Proceedings of the Institute of Acoustics

STI MEASUREMENTS ON SIMULATED ACOUSTIC ENVIRONMENTS

P.W. Barnett (1) P.H. Scarbrough (2)

(1) AMS Acoustics, London, U.K.
(2) Jaffe Acoustics Inc., Norwalk, Connecticut, U.S.A.

INTRODUCTION

This Paper presents some of the results from a series of experiments carried out earlier this year and additionally makes comparisons with the $\%AL_{cons}$ concept. Measurements in simulated acoustic environments (MSAE) is suggested as a predictive tool.

The prediction of intelligibility and the estimation of intelligibility through correlation of measurements are two quite different tasks. It is, of course, easy to be wise after the event but from a consultants standpoint it would be better to make an accurate and informed prediction to be confirmed later.

The calculation and prediction of audio system performance parameters is assuming increasing importance mainly due to an uncompromising attitude from end users and the general public. It is true that for many situations no prediction is necessary since it falls well within the boundaries of our experience. Such predictions and insurance tools are generally only necessary when we wish to increase the scope of our experience or indeed we may wish to tackle a project from another standpoint.

Our endeavour therefore was to verify the existing methods by carrying out a series of measurement on simulated environments. We used simulated environments for two basic reasons, firstly it could all be carried out under controlled laboratory conditions and secondly a vast amount of data could be collected in a very short time.

The data was collected over a relatively short period of time using a TEF Analyser.

EQUIPMENT SET-UP

We make no apology for the simplicity of both the equipment set up and the measurements taken. We freely acknowledge that in practice the situation is far more complex however, we view this as a start or a pilot study to validate the need for further work. The equipment was set up as shown in fig. 1.

STI MEASUREMENTS

Pre-experimental measurements were carried out in an attempt to remove uncertainties in the measurement technique, validate the measurements and to assess any inherent non-linearity in the chain. For example each item of equipment was tested to achieve STI 1.00 when gain only was present. For each unit a series of measurements was carried out by varying the gain over typically 20 dB range to determine any non-causal effects. All items of equipment were examined for frequency response and distortion to ensure they firstly met with manufacturers specifications and secondly did not introduce errors into the experimental measurements. As an added precaution each equipment chain was tested with each item of equipment present and then replaced by wire. The usual controls were made to ensure the authenticity and reputability of the measurements. For the sake of brevity these are not reported here.

MEASUREMENT PHILOSOPHY

Since the acoustic model was necessarily simple then reasonably so was our philosophy. We decided to deal simply with three components, direct sound, reverberant sound and reverberation time. It was then an easy matter to set the reverberation time on the reverberation unit and then adjust the relative levels of the direct and reverberant signal chains.

In addition to checking that an STI value of 1.0 was returned as expected we set the delay prior to the unset reverberation to a reasonable value based on the following:

$$E_{t(t)} = E_{\infty} (1 - e^{-13.8t/RT})$$

where:

$E_{t(t)}$	=	Energy at any given time during the build up
E_{∞}	=	Final attainable (or input) energy
t	=	time in secs.
RT	=	Reverberation time in secs.

If we set say $E_{t(t)}$ to be within say 1dB of E_{∞} (since E_{∞} will never be reached)

then: $E_{t(t)} = 0.79\, E_{\infty}$

and hence $t_{\infty} = RT/9$ sec.

Apart from the method being simple to expedite we believe it provides the data in a very reasonable format since the one parameter which is relatively easy to calculate is direct-to-reverberant ratio.

RESULTS

The results are presented graphically in fig. 2.

Note: The actual plotted values presented here were taken from the best-fit curve from original data.

COMPARISON OF RESULTS WITH EXISTING PREDICTION METHODS

We thought it worthwhile to compare the results of our measurements with the $\%AL_{cons}$ concept which is the most widely used prediction method. Fig. 3 shows our results plotted against %ALcons. The conversion to $\%AL_{cons}$ for STI was:

$$\%AL_{cons} = 170.5045\ e^{(-5.419\ STI)}.$$

To make a direct comparison we rearranged the $\%AL_{cons}$ formula in terms of reverberant-to-direct ratio as follows.

$$Spl_d = Pwl + 10Log_{10}Q - 10Log_{10}D^2 - 11 \text{ ....} \{1\}$$

and $$Spl_r = Pwl + 10Log_{10}RT - 10Log_{10}V + 14 \text{ ....} \{2\}$$

where:

Spl_d	=	direct sound pressure level dB re $2x10^{-5}Nm^{-2}$
Spl_r	=	reverberant sound pressure level dB re $2x10^{-5}Nm^{-2}$
Pwl	=	sound power level in dB re 10^{-12}Watt
Q	=	Directivity of source
D	=	Distance from source in m
RT	=	Reverberation time in secs.
V	=	Volume in m^3.

