Vocal tract effects in wind instrument regeneration. A. H. Benade and P. L. Hoekje (Department of Physics, Case Western Reserve University, Cleveland, OH 44106)

Wind players are much concerned with vocal tract influences on tone production. Laboratory study has been inconclusive, in part from inadequate theoretical formulation. A reed valve is opened and closed by the pressure difference $(p_m - p_M)$ across it: p_m in the instrument's mouthpiece, p_M in the player's mouth. The reed transconductance $A = \partial u/\partial(p_m - p_M)$ depends on its natural frequency ω_r and its damping, becoming large near ω_r. The condition for oscillation is $A[(Z_m + Z_M)/ /Z_r] \geq 1$. We note that the reed impedance Z_r is paralleled by the *sum* of Z_m and Z_M. Oscillation requires $\mathrm{Im}(Z_m + Z_M) \neq 0$, with sign depending on the low-frequency sign of A (positive for woodwinds, negative for brasses); whence woodwinds play with $\omega \leq \omega_r$, brasses with $\omega \geq \omega_r$. These results extend to large amplitude (mode-coupled) regimes of oscillation in the familiar way. Available data show resonance bandwidths of Z_M are much larger than those of Z_m (with smaller magnitude fluctuations), explaining the difficulty of direct measurement of musical effects. During tonal startup on long instruments (e.g., horn, tuba), Z_m changes as successive reflections build up the standing wave. By itself Z_m does not generally satisfy the regeneration condition during onset, thus giving a crucial role to the vocal tract. Results of experiments in progress will be presented. [Work supported by NSF.]

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11 pp.

DOES THE LUNG-THROUGH-MOOUTH AIRWAY INFLUENCE WIND INSTRUMENT PLAYING BEHAVIOR?

MUSICIANS: UNANIMOUS, "YES IT DOES"

MUSICAL ACOUSTIKERS: "PERHAPS". "PROBABLY" "NOT VERY MUCH"

"The phenomenon is too variable for proper study" ← Often translates from "I dont know how to get musicians to do anything twice the same".

A CERTAIN AMOUNT OF WORK HAS BEEN DONE.

1. SOME USEFUL BUT INCONCLUSIVE
2. JUST PLAIN WRONG { Technique / Theory.

THE BASIC DIFFICULTIES HAVE BEEN

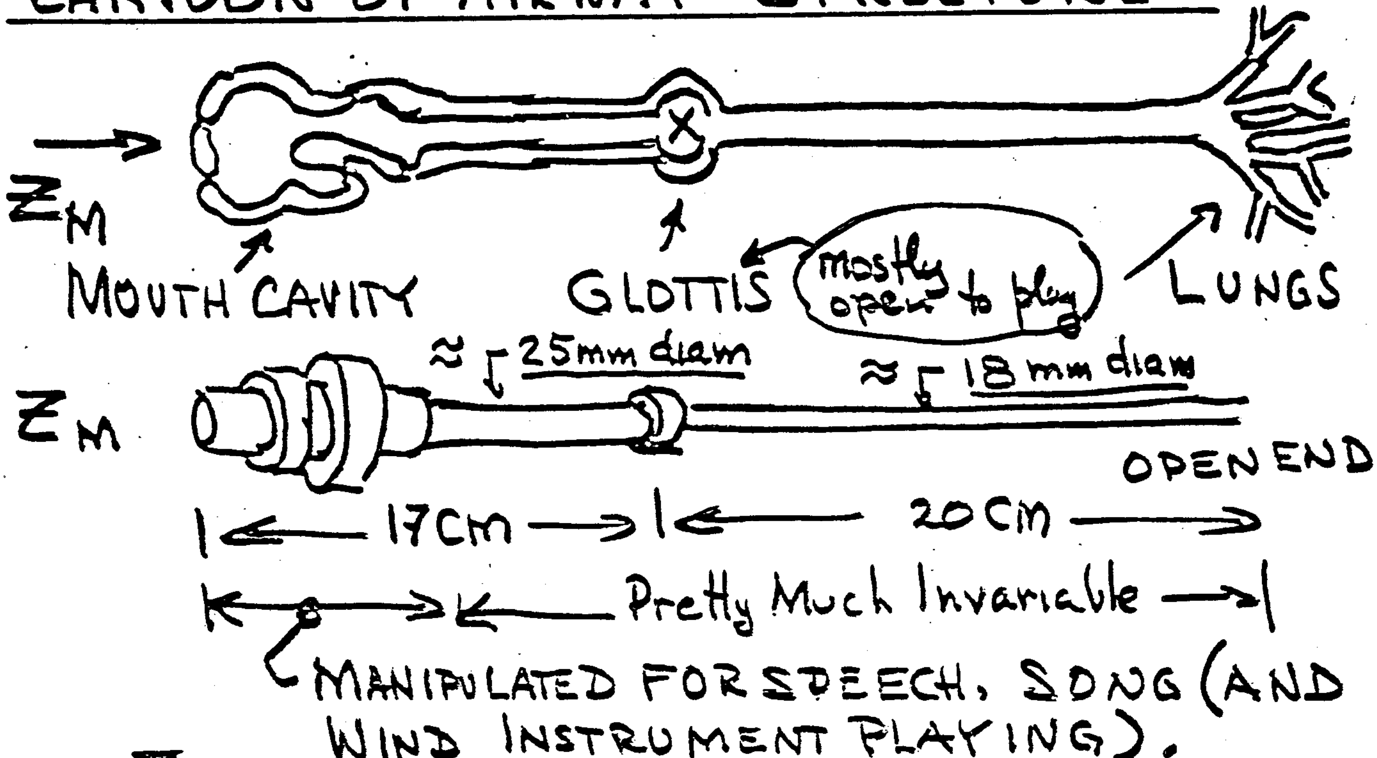
⟹ 1. INADEQUATE KNOWLEDGE OF WIND INSTRUMENT DYNAMICS (Real World)

