Impedance and impulse response measurements using low-cost components. M. I. Ibisi (University of Jos, Jos, Nigeria) and A. H. Benade (Case Western Reserve University, Cleveland, OH 44106)

A thin 27-mm-o.d. disk transducer (from Radio Shack 273-060 signaler) is RTV sealed to the end of a measurement tube whose 15 mm i.d. not only approximates the transducer disk's nodal circle but also the i.d. of a clarinet, sax, or trumpet mouthpiece. A 10-mm-o.d. electret microphone element (Radio Shack 270-092) mounted through the tube wall near the piezo driver picks up the resulting pressure signal. When the high mechanical impedance driver is excited by a sinusoidal sweep via a 6-dB/oct integrator, the resulting pressure signal gives an excellent view of the input impedance of the air column over the musically useful range to 3.5 kHz since the driver resonance is at $\omega_0/2\pi \simeq 5$ kHz and bandwidth $g \simeq \omega_0/6$. A ramplike drive voltage (running between op–amp supply limits) of the form $A(1 - e^{-gt/2})$ for $\theta \leqslant t \leqslant 2\pi/\omega_0$, and constant thereafter, gives a clean pressure pulse $\simeq$ const.$(1 - \cos \omega_0 t)$ whose FWHM$\simeq$0.1 ms is convenient for impulse response studies. Drive signal spectrum, piezoelectric coupling, and driver-to-tube coupling each minimize transducer second-mode ringing effects. Driver-to-mike proximity effects are small, visible, calculable, and easily allowed for in both impulse and sinusoidal drive usage. The driver is not quite rigid, perturbing the air column slightly, but corrections are straightforward. Applications for research and in teaching labs will be described. [Assisted by NSF.]

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IMPEDANCE AND IMPULSE RESPONSE MEASUREMENTS
USING LOW-COST COMPONENTS

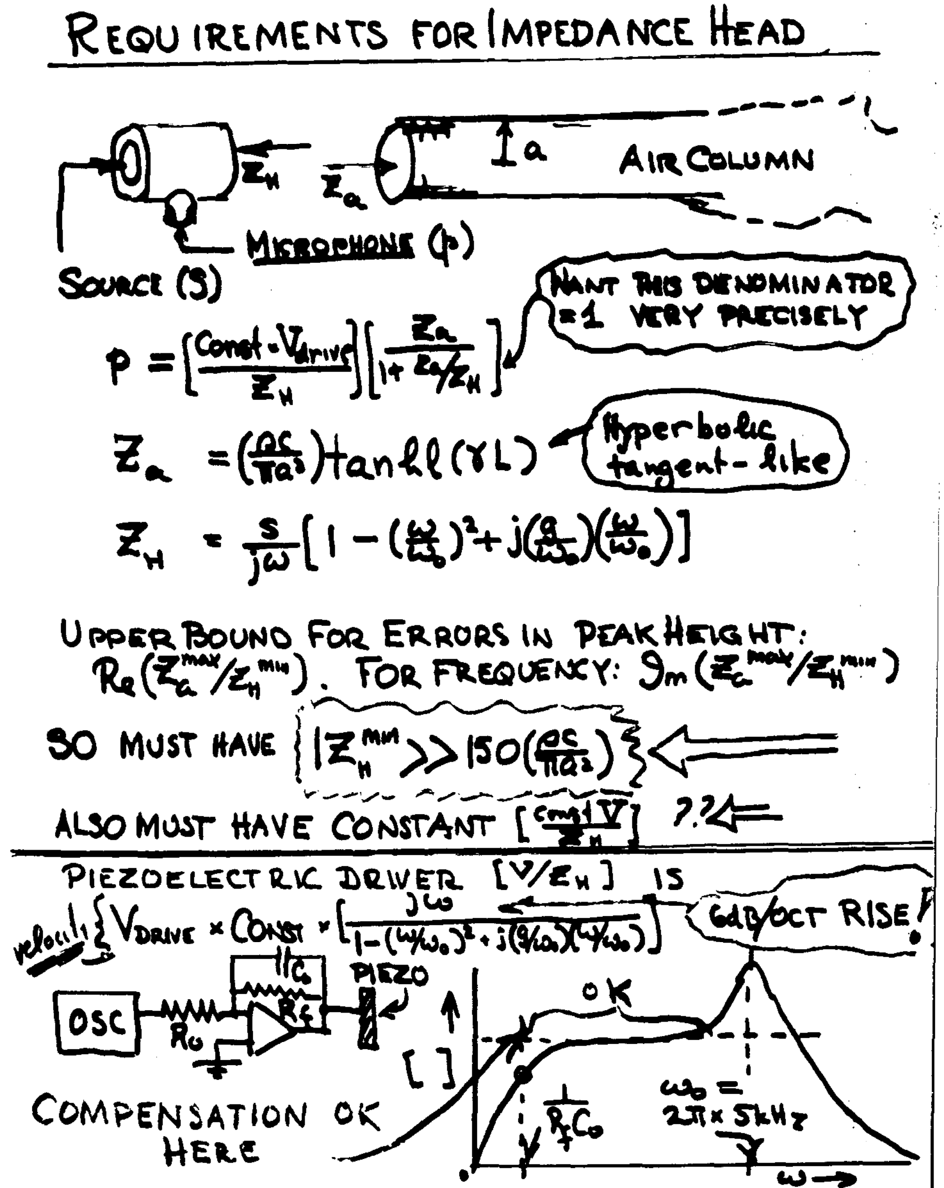
We had four main reasons for pursuing the project that is described in this paper.

