air in a reverberant room are experimentally investigated by measuring the power flowing into the cello from a shaker attached at the cello bridge, the power flow through the cello endpin into the stage, and the acoustic radiation from the cello and the stage. The objective of the study is to evaluate the significance of radiation from the stage relative to the radiation from the cello alone to determine the feasibility of enhancing the total radiated sound by altering the cello–stage coupling and/or changing the stage radiation properties. Experimental techniques employed include direct measurement of power flow between the two structures and acoustic power measurements in $\frac{1}{3}$-octave bands. Four different stage configurations are investigated including a concrete floor, a simple unbaffled wooden panel, a baffled panel of the same dimensions, and a special soloist's podium which incorporates a sounding board connected to the podium top by a sound post. [This research has been supported by the National Science Foundation.]

2:45

JJ4. Harmonic Structure of an Aging Guitar String. J. B. ALLEN, *Bell Telephone Laboratories, Holmdel, New Jersey 07733.*—By application of various signal processing means, namely FFT, linear estimation, and digital filtering, impulse responses of new and old guitar strings were analyzed to determine the important differences. These measurements were compared to the theoretical results derived from the generalized string equation operator $\epsilon\nabla^4+\nabla^2+k^2$, using appropriate boundary conditions. Results are discussed and synthetically generated samples will be played.

3:00

JJ5. Trumpet Acoustics: The Tuning Effect of the Mouthpiece and Leaderpipe. W. T. CARDWELL, JR., *Chevron Research Company, La Habra, California 90631.*—The apparent acoustic length of the mouthpiece–leaderpipe combination increases with frequency through the normal playing frequency range. For example, the apparent length may increase from 23 cm at 165 Hz to 35 cm at 1100 Hz. At higher frequencies it declines. Theory indicates that, at frequencies low enough for losses to be neglected, the apparent acoustic length, l, should be related to the total internal volume of the mouthpiece–leaderpipe combination, V, the cross-sectional area of the main cylindrical tubing to which the leaderpipe is attached, S, the resonances and antiresonances of the mouthpiece–leaderpipe combination, Ω_n and Ψ_n, by the equation:

$$\operatorname{ctn}\left(\frac{\omega l}{c}\right) = \frac{Sc}{V\Omega_1}\left[\frac{(\Omega_1^2-\omega^2)\Psi_1^2(\Omega_2^2-\omega^2)\Psi_2^2(\Omega_3^2-\omega^2)\Psi_3^2(\Omega_4^2-\omega^2)\cdots}{\omega\Omega_1(\Psi_1^2-\omega^2)\Omega_2^2(\Psi_2^2-\omega^2)\Omega_3^2(\Psi_2^2-\omega^2)\Omega_4^2\cdots}\right]. \quad (1)$$

Experiments show that the tuning behavior of the mouthpiece–leaderpipe combination can be quantitatively predicted with this equation in the frequency range from zero to 1000 Hz.

3:15

JJ6. Input Impedance Curves for Reed Instruments. JOHN BACKUS, *Physics Department, University of Southern California, Los Angeles, California 90007.*—Equipment previously described [J. Acoust. Soc. Am. 50, 128(A) (1971)] for determining resonance frequencies in musical instruments is used to give quantitative curves of the input impedance of the instrument as a function of frequency. The equipment also plots along with the impedance curve the frequencies of the harmonics of a chosen fundamental frequency. For the reed instruments, such as the clarinet, bassoon, and oboe, the resonance frequencies (at which the instrument can sound) are those for which the impedance is a maximum. A series of typical input impedance curves for selected notes on the above instruments has been prepared and will be discussed. The input impedance of the clarinet for the resonance used ranges from 500 to 1000 cgs acoustic ohms; that of the bassoon, from 400 to 1200 ohms; and that of the oboe, from 800 to 1700 ohms. For high notes the oboe plays as much as 300 cents flat as compared to the frequency of the resonance on which it operates. [This work was supported by the National Science Foundation.]

