The Acoustics of the Echo Cornet

Robert Pyle

Introduction

An echo cornet is a cornet equipped with an additional valve downstream of the ordinary three valves. It diverts the air flow from a path through the normal bell to one through an echo bell, or echo attachment. Use of the echo bell substantially lowers the dynamic level and may also alter the timbre. In addition to the cornet, all types and sizes of valved brass instruments have been fitted with echo attachments, but the cornet was by far the most often so equipped.

The first attempts to devise an echo attachment for brass instruments may have been made in Europe in 1846 by Josef Kail[1] in Prague and in America in 1853 by the Dodworth family.[2] One date that can be established with certainty is 25 September 1859, when a Prussian patent was awarded to Friedrich Adolphe Schmidt of Cologne for an *Echo Bogen* to be fitted to a trumpet.

Virtually all European echo brasses were built with the Schmidt form of echo bell. While some American makers also used the Schmidt bell, others built alternative shapes. Figure 1 shows a drawing from Schmidt's patent application.

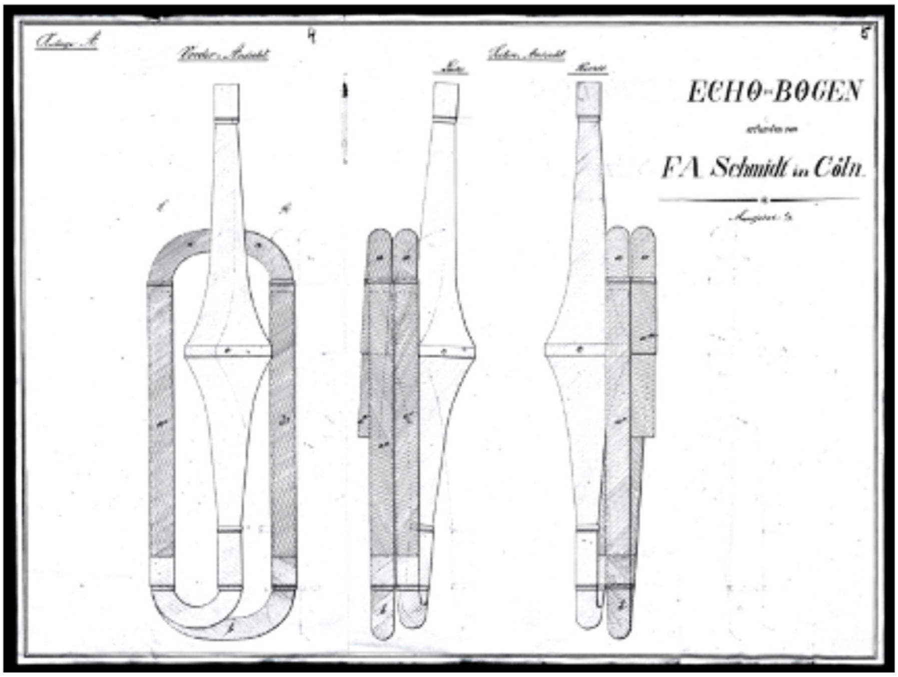

Figure 1: Drawing of an echo attachment for the trumpet, from a Prussian patent awarded to Friedrich Adolphe Schmidt in 1859 (GStA PK, I. HA Rep. 120 TD Technische Deputation für Gewerbe, Patente Schriften, Nr. S 146).

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Widespread use of the echo cornet may have begun in the United States. Rhodolph Hall[3] was very successful performing what he called *The Magic Echo* from 1861 onwards. He toured widely in the United States, from New England to California, and was well received in England. The heyday, if it can be so termed, of the echo cornet was roughly 1880–1920. Cornet soloists playing theme and variations on operatic tunes were very popular, and it seems likely that an echo cornet could have been used even if the music did not explicitly call for it. Interviews with two knowledgeable players and a search of pertinent literature revealed only two pieces specifically composed for echo cornet: *Alpine Echoes*, by Basil Windsor, written for the British cornetist Harry Mortimer, and *Fleurs des Alpes*, by Theodor Hoch, written for himself.

Basil Windsor, whose real name was Eli Smith, also composed under the names Allan Banks and Don Gomez. He may have written *Alpine Echoes* early in the twentieth century, but it was first published in 1929, by which time the manufacture of echo cornets had largely ceased.

Theodor Hoch was a German cornet and trumpet player who emigrated to the United States, where he played in a four-piece ensemble called the Mozart Symphony Club of New York. Hoch dubbed his echo cornet, made by C. G. Conn, an "Alpine Echo Horn." In a promotional brochure for the group for the 1901–02 season, a sample program included "Fleurs des Alpes, Duet, Alpine Echo Horn with Zither accompaniment." A review from a concert in Kingston, Ontario, read "Herr Hoch displayed the capabilities of an Alpine Echo Horn in an Idylle, one portion of the double instrument repeating or modifying in gentle far away tones the theme propounded by the other."[4]

While audiences of the day evidently warmed to the novelty of the echo cornet, it was not universally admired. In 1960, Reginald Morley-Pegge wrote of "that erstwhile military band horror, the echo-cornet."[5] Perhaps programs from British military-band concerts would reveal pieces explicitly composed for echo cornet.

This paper examines three echo cornets. One is a piston-valve cornet made in Paris by Courtois & Mille about 1882; the other two are both American-made rotary-valve instruments dating from the 1860s, one by D. C. Hall of Boston, Massachusetts, and the other by Isaac Fiske of Worcester, Massachusetts. These instruments were selected because they use three different forms of echo bell and because they are in excellent physical condition. In addition, a professional-quality B♭ trumpet made in 1981 by Vincent Bach serves as a yardstick to help evaluate the echo cornets. (The trumpet is in the Utley collection in the National Music Museum, number NMM 6787.)

Using the BIAS system,[6] acoustic measurements were made on these four instruments and several others. The current version of BIAS, used to measure the Hall and Fiske cornets, injects a sinusoidal sound (i.e., a pure tone), swept in frequency, into the closed mouthpiece cup and records the resulting sound pressure generated in the mouthpiece. An earlier version, used for the measurements on the Courtois & Mille and the Bach trumpet, injected a broadband noise-like signal instead of a sine wave.

The instrument's acoustic input impedance and impulse response are then calculated from the recorded sound.

Acoustic impedance is defined as[7] "At a specified surface, complex quotient of acoustic pressure by volume velocity through the surface." Here, the specified surface is the plane of the mouthpiece rim and in the BIAS system the acoustic volume velocity is injected into the cup from a small number of extremely narrow capillary tubes in parallel, driven at the other end by a loudspeaker. The acoustic pressure is sensed by a small microphone centered amid the capillary tubes. Acoustic pressure and volume velocity are measured in SI units,[8] the pressure in Pascals and the volume velocity in cubic meters per second. Acoustic impedance is measured in *acoustic ohms* (abbreviated Ω). In general, the volume velocity and pressure are not in phase, so the value of impedance is a complex number, or alternatively, a magnitude and phase. The BIAS system measures the impedance magnitude directly; the phase of the impedance is then calculated from its magnitude in a very complicated way using Fourier and Hilbert transforms. Since the input impedance of brass instruments typically ranges up into tens of millions of ohms, the ohm is an inconveniently small unit. Therefore, in this paper impedance will be measured in megohms, or millions of ohms (abbreviated MΩ).

Figure 2 shows the input impedance of the Bach trumpet for two fingerings: open (sounding the harmonics of *B♭*) and with valves 1+3 actuated (sounding the harmonics of a somewhat sharp *F*). The height of an impedance peak is determined by how much energy is lost at its resonance frequency. The greater the loss, the lower is the peak. For cornets and trumpets, below 900 Hz or so, most energy is lost within the instrument through friction and heat conduction along the walls of the tubing. Above 900 Hz, energy lost to sound radiation increases and adds to the losses within the instrument. Consequently, the heights of the impedance peaks drop off rapidly with increasing frequency. By 1500 Hz, the peaks have virtually disappeared.