If there is more than one source involved then equation [2] becomes:

$$Spl_r = Pwl + 10Log_{10}RT - 10Log_{10}V + 10Log_{10}(N + 1) - 11 \text{ ....} \{3\}$$

where: N = number of like primary sources.

Combining equations [1] and [3] we get:

$$Spl_r/Spl_d = 10\ Log_{10}\ RTD^2(N+1)/VQ + 25$$

which may be re-arranged to give:

$$TD^2(N+1)/VQ = 10^{[(P-25)/10]}$$

where: P = reverberant to direct sound pressure level ratio (dB).

Hence the $\%AL_{cons}$ formula becomes:

$$\%AL_{cons} = 200\ RT\ 10^{[(P-25)/10]} \quad \text{.................................} \quad (4).$$

Fig. 4 shows the above equation represented graphically for reverberation times 1 sec., 2 sec., 4 sec. and 6 sec.

DISCUSSION OF RESULTS

It can be seen from figs.3 & 4 that there is a divergence of opinion regarding measurements made in simulated environments and those predictions by the $\%AL_{cons}$ formula. There could, of course, be many reasons for this, not the least of these being a fundamental flow in our hypothesis. To this end we would advocate further work to be carried out including corroboration with practical installations. In terms of comparison with the results obtained by the $\%AL_{cons}$ method we would make no definitive claims except that our results fit comfortably within the framework of our experience.

It is interesting (and contrary to our expectations) that STI should be reverberation dependent beyond the single term contained in the reverberant-to-direct ratio. It is also noteworthy that this apparent secondary dependence is independent of the reverberation-to-direct ratio in the $\%AL_{cons}$ concept whereas from our results it appears that the secondary effect becomes more predominant at high reverberant-to-direct ratios.

THE USE OF MEASUREMENTS ON SIMULATED ACOUSTIC ENVIRONMENTS AS A PREDICTION TOOL

We can see no reason why the MSAE may not be used in conjunction with other methods as a prediction tool, it after all represents an additional opinion. At the time of writing this Paper we have not formulated a method. However, essentially fig. 5 may be used after calculating the reverberant-to-direct ratios.

CONCLUSIONS

As we have stated before further work should be carried out, we are however of the opinion that MSAE should be given serious consideration as a prediction tool. The real problem is the corroboration with practice. Taken at face value this would seem a relatively simple matter, however in practice there are many other variables to be taken into account.

STI MEASUREMENTS

It has been suggested that articulation may be expressed as a function of a number of variables.

Articulation = f ($R_1, R_r, R_a, R_s, R_n, R_t, R_i, I_q, I_m$)

where:
- R_1 = the reduction factor for inadequate loudness
- R_r = the reduction factor for extended reverberation time
- R_a = the reduction factor for ambient noise
- R_s = the reduction factor for the shape and size of the space
- R_n = the reduction factor for increased number of sources
- R_t = the reduction factor for differing arrival times for individual sources
- R_i = the reduction factor for reflections from surrounding surfaces
- I_q = the improvement factor for the direction properties of the source
- I_m = the improvement factor for optimisation of audience absorption.

In practice we find that often systems do not meet the expectation of the simple theoretical prediction and hence other additional factors must be involved..

We have found that much depends not surprisingly upon adequate and correctly applied equalisation and the quality of the input and output transducers.

We should be at pains to remember that all of the onus should not be directed solely towards the environment, all of the prediction methods assume perfect system components. In practice, of course, system components cannot be perfect but they can and should be good.

