Acoustics 2008
Geelong, Victoria, Australia 24 to 26 November 2008

Acoustics and Sustainability:

How should acoustics adapt to meet future demands?

Directional assessment of acoustic stage support in a drama theatre

Robin McCarthy, Densil Cabrera and John Bassett

Faculty of Architecture, Design and Planning, University of Sydney, NSW 2006, Australia

ABSTRACT

The acoustic environment of an auditorium stage can enhance the ability of musicians or actors to hear each other clearly, and this is assessed through a set of parameters called 'stage support'. Stage support parameters are conventionally measured using an omnidirectional source and microphone separated by 1 m (with an elevation of 1.2 -1.5 m) on the stage. Various stage support parameters are derived from energy ratios of the direct and reflected (or reverberant) sound in the impulse response from source to microphone. The present paper examines the possibility of assessing the directional characteristics of the reflected soundfield by using a multi-directional microphone. Measurements were made in the Sydney Theatre Company's 'Sydney Theatre' with and without a stage set. The microphone used allows first order spherical harmonic decomposition of the soundfield, which was transformed to cardioid components for orthogonal directions (upstage, downstage, left, right, up and down). Results demonstrate the potential of this simple extension of standard stage support measurement by showing the acoustical effect of the set.

INTRODUCTION

Acoustical research in performance auditoria has been focused mostly on the perspective of the audience, due to the importance of improving the experience of ticket paying customers seated in the auditorium. Comparatively little research has been directed in the subcategory area of acoustics known as, stage support. This is an important area of research as it investigates conditions for performers onstage and their ability to respond to feedback in the form of acoustics. Stage acoustics research has almost exclusively focused on stage support for orchestral and small ensemble musical performance in concert and recital halls.

From a performer's perspective, stage acoustics involves five basic issues: (i) the ability to hear one's own sound clearly; (ii) the ability to hear other performers and so to form an ensemble; (iii) the sense of the room's acoustical quality; (iv) the ability to project to an audience; and (v) the sense of sound from the audience (in good circumstances, audience feedback can energise a performance). Early reflections are important for creating a sense of 'stage support' so that a performer does not feel that their sound is simply disappearing into the auditorium. Yet reflections can create a disturbing sound (eg echoes or 'coloration') that detracts from the ability to perform. To perform as an ensemble, the sound of other performers must be both adequately loud and clear – loudness without clarity results in an inability to synchronise. The temporal, spatial and spectral distribution of the reflected soundfield together contributes to a performer's sense of room acoustical quality, which can enhance their sense of their sound. The projection of sound into the audience area, and the feedback from audience is controlled to a large extent by the geometry and acoustical properties of major surfaces around the stage.

In architectural acoustics, stage acoustics are assessed primarily through the 'stage support' parameters, proposed by Gade (1989a). These measure the energy ratios of direct sound to early reflections (ST1), and direct sound to early and late reflections combined (ST2) for an impulse response from an omnidirectional sound source (elevated 1.2 – 1.5 m) to a microphone position having a horizontal separation of 1 m. ST1 (also known as ST_{Early}) indicates the degree of support that performers receive of their own and each other's sound, and ST2 also includes some of the later reflections and early reverberance of the auditorium as heard from the stage. There are several other similar parameters with different integration periods that may also be of use in assessing stage acoustics, including ST_{Late}, which assesses the perceived reverberance of the auditorium on the stage (ISO3382:2000). Integration times for these stage parameters are given in Table 1

Table 1. Integration time limits for determining three stage support parameters

	x	*y*
ST1	0.02 s	0.1 s
ST2	0.02 s	0.2 s
ST_{Late}	0.1 s	1 s

The calculation of these parameters is simply the ratio of impulse response energy in the time periods of Table 1 to the energy of the direct sound (0-10 ms) in the impulse response, expressed in decibels.

$$ST = 10\log\left(\frac{\int_{x}^{y} p^2}{\int_{0s}^{0.01s} p^2}\right) \quad (1)$$

Values are measured in octave bands, and a single number rating of each stage support parameter is achieved through an arithmetic average of ST values in the 250 Hz – 2 kHz octave bands.

