Report on Sound Quality Test for Flutes

Junru Wu, Ph. D
Professor of Physics
Fellow of Acoustical Society of America

Introduction

Sound quality of two structurally identical flutes, one is made of silver (SF) and the other of titanium (FT) were tested in the Acoustics Laboratory, University of Vermont on December 6, 1998.

Research in Musical Acoustics has shown that timbre is used to distinguish and characterize quality of a sound; it is by timbre that we recognize an instrument. Timbre of a sound is determined by the proportions in which the various harmonics are heard in it; in other words, timbre depends on the relative intensity of harmonics of a sound.

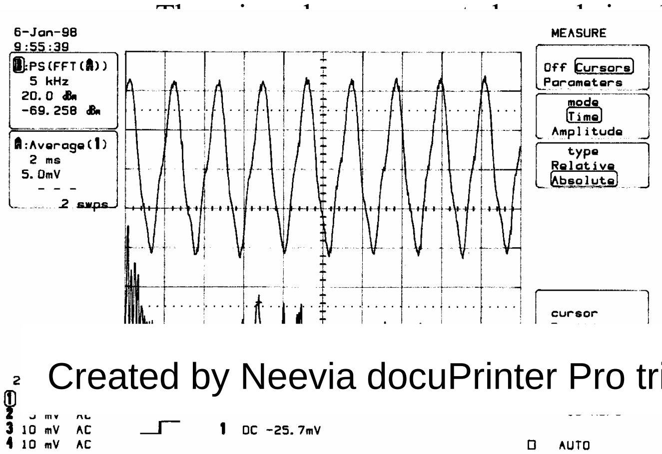
A sound generated by an instrument may include harmonics. If the fundamental frequency of the sound is f, its second, third, and fourth harmonics are 2f, 3f and 4f respectively. For example, the fundamental of note A is 440 Hz, the frequencies of its second, third, and fourth harmonics are 880 Hz, 1320 Hz, and 1760 Hz. Generally speaking, the second and fourth harmonics add clearness and brilliance; they introduces no difference of timbre. The third harmonic, in addition to adding a certain amount of brilliance, introduces a difference of timbre, thickening the tone, and adding to it a certain hollow, throaty or nasal quality. The fifth harmonic adds a rich somewhat horn-like quality to the tone.

The main purpose of the test is to determine if there is any detectable difference in timbre when those two flutes are "played" in a similar condition.

Experimental Method

It is essential to "play" those two flutes in a same controlled condition during the test. A flute blowing apparatus was designed and fabricated by Mr. Jonathon Landell. This apparatus generates a reproducible repeating air flow, which simulates the air stream generated by an experienced flute player. The detail of the apparatus can be found in an attached document titled "Flute Blowing Apparatus."

A flute was placed horizontally on a wooden table. A calibrated B&K (model 4134) 1/2" diameter condenser microphone mounted on a stand was kept facing the flute at the same height; the vertical distance between the microphone and the flute was 15 cm.