STI MEASUREMENTS

REFERENCES

1. H. Kuttruff - Room Acoustics - Applied Science

2. L. Cremer, H.A. Muller (Translated by T.J. Schultz) - Principles and Applications of Room Acoustics - Applied Science

3. D. Davis, C. Davis - Sound System Engineering - Sams.

4. P.W. Barnett - Intelligibility in Public Address and Sound Systems - Proceedings of the I Institute of Acoustics Vol. 7 Part 3 (1985)

5. J.P.A. Lochner, J.F. Burger - The Influence of Reflections in Auditorium Acoustics - Journal of Sound and Vibration Vol. 1 (1964)

6. W. Klein - Articulation Loss of Consonants as a Basis for the Design and Judgement of Sound Reinforcement Systems - Journal of the Audio Engineering Society (Dec. 1971)

7. V.M.A. Putz - Articulated Loss of Consonants as a Criterion for Speech Transmission in a Room

8. J.S. Lim - Speech Enhancement - Prentice Hall

9. T. Houtgast, H.J.M. Steeneken - A Review of the MTF Concept in Room Acoustics and its Use for Estimating Speech Intelligibility in Auditoria - Journal Acoustical Society of America (March 1985)

ACKNOWLEDGEMENTS

1. We would like to acknowledge the assistance, encouragement and loan of equipment from T. Oates and M. Burgin of Shuttlesound Ltd.

2. We would like to thank Mr. P. Huffer who was responsible for making the many measurements.

STI MEASUREMENTS EQUIPMENT SET UP

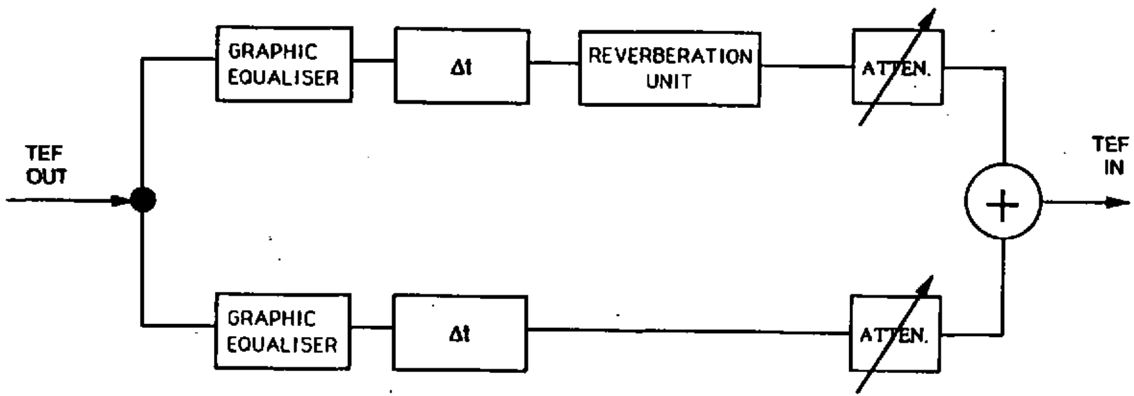

fig 1

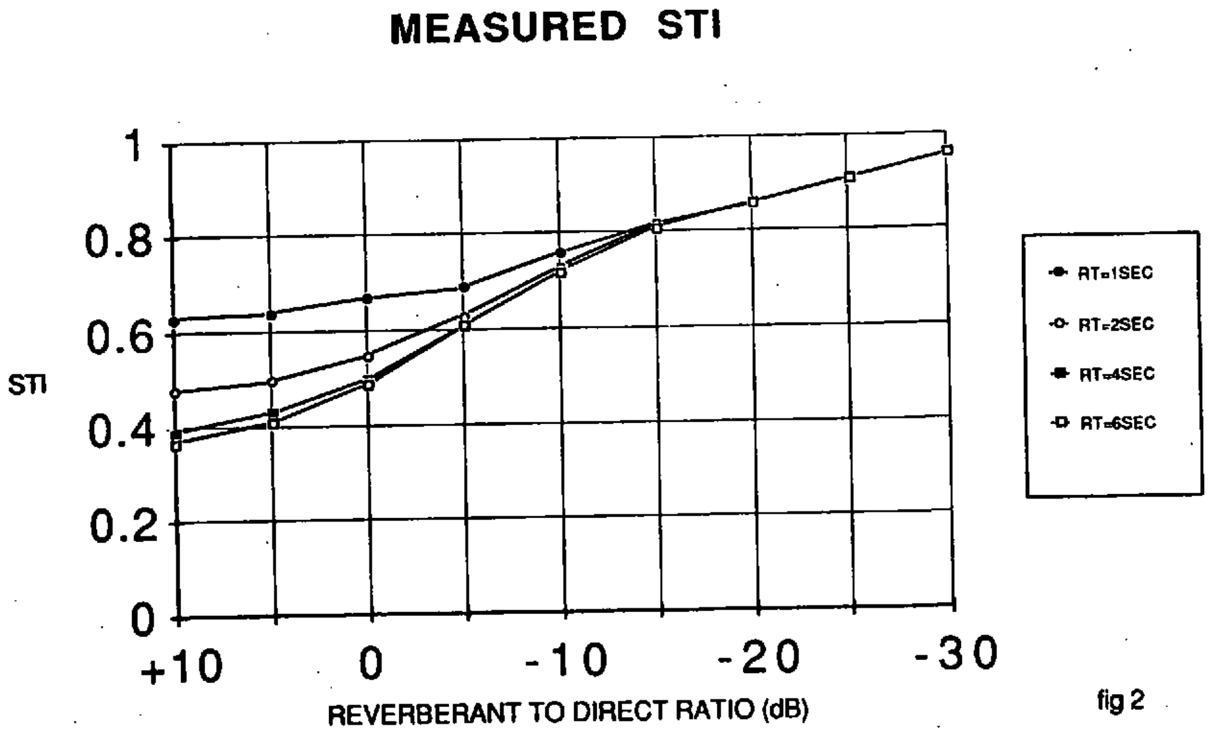
MEASURED STI
STI
1
0.8
0.6
0.4
0.2
0
+10
0
-10
-20
-30
REVERBERANT TO DIRECT RATIO (dB)
RT=1SEC
RT=2SEC
RT=4SEC
RT=6SEC

