NDT Modelling An Overview

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Abstract:

This paper is a summary of the various aspects of “modelling” used in NDT. A definition that encompasses the variety of modelling options used is proposed and a classification of the various options is outlined. Although the entire spectrum of NDT modelling is touched on, special consideration is given to ultrasonic modelling. Some of the background options are examined and examples are used for illustration. Present practices are summarised and the driving aspects of industry to further the use and development of modelling are explored.

Introduction:

Modelling has been a part of NDT since its earliest applications. It has been used for several of the common NDT methods including radiography, ultrasonics, eddy current, remote field and a variety of others.

However, the concept of modelling may vary from method to method or even from user to user! To allow for a general approach that encompasses as many NDT modelling concepts as possible, a definition of NDT modelling is proposed for this paper. Generically we may state that:

> ***“Model, models, or modeling may refer to a pattern, plan, representation, or description designed to show the structure or workings of an object, system, or concept.”***

For our NDT applications *NDT modelling is any tool that assists in the understanding of our NDT method and its application to a test piece.*

Such a definition allows for both the visualisation and the now more common mathematical methods of modelling.

From the NDT.net Lexicon [1] the definition of modelling is synonymous with “simulation” and is primarily concerned with the mathematical case:
“The benefit of mathematical modelling codes for modern NDT is well-known, as they are increasingly applied to simulate ultrasonic experiments in real-life inspection. They yield valuable information on the propagation of ultrasound and its interaction with defects and allow for visualization of sound fields and sensitivity zones of ultrasonic transducers.”

Depending on the extent or type of the modelling, the main expectations from modelling may include:

- Volume coverage by the test setup
- Improved understanding of basic principles
- Improvement of the inspection technique
- Refinement of sensor design to optimise sensor placement and detection capabilities
- POD (Probability of Detection) evaluation on more specific structures by mixing real and virtual data

Not all applications require elaborate modelling calculations. Likewise, not all modelling calculations provide the desired solutions to the applications under scrutiny. We will need to pick and choose from the modelling options available and decide when a modelled solution is desirable for an application. To do so requires that we have knowledge of the modelling options available.

Categories of NDT Modelling:

Based on our definition of modelling that it is *any tool that assists in the understanding of our NDT method and its application to a test piece,* we may group the modelling methodologies into three general categories;

1. Simple Geometric
2. Mathematic computations
3. Visualisation

Simple Geometric options would be line or curve representations of the sensing fields. These lines may be manually or computer drawn.

The second option, mathematic computations, generally consider field source strength and effects of the test method and take into account the attenuation effects of the tested material. Depending on the detail to which the parameters are considered and the methodology used, the complexity of the mathematics varies.

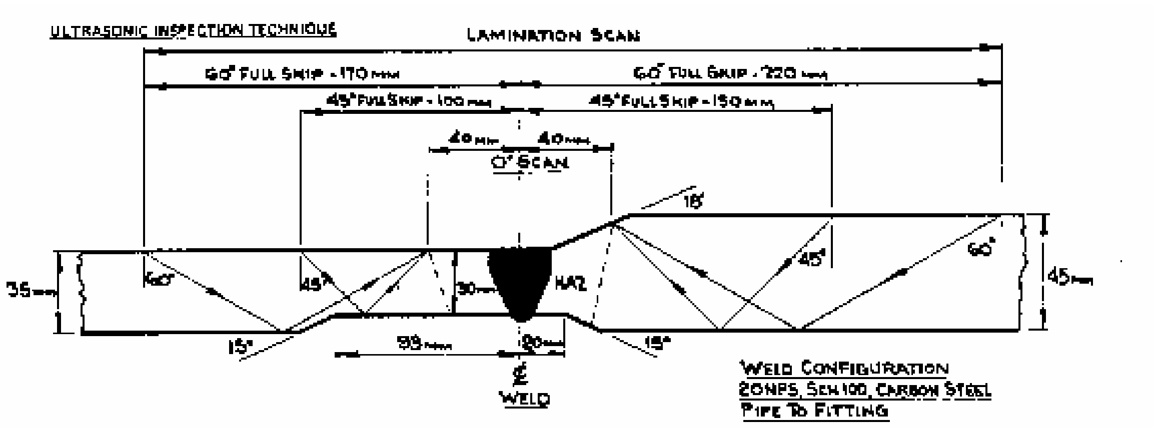
The third option, visualisation methods, use the actual sensor or field effects and adapt methods of displaying the field. For some NDT methods this is done as part of the normal test (e.g. fluoroscopy) but we do not generally consider fluoroscopy a modelling visualisation method. The main beneficiary of NDT visualisation has been the ultrasonic method. Ultrasound has been displayed using schlieren, photoelastic and acoustography techniques.

A Brief History of Some Aspects of NDT Modelling:

Simple Geometric Options

Perhaps the oldest option of “modelling” we have used in NDT is the simple geometric process of line representations of the sensing fields. Ultrasonic operators of any age will recall the process of making a scale drawing of weld profile and then making lines representing the centre of beam from a probe. These lines may be extended to indicate skips and are used to indicate either the coverage of the technique or the point of interaction of the beam with an indication. Figure 1 illustrates a typical hand drawing of a weld with the probe positions required to produce the volume coverage of the weld and heat affected zone. (This was taken from a technique developed in the 1970s).

Figure 1 Manual Technique Drawing



These simple line drawings sufficed for decades. By producing scale drawings and assuming the beam followed simple straight lines it was even possible to predict the locations where mode conversion would occur (such as at the counterbores in Figure 1).

Mathematic Options

From Wikipedia, the free online encyclopedia

> *A **mathematical model** is an abstract model that uses mathematical language to describe the behaviour of a system. Mathematical models are used particularly in the natural sciences and engineering disciplines (such as physics, biology, and electrical engineering) but also in the social sciences (such as economics, sociology and political science); physicists, engineers, computer scientists, and economists use mathematical models most extensively.*
> *Eykhoff (1974) defined a mathematical model as 'a representation of the essential aspects of an existing system (or a system to be constructed) which presents knowledge of that system in usable form'.*

Pierce [2] points out that the basic mathematic principles underlying sound propagation include the principles of continuum mechanics, which include the laws that deal with conservation of mass, changes in momentum, changes in energy brought about by work and heat transfer, symmetry conditions, and properties of the substances through which sound can propagate.

In fact, the mathematic theory of wave mechanics can be considered to start with Newton and Galileo with further contributions in the subsequent centuries from Euler, Lagrange, Stokes, Helmholz, Kirchoff, Rayleigh and many others.

Closely related to the wave motion considerations in NDT is the nature of the source of energy. Electro-Mechanical equivalent circuits are used for transducer modelling. The basics for the equations for this theory are derived from Kirchoff’s equations [3].

A similar set of mathematical considerations can be made for electro-magnetic fields and these have provided the foundations for modelling of eddy current applications.

Although mathematic models existed for wave motion they were not “practically” applied until computers were available to process results with some speed in calculations. This did not occur until about the late 1970s. By “practical” we mean here that some form of rapid graphic representation was possible. The “number crunching” capabilities of computers allowed useful iterative solutions to the equations.

