"Put a Sock in It!" Mutes for Musical Horns

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Introduction

"Take the A Train" was first recorded by Duke Ellington and his orchestra in January 1941 and rapidly became the signature tune of this famous swing band. The recording (which can be heard at bit.ly/3pr3g7e), features two solos improvised by trumpeter Ray Nance. In the first solo, which starts around 50 seconds into the recording, Nance conjures a thin, edgy sound quality from his instrument; in the second solo, beginning at 1 minute 50 seconds, the full brassy brilliance of the trumpet is unleashed. How was this remarkable transformation of timbre achieved?

The answer to this question is revealed in a 1962 filmed performance of "Take the A Train" by the Ellington band in which Ray Nance reprises his 1941 solos (available at bit.ly/3u82DD5). When he walks forward to take the first solo, a copper-colored object can be seen protruding from the bell of the trumpet, almost completely blocking the opening through which the sound is radiated. This obstruction, which Nance removes during a break by the full band before the start of his second solo, is an example of a mute (in this case, a "harmon mute"). Brass instruments come in many different shapes and sizes; some examples of common trumpet mutes are illustrated in **Figure 1**. The acoustical behavior of mutes for musical horns is the subject of this article.

Figure 1. *Examples of trumpet mutes.* ***A:*** *plunger mute.* ***B:*** *fiber straight mute.* ***C:*** *aluminum straight mute.* ***D:*** *cup mute.* ***E:*** *harmon mute.*

Muting Musical Instruments

The curtailment of social interaction arising from the Covid-19 pandemic has resulted in an explosive growth in the use of conference software platforms such as Zoom. A large fraction of the population is now familiar with the "mute button," which an online host can use to silence the contributions of other participants in a meeting. The mutes used on musical instruments such as the violin and the trumpet have a more subtle effect than the mute button; a musical mute is not usually designed to completely suppress the radiated sound but to modify its loudness and timbre. A typical mute on a stringed instrument is a mechanical device that can be clamped on the bridge, reducing the efficiency with which vibrational energy is transferred from the strings to the body of the instrument. The primary role of a brass instrument mute is as a partial reflector of acoustic waves, controlling the balance between the energy trapped in the internal air column and the energy radiated as sound.

The use of an outwardly tapering horn to increase the radiated power of a wind instrument has a long history. For at least three millennia, the shofar, a lip-excited ram's horn, has been used in Jewish religious ceremonies, and the metal trumpets found in the tomb of the Egyptian Pharaoh Tutankhamun expand into conical terminations. All the sound from one of these ancient instruments is radiated from the mouth of the horn, and the same is true of the trumpets, trombones, French horns, and tubas of the modern brass family. These instruments can therefore be muted very effectively by introducing modifications in the region of the horn mouth, usually described as the bell. This article surveys some of the inventive techniques that performers have developed to mute musical horns.

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A

B

C

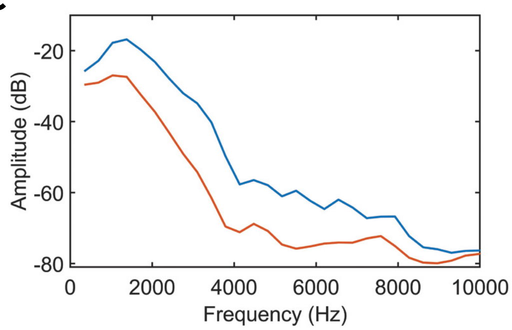


Figure 2. ***A:*** *British cartoon, c. 1939. Reproduced from the National Archives Image Library, with permission.* ***B:*** *His Masters Voice horn gramophone, early twentieth century.* ***C:*** *long-term average spectra of radiated sound with horn open (**blue line**) and muted by sock (**red line**).*

Putting a Sock in It

The phonographs marketed by the Edison Company and other manufacturers at the beginning of the twentieth century relied on a large flaring horn to radiate the sound energy derived from the vibrations of the stylus in the record groove (available at bit.ly/3atI1gI). The timbre of music played through the horn was inevitably colored by its internal resonances, and the poor radiation efficiency of the horn at low frequencies resulted in a sound that was often strident. A large consignment of cheap Edison phonographs was sent out to entertain American troops fighting in the First World War after 1917. About this time, the colloquial injunction to "put a sock in it" became current among groups of soldiers, and the cartoon in **Figure 2A** illustrates a common (though contested) view that this phrase originally referred to the use of a sock to mute a phonograph.

