25 Aniversario 1981-2006

P-7545/4-v00 NOVEMBER 2009

ACOUSTIC ASSESSMENT IN THE PROJECT OF THE AUDITORIUM OF TROYES (FRANCE)

SIMULATION RESULTS

Presented to: D. JOSÉ IGNACIO LINAZASORO RODRÍGUEZ (ARCHITECT)

GARCIA-BBM: V. Mestre Sancho
V. Menéndez Rodríguez
J. Simó Tercero

TABLE OF CONTENTS PAGE

1. INTRODUCTION ... 1

2. OPTIMUM ACOUSTIC CRITERIA ... 1

2.1 Reverberation Time ... 1
2.2 Clarity ... 3
2.3 Tonal Balance ... 4
2.4 Lateral Energy ... 4
2.5 Speech Intelligibility ... 5
2.6 Central Time ... 6
2.7 Loudness Index ... 6
2.8 Criteria adopted in the present Report ... 7

3. ACOUSTIC SIMULATION MODEL ... 7

4. DATA FOR USE IN CALCULATIONS ... 8

5. ANALYSIS OF THE RESULTS ... 9

5.1 Reverberation Times ... 10
5.2 Sound Distribution ... 10
5.3 Lateral Energy ... 10
5.4 Central Time ... 11
5.5 Intensidad sonora ... 11
5.6 Tonal Balance ... 11
5.7 Clarity ... 11
5.8 RASTI ... 12

6. CONCLUSIONS ... 12

FIGURES

APPENDIX

1. INTRODUCTION

The present report is part of the work which GARCIA-BBM S.L has been requested to carry out for the Architect JOSÉ IGNACIO LINAZASORO RODRÍGUEZ and compiles the results of the acoustic response of the Auditorium of Troyes (France). These results have been obtained by using the appropriate software for acoustic simulation.

2. OPTIMUM ACOUSTIC CRITERIA

The general characteristics of an acoustically excellent hall will depend on the uses for which the hall has been designed. However, there is an underlying objective which all halls must meet. This can be defined as good communication between the source (orchestra, speaker) and the spectator (conductor, public etc.). This applies to both halls for listening to music and halls where speech intelligibility is essential.

The acoustic conditions of a Hall are affected by purely architectural considerations such as the shape and volume of the hall, the treatment of inner surfaces, seating capacity etc.

The following aspects are essential to ensure acoustic quality in large halls:

2.1 Reverberation Time

The reverberation time of a room (the time it takes for the sound signal to decay by 60 dB once the tone that created it has stopped) is a measure of the permanence of the sound energy in the room. This parameter is, without any doubt, the best indicator of the acoustic quality of the room.

At the same time the reverberation time of a room is a measure of the absorbent or reflecting properties of the room’s interior surfaces.

The optimum reverberation time of a room to be used for a certain activity depends on its volume and frequency. For a certain volume the optimum reverberation time is usually recommended for the mid-frequencies (500 Hz – 1000 Hz), adjusting this value later to obtain values for other frequencies.

Figures 1 and 2 present the optimum times recommended for different volumes of large halls at mid-frequencies (500 Hz to 1000 Hz). Figure1 shows the optimum reverberation times for halls for music and Figure 2 for halls where speech is important. Table 1 summarises these ranges of values for different rooms.

TABLE I	
OPTIMUM REVERBERATION TIMES RECOMMENDED AT MID-FREQUENCIES	
AUDITORIUM FOR SYMPHONIC MUSIC	1,7 - 2,2 seconds
AUDITORIUM FOR CHAMBER MUSIC	1,4 - 1,7 seconds
OPERA HOUSES	1,1 - 1,4 seconds
CONGRESS AND CONFERENCE HALLS	0,8 - 1,4 seconds
REHEARSAL ROOMS	1,0 - 1,5 seconds
ROOMS FOR TEACHING MUSIC	0,8 - 1,0 seconds
LECTURE ROOMS	0,8 - 1,0 seconds
FOYERS	1,0 - 1,2 seconds
LIBRARIES	0,8 - 1,0 seconds
OFFICES	0,8 - 1,0 seconds

The optimum reverberation time of a room for music varies slightly with frequency. Compared to mid-frequencies the reverberation time is longer for low frequencies and shorter at high frequencies. A reverberation time which varies with frequency forming such a curve assures tonal balance and warmth of sound.

For speech the reverberation time can be uniform for different frequencies, although it is not particularly critical if there is more reverberation, as the frequency spectrum of a speaker centres around the mid-frequencies.

Those rooms with very short reverberation times are said to be “dry“ or “dead“ whereas those rooms with long reverberation times are considered “ live “.

Rooms with long reverberation times at low frequencies sounds “warm“. However, it is important to ensure appropriate reverberation times at all frequencies in order to obtain a rich tonal quality of sound.

If the listener is seated near the sound source in a room with a short reverberation time and short reflections, the room is then said to possess “clarity” or “definition”.

2.2 Clarity

The primary energy resulting from the energy of the direct sound and the energy of the early reflections is an important parameter which, when compared to the total sound energy received, determines the clarity of a room.

This clarity can be determined by establishing various time limits to discern the first word. In rooms where speech intelligibility is important the time limit is around 36 to 50 milliseconds whereas for music the limit is around 80 milliseconds.

Thus the parameters for clarity are defined as:

$$C_{50} = 10 \log \frac{\int_{0}^{0,05} P^2(t)dt}{\int_{0,08}^{\infty} P^2(t)dt}$$

and

$$C_{80} = 10 \log \frac{\int_{0}^{0,08} P^2(t)dt}{\int_{0,08}^{\infty} P^2(t)dt}$$

where P is sound pressure.

The optimum values for these parameters are between -1 and +5 for C_{50} and -2 and +2 for C_{80}.

2.3 Tonal Balance

Warmth is defined as the ratio between the reverberation time at low frequencies and that measured at mid-frequencies. The optimum value should be between 1.2 and 1.5.

Brilliance is defined as the ratio between early reverberation times at high frequencies and those measured at mid-frequencies and varies between 0.8 and 0.9.

2.4 Lateral Energy

Lateral reflected sound energy increases the sensation of spaciousness and of acoustic intimacy.

This energy may reach the listener after a first reflection or as a result of a second, even oblique, reflection from the ceiling via lateral walls or lateral reflectors.

Reflections arriving earlier than 50 milliseconds are very important although those which arrive with time delays of up to 80 - 100 milliseconds are also welcome as long as they are not dominant or loud. In terms of energy, lateral energy can be defined as:

$$EL = \frac{\int_{0,005}^{0,08} P_L^2(t)\cos^2\theta\, dt}{\int_{0}^{0,08} P^2(t)dt}$$

The optimum value of this parameter of fine adjustment should be between 20% and 35%.

2.5 Speech Intelligibility

In the open air the sound pressure level which reaches the listener depends initially on the strength of the sound source and the distance between the source and the listener.

However, the presence of background noise impedes speech intelligibility, rendering a certain number of syllables incomprehensible. The number of syllables masked depends on the level of background or environmental noise, and on the two factors mentioned in the previous paragraph.

Once a certain number of syllables cannot be heard the listener is no longer able to understand whole sentences. However, other factors play an important role. A simple, everyday type of vocabulary, for example, is easier to follow than a more extensive one. Knowledge of the topic, lip reading etc., enables the listener to grasp the meaning without actually hearing every word. When speech intelligibility is difficult people have to raise their voices in an effort to make themselves understood.

In the open air there is generally only the direct sound from the speaker. In a closed room there are also the sound reflections which come from the walls and the ceiling and which arrive at the listener's ear with different time delays after the direct sound.

These reflections multiply with time with the result that in a room with flat, reflecting walls hundreds of reflections reach the listener in tenths of a second. Those which arrive with a short time delay (less than 30 milliseconds) are integrated by the ear and increase speech intelligibility, reinforcing the level of the direct sound. However those reflections which have longer delay times cause interference and impair intelligibility.

The above mentioned reverberation is none other than the sum of all those reflections coming from the surfaces of the room. If the reverberation is very long (a long T60), the syllable which arrives directly can merge into the one before which has remained in the room as a result of the reverberation, thus creating confusion.

Speech intelligibility can measured in terms of the percentage of syllables understood in a test of articulation or by the more modern index of RASTI, whose optimum value is 0.75.

2.6 Central Time

Another parameter used to evaluate the balance between primary and secondary energy is called Central Time (T_s) which is defined as:

$$T_s = \frac{\int_0^\infty t.[P(t)]^2.dt}{\int_0^\infty [P(t)]^2.dt} [ms]$$

In contrast to the values for clarity and definition, Central Time does not have time limits, which makes it very useful for expressing speech intelligibility levels. Low levels of t indicate clarity whereas high values of t indicate masking of the sound. The recommended upper limit is 140 milliseconds at mid-frequencies.

2.7 Loudness Index

The ability to increase the strength of a sound source is measured as a Loudness Index defined as:

$$G = 10 \log \frac{\int_0^\infty P^2(t)dt}{\int_0^\infty P_A^2(t)dt} [dB]$$

where $P_A(t)$ is the pressure generated by the same source but in an anechoic chamber at a distance of 10m. The optimum value for this parameter is above 3.

2.8 Criteria adopted in the present Report

Table II presents optimum and acceptable criteria to ensure a good acoustic response. Optimum values have been adopted throughout the project.

TABLE II		
CRITERIA FOR FINE ADJUSTMENT		
Parameter	Optimum Criteria	Acceptable Criteria
Time Classic (T_{60}), secs.		
Music	1,6	±0,1
Speech	1,2	±0,1
C_{50}, dB	-1 to +5	-2 to +6
C_{80}, dB	-2 to +2	-3 to +3
Lateral Energy	≥20%	≥15%
Warmth	1,2 – 1,5	1,0 – 1,2
Brilliance	≥0,9	≥0,8
Sound Intensity (G), dB	≥3	≥0
Central Time (T_S), mseg.	≤140	≤140
RASTI	≥75	≥6
Sound Distribution	<10	<15

3. ACOUSTIC SIMULATION MODEL

GARCIA-BBM uses the acoustic software CATT-Acoustic v8.0 for simulation calculations. This program is based on Geometric and Statistic Acoustic Models.

The Auditorium is virtually constructed by inserting the necessary co-ordinates and by defining the materials to be used on surfaces. It is thus possible:

– To predict the primary reflections generated by all or specific surfaces in a room using the Image Source Method (ISM).

