# DETAILED SIMULATION OF ULTRASONIC INSPECTIONS

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## ABSTRACT

Simulations of ultrasonic inspection of engineered components have been performed at the Chalk River Laboratories of AECL for over 10 years. The computer model, called EWE for Elastic Wave Equations, solves the Elastic Wave Equations using a novel finite difference scheme. It simulates the propagation of an ultrasonic wave from the transducer to a flaw, the scatter of waves from the flaw, and measurement of signals at a receive transducer. Regions of different materials, water and steel for example, can be simulated. In addition, regions with slightly different material properties from the parent material can be investigated. The two major types of output are displays of the ultrasonic waves inside the component and the corresponding A-scans.

EPRI and other organizations have used ultrasonic models for: defining acceptable ultrasonic inspection procedures, designing and evaluating inspection techniques, and for quantifying inspection reliability. The EWE model has been applied to the inspection of large pipes in a nuclear plant, gas pipeline welds and steam generator tubes. Most recent work has dealt with the ultrasonic inspection of pressure tubes in CANDU reactors. Pressure tube inspections can reliably detect and size defects; however, there are improvements that can be made. For example, knowing the sharpness of a flaw-tip is crucial for fitness for service assessments. Computer modelling of the ultrasonic inspection of flaws with different root radius has suggested inspection techniques that provide flaw tip radius information. A preliminary investigation of these methods has been made in the laboratory.

The basis for the model will be reviewed at the presentation. Then the results of computer simulations will be displayed on a PC using an interactive program that analyzes simulated A-scans. This software tool gives inspection staff direct access to the results of computer simulations.

## 1. INTRODUCTION

At AECL, we have developed a computer program called Elastic Wave Equations (EWE) to simulate the propagation of elastic waves in solids and liquids [1,2,3,4,5,6,7]. EWE numerically solves the fundamental equations governing the motion of sound in materials. EWE has been applied to ultrasonic testing both to improve understanding and to develop new capabilities.

Although conceptually simple, ultrasonic testing produces varied and confusing results because of the complicated interactions of waves with materials. There are three types (modes) of ultrasonic waves in solids: compression, shear, and surface. One mode of wave is converted at interfaces into the other two modes, producing more than a dozen waves even in simple situations. The ultrasonic inspector measures many signals with sensors (transducers) outside of the inspected object; then, the inspector infers what is happening inside the inspected object.

As modelled by EWE, a numerically-generated pulse of sound from the input transducer propagates through a bounded region that contains areas of different material properties and defects of different types. The wave reflects, diffracts, refracts, mode converts, and performs other wave phenomena. EWE offers insight into these processes, first, because it is based upon the fundamental physics, and does not adjust the results to conform with experience. Second, EWE produces "wave displays" that show complex ultrasonic processes occurring inside a sample during an inspection, instead of relying upon measurements made outside the sample.

Simulations can be performed with no defect, with different size or type of defect or with send transducers with different characteristics. Numerical A-scans, which simulate inspection results, can be produced for many different receive transducers. The wave displays and numerical A-scans can be compared to gain insight into how to interpret inspection results and how to improve inspection techniques. The model can assist in issues related to detection, sizing, and characterization of defects or materials.

The model was designed to simulate the most important factors in ultrasonic inspections. The modelled input transducer can produce a pulse train with the frequency, length, width, and focussing similar to a real transducer. The theoretical beam profile can be calculated and compared to an experimental beam profile. The model of the transducer can be adjusted until the amount of focussing is correct. A back-wall reflection from the modelled transducer can be compared to that from a real transducer and the bandwidth can be adjusted. The input wave is then propagated from the focussed probe to the interface of the material, possibly through large amounts of water. At the interface, the input wave reflects, refracts, and mode converts so that a shear, compression, and a surface wave enters the inspected material. The simulated material can have the shape and material properties of the real sample. For example, the circumferential inspection of a tube has been modelled. The receive transducer can be focussed, positioned far away, and can have the size and orientation of a real transducer. Typically, many different numerical A-scans are produced for each simulation.

