Acoustical Renovation of The Orpheum, Vancouver
I. Measurements Prior to Renovation

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ABSTRACT

This paper reports measurements and analyses of acoustical conditions in The Orpheum, the home of the Vancouver Symphony. These measurements were made prior to renovations to the hall and were an integral part of designing those renovations. The measurements were derived from impulse responses both on-stage and at audience seats in the hall and for several configurations of the hall. Average values of several common room acoustics parameters are compared to the range of values from other halls. Measurements of conditions on-stage indicate conditions were in the range of normally accepted values. The variation with distance of sound levels and decay times is seen to be different at locations under the balcony than on the balcony. The existing over-stage reflectors were found to be useful on-stage. The large balcony overhang leads to reduced late arriving sound levels at seats under the balcony.

SOMMAIRE

Cet article présente les mesures et analyses des conditions acoustiques dans L'Orpheum, la salle de concert de l'Orchestre Symphonique de Vancouver. Ces mesures ont été prises préalablement à la rénovation de la salle et ont été une partie integrante du projet de rénovation. Les mesures ont été dérivées des réponses impulsionelles sur-scène ainsi qu'aux sièges des spectateurs dans la salle, et pour quelques configurations de la salle. Les valeurs moyennes de quelques paramètres acoustiques sont comparées aux valeurs des autres salles. Les mesures des conditions sur-scène indiquent que les conditions sont dans la portée des valeurs acceptables. La variation des niveaux sonores et la durée de décroissance du son avec distance est différent pour les endroits en dessous et sur le balcon. On a constaté que les réflecteurs existants par-dessus la scène sont utiles sur-scène. Le surplomb large du balcon réduit les niveaux des sons qui arrivent plus que 80 ms après le son direct aux sièges en-dessous du balcon.

1.0 Introduction

The Orpheum Theatre is a 2800 seat vaudeville house that was renovated for the Vancouver Symphony in the 1970s. The acousticians responsible for the work were Bolt Beranek and Newman of Cambridge, USA in collaboration with Barron and Associates of Vancouver. The project leaders for the respective firms were Ted Shultz and Ken Barron. Funds ran out prior to completion and some problematic conditions remained for the following fifteen years. Although The Orpheum is the principal home of a symphonic orchestra, it is not a concert hall in the classical 19th century sense. It is, rather, a modification of a proscenium arch vaudeville theatre that is now often used as a concert hall. As such, there have been some notable acoustical short comings including: excessive room noise, a long balcony overhang that compromises sound for a significant portion of the audience seated under the balcony and a curved ceiling that has produced disturbing focussed sound and acoustical image shifts. For patrons seated in the front of the balcony, the orchestral balance was poor and it was not unusual to hear voices or instruments that appeared to be located somewhere above the ceiling. In the 1970s, some plastic reflectors had been placed over the stage. These blocked important lighting positions and their acoustical efficacy had always been in doubt. Finally, an electro-acoustic system had been installed underneath the balcony in an effort to negate the effects of the very long balcony overhang. The system had been tampered with over the years and had long since fallen into disuse.

Vancouver Civic Theatres proposed a long term renovation project to address these and other issues. The subject of this paper is to describe the measurements and analyses that were carried out in an effort to understand these various problems. It is intended that subsequent papers will describe how solutions to these problems were developed and implemented. These subsequent papers will describe (i) subjective evaluations to determine the detection thresholds of focussed reflections and (ii) acoustical scale model studies to develop design solutions and full scale tests to verify the success of the modifications to the hall.

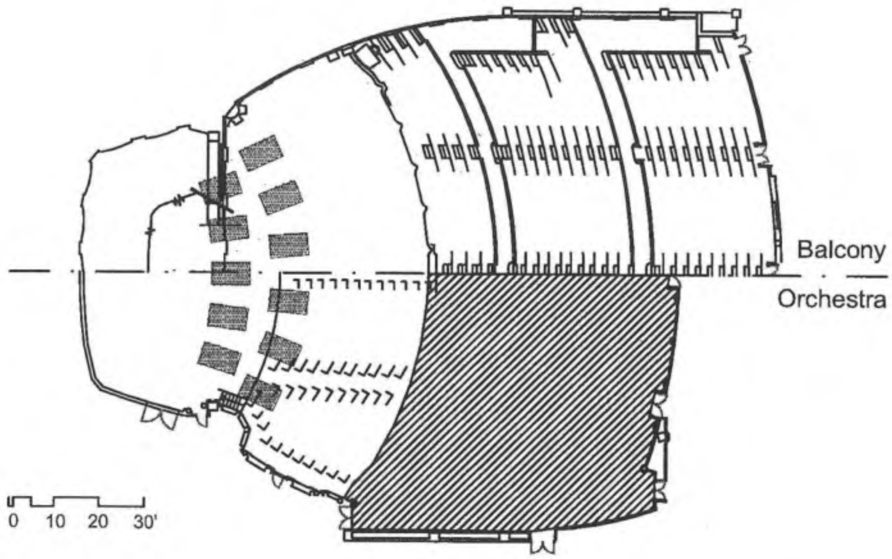

Figure 1. Schematic Details of the Orpheum Theatre, Vancouver (Plan).

It is hoped that the measurement results published in this paper will serve as a useful record of the acoustical conditions in this significant Canadian hall, as found in 1994. It is also hoped that the measurement and analysis procedures reported here represent a good example of the current state of the science of concert hall acoustics with respect to resolving practical problems in halls. Finally, the range of the acoustical problems in The Orpheum, shown in Figure 1, is quite unique and makes it possible to demonstrate a large number of problems for a single venue.

2.0 Measurement Procedure

2.1 Measurements and Measurement Systems

All measurement results reported in this paper were obtained in 1994 before any changes were made to The Orpheum. Two different acoustical measurement systems were employed, one by Aercoustics Engineering Limited and the other by the National Research Council. For the measurements prior to the renovations (reported here) the Aercoustics system was used for stage measurements and the NRC system for the audience measurements. After the renovation, all measurements were performed with the Aercoustics system.

