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# Results of the 2016 UT Modeling Benchmark Proposed by the French Atomic Energy Commission (CEA) Obtained with Models Implemented in CIVA software

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**Abstract.** For several years, the World Federation of NDE Centers, WFNDEC, proposes benchmark studies in which simulated results (in either ultrasonic, X-rays or eddy current NDT configurations) obtained with various models are compared to experiments. This year the proposed UT benchmark proposed by CEA concerns inspection configurations with multi-skips echoes i.e. the incident beam undergoes several skips on the surface and bottom of the specimen before interacting with the defect. This technique is commonly used to inspect thin specimen and/or in case of limited access inspection. This technique relies on the use of T45° mode in order to avoid mode conversion and to facilitate the interpretation of the echoes. The inspections were carried out with two probes of different aperture working at 5MHz.

## INTRODUCTION

The T45° multi-skips inspections have been carried out on two steel planar specimens containing one vertical backwall breaking flaw. To evaluate the influence of the beam divergence on the detectability after several skips, inspections were done with two probes working at the same frequency (5MHz) but with two different apertures. The inspections were performed using immersion technique rather than a contact one to ensure a better reproducibility.

This communication presents the results obtained with the models implemented in the CIVA software. In CIVA, the field radiated by the probe is computed by applying the so-called pencil-model [1], the elastodynamic (for acoustics see [2], [3]) PTD (Physical Theory of Diffraction) system model [4], [5] is then applied to predict the response of notches and the SOV (Separation Of Variables) model [6] is used for the SDH responses used as reference. The comparison between simulated and experimental results are presented and discussed.

This work is done in the context of experimental validation [7] of the ultrasonic module of CIVA which results are available on the EXTENDE website [8].

## DESCRIPTION OF THE 2016 ULTRASONIC BENCHMARK PROPOSED BY CEA

Experimental measurements were carried out at CEA LIST. Acquisitions were performed using two immersion probes working at 5MHz, tilted in order to generate transversal waves at 45°. Two setups were considered, one for each probe (Figure 1). For setup 1, a Ø12.7mm probe was used to inspect a 12mm thick planar block while for the setup 2, a Ø6.35mm probe was used to inspect a 5mm thick planar block. This second setup aims at assessing the multi-skips echoes after a maximum number of skips. For each setup the probe was moved in two perpendicular directions over the notch. During the displacement of the probe, the multi-skips echoes waveforms received at each position were stored (experimental C-scans) and the maximum amplitude of each echo was also recorded. The reproducibility of the results has been checked and the confidence interval of the experimental data presented in this paper has been evaluated at +/-2dB.

An example of experimental C-scan obtained on setup 1 including the first 4 multi-skips echoes and the B-scan extracted above the defect center (red dotted line on the C-scan) are presented in Figure 1.

The echoes of highest amplitude (numbered 1 to 5 on the figure) correspond to paths for which the difference between the number of skips of the beam on the backwall of the block during the forward path (probe-> notch) and the number of skips during the return path (notch-> probe) is 1. These paths, corresponding to specular echoes, are represented in Figure 1 from echo number 1 corresponding to the T corner echo (1 skip of the beam on the backwall

for the forward path and no skip during the return path) to echo number 4 (4 skips of the beam for the forward path and 3 skips for the return path).

In this communication, the overall amplitude of these echoes numbered 1 to  $n$  are compared on the figure (and referred to as "multi-skips echoes"  $n^{\circ}1$ ,  $n^{\circ}2$ ,  $n^{\circ}3$  ...).

The amplitude reference  $A_{REF}$  for all the amplitudes given in dB is the maximum amplitude of the direct echo obtained from a side drilled hole of 2mm diameter located at 6mm depth for the setup 1 and at 4mm depth for the setup 2. The measured relative amplitude of the echo from a notch is given in dB:  $20 \log (A / A_{REF}) - (G - G_{REF})$ , where  $G$  and  $G_{REF}$  are the gains in dB used during the measurement carried out respectively on the current notch and on the reference reflector.

