location of the closed end at the bottom of the stack.
- Temperature variations along the stack.

Accordingly, the position of the maximum was obtained by measurement. A thin copper tube with a

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Table I.

Temperature °C	Velocity of sound m/s	Wavelength at 25Hz m	Harmonic number n
200	450	18	5
400	525	21	6

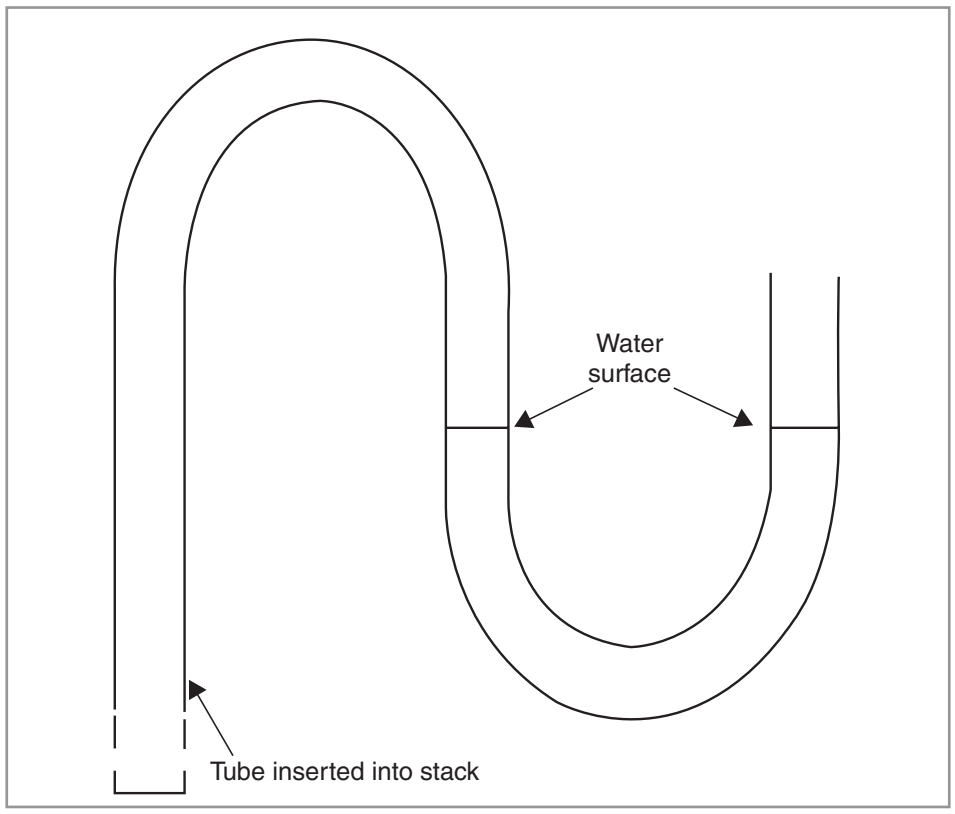

Figure 6 Manometer for location of pressure maximum

closed end and side holes drilled near the end to act as static pressure tappings (Fig 6) was introduced into the stack by passing it through the links of a heavy chain and then lowering the chain down the stack. The chain had to be sufficiently long so that the personnel working near the top of the stack were not subjected to the exhaust gases.

The free end of the tube was connected to a water manometer and when the maximum was located the water rose up the manometer quite aggressively.

The static pressure measured was most probably not a true static i.e. there was some measure of velocity pressure included. Nevertheless a location at around 8m from the top of the stack was chosen by experiment and a hole drilled.

On checking the attenuation at 25Hz, a reduction of 29dB was obtained when running on by-pass. This was insufficient attenuation and some form of additional reactive attenuation might be required. However, standard reactive attenuators do not give sufficient attenuation at 25Hz, even if space was available to fit them.

4. LOW FREQUENCY THROB

Reduction of the 25Hz noise had made it possible to hear a new low frequency noise within the Royal College of Music. The noise was throbbing rapidly, giving the impression of a very high level at a very low frequency. As there were two engines, beating between them was considered, but the throbbing noise was present when only one engine was

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running.

Sound level meter measurements did not show a rising spectrum into low frequencies (Fig 7) and in order to identify the sound, it was decided to take tape recordings on a DAT recorder for later analysis and inspection on an oscilloscope. Narrow band spectrum analysis showed many harmonics of 8.3Hz, the firing rate of each cylinder, as shown in Fig 8. But any frequency analysis involves averaging, so that temporal characteristics of a noise are lost.

Examining the waveform, Fig 9, revealed that the noise was a relatively high frequency of 125Hz, modulated at 8.3Hz, resulting in the audible throb. Reference to Fig 8 shows a prominent component at 125Hz with adjacent

VIBRATION SOLUTIONS

A Cedar Falls dentist and Iowa State University professor have formed a company they say will "revolutionize the design of noise-generating machinery." Dr Ken Budke and Atul Kelkar, professor mechanical engineering at ISU, have founded Vibroacoustics Solutions. The company intends to develop a "smart" material that can control noise and vibrations in applications ranging from home appliances and office furniture to construction equipment and vehicle suspension systems. The material will have active and passive vibration-reduction features that can cover a wide spectrum of vibration frequencies and also be molded like conventional plastics for use in engineered products. For example, Vibroacoustics is working on a seat application that minimizes vibrations that cause spinal injuries in people who spend long hours driving. "We want to make it easier to work in an environment with noise and vibrations," Budke said.