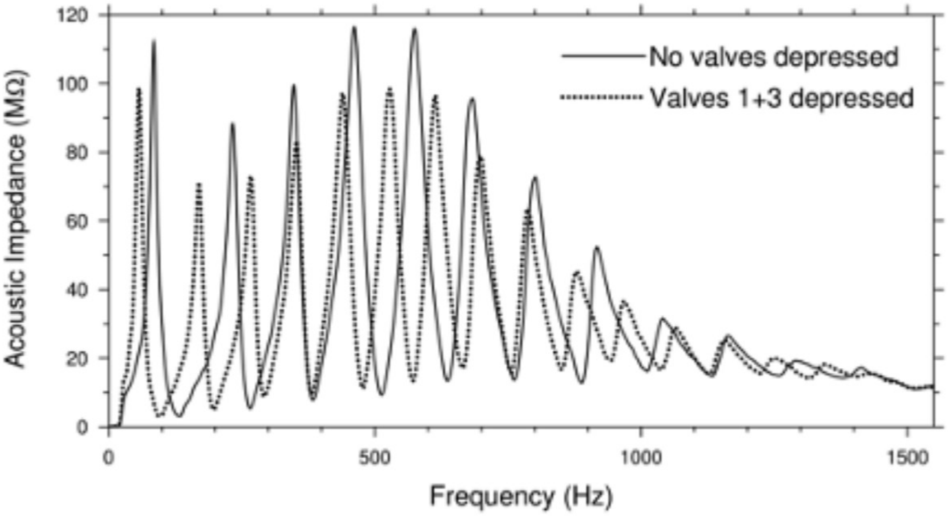

Figure 2: Acoustic input impedance of the Bach B♭ trumpet fingered open and with valves 1 and 3 depressed.

Note that the impedance peaks fingered 1+3 are all lower than their neighbors fingered open. This is caused by the loss of energy as the sound passes through the tubing added by the valves. Note also that if a curve passing through the peaks for a given fingering were drawn, marking the envelope of the peaks, it would be smooth. That is, no peak is greatly higher or lower than the average of its neighbors. In the 1950s the research department at C. G. Conn pioneered the use of acoustic impedance measurements in the study of brass instruments. They concluded that a smooth impedance peak envelope, like that seen on this trumpet, was one attribute of a good instrument.

Not surprisingly, the Conn researchers also found that on a good instrument the frequencies of the impedance peaks throughout the playing range should lie very close to a harmonic series based on the nominal fundamental of the fingering in use. That is, for the present trumpet, the peak frequencies with no valves depressed should be close to integer multiples of *B*♭, about 116.5 Hz (at a tuning frequency of a^1=440 Hz). This trumpet is quite good in this regard, but it should be noted that the first peak, which lies below the normal playing range, is more than five semitones flatter than the nominal fundamental, *B*♭. This very flat first resonance is characteristic of "narrow" instruments that end in rapidly flaring bells, such as trumpet, cornet, French horn, and trombone. The first peak on "wide" instruments, such as flugelhorn and euphonium, is also flat, but much less so.

The close adherence to a harmonic series affects the form of the impulse response. As noted above, BIAS computes the impulse response from the impedance, but it is easier to visualize the impulse response as the time history of the sound pressure that would be produced in the mouthpiece cup by the abrupt introduction of a small volume

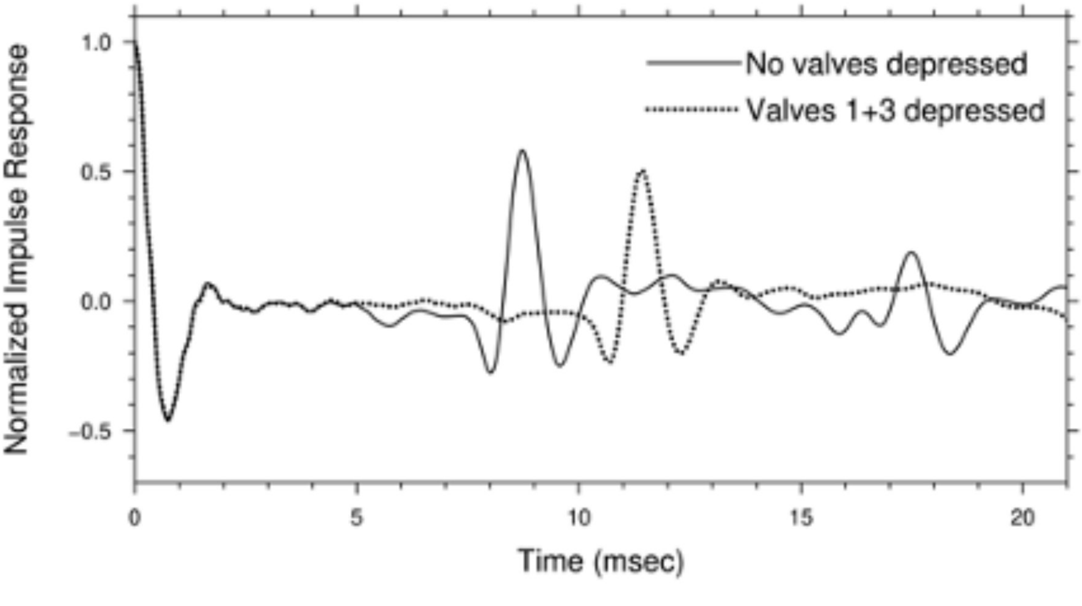

Figure 3: Impulse response of the Bach B♭ trumpet fingered open and with valves 1 and 3 depressed.

of air. The impulse response is presented here in a non-dimensional form, normalized so that the initial (and largest) value is 1.0.

Figure 3 shows the impulse responses of the Bach trumpet for the two fingerings. The two curves are identical out to about 5 msec, corresponding to the point where the air column for the 1+3 fingering diverges from the path with open fingering. The shorter air column shows a relatively narrow, relatively tall pulse peaking at 8.7 msec. The longer air column shows an almost identical (but lower amplitude) pulse at 11.4 msec. These are the times for sound to travel from the mouthpiece to the far end of the instrument and back. The shorter air column also shows a smaller, less well-defined pulse between 17 and 18 msec, corresponding to two round trips from mouthpiece to bell. The lower-amplitude pulse of the longer air column is of course another manifestation of the loss of energy in the added tubing.

Henceforth, the nominal fundamental will be defined as having a period equal to the time of the first major reflection in the impulse response, because that reflection is the signal with which the lip synchronizes its vibrations.

A well-defined peak like the one at 8.7 msec for the open fingering indicates that the frequencies of a number of strong resonances lie very close to integer multiples of the trumpet's nominal fundamental frequency, in this case 115 Hz (slightly flatter than *B*♭ if the tuning frequency is a^1=440 Hz). Each peak in the input impedance can be likened to a simple damped mass-spring resonator. The impulse response measurement effectively sets all of these into vibration simultaneously, after which the vibrations die away. The overall impulse response is the sum of the vibrations of the individual resonators. If the resonance frequencies are exact harmonics of the nominal fundamental, then in one period of the fundamental, the second resonator vibrates twice, the third resonator three times, the fourth four times, etc. Thus, at the period of the nominal fundamental, all the resonators add constructively, giving the observed peak in the impulse response. Small deviations from exact harmonicity would broaden and lower the peak because the various resonators would not be exactly in step. One out-of-tune resonator, like the lowest one at 85 Hz, has very little effect other than to alter the small ripples between the principal peaks.

A third type of graph is a "harmonicity diagram," intended to show something about the intonation of the instrument.

