CCRMA – Stanford University
Music 318 – Free Reed Instruments
15 February 2013

Reed Vibration and Pitch Bending in Western Free Reed Instruments

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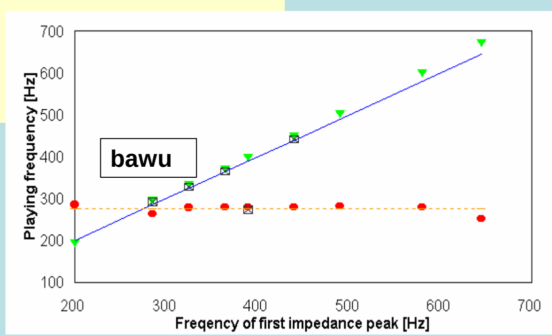
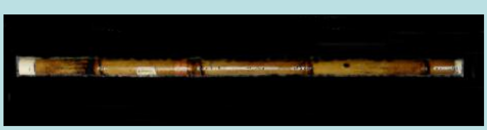
Essentials of pitch bending:

1. Coupling of reed to resonator(s)
2. Pressure (how hard you blow)
3. Bonus for harmonica – 2^{nd} reed in the chamber





Overview

I. Western free reeds
- A. Sound production
- B. Modes of vibration

II. Pitch bending
- A. Mouth blown (harmonica)
- B. Mechanically blown

III. Brock's work on the harmonica

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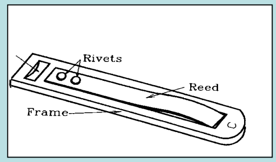
I. Western free reed instruments

- **Introduction**
- **The reeds**
- **Studies of individual free reeds**
  - **Displacement**
  - **Pressure**
  - **Airflow**
- **Modes of vibration of air-driven free reeds**
  - **Mode frequencies**
  - **Transverse modes**
  - **Torsional modes**

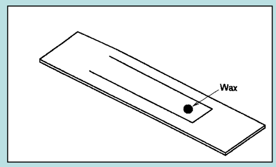
The free reed instruments --- two main families

- **Western free reed instruments:**
  - **reed organ and harmonium**
  - **accordion/concertina family**
  - **harmonica**

The Asian free reed mouth organs:
- ***khaen, naw***
- ***sheng, sho***
- ***bawu, hulusi***



…use <u>asymmetric</u> reeds like this one from an American reed organ.



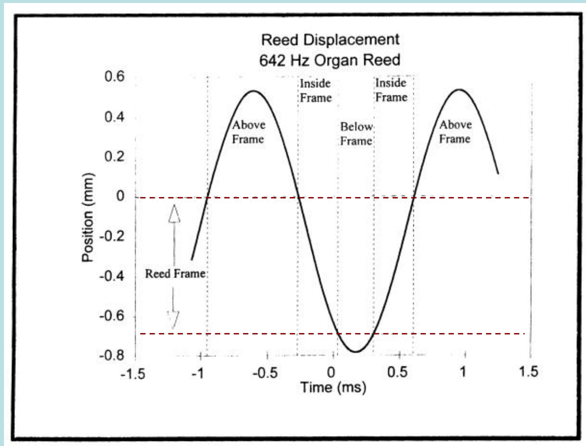
…use <u>symmetric</u> free reeds like the reed from a sheng.

Some Western free reeds …

Reeds from a Hohner *Verdi I* accordion

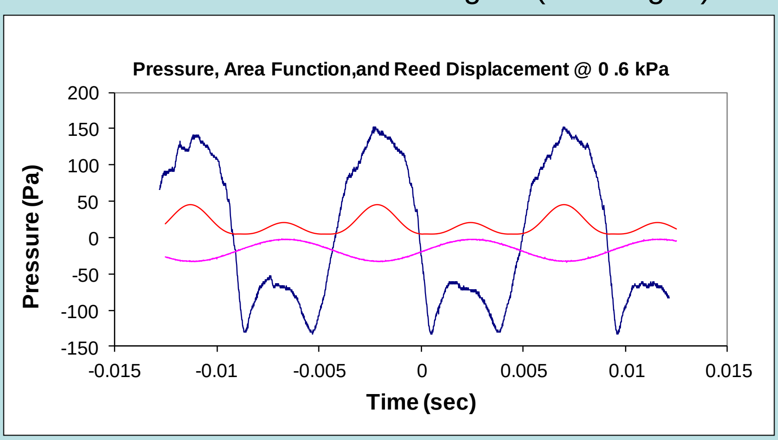
Reed from an Estey 2-manual/pedal reed organ once owned by Wilson Nolle

Measurements of reed motion can be made using a variable impedance transducer (VIT) or a laser vibrometer system.



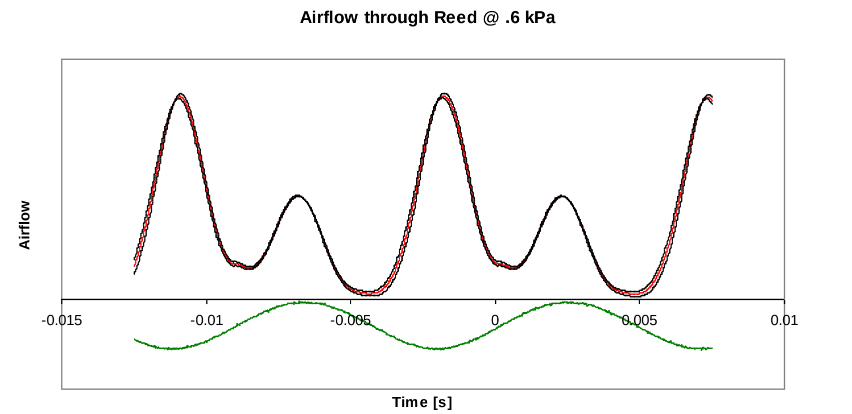
Example from Busha (1999)

Pressure measurements taken by a probe microphone a few millimeters from the reed tongue. (reed organ)



This graph of the pressure waveform (blue) also includes unscaled graphs of the reed displacement (magenta) and the area function (red).

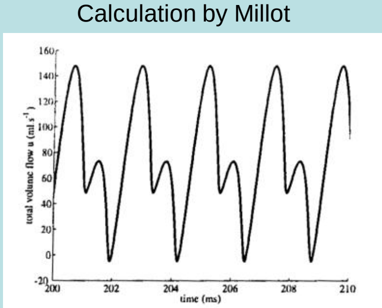
Volume airflow as a function of time is calculated from the pressure waveform and area function. (reed organ)

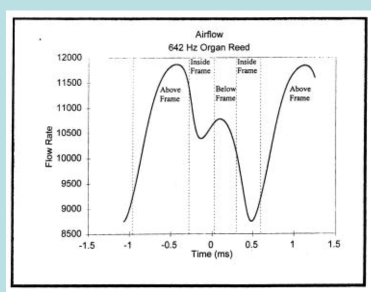


The red curve is the calculated volume airflow. The black curves are volume airflows calculated using minimum air speed value raised and lowered by 50%.The green curve is the reed displacement, shown for reference (unscaled).