Parameters such as ST1 have been the subject of several existing auditorium surveys. For ST1, the surveys of Gade (1989b) and Beranek (2004) of concert halls find a median value of -14.6 dB, within a range of 8 dB. Chamber music halls tend to have ST1 about 5 dB greater (Hidaka and Nishihara 2004). Specific data for opera theatres have not been published in detail because the set is assumed to influence the measurement – supported by studies by Gade (1989a) and Jeon and Barron (2005) showing that stage support can be varied in a given auditorium by changing the position of reflective surfaces above and around the stage. However, a median ST1 value of -16.2 dB (from a range of -21.4 dB to -11.9 dB) was found in an unpublished survey by Beranek and Hidaka (personal communication), indicating that stage support ST1 tends to be less than that of concert and chamber music halls. Measurements by Ternström et al. (2005) find an ST1 value of -16.2 dB under the proscenium arch of the Sydney Opera House Opera Theatre when measured with a sparse set. These comparatively low values for opera theatre stages may be juxtaposed with Bistafa and Granado's (2005) finding that the desirable stage support for unassisted speech is significantly greater than for orchestral music. This supports the idea that substantial practical benefit could be achieved by designing stage sets with supportive acoustic properties, which is one of the issues considered in this paper in the context of a drama theatre.

Current methods for measuring stage support (Gade 1989a, ISO3382:2000) have the advantage of being very simple, and an accompanying disadvantage of lacking refinement, and so being susceptible to misrepresenting the degree of acoustic support experienced by a performer. For example, the spatial distribution of the stage soundfield is not assessed at all, meaning that a single reflection from one direction achieves the same rating as a fully diffuse reflection pattern if the ratio of direct to reflected sound energy is the same. However, research into spatial unmasking has shown that the spatial distribution of a soundfield has a large effect on its subjective clarity (e.g., Best et al. 2005), and research into the perceptual spatial aspects of auditorium soundfields shows that envelopment (which is a desirable characteristic) is also strongly affected by spatial distribution (Beranek 2004, Farina 2000). Similarly, the temporal distribution of the reflected soundfield within the integration window is unassessed. This means that a single echo within the integration period can receive the same stage support rating as temporally diffuse reverberation, although the perceptual effect (and evaluation) will be entirely different (Beranek 2004). Finally, the spectral quality (or timbre) of the reflected soundfield is not assessed, meaning (for example) that ringing effects at specific frequencies due to close parallel surfaces do not degrade the objective rating (when the auditory quality is substantially degraded), or that a reverberant decay with a heavy bass emphasis or treble emphasis has no effect on the rating. This paper considers just one of these issues: the spatial distribution of reflected energy.

The Sydney Theatre

This paper investigates the environment of stage support measurements in the field of drama based productions. The performers in this environment are not a collection of musicians, rather a company of actors performing on a stage set.

The location of the measurements was the recently opened Sydney Theatre in Walsh bay. The following is a quote taken from the Sydney Theatre Company (STC) website that best summarises the purpose this building;

> The Sydney Theatre is situated opposite Pier 6/7 on Hickson Road and is considered a state of the art 850 seat theatre, designed as a specialist drama and dance venue and provides the missing link between the Drama Theatre (seating 544) and Sydney's larger venues such as the Opera house and Capitol Theatres.
>
> Sydney Theatre offers STC the opportunity to expand the range of work we both produce and present. Not only can our own productions be more ambitious and reach grander scales artistically and aesthetically.

In late 2006 the STC staged a production of Molliere's play *A Bourgeois Gentleman.* What makes this production of particulat note is that it followed a series of productions staged by the STC in the recently built theatre, that have come under constant criticism for poor acoustic performances. The production of *A Bourgeois Gentleman* placed extra emphasis on improving the acoustic qualities of the set design, which included pushing the acting area forward and greater use of reflective surfaces and set elements in supporting the actors' vocal projection.