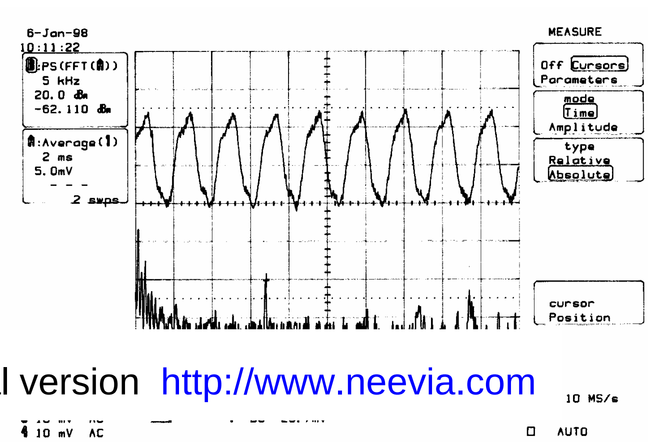
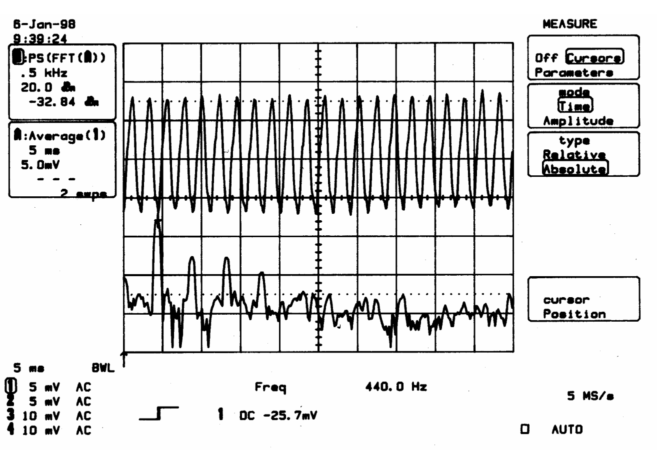
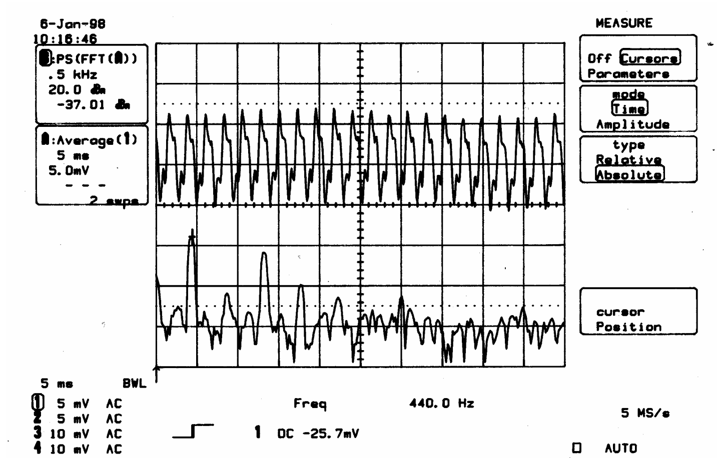


Figure 1 **Figure 2**

Figures 1 and 2 contain signal traces for SF and TF respectively. They were "blown" by the flute blowing apparatus under the same condition. The top trace of each figure recorded the electrical voltage verse time and the bottom one was frequency spectrum of the top signal. Comparing figure 1 with figure 2, it is clear that the signal produced by SF was smoother. Consequently, the relative amplitudes difference between the fundamental and harmonics in figure two was higher than that in figure 1. The frequency span in both figure 1 and 2 is 0-50 kHz. For example, the amplitude at 17 kHz





was -69 dBm in figure 1 while that was -62 dBm in figure 2. The latter was 7 dBm higher.

Figure 3 **Figure 4**

To see the detail of the frequency spectrum of each trace for low harmonics, we re-plotted figure 1 and 2 in a smaller frequency range as shown in figures 3 and 4. Figures 3 and 4 are for signals generated by SF and TF respectively, but the frequency range is only between 0 to 5 kHz. It is quite evident that the amplitudes of the third and fifth harmonics relative to the fundamental in figure 4 are higher than those in figure 3. As mentioned earlier that it is the third and fifth harmonics that determine the timbre of a sound, therefore, the timbre of the TF is richer than that of SF.

