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PRESENTS

Non-linear decays in simple spaces and their possible exploitation

a power point presentation by Mike Barron

ABSTRACT

Standard room acoustic theory is based on the assumption that the sound field is diffuse. Yet in auditoria one might consider the likelihood of a diffuse sound field to be remote, since nearly all the absorption is on only one of the six principle surfaces, the floor. In practice, the situation regarding diffusion in auditoria is generally less extreme than this thought might suggest.

However, spaces with poor diffusion are not uncommon, which often means that the Sabine or Eyring reverberation time equations do not predict accurately. In such situations, one is usually dealing with non-linear decays, so that even quantifying the measured situation becomes difficult. The traditional methods for measuring reverberation time (such as T20 and T30) may be of questionable validity with non-linear decays.

This paper considers first the question of quantifying the situation in spaces with poor diffusion. The subsequent discussion is concerned with the physical requirements for auditorium spaces to exhibit non-linear behaviour and how that might be valuable in certain multi-purpose halls. Four auditorium spaces will be reviewed: two scale model spaces, a real auditorium with non-linear behaviour and fourthly rectangular shoebox halls. Click to go to full paper

Related papers:

The effect of scattering surfaces in rectangular concert halls: A scale model analysis by Green, Barron and Thompson

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Concert Hall Acoustics

Non-linear decays in simple spaces and their possible exploitation

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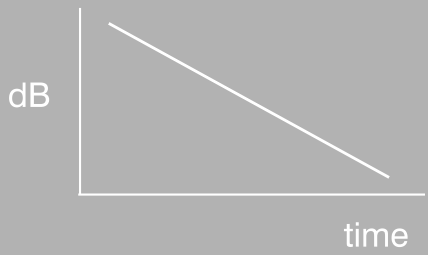
Non-linear decays in simple spaces and their possible exploitation

Programme

- Quantifying curved decays and diffusion
- Behaviour in four spaces:
  - Generic concert hall scale model
  - Scale model lecture hall
  - Stadthalle, Goettingen, Germany
  - Shoebox concert halls
- Subjective response to non-linear decays
- Conclusions

How often do we assume that a reverberant decay is linear?



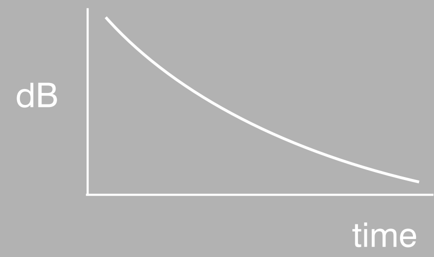
Quantified by a single number representing the slope

Easy!

Quantifying a curved decay?

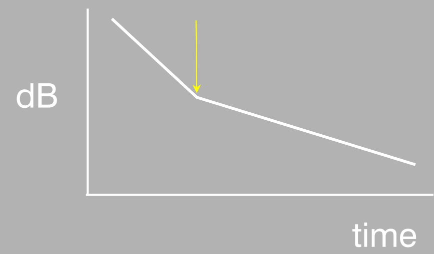
Mean slope and curvature?

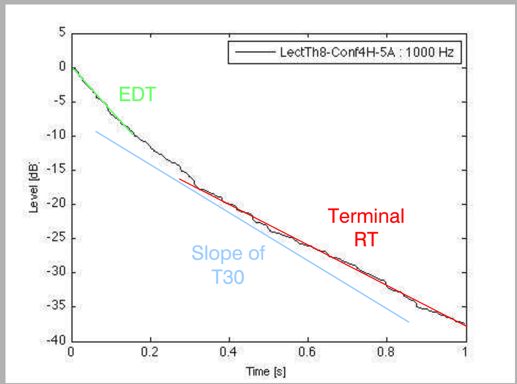
Slopes at different dB levels?



Quantifying a double-sloped decay?

Measure slopes and level in dB where the slope changes





Analysis of a real double-sloped decay

Level at change of slope -18 dB

Quantifying the state of diffusion in a space

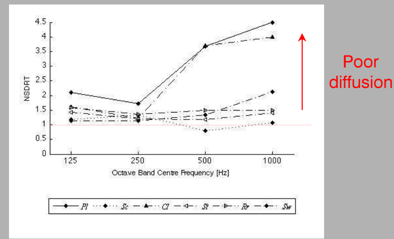
1. Measuring the non-linearity of decays
2. Ratio of measured to Sabine reverberation time

   Accuracy of Sabine RT calculation?