3:30

JJ7. Transient Analyzer for Wind Instrument Tones. T. L. FINCH, *St. Lawrence University, Canton, New York 13617*, AND A. H. BENADE, *Case Western Reserve University, Cleveland, Ohio 44106.*—The starting or decay transient of a wind instrument tone may be written $p(t)=\Sigma f_n(t)\cos(2\pi\nu_n+\phi_n)$, where $f_n(t)$ is the time-varying amplitude of the nth component and ν_n and ϕ_n may vary slightly in time. To extract a particular $f_i(t)$, $p(t)$ is multiplied by $\cos 2\pi\nu t$ to give a heterodyne difference $\nu_h=|\nu_i-\nu_0|<\frac{1}{2}|\nu_i-\nu_{i\pm1}|$. The produce enters three stages of second-order LP filtering (cutoff ν_c). A tap at the stage 3 input goes via a hard limiter to a similar LP stage, providing a "sinusoid" of constant amplitude with frequency and phase identical with that of the three-stage filter output. Multiplying these two synchronous signals together gives $F_i(t)=f_i(t)[1+\cos(4\pi\nu_h t+\theta_i)]/2$. For $\nu_1>200$ Hz, $\nu_c=100$ Hz, so that $\nu_h\simeq50$ Hz is useful. Careful design gives filter rise times near 6 msec with small distortion of $f_i(t)$. Tones recorded on tape loops are analyzed by photographing superposed traces from several repetitions, $f_i(t)$ appearing as an envelope. Since θ_i is random between repetitions, the envelope defines $f_i(t)$ better than does one trace. Results for clarinets, flutes, and organ pipes are presented, and compared with the work of others.

3:45

JJ8. Quasi-Turbulent Damping at Wind Instrument Joints and Tone Holes. A. H. BENADE, *Case Western Reserve University, Cleveland, Ohio 44106*, AND JOHN K. CUDDEBACK, *School of Medicine, Indiana University, Bloomington, Indiana 47401.*—The measured Q of air column resonance can fall quickly with playing level by a factor of three or more at fortissimo (SPL $\gtrsim$ 143 dB inside first open tone hole) below the classical nonturbulent value associated with softer playing (SPL < 100 dB). The increased damping arises at all sharp-edged discontinuities in the bore, such as in mouthpiece receivers, valves, and tuning slides of brass instruments, and the sockets, tenons, and tone holes of woodwinds. Rounding these edges gradualizes the growth of the damping. Good instruments so treated become responsive and "flexible." When an instrument is thoroughly warmed up, similar changes arise via the temperature dependence of the kinematic viscosity and thence of the Reynolds number. Rounding of even a single corner is noticed by many players. Rounding also produces a "darkening" effect on tone color, owing to reduction of nonlinear turbulent effects. Musicians recognize a tonal distinction between drawn and soldered tone holes on saxophones. Rounding the corners of the latter eliminates the distinction. Study of numerous instruments and modification of many confirm that rounding from long use is one way that age improves wind instruments, provided bore and tone hole dimensions are not deranged by wear. Care with rounding can eliminate many problems of "unvented" tone holes (such as hissing, stuffiness, and unclear tone) if they are also sized correctly to maintain uniformity of tone hole lattice cutoff frequency.

The following 12 pages:

A paper on:

THE TUNING EFFECT OF THE
MOUTHPIECE AND LEADERPIPE.

presented to the

Acoustical Society of America

Fall Meeting
Los Angeles, November 1, 1973.

The first page is the abstract submitted to the Program Committee in advance of the meeting, and the rest is the typescript, read at the meeting by Professor John Backus (USC) because WTC had just had an emergency eye operation on October 27.