## 2. APPLICATIONS

In the 1980's, laboratory A-scans and EWE generated A-scans were compared with good results [6]. Since then, the computer model has been applied to many different problems. The gas pipeline industry wanted to distinguish between geometric problems, like high/low, in pipeline welds and serious flaws, like cracks. A nuclear steam generator inspection company was interested in techniques for flaw sizing in the small diameter tubing. In recent years effort has been directed towards improving the ultrasonic inspection of pressure tubes in CANDU reactors.

Pressure tubes are thin-walled seamless tubes that hold the fuel and coolant in CANDU nuclear power reactors. There are many thousands of pressure tubes in the cores of 25 operating CANDU reactors. Pressure tubes are in a challenging environment and demand a very detailed ultrasonic inspection. The EWE model has been applied towards the three CANDU pressure tube inspection problems described below.

### a) Ultrasonic Inspection Interpretation

Ultrasonic inspection results can be difficult to understand. Many signals are measured even when there is no flaw. Furthermore, the interaction of waves with flaws is very complex. The primary focus of early CANDU modelling work was simulation of inspections to give inspection personnel a better understanding. An interactive PC program, EWEView, that animates wave displays and shows A-scans has been developed for this purpose. Most importantly it allows easy identification of which wave in the simulated wall of the pressure tube produced which signal in a simulated A-scan. Now, a Compact Disk containing simulations and EWEView can be given to utility personnel, to allow them to view and analyse simulations themselves.

### b) Measurement of Flaw Shape

Early modelling work investigated improvements in flaw sizing, for very small flaws. More recently, interest has developed in the radius of curvature of the tip of a flaw (root radius). It is required for effective application of fitness-for-service guidelines in CANDU pressure tubes. This is a far more complex problem than either flaw detection or flaw depth measurement. EWE has identified two different inspection techniques that offer promise to help characterize the shape of a flaw from its ultrasonic signature. The first, described briefly herein, is an on-going investigation with the following steps:

- define an inspection geometry similar to pressure tube inspections in key respects, but simpler in others, allowing easier analysis of the wave/flaw interaction
- simulate the inspection of flaws with different root tip radii
- analyse wave displays to determine waves that scattered differently from blunt and sharp flaws
- choose transducers to measure these waves
- simulate A-scans to determine if blunt and sharp flaws can be differentiated
- run laboratory experiments to determine if model predictions are accurate.

Figures 1 to 4 summarize the results of the above steps. The wave displays in the top of Figures 1 and 2 show the basic inspection geometry. The inspection shear wave is approaching a flaw from the bottom of the wave display. The flaw is adjacent to water and is water filled.

Figures 1 and 2 contain wave displays that compare the results of an inspection shear wave impacting a blunt flaw (middle of each figure) and a sharp flaw (bottom of each figure) at different time periods. Figure 1 shows the center of a wave striking a flaw and producing a very large compression wave from the blunt flaw and a much smaller compression wave from the sharp flaw. Figure 2 shows the edge of the same wave reflecting from the water/pressure tube interface, striking the flaw, and producing a barely visible compression wave from the blunt flaw and a significant compression wave from the sharp flaw.

Figure 3 shows A-scans from the above simulations. The blunt flaw simulation produced a large signal followed by a small signal. The sharp flaw simulation produced a small signal followed by a large signal. For the sharp flaw simulation, the first signal dropped in amplitude by more than a factor of 3, while the second signal rose in amplitude by more than a factor of 3.

Laboratory experiments were performed to determine if these predictions were accurate. Figure 4 shows the amplitude of these two signals as an ultrasonic transducer scans over a blunt and a sharp flaw. The blunt flaw scan had a large first signal followed by a small second signal. The sharp flaw scan showed the opposite, both as predicted by EWE.

c) Detection of Zirconium Hydride Blisters

CANDU pressure tubes are known to absorb hydrogen (deuterium) slowly over their lifetime. Under certain conditions, the hydrogen can accumulate in a localized region to form what is called a zirconium hydride blister. These must be detected before cracks develop in them, which requires measuring a subtle material change.

