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A REVIEW OF THE PIPE ORGAN RELATED RESEARCH CARRIED OUT AT THE UNIVERSITY OF EDINBURGH OVER THE PAST TEN YEARS

A Woolley University of Edinburgh, Edinburgh, UK
M Campbell University of Edinburgh, Edinburgh, UK

1 INTRODUCTION

The pipe organ research at The University of Edinburgh started in 2002 with a PhD project entitled "The Physical Characteristics of Mechanical Pipe Organ Actions and how they Affect Musical Performance". This largely came about as the result of the widespread belief that mechanical actions allowed the player to vary the transient whilst it was also reported that the mechanical consoles of a number of dual action organs were hardly ever used. An analysis of the mechanics suggested that control of the pallet and thus the transient would be difficult. This was confirmed by experiments.

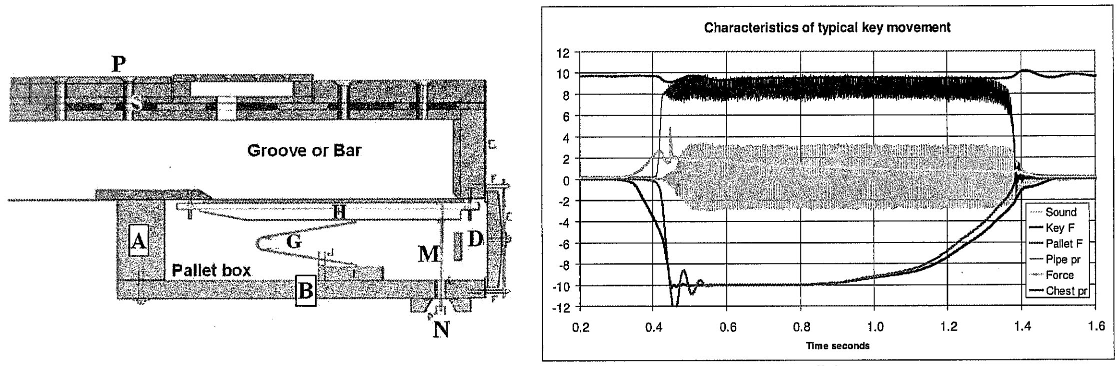
The Arts and Humanities Research Council funded further study on how rhythm and timing are used to play expressively, particularly on mechanical action organs. Electric and electro-pneumatic actions do not allow even a theoretical degree of control of the pallet. There are a number of other mechanisms by which transient variations, both real and perceived, may occur that are independent of the type of action and are just as likely to occur with mechanical and electric or electro-pneumatic actions. Some of these have been investigated and are described in this paper.

Much of this work has been presented elsewhere[1,2,3,4,5,10]

2 BACKGROUND

The bar (groove) and slider windchest has existed more or less unchanged for some six centuries and its basic operation is described below in its mechanical form. Solenoids or pneumatic motors may be used instead of the mechanical linkage.

The defining characteristic of the touch of a mechanical pipe organ action is pluck (being analogous with the feel of the plectrum plucking the string of a harpsichord. It is also called "top resistance"). Figure1(a) is a modification of an illustration by Audsley of a cross section of a bar and slider wind chest[6]. The bar is the channel on which all the pipes for one note are planted. The sliders (S) are movable strips, usually of wood, that determine which ranks of pipes receive air from the groove by lining up holes in the slider with corresponding holes on the top of the groove. They move perpendicular to the plane of the diagram.



(a) (b)

Figure 1(a) Cross section of a bar (groove) and slider windchest adapted from Audsley Figure CLIX. The significant parts are: N connected to the tracker from the key and pulling open pallet H via tracker M, compass spring G providing the closing force on the pallet, pallet box containing pressurised air, bar connecting all pipes played with one key, slider S shown open so that the pipe, planted in tapered hole P, will speak when the pallet is opened. (b) Graph showing key movement (dark blue), Pallet movement (red), wind pressure immediately under the pipe foot (purple), force applied to key head (F, light blue), sound recording (green) and pressure in the windchest (mid blue) for a representative "slow" note on the model organ in Edinburgh University. To a constant time scale, but arbitrary units of magnitude.