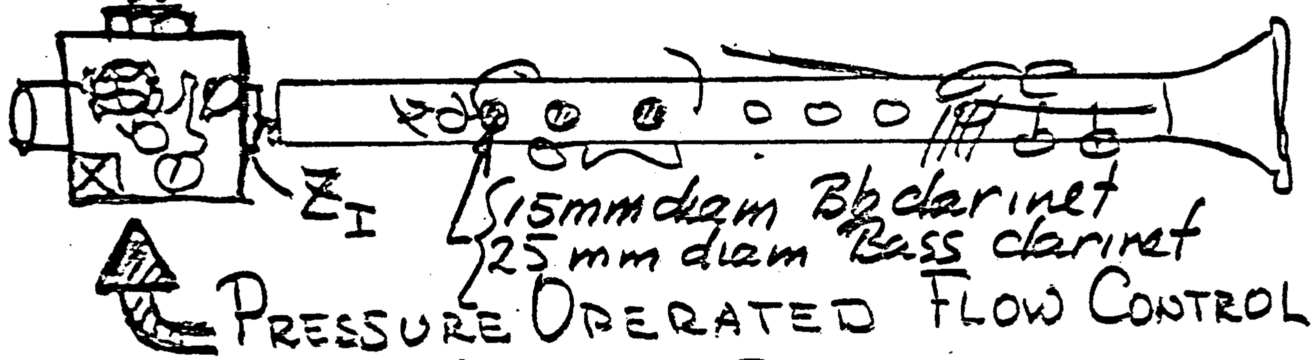
⟹ 2. INADEQUATE KNOWLEDGE OF HUMAN AIRWAY STRUCTURE & FUNCTION

