Why choose Leadpipes and Bells?

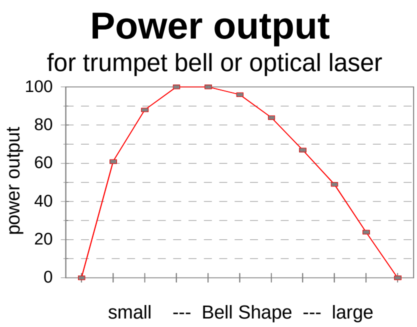
How the Bell and Leadpipe size affect the musical qualities of an Instrument

At a fairly basic level, it is assumed that a brass instrument is a tube that refines and amplifies the buzz from a players lips and the sound just comes out of the flared end. This would be true if the instrument - a conical shape- was very wide (like a megaphone or loud speaker) where all the sound is immediately transmitted to the outside air. When you audition an expensive loud speaker you expect faithful reproduction of your CD; you do not expect 'resonances' or false colouring in the sound. The best loudspeakers have a wide even frequency range and are also designed to respond very quickly to changes of sounds - e.g with percussive sounds. This is their transient behaviour.

However, this is ***not*** how a brass instrument works. It *must* have resonances to select certain frequencies that make the notes of the scale, and the transient is only important when starting and ending each note. Incidentally, these resonances are the *natural notes* of the air in the tube and are not necessarily *harmonics* in the true meaning of the word since their relationship can be modified by subtle changes to the cone shape.
Resonances start to occur when the cone (angle) of the megaphone or loudspeaker is gradually made narrower; - eventually there is a cone in the region of a trumpet/flugel horn shape, having the resonances familiar to all brass players. To demonstrate this, I once made a set of brass cones of different angles, but having the same pitch. With the widest, it was almost impossible to sustain a resonance (note), but it was much easier with the medium/small shapes. Going to the other extreme, with a shallow cone (nearly a cylindrical tube), it was possible to play both the resonances of a conical instrument and also those of a cylindrical instrument like the clarinet (in $1/12^{th}$s) - but that is a different story!

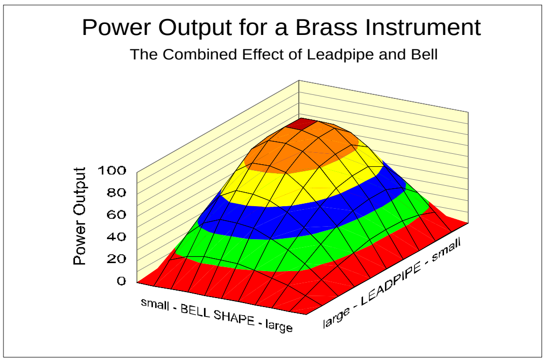
Experience with many professional clients suggests that given the choice of larger or smaller leadpipes and bells, the player would find the narrower shapes easier to play than the wider ones. This often conflicts with the logical idea that a wider tube allows more air to pass through and should therefore be easier.
For an adequate explanation we need look at basic principles:
When an instrument sounds an A440Hz, the players lips are vibrating, open and closed, 440 times in one second. We know this by taking high-speed photographs through a clear plastic mouthpiece.
Imagine your lips opening and closing in slow motion. When the lips are open, a pulse of air is released into the instrument and causes a longitudinal wave[1] to travel down the tube at the speed of sound (780 m.p.h.) towards the *bell* where most[2] of it is reflected back into the instrument to create and support a resonance. A small amount of the energy is transmitted out of the bell as the sound we hear.

The shape of the bell or leadpipe determines how much of the wave is reflected back inside, and consequently affects the strength of the resonance. A smaller bell reflects more energy into the instrument.
The discussion above showed how the wide megaphone/loudspeaker does not reflect the sound, therefore little or no resonance occurs and the entire wave is transmitted outside. It is usually easier to play a smaller bell than a larger one because the increased reflection would need less energy from the player to sustain the same degree of resonance. Conversely, for a larger bell, more is transmitted outside and less reflected, making it harder for the player to replace the lost energy. At both extremes of trumpet bell we might expect a decrease in sound output from the instrument, either by restriction (too small) or fatigue (too large). Therefore an optimum bell size ***for that player*** would lie somewhere in between. Our study of the optical analogy - a Laser - has proven useful; where mirrors, which partially reflect and transmit the light energy, represent the bell and leadpipe. A laser has a considerable amount of energy inside – but only .01% comes out through the mirrors as an intense light beam. The output power of the light beam or trumpet sound can be shown like this, with a maximum at the optimum reflectivity of the mirror or bell:



The reflected wave going back up the instrument meets up at the lips when the lips are open for the second time[3] and is reinforced by the next pulse of energy from the lips. In a similar way to the bell, the **shape of the leadpipe** is important in deciding how much of the wave is reflected back into the instrument again and how much is transmitted (wasted?) through to the lips and head cavities. It would be logical to choose a small leadpipe with high reflection, but it cannot be too small since this is the same route the player uses to put the energy into the instrument! We therefore have to make a compromise and the optimum size of pipe ***for that player*** would lie somewhere between the extremes.