Simulations, which were based upon previous work[5], were performed of a shear wave directed at the back-wall at an inspection angle above critical angle[1] for a zirconium hydride blister but below critical angle for normal pressure tube material. For the blister, the simulations indicated that the inspection shear wave reflected as expected from simple wave theory and only a small compression wave was produced. For normal pressure tube material however, the simulations indicated that the inspection shear wave shifted along the interface during reflection and a high energy compression wave was produced. The resulting A-scan from the blister had a small first signal from the compression wave followed by a larger second signal from the shear wave reflected from the back-wall. The normal pressure tube material had the opposite.

## 3. CONCLUSIONS

The EWE computer model is a mature tool for simulation of ultrasonic inspections. It has been compared to experimental results with good agreement and has been applied to difficult inspection problems. Interactive software tools that allow detailed analysis of simulated results have been developed for the PC.

## REFERENCES


[1] S.R. Douglas and K.R. Chaplin, "EWE: A Computer Model for Ultrasonic Inspection", Atomic Energy of Canada Limited, Report AECL-10507, 1991 November.


[1] Wave interaction is dominated by reflection above critical angle. The interaction is more complex below critical angle.


[2] S. Douglas, K. Chaplin and D. Dunford, "Computer Simulation of Ultrasonic Inspections", Proceedings of the NDT Tools of Tomorrow, 1995 May 15-18.

[3] K.R. Chaplin, D.B. Duncan and R. Parker, "Ultrasonic Computer Model Verification", Proceedings of the 11th World Conference on NDT, pp. 1913-1919, Las Vegas, 1985 November.

[4] K.R. Chaplin, D.B. Duncan, and V.N. Sycko, "Modelling Ultrasonic Transducer Performance", Atomic Energy of Canada Limited, Report CRNL-4097, 1987 March.

[5] K.R. Chaplin, V.N. Sycko, and D.B. Duncan, "Computer Modelling of 60 Degree Shear Waves", Ultrasonics International 87 Conference Proceedings, pp. 577-582, London, England, 1987 July.

[6] K.R. Chaplin and V.N. Sycko, "Computer Modeling of A-scans", Ultrasonics International 87 Conference Proceedings, pp. 389-394, London, England, 1987 July.

[7] K.R. Chaplin, D.B. Duncan, and V.N. Sycko, "Ultrasonic Modelling of the Normal Beam Response from Notches", Proceedings of the Fifth Pan Pacific Conference on Nondestructive Testing, pp. 229-242, Vancouver, 1987 April.