What are the acoustic consequences of stuffing a soldier's sock into a phonograph horn? To answer this question, we carried out an experiment with an early twentieth-century horn gramophone (**Figure 2B**), playing a 1926 recording of Sousa's "Stars and Stripes Forever" by the band of H. M. Coldstream Guards (**Multimedia 1** at acousticstoday.org/campbellmultimedia). We recorded the sound radiated by the gramophone with a microphone about 1 meter in front of the horn in a domestic room. The A-weighted equivalent continuous sound level, measured over the final 64 seconds of the recording, was reduced by 12 dB when a woolen sock was pressed into the horn. The long-term average spectra in **Figure 2C** show that the attenuation was significant over a broad frequency range, rising to over 20 dB around 3.5 kHz.

In 1919, the Edison Company introduced the model H19 Hepplewhite disc phonograph, which included a volume control. This control was, in effect, a more sophisticated version of the sock (available at bit.ly/3u90sPF). The horn was mounted inside a cabinet, and an externally operated mechanism allowed a soft "muting ball" to be inserted into the mouth of the horn. By changing the degree of insertion, the operator was able to adjust the loudness of the radiated sound. This device was apparently effective since the model continued in production until 1927.

Muting Brass Instrument Horns

A sock does not make a successful brass instrument mute because inserting it into the bell changes the playing pitches as well as the timbre and loudness. On the phonograph, the vibration frequency of the needle is determined by the undulating profile of the groove and the rotation speed of the record (see bit.ly/3b8KBIi starting at 12 minutes 45 seconds). Altering the resonant properties of the horn has a negligible effect on the needle vibration rate, and the pitch is therefore unaffected by muting. On a

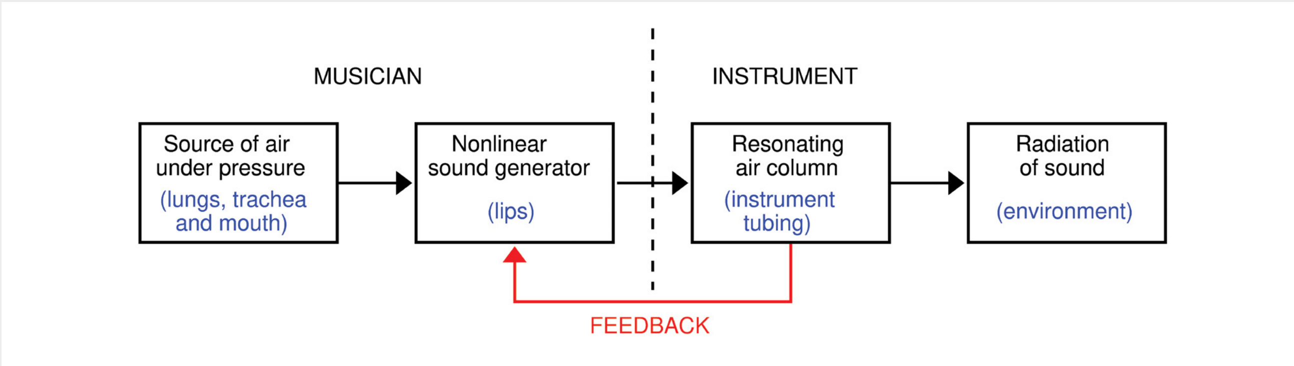


Figure 3. *Schematic diagram of brass instrument sound production.*

brass instrument, however, the resonances of the horn strongly influence the pitches that can be easily played on the instrument. This is because the player's lips are coupled to the resonant modes of the instrument's internal air column in a feedback loop, (**Figure 3**, *red arrow*). To play a note, the performer presses the lips against the mouthpiece, using facial muscles to set the lip mechanical resonance frequency close to the frequency of one of the air column resonances. When air is blown through the aperture between the lips, the coupled system of lips and acoustic resonance is destabilized, and an oscillating regime is established at a frequency near but not exactly equal to the selected acoustic mode frequency (Benade, 1973; Moore, 2016). If the insertion of a mute changes the frequency of the acoustic mode, the frequency and pitch of the played note will also change.

The acoustic resonance frequencies of a brass instrument correspond to maxima in the input impedance, which is the ratio of pressure to volume flow rate measured in the mouthpiece (Backus, 1976). A trumpet bell is carefully shaped so that most of the acoustic resonances have frequencies close to a harmonic series, as shown in **Figure 4** (Campbell et al., 2021). When no valves are activated, the resonance frequencies are similar to those on a B♭ bugle, and the corresponding set of natural (easily playable) notes include those required to play familiar bugle calls such as "Taps" (**Figure 5**). An experiment with a trumpet and a sock quickly confirms that when the sock is pressed firmly into the bell, the sound level is reduced, but the pitches of the natural notes are so distorted that it is impossible to play a well-tuned bugle call.

