Noise Generation by Water Pipe Leaks

Problem presented by

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Problem statement

Leaks from water supply pipes generate noise, which can be used to locate the position of the leak. The Study Group was asked to clarify the processes generating the noise, so that the noise characteristics might provide other information about the leak, in particular the size of a leak if possible.

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1 Introduction

Leaks from water supply pipes generate noise, which can be used to locate the position of the leak. Mecon would like to understand the processes generating the noise, in order to use the noise characteristics to provide other information about the leak, in particular the size of a leak if possible.

Experiments carried out by Mecon have used the experimental setup indicated in Figure 1.

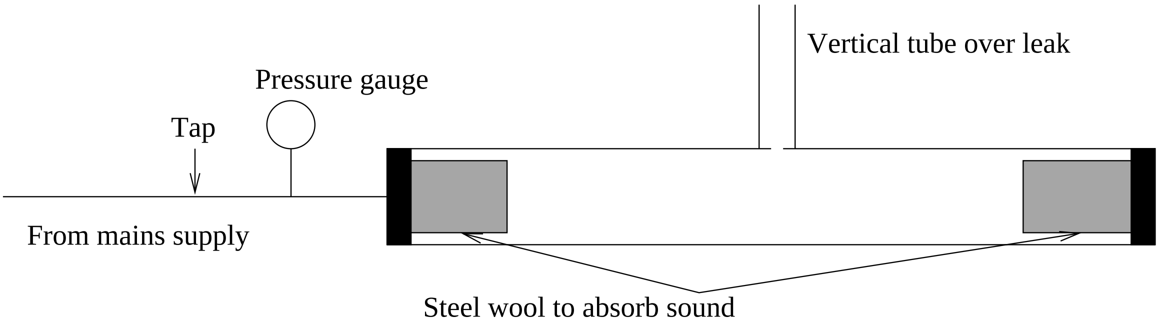

Figure 1: Diagram of Mecon experiment

Water supply was taken from the mains, via a length of hose, through a garden tap which was used to control the pressure, then to a pressure gauge, then into a 5 m long ductile iron (DI) pipe of diameter 100 mm. The pipe was supported on bags of grit at 0.5 m intervals to provide some mechanical damping, and coarse steel wool was inserted in the ends for the same reason. A leak hole was drilled half way along the pipe, and noise was measured with a microphone attached to the outside of the pipe at different positions. The noise was analysed over 0–40 kHz. Water leaking into air was found to be very quiet. Therefore a plastic tube, of diameter 30 mm, was attached to the pipe over the leak with a silicone sealant, and provided a head of 200 mm of water for the leak to drive into. An increase in this height to 1 m made little difference to the noise. However, with 200 mm, there were significant differences depending whether the tube was vertical or at 20° to vertical, apparently due to swirl and induced air entrainment in the tube.

The main set of experiments was therefore conducted with a vertical 200 mm tube over the leak. The leak noise spectrum was measured for circular holes of diameter $d = 1\,\mathrm{mm}$, $2\,\mathrm{mm}$, $4\,\mathrm{mm}$, $6\,\mathrm{mm}$, $8\,\mathrm{mm}$, at pressure levels $p = 1, 2, \ldots$ Bar up to the maximum pressure that occurred with the tap fully open. (This maximum pressure was $p = 5.6$ Bar for $d = 1, 2\,\mathrm{mm}$; $p = 4.6$ Bar for $d = 4\,\mathrm{mm}$; $p = 2.7$ Bar for $d = 6\,\mathrm{mm}$; and $p = 1.4$ Bar for $d = 8\,\mathrm{mm}$. These pressures are relative to atmospheric.) The detailed noise spectra are included in the Mecon report [1], along with some discussion of them.

An independent comment on the problem was provided by S. V. Sorokin of St. Petersburg on 30-Mar-2001, and this is included as an Appendix. However, the Study Group participants did not have the chance to meet Prof Sorokin and therefore did not really discuss his comments.