Comparisons with models and earlier measurements

Calculation by Millot

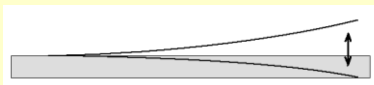




Results agree qualitatively with a calculation from a model of a harmonica reed by Laurent Millot 2007 and earlier measurements by Busha (1999).

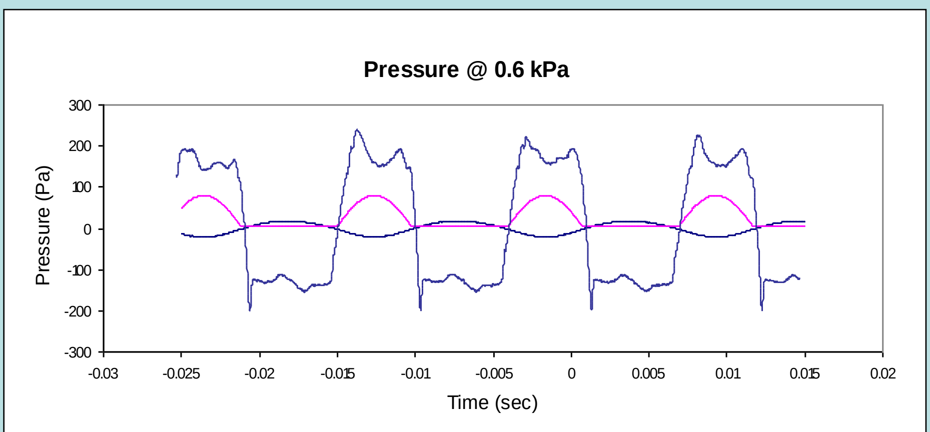
Similar plots for the accordion reed :

- Reed displacement
- Sound pressure
- Airflow

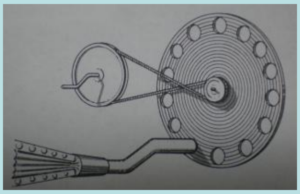


Because the accordion reed never passes below the (thick) reed frame, the accordion area function differs from that of the organ reed.

Pressure measurements are taken by a probe microphone a few millimeters from the reed tongue.



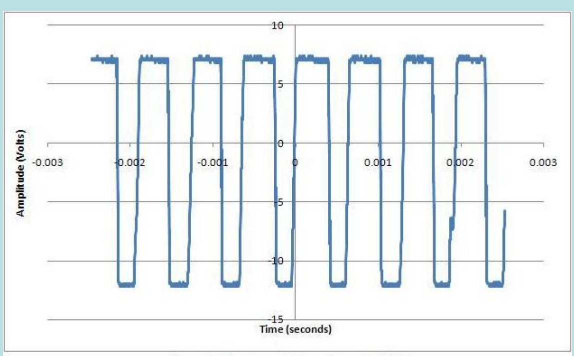
This graph of the pressure waveform (blue) also includes unscaled graphs of the reed displacement (black) and the area function (magenta).



Siren song - Helmholtz

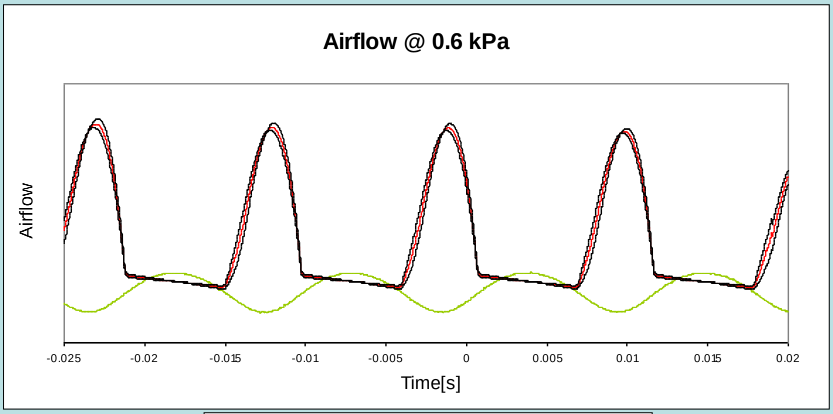
- At a simple level of analysis, the sound production of a free reed is similar to that of a siren.
- Hermann von Helmholtz: **"The passage for the air being alternately closed and opened, its stream is separated into a series of individual pulses. This is effected on the siren . . . by means of a rotating disc pierced with holes."**
- For the free-reed instrument, the air stream is interrupted by the oscillating reed tongue.

The thick reed frame results in a pressure waveform form similar to that from a siren, shown below …



Waveform found by placing a probe microphone 1 mm from the siren.

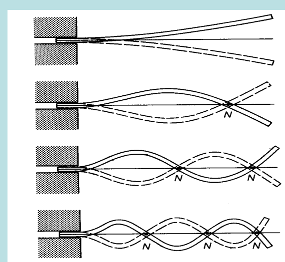
Volume airflow for the accordion reed as a function of time



Red curve is calculated volume airflow.
Green is (unscaled) reed displacement.

Modes of Vibration of the air-driven reed

- An free reed can be modeled as a cantilever beam (though the reed cross section is often not uniform)
- Reed motion is scanned with a laser vibrometer or VIT sensor.
- Peaks in frequency spectra are used to detect modes.
- A search for nodes is made to confirm mode identification.
- The first three transverse modes and the first torsional mode are present and can often be detected for an air-blown free reed in the laboratory

