Observation of the Brass Player's Lips in Motion

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Abstract: Stroboscopic images of the lip reed in motion show that the upper lip does not act as a lumped element. Instead, a heavily damped, strongly driven Rayleigh wave propagates in a thin, passive layer of flesh on that lip. It is this motion that provides the valving action on the volume velocity injected into the mouthpiece. Beginning brass players may advance more rapidly if they can observe the wave motion on their own lips.

THE OUTWARD-STRIKING REED MODEL

This well known model for the driver of a brass instrument treats each lip as a hinged door that is blown open by a difference in air pressure acting on its two large surfaces. A spring force provides a restoring torque, and that combines with the moment of inertia to determine a natural frequency for the door. Continuous changes in the stiffness and perhaps the moment of inertia can vary this frequency continuously when the reed is operated in isolation. If it is attached to an air column with strong resonances, acoustic feedback from that structure prevents a "soft" reed from sounding except at frequencies close to the maxima of the air column's input impedance.

Proposed by Helmholtz more than a century ago as the basic model for the brass player's lip reed, this is a perfectly natural first guess at the operation of that driver. Most brass players who have given any thought to the matter would probably say that their lips are being blown open by air pressure inside the mouth which is higher than that on the other side of the lips (1). This mental image is so obvious that it should not require any exposure to musical acoustics or music pedagogy. Plausible as it may seem, however, this model is simply not correct.

TECHNIQUES FOR CAREFUL OBSERVATION

To see the wave motion on the upper lip, one must be able to resolve fine details on its surface, preferably without distortion. This can be done by using a mouthpiece with a flat window and a backbore that comes off at an angle, rather than straight ahead (2). If the volume of the cup is correct and the edges of the throat are smooth, such a mouthpiece behaves remarkably like a normal one, even if the backbore comes off the cup at a right angle. A stroboscope can then be used to get a slow-motion image during the steady part of a note, and a magnifying mirror makes the details of this motion easy for the player to see. Alternatively a video camera with a fairly high shutter speed (1/10000 S) provides an image with only minor blurring. A zoomed image can be made quite large on the screen of a regular TV set or a monitor. The focus must be adjusted manually and quite carefully, with the camera and the mouthpiece mounted at a fixed distance from each other. This technique limits the playing frequencies to those close to the harmonics of 60 Hz, but it allows many people to see the image simultaneously.

The first thing to observe is not the opening between the lips, but the motion on the front surface of the upper lip. One can see that this is clearly a wave disturbance, with different parts of the surface moving out of phase with each other. The straight-on view provided by an end window emphasizes the in-plane or longitudinal component of the motion. The side view through a vertical window in the rim of the mouthpiece provides clear evidence that these are Rayleigh waves, with each particle on the surface of the lip moving in a roughly elliptical orbit.

These views do not provide direct information about the valving action on the flow of air into the mouthpiece. The wave disturbance visible on the front surface of the lip could be just a side effect from some other type of motion in the narrow passageway between the lips. Carefully orienting the mouthpiece and the camera for sighting directly along the channel shows that this is not the case, and that the Rayleigh wave actually propagates along the upper surface of the air channel. A slight tilt to the end window helps with this view, since the channel is almost always directed below the center of the mouthpiece cup, with considerable variation among performers. The viewing angle is important because the channel can be fairly long compared to its height.

There is no single, continuously existing flap of flesh that moves back and forth like a swinging door. Instead, a (downward pointing) crest of the Rayleigh wave disturbance propagates downstream with the net flow of air,
growing larger under the influence of transverse forces due to the Bernoulli effect, and reaching its maximum amplitude at the downstream end of the channel. The valving action is a brief closure rather than a brief opening. Even as the height of the channel diminishes and the volume velocity drops along with it, the transverse force that causes further closure can still be large, because it is proportional to the square of the particle velocity, rather than the volume velocity. The longitudinal forces that are of primary importance in Helmholtz's outward-striking reed model are present and significant, since they move the wave crests in the downstream direction and out of the channel. However the longitudinal pressure difference acts only on the area projected normal to the channel axis. That is noticeably smaller than the area acted upon by the variable transverse pressure at the constriction, except when the crest develops a cusped shape near the end of the channel. This motion is easier to observe if the strobed image runs backwards. Each crest can then be followed back into the channel until it is eclipsed by another.

The idea that the air stream blows the flexible channel closed rather than open can be illustrated by a simple demonstration. A sheet of paper is rolled into a tube and supported horizontally on a rod to represent the upper lip. The less flexible lower lip is represented by a tube made from two sheets of paper, supported behind and above the first one, so that this embouchure model is upside down. Gravity causes the aperture to be open fairly wide at first. An air stream directed between these paper tubes pulls them together and generates waves in the thinner one; these valve the flow of air through the aperture at a frequency of around 5 or 6 Hz. The other tube performs a rocking motion as a lumped element, so that it contributes little to the valving action. Its motion can be stopped without destroying the wave motion on the other "lip." Those who can buzz their lips into open air can perform a similar experiment by touching each lip with a pencil eraser, or by covering each one with a sheet of paper.

**SIGNIFICANCE FOR PEDAGOGY AND MODELING**

Some brass players are fortunate enough to have a "natural" embouchure, so that they can get a decent sound very early and develop it using aural feedback. Others must get past initial difficulties by paying conscious attention to some of the many muscles that must be coordinated to generate a musically useful buzz. What different individuals think about to correct a problem can vary considerably, and this can make it difficult for a teacher to help a student. Verbal suggestions like the "puckered smile," "directing the stream of air," and many others have only an indirect effect on the sound generator, so that what works for one player may not work for another. An analogy is provided by the task of hitting a golf ball. Everything that is done or thought about before or after contact affects only a small number of parameters involved in the brief collision between the head of the club and the ball; there is too little time for you to alter anything during the contact. Similarly, it can be very useful to know that there are no muscles in the part of the upper lip that actually makes the buzz. Changes in the embouchure only adjust muscles to vary the tension and dimensions of a passive layer of flesh. Thus there is a remoteness in space here that is like the remoteness in time for hitting the golf ball. With this knowledge, a student may learn more quickly to generate a sound efficiently, without unnecessary tensing of muscles against each other.

It will be considerably more difficult to create a realistic computer model of this system than Helmholtz's lumped element model. However it is interesting to notice that the two-dimensional model of Adachi and Sato (3) includes large transverse forces as well as longitudinal ones and shows a very realistic asymmetry in response to driving a mode sharp or flat. One difficulty with this model is that it fails to conserve the volume of the lip material, which is negligibly compressible. If the piston surface and side walls in their model are allowed to flex for that purpose, then we begin to see motion similar to that of the Rayleigh waves. (The motion in roughly elliptical orbits is there even without this modification.) Quite likely the development of a wave model will involve adding coupled elements to the Adachi-Sato model, paralleling similar refinements of models for the vocal folds (4).

**REFERENCES**

1. Farkas, P., *The Art of Brass Playing*, Bloomington, IN: Brass Publications, 1962, Ch. 1, especially Fig. 18 on p. 22.