2.1.1 The Aercoustics System

The Aercoustics system used a Maximum Length Sequence System Analyser (MLSSA) manufactured by DRA Laboratories. Measurements were performed using a Maximum Length Sequence of order 15, i.e. 32,767 points per period. Sound was radiated by dodecahedron source with 75mm diameter loudspeakers. Responses were measured with an omni-directional Bruel & Kjaer Type 4165 microphone, powered by a Bruel & Kjaer 2230 sound level meter.

2.1.2 The NRC System

The RAMSoft II software, developed by NRC used a larger dodecahedron loudspeaker with 105 mm drivers powered by a 400 watt Carver power amplifier. This system was also computer based and used a 15^{th} order maximum length sequence source signal. The signals from two microphones were amplified by a Stanford Research programmable filter amplifier controlled by the program and the output was digitized by a 16 bit Analog Devices converter. For all but one parameter, a Bruel & Kjaer Type 4165 omni-directional microphone was used. For Lateral Fractions, an AKG EB414 figure-of-eight microphone was also used with the sensitive lobes pointed towards the side walls.

2.1.3 Stage Measurements

For the ease of performance, the acoustics of a good stage must satisfy a delicate balance. The stage must reflect enough energy back to a performer so that he can hear his own instrument and maintain intonation. If too much energy is returned though, the musician may not be able to hear his associates and orchestral ensemble will suffer.

Stage measurements were performed at and between five locations corresponding to typical positions of a: Soloist, Violin, Viola, Horn and Bass. Support ratios (ST_{total} and ST_{late}) were measured at a distance of 0.5 m from the dodecahedron sound source. The stage measurements were made in 1994 prior to the renovations and both with and without the plastic over-stage reflectors in place. The measurement procedure is based on the one developed by Gade (1,2,3). Gade has established correlations between ST_{total} and the subjective parameter musicians refer to as Support. Naylor (4) has referred to a similar parameter as Hearing of Self.

Gade's original work on stage acoustics measurement applied a 1.0 m source receiver distance. Naylor used a 0.5 m source receiver distance, suggesting that it is closer to the actual conditions experienced by performers on stage. Stage measurements reported here were performed at a 0.5 m source receiver distance. (There is no simple conversion factor between measurements taken at 0.5 and 1.0 m. On an empty stage a simple spherical divergence correction of 6 dB might apply. On a stage with chairs, music stands and musicians the difference is in the range of 4 dB.)

2.1.4 Audience Measurements

Measurements were performed at all combinations of fifteen different seating locations in the audience seating and 3 different source locations on the stage for a total of forty-five measurements for each of three conditions of the hall. Because the hall is laterally symmetrical, the seat locations were all on the same side of the room. Nine were on orchestra level, six were distributed evenly across the balcony and two were near the front cross-aisle of the balcony where a profound image shift was noted. The source locations were at centre stage, 2 m from the foot and 3 m to the left and right of the central location, and 1 m further back. Source and receiver heights were 1.5 m and 1.2 m respectively.

One of the first questions posed by both the owners and users of The Orpheum was the efficacy of the plastic reflectors located above and slightly in front of the stage. There were two rows of 1.5 x 2.6m reflectors, 6 in one row above the foot of the stage and 5 in a second row above the front of the audience. It was this second row that was interfering with lighting positions.

Three sets of audience measurements were performed for different conditions of the hall prior to renovations in February 1994 - Plastic reflectors removed; Plastic reflectors in place, under balcony enhancement off; and Plastic reflectors in place, under balcony enhancement on.

The purpose of these last three sets of measurements was to: (i) determine the efficacy of the plastic reflectors located over the stage and (ii) determine the efficacy of the electro-acoustics sound system installed underneath the balcony during the 1970s renovation.

	Octave Band (Hz)					
Parameter	125	250	500	1000	2000	4000
RT_{60} (sec)	3.23	2.41	1.97	1.79	1.51	1.30
EDT (sec)	3.01	2.28	1.82	1.61	1.16	1.16
C_{80} (dB)	-3.4	-1.4	0.6	2.3	2.4	3.2
G (dB)	3.4	1.5	2.1	1.8	-0.6	-2.6
LF	0.14	0.19	0.18	0.17	0.19	0.22

TABLE 1. Orpheum Audience Measurements

	Octave Band (Hz)				
Parameter	250	500	1000	2000	4000
ST_{total}	20.1	21.7	23.7	25.6	25.2
EDT	1.82	1.67	1.81	1.33	1.15
ST_{late}	22.0	23.6	26.4	29.0	29.2

TABLE 2. Orpheum Stage Measurements

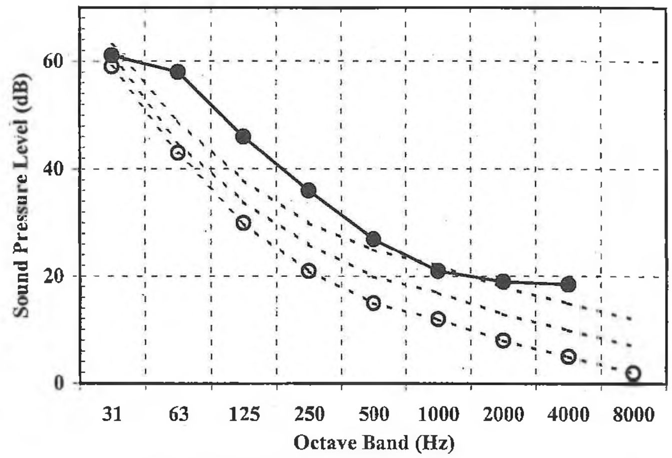

Figure 2. Balcony HVAC noise levels.

2.1.5 Dummy Head Measurements

Binaural impulse responses were obtained using a variation of the RAMSoft measurement system with a Bruel and Kjaer head and torso simulator. Measurements were repeated with and without the Plastic reflectors installed over the stage. These were used to calculate inter-aural cross correlation measures but these are not included here. The binaural impulse responses were also convolved with music for subjective evaluations of the focussed reflections observed at some balcony seat locations.