3. Comparing standard deviation of RT with theory

   Theory due to Davy. Theoretical standard deviation = f(RT, bandwidth)

   $$\text{Normalised standard deviation (NSDRT)} = \frac{\text{Measured standard deviation}}{\text{Theoretical standard deviation}}$$

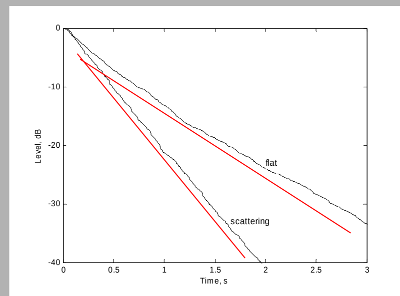


Experiments in a scale model generic concert hall

Scale 1:25. Air absorption corrected by computer.

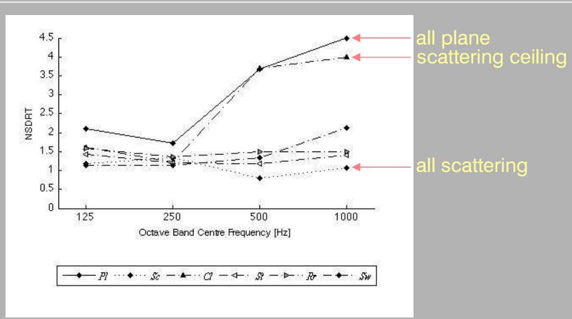
Wall and ceiling openings allow plane or scattering panels to be inserted

Experiments in a scale model generic concert hall



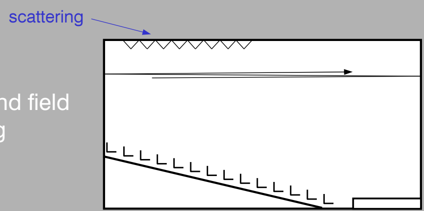
Typical decays with all panels plane (flat) and all panels scattering

Red lines added to help judge linearity



NSDRT (Normalised standard deviation of RT) for a series of configurations in the concert hall model. *Sc* = all panels scattering; *Pl* = all panels plane; *Cl* = plane except for 8 panels on the ceiling.

Explanation: 'horizontal' sound field remote from the ceiling



1:25 scale model lecture theatre

Mixture of model people and seats, capacity 300

All surfaces plane, though flutter echoes suppressed

Could we exploit the non-linear decay in this space in order to have intelligible speech but a longer terminal decay rate?

Findings in case with raked seating

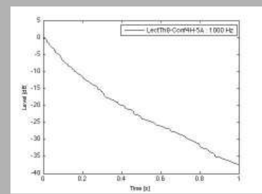
- Reverberation times (T20) were about 20% higher than predicted by the Sabine equation and by CATT
- CATT prediction of early energy fraction (D_{50}) agrees well with measurement in spite of non-linear decays
- CATT used to investigate possible reverberation times which allow intelligible speech, absorbing material was added to control RT

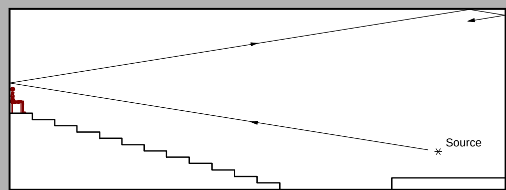
Reverberation times for intelligible speech, $D_{50} > 0.5$

Measure	Level range (dB)	Reverberation time (s)
Early Decay time (EDT)	0 to -10	1.28
T15 (RT measured over 15 dB)	-5 to -25	1.51
T30 (RT measured over 30 dB)	-5 to -35	1.64
Sabine prediction	-	1.05

A possible solution for multi-purpose acoustics for speech and music

Typical decay from the lecture theatre model:





Note that you cannot have a horizontal sound field without scattering/diffraction !

