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DESIGNING STAGE CANOPIES FOR IMPROVED ACOUSTICS

Trevor J Cox (1), Peter D'Antonio (2)

1) Department of Acoustics and Audio Engineering, University of Salford, Salford M5 4WT, UK.
2) RPG Diffusor Systems Inc., 651-C Commerce Drive, Upper Marlboro, MD 20772, USA.

1. INTRODUCTION

Overhead stage canopies may be designed to promote better communication between musicians across the orchestral stage. A well designed canopy will lead to better ensemble among musicians and consequently better quality concerts. This is achieved by ensuring an even distribution of reflected energy from each of the musicians' instruments on the stage to other musicians, with the reflected energy being delayed by about 20-30ms[1]. A canopy may also be used to reflect sound towards audience areas lacking sound energy. There is risk, however, that providing extra overhead reflections from the stage canopy could lead to the comb filter effect and image shift. The comb filter effect is sound coloration due to strong short delayed reflections interfering with the direct sound.

This study started by investigating how energy can be evenly spread over the orchestral stage. Previous work by the authors[2,3] have produced iterative design methods which produce 'optimum' diffusers which scatter sound evenly in all directions. These design methods has been adapted and applied to stage canopies. The new optimized stage canopies have been compared to a number of surfaces typical of those used in auditoria. It would be a logical extension to the methods described here to look at how stage canopies can be designed to achieve a certain amount of reflected energy into specific audience blocks, but this has not yet been attempted.

2. CANOPY DESIGN CRITERIA

To test the possibilities for using the optimization methods to improve canopy design a case study was chosen. The case study is based on an actual canopy being designed for a hall, and the requirements for the hall motivated the choice of canopy size and approximate configuration. Figure 1 shows a cross section of one of the canopies tested showing the variation from the front to the rear of the stage.

The canopy is of a design where there are relatively small gaps between the adjacent sections to allow lighting. These will also allow a certain amount of the sound energy into the void above the stage.

The design of the canopy has to be carried out assuming that the scattering produced across the width and from front to back of the stage are independent and so can be predicted separately. This is necessary because of the computing required to carry out predictions on

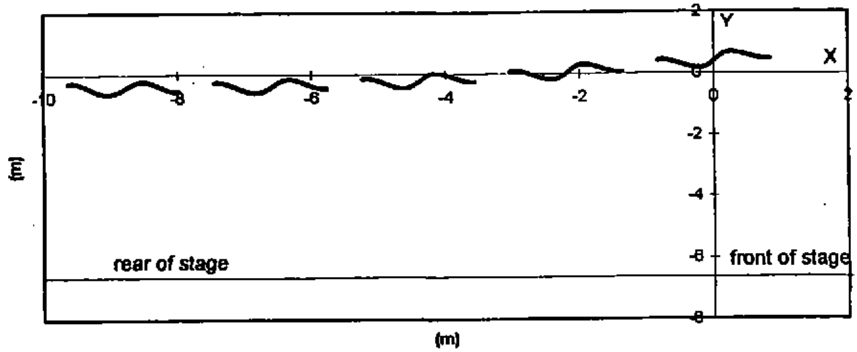

Figure 1 Cross section through optimized stage canopy

the canopy as a complete three dimensional object. This is a common assumption in acoustic design. As computing power increases exponentially, it may not be too many years before the design can be done for the full 3D surface in one go. The design criteria are therefore considered in the two orthogonal directions (1) across the width of the stage and (2) from the front to the back of the stage.

2.1 Across the width of the stage

Common with many canopy designs, the canopy is essentially a large plane surface across the width of the stage with no gaps between. All diffusers tested had the same geometry across the stage width, so essentially the change in performance is limited to one plane from the front to the rear of the stage. As the canopy is a large planar surface across the width, this will mean that the distributed energy across the width will be fairly even for any source and receiver pair on the stage, although there will be small variations due to different reflection path lengths. This is a reasonable design if energy propagating across the width of the stage is only required to be directed back to the stage. If sound travelling across the width is required to be directed into the void above the stage, or to side terrace seating, a different design might be suitable. There is no reason why the width profile could not be optimized for a different criteria if required.

2.2 Front to the back of the stage

A diagram of the front to back section of the stage canopy was shown in Figure 1. The stage area is roughly for $0.5<x<-9$m and the audience is to the right of the section shown in the positive x direction. The canopies have a little open space between each of the reflectors to allow some energy into the void above. The canopy is about 7m above the stage so that the reflections are delayed by an amount known to give a good chance of reflections aiding ensemble and support[1]. The five diffusers are arranged on the arc of a large circle.

