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TITLE

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Consistency of oboe manufacturing

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ABSTRACT

For large-scale woodwind instrument makers, producing instruments with exactly the same playing characteristics is a constant aim. This paper explores manufacturing consistency by comparing five Howarth S10 student model oboes. Psychophysical testing involving nine musicians is carried out to investigate perceived differences in the playing properties of the two Howarth oboes believed to be most dissimilar. Further testing, involving one musician and combinations of the five oboes, provides information regarding the relative playabilities of the instruments at specific pitches. Meanwhile, input impedance measurements are made on the five oboes for fingerings throughout the playing range and their bore profiles are measured. The main findings are (i) the two instruments used in the preliminary psychophysical testing are perceived as identical by most of the musicians, although differences are identified by two players when playing the note F6 and by one player when playing in the lowest register, (ii) a variation in the playability of F6 across the five oboes is due to differences in the elevation of the C key, and (iii) variations in the playing properties in the lowest register are related to input impedance differences which, in turn, appear to be at least partly due to bore profile differences.

I. INTRODUCTION

Most large-scale woodwind instrument makers produce several different models of each type of instrument (e.g. flute, oboe, clarinet, bassoon) that they manufacture. These different models tend to be marketed towards particular standards of player. For example, a maker might produce one model of oboe aimed at student players, another model targeted at intermediate players, and a further model for professional players.

For student models in particular, the ability to produce instruments in a consistent and reproducible manner is a priority for woodwind manufacturers. Any physical differences between instruments will most likely lead to differences in their acoustical properties which, in turn, may result in perceptible differences in their playing characteristics. For professional models, such differences – provided they are not too large – are usually less of a concern to the makers. At this level of playing, musicians tend to have their own personal requirements regarding an instrument's playing properties; they welcome a small element of variation when testing instruments with a view to purchase. However, for student models, makers generally prefer their products to behave in an essentially identical manner.

In this paper, the issue of woodwind instrument manufacturing consistency is investigated through measurements designed to highlight any physical, acoustical and perceptual differences between five nominally-identical Howarth S10 student model oboes (see Figure 1). The instruments were provided by the manufacturers in a newly-made state, straight from the workshop. They are made from African Blackwood, have thumbplate fingering system keywork and are all from the same manufacturing run (serial numbers K619, K853, K855, K856 and K862). The geometries of the instruments are established through bore profile measurements, made both directly using a set of high precision measurement discs and non-invasively using the technique of acoustic pulse reflectometry[1,2,3]. The strengths and frequencies of the instruments' resonances are determined through measurements of input impedance[4,5,6]. In addition,

psychophysical testing[7] is employed to evaluate the abilities of oboists to perceive differences in the playing properties of the instruments. This combination of approaches has previously been used to investigate the effect of the crook profile on the playing properties of the bassoon[8,9] and to compare the characteristics of French horn mouthpieces[10]. Meanwhile, the suitability of the methodology for the study of musical wind instrument manufacturing consistency has been evaluated through measurements on two low-cost trumpets[11].

Section II describes playing tests undertaken by nine oboists during the 2009 International Double Reed Society (IDRS) annual conference, which took place in Birmingham, UK. These tests were carried out in the early stages of the investigation, partly due to the timing of the IDRS conference and partly so that the findings could inform the direction of the rest of the research. That is, so that any differences in the playing properties of the instruments perceived by the oboists could be explored and potentially correlated with physical and acoustical differences. Indeed, Sections III and IV are dedicated to the explanation of differences perceived when producing notes in the upper registers of the instruments. Meanwhile, Section V is concerned with the investigation of differences perceived when producing notes in the lowest register.

Figure 1 Five Howarth S10 student model oboes

II. PRELIMINARY PSYCHOPHYSICAL TESTING

In order to investigate the abilities of players to perceive differences between oboes of the same model type, a set of playing tests was carried out using the Howarth S10 oboes. To keep the scope and duration of the playing test manageable, only two of the five oboes were used. These two instruments (serial numbers K619 and K856) were pre-selected during an initial playing session by one of the authors (DS), who is an intermediate level oboist. After playing all five oboes, his perception was that, over the pitch range of the instrument, oboes K619 and K856 exhibited the largest difference between their playing properties.

A. 2-alternative forced choice test with warm-up

Nine oboists of various standards participated in the playing tests. Four were professional players, four were of intermediate ability and one was a beginner.

The purpose of the playing tests was to evaluate the extent to which the oboists were able to discriminate the two oboes. In order to do this, each player undertook a 2-alternative forced choice test with warm-up[7,12]. The test procedure was as follows. At the start of the test, the musician was given five minutes to play the two oboes (referred to throughout the tests simply as oboe A and oboe B) and become familiar with them. Following this, five warm-up trials were carried out in which the oboes were presented in a random order. By playing them both, the oboist attempted to determine which instrument was oboe A and which was oboe B. After each warm-up trial, the player was informed whether they had answered correctly or not. Finally, the pair of oboes was presented twenty further times in random order and each time the musician was again asked to judge which instrument was which. Each trial was separated from the next by a gap of approximately thirty seconds, ensuring that there was no perceptible difference between the temperatures of either the bodies or the keys of the two instruments whenever they were presented to the player. At all stages in the test, the oboist was free to play whatever notes and

melodies, and at whatever dynamic level, they chose. To ensure the experience was as comfortable as possible, the participant played the oboes using one of their own reeds.

Even though the instruments were brand new and had no noticeable cosmetic differences, all the playing tests were carried out in a darkened room to minimise the possibility of visual identification.