ABSTRACT

Trumpet Acoustics: The Tuning Effect of the Mouthpiece and Leaderpipe. W. T. Cardwell, Jr., Chevron Research Company, La Habra, California 90631. - The apparent acoustic length of the mouthpiece-leaderpipe combination increases with frequency through the normal playing frequency range. For example, the apparent length may increase from 23 centimeters at 165 Hz to 35 centimeters at 1100 Hz. At higher frequencies it declines. Theory indicates that, at frequencies low enough for losses to be neglected, the apparent acoustic length, ℓ, should be related to the total internal volume of the mouthpiece-leaderpipe combination, V, the cross-sectional area of the main cylindrical tubing to which the leaderpipe is attached, S, the resonances and antiresonances of the mouthpiece-leaderpipe combination, Ω_n and Ψ_n, by the equation:

$$\operatorname{ctn}\left(\frac{\omega\ell}{c}\right) = \frac{Sc}{V\Omega_1}\left[\frac{(\Omega_1^2-\omega^2)\ \Psi_1^2\ \ (\Omega_2^2-\omega^2)\ \Psi_2^2\ \ (\Omega_3^2-\omega^2)\ \Psi_3^2\ \ (\Omega_4^2-\omega^2)\ldots}{\omega\Omega_1\ \ (\Psi_1^2-\omega^2)\ \ \Omega_2^2\ (\Psi_2^2-\omega^2)\ \ \Omega_3^2\ (\Psi_3^2-\omega^2)\ \ \Omega_4^2\ \ \ldots}\right] \quad (1)$$

Experiments show that the tuning behavior of the mouthpiece-leaderpipe combination can be quantitatively predicted with this equation in the frequency range from zero to 1000 Hz.

Technical Committee: Musical Acoustics

Subject Classification number: 6.3

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SLIDE 1

Definition Slide

A trumpet, by definition, has a cylindrical, or non-tapered, mid-portion.

At the player end, at the lip plane, the air column has a relatively large diameter; then it rapidly contracts into a small throat, after which it expands again, first relatively rapidly, in the backbore of the mouthpiece, then less rapidly in the leaderpipe.

(This particular slide, was made for a previous paper, and it does not depict as it might, the gentle tapering of the leaderpipe following the rapidly tapering mouthpiece backbore.)

Typically the backbore is a conic frustum about 3" long and the leaderpipe is another conic frustum about 9" long.

For our discussion, we are defining here the apparent length of the mouthpiece-leaderpipe combination as the length of a closed cylindrical tube of cross sectional area the same as the large end cross sectional area of the leaderpipe that would have the same reactive impedance as does the actual mouthpiece-leaderpipe combination. The impedance is considered to be measured looking into the large end of the leaderpipe toward the mouthpiece, and the mouthpiece is considered to be closed off at the lip plane.

The preceeding definition of the apparent length of the mouthpiece leaderpipe combination leads mathematically to an entire continuous function of apparent length versus frequency. At frequencies low enough for losses to be neglected, this entire function is given by the relationship shown on the next slide.

Slide 2

The large omegas are experimentally measured resonance (angular) frequencies. The large psi's are experimentally measured anti-resonance (angular) frequencies.

(Eight experimental resonances and seven anti-resonances are all that have ever been needed in any computation in the author's work to date.)

S is the cross sectional area
C is the velocity of sound
V is the experimentally measured total internal volume
of the mouthpiece leaderpipe combination.

The equation is solved for l, the apparent length, as a function of small omega, the angular frequency.

It is easy to show that the equation must be correct when the frequency is zero or is any one of the resonance frequencies or anti-resonance frequencies. Some of these relationships are shown on the slide.

For instance, when the frequency goes to zero, the apparent length approaches the total internal volume divided by the cross sectional area, as it must of course, from physical considerations.

When the frequency equals the first resonance frequency, the equation simplifies into an equation that says merely that the apparent length is a quarter wave length.

Similar relationships exist for all the other resonances and anti-resonances.

Slide 3

Experimental verification

On this slide, the solid curve of length versus frequency was computed from the experimentally measured resonance frequencies and anti-resonance frequencies and the total internal volume of the mouthpiece leaderpipe combination. The points represent apparent lengths calculated from the experimentally measured natural modes of a system consisting of the mouthpiece leaderpipe combination plus a 40" cylndrical tube of the same cross sectional area as the large end of the leaderpipe.

