Effects of Centrifugal Blowers and Reservoir Resonance on Organ Pipe Flutter

Alan J Taylor

Acoustics Research Centre, University of Salford, Salford M5 4WT, UK.
A.Taylor22@edu.salford.ac.uk

Abstract

The aim of this paper is to investigate the noticeable flutter or amplitude modulation that may accompany the sound of an organ pipe. For pureness of tone it is important that the wind supply is perfectly steady and without any imperfections that may influence the pipe tone and cause pipe flutter. For many years Pipe Organ Builders have been aware of flutter that is present when voicing and tuning organ pipes and some have tried to address this problem with little success. This is investigated in the frequency domain using noise and vibration measurements for different combinations of fan and reservoir types operating at various wind pressures. Preliminary measurements indicate that under certain conditions, the fan excites the reservoir at its resonant frequency with sufficient amplitude to cause unwanted modulation.

Keywords: Pipe organs, timbre, modulation, vibration, Tremulant

PACS no. 43.66.Jh, 43.75.Np

1 Introduction

The first pipe organ was developed by Ctesibius, [1] a Greek engineer around 300 BC. The wind supply was pressurised by a column of water which gave the organ its name Hydraulus. Two thousand years later at the end of the nineteenth century, Sabine [2] used a similar arrangement in his famous experiment to resolve the acoustic problems in the Lecture room at Fogg Art Museum and derive the first reverberation time equation.

The development of the pipe organ has continued over the intervening centuries. Today the largest pipe organ in the world has over 33,000 pipes with seven keyboards and a pedalboard. The pipes vary from bass pipes with a speaking length of approximately 10 metres weighing over 1 tonne to treble pipes that have a speaking length of 5mm weighing just a few grams To supply this large copious supply of air requires mechanical means. Initially, the first pipe organs used a reservoir fed from a set of feeder bellows as shown in Figure 1. The air in the reservoir is pressurised by adding weights or springs to the reservoir top to obtain the organ pipe wind pressure. This will vary from organ to organ but is generally from 500 Pa to 1000 Pa. Normally single rise reservoirs are sprung and double rise reservoirs are weighted.

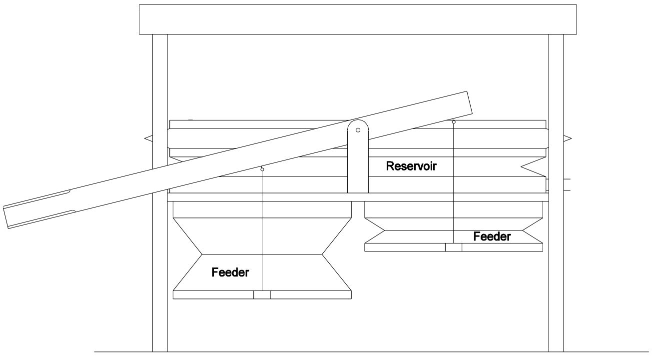

Figure 1 – Double Rise Reservoir and Feeders

Hand blowing of pipe organs continued until well into the twentieth century and was replaced by electrically driven fans. Initially the fans were very crude with impellers made from wood in a simple cruciform shape mounted in a wooden enclosure. In principal these early fans were a miniaturised version of the large mine ventilation fans described by Hoover [3] and the theory and design of these machines was first published by Kenealy [4].

The main restriction of these early fans was the restriction in electric motor choice. The development of 6, 4 and 2 pole motors running at 1000, 1500 and 3000 rpm allows the use of much smaller impellers with backward facing blades. Today, generally two motor speeds are used, 1500 and 3000 rpm, referred to as slow and high speed fans. A comprehensive history of organ blowing is well documented by Elvin [5].

Quantification of the dynamic behaviour of a simple single wedge reservoir wind system is described by Carlsson [6]. The use of a turbulence attenuator to reduce the effects of turbulence caused by a centrifugal organ blower is proposed by Ngu [7], while Pitsch [8] explores various means to reduce the transient pressure drop that occurs when a chord is played. This includes the use of a reservoir-less wind system which minimises the strong pressure oscillations that normally occur with a reservoir wind system.

