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# Results of the 2015 UT Modeling Benchmark Obtained with Models Implemented in CIVA

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**Abstract.** This communication presents the results of the 2015 UT benchmark obtained with the models implemented in CIVA. The benchmark addresses the TOFD technique. To calculate the diffraction echoes, field by applying the pencil-model and diffraction on notches edges is modelled by GTD (Geometrical Theory of Diffraction). We present comparisons between experimental and simulated results. We discuss the results obtained with and without applying the so-called “plane wave approximation” on the incident field.

## INTRODUCTION

Every year the World Federation of NDE center proposes benchmark for the main NDE modalities (UT, ET, RT,...). On previous years UT benchmarks have mostly addressed pulse echo mode. This year the proposed benchmark concerns TOFD technique. TOFD is today commonly used for locating and sizing cracks from tip diffraction echoes. This technique relies on an arrangement of two probes with opposite beam directions. Experiments have been carried out on a planar block containing one vertical planar surface breaking flaw of 15mm height. L45°, L60° and L70° acquisitions of top and bottom tip diffraction echoes have been performed with various PCSs (Probe Centre Spacing), the PCS being an important parameter for the TOFD inspection performances. Experimental measurements were carried out at CEA LIST.

This communication presents the results of the 2015 UT benchmark obtained with the models implemented in CIVA [1]. In CIVA, the incident field on the defects is calculated by applying the so-called pencil-model and used, as an input for the beam/defect interaction model which may depend on the defect considered. In the present case diffraction on notch edges is modeled by using GTD (Geometrical Theory of Diffraction) [5].

This work is done in the context of systematic experimental validation of the ultrasonic module of CIVA whose results are available on the EXTENDE website [2].

Up to now in CIVA the model applied was the so called “plane wave approximation” which amounts to simplify the description of the incident field inputted in the GTD calculation. A new version has been recently developed which overcomes this approximation [6]. We have in this study compared the results of these two versions of the CIVA model with the experimental results. Simulated results involving the plane wave approximation have been obtained with the current CIVA 2015 version of the software while the results overcoming this approximation are obtained with a version of CIVA under development.

## DESCRIPTION OF THE 2015 ULTRASONIC BENCHMARK

For a complete description of the configurations studied, see [3]. Experimental measurements were carried out at CEA LIST. Acquisitions have been carried out using a pair of contact probes of 6.35mm diameter, working at 5MHz. Different wedges were used in order to generate longitudinal waves at 45°, 60° and 70°. The pair of probes was moved in two perpendicular directions over the top edge of the defect in the case of a backwall breaking notch, and over the bottom edge of the defect in the case of a surface breaking notch (Figure 1). During the displacement of the pair of probes, the waveforms received at each position were stored (experimental C-scans) and the maximum amplitude of the echo was also recorded for each Probe Centre Spacing (PCS). The reproducibility of the results has

been checked and the confidence interval of the experimental data presented in this paper has been evaluated to +/- 3dB.

Simulations were performed for the corresponding cases and measured and simulated amplitudes of the echoes were compared. The amplitude reference AREF for all the amplitudes given in dB is the maximum amplitude of the direct echo obtained in TOFD mode from a side drilled hole of 0.7mm diameter. The measured relative amplitude of the echo from a flaw is given in dB:  $20 \log (A / AREF) - (G - GREF)$ , where G and GREF are the gains in dB used during the measurement carried out respectively on the current flaw and on the reference reflector.

Echoes from the side drilled holes were calculated with the SOV model [4] the GTD model was used for the calculation of the top and bottom edge notch echoes [5].