TODAY

↳ THESE ARE BOTH IN PRETTY GOOD SHAPE

CARTOON OF AIRWAY STRUCTURE

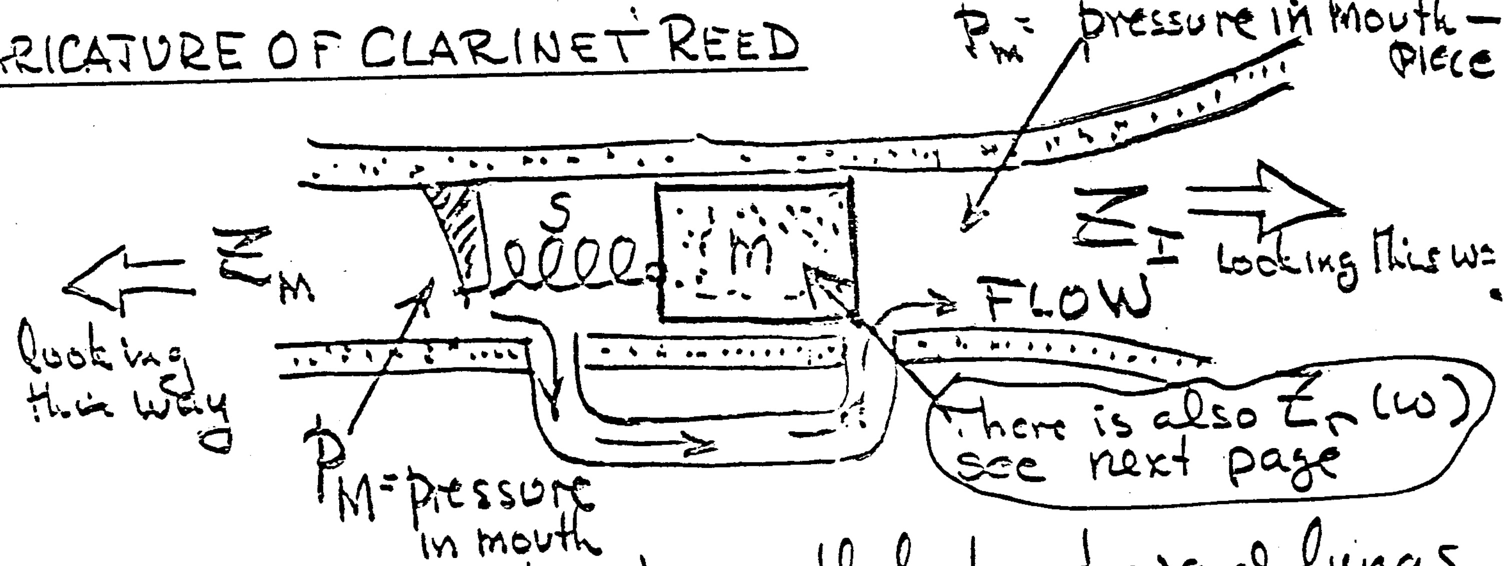




(a) NON LINEAR

(b) FREQUENCY DEPENDENT

CARICATURE OF CLARINET REED



② $Z_M(\omega)$ Measured in player's mouth looking toward lungs

Z (ω) Measured in mouthpiece looking down the INSTRUMEN

RECAPITULATE AND CONTINUE

Z_M = players airway input impedance as seen by the reed (New Stuff)

Z_I = Instruments input impedance as seen by the reed (Old Familiar)

Z_r = Reed's own impedance = $\frac{\text{(net driving pressure)}}{\text{(displaced air flow rate)}}$
(Since Weber, Bouasse belabored by Benade)

A_r = Transconductance of reed as a flow Controller = flow/activating pressure diff

A VERY SMALL EXTENSION OF THE FAMILIAR RESULTS OF
(Weber, Helmholtz, Bouasse, Benade, Backus, Worman, Schumacher, Fletcher, Thompson ....)
SHOWS THAT IN LINEAR LIMIT

