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SPECTRAL ANALYSIS OF CLARINET'S THROAT TONE PLAYED WITH ALTERNATE FINGERINGS

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Abstract

The top portion of the lowest register of clarinet, called sometimes the "break" or throat register, is known as the most troublesome portion to the average player in keeping proper pitches and producing characteristic timbre. A remedy for this is the use of cross fingering (CF for short) in place of the normal fingering (NF). This paper studies the effect of CFs on the spectral structure of the clarinet tone experimentally for the typical throat note $A\flat_4$ in the $B\flat$ clarinet with two amateur players. The result showed that 10 out of 39 CFs provided for the experiment raised the power of the 3rd partial by 10 dB or more as compared with that of NF. These CFs have a common property that they close 3 specific holes in the middle part and 2 specific holes in the lower part together with some other holes.

INTRODUCTION

The top portion of the lowest register of clarinet, called sometimes the "break" or throat register, is known as the most troublesome portion to the average player in keeping proper pitches and producing characteristic timbre. A remedy for this is the use of certain cross fingerings as alternate ones to the normal fingering. Here, the normal fingering refers to a fingering by which all the press-down fingers are at the upper end and all the lift-up fingers are at the lower end, while the cross fingering refers to a fingering by which a press-down finger or fingers are below a lift-up finger.

This paper studies the acoustical characteristics of the normal and cross fingerings in the above context. Experiment was done on $A\flat$ note in the throat register of the clarinet in $B\flat$ (of the Böhm system). Associated with the normal fingering, labeled NF, for the target note, total 39 cross fingerings, labeled CF1 to CF39, were provided to compare with NF.

Throughout this paper, all notes will be written as they sound, e.g., D_3 for a notated E_3 which is the lowest note of the clarinet in B♭. The subscripted numerals denote different octaves by following the convention A_4 = 440 Hz.

METHOD OF EXPERIMENT

Players and Instruments

Two female university students, who were clarinet players in an amateur orchestra, participated in the experiment. Their playing experiences in the clarinet were ten years (player A) and six years (player B).

Player A played a Buffet Crampon R-13, and player B played an Henri Selmer 10S. Both of them used a reed of strength 3-1/2. The instruments were not interchanged during the experiment.

Production of Tones

The experiment was conducted in a low reverberant listening room (reverberation time: 0.28 s at 500 Hz, background noise: 21 dBA). The sound pressure level of the produced sound was about 90 dB SPL at the point of recording microphone (a type 4190 microphone with a type 2669L preamplifier, B&K) which is set at 1 m off the instrument. The produced sounds were recorded digitally at 44.1 kHz sampling rate, and processed by DFT and band pass filter.

Experiment 1. The purpose of this experiment was to know the power spectra of the characteristic timbre of clarinet when played loudly. The players blew notes D_3 to E_4 in the lowest (or chalumeau) register, and of A_4 to B_6 in the upper (or clarion) register. They were asked to blow each of them loudly at a constant blowing pressure as much as possible with normal fingering (NF).

Experiment 2. The purpose of this experiment was to compare the effect of alternate fingerings on the timbre of tone $A\flat_4$ (the highest note in the break register), which is known as the typical *throat* note, or one of the most difficult notes to play in good timbre.

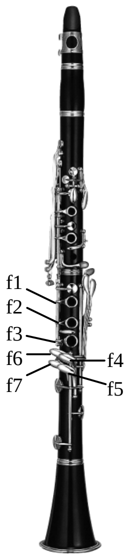
Table 1 shows the listing of cross fingerings as altenate ones for the experiment, 39 fingerings in total, labeled CF1~CF39, together with NF.

The left part of Table 1 defines the concerned subset of keywork on the press-down and lift-up of fingers at finger holes and levers, labeled f1~f7, with black and white circles, for NF and each of CF1 ~ CF39; and the right part indicates the associtated open/close status of tone holes, labeled h1~h8, with black and white circles. The reason for showing these two parts is that in the clarinet, pressing-down of a finger over an open finger hole closes the concerned hole solely or together with one or more auxiliary small tone holes, and pressing-down of a lever either closes or opens one ore more tone holes. Hence the keywork indicated with black and white circles in the left part is not identical to closing and opening of tone holes.

The players were asked to blow the target note $A\flat_4$ loudly as sustained tones, about 2 seconds each in duration at a constant blowing pressure as much as possible, with normal fingering (NF) and each of cross fingerings (CF) in this order (i.e., NF–CF) without a break

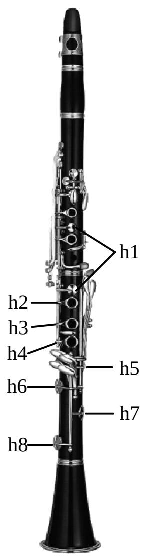
Table 1: Normal fingering and 39 cross fingerings experimented.
Shown is the concerned subset of keywork.

