How mechanical pipe organ actions work against transient control

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It can be clearly demonstrated by blowing an organ pipe that it's transient can be varied, although the effect is not generally considered 'musical'. It has been debated for several decades whether mechanical pipe organ actions allow the player to vary the transient by the way in which the key is moved. Opinions vary from transient control being fundamental to organ playing to it not being possible. This work shows that the physical characteristics of mechanical organ actions work against transient control and this is corroborated by measurements of key and pallet movements and pressure changes whilst organists are playing. It also looks at what other methods organists are using in order to play expressively. The paper considers how transients might vary due to other characteristics of organs that are outside players' direct control but might lead them to believe that variations are due to differences in their key movements.

1 Introduction

This paper summarises work published and presented elsewhere and also introduces some new material [1,2,3]. Funding was received from the Arts and Humanities Research Council to investigate the extent to which organists use rhythm and timing to achieve expression on mechanical action pipe organs rather than varying the transient by the way in which they move the key. This followed from earlier research into the characteristics of mechanical pipe organ actions that concluded that players did not vary the way in which they moved the key to a significant extent [4]. The organ world is split between the belief that transient control is fundamental to organ playing and the belief that it is not possible. There is, however, little published research.

2 Background

The bar (groove) and slider windchest has existed more or less unchanged for some six hundred years even down to the materials generally used.

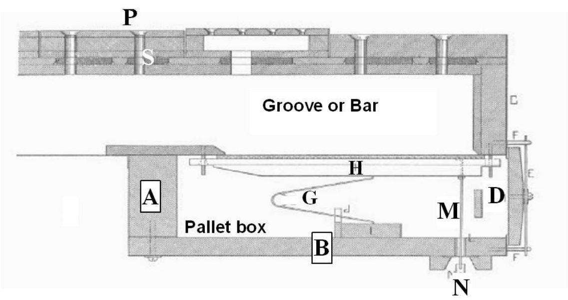

Figure 1: Cross section of a bar (groove) and slider windchest adapted from Audsley Figure CLIX. The significant parts are described in the text

The one characteristic that defines the nature 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"). Figure 1 is a modification of an illustration by Audsley of a cross section of a bar and slider wind chest [5]. 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. 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 2). The feeling has been likened to pushing a finger through a thin layer of ice.

It is unlikely that the original builders of the first windchests applied theoretical fluid dynamics to the design and it seems probable that the principle advantages were ease of construction, reliability, ease of repair and positive sealing of the pallet against the opening due to the air pressure in the groove thus reducing leaks. There may be other advantages, which will be discussed later.

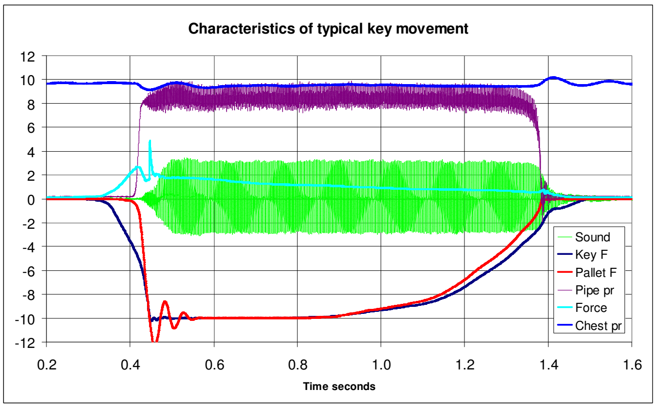

Figure 2: Graph showing key movement (dark blue), pallet movement (red), wind pressure immediately under the pipe foot (purple), force applied to key head (light blue), sound recording (green) and pressure in the windchest (mid blue) for a representative "slow" note on the model organ in Edinburgh University. Constant time scale, arbitrary units of magnitude.

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 (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 2.

The most important features of Figure 2 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, 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 react fast enough to reduce the force being applied by the finger
- 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)
- 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 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.

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.