The agreement between the predictions based on measurements of the mouthpiece leaderpipe combination only and the measurements made on the long composite system is within experimental error in the range from zero to 1000 hertz. Above 1000 hertz, the prediction equation becomes inaccurate because of losses.

Slide 4

"The Anti-Mouthpiece-Leaderpipe"

Instead of giving several repetitious examples of conventional mouthpiece leaderpipe behavior as illustrated in the last slide, it seems more interesting to give an example showing just the opposite kind of apparent-length-versus-frequency behavior.

This slide represents a configuration that may be called "an anti-mouthpiece leaderpipe combination". In very simple terms, it has a bulge in its cross section just where the conventional mouthpiece leaderpipe combination has a contraction. As you see, its apparent length starts out at a high value and decreases with frequency well past 1000 hertz.

The apparent length of the conventional mouthpiece leaderpipe of the previous slide is shown dotted on this slide for comparison.

The anti-mouthpiece-leaderpipe combination was made into a composite system with a long cylindrical tube and the plotted points on the solid curve show how the predicted curve for the anti-mouthpiece-leaderpipe combination agrees with experimentally determined values for the composite system.

The obvious over-all lesson from this slide is that the type of behavior exhibited by the conventional mouthpiece leaderpipe combination of increasing apparent length with increasing frequency is just one possible type of apparent length variation which can be easily modified by design changes and indeed can even be reversed.

Slide 5

Comparison of two MPLP Combinations

This slide illustrates the most obvious possible use of the generatable apparent-length versus frequency curves: the comparison of the behaviors of differently shaped mouthpiece-leaderpipe combinations. It also illustrates one of the general truths that Art Benade is fond of pointing out, that the empirical evolution of musical instrument air columns has sometimes made at least approximate approaches to ideal shapes, which can hardly be improved by intuitive guesses - unless the intuition has become very sophisticated.

In this slide, the experimental mouthpiece-leaderpipe combination represented by the dashed line had its internal shape smoothed, by fairing out the abrupt profile slope change at the backbore-leaderpipe junction and also the abrupt profile slope change at the leaderpipe-cylinder junction.

The subtle technical point is that bore perturbations and perturbations of the apparent length vs frequency curve are Fourier transforms of each other, and smoothing one may unsmooth the other!

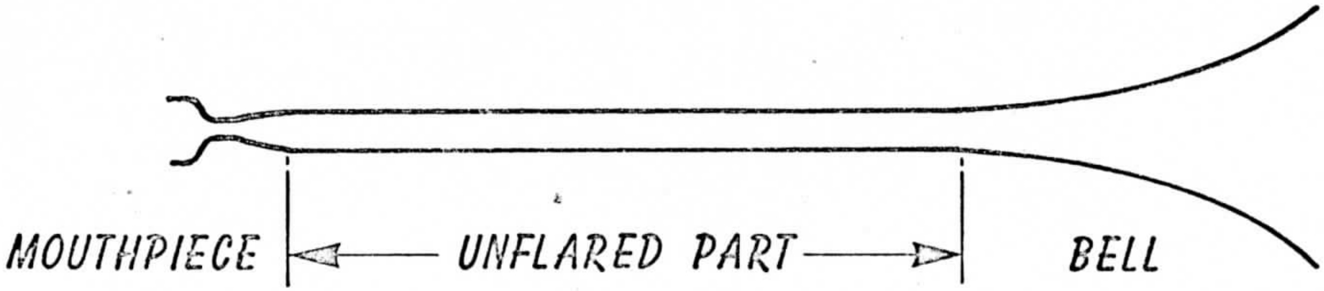
The internally smoothed mouthpiece-leaderpipe combination is not as good as its broken-line-profiled predecessor. It is interesting that the worst of its faults, according to the trumpeter who used it on a playing job, was its flatting effect at written middle C (233 Hz). The curves show clearly that the smoothed mouthpiece leaderpipe has excess length in the low frequencies.