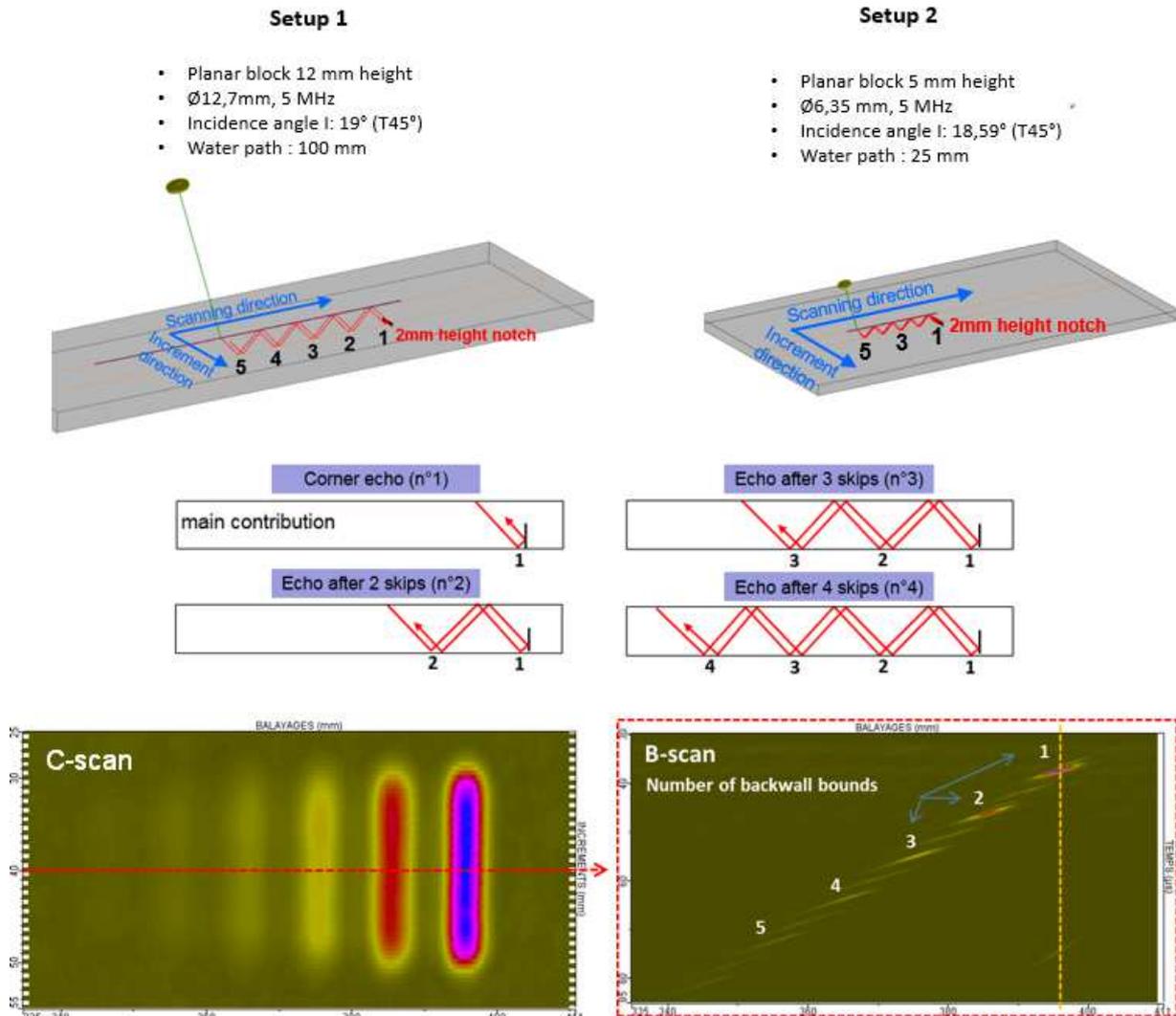


FIGURE 1. Description of the T45° multi-skips echoes inspection setup

## SIMULATION PROCEDURES

### Input Parameters

Mock-ups: Acquisitions were carried out on two planar blocks, one of 12mm thick, and another one of 5mm thick. Both are made of steel and contain one artificial vertical backwall breaking notch of 2mm height. The material homogeneity was experimentally checked and the specimen material was modelled as isotropic and homogeneous.