The pallet box (ABDH) contains pressurised air whereas the groove contains air at atmospheric pressure. Pluck is caused by the pressure difference across the closed pallet (H).The net force of the pressurised air on the bottom of the pallet has to be overcome in order for the pallet to start opening. As soon as the pallet starts to open as the tracker (attached to N) moves downwards, the pressures on either side of the pallet start to equalise and the additional force reduces very quickly (Figure 1(b)). The feeling has been likened to pushing a finger through a thin layer of ice.

When a note is not sounding the pallet is kept closed by the force exerted by the pallet spring and the air pressure against its lower surface. As a force is applied to the key, the various action components bend, twist, stretch and compress etc until sufficient energy is stored to overcome the force keeping the pallet shut. As soon as the pallet starts to open (red line) and pluck is overcome the effect of air pressure reduces and the pallet "catches up" with the rest of the action. This is illustrated in Figure 1(b) and the most important features are:

- The key moves a significant distance before the pallet starts to open ~ 40%
- The key slows down due to the increasing resistance as the action flexes (rollers twisting, washers compressing, levers bending etc.)
- When sufficient energy is stored in the flexed action (in this case after about 44% key travel), pluck is overcome and the pallet springs open and catches up with the rest of the action
- As the resistance due to pluck is overcome the key increases in speed of movement as it is not possible to reduce the force being applied by the finger in the time available
- The air pressure in the groove starts to rise at the same time as the pallet starts to open
- The air pressure reaches a peak early in the pallet movement (after about 45% pallet travel – 20ms)
- The pallet starts to open at about 40% key travel and the pressure in the groove reaches a maximum at about 57% key travel. This is the only part of the key movement that could affect the transient and during this movement the pallet is out of control of the key.
- There is a delay before the pipe starts to speak

- The key is on the key bed and the pallet is fully open before the pipe has reached stable speech
- There is a delay before the pallet starts to close when the key is released (probably due to friction)
- Later in the release movement the pallet starts to close in advance of the key movement (due to air pressure)
- The pallet is firmly seated before the key has returned to its rest position (in this case the key has 23% further to travel)
- The sound envelope does not start to diminish until the point at which the pallet closes.
- The force applied increases until the pluck point when it reduces, although not suddenly, due to the airflow through the pallet opening applying a closing force to the pallet
- The force increases suddenly as the key hits the key bed.
- The force is gradually reduced but the key does not start returning until the force due to the pallet spring is greater than the force applied by the finger.
- There is slight increase in force as the pallet "snaps" shut due to the flow of air through the opening. This helps to reduce leaks round the closed pallet.
- The pressure in the windchest reduces as the pallet opens and increases when it closes until the regulator can compensate after a few oscillations. This is reflected in the pressure under the pipe foot and in the sound envelope.

These effects were noted in every organ measured to a greater or lesser extent depending on the size and rigidity of the action and the magnitude of pluck, and even on a light, suspended action the effect of pluck is significant resulting in small variations in the movement of the pallet compared with the variations in movement of the key.

3 RELATIVE TIMING

A test was designed to indicate the point at which the player perceived the note to start. He was asked to play a "fast" and a "slow" attack simultaneously one octave apart. The results indicated that the player perceived the start of the note to be the point at which the key started to move. This introduces a timing difference between the two notes of approximately 30ms as the pipes will not start to speak until after the pluck point at a key displacement of approximately -1. The "slow" note will sound after the "fast" note and is also slightly longer by about 10ms. This may also be apparent on electric actions where the contact point is typically at one half to two thirds of the key's travel. There was little difference between the key movements after the pluck point.