Organ Builders have at their disposal wedge, single, double rise reservoirs and concussion units. Alternatively some choose to use wind-chest regulation with a Schwimmer arrangement. The Organ Builder selects a system of winding that best supports their style of pipe regulation and voicing with the ability for the wind system to handle large variations in demand as described earlier.

Most research examining in detail the changes in the pipe wind pressure for various playing conditions has been conducted in the time domain. Research by Steenbrugge [9] into the operating regimes and voicing practices and other work in this area of research assumes a pure unmodulated flutter free air supply. The Tremulant is a device that is designed to create extreme modulation of the sounding organ pipe and produce a vibrato effect. Its construction and use are comprehensively described by Audsley. [10] Several types exist but the most popular is the wind dumping Tremulant which relies on creating shock waves in the wind system. It is normal to be able to adjust the speed and depth of the Tremulant so that a gentle effect can be achieved on low pressure solo stops whilst a more extreme effect is desirable for higher pressure cinema organ pipework.

This paper examines in the frequency domain the steady state condition of a single pipe with a frequency of 1050 Hz connected to a reservoir supplied by an electrically driven fan. The structure of the paper is as follows: firstly, experiments are detailed to determine the presence of amplitude modulation on a sounding organ pipe and associated reservoir vibration. The results are presented and then discussed together with some implications relevant to the design and construction of pipe organs. Finally, conclusions are drawn and presented with suggestions for further work.

2 Methodology

The arrangement of the test apparatus is shown in Figure 2 and consists of a 1200mm x1200mm single rise reservoir with a height of 400mm. Air is supplied to the reservoir from an organ blowing fan fitted with a .75 Kw electric motor running at 3000 rpm controlled by a variable speed invertor. The reservoir is fitted with a simple inlet flap control valve connected to the reservoir top. The pressure in the reservoir and the feed pipe is measured using two electronic pressure sensors connected to a laptop computer.

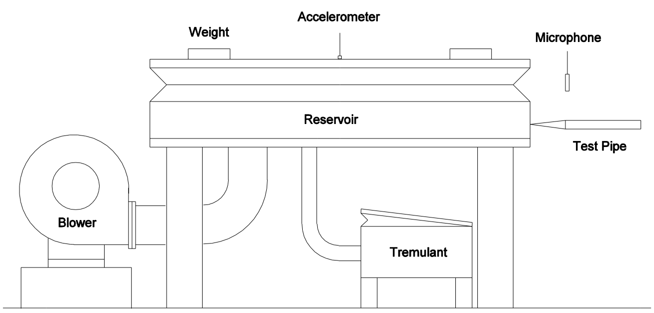

Figure 2 – Experimental Test Apparatus

The test reservoir is pressurised using springs or weights that are applied to the lid. The Tremulant is driven by an electronic controller that allows the adjustment of frequency and depth. The test organ pipe is arranged to project horizontally from one side of the reservoir.

Instrumentation is provided by a two channel measuring system with frequency analysis. Channel 1 connects to a measurement microphone placed 150 mm from the pipe mouth. Channel 2 connects to an icp accelerometer mounted centrally on the reservoir top**.** Alternatively it is possible to use two microphones or two accelerometers. Using 01dB dBFA32 software the fundamental frequency of the test pipe is analysed using a frequency range of 1250 Hz, 801 lines with Hanning window and 8 times zoom centered on 1050 Hz. The low frequency reservoir vibration, using the icp accelerometer, is analysed using a frequency range of 1250 Hz, 801 lines with Hanning window.

3 Results

The frequency spectrum of the test pipe, a treble c pipe from an 8 foot open diapason stop, with a fundamental frequency of 1050 Hz and subsequent harmonics up to 18 kHz is shown in Figure 3. Figure 4 shows the expanded fundamental portion of the frequency spectrum shown in Figure 3. The two small peaks or side-bands on each side of the fundamental are responsible for the modulation causing the flutter effect that can be heard on the sounding pipe. The side-bands occur at approximately 12 Hz on each side of the fundamental. Figure 4 also shows the fundamental portion of the spectrum for the test pipe when hand blown by closing a valve that isolates the blower. It is seen that there are no noticeable side bands and no audible effect on the pipe sound for the hand blown case.