3.0 RESULTS

Average Results for the Base Case Consisting of Plastic Reflectors in Place and the Enhancement System Operating Audience Measurements are shown in Tables 1and 2.

3.1 HVAC Noise

Noise control work on The Orpheum's HVAC system was never completed during the 1970s renovation. When the money ran out, work was halted on the spot. Unfortunately, silencers and other noise control equipment were not installed. For the next twenty years, noise from the fans and pumps has remained a problem. Measured noise levels are shown in Figure 2. The dashed lines indicate the Balanced

Noise Criteria (NCB) used to assess the noise levels. Ideally a concert hall should have a NCB of 10 to 15. The measured levels on the balcony are well in excess of this and in the range of NCB 35.

3.2 Flutter Echo

Although not quantified directly in our measurements, there was an audible flutter echo in the audience chamber of The Orpheum. There was also a pronounced echo on the stage, which will be discussed in Section 3.5.

3.3 Comparisons with Other Concert Halls

Comparisons have been made between the (space) average measurement results from The Orpheum and a number of concerts halls listed in Table 3. Data associated with Table 3 is taken from the survey carried out by the Concert Hall Research Group (5).

Figures 3 to 7 compare the average measured values for audience seats in The Orpheum with the range of average values from the halls in listed in Table 3. In each figure the solid lines are the average measured values obtained in The Orpheum for the base case with the plastic stage reflectors in place. The error bars indicate the spatial standard deviation of the measured values. In Figures 3 to 7 the dashed line indicates the average measured result for the case with the plastic stage reflectors removed. The grey shaded area indicates the range of average values from the eleven halls listed in Table 3. Although we now know that the Reverberation Time is subjectively less important than the Early Decay Time (6), it does possess convenient relations to other physical properties of the hall. Figure 3 gives average measured Reverberation Times and illustrates that the spatial variation of the Reverberation Time is quite small. The average values of the Early Decay Time are found in Figure 4.

Location	Auditorium	Seats
Toronto	Massey Hall	2,500
Detroit	Orchestra Hall	2,022
Philadelphia	Academy of Music	2,984
Cleveland, Ohio	Severance Hall	1,890
Boston, Mass.	Symphony Hall	2,631
Buffalo	Kleinhans	2,839
Akron, Ohio	E.J. Thomas	2,969
Washington, DC	Kennedy Centre	2,759
Worcester, Mass.	Mechanics Hall	1,400
Baltimore	Meyerhoff Concert Hall	2,467
Troy	Music Hall	1,235

TABLE 3. Concert Halls.

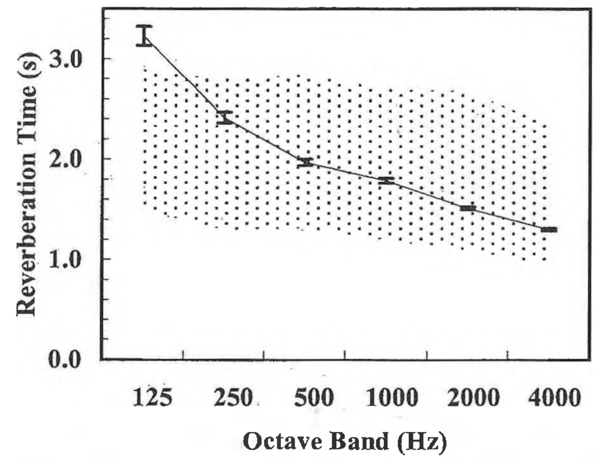

Figure 3. Comparison of Reverberation Time with North American concert halls, listed in Table 1.

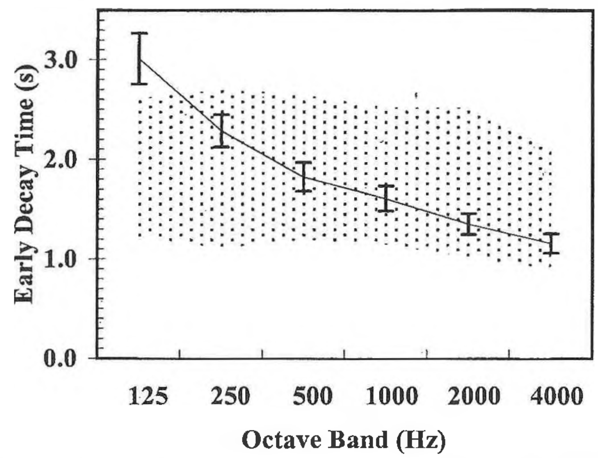

Figure 4. Comparison of Early Decay Time with North American concert halls.

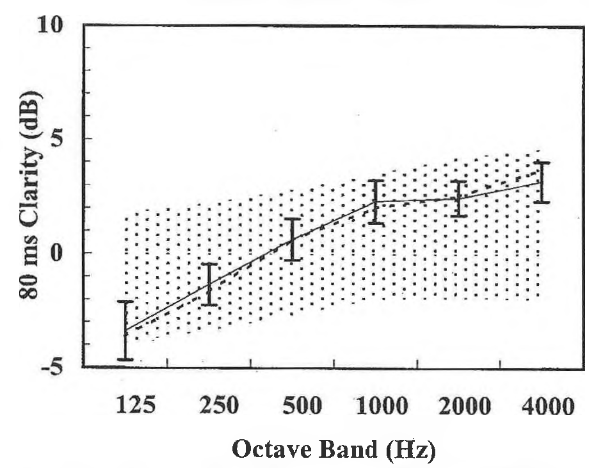

Figure 5. Comparison of musical Clarity with North American concert halls.

The preferred decay time for a concert hall is 2 seconds at middle frequencies and a little longer at lower frequencies. The Orpheum has a longer low frequency (125 Hz) decay time than any of the other eleven North American Halls. At high frequencies, the decay seems to be shorter than average.