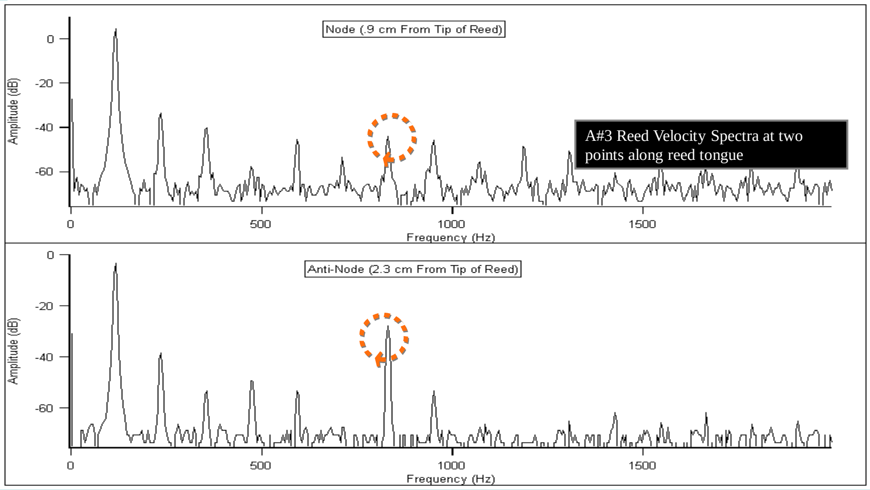


Modes of vibration observed include:

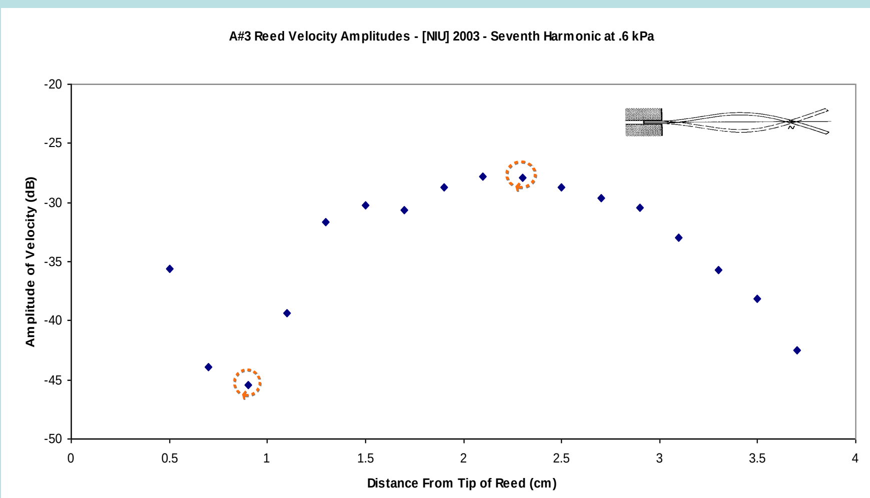
- the fundamental
- 2nd, 3rd transverse
- first torsional mode

Spectra of Second Mode in Air-Driven Reeds:

These spectra show the presence of the second transverse mode frequency at an anti-node of that mode and its absence at the node.

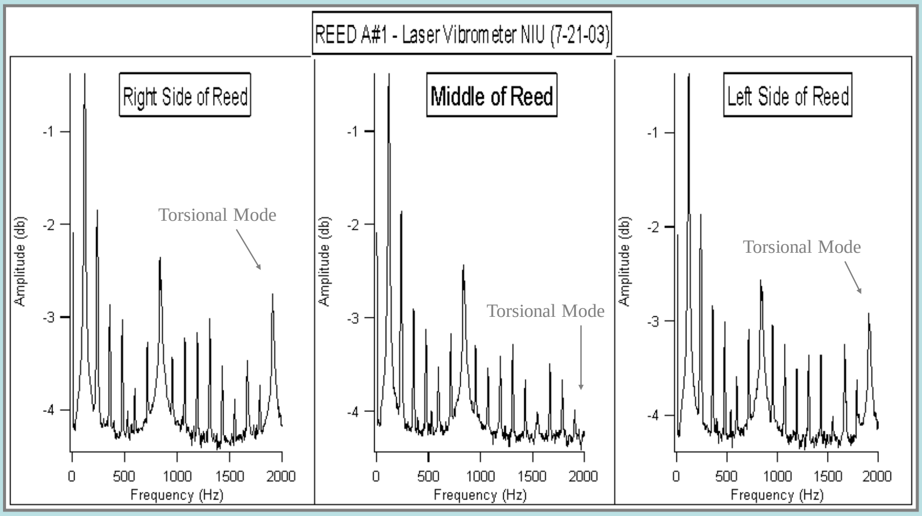


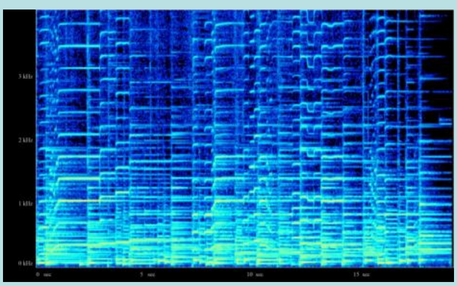
Velocity spectra from the laser vibrometer give the peak amplitudes of the second mode frequency taken at points along the reed tongue. Highlighted are points near a node and anti-node of mode 2.



Torsional Modes in Air-Driven Reeds:

The amplitude of the torsional mode frequency is large at points measured near the edges of the reed and absent in the middle, at the node.





II. Pitch bending and higher mode reed vibration in mechanically-blown free reed instruments

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Outline

- **Prelude: Pitch bending in the harmonica**
- **Question: Pitch bending in the accordion – Is it possible?**
- **Interlude: Pitch bending in free reed pipes**
  - **Aside: A few interesting multiphonics**
- **A pitch bending accordion design (Tom Tonon)**
- **Finale: A short demo –pitch bending accordion played by Kenny Kotwitz**

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Pitch bending

- Pitch bending in the harmonica, in which manipulation of vocal tract resonances plays an essential role, has long been a common practice.
- Here is an extreme example
- Howard Levy Playing *Evanston Tango* –
  - **in F$^{\#}$-minor** on a diatonic harmonica in C

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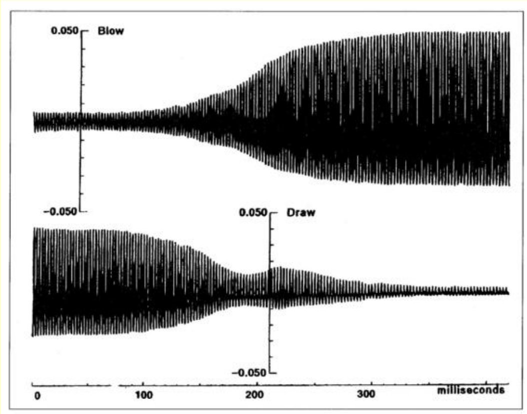
- Relative displacement of blow and draw reeds entering a draw bend from G to approximately F#.



- The draw reed speaks initially as a closing reed but the blow reed takes over as an opening reed as the player continues to draw, but changes embouchure.

Figure from Bahnson, Antaki, and Beery, *JASA* **103**, 2134 (1998).

