Apparent Source Width and the Church Organ

Brian FG Katz, Christophe d'Alessandro

LIMSI-CNRS, BP 133, F 91403 Orsay, France, Email: brian.katz@limsi.fr, Christophe.d'Alessandro@limsi.fr

Introduction

The Concert Organ and the Cathedral are the two major extremes of their disciplines: Musical Acoustics and Architectural Acoustics. With that, they represent some of the most difficult problems in both domains, violating many of the assumptions typically used. The interest of the current work is preliminary examination of the effectiveness and interpretation of the Apparent Source Width (ASW) in evaluating the acoustic of both the church and also of the instrument itself. The ASW is becoming more commonly used in concert Hall acoustics as one of the descriptions of spaciousness of the hall. The measure of ASW is based on the Inter-Aural Cross-Correlation (IACC) using a binaural recording.

The paper presents an investigation of the ASW first in the context of the church acoustic. Subsequently, the variations due to the church organ itself, presented as a large distributed source having a non-negligible width. How the ASW varies with distance from the organ, in contrast to a simple source, is investigated.

Church / Organ

The Church St. Elisabeth du Temple was constructed from 1628 – 1646, and enlarged in 1829.[1] The tribune, shown in Figure 1, has an arched ceiling height of 17 m in the central portion (ceiling arches notated with dotted lines) with a floor area of ~400 m^2, and an arched ceiling height of 5.5 m on the side sections with a floor area of ~800 m^2 (approximate volume 6300 m^3). Seating capacity is roughly 250-300 parishioners in front of the alter.

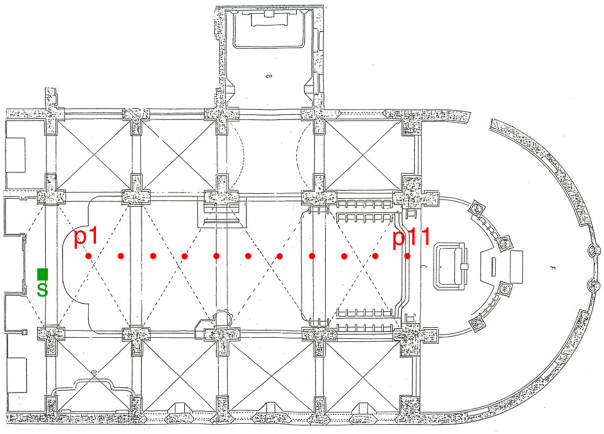

Figure 1: Plan of the tribune of Church St. Elisabeth du Temple. Impulse source and front organ façade position S (in green) and measurement positions, p (in red).

The Grand Organ was constructed by Antoine Suret in 1853 and entirely restored from 1994-1999 by the organ builder Giroud. The organ comprises 39 stops with 42 registers portioned on 3 keyboards of 54 notes and a pedal-board of 30 notes. The organ has 17 reed stops, including two 16' bombards, five 8' trumpets, and three 4' clarions.

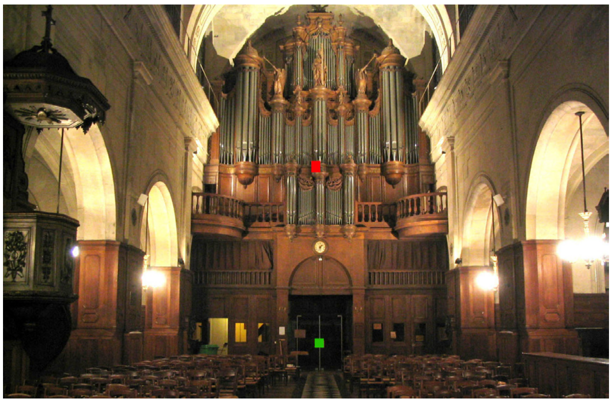

Figure 2: The Grand Organ of the Church St. Elisabeth du Temple, Paris, France. Loudspeaker (red) and balloon (green) source positions indicated.

Source / Receiver

Three sources were use for the measurements. The first was on ground level, in-line with the front façade of the organ. This position was used for balloon burst measurements, highlighted in green in Figure 2. The second position was atop the positive chest, where a loudspeaker was placed, highlighted in red in Figure 2. A sweep sine excitation signal was used, and then deconvolved to obtain the impulse response. Finally, a third source consisted of the excitation of the entire organ (consisting of more than 2500 tubes) using all keys (keyboards coupled), all pedal keys, and all stops.

Binaural measurements were made using a KEMAR dummy head with torso, orientated along the centerline. Eleven measurement positions, at 3 m intervals, were chosen along the centerline, as shown in red in Figure 1.

Measurements

Reverberation Time

Reverberation time measurements were made to in order to characterize the room following current standards.[2] The results of these measures are shown below in Table 1. No significant variations were found between positions.

	125	**250**	**500**	**1000**	**2000**	**4000**
mean(T_{20})	2.70	3.10	3.68	3.68	3.03	2.14
std(T_{20})	0.18	0.12	0.10	0.07	0.04	0.03

Table 1: Spatial average and corresponding standard deviation of reverberation time, T_{20}, in octave bands.