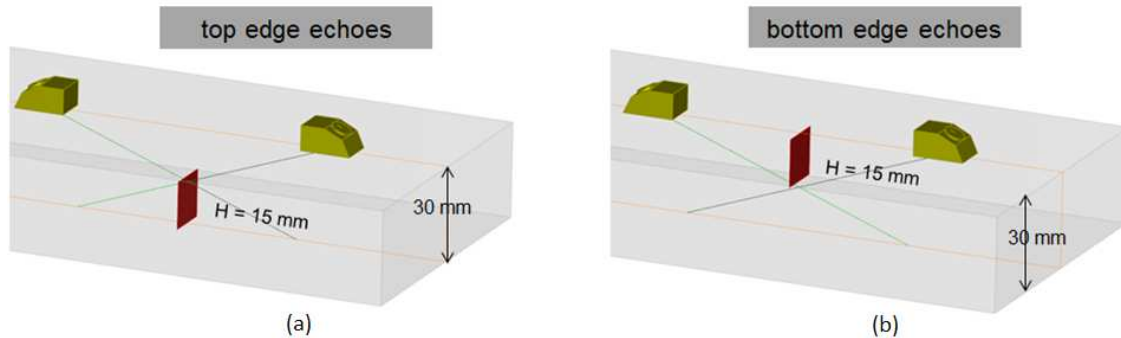


FIGURE 1. Description of the TOFD configurations.(a) top edge echoes (b) bottom edge echoes

## SIMULATION PROCEDURES

### Parameters Related to the Part

The reference block, of 30mm thickness, is made of steel and contains an artificial notch of 15mm of extension and height. The material homogeneity was experimentally checked and the specimen material was modelled as isotropic, homogeneous and the attenuation was ignored. The longitudinal (L) and transversal (T) velocities were measured using successive backwall echoes ( $V_L = 5900\text{m.s}^{-1}$  and  $V_T = 3230\text{m.s}^{-1}$ ). The density was  $7.8\text{g.cm}^{-3}$ .

### Parameters Related to the Probes

**Shape and wedge:** the probes used were single element conventional probes with a center frequency of 5MHz and a diameter of 6.35mm. The probes are mounted on wedges designed to generate longitudinal waves at  $45^\circ$ ,  $60^\circ$  and  $70^\circ$  in the specimen. The measured longitudinal and transversal velocities in wedges are respectively  $V_L = 2730\text{m.s}^{-1}$  and  $V_T = 1340\text{m.s}^{-1}$  and the density is  $1.18\text{g.cm}^{-3}$ .

**Probe arrangement:** three couples “transmitter-receiver” were used ( $L45^\circ$ ,  $L60^\circ$  and  $L70^\circ$ ). For each couple, the TOFD inspection of the top or the bottom edge of the notch was performed for different PCSs, allowing various incidence angles of the L waves on the notch edge and various positions of the “L axis crossing point” (point where the L axis of the transmitter and receiver intersect) relative to that of the notch edge (Figure 2, case of the  $L60^\circ$  top edge inspection).

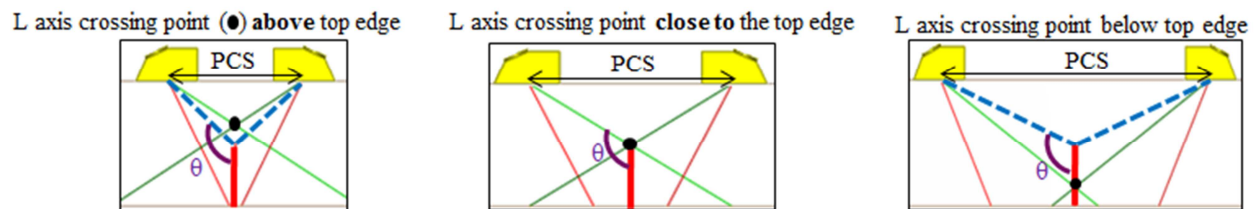
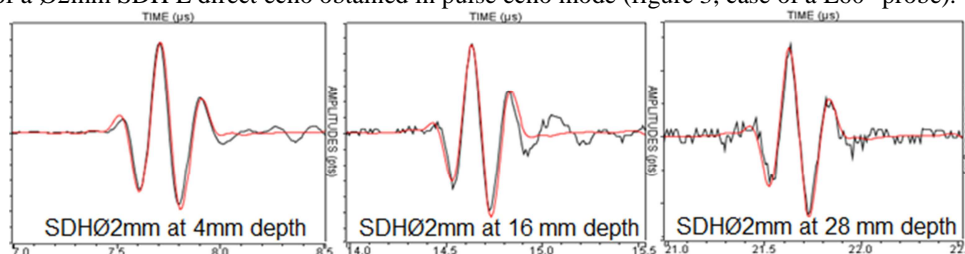


