ACOUSTIC SCALING:  
examination of possible modifications  
to Maida Vale Studio No.1

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Summary

Earlier reports have described the techniques of acoustic scaling and the success of an experiment to prove their adequacy. This report describes some of the subsequent modifications made to the model of Maida Vale Studio No.1 in an endeavour to understand and, if possible, to remedy some of the weaknesses in the acoustics of the studio. These experiments involved devising means for a subjective assessment, in both qualitative and quantitative terms, of the sound quality obtained with each modification.
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1. Introduction

The theory and techniques of acoustic scaling have been described in several earlier reports\(^1,2,3,4,5\) and the success of the proving experiment has been indicated.

Several criticisms of the sound quality of the real Maida Vale No. 1 studio had been made from time to time and it therefore seemed worthwhile, in view of the existence of the studio model, to determine whether any of the faults causing criticism could be identified and cure found for them. As a corollary, it proved essential to decide what factors determine the sound quality of a studio, and to devise means of assessing them both qualitatively and quantitatively.

2. Experimental details

2.1. General

The starting point of the present experiments was to try and determine as precisely as possible what the complaints about the studio quality really were. To this end a questionnaire was prepared and issued to all the Programme Operation Assistants (P.O.A.s) who used the studio and to a few other persons, such as representatives of the orchestra; a total of 25 questionnaires were returned. In the questionnaire a fairly comprehensive set of twenty characteristics was selected from those already used on previous psycho-acoustic studies, and the recipients of the questionnaire were asked to indicate quantitatively, on a scale provided, their opinion of the status of the studio for each characteristic; a sample questionnaire is given in Appendix I. To avoid any effect due to the order of the questions, alternate forms were reversed with the original question No. 1 appearing as question No. 20 and those opinions associated with approval also reversed left to right. In order to help in assessing the answers, a second similar questionnaire was issued in which the same persons were asked to indicate their rating of an ideal studio. The questionnaire was drawn up so that, for some factors such as ‘brilliance’, the ideal condition was not represented by either extreme of the range provided.

A detailed analysis of the results of the questionnaires is given elsewhere;\(^6\) it confirmed the report that the acoustics (in particular the quality of the string tone) with a small number of performers in the studio was preferred to that with a full orchestra. The first experiment using the model was therefore designed to deal with this point.

A frequent comment about the studio has been that the ceiling is very low for such a floor area and it was thought that this might well have some bearing on the sound quality. It has been stressed, in the literature,\(^9\) that early reflections have a pronounced effect on the sound quality in a studio, and the low ceiling directly affects these. Experiments were therefore carried out to change the reflection pattern from the ceiling in the hope of finding some improvement in quality without resorting to the extremely expensive expedient of raising the roof height. (Estimates for the cost of this change were in excess of £250,000 in 1969/70.) The second model experiment was therefore designed to reduce reflections from the ceiling by covering it with an absorbent. This would effectively place the ceiling at an infinite height if total absorption were used, and various combinations of absorbent and unmodified ceiling were employed to modify the arrangement.

The third experiment attempted to change the pattern of reflections from the roof by suspending from it a number of diffusing elements. These were of two types: the first was made by vacuum forming plastic sheet to form a curved surface, and the second\(^*\) consisted of lengths of flat pieces of wood suspended vertically but at various angles to the axes of the studio.

The fourth experiment was designed to examine the effect of hanging a reflecting canopy over the orchestra; thus increasing the ratio of direct to reverberant sound at the microphone position, but also having the effect of reducing the effective height of the ceiling still further. Both flat and curved canopies were used.

The fifth experiment of this series was intended to discover the effect of replacing the existing ceiling, which has a high absorption at low frequencies, by a totally-reflecting ceiling.

The sixth experiment concerned the position of the orchestra. In this studio, provision had been made for a large choir to be seated on a stepped rostrum behind the orchestra as shown in Fig. 1. This has two possible effects. Firstly the regular series of steps and seats could give rise to a reflected sound wave which could be highly coloured\(^7\) by virtue of the regularly occurring reflections, and secondly the space occupied by the choir seating meant that the orchestra was placed relatively near to the centre of the

\(^*\) Suggested by A. Brown, Acoustic Architect, Building Department.
then decided upon. As the engineers heard the gross changes at the beginning of the tests they were also in a more favourable position to detect smaller changes than the average listener.