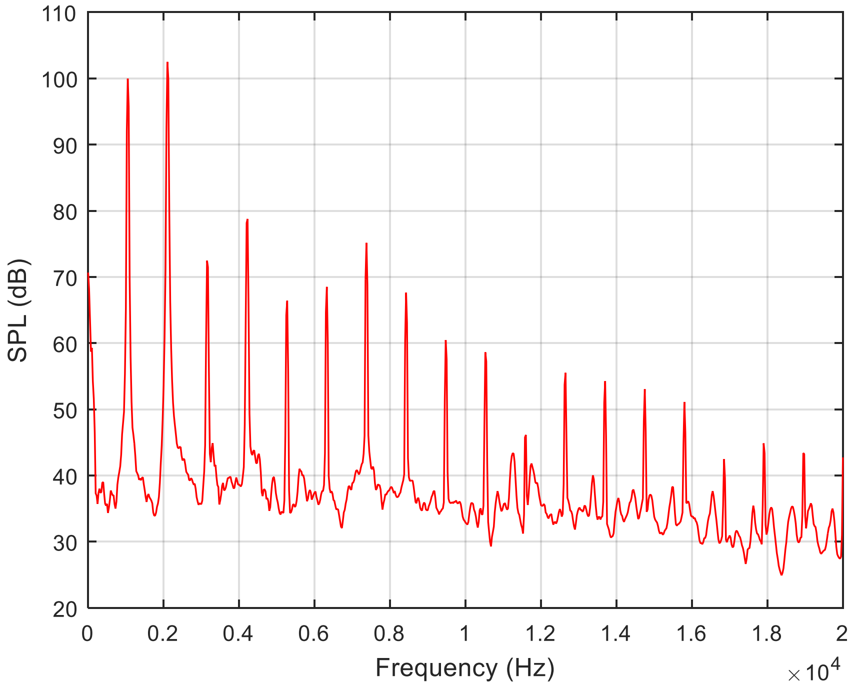

Figure 3 – Frequency Spectrum of a treble c pipe

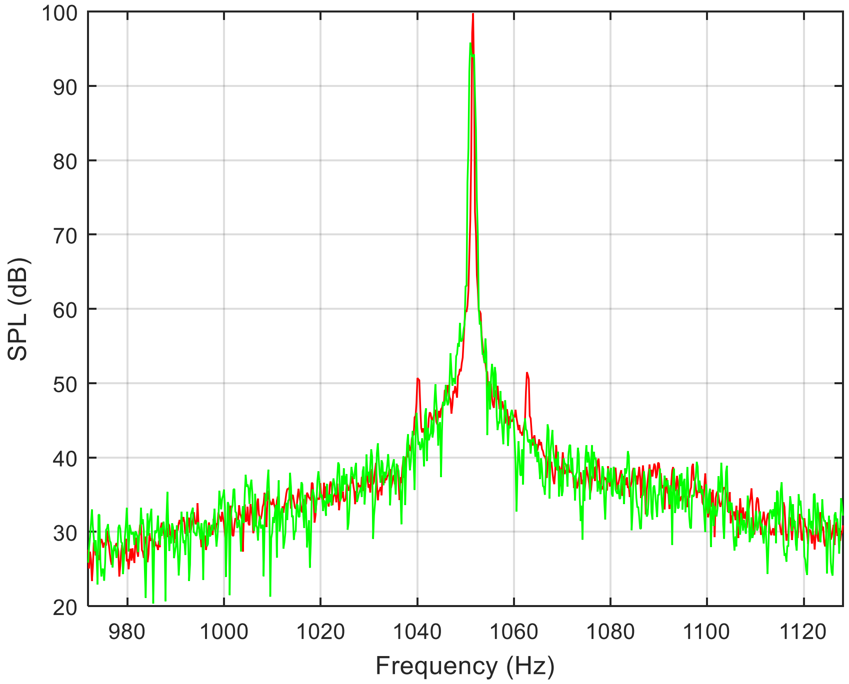

Figure 4 – Expanded Fundamental for Electric Blown (red) and Hand Blown (green)