(a) There is a continuous need for reasonably precise measurements of the input impedances of air columns among those of us who study musical wind instruments. With some practice one can learn to "read off" not only the type of instrument and the note that is fingered, but also its general docility in the hands of the player and even something about its tone color.

(b) From time to time we have also felt the need for measurements of the impulse response behavior of instruments, especially the brasses (which tend to be several wavelengths long in their normal playing range). More important: McIntyre, Woodhouse, and Schumacher have devised an elegant and powerful time-domain approach to the nonlinear regeneration processes of violins (their original problem) and of wind instruments. This makes it essential that we be able to precisely measure the impulse response of our oscillating subjects. A particular virtue of their methods is that one need have an accurate picture of only the "first return" after the initiating impulsive stimulus.

(c) As our understanding of wind instruments has grown to the point where scientific insights can actually be used to guide the development and adjustment of instruments, the craftsman is beginning to ask for straightforward and inexpensive pieces of measurement apparatus which he can use in his daily work, apparatus which may not have the versatility and precision of laboratory equipment, but which is robust and dependable.

(d) Finally, many of us in the academic world wish to provide our students with sturdy pieces of equipment to show the fundamentals of waveguide and horn acoustics. The equipment should be simple, so that even the beginner can use it; it should work in ways close enough to first principles that its operation <u>can</u> be given an elementary explanation; and its structure should be such that more esoteric aspects of its behavior can readily be studied at a more advanced level. Of course, in these days of constricted financing, cheapness is a nontrivial virtue to add to the list of desirable qualities!



HOW TO VERIFY ALL THIS ?

1) FOR ARBITRARY TERMINATION, LOSSES, AND FOR "HORN" WITH CYL INPUT END ...

$$(Z_a)^{max}_{min} = \left(\frac{\rho c}{\pi a^2}\right)\left(\frac{1+F}{1-F}\right)^{\pm 1}$$ (1st returnwave ampl / F × Inc wave ampl)

Geometric mean of peak, dip = const

$\binom{max}{min}$ Obs pressure = $S(\omega)$ const $\cdot \left(\frac{1+F}{1-F}\right)^{\pm 1}$

S=Const? → USE DECIBEL PLOT MIDLINE

S(ω) OK IF MIDLINE HORIZONTAL

BUT ALSO

2) FOR CYLINDRICAL PIPE, Z_{peaks} LIE AT

$$f_n = (2n-1)\frac{c}{4[L+\Delta L]} \times \left(\begin{matrix}\text{Boundary layer}\\ \text{correction}\end{matrix}\right)$$