Figure 4. ***Blue line***, *input impedance of a B♭ trumpet.* ***Red lines***, *B♭ harmonic series (integer multiples of 116.5 Hz).*

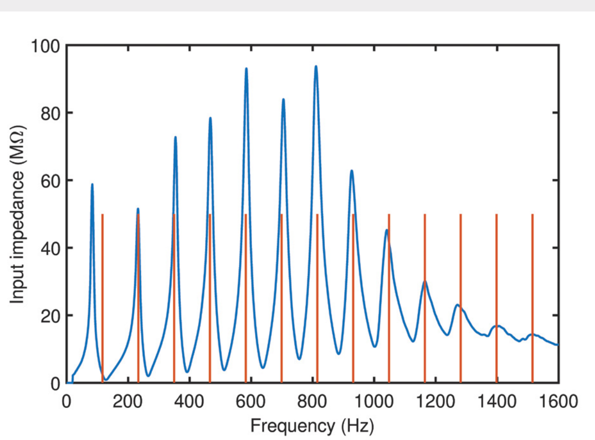


Figure 5. *The bugle call "Taps," sounding a tone lower than written when played on a B♭ instrument (available at bit.ly/3at4lqZ).*

The problem with the sock is that it intrudes on the internal acoustic field of the instrument; muting devices that do this are known as internal mutes. Disturbance of the acoustic resonance frequencies and natural note pitches can be minimized if the muting object does not penetrate significantly into the horn mouth. Mutes that satisfy this rule are known as external mutes. Some examples of external mutes are reviewed in **Derby Hats and Drain Plungers,** after which we examine various ways in which internal mutes have been adapted to serve musical purposes.

Derby Hats and Drain Plungers

An important characteristic of a brass instrument bell is the cutoff frequency, which depends on the diameter and rate of flare of the bell near its exit. For frequencies well below this cutoff, most of the sound energy in a wave traveling down the instrument tube is reflected back into the instrument on reaching the bell, whereas for frequencies well above the cutoff, most of the energy travels outward as a radiated wave. Because the standing waves in the instrument arise from the addition of the forward traveling and reflected waves, the peaks marking the acoustic resonances in the input impedance curve diminish rapidly above the cutoff frequency. Inspection of the trumpet impedance curve in **Figure 4** shows that the cutoff frequency for this instrument is in the region of 1,200 Hz.

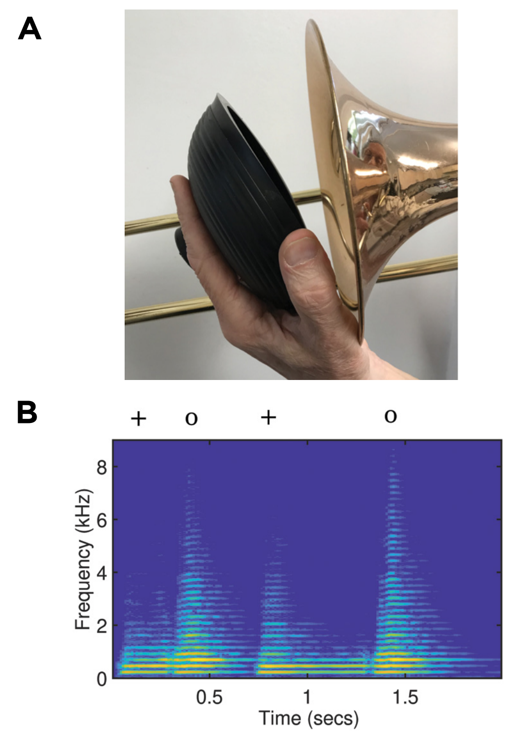


Figure 6. ***A:*** *trombone plunger mute.* ***B:*** *spectrogram of trombone note with plunger closing (+) and opening (**o**) the bell mouth. Adapted from Campbell et al., 2021, with permission of Springer Nature.*

The sound radiated from the instrument can be partially interrupted by placing any solid object in front of the bell. Inventive early jazz musicians discovered that derby hats and the rubber cups used on drain plungers made effective mutes. External mutes are most effective at reducing the amplitudes of the high-frequency components in the sound because these are radiated more strongly along the bell axis. The instruction "in hat" on a big band trumpet or trombone score instructs the player to play into a derby hat or a specially manufactured mute in this shape (available at bit.ly/3pIj9qh). Because the hat intercepts much of the high-frequency radiation, the sound is both quieter and more mellow than when the instrument is unmuted. A presentation of trumpet mutes by Jon-Erik Kellso (available at bit.ly/3qu6Xum) includes an entertaining demonstration of the use of an aluminum derby (at around 4 minutes 25 seconds).