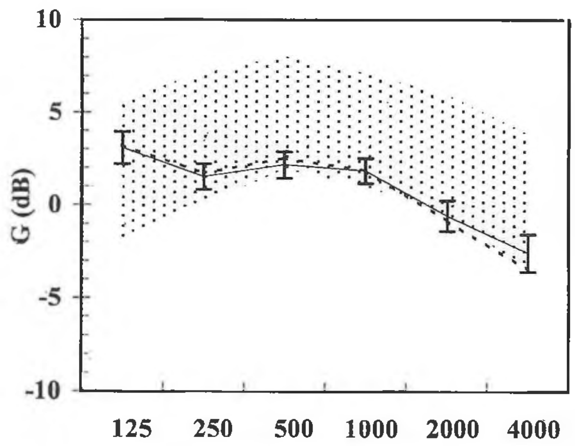

Figure 6. Comparison of Strength with North American concert halls, listed in Table 1.

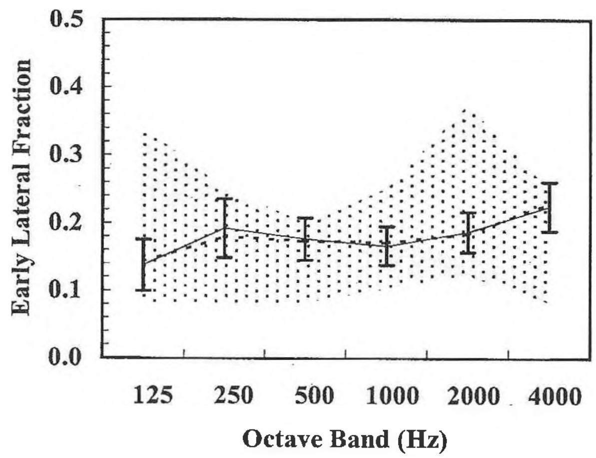

Figure 7. Comparison of Early Lateral Fraction with North American concert halls.

The mid-frequency (250 Hz to 2 kHz) average Reverberation Time is 1.92 seconds, the average Early Decay Time is 1.77 seconds. Although sound decays are often assumed to be exponential, it is quite common for the initial decay to be a little more rapid than the later decay as indicated by these mid-frequency reverberation and early decay times. In The Orpheum, as in other similar rooms, the Early Decay Time is significantly reduced underneath the long balcony overhang, while the Reverberation Time hardly changes at all.

Figure 5 compares the average measured Clarity (C80) with the average values from the other eleven halls. For mid and high-frequencies, Clarity in The Orpheum is greater than the average of the other halls. Since Clarity tends to be inversely related to Reverberance, this naturally follows from the shorter than average Early Decay Times shown in Figure 4. Strength values (G) indicate the effect of the hall on the level of sounds. The average Strength values in Figure 6 indicate that The Orpheum is close to the bottom of the range of values found in the other halls. Thus sounds will tend to appear to be weaker in The Orpheum. There are two reasons for this. First, The Orpheum, at 2800 seats is larger and Strength is inversely proportional to room volume. Second, the long balcony overhang leads to particularly low G values at seats under the balcony which, in turn, bring down the overall average G values.

In spite of this general trend, the average measured Strength in the lowest 125 Hz octave band is relatively stronger and above the average of the other halls. The Strength of low frequency sounds has been shown to relate to the perceived Strength of bass sounds in halls (7) and hence this result explains the reputation of The Orpheum to have a warm sound.

The Early Lateral Energy Fraction, ELF, is a measure of spatial impression and specifically relates to source broadening (8,9) and the ELF results are shown in Figure 7. One expects that in general Early Lateral Energy Fractions will be lower in wide halls. Compared to other concert halls, The Orpheum is very wide. Vienna's Musikvereinssaal, for example is 20 m wide, compared to 35 m in The Orpheum. In spite of its width the average measured ELF is about average, slightly less than 0.2 .

3.4 Stage Comparisons

Musicians' ability to hear themselves on stage is quantified by the acoustical parameter called Support (ST_{total})(3), shown in Figure 8. In this bar chart the optimum range is approximately -16 dB ±2 dB. At levels greater than this, the musician may not be able to hear his associates. At levels below this range, he may not be able to hear himself. With both rows of reflectors installed above the stage, Support on The Orpheum stage falls within the optimum range and is similar to values measured at Kitchener's Centre in the

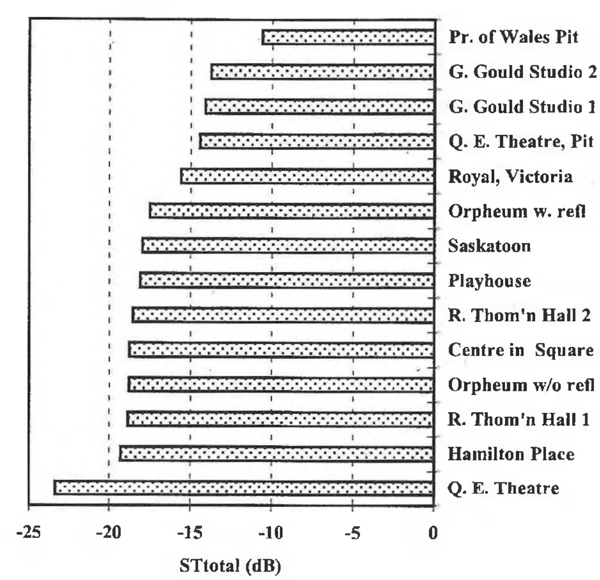

Figure 8. Comparison of Orpheum's Support (Hearing of Self) with other halls.