Conclusion

Comparison of different mouthpiece-leaderpipe combinations is only the most obvious, simple use of the generatable apparent-length versus frequency curves. The author's main use has been in the design of actual entire trumpets, according to a method first outlined in a paper presented to this Society in 1966.

Those who are interested in computing the natural frequencies of trumpet-like air columns may find that the generatable apparent-length versus frequency function provides a useful way of handling the apparent moving boundary at the mouthward end of the air column.

The author believes that several other uses of the generatable apparent length versus frequency function will suggest themselves.


MOUTHPIECE
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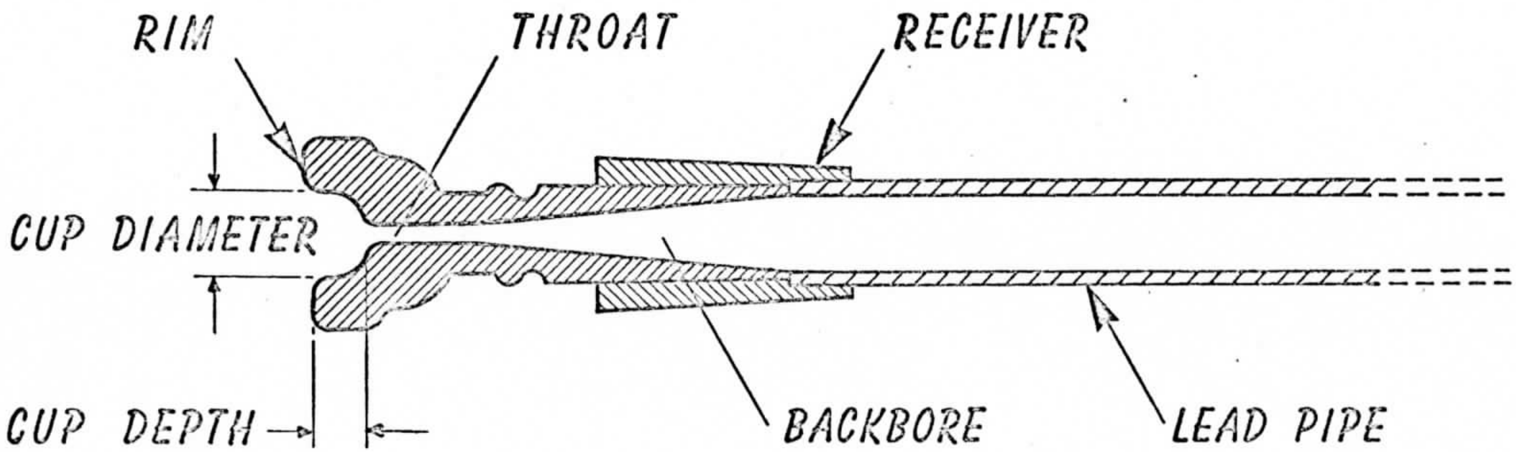

RIM
THROAT
RECEIVER
CUP DIAMETER
CUP DEPTH
BACKBORE
LEAD PIPE

$$\operatorname{ctn}\left(\frac{\omega l}{c}\right) = \frac{Sc}{V\Omega_1}\left[\frac{(\Omega_1^2-\omega^2)\quad \Psi_1^2\quad (\Omega_2^2-\omega^2)\cdots\cdots}{\omega\Omega_1\quad (\Psi_1^2-\omega^2)\quad \Omega_2^2\quad \cdots\cdots}\right]$$

