Measurements on tones generated in a corrugated flow pipe with special attention to the influence of a low frequency oscillation.*

Ulf R. Kristiansen
Acoustics Research Center,
NTNU, O.S. Bragstads plass 2b, 7491 Trondheim, Norway

Pierre-Olivier Mattei , Cedric Pinhede
Laboratoire de Méchanique et d'Acoustique, CNRS,
31 Chemin Joseph Aiguier,13009 Marseille, France

Muriel Amielh
Institut de Recherche sur les Phénomènes Hors Équilibre,
49 rue F. Joliot Curie, 13013 Marseille, France

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Abstract

When air is flowing through a corrugated pipe strong single frequency sounds may be generated. For short pipes these tones normally correspond to the pipe's longitudinal resonances. In this communication we present results from experiments where a fluid oscillation has been added to the constant flow. It was found that depending on the oscillation strength, the pipe may be silenced or moved to higher harmonics. It was also found that a purely oscillating flow by itself may generate pipe resonances. The phenomenon is discussed with basis in acoustic pressure measurements taken at a fixed position inside of the pipe.

1 Introduction

Sound production in corrugated pipes is a well known phenomenon. The sound will be powerful for relatively low flow velocities, which again makes a short corrugated pipe ideal for physics demonstrations, or as a musical toy (the Hummer). Corrugated pipes are also quite common in industrial applications, and may cause noise problems. The flow acoustic interaction is complicated as it involves a close interaction between the flow and the acoustic resonances in the pipe. A review of the literature on the topic up to about 2006 is given by Kristiansen and Wiik [4]. The studies up to that time were largely experimental. Simplified models of sound sources interacting with the pipe flow has later been presented by Goyder [3], Debut et al.[2], and Mironov et al. [5]. Tonon et al. [8] point out the similarities between pipes having multiple side branches and fully corrugated pipes. Numerical approaches have also started to appear, Popescu and Johansen recently modeled the flow and acoustic field in a short pipe solving the compressible Navier-Stokes equation [6]. The acoustic system active for short pipes is linked to the longitudinal pipe resonances while the aerodynamic one is seen as the hydrodynamic modes of the shear layer above each cavity. The interaction appears complicated as both source and sink regions may appear along the pipe.

The topic has received renewed interest as the so called "singing riser" problem has become apparent in the natural gas industry. The long flexible pipes used for conveying gas are corrugated on the inside and are known to exhibit strong sound levels at pure tones on some off shore installations. A recent publication directly treating the singing riser problem is published by Belfroid et al. [1]. Riser pipes are generally very long. The resonant frequencies for such systems are believed to be associated with shorter, connected pipes on the top-side rather that the length resonances of the full length riser.

In this presentation we report the influence of low frequency sound on corrugated pipe resonances in a simple experimental arrangement. Adding an oscillation to the flow makes the flow situation rather special. The effect is however interesting and it is the discussion of the physics of the situation that has been our primary aim by this presentation, rather than presenting a mitigation technique for singing riser pipes. A strong added low frequency tone may be detrimental to such structures.

The corrugated pipe was connected to a wooden box with a volume large enough to represent an open end condition for the pipe. The pipe therefore has open-open boundary conditions. The box and corrugated pipe can be regarded as a Helmholtz resonator at low frequencies. We used a test signal of 10Hz, which is close to the theoretical Helmholtz frequency for the box/pipe combination. A vacuum cleaner is connected to the box to provide an air flow through the system. At 10 Hz, the air in the pipe is expected to vibrate as a single body. The sound field will however decrease from the box side towards the open entry end.

The presented measurements are mostly of sound levels measured at a position 30mm inside of the pipe from the flow entry section. At this point all the modes measured in the present investigation are present.

2 Experimental set up

A sketch of the experimental set up is shown in Figure 1. The inner box volume measures 0.29×0.29×0.55 m. The corrugated pipe has an inner diameter of 25.4 mm, and is 0.64 m long. The cavity pitch is 5 mm. The pipe geometry is similar to the one discussed reference 4, but is also illustrated in Figure 2. A 35 mm inner diameter pipe connects the box to a vacuum cleaner. A 240 mm diameter loudspeaker is positioned at one of the box walls. The loudspeaker was fed 10Hz signals between 0 and 12 V. By sucking air through the system, the loudspeaker might be displaced from its neutral position. To compensate for this, a 0.07 m^3 volume was constructed on the back side of the loudspeaker. Small holes were drilled in the wall between the volumes to ensure a static pressure equilibrium. The velocity is measured with a Pitot tube at the box side opening of the pipe. The Pitot tube is con-