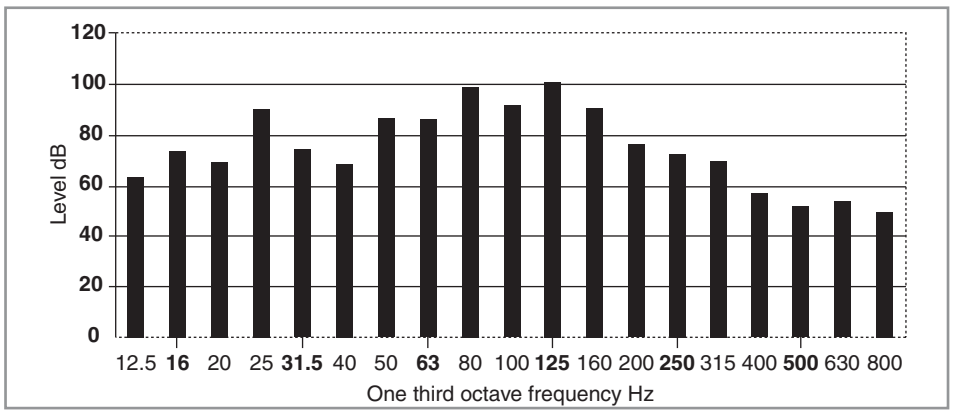

Figure 7 *Conventional 1/3 octave analysis of the engine noise near the top of the stack*