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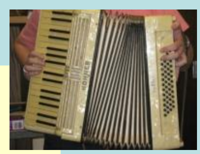
Pitch bending



- Pitch bending in free reed instruments with mechanically driven air supplies, such as the reed organ and the accordion, is a different matter.
- Some limited pitch bending can be done using partial opening of the pallet valve combined with variations in blowing pressure
  - R. Llanos-Vazquez, M. J. Elejalde-García, and E. Macho-Stadler, "Controllable pitch-bending effects in the accordion playing," *JASA* 123, 3662, 2008.
  - W. Coyle, S. Behrens, J. Cottingham, “Influence of Accordion Reed Chamber Geometry on Reed vibration and airflow,” *JASA 126, 2216*, 2009.

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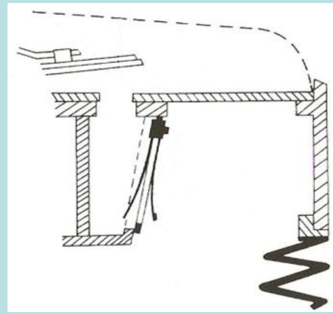
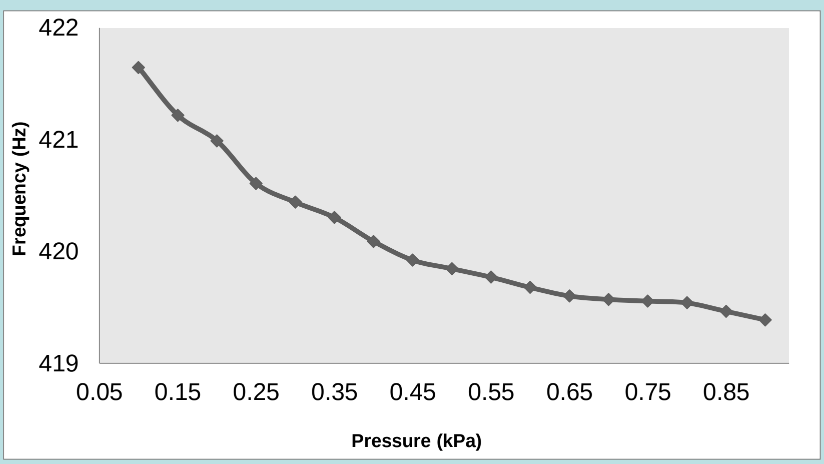
- **Pitch Bending:**
  - **Varying air pressure**
  - **Partial pallet opening**
  - **Changing reed chamber volume with inserts.**

Some data from
Whitney Coyle (2009) …



Pitch Bending

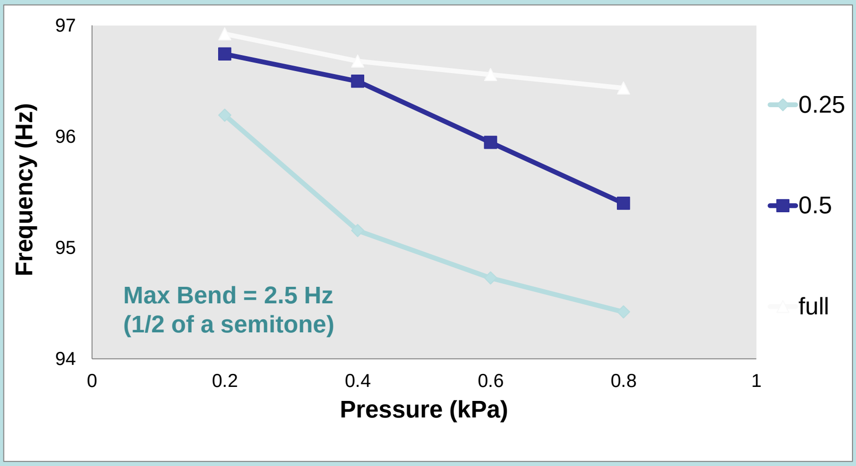
Frequency decreases (slightly) with increasing pressure



Sounding Frequency of G# reed as a function of blowing pressure

Pitch Bending - Partially Opened Pallet

Less key depression = greater decrease in frequency



Frequency of G# reed with varying key depression at increasing pressures

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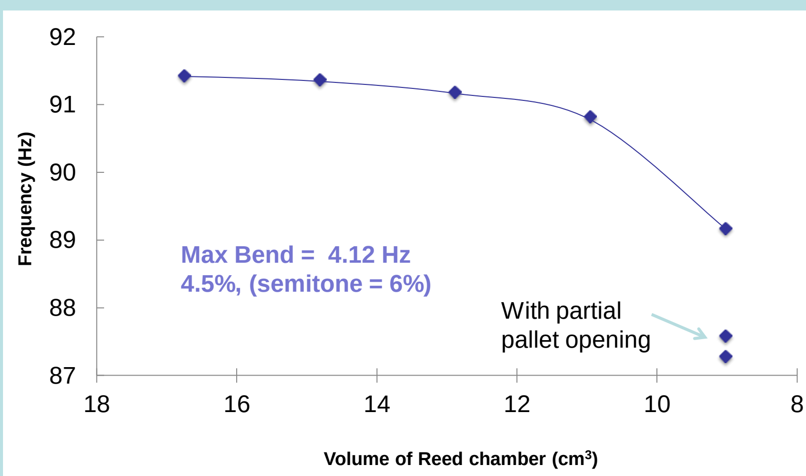
Pitch Bending – Decreasing reed chamber volume



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- Before looking at a more sophisticated, flexible method for pitch bending in the accordion, consider the free reed-pipe system …

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A blown-closed free reed coupled to a cylindrical pipe

- A harmonium type reed from an American reed organ coupled to a cylindrical pipe resonator
- Pipe resonance can pull the sounding frequency below the reed frequency
- The sounding frequency can be near the second or third pipe resonance.

