



### Simulation platform for NDE

*The CIVA software is an expertise platform dedicated to non destructive testing. It is composed of simulation, imaging and analysis modules, enabling the user to conceive or to optimize inspection techniques and to predict their performances in realistic NDT configurations. Currently, CIVA includes Ultrasonic (UT), Guided Waves (GWT), Radiographic (RT), Computed Tomography (CT) and Eddy Current techniques (ET). The UT module proposes an extension based on a coupling with the FEM code ATHENA (CIVA ATHENA 2D).*

## INTRODUCTION CIVA 10

**User oriented:** CIVA Version 10 has been designed to allow CIVA users to easily benefit from the significant advances integrated in this version.

For example, positioning of a flaw or a probe in a specimen (Parametrical specimen or CAD) is easily made **interactively** with the mouse. In addition, the entire user interface has been redesigned so that CIVA has a **single window** that integrates all images, panels and the file manager. This new window provides a **customizable** layout and adapts to user needs. Imaging allows for real **analysis** through numerous functions integrated as buttons.

**More realistic:** **CAD** is now at the heart of CIVA. Importing a 3D CAD part (STEP or IGES format) is easy. The interactive positioning of defects and probes in these pieces makes configuration settings easier. UT interaction with defects is now possible on homogeneous 3D CAD parts. In addition, the CAD editor for 2D profiles with planar or circular extrusion proposes new powerful functionalities (copy and paste, adjust, extend...). Finally, images from calculation results can be exported in the 3D view by simple "Drag and Drop".

Models include new phenomena that allow the simulation to be more realistic. Consideration of **creeping waves** in UT, **coupling with the FEM** code **ATHENA 2D** in UT allowing to **consider all phenomena** in the beam/defect interaction, **material bridges** (defects partially closed) in ET, taking into account the **granularity of the film** in RT are just a few examples.

Also worth mention are more realistic morphologies of defects such as **branched defects** for UT, **combined defects** in ET, and volume 3D CAD defects in RT. Finally the UT simulation on **"coarse grain"** steel structures is now possible.

**More powerful:** Compiled on 32 and **64-bit** processors, Windows 7, all features have been optimized. Part of the more expensive simulation calculations in UT and RT (integrating the scattered radiation in RT) benefit from the **parallelization of the code** (taking advantage of multi core PC) and the ability to rapidly perform recalculations when some parameters (exposure time, detector, etc.) change. The opening of **"large" files** has been optimized (at least 1 Gb or more).

**Always an expert:** The effort to facilitate the use of CIVA is unprecedented. However, CIVA remains an expertise software and new functionalities will satisfy the most demanding users.

In the UT module, calculation with **more than one skip** is now possible. This involves calculation of a great number of modes taking into account mode conversions. That's why CIVA proposes the **list of possible modes** and allows the user to select the modes to calculate. Helped by **a suitable Ray tracing**, users can better understand complex phenomena by selecting modes in the list and viewing corresponding paths in the 3D view. As for the ET module, CIVA is ready for most advanced sensors: in addition to new coils, for example **rectangular coils**, CIVA provides access to **GMI** or **GMR** probes, as well as **multi-elements** probes.

Finally, CIVA 10 includes the ability to calculate **POD** curves (Probability Of Detection). Incorporating the uncertainties of inspection settings as input parameters, CIVA 10 calculates their impact on output signals and thus derives POD curves with respect to a defined detection threshold.

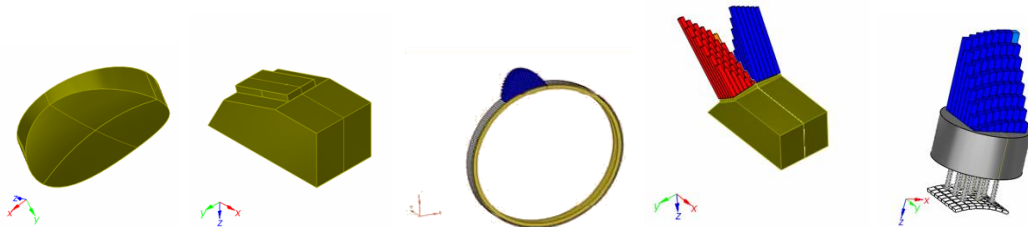
## UT SIMULATION

UT simulation tools include beam propagation and its interaction with flaws or specimens (backwall echo, surface echo, corner effects and shadowing). They allow the user to simulate a whole inspection process (pulse echo, tandem or TOFD) with a wide range of probes, components, and flaws.

## PROBES

A wide range of UT probes, standard and advanced designs can be handled:

- Contact, Immersion, dual element probes and Tandem probes
- Rectangular or circular emitting surfaces
- Focused probes via either shaped surfaces or probes with added acoustic lens
- Planar or spherical/bifocal/Fermat focusing surfaces
- Dual element probes, even if used on non-symmetrical configurations
- Single element or phased-array probes (see Phased Arrays section).
- Encircled or Encircling curved arrays for tube inspection
- Flexible phased-array probe (in contact with parametric or CAD specimen, linear or matrix pattern).



## SPECIMEN

### Parametric geometries:

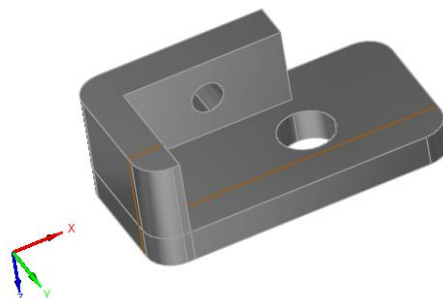
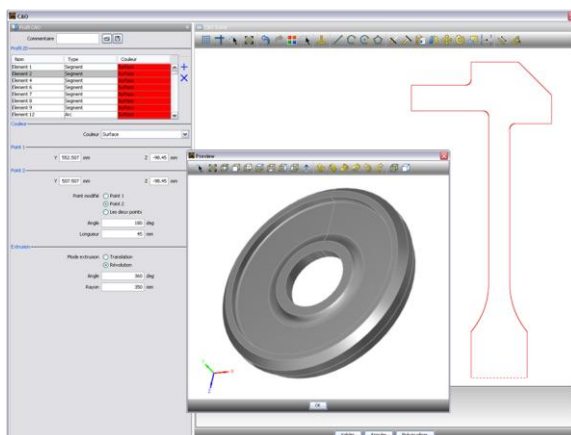
The graphic interface allows the user to define parametric geometries

- Planar, cylindrical, conical, spherical
- 3D parametric elbows, nozzles or bores

### CAD files:

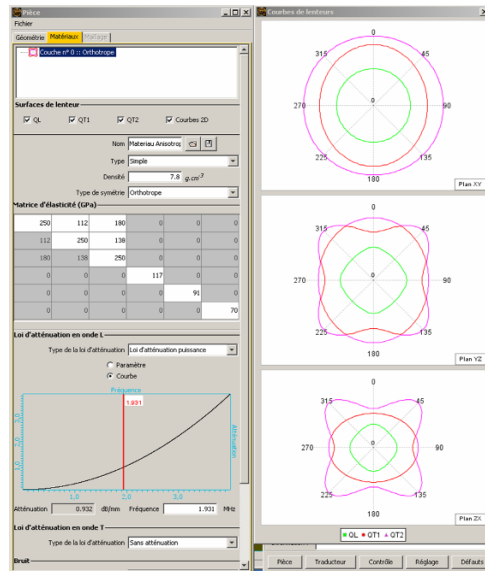
Computations can be done on components described by CAD files imported into CIVA.