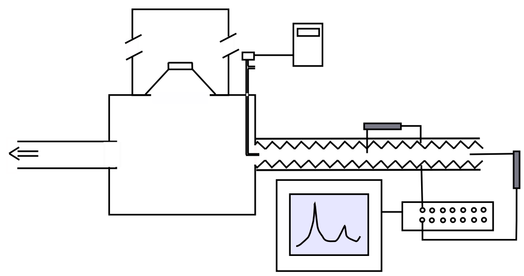

Figure 1: A sketch of the experimental set up.

nected to an electronic manometer of type Alnor AXD. In a special test, a standard hot wire anemometer probe (type 55P11 operated with a DANTEC Streamline CTA system) was used to measure the fluctuating velocity at the pipe's entry section. The sound levels were recorded with a 160 mm long probe microphone (type G.R.A.S. 40SC), positioned so that it measured the sound levels 30 mm into the pipe. A second probe microphone was used as a control microphone in the middle of the tube. The signals were transferred to a computer and analyzed by the dBFA suite 4.9 (01dB Metravib). The microphone was calibrated using standard calibration equipment. The probe corrections are supplied by the manufacturer and were accounted for.

3 Results

3.1 Flow generated resonances

In Figure 3 are shown the resonances generated by letting the vacuum cleaner draw air through the pipe. The sound pressure level of the dominant peak (measured 30mm into the pipe from the air entry end) is plotted against the velocity

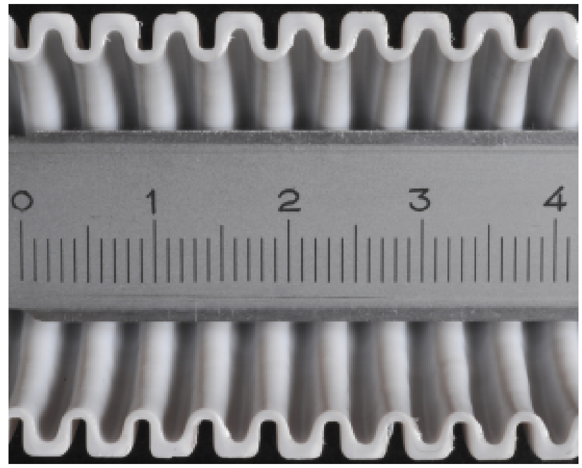

Figure 2: Section of the pipe.

measured at the box end of the pipe by the Pitot tube. The fundamental longitudinal resonance could not be excited. By increasing the velocity, harmonics were found at 506 Hz (square), 751 Hz (circle), 1012 Hz (star), 1256 Hz (diamond), and 1517 Hz (plus).

The strong increase in sound pressure level with velocity seen in Figure 3, is due to two phenomena. Higher velocities will generally generate higher sound pressure levels, and also, the 30 mm position approaches the position of a modal maximum with increasing modal order.

3.2 Resonances generated by 10Hz oscillation alone.

It was also observed that with no air flow drawn through the system, the 10 Hz oscillation could by itself excite resonances in the corrugated tube. Figure 4 shows the different dominant peaks as function of $L_{10}(30)$, the 10 Hz sound pressure level measured 30 mm from the flow entry opening. Figure 5 shows the spectrum at a

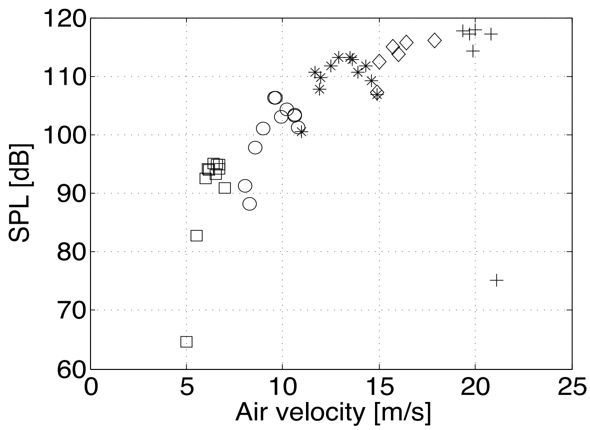

Figure 3: Sound pressure levels of dominant frequencies measured at 30mm position as function of flow velocity. Square: 2nd mode, circle: 3rd mode, star: 4th mode, diamond: 5th mode, and plus: 6th mode.