The "plunger" mute (**Figure 6A**) performs a similar function to the hat, but because it can be firmly gripped in the player's hand, it can be easily manipulated to make rapid timbral changes. One characteristic effect, popular in swing band arrangements in the 1940s, involves the playing of a succession of notes with the plunger alternately close to the bell and swung away from it (**Multimedia 2** at acousticstoday.org/campbellmultimedia). Closed and open positions of the plunger are marked "+" and "o," respectively, on a musical score. A spectrogram of a performance of this effect on a tenor trombone is shown in **Figure 6B**. Notes that are played with the plunger in the open position have a rich harmonic spectrum with significant components up to at least 8 kHz. Moving the plunger to the closed position strongly attenuates the high frequencies, with little energy above 4 kHz. The effect is similar to that obtained by singing the vowel "ah" while alternately opening and almost closing the lips, creating a "wah-wah" sound.

Baroque Transposing Mutes

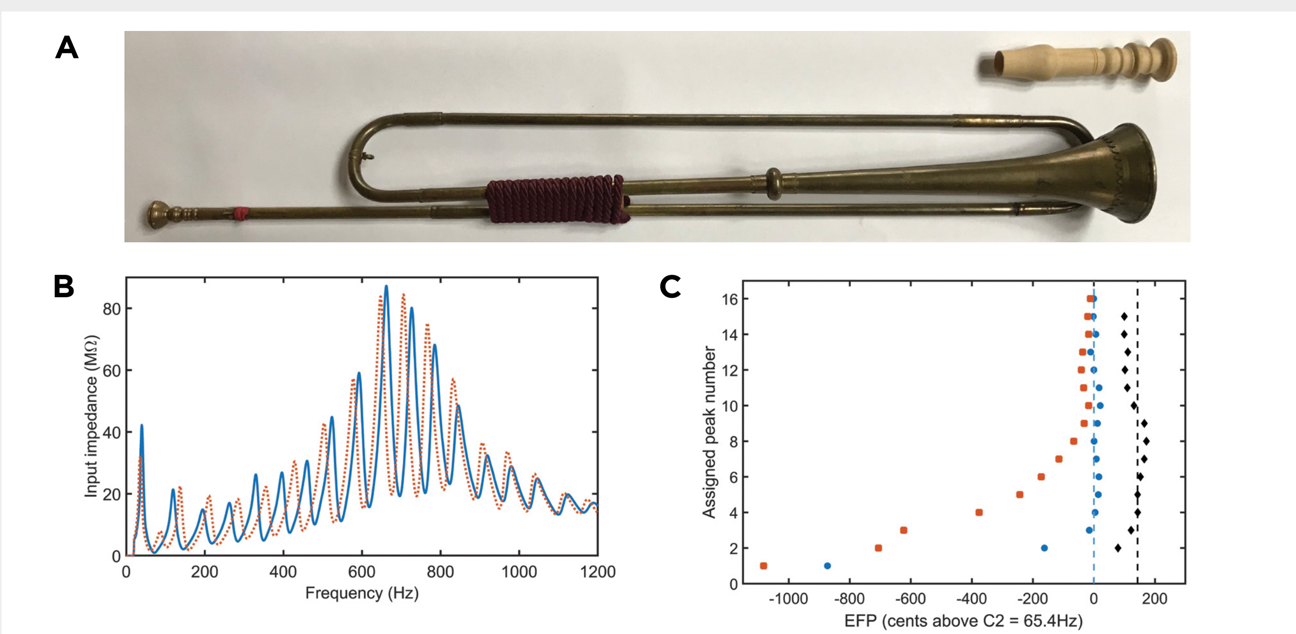
The earliest reference to the use of mutes in brass instruments appears to be in a description of a carnival procession in Florence in 1511. One of the floats in the procession was described as the "Chariot of Death." On this chariot drawn by oxen, singers dressed as corpses rose from their tombs to sing a mournful song, accompanied by "muted trumpets with a hoarse and deadened sound" (Vasari, 1568). There is no record of the type of mute used by the Florentine trumpeters. In 1607, however, the composer Claudio Monteverdi clearly had a solid internal mute in mind when he suggested the use of mutes in the opening "Toccata" of his first opera *Orfeo*. In a note on the score for the trumpet ensemble that plays this fanfare, he comments that the use of mutes will raise the pitch of the instruments by a tone so that the accompanying strings will have to transpose their parts accordingly.

