Fluid dynamic aspects of human voice and brass instruments: implications for sound synthesis

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Abstract: The challenge of physical models of musical instruments is to provide a global description of a highly complex instrument which has to be accurate but simple enough to be numerically implemented. For this purpose, a logical approach is to extract, from a theoretical or experimental study, what are the most important phenomena involved which are thus to be taken into account. Two examples of such an approach are given by the physical models of human voice and brass instruments presented here. Although both instruments share in common the same basic principle: a self-oscillating source coupled with a resonator, crucial physical aspects are quite different.

EXPERIMENTAL RESULTS

In the case of voicing, the acoustical coupling between the source (the glottis) and the vocal tract has been widely studied experimentally or theoretically. It is generally well accepted that this coupling is weak but has some limited effects concerning the skewing of the glottal pulses (1) or on the threshold of voicing (2). In the case of brass instruments, mouthpiece pressure measurements clearly show the strong acoustical coupling with the instrument. This coupling can be evidenced by comparing the mouthpiece pressure measured with and without the instrument attached. Figure 1 presents an example of such a comparison in the case of the F_1 note (117 Hz) (3). As without the instrument the mouthpiece pressure clearly exhibits interaction ripples due to the coupling with the mouth cavity (4), there is no more trace of such a coupling when the instrument is attached.

FIGURE 1. Comparison between the Mouthpiece pressure measured with (solid line) and without (dotted line) the instrument attached to the mouthpiece.

Wave propagation inside the vocal tract or the trombone is generally described in terms of one-dimensional linear acoustics. Considering the internal width of a brass instrument, the assumption of plane wave propagation appears quite a reasonable one. This might not be the case in the case of voicing due to the presence of much wider cross-sections. In such a case, allowance for the propagation of higher acoustical modes must be made. Recently, Hirschberg et al (5) have evidenced the presence of shock waves in trombones when played at fortissimo levels. This has been further confirmed by Gilbert and Petiot (6) in-vivo or using an artificial mouth. An example of results is presented in figure 2.
This effect, which be explained by a non-linear distortion of the propagating waves, can only occur if the pipe is long enough. Due to the relative short length of the vocal tract, these non-linear propagation effects are not relevant for human voice.

![Graphs showing pressure over time for different sections of a trombone](image)

**FIGURE 2.** Pressure measured inside the mouthpiece (left) and at the exit of of slide section (right) of a trombone.

**IMPLICATIONS FOR THE PHYSICAL MODELS**

Although human voice and brass instruments can be understood on a common basis: a self-sustained oscillating source coupled with a resonator, the results presented above enhance important differences which must be taken into account and will lead thus to different physical models. In the case of brass instruments, the lips self-sustained oscillations are mainly driven by the acoustical coupling, therefore the simplest one degree of freedom model for the lips is sufficient. As a matter of fact, Elliot and Bowsher (4) have verified that a regeneration process in brass instruments based on a one-mass model of the lips is in good agreement with their experimental results (4). Similarly, simplified flow models are sufficient. On the opposite, much more attention must be paid on the vocal-folds models: at least two degrees of freedom are needed and "details" of the flow such as unsteady flow separation are to be taken into account (7). Non-linear wave propagation is another major difference between voice and brass instruments. A simple approach, proposed by Msallam et al. (8) describes the distributed non-linearity as concentrated in the slide. Assuming lumped visco-thermal losses, the distortion is simply modelled using a time varying delay propagation line where the delay is a function of the amplitude of the input signal.

**SIMULATION RESULTS**

The sound samples presented during the conference can be found online: [http://www.icp.inpg.fr/~pelorsosounds](http://www.icp.inpg.fr/~pelorsosounds).

**REFERENCES**