$$(1/A_r) = Z_r // (Z_I + Z_M)$$

HERE IT IS! ⟹ Simply Replace Z_I by $(Z_I + Z_M)$

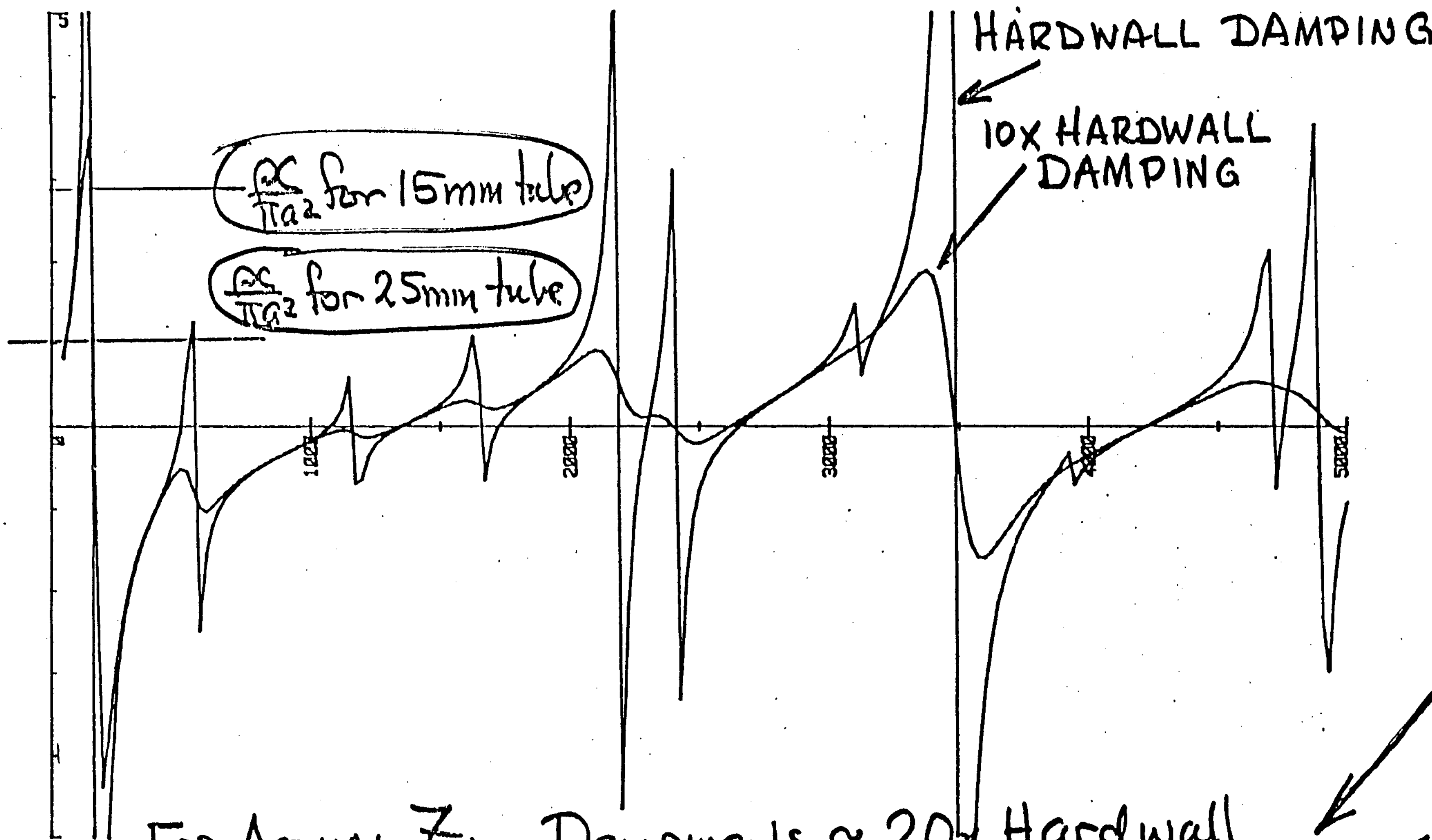
AT HIGHER PLAYING LEVELS ... REGIMES OF OSCILLATION EXACTLY AS BEFORE

ONCE AGAIN ⟹ SIMPLY REPLACE AIR COLUMN Z ($\equiv Z_I$) BY SUM OF { AIR COLUMN Z_I AND PLAYER'S AIRWAY Z_M }

Why then has Z_M not intruded on our Consciousness till now?!??

3

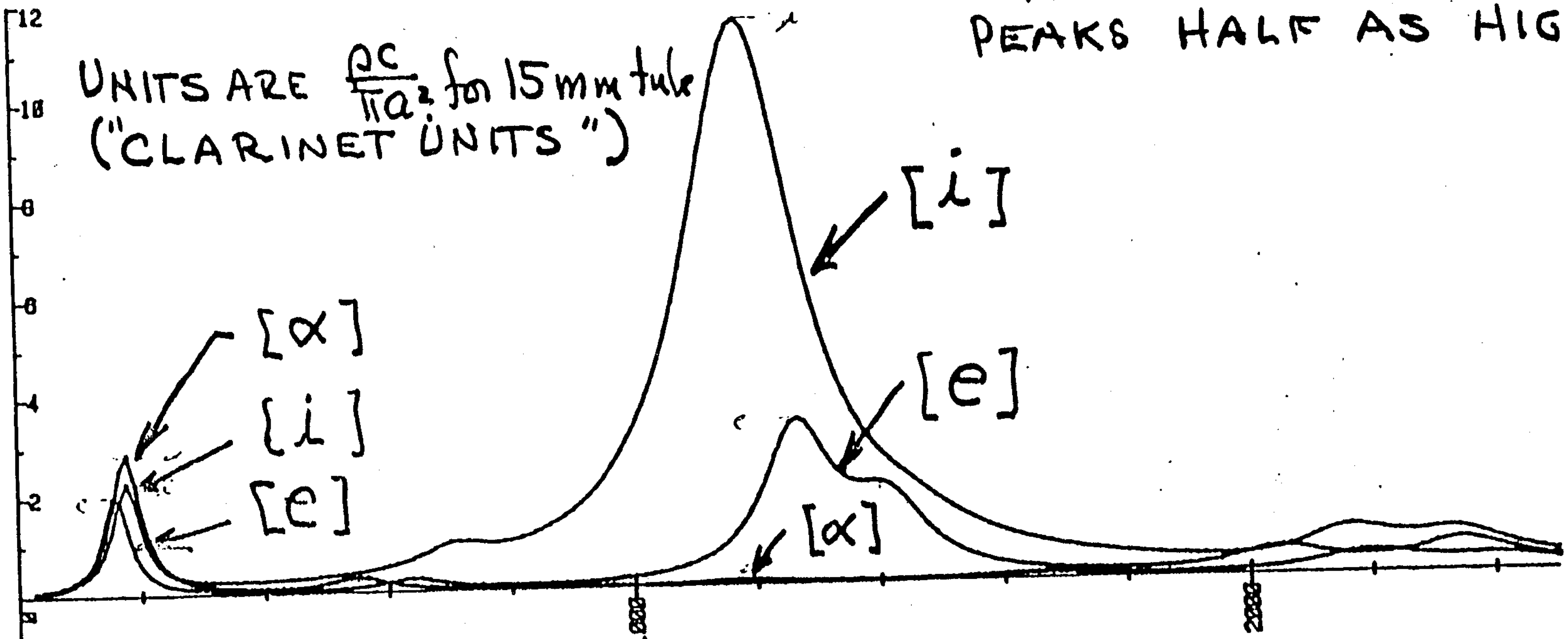
CALCULATED Z_M FOR UPPER TRACT CONFIGURATION CORRESPONDING TO VOWEL [ɑ] (FANT'S DATA)
Shows $\mathrm{Im}\, Z_M$ ONLY!