- 2D CAD files containing a profile and generation of the 3D geometry either by translation or rotation of the profile:
  - 2D CAD files import in DXF or IGES format
  - User-defined profile using a CAD tool inside CIVA (**new interface, new functionalities**)
- 3D CAD files (IGES or STEP format) (homogeneous specimen)

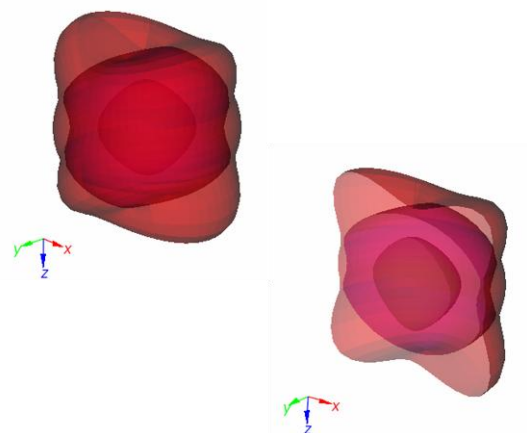


## MATERIALS

The component can be homogeneous or made of several layers (for example cladding). Each layer may be isotropic or anisotropic, of arbitrary symmetry and orientation. Materials can also be fiber-reinforced, multi-layer or granular composites. The acoustical characteristics of the materials, including attenuation coefficients, are defined by the user. Heterogeneous components can be defined using the CAD design tool in CIVA.



2D slowness curves



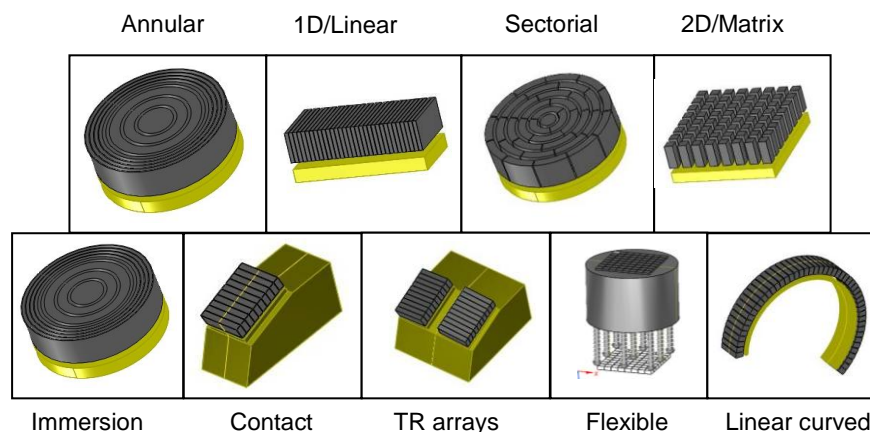
Simulation of structural noise is possible (randomly distributed point-like scatterers, of arbitrary density and reflectivity, adjustable for each constitutive material of the component).

Simulations on « coarse grains » structures can be done by creation of volumes with the help of Voronoï diagrams.

## Phased array Settings

CIVA allows the user to easily define various array designs: linear, matrix, circular arrays, and to compute delay laws and sequences of delay laws for standard and advanced phased-array techniques:

- Independent definition of emitting or receiving elements
- Variable aperture at emission or reception, for size or position
- Electronic scanning, simple or advanced (distinct elements in emission from reception)

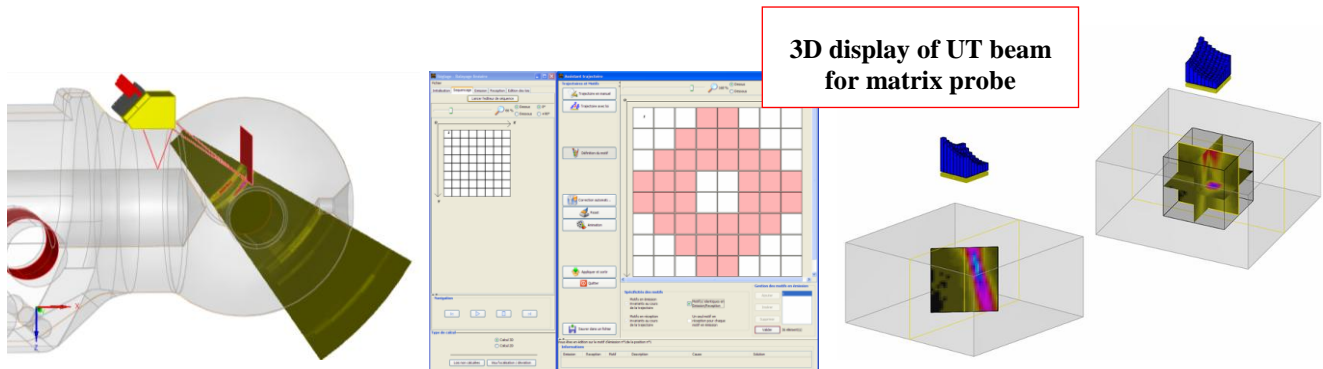


Delay laws can be computed for specimens of arbitrary geometry (canonical or complex) and materials

(homogeneous or heterogeneous materials, isotropic and anisotropic) from the simplest to the most advanced configuration:

- Focusing on one or several arbitrary points
- Electronic scanning
- Sectorial scanning
- Application of dynamic delay laws,
- Application of non-uniform amplitude laws (influence of non-homogeneous element responses, beam apodization)

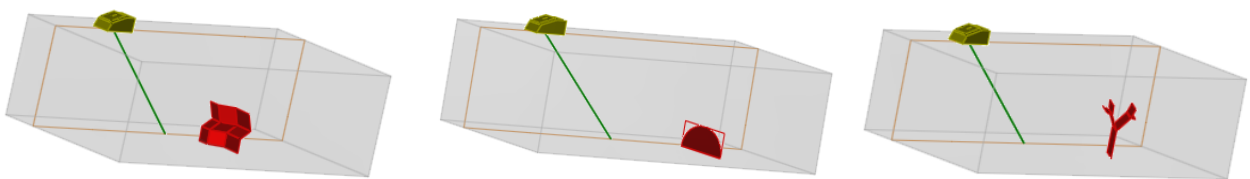
For the case of complex geometries and heterogeneous materials, delays laws are computed independently for each probe position along the scanning axis.



## FLAWS

An arbitrary number of flaws may be inserted into the component; these defects can be:

- Calibration defects: spherical pores, side-drilled holes, flat-bottom and hemispherical holes
- Planar defects, of arbitrary size and orientation, rectangular or semi elliptical
- Multifaceted defects and 2D contour CAD defects, **Branched defects**
- Solid inclusions (cylindrical, spherical or elliptical shapes): flaws constituted of a solid material



## RESULTS

### Beam Calculation

A first module simulates the ultrasonic beam in the specimen and if asked in the coupling material.