- To represent the Acoustic Parameters in a specific part of the Audience using the Ray Tracing Method (RTM). This method is based on the principles of Geometric Acoustics and assumes that at certain frequencies sound behaves like light.

- To render in detail the existing sound field within the simulation model using the Randomized Tail-corrected Cone Tracing Method (RTC).

The advantages of this computer-aided acoustic simulation model are many. It calculates rapidly; it permits geometric changes to be made; it is possible to place various sound sources and to obtain data on the acoustic impulse response of the Hall.

The pitfalls or limitations of the systems are that it uses the theory of rays; there is a large amount of data and a limit of surfaces and the interaction of objective data and subjective considerations.

4. DATA FOR USE IN CALCULATIONS

The Auditorium is designed to be used as a venue both for concerts with orchestra and choir, and for conferences. It has a seating capacity of 775, a surface area of 844m2 and an approximate volume of 7.000 m3 (see Appendix A).

The Architectural Studio responsible for the Project has chosen the following finishes for the interior surfaces of the Auditorium:

- Hall

Floor: Wooden floor 20-22 mm thick over slab or thin joists.

Walls: Plastered and painted. Covered with DM type natural wood to be painted or veneered with a noble wood finish (oak, walnut, beech) (at the discretion of the Board of Directors) 19mm thick. Plasterboard 20 mm thick can also be used.

In order to prevent unwanted reflections towards the stage (echoes), the wall at the back of the Hall will be covered with a rockwool panel 40 mm thick faced with a black film and concealed with wood lathing with a perforation ≥30%.

Ceiling: DM type board to be veneered or painted (at the discretion of the Board of Directors) 19 mm thick. Plasterboard 12.5+1.5 mm thick can also be used. There must be allowance for the mobility of some parts of the ceiling.

– Stage

Floor: Wooden floor 35 – 40 mm thick (consult Stage Equipment).

Walls: As in Hall.

Ceiling: As in Hall. However the reflectors in the ceiling will be mobile.

Notes: The walls above the level of the first line of lights (lateral and/or back) will be covered with pressed rockwool panels 40 mm thick and with a density ≥70 kg/m^3 its external face protected by a film of black fibreglass. 400 m^2 of this absorbent treatment is necessary.

For the present study the sound source has been placed in the centre of the stage and 200,000 rays have been emitted. Two different situations have been analyzed: for Speech Mode without any panels on stage and for Concert Mode with the panels installed.

5. ANALYSIS OF THE RESULTS

Based on the results obtained from the simulation calculations the following conclusions can be reached:

5.1 Reverberation Times

Figure 3 presents the reverberation times calculated for the Auditorium in Concert Mode with the Hall unoccupied and with the Hall fully occupied and with an orchestra of 80 – 90 musicians.

The reverberation time at mid-frequencies (500 and 1000 Hz) is 2.0 seconds with the Hall unoccupied and 1.6 seconds occupied. The latter is within the range set out in the criteria (1.5 to 1.7 seconds)

For Speech (Figure 4) the reverberation time at mid-frequencies is 1.6 seconds with the Hall unoccupied and between 1.3 and 1.2 seconds with the Hall occupied. The latter adjusts to the range set out in the criteria (1.1 - 1.3 seconds).

5.2 Sound Distribution

According to Figures 5 and 6 both in Concert Mode and in Speech Mode the differences in the existing levels at different points around the audience (except in areas near the walls) vary between 6 and 8 dB(A), thus presenting a uniform distribution of sound and satisfying the established optimum criteria (10dB(A)).

5.3 Lateral Energy

For both of the analysed modes (Figures 7 and 8) with the exception of points very near the source the values obtained for Lateral Energy (LF) in most of the audience area are within the range set out as optimum ($\geq$20%)

5.4 Central Time

In both modes (Figures 9 and 10) the practical range of variation of the parameter Central Time (T_S) is within the established optimum range ($\leq$140 milliseconds).

5.5 Intensidad sonora

Figures 11 and 12 present the values for the parameter Sound Intensity (G) for both Speech and Concert Mode. Except for points very near the walls these meet the established optimum criteria ($\geq$3 dB).

5.6 Tonal Balance

Based on the reverberation times obtained in the occupied Hall the values for Warmth and Brilliance have been calculated. These are 1.21 and 0.93 respectively, both of which are within the established optimum ranges.

5.7 Clarity

Figure 13 presents the variation of the parameter Clarity 80 (C_{80}) established for music. As can be seen the values obtained are with the optimum range (-2 to +2) with the exception of seating areas near the stage and walls.

Figure 14 presents Clarity 50 (C_{50}) defined for speech. Again the values obtained are within the optimum range (-2 to +6) with the exception of seating areas near the wall.

5.8 RASTI

Figure 15 presents the variation over the audience of the RASTI parameter for speech. As can be sen almost all of the audience are within the optimum criteria (≥75).

6. CONCLUSIONS

The results of the calculations carried out during this study and their analysis show that the acoustic response of the Auditorium is perfectly adequate for both uses of the Hall: Concert Mode and Speech Mode.