When $\omega \to 0$

$l \to V/S$

When $\omega \to \Omega_1$

$\frac{\omega l}{c} \to \frac{\pi}{2}$

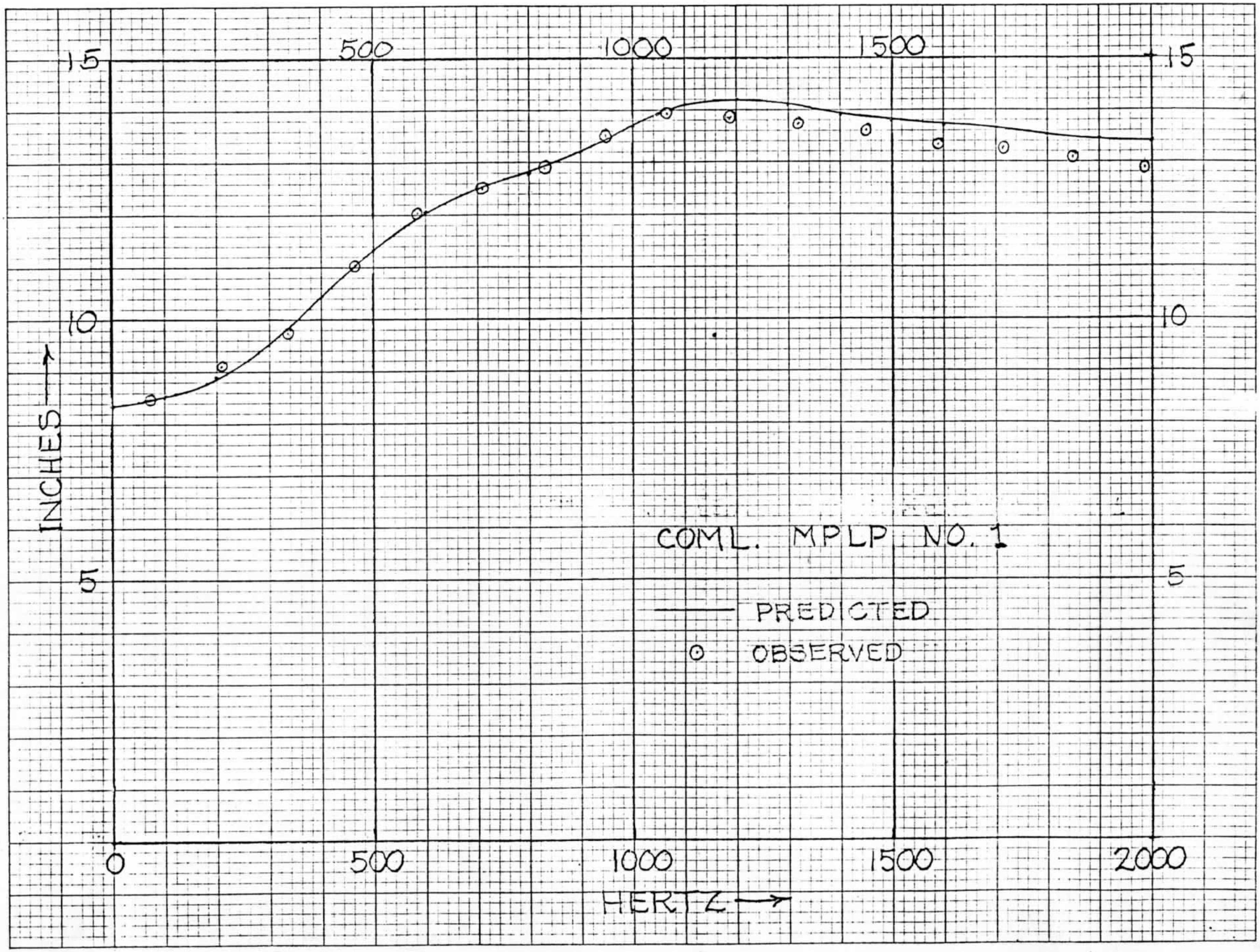
$l \to \frac{\pi c}{2\Omega_1} = \frac{c}{4F_1}$