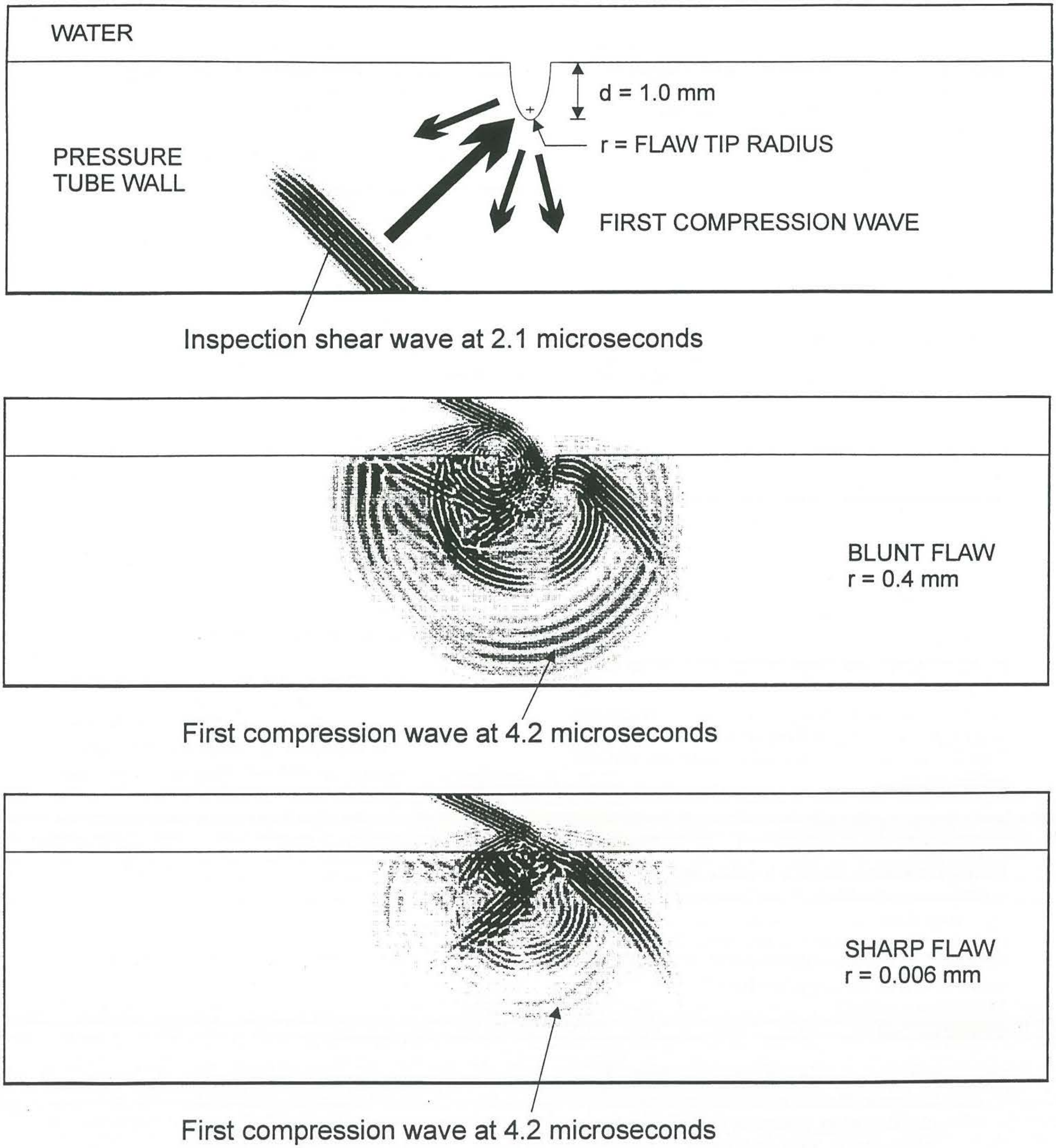



Figure 1: Wave displays from simulations of a blunt flaw (middle) and a sharp flaw (bottom). The first compression wave, used to discriminate blunt and sharp flaws, is emphasized.