4 PLAYING STYLES

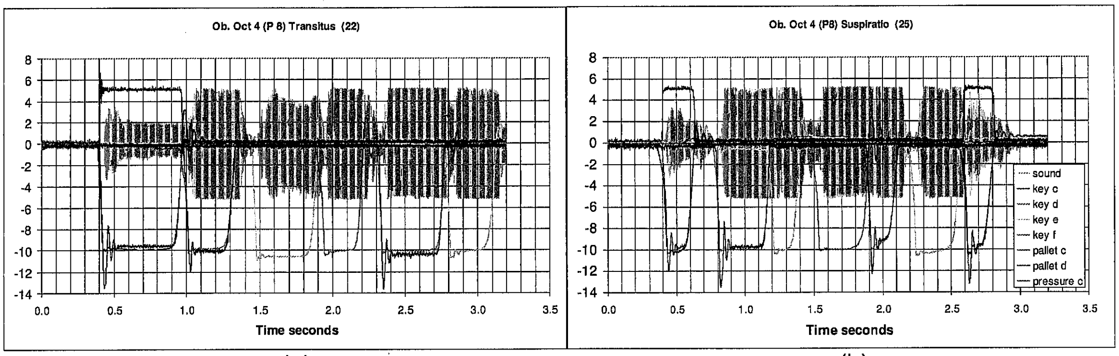
4.1 Rhetorical Figures

Organists frequently commented that, even if it was possible to vary the way that they moved the key at the start of a piece of music, it was not possible to maintain these variations throughout a piece. One way to do this is through physical gestures at the keyboard based on the study of musical-rhetorical figures in German baroque music described by Bartel and others.[8] These figures produce a consistent variation in rhythm and timing and "strength" of note throughout a performance – Baroque music was never played in strict tempo. Dr Joel Speerstra has studied these as part of his research into clavichord technique at the University of Göteborg.[7]

Two examples of Speerstra's figures are listed below with his descriptions along with graphs showing the key movements, pallet movements, pressure rise in the groove and sound recordings. Measurements were made of Speerstra playing in these and other styles on the North German

Organ in the Örgryte Church in Göteborg built in the style of Arp Schnitger by the Göteborg Organ Art Centre [GOArt] in 2000 as a research instrument, IVP53. The key movement (middle C, D, E, F, pallet movement (C, D) and pressure in the groove of middle C (measured by removing the Principal 8 pipe) were measured as well as sound recordings being made. All magnitudes are to an arbitrary scale.

The measurements taken showed that phrasings closely followed the descriptions given:
Transitus (Figure 2(a)): "Basically you are standing a certain amount of the weight of your arm on a stiffened finger with a relaxed elbow and moving from the first finger to the second without completely engaging the muscles of your arm that would lift it off the keyboard. This technique makes it easy to control heavy actions and you would expect this kind of paired fingering to have fast attacks for both notes and a longer first and third note, a shorter second and fourth note and hopefully as slow a release as possible after the second and fourth note."



(a) (b)

Figure 2: Graph showing the key and pallet movements. pressure in the groove and sound recording for a theme played with (a) Transitus Rhetorical Figure and (b) Suspiratio Rhetorical Figure. Örgryte Church, Göteborg

Suspiratio (Figure 2b): "It is a figure that starts with a rest followed by three notes, so the first note is now an upbeat and I would expect that there is a faster release after the first note and the second and third would form a pair much like the first and second in the transitus example."

There are many Rhetorical Figures and to these can be added more familiar styles such as Legato and Staccato, although these may benefit from being more clearly defined.

Figure 3 shows all of the key movements and pressure profiles for the Rhetorical Figures used. Despite the low number of data points, it can be seen that there are two groups of key movement and two very close groups of pressure rise profiles. The graph has been produced to show the two groups superimposed within the group but separated between the groups. If the player perceives the note starting at the point at which the key starts moving there will also be time differences between the start of the notes. Full listening tests have not been carried out, but initial tests with subjects across a wide range of musical backgrounds did not indicate consistent differences in transient between styles. This organ is unbushed and there is considerable action noise when keys are hit hard. This can mask the attack transient of the pipe, or even be mistaken for it, particularly close to the console.

