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THE ACOUSTICS OF THE REDEVELOPED ROYAL OPERA HOUSE

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1. INTRODUCTION

The Royal Opera House, Covent Garden, London will reopen in December 1999 with a refurbished main auditorium seating 2157 (formerly 2101) plus 100 standing places (formerly 65). There is also a new studio theatre, spacious new public areas including a reconstruction of the historic glazed Floral Hall as a foyer, function and informal performance space, new and rebuilt opera, ballet and chorus studios and vast new backstage and mechanised set handling facilities. The construction cost is £176M.

The acoustic design applied to the development has been summarised in a previous paper [1].

At the time of publication of this second paper, the acoustics of the development are being analysed by extensive acoustic testing and listening sessions.

This paper reports some of the early results and impressions in the principal spaces. The values in parenthesis, immediately following the measured values, are the design targets. All values are for unoccupied spaces and are averages of the 500 Hz and 1 kHz octave bands unless noted or different by definition.

A number of the more interesting acoustical aspects of the design and construction are also described.

2. THE MAIN AUDITORIUM

Unfortunately neither objective nor listening tests had been carried out at the date of submission of this paper. Measurements have been carried out without the seats installed, to enable future addition to knowledge regarding the installed performance of auditorium seating (the laboratory sound absorption characteristics of both the old and the new seats have been measured).

3. THE LINBURY STUDIO THEATRE

This new 420 seat flexible theatre has been built as a box-in-box construction. External noise and noise from the operation of the nearby 24 tonne capacity get-in lift (which carries a full size articulated lorry, both tractor and trailer) are inaudible within the space.

Ventilation is by overhead supply (through swirl diffusers) and high level extract. The services noise level is PNC19 (PNC20). The noise spectrum follows the PNC curve very closely from 250 Hz to high frequency, at low frequency the noise is less than PNC 10.

In the chamber opera / ballet performance mode (audience bleacher seating extended, variable sound absorption panels retracted, pit lowered, some stage end soft masking) the RT is 1.2 s (1.2 s to 1.3 s).

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The theatre was designed with the aid of ODEON software, which predicted that the RT would be 1.25 s (or 1.18 s by the point response method). For interest, the classical Sabine theory predicted 1.2 s, Eyring 1.1 s. The 125 Hz RT in this format is 1.15 s (1.2 s to 1.4 s). The orchestral clarity C_{80} is around 3 dB (> 0 dB) and the D_{50}, taken here as an indicator of libretto intelligibility, is 0.55 (> 0.5). The average RASTI value is 0.58 (0.55).

In the education mode (bleacher seating extended, variable sound absorption panels exposed, flat floor, some stage end masking) the RT is 1.15 s (1.0 s to 1.2 s). As anticipated and appropriate, the D_{50} and RASTI values are a little higher: D_{50} 0.6 (> 0.55), RASTI 0.61 (0.6).

In the orchestra rehearsal mode (seating retracted, variable sound absorption extended, flat floor, some soft masking) the RT is 1.2 s (> 1.0 s). The low frequency RT equals the mid-frequency time. The C_{80} is around 3.5 dB (> 0 dB).

Subjective tests have been carried out in the orchestral rehearsal and chamber opera modes, plus a recital mode, with the Orchestra and Chorus of the Royal Opera House and soprano, tenor and bass soloists.

A number of points were recording emerged from the first sessions:

Orchestral rehearsal mode

- the designer's concern that the theatre would prove overloud for full scale orchestral rehearsal was found not to be an issue. This enabled the variable reverberance to be retracted, increasing reverberance to the pleasure of the musicians;
- as an acoustic tuning item it is probable that the limited permanent sound absorption installed on the upper walls in the stage area will also be removed, as it is now clearly established that some soft masking will remain in place during rehearsals;
- there was a very significant difference in the acoustic according to the orientation of the orchestra. The arrangement with the upper strings in the 'audience' part of the space (where gallery soffits provide useful ensemble reflections) and the brass and percussion at the 'soft' stage end was universally preferred.

Chamber opera performance mode

- the sound from the pit and from recital, eg lieder, on the stage is very good. Clarity and intimacy are high and frequency balance is fine. The upper strings have sufficient reverberance. No image shifts, echoes or other defects were noted;
- singers, soloists and chorus, were very clear but less intimate, being separated by the pit from the audience. Stage / pit balance was largely determined by the orchestra size. The bleacher seating is fairly steeply raked for functional and sightlines reasons, and this resulted in singers reporting only limited response from the room. The balcony fronts were designed to be acoustically-transparent or sound reflecting (by screwing on back panels) and it is now intended to experiment with reflective balcony fronts facing the stage;

- a large percentage of the ceiling of the theatre is covered by motorised suspension systems, coordinated with structures and ductwork. This prevented conventional overhead reflecting surfaces being installed in the forestage zone (and is a probable reason that overloudness does not occur during orchestral rehearsals), but the design allowed for panels to be fitted as part of the acoustic tuning. It is probable that a number of panels will now be inserted, primarily to improve mutual hearing between the pit and stage.