According to the binomial probability distribution, the probability of an individual achieving 16 or more correct answers by chance over the 20 trials is only 0.59%. It can therefore be concluded that, at the 1% significance level, a musician was able to consistently tell the two instruments apart if they exhibited at least 16 successes in the 2-AFC test. Those players who were considered to be able to consistently distinguish between the oboes were asked to comment on the playing features that they perceived to be different between the instruments. The players were free to consider any differences in how the instruments behaved. Such differences might include variations in the mechanical feel of the instruments during note transitions, in the tonal quality of the notes produced, in the ease of playing notes etc.

It should be noted that with nine musicians participating in the playing tests, the likelihood of a chance occurrence of 16 or more correct answers in the test results is increased. However this likelihood is still small; the probability of at least one of the nine musicians randomly achieving such a score is 5.2%.

B. Results

The scores achieved by the subjects in the playing tests were 6, 9, 10, 12, 12, 12, 16, 18 and 20. From these scores, it can be seen that six of the participants were unable to discriminate the two oboes at the 1% significance level. Indeed, these six players correctly identified the instruments no more than 12 times out of the 20 trials. This result suggests a high level of manufacturing consistency in the production of this model of oboe. However, there were three players who did

demonstrate the ability to distinguish between the two oboes at the 1% significance (it is worth noting that the probability of three of the nine musicians achieving 16 or more correct answers purely by chance is tiny, at only 0.0017%). Two of these musicians correctly identified the instruments at least 18 times out of the 20 trials while the other correctly identified them 16 times. When questioned about the playing features that they found to be different between the oboes, the two players who achieved 18 or more correct answers both focussed on a variation in the playability of the note F6. Meanwhile, the player who achieved 16 correct answers in the test stated that he had perceived differences in the sounds produced by the instruments when playing in the lowest register, commenting that one oboe (K856) seemed to have a brighter sound than the other (K619). None of the players indicated that they had perceived any tactile differences between the oboes.

It is worth noting that there does not appear to be any correlation between the ability to discriminate the two oboes and the standard of the player. Of the three musicians who were able to distinguish the instruments at the 1% significance level, two were intermediate level players and one was a professional. In other words, three of the professionals, two of the intermediate players and the beginner were unable to discriminate the instruments.

III. INVESTIGATING PERCEIVED DIFFERENCES IN PLAYABILITY OF F6

The preliminary psychophysical testing carried out during the IDRS conference revealed that two participants in the playing tests perceived differences between the playing properties of two of the Howarth S10 oboes when sounding the note F6. In this section, the reasons for differences in the playability of this note are explored through further psychophysical testing using all five Howarth S10 oboes, as well as input impedance and bore profile measurements on the instruments.

A. Further psychophysical testing

To gain further insight into the playability of the note F6 across the five Howarth S10 oboes, additional psychophysical testing was carried out using intermediate standard oboist DS as the test subject. In a blindfold test, the musician was asked to order the five oboes in terms of the playability of F6. The oboist was free to play the instruments as many times as he wanted and no time limit was imposed on the test. Once the player was satisfied with his ranking, the oboes were mixed up and the whole test was repeated.

The ordering chosen by the musician was the same in each repetition of the test, namely oboe K619 (perceived to produce the note F6 most cleanly), oboe K853, oboe K862, oboe K856 and oboe K855 (perceived to be the most difficult instrument to produce the note F6 on).

B. Input impedance measurements

The input impedance of a musical wind instrument is a quantitative measure of the strengths and frequencies of the instrument's air column resonances. Hence, for a given fingering on the oboe, a measurement of input impedance provides information regarding the playability and sounding properties of the note associated with that fingering.

1. Measurements with F6 fingering

To investigate the perceived differences in the playability of the note F6 across the five oboes, input impedance measurements were carried out on the five instruments when the F6 fingering used by oboist DS was applied to them.

The measurements were made using the commercially available BIAS system[13,14]. This apparatus is primarily designed for measuring the input impedance of brass instruments. To enable oboe measurements to be made, a bespoke coupler was constructed which connects the BIAS measurement head to the oboe via a blank oboe staple (a staple with the two pieces of reed

cane removed). A 253 mm^3 volume within the coupler (equal to that normally contained within the two pieces of reed cane) separates the BIAS head from the tip of the staple. The coupling of the BIAS head to an oboe is illustrated schematically in Figure 2.
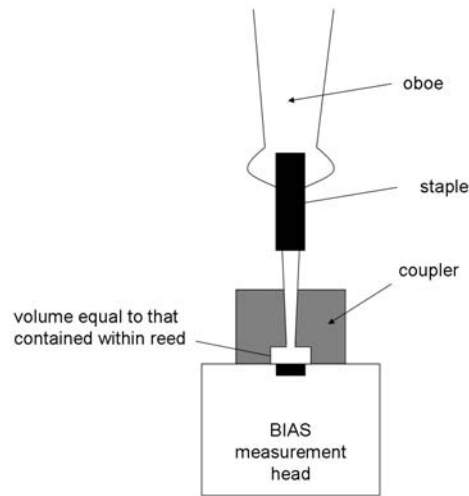