fig 2

%Alcons Calculated From Measured Data

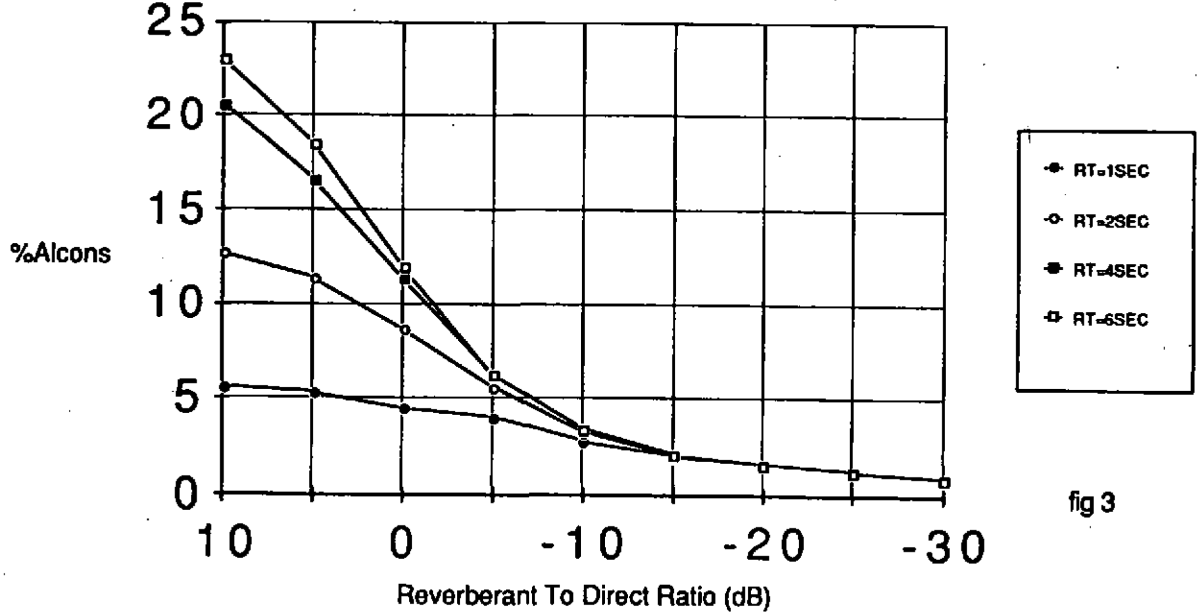

fig 3

%Alcons Calculated From Equation {4}