3 Direct effect of pluck

There are two immediate effects of pluck that reduce the possibility of controlling the key. Firstly the player has to reduce the force that he is applying to the key immediately beyond the pluck point. The International Amateur Athletic Federation has ruled that any reaction within 100ms constitutes a false start whereas the entire pallet movement is typically around 30ms [6]. Secondly the action acting as a spring means that as soon as the pluck point is passed and the pallet starts to open it “catches up” with the rest of the action. In Figure 2, above, the key moves 40% of its travel before the pallet starts to open and the pallet “springs” open by this amount once the pluck point is passed.

4 Pressure rise in the groove

In the example illustrated in Figure 2, the pressure immediately beneath the pipe reaches its peak in the time between the pallet starting to open and it catching up with the key. This was predicted by the project’s collaborators at the Fraunhofer Institut für Bauphysik in Stuttgart in earlier computer models but not supported by experimental data [7]. This effectively placed the possibility of influencing the pressure rise outside the player’s control.

5 Action flexibility

Some tests were carried out with Dr John Kitchen, University of Edinburgh and City organist, playing the 1978 Ahrend organ in the Reid Concert Hall (IIP21). This has a very light, suspended action. In the first exercise he played an improvised theme and was then asked to repeat it varying nothing but the speed of key movement. The measurements of the key movements are shown in Figure. 3 in which the curves are superimposed approximately at the pluck point. He felt that he had moved the key “five time faster” the second time (blue curve). Figure 3 does not show that the overall tempo was also faster with the fast key movement. Even on this relatively rigid action, the effect of pluck is apparent at the beginning of the key movement. The explanation for the two shapes of the initial movement will be considered later.

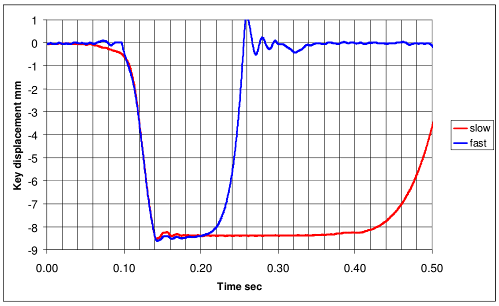

Figure 3: Key movement from two performances of the same theme. Player was asked to vary nothing but the speed of key depression. Reid Concert Hall, Edinburgh.

Other tests produced a similar variation in the pre-pluck movement with the post-pluck movement remaining relatively constant.

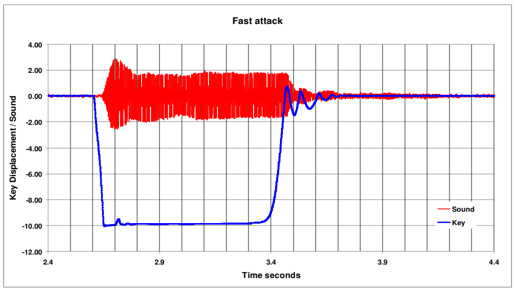

Figure 4: Key movement and sound recording for a “fast” key attack. Canongate Kirk, Edinburgh.

A further exercise was carried out at the Canongate Kirk in Edinburgh (Frobenius 1998, IIP20). A simple visual examination (confirmed by informal listening tests) shows that distinctly different key movements are not reflected in the sound profiles. Figure 4 represents a “fast” and Figure 5 represents a “slow” attack as perceived by the player.

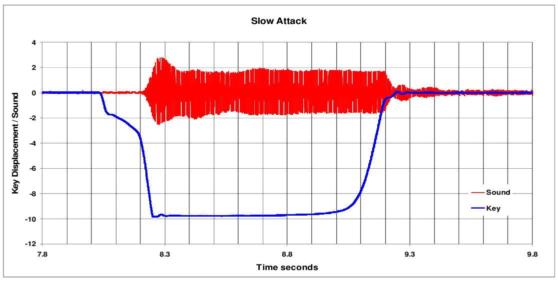

Figure 5: Key movement and sound recording for a “slow” key attack. Canongate Kirk, Edinburgh.