**Probes:** the probes used were single element conventional immersion probes with a center frequency of 5MHz and diameters of 12.7mm and 6.35mm. The water path was 100mm for the 12.7mm probe and 25mm for the 6.35mm probe. The incident angle was applied in order to generate transversal waves at 45° in each specimen.

**CIVA input signal:** the probe input signal was a 5MHz synthetic signal generated by CIVA which parameters (bandwidth and phase) were precisely adjusted to ensure a good matching of the experimental and simulated wave forms of a T direct echo obtained in pulse echo mode on the reference amplitude SDH.

Echoes from the side drilled holes were calculated with the SOV model and the PTD model was used for the calculation of the notch multi-skips echoes [2].

## Material Parameters Measurement

The longitudinal (L) and transversal (T) velocities were experimentally estimated using successive backwall echoes.

**Setup 1:**  $V_L = 5950\text{m.s}^{-1}$  and  $V_T = 3290\text{m.s}^{-1}$ . The density was  $7.8\text{g.cm}^{-3}$ .

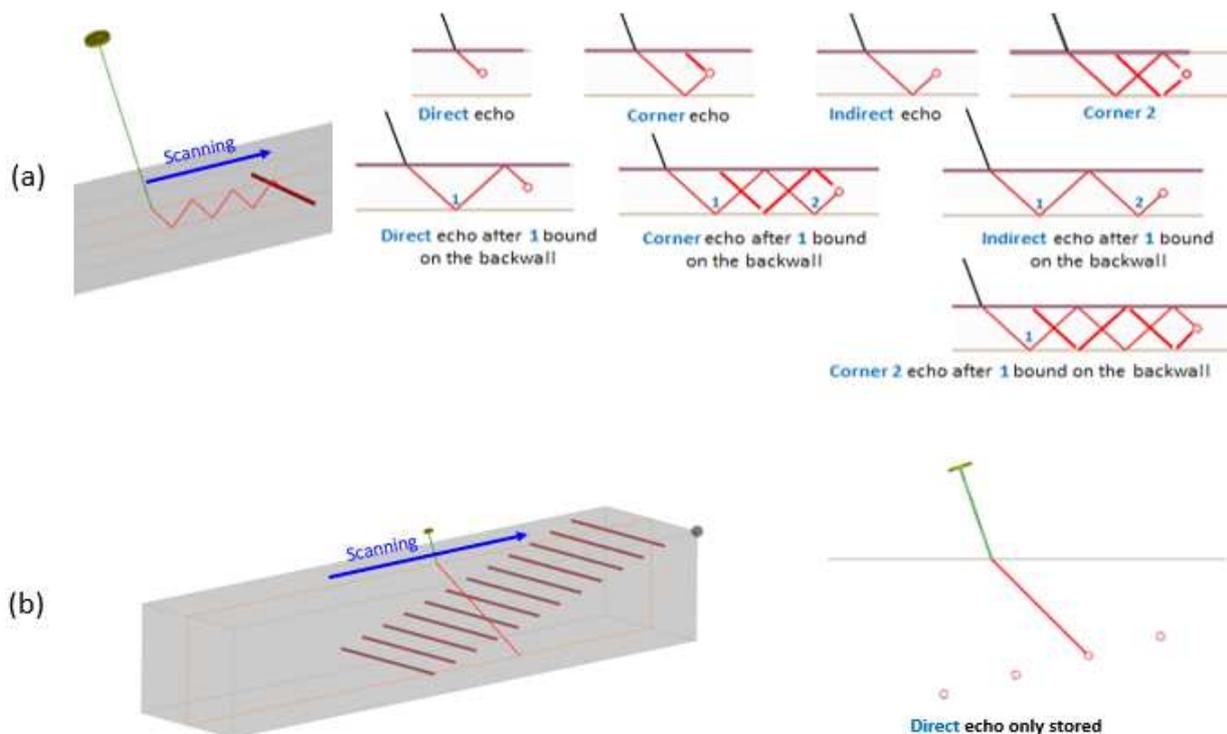
**Setup 2:**  $V_L = 5900\text{m.s}^{-1}$  and  $V_T = 3220\text{m.s}^{-1}$ . The density was  $7.8\text{g.cm}^{-3}$ .