The beam can be displayed in the specimen as an amplitude color coded image or as an iso-amplitude surface. Local orientation of the beam and wave fronts can be displayed (and saved as animated files, AVI format).

### Defect Response

This module simulates the beam-defect interaction and predicts the amplitude and the time of flight of various echoes: direct echo, corner effect, etc. The number of skips has no limit. It calculates echoes caused by the geometry, surface echoes, takes into account mode conversions and in some cases creeping waves.

For TOFD configuration, direct tip echoes generated by the edge of the defects are simulated as well as lateral waves and the shadowing effect on the back-wall echo. The list of modes allows the user to choose which modes to calculate. For a 3D CAD specimen, zones of interest are useful to select "rebound and geometry" to account for bouncing within the specimen and geometric reflections (such as backwall echoes).

## Analysis tools

The software offers a wide range of signal processing methods, some are classical (filters, deconvolutions, etc.) others are more sophisticated (wavelets, Double Bernoulli Gaussian deconvolution, and more). A Segmentation tool allows 3D grouping of signals, managing of these groups and report export to spreadsheets.

Reconstruction tools are integrated, in particular the synthetic focusing one, called FTP and usable in 3D areas.

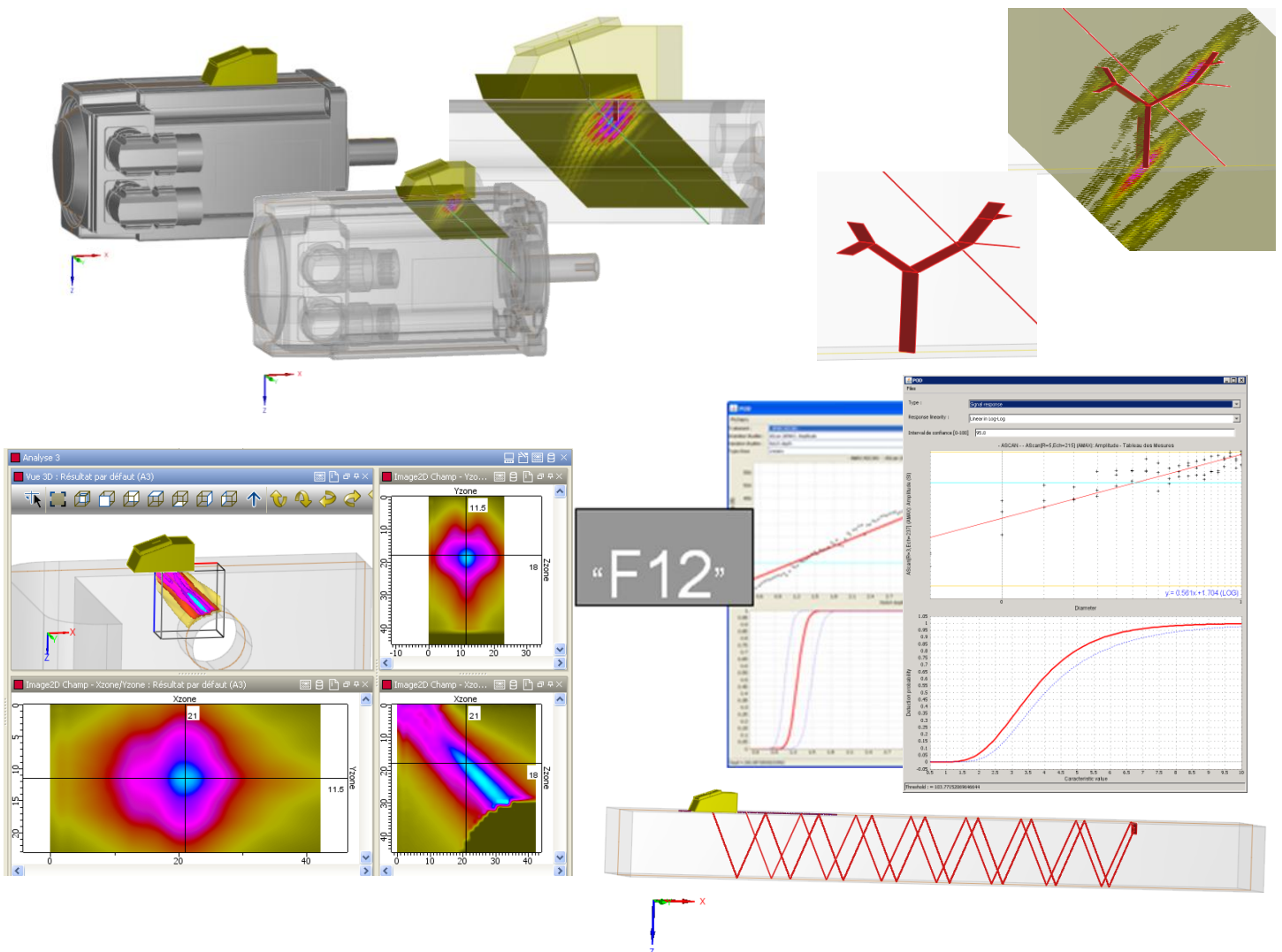
This processing allows, from an acquisition file or a phased-array simulation, reconstruction of an image by combining signals to have the best focusing on this particular point, thus displaying the amplitude obtained for each pixel.

A ray tracer completes these tools (it takes into account mode conversion, reflections, displays time of flight, etc.). This tool is connected to the list of modes, and helps in understanding different interactions.

Finally, the graphical interface can be customized (this customization can be saved) and some classical tools have been added : amplitude or distance measurements, image mirroring or rotation, choice of images displayed (BScan, AScan, CScan, DScan, SScan...), their position and size, surface reconstruction or export of images in 3D views.

The different phases of analysis (limitations, signal treatments...) are saved and settings can be edited. Thus, for "big" files analysis, extracting or limiting data to interested areas is possible, saved and can be annotated (titles, observations...).

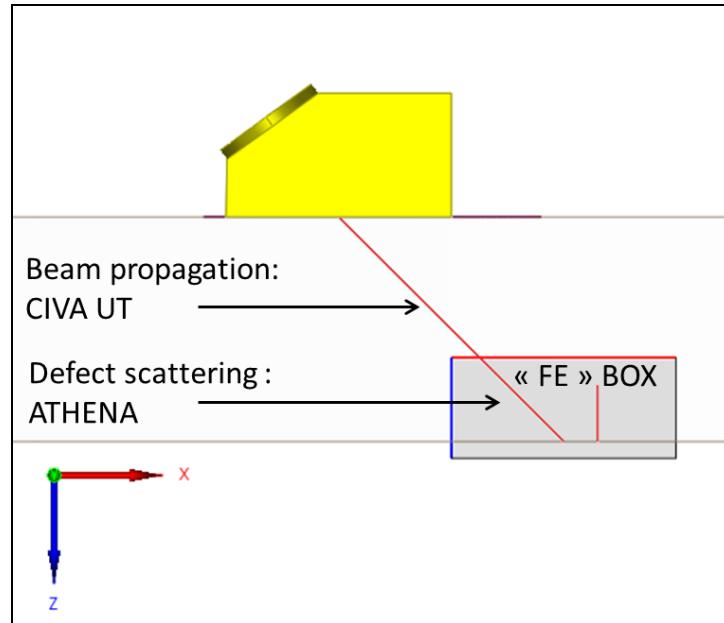
## SIMULATION EXAMPLES





## CIVA ATHENA 2D

In CIVA ATHENA 2D, a finite element rectangular box is defined. Out of this box, the UT beam propagation is modeled with the conventional CIVA semi-analytical pencil method. In the box, calculation is made by FEM using the incident beam calculated on the box boundaries as an input. Typically, FEM will be used to simulate UT beam/defect interactions (and beam/geometry interactions) whereas the fast semi-analytic model is used to simulate the round trip propagation of ultrasounds from the transducer.



