Overview of Paul Sabine's 1931 paper on "A Critical Study of the Precision of Measurement of Absorption Coefficients by Reverberation Methods"

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OUTLINE

- Who was Dr. Paul Sabine?
- Context Prior to the Classic Paper
- Main Thrust of the Classic Paper
- Influence on Subsequent Research
- Recreating the Methodology

WHO WAS DR. PAUL SABINE?

- Physicist and Harvard graduate
- Distant cousin of Wallace Clement Sabine
- Continued research at Riverbank after W.C. Sabine's passing in 1919
- One of the founding members of ASA in 1929

J. Kopec (1994)

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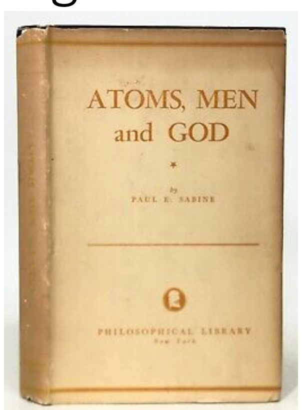
WHO WAS DR. PAUL SABINE?

- Published over 50 papers on architectural acoustics
- Spent considerable effort looking to unite religious teachings with modern science



J. Kopec (1994)

WHO WAS DR. PAUL SABINE?

- Consulted on acoustical design of Kleinhans Music Hall in Buffalo, NY (and many others)
- Pioneer in developing test procedures, standards for absorption testing, sound transmission and sound power measurements
- Father to Hale Sabine, a distinguished acoustician (21st ASA President)

J. Kopec (1994)

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CONTEXT PRIOR TO THE CLASSIC PAPER…

PRIOR TO…
"A Critical Study of the Precision of Measurement of Absorption Coefficients by Reverberation Methods"

- (1895) W. C. Sabine first asked to diagnose the acoustical problems of Fogg lecture hall. Develops reverberation theory and organ pipe test method

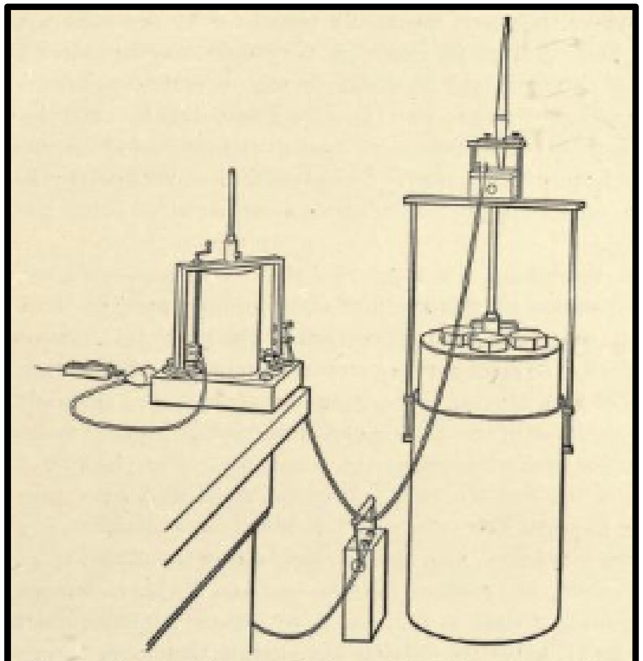

FIG. 1. Chronograph, battery, and air reservoir, the latter surmounted by the electro-pneumatic valve and organ pipe.

PRIOR TO…
“A Critical Study of the Precision of Measurement of Absorption Coefficients by Reverberation Methods”

- (1895) W. C. Sabine first asked to diagnose the acoustical problems of Fogg lecture hall. Develops reverberation theory and organ pipe test method
- (1900) W. C. Sabine applies theory to design of Boston Symphony Hall
- (1913) Col. George Fabyan leads the construction of Riverbank Acoustical Laboratories
- (1919) W. C. Sabine passes away shortly after completion of Riverbank

PRIOR TO…
"A Critical Study of the Precision of Measurement of Absorption Coefficients by Reverberation Methods"

- (1919) Col. Fabyan located P. Sabine to take over as director at Riverbank
- (1924) More acoustical labs are constructed (e.g., Bureau of Standards).
  - Leads to more interlaboratory studies
  - Electric powered sources and equipment are starting to appear
- (1931) P. Sabine publishes "A Critical Study of the Precision of Measurement of Absorption Coefficients by Reverberation Methods"

