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Acoustic challenges in large opera houses

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ABSTRACT
In Copenhagen, Denmark, a new, large opera opened in 2005. For the opera company, which used to perform in a smaller theatre (The "Old Stage" of the Royal Theatre), this has given at least two challenges: 1) the singers are weaker as heard primarily by the singers themselves, and 2) and musicians playing in the pit feel an increased demand for playing louder in order to fill the larger auditorium volume with sound. These two challenges lead to two studies ordered by the Opera: one dealing with guide lines for the design of stage sets in order for them to contribute as much as possible to the support of the singers' voices, and one investigating how the sound levels in the pit can be reduced without compromising the artistic quality of the performance. The latter is strongly related to implementation of the EU Directive 2003/10/EC "on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise)", with which the music and entertainment sectors in all EU countries must comply after 15th February 2008.

INTRODUCTION
The Royal Theatre in Copenhagen serves as Denmark's national stage for drama, opera and ballet. In 2005, a new, large opera house donated by the Maersk shipping company was opened, with the purpose of providing a more suitable home primarily for performances of large, late romantic operas (Wagner and Straus) and large ballets than the much smaller "Old Stage" dating from 1874, (which will still be used for smaller scale operas and ballets). The number of seats in the new opera is only 10 % larger than in the old one: 1450 against 1300; but the volume of the auditorium is about 50% larger (10.300m^3 rel. 6,500m^3 the Old Stage"), and the stage is much larger (the maximum width of the stage openings being 17.2m and 12m respectively) leading the stage set designers to create much larger stage sets. In the occupied state, the mid frequency reverberation time value is about 1.4s in both halls[1]. The acoustic design of the new Opera was carried out by Arup Acoustics.

After two seasons in the new venue, two acoustic challenges related to moving into this larger house have prevailed: the subjective observation by the musicians' that the sound level in the orchestra pit is too high (and apparently higher than in the smaller pit in the Old Stage) due to conductors asking for louder playing, and the singers often lack support to their voices and are heard weaker in the auditorium.

Obviously, these two issues are related. In the larger auditorium and stage volume, the energy density of the sounds of singers as well as orchestra will be weaker. Considering the volume ratio alone, the level in the new Opera can be expected to be about 2dB lower than in the Old Stage. When the conductor ask orchestra members to play louder to compensate for this, their neighbours in the pit will receive a louder direct sound. The conductor will seldom ask a singer to increase his/her level, but a lower level of the voices experienced by the audience and a lower support experienced by the singers can easily be imagined.

In an attempt to create strategies for dealing with the problems, the author has been engaged in two projects at the Royal Theatre. Ideas and results from this work as well as from involvement in the implementation of the EU Directive 2003/10/EC will be presented in the following.

[1] In the Old Stage, this relatively high value is achieved by means of a reverberation enhancement system. Without this system in use, the value in the occupied Old Stage hall is about 1.0s.

THE PIT LEVEL PROBLEM

The investigation of the pit level problem was carried out as a subjective survey with questionnaires distributed to the orchestra members in the new Opera during rehearsals of two operas with different orchestra size requirements: "Maskarade" by Carl Nielsen (66 musicians) and "Elektra" by Richard Strauss (92 musicians). In both cases two rehearsals were studied between which the types of screens applied between the musicians and - in the case of the Maskerade - the position of the four horns were changed. In the case of the Elektra, the Opera found it impractical to try a different orchestra lay out in the densely furnished pit. The objective properties of the screens are described in a later section.

The questionnaire survey

The questionnaire encouraged the musicians to scale their judgements regarding 1) the general sound level, 2) ease of ensemble playing, 3) the support to their own instrument and 4) the physical seating space. Besides, they were asked to list which other instruments in the orchestra they heard to loud or to weak. Thus, the investigation did not address whether it was actually necessary to produce the level required by the conductor in these operas in this hall, it only dealt with the musicians' experiences under the circumstances in order to find targets for improvements in the form of introducing/changing screens or rearranging of the seating. After the rehearsals, the questionnaires were filled in by about 20 musicians situated in the most critical positions in the orchestra: violins sitting in front of woodwinds, viola/celli sitting in front of brass players and French horns, woodwinds sitting in front of other wood winds/horns and brass players sitting in front of percussion.