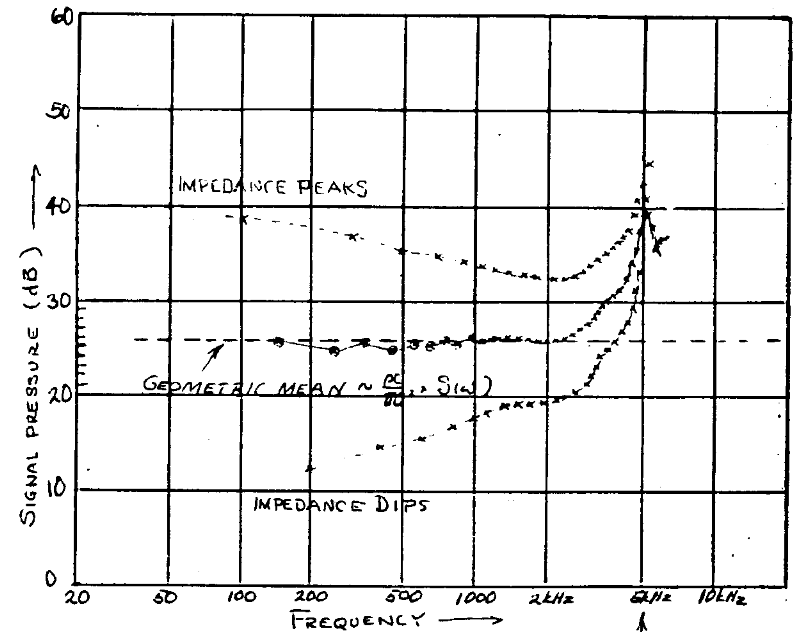
ΔL = EFFECT OF $\mathrm{Im}(Z_H/Z_a)$ ON f_n

PLOT $\left(\frac{f_n}{2n-1}\right)$ LOOK FOR FLUCTUATIONS NEAR PIEZO ω_0 (WORST CASE)

(3) FOR CYL PIPE DO $\left[\begin{matrix}\text{PEAKS}\\ \text{DIPS}\end{matrix}\right]$ TREND AT ±3dB/Oct?

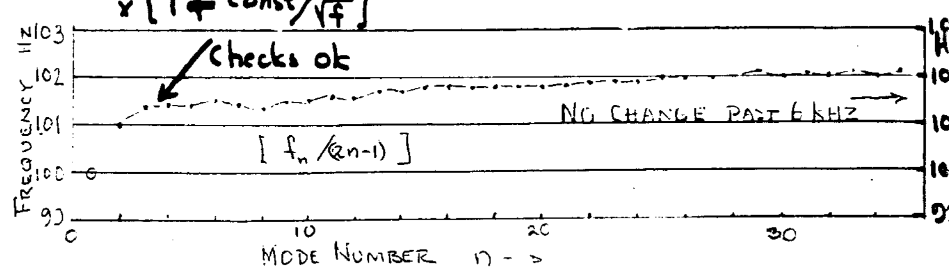
SHOWS ~~CHECKS~~ LOSSES ONLY AT WALLS, NOT AT DRIVER

AN EXPERIMENTAL CHECK



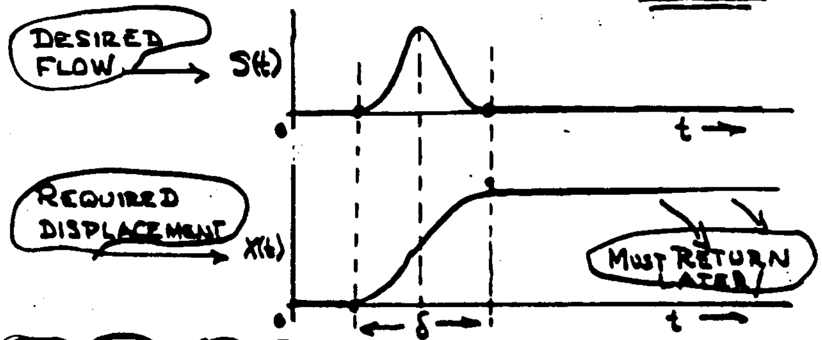
TRANSDUCER RESONANCE 5kHz, Q ≅ 6

BOUNDARY LAYER CORR × [1 + Const/$\sqrt{f}$]