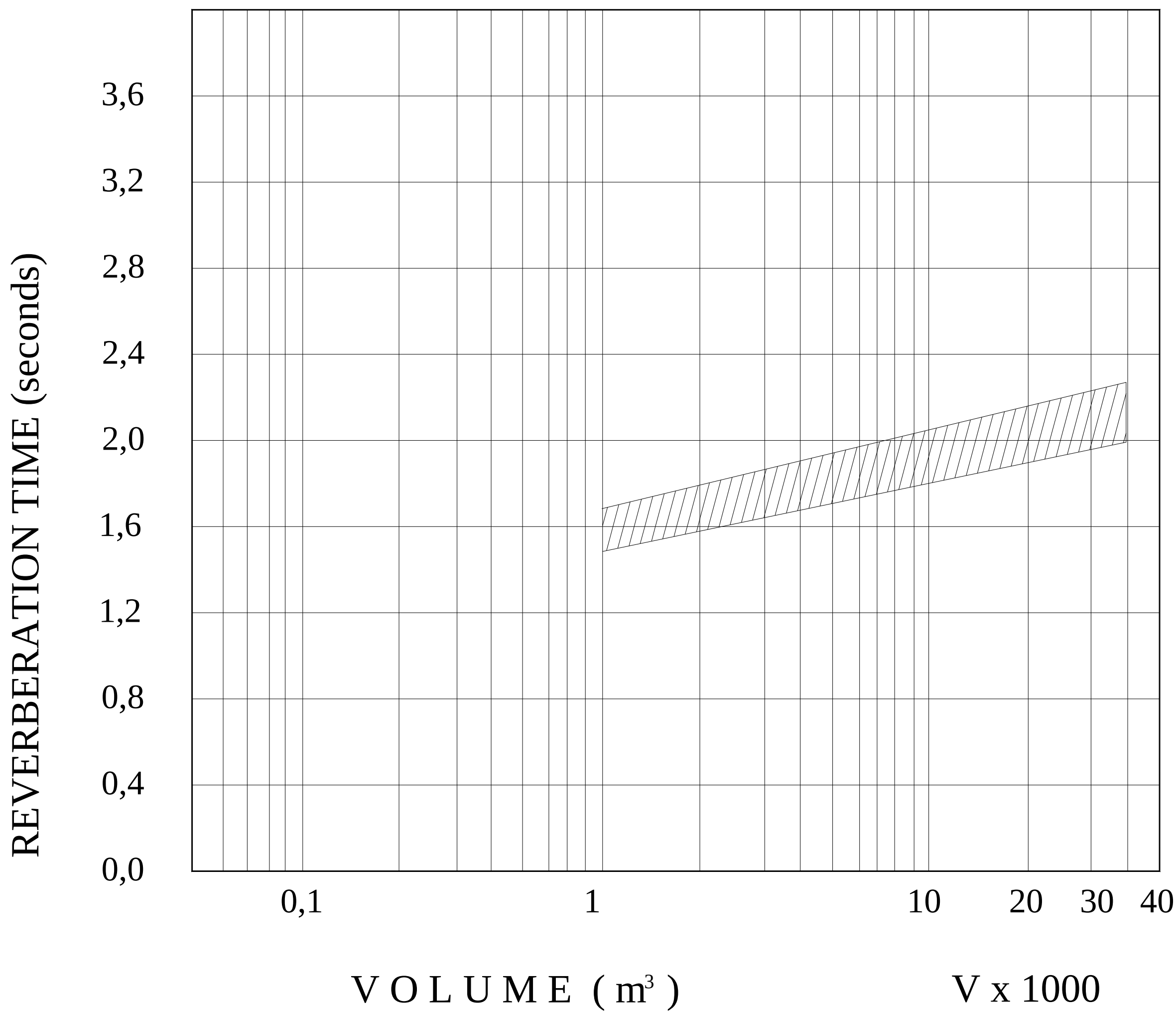


Figure 1.- Optimum Reverberation Time for Music

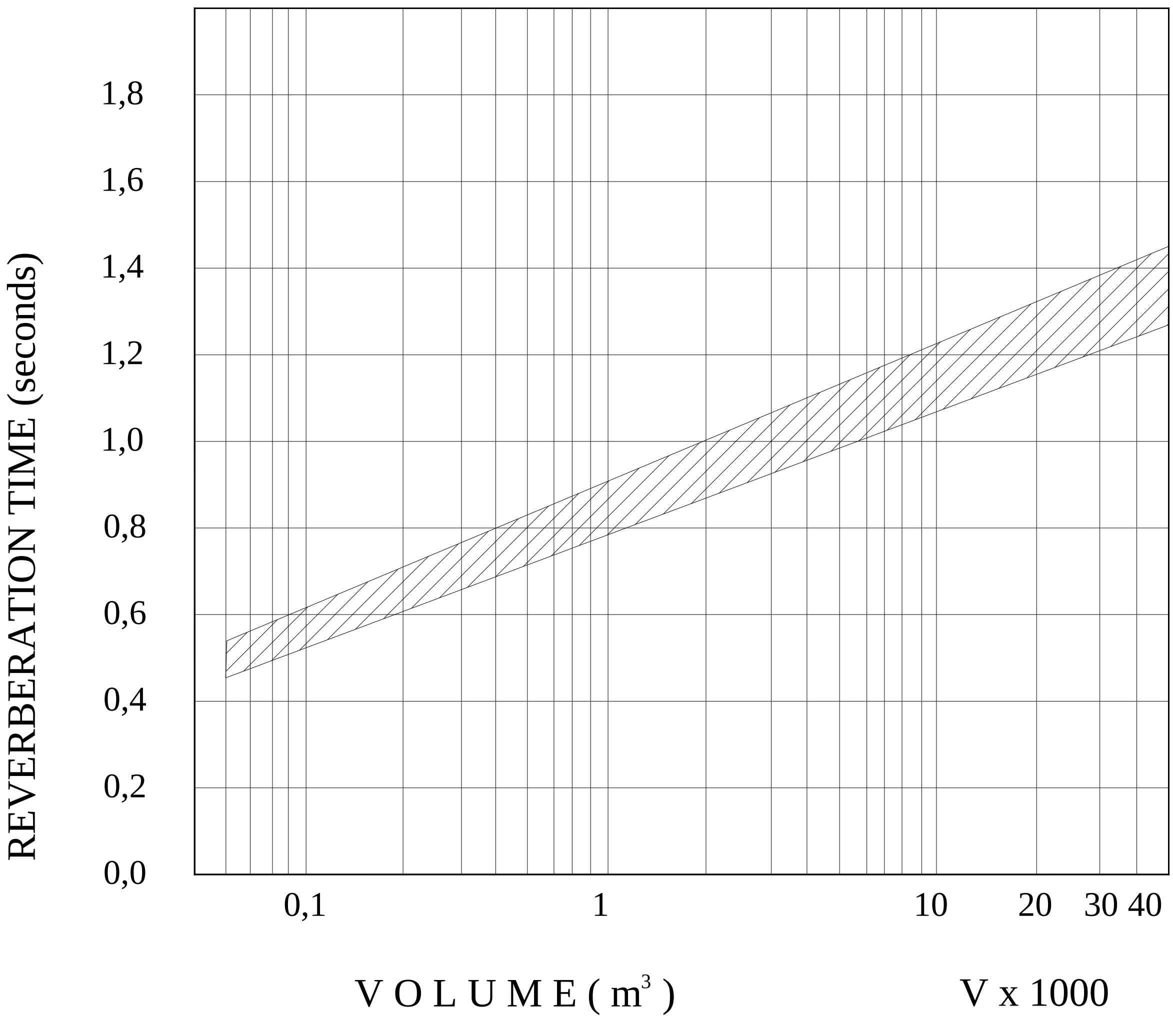


Figure 2.- Optimum Reverberation Time for Speech

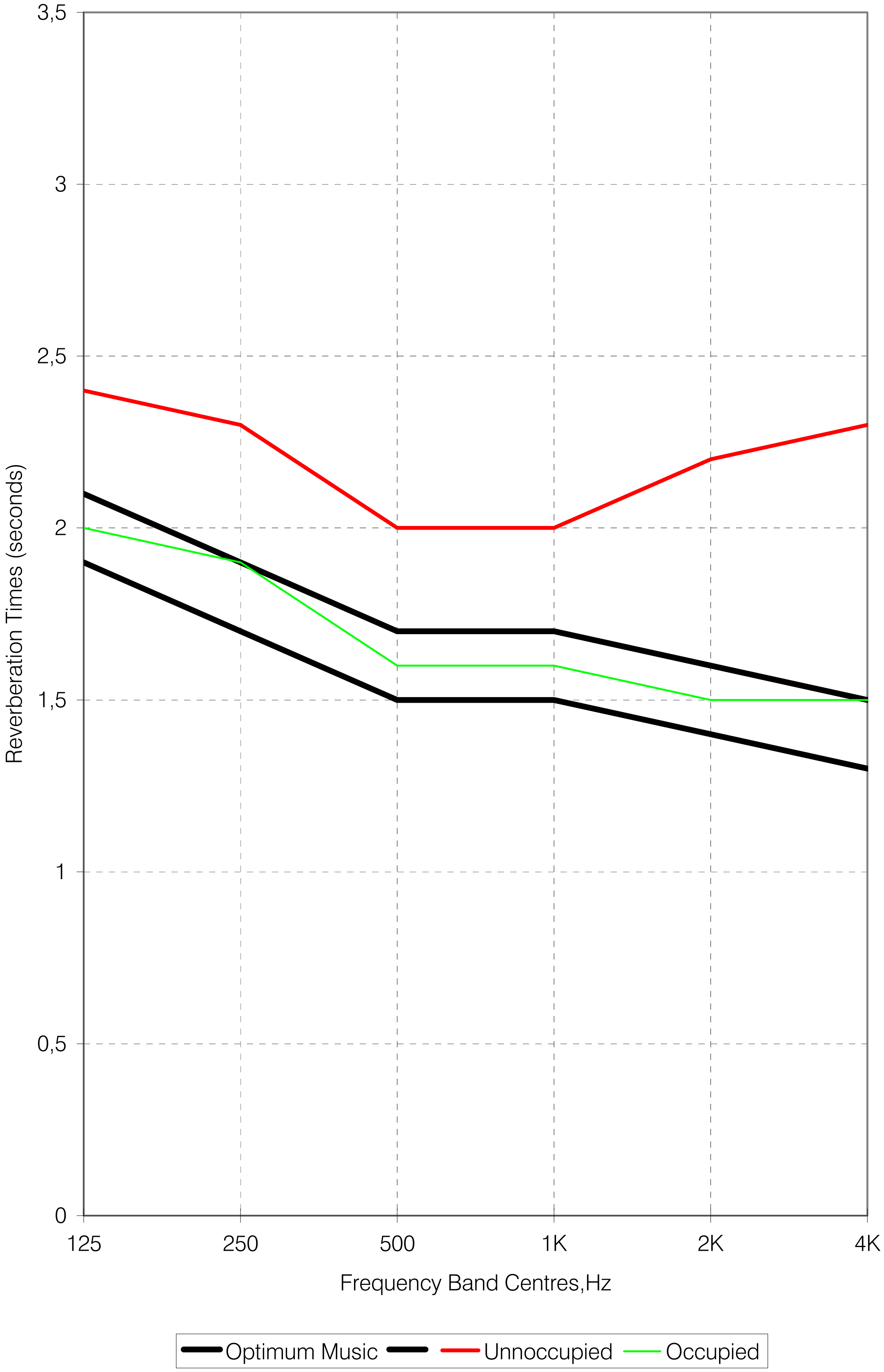


Figure 3.- Concert Mode. Optimum Reverberation Times and Calculations with unoccupied and occupied Hall

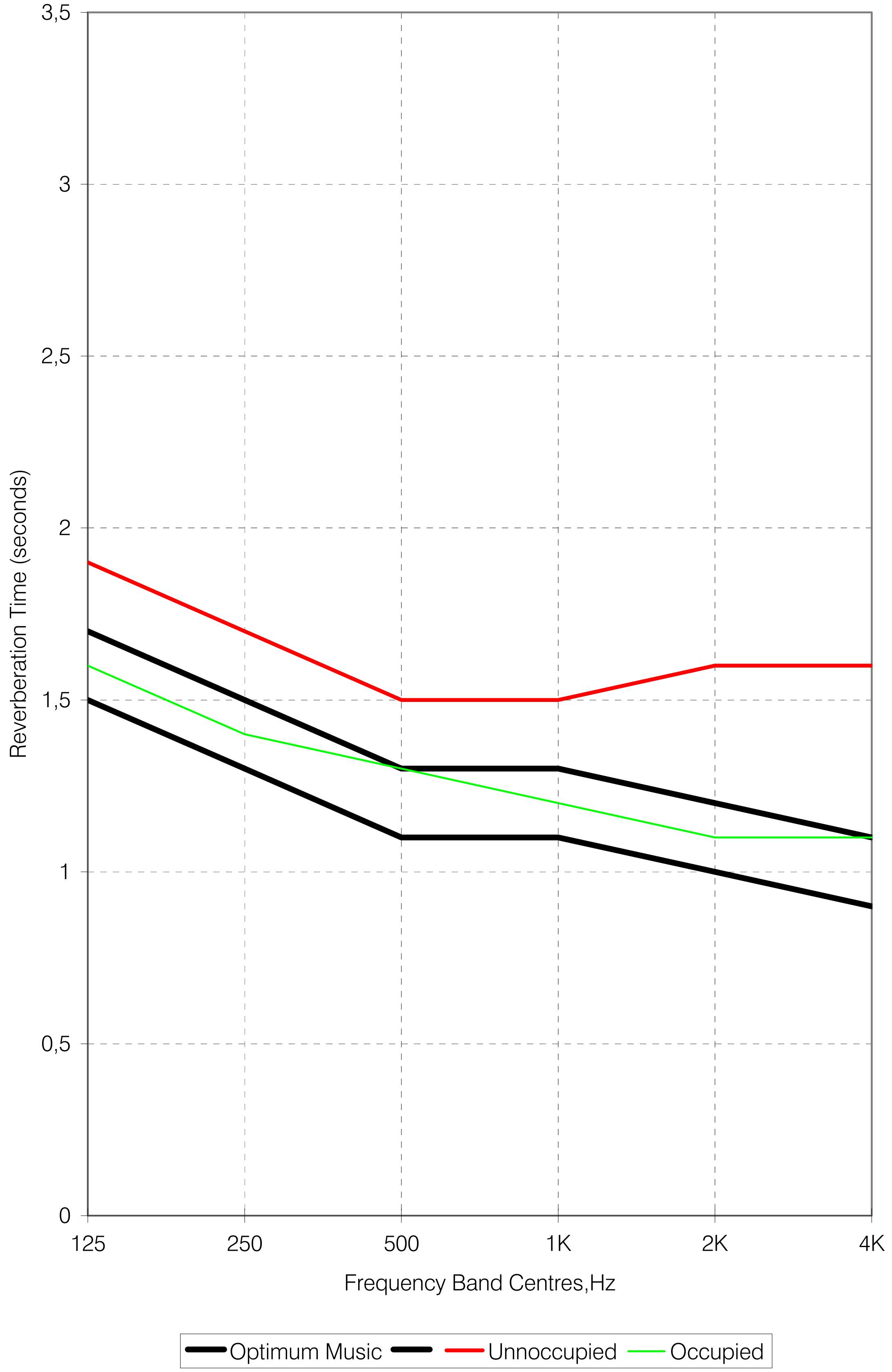


Figure 4.- Speech Mode. Optimum Reverberation Times and Calculations with unoccupied and occupied Hall.

