THE ROYAL FESTIVAL HALL: THE HISTORY OF THE ACOUSTIC DESIGN

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1 INTRODUCTION

The Royal Festival Hall was 50 years old in May 2001. As the first public building to be erected in the UK after the Second World War, and the first concert hall of its size in the world, it is of great significance both architecturally and acoustically, and is a landmark in concert hall design. The acoustic design of the auditorium involved many innovative and pioneering ideas, and laid the foundations for concert hall research and design in the second half of the 20th century.

The main features of the Royal Festival Hall have been described in detail elsewhere [1-6]. This paper describes the background to the building of the hall and discusses the consultations, research and experimental work in acoustics that contributed to the original design process.

2 BACKGROUND TO THE BUILDING OF THE HALL

London's major pre war concert venue, the Queen's Hall in Langham Place, had burnt down as a result of bombing in 1941. Since then most orchestral concerts in London, including the Promenade concerts every summer, had taken place in the Royal Albert Hall. In 1943 the Abercrombie and Forshaw plan for London [7] included a recommendation that the South Bank area should be redeveloped to include a concert hall, and this was subsequently adopted as policy by the London County Council (LCC). The intention of the LCC was to build a hall for an audience of approximately 3000, an orchestra of up to 150 players, and a choir of up to 300 singers. A few years later the Festival of Britain was planned to celebrate the centenary of the 1851 Great Exhibition and Britain's emergence from the war years, by providing a showcase for British contributions to the arts, science, technology and industrial design. As part of the Festival of Britain plans it was suggested that London needed a major concert venue, and the LCC agreed to build its South Bank concert hall in time for the Festival. The design team was appointed in the autumn of 1948 and the hall was completed a remarkable 30 months later.

2.1 The Architects and Acoustic Consultants

In the autumn of 1948 the LCC architect, Robert Matthew, appointed a team of architects and designers to work on the hall. Leslie Martin was appointed as deputy architect to the LCC with specific responsibility for designing the concert hall, while he in turn appointed Peter Moro to be responsible for the interior design of the building. A team of enthusiastic young architects was recruited to work on the project, the work being coordinated by the LCC senior architect Edwin Williams.

Also appointed at this time were the acoustic consultants Hope Bagenal and a team from the Building Research Station (BRS) led by Peter Parkin and Bill Allen. It is thought that the Festival Hall was the first building in which acoustic consultants were an integral part of the design team from its inception. The conductor Sir Malcolm Sargent was appointed as musical consultant.

Hope Bagenal was the leading figure in British acoustics and, at the time, the only independent acoustic consultant in the country. He was originally trained as an architect but became increasingly interested in room acoustics, corresponding with Wallace Sabine and other American acousticians in the early years of the 20th century. He had been involved in the design of theatres and concert halls since the 1920s, including the White Rocks Pavilion, Hastings, the Shakespeare Memorial Theatre in Stratford upon Avon, and the Liverpool Philharmonic Hall. He wrote and lectured extensively on concert hall and theatre acoustics, and was particularly interested in the relationship between architecture, music and acoustics. Bagenal was employed at BRS during the war, where he and Bill Allen worked together on alterations to the Albert Hall when the Proms were transferred there in 1941. Peter Parkin had gone to BRS after the war having spent the war years in the mine sweeping division of the Admiralty. The acoustics team symbolised the 'old' and the 'new' in acoustics at the time. Hope Bagenal represented the classical tradition, with an intuitive understanding of the subject, while the BRS team applied the latest theoretical and experimental techniques and instrumentation to the design. Trevor Dannatt, one of the original design team, remembers Hope Bagenal walking around the completed hall assessing the acoustics by listening with a cardboard tube to his ear, while 'the scientists sat twiddling their dials'!

The acousticians had enormous respect and affection for each other, as is evidenced by their correspondence and other writings. Leslie Martin observed that Peter Parkin believed that 'in matters of quality Mr Bagenal is always right' [8]. There was also exceptional rapport between the architects and acoustics teams, Robert Matthew commenting that 'We were, indeed fortunate, as architects, in having such an unusual and happy combination of scientific outlook' [8]. The close collaboration between architects and acousticians was acknowledged by both Parkin and Allen as having contributed to the success and speed of construction of the hall [1,9].

