A specific cabin for restitution of sonic boom : application for perceptive tests

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1. Introduction

A French research project about future supersonic planes has risen the need for assessing the loudness of a sonic boom. All previous studies had been done for the Concorde project or military fighter many years ago [1] [2], and did not provide definitive conclusions about the possibility to use supersonic planes above or near populated areas. Conducting psychoacoustic tests [3] [4] about sonic boom rises two main difficulties : first, the sonic boom spectrum has its maximum at subaudio frequencies, and second it is a transient signal, which means that higher frequencies play a significant role even if their average energy is far lower than lower frequencies. As it is not yet known how these two aspects are perceived together, reliable tests require a dedicated reproduction tool which must ensure that the listener is immersed in a sound field as close as possible to the actual one. This requirement led to the design of a "closed simulator" for which the boundary conditions and the sources have been optimized as a whole for the reproduction of the subsonic and audio spectrum of sonic booms. This design is also part of a longer term project aiming at reproducing arbitrary 3D sound fields inside a volume.

2. The sonic boom

An example of sonic boom signal is given by figure 1. It is an "N-wave", with a quite high peak pressure (over 120 Pa). Its spectrum is maximum around 3Hz, and extends over the full audio range, even if most of the energy is below 30 Hz.

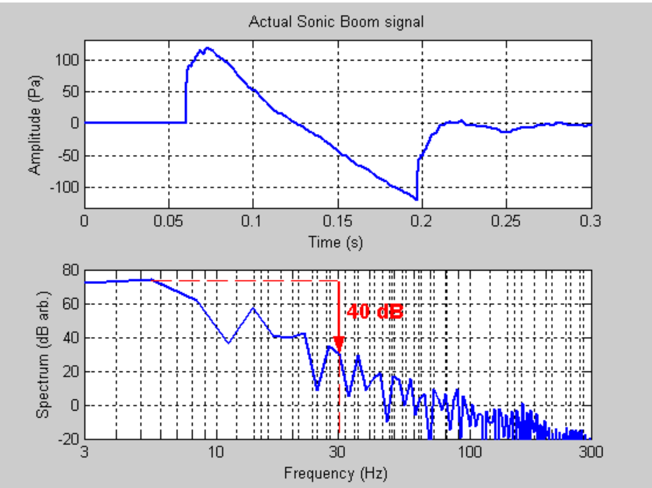

Figure 1 : Example of an actual Sonic boom signal and its spectrum

Of course, this signal is scaled down for the psychoacoustic tests, as annoyance assessment does not require such high levels. Our goal is thus to reproduce with good accuracy sonic boom peaks up to 110dB .

3. Reproduction system

At very low frequencies, monopole subwoofers inside a room create a virtual variation of the overall volume, resulting in an uniform adiabatic compression of air inside the room. This allows reproduction of nearly DC components, if the room is almost sealed ("pressure chamber"). For increasing frequencies, the structure of the field may be represented by an eigenmodes expansion. Even for small rooms, this starts at frequencies low enough that it is not realistic to damp all the corresponding resonances by absorbant materials. Conversely, at higher frequencies, a suitable lining on the walls allows to consider the room as close to semi-anechoïc. The whole frequency range is therefore splitted into three parts : very low frequencies (VLF, below the first resonant mode), low frequencies (LF, up to about 200 Hz), and the remainder of the audio spectrum (HF). This division leads to a triple control system, with different constraints for each frequency band.

3.1 Multi-channel control

The VLF range includes most of the sonic boom energy, and thus requires a high output level. As the VLF pressure is proportionnal to the volumic velocity of the source, any monopole source able to move the required volume of air is adequate. From a practical point of view, this requires multiple speakers, so that their membrane displacement is low enough to ensure linearity, but they can be driven by a common signal. The LF range contains much less power, but requires multiple sources in order to control independently the different modes of the room. These two frequency bands can share the same loudspeakers, if they are controlled using two different criteria. The positions of the speakers are chosen for the LF range, as they are unimportant for VLF. The third frequency range (HF) contains very few energy, and can be reproduced by small HiFi speakers fed by a single signal (for a front coming wave). The resulting reproduction system therefore consists of 16 subwoofers fed by 16 separate power amplifiers for both VLF and LF, plus 2 small monitor speakers (GENELEC 1031A) for the HF range. A stereo PC soundcard outputs one signal for the HF speakers, and the second one is fed to an analog splitter (Rane DA216A) which outputs the subwoofer signals. Sonic boom samples are digitally pre-filtered, both for splitting the spectrum and for equalizing the system response.

