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THE DESIGN OF VARIABLE ACOUSTICS AT THE NEW MILTON KEYNES THEATRE

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1. INTRODUCTION

Milton Keynes Theatre is a 1400 seat auditorium which opened on 4 October, 1999. It caters for a broad range of performances including small and large scale drama, musicals, opera and orchestral concerts.

This paper describes the principal features of the acoustic design of the Theatre with particular emphasis on the design of a variable acoustic system which adjusts conditions to suit different types of performance. The development of the design with the help of an acoustic scale model is discussed and the results achieved in the completed Theatre are presented.

2. THE BRIEF

The Brief describes the theatre as a multi-purpose performance venue with the following main uses:

- Drama
- Musicals
- Opera and ballet
- Variety and light entertainment
- Orchestral concerts

There is also a requirement for the theatre to be adjustable in audience capacity from 1400 seats down to 900.

Each type of performance requires its own particular acoustic characteristics and to provide these, there is a need for extensive acoustic variability.

The theatre capacity is varied by a movable ceiling and this element is utilised to physically change the volume of the auditorium and therefore the acoustics.

3. THE ACOUSTICAL DESIGN OF THE AUDITORIUM

3.1 Key Requirements

The primary function of the auditorium is lyric theatre (musical theatre, both natural and reinforced, opera, ballet and cabaret type productions). The acoustic is optimised for these types of performances. Drama, both large and small scale, is also important and demands good speech intelligibility.

The theatre is also used for serious music, for example for performances by the Milton Keynes City Orchestra. The acoustic conditions for music must be as good as possible within the constraint that the basic theatre form, in terms of geometry and volume, is significantly different to that of a purpose designed concert hall. The acoustics for lyric and dramatic use are not compromised by designing for music.

Provision of a good drama acoustic also ensures good acoustic conditions for cinema and modestly amplified music performances such as folk and jazz groups.

In specific acoustic terms, good Clarity of the voice is required together with good Speech Intelligibility. Acoustical Intimacy is also desirable. These are all prime considerations in theatre design and imply the provision of strong 'early' reflections.

Reverberance needs to be variable by providing an appropriate Reverberation Time (RT) for each type of performance.

A good Balance between stage sound and pit sound is required for as many listeners as possible throughout the auditorium.

Also, Loudness is important for dramatic effect and to provide a wide dynamic range. This implies avoidance of excessive sound absorption and a very quiet background.

These aims have been translated into technical criteria, a selection of which are shown in Table 1. It is emphasised that, whilst the criteria for theatre uses are optimum, those for music are not ideal since this is not achievable in a theatre form.

3.2 Acoustic Variability

The centre value of the RT, around 1.25 s occupied, has been set relatively high for a theatre, to optimise sound for the principal use, namely, lyric theatre. A shorter RT is required for drama and a longer RT for music. This is principally achieved by varying the auditorium volume by adjusting the height of the auditorium ceiling.

At its lowest height the ceiling provides a volume per seat of 4.5 m^3. This increases to 6 m^3 at the mid position and then increases again to 8.5 m^3 at its highest position.

3.3 Auditorium Shape

Plans of the auditorium are shown in Figure 1 at various levels. The architectural concept is for a largely 'frontal' audience, with relatively few seats at the sides, to produce the best possible sightlines. This results in an auditorium of considerable width. Such width would be a disadvantage for a mainly music auditorium, but is acceptable for theatre. The fan form of the front side walls does not provide early reflections to the central seating areas. The consequence of this geometry is that, for most of the audience, the ceiling – rather than the walls - provides the strong early reflections which are essential for Speech Intelligibility, Clarity and acoustical Intimacy. This is typical of theatre design.

As the ceiling is also required to move, to adjust the acoustic volume, the design of the ceiling is of great importance acoustically.

3.4 The Moving Ceiling

Figure 2 gives a section through the auditorium showing the three heights of the moving ceiling. The distance between the maximum and minimum heights is 10 m.