3 PREPARATORY WORK AND CONSULTATIONS

Since 1947 BRS had been carrying out subjective and objective surveys of concert halls in the UK. Reverberation times of seven halls including the Albert Hall, New Philharmonic Hall Liverpool, St Andrew's Hall Glasgow and Usher Hall Edinburgh were measured with the halls both full and empty [10]. A questionnaire survey of music critics, professors of music and composers was carried out which showed Liverpool (with a mid- frequency RT of 1.6 s and low frequency RT of 1.3 s when full) to be their preferred hall. This soliciting of the views of music specialists was continued by lengthy discussions between the acousticians, architects and musicians on the most important characteristics of a hall and the best ways to achieve them.

An important meeting, at which the fundamental acoustic criteria of the new hall were determined, was organised by the Acoustics Group of the Physical Society at the Royal Society of Arts in November 1948 [11]. The meeting was addressed by Hope Bagenal with additional contributions from conductors (including Sir Adrian Boult and Sir Malcolm Sargent), music critics, and other acoustics specialists including Peter Parkin and Bill Allen.

In addition, during the design and construction period, the acoustics team had many meetings and consultations with international experts in auditorium acoustics, including Bolt and Beranek of the USA, Jordan and Ingerslev of Denmark, and Canac of France.

3.1 'Egg in a Box'

At a very early stage in the planning of the hall Leslie Martin proposed the overall 'egg in a box' design in which the auditorium would be situated above, and enclosed on all sides by, bar and foyer areas. The main reason for this construction was to maximise space on what was a very limited site. However, the design had an obvious acoustics advantage in that the surrounding areas would shield the auditorium to some extent from external sound.

3.2 Noise and Vibration Surveys

One of the first issues facing the acoustics team was that of the exclusion of external sound from the auditorium, as the site was exposed to high levels of noise from various sources. Indeed there was a great deal of criticism in the press over the choice of site because of the prevalence of noise, mainly from trains going over Hungerford Railway Bridge adjacent to the site, and also from river traffic and aircraft.

The BRS had recently acquired a mobile laboratory, a van which was equipped with the latest sound measurement equipment for carrying out field measurements of sound insulation. The van was driven to the site in order to carry out noise and vibration surveys. The average noise level of trains on the nearest track to the site was found to be 104 dB (linear), or 97 phons (measured with a Barkhausen meter). The sound energy was mainly below 500 Hz and it was concluded that the main source of noise was vibration of the bridge. As a result of the survey the LCC requested that the track on the bridge be relaid using ballast, under rail pads and with welded rail joints; this was done in 1949 with a resultant reduction of 17 dB or 12 phons. There was also concern about possible noise and vibration from an underground train line passing directly below the site. Vibration due to overground and underground trains was therefore measured in the basement of an existing building on the site, and was found to be 'not perceptible' and unlikely to produce audible noise in the concert hall. (Parkin later admitted that there had been a mistake in the calculations and that vibration induced noise would have been a problem if a smaller hall had been built underneath the main auditorium, as originally planned [12].)

3.3 Sound Insulation

The results of the noise survey were used to determine sound insulation requirements for the hall. Parkin was aware that in the Queen's Hall it had been possible to hear the rumble of traffic noise, and wished to avoid this in the new hall. To decide on an appropriate level of background noise in the hall sound levels were measured during quiet passages and pauses in the music at concerts in halls where the external noise was imperceptible. The required background level for the new hall was taken to be 30 to 40 phons, which meant that the level of sound insulation required was 70 dB.

To provide sufficient sound insulation a double leaf wall of reinforced concrete, each leaf being 10 inches thick, separated by a 12 inch cavity containing wood wool absorbent, was proposed. The roof was to consist of a 6 inch thick inner leaf separated by a 12 inch cavity from the outer leaf of 4 inch concrete. In order to test the sound insulation of the proposed construction an 'experimental hut', completed in September 1949, was built on the site adjacent to the railway bridge. The acousticians measured the sound levels of passing trains inside the hut, and also carried out tests using loudspeakers placed on the bridge and on the roof of the hut. The sound insulation of the walls and doors was found to be satisfactory, but that of the roof less so. For the actual auditorium it was therefore decided to use the proposed wall construction, but to increase the cavity of the roof to 24 inches.

The sound insulation was a very successful feature of the building, the external noise being almost completely excluded which contributed to very low background noise levels in the hall. As well as preventing noise from trains being heard in the auditorium the consultants, in the words of Peter

Parkin 'successfully stopped train drivers on Hungerford Bridge hearing snatches of Beethoven as they passed by' [12]!