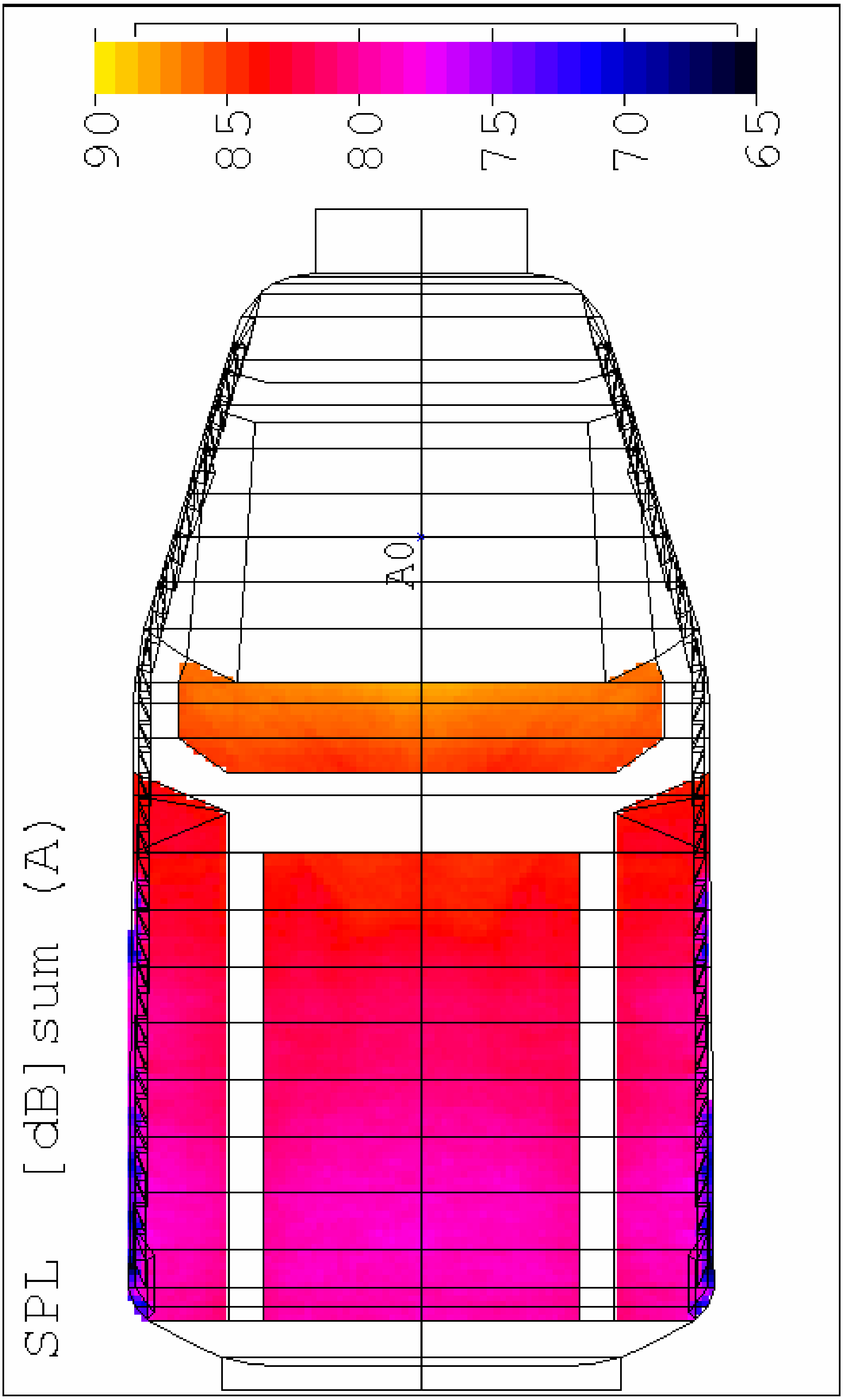


Figure 5.- Concert Mode. Sound Distribution

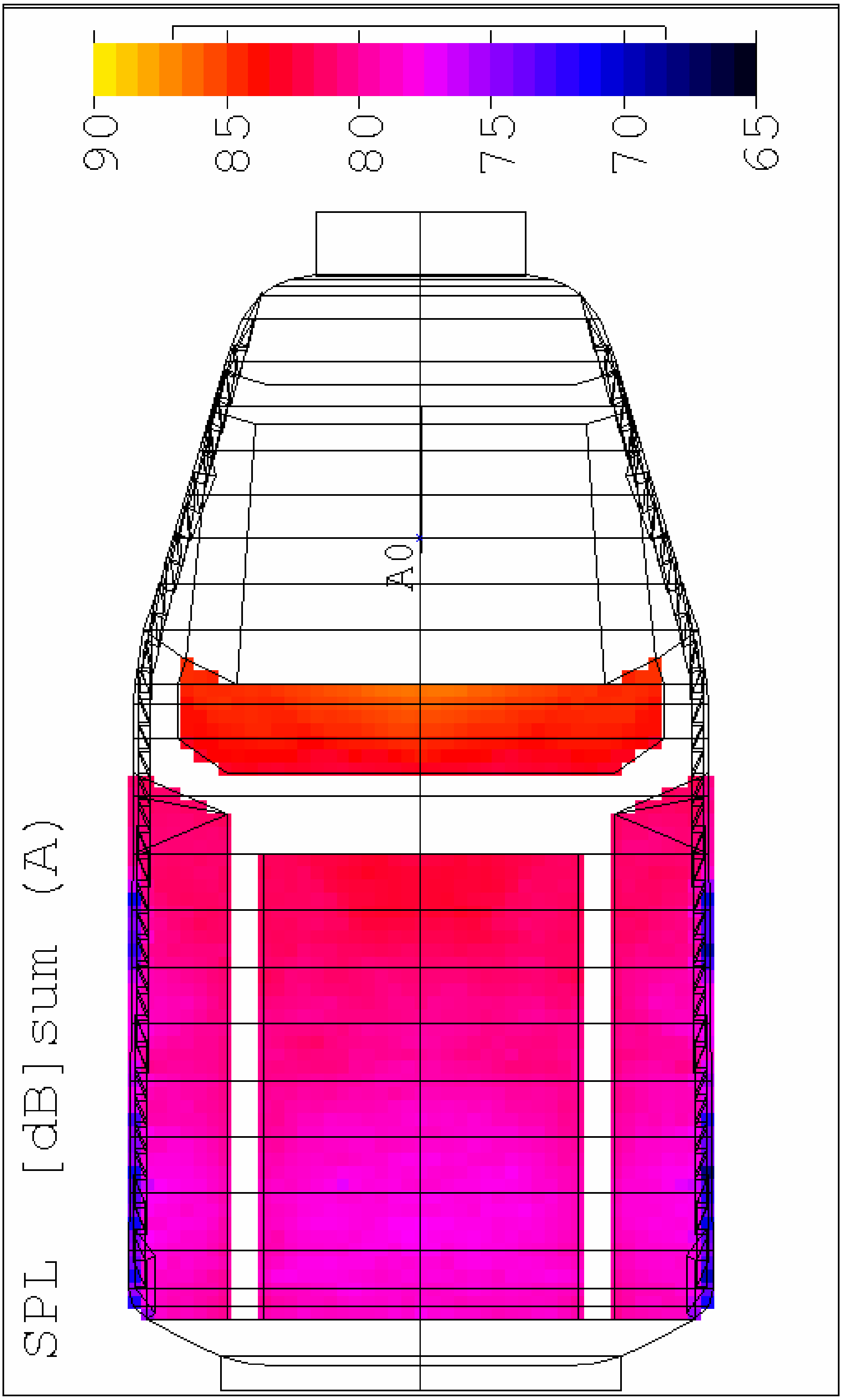


Figure 6.- Speech Mode. Sound Distribution

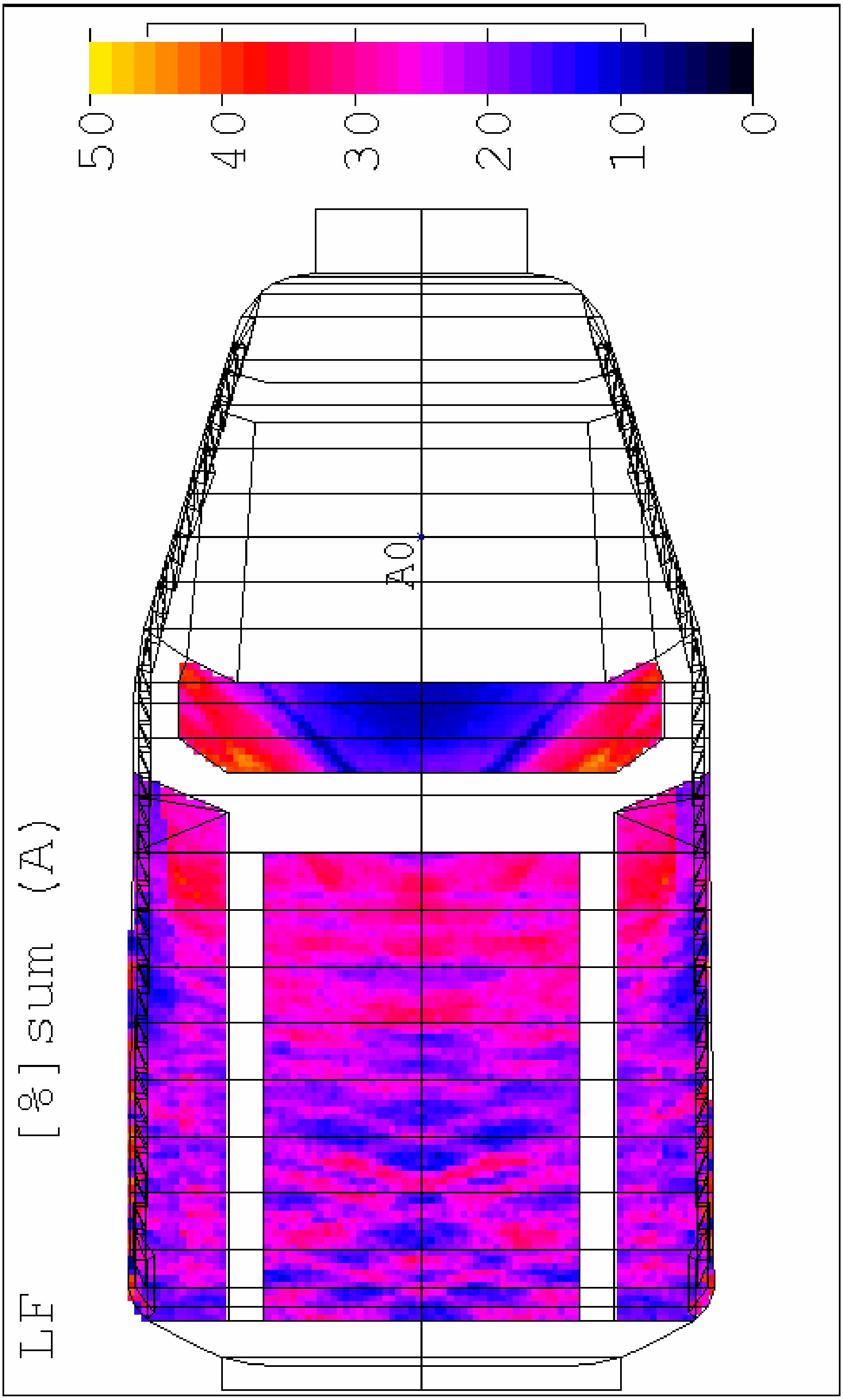


Figure 7.- Concert Mode. Lateral Energy

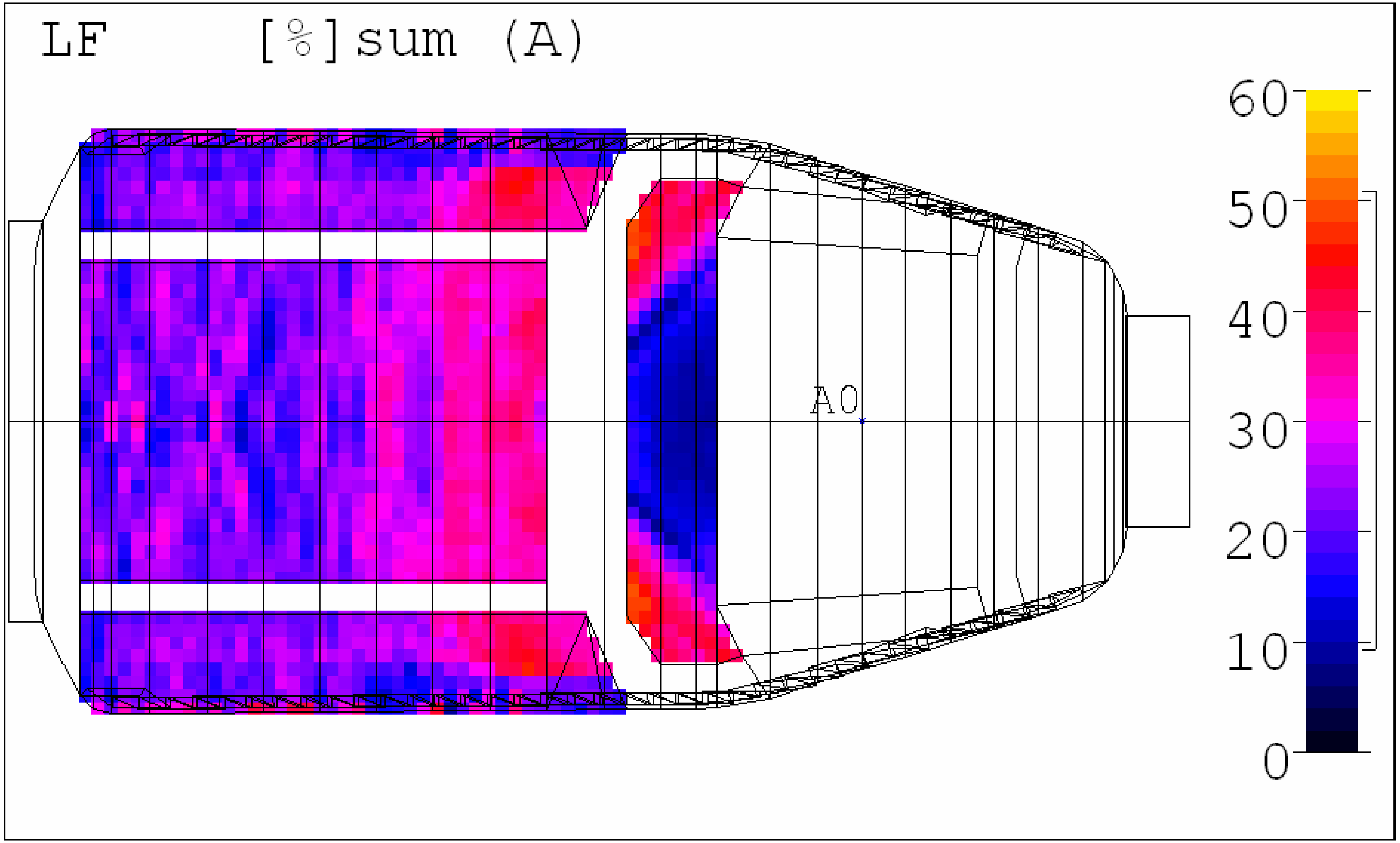


Figure 8.- Speech Mode. Lateral Energy

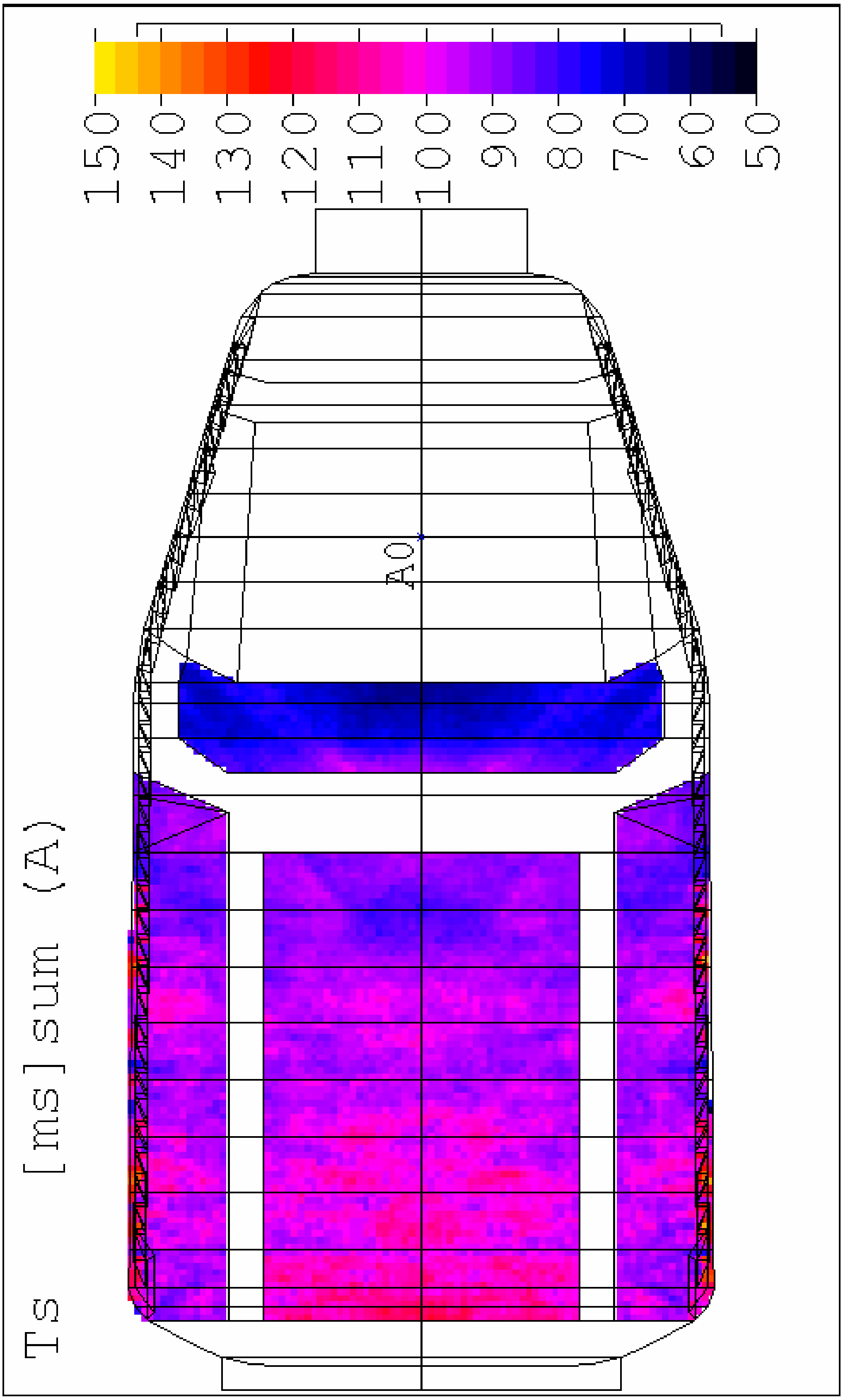


Figure 9.- Concert Mode. Central Time