The auditorium and the roof void above the movable ceiling are inevitably acoustically coupled spaces and steps were take to reduce this coupling to a minimum. The gap between the movable ceiling and the fixed structure is limited to 200 mm except in the small drama mode where it increases to 500 mm between the balcony and ceiling. Gaps via the lighting bridges are also limited. To further reduce coupling with the roof void, it was made acoustically 'dead' by treating large areas with absorbent.

The moving ceiling is constructed of 25 mm thick plywood to provide a good sound reflecting surface without excessive low frequency absorption.

The geometry of the moving ceiling consists largely of a number of flat planes which are stepped to accommodate lighting bridges. Sound reflections from the ceiling were carefully mapped using a scale model and a laser and adjustments were made to the geometry, particularly at the sides of the ceiling, to provide a uniform coverage over the seating area.

3.5 The Orchestra Shell

In concert mode with the ceiling at its highest position, an orchestra enclosure is located above and behind the orchestral performance area. Its purposes are to provide support in the form of early reflections to the orchestra, vital for ensemble; to reflect sound to the auditorium; and to cut off the unwanted acoustic volume of the flytower. It also forms a visual focus onto the concert platform rather than the proscenium.

The enclosure consists of a horizontal canopy above the orchestra together with 14 triangular towers which complete the shell behind the orchestra. The surfaces of the enclosure are a combination of modulated,curved and flat planes to provide a mixture of early reflections and diffusion.

3.6 Seating

The acoustic absorption of the seating was carefully specified to ensure that RT criteria were met and that the change in RT between occupied and unoccupied conditions is minimised.

As is usual for Arup Acoustics, the seats were tested both occupied and unoccupied in a reverberation chamber using a procedure based on the Kath and Kuhl method [1].

4. ACOUSTIC MODELLING

To test whether this bold design would be successful acoustically, it was important to carry out detailed acoustic modelling. The curved geometry coupled with the need to practically demonstrate the changes in acoustics obtained by moving the ceiling suggested that a scale model was preferable to a computer model. The main modelling tool was therefore a 1:50 scale acoustic model. This scale of model is preferred by Arup Acoustics as it is relatively inexpensive, portable and can be quickly updated in response to design changes and to test design options [2].

The model was constructed in perspex to model masonry and concrete. Miniature battened foil panels were applied to the surface of the moving ceiling to simulate the low frequency absorption of the relatively lightweight ceiling construction. The absorption coefficients of this element as well as other surfaces, including the model seating, were verified using Arup Acoustics' 1:50 scale reverberation chamber. A standard impulse modelling technique was used with a spark source and 1/8" microphone controlled by MIDAS software [3]. In addition, the model was used for an optical investigation of first reflections using a laser and mirrored surfaces.

The key aims of the acoustic scale model tests were as follows:

- To test the acoustic variability resulting from the movable ceiling
- To refine the acoustic design of the ceiling in terms of ceiling movements and geometry
- To optimise principal sound reflecting surfaces
- To identify and remove any acoustic faults
- To obtain measures for acoustic parameters for comparison with criteria

Initial model tests showed that the RT in the concert format was slightly too short and this led to a revision of the model where additional volume was provided at high level above the balcony level seating area.

The model also showed the importance of the ceiling and balcony fronts in providing early reflections in an overall geometry where the sidewalls provide little in the way of early reflected energy. The balcony fronts were therefore carefully shaped and angled and the movable ceiling geometry adjusted to provide an even coverage of early reflections.

In the case of small and large drama formats, the model confirmed the need for additional absorption to meet RT criteria. The location of this variable absorption is on the sidewalls and is realised at full scale by movable drapes.

In terms of diffusion, the model showed that the circular plan form is not strongly focusing sound as might be expected. Although the circular geometry is evident, it is considerably broken up by large and small elements in plan and section. Where late reflections were identified in model impulse responses, convex panels were installed to provide diffusion. These are located mainly on the rear wall.