4 ACOUSTIC CRITERIA FOR THE HALL

The criteria for the hall's acoustics were largely determined by the views expressed at the 1948 meeting of the Physical Society [11]. Hope Bagenal believed that the two most important criteria for a hall were 'definition' (that is, clarity of sound) and 'fullness of tone' or 'singing tone' (which would today be referred to as warmth or resonance). He believed that one factor in achieving good definition was to have free direct paths from orchestra to audience. 'Ideally the audience should sit on the slope of a big hill, and the instruments on the steeper slope of a little hill, and there should be a hard reflecting space or little lake between the two hills' [11]. He also recognised that rapid early reflections contributed to 'definition' so that it was necessary to have reflecting surfaces close to the orchestra. Other important musical requirements aimed at in the hall as a result of this meeting and the other surveys of musicians and music critics, included balance, blend, and absence of echoes.

It was acknowledged that there was a conflict between the RT requirements for 'fullness of tone' and 'definition' in that whereas fullness of tone required a long RT, definition could only be achieved with a short RT. At the 1948 meeting, musicians expressed a greater preference for fullness of tone than for definition. The acoustics team therefore decided to design for as long an RT as possible on the grounds that it would be relatively simple to reduce the RT if necessary, through the use of Helmholtz resonators.

4.1 Shape of the Hall

The favoured plan shapes for a hall at the time were the rectangular 'shoe box' shape and the fan shape. The former was the shape of many successful older halls such as the Gewandhaus in Leipzig which had been used by Sabine as a model for Boston Symphony Hall. The fan shape was a more recent development, variants of which were used for the Salle Pleyel in Paris (1927) and the Liverpool Philharmonic Hall (1939) (Hope Bagenal having been the acoustic consultant for the latter hall). Bagenal had many reservations about the size of the new hall, having always believed that it was not possible to have a successful concert hall seating more than 2000 people. He therefore considered that for a large auditorium an adaptation of the rectangular plan would be the most appropriate, the parallel side walls providing cross reflections which would add to the 'fullness' of sound and avoiding the risk of focusing and echoes associated with a large fan shape. In order to avoid problems of very wide rows at the front near the orchestra it was decided to arrange the stalls seating area in a fan shape within the parallel walls.

To obtain the 'hill and lake' effect, the auditorium seating was raked, with a single line of slope. Bill Allen later said that ideally there should have been a double slope but, as he and Parkin were newly arrived members of the team when the single slope was discussed, they did not like to challenge this proposal, a decision which they later regretted [9].

4.2 Stage Design and Orchestra Layout

The acoustics team at BRS carried out detailed studies of platform design and orchestral layout, in discussion with various musicians including Malcolm Sargent. It was decided that the platform should be as compact as possible to avoid time delays between the sounds of different instruments reaching the audience, and thus aid definition. Special music stands were designed which moved on wheels in grooves along the fronts of the tiers, rather than taking up floor space. In keeping with the 'hill and lake' scheme, the original height of the platform was only 9 inches above the level of the front stalls, with the players arranged on tiers on the platform. After a few years the platform was raised to its present height largely because soloists did not like performing on such a low stage. It was also realised that a higher platform would assist the projection of sound to the seats under the balcony, by reducing the absorption of direct sound by the audience in the stalls.

Wooden reflecting surfaces were placed around and behind the platform to assist the players in hearing each other, thereby contributing to the balance and blend of the orchestra. These surfaces also produced short reflected sound paths to the audience to increase the definition of the sound heard. The 'little lake' required by Bagenal, to reflect sound from the orchestra to the audience, is provided by an area of green slate embedded in the auditorium floor between the stalls and the stage.

In examining different orchestral layouts the BRS team considered that placing all the strings on the left, enabling as much string tone as possible to be projected into the hall, would be a successful arrangement. This arrangement was tried soon after the hall was built (see Section 7 below), to critical acclaim.

4.3 Other Reflecting and Absorbing Surfaces

It was feared that, with the solid construction of the walls and floor, the low frequency RT might be excessive. For this reason many of the wall surfaces in the hall were covered with wood panelling to act as low frequency absorbent. The depth of air space and the bracing of the panels were varied to extend the effective frequency range of absorption, and the air space was filled with different types of absorbent. To avoid echoes the rear wall and lower parts of the side walls were covered with red leather cushioning, filled with glass wool, which was mounted on battens with rock wool in the air space. A new form of panelling, designed in Copenhagen to reduce problems caused by low frequency resonances in the concert hall of the Danish Broadcasting Corporation, was installed around the platform and the front stalls area. This consists of thin ribs of wood a short distance apart with an air space behind filled with glass silk.

