# Timbre and Loudness of Flute Notes

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Abstract: Spectrum analysis of flute sounds published by Fletcher [*J. Acoust. Soc. Am.* 57, 233-237 (1975)] has been used to compute loudness level and tristimulus coordinates for three notes $C_4$, $C_5$, $C_6$ played both loud and soft by four players. The differing timbre values for the same note played by the four flutists and the differences between loud and soft notes are clearly revealed in tristimulus diagrams.

## 1. INTRODUCTION

As part of a study of the physical parameters involved in flute playing, Fletcher [1] presented tonal analyses of three notes played both loud and soft by four flutists. For the note $C_4$ the fundamental was found to be lower in level than either the second or third harmonics and remained at the same level for both loud and soft playing. For both $C_5$ and $C_6$ the fundamental was the dominant partial tone for both loud and soft playing but changed little in level. For all notes there was a marked reduction in the levels of the higher harmonics during softer playing. Both the loudness and timbre are dependent on the level of higher harmonics compared with the fundamental. In this paper the spectrum data has been reprocessed to quantify the changes in timbre and loudness that occur between loud and soft playing.

## 2. LOUDNESS

Fletcher's spectrum measurements have been grouped into 1/3 octave bands and the band levels converted into loudness values using standard ISO procedures [2]. Harmonics 1 to 6 fall in separate bands but it is necessary to combine spectrum levels for the higher harmonics since more than one harmonic falls within each band. Table 1 includes the mean loudness level in phons, the standard deviation and coefficient of variation (standard deviation divided by the mean) for each of the notes $C_4$, $C_5$, and $C_6$ played soft and loud by the four flutists.

## 3. TRISTIMULUS COORDINATES

Steady musical sounds are often analysed in terms of three main parameters: pitch, loudness and timbre. These parameters are not always independent. One method of presenting timbre information is to compute tristimulus values [3,4] which are independent of pitch and loudness. From 1/3 octave band loudness values, three normalised tristimulus coordinates may be computed:

$$x = N(5,n) / N$$
$$y = N(2,4) / N$$
$$z = N(1) / N$$

where $N(1)$ is the loudness of the fundamental, $N(2,4)$ is the loudness of partials 2-4, $N(5,n)$ is the loudness of partials 5-$n$, $N$ is the total loudness, and $x + y + z = 1$. The loudness of each group is computed using Stevens Mark VII method [5].

Using the fundamental of the note as reference renders the analysis independent of pitch while the normalisation procedure renders the analysis independent of loudness. A further advantage of using normalised coordinates is that the data can be represented by a 2-dimensional diagram using a selected pair of coordinates. For flute notes, plotting $x$ versus $z$ is useful for showing the relative changes between the higher partials *(x)* and the fundamental *(z)*.

Figure 1 is a set of *x-z* tristimulus diagrams for the notes $C_4$, $C_5$, $C_6$ played both soft and loud by the four players A, B, C, D; solid squares represent loud notes, open circles soft notes. The points for $C_6$ all lie on the *z*-axis since $x = 0$ for all these points (there are no significant partial tones higher than the fourth).

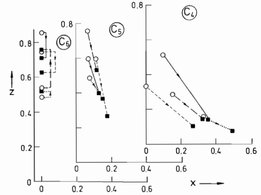


Figure 1. *x-z* tristimulus diagrams for flute notes $C_4$, $C_5$, $C_6$ played both soft (open cirles) and loud (solid squares) by players A, B, C, D. The lines point from soft notes to loud: solid lines player A, heavy dashed lines player B, dotted lines player C, light dashed lines player D. The points for $C_6$ all lie on the z-axis since $x = 0$ for these points. The mean distances (in tristimulus units) between soft and loud notes are: $C_4$ 0.30, $C_5$ 0.23, $C_6$ 0.13.

Table 1. Mean values, standard deviation (SD) and coefficient of variation (% varn) for the loudness level and tristimulus values of notes $C_4$, $C_5$, $C_6$.

| | Loudness Level (phons) | *x* | *y* | *z* |
|---|---|---|---|---|
| **$C_4$ soft** | | | | |
| mean | 29 | 0.142 | 0.536 | 0.322 |
| SD | 7 | 0.12 | 0.10 | 0.13 |
| % varn | 23 | 83 | 19 | 40 |
| **$C_4$ loud** | | | | |
| mean | 45 | 0.356 | 0.525 | 0.119 |
| SD | 1.4 | 0.08 | 0.07 | 0.03 |
| % varn | 3 | 23 | 14 | 24 |
| **$C_5$ soft** | | | | |
| mean | 39 | 0.082 | 0.310 | 0.609 |
| SD | 2.5 | 0.02 | 0.09 | 0.10 |
| % varn | 6 | 23 | 30 | 16 |
| **$C_5$ loud** | | | | |
| mean | 48 | 0.144 | 0.467 | 0.390 |
| SD | 3 | 0.02 | 0.07 | 0.10 |
| % varn | 6 | 16 | 16 | 24 |
| **$C_6$ soft** | | | | |
| mean | 37 | 0.000 | 0.346 | 0.654 |
| SD | 5 | – | 0.15 | 0.15 |
| % varn | 13 | – | 42 | 22 |
| **$C_6$ loud** | | | | |
| mean | 50 | 0.000 | 0.347 | 0.653 |
| SD | 4 | – | 0.09 | 0.09 |
| % varn | 7 | – | 27 | 14 |

For notes $C_4$ and $C_5$ the lines joining soft to loud notes all slope downwards to the right indicating significant shifts away from a predominantly fundamental tone to a brighter tone containing more higher partials in accordance with Fletcher's observations.

Table 1 includes the mean value, standard deviation and coefficient of variation of *x, y, z* for each set of soft and loud notes. Note that the means of the data for both $C_6$ soft and loud notes overlap.

Fletcher also studied the effects produced by vibrato, an important contributing factor in assessing timbre. Vibrato can be studied by analysing segments of the steady tone [6] but such data is not included in this study.

## 4. CONCLUSION

From spectrum analysis of a set of musical notes and grouping of partial tones into 1/3 octave bands, measures may be derived which quantify the timbre of the notes. Computation of tristimulus coordinates and two-dimensional graphs using selected pairs of coordinates provide valuable tools for the understanding, design or teaching of a musical instrument.

## REFERENCES


[1] Fletcher N H, "Acoustical correlates of flute performance technique", *J. Acoust. Soc. Am.* **57**, 233-237 (1975)

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[6] Segal A I, "Timbre vibrato", *Bull. Aust. Acoust. Soc.* **11**, 104 (1983).