Figure 1. Sydney Theatre stage with *A Bourgeois Gentleman*

Figure 1, is a photo of the set design for *A Bourgeois Gentleman* from the perspective of the audience in the Sydney Theatre and Figure 2, is a photo of the same stage without a set, during a venue maintenance period.

This particular production presented itself as the perfect opportunity in measuring stage support and was followed by a period of time where the theatre was empty for annual maintenance and comparative measurements of the same positions could be made.

Figure 2. Sydney Theatre stage empty for maintenance

MEASUREMENT AND ANALYSIS PROCEDURE

Measurements

Measurements were made using a Bruel & Kjaer omnidirectional loudspeaker ('Omnisource' type 4295), which involves an inverted horn that concentrates the power of a loudspeaker driver into a small radiating area. This type of loudspeaker should yield more consistent measurements than a dodecahedral loudspeaker in stage support measurements because it a much simpler and smaller sound source. A Soundfield microphone SPS422B was used at a distance of 1 m from the acoustic centre of the source. The Soundfield microphone is a near-coincident multidirectional microphone, yielding four output channels in 'B-format', i.e., figure-of-eight (pressure gradient) responses in three orthogonal directions (front-back, left-right and up-down, or X, Y, and Z) and an omnidirectional signal (W). The measurement height was 1.5 m (i.e., standing height, because this is the predominant use of the theatre). Impulse responses were derived from a logarithmic swept-sinusoid measurement signal.

Figure 3. Left is the B& K measurement mic, Centre is the Soundfield mic and Right is the Tulip, ominsource speaker.

On the stage floor of the Sydney Theatre, four loudspeaker locations were marked in a line at 2 m intervals across the front of the stage nearer the audience. Around each of these four positions, four microphone positions were selected at 90 degree intervals, 1 m from the relevant loudspeaker position. These microphone positions were upstage, downstage, left of stage and right of stage with respect to the loudspeaker. The measurement scheme is shown in figure 4 and figures 7, 8. The four loudspeaker positions are referred to as A, B, C and D in this paper, the position A is located to the Left of Figures 7 and 8.

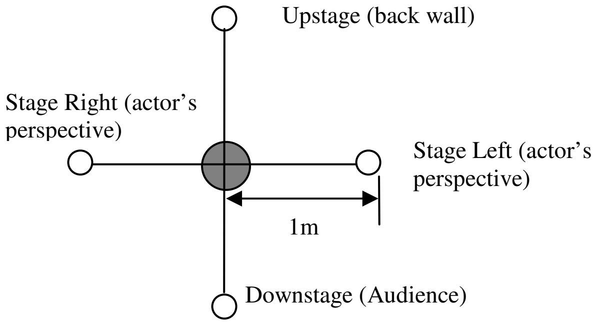

Figure 4. A ground plan view of the Tulip speaker position (centre circle, grey) and the surrounding Mic positions.

These measurements were made with and without a set, so that the acoustic effect of the set could be assessed.

Processing of impulse responses

Conventional stage support parameters could be derived from the W channel alone of the B-format microphone. The B-format impulse responses were also converted into six orthogonal cardioid impulse responses. This is done by averaging with and without phase reversal each of X, Y and Z with the W channel. In other words, the channels are combined as: (X+W)/2, (X-W)/2, (Y+W)/2, (Y-W)/2, (Z+W)/2 and (Z-W)/2. These corresponded to a cardioid microphone facing upstage, downstage, stage left, stage right, up and down. However, for spatial stage support measurements, the direct sound (0-10 ms of the impulse response) should be from the W channel, so the channel summations were only performed for the period after 15 ms (note that the 10-20 ms period is not assessed in stage support measurements because it is dominated by the first order floor reflection). That is, in making directional stage support measurements, we take the view that the numerator of equation 1 should be directional, but the denominator remains omnidirectional – otherwise the denominator will vary greatly with the directivity of the microphone, with results that may be difficult to interpret.