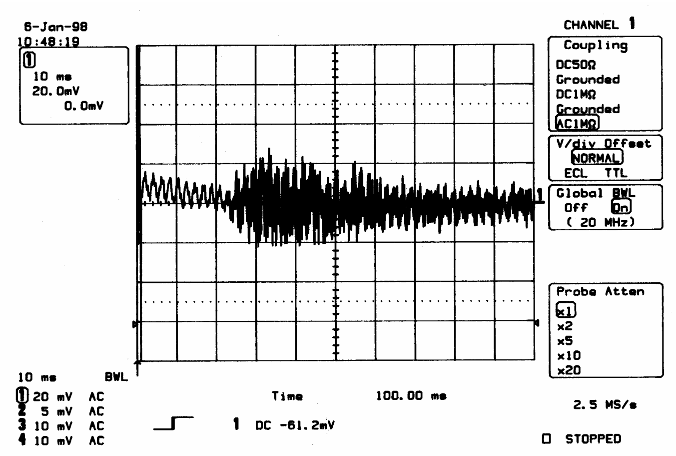


Figure 5

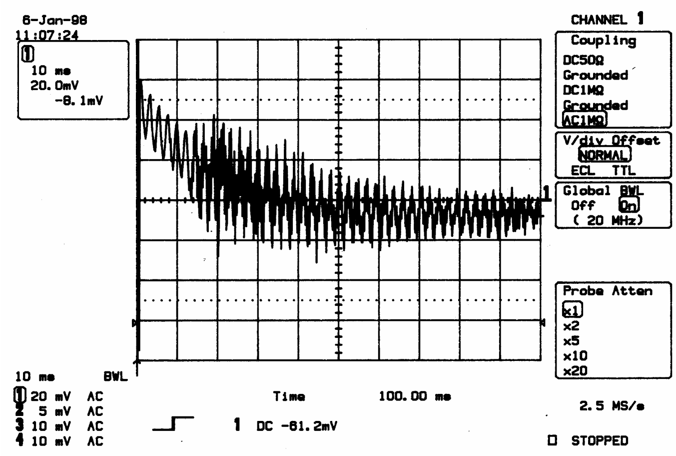


Figure 6

It was noticed by Mr. Jonathon Landell that the response time to an impulsive flow (flow pulse) of those two flutes were different. To verify that, additional experiments were performed. This time, they were driven by an air flow pulse controlled by the flute blowing apparatus. The length of the air flow pulse was less than 1 second. Figures 5 and 6 recorded the signals of the response for SF and TF respectively. Both traces were triggered by the air pulse. The dark and thick traces are responses of the flutes. It is clear that the response time of SF was about 20 ms and that of TF was around 12 ms. The response time of TF was about 8 ms shorter than that of SF.

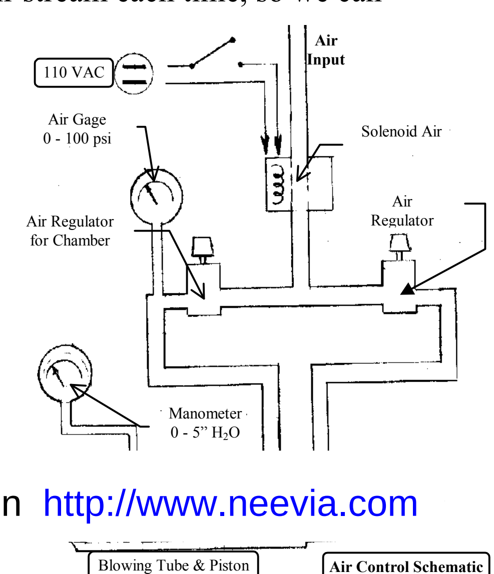
Flute Blowing Apparatus

Jonathon A. Landell

The experiments were conducted at the University of Vermont using an apparatus for blowing the flute which uses compressed air from the shop, and has controls and adjustments that make it possible to make a sound from the flute that is similar to the way a flutist would play the instrument. There is a simple clamping arrangement for the flute that allows removing and replacing one instrument with another, repeating the experiment with exactly the same air stream each time. This assures that the sound produced from one flute to another has exactly the same air stream each time, so we can compare the qualities of different instruments with a predictable and repeatable air stream.