FOR ACTUAL Z_M, Damping Is ≈ 20x Hardwall
MOST OF THE PEAKS ARE OBLITERATED

REAL PART OF Z_M FOR THREE VOWEL CONFIGURATIONS
(DAMPING 10x HARDWALL)

REAL SYSTEM 20x, SO PEAKS HALF AS HIGH

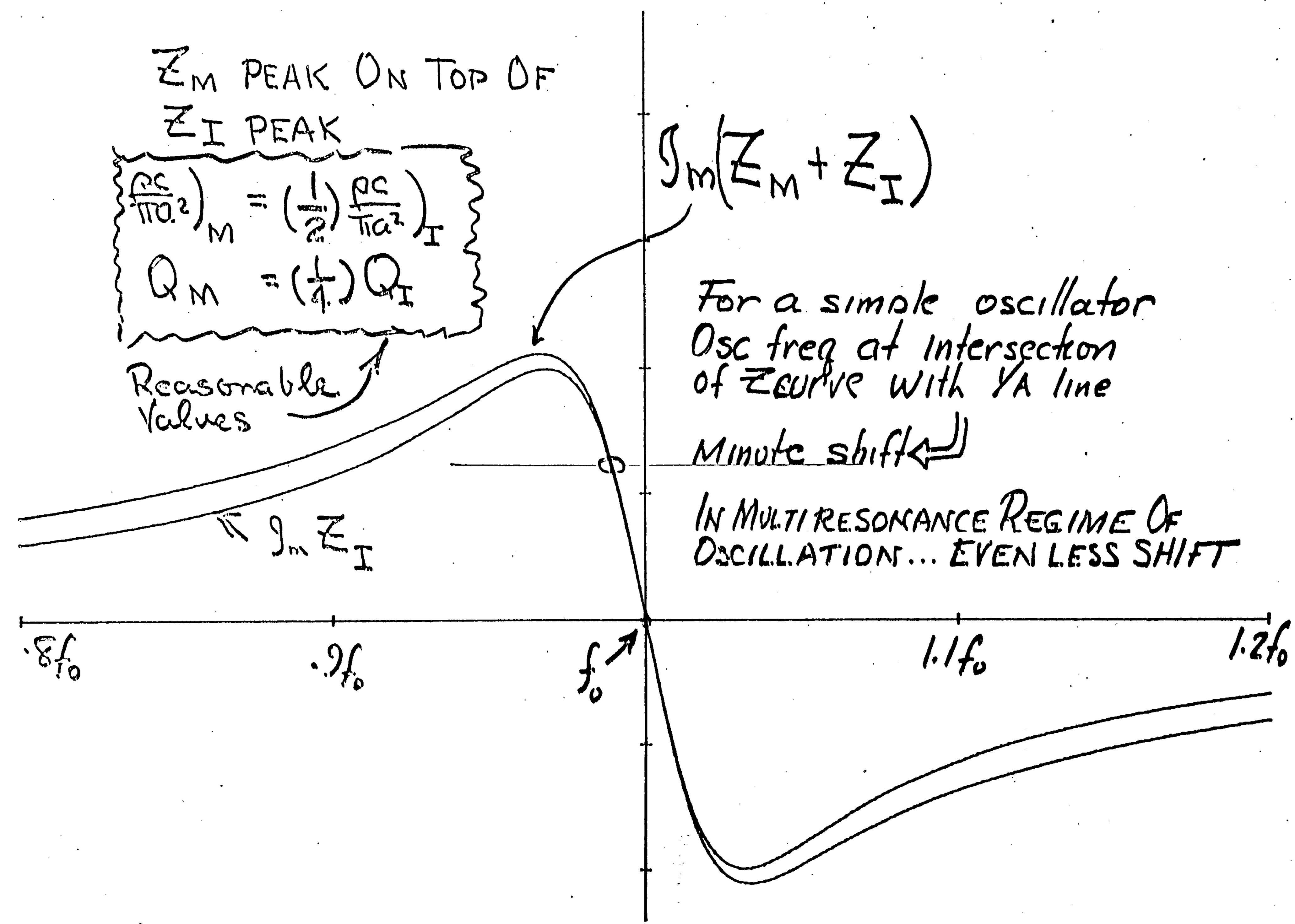