When $\omega \to \Psi_1$

$\frac{\omega l}{c} \to \pi$

$l \to \frac{\pi c}{\Psi_1} = \frac{2c}{4G_1}$

etc.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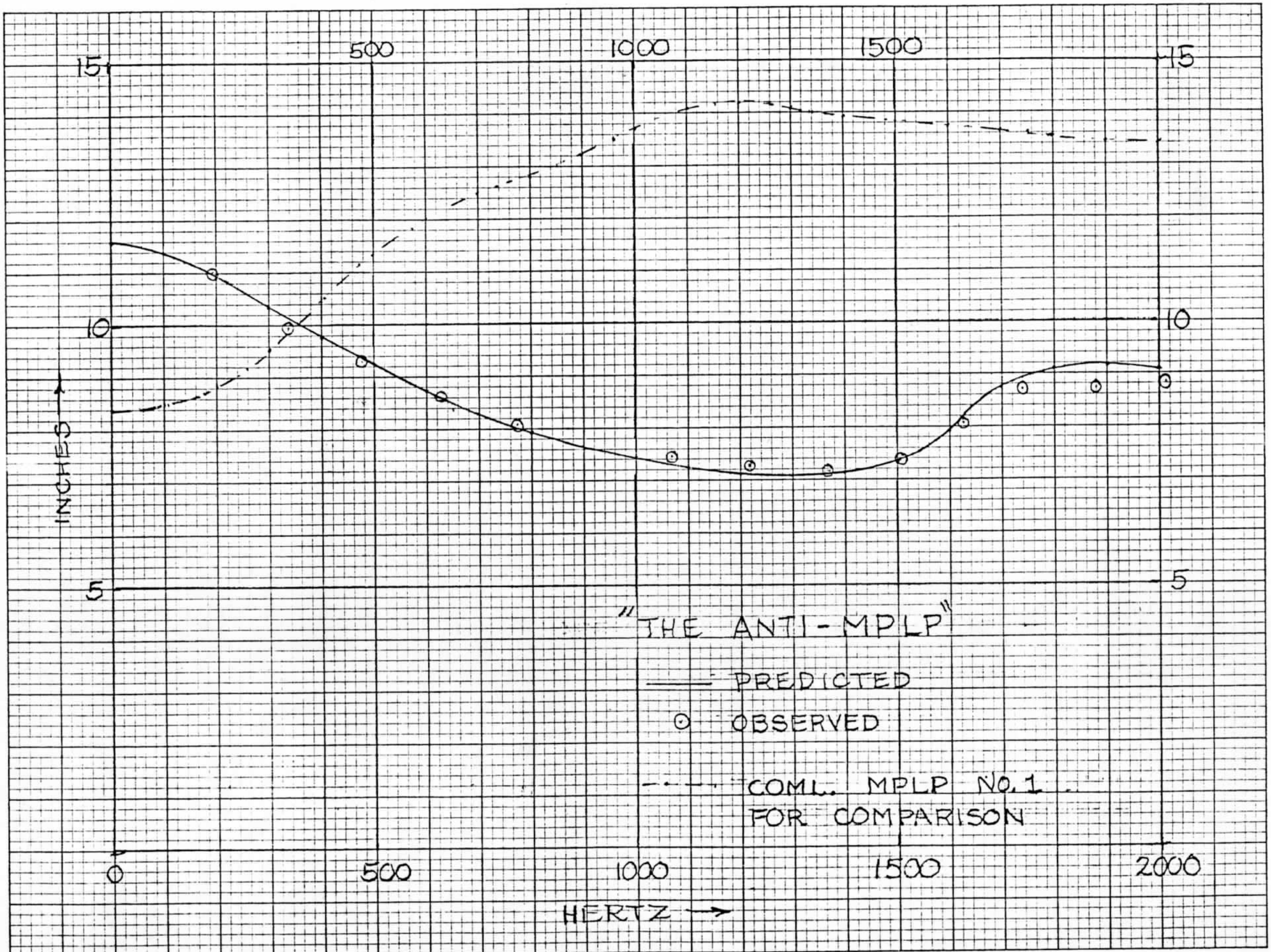