2 Comments on the experimental results

It seemed to those working on this problem at the Study Group that the differences between leaking into air, leaking into water in a vertical tube, and leaking into water in an inclined tube were probably the most significant observations: they show that the *environment the water leaks into* probably has much more influence on the noise generated than the size of the leak itself.

A further observation about the spectra, in addition to those noted in [1] is most noticeable in the results for $d = 1\,\mathrm{mm}$. Whereas in general there is a trend that as the pressure increases the noise level increases, a distinct exception to that is noticeable in Graph 2 of [1]. Below about 4 kHz, the noise level for $p = 1\,\mathrm{Bar}$ *exceeds* that for $p = 2\,\mathrm{Bar}$, perhaps by 20 dB. The only explanation that the Study Group could offer for this is to suggest that it may be an effect of noise generated at the *tap* that is used to reduce the hydrostatic pressure in the pipe. It may be that with $d = 1\,\mathrm{mm}$, and with the tap closed off enough to reduce the pressure to 1 Bar, the noise generated by the tap is in fact *greater* than that generated by the leak. Thus when the tap is opened up slightly to increase the pressure to 2 Bar, although the leak noise as such increases, the drop in tap noise is actually the main change, and results in a lower overall recorded noise level. Checking with Mecon, it was confirmed that this was possible, and that no particular care had been exercised to prevent tap noise from leaking into the experiment, other than the steel wool already referred to.

This observation led the Study Group to treat the experimental data with some caution, since we clearly cannot always be sure how much of what is recorded is genuinely leak noise and how much is tap noise — which of course will have a generally similar character.

3 Noise generation mechanisms in the experiment

3.1 Turbulent flow in the vertical tube

Following Mecon's observation that the presence of the vertical tube is a significant element in the noise generation, we discuss the general nature of the flow in the tube.

The velocity at exit from the leak will be $U = \sqrt{2p/\rho}$ if all the pressure drop p is across the leak. This gives $U = 14\,\mathrm{m/s}$ for $p = 1\,\mathrm{Bar}$, $16\,\mathrm{m/s}$ for 1.4 Bar, and $32\,\mathrm{m/s}$ for 5.6 Bar. The Reynolds number $\mathrm{Re} = Ud/\nu$ for $d = 1\,\mathrm{mm}$ and $U = 16\,\mathrm{m/s}$ is $\mathrm{Re} = 1.6 \times 10^4$. So there will be a turbulent jet in the tube, and we also note that the boundary layers on the edges of a drilled hole will be thin. (Of course, real leak holes present considerably more variety than the drilled hole in the experiment.)

In general the turbulent jet in the exit tube will have a half angle of about 10°, which will mean that it hits the wall of the tube at a height of about 85 mm. In general terms, the jet will "run out of momentum" in a distance of order $l = d\sqrt{\mathrm{Re}}$, and for the figures above, this jet length $l = 120\,\mathrm{mm}$. For larger diameter holes or larger pressures, the jet length is larger than this. Hence when the jet hits the walls of the tube it will still be carrying significant turbulent pressure fluctuations which will be transmitted to the tube, and hence to the pipe.

We should point out that we have *not* estimated the fluid-solid coupling at all, merely shown that the turbulent jet in the tube will reach the walls.

The aeroacoustics of the sound generated by a fluctuating flow in the vicinity of a small stationary object show that the total power radiated is proportional to

$$\rho_0 U_c^6 L^2 / c_0^3 \tag{1}$$

where ρ_0 and c_0 are the fluid density and sound speed, U_c is an appropriate characteristic flow velocity and L the size of the object. (See [5] p.125). This is expected to give the scaling of the dipole sound generated by this interaction of the turbulent flow with the rigid boundary.

3.2 Pressure fluctuations in shear layers

These are internal to the fluid, and would be expected to be only weak sources of noise.