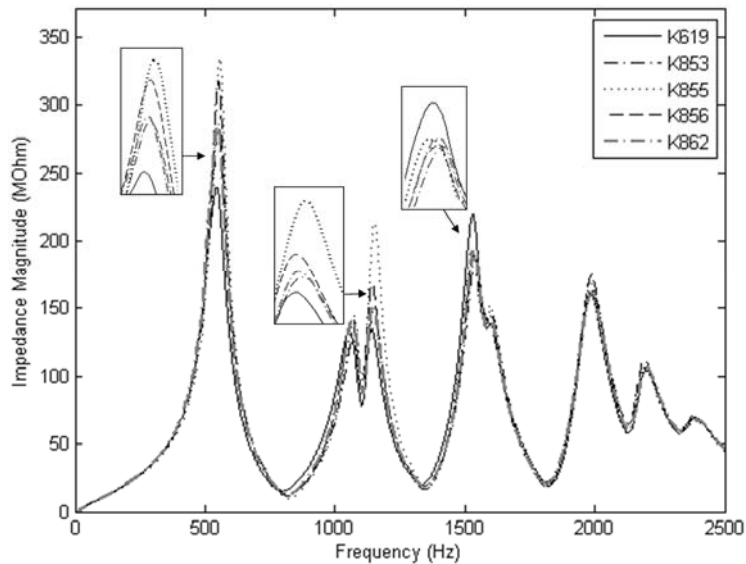Figure 2 Schematic diagram of BIAS measurement head coupled to oboe

Figure 3 Input impedance magnitude curves for the five Howarth S10 student model

oboes with F6 fingering applied

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Figure 3 shows input impedance magnitude curves for the five Howarth S10 student model oboes with the F6 fingering applied. Noticeable differences, in terms of both the frequencies and the amplitudes of corresponding peaks, can be seen between the five impedance curves. Most significantly, the amplitude of the first resonance peak varies by nearly 100 MΩ across the five curves while the amplitude of the second resonance peak varies by around 80 MΩ. Furthermore, the third resonance peak in the impedance curve for oboe K619 is around 25 MΩ higher than in the impedance curves for the four other oboes. Meanwhile, each of the first three resonance peaks varies in frequency by about 10 Hz across the five curves.

To understand the effect that these variations might have on the playing properties of the oboes, it is important to consider that the note F6 lies in the third register of the instrument. Applying the F6 fingering causes the first two resonances of the air column to be reduced in strength relative to the higher resonances. It also shifts their frequencies, thereby weakening the harmonic relationship between them and the higher resonances. These effects combine to ensure that the note pitch produced by the instrument is based on the third resonance frequency; that is, the note has a fundamental frequency which approximately matches the frequency of the third resonance. It can reasonably be assumed that, the more effective the perturbation of the first two resonances relative to the third and higher resonances, the easier it is to produce the F6 note pitch cleanly.

The perceived differences in the playability of the note F6 across the five oboes revealed by the psychophysical testing therefore arise as a result of the observed differences between the amplitudes and frequencies of corresponding peaks in the five impedance curves shown in Figure 3. In percentage terms, the peak amplitudes vary by as much as 30% across the five curves while the peak frequencies differ by no more than 2%. It can therefore be hypothesised that it is the variation in the strengths of the first two resonances relative to the higher resonances across the curves, rather than the variation in their frequencies (and consequently the variation in their harmonicity), that is the dominant reason for the differences in the playability of the note F6

on the five oboes. Further evidence supporting this hypothesis can be found in Figure 3 where, if the oboes are ranked in terms of the amplitudes of their first and second resonance peaks, the following ordering is achieved: K619 (lowest amplitude peaks), K853, K862, K856 and K855 (highest amplitude peaks). This order matches exactly with that chosen by the oboist in Section III.A when asked to rank the playability of F6 on the five instruments. Moreover, as noted previously, the amplitude of the third resonance peak in the impedance curve for oboe K619 is greater than in the impedance curves for the other oboes. This emphasises the fact that, relative to the higher resonances, oboe K619 exhibits the weakest first and second resonances in the F6 fingering configuration.

2. Measurements over whole pitch range

The variations in the acoustical properties of the five Howarth oboes with F6 fingering that were observed in the previous section, must arise as a result of physical differences between the instruments in this fingering configuration (e.g. disparities in bore profile, discrepancies in the positioning and sealing of side holes). Pinpointing these physical differences is not a trivial task. However, the task can be simplified if it is considered that the physical differences will most likely affect a number of notes, not just F6. Identifying all the notes at which the acoustical properties of the instruments show large variations, and searching for common features in their fingerings, should provide additional clues as to the nature of the physical differences.

To this end, input impedance measurements were carried out on the five oboes for every note from B♭3 to E♭6 (31 notes in total). The measurements were again made using the BIAS system with the fingerings used by oboist DS applied to the instruments. However, rather than laboriously plotting 31 more graphs of the type shown in Figure 3 and examining each of them for differences between the impedance curves of the five oboes, an alternative way of representing the impedance data was employed.

At each note pitch, average values for the amplitude and the frequency of the first resonance peak were calculated from the five oboe impedance curves. For each of these impedance curves, the difference in the amplitude and the difference in the frequency of the first resonance peak from the corresponding average values were then determined. Finally, these differences were plotted on a scatter diagram, with the difference in frequency plotted in cents on the x-axis and the relative difference in amplitude plotted on the y-axis.

Figure 4 shows a scatter diagram plotting the amplitude and frequency differences between the first resonance peaks for the five Howarth S10 oboes at the 32 note pitches (including F6) investigated. Three distinct groupings can be observed on the diagram. Region I contains eight notes (C#5, D5, E♭5, C#6, D6, E♭6, E6 and F6) produced on oboe K619. For all of these eight notes, the amplitude of the first resonance peak in the oboe K619 impedance curve is at least 0.15 times lower than the mean value for the five oboe impedance curves. Similarly, its frequency is at least 15 cents lower than the mean value. Meanwhile, Region II contains the same eight notes produced on oboe K855. In this case, for all of the eight notes, the amplitude of the first resonance peak in the oboe K855 impedance curve is at least 0.15 times higher than the mean value for the five oboe impedance curves. Similarly, its frequency is at least 15 cents higher than the mean value. Finally, Region III on the diagram contains the remaining 24 notes produced on oboes K619 and K855, together with all 32 notes produced on oboes K853, K856 and K862. For all of these notes, the amplitude of the first resonance peak in the corresponding oboe impedance curve is within 15% of the mean value.