Attenuation was measured in two ways depending on the setup as following:

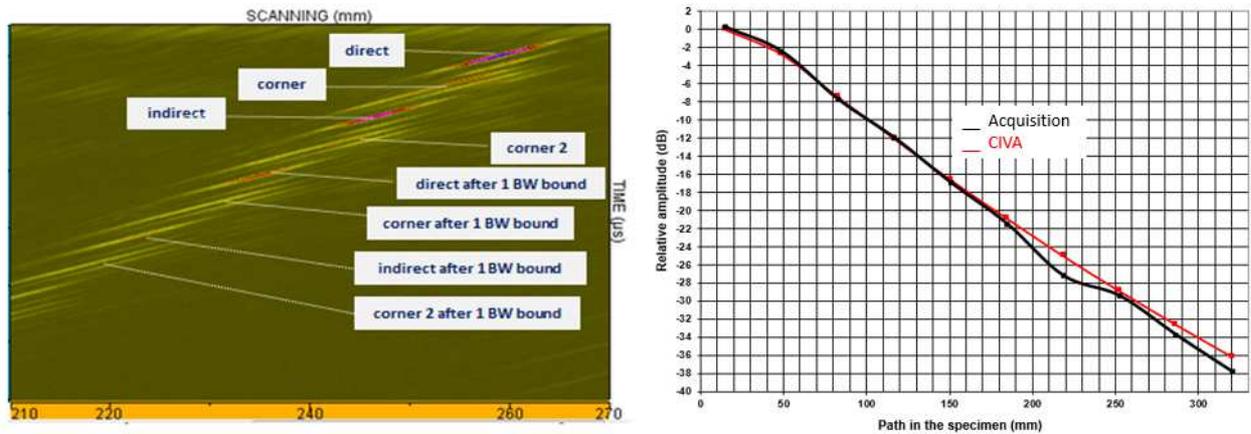
**Setup 1:** Multi-skips echoes on the SDH located at 6mm depth in the 12mm thick mock-up were measured in order to evaluate the attenuation on the specimen (Figure 2 (a)). Ray-paths corresponding to the measured amplitudes are also presented in the figure. Results are represented against the sound-path in the specimen with a reference amplitude which is the SDH direct echo amplitude (Figure 3).

**Setup 2:** A mock-up made of the same steel grade than for the 5mm planar block and including SDHs from 4mm to 60mm depth was used to evaluate the attenuation (Figure 2 (b)). In this setup, amplitudes are presented according to the SDH depth with, as reference in amplitude, the one of the 4mm depth SDH (Figure 4).

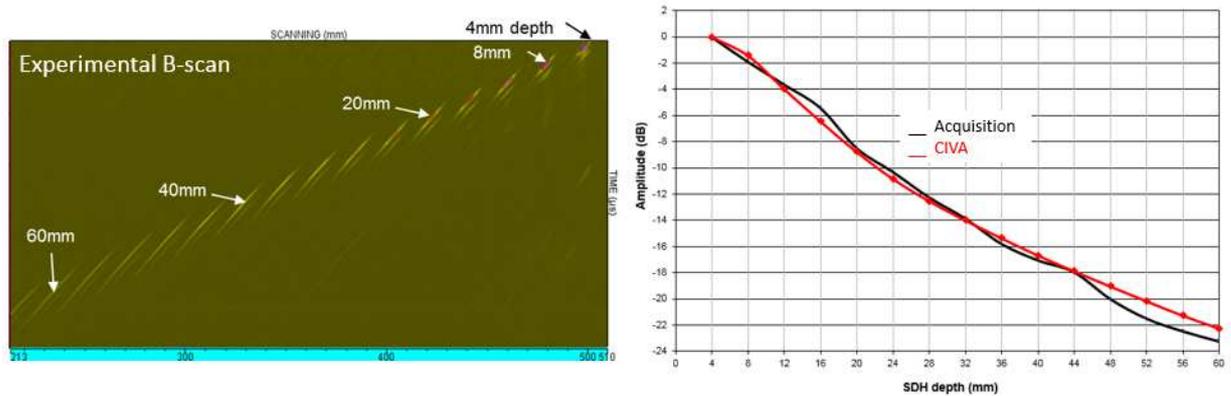
For the both setups, attenuation was adjusted so that the simulated curve representing the SDH amplitude according to the ultrasonic path fits the experimental one (Figures 3 and 4).