4. THE OPERA REHEARSAL ROOMS

There are two large opera rehearsal rooms, one new and one refurbished. Perforated metal clad sound absorption has been installed on walls and soffits (these are too high to provide useful early reflections). Regrettably, no data are available at the time of writing this paper.

5. THE BALLET STUDIOS

There are 4 new and 2 refurbished ballet studios. One of the new studios has been fitted with bleacher seating for an audience of 200 and named 'The Studio Upstairs'. Incorporating sound absorption at high level along walls and in ceiling perimeter zones, the new studios are top lit (one studio has sound absorptive cylindrical rooflights) and are of very high architectural quality.

The services noise limit was set at NR25. External noise was specified not to exceed L_1 = NR 25 + 5. The measured L_1 did not exceed NR25. Residual L_1 noise from one ballet studio to another was specified not to exceed NR25. Source data from existing Royal Ballet studios was used for the design calculations. The analysis was carried out in octave bands, but for this summary a target average level difference (63 Hz to 8 kHz) of 50 dB may be assumed. Full box-in-box constructions, with jack-up concrete floors (as the studios are directly above the sidestage), isolated stud partitions, concrete structural dividing walls used for structural mass damping of the supporting slab and resiliently - suspended ceilings enabled an average level difference of 60 dB to be achieved. Over the 125 Hz to 4 kHz range the average level difference is 67 dB (54 dB).

Ballet Studios 1- 4 (new) have a RT of 1.15 s (1.0 s). The 125 Hz RT is 1.25 s (1.3 s). Subjectively speech intelligibility is judged to be very good, with no flutter or other acoustic defects detected.

A previous severe floor / ceiling flutter echo in the refurbished De Valois studio has been eliminated by the use of large convex light fittings.

6. MUSIC PRACTICE ROOMS/LANGUAGE STUDIOS

There are 8 music practice rooms/language studios, all built as box-in-box dry wall constructions with concrete jack up floors and resiliently-suspended plasterboard ceilings. The services noise limit (not yet measured) is NR25. The sound level difference target between rooms was 58 dB (average 125 Hz to 4 kHz), an average of 62 dB has been achieved.

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7. ACOUSTIC DESIGN ELEMENTS

7.1 Large Sound Insulating Doors

These are described in [1]. The largest door is between the stage and the backstage, with dimensions of 18 m by 17 m and a weight of 64 tonnes. The doors have been constructed on site with top-hung steel I-section frames. They are of steel / neoprene / plasterboard multiple layer construction, with pneumatic perimeter seals (no test data at time of writing this paper).

7.2 Ballet Rehearsal Dynamics

The ballet studios are located above other work areas on long-span beams, and Opera Rehearsal Room 2 is immediately above the studio theatre. Considerable dance impact measurement, structural research and finite element analysis was carried out to ensure that dancer movements would not result in perceptible vibration, causing neither disturbance to fellow workers nor production problems such as light beam shake.

7.3 Lighting Noise

As is now generally the case in performing arts buildings considerable effort was needed to limit noise from lighting, including stage lighting, decorative house lighting and functional lighting. This included specification of noise control measures for fibre optic projectors, liaison with moving stage light manufacturers on the development of quiet motor, fan and scroller systems and the banning of certain types of fittings from acoustically-critical areas. The choice of dimmer and production lighting instrument combination was made after a programme of testing of different configurations in conjunction with the theatre consultants.

7.4 Stage Machinery Noise

At an early stage in the project, noise limits were agreed for stage equipment which moves in the presence of the audience. The power flying system is based upon low noise output electrically-powered winches, located in enclosed winch rooms at the top of the flytower.

Very noisy hydraulic machinery is associated with the compensating elevators in the stage areas. Further, the hydraulic plant room is of necessity sited relatively close to the stage and auditorium. It has therefore been constructed as a masonry box-in-box.

8. CONCLUSIONS

The first objective data and subjective impressions for the acoustics within the refurbished Royal Opera House, London are encouraging and in line with overall perceived success of the project.

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9. DESIGN TEAM

Architect:	Dixon Jones BDP
Building Engineers:	Ove Arup & Partners
Theatre Consultants:	Royal Opera House Theatre Consultants
Acoustic Consultant:	Arup Acoustics
Construction Manager:	Schal

REFERENCE

1 Harris, R (1999)
Acoustic considerations in the redevelopment of the Royal Opera House, London
Proc. 137th Meeting ASA, Berlin