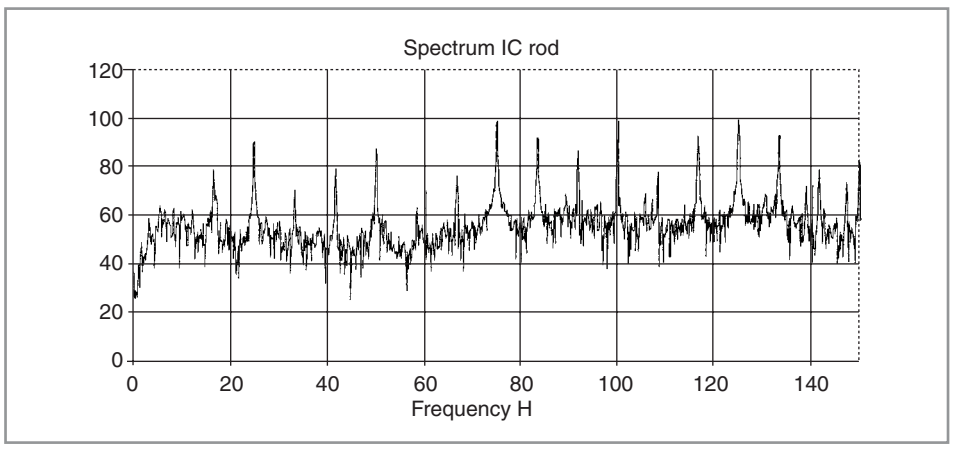

Figure 8 *Narrow band analysis of noise near top of stack*

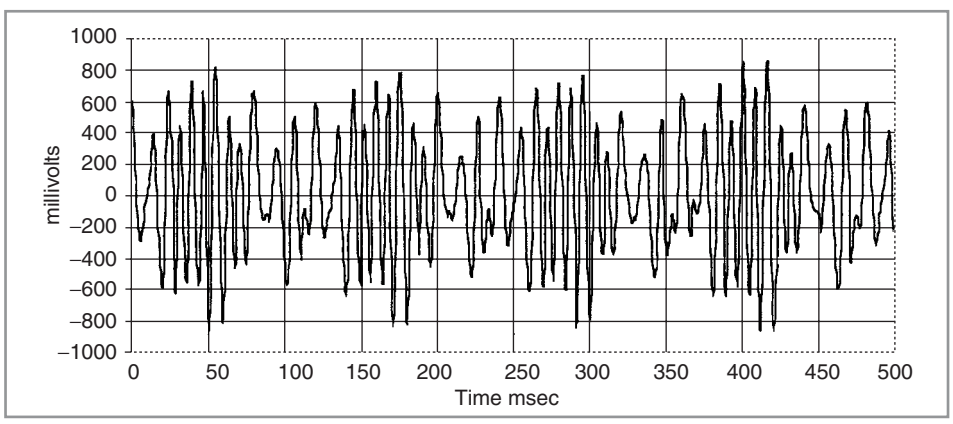

Figure 9 *Waveform near top of stack*

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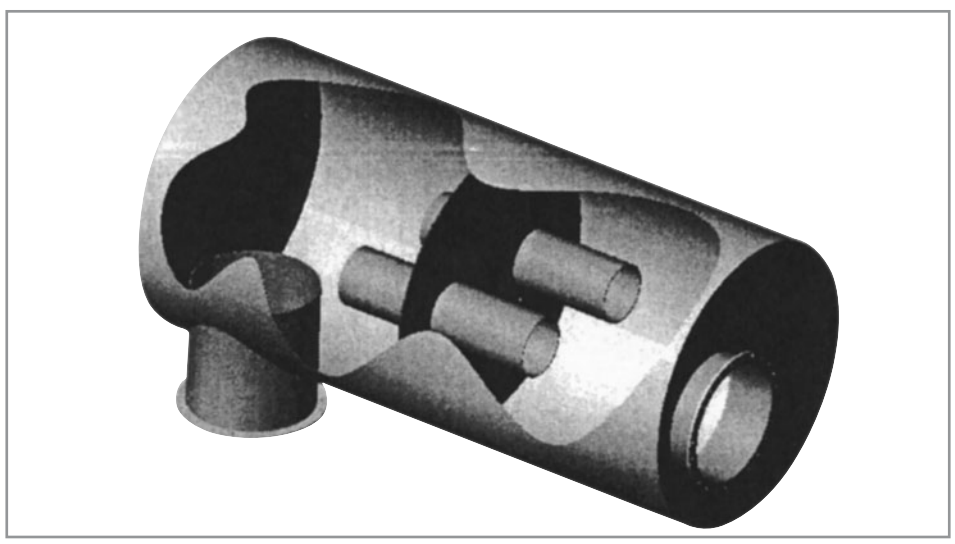

Figure 10 Reactive exhaust silencer fitted close to each engine

Table II. Attenuation by reactive silencer of Fig 10

Harmonic	Freq Hz	Without silencer dB	With silencer dB	Attenuation dB
3	25	90	76	14
6	50	87	75	12
9	75	99	79	20
10	83	92	74	18
12	100	91	64	27
14	117	93	66	27
15	125	100	75	25
16	133	93	61	32
18	150	83	60	23

frequencies of 125 ± 8.3Hz. These are the conditions for an amplitude modulated waveform. The problem was therefore shown to be at around 125Hz, rather than at very low frequencies, and consequently much easier to control.

Reactive attenuators of suitable size and performance were supplied by Industrial and Marine Silencers Ltd. Silencer configuration is as in Fig 10.

Measurements were repeated after the silencers were fitted. Table II compares before and after results at a point about 3m from the top of the stack. The attenuations, when referred to octave bands, were close to the manufacturer's specification for the silencer.

The noise was not audible within the main complaint locations of the Royal College of Music and the problem considered as solved.

5. CONCLUSIONS

Standard sound level meter measurements of low frequency noise may be misleading, because such measurements are always an average and suppress the character of the noise. It may be necessary to inspect the waveform.

A complex installation may have multiple low frequency problems, which become apparent as successive reductions take place.

Low frequencies are enhanced by resonances, both in the system itself and in rooms in adjacent buildings.

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PATROLMAN'S DISCRETION

The Ithaca Council has passed an amendment to Ithaca's noise ordinance that will extend police officers' authority to issue noise violation citations without a third party complainant. The measure was passed by 7 votes to 2. Those against feared the police might exceed their powers, or act in an arbitrary way. Those for cited citizens reluctance to complain for fear of retribution, the likelihood that a frequent subjective witness of noisy situations – the patrolman – might quickly become a better judge of whether a noise really was unreasonable than an individual citizen whose perceptions might involve an isolated case.

AIRPORT & COMMUNITY HEALTH

The lack of independent studies on airport expansion could compromise community health, according to one of Stop Stansted Expansion's campaigners. According to a comment column in the medical journal The Lancet, the health of the community runs the risk of being severely compromised by airport operator BAA carrying out all environmental and health impact assessments, with no independent input. The issue was highlighted by Professor Jangu Banatvala who heads the Stop Stansted Expansion's health committee. Professor Banatvala cited air quality and noise as posing particular threats to children, elderly people and those with disabilities. He explained how the performance of primary school children was affected when exposed to noise and how official Government papers recommended funding of school trips away. Adults who suffer sleep-loss and fatigue from regular aircraft noise are also in danger of having accidents caused by concentration failure, especially while doing complex tasks. Expanding on his comment column, Professor Banatvala said: "The fact that as the planning authority Uttlesford District Council will have the opportunity to audit the assessments is of little value, since it can do little more than scratch the surface of the extensive work which is needed to safeguard the community's health and the environment. This is all the more reason for a truly independent study that people and planners can trust as an accurate assessment of potential impacts." Professor Banatvala suggests that studies should be carried out before key policy decisions regarding expansion are taken, rather than at the planning stage.

WHO IS RIGHT?

The Pink Picnic, an event at Cherry Hinton Hall, Cambridgeshire, attracted 7,000 visitors at the August Bank Holiday. Organisers insisted that they did follow the City Council's guidelines on environmental health-noise. In the light of that, why was one resident reported as saying "My family and I are now recovering from the flagrant assault on our peace and sanity"? How could such a comment arise if there were adequate regulations, properly enforced?