It is clear from Figure 4 that the largest acoustical differences between the five Howarth S10 oboes occur at eight specific notes (C#5, D5, E♭5, C#6, D6, E♭6, E6 and F6), with the most extreme variation occurring between oboes K619 and K855. A common feature in all the fingerings used by oboist DS to produce these notes is that the C key (see Figure 5) is left unpressed. In this way, the C hole acts as a register hole, weakening either the first resonance or

the first and second resonances of the air column and enabling notes in the second register (C#5, D5, E♭5) or the third register (C#6, D6, E♭6, E6 and F6) of the instrument to be produced. The physical differences responsible for the observed acoustical variations between the five oboes therefore appear to be associated with the C key and its underlying hole.
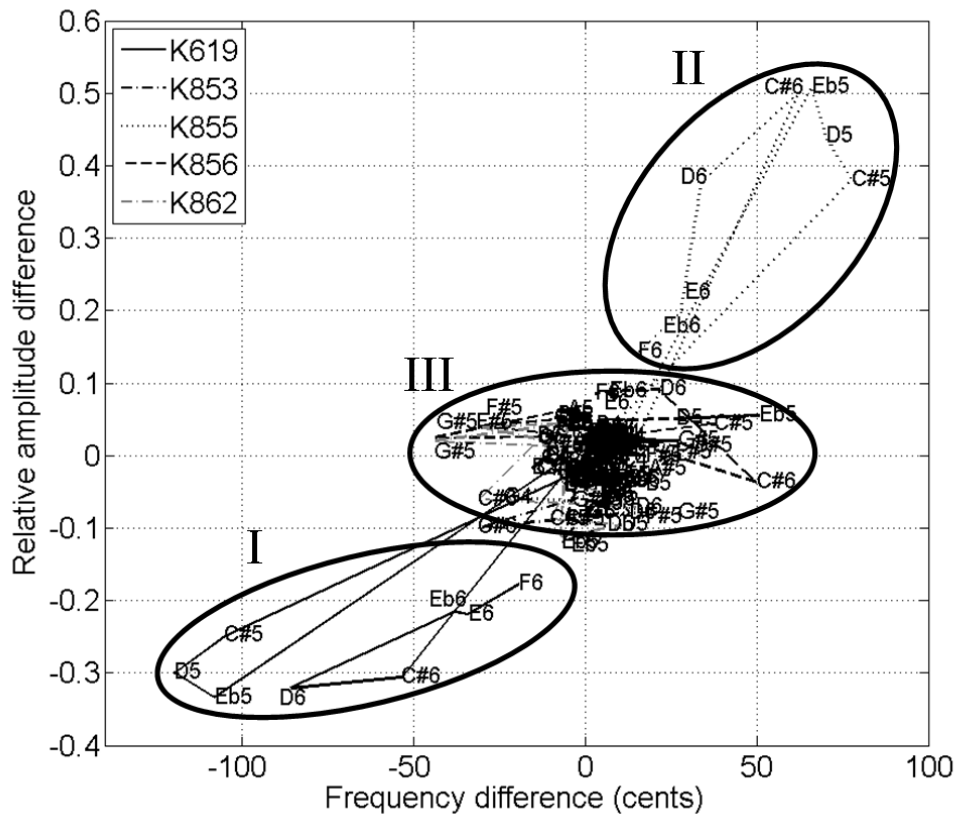

Figure 4 Scatter diagram plotting deviations in the frequencies and amplitudes of the first resonance peaks from the corresponding mean values for five Howarth S10 student model oboes at 32 note pitches.
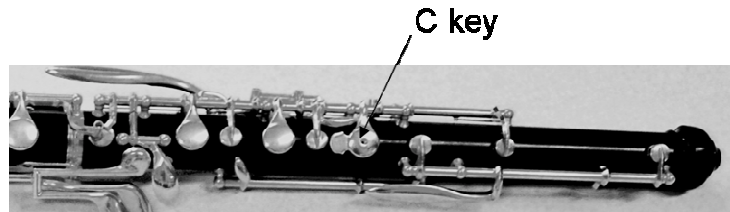
Figure 5 Position of C key on top joint of oboe

C. Bore profile measurements

In order to investigate the hypothesised physical differences between the C keys/holes of the five Howarth oboes, bore profile measurements of the top joints of the instruments were made using acoustic pulse reflectometry. The measurements were made with all the holes closed except for the C hole (where the key was left unpressed).

Figure 6 shows the resulting bore reconstructions of the five oboe top joints, starting at the wide end of the joint and progressing towards the reed input end. The internal dimensions of the five joints are initially in close agreement, each showing a gradual decrease in radius with distance (with small localised increases in radius at the positions of the closed holes). However, around 0.15m along the joint, the measured bore profiles expand spuriously due to the change in acoustic impedance presented by the open C hole. The greater the change in the impedance, the more rapid the rate of expansion. It can be seen that the rates of expansion of the bore reconstructions at the position of the C hole take the following order: oboe K619 (least rapid), oboe K853, oboe K862, oboe K856 and oboe K855 (most rapid). These differences in the measured bore profiles of the five top joints are a result of differences in the elevation of the C key above the hole. In the K619 top joint, the C key sits a relatively small distance above the hole, presenting a lower acoustic impedance change. In the K855 top joint, the height of the C key above the hole is greater, and consequently the change in acoustic impedance presented by the hole is greater. An attempt was made to determine the absolute elevations of the C keys of

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the five instruments above their respective holes using measuring calipers. However, accurate measurements proved impossible due to problems of inaccessibility, caused partly by the proximity of the surrounding keywork but mainly by the fact that the C hole on the Howarth S10 student model oboe is recessed, with the pad of the unpressed key sitting approximately level with the surface of the instrument body.