Prof. Dr. Kasaburo Harumi [4] was one of the early pioneers in the computed mathematic modelling of ultrasound. He used computers to display the nature of wave mechanics to the NDT user. Over a period of several years starting in about 1982, Dr. Harumi and his associates produced a multi-part educational film with computer graphics simulating the behaviour of ultrasound in a solid. It consists of 14 parts starting with the basics illustrating lattice and vector representations of the compression and transverse waves and then on to several other examples including reflection of a longitudinal wave by a crack for 60° incidence and reflection of a transverse wave by a surface crack for 60° incidence.

Mathematic modelling has used a variety of methodologies known by the names of processes used. Some of the methodologies include:

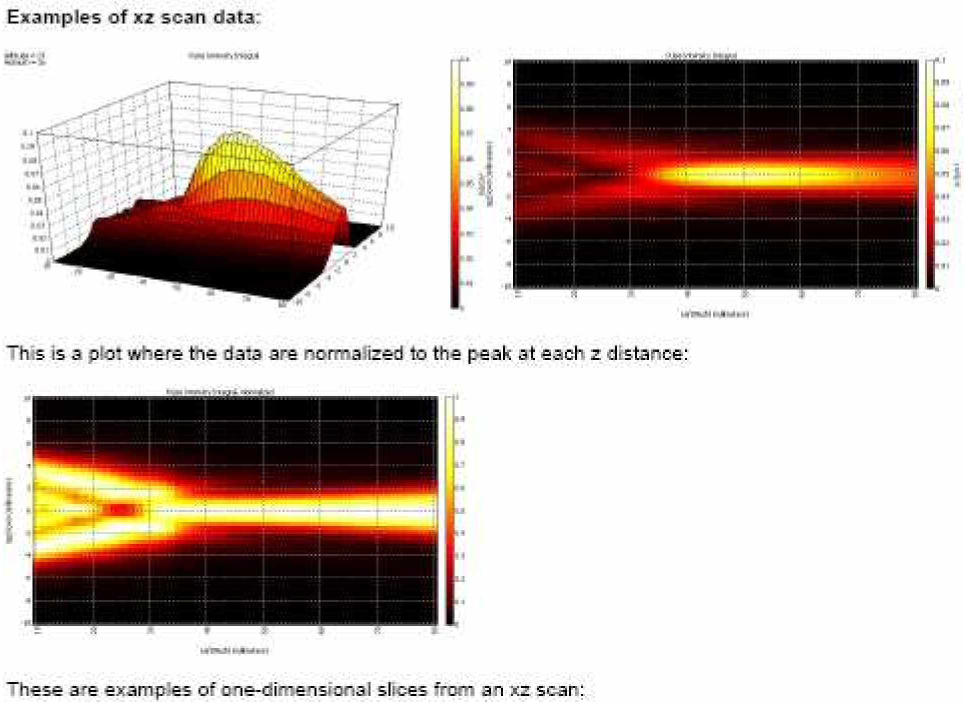
FEM	Finite Element Method
EFIT	Elastodynamic Finite Integration Technique
BEM	Boundary Element Method
FDM	Finite Difference Method

Visualisation Options

One definition of visualisation states that “A visualisation is a graphic that represents data in a visual format.” The concept of “Visualisation” is used throughout NDT processes in normal data acquisition work. Typically a series of data points is reassembled into a display that represents the part and/or an internal feature. In ultrasonics the data points are comprised of “A-scans”. In eddy current the impedance plane components are used to re-construct an image representing a flaw. When a component is tested from a variety of angles, such as is possible with X-ray and ultrasound, the results can be reconstructed in 3D and a Tomographic image made.

For example, by scanning a steel ball or hydrophone in an X-Y raster pattern with incremental increases in the Z axis an intensity plot of the radiated beam can be made using the appropriate software. Results such as illustrated in Figure 2 provide a “model” of the sensitivity regions of the probe.

Figure 2 Hydrophone Intensity Plot (courtesy Onda Corp., USA) (Not “modelling”)



Examples of xz scan data:

This is a plot where the data are normalized to the peak at each z distance:

These are examples of one-dimensional slices from an xz scan:

Instead of “modelling” such representations are more often considered to be data “imaging” and as such would not be grouped in our “visualisation” category.

Not all test media are as convenient to work in as the water in which the image in Figure 2 was made. When the medium is a solid the continuous changes in the beam or field shape are not so easily obtained.

Visualisation may be considered a special form of modelling whereby the inspection field mechanism is made to propagate through an actual or simulated test medium and “optical” methods are used to “see” the results of beam movement and interactions. Ultrasonic testing has benefited most from visualisation. Two main visualisation options have been developed over the years;

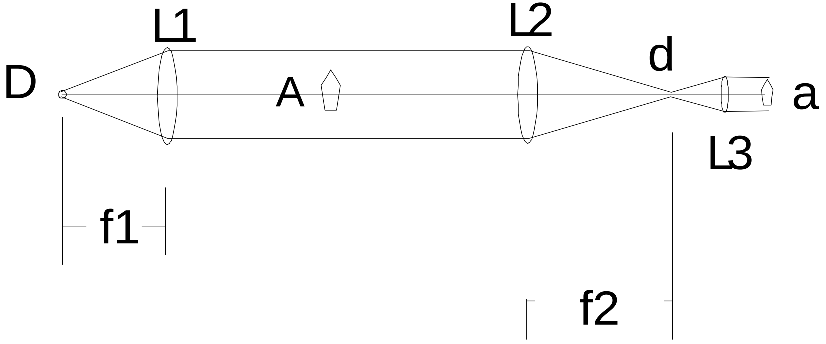
Schlieren techniques
Photo-elastic techniques

Schlieren Modelling Techniques

The conventional schlieren system can be credited to August Toepler. Toepler's original system was designed to detect schlieren (from the German meaning streaks or scratches) in glass used to make lenses.

In its basic form, the schlieren setup is simply a collimated light beam directed over the specimen and then the beam is focused to a point where a “stop” is placed. The “stop” is typically a “knife-edge” plane (e.g. a razor) or may be a small dot (e.g. solid black paint or epoxy circle pasted to a flat glass plate). Under the steady-state condition no light gets around the stop. When a change in the steady-state condition occurs it causes the light to deviate its path. This light deviation is converted to shadows in a schlieren system. The main components are seen in Figure 3.