Fingering	f1	f2	f3	f4	f5	f6	f7
NF	○	○	○	○	○	○	○
CF1	●	○	○	○	○	○	○
CF2	○	●	○	○	○	○	○
CF3	○	○	●	○	○	○	○
CF4	○	○	○	●	○	○	○
CF5	○	○	○	○	●	○	○
CF6	○	○	○	○	○	●	○
CF7	○	○	○	○	○	○	●
CF8	●	●	○	○	○	○	○
CF9	●	○	●	○	○	○	○
CF10	●	○	○	●	○	○	○
CF11	●	○	○	○	●	○	○
CF12	●	○	○	○	○	●	○
CF13	●	○	○	○	○	○	●
CF14	○	●	●	○	○	○	○
CF15	○	●	○	●	○	○	○
CF16	○	●	○	○	●	○	○
CF17	○	●	○	○	○	●	○
CF18	○	●	○	○	○	○	●
CF19	○	○	●	●	○	○	○
CF20	○	○	●	○	●	○	○
CF21	○	○	●	○	○	●	○
CF22	○	○	●	○	○	○	●
CF23	○	●	●	●	○	○	○
CF24	○	●	●	○	●	○	○
CF25	○	●	●	○	○	●	○
CF26	○	●	●	○	○	○	●
CF27	●	○	●	●	○	○	○
CF28	●	○	●	○	●	○	○
CF29	●	○	●	○	○	●	○
CF30	●	○	●	○	○	○	●
CF31	●	●	○	●	○	○	○
CF32	●	●	○	○	●	○	○
CF33	●	●	○	○	○	●	○
CF34	●	●	○	○	○	○	●
CF35	●	●	●	○	○	○	○
CF36	●	●	●	●	○	○	○
CF37	●	●	●	○	●	○	○
CF38	●	●	●	○	○	●	○
CF39	●	●	●	○	○	○	●



○ ··· lift-up
● ··· press-down

Fingering	h1	h2	h3	h4	h5	h6	h7	h8
NF	○	○	○	○	●	○	●	○
CF1	●	●	○	○	●	○	●	○
CF2	●	○	●	○	●	○	●	○
CF3	●	○	○	●	●	○	●	○
CF4	○	○	○	○	○	○	●	○
CF5	○	○	○	○	●	●	●	○
CF6	○	○	○	○	●	●	○	○
CF7	○	○	○	○	●	●	●	●
CF8	●	●	●	○	●	○	●	○
CF9	●	●	○	●	●	○	●	○
CF10	●	●	○	○	○	○	●	○
CF11	●	●	○	○	●	●	●	○
CF12	●	●	○	○	●	●	○	○
CF13	●	●	○	○	●	●	●	●
CF14	●	○	●	●	○	○	○	○
CF15	●	○	●	○	○	○	●	○
CF16	●	○	●	○	●	●	●	○
CF17	●	○	●	○	●	●	○	○
CF18	●	○	●	○	●	●	●	●
CF19	●	○	○	●	○	○	●	○
CF20	●	○	○	●	●	●	●	○
CF21	●	○	○	●	●	●	○	○
CF22	●	○	○	●	●	●	●	●
CF23	●	○	●	●	○	○	●	○
CF24	●	○	●	●	●	●	●	○
CF25	●	○	●	●	●	●	○	○
CF26	●	○	●	●	●	●	●	●
CF27	●	●	○	●	○	○	●	○
CF28	●	●	○	●	●	●	●	○
CF29	●	●	○	●	●	●	○	○
CF30	●	●	○	●	●	●	●	●
CF31	●	●	●	○	○	○	●	○
CF32	●	●	●	○	●	●	●	○
CF33	●	●	●	○	●	●	○	○
CF34	●	●	●	○	●	●	●	●
CF35	●	●	●	●	●	○	●	○
CF36	●	●	●	●	○	○	●	○
CF37	●	●	●	●	●	●	●	○
CF38	●	●	●	●	●	●	○	○
CF39	●	●	●	●	●	●	●	●



○ ··· open
● ··· close

Left: Finger holes f1~f3 and levers f4~f7 on which fingers work.
Right: Tone holes h1~h8 to open/close.

between the two; then to blow in the reversed order (CF–NF) under the same condition.

