

CANOPY ARRAYS: DENSITY, SIZE, SHAPE AND POSITION

P. D'Antonio RPG Diffusor Systems Inc., Upper Marlboro, USA
T. J. Cox Acoustics Research Centre, University of Salford, UK

1 INTRODUCTION

The reflecting surfaces around a stage area play an important part in enabling ensemble amongst musicians. Energy must be reflected back to the stage to enable musicians to hear themselves and others and so achieve the correct rhythm, intonation, balance, and timbre. Gade¹ summarised the current understanding of stage acoustic requirements; in particular, when stage reflections should arrive, and how loud they should be. The study presented in this paper concentrates on the design of overhead canopy arrays, in particular investigating effects of density, size, shape and position. This aspect has surprisingly been little researched, although work by Rindel² investigated similar questions to those being posed here.

The advent of modern computer processing power allows stage canopy arrays and towers to be optimized using iterative algorithms, based on wave-based acoustic prediction models. A shape optimization program has been developed to optimize both the shape and tilt of overhead canopy arrays. Previously, the height and density have been inputted based on experimental evidence and lighting/scenery considerations. The program has recently been updated to address the question of optimal canopy density and size, and some preliminary results from this work are presented below.

2 METHOD

2.1 Concept

The design of surface diffusing elements using numerical optimisation algorithms is now well established, with predictions and measurements showing these surfaces have superior scattering abilities in comparison with other surfaces³. Numerical optimization tasks a computer to search to find an optimum solution to a problem. For acoustic diffusers, the computer looks for the surface shape which gives optimal scattering. Consider the case of designing a curved diffuser to scatter evenly into all angles of reflection; the procedure follows an iterative regime. The computer starts by guessing some curved surface shape. Then the scattering from the surface is predicted in terms of a polar response. The predicted polar response is then rated for its quality by a single figure of merit. The computer can then use a process of trial and error, changing the surface shape to try and minimize the figure of merit. The process continues until an optimum surface shape is designed, which occurs when a minimum in the figure of merit is found.

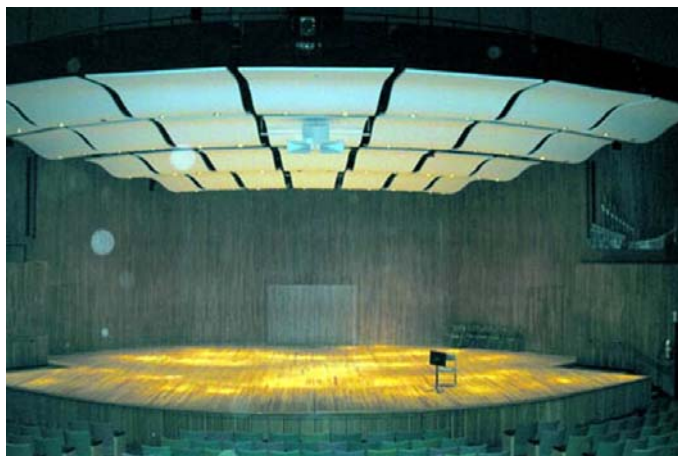


Figure 1 Optimised stage canopy in Kresge Auditorium, MIT

Previous work on stage canopies⁴ examined whether

optimisation could be applied to overhead canopies. In this case the criterion for optimisation was even distribution of energy over a stage area. Figure 1 shows an example of a canopy designed using such a process.

In previous work, the width and depth of the canopy elements were fixed at the start of the optimisation, as was the location of the canopy elements. In this work, the effects of allowing the optimisation process to choose all the defining parameters for the canopy have been explored. For simplicity, the canopy being designed extends unbroken across the stage width. In this case, the optimiser controls:

1. The shape of the base canopy element:
 - The size;
 - The number of spline points;
 - The positions of the spline points.
2. The position of the elements in the canopy
 - The number of the canopy elements;
 - The location of the canopy elements in terms of their positions upstage/downstage and height;
 - The tilt of each canopy element.

In the optimisation process, the diffuser shape needs to be defined in terms of some variables that can be altered to change the canopy shape. For this optimisation, the canopy shape is defined by a series of spline points on the surface (typically between 3 and 6). A cubic spline algorithm is then used to form the curved shape of the canopy elements that passes through these points.

The stage was assumed to be 12m deep. The canopy elements were assumed to be evenly spaced upstage-downstage. Consequently, the locations of the first and last canopy elements were optimised and the rest were evenly spaced in between. The width of the canopy was constrained so that no overlap of elements was possible. The canopy was constrained to be within 8-10m above the stage floor so that the reflections are delayed by an amount known to be good for ensemble and support.

