Proceedings

AUDITORIUM ACOUSTICS AND ELECTRO-ACOUSTICS

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DAVID HUME TOWER
UNIVERSITY OF EDINBURGH

8th–10th September 1982

INSTITUTE OF ACOUSTICS

PREPRINTS.

AUDITORIUM ACOUSTICS AND ELECTRO-ACOUSTICS

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AUDITORIUM ACOUSTICS
AND
ELECTRO-ACOUSTICS

8TH-10TH SEPTEMBER 1982

DAVID HUME TOWER

UNIVERSITY OF EDINBURGH

MEETING CO-ORDINATOR

ROBIN MACKENZIE, FIOA
DEPARTMENT OF BUILDING
HERIOT-WATT UNIVERSITY, EDINBURGH.

ORGANISING COMMITTEE

Dr. D. Fleming	Bickerdike Allen Partnership
Dr. R.K. Mackenzie	Heriot-Watt University
Mr. P. Mapp	Arup Acoustics
Mr. P. Newman	Heriot-Watt University

EXHIBITORS

BRUEL & KJAER (UK) LTD.

COMPUTER ENGINEERING LTD.

W. GRACEY ASSOCIATES

KEMO LTD.

WEDNESDAY 8 SEPTEMBER 1982

0830-0915 REGISTRATION

0915 OPENING ADDRESS - Robin Mackenzie

SESSION - CRITERIA FOR MEASUREMENT, ASSESSMENT & DESIGN - I

Chairman - Robin Mackenzie

0930 "Subjective Preference Design Criteria for Evaluating Acoustic Quality", H.G. LATHAM and P.I. NEWMAN, Heriot-Watt University, Edinburgh.

1000 "Predicting and Measuring Speech Intelligibility in Rooms", T. HOUTGAST and H.J.M. STEENEKEN, Institute for Perception, T.N.O., Soesterberg, The Netherlands.

1030 C O F F E E

1100 "The Psychoacoustical Background of Auditory Spaciousness", J. BLAUERT, Lehrstühl fur Allgemeine Elektrotechnik und Akustik, Ruhr-Universitat, 4630 Bochum, Federal Republic of Germany.

1130 "Fifteen Years Experience with a Computerised Ray Technique Program", A. KROKSTAD, S. STROM and S. SORSDAL, Laboratory of Acoustics, Elab-Sinter, Technical University of Trondheim, Norway.

1200 L U N C H

SESSION - MUSIC AND THE AUDITORIUM - CHAIRMAN - DAVID FLEMING

1330 (Invited Lecture)
"The Physics of the Interaction between the Player, his Instrument and his Acoustic Environment",
PROF. C.A. TAYLOR, University College, Cardiff.

1430 "How Players adapt psychologically to their Acoustic Environment", P.J. SIMPSON, The University of Surrey.

1500 T E A

1530 "Subjective Assessment of Concert Hall Acoustics", ALEXANDRA SOTIROPOULOU, University College London.

1600 "Listener Survey of UK Auditoria", M. BARRON, The University of Cambridge.

1630 "The Acoustic Design of Partially Enclosed Orchestra Pits", G.M. NAYLOR, R.M. BORKUM and R.K. MACKENZIE, Heriot-Watt University, Edinburgh.

THURSDAY 9 SEPTEMBER 1982

SESSION - ELECTROACOUSTICS - CHAIRMAN - PETER MAPP

0830-0900 REGISTRATION

0900 "Electro-acoustic Systems - A Review of Their Uses, Abuses and Implementation",
P. MAPP, Arup Acoustics.

0930 "Recent Advances in Assisted Resonance",
A. JONES and R. HILL, AIRO.

1000 "Multi Channel Reverberation Systems",
S. DE KONING, Philips, Breda, The Netherlands.

1030 C O F F E E

1100 "Vilhelm Jordan - Memorial Address",
B. DAY, University of Bristol.

1130 "Electro-acoustic Systems in the Harrogate Conference Centre and Theatre Royal Plymouth",
J.R. COWELL, Arup Acoustics and P. ANGIER, Carr & Angier.

1200 L U N C H

1330 "Room Simulation using Speaker Array and Audio Delay Systems",
D.K. OLDMAN, University of Sheffield, N.W. HEAP, Open University.

1400 "Show Sound in the British Theatre",
J. BEECH, Autograph Sound.