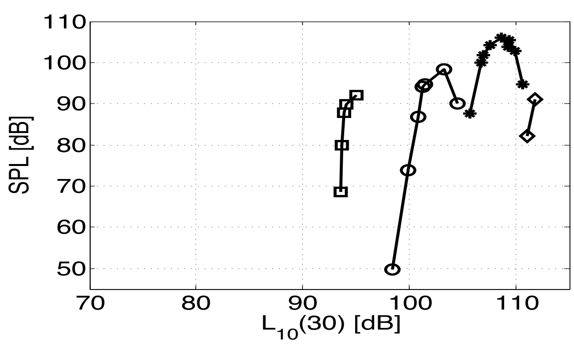

Figure 4: Resonances generated by 10 Hz tone alone. Square: 2nd mode, circle: 3rd mode, star: 4th mode, and diamond: 5th mode.

$L_{10}(30)$ level of 107.6 dB. We see that the peak is rather broad and modulated by the 10 Hz tone.

In what follows, the oscillating field is represented by a sound pressure level value at a given position, namely the $L_{10}(30)$ value.

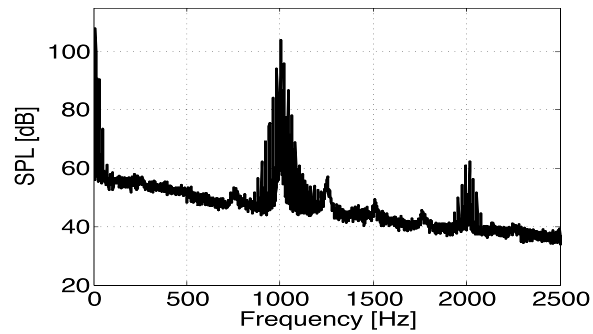

Figure 5: Spectrum measured for $L_{10}(30)$ = 107.6 dB.

3.3 Hot wire measurement

A hot wire velocity measurement was done at the pipe's inflow end to record oscillation velocities directly. It was not attempted to find a general relationship between the measured velocity and the sound pressure level at a specific position for the experimental set up. The purpose of the velocity measurements was to record order of magnitude values, and visualize signal forms. The measurements were done in the entry plane of the pipe on the axis position. Figure 6 shows an example of a fluctuating flow driven by the 10Hz tone alone. The vacuum cleaner end was in this case closed. An interpretation of the difference in heights is that this is caused by the difference in exit and entry flows at this position. The exit flow would be more jet like than the entry flow, where air is sucked from all directions. It is interesting to note that small Helmholtz resonators making use of this difference in entry and exit amplitudes are made use of as so-called "micro movers" see instance the paper by Surti et al [7]. In Figure 7 is plotted the velocity when air is drawn through the system by the vacuum cleaner. The flow is here always entering the pipe which makes the signal more symmetric. The velocity measured with no loudspeaker signal is also plotted. As this signal also contains the flow excited resonance, we can observe the orders of magnitude difference in 10Hz oscillation velocities and the high frequency particle velocities. The difference in the mean level measured by the hot wire and the Pitot value is attributed to the difference in exit and entry flows discussed above. At this velocity the pipe is nearly silenced.

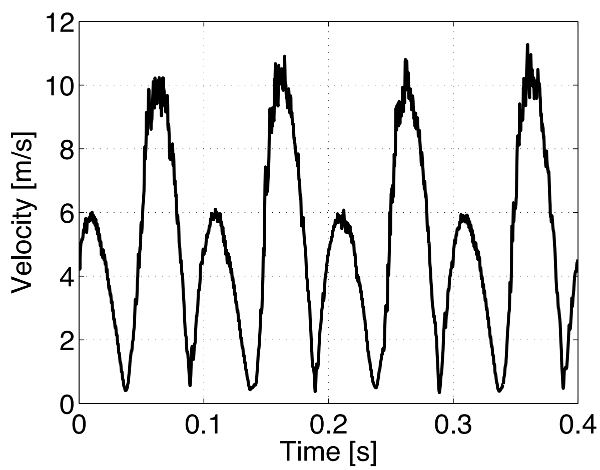

Figure 6: Hot wire measurement at center of the pipe's entry section. U_{pt} = 0m/s; Vacuum cleaner end closed. Loudspeaker voltage 7.5 V, $L_{10}(30)$=101.1 dB. Note that the hot wire used measures amplitude, not direction.