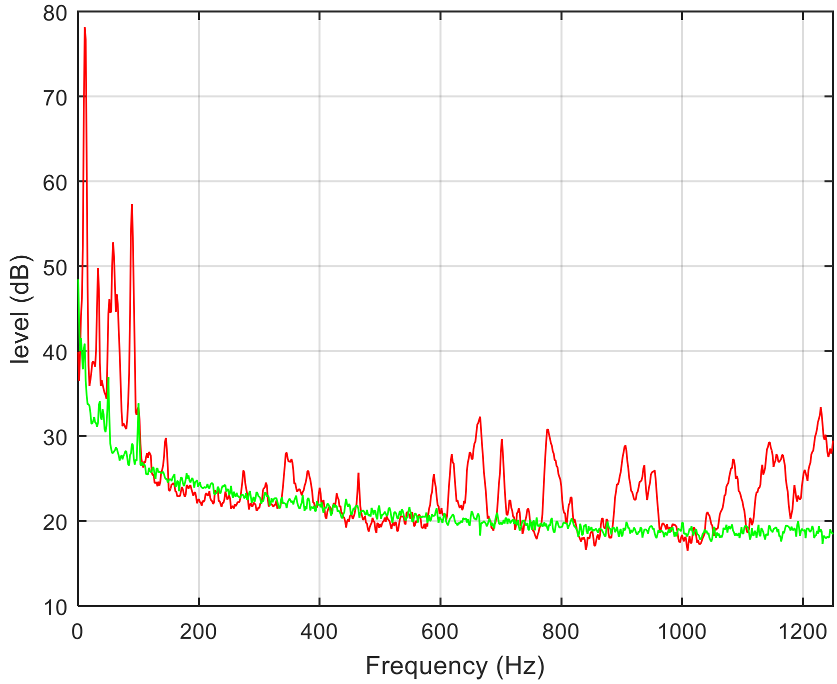

Figure 5 – Reservoir Vibrations for Electrically Blown (red) and Hand Blown (green)

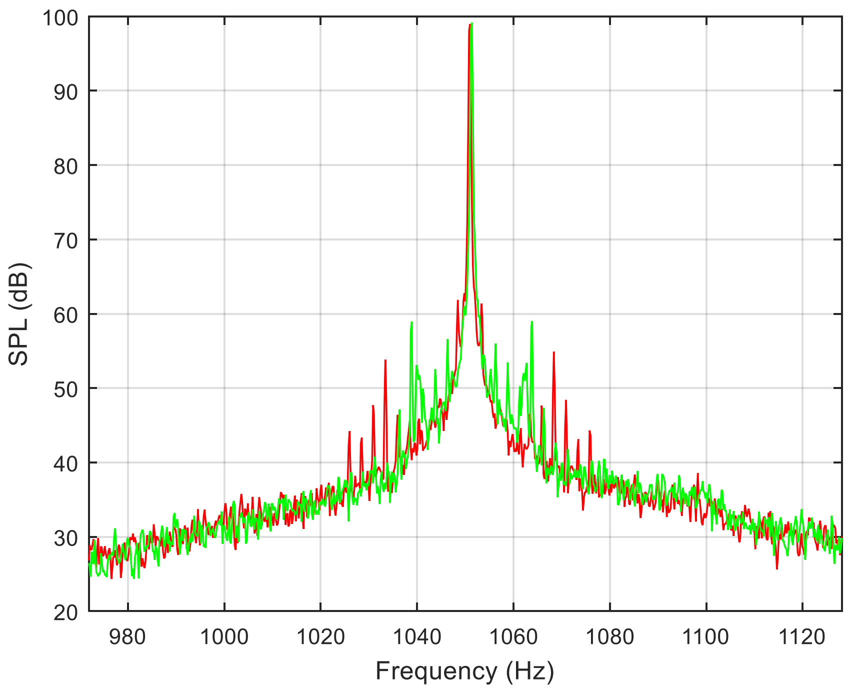

Figure 6 – Weighted (green) and Sprung (red) Reservoir Tremulant modulation

Figure 5 shows the frequency spectra of the single accelerometer mounted centrally on the top of the test reservoir for electric and hand blowing. The lower curve shows the frequency spectrum of the reservoir vibration for hand blowing and the upper curve for electric blowing. The correlation between the side-band frequency measured using the pipe microphone and the frequency of vibration of the reservoir using the reservoir accelerometer is good, indicating that the low frequency vibration of the reservoir is the cause of the effect that we can hear.