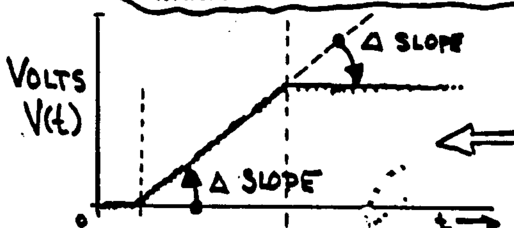


REQUIREMENTS FOR IMPULSE MEASUREMENTS

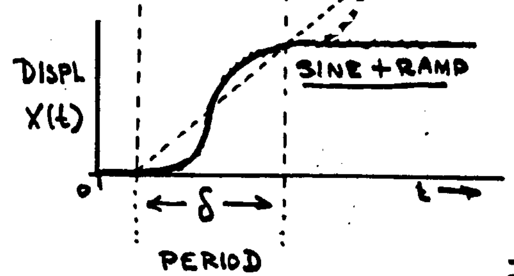
IMPULSE OF FLOW ⟶ IMPULSE OF DRIVER VELOCITY

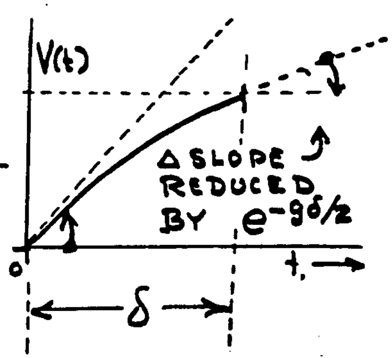


MUST HAVE STEPLIKE VOLTAGE DRIVE ON HARMONIC OSCILLATOR TYPE PIEZO ....



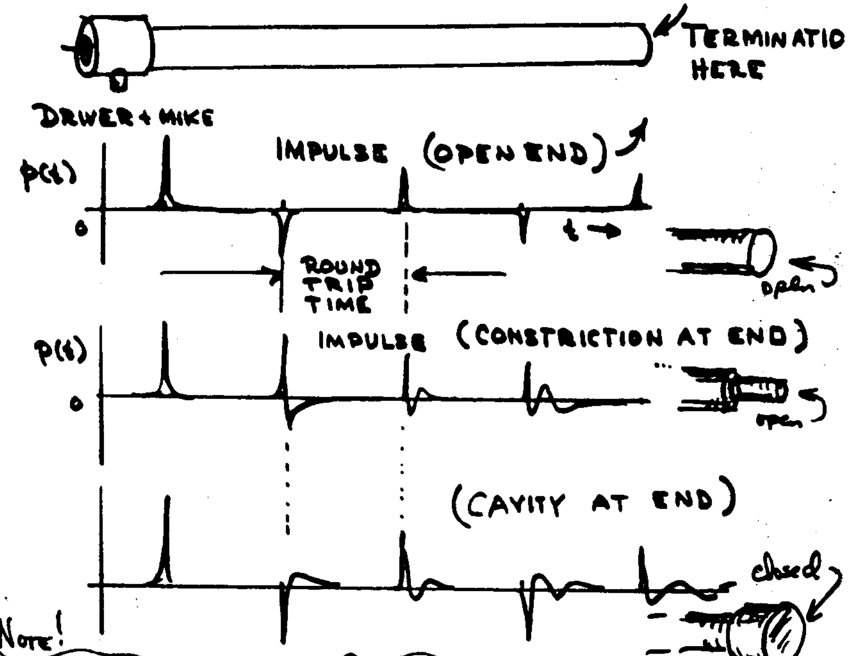
SIZE OF RESPONSE PROPORTIONAL TO Δ SLOPE





$$\ddot{x} + \omega_0^2 x = Kt$$
$$x(t) = A\sin\omega_0 t + Bt \qquad \boxed{x(0)=0 \quad \dot{x}(0)=0}$$