Due to the limited number of responses for each instrument group and due to certain differences in conditions between the rehearsals beyond our control (changes in musicians participating, different parts of the score being rehearsed etc.) the data were not suitable for strict statistical analysis. However, the following tendencies seemed clear:

Sound level: most musicians agree that the levels are too loud and more so in the case of the Strauss score with heavy orchestration. It is always the close, loud instruments which cause loudness problems, and the sound in front of the brass is always too loud even when screens are introduced. If placed close to a reflecting wall, individuals among the eight French horn players required for the Strauss opera even found the sound of their own section being too loud. In the case of the Nielsen opera, which is more moderately orchestrated, violins sitting in the opposite side of the pit relative to the strong brass and percussion sections did not experience serious level problems.

Loud/weak instruments: Obviously, close, loud instruments were the ones judged to be too loud, and those being too weak were primarily strings far away (in the opposite side of the pit). This corresponds well with published data for different orchestral instruments as described by Meyer [1], according to which the maximum sound levels (at 2m distance) is roughly about 90dB(C) from string instruments, 10dB louder from wood winds and 20-30dB louder from brass instruments.

Ease of ensemble: The perceived balance between the sections is important for ease of ensemble. Compared to the conditions during the Electra rehearsals, ensemble was easier to achieve in the smaller Nielsen orchestra. Double bass players had problems during the Electra rehearsals in which they were placed close to the large brass sections. Also players placed close to the French horns had problems. Changes in the use of screen between the rehearsals mainly took place between brass and viola/celli. It was observed that the brass strongly disliked having a continuous row of screens in front of them, since they felt that these separated them from the other sections of the orchestra. This is easy to understand considering the fact that this "wall" generated strong reflections of their own sound back to themselves masking the sound from the other sections. In other words, screens should be sound absorbing on the side facing the brass. (The objective properties of the screens is dealt with in the following section.)

Support: In general, the musicians were satisfied with the support conditions in this hall.

Space conditions: As could be expected, the musicians' are more satisfied with the space available when they are 66 rather than 92 in number. With a pit area of 130 m^2 (disregarding 28 m^2 under the forestage, which they prefer not to use), the available area per musician in the two cases is 1.4 m^2 and 2.0 m^2 respectively. Earlier studies [2] have revealed that 1.5 m^2 per musician is the lower limit one should aim for. (This would allow for 100 musicians in the new opera pit - if the area under the forestage is included.) One important advantage of a large pit area is that it gives more freedom to arrange the seating with suitably larger distances to the loud instruments and free space for placing of screens where necessary.

Screen measurements

In connection with the survey, objective measurements of the attenuation and reflection properties of three available screens were carried out. The tests were done in the furnished pit in order for reflections from floor, walls and scattering from neighbour objects to have a more realistic influence on the results than would have been the case in an anechoic chamber. Besides an ordinary reflective visually transparent screen of plexiglass measuring about 60cm x 60cm, two custom built screens with absorbing surface were also studied. Figure 1 below shows these two screens during the measurement session. The rectangular screen to the left measures about 80cm x 100cm and the curved screen to the right measures about 40cm x 60cm. In both cases the height of the screen above the floor is adjustable. The rectangular screen is sound absorbing on one side while the curved one is more or less absorptive on both sides.

Figure 1. Custom built sound absorbing screens used in the pits of the Royal Theatre, Copenhagen

Measurements of the attenuation as well as of the reflection were carried out. A small, directional loudspeaker source (noise generator B&K 4205 and loudspeaker B&K HP1001) emitting pink noise measurements was placed 1.0m behind the screen and the measurement microphone was placed 0.5m in front of the screen for the attenuation measurements and 1.5m behind the screen (i.e. 0.5m behind the loudspeaker directed towards the screen) for the reflection measurements. Both transducers were placed 1.0m above the floor and the top edge of the screen was placed 1.3m above the floor. Both attenuation and reflection were measured as the difference between the received 1/3 octave spectra with and without the screen placed in the setup.