2.2. First experiment: absorbent on end wall

Listening from the balcony of the full-size studio to an impulsive sound revealed the presence of a certain amount of flutter, presumably caused by reflections between the two end walls. This observation prompted the thought that the flutter might be responsible for the criticism of string tone. It was noted in a previous report that the string quality in the studio was considered satisfactory when the studio was almost empty but became 'wiry' when a full orchestra was present. The reasoning was based upon the following argument.

If a person claps their hands under a bridge with the arches about 30 m apart, this gives rise to a signal with a physical repetition frequency of about 10 Hz, i.e. below the audible frequency limit. In contrast, however, the main subjective effect is of a 'twang', i.e. with emphasis in the 1 kHz region, no less than one hundred times the fundamental repetition frequency. It was thought that a similar effect might be taking place in the studio high above the floor and, in the absence of absorption at floor level (provided by a full orchestra) the disturbance remained at a height above that of the microphones. The presence of appreciable absorption on the floor, however, with the full orchestra present would deflect the sound wave-front downwards and bring the effect within range of the microphones.

Two courses were open to experiment. The first was to raise the height of the microphones considerably to see whether the quality then picked up revealed this wavy effect when the studio was relatively empty. This was carried out and produced the expected effect. The next stage was to place absorbent on one end-wall to remove the flutter and see if the wavy quality disappeared when the microphones were placed at the normal height. Accordingly, in the model, the whole wall behind the orchestra was covered with velvet of the type used on the floor to imitate carpet. The effect on the sound quality was immediately obvious, the wavy quality disappeared and the tone was much warmer. However, with this amount of absorbent present the reverberation time at middle and high frequencies was much reduced and tests were therefore carried out to determine the minimum quantity of velvet which would remove the wavy quality. The reverberation time/frequency characteristic under this last condition is shown in Fig. 2 which can be compared with that of the model without the additional velvet, i.e. in the original condition, given in Fig. 3. The difference shown in the curves is within the limits of experimental error and was, in fact, inaudible as a change in reverberation.

2.3. Second experiment: absorbent on ceiling

The first tests in this experiment were made with the ceiling of the model covered with a 6 mm layer of a fairly dense polyurethane foam. In this condition the reverberation time was reduced drastically at middle and high
Fig. 2 - Scaled reverberation time of model with velvet on end wall and model orchestra

Fig. 3 - Scaled reverberation time of model with model orchestra only, i.e. standard condition

Fig. 4 - Scaled reverberation time of model with model orchestra and with 6 mm plastic foam on ceiling

frequencies and the general tone was much warmer. The wiry string tone had also disappeared and this is in accordance with the theory outlined above; the presence of the absorbent on the roof would redirect the wave-front upwards and reduce the flutter. Further tests were carried out with reduced amounts of absorbent on the roof to improve the reverberation time curve, but no very satisfactory compromise was found. The reverberation time/frequency curve for one condition is shown in Fig. 4 and it will be seen to be appreciably lower at middle and high frequencies compared with that of Fig. 3.

As a corollary to this experiment, absorbent was placed on the vertical surfaces of the trusses supporting the roof to see whether these large parallel surfaces gave rise to any audible colouration. No such effect was discovered.

2.4. Third experiment: diffusers suspended from ceiling

The shape of the curved plastic model diffusers used for this experiment is shown in Fig. 5. This shape was

Fig. 5 - Shape of Bextrene diffusers
chosen as being similar to that used for the canopy over the orchestra at the Royal Albert Hall so that, if successful, the same moulds could be used. The full-scale devices were made of plastic reinforced with glass fibre and the use of plastic of appropriate thickness for the model was not thought to influence significantly their acoustic properties. The modeldiffusers were hung at an angle of about 30° to the horizontal so that the lower portion of the curved surface was itself approximately horizontal, the convex surface facing the orchestra. Thirty-two diffusers were used, the base dimensions being 17 cms wide x 32 cms long; they were hung at a distance of about 15 cms from the highest point on the diffuser to the ceiling. The reverberation time curve is shown in Fig. 6 and, as expected, is seen to be very similar to that of Fig. 3; initial listening tests showed very little audible difference in sound quality as compared with that from the unmodified model studio.

Tests were also carried out with plane diffusers. These consisted of sheets of plywood of dimensions 75 cms x 23 cms x 1 cm hung vertically but at an angle to the major axis of the studio; the diffusers were varnished on both sides to reduce sound absorption. Twelve diffusers were used hanging about 15 cm from the roof. No reverberation time curve was taken as no change in reverberation time was expected. Listening tests showed very little change from the studio in the standard condition except that there was a long low-frequency ‘ring’, which was traced to resonance of the diffusers themselves.