FIGURE 2. CIVA schematics of TOFD configurations with different PCSs, showing the variation of the L waves incident angle on the top edge of the notch ( $\theta$ ) and of the L axis crossing point position relative to that of the top edge with the PCS

**Calibration in pulse echo mode:** the transmitter and receiver of each TOFD arrangement were used separately in a pulse echo mode to perform a calibration inspection over  $\varnothing 2\text{mm}$  SDHs at different depths. The two experimental scanning echodynamic curves thus obtained were superimposed to check the probe resemblance in terms of

sensitivity and L refraction angle. A good agreement was obtained. The refraction angle of the longitudinal waves in the specimen was estimated from this calibration: we obtained  $44.5^\circ$  with the wedge designed to generate L waves at  $45^\circ$  in the specimen,  $59^\circ$  with the L60° wedge and  $70^\circ$  with the L70° wedge. Another calibration block was used to measure the index point and the wedge height.

**CIVA input signal:** the probe input signal was a 5MHz synthetic signal generated by CIVA whose parameters (bandwidth and phase) were precisely adjusted so as to ensure a good matching of the experimental and simulated wave forms of a  $\varnothing 2\text{mm}$  SDH L direct echo obtained in pulse echo mode (figure 3, case of a L60° probe).



**FIGURE 3.** Superposition of measured and simulated L direct echoes of a SDH  $\varnothing 2\text{mm}$  obtained in pulse echo mode with the L60° probe

### Accounting for Artificial Notches Responses

**Shape (manufacturer information):** the artificial notch is rectangular of 15mm height and extension, with an aperture of 0.2mm in a U shape.

**Echoes studied:** during the TOFD inspection, the amplitude of the longitudinal echo coming from the top or the bottom edge echo of the 15mm notch was measured.

**Model used to compute the L top edge echoes (TOFD mode):** the appropriate model in CIVA to compute the diffraction echoes is based on the GTD (Geometrical Theory of Diffraction) [5]. In this model, a quasi-null aperture of the defect is assumed. This null aperture assumption is particularly well-suited for the description of a real fatigue crack but does not describe exactly the aperture shape of artificial notches.

Before the beam/defect interaction computation with the GTD model, the field radiated by the probe on the notch edges was described with two different approaches:

- The current echo calculation available in the CIVA 2015 release (plane wave approximation)
- A ray-based method considering the whole description of the elastodynamics field as an input of the defect response model [6].

**Accounting for the notch aperture:** previous studies carried out at the CEA-LIST had shown that, in the case of artificial notches, the notch aperture is an important parameter that may affect the amplitude of the top edge echo. As such, to take this parameter into account, we have also computed the top edge echo with the module CIVA-ATHENA-2D, a hybrid module using both conventional semi-analytical methods of CIVA and the FEM (Finite Element method) code ATHENA from EDF. The connection with Finite Elements allows taking into account more complex flaw scattering phenomena that can occur during the echo formation (and not only the diffraction phenomena as the GTD does).

To illustrate the influence of the notch aperture on the longitudinal top and bottom edges echo amplitude, we have simulated in CIVA a symmetrical TOFD configuration studied by Ravenscroft [7] and using circular contact probes of 10mm diameter and 5MHz center frequency. The amplitude of the top and bottom edge echoes were compared for two configurations with CIVA-ATHENA 2D:

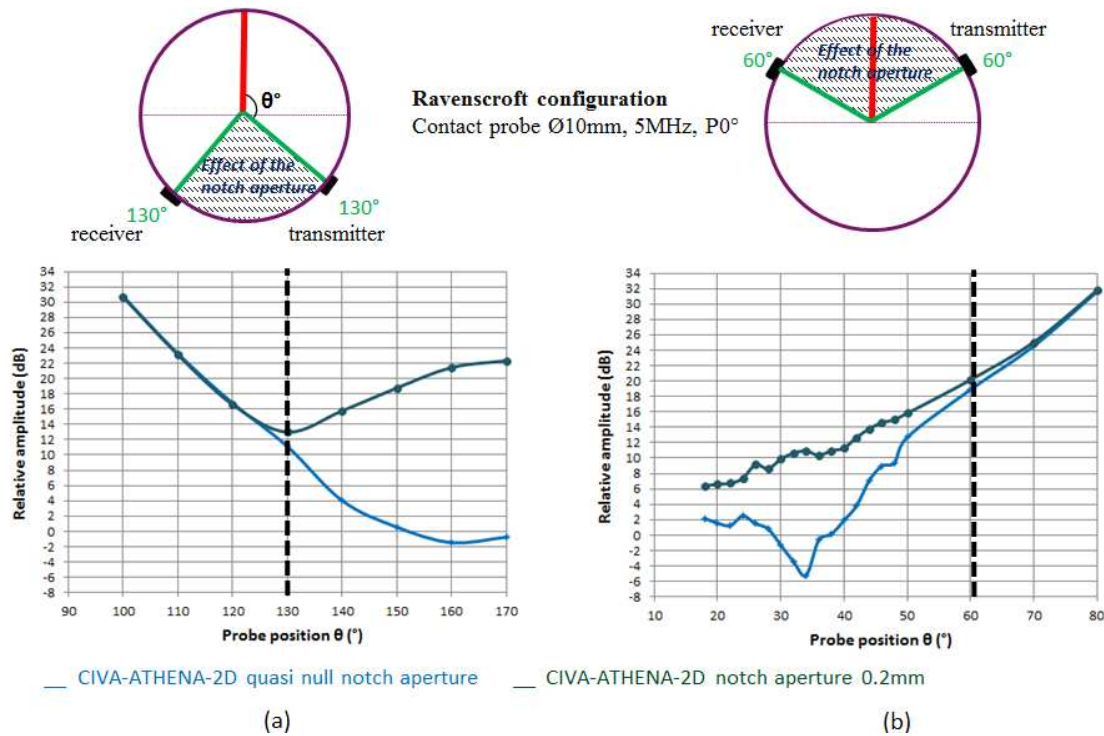
- with a notch modeled by a rectangular defect of quasi null notch aperture
- with a notch modeled by a multi-faceted defect composed by 3 facets, two vertical and one horizontal of 0.2mm length simulating the notch aperture.

NB: In the two cases, the field and the flaw interaction are computed in 2D.

The Ravenscroft configuration and the simulated results obtained with or without the notch aperture are presented Figure 4 in the case of the top edge echo and the bottom edge echo. They show that, at incident angles  $\theta$  greater than  $130^\circ$ , the amplitude of the top edge echo is significantly more important in the case of the notch with the aperture of 0.2mm than in the case of that with a quasi-null aperture. This difference is attributed to an additional specular echo coming from the horizontal part of the notch top. The GTD model does not compute this specular

echo. In the case of the bottom edge echo, the amplitude increase at incident angles  $\theta$  lower than  $60^\circ$  when the aperture is taken into account. This increase is attributed to an additional creeping wave along the bottom edge.

These results show the necessity (in this case where this is not a real crack) of taking into account the aperture of the artificial notches in the simulation of longitudinal top and bottom edge echo amplitude depends on the L waves at some angles.



