inter.noise 2010
noise and sustainability
13-16 June 2010 . Lisbon . Portugal
www.internoise2010.org

IS GADE'S "SUPPORT" PARAMETER ST_{Early} A SURE METHOD TO FORECAST STAGE ACOUSTICS?

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Abstract
Whenever orchestral music is played on stage, conductors have the important role of controlling the entire orchestra, so the musicians must be able to hear themselves well. Therefore, the stage must be designed so that there is good audibility between musicians and by the musicians themselves. The "support" parameter was proposed by Gade so these questions could be analyzed.
This paper analyzes two concert halls. The first concert hall has excellent hall acoustics but poor stage acoustics. However, the ST_{Early} measured on stage, even after several repeated measurements, has been found to be very similar to that of other concert halls of great reputation. The second concert hall has good measured stage values but musicians have trouble focusing and the echoes are very strong.
In this paper we show that the criterion proposed by Gade does not, by itself, assures the prediction of good stage acoustics. We have found that Gade's Criterion is a necessary but not a sufficient condition.

Keywords: Concert hall, Objective parameters, Acoustical quality.

1. INTRODUCTION

In section 2 we provide a brief description of the acoustic parameters of the Barcelona Symphony Hall [1] in comparison with reference halls, such as Vienna's Grosser Musikvereinsaal, Amsterdam's Concertgebouw, and Boston's Symphony Hall.

In section 3 we develop the problem found on the Barcelona stage. In section 4 we describe the sound problem in the second hall – the Tonhalle of St. Gallen. Finally in section 5 we emit the final observations and conclusions.
We introduce here the main concepts used in the paper.
Support is the acoustic property which makes the musician feel that he can hear himself so that it is not necessary for him to force his instrument.
ST1 describes the ratio between the energy of the early reflections (20 to 100 ms) and the energy of the direct sound (0 to 10 ms): ST1= 10 log (E(20-100 ms)/E(0-10 ms)).
ST_{Early} is used as a descriptor of ensemble conditions, i.e. the ease with which orchestra members hear each other. This ratio is measured at 1 meter from the source, and the values are evaluated at the four octaves between 250 and 2000 Hz and also averaged to give a single value for the particular stage. Normally, measurements are carried out at three positions on stage and later averaged [5].
According to Jürgen Meyer (1978), [4], if you hear your coplayers well, but not yourself, rhythmic precision is possible, but intonation suffers; whereas if one hears oneself well but not the coplayers, the intonation may be all right, but rhythmic precision will be hard to achieve.
ST_{late} = 10 log (E(100-1000 ms)/E(0-10 ms)). This parameter describes the sensation of reverberation, but in our case it is not important because the reverberation is good in both cases.

ST_{total}. = 10 log (E(20-1000 ms)/E(0-10 ms)), describes the support provided by the room to the musician’s own instrument.

2. **FIRST CASE:** ACOUSTICAL PERFORMANCE OF THE BARCELONA AUDITORIUM HALL COMPARED WITH THREE OTHER MAJOR HALLS.

The acoustical design of the project was finished in 1990 but it was built later and finally opened on March 22nd, 1990 (?) to wide acclaim. The Architect was Rafael Moneo and the Acoustician was Higini Arau. Since 2008, L’Auditori is member of ECHO (European Concert Hall Organization).
The hall’s standard seating capacity is 2326, but it can be expanded to 2335. Its volume is 24298 m^3, and it is the home of the Barcelona City and National Catalonian Orchestra, see figure1. The hall is rectangular with a length that is double its width. It has a width of nearly 31.1m between sidewalls, with a ceiling height above the stage area of 19.3m. There are large areas for the performers: the orchestral platform is 210m^2 and the choir occupies 60m^2.