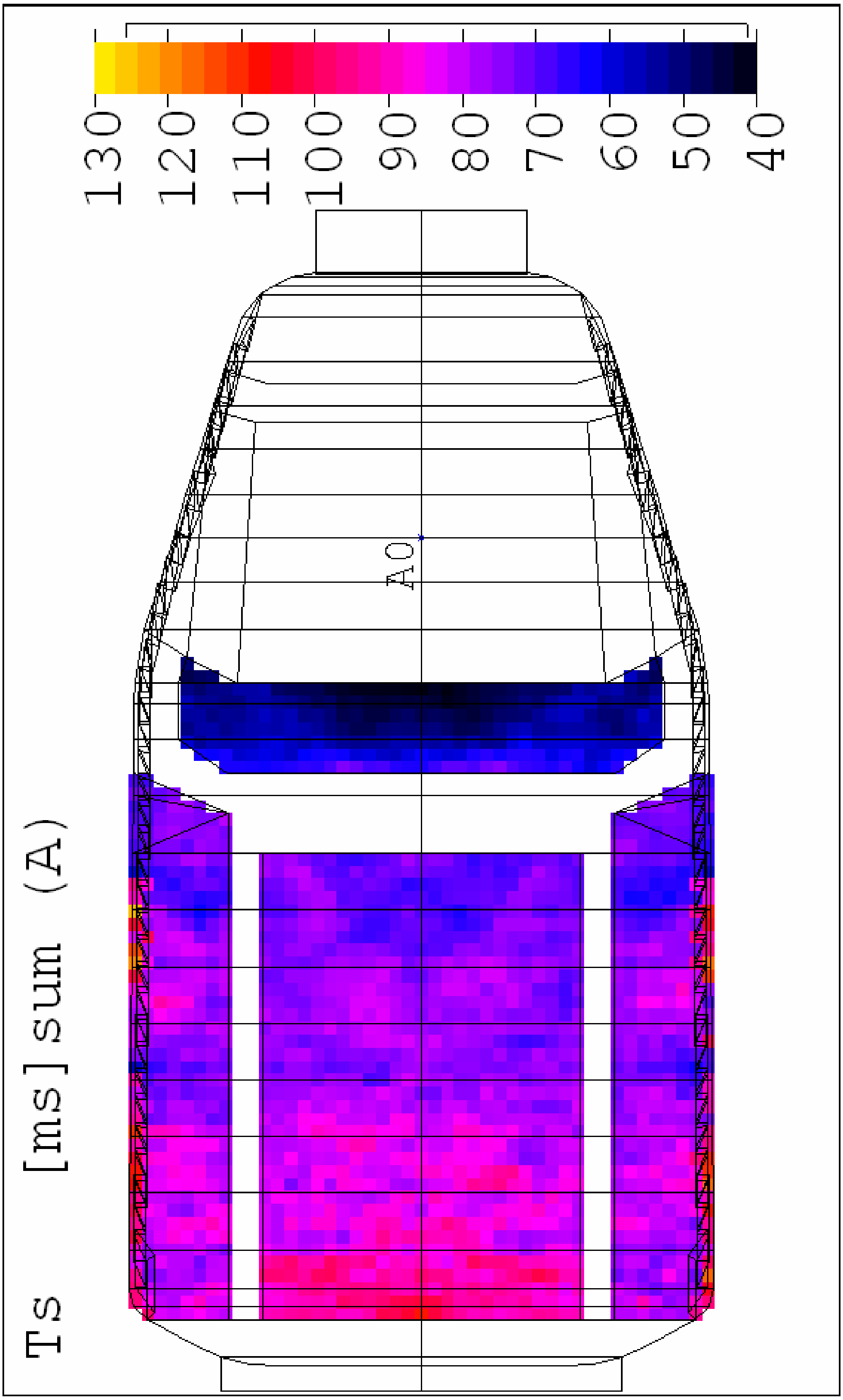


Figure 10.- Speech Mode. Central Time

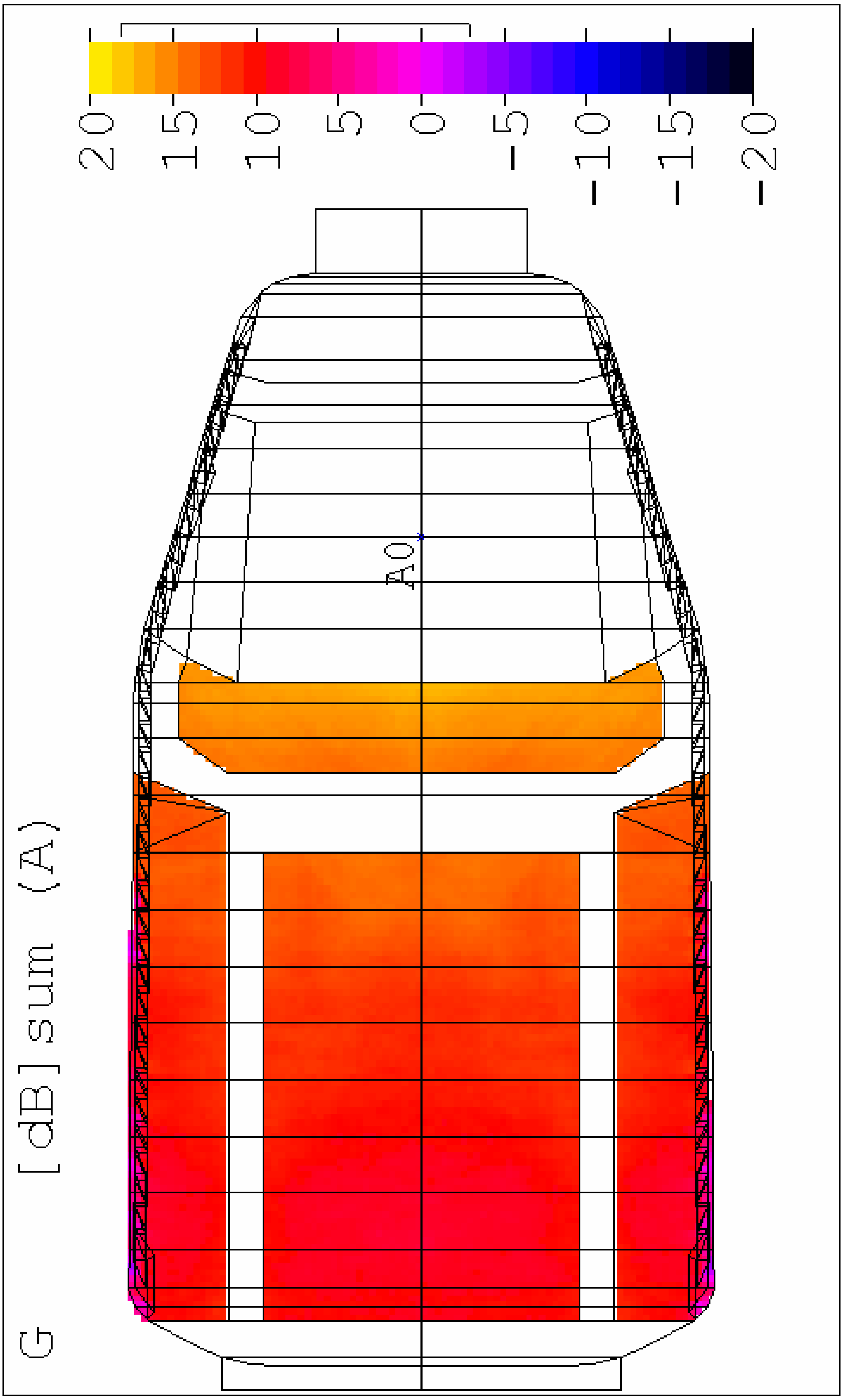


Figure 11.- Concert Mode. Sound Intensity

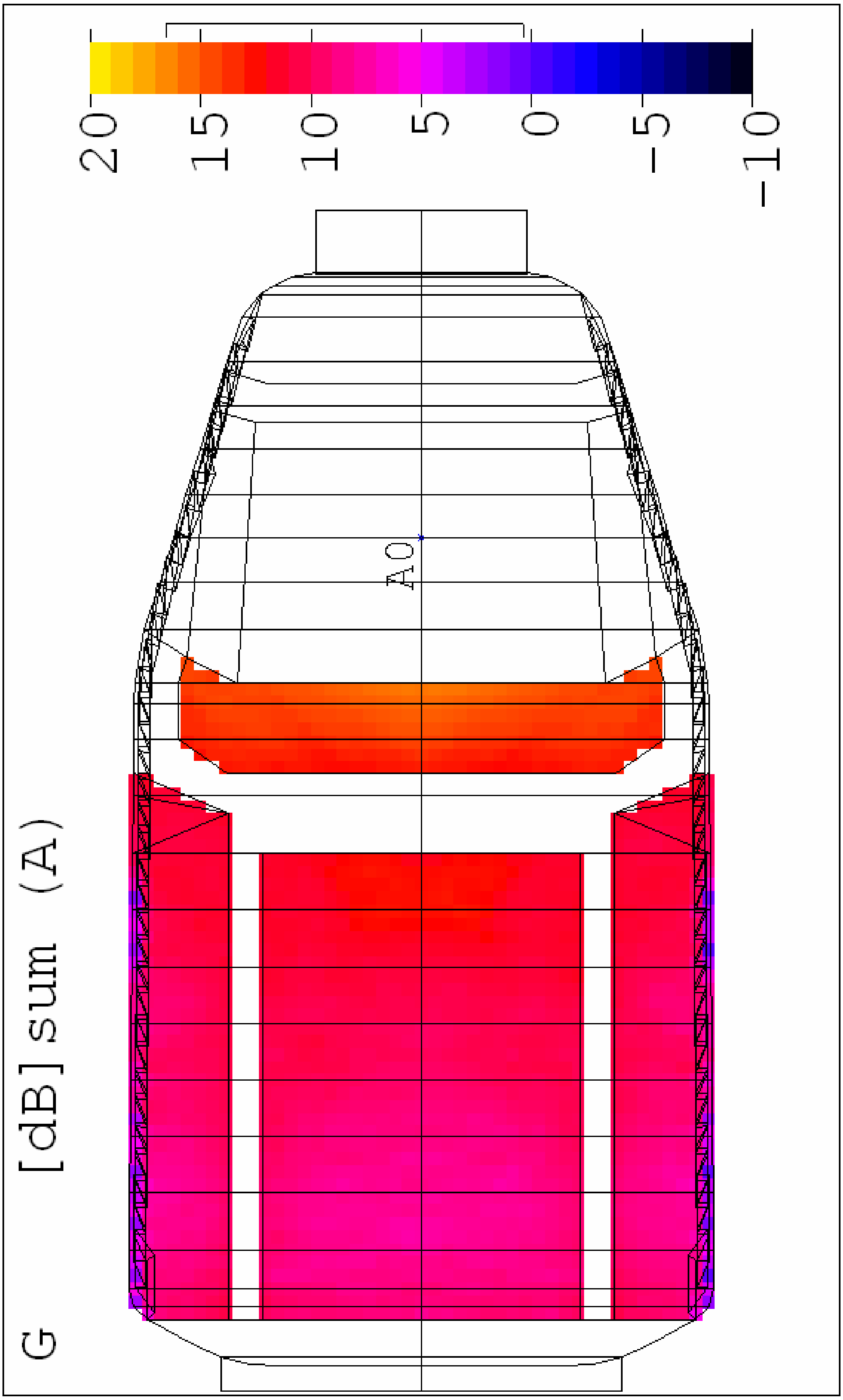


Figure 12.- Speech Mode. Sound Intensity

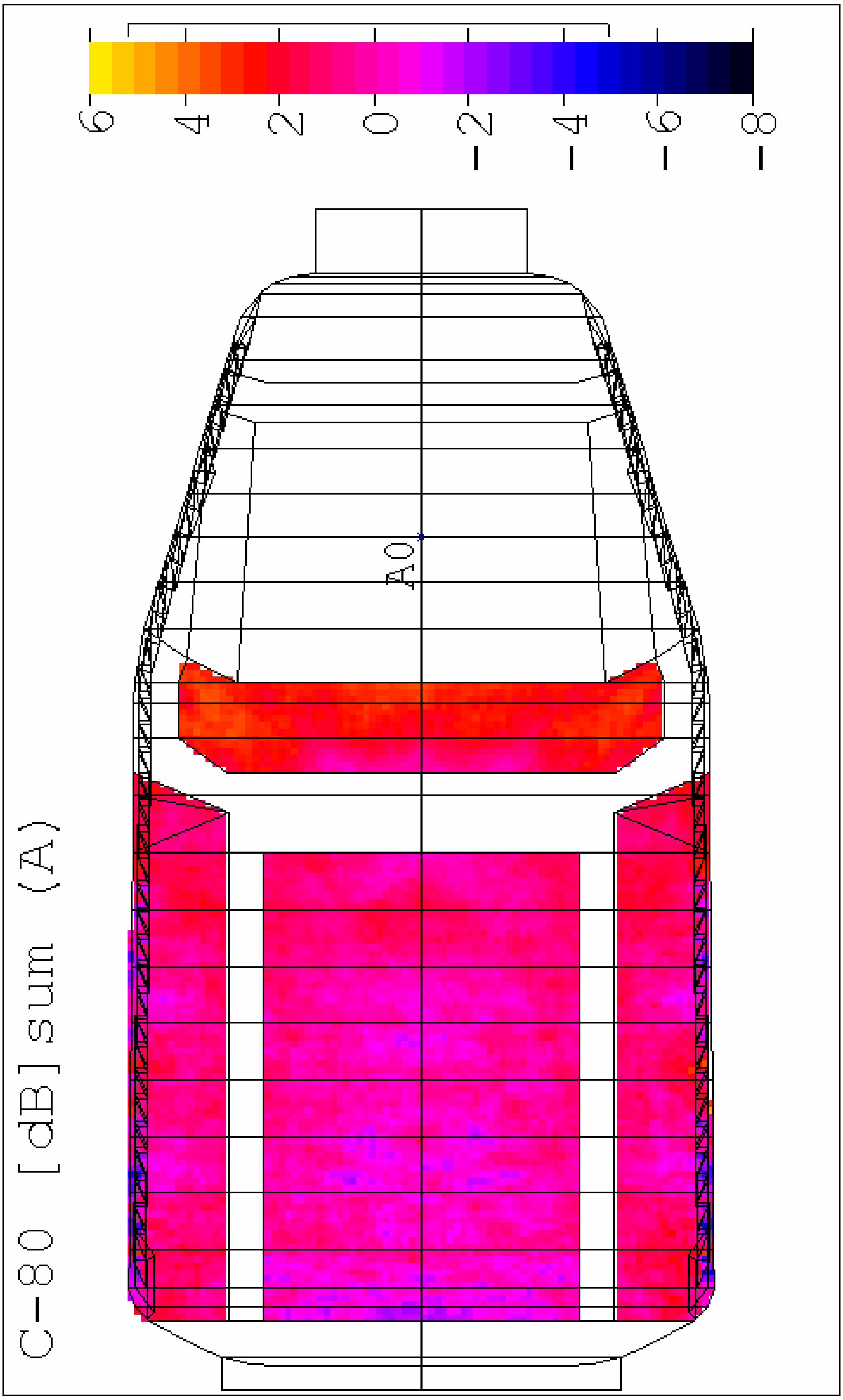


Figure 13.- Concert Mode. Clarity C_{80}

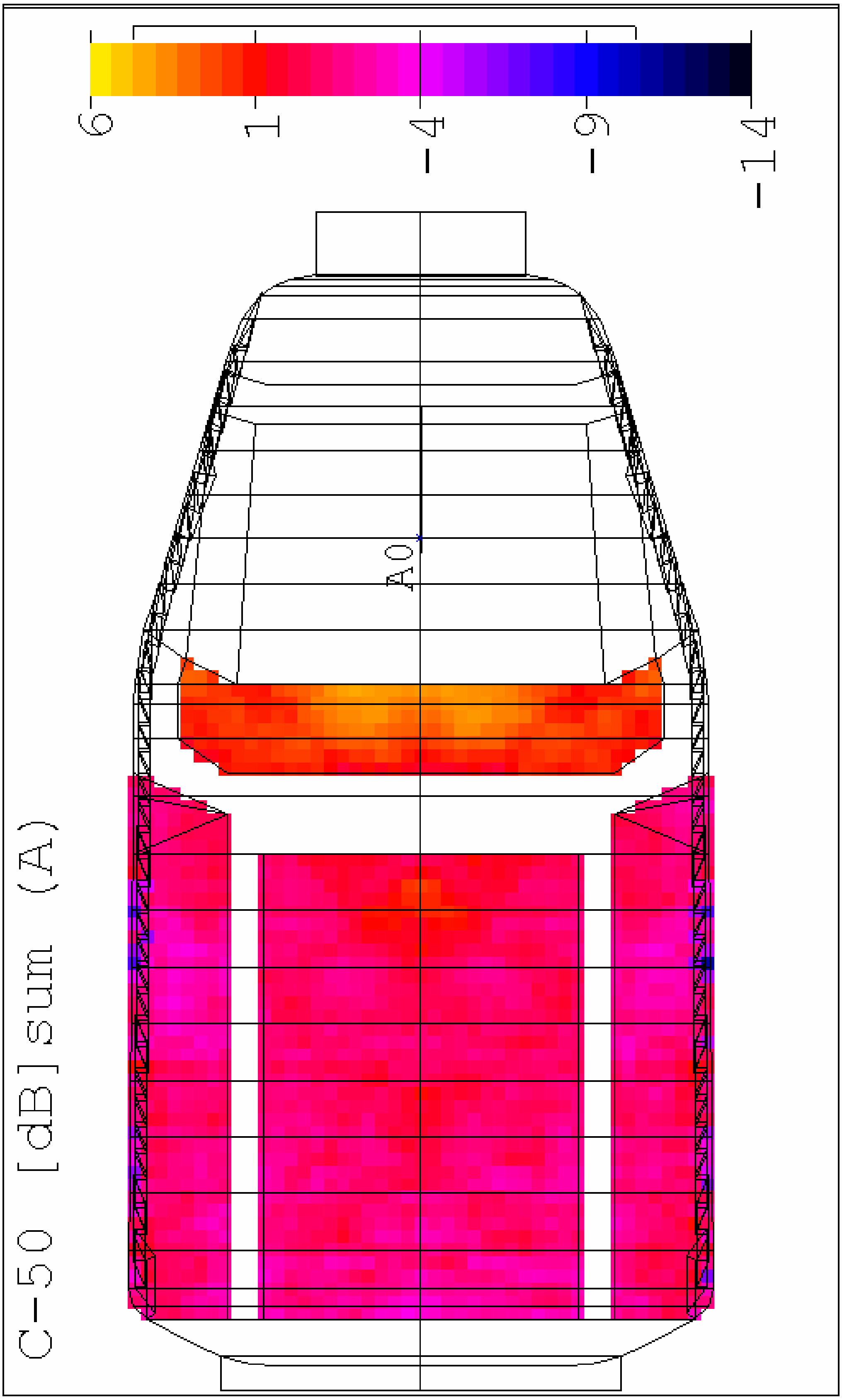


Figure 14.- Speech Mode. Clarity C_{50}

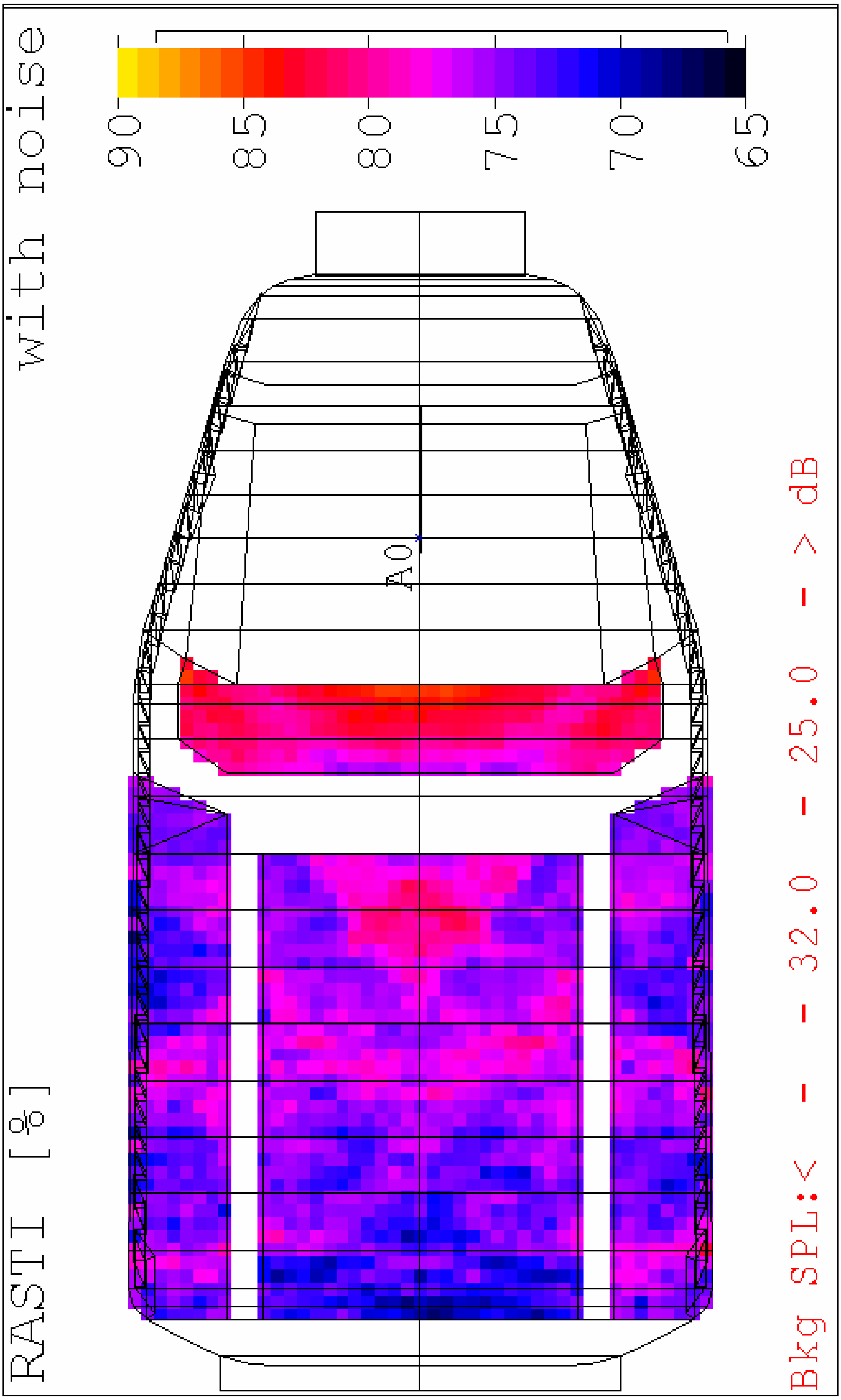