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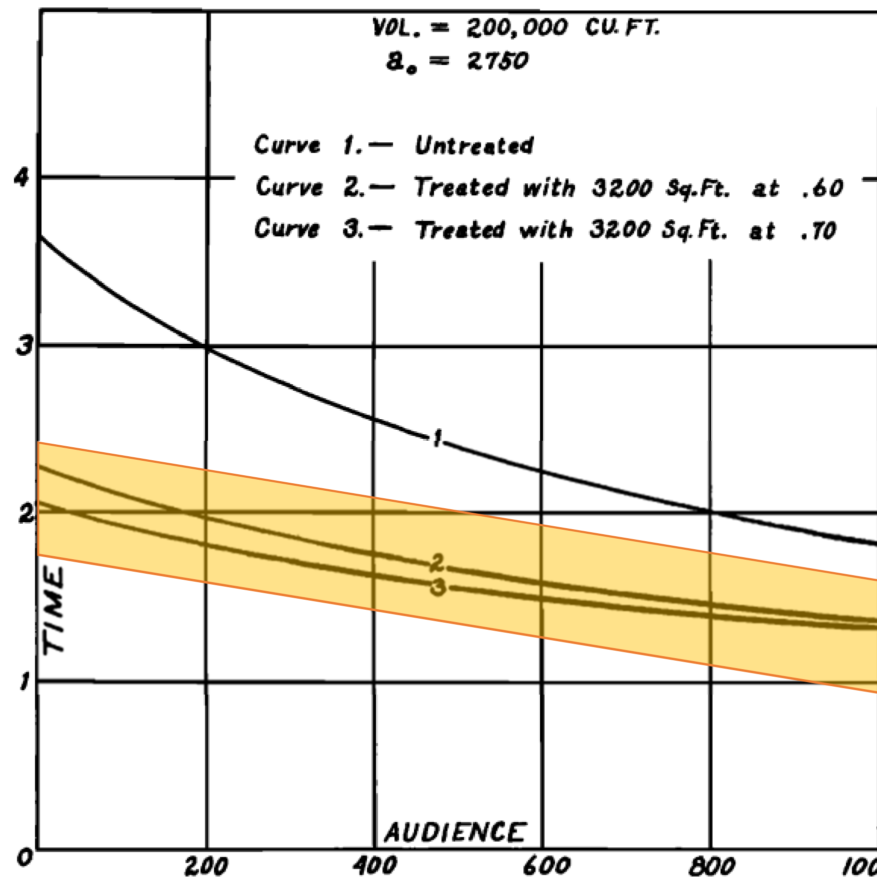
MAIN THRUST OF P. SABINE'S PAPER

- A practical example to illustrate tolerance of absorption measurements:
  - Take a 1000 seat auditorium of volume 200,000 ft^3 and absorptive seats (1.5 Sabins/seat)
  - When adding 3200 ft^2 of absorptive treatment, there is only a subtle difference in predicted RT between α = 0.6 and α = 0.7



15% Error produces only a 0.2 second change in unoccupied RT

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MAIN THRUST OF P. SABINE'S PAPER

- In parallel, absorption coefficient measurements across laboratories were yielding inconsistent results

