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The Brassiness Potential of Chromatic Instruments

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A chromatic brass instrument (i.e., one equipped with toneholes, a slide or valves) is in effect an assembly of tubes with different sounding lengths and different bore profiles. Although the differing bore profiles will result in differing timbral characteristics, these differences in a well designed instrument cannot be too great if the instrument is to have a consistent sound quality in scalar passages. This paper presents investigations into the timbral effects of non-linear propagation in chromatic brass instruments with varied sounding lengths. Experimental results are correlated with calculated values of the Brassiness Potential parameter. Additionally, results are presented which compare the brassiness curves of instruments with similar Brassiness Potential but differing in their absolute bore diameters. An explanation is offered for the perceived phenomenon that narrow-bore instruments are brighter than wide-bore models of the same kind of instrument.

1 Introduction

The Brassiness Potential parameter as defined by the authors [1,2] has proved very successful in distinguishing the various accepted families of brasswind instruments, and in creating a taxonomy [3]. Its strengths as a parameter are that it is (a) closely related to the design of an instrument as conceived or adopted by instrument makers, (b) is closely related to a measurable acoustical phenomenon (non-linear propagation) which directly affects the timbre of an instrument, and (c) can be easily computed from simple measurements. Additional strengths are that it is dimensionless and that it sidesteps the effects of mouthpiece choice, reflecting the common practice of musicians of selecting instruments and mouthpieces separately.

The Brassiness Potential parameter B is derived from D_0 (the initial or minimum bore diameter), $D(x)$, the bore diameter at each point distance x along the windway from the mouthpiece end, and L_{ecl}, the equivalent cone length corresponding to the nominal pitch of the instrument at the appropriate pitch standard. Values of B have been computed using a very close approximation to this definition which is computed from bore diameters at a number of measured points along the windway, and these values have been used in taxonomic analyses of brasswind instruments of all kinds.

The simple assumption which has been made so far is that the use of slides, valves and other devices which change the sounding length of an instrument can be ignored, and that chromatic instruments can be treated as equivalent to natural instruments. Nevertheless, in normal playing of a chromatic brasswind the sounding length differs from the length associated with the nominal pitch of the instrument for most of the notes sounded. There is a range of B values corresponding to the different valve or slide positions (for a three-valve instrument or a normal trombone slide there will be seven values of B associated with the seven positions). If the compass of a common valved instrument or a trombone is taken to extend from the second natural note to the sixth natural note, and if all notes of the chromatic scale are used equally frequently, and if the shortest tube length is selected where there are alternatives, then the average extension of the tube for these twenty pitches is that required to lower the pitch by two semitones. Instruments with a compass extended upwards or with a higher tessitura (such as trumpets) will have a smaller average extension, whereas instruments with compass extended downwards or with a lower tessitura (such as tubas) will have a larger average extension.

A series of measurements of spectral enrichment were carried out for a number of instruments set with valves or slides to give the shortest tube length and to give longer tube lengths. Values of the Brassiness Potential parameter were calculated for the corresponding physically measured bore geometries. In addition, a model of non-linear propagation [4] within instruments of these measured geometries was used to give theoretical simulations of spectral enrichment.

2 Measurements of spectral enrichment

It is possible to make measurements using musicians to sound instruments, but this is time consuming and leads to dispersed results [2]. There are advantages in using a loudspeaker which can deliver a sine wave input signal [spectral centroid *SC1*=1] at the mouthpiece receiver, resulting in a well-defined curve for the spectral centroid of the radiated sound [spectral centroid *SC2* as a function of sound pressure level at input *P1rms* or at output *P2rms*]

Initial experiments used brass instruments at 9-ft pitch. These have bell flare cutoff frequencies ranging from under 700Hz (for a euphonium) to around 1100Hz (for a trombone) and fairly strong low modes of resonance, with relatively little reflection from the bell above 1500Hz. A pure sine wave excitation was provided by a loudspeaker in place of the mouthpiece, and a microphone measured the

output at the bell. In each test the sound pressure level at the input was increased from zero to a maximum (determined by the safe limit of the loudspeaker cone). The signals from a microphone at the input and the microphone at the bell were simultaneously recorded. The spectral centroid (as defined by Beauchamp [5]) of the signal at the bell gives an indication of the timbre as heard by the audience, in particular the brightening of the timbre as the dynamic is increased. The variables required to be set for each test were (a) the settings of the valves or trombone slide position; (b) the input sine wave frequency; and (c) the position of the bell microphone.

The input sine wave frequency was varied, with values selected between 1500Hz and 3000Hz. The aim was to find a frequency which was above the bell cut-off frequency and thus obviated internal reflections and standing waves, but not so high that higher order modes were excited. In practice the sensitivity of the tests was limited by the presence of relatively weak fluctuations in amplitude well above cutoff frequency. Some tests were carried out at a frequency tuned to one of these amplitude peaks.