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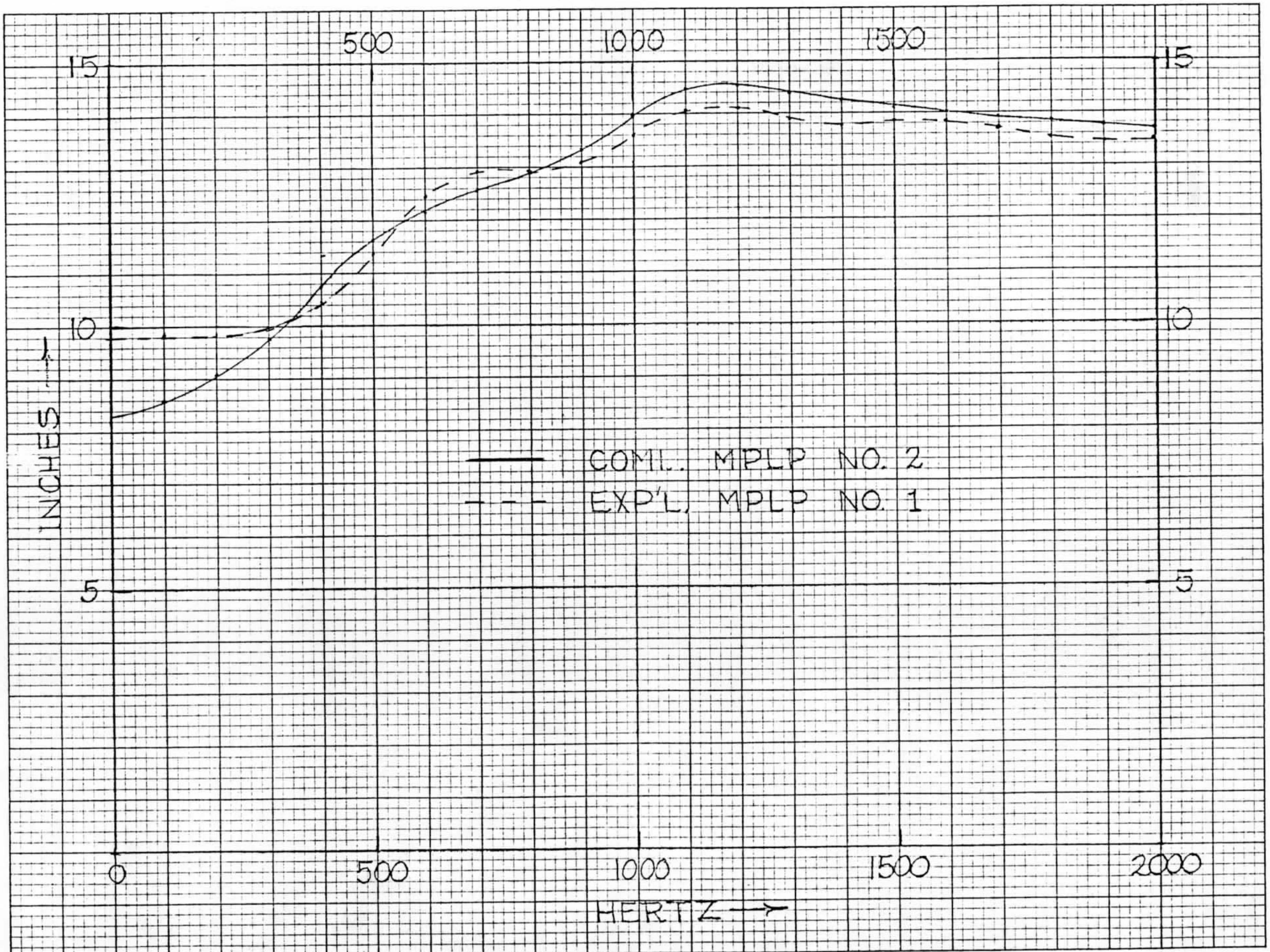
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