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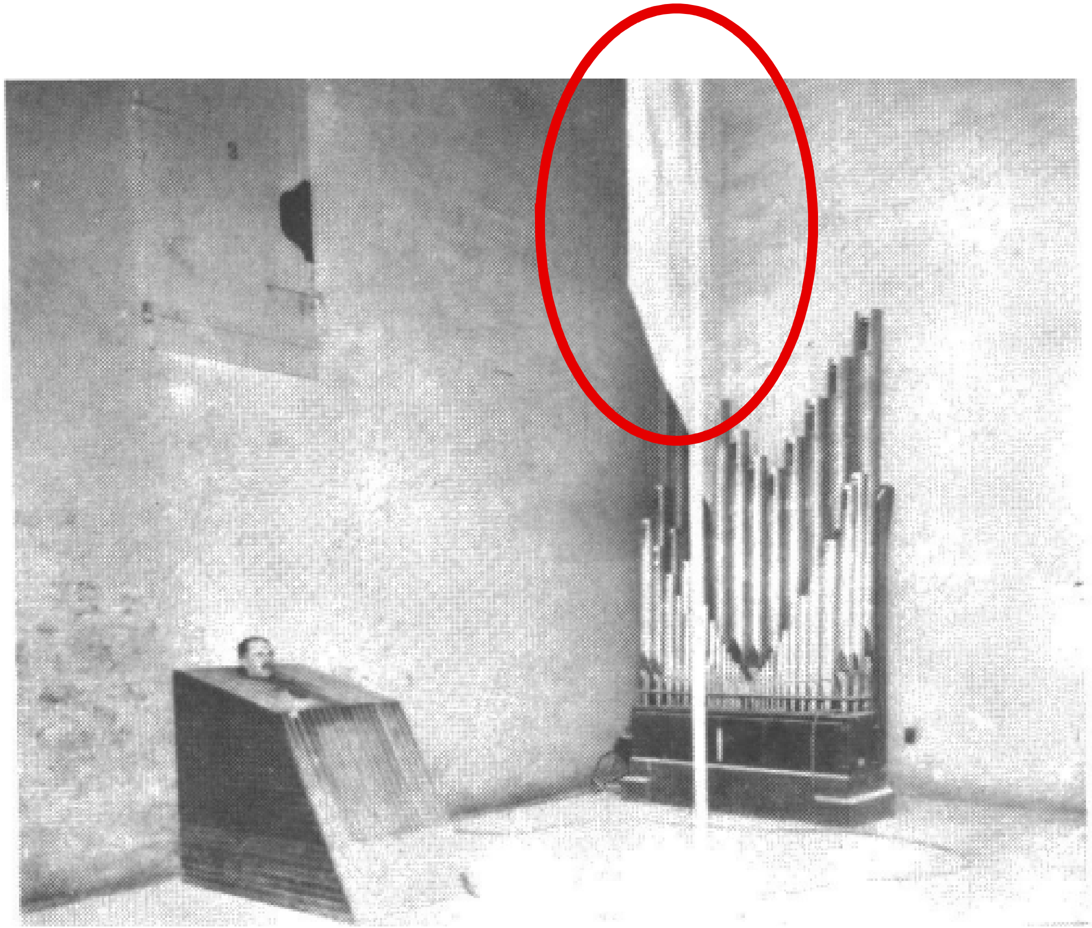
- Measuring absorption coefficients of four test specimens
- At five frequencies (128 Hz, 256 Hz, 512 Hz, 1024 Hz, 2048 Hz)
- In Riverbank Reverberation Chamber
- Using organ pipe and loudspeaker (steady and flutter tone) sources
- Compared to Bureau of Standards tests on same samples

MAIN THRUST OF P. SABINE’S PAPER



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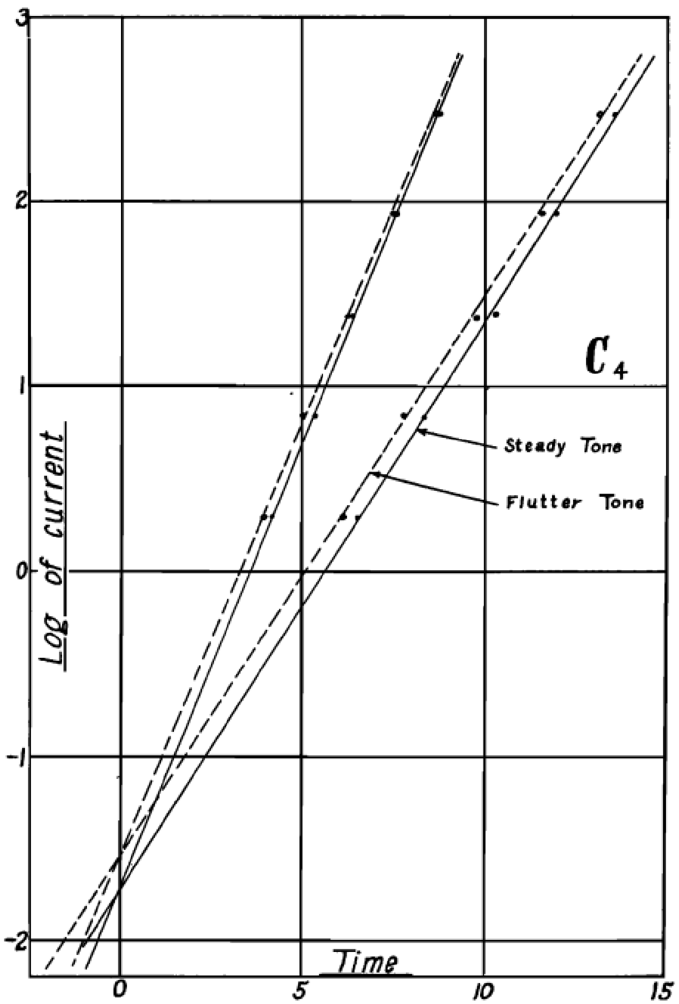
MAIN THRUST OF P. SABINE'S PAPER



