A Comparison of Acoustic Effects of Two Stopper and Crown Systems in the Modern Flute

Jasmine Tait
Winner of the CAA Youth Science Foundation Award, 2001

ABSTRACT

A new stopper and crown system developed by flute maker Robert Bigio is reported to produce a louder, harmonically richer and faster response in the orchestra flute. Using spectral analysis software, the author compared the two systems (Standard and Bigio) in a test flute to find any significant differences in relative loudness and amplitude of recorded test note harmonics. A homemade impedance head mounted on the flute's embouchure plate was used to measure the pressure response of the flute sound wave produced in response to signal excitation (Schroeder chirp, 500 to 5000 Hz). Results showed that the Bigio unit was associated with stronger levels of amplitude and total power, higher amplitude in harmonics, and a slightly higher pressure response. The Bigio unit may be important for improving the timbre of the flute, but more work must be done to ensure that harmonic changes are more consistent, and to decide whether pressure differences make for an easier or harder blowing flute.

RÉSUMÉ

Plusieurs annoncent qu'un nouveau système de taquet et couronne dévéloppé par le fabricateur de flûtes, Robert Bigio produit un réponse plus fort, plus vite et des harmoniques plus prononcées dans la flûte d'orchestre. En utilisant des logiciels d'analyse spectrale, l'auteur avait comparé deux systèmes (Standard et Bigio) dans une flûte d'épreuve pour découvrir de différences en force relatif et l'amplitude harmonique de notes enregistrées. Un appareil de mesure d'impédance fait à la maison, installé sur la plaque d'embouchûre était utilisé pour mesuré la pression de

Canada Wide Science Fair

Report by Annabel Cohen

Jasmine Tait, a Grade 9 student from Ottawa won this year's acoustics prize at the Canada Wide Science Fair.

This project was conducted last year as an individual class assignment for the grade 8 science teacher, Mr. B. Hartnett of Greenbank Middle School, Ottawa. The research work was conducted at her home using funds awarded at the previous Ottawa regional Science Fair, 2000. At that event she won a first place in Junior Engineering for her work on optimum aperture size in pinhole photography. Jasmine Tait now attends the Grade 9 program at Sir Robert Borden High School in Ottawa.

Editor's Note: We are very happy to note that Ms. Tait submitted a brief summary of her project work that won the prize at the fair. Her full article is reproduced above.

Jasmine Tait- CWSF 2001
Recipient of the CAA Special Prize in Acoustics

la vague de son produit en réponse à le signal d'excitation (Schroeder chirp, 500 a 5000 Hz). Les résultats montrent que l'unité de Bigio était associé avec des niveaux plus forts d'amplitude et de puissance totale, et des niveaux plus haut d'amplitude harmonique et de réponse de pression. L'unité de Bigio peut être importante pour l'amélioration du timbre de la flûte, mais plus de travail doit être completé pour assurer que les changements en harmoniques sont logiques et pour décider si les différences en pression crée un flute qui est facile ou difficile à souffler.

BACKGROUND

British flute maker Robert Bigio has developed a stopper and crown (S/C) system to replace the traditional "cork" stopper-and-screw used in most flutes today (Fig.1). The stopper is cylindrical plastic (Delrin), 8 mm. long. The crown of Grenadilla wood has a hole drilled through its center. Both parts are held in place inside the flute headjoint with the pressure of O-rings. Bigio has eliminated the screw connecting stopper to crown, resulting in a longer cavity between the stopper and crown.

His innovation has been well-received internationally by flute players, some reporting a louder, richer, and faster response from their instruments. Much has been written about the importance of the stopper and crown as a tuning device, but there appears to be no published scientific studies which evaluate Bigio's invention, just discussion and speculation. Joseph S. Wisniewski, scientist and flute experimenter, has offered several interesting observations regarding the operation of the Bigio S/C: 1) The O-rings on the stopper act like a spring, sealing the tube but also allowing the stopper to vibrate under air pressure. Air in the tube between the stopper and crown also acts like a spring. The small hole drilled through the crown acts like an energy absorbing device or damper on the spring action of the stopper. 2) Changing the stopper and crown (to the Bigio S/C) would affect the partials more than the fundamental frequency of notes played. 3) The light mass of the Delrin stopper is comparable to the mass of the air column in the tube. Thus, if the mass of the stopper and the force of the springs are correctly adjusted, they could act like an extension of the flute.