It is worth noting that the rates of expansion in the five bore profile measurements (and hence the elevations of the C keys in the five top joints) follow the exact same order as (i) that chosen by oboist DS when ranking the playability of F6 and (ii) the heights of the first resonance peaks in the impedance curves for the F6 fingering. It therefore appears that, with the fingering employed by oboist DS, the mechanical adjustment of the height of the C key has a major effect on how easily and cleanly the instrument will produce the note F6.
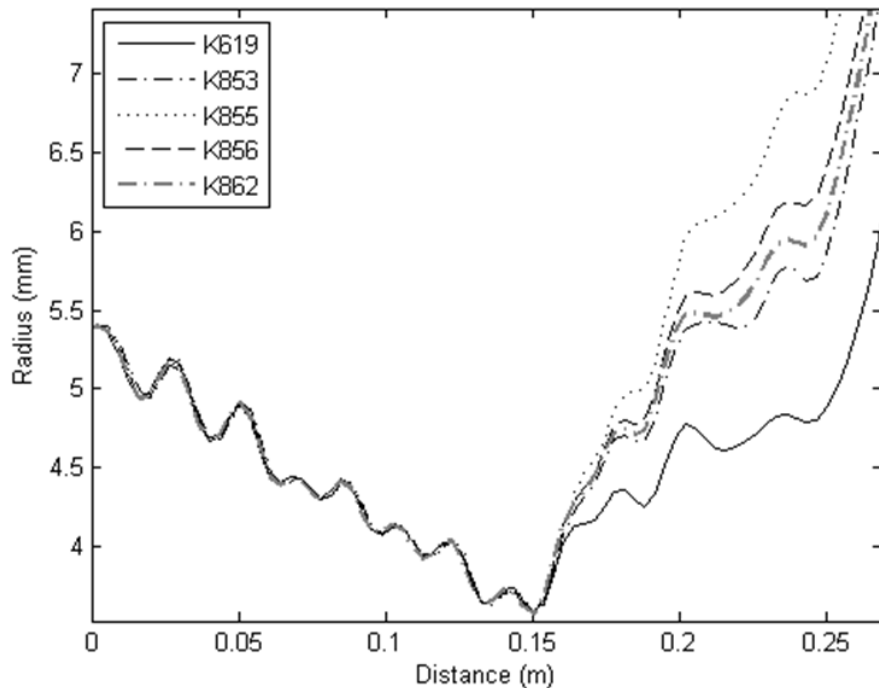

Figure 6 Bore reconstructions of the top joints of the five Howarth S10 student model oboes, with all holes closed except for the C hole.

D. Alternative fingering

All the psychoacoustical testing, impedance measurements and bore reconstructions presented so far in Section III have been carried out with the F6 fingering used by oboist DS applied to the five Howarth oboes. This fingering involves leaving the C key unpressed. However, there is an alternative to this fingering in which the C key is pressed down but the small vent hole present in the centre of the key is left uncovered.
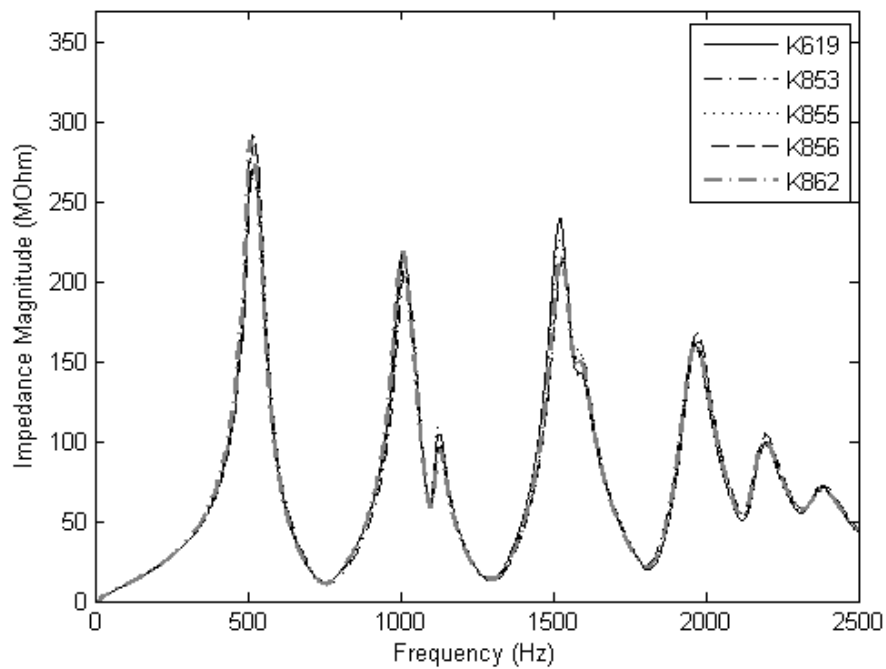

Figure 7 Input impedance magnitude curves for the five Howarth S10 student model oboes with alternative F6 fingering applied

Figure 7 shows input impedance magnitude curves for the five Howarth S10 student model oboes with this alternative F6 fingering applied, again made using the BIAS system. In comparison with Figure 3, the differences between the five impedance curves are much less significant. Now that there is no variation between the oboes in the elevation of the C key above

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the hole, the amplitude of the first resonance peak only differs by approximately 25 MΩ across the five curves while the amplitude of the second resonance peak only varies by around 15 MΩ. However, as might be expected, the variation in the amplitude of the third resonance peak across the five curves is relatively unchanged. The third resonance peak in the impedance curve for oboe K619 is still around 25 MΩ higher than in the impedance curves for three of the other oboes but is now only about 15 MΩ higher than in the impedance curve for oboe K855. Again, each of the first three resonance peaks varies in frequency by about 10 Hz across the five curves.

