UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

JOINT SEMINAR

AERONAUTICAL AND ASTRONAUTICAL ENGINEERING

AND

THEORETICAL AND APPLIED MECHANICS

"WALL VIBRATION AND BOUNDARY LAYER EFFECTS IN WIND INSTRUMENTS"

BY

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Professor Benade has authored numerous articles and several well-known books on musical acoustics, including the text Fundamentals of Musical Acoustics published in 1976, by the Oxford University Press.

3:00 P.M., FRIDAY, NOVEMBER 13, 1981
314 ALTGELD HALL

RECEPTION AT LEVIS FACULTY CENTER,
MUSIC ROOM FROM 5:00-7:00

(1)

Wall Vibration and Boundary Layer Effects in Wind Instruments

U of Illinois. 13 Nov 1981 A.H. BENADE

I INTRO REMARKS

Transparency 1 — Folk Theorems

(a) Tell about the first flute I ever heard and saw while being made .... and 2nd... paper one was failure.

(b) DEMO WITH 2 PLASTIC FLUTES — ~~corners rounded~~ + unrounded

(c) Tell a little about reproducibility of data with musical instr. and about room effects.

(d) PLAY the flutes again

TRANSPARENCY 2 — Spectra of the two flutes

(2)

II Describe self-sustained osc behavior briefly

SLIDE 1 → Water trumpet

SLIDE 2 → Single res. breakeven

DEMO with clarinet
- (a) Normal
- (b) Single res... chokes up
- (c) normal again

Cooperation

SLIDE 3 → Regeneration Eqns

internal Spect $p_n \approx \dfrac{Z_n p_1^n}{1 - A Z_n}$

SLIDE 4 → Spectral implications internal ⇄ external

Most of the energy produced at low freq., but very little is radiated

(III) Where does the energy go?

Transparency 3

Refers back to loss of tallness of peak in slide?

Thermal losses to the walls are not small —— but how much does change of material affect it?

Transparency 4 Thermal effects

What is player's sensitivity? 2% change in damping is detectable

In the complete pot of low level dissip Wood vs Metal only ½ enough! (Less at strong playing levels)

(IV) But players insist (most can tell) diff between wood & metal —— so can I!
(Listeners also in many cases)

Porosity? Varnish can get this small & players mostly like the result But not always good idea.

Plastic ≅ Wood if varnished

Tell about Alex Murray's question.. Hot day etc etc

(V) TURBULENCE?! —
Kinematic Visc — Reynolds No

Sharp corners are bad —
→ Workman & his materials ——

Demo the flutes again & explain this time about corners.

Transparency 5

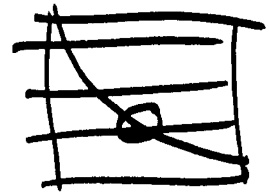
Flow etc near tone hole

→ DHK ←

Proneness to complication and turbulence

$\frac{\partial^2 v_x v_y}{\partial x \partial y}$ etc etc → (V^2/δ^2)

Transparency 6



DEMO DHK's THL's !

Comment on flutes ~~sax~~ - etc

VI Wall Vibrations

(a) Tell about DCM's expts (1909) organ pipe

(b) blow ~~[illegible]~~ plastic bottles

(c) Tell about David Shostak's flute

VII Describe my New Clarinet & demo slightly

VIII As time permits

(a) Alignment errors vs damping. (Sax Ltd, Stack fix)

(b) Radiation from walls { Zikh ww, ob brass

(c) Feel in player's hands

(d) disruption etc mech vibrat mpr

(e) AH-AHB Rosned mpc expt → eterna & plating

Pyle

Conclusion { big effects — Some big physics, " big perception } be careful

AN IMPORTANT THEOREM IN PHYSICS

(Invariant under all changes of
Coordinate system)

Everything Works according to FRESHMAN PHYSICS

Except what I do!

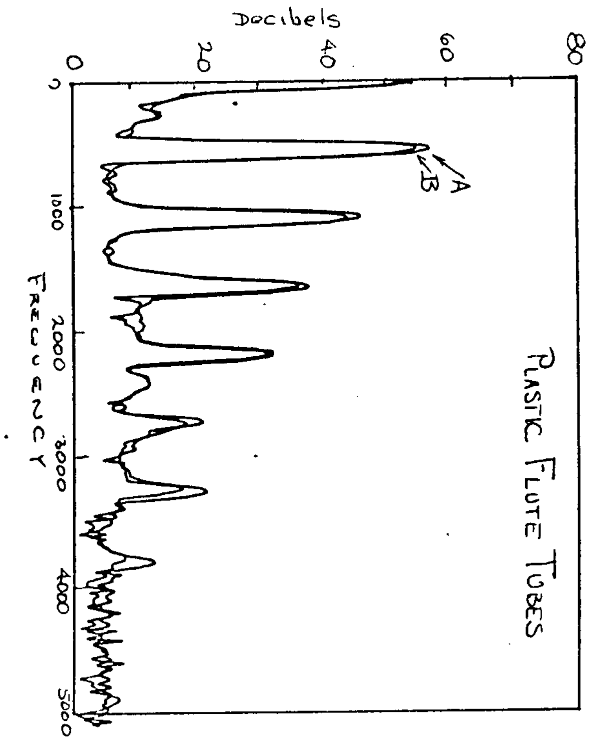
An Illustrative Example

"A fable, the more remarkable since it is always discussed, is that the material of which a wind instrument is made, has an influence upon the sound of the same; that this is not so rests upon incontrovertible acoustical laws, about which there should be absolutely no more discussion."