1430 "Sound System Design for Multipurpose Halls (Case Study based on Warwick University Art Centre)"
K. DIBBLE, Consultant.

1500 T E A

1530 "Recent Developments in Loud Speaker and Drive Unit Design",
G. BANK, Celestion International.

1600 "Loud Speaker Design for Speech Intelligibility in Reverberant Spaces",
P.W. BARNETT and W.R. STEVENS, AIRO.

FRIDAY 10 SEPTEMBER 1982

SESSION - CRITERIA FOR MEASUREMENT, ASSESSMENT & DESIGN - II

Chairman - Robin Mackenzie

0830-0900 REGISTRATION

0900 "Acoustical Modelling of the Troy Music Hall",
D.P. AYYAPPAN, Pelton/Blum, Inc., 1801 North Lamar, Dallas, Texas 75202, U.S.A.

0930 "Objective Testing for Auditorium Survey",
M. BARRON, University of Cambridge.

1000 C O F F E E

1030 (Invited Lecture)
"Sightlines and Soundlines - The Design of an Audience Seating Area",
PROF. ANITA LAWRENCE, Graduate School of the Built Environment, University of New South Wales, Australia.

1130 "The Acoustical Design of Wellington Town Hall : Design Origins, Research and Criteria Development",
A.H. MARSHALL, University of Auckland, New Zealand and J.R. HYDE, Consultant, Box 55, St. Helena, California 94574, U.S.A.

12.00 L U N C H

SESSION - NEW AUDITORIA - CHAIRMAN - PAUL NEWMAN

1330 "The Acoustical Design of Wellington Town Hall : Design Development, Implementation and Modelling Results",
A.H. MARSHALL, J.R. HYDE and M. BARRON.

1400 "St. David's Hall, Cardiff"
A. BURD, Sandy Brown Associates.

1430 "Theatre Royal, Plymouth"
J.R. COWELL, Arup Acoustics.

1500 T E A

1530 "Nottingham Concert Hall and Northampton Multi-Purpose Hall",
N. THOMPSON, Renton Howard, Wood, Levin Partnership.

1600 "Warwick University Multi-Purpose Hall"
D. FLEMING, Bickerdike, Allen Partners.

1630 CLOSING REMARKS

N.B. PAPERS WITHDRAWN : D. COLLISON and J. PILCHER, and N. SPRING.

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SUBJECTIVE PREFERENCE DESIGN CRITERIA FOR EVALUATING ACOUSTIC QUALITY

H.G. LATHAM AND P.I. NEWMAN

HERIOT-WATT UNIVERSITY, EDINBURGH.

INTRODUCTION

Our work at Heriot-Watt University has sought to answer two fundamental questions in architectural acoustics:

- What exactly are the important subjective acoustic qualities and how do they interact to differentiate good and bad acoustics?
- How can the designer make use of such knowledge to produce better auditoria?

Answers to these questions provide a contribution towards a design guide.

MEASURING THE QUALITY OF SPEECH AND MUSIC ACOUSTICS

To simplify the research problem, we concentrated our efforts primarily on speech acoustics with the intention of returning to the evaluation of music quality at a later stage. Four stages were envisaged:

1. The subjective measurement of speech intelligibility in rooms. Knowledge in this area of auditorium acoustics has been ascertained by observation and experiment and brought under a set of general principles. Objective indices (The Signal-to-Noise Ratio (1), The Modulation Transfer Function (2)) are available for measuring and predicting speech intelligibility levels without the need for traditional subjective testing procedures. However, further work is needed to establish a valid basis for speech intelligibility design criteria based on objective measurements. To this end, a catalogue of subjective and objective measures of speech intelligibility should be determined for a set of conditions in well-known auditoria to produce a relative scale of intelligibility values for use by practitioners.
2. Next, a more exacting subjective measurement scale - Speech Quality - was proposed to provide a subjective measure of overall excellence as determined by preference testing. This stage required the development of two design tools: a real-time multi-channel electroacoustic model to simulate physical sound fields, and a linear/scalar products mathematical model to analyse subjective preferences (together with an analysis of variance method for determining statistical significance and scalability levels). It was found that speech quality could be either multi-dimensional or uni-dimensional in configuration, and valid at either interval or ordinal levels of measurement. Four unipolar consensus dimensions (reflections ratio; excessive reverberation; discrete echo disturbance; naturalness) and three bipolar individual differences dimensions (reverberance; spatial colouration; evenness of echogram) were identified. The objective index, signal-to-noise ratio, gave a high correlation with speech quality for simulated sound fields without excessive background noise.
3. Finally, the problem of measuring music quality should be tackled using methods similar to Schroeder et al (3) but applying the more advanced statistical analysis methods developed at Heriot-Watt (4). Developments in sound field simulation methods and in subjective measurement techniques would then lead to the fourth stage.