Various positions were tried for the position of the microphone at the bell. Two standard positions were used: in the plane of the bell and one metre from the plane of the bell, both on the axis of the bell. The tests were conducted in an anechoic chamber. It was found that the sensitivity of the tests was limited by the small frequency-dependent fluctuations (detectable in the plane of the bell) or anisotropy of the far field radiated sound (small directional radiation effects at one metre from the plane of the bell). Small movements of the microphone off-axis indicated the scale of these effects.

These limitations on the sensitivity of the tests meant that small changes in instrument settings (such as a semitone difference in valve or trombone slide positions) produced changes in the spectral centroid which could not reliably be detected, but larger changes in instrument settings (such as five semitones difference in valve or trombone slide positions) produced distinct changes in the spectral centroid. These could then be compared with values of the Brassiness Potential parameter *B* derived from bore geometries and the spectral enrichment predicted by simulation.

Figures 1 and 2 show plots of the spectral centroid of the radiated sound *SC2* as a function of input 1500Hz sound pressure level *P1rms* for an instrument with a high value of *B* and for an instrument with low value of *B* respectively

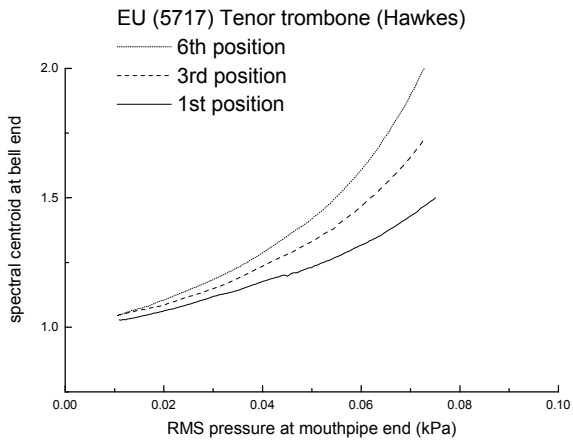

Figure 1 : Increase of radiated spectral centroid with input sound pressure level for a narrow-bore trombone by Hawkes (EUCHMI 5717) in 6th, 3rd, and 1st positions (*B* = 0.72, 0.71 and 0.70 respectively)

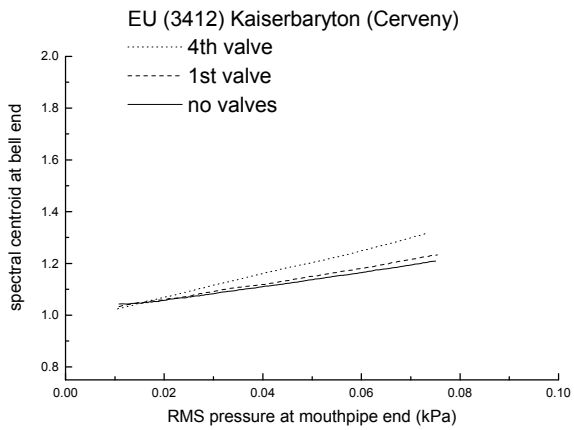

Figure 2 : Increase of radiated spectral centroid with input sound pressure level for a Kaiserbaryton (wide-bore euphonium) by Cerveny (EUCHMI 3412) with 4th valve, 1st valve, and no valves (*B* = 0.42, 0.40 and 0.36 respectively)

Note that although the spread in values of *B* is greater for the wide-bore euphonium with diffferent fingerings, the effect of changing fingerings on the spectral centroid appears to be less than for the narrow-bore trombone with different slide positions where the spread in values of *B* is less.

The spectral enrichment predicted by simulation [4] for instruments in general agreed with the measured results.

3 The Brassiness Potential parameter derived from bore geometries

If we chose to define a version of the Brassiness Potential parameter B based on the average equivalent cone length rather than the shortest, and on the corresponding bore profile, would it be very different? Looking at a baroque tenor trombone in B-flat (EUCHMI 3205), the sounding length in first position is 2711mm, and the computed value of *B* is 0.81. If instead we regarded it as a tenor trombone in

A-flat whose sounding length could be shortened as well as lengthened, its sounding length in third position would be 3043mm and the computed value of *B* is 0.82. It would in no way correspond to normal playing technique to regard it as an instrument in E whose sounding length could be only be shortened, but if we did, the sounding length in seventh position is 3834mm and the computed value of *B* for this instrument in E is 0.83. These are clearly small differences when related to the larger taxonomic picture.