2.2 Optimisation criteria

It was decided to change somewhat the optimisation criterion previously used to evaluate the stage canopies⁴ in order to bring the criterion in-line with metrics used to assess real stage shells. Support was a measure developed by Gade¹ and is currently the standard measure for evaluating the quality of stage acoustics for musicians, and so is adapted here. The procedure is to place a source and receiver 1m apart on the stage and calculate the ratio of the early reflected to direct sound energy. For good ensemble conditions, support should be -12 ± 1dB averaged over the 4 octave bands 250Hz - 2kHz. In measurement, typically 3 source and receiver positions are placed on stage. For the optimisation, a much greater density is required to ensure good conditions across the whole stage and not just at the positions selected for optimisation. Consequently, 12 source positions were randomly placed on stage between 0.8 and 1.4m from the stage floor. For each source position, two receivers, one either side of the source were used. This meant that for each stage canopy, and each octave band, 24 values of support were evaluated. The optimisation requires a single figure of merit to evaluate the quality of the canopy's scattering. To achieve this, the mean square difference between the 96 evaluated support values and a user-defined target support value was used. Consequently, the best canopy should have an even distribution of support reflections across the stage and across the 4 octave bands being considered.

The target value of support suggested by Gade of -12dB can not be achieved across the stage purely from first order canopy reflections. Consider a canopy 7m above the source and receiver. Furthermore, the canopy is assumed flat and large because this should provide the strongest possible reflection. Then a simple image source consideration gives a support value of about -23dB

for the stage canopy reflection. Even allowing for the absence of first-order reflections from side and rear walls, it appears that on stages the contributions from many higher-order reflections are important to give the correct value of support. Without full modelling of the stage area, the support values that can be achieved by this study will always fail to meet the optimal value. Consequently, target values for the support were chosen which gave different open areas for the canopy. Ultimately, this optimisation will produce a canopy which will optimally spread the reflected energy over the stage area, and so in many ways the criterion is not so different from previous work.

2.3 Algorithm

A numerical optimisation algorithm is required to alter the optimisation parameters in an 'intelligent' manner to speed the search for best canopy designs. Currently, the most popular algorithm is to model the problem as an evolutionary process, using survival of the fittest principles to carry out an efficient search. The technique is called a genetic algorithm and is very suited to the problem being considered here because there are a mixture of integer (e.g. number of canopy elements) and real-valued parameters (e.g. canopy element width) to be optimised⁵.

A genetic algorithm mimics the process of evolution that occurs in biology. A population of individuals is randomly formed, and the traits of each individual are determined by their genes. When designing diffusers, the genes are simply a set of numbers which describe the canopy. Each individual (or canopy design) has a fitness value (figure of merit) that indicates how good they are at diffusing sound. Over time new populations are produced by combining (breeding) previous shapes, and the old population dies off. Offspring are produced by pairs of parents breeding, and the offspring have genes that are a composite of their parents' genes. The offspring shape will then have features drawn from the parent canopies, in the same way that facial features of a child can often be seen in the parents. A common method for mixing the genes is called multi-point cross over. For each gene, there is a 50% chance of the child's gene coming from parent A, and a 50% chance of the gene being from parent B.

If all that happened was a combination of the parent genes, then the system never looks outside the parent population for better solutions. The fish canopy would never get lungs and walk about on the land. As with biological populations, to enable dramatic changes in the population of canopies, mutation is needed. This is a random procedure whereby there is a small probability of any gene in the child sequence being randomly changed, rather than directly coming from the parents.

Selecting canopies to die off can be done randomly, with the least fit (the poorest canopies) being most likely to be selected. In biological evolution, the fittest are most likely to breed and pass on their genes, and the least fit the most likely to die, this is also true in an artificial genetic algorithm used in numerical optimisation. By these principles, the fitness of successive populations should improve. This process is continued until the population becomes sufficiently fit so that the best shape produced can be classified as optimum.

A prediction model is needed to calculate the direct and reflected sound levels. The prediction model used was based on the Helmholtz-Kirchhoff integral equation. A 2D Green's function was used as a cross-section of the canopy from the back to the front of the stage was only considered. The Kirchhoff boundary conditions were applied enabling a simple numerical integration of the integral equation to give the receiver pressures³. Because a 2D model was used, the support values given are larger than would be obtained in reality, because a 2D model gives cylindrical rather than spherical spreading.

For each target support value (-15, -18, -21 and -24 dB), twenty separate optimisations were carried out. While for each target support value, a best possible canopy design was found, what is of interest here is to see whether the different optimisation results indicated preferences for canopy density, size and shape. Consequently, the results were then statistically examined to see if underlying trends could be determined. To simplify the analysis, the tilt of the canopy elements was not optimised, and the canopy was forced to lie horizontally.

3 RESULTS

For each target support value, the average value of the parameter being considered (e.g. element width) is calculated; this is an average across the 20 solutions. In addition, 95% confidence limit in the mean value is also found to determine the spread in the parameter between the different solutions.