The fact that there is generally much less variation between the impedance curves suggests that, with this alternative fingering, the playability of the note F6 across the five oboes will be much more comparable.

IV. INVESTIGATING PLAYABILITY OF E♭5

The input impedance measurements reported in Section III.B.2 revealed significant acoustical differences between the five Howarth S10 oboes for eight of the note fingerings used by oboist DS. For the F6 fingering, it has been shown that these acoustical differences have a direct effect on the playability of the note across the five instruments. In contrast, in this section, it is demonstrated that for the E♭5 fingering the acoustical differences do not result in perceptible differences in the playing properties of the instruments. The reason for this is explained by reference to the input impedance measurements for this fingering.

A. Further psychophysical testing

To explore the playing properties of the Howarth oboes with the E♭5 fingering applied, a 2-alternative forced choice test with warm-up was carried out using oboist DS as the test subject. The two instruments chosen for use in the test were those that exhibited the largest acoustical differences, namely oboe K619 and oboe K855. The test procedure was as described in Section II.A but with the musician constrained to play the note E♭5 only.

The musician only identified the oboes correctly 14 times out of the 20 trials. That is, he was unable to discriminate the instruments at the 1% significance level, suggesting that any differences in their playing properties were so small as to be imperceptible.

B. Input impedance measurements

The note E♭5 lies in the second register of the oboe. Applying the E♭5 fingering causes the first resonance of the air column to be reduced in strength relative to the higher resonances. It also shifts its frequency, thereby weakening its harmonic relationship with the higher resonances. The combination of these effects ensures that the note pitch produced is based on the second resonance frequency.

Figure 8 shows input impedance magnitude curves for the five oboes when the E♭5 fingering used by oboist DS is applied. Noticeable differences can once more be seen in the amplitudes and the frequencies of the first resonance peaks of the five impedance curves. Specifically, the amplitude of the first resonance peak varies by nearly 125 MΩ across the five curves while its frequency varies by around 45 Hz. However, with this fingering, the first resonance peak is in all cases significantly lower in amplitude than the second resonance peak. It also has a high degree of inharmonicity in each curve in relation to the higher resonances. Consequently, on all five oboes, the E♭5 fingering both weakens the first air column resonance

sufficiently and shifts its frequency enough to enable the note to be produced very cleanly and no difference in playability is perceived between the instruments.
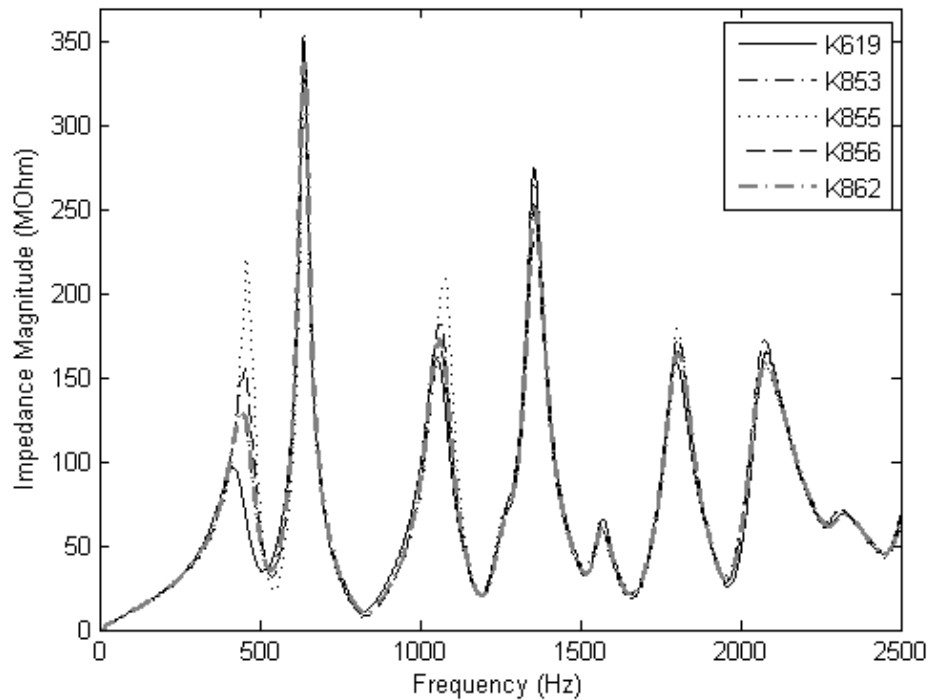

Figure 8 Input impedance magnitude curves for the five Howarth S10 student model oboes with E♭5 fingering applied

V. INVESTIGATING PERCEIVED DIFFERENCES IN LOWEST REGISTER

Most of the outcomes of the preliminary psychophysical testing carried out at the IDRS conference can be explained in terms of (i) differences between the oboes in the resting height of the C key and (ii) the fingerings that the participants used to play particular notes. However, one of the participants in the playing tests proved able to perceive differences between the oboes when playing in the lowest register, where the C key is always pressed down.