It might be observed that the six orthogonal cardioid directivities derived from an ideal B-format microphone do not sample directions with equal weight. There is a deviation of 1 dB between maximum and minimum summed power sensitivity of the six channels over the full range of azimuth and elevation angles. In practice this should have a minimal effect on the measurements if the sound reflections come from many angles.

In summary, there were four loudspeaker positions, each with four microphone positions, seven microphone directivity patterns (including W), and two set conditions, yielding 224 impulse responses leading to measurements of stage support parameters, or 112 measurements in each of the two set conditions.

RESULTS

Values for stage support measurements for the four stage positions are shown in Figures 5 (without set) and 6 (with set). These are summarised in Figure 9, which shows the effect of the set (i.e., the difference between stage support parameters due to the presence of the set).

Since directional measurements have their sensitivity weighted to a portion of the space, rather than the whole space, the ST values tend to be lower for directional measurement than omnidirectional measurements. A cardioid microphone pattern has a diffuse field energy sensitivity of 1/3 (compared to 1 for an omnidirectional microphone), which would result in a -4.77 dB difference in cardioid (re omnidirectional) values if stage support was uniformly distributed. As stage support is not evenly distributed, the difference between cardioid and omnidirectional values is not predictable (although the average difference should be -4.77 dB). Therefore 4.77 dB was added to the directional stage support values of Figures 5 and 7 to make values comparable to omnidirectional data. The power average of the six directional values (boosted by 4.77 dB) should be similar to the omnidirectional value, and the maximum deviation from this in the data on Figures 5 and 7 is 0.69 dB (median deviation 0.48 dB). Although for the most part these are quite small deviations, they are positive in every case (meaning that the averaged spatial ST values are slightly greater than the respective omnidirectional value), suggesting a small but systematic error – which, for instance, could be due to an imperfect realisation of cardioid directivity due to physical constraints in the microphone.

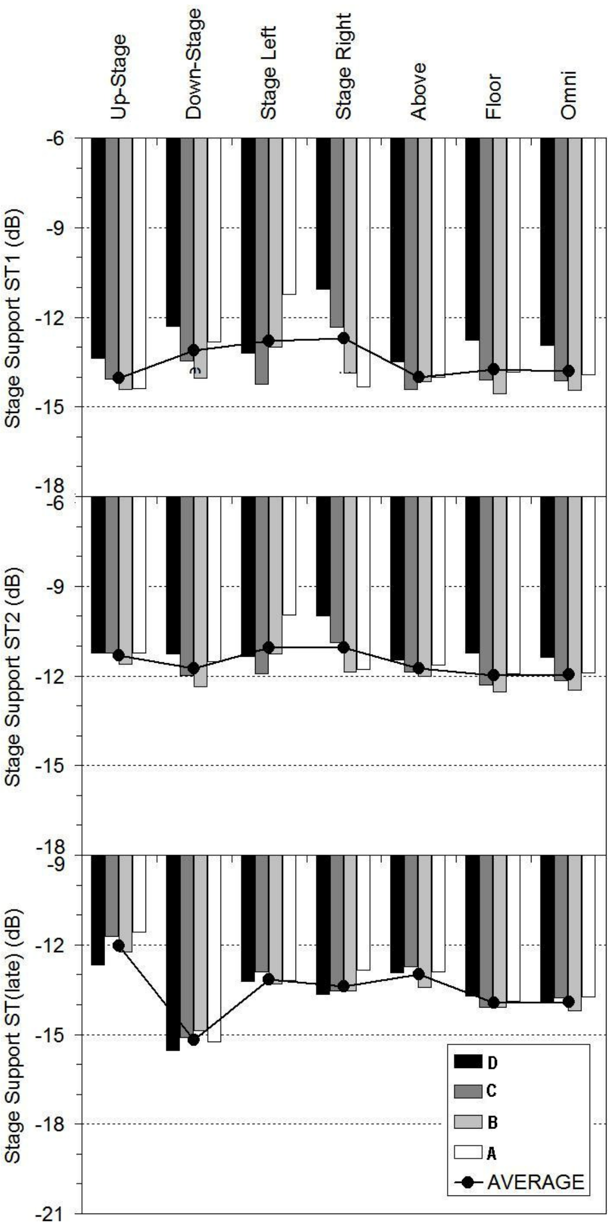

Figure 5. Stage support measurements in each of the six directions (boosted by 4.77 dB), and for omnidirectional sensitivity, for the four stage conditions – with no stage set. Each value is a power average (arithmetic) of the stage support parameter result for the four microphone positions around the loudspeaker.