Figure 3 Schlieren setup

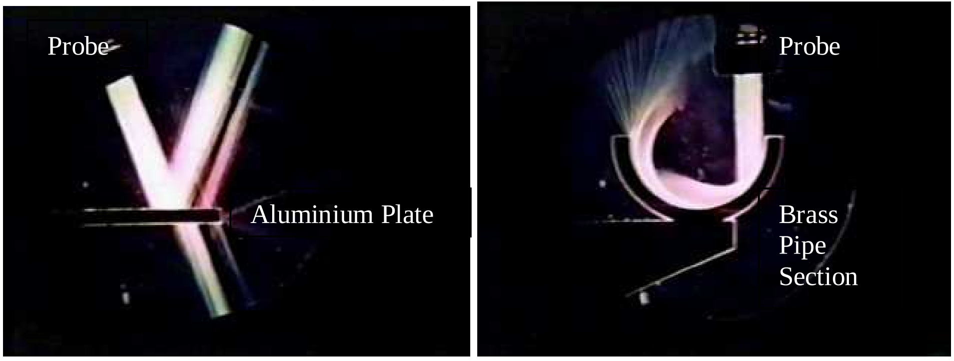


D is the light source. L1 and L2 are the collimating and focusing lenses respectively. “d” is the stop and “a” is the observer located after the magnifying lens L3.

Schlieren systems have been used in NDT for transducer beam analyses by a variety of researchers [5,6,7, 8]. In 1959 McMaster notes that “*methods for direct optical visualisation of continuous-wave systems are “well known” and are usually modified schlieren apparatus techniques*”.

Visualisation using schlieren techniques are the only ones that have commonly used continuous wave excitation of the transducer (although McNamara describes a CW analysis [9] using a photoelastic system in his paper). Figure 4 illustrates 2 images of the schlieren technique taken from a movie made by Automation Industries Inc. in 1970[1]. A year or so later the NDT department of Battelle Northwest labs made a similar movie using a pulsed neon laser with almost the same sequence of demonstrations. The Battelle narrator noted that the modelling applied to both ultrasonic and electromagnetic applications.

Figure 4 Schlieren Images using Continuous Wave Excitation



When the light source is of sufficiently short duration the normal pulsed operation of ultrasound can be used and pulses can be “stopped” for viewing. This was done by the writer for the images in Figure 5 where an acousto-optic modulator is used to provide a strobe laser illumination of a 2MHz pulse striking a stainless steel cylinder.

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[1] The same schlieren apparatus was demonstrated to the writer in about 1995 by Mike Shakinovsky in Danbury Conn., USA at the Sperry Rail Corp. Sperry Rail and Automation industries were sister companies and the equipment from Automation Industries had been moved from Boulder, Colorado to Danbury to evaluate the performance of the wheel probes used in Sperry’s rail inspection systems.

Figure 5 Schlieren Images using Pulsed Excitation

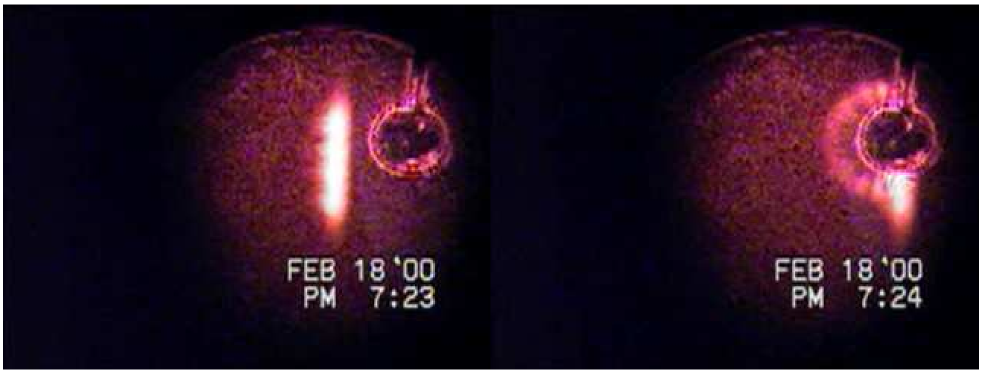
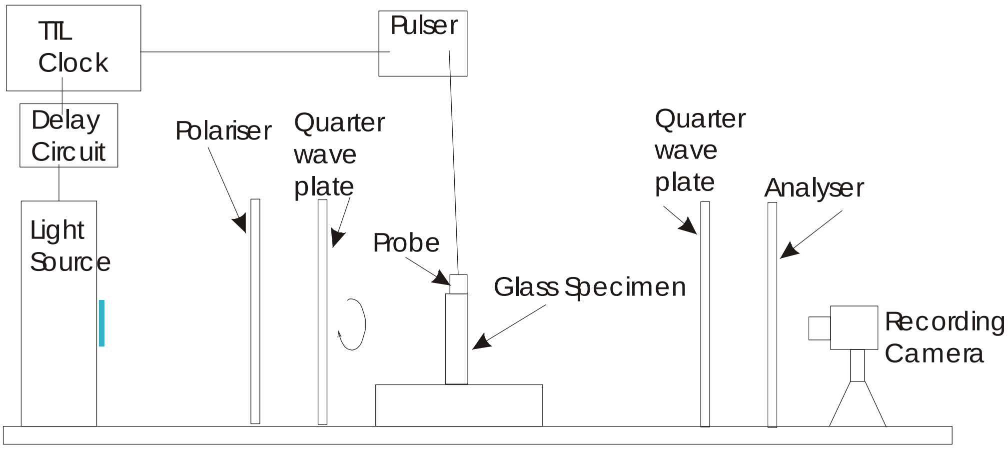


Photo-elastic modelling Techniques

For many years the preferred ultrasonic visualisation method seemed to be the schlieren technique. Photoelastic visualisation, although known about since the 1930s [10] was not used for ultrasonic beam analysis until about 1970. The basics of the system are illustrated in Figure 6.

Figure 6 Photoelastic Setup



Polarised light is passed though the sample and the light reaching the observer is “nulled” by a second polariser (the analyser). Stresses in the sample then rotate the incident polarised light and are no longer “nulled” when they reach the analyser. These pass through the analyser and are visible to the observer.

Hanstead [11] developed a compact photoelastic system that was adaptable to a schlieren system and described the advantages and disadvantages of each. Whereas the schlieren images are obtained as a result of refractive index changes due to stress gradients, the photoelastic visualisation is a result regions of stress. Hanstead noted that the schlieren technique was generally more sensitive when used to analyse in liquids. However, the shear stresses that can form in solids are not seen using the schlieren technique but are very easily seen using the photoelastic technique.

The white on black images of the ultrasonic pulses in glass models, such as seen in Figure 7, became a common sight in many of the NDT journals of the 1970s and early 1980s

[12.13.14,15, 16]. Figure 7 is a multiple exposure of four stops of the transverse wave pulse of a nominal 4MHz probe in fused silica glass.

Figure 7 Photoelastic Image from Hanstead and Wyatt (1974)

Early efforts were made to use the combination of schlieren and photoelastic techniques to quantify sound intensity [17]. Light's measurements in 1982 were based on the Raman Nath principle using the diffraction effect that sound pressure has on a light beam in an ultrasonic beam. This is different from the quantitative measurement techniques suggested by Wyatt [13] who proposed using the photoelastic system with the Senarmont method which involves rotating the analyser to minimise the intensity at the point of interest at the image.

In 1986 an advertisement in NDT International announced that a company had made a commercial system using the photoelastic technique and was selling it starting at around £19,000 (or about 35,000$US at that time) but when the writer enquired no commercial systems had been made or sold and the method faded out of the literature by the late 1980s.