2.5. Fourth experiment: reflecting canopy over orchestra

Two types of reflecting canopy were used over the orchestral area. The first was a flat type whose angle to the horizontal could be adjusted. It was hinged down the centre line so that the two halves could be hung to form a dihedral angle.

The size of the reflector overall was 210 cm wide by 60 cm deep by 1 cm thick and it was sprayed on both sides with polyurethane varnish.

The upper end was close to the roof and the maximum angle to the horizontal was determined by the need to allow hypothetical choir members to see the conductor; in these circumstances the lack of height of the ceiling was definitely a restricting factor. Tests were carried out for various angles of inclination, for various dihedral angles.

Listening tests showed that the sound quality was brighter than for the studio in the standard condition, and this is already regarded as rather over-bright; the reverberation time was apparently shorter than that of the standard condition. These results were not unexpected and were both due to the increased ratio of direct to reverberant sound brought about by the reflector.

The second type of reflecting canopy was curved from back to front so as to produce a more diffuse reflection than the first type. The depth from back to front was kept at 60 cm but the total width of 210 cm was broken up into three portions so that the axis of the centre portion could be kept horizontal whilst the outer two could be inclined if necessary to form a dihedral angle. Various combinations of angles were tested. The reverberation time was measured for one condition and is shown in Fig. 7. It will be seen that, as expected, there is very little difference between this curve and that of Fig. 3.

2.6. Fifth experiment: hard reflecting ceiling

It was pointed out in a previous report that the ceiling of the real studio resonates at low frequencies and absorbs sound appreciably; it is this absorption which accounts for the dip in the reverberation time curves at 100 Hz. This fifth experiment was designed to be the opposite of the second (see 2.3), that is, it was designed to make the ceiling as reflecting as possible at all frequencies. To this end the ceiling in the model was covered with 1 cm thick plywood which had been coated with layers of polyurethane varnish. The normal diffusers on the roof were
removed in this experiment. A reverberation time curve was taken and is shown in Fig. 8. It will be seen that the dip centred at 100 Hz has been removed but that the remainder of the curve is substantially as that of Fig. 3.

Listening tests confirmed the expected increase in reverberation in the bass. The overall impression, however, was that it was less liked than the standard condition, as the sound seemed more muddled.

2.7. Sixth experiment: effect of rostra

It was indicated in Section 2.1 that doubts were felt about the effects of the choir seating on the sound quality, and that there was the possibility that the regular stepped construction might give rise to some colouration as has been experienced elsewhere.\(^7\)

In order to explore this point the ceiling was replaced in its normal condition, the choir seats were removed and the whole of the area formerly occupied by them was covered with a 1 cm layer of lacquered plywood, thus forming a flat, sloping, reflecting surface.

Listening tests were carried out for this condition but no improvement in sound quality was found; if anything, the sound was slightly harder. It was therefore deduced that no deleterious effect resulted from the step-like structure as used in the studio. The whole of the choir rostrum was then removed and tests carried out with the orchestra right at the back of the studio and at intermediate positions to check the effect of orchestra positions in the studio.

Reverberation measurements were also taken for one condition and the results are shown in Fig. 9. It will be seen that there is very little difference between this curve and that of Fig. 3 showing that as expected the choir rostra absorbed very little sound.

Listening tests, however, showed an appreciable difference between these conditions and the standard condition. The sound was definitely warmer, which was approved of, but at the same time was unfortunately more muddled. The final assessment as to overall quality therefore depended mainly on the relative importance attached to these two aspects by the particular listener.

2.8. Seventh experiment: Boulez layout

In this experiment a modification suggested by the new chief orchestral conductor, Pierre Boulez, was examined. The old choir seating and rostrum, and the orchestral rostrum were removed and the latter replaced by one which was of a different shape and much less raked. As the choir rostrum was not replaced, the whole orchestra was placed further towards the back of the studio. On carrying out listening tests the sound quality was not altogether liked and sound-absorbent treatment was mounted on the end wall behind the rostrum to absorb sound reverberating between the end of the rostrum and the end wall. The appearance of the model under these conditions is shown in Fig. 10. This change effected an appreciable improvement, and the general sound quality was felt to be slightly better than that of the studio in its original state. Reverberation measurements were also made and the results are shown in Fig. 11.