The trumpets of Monteverdi's time were natural instruments (without valves) almost twice the length of a modern orchestral trumpet. A natural trumpet based on an instrument made in 1632 is illustrated in **Figure 7A**. No mutes have survived from this period, but a wooden mute of the type in use around a century later is also shown in **Figure 7A**. The mute fits snugly into the bell of the trumpet, allowing the sound to radiate only through a small internal cavity, terminating in a cylindrical channel around 6 mm in diameter (Pyle, 1991).

A playing experiment with this mute (**Multimedia 3** at acousticstoday.org/campbellmultimedia) reveals that its insertion does indeed raise the pitches of the natural notes, although by a little less than the whole tone described by Monteverdi. It might appear surprising that the pitches are raised by the mute because the partial closure of a pipe end usually lowers the frequency of the acoustic modes. A close inspection of the measured input impedance curves of the trumpet with and without the mute provides an explanation for this apparent paradox (**Figure 7B**). Measured without the mute, the peaks correspond to the first 18 acoustic modes, the highest at a frequency just below 1,200 Hz (**Figure 7B**, *blue curve*). These peaks are modified by the insertion of the mute (**Figure 7B**, *red curve*). In the frequency range from 500 Hz upward, each muted peak is indeed slightly lower in frequency than the corresponding unmuted peak. Below 500 Hz, however, the frequency shift increases, to the extent that the third red peak appears slightly above the second blue peak. The second red peak is greatly diminished, and the first peak is almost unaffected by the insertion of the mute.

A useful graphical illustration of the extent to which the acoustic mode frequencies of an instrument depart from a perfect harmonic series is provided by the equivalent

Figure 7. ***A:*** *natural trumpet (after Hanns Hainlein, 1632) with a modern copy of a baroque mute.* ***B:*** *input impedance curves for a natural trumpet without a mute (**blue curve**) and with a mute (**red curve**).* ***C:*** *equivalent fundamental pitch (EFP) for a natural trumpet without a mute (**blue circles**), with a mute (**red squares**), and with reassigned peak numbers (**black diamonds**).*



fundamental pitch (EFP) plot, which can be derived from the input impedance curve (Campbell et al., 2021). An EFP plot for the natural trumpet without a mute is shown in **Figure 7C**, *blue circles*. Each impedance peak is assigned an index number (n) starting from the lowest frequency mode. The nth mode, with peak frequency (f_n), has an equivalent fundamental pitch

$$\mathrm{EFP}(n) = (1200/\log 2) \log(f_n/nf_{\mathrm{ref}}) \qquad (1)$$

where f_{ref} is the frequency of a reference pitch. EFP(n) is the deviation in cents (hundredths of a semitone) of the pitch of the nth mode from the exact nth harmonic of f_{ref}. For an ideal harmonic series with fundamental frequency f_{ref}, EFP(n) = 0 for all n, and all the points on the EFP plot lie on a vertical line at frequency f_{ref}.

The EFP plot for the unmuted trumpet shows that the impedance peaks from the 3rd to the 16th lie very close to the *dashed blue line* in **Figure 7C**, marking a perfect harmonic series with a fundamental frequency of 65.4 Hz, corresponding to the pitch C2, 2 octaves below "middle C." This is expected because the length of the removable crook at the input of the instrument has been chosen to allow it to play "in C." **Figure 7C**, *red squares*, shows the EFP values when the mute is inserted, confirming that the pitches of the acoustic modes from the eighth downward are increasingly flattened by the insertion of the mute.