PURPOSE

The purpose of the experiment was to find out whether there are observable acoustic differences in a standard test flute between the Bigio stopper and crown (Bigio S/C) and the Standard stopper and crown (Standard S/C) with respect to the following: 1) the relative loudness of the instrument over a wide range of test notes, 2) the relative amplitude of harmonics above the fundamental (affecting the timbre or "colour") for test notes, and 3) the pressure amplitude response of the flute headjoint when measured by a homemade impedance head with a piezodisk transducer.

HYPOTHESIS

1. The flute with the Bigio S/C will produce some notes with higher peak amplitudes and total power measures (dB) in frequency spectra than the Standard S/C. The greatest amplitude difference will occur in spectra of middle and higher frequency notes produced by the flute with the Bigio S/C.
2. The flute with the Bigio S/C will show some difference in the amplitude of harmonics in test notes.
3. There will be some observable difference between the two S/C units in the pressure amplitude response of the headjoint measured at the embouchure hole by my homemade impedance head .

PROCEDURE - MATERIALS

Sound Recording

A semi-professional flute (Gemeinhardt) with solid silver headjoint and B foot.

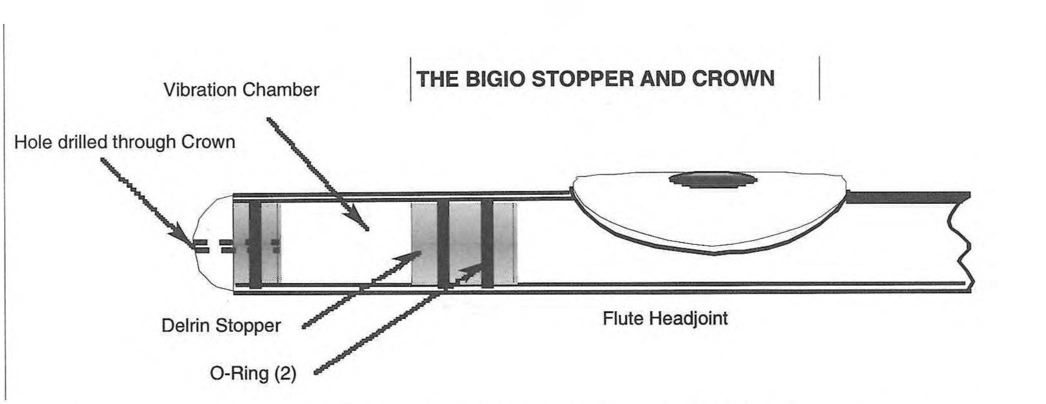

Figure 1. Diagram of a Flute Headjoint fitted with a Bigio Stopper and Crown.

An electret condenser microphone with flat response and wide frequency response 100-15000 Hz (Sony ECM - MS907) for computer recording of flute test notes.
A Pentium II computer fitted with SoundBlaster Awe 64 sound card for analogue-to-digital processing
A crown and stopper set made by Mr. Robert Bigio, flute maker, of London, England.

Impedance Measurement Head

Piezoelectric buzzer disk (Radio Shack buzzer 273-073).
A small electret, omnidirectional microphone with flat response, low impedance and wide frequency response (70 - 16000 Hz), (Optimus Tie Clip Microphone, # 33-3013).
13 mm. length of 3/4" cpvc plumbing pipe.
1/8" stereo mini plug for connecting the piezodisk to the computer sound card.
HANDI-TAK reusable adhesive used for sealing the impedance head to the lip plate.
Specifications for this impedance head came from a paper by physics professor P.L. Hoekje.

Fig. 2 shows my use of the head to measure pressure amplitude response of the flute to a test signal.