The frequencies of impedance peaks in the playing range determine the frequencies where the instrument plays most easily. The played frequency depends mostly, but not entirely, on the frequency of the nearest resonance. Strong resonances near integer multiples of the played frequency also affect the played pitch, to a degree depending on the dynamic level. For example, suppose the player sounds written middle C. There is a resonance very near the frequency of that note, and also strong resonances close to an octave, a twelfth, and two octaves higher. Now suppose that the actual "middle C" resonance frequency is somewhat flat, that the octave resonance is where it should be, that the resonance at the twelfth is a little sharp, and that the double-octave ("high C") resonance is rather flat. At very soft playing levels, the instrument will be dominated by the middle C resonance, and it will play flat unless the player can lip the pitch up sufficiently. With increasing dynamic level, the resonances at the octave and the twelfth become progressively more involved and the played pitch will rise. At the very loudest playing levels, perhaps the high C resonance will try to bring the pitch down a bit.[9]

The harmonicity diagram shows the departure in cents[10] of the resonance frequencies from exact harmonics of the nominal fundamental. Unfortunately, it has nothing quantitative to say about the interaction of several resonances as just described. Only resonances between 200 and 1200 Hz are plotted since those are the ones affecting the intonation in the normal playing range of a trumpet or cornet.

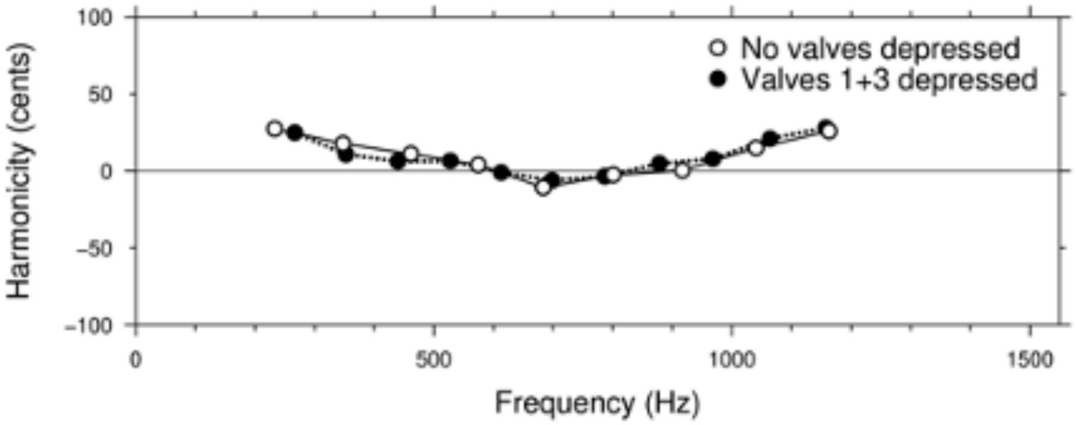

Figure 4: Harmonicity diagram for the Bach B♭ trumpet fingered open and with valves 1 and 3 depressed. If the resonance frequencies followed a harmonic series exactly, all the dots would lie on the 0 cents line.

It is interesting that the additional tubing introduced by the valves has almost no effect on the intonation pattern. The spread, top to bottom, is 38 cents for the open fingering, 34 cents for fingering 1+3. It appears that this trumpet, at least when softly played, will be slightly flatter around 700 Hz (the written G at the top of the staff) than at either higher or lower pitches.

For each of the three echo cornets studied here, these three graphs have been generated from BIAS measurements. The measurements compare the normal bell with the echo bell, but only for one fingering: no valves actuated (other than the fourth valve that switches bells).

The Courtois & Mille echo cornet

This Courtois & Mille cornet, seen in Figure 5, is typical of piston-valve cornets equipped with the Schmidt bell. With minor variations in the layout of the tubing, similar instruments were made in France, England, and the United States. It seems likely in this case that a conscious effort was made to hide the presence of the echo bell.

The player's left hand would cover much of the echo bell (upper photo). The major bend in the echo bell follows the "shepherd's crook" bend in the normal bell almost perfectly, and viewed from the right (lower photo), the instrument, when played, would be nearly indistinguishable from a cornet without an echo bell. (Throughout this article, "left" and "right" are from the viewpoint of the player.)

Figure 5: Echo cornet by Courtois & Mille, Paris, ca. 1882, crooked in B♭. (NMM 6856. Photo: Mark Olencki © National Music Museum, The University of South Dakota, Vermillion.)

Figure 6: Another view of the echo cornet by Courtois & Mille. The fourth valve, more clearly seen from this angle, is to the left of the first valve and below the normal bell. (NMM 6856. Photo: Mark Olencki © National Music Museum, The University of South Dakota, Vermillion.)

Figure 7 shows the contours of the normal and echo bells, drawn along the same axis at the same distance from the mouthpiece. The air column through the echo bell is 158 mm longer than the path through the normal bell. The echo bell has a short tuning slide of its own, visible in the upper photo of Figure 5 to the left of the lower part of the second and third valves. This is used to match the playing pitch of the two bells. There is also a small telescoping tube at the end of the echo bell that can extend its air column even further. Pulling this tube out changes the timbre of the echo bell slightly, but does not alter the playing pitch. In other words, it is not a tuning device. One would think that extending the length of a brass instrument would always lower the pitch, so how is it possible that the echo bell plays at the same pitch as the normal bell? This can be understood by comparing the two bells, both in the frequency domain (input impedance) and the time domain (impulse response).

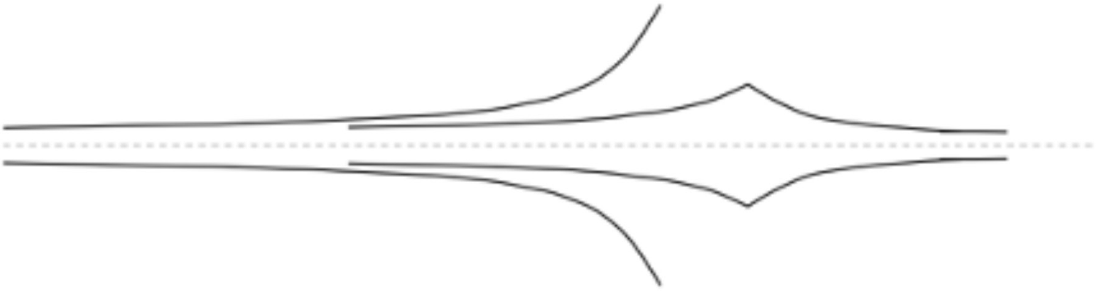

Figure 7: Comparison of the normal and echo bell contours of the Courtois & Mille cornet.

First, consider the input impedance, shown in Figure 8. The echo bell has in fact lowered the frequencies of *all* the resonances. However, in the normal playing range (about 200–900 Hz), the impedance of the echo bell agrees very well with the impedance of the normal bell, except that it is the *third* peak of the echo bell that lines up with the *second* peak of the normal bell, and so on. Below the playing range, the echo bell has an "extra" impedance peak. The lowest peak of the normal bell has apparently been split in two, bracketing the first peak of the normal bell. The added peak, between the first and second impedance peaks of the normal bell, has been aptly termed a *parasitic resonance* by Sluchin and Caussé.[11] Such a parasitic resonance occurs with several types of mute, and does not cause problems unless the instrument is played near the frequency of the parasitic resonance. The cornet is never asked to play that low, but certain low notes on the trombone become difficult to control with a straight mute.[12] Since the echo bell radiates less energy than the normal bell, its high-frequency peaks are taller than those of the normal bell.