3. Subjective assessment of sound quality

3.1. General

In the previous section, assessments of the effects of the various modifications were made by the staff directly concerned with the experiments. When these were completed, it was felt to be desirable to base the assessments on a greater number of observers and at the same time to try and obtain a numerical rating of the sound quality so that the various conditions could be compared and evaluated against their likely cost, if carried out in the real studio.

It was hoped that a simple listening test comparing the different recordings would enable an overall assessment to be made of the various sound qualities, and that in this way a single figure would suffice to grade them in rank order.
3.3. Second assessment

Since it was clear that different observers gave differing weights to the various qualities which contribute to the overall assessment, it was decided to list the most important qualities and to ask the listening team to assess these as well as the overall impression; the list contained ten qualities as well as the overall judgement and is shown in Appendix II.

In view of the magnitude of some of the assessments made in the previous tests, it was felt that some observers were not making consistent judgements and to decide on this a check was carried out. Without informing the subjects, one of the assessments involved two identical tapes, i.e. the standard was repeated against itself. A number of P.O.A.s were again used as subjects as it was felt that their training should make them particularly sensitive to the differences between the effects provided by various conditions but, in addition, a number of members of the Research Department, not working in the field of acoustics, were also used as subjects to provide results representative of relatively untrained observers.

The consistency tests were very revealing in that only two of the P.O.A.s returned results which indicated that they were aware of the identity of two of the tapes, whilst none of the untrained observers did so. It was clear from this experiment that some modification to the technique was necessary so as to permit more consistent judgements to be made.

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* The Acoustic Committee of BBC Engineering Division.
3.4. Third assessment

As already stated, the previous subjective tests were carried out by running the standard tape and the test tape simultaneously on two machines and switching alternately between them at intervals. It is, of course, clear from this procedure that, during any one test, the same excerpt of music is never heard twice (i.e. once for each condition). One excerpt has to be compared with another, possibly with different instrumental contributions, and this obviously makes comparisons more difficult. Although attempts had been made to switch between the two conditions at appropriate points in the music, it was felt that it would be more helpful if the same excerpt could be heard consecutively for each condition. To this end each pair of recordings was divided into small portions and spliced together in an alternating sequence. The length of each portion was arrived at by listening tests, and had to be long enough to give a proper appreciation of the tonal quality yet short enough to avoid forgetting the beginning of it; a length of roughly fifteen seconds was found to be about the optimum. To aid the operation further, the same sequence was repeated, so that the sequence ran A, B, A, B. Quiet announcements identified each individual excerpt at its beginning and the excerpts themselves were faded in and out in a musically satisfying manner so as to avoid irritating the subjects.

A further test with the P.O.A.s and other experienced listeners was carried out using this new technique and subsequent comments showed that it was preferred to the original presentation.

The discrimination of the subjects, as indicated by the consistency test, improved considerably, eight subjects returning essentially identical results for the identical recordings and many of the remainder were reasonably close in their assessments. It was therefore considered worthwhile to analyse this set of results more closely.

To start with, the group of eight very consistent subjects was taken and a linear regression analysis performed to investigate the way in which the group appeared to use their assessment of the individual qualities to synthesise an overall judgement. Good agreement was obtained and the linear regression curve relating the directly observed overall assessment to that calculated by Equation (1) is shown in Fig. 12. The equation is as follows,

\[ R_{11} = 0.470R_1 - 0.102R_2 - 0.157R_3 + 0.140R_2 \\
- 0.728R_8 + 0.651R_9 + 0.079R_{10} \]  \hspace{1cm} (1)

where

- \( R_1 \) = rating of quality 1 (tonal warmth)
- \( R_2 \) = rating of quality 2 (clarity)
- \( R_3 \) = rating of quality 3 (colouration)
- \( R_6 \) = rating of quality 6 (intimacy)
- \( R_8 \) = rating of quality 8 (timbre)
- \( R_9 \) = rating of quality 9 (brilliance)
- \( R_{10} \) = rating of quality 10 (string tone)
- \( R_{11} \) = rating of quality 11 (overall assessment)

\[ R_{calc} \]

\[ R_{obs} \]

\[ S.E. \]

\[ B.S. \]

Fig. 12 - Regression curve showing calculated and directly observed overall assessment

The multiple correlation coefficient is 0.90 so that the probability that this correlation is due to chance is much less than 0.1%.

A further analysis of the assessments by all the subjects for the individual qualities, and for the overall judgements, showed in some cases a bimodal distribution of sufficient dispersion to be significant. No refinement of experimental technique could eliminate this and the experimenter is left with the difficult choice of which, if either, of the two peak values to take. This sort of situation must often arise where two prominent factors are present and it is a question of personal taste as to which is regarded as the more important. However, it is satisfying to note that the magnitudes of the judgements obtained in the last set of subjective assessments were largely in accord with those obtained in the previous assessments but with higher confidence limits.