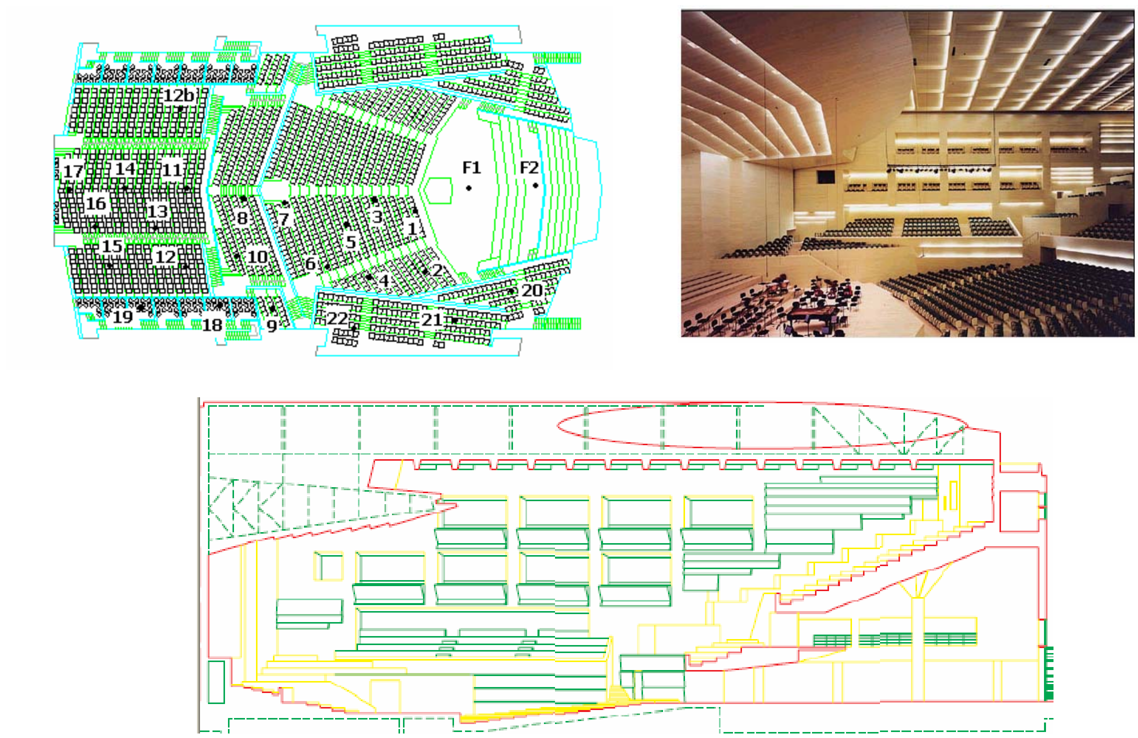


Figure 1: Barcelona Auditorium **Concert Hall in plan.** The numbers indicate the measurement points. F1and F2 are source positions.

The values were measured in the hall using an MLS testing system, as shown below. The prescriptions in ISO 3382 were followed. Comparisons are made with the best halls studied in references [8] , [9]. Measurement positions are given in Figure 1 and Table 1:

Table 1: Measurement positions

Measurement point	Zone	Source-receiver distance for F1 (m)
1	Stalls	6.57
2	Stalls	10.64
3	Stalls	10.50
4	Stalls	14.09
5	Stalls	14.50
6	Stalls	17.53
7	Stalls	20.49
8	First Tier	24.69

9	Lateral second Tier	25.81
10	First Tier	27.02
11	Second Tier	31.37
12	Second Tier	32.58
13	Second Tier	33.28
14	Second Tier	38.97
15	Second Tier	40.42
16	Second Tier	42.00
17	Second Tier	44.07
18	Lateral 2 Tier	30.44
19	Lateral 2 Tier	39.09
20	Lateral Stage	13.27
21	Lateral 1 Tier	15.32
22	Lateral 1 Tier	19.61
23	Place 6–8 3erd Balcony	-
24	Place 6–8 2ond Balcony	-
25	Place 14–16 2ondBalcony	-

AVERAGE MEASURED VALUES

The values measured in 1999 for unoccupied and occupied seats are [1]:

RT REVERBERATION TIME

Frequency Hz	125	250	500	1000	2000	4000	T_{low}	T_{mid}	T_{high}
RT Barcelona (occ.)	2.45	2.30	2.09	2.03	2.02	2.00	2.37	2.06	2.01
RT Boston (occ.)	1.95	1.85	1.85	1.85	1.65	1.30	1.90	1.85	1.47
RT Vienna (occ.)	2.25	2.18	2.04	1.96	1.80	1.62	2.21	2.00	1.71
RT Amsterdam (occ.)	2.20	2.15	2.05	1.95	1.80	1.55	2.17	2.00	1.67

BASS RATIO AND **BRILLIANCE** INDEX

Averaged (occupied)	Bass Ratio(T_{low}/ T_{mid})	Brilliance(T_{high}/ T_{mid})
Barcelona	1.18	0.97
Boston	1.03	0.79
Vienna	1.11	0.85
Amsterdam	1.08	0.83

EDT EARLY DECAY TIME

Frequency Hz	125	250	500	1000	2000	4000	EDT_{mid}
T Barcelona (occ.)	2.05	1.96	2.07	2.02	2.104	1.92	2.04
EDT Boston (occ.)	1.87	1.83	1.73	1.76	1.63	1.22	1.75
EDT Vienna (occ.)	2.25	2.19	2.04	1.93	1.82	1.61	1.99
EDT Amsterdam (occ.)	2.20	2.15	2.05	1.95	1.80	1.55	2.00

C_{80} CLARITY INDEX

equency Hz	125	250	500	1000	2000	4000	**C_{80mid}**
C_{80} Barcelona (occ.)	-2.39	-0.73	0.42	0.72	0.30	0.58	0.57
C_{80} Boston (occ.)	-1.92	-1.43	-1.29	-0.53	-0.27	1.1	-0.91
C_{80} Vienna (occ.)	-3.71	-3.61	-2.43	-1.45	-1.09	-0.1	-1.94
C_{80} Amsterdam (occ.)	-4.29	-3.8	-2.96	-1.4	-1.05	-0.4	-2.18

G STRENGTH

Frequency Hz	**125**	**250**	**500**	**1000**	**2000**	**4000**	**G_{mid}**
G Barcelona (occ.)	**3.47**	**3.16**	**2.67**	**2.37**	**2.68**	**2.39**	**2.52**
G Boston (occ.)	0.82	1.13	1.89	1.83	0.38	-1.86	1.86
G Vienna (occ.)	4.17	3.75	3.15	3.5	3.3	2.71	3.33
G Amsterdam (occ.)	4.09	3.91	3.85	3.66	3.26	2.57	3.76

X ST_{Early} SUPPORT FACTOR measured in 2001

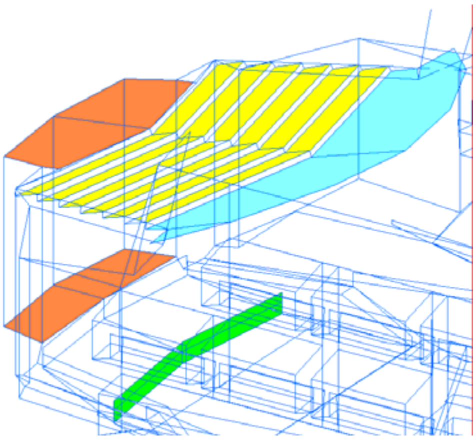
Auditorium	ST_{Early} (dB)
X Barcelona	-14.2
Boston	-13.7

Vienna	-13.9
Amsterdam	-17.8

In conclusion, we can see that the values of all acoustic parameters obtained for the Barcelona's hall and stage were comparable to those of the most renowned in the world. However, two years after opening there were reports that indicated that some problem existed in the stage area.

3. ANALYSIS OF THE BARCELONA STAGE PROBLEM

We will analyze the acoustics on stage where the musicians couldn't hear the reflections from their own ensemble, or even their own sound.



