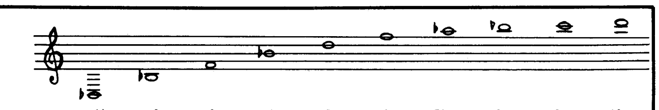
Sweetening Sour Notes

Physical analysis can help trumpets sound better

BY DIETRICK E. THOMSEN



Resonance	1*	2	3	4	5	6	7*	8	9	10
Note	$B\flat_2$	$B\flat_3$	F_4	$B\flat_4$	D_5	F_5	$A\flat_5$	$B\flat_5$	C_6	D_6
Frequency (Hz)	116.54	233.08	349.23	466.16	587.33	698.46	830.61	932.33	1,046.5	1,174.7

Smith and Daniell/Nature

Notation and frequencies of the first ten trumpet resonances. Starred ones are not actually used in playing.

Anyone who has heard a child beginning to learn the trumpet knows how sour many of the beginner's notes will sound. Parents, who may anxiously wonder whether they are wasting the money, will be relieved to learn that not all of the unwanted sharping and flatting is the child's fault. Wind instruments have idiosyncracies of design that contribute to off-pitch notes, and part of becoming an experienced player is to learn to compensate for them by lipwork. Indeed, clarinetists are frequently taught that the way to make that instrument's highest notes come out on pitch—they tend to sound like a banshee with a frog in her throat when the beginner first tries them—is to "sing" them mentally, a process that comes close to psychokinesis.

The manner of designing and playing musical instruments has grown up as a tradition based on trial and error and imitation of masters that is something of a mystique. Experienced players usually cannot analyze how they achieve the results they do. They know only that somehow, by imitation of their teachers and a lot of emotional and physical strain, they have managed to acquire the technique.

Scientists interested in musical instruments tend to take a less romantic view. To the traditional inspiration and perspiration of the artistic genius they would add a soupçon of mathematical analysis. The question is: Can science help the design of musical instruments to provide reliable ways of achieving optimum tone quality? A good deal of work has been done on stringed instruments, and a rather odd-shaped family of viols has resulted. Now it is the turn of the winds. In the Aug. 26 NATURE Richard A. Smith and Geoffrey J. Daniell of Southampton University in England report work they did with trumpets to see whether scientifically determined alterations in design could improve the intonation of the instruments.

A trumpet is basically a long metal tube in which a standing sound wave is excited to produce a tone. To go up in pitch from the lowest possible frequency of the tube, the player excites successive higher resonances (basically these are multiples of the lowest frequency, but in what musicians call equally tempered tuning, they are not quite). A single series of resonances does not supply all the notes of the chromatic scale so the modern trumpet is fitted with valves that add various lengths to the tube. This adds different series of resonances that supply all the desired notes.

But an artist's life is more complicated than this. When any particular note is played, its overtones are set ringing in various combinations of loudness and—because the overtones of a given note do not always correspond exactly to resonances of the basic sound tube—various combinations of slight sharpness or flatness. The total impression of this ringing together provides what is called the tone color of the instrument. Tone color allows the ear to tell the trumpet from the clarinet and both of them from a soprano. Without it an orchestra would sound like a collection of tuning forks. With it much of the art of music is possible. The traditional duel between the soprano and the flute that occurs in almost every Italian opera (the mad scene in *Lucia* is a spectacular example) delights because of the difference in tone color.

What Smith and Daniell intended was to find a mathematically justified method for altering the bore of the trumpet, that is, changing the diameter of the tube at the nodal points of the standing waves so as to adjust the resonances for the best balance of overtones for optimum intonation. In doing this one must be careful that an improvement in the balance of one note does not destroy that of another and that the method does not require too large a set of changes in the cross section of the bore over short stretches of its length.

The two physicists derived a set of equations based on the pressure at the nodal points, the cross section of the tube at those points and a number that represents the change in resonance frequencies brought about by a small perturbation of the cross section. Solving the equations analytically seemed too tedious so they did it experimentally using an apparatus that plays the trumpet automatically and measures the pressure at the nodal points.

The result leads to a design that gives an optimum intonation—what is optimum was decided somewhat arbitrarily by setting limits on the permitted tone shift of certain resonances and restricting the perturbations of the cross section to the first 0.9 meters of the tube. The shape this leads to was produced with glass-reinforced plastic, and it shows an intonation quite close to what the theory predicts.

Even so, Smith and Daniell believe that their method will be useful not so much for completely redesigning the trumpet as for "the improvement of the individual notes of prototype instruments." They give the particular example of an instrument that had a weak second harmonic when playing the note D_5 (587.33 hertz or the ninth above middle C). This harmonic happens to use the trumpet's tenth resonance for reinforcement, which was found to be flat with respect to the fifth resonance. The tenth resonance is not normally used for a fundamental note of the scale, so altering it would not hurt something else. "Using our new technique," Smith and Daniell conclude, "we were able to raise this tenth resonance by 10 cents [one cent is one hundredth of a tempered semitone, or one hundredth the distance between C and C sharp] to give the improved response." □

The temper of the tones

In the accompanying article the term "equally tempered tuning" is used. As every child knows, on a piano the notes C sharp and D flat are the same tone, produced by striking the same black key. That is tempered tuning. Violins and other strings on which the player can stop the string at any point along the fingerboard do not have it. On a violin C sharp is slightly higher than D flat. That is natural tuning, and it was the way musicians played for centuries.

For a keyboard instrument to have natural tuning would require something more than twice the black keys it already has, and at that keyboard players would throw up their hands. So designers compromised and split the difference between sharps and flats. About the turn of the 18th century, when keyboard instruments were becoming popular for household use and as supporting instruments for chamber ensembles, their tempered tuning required some adjustment in composing and performing techniques, hence the discussions and examples of how to deal with tempered tuning in the literature of the time.

Modern woodwinds have tempered tuning built into the arrangement of their finger holes. Modern horns (brasses) are also arranged for tempered tuning. In notation, the old distinction between C sharp and D flat, and—even more useless-seeming to the beginning piano student—between E sharp and F, are retained because strings operating alone still like to use natural tuning.

—Dietrick E. Thomsen