The design criteria was that for any source position on the stage, as even as possible energy distribution would be created to all positions on the stage: i.e. each musician has an equally good chance of hearing each other as far as the stage canopy reflections are concerned.

3. OPTIMUM DESIGN

The optimum design technique for diffusing surfaces has been documented in detail elsewhere [2,3]. The process is an iterative regime:

1. A first guess for a stage canopy configuration is made;
2. The scattering from the canopy is predicted;
3. The scattering is assessed to determine how good the canopy is;
4. The canopy design is altered using standard optimization algorithms in an attempt to improve the performance;
5. If an optimum design has been reached, then the design is completed, otherwise return to step 2.

This iterative regime is implemented in a computer program. It takes overnight for the computer to generate a few suggested optimum canopies on a Pentium PC. Some details of the above steps are given in the following sections.

3.1 STEP 1 : STAGE CANOPY CONFIGURATION

The size and number of reflectors of the canopy were fixed for the design. The optimization could alter the shape of the reflectors, with each of the five reflectors having the same shape. The shape was determined by a Fourier series of sinusoidal harmonics which then can form a variety of curved surfaces - Figure 1 showed an example of one shape. In theory if enough harmonics are used, any shape can be represented, but in practise only three harmonics were used. The optimization process was allowed some limited control of the reflector position. The reflectors were constrained to lie on the arc of a circle, the radius of which could be altered by the optimiser. The angle of tilt of the reflectors could be controlled by altering which part of the circle was used to determine the reflector positions.

This choice of stage canopy configuration represents what seemed a reasonable configuration for a case study. The power of the optimization technique is that it can accommodate many different shapes, configurations and design criteria. Indeed for the diffuser design, they have already been applied to curved surfaces, Schroeder and stepped diffusers.

3.2 STEP 2 : PREDICTION TECHNIQUE

The optimization method used a Kirchhoff prediction technique [4]. This has been demonstrated in the past to be a good accurate predictor of surface scattering for rigid simple reflectors. During the optimisation, the scattering was predicted for 30 receiver positions, 10 source positions and 36 frequencies from 80 to 3200Hz. The source and receiver positions were roughly evenly spaced from the front to the rear of the stage.

3.3 STEP 3 : ASSESSING THE QUALITY OF THE SCATTERING

The optimization algorithm requires a single cost parameter which measures the quality of the diffusion produced. First the pressures from the prediction are averaged over roughly 1/3 octave bands. Then a standard deviation calculation involving the levels at the receivers for all sources is carried out. If the pressures at all receivers for all sources were the same, then the standard deviation would be zero. As the scattering becomes less even then the standard deviation increases. Therefore, the optimization routine looks for a minimum in the standard deviation cost parameter which then indicates that there is the most even pressure across the stage area. This type of parameter has been shown to be useful for optimum diffuser design.

4.0 COMPARISONS

The optimised design was compared to several other reflector shapes. Figure 2, shows the various reflector shapes in more detail. The 5' and 10' arcs are simply sections of a circle; the optimised diffuser is the s-shaped curve; the plane surface is self explanatory, and the elbow is constructed from three straight sections.

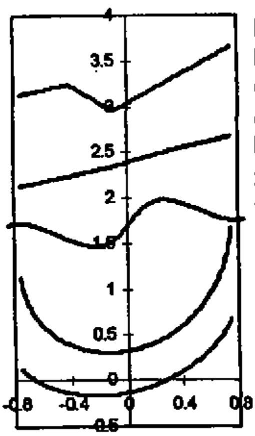

Figure 2. Individual diffuser shapes. From top to bottom: Elbow, plane, optimized, 5' arc and 10' arc

5.0 RESULTS

The optimised surface out performed the other diffuser shapes in producing the most even energy distribution across the stage area. To test the performance of the canopies, a set of predictions with different frequencies, source and receiver positions from that used in the optimization was used.

Figure 3 shows the scattering *coverage plot* from the plane reflector canopy at 2 kHz for a source in the middle of the stage. The variation in pressures across the width is small because this was modelled as a large flat surface - any variation is due to inverse square law decreases due to different path lengths. The front of the stage is at about 0.5m on the front to back axis. As is to be expected for plane surfaces, there is a large reflection level directly below the source - much of the energy is being transmitted straight back to the musician who is playing the instrument. Dips in the reflected pressures occur when there is no geometric reflection point on one of the reflectors due to the spaces in the canopy design. It is well established that the effects of pressure minima can be reduced by shaping the reflectors, this is often done by forming convex arcs [5].