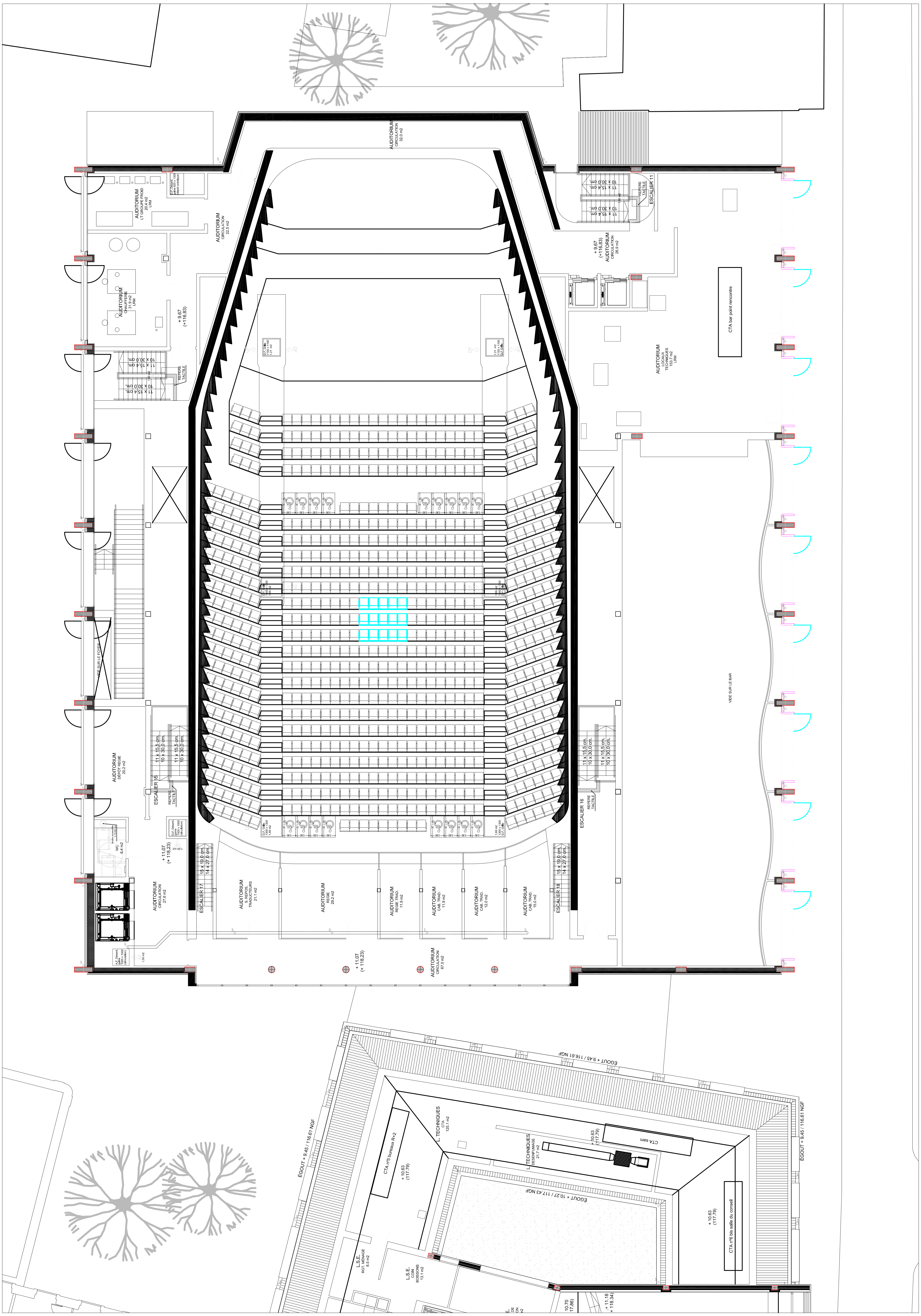


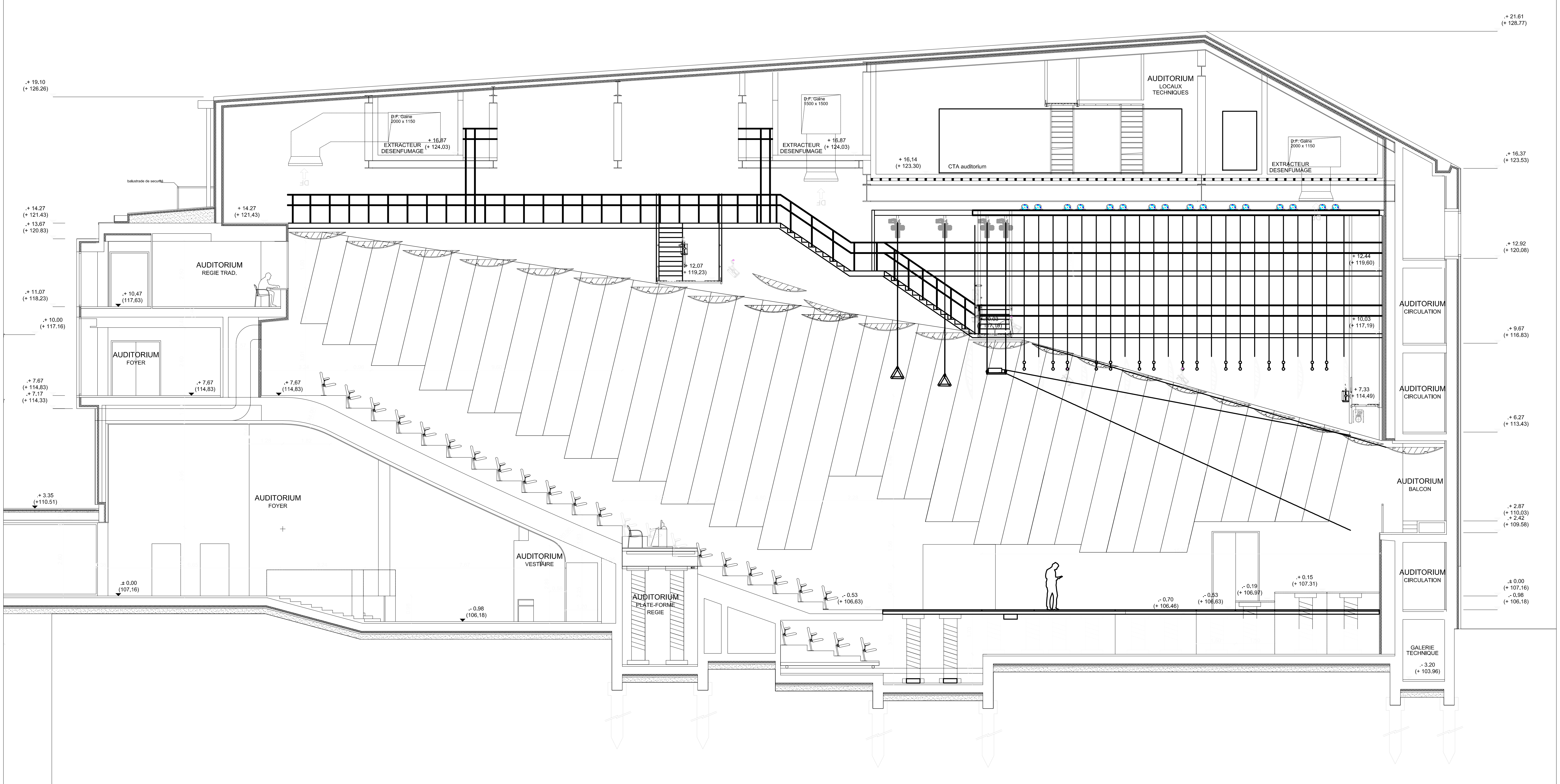
Figure 15.- Speech Mode. RASTI

APPENDIX A

CONTENTS

This Appendix contains ground and section plans of the Auditorium.


AUDITORIUM
CIRCULATION
32,0 m2
ESCALIER 11
CTA bar point rencontre
VIDE SUR LE BAR
ESCALIER 15
ESCALIER 16
ESCALIER 17
ESCALIER 18
L. TECHNIQUES
CTA n°5 bureaux R+2
CTA n°6 bis salle du conseil
ÉGOUT + 9,45 / 116,61 NGF