It was evident that the new subjective presentation enabled much more consistent results to be obtained. The question which now arises is how many and what attributes are necessary to describe completely the sound qualities of a studio?

3.5. Fourth assessment

In an attempt to limit the qualities to the minimum number necessary to define overall acoustic quality, the help was secured of Dr. Hawkes of University College London, who had previously made a study of this nature in relation to concert halls and samples of the test tapes of
all the conditions were supplied to him. Selections from these were presented in pairs to his subjects and they were merely asked if there was any difference between them. By use of a confusion-matrix technique he showed that the tapes could be arranged in order in four groups, this being the number of independent variables which he found sufficient to account for the data. Unfortunately this type of test does not indicate what each variable actually is, and listening tests were carried out at Kingswood Warren to try and elucidate the problem. Tapes were selected in four groups of three, each group corresponding to the mean and to each end of the scale of the particular variable being investigated and these were listened to by a team of observers. The Hawkes type of test is, of course, all embracing in the sense that if, for example, there is a difference in signal-to-noise ratio or in distortion, the test will reveal this just as it indicates a variation of the desired parameters. The listening team were unable to select any one acoustic parameter for any of the four groups which would definitely account for the scalar ratings. It has therefore been considered necessary to find out if any objective parameters correlate with the variables discovered by the test, and this will be investigated in the future; to this end recordings of responses to impulses and pink noise have been made, and further reverberation tests have been carried out in the model.

4. Discussion of results

It is apparent from the previous section that since the engineering problems of modelling have largely been solved, it is appreciably easier to obtain recordings of the various acoustical conditions than it is to assess them on a quantitative basis. The latter is essential if any further progress is to be made.

It is also evident that comparing the various conditions on an A B A B basis yields more consistent results than any other method (and, hopefully, gives the same results in the five minutes of the test as would be obtained in, say, five months of experience). Even so, further help is obviously needed if the questionnaire is to be reduced to the necessary yet sufficient number of items.

The individual assessments of the Boulez studio arrangement showed that a majority considered it to be a small but significant improvement in quality, although a minority held an opposite view. The majority view prevailed and the modifications have been carried out in the real studio. Reactions of users both from the orchestra and P.O.A.s have been favourable and confirm the predictions made in the model. Furthermore, recordings of the anechoic music in the full-size, modified studio compare well with the tonal quality produced in the model and the predicted reverberation time is closely similar to that measured in the real studio. A comparison is shown in Fig. 13 for the model with model orchestra and for the real studio.

Fig. 13 - Comparison of scaled reverberation time of model with modified Boulez layout (a) and reverberation time measured in completed studio (b)

5. Conclusions

Acoustic modelling is capable of yielding practical results in a short time and at a relatively low cost. Further work is necessary to find out the minimum number of parameters required to describe adequately the sound quality of a studio, and to define them. It is proposed to seek correlation between the sound quality and those objective measurements that are possible. In addition, it is also proposed to examine the effects on sound quality of changing the height of the ceiling of the model by the equivalent of up to sixteen feet; the reduction in height of a studio is a potential source of financial saving in future studio designs.

6. References


Appendix I
FORM 1A

1. Colouration
   Highly Coloured
   Not Coloured

2. Diffusion
   Poorly Diffused
   Well Diffused

3. Echoes
   Prominent Echoes
   No Echoes

4. Pitch Changes
   No Pitch Changes
   Large Pitch Changes

5. Singing Tone
   Good Singing Tone
   Poor Singing Tone

6. Ensemble
   Poor Ensemble
   Good Ensemble

7. Fullness of Tone
   Full Tone
   Thin Tone

8. Hardness
   Hard
   Mellow

9. Loudness
   Quiet
   Loud

10. Intimacy
    Intimate
    Distant

11. Liveness
    Dead
    Live

12. Tonal Warmth
    Warm
    Cold

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13. Definition
Muddy  Clear

14. Brilliance
Brilliant  Dull

15. Balance
Unbalanced  Balanced

16. Blend
Well Blended  Not Blended

17. Attack
Poor Attack  Good Attack

18. Dynamic Range
Large  Small

19. Timbre
Poor  Good

20. Overall
Liked  Disliked

21. Remarks:

Signature ..................................  Date  .........................

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