**FIGURE 2.** Attenuation measurement configurations. (a) Multi-skips echoes on a SDH for the configuration 1; (b) Direct echoes on SDHs located at different depths for the configuration 2



**FIGURE 3.** Attenuation measurement for the setup 1. Experimental B-scans and superposition of measured and simulated multi-skips echo amplitudes on the SDH located at 6mm depth



**FIGURE 4.** Attenuation measurement for the setup 2. Experimental B-scans and superposition of measured and simulated direct echo amplitudes on SDHs against the SDH depth

### RESULTS FOR THE NOTCH IN THE SETUP 1

Figure 5 shows the experimental B-scan including the first 4 multi-skips echoes of the 2mm high notch but the evaluation had been done until multi-skip echo n°7. The bottom of the figure presents the superposition result of the experimental and simulated echodynamic curves and normalized A-scans (corresponding to the maximum amplitude of multi-skip echoes n°1 (corner echo) and n°3). This comparison shows the good prediction of the multi-skips echoes shape by CIVA.

Figure 6 presents a comparison between experimental and simulated multi-skips echoes amplitudes according to the path in the specimen. The evaluations were done for multi-skips echoes from n°1 to n°7 which corresponds to a path from 34mm to 440mm in the specimen. For this setup, the reference for the amplitude is the T direct echo of a Ø2mm SDH located at 6mm depth in the same mock-up.

A very good agreement between experimental and simulated multi-skips echo amplitudes is obtained with a maximum discrepancy of 2dB.