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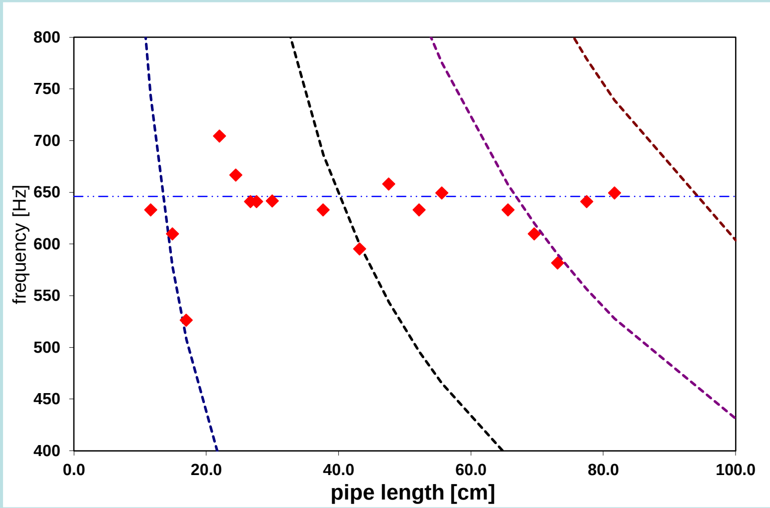
Sounding frequency of 646 Hz free reed coupled to pipe



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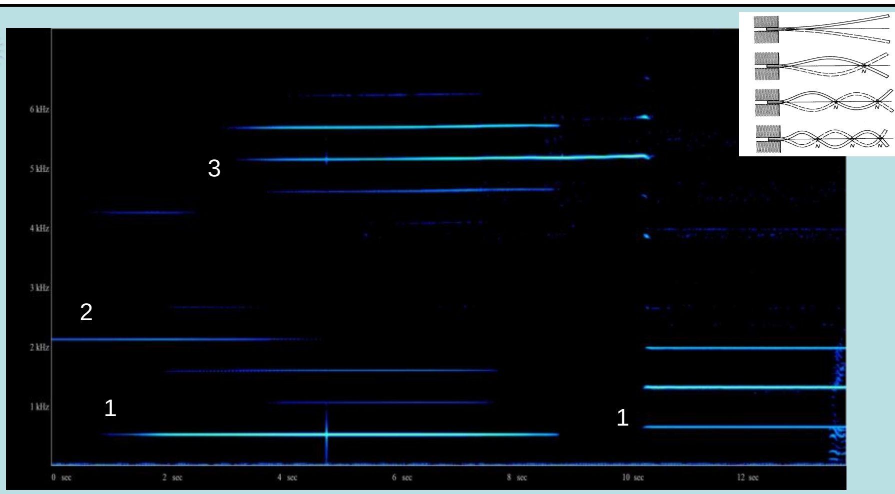

Spectrogram frequency of a free reed coupled to mismatched pipe as blowing pressure is gradually increased shows frequencies of transverse modes 1, 2, and 3 … sometimes simultaneously

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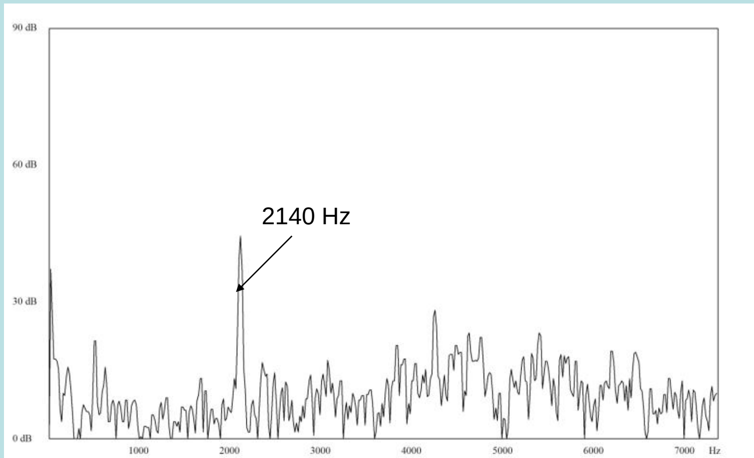
2nd mode



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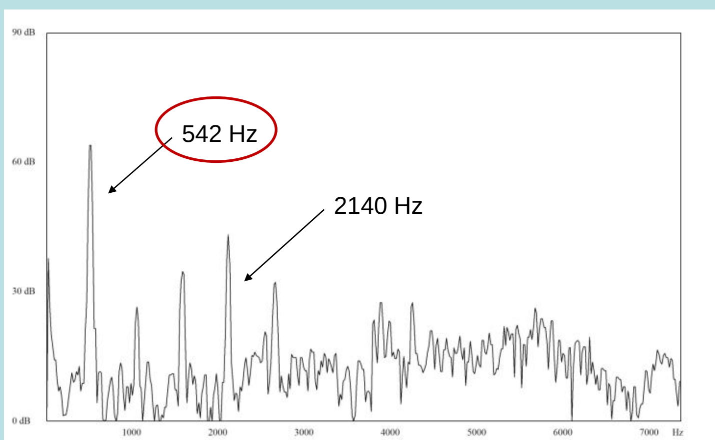
1st and 2nd mode



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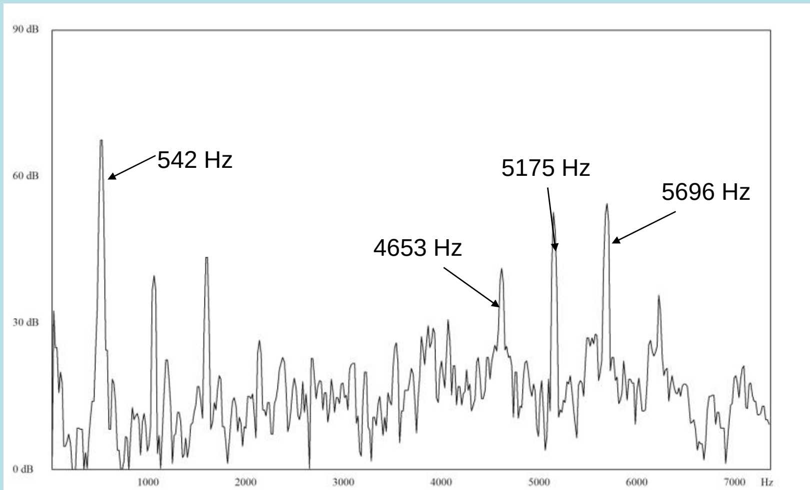
1st and 3rd modes



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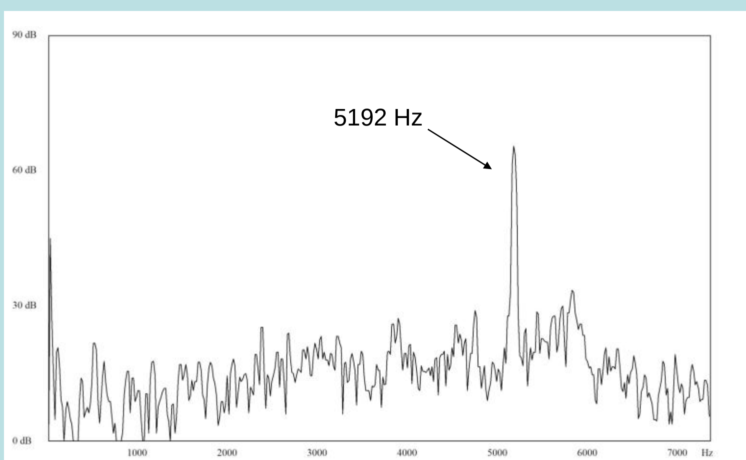
3rd mode