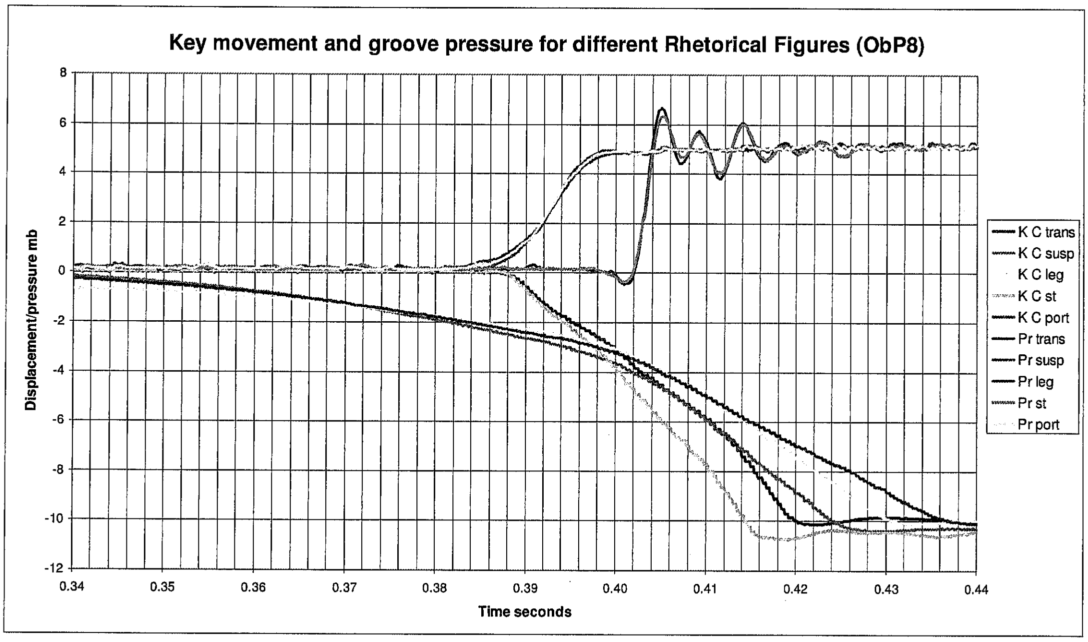


Figure 3: Graph showing key movements (K) and pressure in the groove (Pr) for the first note of a theme played with the Rhetorical Figures Transitus, Suspiratio, Legato, Staccato and Portato. Pressure curves aligned to highlight similarity. Örgryte Church, Göteborg

4.2 Other Styles

Measurements were also made on the copy of the Casparini organ of 1776 in Vilnius built by GOArt in Christ Church, Rochester, NY for the Eastman School of Music (ESM) in 2008, IIP31. A number of doctoral organ students played in styles of their choice that they considered resulted in variations of expression including varying transients. They used their own descriptions of these styles and some of these were long and descriptive and cannot be incorporated onto the graphs. The pressure was measured directly under the pipe foot using a device made by the ESM Organ Technician, Rob Kerner and is not directly comparable with the previous example. The groupings of pressure rise profile again fell into distinct groups similar to those in Figure 3.

4.3 Explanation of attack groupings

These tests show a consistent grouping of key attacks with distinctive characteristics of each. This has not yet been fully investigated, but it seems probable that the difference is due to whether the finger is in contact with the key at the "start" of a note and thus the whole system accelerates from rest or whether the finger is some distance above the key and thus hits the key with significant momentum and causes it to accelerate initially much faster. It should be noted, however, that both Dr Kitchen and Dr Speerstra stated that they actively avoided playing styles that generated excessive mechanical noise. This is particularly relevant to unbushed actions like most of those discussed here. This may mean that only one pressure rise profile is evident in practice. In some cases at the ESM there was a third group that requires further investigation but appears to represent a "faster" attack than the other two groups. The reason for this is not clear.