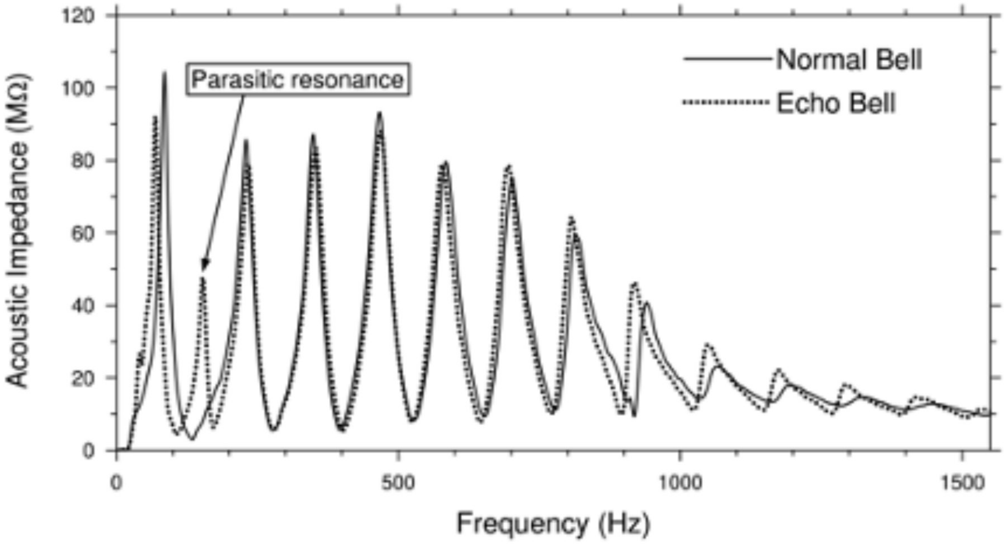

Figure 8: Acoustic input impedance of the Courtois & Mille cornet.
It is pitched in B♭ and no valves are depressed.

Next, consider the impulse response, shown in Figure 9. Both bells show a peak at about 8.5 msec, or one period of the fundamental B♭ of the instrument. A lesser peak is also visible at 17 msec, or two periods.

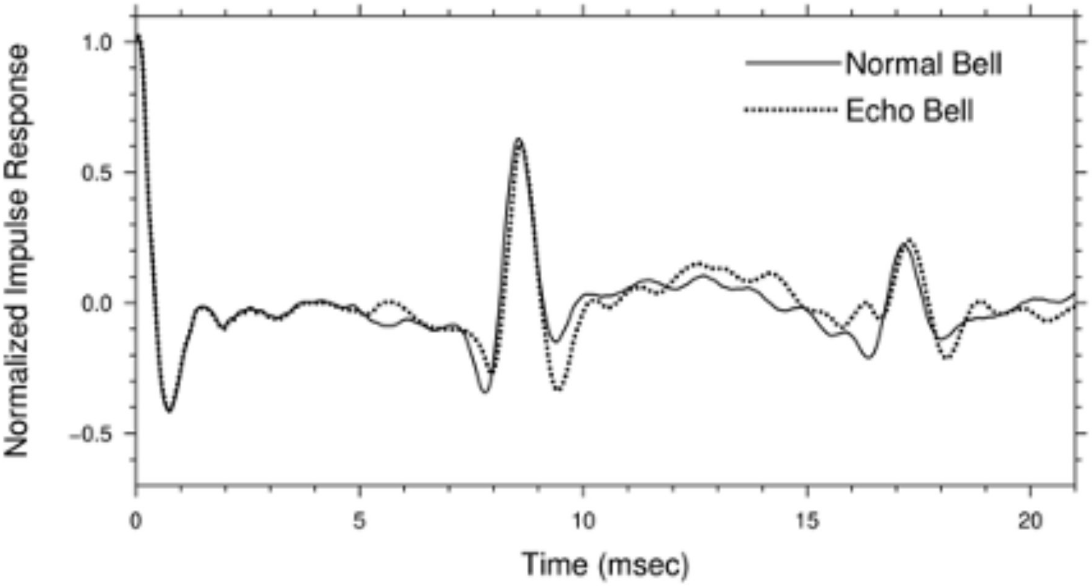

Figure 9: Impulse response of the Courtois & Mille cornet, crooked in B♭ with no valves depressed. It appears that the echo bell was tuned very slightly flatter than the normal bell when this instrument was measured.

The 8.5 msec peak in Figure 9 corresponds to the time sound takes to make one round trip from the mouthpiece to the *acoustic end* of the instrument. The acoustic end is thus defined as the point from which the reflected pulse *appears* to have come. It is a small distance beyond the physical end of the instrument. That distance is termed the *end correction*. Acoustic horn theory can help locate the acoustic end of an instrument.

The differential equation describing sound propagation in a tube of variable cross section is often called the Webster horn equation, after A. G. Webster.[13] Webster was by no means the first person to derive the horn equation. More importantly, he *was* the first to define acoustic impedance.[14] The horn equation is only approximate, based on the assumption that sound wavefronts within the horn are plane cross sections of the horn. It also neglects energy losses along the wall of the tube due to viscosity and heat conduction. These assumptions do in fact have real-world musical consequences in brass-instrument acoustics. Nonetheless, solving the horn equation suffices to locate the acoustic end of an instrument reasonably well.

The horn equation reveals that a wave of sound pressure traveling through a horn is partially reflected wherever the slope of the horn contour changes. The greater the change in slope, the greater the reflection. This means that there is continuous partial reflection where the contour curves, as in a cornet bell. The total reflected wave is the sum of all the partial reflections.

For a bell that flares very rapidly near the rim, the acoustic end is approximately where its diameter would become infinite if the contour were continued smoothly. The most common examples of this type of bell are trumpet, cornet, and trombone. For the Schmidt echo bell, the acoustic end is at the cusp where the bell contour abruptly changes from expanding to contracting. If one looks at Figure 7, it is easy to believe that the two acoustic ends thus found from the horn equation are at the same distance from the mouthpiece. Of course, that should already have been clear from the impulse response.

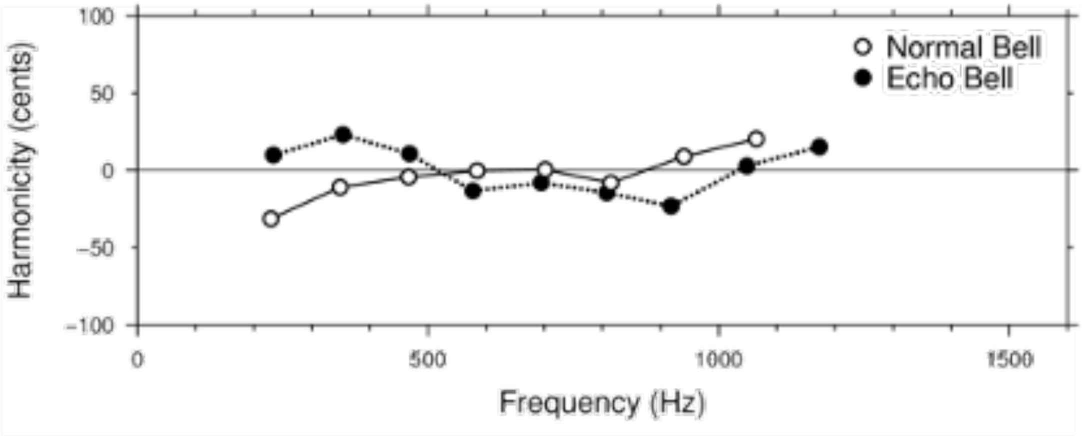

Figure 10: Harmonicity diagram for the Courtois & Mille cornet.

How closely do the resonance frequencies follow a harmonic series? Figure 10 is the harmonicity diagram for the Courtois & Mille. The top-to-bottom spread from exact harmonicity is 52 cents for the normal bell and 46 cents for the echo bell. This is a greater spread than that of the Bach trumpet, but the principal reflection is still very well defined.

The D. C. Hall echo cornet

Figure 11 shows two views of the D. C. Hall cornet. This instrument differs from the Courtois & Mille in the shape of the echo attachment and in the use of J. Lathrop Allen's flat-windway rotary valves rather than Périnet piston valves. The air passage through an Allen rotary valve is not circular, but is expanded along the length of the rotor and reduced in the radial direction, while maintaining the cross-sectional area of the cylindrical valve slides. This allows the rotor to be reduced in diameter. Allen and his successors claimed that the smaller-diameter rotor gave a faster valve action.

The fourth valve can be used as an ordinary valve (to lower the pitch a perfect fourth), as shown in the upper photo of Figure 11. Notes normally fingered 1+3 or

1+2+3 are quite sharp; using valve 4 as an ordinary valve with alternate fingerings 4 and 2+4 corrects the intonation quite well. While the fourth valve could also be used to extend the low register, this was probably not often done.