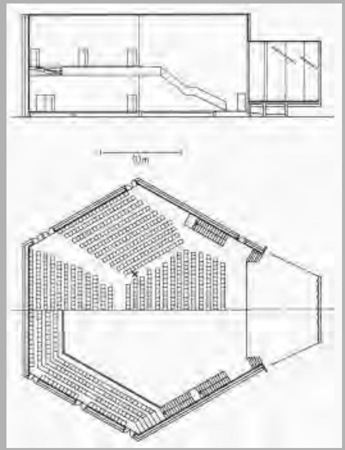
Stadthalle, Goettingen, Germany

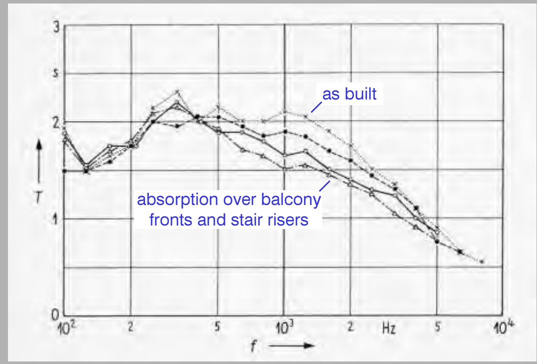
Opened in 1964, 1250 seats

Uses: orchestral concerts, theatre, conferences etc.

Predicted reverberation time 1.6 seconds

Highly diffusing ceiling

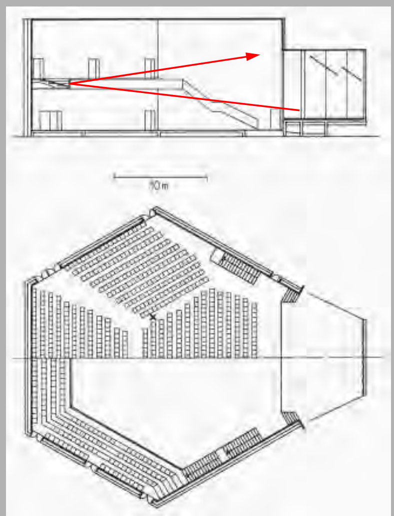




Measured reverberation times in the unoccupied Stadthalle

x——x, as built; ●- - - - ●, with absorption on central balcony front;
○——○, with absorption over whole balcony front;
△- - -△, with absorption over whole balcony front and stair risers.

Measured RT 25% greater than predicted. RT can be reduced by placing absorbing treatment on balcony fronts – another example of a horizontal 2D sound field. Subjectively liked by audience and performers.



Two dimensional reverberation in the ceiling area that is coupled to the lower space via reflection off the balcony fronts

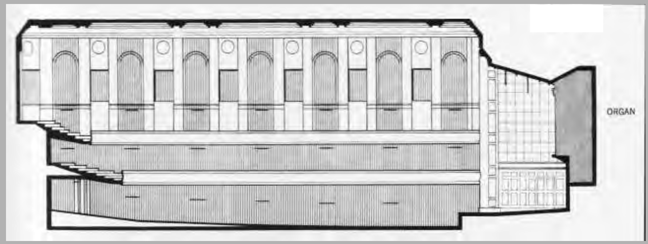
Reverberation prediction in shoebox (rectangular) halls and non-rectangular halls (such as terrace halls)

Beranek (JASA **120**, 1399-1410) proposed in 2006 on the basis of measurements that, for prediction, different absorption coefficients were appropriate for occupied seating.

Because in rectangular halls there is on-going reverberation at high level, the effective absorption by the seating is less

Octave frequency	500 Hz	1000 Hz
Rectangular halls	0.79	0.85
Non-rectangular halls	0.85	0.89

Difference in absorption coefficients is 6%, leading to an RT difference of ~ 4.5%



Example of Boston Symphony Hall

Note significant height between highest balcony and the ceiling

Subjective issues

The ability of our hearing system to detect non-linear decays appears to be limited. The main requirement is it does not sound unnatural.

Non-linear decays are associated with poor diffusion, and if reverberation arrives from distinct directions, this may be detected (a possible problem with reverberation chambers).

CONCLUSIONS

Several examples of auditoria with vertical walls which generate non-linear decays. In each case, terminal decay associated with a horizontal sound field below the ceiling which involves reflection off hard surfaces.

To quantify the state of diffusion, the Normalised Standard Deviation of Reverberation Time (NSDRT) appears to be a useful parameter.

Our ears appear to be relatively insensitive to non-linear decays, unless directional cues are present.

Non-linear decays have the interesting potential of offering multi-purpose acoustics for spaces which could offer intelligible speech, for instance, and be used for unamplified music. Useful for community and school halls?

The design requirements to create horizontal sound fields are not trivial and deserve further investigation.