5 PRESSURE CHANGES IN THE WIND SYSTEM

In most organs the pressure regulator is remote from the windchest. Any variation in the air supply, such as when a note is sounded, will not be immediately compensated for. There will therefore be an initial pressure reduction when a note is started and a pressure increase when it is released. The effect of the playing and releasing of notes on the pressure in the wind trunking was investigated by

Arvidsson and Bergsten at GOArt in 2009[9]. This has been extended at Edinburgh to consider how these pressure variations in the wind system might affect pipe speech both with mechanical actions and electric actions. Figure 4 shows a single note being played on a mechanical action and it can clearly be seen that the pressure in the pallet box (blue line) reduces as the pallet opens, oscillates for a few cycles and then steadies. This is reflected in the pressure measured under the pipe foot (purple) and also in the sound envelope of the pipe speech. When the pallet closes there is a corresponding increase in pressure. The variations shown here are around 35% of the steady pressures. These measurements were made on the model organ with mechanical action in Edinburgh and, whilst the effect will occur in any organ, the magnitude of these effects may be greater than normally encountered. A Schwimmer pressure regulation system will reduce these effects.

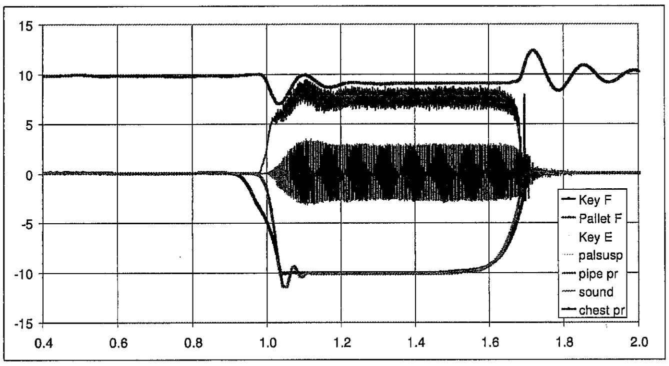
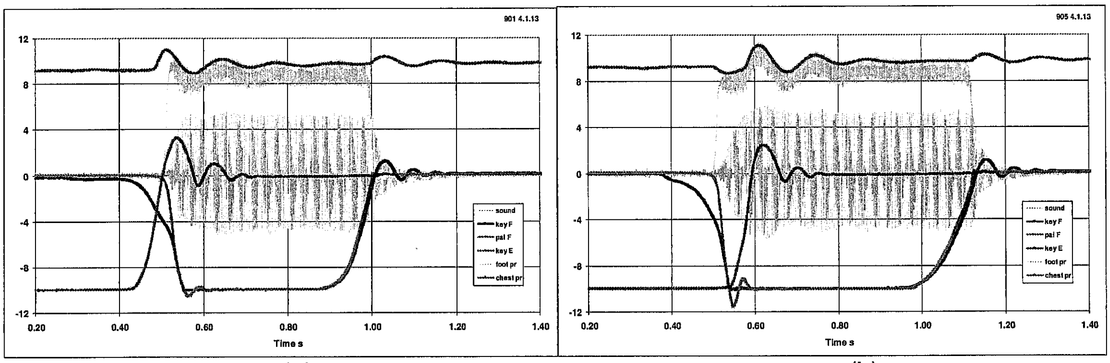


Figure 4: Effect of the variation on the pressure in the wind system due to the playing of a note. Model organ, mechanical action University of Edinburgh

Figure 5 shows the effect of playing a note before the note being measured. The pipe of the first note, E (red), was removed so that its sound did not interfere with that of the pipe being investigated. It can be seen that the effect of the release of the first note and that of the attack of the second, F (dark blue), have resulted in an even greater variation in the pressure throughout the wind system and this is reflected in the outline of the sound recording.



(a) (b)