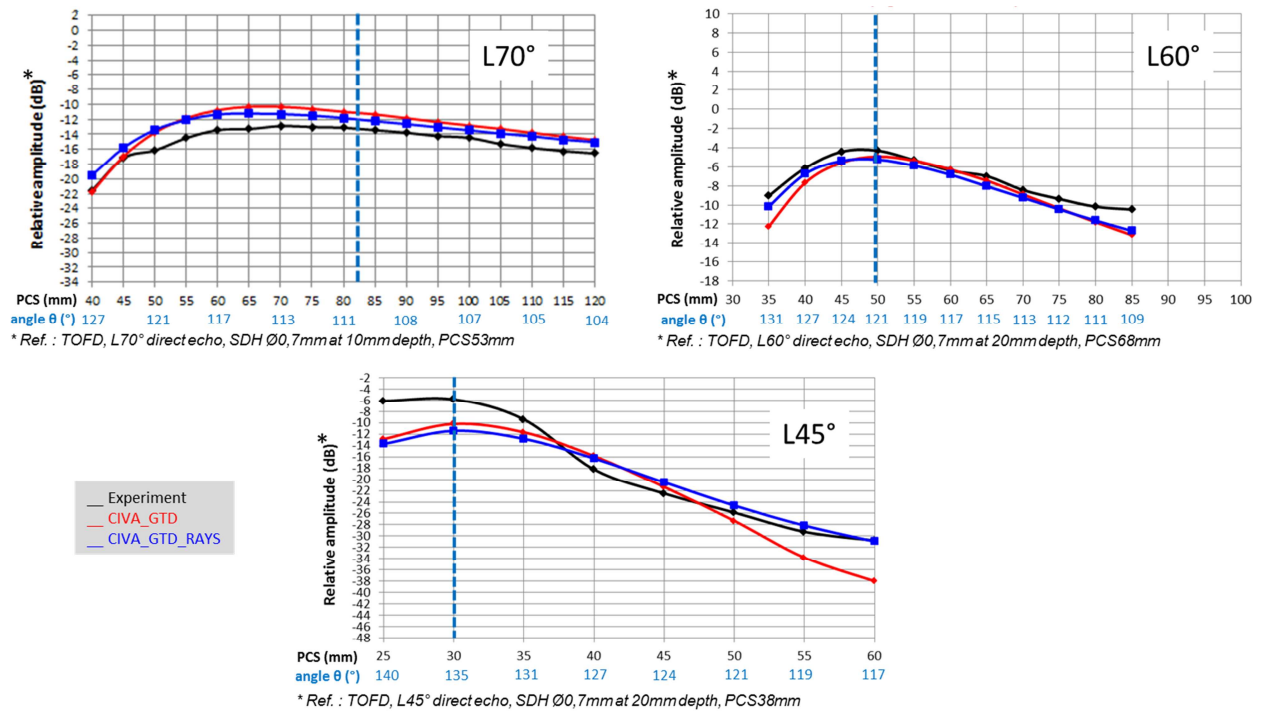
**FIGURE 4.** Ravenscroft configuration modeled with CIVA and simulated results. (a) top edge echoes (b) bottom edge echoes

### Reference for the Amplitude

The physical quantity considered for the comparisons is the echo amplitude. Previous experimental validation study concerning Side Drilled Holes reflectors of decreasing diameters from  $\varnothing 3\text{mm}$  to  $\varnothing 0.5\text{mm}$  (SDHs) inspected in TOFD mode had showed the reliability of CIVA predictions for L direct echoes of all SDHs [8]. So, the amplitude reference for all the results of the current study is the longitudinal echo of a SDH  $\varnothing 0.7\text{mm}$  (precise information regarding this reference will be given for each graph).

### RESULTS ON THE TOP EDGE OF THE NOTCH

Figure 5 shows the experimental and simulated amplitudes of the top edge echo obtained for the TOFD inspection of the 15mm height back-wall breaking notch performed with the three pairs of probes  $L70^\circ$ ,  $L60^\circ$  and  $L45^\circ$  in the specimen against the various PCSs (or incident angles). Predictions with CIVA are presented when the plane wave approximation of CIVA 2015 is applied to the field on the notch edge before defect interaction computation (CIVA\_GTD in the legend) and when the ray-based method of the development version is used for the defect interaction computation (CIVA\_GTD\_RAYS in the legend). The reference for the amplitude is the L direct echo of a SDH  $\varnothing 0.7\text{mm}$  indicated at the bottom of the figure for each pairs of probes. The blue line indicates the PCS where the crossing point of the L axes is on the top edge of the notch (see figure 2).



