Overview of Paul E. Sabine’s 1931 paper: A Critical Study of the Precision of Measurement of Absorption Coefficients by Reverberation Methods

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Overview of Paul E. Sabine’s 1931 paper: A Critical Study of the Precision of Measurement of Absorption Coefficients by Reverberation Methods

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Books by Paul E. Sabine
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Wallace C. Sabine
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- Compare tests from different sources and places.
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1931

• Similar labs are built (Bureau of Standards and other universities).

• Compare tests from different sources and places.

• Published the paper that studies the precision of reverberation measurements.
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A CRITICAL STUDY OF THE PRECISION OF MEASUREMENT OF ABSORPTION COEFFICIENTS BY REVERBERATION METHODS

By Paul E. Sabine
Riverbank Laboratories

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- Similar labs are built (Bureau of Standards and other universities).
Better understand the numerical results from material test

- Tolerance of error in results that will not significantly affect the acoustical quality in a room.

Meet the designed absorption:

- If absorption coefficient is 0.7, 3200 square feet is needed.
- If absorption coefficient is 0.6, 3700 square feet is needed.
- But no significant effect on reverberation time, if a material of 0.6 is measured as 0.7 (an error of 15%).
Motivation of the Paper

- Better understand the numerical results from material test
  - Tolerance of error in results that will not significantly affect the acoustical quality in a room.
  - Consistency among tests from different sources, different ways to calculate the absorption coefficient and different labs.
  - How much error is expected from different test methods
  - What factors can affect the measurement errors.
Experimental Parameters

- **Reverberation time**: time for the sound decay from the stop of the source to audibility.

- **Sources**: organ pipes and loudspeaker (steady and flutter tone).

- **Observations**: 25 observations from 5 locations for each test condition.

- **Test sequence**: alternating measurements with and without the material sample in the chamber.
Calculus Absorption Coefficient

- Reverberation theory *(Wallace Sabine)*:

\[ w(t) = w_0 e^{-\left(\frac{4V}{cA_s}\right)t}, \]

- \( w \) – intensity (energy density),
- \( c \) – sound speed,
- \( V \) – room volume.
- \( A_s \) – room absorption.
Calculating Absorption Coefficient

- Reverberation theory \((Wallace Sabin)\):
  
  \[ w(t) = w_0 e^{-\left(\frac{4V}{cA_s}\right)t} \]
  
  - \(w\) – intensity (energy density), \(V\) – room volume.
  - \(c\) – sound speed,
  - \(A_s\) – room absorption.

- Loudspeaker measurements:
  - Fixed Current
    - Regardless of room condition
    - Radiation power proportional to room absorption
  - Fixed Intensity
Loudspeaker measurements:

- Variable intensity method

\[ \frac{A_s' - A_s}{S} = 15.4 \frac{m' - m}{S}, \]

- Variable source method

\[ A_s' T' = A_s T, \]

Organ pipe measurements (constant radiation power):

- Constant source method

\[ A_s' = \frac{1}{T'} \left( A_s T - \frac{4V}{c} \ln \frac{T}{T'} \right), \]

\[ V - \text{room volume}, \quad c - \text{sound speed} \]
Magnitude of Errors

- Error in absorption coefficient and its contributing factors
  - Assume 1% error in $A_s'$, the percent error in absorption coefficient can be calculated:

<table>
<thead>
<tr>
<th>Ratio of absorbing power $A_s'/A_s$</th>
<th>Percent error in coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25</td>
<td>9.0</td>
</tr>
<tr>
<td>1.50</td>
<td>5.0</td>
</tr>
<tr>
<td>1.75</td>
<td>3.7</td>
</tr>
<tr>
<td>2.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

- Better to use a more reverberant room, however, the error in determining the reverberation time by ear is greater.