Recent Developments in Modelling:

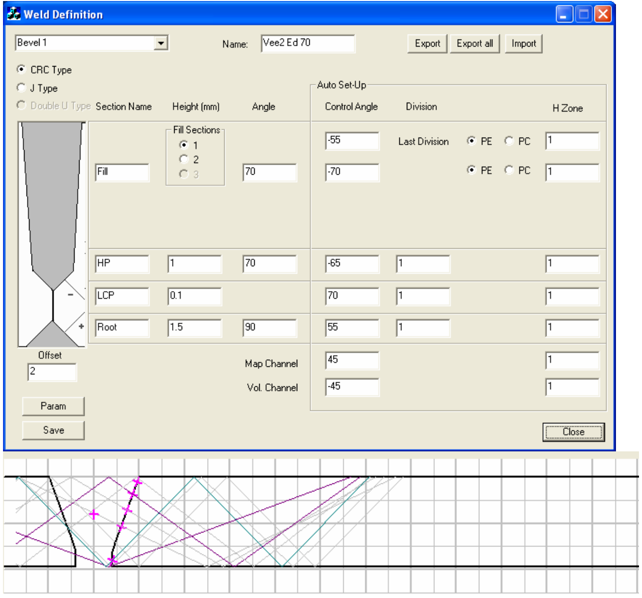
Raytracing

Each of the categories of modelling has experienced enhancements over the years.

The Simple Geometric Option has greatly benefited from computerisation. In its more familiar form as "Ray Tracing" this is now the easiest-to-use and most useful modelling tool available to the "average" NDT technician. Ray Tracing allows the user to draw two or three dimensional figures and place probes on the part.

For several years (since 2000) a modelling feedback tool has been used in phased array girth weld inspections [18]. Operators enter wedge and probe parameters and weld parameters including steel velocities. The centre-ray lines are drawn and a whole series of parameters are generated to supply a phased array system all the information required for the focal laws. Figure 8 illustrates the graphic presentation of the calculations for the zonal discrimination technique. Figure 9 is the associated data output for the essential parameters of the focals laws generated to produce the beams calculated in Figure 8.

Figure 8 Calculated Ray Tracing from weld and probe parameter inputs



Bevel 1

Name: Vee2 Ed 70

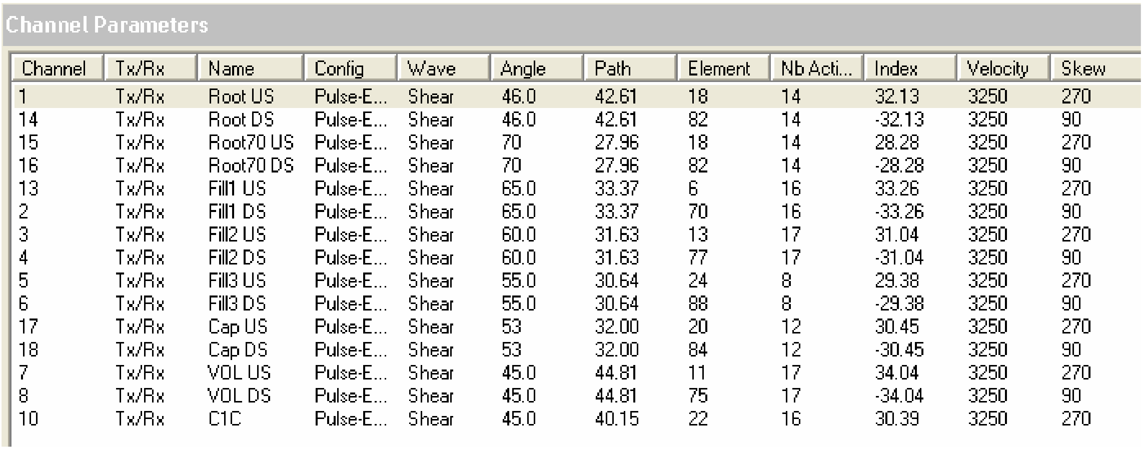
● CRC Type
○ J Type
○ Double U Type

Auto Set-Up

Section Name	Height (mm)	Angle	Control Angle	Division		H Zone
Fill	Fill Sections ● 1 ○ 2 ○ 3	70	-55 -70	Last Division	● PE ○ PC ● PE ○ PC	1 1
HP	1	70	-65	1		1
LCP	0.1		70	1		1
Root	1.5	90	55	1		1
		Map Channel	45			1
		Vol. Channel	-45			1

Offset: 2

Figure 9 Focal law parameter outputs

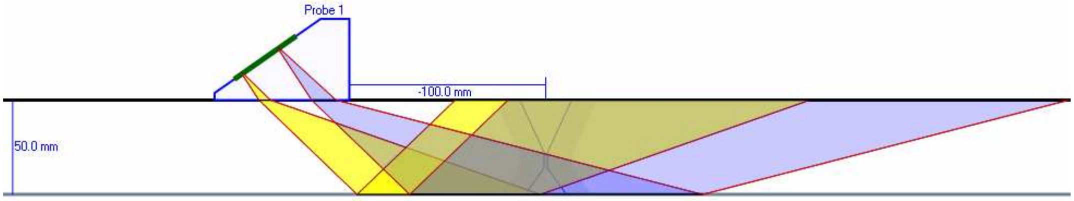


Channel Parameters

Channel	Tx/Rx	Name	Config	Wave	Angle	Path	Element	Nb Acti...	Index	Velocity	Skew
1	Tx/Rx	Root US	Pulse-E...	Shear	46.0	42.61	18	14	32.13	3250	270
14	Tx/Rx	Root DS	Pulse-E...	Shear	46.0	42.61	82	14	-32.13	3250	90
15	Tx/Rx	Root70 US	Pulse-E...	Shear	70	27.96	18	14	28.28	3250	270
16	Tx/Rx	Root70 DS	Pulse-E...	Shear	70	27.96	82	14	-28.28	3250	90
13	Tx/Rx	Fill1 US	Pulse-E...	Shear	65.0	33.37	6	16	33.26	3250	270
2	Tx/Rx	Fill1 DS	Pulse-E...	Shear	65.0	33.37	70	16	-33.26	3250	90
3	Tx/Rx	Fill2 US	Pulse-E...	Shear	60.0	31.63	13	17	31.04	3250	270
4	Tx/Rx	Fill2 DS	Pulse-E...	Shear	60.0	31.63	77	17	-31.04	3250	90
5	Tx/Rx	Fill3 US	Pulse-E...	Shear	55.0	30.64	24	8	29.38	3250	270
6	Tx/Rx	Fill3 DS	Pulse-E...	Shear	55.0	30.64	88	8	-29.38	3250	90
17	Tx/Rx	Cap US	Pulse-E...	Shear	53	32.00	20	12	30.45	3250	270
18	Tx/Rx	Cap DS	Pulse-E...	Shear	53	32.00	84	12	-30.45	3250	90
7	Tx/Rx	VOL US	Pulse-E...	Shear	45.0	44.81	11	17	34.04	3250	270
8	Tx/Rx	VOL DS	Pulse-E...	Shear	45.0	44.81	75	17	-34.04	3250	90
10	Tx/Rx	C1C	Pulse-E...	Shear	45.0	40.15	22	16	30.39	3250	270