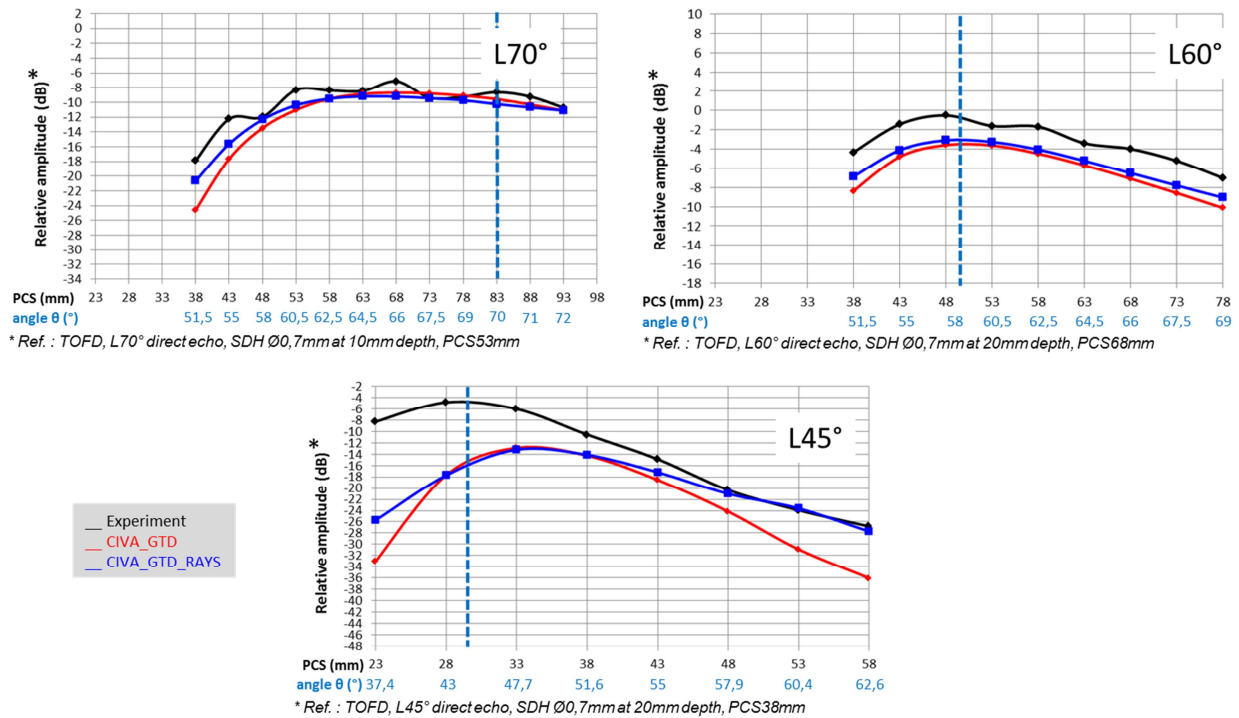
**FIGURE 5.** L70°, L60° and L45° TOFD inspection, top edge echoes. Compared experimental and simulated amplitudes of the L top edge echo versus the PCS and the incident angle  $\theta$

Regarding L70° and L60° results, we have a good agreement between experiment and CIVA predictions obtained with the two approaches of CIVA (lower than the measurement uncertainty of 3dB). In these configurations, except the PCS35 with the L60° probes, no effect of the notch aperture is expected if we look at the results obtained with the corresponding incident angles  $\theta$  shown Figure 4.

In the L45° case, we observe discrepancies when the effect of the notch aperture is expected i.e. for PCS from 25mm to 35mm according to the results obtained in the Ravenscroft configuration ( $\theta > 130^\circ$ ). For the PCS 40mm and 45mm, no effect of the notch aperture is expected, and a good agreement is obtained between experiment and the two methods of field description on the notch of CIVA. But for the large PCSs where no effect of the notch aperture is expected, discrepancies between experiment and simulation are obtained when the plane wave approximation is used. Those discrepancies are reduced when the ray based method is used. These results show the limitation of the plane wave approximation when the top edge goes away from the crossing point of the L axes of the probes.