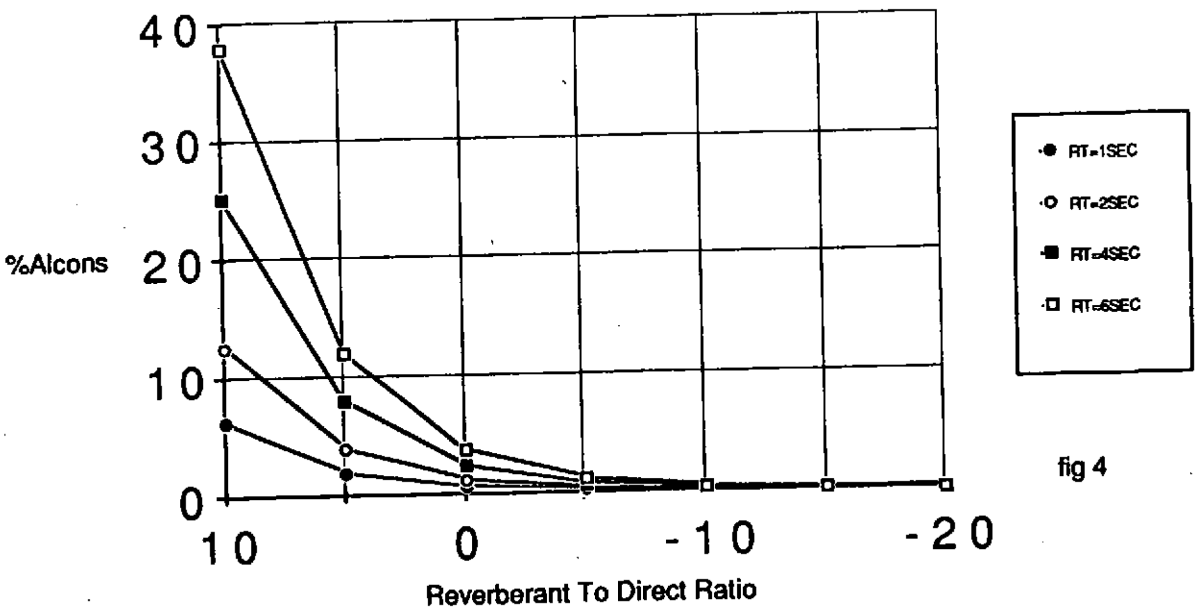

fig 4

MSAE %Alcons Prediction

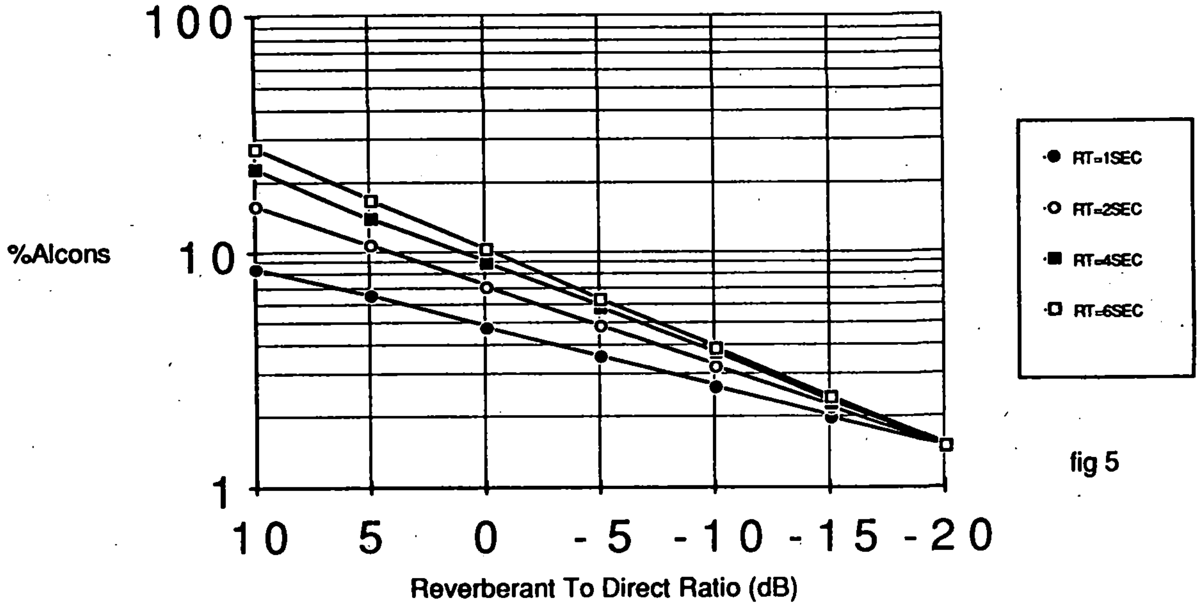

fig 5