As observed throughout, the “slow” attack also resulted in a longer note. Other tests showed that the player perceived the note as starting when the key started to move thus introducing a timing difference.

6 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. Speerstra has studied these as part of his research into clavichord technique at the University of Göteborg [7].

Examples of Dr Speerstra’s figures are listed below with his descriptions and graphs of some of these showing the key movements, pallet movements, pressure rise in the groove and sound recordings. The organ is the “North European Organ” built by GOArt in 2000, IVP53, in the style of Arp Schnitger. The measurements taken showed that phrasings closely followed the descriptions given:

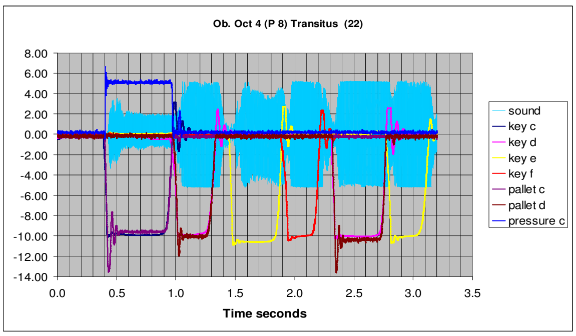

Figure 6: Graph showing the key and pallet movements. pressure in the groove and sound recording for a theme played with Transitus Rhetorical Figure. Örgryte Church

Transitus (Figure 6): “…. 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. “

Suspiratio (Figure 7): “… 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. “

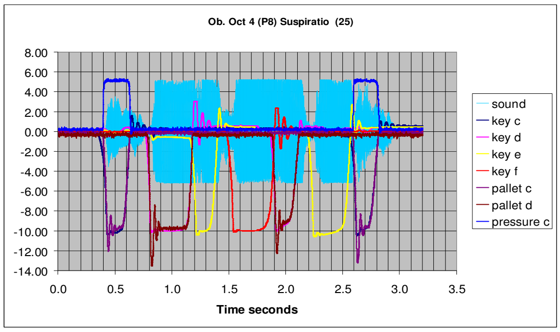

Figure 7: Graph showing the key and pallet movements. pressure in the groove and sound recording for a theme played with Suspiratio Rhetorical Figure. Örgryte Church

To these can be added other figures such as Portato (“separated notes but with slower attacks and releases”) and more familiar styles such as Legato and Staccato, although these may benefit from being more clearly defined.

Measurements were made of Dr Speerstra playing in these 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] as a research instrument). 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.

Figure 8 shows all of the key movements and pressure profiles for the Rhetorical Figures described above. 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.

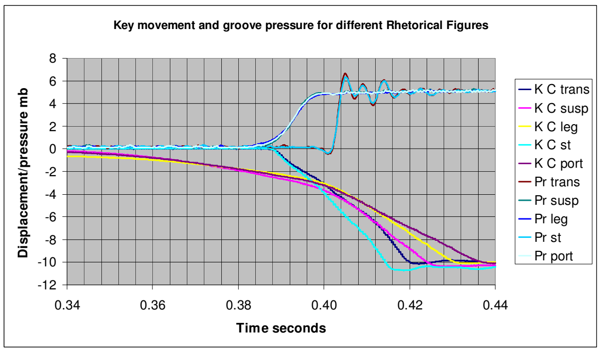

Figure 8: Key movements (K) and pressure in the groove (Pr), first note played with the Rhetorical Figures described. Curves aligned to highlight similarity. Örgryte Church

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 across a wide range of musical levels 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, particularly close to the console.

7 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 different 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 and may not be directly comparable with the previous example. The groupings of pressure rise profile have again been superimposed to highlight the similarities and the time scale does not represent a constant start point of the note. All recordings are of the same theme used in the previous exercise.