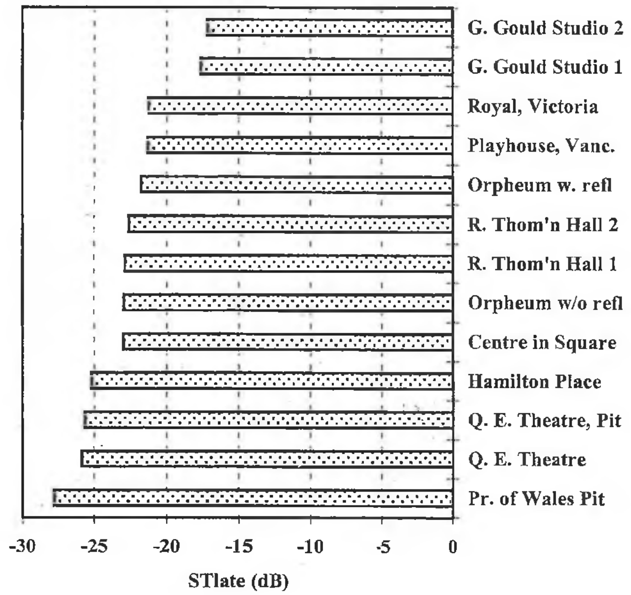

Figure 9. Comparison of Orpheum's Late Reverberant Energy with other halls.

Square and Roy Thomson Hall in Toronto. Reverberance heard by musicians on stage is quantified by ST_{late} (3). In the Orpheum it is about average and does not change when the plastic stage reflectors are removed. Please see Figure 9.

3.5 The Effect of the Plastic Reflectors

3.5.1 Audience Effects

The solid lines in Figures 3 to 7 are averaged measured values for the case with the over-stage plastic reflectors in place while the dashed lines represent levels measured when the reflectors were removed. Thus one can determine the average effects of the plastic reflectors at audience seats by comparing the dashed line and the solid line on each of Figures 3 to 7. These comparisons show that there is little or no difference in the audience chamber when the reflectors are removed. In some cases at low frequencies, there is very little difference and in these figures the dashed line is hard to see. At higher frequencies there is a slight difference but it is much less than the standard deviation indicated by the vertical bars. In other words, the effect of the reflectors is less than would be experienced by moving to a different seat. These differences are all less than the difference limen for in each of these quantities. Difference limen for Reverberance is usually taken as 0.1s (10). For Clarity, difference limen have been established at 0.67 dB (11). Although difference limen for Strength have not been determined, it is normally assumed that for most sound level measures that differences as small as 1 dB can be detected.

The effect of the plastic reflectors was also assessed subjectively. Measured binaural impulse responses were convolved with anechoic music and played back to listeners. The result was a series of fifteen second samples of Handel's Water Music and the Marriage of Figaro overture with and without the reflectors in place. The listening rig was developed by Soulodre and Stammen (12). It consists of two small loudspeakers enclosed in open ended boxes When the subject places his head between the speakers, the combination of the boxes and his head effectively eliminates the need for an anechoic space and cross-channel compensation. Back to back blind listening tests were performed informally by a four groups of listeners including the authors, the architects and members of Vancouver Opera and the Vancouver Symphony, respectively. It was very difficult to tell the difference between the two conditions and no one could express a conclusive preference for one or the other.

The conclusion drawn from this exercise is that the reflectors do not have a significant affect on listening conditions in the audience chamber.

3.5.2 Stage Effects

A three dimensional computer model study suggested that the reflectors were effective at producing on-stage reflections. In particular there were a number of reflections directed towards the front part of the stage. Figure 8 and Figure 9, above, include stage measurements with and without the reflectors in place. The reflectors appear to have a minimal affect on Support (Hearing of Self). There is a noticeable change in reverberant energy (ST_{late}) when the reflectors are removed. The change is for the worse.

The more significant stage effects however are associated with Ensemble reflections (Hearing of Other). This was probably the main reason why the over-stage reflectors were installed in the first place, although there is no way of knowing for sure. Modulation Transfer Functions (a reliable measure of Hearing of Other (4)) were significantly reduced between the Violin and Bass sections when the reflectors were removed.

In 1978, Marshall et al. (13) found that musicians are more sensitive to reflected sound arriving from above than in the horizontal plane. This suggests that, in terms of Ensemble, stage ceilings and overhead reflectors are more important than wall surfaces. The tests with the musicians also suggested that reflections that arrive between 17 and 35 ms after the direct sound are more useful than others. Using this optimum temporal window, the following parameter was devised and investigated. It is a simple ratio of the sound arriving between 17 and 35 ms to the sound that arrives between 0 and 10 ms. The latter is, for all intents and purposes, the direct sound (15).

The ensemble sound is evaluated from Equation 1. The results, calculated fron Equation 1 and presented in Figure 10 to Figure 12, show that the reflectors in The Orpheum and Centre in the Square significantly affect Ensemble

Reflections but that at Roy Thomson Hall, the change is hardly noticeable.

$$\text{Ensemble Reflections} = 10\log\frac{\int_{17}^{35\,ms} p^2(t)dt}{\int_{0}^{10} p^2(t)dt} \qquad (1)$$

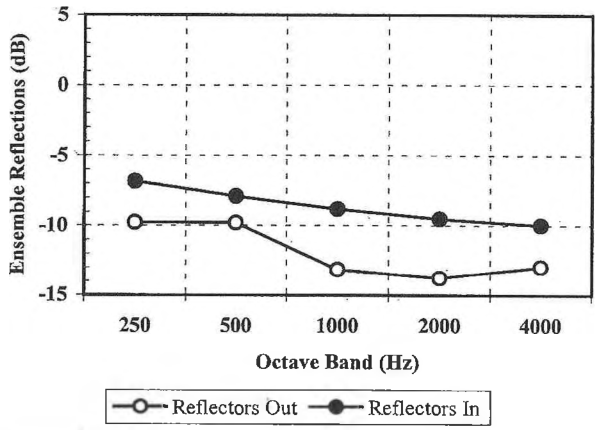

Figure 10. Direct and reflected sound in Orpheum.