Figure 11: Echo cornet by D. C. Hall, Boston, ca. 1865. When used conventionally, the fourth valve lowers the pitch five semitones. The instrument is shown pitched in C; the two crooks are used to lower the pitch to B♭ or A. (Owner: Steven Ward; photo: Robb Stewart)

If the inner (narrower) slide on the fourth valve is removed, the echo bell can be inserted in its downstream leg as in the lower photo. Upon actuating the fourth valve, the air then passes through the outer (wider) fourth-valve slide and thence through the echo bell. The outer tuning slide of the fourth valve can be used to tune the echo bell to match the pitch of the normal bell.

D. C. Hall was leader of the Boston Brass Band from 1853 to the 1880s, and his younger brother Rhodolph became second leader. Both brothers were renowned soloists. After learning brass-instrument making from Allen, D. C. Hall started his own company in 1862. Hall's company made a complete set of echo brass instruments for the Boston Brass Band, including even a B♭ bass. The echo bells were all of the same general design as the bell here, scaled in size appropriately for the instruments. The D. C. Hall company, under that name, existed only from 1862–66, so the present instrument must date from that period.

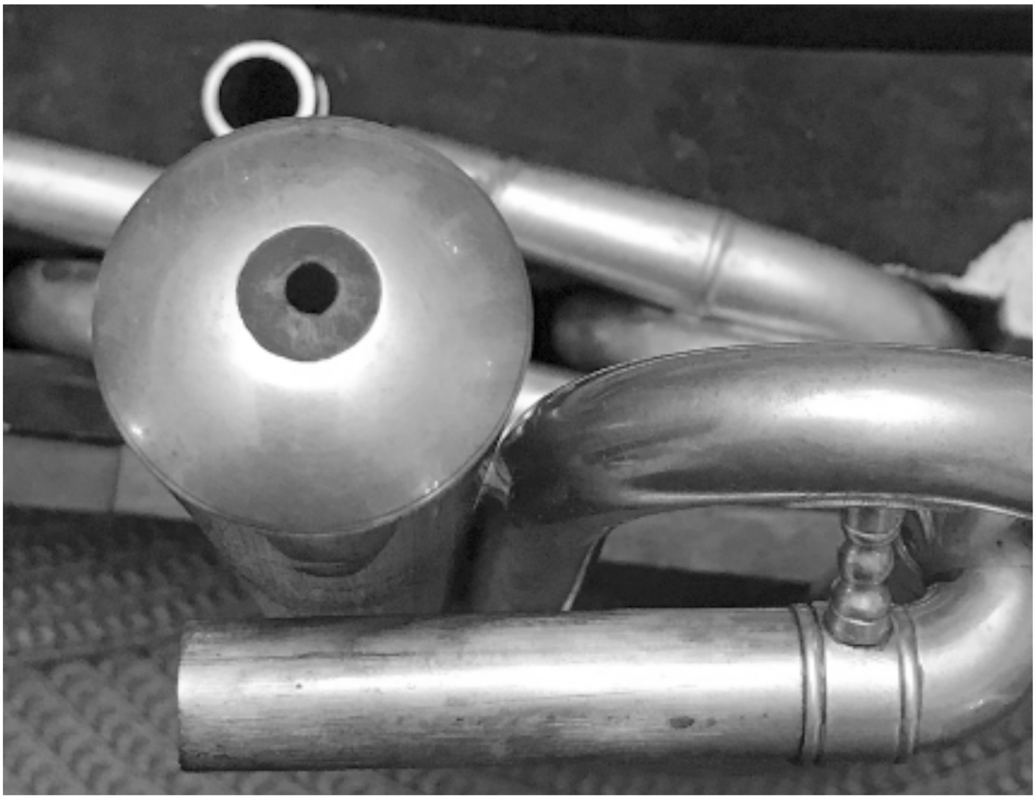

Figure 12: Closeup of the end of the Hall echo bell. The dark area in the center is a wood insert. The central hole through the wood is about 3.2 mm in diameter and 19 mm long. (Photo: Steven Ward)

Like the Courtois & Mille, the acoustic input impedance of the Hall shows a parasitic resonance for the echo bell, albeit a weaker one. In the playing range, the impedance peaks of the two bells, both in frequency and height, do not match each other nearly as well as for the Courtois & Mille.

The resonance frequencies of the Hall do not follow a harmonic series as closely as those of the Courtois & Mille. The greater inharmonicity compared to the Courtois & Mille manifests itself as a "less tidy" impulse response (Figure 14). The various resonances do not add cooperatively enough to produce a single strong peak as they do in Figure 9. Without detailed measurements of the cornet's dimensions, the location of the acoustic end of the echo bell cannot be determined with any certainty, but it is

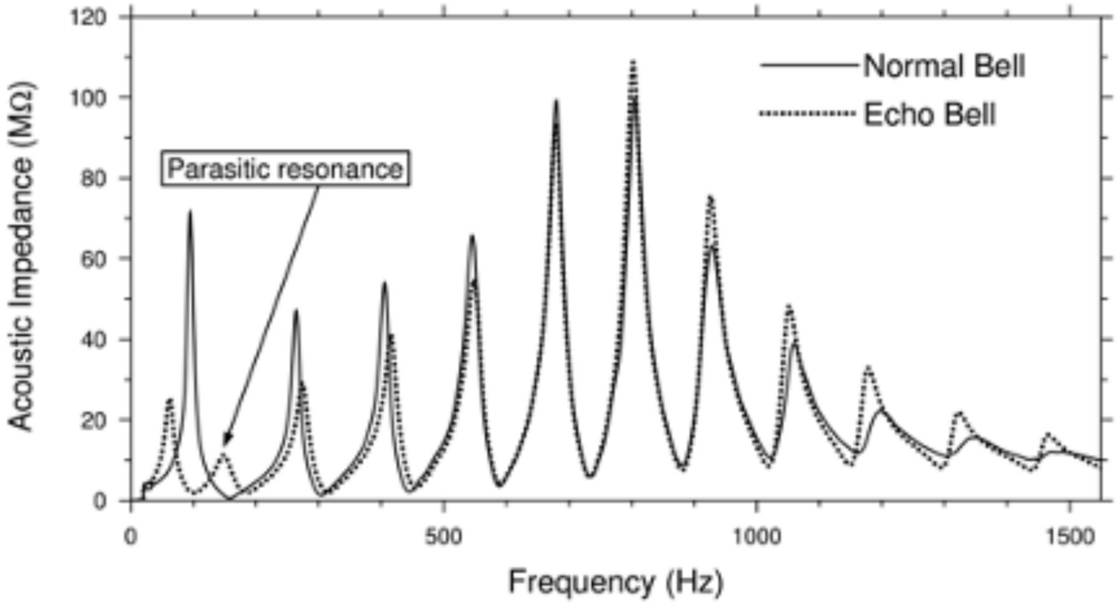

Figure 13: Acoustic input impedance of the Hall cornet, tuned to C, no valves depressed.

likely to be where the air stream contracts abruptly entering the wooden insert at the end of the echo bell, shown in Figure 12.

The spread in the harmonicity diagram Figure 15 is 58 cents for the normal bell and 98 cents for the echo bell. This is a much greater departure from exact harmonicity than in the Courtois & Mille. It is notable that above 400 Hz the echo bell resonances grow progressively flatter. Close examination of the impedance (Figure 13) shows this also.