A major feature of the hall is the wooden canopy suspended over the stage. This has two functions: to reflect sound to the audience, particularly those seated under the balcony; and to provide further reflections of the sound back to the orchestra. The canopy consists of three separate convex sections, each designed to reflect sound from a particular part of the orchestra, the overall contour being slightly convex to avoid focusing effects. The organ consultant, Ralph Downes, objected to the canopy and insisted on a large opening for the organ, which was the source of some contention between him and the acousticians. Eventually a compromise was reached whereby the canopy was installed but at a much greater height than originally intended, thus reducing its effectiveness.

In order to ensure as far as possible that the acoustics of the hall would be the same for rehearsal and performance, that is, with and without an audience, the auditorium seats were specially designed with absorbent undersides which would be exposed when the seats were unoccupied and in an upright position.

4.3.1 Experimental testing of materials

At the time the hall was built there was very little data available on absorption characteristics of materials, particularly at low frequencies. A large space attached to nearby County Hall (the LCC offices), under the approach to Westminster Bridge, was made available to the acoustics team, who converted it into a reverberation chamber. The absorption of the seating and of various configurations of wooden panelling was measured in this space. The measurements took place at night, the police diverting the traffic to prevent interference from traffic noise and vibration.

4.4 Reverberation Time

At the time of the building of the Royal Festival Hall the only measurable and predictable parameter for a concert hall was the reverberation time. Appropriate RT values for music had been given in the UK by Bagenal and Wood [13] and in the US by Knudsen and Harris [14]. For a hall of the volume of the Festival Hall Bagenal and Wood recommended 2.2 s and Knudsen and Harris 1.7 s.

The original aim for mid–frequency RT was 2.4 s, which was considerably longer than that in existing British halls of the time, but this was quickly revised to 2.2 seconds. Over 1200 holes, filled with wooden plugs, were left in the ceiling for the installation of Helmholtz resonators if needed. During the course of construction of the hall it was realised that, with an audience of 3000 and the given volume of the hall, this RT would not be achieved and the target was reduced to 1.7 s (at 500 Hz), the value recommended by Knudsen and Harris.

When the hall was finished the RT was found to be significantly shorter than predicted, 1.5 s at 500 Hz and less at lower frequencies. One reason given for this at the time was that the ceiling specification and thickness were changed suddenly, without consultation with the acousticians, the resultant ceiling being more absorbent than the original design, particularly at low frequencies. Also, the standard method at the time for measuring the seating absorption, plus the figures used for audience absorption, have since been shown by various authors, notably Beranek [15], to be inaccurate. The total absorption in the hall was therefore underestimated. Another, minor, factor was that the architects had introduced some areas of carpeting in the auditorium, against the advice of the acoustic consultants. Bagenal recommended that the carpet be taken up and 500 seats removed, although neither of these recommendations was implemented.

5 TUNING OF THE HALL

Once the main construction of the hall was completed three concerts were held, between February and April 1951, to test the acoustics and ‘tune’ the hall. The concerts were attended by audiences of between 2000 and 3000, made up mainly of people working on the hall, LCC employees and their friends and families. The audiences at all three concerts also included groups of specialist listeners, comprising regular concert-goers, acoustics experts and music critics, who completed questionnaires on the acoustics of the hall. At all the concerts reverberation times were measured using pistol shots, chords and the actual music played as the sound sources. As a result of the subjective and objective surveys during these concerts, alterations were made to many of the surfaces of the hall prior to its opening, including the removal of much of the absorbent and the reduction of the air space behind the panels.

6 OPENING OF THE HALL

The ceremonial opening of the hall took place on May 3 1951. A religious Service of Dedication was
conducted in the hall by the Archbishop of Canterbury, in the presence of King George VI and Queen Elizabeth. This was followed by a concert of British music involving all the major London based orchestras and choirs, conducted by Sir Adrian Boult and Sir Malcolm Sargent. During the following week a series of inaugural concerts was held. The other great British conductor of the time, Sir Thomas Beecham, famously refused to take part in any events in the hall at its outset, regarding it as a 'repellent' and 'monstrous' structure. However, after the hall had been open for a few weeks, he relented and agreed to conduct 4 concerts there during the following winter.

7 REACTIONS TO THE HALL

When the hall opened it was widely praised by audiences, critics, conductors and performers for its clarity, although there was some disquiet over its lack of ‘warmth’. The violinists Jascha Heifetz and Yehudi Menuhin thought it had the best acoustics of any hall they had played in; Joan Hammond the singer ‘found the acoustics excellent’; and the pianist Denis Matthews enjoyed both playing and listening in the hall. Among conductors Leopold Stokowski said it was the finest hall in the world; Malcolm Sargent thought the acoustics were excellent; Adrian Boult ‘liked it very much indeed’; and Josef Krips said it was the most perfect hall he knew. Other conductors, however, were more critical. For example, Otto Klemperer cancelled a performance of Elgar’s Enigma Variations as he felt the acoustics of the hall were ‘not suited to the sonorities of Elgar’s masterpiece.’