The Air Controls

The drawing at the right shows the arrangement of controls for the apparatus. A push-button switch activates a solenoid air valve which opens the compressed air to the system. The air stream divides

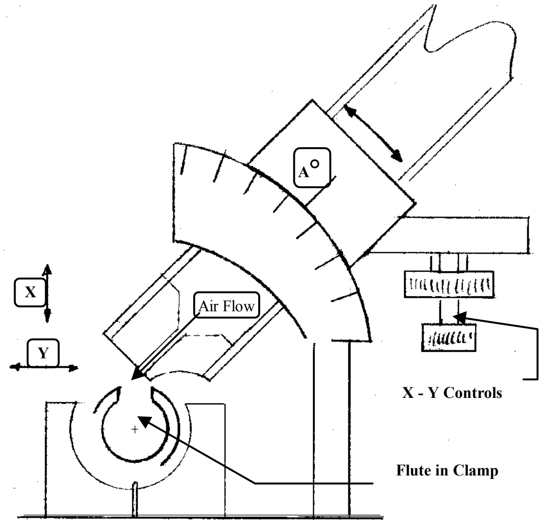


Air Control Schematic

into two paths, one for the blowing tube and one for the air piston. Separate regulators control pressure for each stream. When compressed air enters the blowing tube, a low pressure manometer indicates the actual air pressure for the stream, which can be accurately adjusted by the regulator. At the same by a regulator, which is adjusted to open the air stream when the initial air pressure in the blowing tube is about 1.5" H_2O. (This is the normal blowing pressure measured inside the mouth of a typical flutist while playing the note, A3.)

Blowing Apparatus - Side View

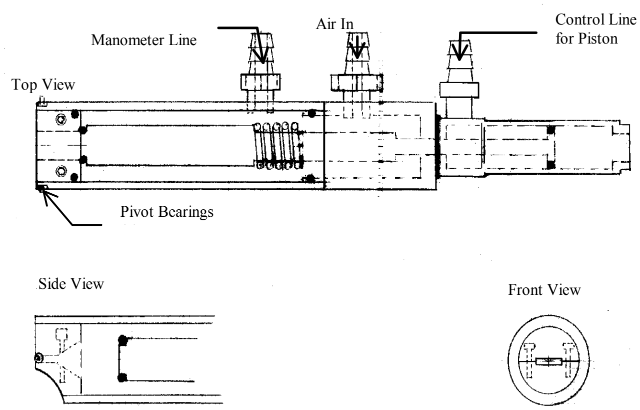
The blowing tube is suspended above the flute with controls for vertical (X) and horizontal (Y) movement, and it pivots on ball bearings that are mounted on either side of the exit point of the air. Angular adjustment (A°) is controlled and measured by a graduated vernier on the side of the blowing tube. With these movements, it is possible to measure the exact position of the blowing tube to a precision of .1 mm in X and Y, and to a rotational precision of 10 min. of the arc angle. When a new flute is mounted in the apparatus, there is a small gage that accurately adjusts the rotational position of the flute in the clamp, which brings each specimen onto the fixture at a consistent position. The X and Y movement is accomplished by adapting a microscope slide manipulator to the purpose at hand.



Flute Blowing Apparatus - Side View

Blowing Tube Detail

The blowing tube is made from a 1" diameter Lexan tube about 4 ½" long. The air piston is mounted on a mating piece of plastic at the end of the tube. A plunger made from ½" nylon rod is mounted on the end of the piston with a compression spring, such that the end of the rod contacts the exit point of the air, and a rubber O-ring seals the opening when the plunger is at rest. The air stream is formed by a piece of nylon, which was cut in half, milled with a narrow slot, and then held together with cap screws. The inside surface of the nylon is chamfered to receive the O-ring, and forms a smooth surface for the air stream. A pair of ball bearings are mounted in the Lexan tube exactly centered with the exit point of the air.



In use we found that the sound of the flute blown by this machine was not as complex as with a human player. The problem was the lack of "lips" above and below the exit point of the air stream. This was corrected by placing some modeling clay on the end of the tube to simulate the rounded shape of the lips. This corrected the problem to a certain degree, but we found that a human player, though not at all consistent in playing one tone exactly the same each time, was able to produce a tone that was more complex and interesting than the machine. More work is needed on this detail!

Blowing Apparatus Close-Up Photo

Dr Wu in the Lab