The effect of the stage set is to increase ST1 values for directions other than down-stage (which is not affected by the set as it is the audience area). ST2 values also tend to increase, although to a smaller extent than ST1 values. On the other hand, the ST_{Late} values are reduced by the set, which is due to the set closing off the large (reverberant) volume of the stage house. Hence we can think of the set as increasing the strength of early reflections, and reducing the strength of reverberation.

The floor directional component does not include the first-order reflection from the floor (which lies in the 10-20 ms period that is excluded from the derivation of ST values.

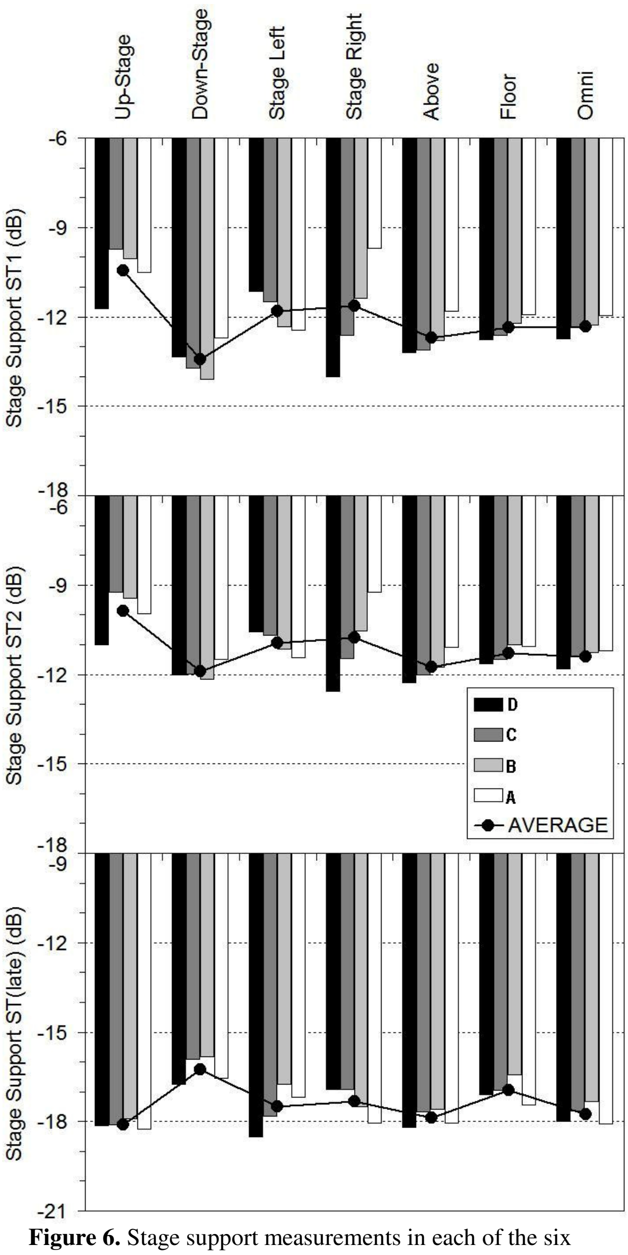

Figure 6. Stage support measurements in each of the six directions (boosted by 4.77 dB), and for omnidirectional sensitivity, for the four stage conditions – with the stage set of *A Bourgeois Gentleman*. Each value is a power average of the stage support parameter result for the four microphone positions around the loudspeaker.