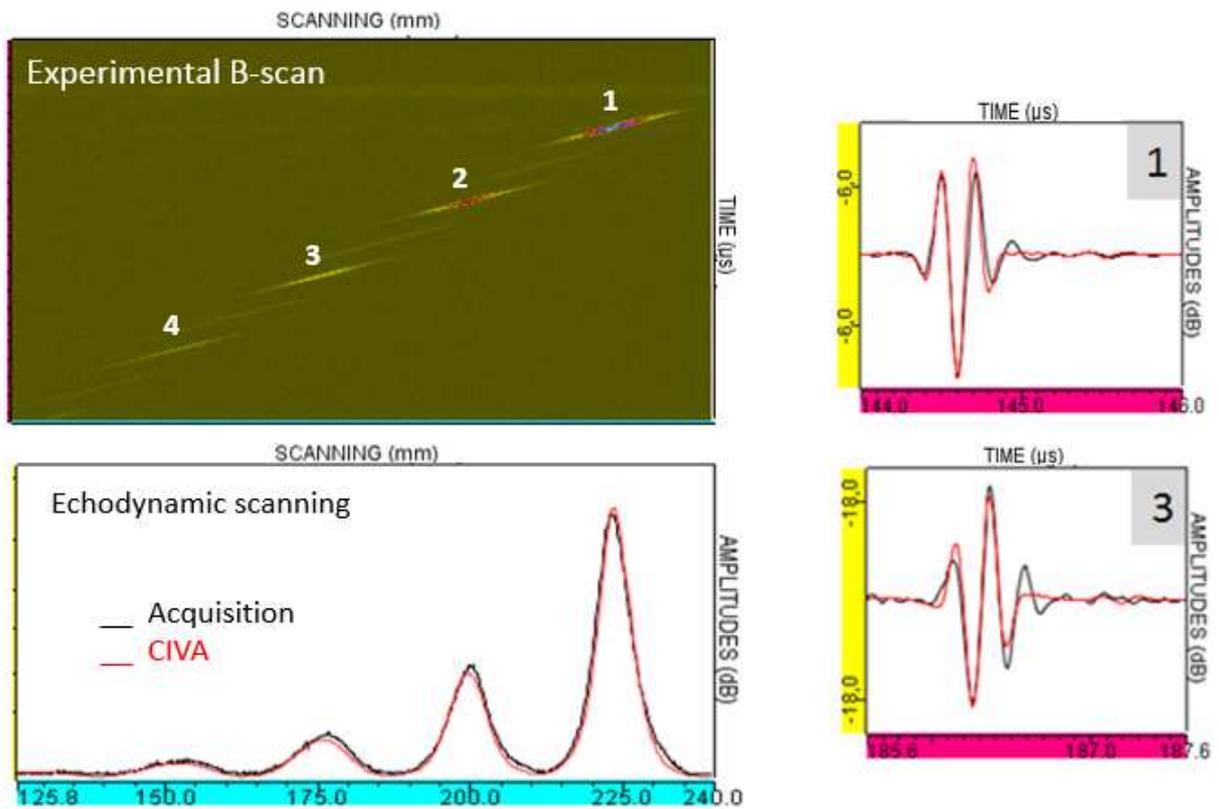


FIGURE 5. Experimental B-scan (top); superposition of experimental and simulated echodynamic curves of the first four multi-skip echoes for the setup 1; example of experimental and predicted A-scans

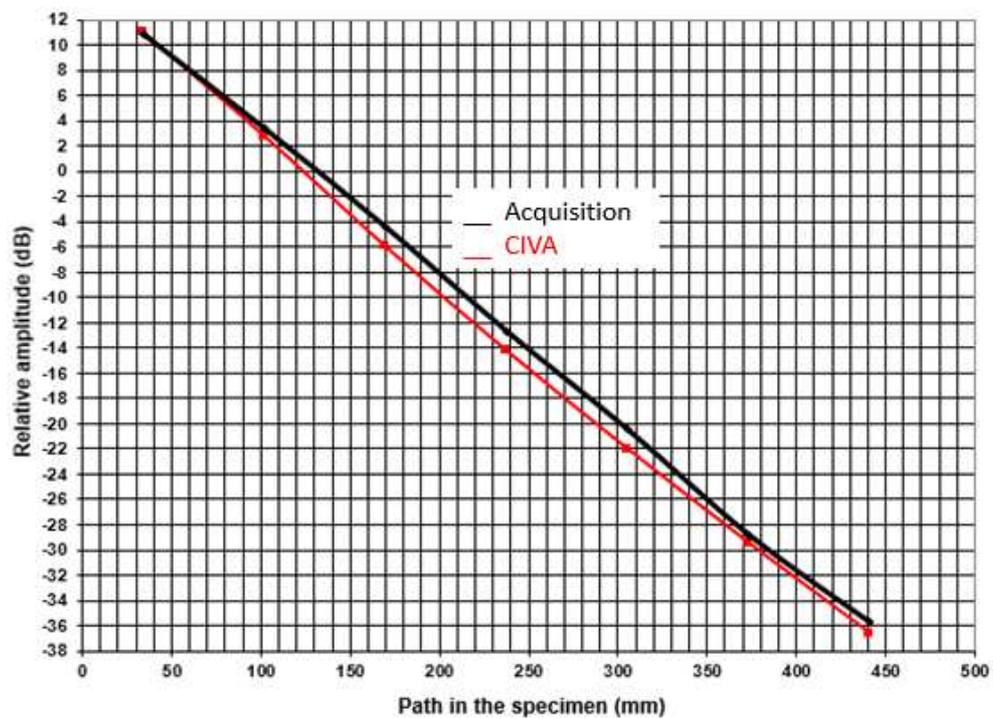


FIGURE 6. Superposition of the experimental and simulated multi-skip echoes amplitudes for the notch in the Setup 1

## RESULTS FOR THE NOTCH IN THE SETUP 2

The same comparisons as in Figures 5 and 6 are presented in Figures 7 and 8 for the setup 2. The reference for the amplitude is the T direct echo of a  $\varnothing 2\text{mm}$  SDH located at 4mm depth.