4. The ultimate aim would be to develop and evaluate a design guide utilising computer prediction methods, physical scale modelling and sound field simulation, together with subjective criteria based on a catalogue of known conditions.

A STATISTICAL TEST FOR ACOUSTIC QUALITY MEASUREMENTS

Our work has utilised Bechtel's linear utility model (5) to provide a statistical test for multi-dimensional preference criteria:

$$p_{ijk} = \upsilon_{ij} - \upsilon_{ik} + \gamma_{jk} + e_{ijk} \qquad \text{Eqn. (1)}$$

where P_{ijk} is mean preference comparison between stimulus j and k for subject i; υ_{ij} is the value of stimulus j on the linear utility scale of subject i; υ_{ik} is the value of stimulus k on the scale for subject i; γ_{jk} is the unscalability of the stimulus pair j,k for all subjects; and e_{ijk} is random error in the preference comparison p_{ijk}.

It is assumed that the distribution of residual errors e_{ijk} in the linear utility model are random (uncorrelated with common variance) and mutually independent (jointly normal). If these assumptions hold, any two least squares estimates in different subsets (defined by each subject's preferences) are uncorrelated random variates. The calculated mean square values can then be compared with the hypothesis mean square error to derive an F-Ratio and thereby the significance level. A check for the validity of the assumptions is given by:

$$\text{cov} \quad (\hat{\upsilon}_{ij}, \hat{\upsilon}_{hk}) = 0 \qquad \text{Eqn. (2)}$$

for all subjects $(i \neq h)$
and all stimuli $(j;\ k = 1,\ldots,n)$

OPERATIONAL SEQUENCE FOR A MULTI-DIMENSIONAL ANALYSIS OF SUBJECTIVE PREFERENCE CRITERIA

1. The preliminary computations involve constructing a matrix of preference values (+1,-1,0) to determine utility values $(\hat{\upsilon}_{ij})$, unscalability components $(\hat{\gamma}_{jk})$ and error components $(\hat{e}_{ijk})$.

2. Means, sums of squares and degrees of freedom are calculated to construct an analysis of variance table for the untility scales and to estimate statistical significance levels ($p < 0.01$). If all data is significant and scalable go to step 4.

3. Return to step 1 for re-analysis of data omitting non-significant subject scales and unscalable stimuli effects.

4. The scalar products submodel is computed by Carroll and Chang's MDPREF (6), for a full variance solution,

5. A restricted variance solution is calculated with dimensionality determined by the number of roots which account for 90 per cent of the total variation.

6. The multi-dimensional configuration of subjects and stimuli in the geometric preference model is interpreted in terms of acoustic quality parameters.

REFERENCES

1. H.G. LATHAM 1979 Applied Acoustics 12(4), 253-320. The signal-to-noise ratio for speech intelligibility - an auditorium acoustics design index.

2. T. HOUTGAST and H.J.M. STEENEKEN 1973 Acustica 28, 66-73. The modulation transfer function in room acoustics as a predictor of speech intelligibility

3. M.R. SCHROEDER, D. GOTTLOB and K.F. SIEBRASSE 1974 JASA 56, 1195-1201. Comparative study of European concert halls: correlation of subjective preference with geometric and acoustic parameters.

4. H.G. LATHAM 1981. PhD thesis, Heriot-Watt University. Acoustical designing for speech quality in theatres.

5. G.G. BECHTEL 1976. Multi-dimensional preference scaling, Mouton, The Hague.

6. J.D. CARROLL 1972 pp. 105-155 in Multi-dimensional scaling : theory and applications in the behavioural sciences Vol. 1, Eds. R.N. Shepard, A.K. Romney and S.B. Nerlove, Seminar Press, New York.

ACKNOWLEDGEMENT

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