5. RESULTS ACHIEVED

Measurements of the acoustic response of the auditorium have been carried out during the final stages of construction and commissioning. The large number of configurations means that it has not been practical yet to gather data for all possibilities in the presence of an audience and with stage sets in the flytower. Data referred to here relates to the auditorium in the unoccupied condition and with the safety curtain down.

Table 1 sets out measured Reverberation Time (RT), Early Decay Time (EDT), Speech Transmission Index (STI) and Clarity Index (C_{80}) values at representative seats in the auditorium for various positions of the movable ceiling compared with target values. The fundamental result is that the movable ceiling changes the RT in line with the anticipated response.

The bass rise in RT is modest, slightly less than originally proposed, but significant. The EDT is around 90% of the RT for all ceiling positions which is a favourable result in terms of perceived reverberance. Values of C_{80} and STI both achieve their targets.

Subjective tests before the opening were made by a panel of acousticians listening to a string quartet, a variety of solo instruments, singers and actors. The general impressions were that the sound was clear with adequate reverberance and ample loudness. Furthermore, conditions were observed to be relatively uniform over the whole seating area.

Parameter	Technical Index	Criterion	Measured Value
REVERBERANCE	Mid-frequency Reverberation Time, RT (500 Hz – 1 kHz) Lyric mode Drama modes Concert mode	 1.2s – 1.3s 0.9s – 1.0s ≥1.5s	 1.25s 1.1s * 1.5s **
SUBJECTIVE REVERBERANCE	Early Decay Time, EDT (500 Hz – 1 kHz) As % of RT	------	87-92%
WARMTH	Low frequency RT (125 Hz) As % of mid-frequency RT	120%	100 – 110%
MUSICAL CLARITY	Clarity Index (C_{80}) (500 Hz – 1 kHz) Lyric + Concert mode	> O dB	1.9 – 3.9 dB
SPEECH INTELLIGIBILITY	Speech Transmission Index (STI) Drama mode	> 0.6	0.61 *
QUIETNESS	Services Noise Limit	PNC 20	PNC 20

TABLE 1: Acoustic design parameters

* 900 seat configuration, no curtains exposed
** without additional volume of orchestra shell

6. NOISE CONTROL

The site is in an urban area, surrounded by road traffic, but away from other noise sources such as railway lines and aircraft flight paths. To provide the necessary sound insulation, the roofs and walls of the auditorium and flytower were constructed of dense concrete. The movable ceiling adds a second skin to the auditorium roof although its potential is clearly limited. At low level, the auditorium and flytower are surrounded by circulation spaces and ancillary accommodation.

Inside the Theatre building, the 'front-of-house' toilets and bars are located within the concrete drum adjacent to the auditorium and this has required special sound insulation measures. These have involved resiliently isolating the complete toilet and bar section from the main structure.

Conditioned air is supplied to the occupants of the auditorium from air handling units located mainly in the basement area below the auditorium via large ducts and primary and secondary attenuators. The air enters the auditorium under the seating at very low velocity. Measurements carried out when the airflow systems for the auditorium had been commissioned showed that noise levels met the target value of PNC 20. The residue of noise from external sources and also operational noise from lighting was significantly below this level.

7. PROJECT TEAM

Client	Commission for the New Towns
Architect	Blonski and Heard
Structural and Services Engineers	Whitby and Bird
Theatre Consultants	Carr and Angier
Acoustic Consultants	Arup Acoustics
Cost Consultants	Gardiner and Theobald
Main Contractor	John Laing Construction Limited

REFERENCES

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3. X Meynial, G Dodd, J-D Pollack and A H Marshall, *All-scale model measurements: the MIDAS system,* 121st ASA meeting, Baltimore, USA, Journal of the Acoustical Society of America, 89 (4,2) 4AA2 (1991).