SOUND ANALYSIS SOFTWARE

1. **SpectraPlus,** version 2.32, FFT Spectral Analysis System, Sound Technology Inc., California, USA.
2. **G-Tune**, version 1.22. JHC Software, by James H. Clarke. www.jhc-software.com

PROCEDURE - METHOD

Sound Recording and Spectral Analysis of Test Notes

1. The position of each stopper in the headjoint was set at 17.3 mm from the center of the embouchure hole, and the tuning slide at 3 mm. These values are typical for many commercial flutes.
2. The assistant recorded a wide range of test notes (played by me) using SpectraPro software and saved individual samples as .WAV files on the hard drive.
3. The microphone was isolated from computer noise by a wall and pink foam insulation covering the doorway. The microphone distance from the flute player was kept at 1 m.
4. During recordings the assistant carefully tested the tuning accuracy of each note by referring to G-Tune software while I played. Test samples were accurate to within 3 cents of the note's fundamental frequency based on a scale of 440 Hz. I was told to replay notes out of tune. Microphone levels were maintained at a constant level using the Windows volume control. As the flute player, my eyes were blindfolded to prevent knowing which one of the stopper units was in use.
5. Measurements were made at a fairly consistent room temperature of 70-72 degrees F.
6. I. conducted a spectral analysis of each of the test notes using SpectraPlus software for both the Standard and Bigio S/C setups. Spectral analysis graphs were printed.
7. I entered measures of Peak Amplitude and Total Power for all test notes in a spreadsheet and represented these data in graphs.

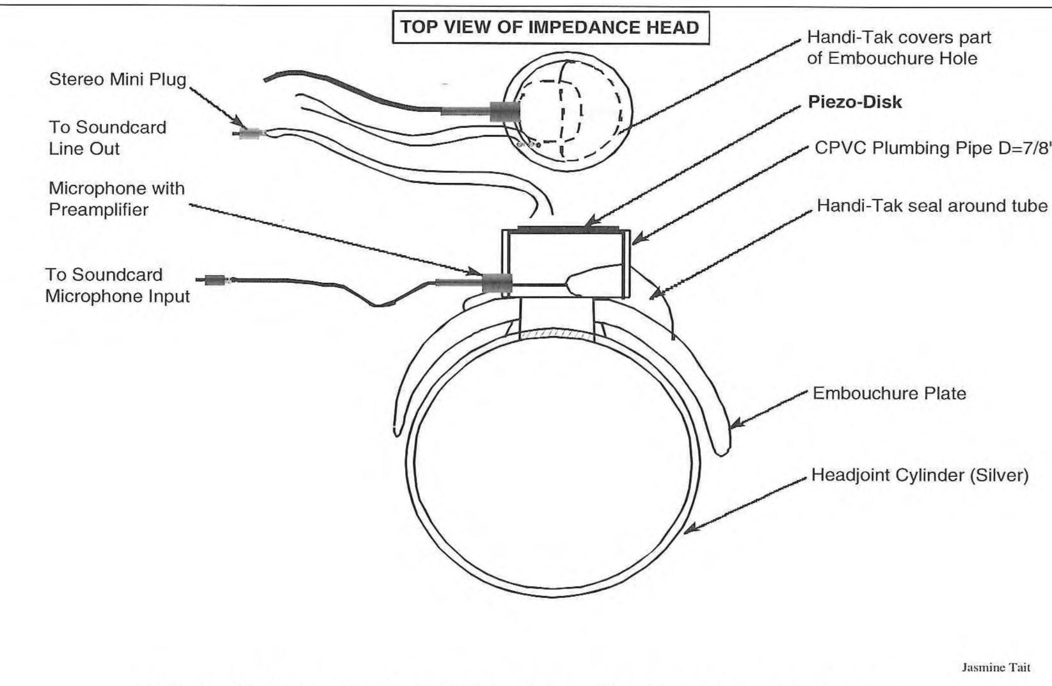

Figure 2. Cross Section of Impedance Head and Flute Headjoint.