For this reason, we use a set of finely calibrated interchangeable leadpipes in our trumpets and cornets so that the individual player can find their own ideal combination.



If the leadpipe and bell are combined in one 3D chart we can see that the ideal combination would be at the peak. It is our aim to find this point for all our customers!

Making the notes

Eventually, when the waves going up and down the instrument are settled, a steady note will be produced. The lips will have 'locked' into the resonance of the tube, and you have found what is technically called a 'mode of vibration' or some players refer to it as a 'groove' or 'slot'. The 'pedal' note or 1st mode of vibration (B♭=116.5Hz) is when the lips open and close once for a complete travel of the wave down to the bell and back again. If the lips double in speed, (double the frequency = octave above, B♭=233Hz) a second wave will start from the lips when the first has just reached the bell. This is the second mode. The 3rd mode will be three times the fundamental speed/frequency which gives the F=349Hz, and so on.

A sign of a well-designed instrument is when these modes, 'grooves' or 'slots' are in tune with each other, evenly spaced and of similar strength.

Looking at the instrument as a whole, the bore holds a certain amount of energy, maintained solely by the player, but this is gradually lost through the bell and leadpipe. If the loss is too great through an excessively large bell and/or leadpipe the player will become fatigued and no resonance is possible. Conversely, if the bell and/or leadpipe are too small the instrument would become harder to play and little sound would radiate.

Somewhere in between these extremes there will be an optimum *balance* for the size of bell and leadpipe *for each player*, according to his/her embouchure and mouthpiece set-up and playing environment, e.g studio, orchestral, quintet, theatre pit etc.

Notes:

1. By closing off the instrument bore with a thin membrane, we can demonstrate that only the wave and not the air has to travel into the tube to make a note. (See publication: *Exciting Your Instrument!*)
2. On average, less than 1% of the energy you put in is actually transmitted as sound from the bell!!
3. If you are a beginner and mistime your lips, i.e. aim for the wrong note; you will be making some unwanted noise. 'Practice makes Perfect!'

Bore size (through the valves) seems to play a less important rôle and is the main reason why Smith-Watkins now only have two sizes for the Bb and C trumpets

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Technical Publications by Smith *et al*:

14. *Distinguishing between similar tubular objects using pulse reflectometry: (A study of trumpet and cornet leadpipes.)* Measurement Science and Technology **13** (5) 750-757 (2002). Press release: *Scientists blow their own trumpet* - http://physics.iop.org/IOP/Press/PR4302.html

13. *Exciting Your Instrument!* Journal of the International Trumpet Guild (USA), 44-45 (May 1999)

12. *Its all in the bore!* Journal of the International Trumpet Guild (USA), 42-45 (May 1988).

11. *Holographs of bell vibrations*. News and Views, Nature **329**, 762 (29 October 1987).

10. *Ensuring high quality in the production of musical instruments*. Commissioned by British Embassy for Das Musikinstrument **4**, 131-132 (April 1986).

9. *The effect of material in brass instruments*; a review. Proceedings of the Institute of Acoustics **8**, 91-96 (1986).

8. *Improved brass instrument design methods*. a) Acoustics conference, Kraslice-Czechoslovakia (September 1983).
b) Proceedings of the Institute of Acoustics, 17-20 (April 1984).

7. *Material vibration and its influence on performance of wind instruments*. Proceedings of the Institute of Acoustics, 317-319 (April 1981).

6. *Recent work on musical acoustics* (review). Reports on Progress in Physics (Commissioned by Institute of Physics) **42**, 1085-1129 (July 1979).

5. *Recent developments in brass design*. Journal of the International Trumpet Guild (USA), (October 1978).

4. *Improving the timbre and responsiveness of a bass trombone*. Nature **271**, 146-147 (1978).

3. *Systematic approach to the correction of intonation in wind instruments*. Nature **262**, 761-765 (1976).

2. *Possible causes of woodwind tone colour*. Journal of Sound and Vibration **32**, 347-358 (1974).

1. *The effect of lip pressure and air pressure on the intonation and tone quality of the bassoon*. Journal of Sound and Vibration **32**, 262-262 (1973).