The average open area for the different target support values are shown in Figure 2. For a target value of -15dB, the canopy occupies most of the available space. For the -24dB case, the canopy occupies only a fifth of the available area. Achieving a particular target support value requires the open area to be within relatively tight limits as indicated by the small error bars.

Figures 3 and 4 show how the width and the depth of the canopy elements varied with the target support value. There is a significant trend for both the average width and depth of the elements. A significant variation is also found when the number of panels in the canopy is considered - these results are shown in Figure 5. This significant variation was statistically demonstrated using an analysis of variance ($p=0$ in all three cases) and a significant difference between all adjacent cases was then demonstrated using t-tests ($p=0$ in all cases).

Figures 3-5 show that when a high support value is required, the canopy is fuller, the canopy elements are wider and deeper, and there are more canopy elements in the array, in comparison with canopies with lower support values.

There is a slight tendency for the fuller canopies to be slightly lower (graph not shown), but the difference in heights is only about 20cm. Consequently, although a statistically significant variation is found for height, it seems to be of little practical significance.

Figure 5 also shows that fuller canopies tended to have fewer spline points on the panel. This was shown to be statistically significant using a Kruskal-Wallis test ($p=0$). This means that fuller canopies have simpler, less wiggly shapes than canopies with larger open areas. The role of the

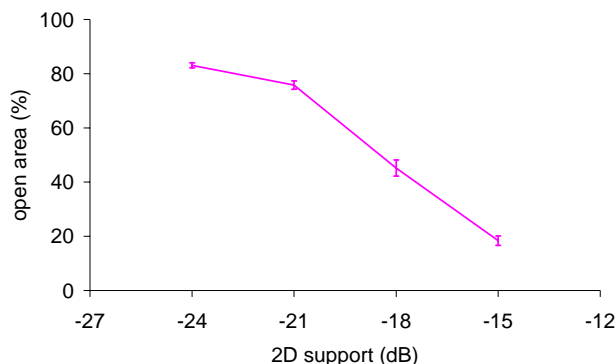


Figure 2 Open area vs target support value

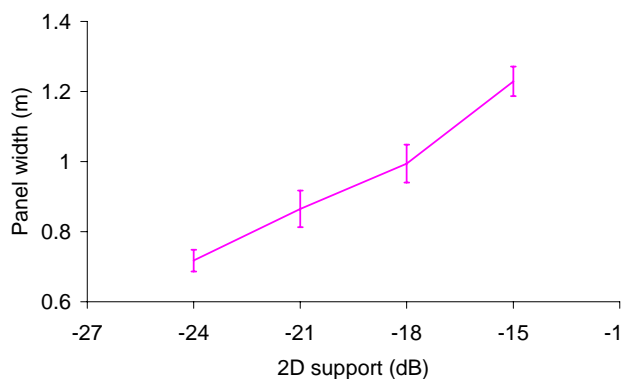


Figure 3 Average panel width vs target support value

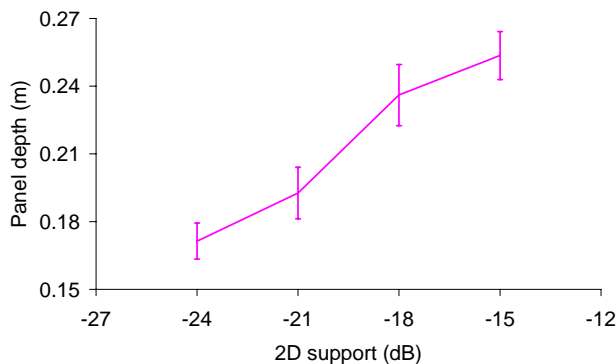


Figure 4 Average panel depth vs target support value

canopy shape is to deal with the gaps in coverage that would occur if the panels were flat. With flat panels, there will be source-receiver pairs where there is no specular reflection possible from the canopy; this is when the geometric reflection point lies between the canopy elements. In this case, shaping of the panels is necessary to ensure sufficient energy is reflected to the receivers. When there is a greater open area, there are more gaps between the canopy elements, and so greater scattering is required. Consequently, the canopy elements become wigglier for canopies with larger open areas.

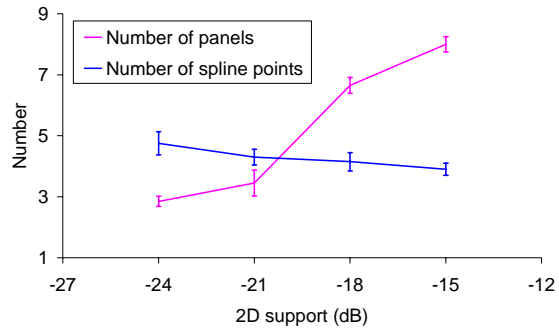


Figure 5 Average number of panels and number of spline points on the canopy elements vs target support.