CIVA ATHENA 2D uses a 2D beam computation and a 2D FEM calculation from ATHENA. 3D effects are intrinsically ignored while it gives precised results as soon as the 2D hypothesis can be credited. Out of 2D configurations, the use of CIVA ATHENA remains interesting for qualitative analysis.

## SPECIMEN

Even if 3D effects are ignored, no restriction is made on the available components in the user interface compared to CIVA UT. As this is a 2D module, to give quantitative results, the user shall consider component geometries that can be locally considered as 2D, or at least that makes sense in 2D.

## PROBES

As this is a 2D code, only a 2D section of the transducer is modeled. But no restriction is made in the transducers available in the user interface.

As soon as the divergence of the beam in the orthogonal plane has no effect on the flaw response (same extension for the flaws and flaws at the same depth, or extension larger than beam width), a 2D calculation can give quantitative results.

User will pay attention to the defined transducer (in terms of focusing or crystal shape) so that the 2D simulation makes sense.

The scanning of the probe will be in the incident plane only as the 2D box is fixed in this plane.

Tandem configurations are allowed but only make sense if the incident and reflected beam at the box boundary is a direct beam for both the transmitter and emitter.

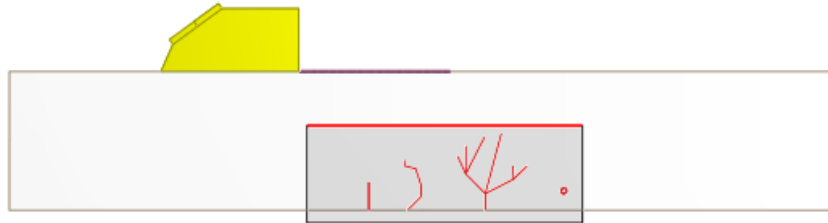
TOFD configurations are also available but only with a scanning in the incidence plane.

## PHASED-ARRAY SETTINGS

The phased array settings of CIVA UT are available in CIVA ATHENA 2D but the calculation is done only for one shot and one sequence at a time.

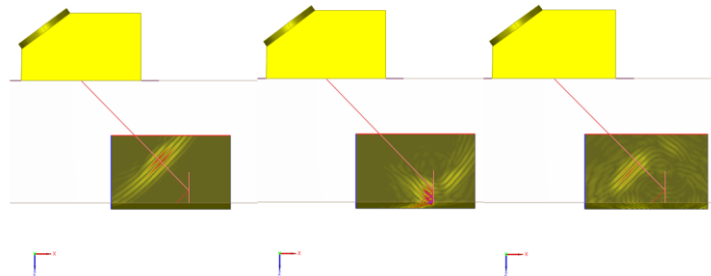
## FLAWS

The flaws that can be defined by their 2D cross-section are available: Planar, multifaceted, branched, Side Drilled Holes.



## RESULTS

In addition to the classical curves and images already available in CIVA UT (A-scans, B-scans, 3D view, reconstructed view, etc.), CIVA ATHENA 2D allows visualizing defect scattering phenomena by displaying snapshots of the beam in the FEM zone (maximum amplitude, or propagation versus time and video).

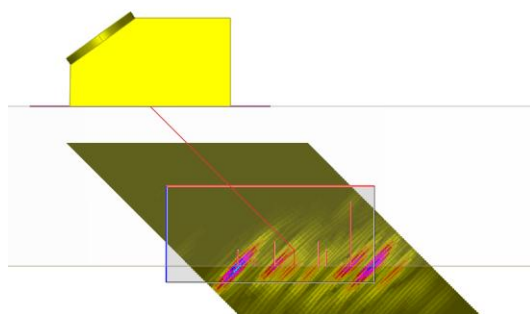


*Snapshots of the beam/flaw interaction vs time*

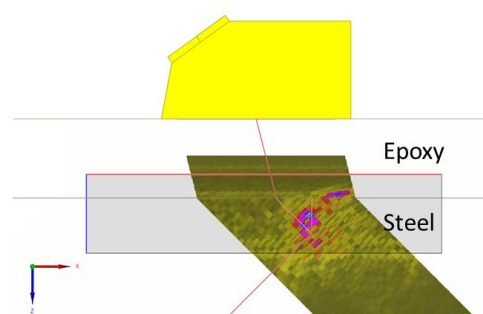
## SIMULATION EXAMPLES

The interest of CIVA ATHENA 2D is to account for all physical phenomena in the beam/defect interaction:

- Accounts for creeping waves and Rayleigh waves generated on flaws
- Simulates multiple scattering by flaws
- Precisely calculates the response from small flaws with respect to the wavelength
- Computes interface echoes



*Network of flaws (multiple scattering)*



*Diffraction on a flaw located below a cladding*

These possibilities allow precisely simulation of the response from clusters of flaws or from complex flaw profiles accounting for multiple reflections and the generated surface waves.

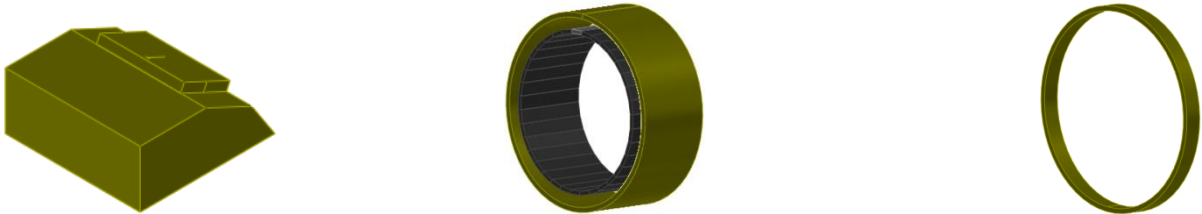
## GWT SIMULATION

Simulation capabilities for guided waves include the propagation of ultrasonic beams in planar and tubular waveguides and their interaction with a flaw. In this first version, it is possible to simulate the entire testing procedure for simple cases. Numerous functionalities and modeling work will be integrated in the next version.