SOME IMPULSE RESPONSES

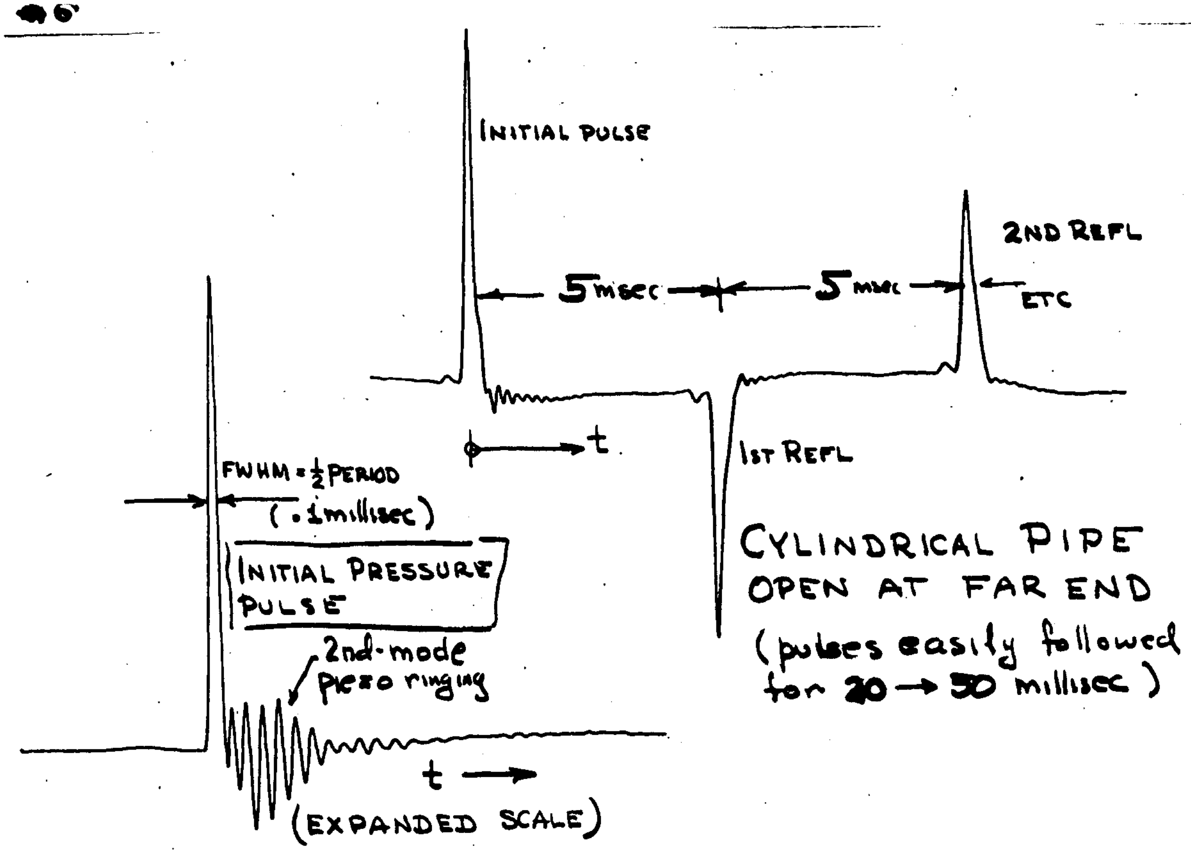


Note!