ONLY
SOME VOWELS GIVE A BIG Z_M PEAK NEAR 1000 Hz

IT IS NOT EASY TO MOVE IT AROUND.......

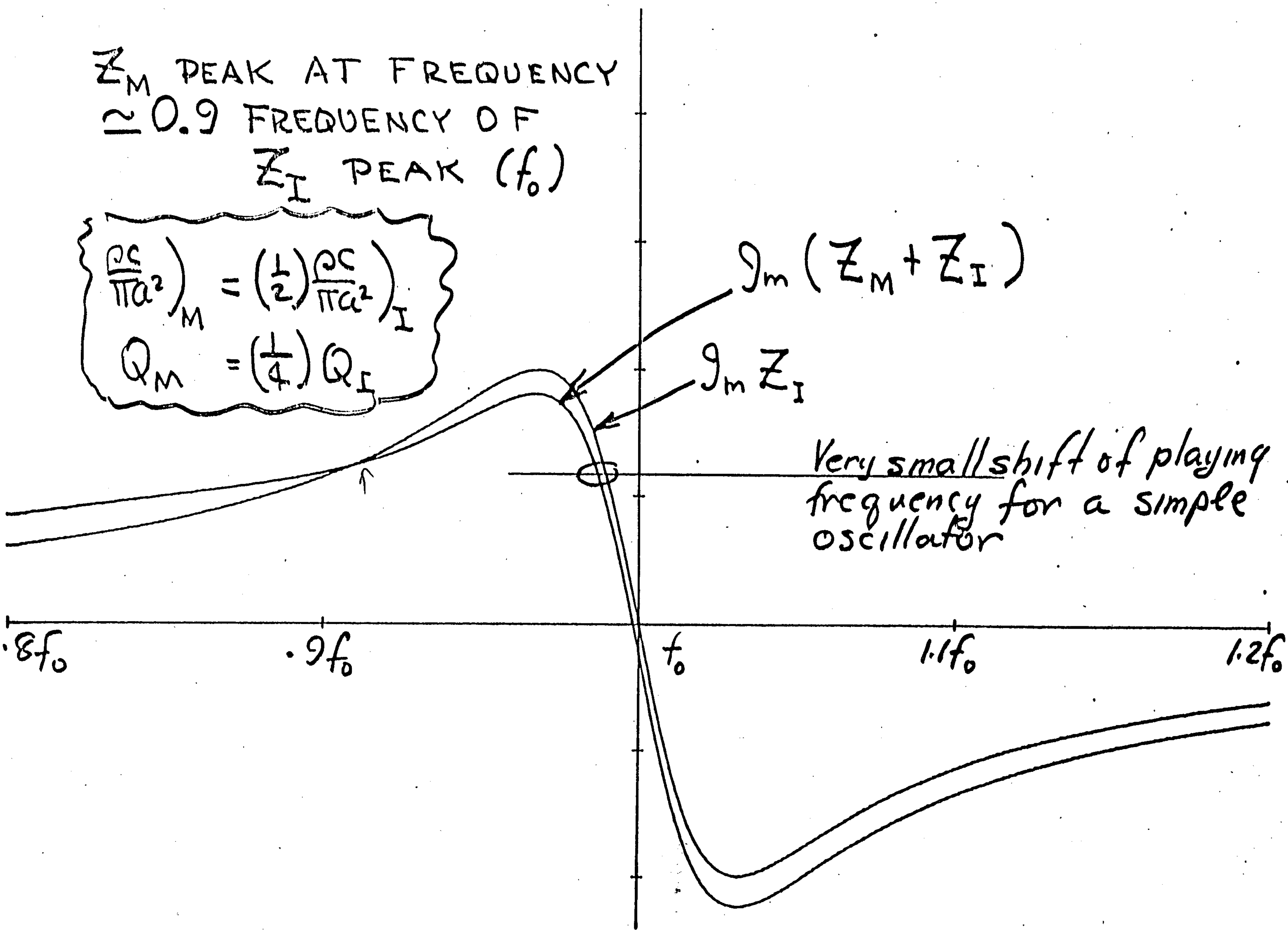
RECALL: RESONANCES BELONG TO THE ENTIRE AIRWAY NOT TO ANY SUB-SEGMENT!