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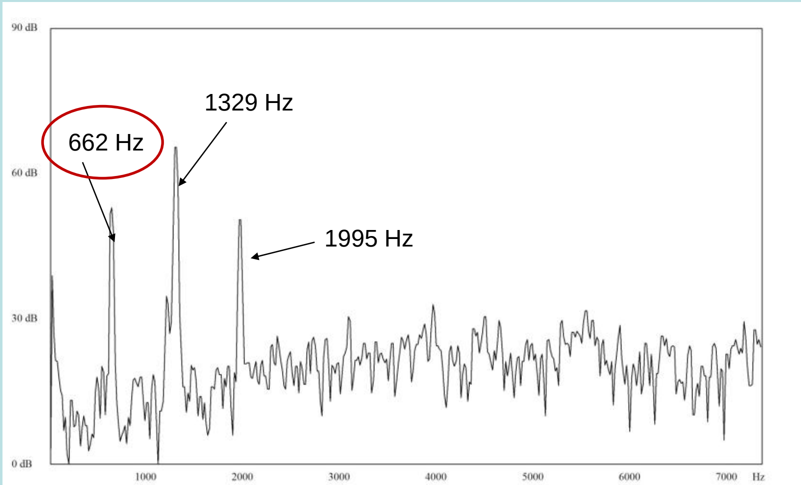
1st mode with Harmonics



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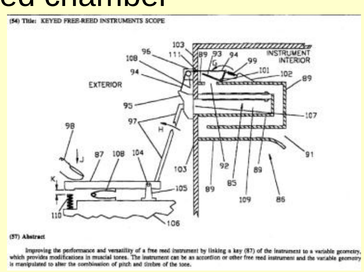
Back to:
Pitch bending in the accordion

- At the 2009 San Antonio ASA meeting, Tom Tonon described and demonstrated modifying accordion construction to include a resonating chamber in addition to the standard reed chamber



*Thomas Tonon, *JASA* 126: 2217 (2009)

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- "In keyed free reed instruments such as accordions and concertinas, the reeds are mounted over cavities that have little effect on the vibration of the reed itself, because resonances between the reed and cavity are rarely encountered…

- "Although these cavities can arguably affect the timbre of the musical tone, with improper design, such resonances can be annoying to the builder.

- "On the other hand, one can exploit such resonances in order to produce pitch bend and other acoustic effects, by intentionally designing the cavity for near resonance, and by providing a mechanism that permits the musician to engage resonance at will …"

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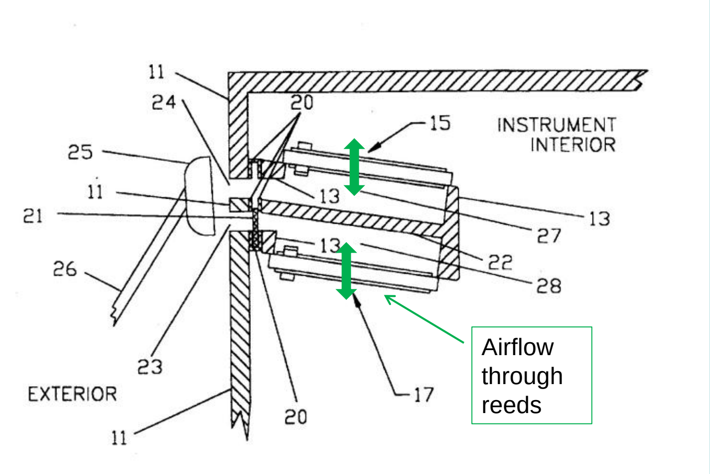
Standard accordion interior (*from T. Tonon patent*)



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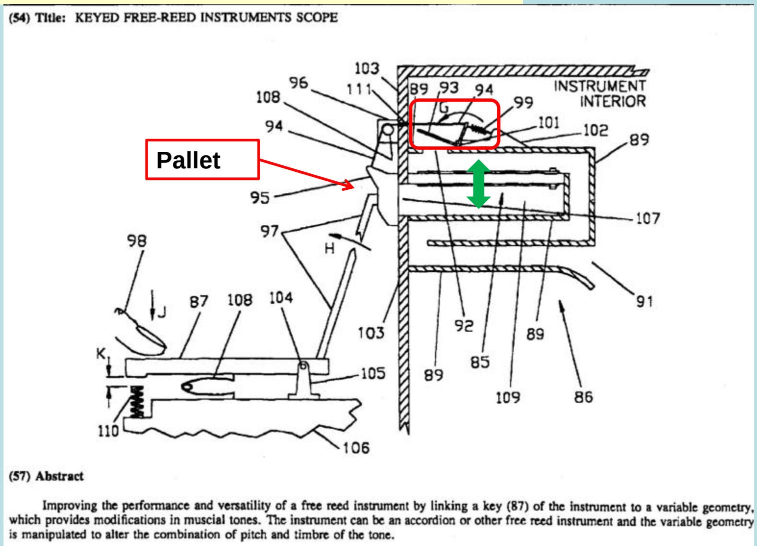
Pitch-bending accordion interior (*from T. Tonon patent*)



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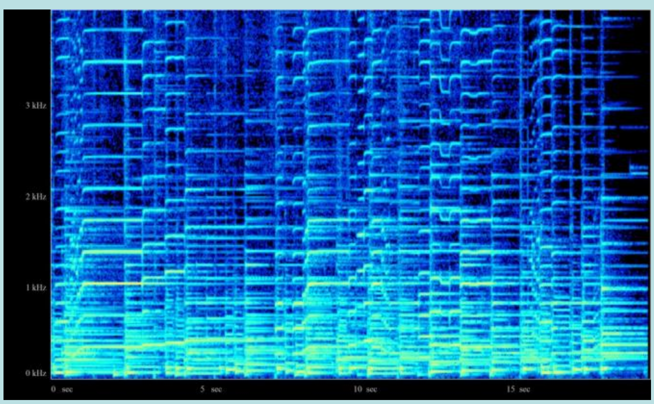
Pitch bending …

Excerpt from "One for My Baby" played by Kenny Kotwitz on accordion designed by Tom Tonon