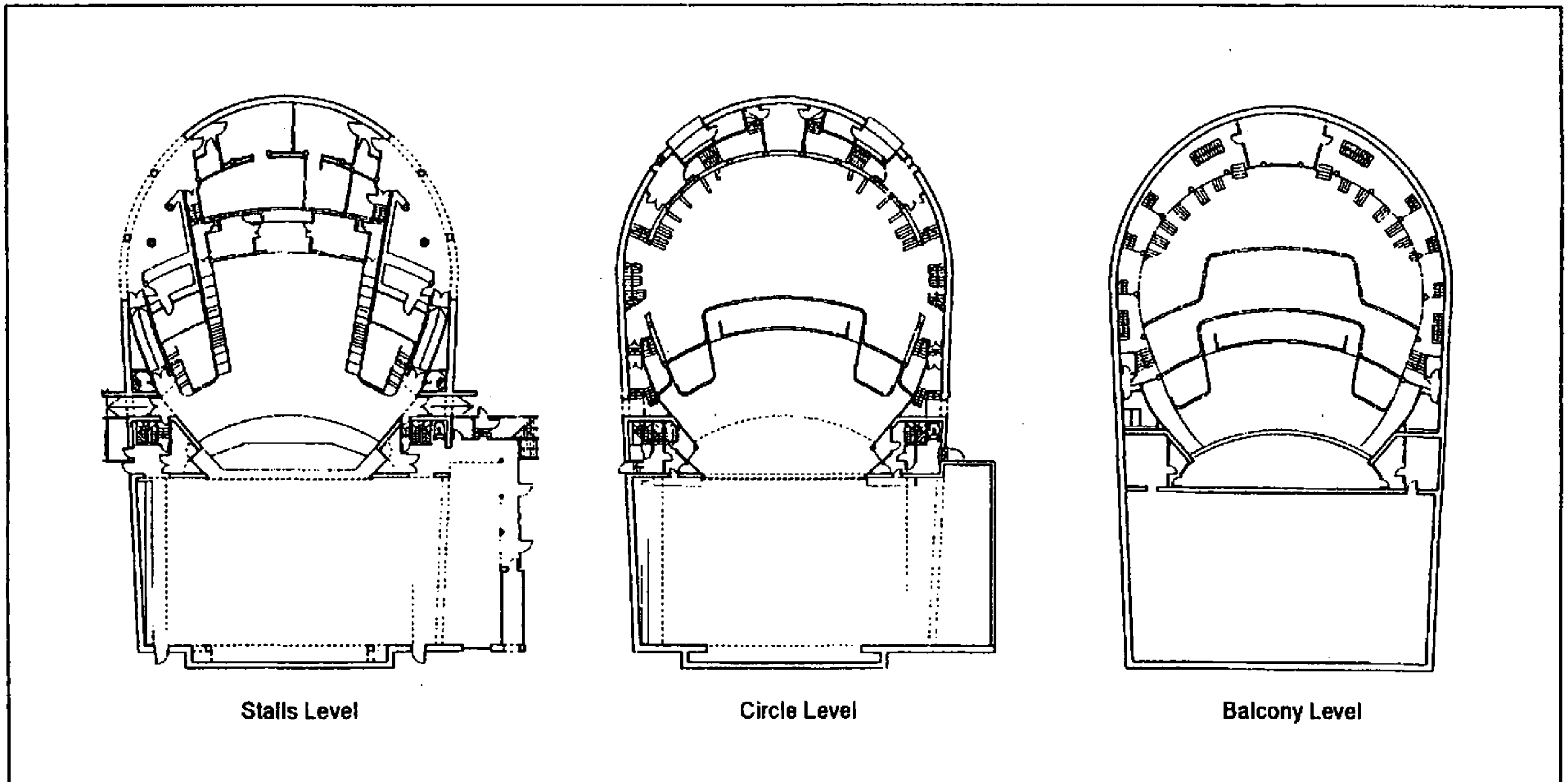

Figure 1: Plans of auditorium at various levels