3.3 Vortex shedding

One possible source of instability in the flow through the hole is vortex shedding. The frequency of this is of order U/d which is of order 10^4–10^5 Hz, larger than shown in the experiments, and with a definite d-dependence, whereas the experiments showed that the spectrum of the noise had a fairly standard form, with features occurring at frequencies that did *not* depend on d.

3.4 Bubbles

No bubbles were seen in the tube in the Mecon experiments. This makes it difficult to see how they can be involved in the noise production, even though of course bubbles are much the most common means of converting pressure fluctuations in a flow into noise. The possibility that there might be small bubbles that escaped observation was raised, but as pointed out in [2] the resonant frequency of an air bubble in water is $340/D$ Hz where D is the diameter in cm. Hence bubbles too small to be seen would produce frequencies higher than we are considering here.

The only way in which bubbles might be playing a role would be if they were entrained in a way that prevents them from rising up the tube.

4 Noise generation mechanisms in practice

If we consider what might happen for a real pipe leak, then of course there are considerable differences from the experiment above. The jet will gradually excavate a cavity, which will either be full of water or have some air in it, depending on the nature of the surrounding material. In a cavity with air, there is the possibility of air entrainment at the free surface, which will be noisy. Whether or not air is present, there is the possibility of solid particles being carried round in swirling flow, generating noise by their impacts on the pipe. The spectrum of this would be expected to have a peak at frequencies of order L/U (the reciprocal of the residence time), so for a cavity of diameter $L \approx 1$ cm, this would be 1.6 kHz.

5 Suggestions for further experiments

The observation made earlier suggests that tap noise should be carefully controlled in any future experiments.

Also, there is perhaps value in looking at the noise generated by water leaking into a cavity, and the dependence of this on cavity size, and on whether the cavity is water-filled or contains some air.

A Appendix: comments of S. V. Sorokin

The mechanism of noise generation most likely is:

At low frequencies — unsteady flow separation at the hole

At high frequencies — cavitation.

Both mechanisms provide a uniform excitation in broad frequency bands. This is why no particular frequency is specified for plastic pipes and measurements may be performed at any frequency up to 200 Hz, *i.e.* at the range of low frequencies. This statement for high frequencies is supported by experimental results reported for DI pipe: there is a broad maximum around 16 kHz. The presence of resonant frequencies at 3.3 kHz and 4.175 kHz in DI pipe may be explained by an influence of some inhomogeneities (*e.g.* joints) which add a discrete frequency spectrum on top of a continuous spectrum of an infinitely long tube. This aspect should be clarified by some additional experimental data. Does a pipe have joints? How is the pipe mounted in the experimental rig? What is the influence of the pipe's thickness and radius on these resonant frequencies?

In the case when noise generation is related to a flow separation (low frequencies), its intensity should depend on the area of the hole, because this area controls the water discharge. In the high-frequency case, the intensity of cavitation-generated leak noise does not depend on the leak size.

The mechanism of transportation of the noise is related to duct (axisymmetric) modes in fluid loaded elastic cylindrical shells; it has been analysed by Fuller and Fahy, see [3] and [4]. The mechanism of generation of the noise is (most likely) of a purely hydrodynamic nature. It is related to an unsteady flow at the hole and is not coupled with the deformation of the pipe.

References

[1] Leak noise tests at AES. Mecon Ltd. Supplied at Study Group.

[2] Waves in fluids. James Lighthill. CUP, 1978.

[3] Characteristics of wave propagation and energy distributions in cylindrical elastic shells filled with fluid. C. R. Fuller and F. J. Fahy. Journal of Sound and Vibration **81** 501–518, 1982.

[4] The input mobility of an infinite circular cylindrical elastic shell filled with fluid. C. R. Fuller. Journal of Sound and Vibration **87** 409–427, 1983.

[5] Aeroacoustics. M. E. Goldstein. McGraw-Hill, 1976.