Exceptions to this are exceedingly rare

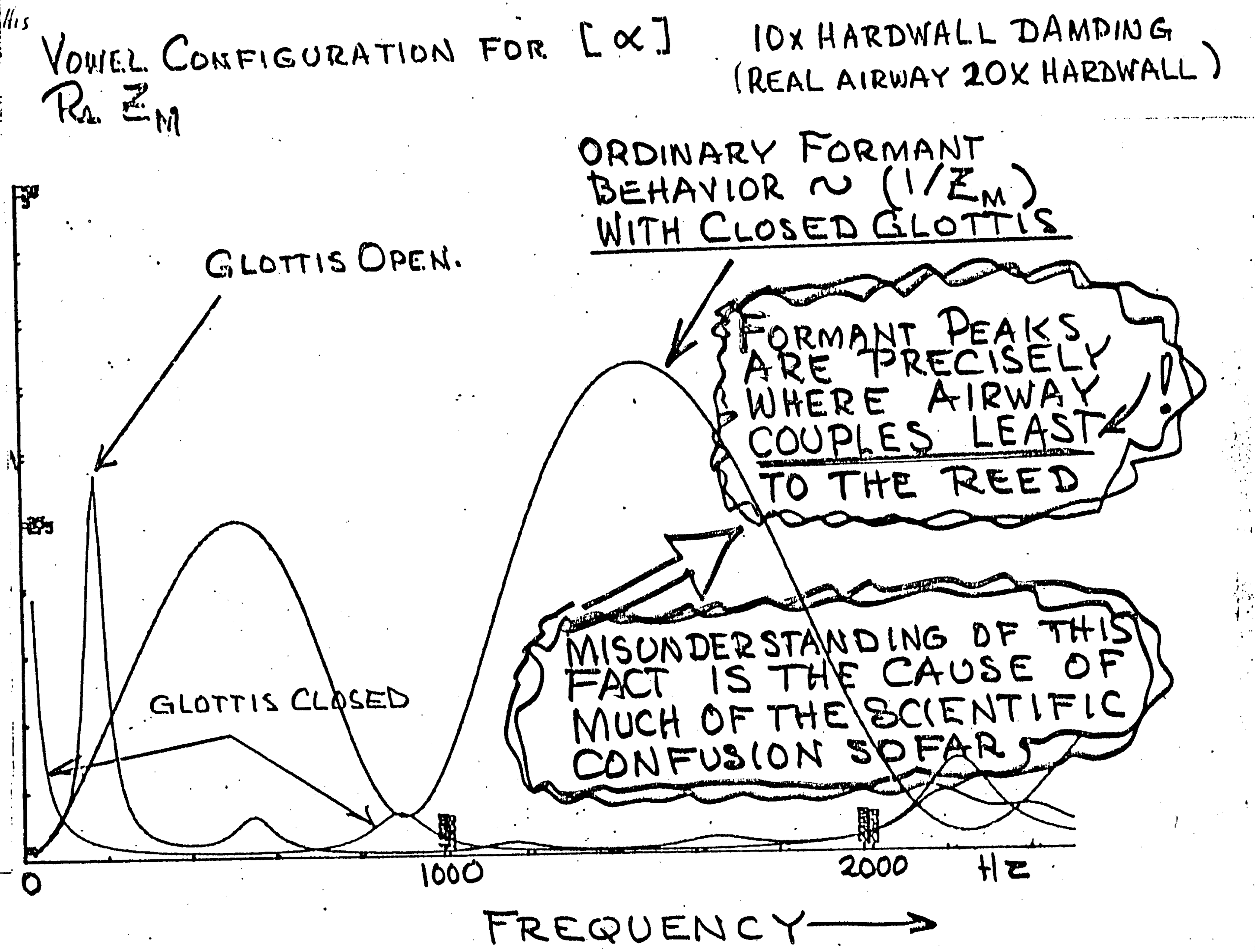


Z_M PEAK ON TOP OF
Z_I PEAK
(ρc/πa²)_M = (1/2)(ρc/πa²)_I
Q_M = (1/4) Q_I
Reasonable Values
Im(Z_M + Z_I)
For a simple oscillator
Osc freq at intersection
of Z curve with YA line
Minute shift
IN MULTIRESONANCE REGIME OF
OSCILLATION... EVEN LESS SHIFT
Im Z_I
.8f₀
.9f₀
f₀
1.1f₀
1.2f₀