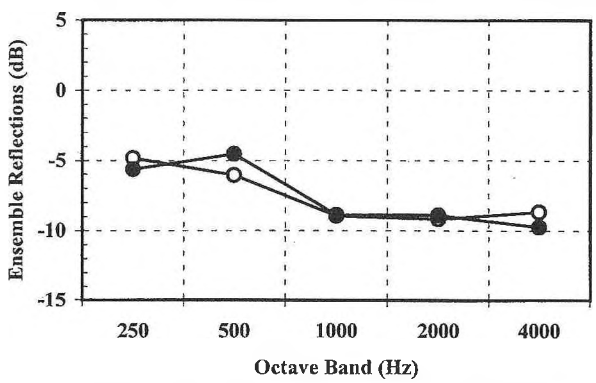

Figure 11. Direct and reflected sound in Roy Thompson Hall, Toronto.

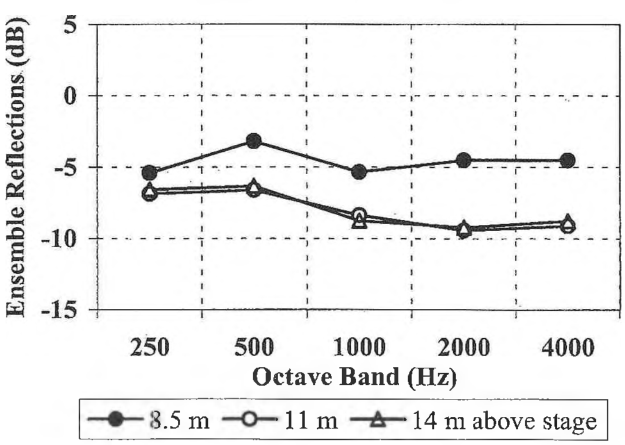

Figure 12. Direct and reflected sound in Center in the Square, Kitchener, Ontario.

An interesting comparison may be made between The Orpheum and The Centre in the Square in Kitchener, Ontario. The overhead reflectors for these two stages are profoundly different. As indicated above, only five of the small reflectors at The Orpheum actually cast reflections on the stage. Conversely, the reflector at the Centre in the Square covers almost the entire orchestra platform and weighs over 30 tons. Figure 10 and Figure 12 however suggest that the important 17 to 35 ms ensemble reflections are equally affected. It was concluded therefore that the upstage row of reflectors (the ones furthest from the audience) do in fact have significant acoustical merit and should not be removed without some form of compensation.

3.5.3 On-Stage Echo

The users of The Orpheum have identified a problem with an echo on the stage. The echo can be heard between upstage right and upstage left and appears to be coming off the back wall of the house. This is a fairly significant problem and its solution is not simple. In the test configuration, the dodecahedron loudspeaker was placed upstage right and the measurement microphone symmetrically upstage left. Figure 13 shows significant reflected energy at approximately 245 ms after the direct sound. This corresponds approximately to the time delay that one would expect for reflections off the back wall of the balcony.

A study of the frequency content of the direct and reflected components reveals further interesting information. The reflected sound is lower in amplitude at both high and low frequencies. Attenuation of the higher frequencies is to be expected. By the time the sound has returned to the stage, it has travelled some 250 ft through the air and, through absorption by the air, it losses some of its higher frequency content.

The low frequencies show evidence of "seat dip" attenuation. Evidence of seat dip in the 245 ms reflection is useful because it suggests the sound has travelled across the seating.

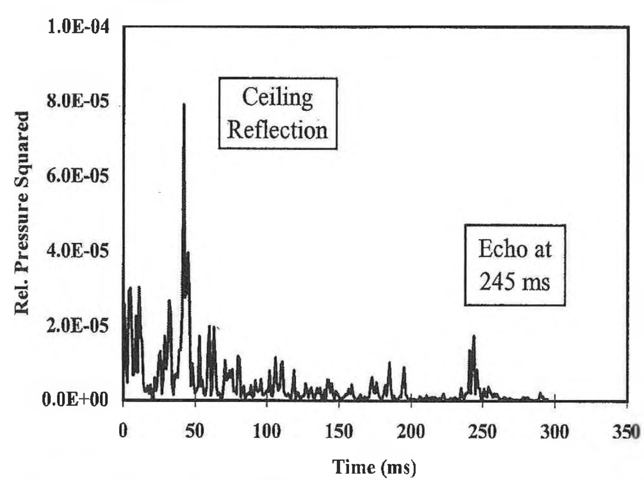

Figure 13 Measurements on The Orpheum stage sound. (strong reflections at 45 ms and 245 ms)

From this we can conclude that the path of the reflected sound is off one of the back walls and not, for example, directly off the dome located in the centre of the audience ceiling.

3.6 The Propagation of Sound in the Audience Chamber

The propagation of sound within The Orpheum was examined using linear regression plots of decays times and sound levels versus source-to-receiver distance. Figures 14 and 15 show that both reverberance and loudness decrease significantly as one moves from the front to the back of the audience chamber. One might hope that these parameters would not vary greatly with distance, but in reality this rarely happens. Research in the 1980s has shown that fan shaped rooms or rooms with too much diffusion demonstrate subjectively significant reductions in Early Decay Times and Strength (G) towards the back of the room (16). Here subjective significance can be judged in terms of two simple facts. Ideal concert halls have reverberation times in the range of 2.0 seconds, but for opera houses preferred reverberation times would be in the range of 1.2 seconds.

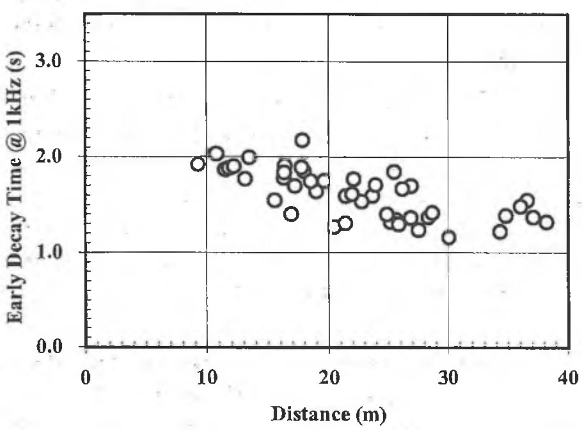

Figure 14. Variation of Early Decay Time inside the audience chamber.