3.2 Subwoofers design

The subwoofers are closed boxes working below their resonance, whose response is therefore constant at low frequencies inside an airtight room. The main requirement is the volumic displacement, which is divided by the number of speakers. The peak displacement of the speaker membranes has been fixed to 2mm. This is conservative when dealing with high-end woofers, but is required to guarantee a sufficiently linear behaviour. Taking into account the volume of the cabin and a 110dB peak pressure, our goal can be achieved using two 12" woofers (HT300G0) inside each of the 16 boxes. These two speakers are mounted in a "push-pull" combination, in order to further reduce the 2nd harmonic distortion of the sources, and they are coupled to the room through a large rectangular vent which acts as an acoustic low-pass filter (cut-off around 250 Hz).

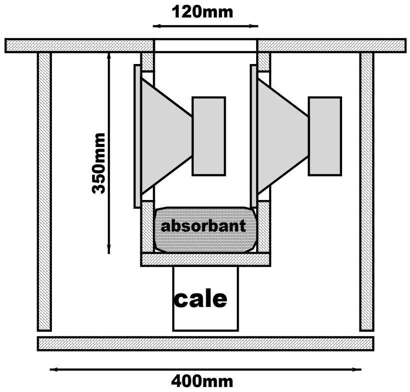

Figure 2 : cut view of a subwoofer

4. Structure of the Cabin

The simulation cabin has been built inside an existing audiometric cabin with concrete walls ensuring a very good insulation from outside noise, and almost airtight so that outdoor turbulence has little effect on the internal pressure field at VLF. Although the existing cabin is rather large, the dimensions of the simulation cabin have been kept to a minimum, because this reduces the requirement on the sources, and shifts modal resonance toward higher frequencies. Cabin dimensions of 3 x 2 x 2 m (L x l x H) have been considered sufficient to receive a listener in the cabin, and leave enough room for fitting the subwoofers at selected locations on the walls.

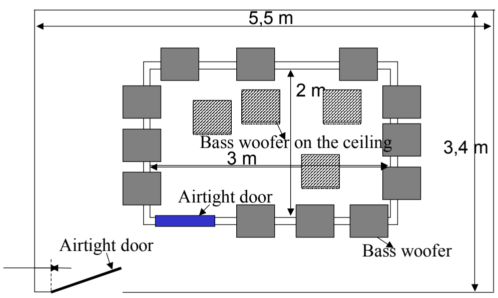

Figure 3 : Schema of the installation of the sonic boom cabin inside the existing audiometric cabin.

The inside walls are built using lightweight materials (aerated concrete bricks for the walls, and thick wood panels for the ceiling). Ribs and damping (sand) allow a significant reduction of boundaries vibrations. Careful sealing of all junction, and choice of the door, result in an almost airtight cabin as required for the VLF reproduction. The 16 subwoofers are mounted on the walls and the ceiling, at pseudo-random locations (to allow coupling with all active modes). The volume between the simulation cabin and the walls of the existing audiometric cabin is filled with acoustical absorbent materials to prevent significant parasitic resonances. The inside of the sonic boom cabin is lined with rockwool panels (Acoustished mural R), which lead to a semi anechoic behavior at higher frequencies.

Photo 1 : Inside view of the cabin (without lining).

5. Conclusion

First tests have demonstrated the ability of this cabin to reproduce a high enough pressure level at very low frequencies, with a very good linearity. Equalization of its response is close to its end, as part of the implementation of the multi-channel control system. These are the last steps of the design of an original system optimized for the reproduction of sonic boom signals. Psychoacoustical tests on the study of the loudness of sonic booms should therefore start very soon. Further work will be to extend the control system for synthesizing various 3D sound fields in a volume surrounding the listener position (Active Field Control).

6. References

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[2] "A new simulator for assessing subjective effects of sonic booms". J.D. Leatherwood and Al – NASA TM 104150, December , 1991

[3] "Etude du sursaut provoqué par le bang sonique chez l'homme". K. Buck and Al, ISL - Rapport R 114/77

[4] "Summary of recent NASA studies of human response to sonic boom". J. D. Leatherwood and Al – JASA **111 (1)**, Pt. 2, Jan 2002.

7. Acknowledgments

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