In this section, the reasons why the musician was able to discriminate the oboes simply by playing in the lowest register are investigated. Some insight can be gained from the scatter diagram in Figure 9, which shows a subset of the points plotted in Figure 4. The diagram again shows the amplitude and frequency differences between the first resonance peaks for the five Howarth S10 oboes, but this time only for the 15 notes in the lowest register of the instrument. It is clear that the amplitude and frequency differences are much smaller than were observed in Figure 4. However, distinct groupings can again be observed. Region I contains the notes produced on oboe K619, region II contains the notes produced on oboe K855, region III contains the notes produced on oboe K853, and region IV contains the notes produced on oboes K856 and K862 (the amplitudes and frequencies of the first resonance peaks of notes produced on these two instruments being almost identical).

In order to investigate the physical differences responsible for these small acoustical differences, further testing of the instruments was undertaken with the B♭3 fingering applied. In this fingering, all the holes are closed, thereby removing any potential variation due to differences in the heights of keys between the five instruments.

Figure 9 Scatter diagram plotting deviations in the frequencies and amplitudes of the first resonance peaks from the corresponding mean values for five Howarth S10 student model oboes at the 15 note pitches in the lowest register of the instrument.

A. Further psychophysical testing

To gain further information regarding the ability of a musician to perceive differences in the playability of B♭3 on the Howarth oboes, a 2-alternative forced choice test with warm-up was carried out using oboist DS as the test subject. Oboes K619 and K856 were chosen for use in the test, as these were the instruments upon which differences in the lowest register had been perceived during the preliminary psychophysical testing. The test procedure was as described in Section II.A but with the musician constrained to play the note B♭3 only.

For each trial, the oboist rapidly repeated the note on each instrument. By observing very small differences in the ease with which the note sounded, the player correctly identified the instruments in all 20 trials and so clearly demonstrated the ability to discriminate the oboes at the 1% significance level. The musician commented that B♭3 was slightly harder to produce cleanly on oboe K856 than on oboe K619.

B. Input impedance measurements

The note B♭3 is the lowest note in the first register of the oboe. When the B♭3 fingering is applied to the instrument, the note pitch that is produced is based on the first resonance frequency of the air column; that is, the note has a fundamental frequency that approximately matches the frequency of the first resonance.

Figure 10 shows input impedance magnitude curves for the five Howarth S10 oboes with the B♭3 fingering applied. As expected from the scatter diagram of Figure 9, the amplitudes of the first resonance peaks are very similar across the five impedance curves, with a variation of less than 15 MΩ. However, greater differences can be observed in the amplitudes of the second and third resonance peaks, with variations of approximately 35 MΩ and 60 MΩ respectively. Meanwhile, the first two resonance peaks vary in frequency by about 2 Hz across the five curves while the third resonance peak varies in frequency by just under 4 Hz.

Focussing on the two oboes used in the psychophysical testing of the playability of B♭3, it can be seen from Figure 10 that the first, second and third resonance peaks are respectively about 5%, 10% and 15% higher in the impedance curve of oboe K856 than in the impedance curve of oboe K619. Given that the variation in the peak frequencies across the two curves is less than 1%, and there is little difference between them in terms of harmonicity, it can be reasonably

assumed that the weaker the first resonance is relative to the higher resonances, the more likely the pitch will become based on the second or third resonance frequency. This may well explain why the note pitch of B♭3 was perceived as slightly harder to produce cleanly on oboe K856 than it was on oboe K619.
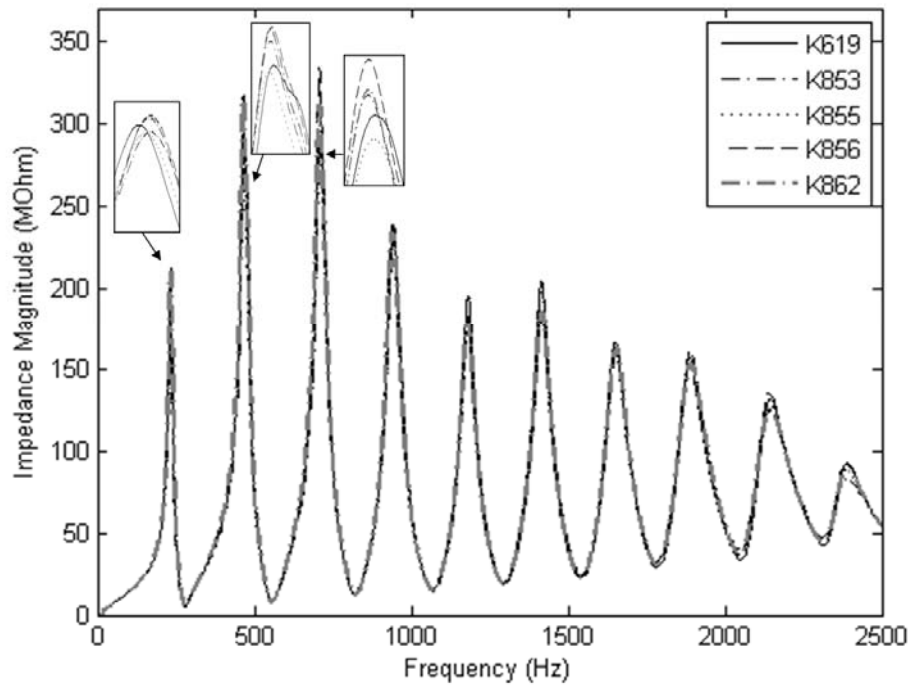