The effects of a traditional wind dumping Tremulant are shown in Figure 6 for a single rise weighted and sprung reservoir with a reservoir pressure of 625 Pa. The period of the Tremulant was set at 2.0 Hz. Each frequency plot shows the strong multiple side bands at 2.0 Hz intervals on each side of the fundamental.

4 Discussions

The results show that the resonant frequency of a weighted reservoir is determined by the height of the reservoir and the reservoir wind pressure. This relationship is shown in Fig 7 for reservoir heights of 200, 300 and 400 mm and reservoir wind pressures of 300 to 1000 Pa. For a given height of reservoir, increasing the reservoir wind pressure lowers the resonant frequency. Alternatively increasing the depth of the reservoir has a similar effect of lowering the resonant frequency.

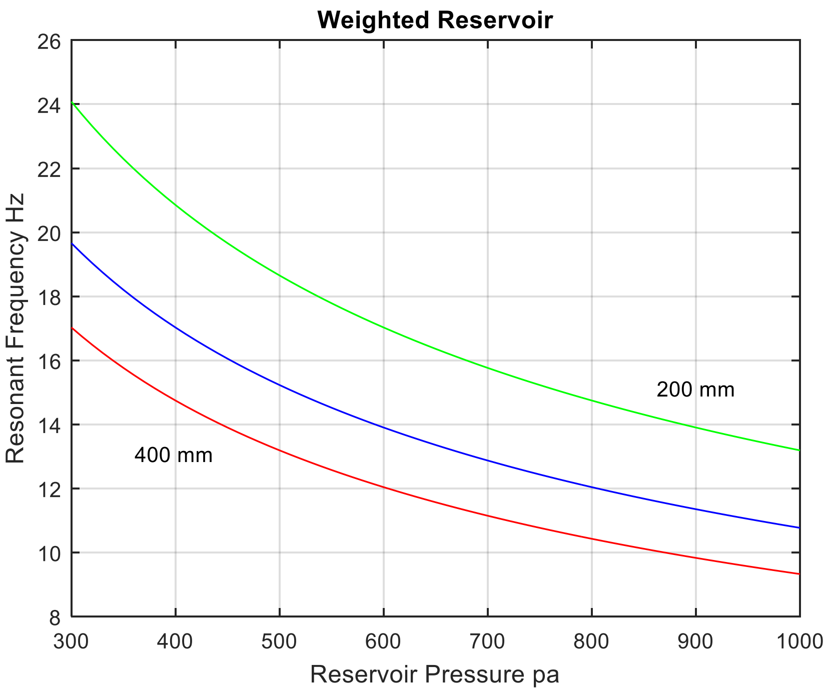

Figure 7 – Resonant Frequency for Weighted Reservoir

In contrast, the resonant frequency of a sprung reservoir is found to be not dependent on the wind pressure or the height of the reservoir but relies on the mass of the lid. This relationship is shown in Fig 8 for reservoir heights of 200, 300 and 400 mm for reservoir top mass of 5 to 50 Kg.