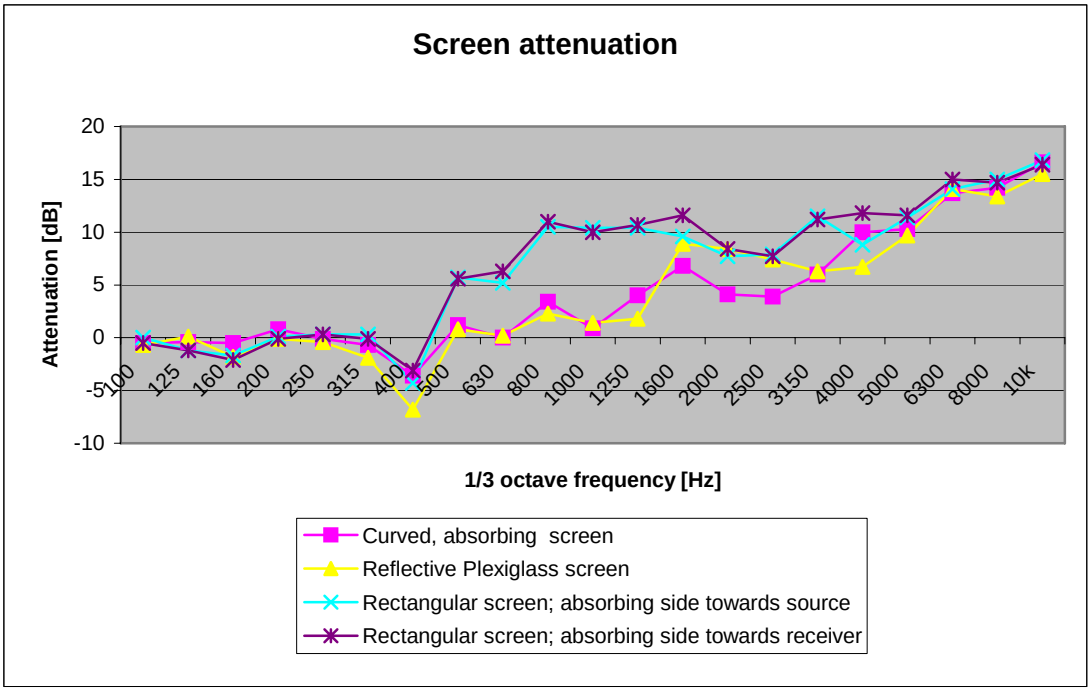

Figure 2.-Attenuation by different screens between musicians in orchestra pit

The results of the attenuation measurements are shown in Figure 2. It is seen that the attenuation in the important 1000-4000Hz region is roughly between 5 and 10 dB for all three screens, and the low frequency limit for the attenuation is determined by the screen dimensions, the large, rectangular screen being efficient already from 500Hz. These results indicate slightly less attenuation compared to results reported in the literature [3], which is probably a result of differences in measurement techniques.

As expected, it is also seen that the effect of the large, rectangular screen is independent of whether the absorptive or reflective side faces the source. However, with other sources being active on the receiver side of the screen, it is important that the absorptive side faces the person to be protected.

As mentioned earlier, the brass players disliked a reflecting screen being placed in front of them. Therefore, also the reflection from the screens was measured. The result is shown in Figure 3.