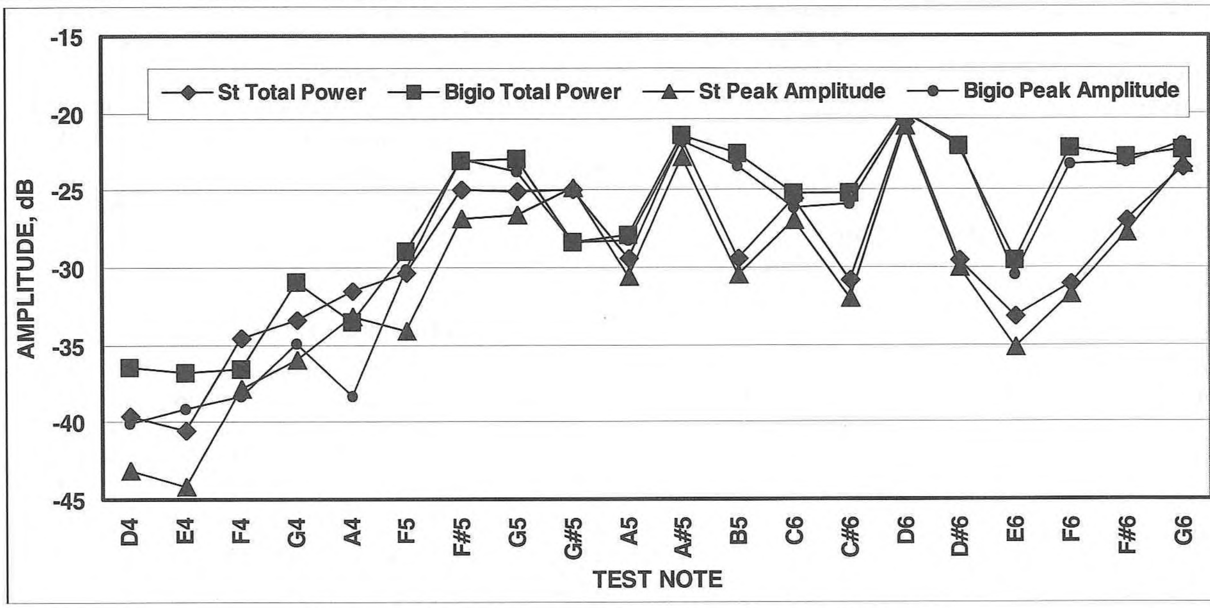

Figure 3. Total Power and Peak Amplitude by Test Note.

8. I made spectrograms of selected test note pairs to illustrate differences in the strength of frequencies over time as a colour spectrum.

Measuring Pressure Amplitude Response of the Headjoint

1. I made an impedance head to measure the pressure response of the flute sound wave coming from the embouchure opening in response to signal excitation.
2. I attached my impedance head to the lip plate using Hand-Tak re-useable adhesive and connected stereo mini plugs of piezodisk and microphone to the sound card "line out" and "mic. input", resp.
3. I attached the test headjoint to two adjustable PanaVises using Hand-Tak. The vises were isolated from vibration with sound-absorbing plastic feet.
4. I followed a simple software calibration procedure to compensate for the effects of sound card, piezodisk and microphone.
5. I loaded a Schroeder chirp test signal (500 to 5000 Hz) in SpectraPlus's signal generation utility and played it through the piezodisk for the two S/C setups.
6. I printed a spectral analysis graphs showing the headjoint pressure responses (dB) for both S/C setups. I looked for