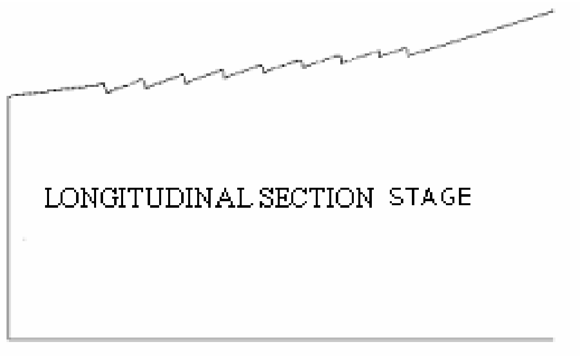
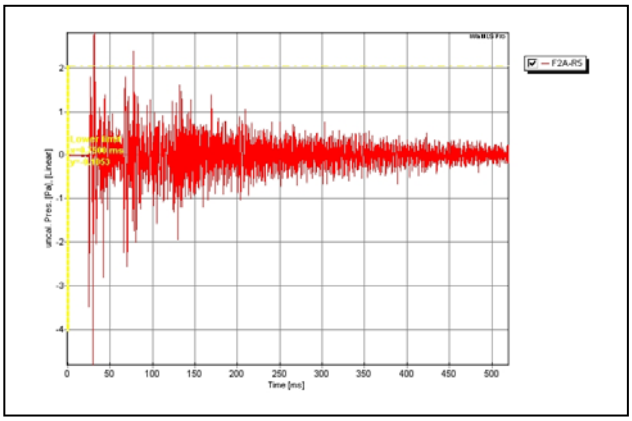


Figure 2: 3D-View and detail of longitudinal section on stage.



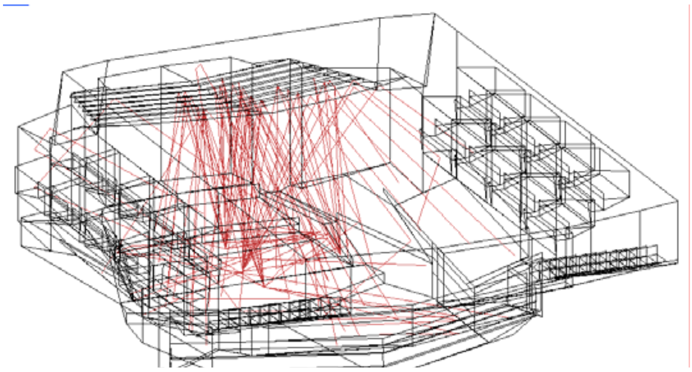


Figure 3: Sample of reflections on stage

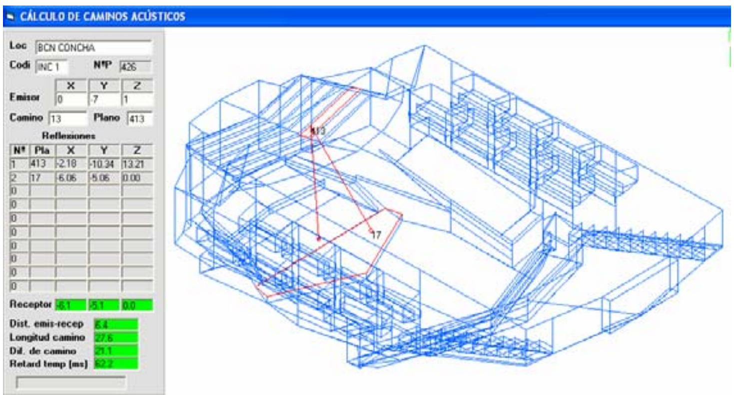


Figure 4: Example of acoustic ways on stage explored

In figure 2 we show a zoom 3D-View and the longitudinal section of the stage. The area of musicians is 210 m^2, but it does not include the area of choir. The average height of the ceiling in relation to the platform of stage is 13.8 m. The minimum height of the ceiling (beginning in the yellow zone) is 12.5 m. The maximum height is 15.25 m (in the last blue zone). The fictitious volume of the orchestra area is V= 2660 m^3, which corresponds, according to Gade [2] to a ST_{early} = - 14.5 dB, a value which is near to what was found experimentally in 2001.