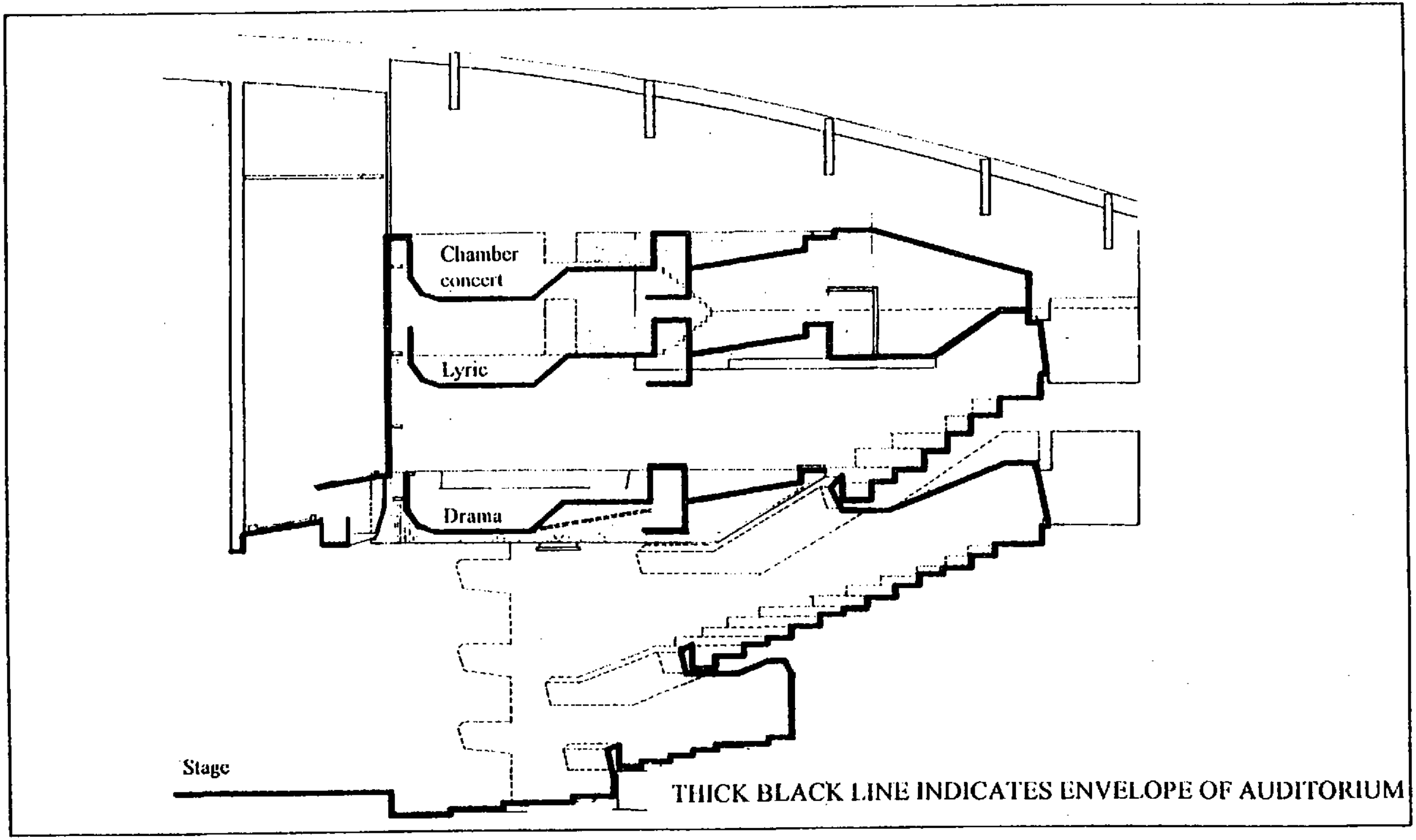

Figure 2: Section Through the Auditorium Showing the Three Heights of the Moving Ceiling