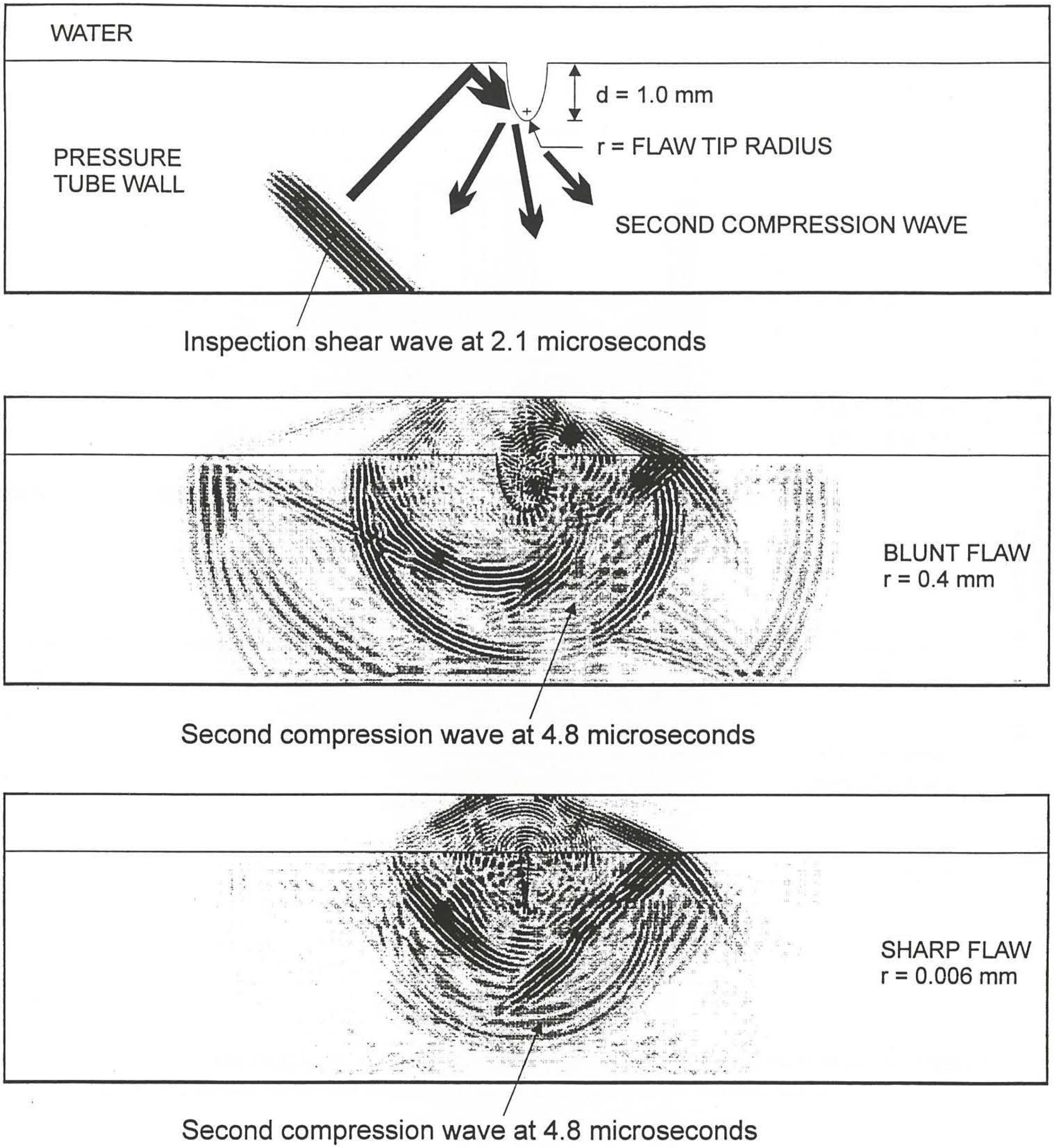



Figure 2: Wave displays from simulations of a blunt flaw (middle) and a sharp flaw (bottom). The second compression wave, used to discriminate blunt and sharp flaws, is emphasized.