3.4 Influence of 10Hz tone on flow generated resonances

In Figure 8 are plotted spectra showing the influence of the 10Hz oscillation on the 2nd. longitudinal pipe resonance. With no 10 Hz tone present, this resonance was easily excited with

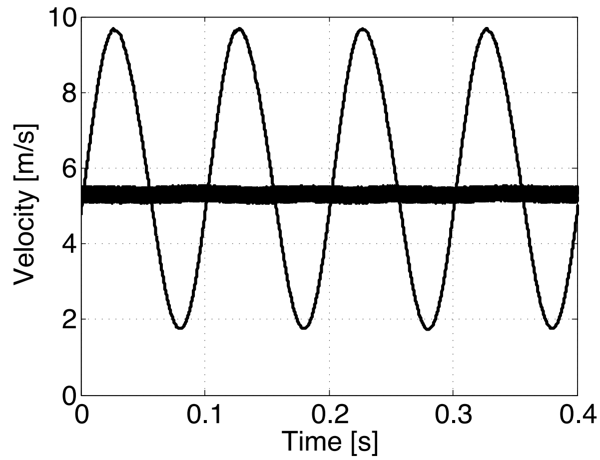

Figure 7: Hot wire measurement at center of entry section, $U_{pt} = 10.9$m/s. Loudspeaker voltage 9.0V. $L_{10}(30) = 110.5dB$

an air flow measured at 6.5 m/s with the Pitot tube. Comparing the upper spectra with the one below, it is seen that the resonant peak is reduced at this position by about 40 dB with an added $L_{10}(30)$ value of 89.4 dB. Increasing the tone's level even more, higher order resonances become apparent. It is also seen that these are much broader. The sound levels are measured at a position 30 mm into the tube from the air entry end. The sound levels will be higher at the different resonances' pressure peak positions inside the pipe.

In Figures 10 to 12, the 2nd, 3rd and 4th longitudinal resonances were generated by flow velocities $U_{pt} = 6.3$, 9.9 and 12m/s. It is seen also here that by adding and increasing the 10 Hz signal, the resonance levels are first lowered before the dominant peaks are shifted to the higher harmonics.

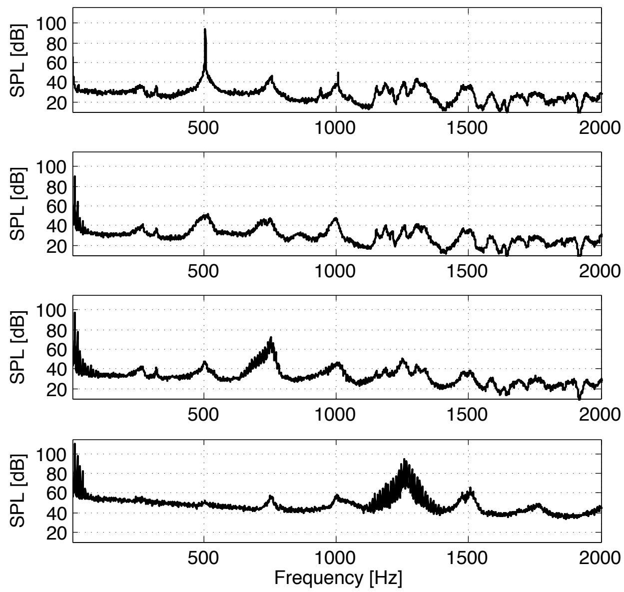

Figure 8: Influence of 10Hz tone on the second longitudinal pipe resonance. Upper Figure: resonance generated with flow velocity $U_{pt} = 6.5$m/s (no 10 Hz tone). Lower panels show the effect of an added 10 Hz tone at increasing levels: ($L_{10}(30) = 0$, 89.4, 96.6, and 109.4 dB)

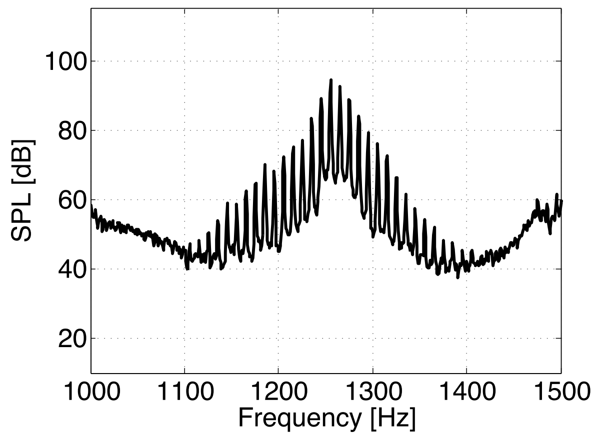

Figure 9: Close up of the resonance peak around 1250 Hz (5th longitudinal resonance) in the lower panel of Figure 8.