Figure 6 shows the support averaged across all solutions and all source-receiver pairs, versus the target support value. The four plots are for each of the octave bands considered. A line of gradient 1 is shown, and ideally the optimised results should lie on that line. At 500Hz, the support values are close to the

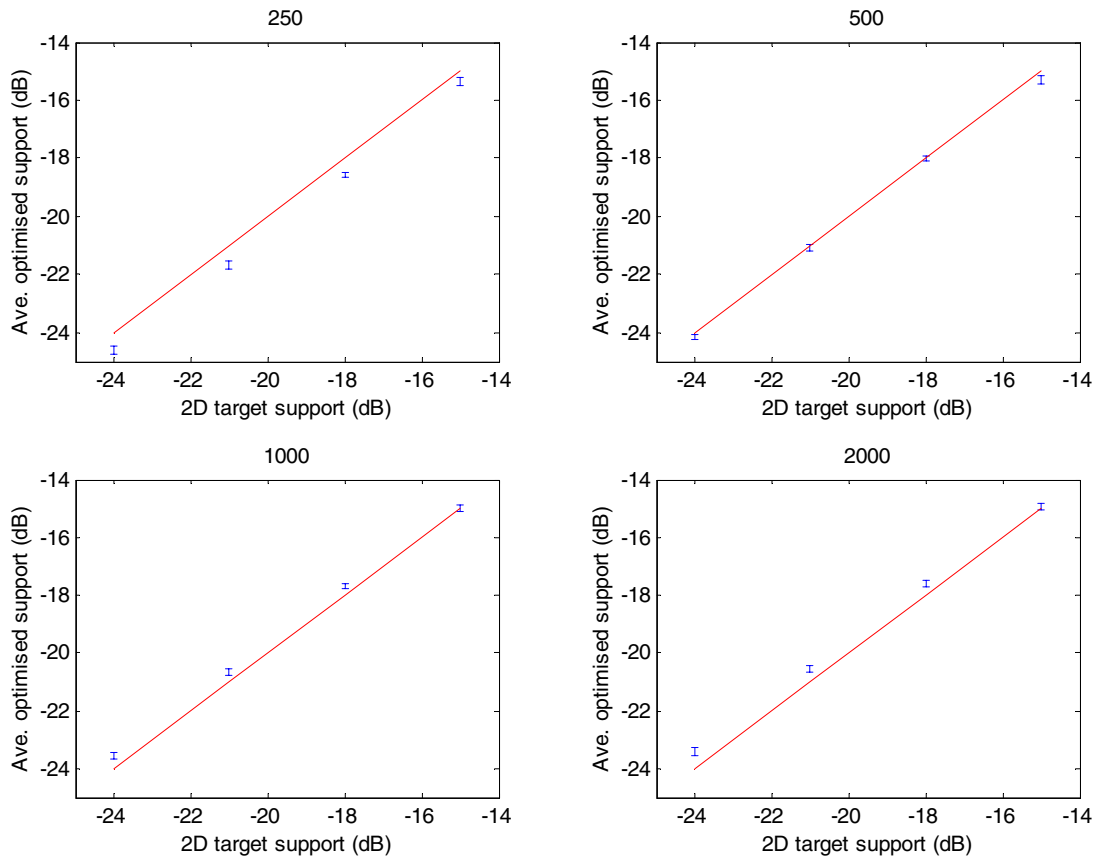


Figure 6. The average optimised support versus the target support for the four octave bands considered (in blue). The red line is of gradient 1, and the data points should lie on this line if the optimisation was perfect.

target values. However, at 250Hz the support values are too small by on average 0.55 ± 0.06 dB, and at 1kHz and 2kHz the values are too large by 0.27 ± 0.05 dB and 0.4 ± 0.06 dB respectively. The discrepancy between the actual support achieved and the target values is not large, but it is consistent across solutions and source-receiver pairs. The exact reason for this trend is not yet known.

Rindel² studied the effect of density and panel size on canopy array performance for flat elements. He concluded that panels needed to be relatively small so that energy is diffracted to receivers who do not receive a specular reflection from the canopy array. For this reason, high frequency performance was determined by panel size. The low frequency performance of the array was determined by the canopy density. The study presented in this paper differs in that the panels were not flat. Despite this difference, the study has also shown that relatively small panels are preferred. However, it has also indicated that the desirable size, both width and depth, is dependent on the open area of the canopy.

4 CONCLUSIONS

A study has been carried out examining the effects of canopy density, element size and shape. A set of canopy designs was formed using numerical optimisations, and these designs were examined to better understand the requirements for good canopy design. In comparison to canopies with large open areas, it was found that fuller canopies, i.e. ones which have least open area, are best made from a large number of wider and deeper canopy elements which have simpler shapes.

5 REFERENCES

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