AUDITORIUM
LOCAUX TECHNIQUES
CTA auditorium
EXTRACTEUR DESENFUMAGE
D.F. Gaine 2000 x 1150
D.F. Gaine 1500 x 1500
+ 16,87 (+ 124,03)
+ 16,14 (+ 123,30)
+ 14,27 (+ 121,43)
+ 12,07 (+ 119,23)
+ 12,44 (+ 119,60)
+ 10,03 (+ 117,19)
+ 7,33 (+ 114,49)
AUDITORIUM
REGIE TRAD.
AUDITORIUM
FOYER
AUDITORIUM
VESTIAIRE
AUDITORIUM
PLATE-FORME REGIE
AUDITORIUM
CIRCULATION
AUDITORIUM
BALCON
GALERIE TECHNIQUE
- 3.20 (+ 103.96)
+ 21.61 (+ 128,77)
+ 19.10 (+ 126.26)
+ 16,37 (+ 123.53)
+ 14.27 (+ 121.43)
+ 13,67 (+ 120.83)
+ 12.92 (+ 120,08)
+ 11.07 (+ 118.23)
+ 10,47 (117,63)
+ 10,00 (+ 117.16)
+ 9.67 (+ 116.83)
+ 7,67 (+ 114,83)
+ 7,17 (+ 114.33)
+ 6.27 (+ 113.43)
+ 3.35 (+110.51)
+ 2.87 (+ 110.03)
+ 2.42 (+ 109.58)
± 0,00 (107,16)
± 0.00 (+ 107.16)
- 0.98 (+ 106.18)
- 0.98 (106,18)
- 0.53 (+ 106,63)
- 0,70 (+ 106,46)
- 0.19 (+ 106,97)
+ 0.15 (+ 107.31)
balustrade de securité