The extreme clarity of the hall allowed even minor errors by players to be easily heard. Bill Allen reported [9] that when he later asked Adrian Boult what he thought of the hall he replied that ‘Malcolm loves it because he is a disciplinarian’, whereas he himself preferred York Minster where ‘it doesn’t matter if a player is a bar late’!

On 9 June Leopold Stokowski conducted the BBC Symphony Orchestra in Stravinsky’s Rite of Spring with the orchestra arranged as suggested by BRS, with all the strings to one side. The music critics were unanimous in their praise for the sound commenting on the ‘ideal balance between blend and definition’, ‘the richness of the string tone’, and the ‘clarity and fullness of tone’ of the strings.

In September 1951 a group of international acoustics experts, including Bolt, Beranek, Canac, Cremer, Harris, Ingerslev, Kosten and Meyer, heard a concert in the hall while attending the 1951 Building Research Congress. According to a questionnaire survey of the experts the majority thought very highly of the hall, comparing it favourably with other halls around the world.

8 ASSISTED RESONANCE

Over the years criticism of the lack of warmth by the public and musicians increased. In the early 1960s Peter Parkin invented the system of 'assisted resonance', an electro-acoustic technique for prolonging the apparent RT in the hall [16-19]. The inspiration for this system came from his work in the 1950s on the speech reinforcement system in St Paul’s Cathedral. The system was tested in the hall in 1964 and installed in 1965 in time for the reopening of the hall following major refurbishment work. The response of the public, critics, conductors and performers was overwhelmingly favourable [17].

The initial installation was limited to the frequency range 70 to 340 Hz and typically increased the RT in the stalls when the auditorium was full from around 1.4 s to 1.8 s at 125 Hz [17]. Between 1965 and 1969 the system was extended to cover frequencies up to 700 Hz [18]. With the system fully operational, in the full hall the RT increased from approximately 1.4 s to over 2 s at frequencies up to 250 Hz, and to 1.8 s at 500 Hz. With the hall empty the RT increased to 2.5 s at 63 Hz and 125 Hz, and to around 2 s at 250 Hz and 500 Hz. There were corresponding increases in sound level of 1.9 dB at 125 Hz, 0.8 dB at 250 Hz and 0.4 dB at 500 Hz. Conductors and performers, as well as recording engineers, agreed that the problem of lack of warmth in the hall had been overcome, and that the hall had become one of the best in the world [18].

The use of assisted resonance in the Royal Festival Hall marked the start of the modern electro-acoustics industry. The system was in use for 30 years in the hall before being switched off permanently in December 1998, owing to a desire on the part of the hall's management to return to a 'natural acoustic'.

9 CURRENT PLANS FOR THE HALL

There are currently plans for redevelopment of the hall which will include refurbishment of, and additions to, the building, and 'transformation' of the auditorium. The principle acoustic consultants advising on the auditorium are Kirkegaard and Associates. Planning permission was granted in March 2002 for the first phase of the refurbishment, that is renovation of the foyer areas. The intention for the auditorium is to return to 'natural acoustics' rather than using electronic enhancement, while maintaining the exceptional clarity of the hall. The reverberation time will be lengthened by changing the surfaces to make them more reflective, and by alterations to the ceiling construction and shape. Adjustments will also be made to the stage and platform area to increase reflections on stage to support the performers. A new canopy is planned and the seating is to be renewed.

10 CONCLUSIONS

Many approaches to the acoustic design of concert halls, which are now standard practice in the construction of a new hall, were used for the first time in the design and building of the Royal Festival Hall. These include the integration of the acoustic consultants as part of the design team from the start of the project, close collaboration between architects and acousticians, internal and external background noise surveys, experimental testing of materials, subjective surveys of musicians and listeners, and 'tuning' and adjustment of the acoustics. Much of the technical and theoretical work carried out by the acoustics team was highly innovative. The invention of the assisted resonance system for the hall was a further pioneering achievement in 20th century acoustics. The building of the hall led to widespread interest in concert hall acoustics and paved the way for much of the research work on concert halls and listening preferences carried out in the second half of the twentieth century. It is important that the enormous contribution made to acoustics research and design by the team of consultants involved in the building of the Royal Festival Hall is recognised and celebrated.

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