RESULTS

Notes in the Chalumeau and Clarion Registers

It is known that the clarinet produces primarily odd partials because it acts as a stopped-pipe resonator ([1], Section 15.9). The actual tones of notes belonging to the chalumeau register have this characteristics clearly so that the first several odd partials have a strong power while the even partials have a weak one, the 2nd one being almost missing. However, higher notes belonging to the clarion register gain some powers also in the even partials.

Figure 1 shows two samples of power spectra (by DFT with Blackman-Harris window on 8192 points), those of $B\flat_3$ (in the chalumeau register) and $B\flat_4$ (in the clarion register), blown by player A. In the power spectrum of $B\flat_3$ (Figure 1, left), the 2nd, 4th, and 6th partials have a very weak power, while the 3rd and 5th partials have a power nearly comparable to the fundamental one. In the power spectrum of $B\flat_4$ (Figure 1, right), the 2nd and 4th partials gain power considerably, the 3rd partial loses slightly, and the 5th partial loses very much in comparison to those of $B\flat_3$.

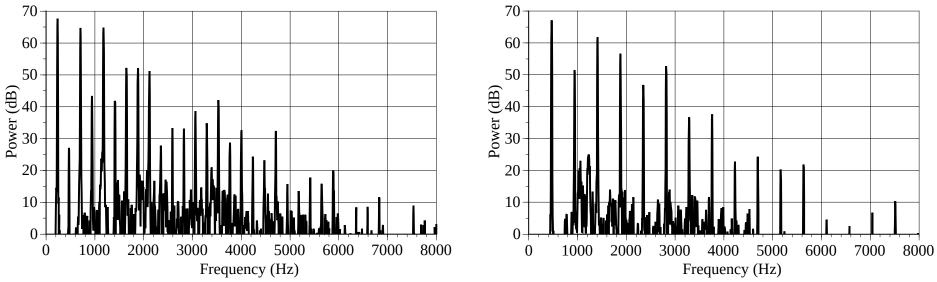


Figure 1: Power spectra of $B^\flat{}_3$ (left) and $B^\flat{}_4$ (right) by player A with NF

Throat Note $A\flat_4$

Normal Fingering (NF)

Figure 2 shows two samples of power spectra of tones $A\flat_4$ blown by players A and B with NF. Apparently, the 3rd partial is very weak. For more details on NF, however, we will discuss in relation to the cross fingering in the section below.

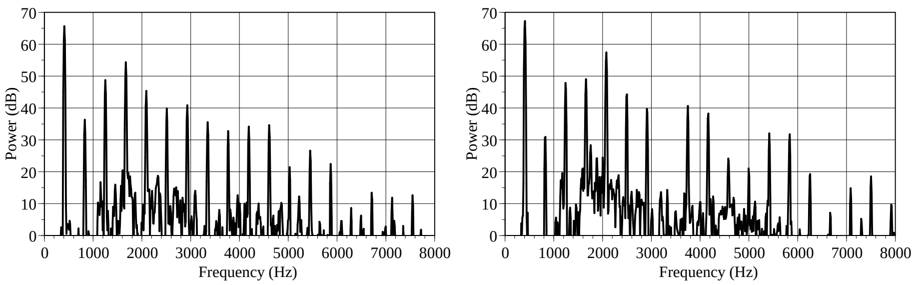


Figure 2: Power spectra of $A^\flat{}_4$ by players A(left) and B(right) with NF

Cross Fingering (CF)

The effects of cross fingerings on the spectral structure (in the sense of relative power levels of partials) of the produced tone may differ one by one, as well as between players, in general.

Hence, by looking at the power spectra in different portions of each waveform of tones produced with 39 CFs listed in Table 1, we picked up those according to the criterion that the power of the 3rd partial was raised by 10 dB or more, together with the powers of 4th and/or 5th partials that were raised to some extent. Table 2 lists up 10 of them in total so that each one is about to satisfy the above criterion for both players A and B.

Table 2: 10 cross fingerings that produced a rich 3rd partial by players A and B.

CF name	h1	h2	h3	h4	h5	h6	h7	h8
CF11	●	●	○	○	●	●	●	○
CF12	●	●	○	○	●	●	○	○
CF13	●	●	○	○	●	●	●	●
CF28	●	●	○	●	●	●	●	○
CF30	●	●	○	●	●	●	●	●
CF32	●	●	●	○	●	●	●	○
CF33	●	●	●	○	●	●	○	○
CF34	●	●	●	○	●	●	●	●
CF37	●	●	●	●	●	●	●	○
CF39	●	●	●	●	●	●	●	●

○ ··· open
● ··· close

All the CFs listed in Table 2 have a common property that they close tone holes {h1, h2, h5, h6} always, where {h1, h2} are closed by press-down of f1 (with the right forefinger), and the {h5, h6} are closed by press-down of one of levers {f5, f6, f7} (with the right little finger).