In the years 2006-2007, we started our research by means of ray tracing calculations. In figure 3 we can see that many reflections exist but these do not return to the musician. Therefore, the musician cannot hear himself.
Later on, we carried out an in-depth analysis of acoustic ways with many tests (≈100), as shown in figures 4 and 5. The emissions of musicians from the red zone towards the ceiling hit the stage in 1st, 2nd or 3rd reflection in the green zone. No ray returned to the musician that had emitted the sound nor to neighbouring musicians in the 1st, 2nd or 3rd reflection within the 100 ms indicated by Gade.
A musician's sound does not come back to him in time during the referred intervals. It is as if there was a slight slope in V in the transversal section, perhaps due to poor design. We also found that the sound emitted from the green zone mainly goes to the lateral 1 Tier of each side hall. Finally, we noticed that the sound hits the stage's ceiling area in the blue zone, located above the strings and conductor areas, then the sound goes towards the stalls, but no wave goes back to the stage.

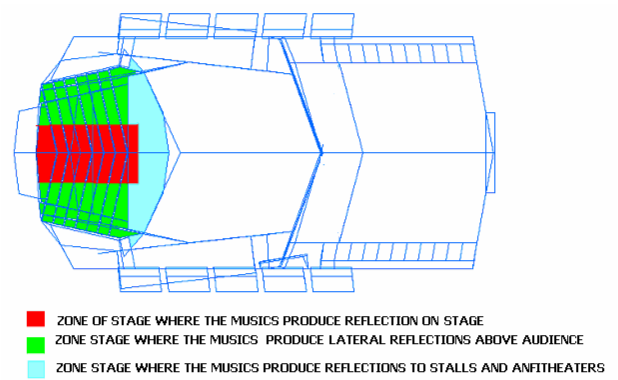


Figure 5: Animation zones of sound

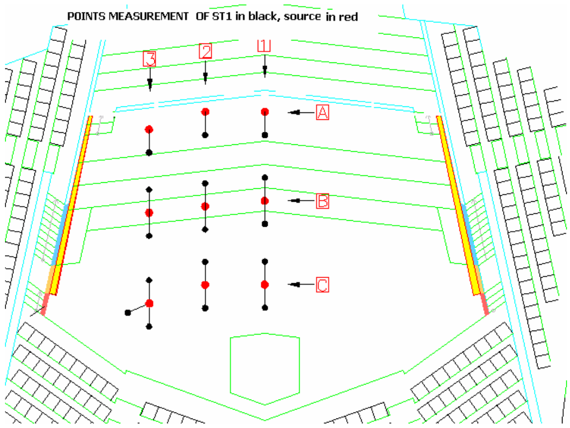


Figure 6: Measurement points. If the source position is IJ, IJ - F indicates a receiver point 1m in front of the source and J-B a receiver point 1m behind the source.

After those ray tracing calculations were completed, we conducted many measurements of ST_{early} in the points of half symmetry of the stage area as shown in figure 6. The source was an omnidirectional dodecahedron and the receiver a microphone with a height of 1.3 m. located at each point indicated in the figure 6.
The spacing between the source, placed in each point IJ, and microphone was 1m. either to the front F or behind B as indicated in figure 6. The measurement points were distributed about the stage along longitudinal lines. Due to the symmetric nature of the stage and the hall, measurements were made in only half the stage area.
Finally, in figures 7 and 8 we show the results obtained by zones. We obtained a mean value of ST_{early} = -14.83 dB. As we can see from the distributed values, we have ST_{early} = -11.47 dB in the percussion instruments zone, and to ST_{early} = -17.85 dB in the string and conductor zones. The last value is very similar to the mean value ST_{early} at the Concertgebouw in Amsterdam [9][10].
We found that the ST early values obtained follow the geometric incidences on the stage's ceiling. The blue ceiling has a sharp increase in slope, by architectural decision, so that audience members seated at the upper lateral balconies can enjoy good sightings of the stage. This design decision, and others indicated before of the same type**,** produces bad acoustic results in terms of ST1 on stage. Knowing this now the solution is easy.