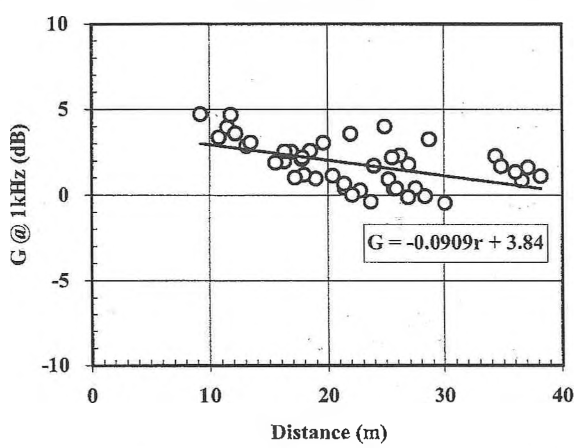

Figure 15. Variation of Strength inside the audience chamber.

Doubling the enclosed volume of the hall decrease levels by 3 dB.

Thus, Figure 14 suggests that the reverberance at 10 m from the stage is similar to what one would prefer in a concert hall but at the back of the room, the reverberance is closer to that experienced in a typical opera house. Likewise, in terms of loudness, Figure 15 shows that seats at the back will experience the sound of an orchestra sound that is "half as big" as the one heard near the front of the room (i.e. the level has decreased by 3 dB). The two preceding figures have grouped all the data for all measurement locations together. It was also desired to determine the effect of the exceptionally long balcony overhang. In the following plots the measurements obtained at seats located under the balcony are separately identified from those in the balcony.

In Figure 16 the Early Decay Times decrease quite significantly on both the orchestra and balcony levels. Decreased reverberance is to be expected on the orchestra level with its long balcony overhang but the decrease on the balcony level is surprising. It is probably due to the proximity of ceiling. Considering the Early Decay Times in isolation, one would expect that listening conditions at the back of the balcony would be less desirable. However, popular opinion suggests that these are some of the best seats in the house. The fact that the Early Decay Time is shorter than optimum only reinforces the argument that concert hall acoustics is a multi-dimensional experience. Other aspects of the sound near the top of the balcony must compensate for the short Early Decay Time. The two most likely candidates being Loudness and Intimacy.

In Figure 17 we see that, as expected, the loudness, as measured by G, decreases most rapidly on the orchestra level where many seats are under the balcony overhang. On the balcony, the linear regression formula shows a rate of attenuation of 0.064 dB/m. This compares favourably with other concert halls and is about the same as the Musikvereinssaal in Vienna (0.06 dB/m) (18).

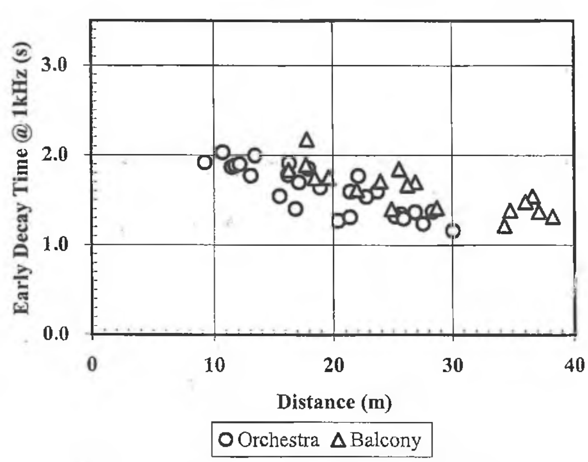

Figure 16. Variation of Early Decay Time in balcony and orchestra levels.

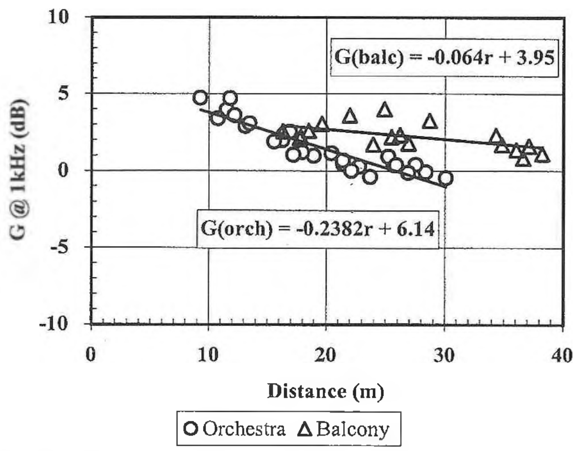

Figure 17. Variation of Strength in balcony and orchestra levels.

The early and late components of the sound were also examined. Physically, early and late components are influenced by different factors and subjectively they lead to different perceived effects. G_{80} refers to the Strength of the sound received in the first 80 ms which includes the direct sound and the important early reflections. G_{late} is the Strength of the reflected energy arriving more than 80 ms after the direct sound. Figure 18 demonstrates that early reflected energy underneath the balcony is really not much different from the levels measured on top of the balcony. Figure 19 on the other hand, shows a clear difference in late energy measured above and below the balcony.

From this we conclude that it is only the late reverberant energy that is lacking under the balcony. This is a rather interesting finding and one that has recently been confirmed in a study of British concert halls (16). It means that the enhancement system used to improve the sound under balcony seats should be designed to increase the late energy and need not enhance the sometimes difficult aspects of early reflected sound.

There is another design advantage that could be developed from this situation. Recent work by Bradley and Soulodre (10) has shown that late energy is an important aspect of spatial impression. Until their work, it was thought that good spatial impression in a room was generated by strong *early* reflections that arrive at the listeners from the side. It turns out that there are two distinct aspects of spatial impression, *apparent source width* and *listener envelopment.* Early lateral reflections generate a sensation of apparent source width (where the sound of a piano fills the stage) and late lateral energy generates a sensation of listener envelopment (where the piano fills the whole room). Bradley and Soulodre found a strong correlation between listener envelopment and the Strength of the late lateral energy (LG_{late}).