- For loudspeaker measurements:
  - Linear relation b/w time and current
  - Current necessary to produce sound at intensity threshold of hearing is same with/without sample

- Variable Intensity Method

$$\frac{a' - a}{S} = \frac{15.4}{S}(m' - m)$$

m = slope of plot (sample-out)
m' = slope of plot (sample-in)

- For organ pipe measurements:

$$a' = \frac{1}{T'}\left(aT - \frac{4V}{c}\ln\frac{T}{T'}\right)$$

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- Considering magnitude of measurement errors:
  - Assuming 1% error in *a'*, the percent error in absorption coefficient can be calculated:

a'/a	Possible per cent error in coef.
1.25	9.0
1.50	5.0
1.75	3.7
2.0	3.0

- Error can be reduced if absorption of untreated reverberation chamber is high, but also noted that observer error seemed to also increase when RT increased.

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- Magnitude of observer hearing error can be seen by investigating results across three days:
  - Hearing error can be reduced by alternating sample-in/sample-out measurements on the same day.

	T	T'	a	a'	$a'-a$
	12.47	7.58	5.17	8.30	3.13
	12.71	7.72	5.08	8.16	3.08
	12.79	7.73	5.04	8.15	3.07
Average	12.66	7.68	5.10	8.20	3.09
Average deviation	.123	.063	.05	.067	.023
Per cent deviation	1.0	0.8	1.0	0.8	0.7

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Comparison of Measured Absorption Coefficients

Pitch	Material	Coefficient			
		Organ Pipe	Loud Speaker Var. Intensity	Bureau of Standards	Absorption Meter
128	A	.08	.03	.09	
128	B	.08	.02	.13	
128	C	.13	.04	.18	
128	D	.—	.—	.19	
256	A	.18	.22	.20	
256	B	.29	.27	.28	
256	C	.46	.48	.38	
256	D	.42	.45	.42	
512	A	.48	.39	.48	.36
512	B	.62	.51	.61	.52
512	C	.67	.62	.64	.58
512	D	.64	.58	.61	.63
1024	A	.54	.62	.64	
1024	B	.55	.64	.73	
1024	C	.57	.67	.73	
1024	U	.69	.77	.72	
2048	A	.54	.62	.66	
2048	B	.59	.66	.73	
2048	C	.62	.83–.70	.73	
2048	D	.71	.79	.76	

- Large variance at 128 Hz
  - Sound field not truly diffuse?
- Better agreement between labs at 512 Hz
- At 1024 Hz and 2048 Hz, organ pipe method is consistently lower than loudspeaker methods

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CONCLUSIONS OF THE PAPER

- Reverberation room measurement methods only approximately estimate absorption coefficients, rather than precisely determine them

- Absorption coefficients may vary considerably without producing appreciable differences in acoustical quality of a room

- Other criteria like color, aesthetic, and cost could weigh more heavily than practically insignificant differences in absorption coefficients

IN SUBSEQUENT YEARS…

- Hunt reaffirms “The Absorption Coefficient Problem” (1939)
- Notes that an international round robin took place but failed to establish common ground!
    - “Coefficients of the same material measured in different laboratories are not usually in agreement.”
    - “Field measurements yield smaller coefficients than laboratory measurements.”
    - “Increasing the sample size leads to smaller coefficients but this effect does not explain the preceding.”

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IN SUBSEQUENT YEARS…

- Normal Modes:
  - Maa (1939) derived the distribution of Eigentones for rectangular chambers

$$N = \frac{4\pi V f_u^3}{3c^3}\left(1 + \frac{3Sc}{16V}\frac{1}{f_u} + \frac{3Lc^2}{8\pi V}\frac{1}{f_u^2}\right)$$

- V = Volume
- S = Total Interior Surface Area
- L = (Length + Width + Height)
- c = speed of sound
- f_u = upper frequency limit for N

  - Hunt, Beranek, and Maa (1939) identified that normal modes influence decay curves
  - Linked experimental decay curves to predictions of theory (damping of normal modes influenced by impedance of the boundaries)