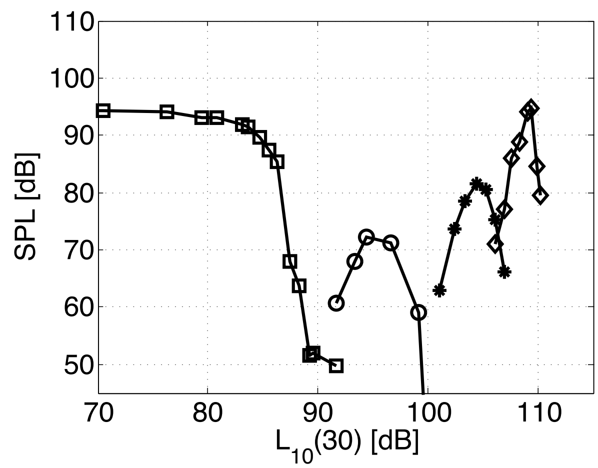

Figure 10: Effect of increasing 10Hz tone level on dominant spectrum peak. Start point is 2nd. harmonic excited with $U_{pt} = 6.3$m/s
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4 Discussion

By our experiments we have shown that by adding an oscillation to a steady air flow in a corrugated pipe, we may shift the resonances generated with no oscillation to higher modal orders. For some oscillation amplitudes the pipe will be silenced. We also found that the oscillating flow by itself may generate pipe resonances. Our acoustic measurements were taken at a position 30 mm into the pipe from the flow entry section. At this point all the modes will be present, that is: there is no pressure node for the modes in question. The relative magnitudes of a given mode should by this method be well represented. Comparing two modes will however give higher

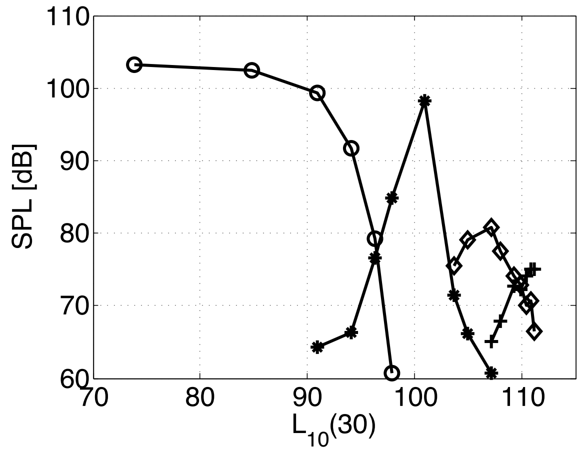

Figure 11: Effect of increasing 10Hz tone level on dominant spectrum peak. Start point is 3rd. harmonic excited with $U_{pt} = 9.9$m/s.

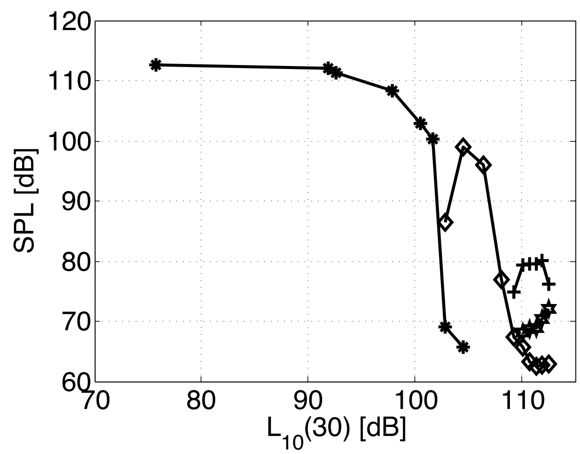

Figure 12: Effect of increasing 10Hz tone level on dominant spectrum peak. Start point is 4th harmonic excited with $U_{pt} = 12.0$m/s.

values for the one having the highest frequency as the 30 mm position will be closer to a pressure maximum. Ideally, the modes should have been measured at their maxima. This would however require a much more elaborate experimental set-up, as the exact positions would have to be searched for.

Some hot wire measurements at the pipe's entry section are presented to show that in the present experiment, the oscillation velocities were of the same order as the constant flow velocities. No detailed measurements have however yet been done on the details of the boundary layer in order to better understand the sound generating mechanism, or features like for instance the presence of acoustic streaming.

5 Bibliography

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