The Early Lateral Fraction, incidentally is good above and below the balcony, suggesting a good apparent source width. To summarise, the seats underneath the balcony could be improved by adding late energy and preferably late *lateral* energy. These seats already have sufficient early lateral energy.

In the 1970s, an attempt was made to introduce room reverberance underneath the balcony. Microphones were hung from the ceiling near the stage. It is not clear why they chose that position. It is possible that they were simply trying to maximise the musical signal at the microphones to minimise possible feedback problems. It is also possible that they were trying to maintain a short time delay between the direct sound and the first reflection - the so-called Initial Time Delay Gap. In hindsight and with the advantage of recent research,(12) we know that this Initial Time Delay Gap is not important in this situation. For seats under The Orpheum balcony, it now seems preferable to reduce the amount of early energy that we pick up in our microphones.

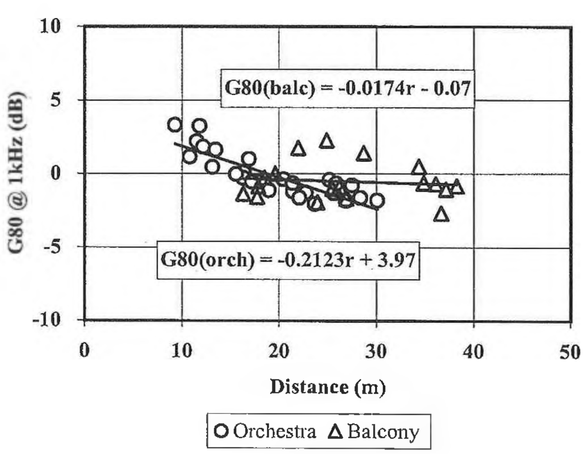

Figure 18. Variation of Early Reflected Sound in balcony and orchestra levels.

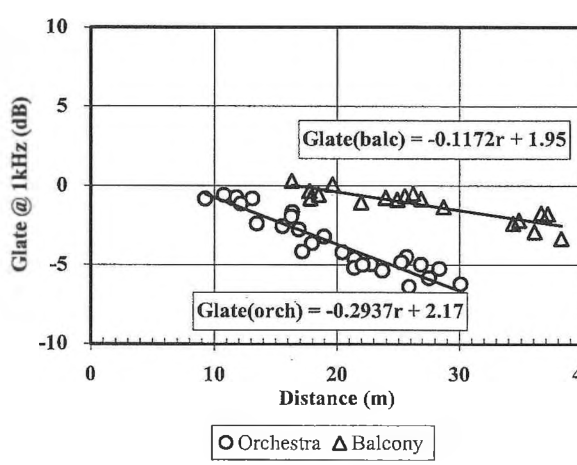

Figure 19. Variation of Later Energy Level in balcony and orchestra levels.

One solution was to move the microphone locations further back into the audience. If, in addition, a directional microphone is employed, with its sensitive lobes pointed at the side walls, it would be possible to further de-emphasise some of the frontal sound and increase the emphasis on the lateral energy. With careful selection of time delays and speaker combinations, one could easily provide listeners underneath the balcony with the late lateral energy required to promote listener envelopment.

4.0 Conclusions

A complete set of modern acoustical measurements were performed prior to a major renovation of Vancouver's Orpheum Theatre. The measured values indicated that while average mid-frequency reverberation times were close to ideal, Early Decay Times were a little bit shorter. Hence, perceived reverberance was a little less than optimum. Similarly, measured Clarity was a little greater than average. The average measured Strength was lower than many other halls and indicated that orchestral sounds would have tended to be weaker in The Orpheum. On the other hand, average measured Early Lateral Energy Fractions were comparable to those in many other halls indicating that some aspects of spatial impression were quite satisfactory.

With the plastic over-stage reflectors in place on-stage support was quite acceptable. An evaluation of the effectiveness of the over-stage plastic reflectors indicated that they had little effect at audience seat locations but they provided important benefits on stage.

Both Early Decay Times and sound levels decreased with increasing distance from the source. Early Decay Times were markedly lower at the rear of the hall suggesting that these seats would have experienced less reverberance. This decrease with distance also contributed to the average Early Decay Times being lower than the Average Reverberation Times. These decreases with distance were most noticeable at seats under the balcony. It was clearly shown that what is most lacking at under-balcony seats was later arriving sound energy. This indicates that the under-balcony enhancement system should mostly increase later arriving sound energy which would lead to an improved sense of envelopment at seats under the balcony.

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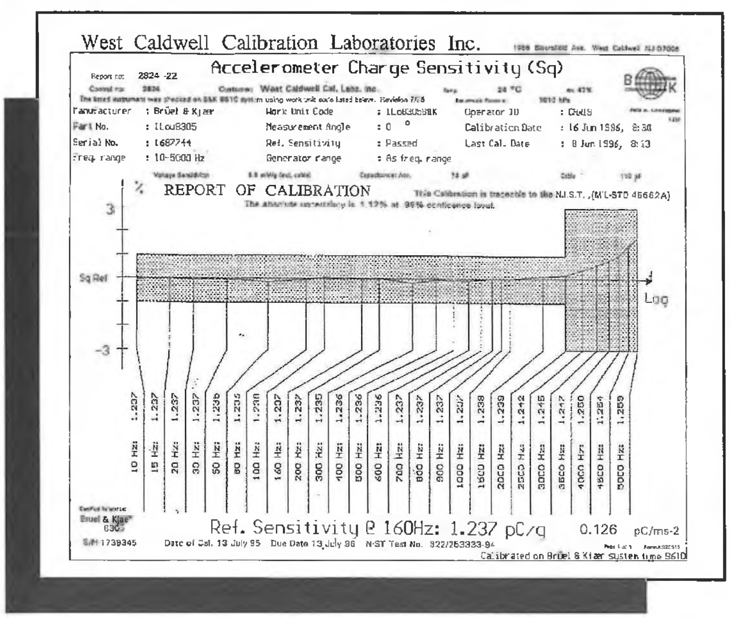

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