ST1 by octaves from 250 to 2000 Hz

Sources Point	250	500	1000	2000	ST1 averaged	ST1 averaged zone
1A-F	-11.5	-11.6	-7.4	-6.5	-9.25	
2A-F	-10.2	-8.3	-8.5	-14.1	-10.28	-11.47
3A-F	-14.5	-17.7	-17.3	-10	-14.88	
1B-B	-14.7	-14.2	-11.8	-15.4	-14.03	
2B-B	-15.9	-17.9	-17.2	-17.1	-17.03	-15.05
3B-B	-13.9	-14.3	-15.1	-13.1	-14.10	
1B-F	-13.7	-15.2	-17.6	-11.5	-14.50	
2B-F	-16.9	-14.8	-10.3	-12.3	-13.58	-13.53
3B-F	-16.4	-10.4	-8.6	-14.7	-12.53	
1C-B	-16.5	-14.4	-16.8	-13.2	-15.23	
2C-B	-19	-20.2	-20.7	-16	-18.98	-16.86
3C-B	-17	-16.5	-15.5	-16.5	-16.38	
1C-F	-19.7	-17.3	-14.3	-14.6	-16.48	
2C-F	-17.1	-16.6	-17.5	-18.1	-17.33	-17.22
3C-F	-16.3	-18.1	-18	-19	-17.85	
3C-L	-16.2	-16.9	-15.5	-11.1	-14.93	
			averaged overall on stage		-14.83	

Figure 7: Measurement results

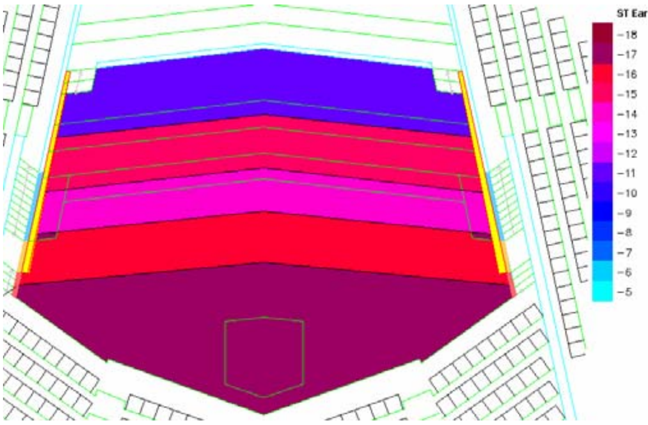


Figure 8: ST_{early} by zones on stage

NOTE: We had always thought that this average value for ST1, as measured on stage, was good and that the musicians were wrong in their assessments because we believed that satisfying Gade's criteria was sufficient, but beginning around the month of April 2009 we started to understand this problem. We discovered that Gade's criterion isn't fail-proof.

4. SECOND CASE

We have checked another hall, the Tonhalle of St. Gallen inaugurated in 1909. It has a volume V= 6150 m^3, the musicians area has192 m^2, fictitious volume is1152 m^3, and has a height of 6 m. The predicted value by Gade [2] ST1 ≈ -10 dB. The average measured value of ST1 support on the stage is ST1= -10.14 dB, and its variation on the stage goes from -6.1 dB in the back of the stage to -14 dB in the front of the stage, see figure 9.
In St. Gallen, the average measured Gade stage value is good, but , due to the variations between the back stage Gade value and the front stage Gade value, the musicians experience a frustrating stage experience with focussing (primary problem) and echoes flutter (secondary problem).

