Physics of Musical Sound

Class 20
Read Chapter 13
Sections 10-14
Lab Friday

Air Jets and Edges

- When air flows slowly through a narrow opening (a jet) then it makes no sound. We say that the flow is Laminar (in thin sheets).
- When air flows somewhat faster the flow becomes Turbulent and starts to make a hissing sound. It starts to create white noise.

Woodwinds (non-reed)

- Energy source
  - Low pressure air stream from lungs or bellows.
- Vibrator
  - Air jet interacting with an edge
  - Converts steady kinetic energy of air stream into an oscillating air flow
- Resonator
  - Tube supports standing waves
  - Sets frequency of vibrator and couples to outside air

Air Jets and Edges

- When air flows slowly through a narrow opening (a jet) then it makes no sound. We say that the flow is Laminar (in thin sheets).
- When air flows somewhat faster the flow becomes Turbulent and starts to make a hissing sound. It starts to create white noise.
- If the air jet is allowed to fall on a narrow edge then the turbulence increases. Under many conditions of jet speed and distance from the edge you hear a tone emerging. It is usually somewhat noisy.

Air Jets and Edges

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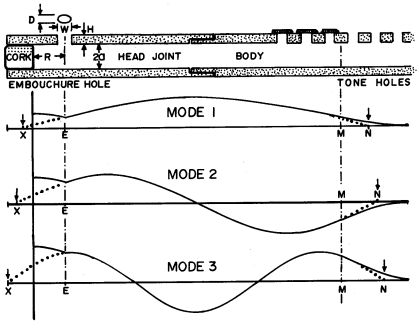
Edge Tones

- The pitch of this edge tone depends on the separation between the jet and the edge and on the air speed in the jet. Larger separations generally producing lower pitches and higher air speeds producing higher pitches.
- The edge tone is believed to arise from a feedback mechanism whereby the air striking the edge generates pressure variations back at the jet that make the air stream wobble up and down.
- The pitch of an edge tone is high and not well controlled. Typical jets produce kHz frequencies. The pitch varies under the influence of small external forces and is not musically useful.

Resonator Coupled Edge Tones

- If we place a resonant chamber near the edge/jet assembly then the jet and the chamber will interact.
  - As the jet wobbles around the pressure at the opening of the chamber will vary. If that variation has a component at a resonant frequency of the chamber then the pressure variation will be magnified by the resonance.
  - The higher pressure variations at the chamber resonant frequency will couple to the jet and induce it to wobble more at that frequency.
  - The increase in jet wobble will increase the strength of the resonance which will increase the jet wobble which will.....
  - The result is to lock the jet frequency to the resonant frequencies of the chamber.

Pressure Profile in a Flute



Air Jet/Resonator Instruments

- Non-reed ranks of a pipe organ.
  - Uses both open/open and open/closed pipes with different scales.
- Straight blown flutes
  - Recorder
  - Penny Whistle
  - Swanee Whistle--the only half closed member of family.
  - Flageolet
  - Tabor Pipe
- Side blown flutes
  - Keyless, old n-keyed, modern Boehm system
- Top blown pipes
  - Pan pipes of both Balkans and South America--all closed at bottom end so sound as if twice as long.

Design of Real Flutes

- The errors in the tuning of the partials for the simple cylindrical flute have two effects.
  - They affect the tuning of the second octave relative to the first.
  - They affect how easy it is to get the flute to play certain notes, particularly those at the bottom and top of the register.
- The tuning is improved by tapering the head-joint of the flute so that the diameter is a little smaller at the embouchure than in the body of the flute. This improves the tuning of the upper partials.
- The embouchure hole is raised up a small distance by adding a lip plate. The chimney so formed alters the relationship between the players lip and the hole to improve the playability.
- The bottoms of the tone holes are rounded to decrease the turbulence in the body of the instrument.
- The head cork is carefully positioned to adjust the frequency of the second harmonic relative to the fundamental. The playing is most stable if it is about 1/5th of a semitone sharp.

Pressure Profiles Inside Flutes

- Simple theory suggests that there should be a pressure node at each end of the pipe.
- Reality is more complex.
  - At foot end of pipe the pressure node is found slightly outside the end of the pipe. This end-correction decreases as the frequency increases. The node is a fraction of a free-space wavelength outside the end.
  - At the head end there must be a significant pressure variation in order to couple to the jet.
    - If you make the head end of the pipe open then you can barely get a note out of the instrument.
    - In reality there is a head cork that closes the pipe just beyond the embouchure hole. The actual pressure node would occur slightly beyond this point--the head node is imaginary!

Large Tone Holes

- Shorten effective length of tube by opening holes in the side.
  - Large diameter holes, nearly diameter of tube, will produce a clear pressure minimum and so determine the length of the tube accurately.
  - Even large diameter hole will have some end effect so have to adjust positions very carefully.
  - With large holes only the position of the first open hole matters. Holes further down the body don't alter the sound because the pressure wave does not extend down there. This means that you have 1-hole 1-note.
  - Because of the 1-hole 1-note rule a flute needs at least 11 holes to play its lowest octave.

Small Tone Holes

- Shorten effective length of tube by opening holes in the side.
  - Small diameter holes (small compared to the diameter of the tube) allow the pressure wave to continue beyond the hole.
  - The effective playing length is significantly longer than the actual distance from head to tone hole.
  - Because pressure wave continues below first open hole, it matters whether holes further down the body are open or closed. Thus there is the possibility of altering the pitch by closing holes below the first open hole-forked fingerings.
  - Because we can use forked fingerings to make semitones, we only need 6 holes to play most of a chromatic scale and with divided holes a recorder is fully chromatic with only 8 holes.
  - Forked notes usually don't sound quite so clearly as un-forked ones, the sound is slightly muffled.