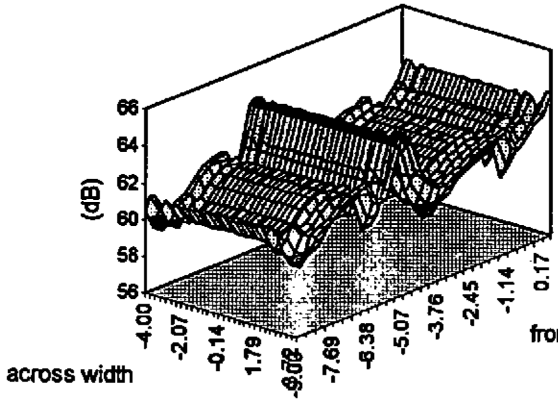

Figure 3 Scattering from plane reflectors, 2000 Hz, source in middle of stage

The effect of moving from the plane surface to a more complex shape with optimum scattering properties is shown in Figure 4. The effect of the surface diffusion is to mask the lack of energy for certain receivers where pure specular energy is lacking. It also greatly reduces the strong specular energy being directed straight back to the musician. The reflected energy is more evenly distributed across the stage - all pressure levels along the front to back axis lie within 3dB of each other.

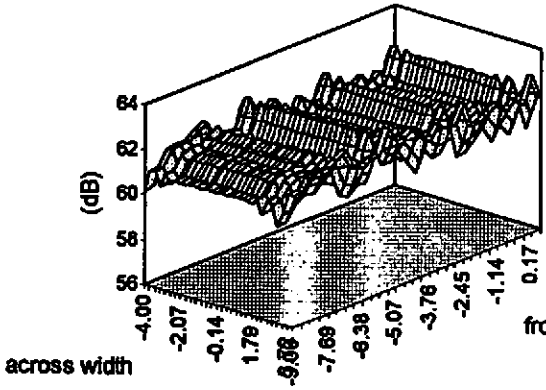

Figure 4 Scattering from optimized diffuser, 2000 Hz, source in middle of stage

To compare all five surfaces, the 'diffusion' produced by the surfaces as a function of 1/3 octave band frequency was plotted as illustrated in Figure 5. The 'diffusion' is a standard deviation of all receiver levels on the stage. This has been shown to be a good measure of diffusion when considering specialised diffusers. A value of zero would indicate the pressure was the same for all receivers. The further from zero the more uneven the pressure and the worse the canopy according to the design criteria. As can be seen the optimised surface performance is better than the plane surface for virtually all frequencies. This confirms the results of the coverage plots shown at the single frequency of 2kHz in Figures 3 and 4.

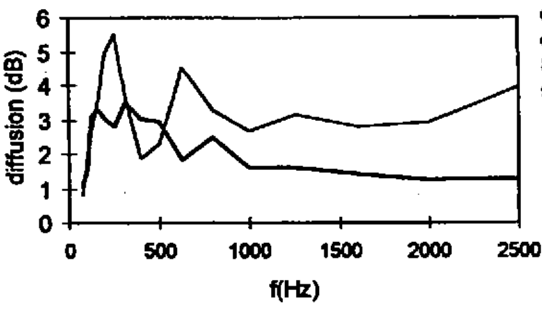

Figure 5. Diffusion compared for plane and optimized canopies. Source in middle of stage

Figure 6 below shows all surfaces compared. The optimised surface performance is as good or better than the other reflectors.

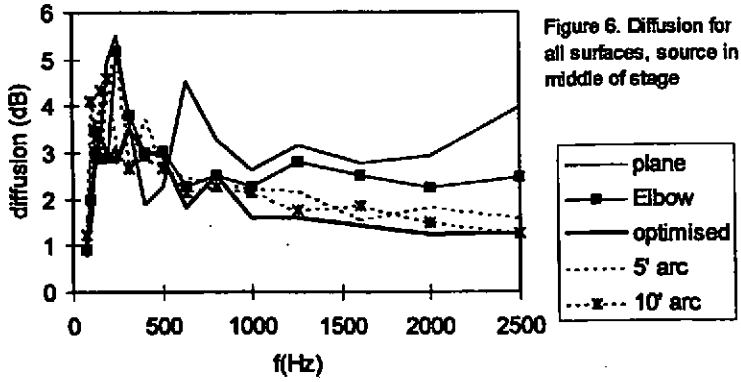

Figure 6. Diffusion for all surfaces, source in middle of stage

As Figure 7 illustrates, with source towards the rear of the stage, the improvement in performance is more marked. For the front of the stage (result not shown), the optimized surface is still the best performer, but the performances of the two arcs are almost as good.