Hence the values for the floor are quite similar to the corresponding upward-facing directional ST values because the floor is essentially acting as a mirror of the sound from above.

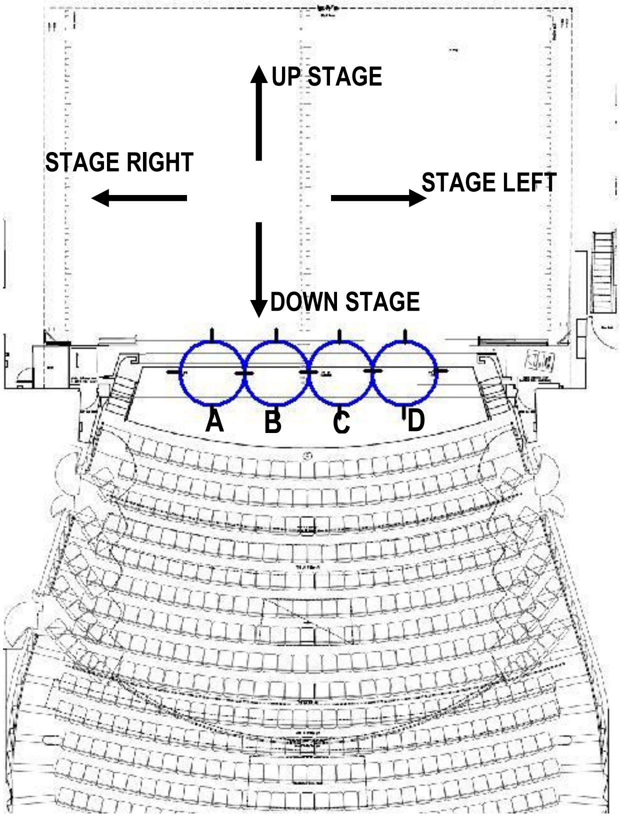

Figure 7. Sydney Theatre Stage without Set and the measurement marks.

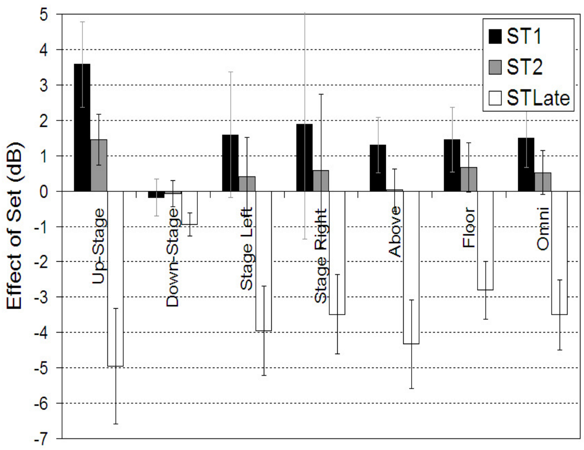

Figure 9. The effect of the set on stage support parameters for the six directions and omnidirectional sensitivity. Error bars are standard deviations of the effect for the four stage positions.

DISCUSSION

This set of measurements produced broadly expected results: namely, that a stage set does add to acoustic stage support, and the direction of acoustic support, including the added effect of the set, can be quantified using a simple directional microphone.