## PROBES

A wide range of UT probes, including standard and advanced designs can be handled:

- Contact (with or without wedge)
- Single element or phased-array probes (see Phased Arrays section)
- Encircling or encircled probes for pipe inspection
- Different types of waves (shear or longitudinal vibration)
- Different configurations (Pulse-Echo, Pitch-Catch transmission or Pitch-Catch reflection)



## SPECIMEN

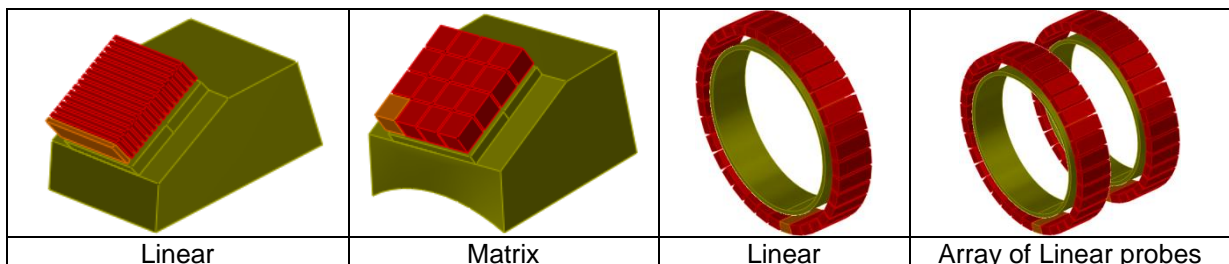
Plate-like and pipe-like structures are considered for guiding waves by CIVA. Specimens may be homogeneous or heterogeneous, taking into account a coating for example. Each medium should be isotropic and linear attenuation laws may be considered for L-waves and T-waves:



## PHASED-ARRAYS settings

With CIVA you can define delay laws for different kinds of probes: linear arrays on plates, linear or matrix arrays on pipes:

- Independent definition of emitting or receiving elements
- Variable aperture at emission or reception, for size or position

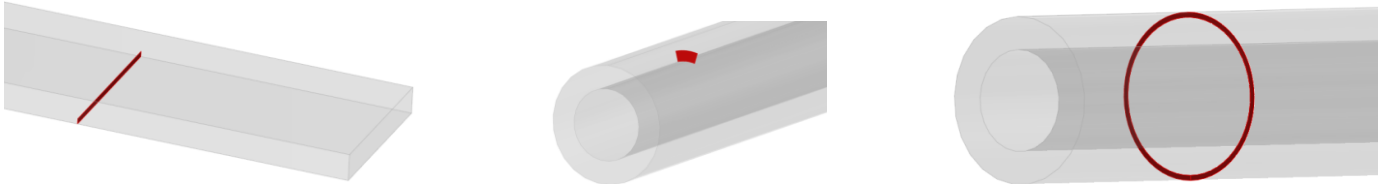


Delay laws are manually defined for each element.



## FLAWS

Simulation takes into account a flaw perpendicular to the waveguide, rectangular on a plate, sectorial on a pipe, and determines its interaction with the incident guided beam.



## RESULTS

### Mode computation

A first module computes the dispersion curves associated with the specimen in a given frequency range.

Modal displacements and constraints are computed for each mode at each frequency of the frequency range.

### Field computation

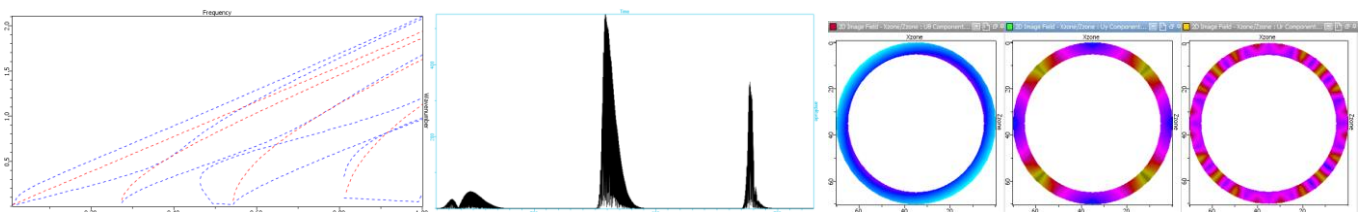
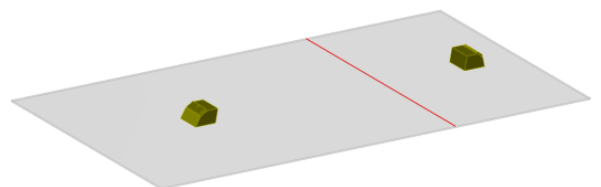
A second module allows simulating the ultrasonic beam radiated in different cross-sections of the specimen. The modal repartition of the emitted energy is displayed versus the frequency in the bandwidth of the probe.

The displacement and constraints are determined in a time range, which allows visualization of the transit of the different waves at each cross-section.

### Defect response

This module simulates the beam/flaw interaction and predicts the amplitude, waveform and time of flight of the different types of echoes: incident, reflected and mode converted.

## SIMULATION EXAMPLES



## RT SIMULATION

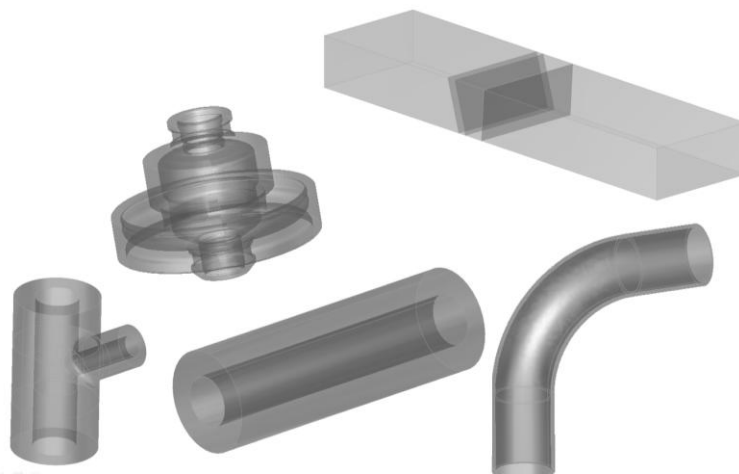
The RT simulation module can compute direct and scattered radiation produced by an X-ray or Gamma-Ray source.

The user can easily and rapidly define its control configuration: Test piece selection, source definition, detector, possibility to insert several flaws, positioning of source and detector, and finally computation options.

## SPECIMEN

The component geometries available in this module are:

- Classical parametric geometries (planar, cylindrical, conical, elbow or nozzle),
- 2.5D CAD, with linear or cylindrical extrusion,
- 3D CAD (format Step, IGES or STL).



*Examples of component geometries*

The material is defined from an available database including more than 110 elements and alloys, with the associated cross-section data. The specimen can be homogeneous (1 single material) or heterogeneous (except for 3D CAD).

## SOURCE

- Radiation :
  - X-ray Source: One defines the intensity of the source in Ampere and the spectral contents of the photons radiated by the source. This spectrum can be defined:
    - By selection in a catalogue proposing predefined ones (Birsh-Marshall)
    - By manual settings
    - By using a spectrum calculator embedded in CIVA based on the physical parameters of the source entered by the user: anode ( angle & material) & voltage
  - Gamma Source: One defines the activity of the source in Gbq and the radiated rays. The more classical ones are already predefined: Cobalt 60, Iridium 192 & Selenium 75.
- Emission Zone: One limits the effective zone of radiation in space with a conical or cylindrical volume. The effective size of the source (anode target with X-rays, radioactive capsule in Gamma) can be assumed as an ideal spot or not, allowing to account for geometrical unsharpness.