Experimental results show a linear decreasing of the amplitudes which is well reproduced by CIVA. The discrepancies observed between simulated and experimental multi-skip echoes amplitudes from  $n^{\circ}1$  to  $n^{\circ}5$  are less than 1dB.

However, the superposition between the experimental and simulated echodynamic curves shows differences after the multi-echo  $n^{\circ}2$ . Indeed, after the second skip of the beam on the backwall, CIVA predicts much larger echoes. It was not observed in the setup 1, where a less divergent probe was used. The reason of this discrepancy is not yet explained but can be assigned to contributions of creeping and head waves due to the divergence of the probe. Analysis of these differences for the setup 2 is in progress.

The experimental and simulated A-scans for multi-skips echo  $n^{\circ}1$  and  $n^{\circ}3$  are in good agreement.

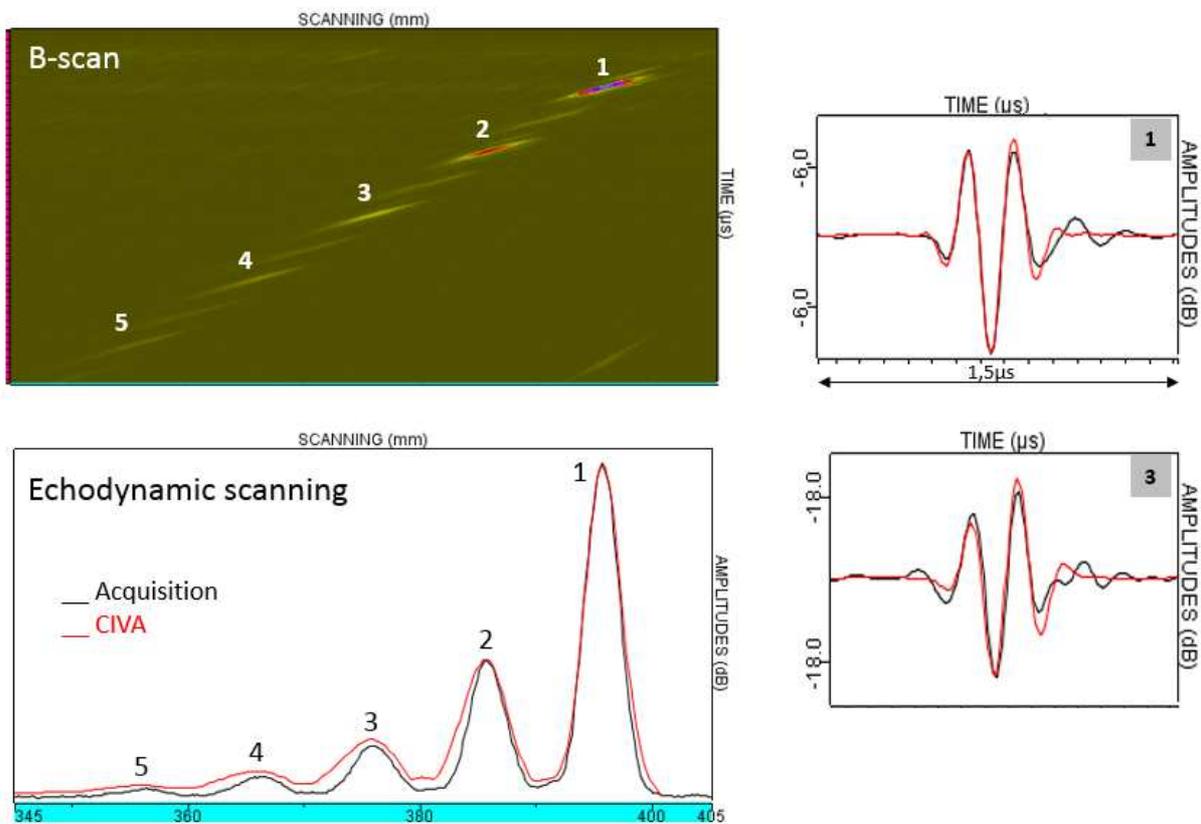
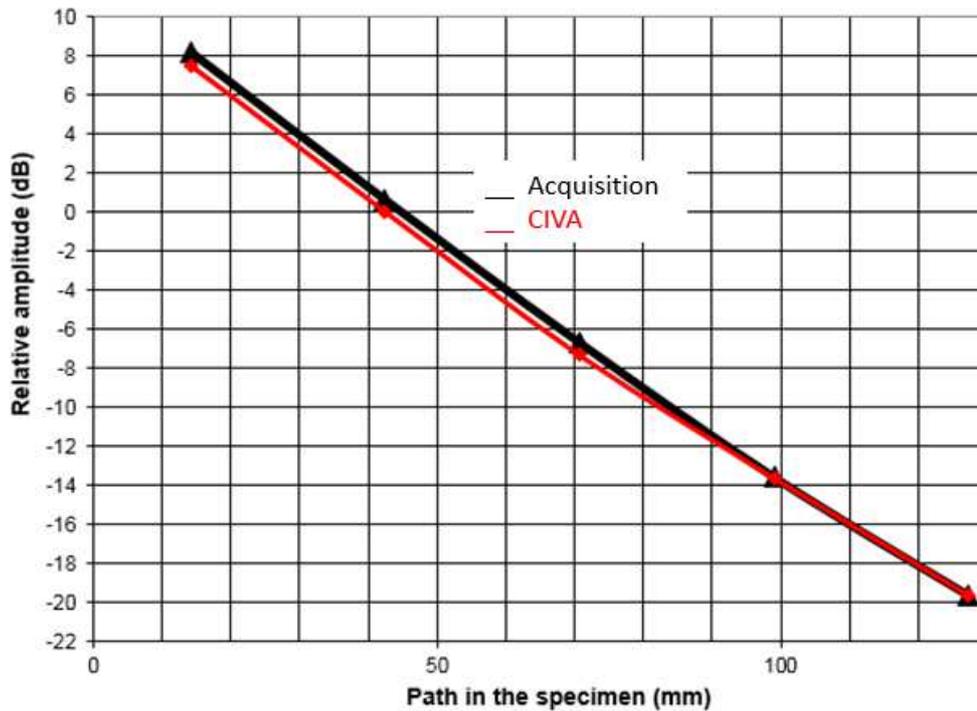