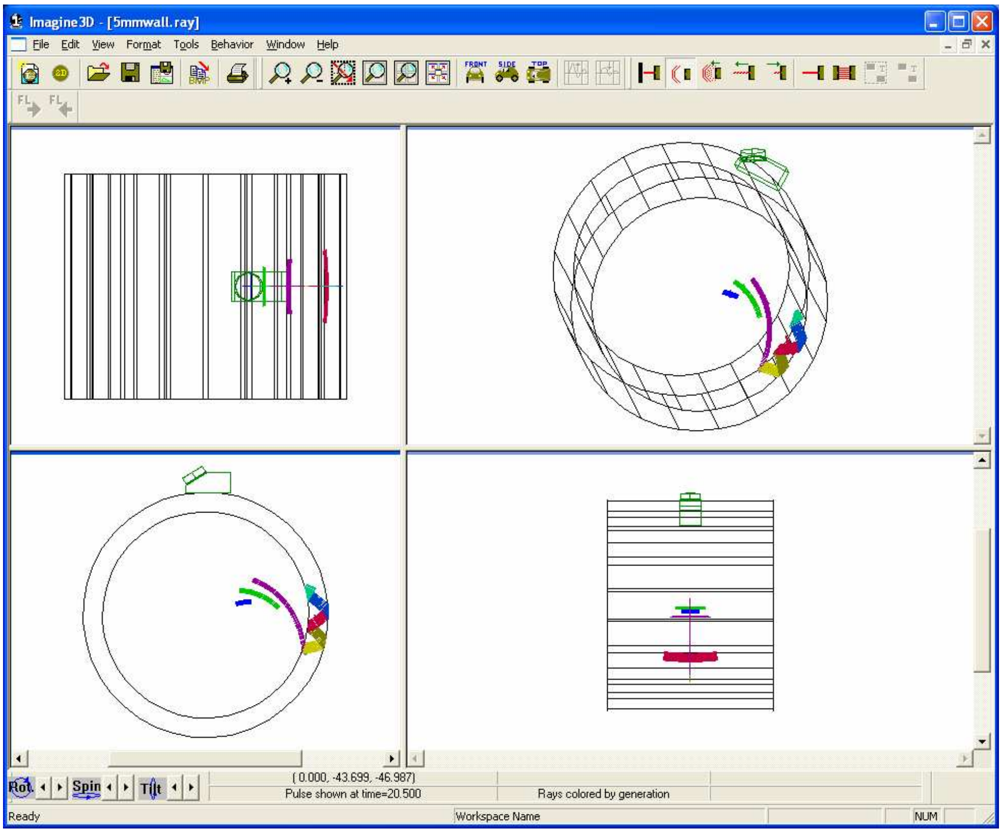
Some codes (e.g. ASME BPV) allow for “verification” of volume coverage using computer modelling. A simple approach can be used to ensure that the weld and HAZ are covered by the centre of beam. Such a tool can provide fast modification of weld basic geometries and placement of wedges and indicate if one or more linear scan is required. The modelled output from such a programme is seen in Figure 10 (courtesy Eclipse Scientific Instruments, Canada).

Figure 10 Ray Tracing showing 2 S-scans for volume coverage (2D only)



Ray Tracing with pulse mode and divergence effects provide a simple approach to the complexities of mode conversion and complex geometries. Ray Tracing models do not consider diffraction effects therefore the effect is to greatly increase the speed of the calculations and still provide an informative display. Figure 11 from I3D illustrates multiple skips of a divergent beam in a water-filled tube with a 5mm wall.

Figure 12 Ray Tracing of an unfocused beam (pulse-mode) in a water-filled tube with a 5mm wall thickness (3D effects)



(0.000, -43.699, -46.987)

Pulse shown at time=20.500

Rays colored by generation

Ready

Workspace Name

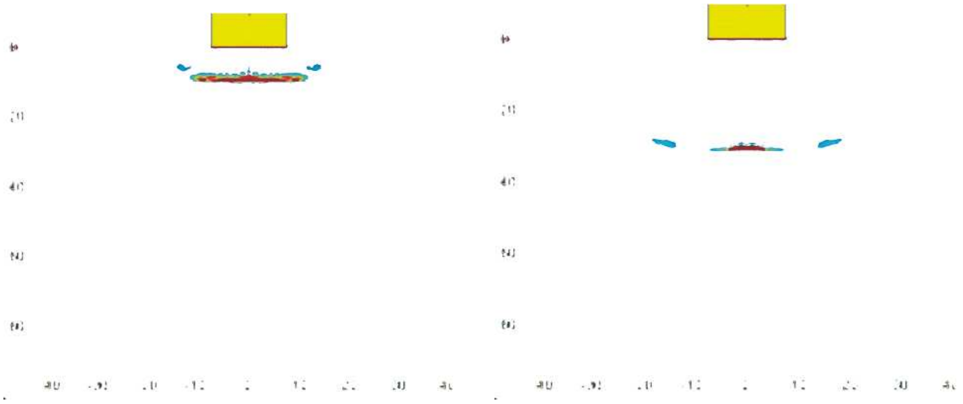
Mathematic modelling advances

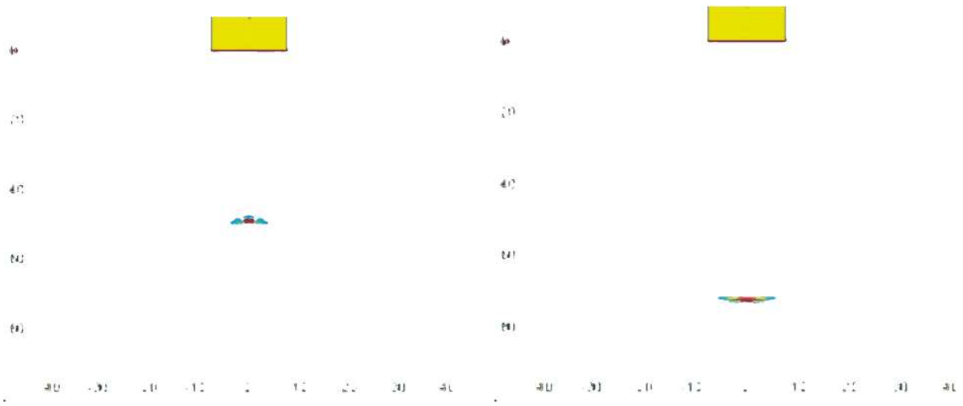
Depending on the perspective, mathematic modelling has seen improvements in either detail or speed of calculations. Generally one advantage precludes the other.

When it comes to detail the Elastodynamic Finitie Integration Technique (EFIT) developed by Langenberg provides what may be the most precise option accounting for essentially all material factors in the propagation of the ultrasonic beam.