- Magnitude of hearing error can be illustrated by results from three different days

<table>
<thead>
<tr>
<th></th>
<th>$T$</th>
<th>$T'$</th>
<th>$A_s$</th>
<th>$A_s'$</th>
<th>$A_s'-A_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>12.66</td>
<td>7.68</td>
<td>5.10</td>
<td>8.20</td>
<td>3.09</td>
</tr>
<tr>
<td>Average deviation</td>
<td>0.123</td>
<td>0.063</td>
<td>0.05</td>
<td>0.067</td>
<td>0.023</td>
</tr>
<tr>
<td>Percent deviation</td>
<td>1.0</td>
<td>0.8</td>
<td>1.0</td>
<td>0.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

- Hearing error can be eliminated by alternately measure times with and without the sample.
Magnitude of Errors

- Precision of different methods
  - Constant source method
    - A trained observer may duplicate the values of absorption coefficient within 4 or 5 per cent (256 to 2048 Hz).
  - Variable intensity method
    - Error is four or five times greater than the constant source method
    - Best reproducibility is 1% for the slope of logarithmic decay curve
    - 1% error in original data may introduce 12% error in absorption coefficient
  - Variable source method
    - More sensitive to error in reverberation for highly reverberant rooms
Comparison of Results

- At 128 Hz, large variation occurs.
  - Sound field is not diffuse
  - Sample size is not large enough

- At 128 Hz, very well agreement.

- At 512 Hz, organ pipe results in Riverbank agree with loudspeaker results in Bureau of Standard.

- At the two highest frequencies, organ pipes give consistently lower values.

<table>
<thead>
<tr>
<th>Pitch</th>
<th>Material</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Organ Pipe</td>
</tr>
<tr>
<td>128</td>
<td>A</td>
<td>.08</td>
</tr>
<tr>
<td>128</td>
<td>B</td>
<td>.08</td>
</tr>
<tr>
<td>128</td>
<td>C</td>
<td>.13</td>
</tr>
<tr>
<td>128</td>
<td>D</td>
<td>.—</td>
</tr>
<tr>
<td>256</td>
<td>A</td>
<td>.18</td>
</tr>
<tr>
<td>256</td>
<td>B</td>
<td>.29</td>
</tr>
<tr>
<td>256</td>
<td>C</td>
<td>.46</td>
</tr>
<tr>
<td>256</td>
<td>D</td>
<td>.42</td>
</tr>
<tr>
<td>512</td>
<td>A</td>
<td>.48</td>
</tr>
<tr>
<td>512</td>
<td>B</td>
<td>.62</td>
</tr>
<tr>
<td>512</td>
<td>C</td>
<td>.67</td>
</tr>
<tr>
<td>512</td>
<td>D</td>
<td>.64</td>
</tr>
<tr>
<td>1024</td>
<td>A</td>
<td>.54</td>
</tr>
<tr>
<td>1024</td>
<td>B</td>
<td>.55</td>
</tr>
<tr>
<td>1024</td>
<td>C</td>
<td>.57</td>
</tr>
<tr>
<td>1024</td>
<td>U</td>
<td>.69</td>
</tr>
<tr>
<td>2048</td>
<td>A</td>
<td>.54</td>
</tr>
<tr>
<td>2048</td>
<td>B</td>
<td>.59</td>
</tr>
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<td>.62</td>
</tr>
<tr>
<td>2048</td>
<td>D</td>
<td>.71</td>
</tr>
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Conclusion of the Paper

- Measurements by reverberation methods are approximate estimates rather than precise determination.

- Precise enough results can be achieved for applications to practical problems.

- There is no optimum reverberation time of a room for best precision.

- Considerable variation in absorption coefficients often does not produce appreciably differences in the acoustical quality of a room.

- Difference in characteristics such as color and appearance may often outweigh the difference in absorption coefficients.
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1988
- International standard, ISO–354, was developed (revised in 2003).

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- Hidaka, et. al. proposed a correction for atmospheric absorption.
Davy, et. al. investigated the optimum locations of the diffusors.
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• Cops, et. al. considered experimental control, locations of source, sample and receivers and using Eyring’s equation.
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• Liu and Bolton proposed a room acoustic simulation method using equivalent source model that can potentially be used to predict the reverberant test results.
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