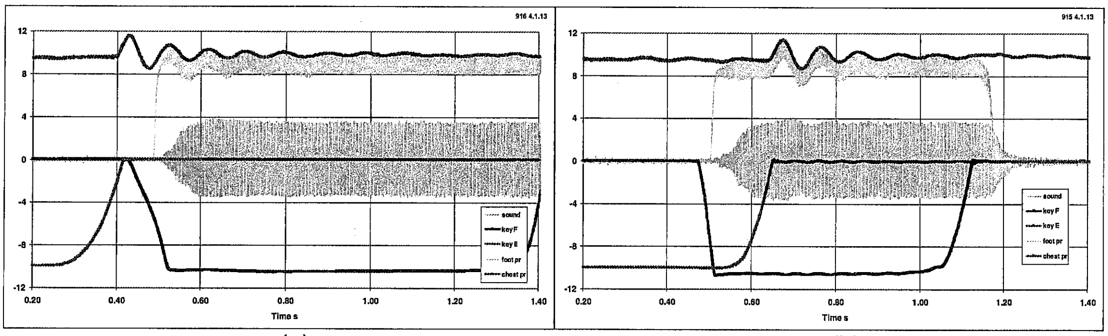
Figure 5: Effect of the variation on the pressure in the wind system due to the release of a note on a subsequent note with two different relative timings. Model organ, mechanical action University of Edinburgh

Full listening tests have not been carried out, but this may lead to an audible difference in the transient of the second pipe and the oscillations in the wind pressure are clearly audible. These two graphs illustrate that the relative timings of the attacks and releases have a significant effect on the pressure at the point at which the pipe starts to speak that is directly reflected in the sound recording.

More notes or stops being played together will produce larger and more unpredictable pressure variations in the wind system.

It should also be noted that since pluck is directly related to the pressure in the pallet box it will vary in proportion to it. It is thus possible that a momentary change in the magnitude of pluck could influence the time at which a key is depressed especially if the player is already applying some force to the key.

A small direct electric action chest was constructed using Kimber-Allen air damped vertical pallet magnets to confirm the effect on the overall wind pressure of playing and releasing notes with an electric action. These are shown in Figure 6. The relative timings are similar to those in Figure 6 above and similar variations in the attack transient can clearly be seen in the sound recording (green).

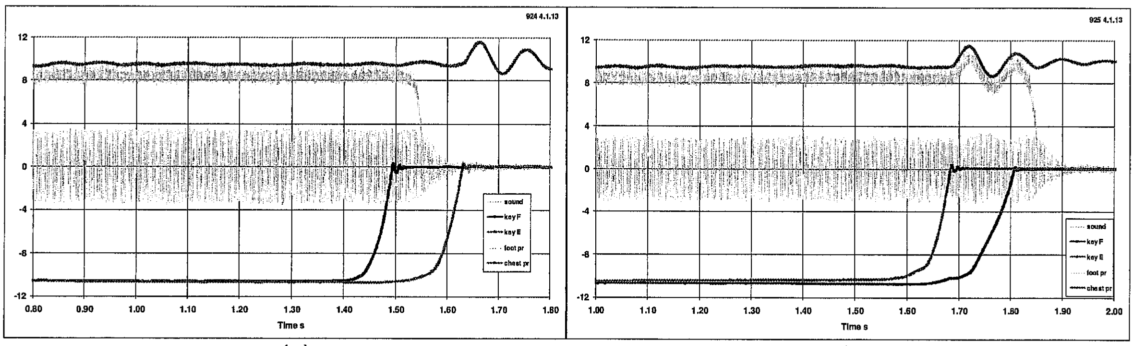


(a) (b)

Figure 6: Effect of the variation on the pressure in the wind system due to the release of a note on a subsequent note. Model organ, electric action University of Edinburgh

6 KEY RELEASE

It has long been recognised that large chords should be released from the top in order to minimise the pressure change on the pipes with the least wind usage.[11]



(a) (b)

Figure 7(a): Effect of the release of a second note before the release of the pipe being recorded. (b) Effect of the release of a second note after the release of the pipe being recorded. Model organ, electric action University of Edinburgh

This is illustrated in Figure 7. Figure 7(a) shows two notes played simultaneously with the recorded pipe, F, corresponding with the dark blue line showing the key movement, released first. Figure 7(b) shows the effect of releasing the recorded pipe after another key is released. The effect on the pressure measured at the recorded pipe is clearly visible and audible.

The effect of playing other notes in addition to a sustained note is clearly shown in Figure 8. Again the effect is very audible and easily repeatable on any organ with any type of action with a conventional regulator.