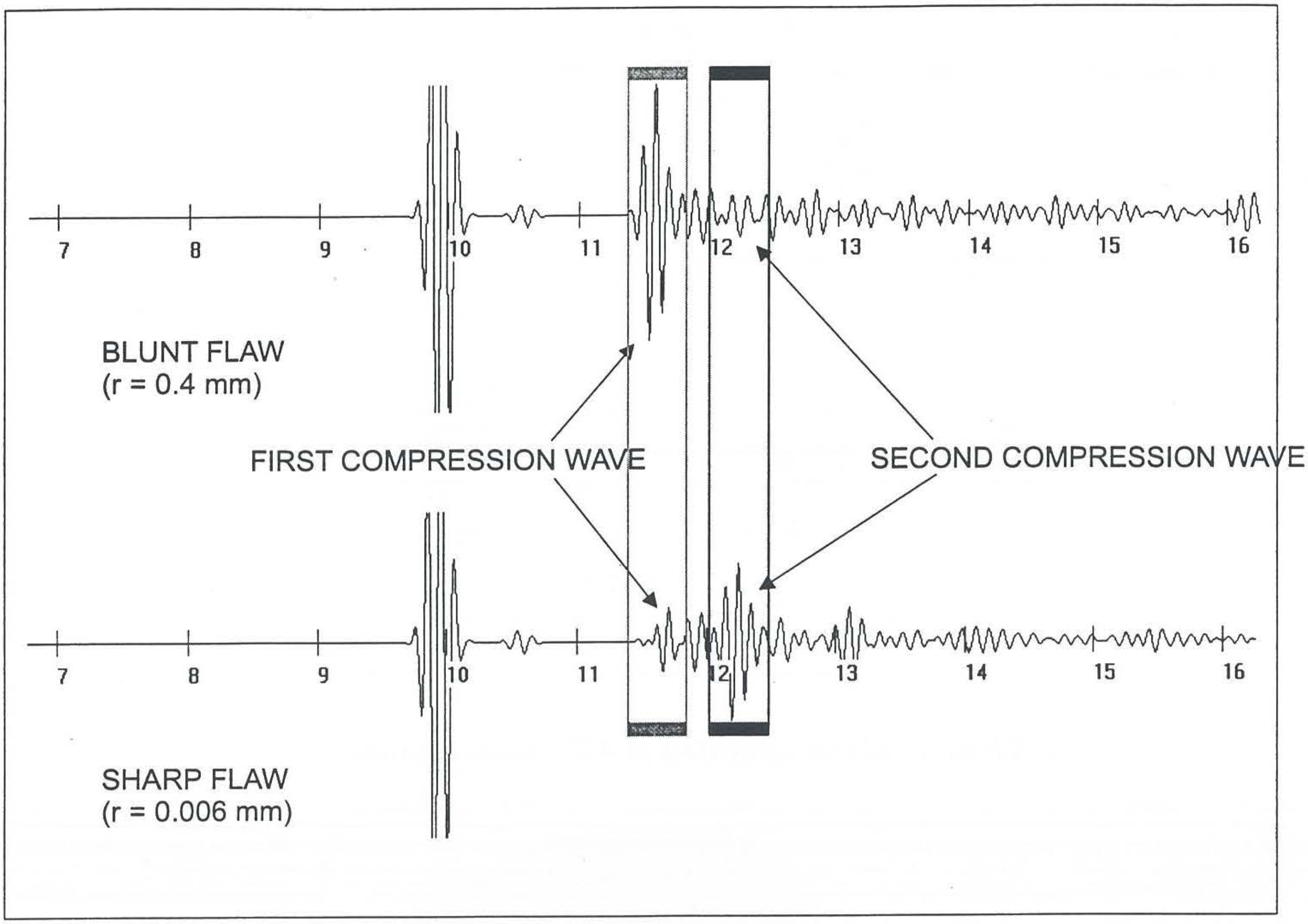
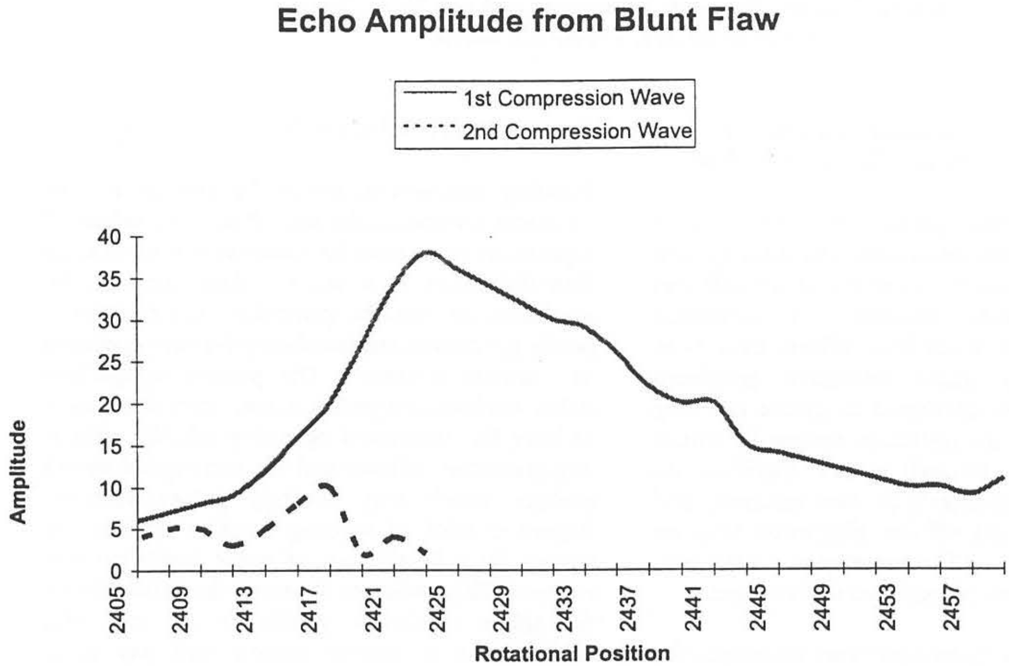