## DETECTOR

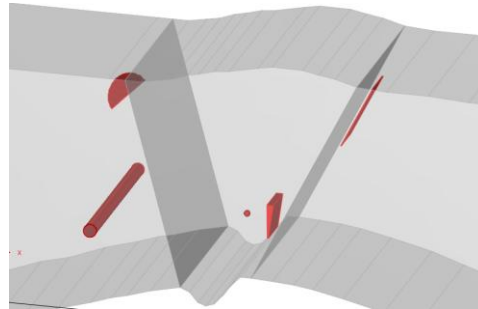
The detectors can be planar or curved. Several ways to define them are possible:

- Definition of all the parameters by the user (gain, material of the sensitive layer, sensitometric curve, ..)
- Simple selection among a list of 16 industrial films.

It is now possible to take into account the granularity of the film. For any type of film, a filter can be added. A region of interest (ROI) can be used to increase the precision of the computation at one part of the detector.

## FLAWS

Several flaws can be inserted in the test piece. They can have different shapes: Planar, spherical, ellipsoidal, trapezoidal, or arbitrary (3D CAD) as well as calibration holes: Flat bottomed Hole, Side Drilled Hole or Hemispherical Bottomed Hole. Flaws can be made of void, gas or solid. It can be an alloy.



*Examples of different types of flaws in a weld*

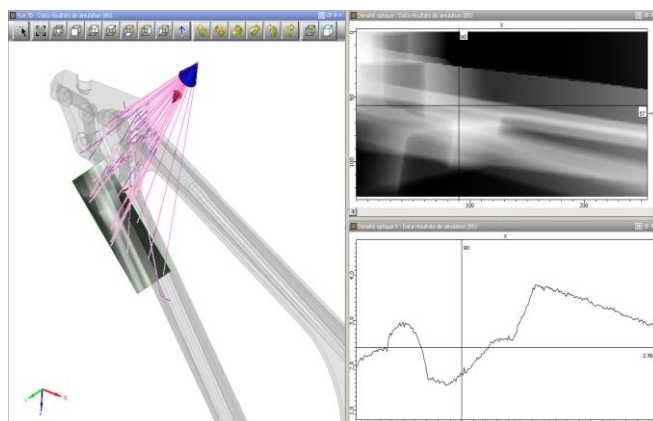
## RESULTS

Two combined methods (analytical Beer-Lambert & Monte-Carlo) compute both the direct radiation and the scattered radiation. The build-up (ratio direct/scattered) is also available in order to estimate the importance of scattering in a given inspection.

For Monte Carlo computations, the algorithms benefit from multi-core architectures in order to reduce calculation times. Moreover, if the MC calculation has been done once, and that user wishes to study the variation of a parameter that does not impact the scattering (variation of the exposure time for instance), it can be reused in the new configuration and associated to a new and fast direct computation.

Users can visualize both the detector response (optical density or gray levels) as well as the incident dose in Gray or the deposited energy on the detector in keV. Results are presented as images in the classical CIVA environment as well as curves following selected cross sections, allowing the user to easily quantify local variations of contrast. The moving of cursors is linked to the 3D graphic view and the photons paths are plotted. The thicknesses of materials passed through are identified in a table.

The images obtained can be exported in the Tiff format.

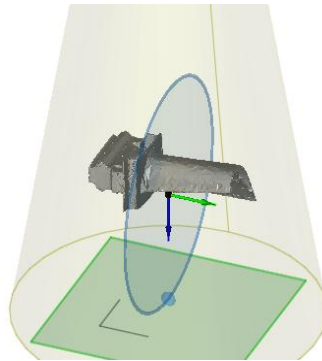


*Result of a simulation of a stiffener radiographic testing: 3D view, photons path, image of the optical density, curves extraction*

## CT SIMULATION

The CT module proposes the same interface and same capabilities as the RT module in terms of:

- Specimens
- Sources (X or gamma sources)
- Detectors
- Flaws
- Computation options : simulation of direct and scattered radiation



## SPECIFIC ITEMS

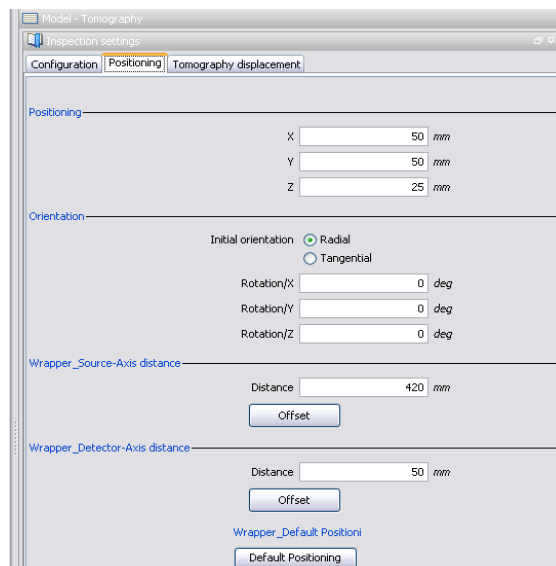
The items specific to Computed Tomography are:

- Positioning
- Tomographic scanning
- 3D reconstruction

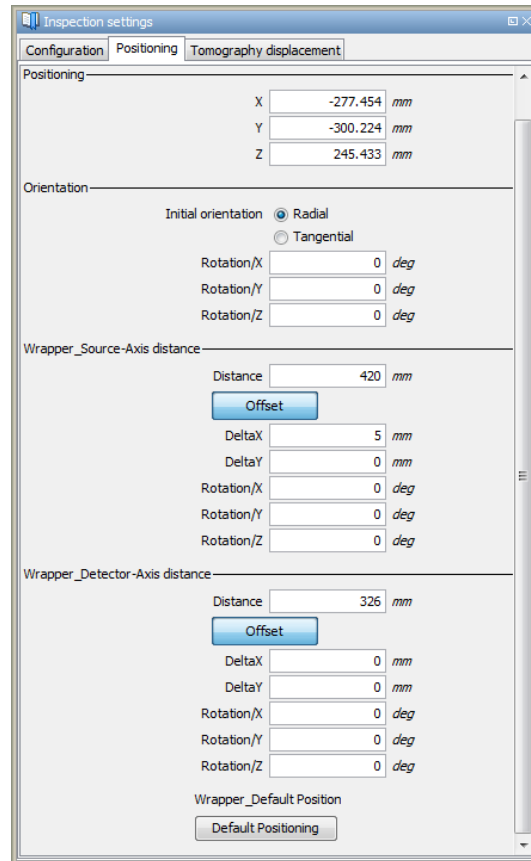
### Positioning

A positioning option allows the user to define the {detector-source} positioning system.

The user can now enter the source-axis distance and detector axis distance in a semi-automatic way.