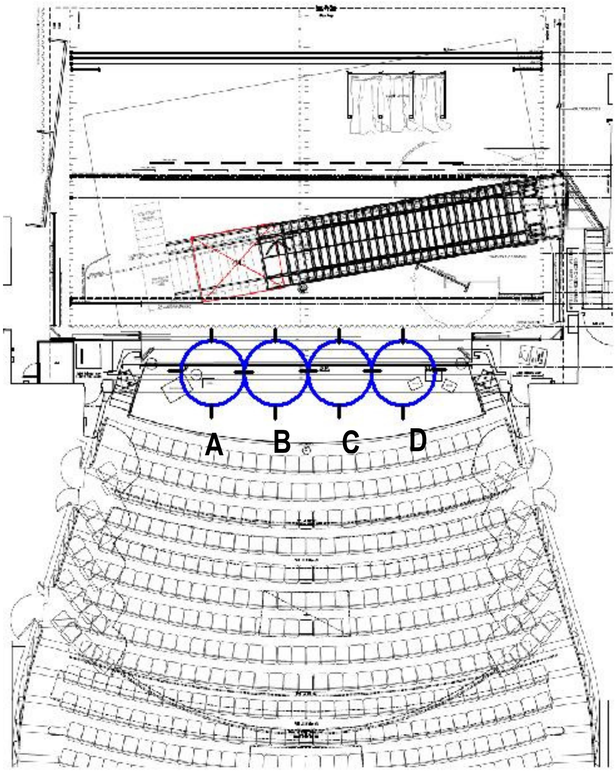

Figure 8. Sydney Theatre stage with *A Bourgeois Gentleman* set design and measurement marks.

The measurements in this paper are about stage support, not speech communication between stage and audience, which perhaps is a more important requirement of a drama theatre. Hence the paper is largely concerned with the question of the extent to which actors can hear each other, where presumably better on-stage communication can lead to a more dynamic and interactive performance. The separate issue of whether a set will improve communication between stage and audience was not investigated, although we did make one indicative measurement from the stage to an audience seat 10 m from the source. In that case, the presence of the set produced a 5.5 dB increase in clarity index C_{50} averaged over the 500 Hz – 4 kHz octave bands. It is likely that set reflections that contribute to ST1 will also contribute to C_{50} in the audience area (so long as the reflections are directed towards the audience).

Although it is clear that an acoustically supportive stage set can enhance the conditions of a performance, set designers are unlikely to design with acoustics in the forefront of their minds. A realistic appreciation of the potential of acoustic problems to damage a performance, and the potential benefits of good design, is an important motivator if set designers are to consider acoustics. This appreciation might come from a combination of acoustical evidence linked to experience by theatre professionals.

CONCLUSIONS

This paper has shown that a stage set can improve stage support values measured on a drama theatre stage, and that a spatial analysis of acoustic stage support using simple equipment and procedures produces useful results.

REFERENCES

Beranek, L.L. 2004, Concert Halls and Opera Houses: Music, Acoustics and Architecture, Springer, New York.

Beranek, L.L. 2003, "Subjective rank-orderings and acoustical measurements for fifty-eight concert halls," Acta Acustica united with Acustica 89(3), 494-508.

Best (et al), V., Ozmeral, E., Gallun, F. J., Sen, K. and Shinn-Cunningham, B. G. 2005, "Spatial unmasking of birdsong in human listeners: Energetic and informational factors." J. Acoust. Soc. of Am. 118, 3766-3773.

Bistafa, S.R., and Granado Jr., M.V. 2005, "A survey of acoustic quality for speech in auditoriums," Technical Acoustics, http://www.eijta.org, 15.

Farina, A. 2000, "Acoustic quality of theatres: correlations between experimental measures and subjective evaluations," Applied Acoustics 62, 889-890.

Gade, A.C. 1989a, "Investigations of musicians' room acoustic conditions in concert halls. Part I: Methods and laboratory experiments," Acustica 69, 193-203.

Gade, A.C. 1989b, "Investigations of musicians' room acoustic conditions in concert halls. II: Field experiments and synthesis of results," Acustica 69, 249-262.

Jeon, J.Y. and Barron, M. 2005, "Evaluation of stage acoustics in Seoul Arts Center Concert Hall by measuring stage support," J. Acoust. Soc. Am. 117(1), 232-239.

Hidaka, T. and Nishihara, N. 2004, "Objective evaluation of chamber-music halls in Europe and Japan," J. Acoust. Soc. Am. 116(1), 357-372.

International Organization for Standardization ISO3382:2000 Measurement of the Reverberation Time of Rooms with reference to Other Acoustical Parameters.

Ternström, S., Cabrera, D. and Davis, P. 2005, "Self-to-other ratios measured in an opera chorus in performance," J. Acoust. Soc. Am 118(6), 3903-3911.