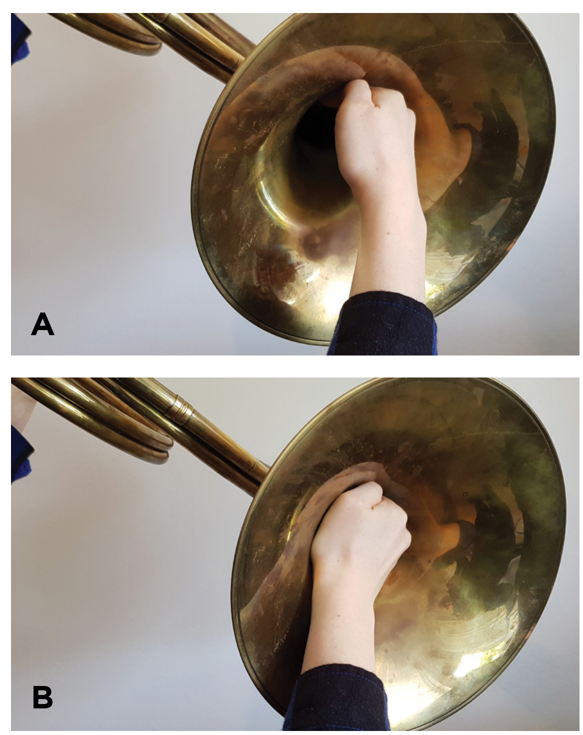
The EFP plot also reveals why an acceptable quasi-harmonic set of resonances with a higher pitch can be found on the muted trumpet (**Multimedia 3** at acousticstoday.org/campbellmultimedia). **Figure 7C**, *black diamonds*, shows recalculated EFP values obtained by discounting the small second peak in the muted input impedance curve and reassigning the index numbers so that the third peak corresponds to n = 2, the fourth peak to n = 3, and so on. This reinterpretation of the pitches of the acoustic modes shows that they lie close to the *dashed black line* in **Figure 7C**, representing a perfect harmonic series with a fundamental pitch around 170 cents above C2. A skilled trumpet player can compensate for the residual deviations by adjusting the natural resonance frequency of the lips, a technique known as "lipping."

Hand Technique on the Horn

A brass instrument can be muted simply by using a hand to partially close the bell. In the eighteenth century, players of the French horn developed a sophisticated technique in which precise positioning of the hand in the bell was used to modify the loudness, timbre, and pitch of individual notes during a performance. At this time, French horns, like trumpets, were natural instruments whose sounding length could be varied only by removing one crook and inserting another; the pitch-changing property of internal muting was in this case an advantage rather than a problem because it could be used to make musically desirable changes to the pitches of the natural notes of the instrument. Although modern French horns have valve systems allowing for almost instantaneous changes of sounding length, the hand technique remains an important aspect of horn performance. The normal position of the player's hand in the bell is illustrated in **Figure 8A**.

The partial obstruction of the horn mouth by the player's hand increases the fraction of the sound energy reflected back into the instrument tube, to an extent that increases with frequency. **Figure 9** shows the result of an experiment in which an artificial hand, cast in gelatin from a mold

Figure 8. *Placement of a French horn player's hand in the bell of the instrument.* ***A:*** *normal position.* ***B:*** *stopped position. Photographs courtesy of Lisa Norman.*



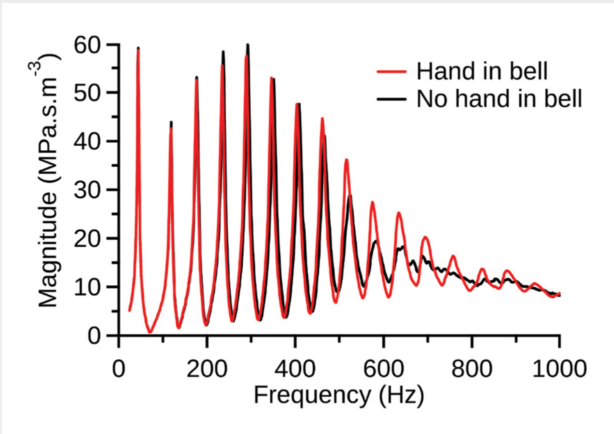


Figure 9. *Input impedance curves for F horn with (**red**) and without (**black**) hand in bell. From Dell et al., 2010, with permission of the Australian Acoustical Society.*

obtained from a human performer, was used to investigate the effect of hand technique on the input impedance curve of a French horn (Dell et al., 2010). The boost in the heights of the peaks in the input impedance curves, particularly in the region around the cutoff frequency, is clearly shown. The strengthening of the high-frequency acoustic modes extends the range of pitches that can be sounded securely (Yoshikawa and Nabarra, 2017), reducing the risk that the player will "crack" or mis-pitch a high note.

The horn mouth can be almost completely closed by a movement of the player's wrist, as shown in **Figure 8B** (see **Multimedia 4** at acousticstoday.org/campbellmultimedia). A note played with this hand position is described as "stopped." The hand is then behaving acoustically as an internal transposing mute; on a horn in F with a sounding length of approximately 4 meters, the effect is to provide the player with a new set of natural notes a semitone higher than the unstopped set. The tutorial by the virtuoso hornist Frank Lloyd (see bit.ly/3uitBs3) includes excellent demonstrations of hand stopping on a modern horn, especially from around 5 minutes 40 seconds.