(7)



Z_M PEAK AT FREQUENCY
$\simeq 0.9$ FREQUENCY OF
Z_I PEAK (f_0)
$\left.\frac{\rho c}{\pi a^2}\right)_M = \left(\frac{1}{2}\right)\left.\frac{\rho c}{\pi a^2}\right)_I$
$Q_M = \left(\frac{1}{4}\right) Q_I$
$\mathrm{Im}(Z_M + Z_I)$
$\mathrm{Im}\, Z_I$
Very small shift of playing frequency for a simple oscillator
$.8f_0$
$.9f_0$
f_0
$1.1f_0$
$1.2f_0$

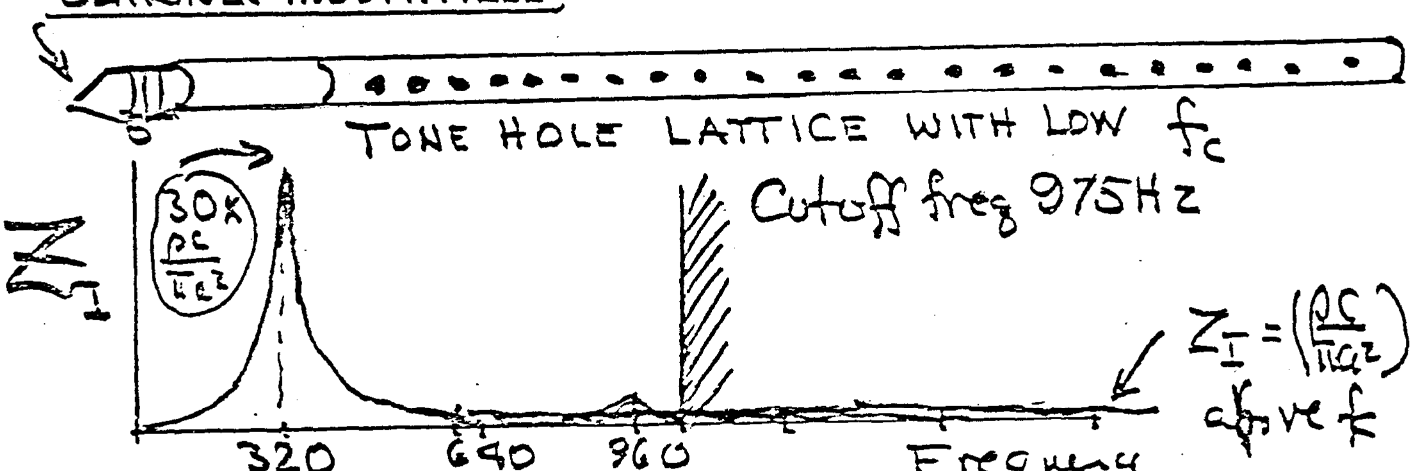

VOWEL CONFIGURATION FOR [α]
Re. Z_M
10x HARDWALL DAMPING
(REAL AIRWAY 20x HARDWALL)
ORDINARY FORMANT BEHAVIOR ~ ($1/Z_M$) WITH CLOSED GLOTTIS
GLOTTIS OPEN.
FORMANT PEAKS ARE PRECISELY WHERE AIRWAY COUPLES LEAST TO THE REED !
GLOTTIS CLOSED
MISUNDERSTANDING OF THIS FACT IS THE CAUSE OF MUCH OF THE SCIENTIFIC CONFUSION SO FAR
0
1000
2000
Hz
FREQUENCY →

HOW CAN WE CHECK ALL THIS???

1 Marshall a great deal of practical examples from The world of players.
Check Z_I RELATIVE TO Z_M
OVER THE PLAYING RANGE
FOR EXAMPLE Bb clarinet diam ≅ 15mm
Bass cl diam ≅ 25 mm
Contra bass diam ≅ 35mm
Mouth and supraglottal region avg-diam 25mm Bass is Specialist's instrument!

2 Try informal playing experiments moving vocal tract to traverse configuration with 1000 Hz peak. Select notes to play that have components near 1000 Hz and look for any odd behavior in PITCH, TONE, STABILITY

3 Devise Air Column with SIMPLE, FAMILIAR ACOUSTIC PROPERTIES, that will "EXPOSE" the effects of the 1000 Hz Z_M peak.



ONE TALL PEAK FOR Z_I { ∴ HARD TO PLAY
~ SINUSOID SIGNAL

WE HAVE TWO SPECTRA TO WORRY ABOUT
(1) "MOUTHPIECE SPECTRUM", (2) MOUTH SPECTRUM