For ease and accessibility and speed, simplified methods have been developed. DREAM by Lingvall & Piwakowski uses the ubiquitous Matlab and a technique they call the Spatial Impulse Response approach to render acoustic field images from transducers. An example of the output from a focused array is indicated in Figure 13.

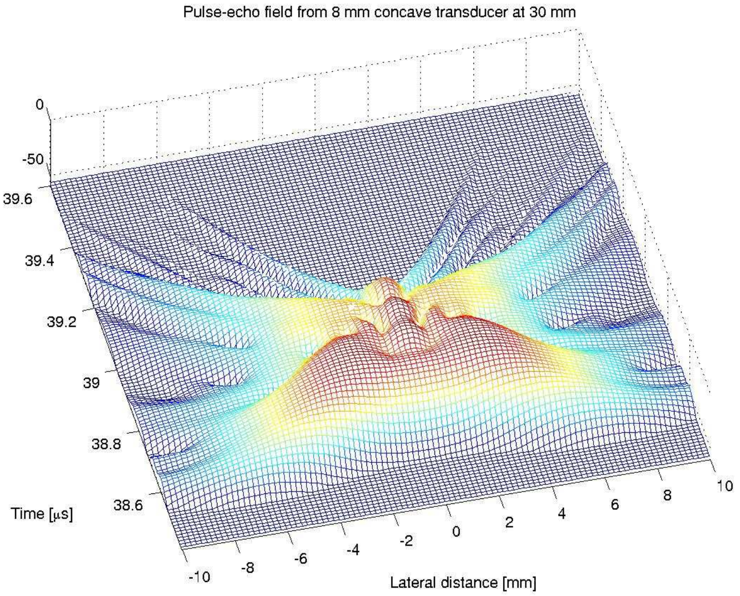
Figure 13 Phased Array focused beam pulses made by Lingvall using DREAM





Similarly Arendt-Jensen's "Field" is also Matlab based. His logo is illustrated in Figure 14. This is a calculation of point spread functions. This example calculates the point spread function for a concave, round transducer with a radius of 8 mm, a geometric focus at 80 mm and a centre frequency of 3 MHz.

Figure 14 Point Function of focused beam by Arendt-Jensen



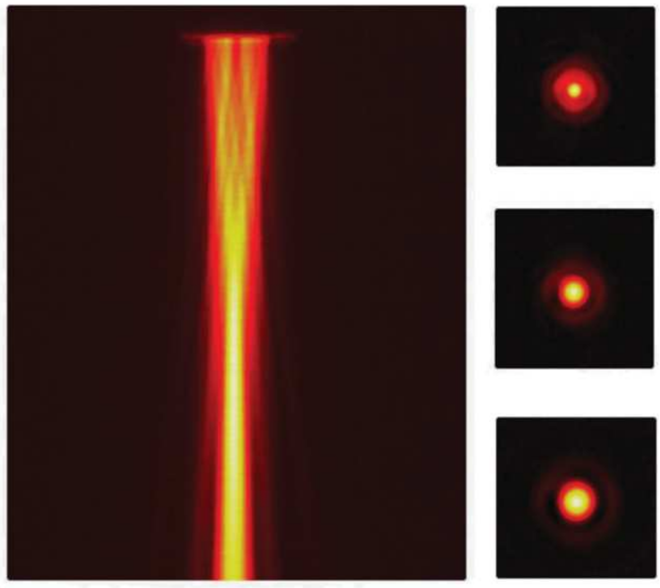
Both Lingval and Arendt-Jensen have provided their Matlab foundations on their websites (see Table below). Another recent addition to the transducer analysis domain is Philippe-Rubbers' CSSP-Diff_Sim. This has also been provided as a free download but functions as a stand-alone package. Rubbers has added a unique feature to the transducer pulse model. In his software you can apply Complex plane-Split-Spectrum Processing to increase signal to noise ratio.

Visualisation modelling advances

Schlieren Tomography

As with the other modelling options, visualisation has also benefited from computerisation of the process. A recent paper by Caliano [20], describes a compact Schlieren system (40 cm x 100 cm x 40 cm) for ultrasound beam imaging and tomography based on an optical fiber laser source developed at Acoustoelectronics Laboratory (ACULAB), University Roma Tre, Italy.

Figure 15 Tomographic reconstruction of schlieren image



The images were obtained by mechanically scanning the entire ultrasound field up to 20 cm length, and merging several sub-images. The correct merging of the sub-images, which is impeded by luminance artefacts due to both the spatial Gaussian distribution of the light source and the non-ideal optical components including lenses, screen and camera, is carried out by an adaptive filtering algorithm developed by the researchers. The left figure is an axial scan of a 3 cm ultrasound field (the emitting surface is on the top) of a 10 MHz ultrasonic transducer for ophthalmic applications. The three figures on the right are, starting from the top, the tomographic sections of the beam at 5 mm, 15 mm, and 25 mm, respectively. Images courtesy of Giosue Caliano, Alessandro Miti, Riccardo Carotenuto, and Massimo Pappalardo, University Roma Tre, Dept. of Electronic Engineering, Roma, Italy.

Acoustography

A relatively new option to model/assess ultrasonic transducer beams is a process called Acoustography. Acoustography is a full-field ultrasonic imaging process where a novel, exceptionally high resolution 2D Acousto-Optic (AO) sensor is employed to directly convert the ultrasound into a visual image in real time. Acoustic images can be formed in through transmission mode (Figure 16) or in reflection mode where acoustic images can be formed using acoustic lens analogous to photography or video camera. The AO sensor converts ultrasound image directly into a visual image due to the inherent acousto-optic effect of a proprietary "mesophase" material contained in the sensor.

Figure 16 Acoustography through-transmission mode

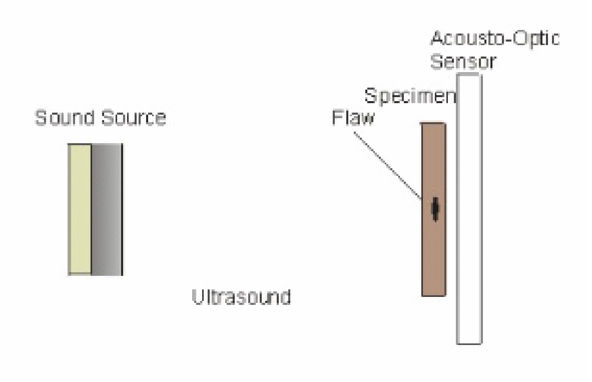
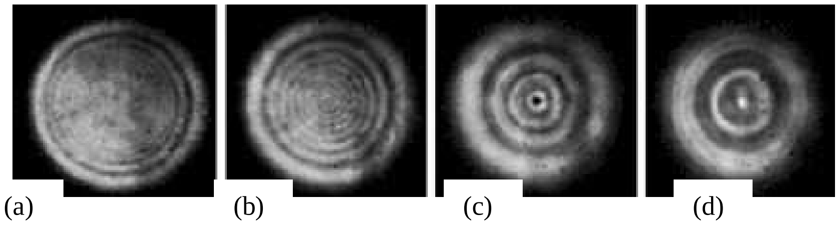