An interesting case is the double french horn, which combines instruments that work well as horns in 9-ft B-flat and in 12-ft F. In normal playing technique a passage of music can be played entirely on the B-flat "side" or entirely on the F "side", or with some notes on one side interspersed with some notes on the other. The compass of the whole instrument is wide, but with usual playing technique performance is achieved with minimal use of valves in combination. Considering a double french horn in B-flat and F by Alexander (EUCHMI 1804), the shortest sounding length (in B-flat, no valves operated) is 2760mm, and the computed value of *B* is 0.515. Regarding it as a horn in A-flat whose sounding length can be shortened as well as lengthened, its sounding length with the first valve operated is 3100mm and the computed value of *B* is 0.525. In F, the shortest sounding length is 3658mm, and the computed value of *B* is 0.535. Regarding it as a horn in E-flat whose sounding length can be shortened as well as lengthened, its sounding length with the change valve and the first valve operated is 4143 and the computed value of *B* is 0.55. These are also small differences when related to the larger taxonomic picture.

Carrying out similar calculations for a four-valve E-flat tuba by Conn, (EUCHMI 3722), the shortest sounding length (in E-flat, no valves operated) is 4105mm, and the computed value of *B* is 0.37. Operating the 4th valve and regarding it as a tuba in B-flat, the sounding length is 5533 and the computed value of *B* is 0.46. On an instrument with low Brassiness Potential, operating the valves clearly has a big effect on the value of *B*- yet a tuba gives the listener the impression of a consistent sound quality in passages that move across differing tube lengths. This effect is probably due to the low incidence of non-linear propagation resulting from the wide bore and the relatively small pressure amplitudes required to produce the dynamic levels commonly used in tuba music.

4 The effect of bore diameter

Narrow-bore instruments are generally considered by musicians to have a brighter timbre than wide bore instruments of comparable bore profile. A significant feature of the development of brass instruments in the course of time has been bore enlargement. The Brassiness Potential parameter *B* depends on bore diameters relative to the initial bore diameter, so (for example) narrow-bore and wide-bore trombones can have the same value of *B* if they are exactly scaled. The intuitive explanation for this apparent anomaly is that to produce a given dynamic output, a narrow-bore instrument requires a higher sound pressure at the mouthpiece (giving rise to more non-linear spectral enrichment) than a wide-bore instrument, so in a performance situation where a certain dynamic level is required the narrow-bore instrument will have a brighter timbre, other things being equal.

Figure 3 show plots of the spectral centroid of radiated sound *SC2* as a function of input 350Hz sound pressure level *P1rms* for a modern bass trombone (JG2) calculated from simulations from (below) the measured bore profile and (above) the measured diameters exactly scaled down by a factor of 1.25). Because the scaling is exact, both bore profiles have the same value of *B* (0.67).

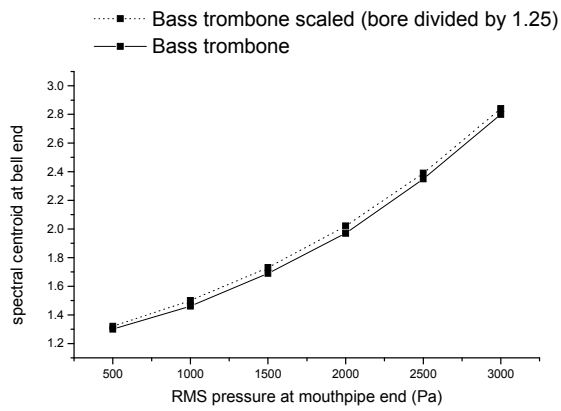

Figure 3 : Increase of radiated spectral centroid with input sound pressure level from simulations for a wide-bore trombone by Courtois (JG2) and the same instrument scaled down in bore diameter by a factor of 1.25

This intuitive explanation was tested by selecting pairs of instruments with similar bore profiles (and thus *B* values), but differing absolute bore diameters. It was found that although the dimensionless Brassiness Potential parameter *B* was the same, when the spectral centroid was plotted against the sound pressure level at the bell, the narrow bore instrument of the pair was brighter in timbre.

5 Conclusions

The contribution of non-linear propagation to the timbre of an individual sounded note of given dynamic level depends on the actual sounding length, bore profile, and bore diameter of the instrument. A chromatic brass instrument places in effect a group of tubes of differing lengths in the hands of a player. For the instrument to have an acceptably homogenous timbre the proportions of these tubes should not differ too much. To characterise a whole chromatic instrument it is convenient to assign a single value of the Brassiness Potential parameter to the instrument as a whole: this has to be a single tube, which could be either the shortest, or one representing an average for the instrument. Since an average in most cases is only slightly longer than the shortest, and is arbitrarily defined, use of the bore profile of the shortest is an acceptable decision.

There is scope for introducing a parameter to quantify the effect of absolute bore size, which should be a topic for further research.

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