Let us compare the effect of these 10 CFs with NF in terms of the relative powers of partials that are extracted by use of a band pass filter. To be more precise, let E (dB) denote the total energy of a waveform, and let E_i (dB) ($i = 1, \cdots, 12$) denote the energy of its i-th partial extracted by the filter. Here, the energy is obtained for a duration of 1 second in a steady state portion of the waveform. Since the spectral structure of the NF tones deviated also sample by sample, we took 10 samples of NF tones, one from each of the paired recordings of NF and CF for the 10 CFs.

The quantity $e_i = E_i - E$ gives the relative power of the i-th partial. Then for each i, compute the mean, $\overline{e_i}$, and standard deviation, s_i, of e_i over all the waveforms concerned.

Player 1. The left side of Table 3 shows $\overline{e_i}$ and s_i of the first 12 partials over 10 samples of NF, and the right side of Table 3 shows those over 10 CFs.

The table tells that the 3rd partial with CF gets raised by about 16 dB on the average, and that other partials with CF are not changed noticeably. Figure 3 shows the profiles of e_i of the 10 samples of NF and those of 10 CFs, together with those of $\overline{e_i}$ indicated in bold lines.

Player 2. The left side of Table 4 shows $\overline{e_i}$ and s_i of the first 12 partials over 10 samples of NF, and the right side of Table 4 shows those over 10 CFs.

The table tells that the 3rd and 4th partials with CF, respectively, get raised by about 10 dB and 6.7 dB on the average, and that other partials with CF are not changed noticeably. Figure 4 shows the profiles of e_i of 10 samples of NF and those of 10 CFs, together with those of $\overline{e_i}$ indicated in bold lines.

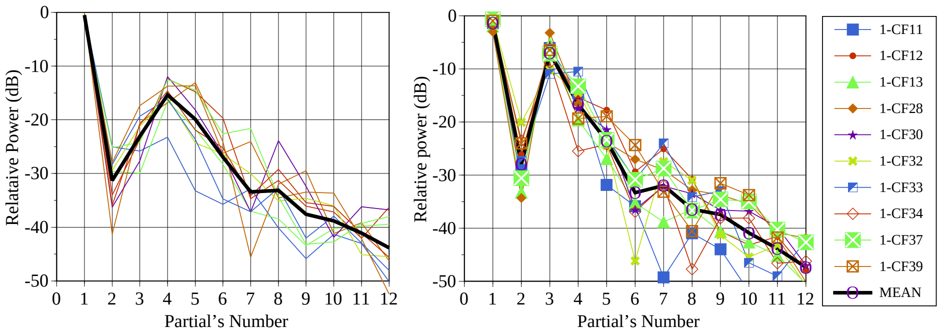
Summary of the effect of CFs. The power of the 3rd partial was raised by considerably (10 dB or more) for both players, and that of 4th partial was raised to a noticeable degree only for player B. The power of higher partials were raised or lowered to some extent on the average. But these variations stayed mostly within the range of standard deviation.

Difference in the CF tones between players A and B. A difference is observed in the CF

Table 3: Mean $\overline{e_i}$ and standard deviation s_i of e_i; Player 1

Left: $\overline{e_i}$ and s_i over 10 samples of NF,
Right: $\overline{e_i}$ and s_i over 10 CFs. (s_i are put in parentheses.)

i	$\overline{e_i}$ over 10 NFs		i	$\overline{e_i}$ over 10 CFs	
1	-0.52	(0.43)	1	-1.37	(0.72)
2	-31.30	(5.33)	2	-27.93	(4.56)
3	-23.07	(3.92)	3	-7.02	(2.34)
4	-15.37	(3.30)	4	-16.66	(4.15)
5	-19.90	(6.35)	5	-23.55	(3.97)
6	-26.93	(4.98)	6	-33.31	(6.20)
7	-33.42	(6.92)	7	-31.96	(7.43)
8	-33.16	(4.60)	8	-36.44	(5.31)
9	-37.59	(5.57)	9	-37.39	(4.14)
10	-38.82	(3.05)	10	-40.87	(6.00)
11	-41.09	(2.54)	11	-43.86	(3.79)
12	-43.85	(5.81)	12	-47.36	(4.20)