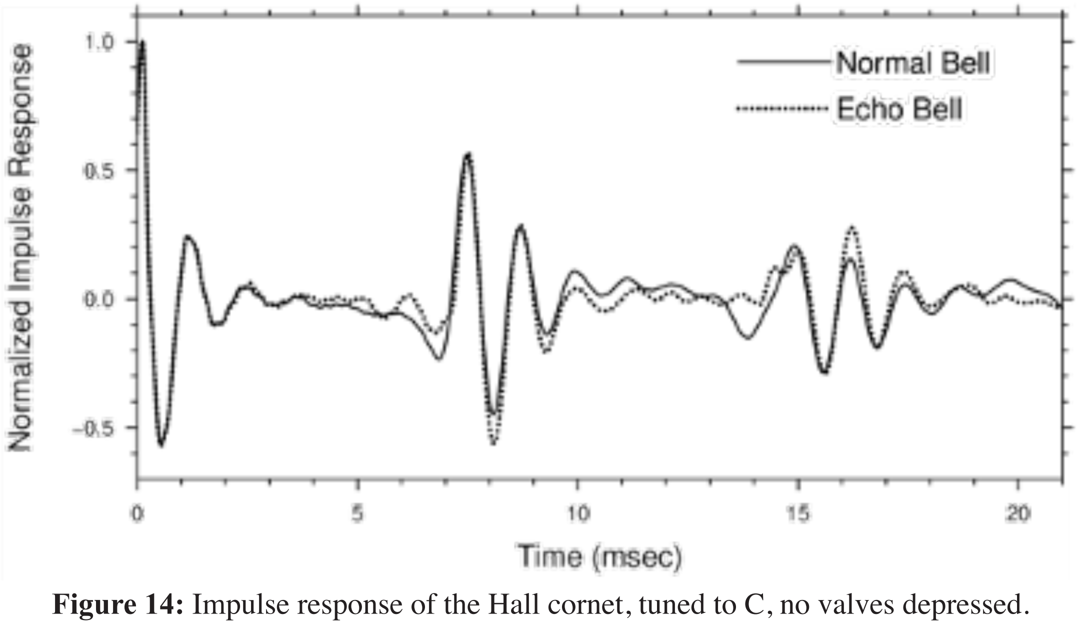

Figure 14: Impulse response of the Hall cornet, tuned to C, no valves depressed.

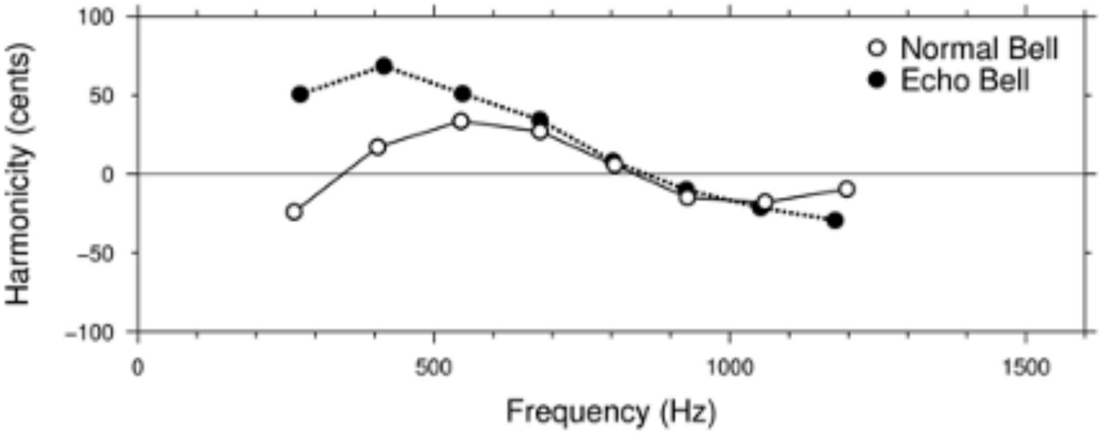

Figure 15: Harmonicity diagram for the Hall cornet.

The Isaac Fiske echo cornet

The last cornet to be considered was made by Isaac Fiske. Figure 16 shows it from the left, with and without the echo attachment inserted. Like the Hall cornet, the fourth valve functions either to route the air through the echo bell, or as a normal valve, in this case lowering the pitch a semitone when the echo bell is not in use. As a second semitone valve, it would greatly simplify otherwise awkward trills, such as semitone trills between written *f*^{2} and *f*♯^{2} or between written *d*^{2} and *e*♭^{2}.

Figure 17 shows the instrument from the right side. Instead of using interchangeable crooks to change its pitch, this cornet is equipped with two mouthpipes and two tuning slides. With the appropriate choice of mouthpipe and tuning slide, it can be tuned to C or B♭. The photo was taken in 2002, at which time the mouthpiece receiver shank shown in the longer mouthpipe was soldered in place. It was clearly not original, since it was silverplated (probably on brass), while the instrument itself is made entirely of nickel silver. This later addition has since been removed and replaced with a longer removable shank similar to the one seen below the cornet to the left of the short tuning slide.

The engraving on the bell garland reads simply, “Isaac Fiske, Maker, Worcester, Mass.” Eliason dates this instrument prior to 1867 because after that Fiske was in the habit of inscribing his patent numbers on his instruments.[15] In his 1861 catalog, Fiske describes in words how a cornet could optionally be equipped with a fourth valve and an echo attachment, but no drawing of such an arrangement appears in any Fiske catalog.

In 1868, Fiske was granted U. S. Patent No. 74331 for an improved construction of rotary valves. Figure 18 is a cross-sectional drawing of two such valves. This instrument uses the form of valve rotor described in the patent, but the tubing joining the valves does not follow the perfectly circular arc shown in the figure. Each rotor is

Figure 16: Echo cornet by Isaac Fiske, Worcester, ca. 1862, as seen from the left. The upper photo shows the fourth valve configured as a conventional semitone valve. The disassembled echo attachment is below the instrument. The echo bell is tuned where the flaring part on the left telescopes onto the output end of the part that plugs into the fourth valve. The lower photo shows the two parts of the echo bell connected to each other and attached to the fourth valve. (Owner: Steven Ward; photo: Robert Pyle)

made in two halves, each half with a channel of semicircular cross section cut into its face. The two halves are then brazed together, face to face, so that the two channels form a duct of accurately circular cross section that passes through the interior of the rotor. The rotors on the present cornet resemble the drawing and the brazing seams are clearly visible.

Figure 17: The Fiske echo cornet as seen from the right. The mouthpiece shank and the longer tuning slide are inserted into the longer mouthpipe to tune the instrument to B♭. The tonality can be changed to C by using the shorter tuning slide and the shorter mouthpipe. (Owner: Steven Ward; Photo: Robert Pyle)

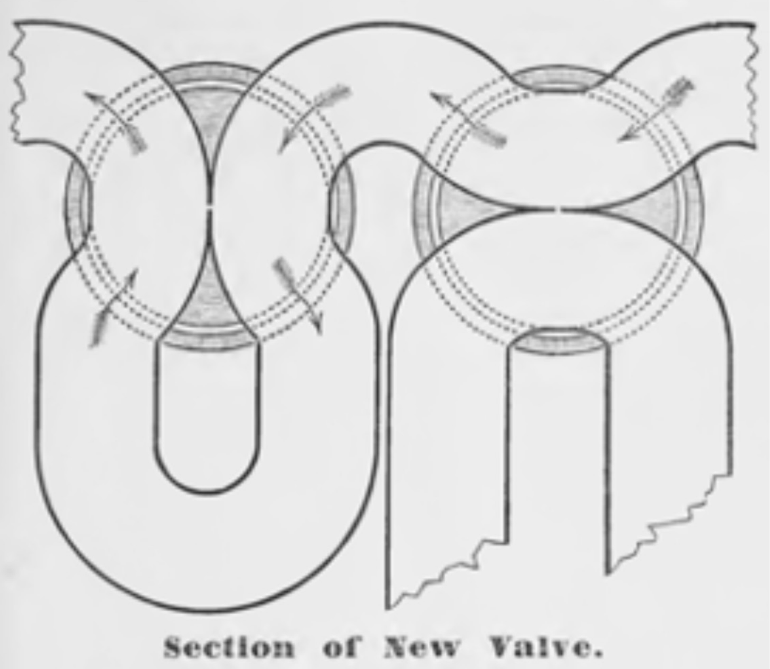

Figure 18: A drawing of Fiske's patented rotary valve construction taken from his 1868 catalog.