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IN SUBSEQUENT YEARS…

- Diffusion:
  - Kosten et. al. (1960) performed a round robin study of absorption coefficients which indicated that sample area and room diffusion can significantly influence the resulting coefficients.
  - Schultz (1971) develops a method to check diffusion during measurements
  - Benedetto et. al. (1981) studied the effect of stationary diffusors on absorption coefficient measurements
- In 1963, International Standard, ISO 354, governing absorption coefficient test in a reverberation room is first developed (later revised in 2003)

IN SUBSEQUENT YEARS…

- Edge Effects:
  - Northwood et. al. (1959) examine effects of edge diffraction for finite-sized test samples, which could cause inflation of true absorption coefficients
  - De Brujin (1973) performs a mathematical analysis to determine edge-effects

MOST RECENTLY…

- Nolan et. al. (2018) considering the spatial decomposition of the sound field in reverberant spaces
- Balint et. al. (2019) using Bayesian estimation of decay time for absorption measurements in a reverberation chamber
- Berzborn et. al. (2021) considering the isotropy of the incident sound field on the absorber

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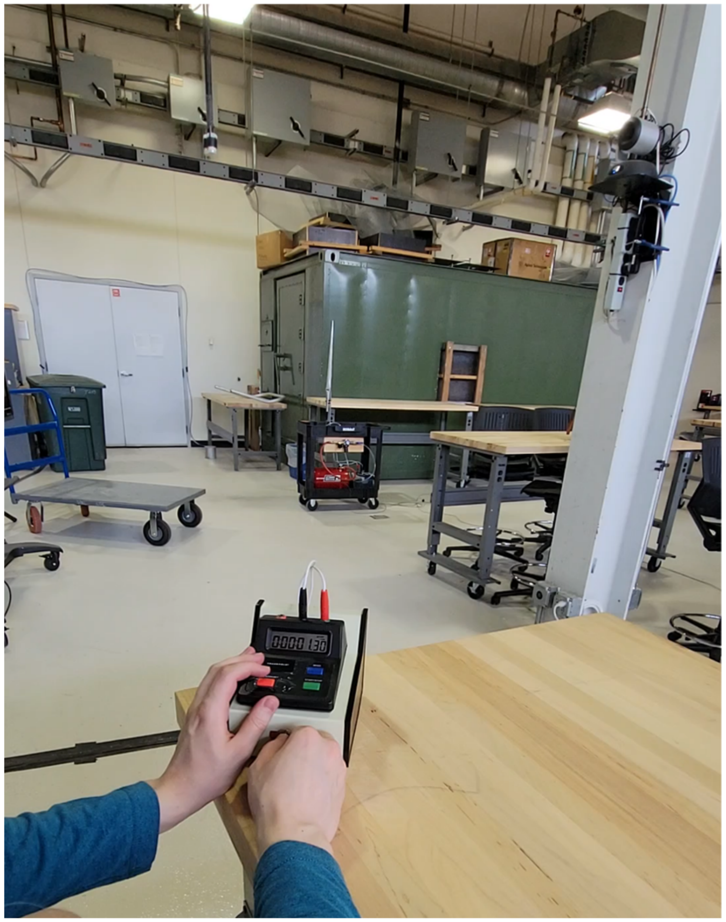
RECREATING THE SABINE ORGAN PIPE METHOD…

RECREATING THE ORGAN PIPE SOURCE METHOD

- Assembled portable test rig:
  - Gemshorn stop organ pipe (one octave above middle C), 512 Hz
  - Compressed air tank
  - Solenoid valve
  - 12V battery
  - Digital stopwatch

- Two-pole switch toggles airflow and activates stopwatch
- Experimenter stops timing when reverberation ceases

TESTING IN ACTION!



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RECREATING THE ORGAN PIPE SOURCE METHOD

- How does our precision compare?

	W. C. Sabine Fogg Lecture Hall C5 Gemshorn Stop	UNL Peter Kiewit Institute 117 C5 Gemshorn Stop	UNL Peter Kiewit Institute 117 C4 Overblown
Average Audible Duration	4 sec	0.68 sec	1.20 sec
Standard Deviation	0.11 sec	0.05 sec	0.08 sec
Maximum Deviation	0.31 sec	0.11 sec	0.12 sec

RECREATING THE ORGAN PIPE SOURCE METHOD

- Next steps for the Sabine Cart?
  - Expanding pipe assembly to include other octaves
  - Lab demo for undergrad acoustics courses
  - Test in reverberation room?

IN SUMMARY…

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Thank you!

Questions?

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