Figure 10   Input impedance magnitude curves for the five Howarth S10 student model oboes with B♭3 fingering applied

C. Bore profile measurements

If it is assumed that there are no leaking pads, the most likely cause of the differences in the impedance curves for the five oboes with B♭3 fingering is a variation in the internal geometries

of the instruments. To test this hypothesis, the bore profiles of the five Howarth oboes were measured using a set of twelve high precision measurement discs with rod attachments. As the diameter of the largest measurement disc is smaller than that of an oboe bell, the measurements were carried out on the bottom and top joints of the instruments only. For each of the five oboes, the twelve different diameter discs were sequentially inserted into the combined bottom and top joints, with the insertion depth noted each time. Figure 11 shows the resulting bore profiles, starting at the wide end of the bottom joint and progressing towards the reed input end of the top joint.
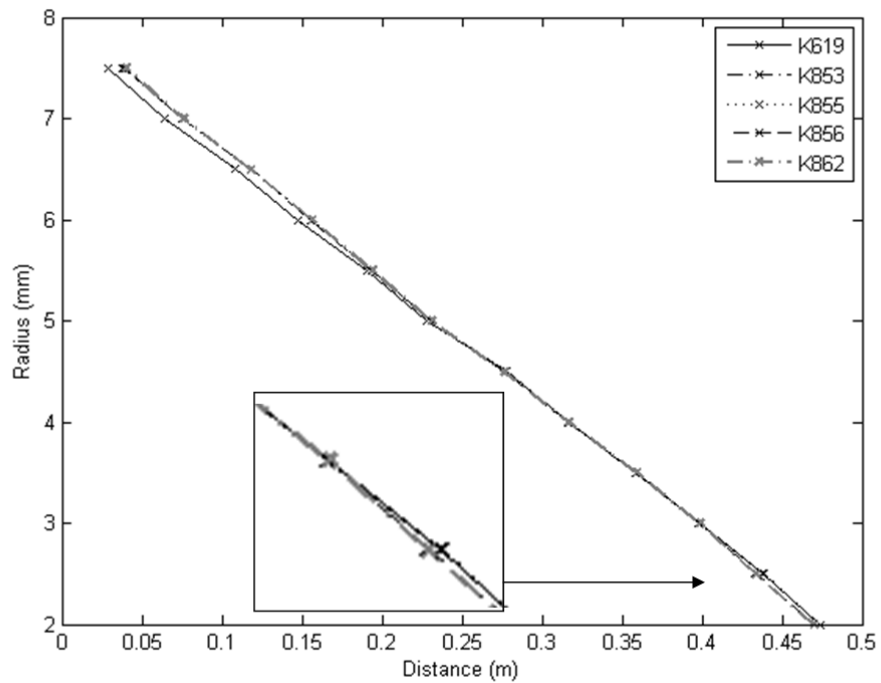
Figure 11   Bore profiles of the bottom and top joints of the five Howarth S10 student model oboes (determined using high precision measurement discs)

It is clear that the bore of the bottom joint of oboe K619 has a slightly slower rate of expansion than the bores of the other bottom joints. Meanwhile, close examination of the figure reveals that the top joints of oboes K619 and K855 both have a slightly wider bore towards the reed input end than the other top joints. It is likely that these small differences in the bore profiles of the five oboes provide an explanation for many of the differences observed in the impedance curves of Figure 10. However, modelling the exact effect of localised bore diameter changes on the resonance properties of a full instrument is not trivial. For example, it requires knowledge of the exact geometry of the whole instrument (including the bell) and precise details of the positioning, diameters and heights of all the side holes. As this paper is primarily concerned with investigating the consistency of musical wind instrument manufacturing, implementation of such a model is left for future work.

VI. CONCLUSION

The consistency of woodwind instrument manufacturing has been investigated by comparing five Howarth S10 student model oboes using a combination of psychophysical testing and acoustical measurement. Preliminary playing tests were carried out using the two instruments initially believed to be the most dissimilar. For the majority of the musicians that participated in these playing tests, the two oboes were perceived as having essentially identical playing properties, suggesting a high level of manufacturing consistency. However, two musicians did perceive differences in the playing properties of the instruments when producing the note F6. This finding was corroborated by further psychophysical testing which revealed a variation in the playability of F6 across all five oboes, caused by small differences in the elevation of the C key. This does not indicate a major issue in terms of manufacturing consistency as the heights of all the keys can be easily adjusted (via the simple turn of a screw) by the manufacturer; although the findings of this paper suggest that special attention should be paid to the adjustment of the C key.

Of more interest are the tiny variations that were observed in the bore profiles of the instrument joints. These variations are the most likely reason that, during the preliminary playing tests, one musician was able to perceive differences between the two oboes when playing in the lowest register (a finding which was again backed up by the results of further psychophysical testing). One possible cause of the differences in the bore profiles of the instruments is a gradual build up of burr on the reamer used to bore out the joints over the course of the manufacturing run. Another possible cause is a variation in the amount of relaxation experienced by the wood of the different joints after the machining has taken place.

In conclusion, the methods reported in this paper have not only successfully identified perceptual and acoustical variations between a set of nominally identical oboes but they have also enabled the physical differences responsible for those variations to be determined. Therefore, even with the high levels of manufacturing consistency already being achieved by some makers, the integration of these methods into the quality control process could be of potential benefit to woodwind instrument manufacturers.

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LIST OF FIGURES

oboe

staple

coupler

volume equal to that
contained within reed

BIAS
measurement
head

C key