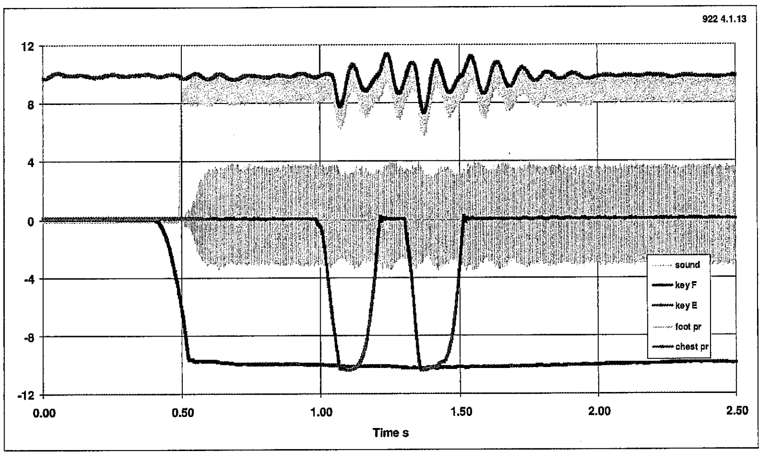
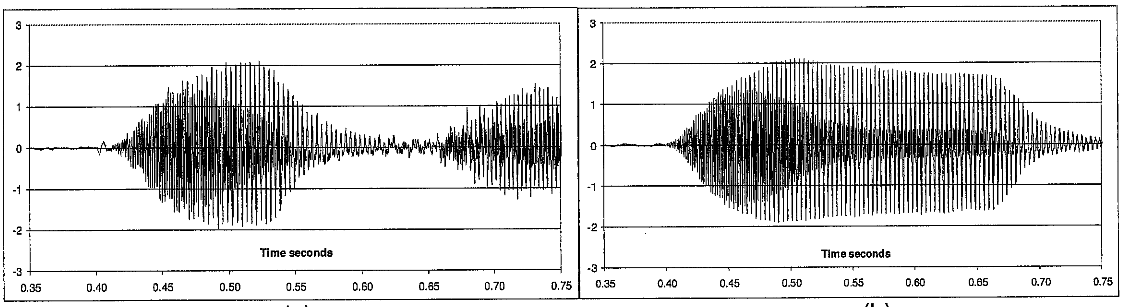


Figure 8 Effect of playing a second note during a sustained note

7 LENGTH OF TRANSIENT

In Figure 9, played on the Italian organ in the Museum of Art, Rochester NY, the pipe is slow to speak and starts at the octave and then breaks back to the fundamental. If a short note is played, as when the player is asked to make a "fast" attack, most of the pipe speech will be at the octave and that is what the listener perceives as the pitch of the note. If a longer note is played most of the pipe speech will be at the fundamental and that is what the listener may hear. If the player is expecting a variation in transient he may associate the different perceived sounds with what he believes are different key movements. In Figure 9(a) there is also evidence of initial mechanical noise.



(a) (b)

Figure 9(a): Sound recording of "Fast" attack, and (b) "Slow" attack. Italian organ, Museum of Art, Rochester NY

8 AIRFLOW MEASUREMENTS

In a mechanical action organ, particularly large ones, it is necessary to optimise the airflow to pluck ratio. This tends to be done on an empirical basis and each organ builder uses his own rules. Particle Image Velocimetry was used to study the nature of the airflow around the pallet and through the pallet opening (viewed from the right hand side of pallet H in Figure 1, the shadow in the middle is the guide pin just above D). Initial measurements, incompletely analysed, appear to show that the air jet, from left to right in the centre of Figure 10, had a height of approximately 2mm in an opening of approximately 3.85mm. This is an area that requires a great deal of further work including the effect of the moving pallet on the airflow. This work my lead to more efficient windchest design and allow mechanical actions to be used in larger organs.