Table 2: ST1 on the stage

	125	250	500	1000	2000	4000	Average
Stage Support ST1(dB)	-8,28	-9,96	-10,11	-11,05	-9,41	-11,61	**-10,14**

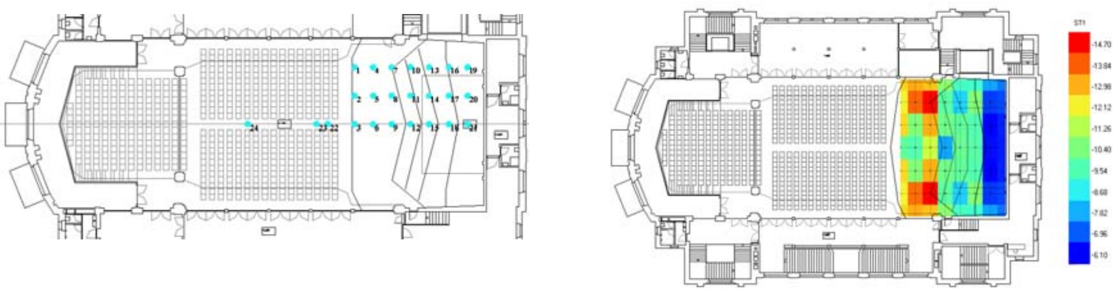


Figure 9: Measurement points and ST_{early} by zones on stage

The focusing is produced the curved corner of union ceiling with wall, to see figure 10.

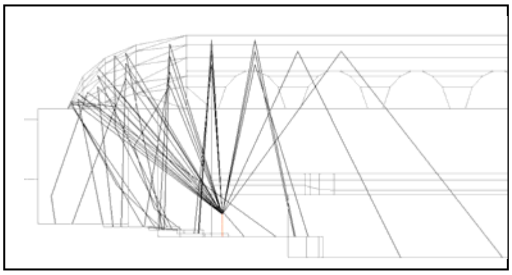
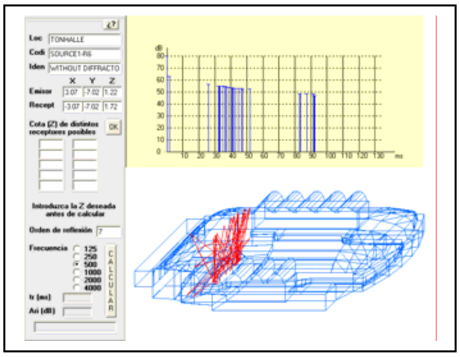


Figure 10. Sound focusing



5. FINDINGS AND CONCLUSION

We conclude this paper by listing several stage acoustics findings based on the analysis of the Barcelona Auditorium and the Tonhalle of St. Gallen. We end with a conclusion.

A. Findings:

1. In Barcelona's Auditorium, the 2006-07 ST_{early} average of 17 points on stage was similar to the 2001 average of three points. These two average results for ST_{early} are equivalent to those of the concert halls with the best reputation, but the acoustic sensation was such that the musicians couldn't hear the reflections from their own ensemble, or even their own sound.
2. At the Barcelona Auditori the zone stage ST_{early} values shown in figures 7 and 8 reveal that the string instruments and conductor areas are the weakest spots. In Barcelona there is a good correlation between the geometry incidences of the ceiling with the acoustics of the stage. However, in St. Gallen the contribution of the ceiling or the walls to the stage acoustics is not clear through of the measurements.
3. The measurement system proposed by Gade can not distinguish from which zone in the stage the measured sound comes from. As a result, we can obtain a good average value but still have a bad acoustic sensation on stage. We found that the ST_{early} measure does not take into account the source directivity nor the direction of the sound reflection and not take into account neither the effect such as echoes flutter and sound focusing. As a result, we obtain a poor acoustics in stage but the measurement perhaps is good.
4. Measurements have been traditionally made at three positions on stage and later averaged [5]; but we have found it is preferable to make numerous measurements of ST1, or ST_{early}, along the stage area and beyond to calculate average values not only for the whole stage but also by zones within the stage and surrounding areas.

B. Conclusion:

As a conclusion we believe that Gade's Criteria fail. We think it is a required condition but it is not sufficient. This criterion can fail like we see in these cases, therefore the Gade criterion it isn't fail-proof. Why do the Gade criteria ST1 fail! Maybe fails because it can not really evaluate effectively where the sound comes from?

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