Left: Profiles of e_i of 10 samples of NF, together with $\overline{e_i}$
Right: Profiles of e_i of 10 CFs, together with $\overline{e_i}$

Figure 3: Relative power of 12 partials of $A^\flat{}_4$ with NF and 10 CFs by Player 1

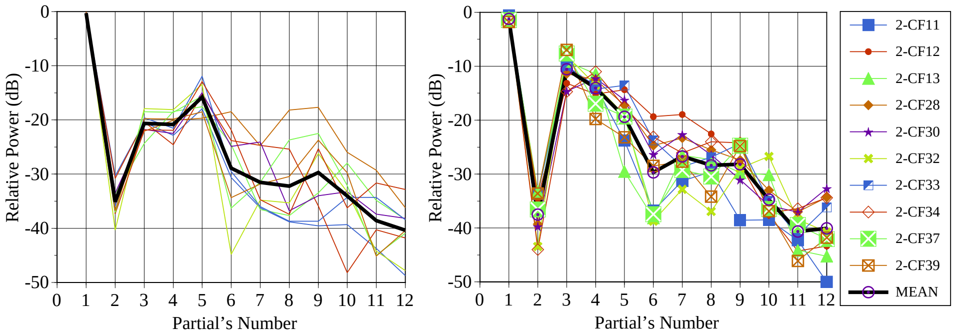
tones between players A and B so that the profile of $\overline{e_i}$ ($i = 1, \cdots, 12$) of player A has a sharper rise at $i = 3$ and a faster decrease at $i \geq 4$ than that of player B. This implies that, on the average, the CF tones by player B are richer in higher partials, at a loss of richness of the 3rd partial to some extent, than those by player A.

Notice, however, that the above difference is the mixed outcome of individual differences in the players and in the instruments, since each player used solely one's own instrument without interchanging with the other's.

Table 4: Mean $\overline{e_i}$ and standard deviation s_i of e_i; Player 2

Left: $\overline{e_i}$ and s_i over 10 samples of NF,
Right: $\overline{e_i}$ and s_i over 10 CFs. (s_i are put in parentheses.)

i	$\overline{e_i}$ over 10 NFs		i	$\overline{e_i}$ over 10 CFs	
1	-0.26	(0.18)	1	-1.24	(0.39)
2	-35.13	(3.09)	2	-37.52	(4.00)
3	-20.66	(1.90)	3	-10.57	(2.82)
4	-20.84	(2.16)	4	-14.06	(2.68)
5	-15.78	(2.59)	5	-19.39	(4.87)
6	-28.91	(7.89)	6	-29.69	(7.35)
7	-31.52	(5.13)	7	-26.73	(4.19)
8	-32.24	(7.40)	8	-28.39	(4.48)
9	-29.70	(7.54)	9	-28.20	(4.39)
10	-34.04	(6.31)	10	-34.73	(3.73)
11	-38.58	(5.90)	11	-40.65	(3.47)
12	-40.36	(4.88)	12	-40.07	(5.56)



Left: Profiles of e_i of 10 samples of NF, together with $\overline{e_i}$
Right: Profiles of e_i of 10 CFs, together with $\overline{e_i}$

Figure 4: Relative power of 12 partials of $A^{\flat}{}_4$ with NF and 10 CFs by Player 2

CONCLUSIONS

The effect of cross fingerings (CFs) on the spectral structure of throat note $A^{\flat}{}_4$ of the clarinet in $B^{\flat}$ was studied experimentally. The result with two players showed that 10 out of 39 CFs (see Tables 1 and 2) have an effect of significant increase on the energy of the 3rd partial. These 10 CFs has a common property that tone holes {h1, h2, h5, h6} are closed always. Note that {h1, h2} are closed with the right forefinger on finger hole f1, and {h5, h6} are closed with the right litter finger on one of levers {f5, f6, f7}.

There was a noticeable difference in the spectral structure of CF tones, on the average, produced by players A and B so that the tones by player B were richer in higher partials, at a loss of richness of the 3rd partial to some extent, than those by player A. This difference is the mixed outcome of individual differences in the players and in the instruments involved in the experiment. The difference in the part of players, if such exists, could be attributed mainly to the individual difference in the vocal-tract resonance of players [2]. Studies in this respect need to be done.

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REFERENCES

References

[1] N. Fletcher and T. Rossing, *The Physics of Musical Instruments, Second Edition*. (Springer, New York, 1998)

[2] Clinch, P.G., Troup, G.J., and Harris, L. “The importance of vocal tract resonance in clarinet and saxophone performance — A preliminary account.” Acoustica **50**, 284-284.