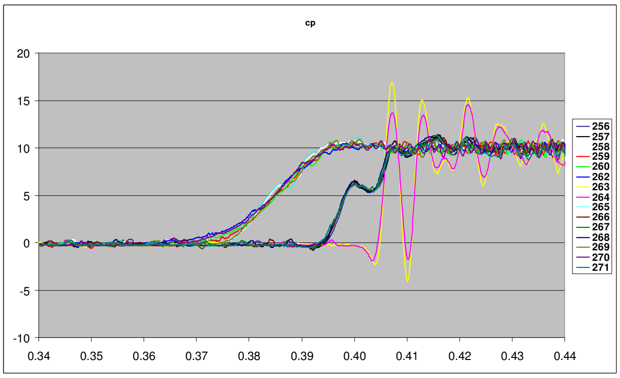

Figure 9: Graph to show groupings of the pressure rise immediately under the pipe foot of a theme played in a number of expressive. Student CP Rochester, NY

Figure 9 shows measurements of one of the students, CP, playing in a number of expressive styles of his choice. There appear to be three distinct groups with Group One being the left hand set of curves, Group Two the middle set and Group Three the right hand set. The initial gradient of Group One shows some variation, but again, initial listening tests did not consistently identify differences even between the extremes of all groups. The other two groups are more closely matched. There were significant variations in the overall tempo, length of individual notes, relative lengths of adjacent notes and overlap of notes. One similar style falls into both groups one and two.

All of the six student subjects demonstrated what appeared to be significant groupings of pressure along the lines of the example shown above in Figure 11.

Throughout this project, players have stated that even if there may be reasons why the attack may be difficult to control, it is completely possible to control the release. All measurements showed that the players made very consistent releases and a "slow" release simply resulted in a longer note.

8 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 tests on the model organ show 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 and may mean that only one pressure rise profile is evident in practice.

9 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 overall pressure reduction when a note is started and a pressure increase when it is released. This was investigated by Arvidsson and Bergsten at GOArt in 2009 [9]. This has been extended at Edinburgh to consider how these pressure waves in the wind system might affect pipe speech. Figure 10 shows a single note being played and it can clearly be seen that the pressure in the pallet box reduces as the pallet opens, oscillates for a few cycles and then steadies. This is reflected in the pressure measured under the pipe foot 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 pressure. These measurements were made on the model organ in Edinburgh.

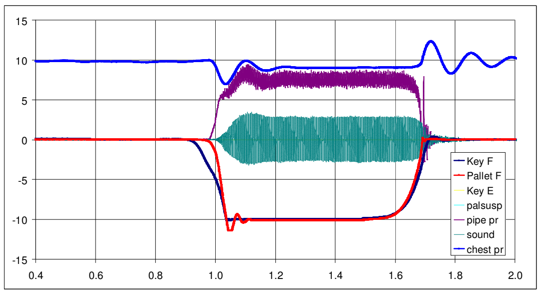

Figure 10: Effect of the variation on the pressure in the wind system due to the playing of a note. Model organ University of Edinburgh

Figure 11 shows the effect of playing a note before the note being measured. The pipe of the first note, E, was removed so that its sound did not interfere with that of the pipe being investigated.

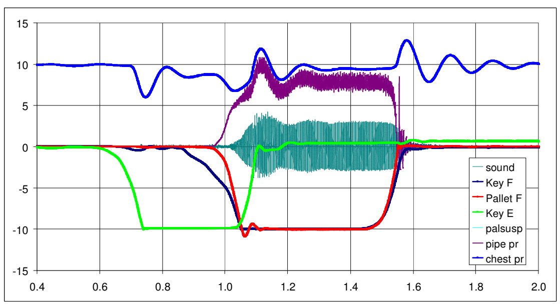

Figure 11: Effect of the variation on the pressure in the wind system due to the release of a note on a subsequent note. Model organ University of Edinburgh

It can be seen that the effect of the release of the first note and that of the attack of the second, F, 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. Full listening tests have not been carried out, but this may lead to an audible difference in the transient of the second pipe.

