Why Can't We Make a Perfectly Tuned Trumpet?

Thomas Moore

The modern trumpet is truly a wonderfully designed instrument and with practice you can do wonderful things even with a mediocre trumpet. What is most amazing to me is that the design is almost completely the result of trial and error. Physicists are the latecomers to the world of the trumpet and we scientists are often left trying to figure out why the instrument is as good as it is.

Although it is a marvelous musical instrument, the trumpet has some really strange quirks. For example, to change the pitch you push down a series of valve combinations that change the length of the horn. This is a very effective and efficient way to change the length; however, when the third valve is used the trumpet becomes a quasi-trombone and the player must position the slide appropriately to play in tune. I think that we are all so used to this action that it seems unremarkable, but when one stops to think about it this is very strange.

All good musicians recognize that valve combinations using the third valve are not tuned very well. We just take this for granted. But why can't someone make a trumpet that is tuned correctly? Many people are working very hard at making state of the art trumpets, but to my knowledge no one is seriously proposing to eliminate the third valve slide and still keep only three valves.

To understand the necessity for the third valve slide it is useful to examine a hypothetical instrument; call it the perfect trumpet. In the perfect trumpet the second valve would lower the pitch by one semitone and the first valve would lower the pitch by two semitones. When the valves are arranged in this way it is possible to lower the pitch by one, two or three semitones by alternately pressing these two valves separately or together. In the perfect trumpet the third valve would lower the pitch by four semitones and all notes could be played in tune by pressing combinations of one, two or all of the three valves. Unfortunately there is no such thing as a perfect trumpet. The problem can be most easily explained through an example.

To lower the pitch of the trumpet by one semitone of an equal tempered scale requires the length of the horn to be increased by 5.95%. Since the average B-flat trumpet is about 140 centimeters long, the length of the tubing added by pressing the second valve should be 8.3 centimeters (about three and one-third inches). Likewise, to lower the pitch two semitones the length added by pressing the first valve should be 12.25% of the length, or about 17.2 centimeters. To get a reduction in pitch of three semitones requires the trumpet to be lengthened by 18.93% or 26.5 centimeters (about 10 inches.)

Clearly we have a problem. Because the change in pitch is calculated based on a percentage of the length, combining the first and second valves do not produce the correct length to lower the pitch by three semitones. This is because the trumpet with the first valve pressed down is longer than the trumpet with all valves up; therefore, to lower the pitch by one more semitone the length of tubing added by the second valve now needs to be 5.95% of the sum of the length of the trumpet with no valves pressed plus the length of the tubing added by pressing the first valve. In this case the second valve needs to add 9.5 centimeters of tubing. Unfortunately, we only need 8.3 centimeters of tubing to lower the pitch by one semitone from the open valve arrangement. So by pressing the first and second valves simultaneously the trumpet is about one-half of an inch too short to reduce the pitch by three semitones.

To overcome this deficiency trumpet makers slightly lengthen the amount of tubing attached to the first two valves so that they are exactly the correct length for no combination of valves. They are slightly long when used by themselves and slightly short when used with other valves. It is incumbent upon the player to lip all of the notes to the correct pitch, which is not too hard to do. Unfortunately, when you add the third valve into the mix it becomes unreasonable to bend the notes far enough to keep all of them in tune.

All of this leads to the conclusion that the third valve needs to add different lengths of tubing depending upon what other valves are pressed. Therefore, modern trumpets have a third valve slide to accommodate this need. Like the other two valves, the length added by depressing the third valve on the modern trumpet does not correspond to any length associated with a perfect pitch transition. It is somewhat close to the length necessary to lower the pitch by three semitones from the open valve configuration but not quite, which is why we usually play notes with the first and second valve in combination rather than with the third valve alone except when absolutely necessary.

The scientific basis for this problem was recognized by musicians and craftsmen quite early in the development of brass instruments and since that time several attempts have been made to overcome the need for the third valve slide. My personal favorite is a design by Adolphe Sax. Since all valved brass instruments have the same problem regarding the length of tubing added by depressing a valve, Sax proposed that all brass instruments should have six valves. With six valves there are no compromises in determining the length of the tubing and the instrument will have excellent intonation. For good or ill, the idea never caught on.

You may occasionally see a nineteenth century trumpet design with only two valves. Given the discussion above it is not obvious how these instruments could ever play the music written at that time. The secret lies in the length of the instrument. Typically these instruments are six or seven feet long rather than the modern length of less than five feet. The added length places the overtones closer together and the need for a third valve can be eliminated.

Before concluding it is important to note that the example presented above explains the main problem with valves and the need for the third valve slide, but it is incomplete. Besides merely adding length to a trumpet, pressing a valve also changes the relationship between the mouthpiece and the bell as well as putting extra bends in the tubing. This makes an exact calculation of the appropriate length for the valve tubing very complicated. However, the basic problem remains; valves must add different lengths of tubing depending upon what other valves are pressed, and unless we opt for Adolphe Sax's version of the trumpet we are stuck with the third valve slide.

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