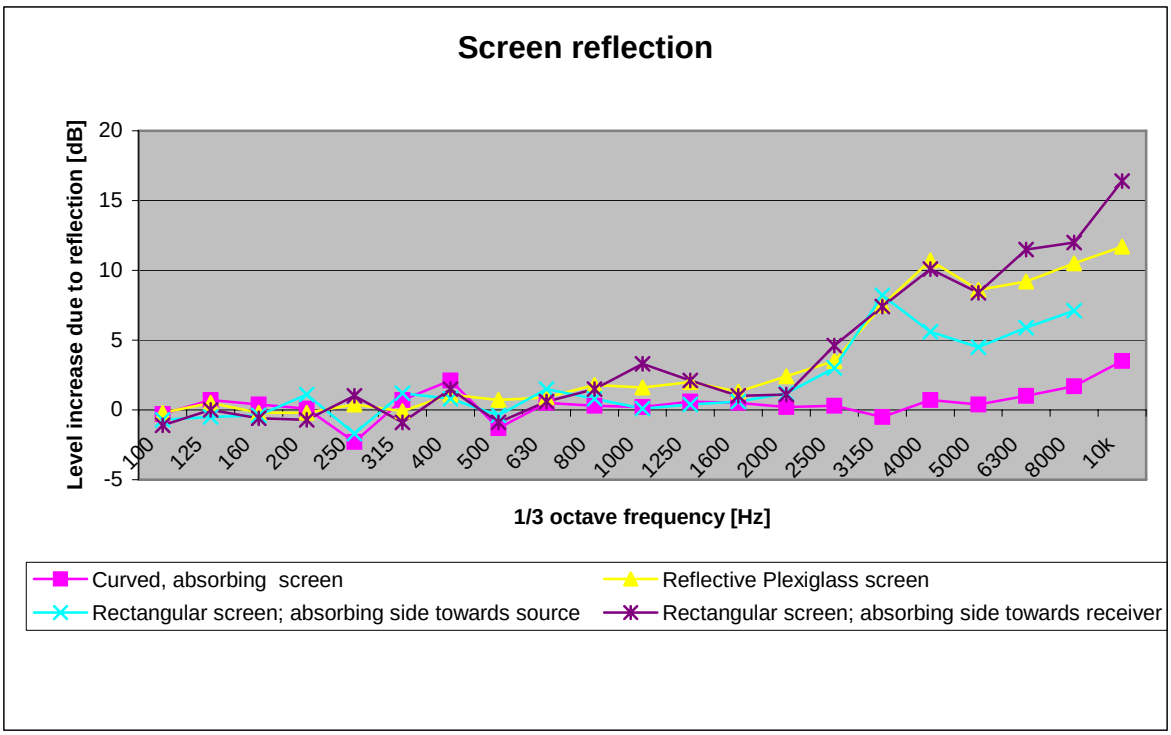

Figure 2.-relative levels of sound reflection from different screens measured in the orchestra pit

As seen the screen of Plexiglass and the rectangular one with the reflective side towards the source generate strong reflections above 2500Hz, so that the level in this region (and in this position behind the directive B&K source) increases by about 10dB when the screen is in place. When the absorptive side is turned towards the source, the level in this frequency region drops about 5dB. As expected, the small, curved, absorptive screen produces almost no reflection.

Discussion: measures for compliance with the EU Directive 2003/10/EC

The questions dealt with above strongly relates to topics of relevance for the implementation of the EU Directive 2003/10/EC according to which the usual 85 (or 87) dB eight hour noise limit must also be fulfilled in the music community from February 2008. The author is a member of a Danish national working group which - based on study of literature and experience - has investigated the risks and possible measures which the music and entertainment can apply in order to comply with this directive.

The introduction of screens and provision of sufficient floor area are obvious measures of relevance; but many other aspects can be imagined. The following is a brief listing of the measures recommended for opera orchestras by the Danish working group:

- Rehearse and perform in halls with a suitable pit floor area. Aim for 2.0 and no less than 1.5m^2 per musician.

- The hall must have a volume large enough to allow for a suitable reverberation time without generating excessive levels. On the other hand the volume must not be so large that loud playing is needed in order to fill the room and so that the musicians lack support of their own sound. (In very large opera halls - such as the Opera Bastille in Paris - the consequence could be a need for amplification of the orchestra and singers in the auditorium.)
- Hire conductors who favour a delicate, moderate playing style and who knows how to create pianissimo levels. If a true ppp is created, the fff does not need to be excessively loud to create the required dramatic effect.
- In order to facilitate playing in ppp nuances, it is important to ensure good sound insulation and low background noise levels from technical equipment in the stage house and in the auditorium.
- Do not select the loudest brass instruments and largest timpani for use in the orchestra. The fff effect is achieved through a rich spectrum of harmonics rather than through mere loudness.
- Choose a repertoire which fits the size of the hall. Abstain from ambitions regarding works which actually require a hall larger than the one available.
- Set up the season so that "loud" works are followed by more quiet and less heavily orchestrated ones.
- Limit the exposure of individual orchestra members to loud sounds by varying the orchestra lay out from time to time and by letting string players in front of winds and percussion rotate positions.
- Organize rehearsal schedules in view of exposure times and play at a lower level during the first rehearsals.
- Make sure to install reflecting surfaces around the orchestra so that the best possible communication between the musicians is ensured. If they can hear also more distant sections well it is more likely that they will moderate their output to achieve a nicely blended - and not too loud - sound. This way the orchestra is also less likely to overpower the singers. Please notice that this recommendation for reflective surfaces in the pit is opposite to the "normal" approach of installing sound absorption on surfaces close to the "noise source"!
- If ever possible avoid placing musicians under an overhang, and if the pit floor is movable, elevate it to the highest position possible considering an unobstructed view to the stage. If it is necessary to use the floor area overhung by the forestage, apply moderate absorption to the ceiling and back wall.
- Use sound absorbing screens of suitable size: not too small for efficient attenuation of the most important range above 500-1000Hz and not so large that the musicians behind feel separated from the rest of the orchestra.
- Provide hearing protectors (as required by the Directive); but use them only if other measures are insufficient.