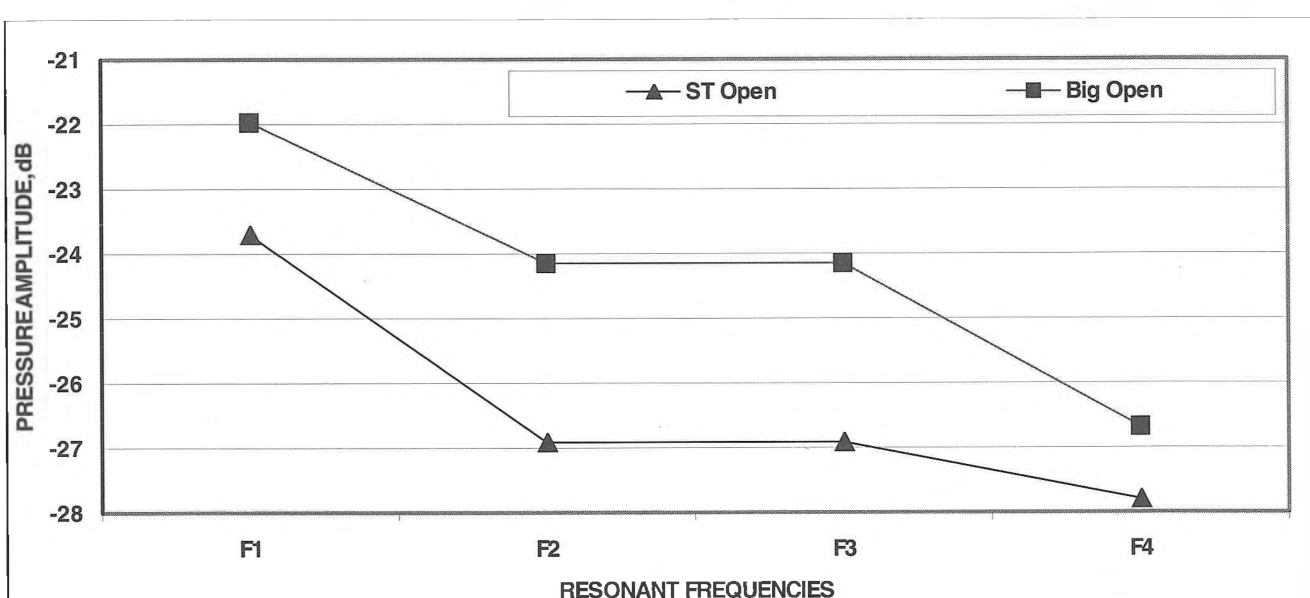

Figure 4. Impedance Measures of the Open Headjoint (Standard and Bigio S/C) for Minima Corresponding to the Headjoint's Resonant Frequencies.

any differences in the amplitude of frequency minima (4) in impedance spectra corresponding to resonant frequencies of the headjoint and I recorded their amplitudes in decibels.

RESULTS

FFT* Spectral Analysis of Recorded Notes

Total Power and Peak Amplitude

The Bigio S/C showed stronger levels of total power and peak amplitude (dB) in 17 of 20 test notes. Greatest differences occurred in frequencies for test notes above A#5 (Figure 3).

Harmonics Comparison

The Bigio S/C notes showed higher and stronger harmonics within middle and low octave notes.
Bigio notes showed highest harmonic amplitudes within low octave notes (D4, E4, F4, G4, A4 & F5).
Above F5, test note pairs showed fewer differences in harmonic amplitude (F#5, G5, G#5, A5. A#5, C6, C#6, & D6). Little significant difference was seen in the harmonic amplitude of upper octave notes above D6 (D#6, E6, F6, F#6, & G6).

FFT* Spectral Analysis of Pressure Response of Headjoint via Impedance Head

The headjoint with Bigio S/C setup showed slightly higher amplitudes at frequency minima in its pressure response to the test signal (Fig. 4). This difference was seen in tests of open and closed headjoints.

CONCLUSION

1. The Bigio S/C contributed to making a louder sound for most test notes. It was linked to stronger levels of amplitude and total power (dB).
2. In general, the Bigio unit was associated with higher harmonics within middle and lower octave notes. This may indicate that the Bigio S/C contributed to a richer flute sound than the Standard S/C in this frequency range.
3. As expected, there was a slight difference in pressure response between S/C setups as measured by the impedance head at the embouchure hole of the headjoint.

Importance: With further development and testing, the Bigio S/C could improve the performance of the flute by enhancing the colour of middle to lower octave notes, while boosting the volume of the instrument. However, work must be done to ensure that harmonic changes are more consistent throughout the flute's range of notes. I would like to see this type of stopper modified to become a digital sensor that could automatically vibrate in sympathy with the frequencies of each note. This could be applied to new digital flute technology. My research could be applicable to many other acoustical situations where damping systems help to minimize vibration caused by air flow past an opening, e.g. cargo doors and wheel wells of aircraft.

ACKNOWLEDGEMENTS

My father assisted me in sound recording of flute test notes while I played them.
Prof. Peter Hoekje, Dept. of Physics and Astronomy, Baldwin-Wallace College, Berea, Ohio gave information by telephone confirming the direction of my sound recording experiment and explaining what I would be measuring by mounting an impedance head on the flute's lip plate.

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