Figure 17 Acoustography C-scan of probe intensity


(a) (b) (c) (d)

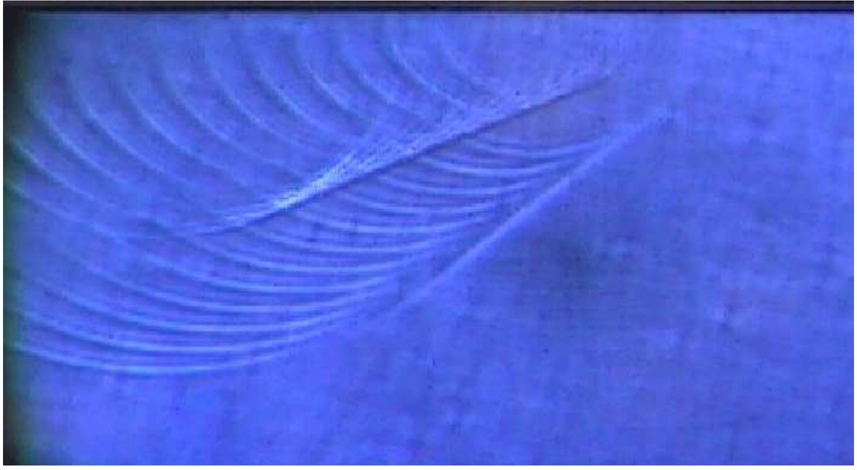
Ultrasonic field of a 5MHz, 25mm diameter, disk-type unfocused transducer at various distances from the radiating surface: (a) 1.65cm; (b) 3.0cm; (c) 6.75cm; and (d) 10.5cm

Digital Video Photoelastic Visualisation

The photoelastic method developed by Hanstead and Wyatt faded out of the NDT journals for many years. Although they had several possible applications described in their papers in the 1970s, these ideas had to wait until the digital age was more developed. With the availability of digital photography and digital video becoming commonplace in the 1990s many of Hanstead and Wyatt's predictions or postulated enhancements became realities.

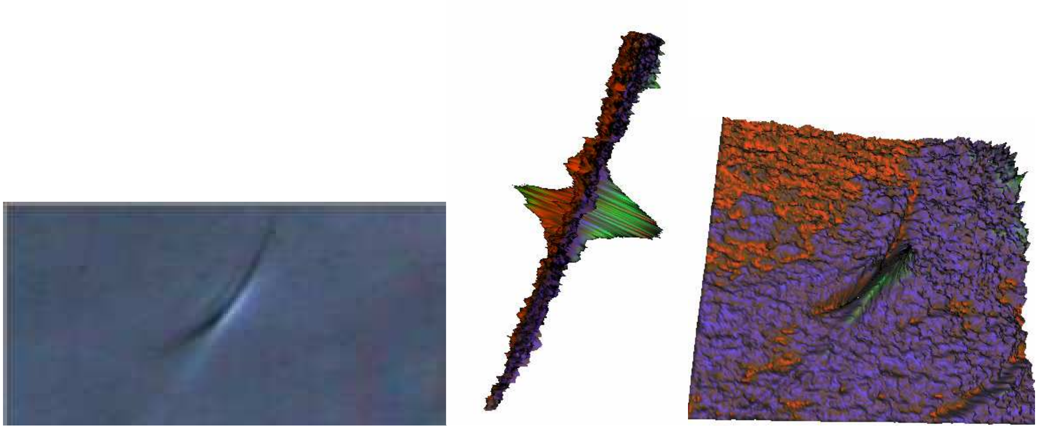
In 2004 Ginzel and Stewart [21] presented the first images of phased array pulses in solids using the photoelastic method. These verified the 'wavelets' that were used to explain the constructive interference upon which the phased array pulses are based. See Figure 18.

Figure 18 Phased array wavelets seen in photo-elastic image of pulse



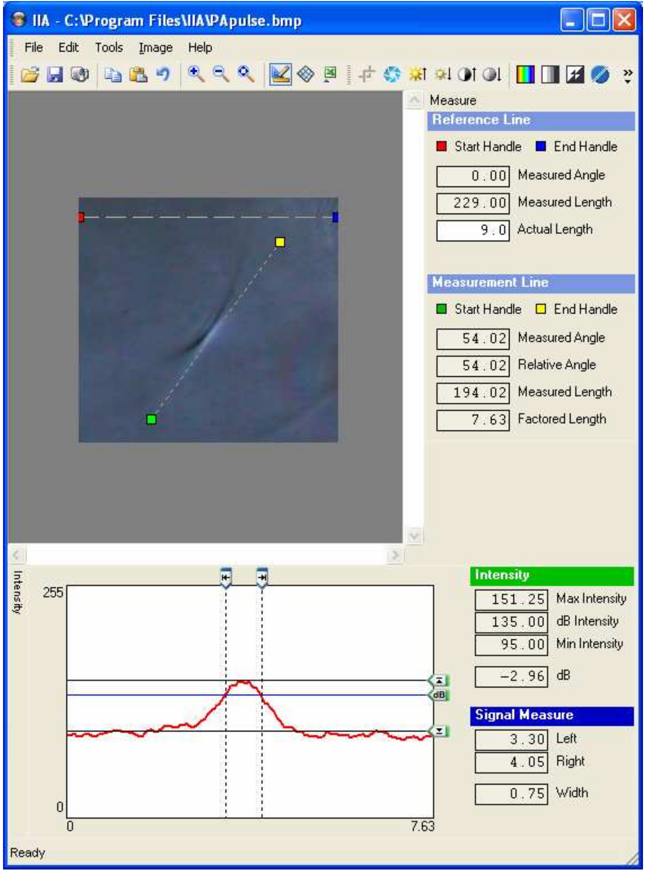
The process of capturing images also presented the opportunity for quantitative analyses as suggested by Hanstead and Wyatt. The image quality instead of the stark black and whites produced 30 years earlier were now capable of indicating more subtle features including the rarefaction and compression aspects of the pulse (see Figure 19) which could then be represented as a rendered figure.

Figure 19 **Pulse with compression and rarefaction and subsequent rendering and rotations**



Using the intensities mapped by the image, quantitative assessments of beam size can be made. Computerisation and digital processing make this a much easier and more accurate method than the photodiode displacements proposed by Hanstead. (See Figure 20)

Figure 20 Beam size analysis of focused phased array pulse



Reference Line

🟥 Start Handle 🟦 End Handle

0.00 Measured Angle
229.00 Measured Length
9.0 Actual Length

Measurement Line

🟩 Start Handle 🟨 End Handle

54.02 Measured Angle
54.02 Relative Angle
194.02 Measured Length
7.63 Factored Length

Intensity

151.25 Max Intensity
135.00 dB Intensity
95.00 Min Intensity
-2.96 dB

Signal Measure

3.30 Left
4.05 Right
0.75 Width

Summary of NDT Modelling Software

All of the categories have benefited from computerisation. A summary of "modelling software" appeared on a 2005 website http://www.computationaltools.com/ [19]. Some of the links where no longer available. The following list of the software available is based primarily on Aldrin's initial list but is updated here, based on those where connections could be established at the time of writing.