Nontransposing Internal Mutes

The invention of a mute that could be inserted into the bell of a brass instrument without seriously modifying the pitches of the natural notes is usually credited to the eighteenth century Dresden horn player Anton Joseph Hampel (Humphries, 2019). The simplest form of a nontransposing mute is simply a hollow truncated cone, closed at the wide end and open at the narrow end. A trumpet mute of this type is illustrated in **Figure 1B**, and a spectacularly large tuba straight mute is demonstrated in **Multimedia 5** (acousticstoday.org/campbellmultimedia). When the open end of the mute is inserted into the bell, it is held in position by three cork spacers. The sound can radiate only through the narrow annular space between the outer surface of the mute and the inner surface of the bell, resulting in a strong attenuation of the low-frequency components in the sound.

The straight-sided cone mute is usually described simply as a "straight mute." The same term is often applied to the metal mute shown in **Figure 1C**, although in this common design, the conical part is tapered to match the internal profile of the trumpet bell. Straight mutes are widely used in most genres of brass performance, and a player will normally use a straight mute unless some other type is specified in the score.

The hollow cavity inside a straight mute has a range of internal resonances. The lowest frequency acoustic mode of the cavity is the Helmholtz resonance, whose frequency can be estimated by blowing across the open end of the mute (**Multimedia 3** at acousticstoday.org/campbellmultimedia). There is also a series of standing wave resonances at much higher frequencies. On a well-designed mute, these internal standing waves do not significantly modify the frequencies of the acoustic modes of the instrument. The influence of the Helmholtz resonance can, however, be seen in the appearance of an additional peak in the input impedance curve. This behavior has been studied by Sluchin and Caussé (1991), who described the additional peak as "parasitic" because it can disrupt the sounding of low pitches on the muted instrument.

Figure 10 illustrates the changes that occurred in the input impedance curve of a tenor trombone when a straight mute was inserted in the bell (Campbell et al., 2021). In the measurements shown in **Figure 10A**, the slide was in first position (fully retracted). **Figure 10A**, *blue curve*, shows the first five impedance peaks with the mute removed. **Figure 10A**, *red curve*, measured with the mute in the bell, shows that the pitches of the second, third, and fourth peaks have been slightly raised in frequency by the mute. More significantly, a small additional peak, corresponding to the parasitic resonance, has appeared at 77 Hz. The second natural note, B♭2, played with the slide in first position, relies on the coupling of

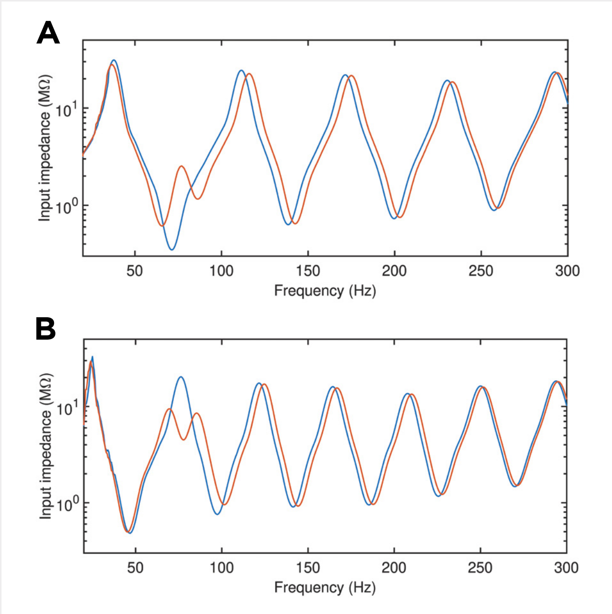


Figure 10. *Input impedance curves for a tenor trombone with a straight mute removed (**blue**) and inserted (**red**). **A:** slide in first position. **B:** slide in seventh position. Adapted from Campbell et al., 2021, with permission of Springer Nature.*

the lips to the second acoustic mode at 116.5 Hz; because the parasitic resonance is not close to this frequency, it does not disturb the playing of the note. When the slide is extended to the seventh position, however, the pitch of the second natural note drops to E2, at a frequency of 82.4 Hz. This is now dangerously close to the parasitic resonance, and the input impedance curves shown in **Figure 10B** reveal that the insertion of the mute has split the second peak into two smaller peaks. Lacking the support that comes from coupling to a single strong acoustic resonance, the player's lips will struggle to sound a stable E2 with the mute inserted.