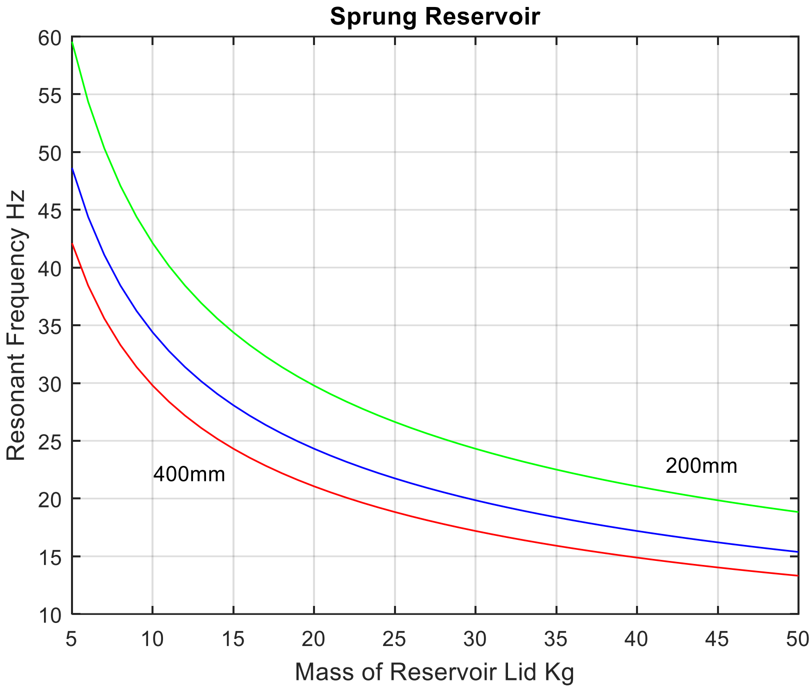

Figure 8 – Resonant Frequency for Sprung Reservoir

The subjective difference between hand and electric blowing is well known by pipe Organ Builders. Many say that the old three-crank feeder system produced the most stable wind followed by the large slow speed fans. The results here present the first objective evidence to support and explain this opinion.

The difference between the weighted and sprung reservoir modulation produced by the Tremulant shown in Figure 6 is not so clear. Tremulants are notoriously difficult to regulate to produce the desired effect. This is often caused by a mismatch between the exciting frequency and the resonant frequency of the wind system. Understanding more fully how the wind system performs in the frequency domain will allow the organ designer to select appropriate dimensions for this critical area.

This research has focused on a single open pipe. The behavior of closed and reed pipes and the effects of different reservoir and blower combinations have yet to be investigated.

5 Conclusions

The results of Figure 4 show that the measured modulation frequency of approximately 12 Hz compares well with the predicted resonant frequency shown in Figure 7 for a reservoir pressure of 625 Pa and a reservoir height of 400 mm. It is also shown in Figure 6 that the extreme Tremulant modulation, which at low levels is percieved as flutter, is a result of reservoir vibrations.

Organ Builders are conscious that their methods may be intuitive rather than scientific with resulting wind systems that are not as consistent as they would like. Considering the wind system from a resonant perspective will provide the Organ Builder with vital information that will allow them to design and construct a more consistent wind system.

Further work is required to determine the just noticeable difference of organ pipe flutter and determine a level of pipe flutter that is deemed acceptable.

Acknowledgements

The author wishes to thank A J & L Taylor UK Ltd, Ramsbottom, England for use of their workshop facilities. Also the support of UK pipe Organ Builders who have donated many of the wind system components used in this research. Thanks also to Professor David Waddington of the University of Salford for useful discussions and comments on this paper.

References

1. Sumner, W.L., *The organ; its evolution, principles of construction and use*. 1973: St. Martin's.
2. Clement Sabine, W., *Collected papers on acoustics, by Wallace Clement Sabine*. 1922, Harvard up.
3. Hoover, H. and L.H. Hoover, *Georgius Agricola De Re Metallica*. Vol. 1. 1912: Mining magazine.
4. Kinealy., J.H., *Centrifugal Fans – A Theoretical and Practical Treatise on Fans for Moving Air in Large Quantities at Comparatively Low Pressures*. 1905.
5. Gołos, J. and L. Elvin, *" Organ Blowing: Its History and Development", Lawrence Elvin, Lincoln 1971:[recenzja]*. Kwartalnik Historii Kultury Materialnej, 1978. **26**(3).
6. Carlsson, T., *On Dynamic Behaviour of Wind Systems for Pipe Organs*. 2002: Chalmers University of Technology.
7. Ngu, J.T., *The effects of turbulence on organ sound quality and its minimisation in blowing systems*. 1995, University of Huddersfield.
8. Pitsch, S., Angster, Milos, *The Influence of new types of wind systems on the sound of organ pipes.* CFA/DAGA 04 Strasbourg, 2004(22-25/03/2004): p. 1229-1230.
9. Steenbrugge, D. *Flue organ pipe operating regimes and voicing practices*. in *Acoustics 2012*. 2012.
10. Audsley, G.A., *The art of organ-building: a comprehensive historical, theoretical, and practical treatise on the tonal appointment and mechanical construction of concert-room, church, and chamber organs*. Vol. 2. 1965: Courier Corporation.