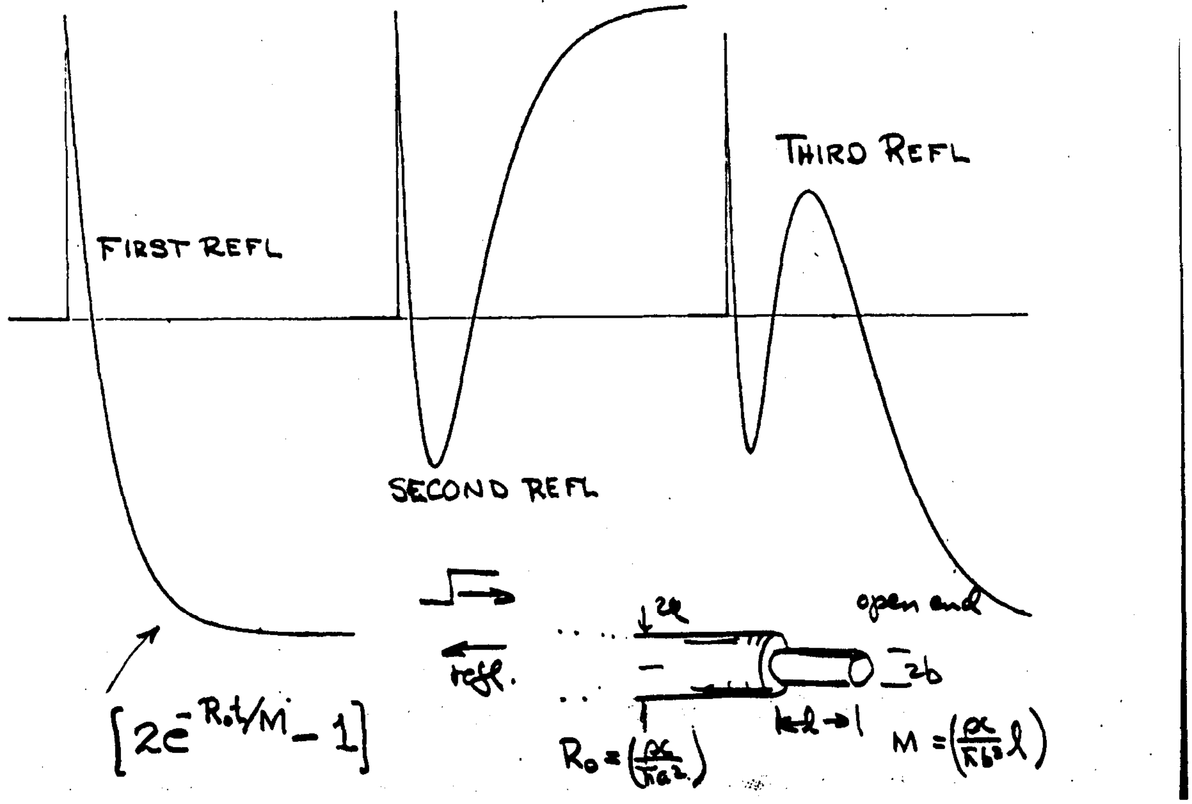
EVEN THOUGH SPIKES RECUR AT $c/2L$, ALL THREE SYSTEMS HAVE DIFFERENT MODE FREQ!

TO KEEP CALCULATIONS CLEAR, DO STEP RESP AND TAKE $\frac{d}{dt}$ AFTER, TO GET IMPULSE RESP

Conceptual and Computational Suggestion:



REFLECTIONS FROM STEP- S(t)
APPLIED TO PIPE WITH CONSTRICTION Z_t



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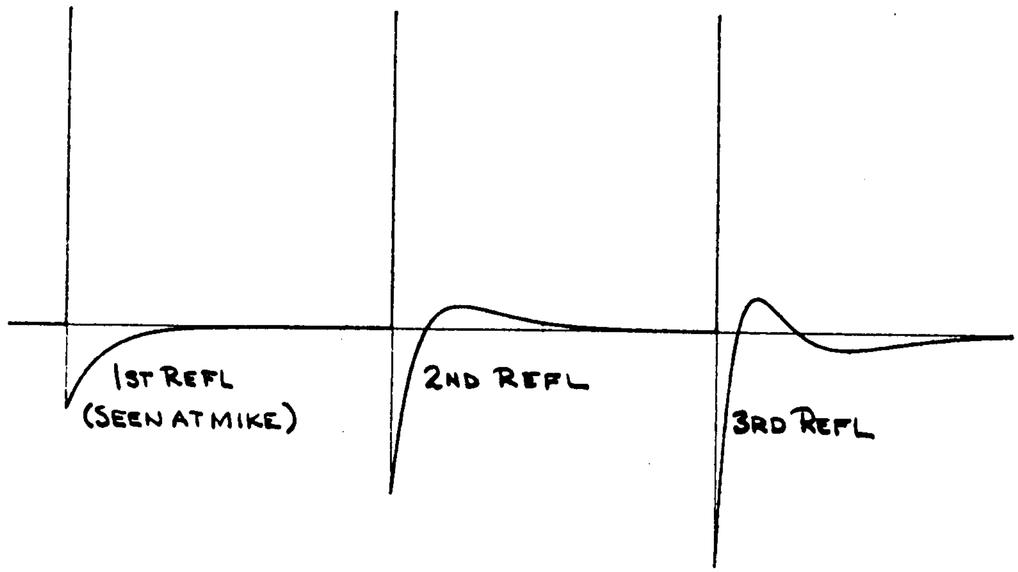
CALCULATED S(t)-IMPULSE RESPONSE
OF PIPE WITH CONSTRICTION
(INERTANCE) AT FAR END



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OBSERVED S(t) IMPULSE RESPONSE
FOR PIPE WITH CONSTRICTION
AT FAR END