FIGURE 7. Experimental B-scan (top); superposition of experimental and simulated echodynamic curves of the first five multi-skips echoes for the setup 2; example of experimental and predicted A-scans



**FIGURE 8.** Superposition of the experimental and simulated multi-skips echoes amplitudes for the notch in the Setup 2

## CONCLUSION

This communication presented the results obtained with the CIVA software of the 2016 UT Modeling Benchmark. Comparisons between simulation and experiments of echoes from SDH and vertical backwall breaking notches after several skips of the beam on the surface and the bottom of two steel planar blocks were presented. Two setups were considered, with two probes of different apertures and operating at 5MHz. Setup 1 considered a  $\text{Ø}12.7\text{mm}$  probe inspecting a 12mm thick planar specimen. Setup 2 considered a  $\text{Ø}6.35\text{mm}$  probe inspecting a 5mm thick planar specimen.

A very good agreement is obtained between experimental and simulated multi-skips echoes amplitudes for both setups. Discrepancies are less than 2dB in amplitude for all echoes. The shapes of the A-scans corresponding to the maximum amplitude of multi-skip echoes are also well predicted by CIVA.

Regarding echodynamic curve shapes, a good agreement is obtained for setup 1 while discrepancies are noted between the shapes of the echoes after the multi-echo  $n^{\circ}2$  for the smallest probe aperture (setup 2). The origin of this disagreement can be assigned to supplementary contributions (head waves) occurring because of the important divergence of the probe that was used, but hypothesis has to be confirmed by complementary studies.

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