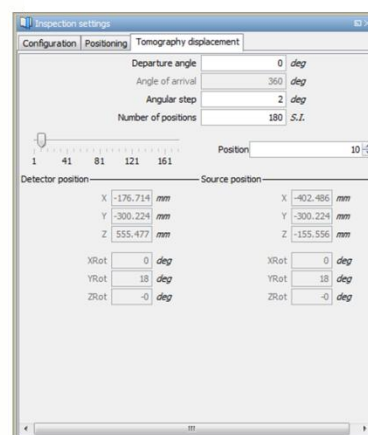
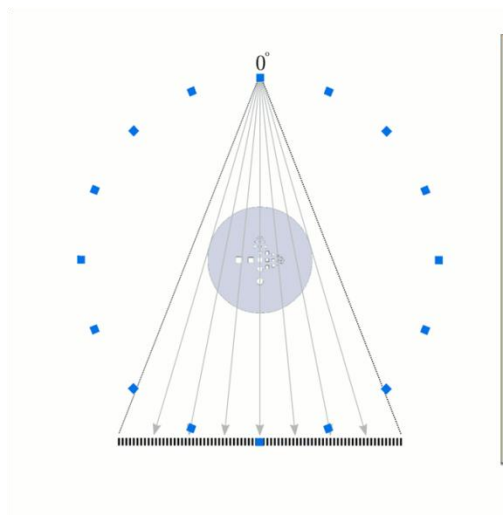
Specific misalignment options complete the positioning options. One can define an offset of the source and/or the detector versus the specimen to be inspected.



## Tomographic scanning

As the part geometry is fixed in CIVA, the X-ray tube and detector rotates around the specimen.

An arbitrary number of steps and shot positions can be defined. Then, CIVA will run the RT simulation for all the projections.



## RESULTS

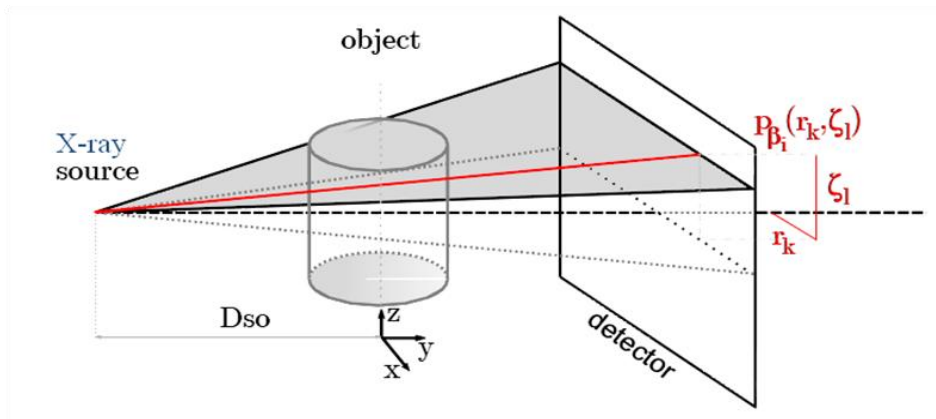
### *Results for each projection:*

X-ray slice data is generated for each position and the corresponding results can be displayed. Those results are identical to the RT module and depend on the detector and the computation options.

All the analysis tools within CIVA RT are also available in CIVA Tomography.

Once the scan data has been acquired, the data must be processed using an algorithm of tomographic reconstruction, which produces a series of cross-sectional images.

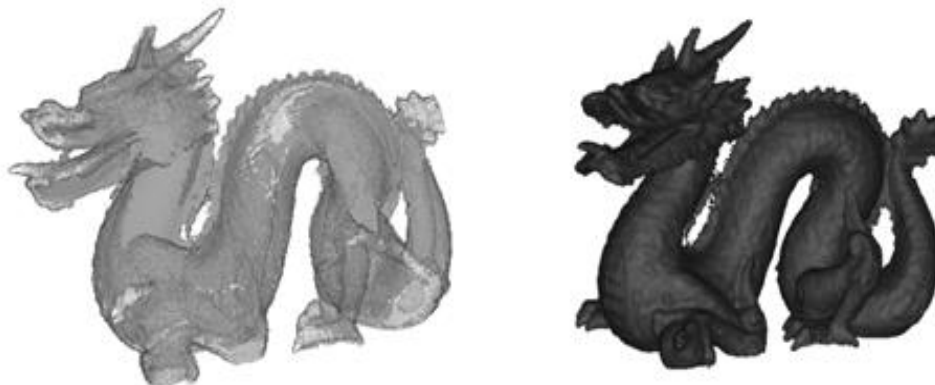
### *3D reconstruction:*



The algorithms used in the current release of CIVA are the FDK algorithm (Feldkamp, Davis and Kress) and PIXTV.

- The first method uses the FDK algorithm (Feldkamp, Davis and Kress). The FDK algorithm is a widely used filtered-back projection algorithm for three-dimensional image reconstruction from cone-beam data.

- The second method of reconstruction uses the PIXTV algorithm based on compressed sensing theory. This is an iterative reconstruction algorithm which minimizes the TV (total variation) norm.





## ET SIMULATION

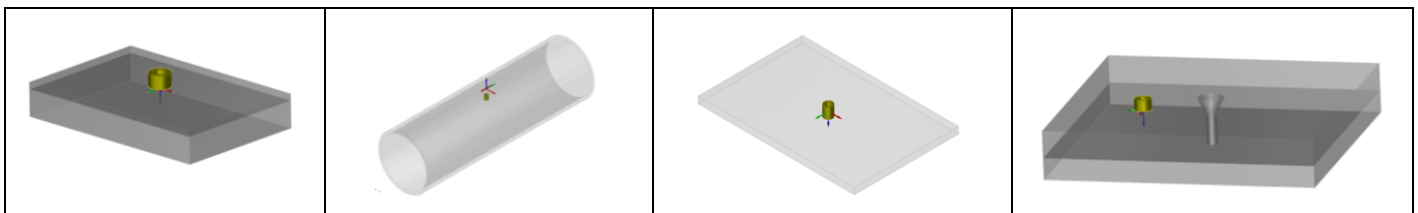
The ET simulation modules can predict the electric field induced in a test piece, compute the impedance diagram of a probe, and also simulate the defect response with one or several ET sensors.

### Specimen

#### Parametric geometries:

The graphical interface allows the user to define the following parametric geometries :

- Tube,
- Plate,
- Riveted structure (possibly multilayers).



*Available component geometries: Tube, Plate, Multilayers plate, riveted plate*

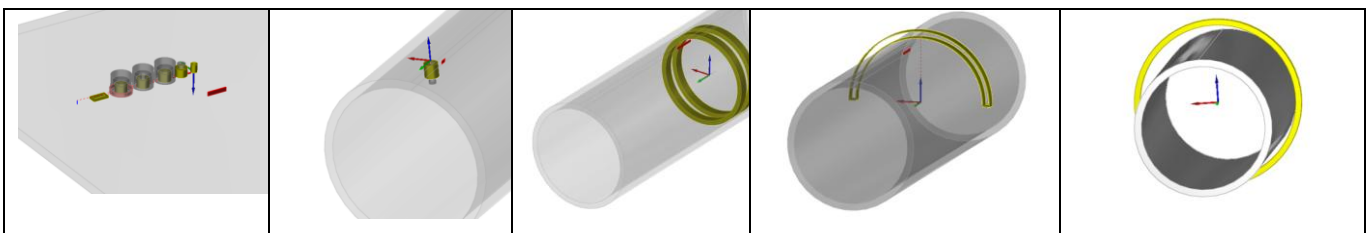
#### Materials

User defines the conductivity and the permeability of the component (constant values). One can also select directly the material in a predefined database including about twenty classical metals.