IACC

The inter-arual cross-correlation coefficient, IACC, is the only measurement which currently makes use of the binaural perception of sound.[2] Previous studies have shown that the IACC is strongly correlated to the subjective impression of envelopment and the perception of Apparent Source Width (ASW).[3][4] Beranek states that the early IACC ($t_1 = 0$, $t_2 = 80$ msec), termed $IACC_E$, averaged over the three octave bands (500, 1000 & 2000 Hz), termed $IACC_{E3}$, is strongly correlated to ASW. The integration over all time, $IACC_{A3}$ where $t_2 \rightarrow \infty$, and IACC late, $IACC_{L3}$ ($t_1 = 80$ msec, $t_2 = 1000$ msec $\rightarrow \infty$) correlate well with the spatial impression of listener envelopment. The results for these parameters for the various sources are presented in Figure 3. Typical values for $IACC_{E3}$ for good halls are in the region of 0.35, while poorer halls have values 0.6 to 0.7.

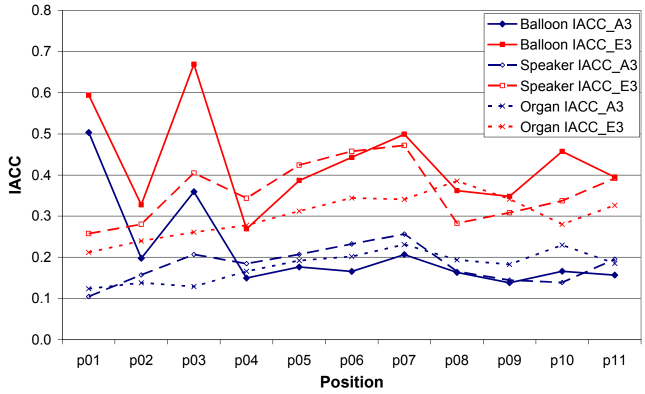

Figure 3: $IACC_{A3}$ and $IACC_{E3}$ results for the three source configurations.

$IACC_{A3}$ is seen to vary little with position (p4–p11), indicating a homogenous reverberant field. This is also little variance with respect to source type or location for the same positions. $IACC_{E3}$ results separate spatially and with regards to source type (point vs. organ). Regarding the variations with position one must consider the geometry of the room. There is an asymmetry in the room (p6-p8) resulting also in a reduction in the size of the room at p8. This high values at p1 for the balloon are expected due to proximity to the source. There is also interesting behavior at p3 for point sources which is likely due to the incident angle of a strong first reflection and the nature of the IACC spatial response. This property of the IACC remains to be fully studied.

Transform from IACC to ASW

Using the values obtained for $IACC_{E3}$, it is possible to estimate ASW. Several studies have shown direct connections between measured IACC and subjective ASW data.[5] The relationship between the parameters is dependent upon absolute level but does not show a linear correlation to level. The RMS level of the loudspeaker source impulse response measurements were calculated and seen to be stable within ±1 dB for all measurement positions. Therefore, once a reference level is chosen for the ASW calculation there is no need to adjust for changes due to receiver position. Based upon the reported data by Morimoto [4] for a source level of 80 dBA, a 2^{nd} order polynomial fit was used for the estimation of ASW from $IACC_{E3}$ values.

As with IACC, these results show very little variation between the impulsive source on the floor and at the organ level for receiver positions 4−11.

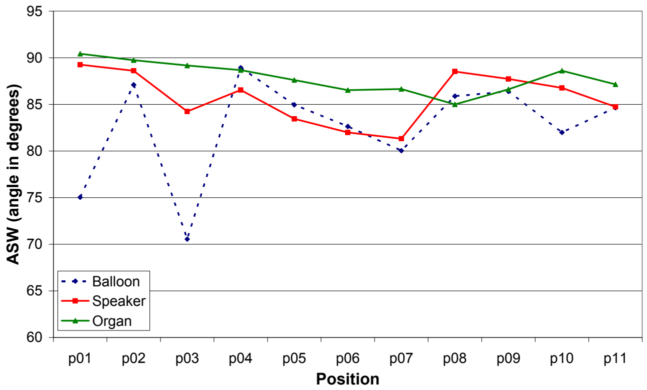

Figure 4: Apparent Source Width (ASW) estimation using $IACC_{E3}$ measurement results.

Comparisons between the impulse source at organ level and the actual organ excitation show that there is a slight increase in ASW of approximately 5° for central positions.

Conclusions

The application of IACC and ASW to an Organ and reverberant Church has been accomplished with some success. The effect of the size of the source (point vs. full Organ) on the ASW has been shown, though not to a great extent. Extrapolation of IACC – ASW correlations from existing studies may not be valid for such low IACC values. The suitability of IACC in highly reverberant space may not be justified.

Acknowledgements

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References

[1] Reference to Sainte-Elisabeth du Temple organ homepage. URL: `http://www.musimem.com/ste-elisabeth.htm`

[2] ISO 3382:1997 Acoustics - Measurement of the reverberation time of rooms with reference to other acoustical parameters.

[3] L Beranek. *Concert and Opera Halls: How They Sound*, Acoustical Society of America, New York, 1996.

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[5] M Morimoto and K Iida, “A practical evaluation method of auditory source width in concert halls,” J. Acoust. Soc. Jpn.(E), 16(2) (1995), 59-69.