Some other common alternatives to the straight mute are illustrated in **Figure 1**. The "Tuxedo Plunger" (**Figure 1A**) is a commercial variant of the simple drain plunger previously discussed. The cup mute (**Figure 1D**) is a straight mute surrounded by an annular bowl that almost covers the bell. It can thus be considered as a combination of a straight mute and a plunger (Sluchin and Caussé, 1991). The increased trapping of high-frequency sound energy by the bowl gives this design of a mute a warmer sound than a straight mute. The space between the bowl, the bell of the instrument, and the external surface of the straight mute has its own internal resonance, at a frequency that depends critically on the gap between the bowl rim and the bell. For a trombone cup mute in its normal position, Sluchin and Caussé found an attenuation of 20 dB in a fairly narrow frequency band around 1,000 Hz, which they ascribed to this additional cavity resonance.

The harmon mute shown in **Figure 1E** has a cork strip surrounding the inner neck, closing off the annular gap through which sound radiates in a straight or cup mute. The radiating aperture in a harmon mute is a circular opening in the outer face of the mute. A short cylindrical tube, known as the "stem," can be inserted into this aperture, and manipulation, removal, or partial covering of the stem by the fingers allows for a wide variety of timbral effects to be achieved. A harmon mute without the stem was used by Miles Davis to create the "cool jazz" trumpet sound that became his hallmark (available at bit.ly/3u34HMK).

Finale: The Active Mute

An interesting recent development in the design of mutes for brass instruments has been the application of the active control technique (Nelson and Elliott, 1991) to cure the problem caused by parasitic resonances in straight mutes (Meurisse et al., 2015). The principle of the method is illustrated in **Figure 11**. Because the Helmholtz resonance of the mute cavity plays no useful role in the sound production of the muted instrument, it can be suppressed without unwanted side effects. A microphone inside the cavity senses the internal acoustic pressure, providing an input signal to the control electronics. The amplified and phase-shifted signal drives a loudspeaker embedded in the mute, with the aim of canceling the pressure changes due to the Helmholtz resonance.

An experimental test of the method was carried out using the modified trombone mute shown in **Figure 11**. When the mute was used in a trombone with the active control switched off, the pedal note B♭1 was very difficult to play because its frequency (58 Hz) was very close to the parasitic peak. Switching on the active control system, with gain $G = 2$ and a phase shift of $\Phi = \pi$ radians, effectively canceled the pressure signal arising from the Helmholtz resonance. The parasitic peak disappeared from the input impedance of the muted trombone, and the playability of the note B♭1 was restored. It seems likely that future developments in electronic enhancement and active control will not only help to correct faults in the

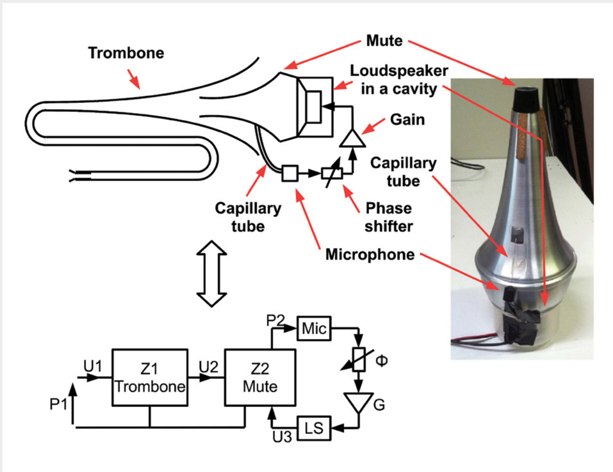


Figure 11. *A trombone straight mute with active control system to suppress a parasitic resonance.* ***Top left:*** *schematic diagram of the trombone, mute, and active control apparatus.* ***Bottom left:*** *equivalent circuit of the mute, trombone, and control system.* ***Right:*** *photograph of the active mute. P1 and U1, pressure and volume flow at the trombone input; P2 and U2, pressure measured inside the mute and volume flow at the mute input; Z1, trombone input impedance; Z2, mute input impedance; U3, volume flow generated by the loudspeaker inside the mute. LS, loudspeaker; Mic, microphone. From Meurisse et al., 2015, with permission of the Acoustical Society of America.*

existing designs of a mute but will also provide brass players with exciting new possibilities for shaping the sounds that emerge from their musical horns.

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