So far, the opera projects have resulted in plans for development of more suitable screens for use in the pit, as scanning the market has not revealed any ideal off-the-shelf product and it will be easy to experiment and build these in the carpenter work shop at the opera. Some other measures which could be considered will take more preparations and time to implement, as these will challenge long traditions in performance practice.

THE WEAK SINGER PROBLEM

Obviously, the large stage dimensions in the new opera have been used by stage set designers to create large stage sets as well deep perspective views. The consequence can easily be, that reflective surfaces in the stage area are either distant or absent, which means that the singers lack support to their own voices and that the voices sound weak in the auditorium. Too few reflecting surfaces around the singer may also cause the singing to sound less reverberant than the sound from the orchestra, exposing the fact that the two types of sources are truly generated in different acoustic spaces, which of course is unfavourable. Another challenge is the ample supply of modern stage lighting equipment on the rear side of the proscenium. For these lamps to be useful, large, open gaps are often left between the proscenium frame and the stage sets behind. Finally, the deep stage can lead directors to place singers deep upstage far from the stage front.

Already before the opening of the opera, the singer support problem was obvious and it was soon reduced by installation of a sound system behind the proscenium, which supply the singers with artificial reverberation of their own voices as well as monitor sound from the orchestra pit. However, for classical opera, electro acoustic solutions to the problem of weak singer sound in the auditorium is out of the question.

Computer simulations (using the Odeon software) has shown, that the seat averaged levels in the auditorium of the voice of a singer facing the audience can easily vary about 3dB between a situation with a sound reflecting stage set which closes off most openings to the stage house and a situation with an absorbing or absent stage set. Moving the singer just 5m upstage can easily cause a 2dB drop in level as well. In other

words, unless the stage set and lighting designers as well as the directors are fully aware of the acoustic requirements, the singer-orchestra balance can easily suffer in this large theatre. This has led to a demand for generating a list of guide lines for directors and stage set designers working in the new Opera. The main elements on this list are:

- close off the stage house volume by reflecting stage sets - also upwards towards the flying bars as much as possible.
- Limit the volume defined by the stage set, within which the singers are placed.
- Place the stage sets close to the technical proscenium so that - as much as possible - a continuous reflecting zone is established from the stage set to the auditorium side walls. This is important not least in cases where the singers turn their side towards the audience.
- Side wall and ceiling elements should be properly angled to ensure efficient projection of the sound from the stage into the auditorium and to avoid flutter echoes on stage.
- Surfaces of the set meant to be reflective should ideally have a weight of a few kilograms per m^2, but an obvious need for ease of handling often sets a lower limit.
- Close the large door between the main stage and the side- and rear stages - particularly if the stage set has large openings.
- The singers (except large groups of choir members) should preferably be placed downstage close to the stage front.
- Avoid any unnecessary noise from technical equipment, e.g. switch off fans on lighting equipment not in use.

It should be added that the solution to the balance problem is not to lower the floor in the pit, as already mentioned. Earlier investigations in the Old Stage [4] has shown that this is not the solution.

CONCLUSIONS

In this paper some acoustic challenges related to large opera houses have been described. It is clear the no simple solutions exist -neither to the problem of high sound levels in the pit nor to the impression of low levels of the singers' voices in the auditorium.

In the pit, provision of sufficient space per musician and development of suitable screens can help; but further improvements - as also demanded by the EU Directive 2003/10/EC - may involve reconsidering both planning of the season and of the work schedules for the individual musicians as well as performance practice - factors which need time as well as motivation and education of organizations and individuals to be made effective.

Regarding the level of the singers in the auditorium, guide lines have been established for stage set designers and directors, which are planned to be used as annexes to their contracts. Also an acoustic consultancy service will be provided for each new production, whereby implementation of good practice should be ensured.

Acknowledgement

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