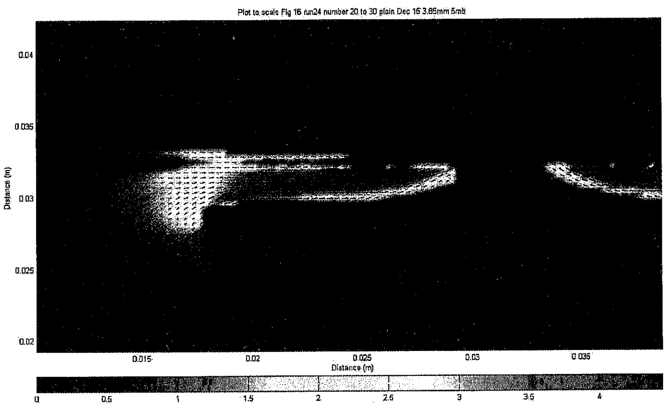


Figure 10. PIV image of airflow round the sides of a pallet

9 CONCLUSIONS

The inherent design of the bar and slider windchest actively works against the control of the transient. Its principal advantages may be the tactile feedback provided by pluck – aiding clean and consistent attacks, reducing the risk of accidentally sounding a note if an adjacent key is brushed, the additional sealing of the pallet due to the air pressure against its bottom surface, ease of construction and ease of maintenance.

Expression is achieved though using basic design features of the instrument such as playing on different stops, on different divisions, using the swell box and using devices such as tremulants.

These tests show that transient variation both real and perceived is equally possible with both mechanical and electric pipe organ actions. Variation in this context is very different from control, but if a player is expecting transient control from the way in which he thinks that he is moving the key, he might attribute any variation to this.

There is clear evidence that rhythm and timing are critical aspects of organ playing. In some cases they are the result of deliberate and systematic efforts by the player, as in the use of Rhetorical Figures, and in others the players may be unaware that they making variations. Analysis of the various performances of the same sequence of notes showed wide variations in overall tempo, relative lengths of notes and degree of overlap of notes all of which will affect how the music sounds to the listener. This does not directly lead to transient variation, but may be perceived as such if that is what the player is expecting.

There are a number of mechanisms by which transients may vary or appear to vary that are not related to the profile of the initial key movement. These include action noise (rattle) due to how "hard" the key is hit. It is not yet clear whether players deliberately make use of any of these mechanisms or whether they simply occur as a by-product of differing playing styles.

Every organ is different, and this project has been limited by the instruments available. Whilst this work may suggest that direct transient control is difficult, this may not be the case on instruments with different characteristics. There are, however, other mechanisms in play that lead to variation of the transients and different perceptions of the sound.

10 ACKNOWLEDGEMENTS

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11 REFERENCES

1. Woolley, Alan,. "Transient variation in mechanical action and electric action pipe organs." ICA 2013 Montreal, June 2013
2. Woolley, Alan. "Mechanical Pipe Organ Actions and why Expression is Achieved with Rhythmic Variation Rather than Transient Control" Proceedings of ISMA 2010 Sydney and Katoomba (August 2010)
3. Woolley, A. "A Dangerously Inexpressive Instrument", The Diapason, Scranton Gillette Arlington Heights IL, in preparation
4. Woolley, A.G. "Can the Organist Control the Pallet Movement in a Mechanical Action?" J. American Organbuilding, Houston TX (December 2006)
5. Woolley, Alan The Physical Properties of Mechanical Pipe Organ Actions and how they Affect Musical Performance, PhD Thesis, University of Edinburgh (2006)
6. Audsley, George Ashdown. The Art of Organ Building (Mineola, Dover 1965 republication of 1905 edition, Dodd, Mead & Co)
7. Discussion with author
8. Bartel, D. Musica Poetica: Musical-Rhetorical Figures In German Baroque Music, University of Nebraska Press
9. Arvidsson, Mats and Bergsten, Carl Johan. Wind system measurements in the Craighead Saunders organ GOArt (2009)
10. Woolley, A. "How mechanical pipe organ actions work against transient control" Proceedings of Acoustics 2012, Nantes, France April 2012 p1969
11. Bishop, J. "In the Wind", The Diapason, Scranton Gillette, Arlington Heights IL, (June 2011)