THE INFLUENCE OF BORE SIZE ON BRASSINESS POTENTIAL

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ABSTRACT

Narrow-bore instruments are commonly perceived to be brighter than wide-bore models of the same kind of instrument. This effect is closely related to the effect of the bore profile of a brass instrument on the potential for nonlinear propagation of sound within the tube. This paper reports on practical tests with trumpets of different bore diameters, experiments with loudspeaker excitation of instruments, and simulations. The brassiness curves of a range of low instruments with similar Brassiness Potential but differing in their absolute bore diameters are compared. The relative importance of the two effects is explored.

1. INTRODUCTION

The Brassiness Potential parameter B [1, 2] relates in a simple way to the propensity for a brass instrument to sound bright (especially at high dynamic levels) due to spectral enrichment caused by non-linear propagation along the tube of the instrument. As defined in Equation 1, B depends on bore diameters relative to the initial bore diameter:

$$B = \left(\frac{1}{L_{ecl}}\right) \int_0^L \left(\frac{D_0}{D(x)}\right) dx \qquad (1)$$

Here we see that straightforward physical measurements of the minimum bore Do, a number of bore diameters taken over the length L of the instrument, and the equivalent cone length *Lecl* allow a computation of B. Typically the physical measurement of one instrument can be made in less than an hour.



Figure 1: This shows clear differentiation of instrument families by Brassiness Potential parameter B and bore size for instrument families at 8-ft and 9-ft pitch.

The Brassiness Potential parameter B has proved to be an effective parameter in constructing taxonomies of brass instruments [3] since it is derived from the kinds of measurements instrument makers adjust when designing instruments, and at the same time relates directly to an effect which is a factor in determining the timbre of the various families of instrument.

Narrow-bore instruments are generally considered by musicians to have a brighter timbre than wide bore instruments of comparable bore profile. So (for example) narrow-bore and wide-bore trombones can have the same value of B if they are similarly scaled, but musicians will say that the narrow-bore instrument is brighter. An intuitive explanation for this apparent anomaly is that to produce a given dynamic output, a narrowbore 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.

To explore this effect we carried out playing tests, laboratory tests, and simulations.

2. PLAYING TESTS

Figures 2 and 3 show the results from playing tests with a modern wide-bore trumpet by the S.E. Shires Co and an older narrow-bore trumpet by Vega.



Figure 2: This shows the variation of spectral enrichment with sound pressure level for narrow bore and wide bore trumpets with similar values of B playing the note F4



Figure 3: Spectral enrichment of B-flat4 played on two trumpets at different dynamics.

The steeper curve for the narrower bore instrument supports the general view by musicians of the effects of bore size

3. LABORATORY TESTS

In our laboratory tests we used a variety of instruments at 8ft to 9-ft nominal pitches (C, B, B-flat) in which the spectral enrichment was measured. The input frequency was a pure sine wave at 2500Hz, the microphone for the output was in the plane of the bell. A steadily increasing sound pressure level results in a well-defined curve for the spectral centroid of the radiated sound. Instruments at 9-ft pitch have bell flare cutoff frequencies ranging from under 700Hz (for a euphonium) to around 1100Hz (for a trombone), with relatively little reflection from the bell above 1500Hz. The sound pressure level of the sine wave excitation provided by a loudspeaker was measured with one microphone and a second 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 normalised spectral centroid [4] 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 input sine wave frequency chosen to be 2500Hz, above the bell cut-off frequency and thus obviating internal reflections and standing waves, but not so high that higher order transverse modes were excited. The sensitivity of these tests is limited by the presence of relatively weak fluctuations in amplitude of the order of 20% well above cutoff frequency [5] These limitations on the sensitivity of the tests meant that small differences in instrument properties produced changes in the spectral centroid which could not reliably be detected, but larger differences in bore profile produced distinct changes in the spectral centroid.



Figure 4: Spectral enrichment of ten instruments input a pure sine wave at 2500Hz, the microphone for the output was in the plane of the bell. The spectral centroid is plotted against rms sound pressure at the mouthpipe.

| Instrument | В |
|--|------|
| Tenor sackbut in 9-ft Bb (Voigt) | 0.76 |
| Tenor trombone in 9-ft Bb (Hawkes & Son) | 0.70 |
| Bass trombone in 9-ft Bb (Rath) | 0.70 |
| Saxhorn basse in 8-ft C (Fischer) | 0.48 |
| Kaiserbaryton in 9-ft Bb (Cerveny) | 0.37 |
| Cornophone ténor in 8-ft C, late (Besson) | 0.43 |
| Wagner tuba in 9-ft Bb (Alexander) | 0.37 |
| Cornophone ténor in 8-ft C, early (Besson) | 0.36 |
| Tuba in 8-ft C (Couesnon) | 0.39 |
| Ophicleide, keyed for B (Gautrot) | 0.30 |

Figure 5: Instruments tested in ranked order of measured spectral enrichment shown in Figure 4 with values of *B* computed from physical measurement of bore profile.