## RESULTS ON THE BOTTOM EDGE OF THE NOTCH

Figure 6 shows the experimental and simulated amplitudes of the bottom edge echo obtained for the inspection of the surface breaking notch performed with the three pairs of probes L70°, L60° and L45° in the specimen and for various PCSs. The incident angle  $\theta$  is also displayed in the abscissa. The blue line indicates the PCS where the crossing point of the L axes is on the bottom edge of the notch. As for the top edge results, CIVA predictions are evaluated with the two approaches (plane wave approximation and ray-based method).



**FIGURE 6.** L70°, L60° and L45° TOFD inspection, bottom edge echoes. Compared experimental and simulated amplitudes of the L bottom edge echo versus the PCS

A good agreement is obtained for the L70° probes for PCSs higher than 48mm. For the other PCSs a discrepancy higher than 3dB appears, due to the effect of the notch aperture, not taken into account with CIVA\_GTD and CIVA\_GTD\_RAYS when  $\theta < 60^\circ$  (figure 3). For the L60° probes, a good agreement is also obtained considering the experimental uncertainty of 3dB. With the L45° probes, the effect of the notch is expected for PCSs < 48mm ( $\theta < 60^\circ$ ). For the other PCSs, a very good agreement is obtained with the Ray-based method while with the plane wave approximation, discrepancies are obtained. These results show the necessity to have a precise description of the field before the interaction computation for a configuration when the notch edge is out of the focal region.

## CONCLUSION

The WFNDEC UT benchmark addressed TOFD case studies. More specifically, comparisons between simulation and experiments concerned diffraction echoes from top and bottom edges of artificial notches inspected in L mode. Simulations have been performed with the GTD model of CIVA. They were done with two different approaches to describe the field radiated by the probe on the notch edges before the defect interaction computation. The first approach is the plane wave approximation available in the CIVA 2015 release. The second approach is a method we called “ray-based method”, allowing a better description of the beam on the notch edge before the defect interaction computation. This approach is currently available only on a development version of CIVA.

It has been shown that for some values of the incident angle on the top or bottom edge of the notch, the notch aperture (0.2mm) is an important parameter which cannot be neglected. Consequently in that cases we observe discrepancy between the GTD models, appropriate for diffraction echo computation in the case of realistic cracks of quasi null aperture, and experiment.

When notch aperture has no effect (representative of the case of real cracks) the comparisons between experimental and GTD predictions show a global good agreement. In the cases where the beam has to be precisely described (cases when the notch edge position is far from the focal region), the new ray-based method improve results compared to the plane-wave approximation. This ray-based method is planned to be made available in CIVA 2016 release.

## REFERENCES

1. More details and references can be found on <http://www-civa.cea.fr>.
2. All the Benchmaks results can be found on the EXTENDE website <http://www.extende.com>.
3. 2015 Ultrasonics benchmarks, <http://www.wfndec.org/benchmarkproblemscurrent.htm>.
4. M. Darmon, N. Leymarie, S. Chatillon, S. Mahaut, "Modelling of scattering of ultrasounds by flaws for NDT" , Ultrasonic Wave Propagation in Non Homogeneous Media, Springer Proceedings in Physics, 128, pp.61-71, Springer Berlin (2009).
5. M. Darmon, S. Chatillon, S. Mahaut, L. J. Fradkin and A. Gaudesen, "Simulation of disoriented flaws in a TOFD technique configuration using GTD approach," in *Review of Progress in Quantitative Nondestructive Evaluation*, eds. D. O. Thompson and D. E. Chimenti (American Institute of Physics 820, Melville, NY), **27A**, 155-162 (2008).
6. V. Dorval, N. Leymarie and S. Chatillon "Improved semi-analytical simulation of UT inspections using a ray-based decomposition of the incident fields", in this volume.
7. F. A Ravenscroft, K. Newton and C. B. Scruby, "Diffraction of Ultrasound by Cracks: comparison of Experiment with Theory", Ultrasonics, Vol 29, pp 29-37, January 1991.
8. R. Raillon, G. Toullelan, M. Darmon, S. Chatillon and S. Lonne, "Validation of CIVA ultrasonic simulation in canonical configurations", 9th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components, (2012).