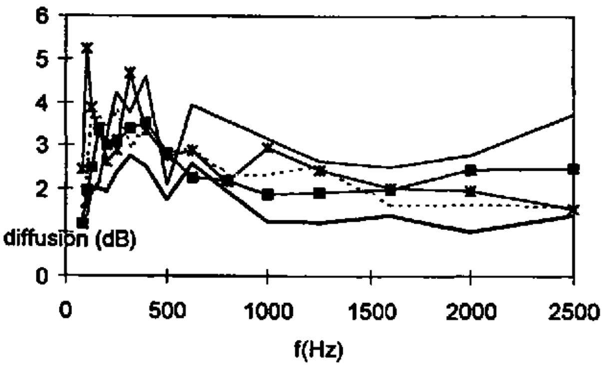

Figure 7. Diffusion for all surfaces, source at rear of stage

The sound levels for a low 1/3 octave frequency for three surfaces are shown in Figures 8 to 10. The coverage plot is more even with the optimised surface or the 5' arc when compared to the plane surface. The optimised surface does have a better performance over the 5' arc, but this may be easier to see from the diffusion plot of Figure 7.

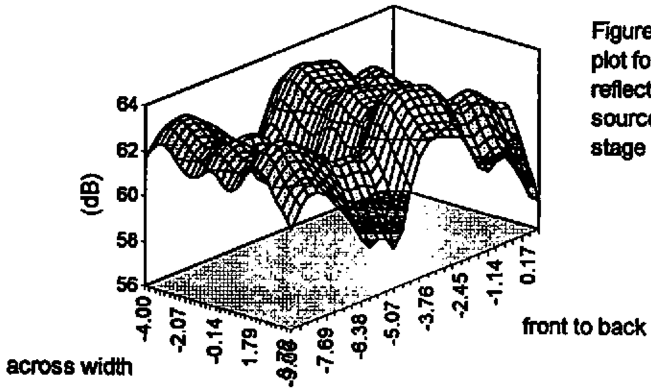

Figure 8 Coverage plot for plane reflectors 315 Hz, source at rear of stage

6.0 CONCLUSIONS

This paper has demonstrated that the use of an optimization technique can result in stage canopies with improved designs. A case study which considered the scattering along a cross section from the front to the back of the stage was used. The optimized canopy was designed so that the reflected energy was the same to any point on the stage from different source positions. The results presented demonstrate that improved performance over conventional designs was achieved.

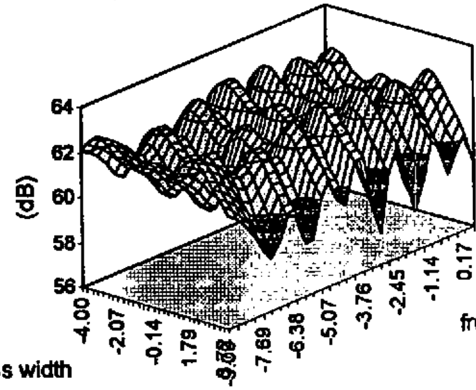

Figure 9 Coverage plot for optimized surface at 315 Hz, source at rear of stage

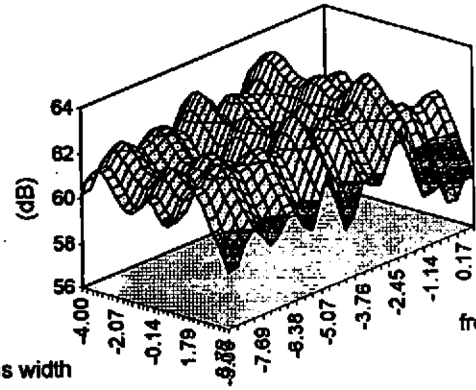

Figure 10 Coverage plot for 5' arcs at 315 Hz, source at rear of stage

7. REFERENCES

1. M Barron. Auditorium Acoustics and Architectural Design. E & FN Spon. Pg 55 (1993)
2. T J Cox. Optimization of profiled diffusers. J.Acoust.Soc.Am. 97(5) 2928-2941 (1995)
3. T J Cox. Designing curved diffusers for performance spaces. J.Audio.Eng.Soc. 44 354-364 (May 1996).
4. T J Cox and Y W Lam. Evaluation of Methods for Predicting the Scattering from Simple Rigid Panels. Applied Acoustics. 40 123-140 (1993).
5. J H Rindel. Design of new ceiling reflectors for improved ensemble in a concert hall. Applied Acoustics. 34 7-17. (1991).