The rankings by spectral centroid (Figure 5) do not perfectly reflect the rankings by brassiness potential parameter B (righthand column). The narrow-bore instruments (the Wagner tuba and the cornophones) are ranked higher than would be expected if B were the only factor. Thus possibly absolute bore diameter makes an important contribution to the enrichment alongside bore profile as characterized by B. Looking at the initial diameters of pairs of instruments with similar values of B (Figure 6):

Instrument B

| Tenor trombone in 9-ft Bb (Hawkes & Son) | 0.70 |
|--|------|
| Bass trombone in 9-ft Bb (Rath) | 0.70 |
| | |
| | |
| Kaiserbaryton in 9-ft Bb (Cerveny) | 0.37 |
| Wagner tuba in 9-ft Bb (Alexander) | 0.37 |
| hagher caba in 5 re bb (menanadr) | 0.07 |

Figure 6: Pairs of instruments with similar values of *B* but different bore diameters



Figure 7: Plots for pairs of instruments with similar values of *B* but different bores diameters. The spectral centroid is plotted against rms sound pressure at the mouthpipe.

From Figure 7, the narrower trombone (green) is clearly brassier than the wide-bore trombone (blue); the much narrower Wagner tuba (navy) is close to and just below the wide-bore Kaiserbaryton (Grey). This discrepancy could be due to the frequency-dependent fluctuations observed before and thus represent a limitation of the experimental method rather than a limitation of the brassiness potential parameter B.

4. SIMULATIONS

The spectral enrichment for four of these instrument bore profiles were simulated using the tool described in 2008 [6] using the physically measured bore profiles. The brassiness curves are shown in Figure 8.



Figure 8: Plots of simulations of four instruments. The spectral centroid at the plane of the bell is plotted against rms sound pressure at the mouthpipe.

| Instrument | В |
|---------------------------|------|
| Green: Tenor trombone | 0.70 |
| Magenta: Cornophone, late | 0.43 |
| Grey: Kaiserbaryton | 0.37 |
| Olive: Ophicleide | 0.30 |

Figure 9: Ranked order of simulated spectral enrichment for the four instruments in Figure 8. This ranking matches that of B perfectly, as might be expected.

To test the effect of absolute bore diameter, the spectral enrichments of exactly scaled instruments were simulated. Three instruments were scaled to larger bore by multiplying the bore diameter throughout by 1.25 and scaled to smaller bore by dividing the bore diameter throughout by 1.25. This scaling did not change the value of B since B is linearly dependent on both initial bore diameter and bore diameter throughout the tube.



Figure 10: Plots of simulations of three instruments, scaled up [dashed lines] and down [dotted lines], centroid at plane of bell plotted against pressure at the mouthpipe

The closest comparison between simulated and measured spectral enrichment is the signal at axial point in the plane of the bell. Here (Figure 10) the ratio between spectral centroid of the bell signal and the input signal is greater when the bore is increased [dashed lines] and lesser when the bore is decreased [dotted lines]; but the output pressure is also reduced (due to greater losses in a narrower tube). If the input signal is increased to compensate for the losses to give the same rms pressure in the bell plane output, the simulated spectral enrichment is unaffected by scaling the bore diameter:



Figure 11: Plots of simulations of three instruments, scaled up and down, centroid at plane of bell plotted against pressure at plane of bell

Figure 11 would suggest that a wide bore instrument of the same proportions as a narrower bore is neither brassier (brighter timbre) nor less brassy for a given output rms pressure. However, to achieve a given sound energy output (volume of sound) a wide bore instrument will require a lower output rms pressure since the sound is being radiated from a larger cross-sectional area, so a wide bore instrument can be expected to sound less brassy than a narrow-bore instrument for the same sound energy output.



Figure 12: Plots of simulations of three instruments, scaled up (dashed lines) and down (dotted lines), centroid at far field plotted against pressure at far field

Looking at the simulated far field signal (500mm from the bell plane on axis), the ratios between spectral centroids of the far field signals and the input signal (Figure 12) are greater when the bore is narrowed [dotted lines] and less when the bore is widened [dashed lines]. This would indicate that a wide bore instrument of the same proportions as a narrower bore is less brassy (brighter timbre) for a given output rms pressure. This effect of bore size is a linear effect and is complementary to the non-linear contribution to brassy sounds. In a musical performance situation the listener hears neither the signal in the plane of the bell nor the far field signal on axis, but the total output of the instrument modified to some extent by room acoustics.

5. PRELIMINARY CONCLUSIONS

Tentative conclusions from this work are that:

- Narrowing the bore by 25% has an effect on brassiness potential equivalent to increasing B by 10%
- Widening the bore by 25% has an effect on brassiness potential equivalent to decreasing B by 10%

The effect on spectral enrichment of a 25% increase or 25% reduction in absolute bore size can be approximately equated to the effect of changing the bore profile to give a 10% reduction or 10% increase respectively in the value of B. This is an initial ballpark figure which needs further testing and theoretical refinement.

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7. REFERENCES

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