Fiske touted the virtues of his valve, claiming that valved notes and open notes on his instruments were matched in tone color and ease of playing, and that this was untrue with other forms of rotary valve. He greatly disparaged all other rotary valves, clearly taking aim at Allen valves, but of course without actually naming Allen or any other makers.

The Fiske echo attachment differs substantially in form from those of the Courtois & Mille or the D. C. Hall. Figure 19 is a closeup view of the two parts of the Fiske echo bell. There is a pronounced constriction at the upstream end of the first part of the attachment, where it plugs into the fourth valve. The internal diameter of the constriction is about 6.4 mm and it extends perhaps 12 mm into the tubing. The second part is a mildly flaring expansion that slides over the output end of the first part, thus allowing the echo attachment to be tuned. It ends in a bulging cap perforated with a hole whose diameter is about 11.8 mm.

Figure 19: Isaac Fiske echo attachment. Note the constriction at the upstream end. (Photo: Robert Pyle)

Figure 20 shows the input impedance of the Fiske. This echo bell does not produce a parasitic resonance. The tuning with the echo bell is “stretched” compared to the normal bell, flatter at low frequencies, sharper at high frequencies.

The impulse response (Figure 21) is similar to that of the Hall in that the principal reflection at 8.8 msec is not a single well-defined peak like the Courtois & Mille. The divergence of the echo and normal bells at about 5 msec marks the location of the fourth valve where the two air paths separate. The ‘N’ shape of the echo bell signal just after 5 msec is consistent with a partial reflection at the constriction shown in Figure 19, positive-going where the bore contracts, then negative-going at the subsequent

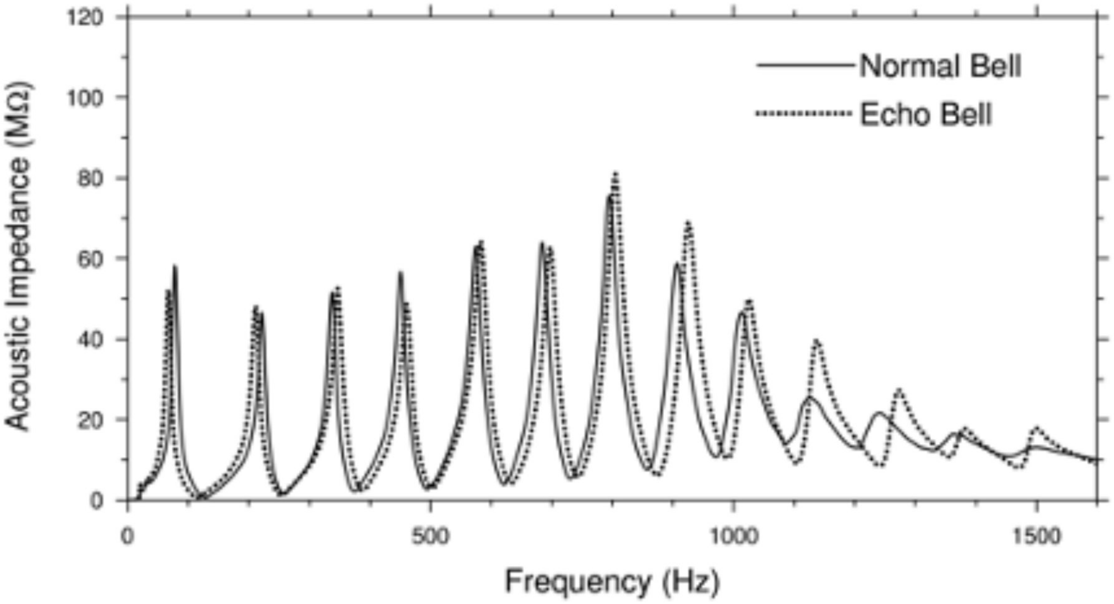

Figure 20: Acoustic input impedance of the Fiske cornet, tuned to B♭, no valves depressed

expansion. A nearly identical pattern appears at about 14 msec, corresponding to the same partial reflection during the second round trip through the instrument.

For resonances above 300 Hz the harmonicity of the Fiske cornet is quite good. The two bells match each other reasonably well. In that frequency range, the resonances of the normal bell lie within 28 cents of a harmonic series, those of the echo bell within 23 cents. The "middle C" resonances tell a very different story. The normal bell resonance is 35 cents flat and the echo bell is much flatter yet, 149 cents below where it "ought" to be.

Summary

How do these three instruments compare? Two players who have played the Fiske and at least one echo cornet with a Schmidt-style echo bell were interviewed. Both report that the timbre of the Schmidt bell is more nasal than that of the Fiske. The Fiske echo bell sounds very much like the normal bell but much softer.

One of these players has also played the Hall and said that its echo tone quality is very like that of the normal bell but the dynamic level is even softer than the Fiske.

As to intonation, all three echo bells are reasonably well in tune in the middle and upper registers. In the low register, both players found (written) middle C on the Fiske to be noticeably flat on the normal bell and disastrously flat (more than a semitone) on the echo bell. This is certainly consistent with the harmonicity diagram, Figure 22. The tuning on the Hall for both bells tends to be a bit "stretched," flat in the low register and sharp in the high register. The two bells tracked each other very closely. Based

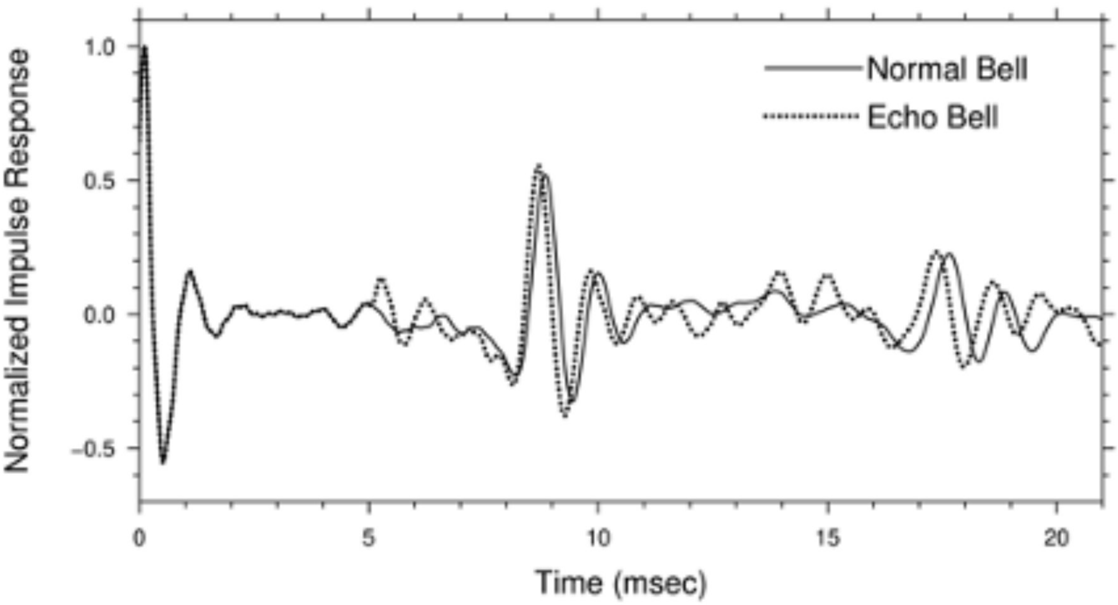

Figure 21: Impulse response of the Fiske cornet, tuned to B♭, no valves depressed. It appears that the echo bell was tuned slightly sharper than the normal bell when this measurement was made.

on the acoustic measurements and the playing properties of similar instruments, the Courtois & Mille appears to be the best of these three instruments overall.

The three configurations of echo bell analyzed here are not the only possibilities. Figure 23 shows an echo cornet signed by Adalbert Riedl (born in Bohemia in 1854, emigrated to America in 1880, died in 1935). It is likely that the cornet was an import to which Riedl added his own design of echo bell. As on a Harmon mute, the tube projecting from the echo bell slides in or out or can be removed completely. It alters the echo timbre but not the pitch. The intonation and response in the low register are reported to be better than on Schmidt-style bells.