Many pipes played together will produce larger and more unpredictable pressure variations in the wind system

11 Length of Transient

In Figures 12 and 13, 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.

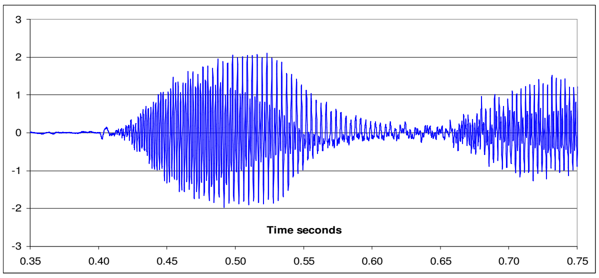

Figure 12: “Fast” attack, Italian organ, Museum of Art, Rochester NY

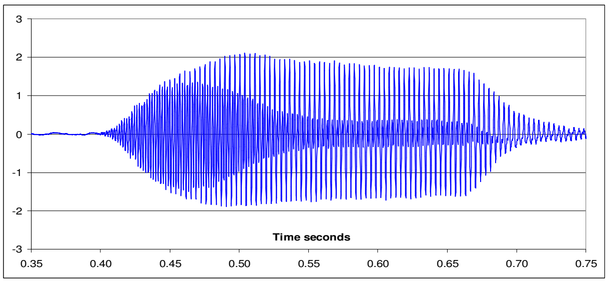

Figure 13: “Slow” attack, Italian organ, Museum of Art, Rochester NY

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 will 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 15 there is also evidence of initial mechanical noise.

12 Conclusions

There is some evidence that transient control is difficult to achieve by the inherent design of the bar and slider windchest. Variations in key and thus, to some extent, pallet movement fall into distinct groups, the reason for which is still under investigation but would appear to be due to whether the note starts with the finger starts in contact with the key or from above the key and thus already moving when it hits the key leading to a faster acceleration of the key and also a timing difference. Initial listening tests do not indicate that these differences always result in audible. Action noise may be a factor in informal listening tests and may influence the player’s interpretation of the transient. The player cannot react to pluck and any variations in key movement are predetermined.

There is clear evidence that rhythm and timing are critical aspects of organ playing. In some cases they are as 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.

The transient may vary depending on variations in the pressure in the windchest. This is outside the player’s control and is also independent of the type of action. Prominent but constant transients may give the impression of variation depending on the overall length of the note.

Many of the characteristics of the bar and slider windchest work against transient control and this may have been one of its advantages – the aiding of clean consistent attacks due to the rapid opening of the pallet when pluck is overcome, but there is clear empirical evidence that players like mechanical actions. The immediate reason for this may be that it provides good tactile feedback. The organist can apply a certain force to the key in the certain knowledge that the note will not sound but the force reduces to a comfortable level when the key has been depressed. It may also help reduce the risk of accidentally sounding a note if an adjacent key is brushed. These are in addition to the historical advantages stated in the introduction.

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 may explain different perceptions of the sound.

References

[1] Woolley, A. “Mechanical Pipe Organ Actions and why Expression is Achieved with Rhythmic Variation Rather than Transient Control” ISMA 2010 Sydney and Katoomba (August 2010)

[2] Woolley, A. “A Dangerously Inexpressive Instrument”, *The Diapason*, Scranton Gillette Arlington Heights IL, in preparation

[3] Woolley, A.G. “Can the Organist Control the Pallet Movement in a Mechanical Action?” *J. American Organbuilding* Houston TX (December 2006)

[4] Woolley, Alan *The Physical Properties of Mechanical Pipe Organ Actions and how they Affect Musical Performance,* PhD Thesis, University of Edinburgh (2006)

[5] Audsley, George Ashdown. *The Art of Organ Building* (Mineola, Dover 1965 republication of 1905 edition, Dodd, Mead & Co)

[6] International Amateur Athletic Federation, Rulebook Chapter 5 Rule 161.2

[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)