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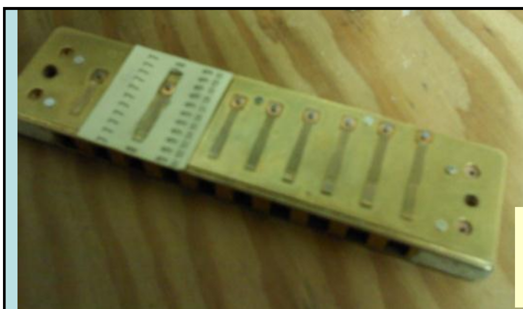
Effects of Pressure and External Pipes on Harmonica Acoustics

Casey Brock
Austin Peay State University

Jim Cottingham
Coe College (2011)



Hohner Marine Band in C

Draw Reeds

Blow Reeds

A 1987 paper by Johnston investigates the coupling of a free reed (harmonica) with a vocal tract approximated by a cylindrical pipe)

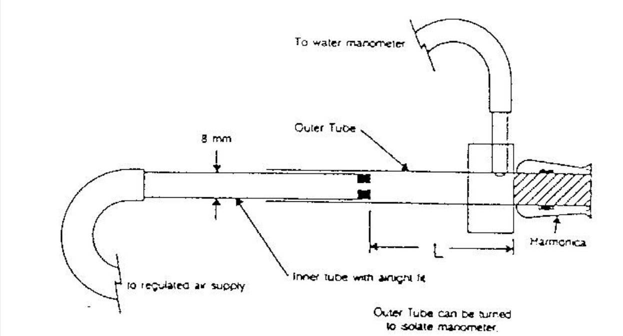
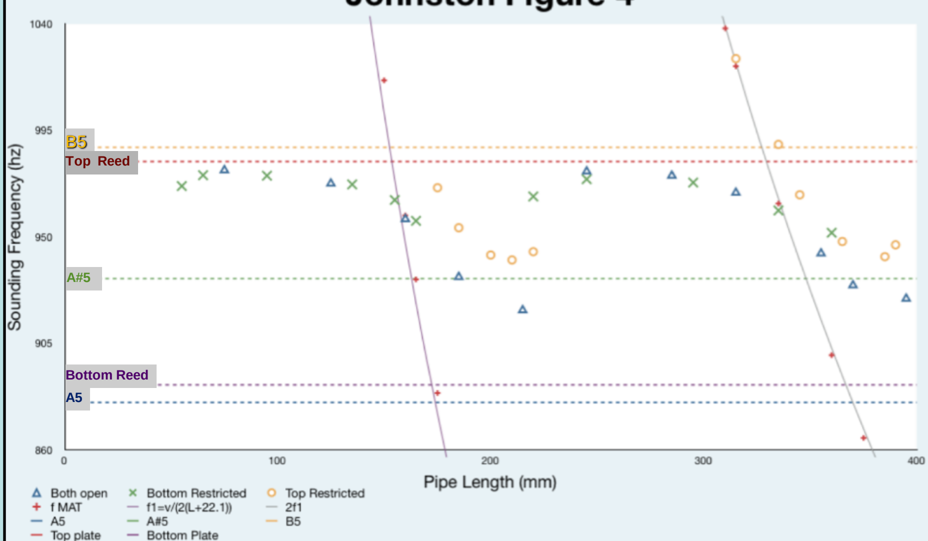


Figure 2: Schematic layout of experimental apparatus

(The theory in Johnston's paper is from Fletcher's 1979 paper)

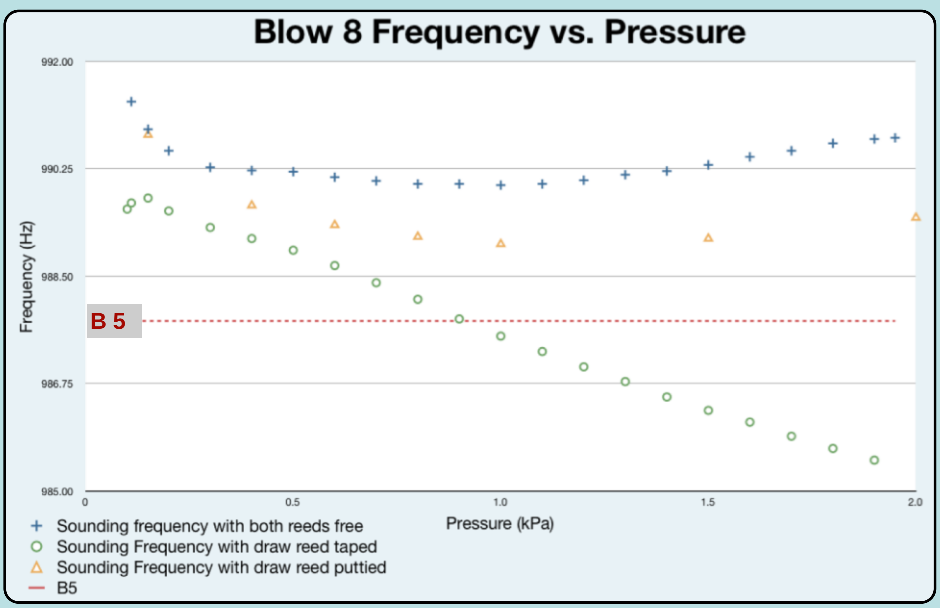
Johnston Figure 4

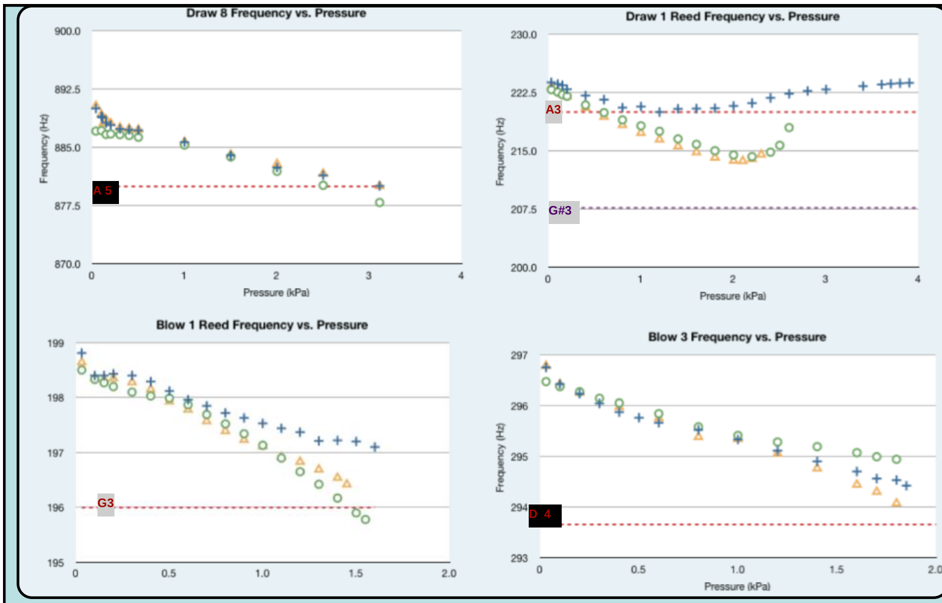


[1]Johnston, Robert B., Pitch Control in Harmonica Playing. Acoustics Australia, *15* (3), (1987), p. 69.