THEOREMS ARE WONDERFUL , (BUT)
WHAT DOES EXPERIMENT SAY?

NOTE THE LECTURERS BIAS!
CASE SCHOOL OF APPLIED SCIENCE

ETHER DRIFT? NEUTRINO-CATCHING? MATERIALS AND TONE?



WHERE DOES THE ENERGY GO?

A. At very low playing levels

Viscous losses $\left(\frac{dW}{dt}\right)_v = K_v \int_{\text{entire surface of air column}} v^2 \, dS$

Thermal losses $\left(\frac{dW}{dt}\right)_T = K_T \int_{\text{surface}} p^2 \, dS$

Porosity losses $\left(\frac{dW}{dt}\right)_p = K_p \int_{\text{surface}} p^2 \, dS$

Wall vibration losses — (Complicated)

OH YES! Sound Radiation into Room (1/10) percent!

B. At medium playing levels

Streaming effects - viscous dissipation via steady circulation in air column (caused by viscosity + nonuniform flows).

Add this to the list in A. (may quadruple the dissipation.)

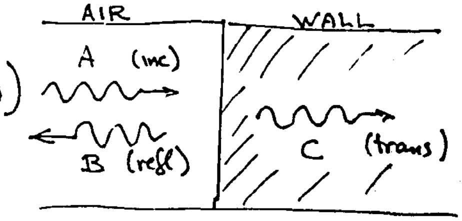
C. At high playing levels

Turbulence at all discontinuities — also begins

Turbulence ~~even in main~~ air column

The Player "Hits A Brick Wall"

General Thermal Wave



$$\psi_{\text{Thermal}} = \psi_0 e^{-x/\delta} \cos(\omega t - x/\delta)$$

Where δ = 1/e skin depth and also $(1/\delta)$ = wave number $(2\pi/\lambda)$

and $\delta = \sqrt{\frac{2}{\omega}} \sqrt{\frac{K}{\rho C}}$

At an interface: Temp on left = Temp on right; Heatflow continuous across boundary

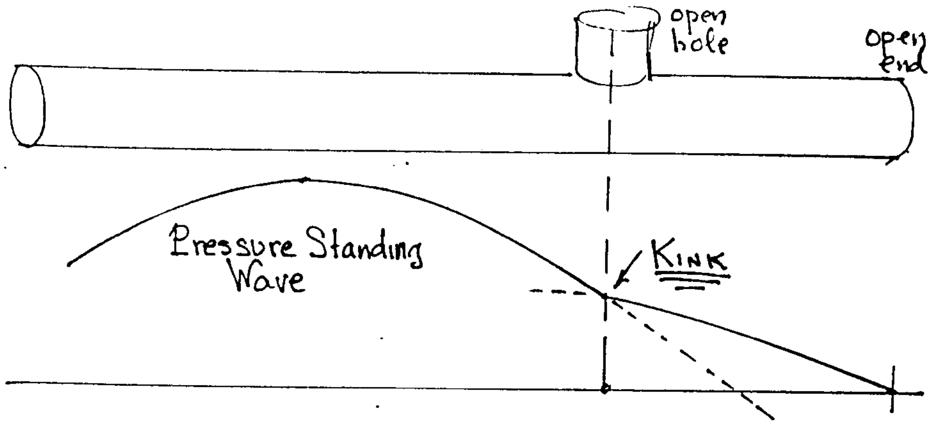
$$B = A\left[\frac{\Pi_{air} - \Pi_{wall}}{\Pi_{air} + \Pi_{wall}}\right] \quad \text{where } \Pi = \sqrt{\rho C K}$$

$$C = A\left[\frac{2\Pi_{air}}{\Pi_{air} + \Pi_{wall}}\right]$$

If $\Pi_{wall} \gg \Pi_{air}$ there is almost no fluctuation at the interface. ie almost perfectly isothermal boundary.

Material	(C/A)
Silver	3.03×10^{-4}
Copper	3.10 " "
Brass	5.80 " "
Nickel Silver	9.4 " "
Wood	1×10^{-2} to 2.8×10^{-2}

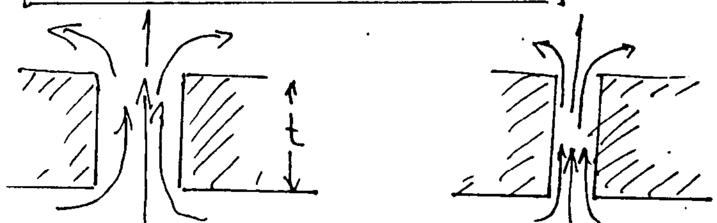
} Very Nearly Isothermal Walls!



Volume flow rate thru hole = [Const / ω][Difference in Slopes]

Velocity of this flow = [Const] [Flow thru Hole / Cross Section of Hole]

Small holes can provoke turbulence



Inner complex flow affects outer flow pattern

Inner and outer complexities are ≈ Independent

Short wide hole

Long narrow hole

(5) To do a given job [Length / diam] = Const × [diam] ∴ Big, tall, Best (6)