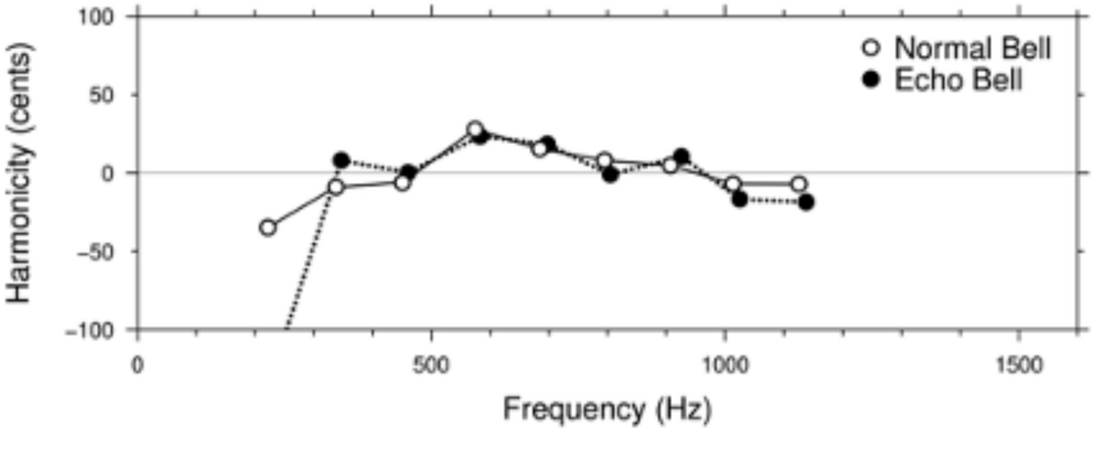

Figure 22: Harmonicity diagram for the Fiske cornet. The "middle C" resonance of the echo bell is 149 cents flat and thus below the range shown on the plot.

Figure 23: An echo cornet by Adalbert Riedl with yet a different form of echo bell. (Owned and photographed by Robb Stewart.)

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The author is obliged to several people for their assistance. Sabine Klaus contributed much useful historical information, performed all the acoustical measurements, and provided the photographs of the Courtois & Mille. Christiane Brandt-Salloum of the Geheimes Staatsarchiv Preußischer Kulturbesitz, Berlin, gave permission to show the drawing from the Schmidt patent. Steven Ward, the current owner of the Hall and Fiske cornets (and several other echo cornets), made his instruments available for testing, and provided insightful comments from the player's point of view. Robb Stewart supplied the photos of the D. C. Hall and the Riedl. His website also had other useful information. Robinson Pyle played on and evaluated the Fiske and an inexpensive modern echo cornet with a Schmidt-style bell. Chris Belluscio assisted in the search for compositions written specifically for the echo cornet.

Notes

[1] C. Sachs, *Real-Lexicon der Musikinstrumente*, 2nd edn., revised and enlarged (New York: Dover, 1964), s.v. *Echomaschine*. Kail was the first teacher of valved trumpet and horn at the Prague Conservatory and was an early performer on both instruments. He was the inventor or co-inventor of twin-piston and rotary valves. His inspiration for the rotary valve is said to have been the tap on a beer keg.

[2] Robert E. Eliason, "Rhodolph Hall: Nineteenth-Century Keyed Bugle, Cornet, and Clarinet Soloist," *Journal of the American Musical Instrument Society* 29 (2003): 3–71. On page 49, Eliason quotes a paragraph from *Dodworth's Brass Band School*, by Allen Dodworth, listing various improvements claimed by the Dodworths, that ends with "the movable embouchure mouthpiece; the echo, &c., &c.".

[3] Ibid., 46–54.

[4] Scans of the four pages of the brochure may be found at https://digital.lib.uiowa.edu/islandora/object/ui%3Atc_55048_55046

[5] Reginald Morley-Pegge, *The French Horn* (New York: The Philosophical Library, 1960), 108.

[6] BIAS, which stands for Brass Instrument Analysis System, is a combined hardware-software system to make acoustic measurements on brass instruments. It was developed by the Institut für Wiener Klangstil at the Universität für Musik und darstellende Kunst in Vienna and is now manufactured and sold by ARTIM www.artim.at

[7] American National Standard for Acoustical Terminology, ANSI/ASA S 1.1-2013. A "user-friendly" description of acoustic impedance as it relates to brass instruments can be found at https://newt.phys.unsw.edu.au/jw/z.html

[8] From Wikipedia, "The International System of Units (SI, abbreviated from the French Système international (d'unités) is the modern form of the metric system. It is the only system of measurement with an official status in nearly every country in the world."

[9] The involvement of multiple resonances in the production of a single tone was first extensively analyzed by Henri Bouasse in *Instruments à Vent*, 2 vols. (Paris: Librairie Delagrave, 1929–30; rpt. Paris: Blanchard, 1986). The phenomenon is well explained by Arthur H. Benade in *Fundamentals of Musical Acoustics*, 2nd, revised edn. (New York, Dover, 1990) in Chapter 20, especially Section 20.2. In an earlier book, *Horns, Strings, and Harmony* (Garden City, NY: Anchor Books, 1960; rpt., New York: Dover, 1992), 25, Benade has this to say about Bouasse, "He is not nearly as well known as he deserves to be, although the cause lay partly within his control. He was a peppery, combative sort of man, who never hesitated to say what was on his mind, and he often said it in a way that made enemies. Because of his controversial approach to things he managed to alienate the editors of several journals, and ended up having to publish all his work in book form, printed in small editions and not widely distributed."

[10] The cent is a convenient unit to measure small differences in pitch. There are 100 cents in an equal-tempered semitone and thus 1200 cents in an octave. Under ideal conditions, in the octave from 1000 to 2000 Hz, the smallest perceptible pitch change for sequentially presented tones is about 4 cents. Smaller differences can be detected for tones presented simultaneously because beats can be heard. As an example of small but noticeable differences between similar intervals, an equal-tempered major third (frequency ratio) is 400 cents, while a just major third (frequency ratio 5:4) is 386.3 cents, and a Pythagorean major third (frequency ratio 81:64) is 407.8 cents.

[11] Benny Sluchin and René Caussé, *Sourdines des Cuivres* (Paris: Editions de la Maison des Sciences de l'Homme, 1991).

[12] D. Murray Campbell, Joël Gilbert, and Arnold Myers, *The Science of Brass Instruments* (New York: Springer, 2020), Section 4.5.

[13] A. G. Webster, "Acoustical Impedance, and the Theory of Horns and of the Phonograph," *Proc. Natl. Acad. Sci.* (U.S.) 5 (1919) 275–82. Webster taught at Clark University in Worcester, Massachusetts, from 1892 until his death. Tragically, he committed suicide in 1923, leaving a note that read, in part, "physics has got away from me and I cannot come back."

[14] Edward Eisner, "Complete Solutions of the 'Webster' Horn Equation," *Journal of the Acoustical Society of America* 41 (1967): 1126–46. Eisner details the early history of the horn equation. It was first derived independently in the mid-eighteenth century by Leonhard Euler, Daniel Bernoulli, and Joseph-Louis Lagrange, friends (and rivals) who corresponded regularly with each other. Eisner suspects that Bernoulli was the first to formulate the equation, perhaps as early as the 1740s, but Lagrange published first in 1761, three years before Bernoulli. Since the eighteenth century, the Bernoulli family has produced more than two hundred professional mathematicians in Switzerland. Readers of this journal may be familiar with the Bernoulli collection of brass instruments bequeathed to the Basel Musikmuseum by the clergyman Wilhelm Bernoulli of that family.

[15] Robert E. Eliason, "More on Echo-Cornets," *Journal of the American Musical Instrument Society* 30 (2004): 193–96.