Determined sounding frequency with function generator and oscilloscope

Air source, harmonica, and microphone

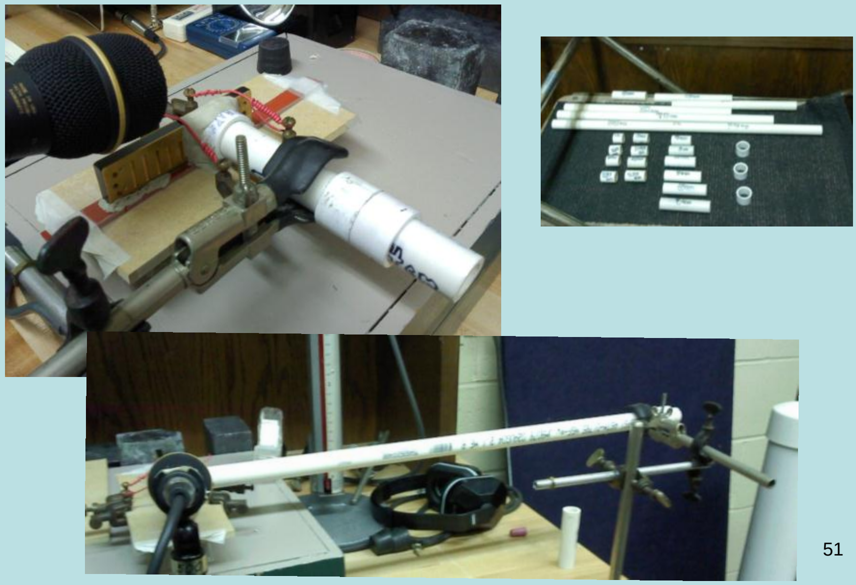




External Pipes

- Added pipes to the outside of the instrument
- Varied length of external pipe instead of vocal tract
  - Measured sounding frequency
  - Measured amplitude
- Similar to an experiment done with siren [2]

[2] M. Mielke, Coe College, 2007



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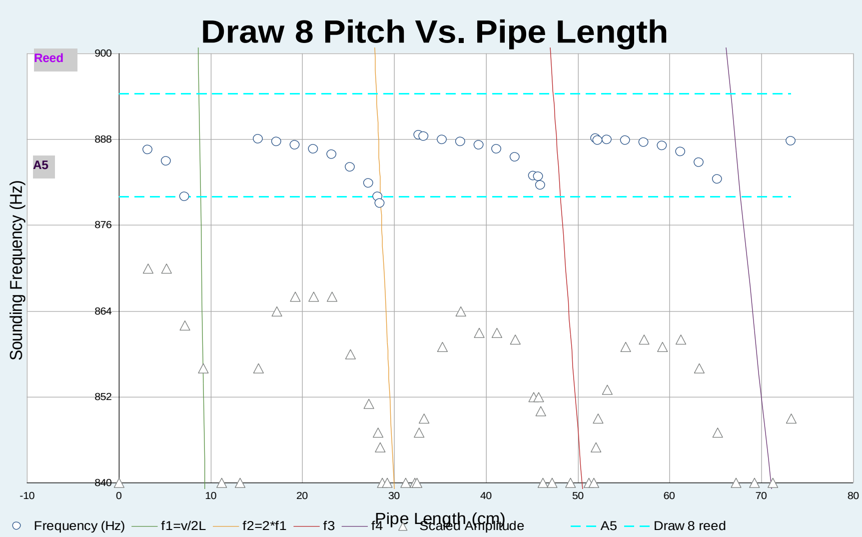
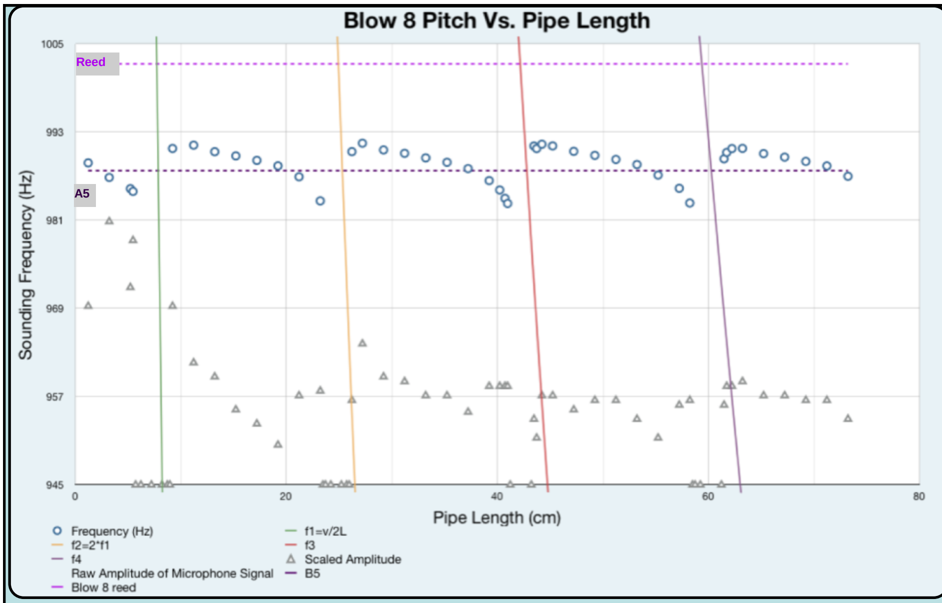


Circles represent sounding frequency (Hz);
Triangles amplitude of reed motion (uncalibrated)



Circles represent sounding frequency (Hz);
Triangles amplitude of reed motion (uncalibrated)

ACKNOWLEDGMENTS

A portion of the work reported in this paper was supported by National Science Foundation REU Grant NO. 0354408.
Financial support was also provided by The Coe College Acoustics Research Fund.

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- International Patent Publication Number WO 97/44777 [http://www.wipo.int/pctdb/en/wo.jsp?wo=1997044777]