Ultrasonic

Software Name	Type	Approach	Marketed via
I3D	Transducer, geometry	Ray tracing	Utex Scientific www.utex.com
Wave2000	Transducer	2D Finite difference	Cyberlogic www.cyberlogic.org
Wave2500 & Wave 3000	Transducer	Full time domain solution to the 3D-axisymmetric viscoelastic wave equation	Cyberlogic www.cyberlogic.org
EWE	Geometry	FEM	Ken Chapman, Atomic Energy Canada, chaplink@aecl.ca
Integrated Sound Software	Acoustic field simulation	boundary element method with the simplest elements in 2-D, 3-D, and axi-symmetric acoustic (or Helmholtz) problems	Stephen Kirkup, developer stephen@soundsoft.demon.co.uk
PiezoFLEX	Transducer, geometry	Finite Element Method (FEM), 2D and 3D Piezoelectric Modelling	Weidlinger Associates, Inc. http://www.wai.com/AppliedScience/Software/Pzflex/index-pz.html
PiezoCAD	Transducer	chain matrix technique to calculate the system characteristics from electric terminals to the front acoustic port (KLM)	SonicConcepts Inc. http://www.sonicconcepts.com/PiezoCAD.htm
CIVA	Geometry, transducer	GTD (geometrical theory of diffraction)	
UTSIM	Geometry, transducer	Ray trace, GTD (geometrical theory of diffraction)	CNDE Iowa State University, http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/CalibrationMeth/utsim.htm
RayTrace v2	Transducer, geometry (welds)	Ray tracing	
UltraSIM	Transducer, geometry	3D CAD, geometric	
ESBeam	Geometry	Ray trace	
3D-CAD	Geometry	Ray trace	Fraunhofer Institut (IZfP) http://www.izfp.fhg.de/index_e.html
Soundfield Characterization and Modeling Software	Transducer, geometry		Fraunhofer Institut (IZfP) http://www.izfp.fhg.de/index_e.html
Universal Program for computing	Planar acoustic waves in	Solution of highly non-linear eigenvalue problems	Prof. Reinhard Wobst, IFW Dresden; http://www.ifw-dresden.de/institutes/iff/research/surface-

acoustic waves	layered anisotropic media.		dynamics/methods/acoustic-wave-computing/universal-program-for-computing-acoustic-waves/?searchterm=surface%20waves
DREAM	Transducer models. (Freeware - implementation in Matlab)	Spatial impulse response (SIR) approach	F. Lingvall - Uppsala Universitet (Sweden) - B. Piwakowski - IEMN - Lille (France)
Field	Transducer	Tupholme-Stepanishen method	
Ultrasim	Transducer (Ultrasound Field Simulation.)	Numerical integration of sub-elements of a transducer	Prof. Sverre Holm - University of Oslo (Norway), http://heim.ifi.uio.no/~ultrasim/
EFIT	Transducer, geometry	EFIT (Elastodynamic Finite Integration Technique)	Prof. Dr. Karl-Jörg Langenberg - Department of Electrical Engineering - Univeristy of Kassel (Germany) http://www.uni-kassel.de/hrz/db4/extern/tetsql/
CSSP-Diff_Sim	Transducer	GTD (geometrical theory of diffraction) with Complex plane Split Spectrum Processing	Philippe Rubbers http://www.ndt.net/article/v09n08/rubbers/rubbers.htm

Guided Wave

DISPERSE	Modelled guided waves – solution to disperision curves	Transfer matrix. Solve dispersion relations via root finding routines	Imperial College London (UK) https://www.imperial.ac.uk/ndt/public/productservice/disperse.htm
ABAQUS	From http://www.abaqus.com/	Finite Element Method	Yves Berthelot www.me.gatech.edu/diagnostics/A2.PDF Dr. Rose www.esm.psu.edu/ultrasonics/pdf%20files/877_1.pdf

Acoustic Emision

AGU-Vallen wavelet	Modelled dispersion curves	Calculate and display the wavelet transform on individual waveforms	Vallen-Systeme http://www.vallen.de/wavelet/index.html

ECT

CIVA	Probe, geometry	Messine module in CIVA	
MagNET	Electromagnetic Design Software	FEM - 2D/3D, (Static,AC, High Frequency.)	Infolytica (Canada) http://www.infolytica.com/en/markets/appspec/Sensors_NDT.html?optionval=Sensors_NDT.html
Oersted & Faraday	Probe, geometry	Boundary Element Method (BEM)	Integrated Engineering Software http://www.integratedsoft.com/products/oersted/
Concerto	Probe, geometry	FEM (Finite Element Method), FDTD (Finite Difference Time Domain)	http://www.vectorfields.com/content/view/126/122/

Vic-3D	Probe, geometry	Volume-Integral approach (FFT)	Victor Technologies LLC. http://www.kiva.net/~sabbagh/
MEGA	Probe, geometry	FEM	University of Bath (UK) http://www.bath.ac.uk/elec-eng/research/emd.html
Max-1, GTD, MMP	Numerical field computations - applied to electromagnetic fields and to acoustics	Semi-analytic method. Amplitudes of the basis fields found by Generalized Point Matching Technique	Christian Hafner, (Switzerland) http://alphard.ethz.ch/hafner/mmp/mmp.htm

X-ray

XRSIM	Geometry	Film Density analysis using different radiation sources and film grades (originally designed at CNDE Iowa State)	NDE Technologies Inc. (USA) http://www.ndetechnologies.com/level3.0.html
X-ray NDT simulation	Geometry	Ray-tracing and on the X-ray attenuation law	

The Future of Modelling:

Traditionally industries such as the offshore (Nordtest) aerospace (USAF) and nuclear (PISC 1-3) have required or used practical demonstrations of equipment and inspection procedures in which statistical results have been the basis for assessment of reliability. But these “practical” assessments are expensive and the scatter is often high due to other factors unrelated to the test method itself, (e.g. operator variables). As well, the results are often based on unrealistic flaw specimens such as embedded “fabricated” flaws and EDM notches. The idea that mathematical modelling could be used to replace or complement the “practical” models has been put forward by several writers. [22, 23, 24].

To a large degree, the future of modelling in NDT seems to have been given a direction by recent regulatory changes. The biggest “nudge” has been the changes in the pressure vessel industry. Both the ASME Boiler and Pressure Vessel code and the ENIQ protocol for nuclear vessels in Europe have incorporated wording in the regulations that require extensive verification and demonstration programmes for new inspection projects.

If the requirements of practical demonstration can be reduced to verification of mathematical modelling the benefits to industry can be significant. This could reduce the number of specimens required to validate the process and these specimens could also provide the practical “feedback” to the modellers as an indication of how closely the mathematic model predicted the real item.

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