Figure 3: A-scans from simulations of a blunt flaw (top) and a sharp flaw (bottom).
The two compression waves in Figures 1 and 2 produced the signals highlighted here.



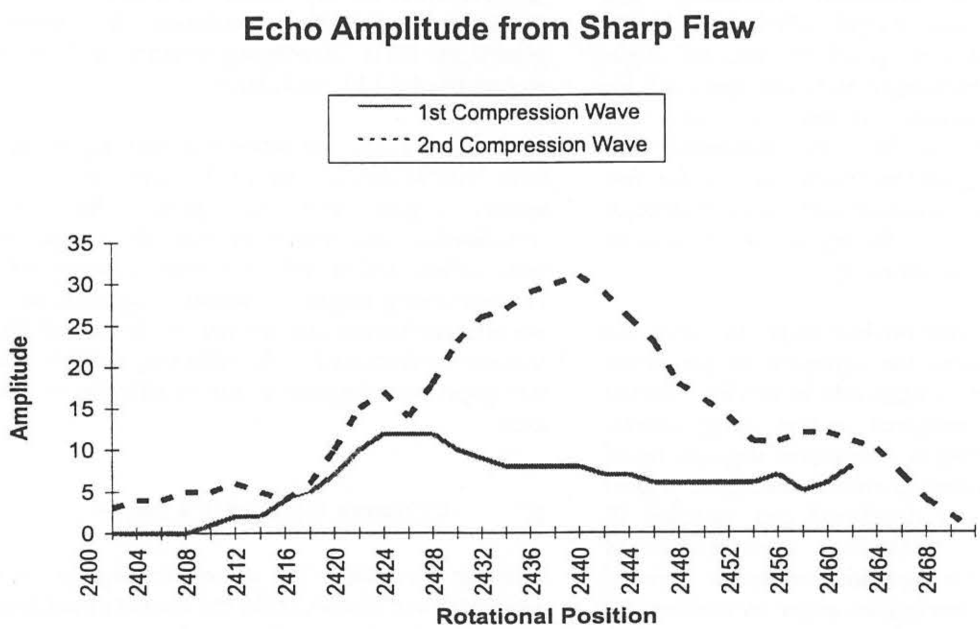




Figure 4: Results of laboratory experiments in which the amplitude of the first and second compression wave are measured and plotted against probe rotational position around the tube for a blunt flaw (top) and a sharp flaw (bottom).