### Probes

The ET module proposes a library of different types of sensors:

- Punctual cylindrical or rectangular coil, bobbin coil, encircling or sectorial coil for tubes,
- Punctual cylindrical or rectangular coil on plates and riveted plates,
- GMR like magnetic sensors,
- Multi-elements sensors.



*Various ET probe configurations in CIVA: Punctual sensors on plate, tube, bobbin coils, encircling off-centered coil, sectorial coil*

A ferrite core can be added to a coil. The core can be cylindrical, or a C or E-shaped pot. A shield ring can also be represented.

CIVA allows the user to model multi-sensors and multi-frequencies channels:

- Independent settings and positioning of sensors: Different phenomena such as lift-off variations, tilt angles and off-centering in tubes can be accounted for,
- Several acquisition channels may be defined (absolute, differential, separated transmit/receive) at different frequencies

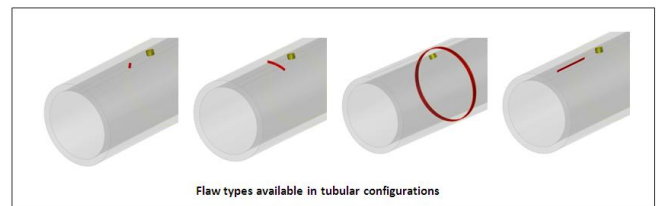
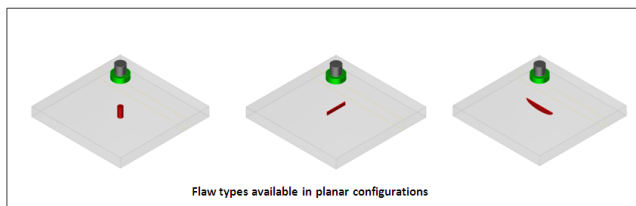
## Flaws

Several flaws can be defined in the test piece. Several types are available:

- Longitudinal or transverse notch in tubes,
- Internal or external groove in tubes,
- Flat Bottomed Hole in all kind of components,
- Parallelepipedic flaw in planar or riveted pieces,
- Semi-elliptical notch in plates.

Flaws can be voids, inclusions or partially filled with materials (“bridge contacts” defect type).

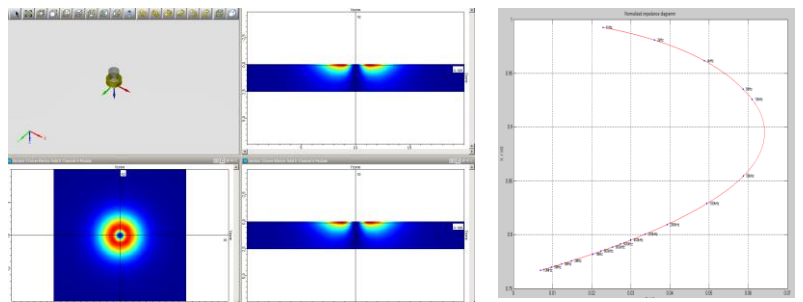
Several flaws can be combined (i.e. crossed) and positioned internally, externally or embedded with a defined ligament.



## RESULTS

### Field, eddy current and impedance computations in free-flaw components

The field computation module proposes a fast analytical calculation tool for flaw-free planar work pieces. Several quantities can be displayed: eddy-current density or electric field. The normalized impedance diagram of a probe can be plotted for various working frequencies (only for sensors on plates) facilitating finding the best operating frequency.



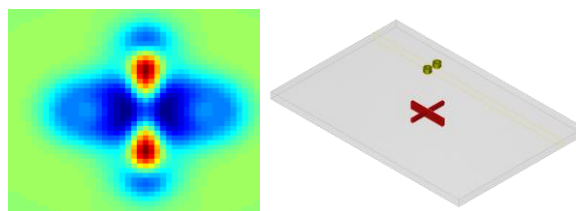
*Computation and visualization of the depth penetration in a flaw-free component / Normalized Impedance diagram*

### Defect response simulations

The defect response module can simulate the inspection of tubes, planar and riveted components having one or several defects (possibly combined), selected among the available list of defects presented above. The sensors scanning can follow linear trajectories, transverse or helicoidal ones.

A planar component can include several conductive materials. A tubular workpiece will be only defined with a single material, that can be ferromagnetic. In particular, CIVA can model the remote field technique for ferromagnetic tubes inspections (so-called RFT).

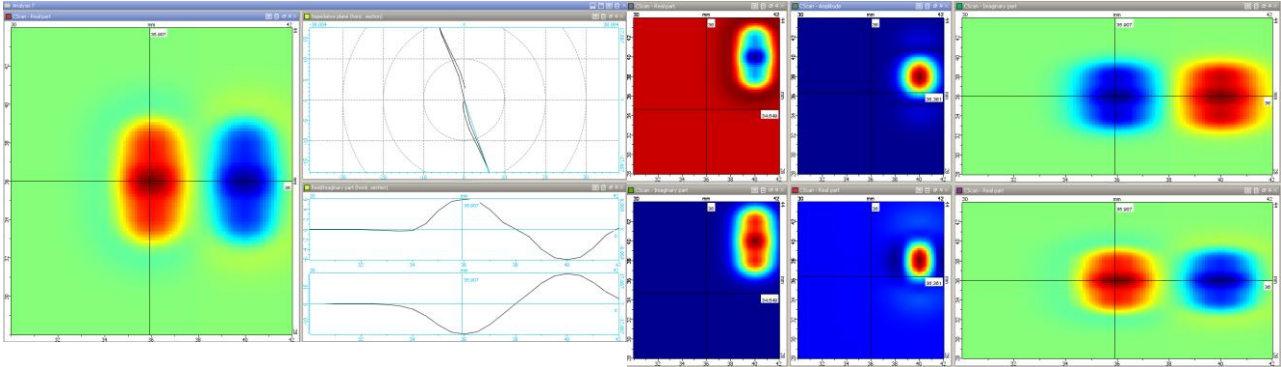
A multi-channel mode gives the possibility to compute in one shot of simulations, several acquisition channels (absolute, differential...) at one or different frequencies.



*Cscan of a simulation of a planar component inspection with crossed flaws*

### ET analysis tool

A dedicated post-processing tool displays the impedance variation signal due to the flaw(s). Results are displayed with a Cscan colored chart or conventional curves in the impedance plane. The environment provides access to classical results for an ET analysis (Amplitude, Phase, X and Y channel, Lissajou curve) as well as other tools to process data: Calibration, Frequency mixing, Interpolation, Balancing, Filtering. It is possible to compare the different channels defined in the same analysis window.



Analysis environment: Cscan, Impedance plane, display of different channels

## HARDWARE AND OS RECOMMENDED CONFIGURATION

**Operating Systems:** Windows XP, VISTA (not recommended), Windows 7

### Standard configuration:

- Dual core
- Ram  $\geq 4$  Gb
- Hard Disk  $\geq 250$  Gb
- Graphic Resolution  $= 1280 \times 1024$  or  $1900 \times 1200$
- DVD ROM
- USB port for dongle

### Optimized configuration:

- Dual / Quad / Octo core
- Ram  $\geq 8$  Gb
- Hard disk  $\geq 250$  Gb
- Graphic Resolution  $= 1280 \times 1024$  or  $1900 \times 1200$
- DVD ROM
- USB port for dongle