RESONANCES IN ACOUSTIC SCATTERING BY CYLINDRICAL OBJECTS

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1. INTRODUCTION

The scattering of acoustic waves from submerged structures is of considerable importance in the marine environment. For isolated objects, both the shape and material properties are known to influence the acoustic behaviour of the object. The *resonant* behaviour of a scatterer is of particular interest as resonances are known to make a significant and distinctive contribution to the field scattered by many structures.

Although theoretical predictions are easily made for scattering processes involving simple structures, such as isotropic homogeneous spheres and circular cylinders, the more realistic scatterers found in the underwater environment are not so easily modelled and their acoustics are consequently less well understood.

Hence the question arises, how is the acoustic behaviour of a target affected by perturbations in the target shape? Two complementary experimental techniques have been used to investigate the scattering and resonance behaviour of brass cylindrical shells as they are deformed from circular to 'elliptical' cross-section.

2. BACKSCATTERING

A laboratory test facility incorporating a parametric source was used to measure the field backscattered by brass cylindrical shells. The facility and measurement technique are described in more detail in [1] (this volume) and the references therein. Two test samples were used; a 1 metre brass cylindrical shell having a circular cross-section with radii 14.25mm (b) and 15.85mm (a) (b/a=0.90), and a 'deformed' sample formed by squashing an identical piece by 5%. The deformed sample had an approximately elliptical cross-section. The samples were suspended from a rotation stage by nylon thread and could be rotated to any angle θ (see Figure 1) with respect to the incident beam. Measurements were made with the samples water filled. Insonification was normal to the cylinder axis and measurements were made at a range (r) of 0.25m from the centre of the cylinder. An asymmetrical envelope was used to modulate the signal (nominally 1 MHz) applied to the transducer, resulting in a broadband demodulated pulse, permitting measurements to be made over a kb range of 2 – 18. The experimental form function was calculated as the ratio of the spectrum of the backscattered signal to that of the incident signal, multiplied by $\sqrt{2r/a}$.

2.1 Circular cylindrical shell

The measured form function of the circular sample is shown in Figure 2, along with theoretical predictions made using the Normal Mode solution for scattering of a plane wave by an infinite circular cylindrical shell. The variation of form function amplitude with dimensionless frequency kb is shown. The theoretical form function incorporates a geometrical spreading factor [1].

The peaks and troughs in the form function are attributed to resonances of the structure. These can be of a number of types and include resonances of the fluid column, the metallic shell and resonances attributed to the propagation of Stonely waves around the shell. Many of the narrowest features seen in the theory are not resolved with the experimental system which does *not* involve a single plane wave but comprises an angular spectrum of plane waves, producing a response that is integrated over a range of incident angles. The frequency resolution is also limited by the length of the time signals analysed. It is noticeable that this shell is more resonant than the thinner walled shells described in [1]. Figure 3 shows the calculated pressure field resulting from a plane wave incident upon the cylinder for different resonant frequencies. The pressure field inside the fluid column is of considerably higher amplitude than the external field.

2.2 Deformed cylindrical shell

Figure 4 shows the measured form function for the deformed shell when the beam is incident parallel ($\theta = 0°$) and perpendicular ($\theta = 90°$) to the major axis of the ellipse. Results for the circular shell are given for comparison. Significant differences can be seen between all three measurements, in particular in the locations of the peaks and troughs in the form function (eg. kb~7). At certain frequencies (eg. kb~14.2) the amplitude of the backscattered signal is seen to differ greatly between the two orientations of the deformed shell. These results indicate the sensitivity of the scattering to orientation.

The complete angular dependence of the backscattered signal is shown in Figure 5 for a narrow band of frequencies (to be discussed in section 3). The cylinder was rotated in 2° steps under computer control, 0° corresponding to the incident beam parallel to the major axis of the ellipse. The strongest reflections are seen to occur when the cylinder is insonified side-on (90°), but at some frequencies the maxima occur at other angles. There is a general tendency for features to move up in frequency as the cylinder is rotated. This is to be expected from simple considerations involving the changing dimensions of the cylinder seen by the incident beam. Examples of the variation of form function with incident angle are given in Figure 6 for two frequencies. The variations in backscattered amplitude are quite large considering the extent to which the cylinder has been deformed.

3. RESONANCES

Many of the features seen in the backscattering form function for the cylindrical shells owe their existence to the excitation of, and re-radiation by, resonance modes of the structure. For the deformed shell, the differing measured form functions corresponding to the different incident angles are, in part, associated with the extent to which the incident waves couple into different resonances at each incident angle.

A Schlieren visualization system [2] has been used to study the resonance spectra of the brass shell as its shape is perturbed from circular symmetry. Only the resonances of the fluid column are discussed here, these being the most abundant.

3.1 Schlieren System

The Schlieren system (Figure 7) uses a standard Z configuration incorporating parabolic mirrors of focal length 1.8m and diameter 0.3m. Light from a high power light emitting diode is focused onto a multiple pinhole array, collimated by the first mirror, passed through the water tank containing the acoustic field and brought to a focus again by the second parabolic mirror. An array of optical stops, matching that of the pinhole array is placed at the focus of the second mirror and used to filter out the zeroth order; the remaining optical orders, containing the light that has been diffracted by the acoustic field, are allowed to recombine in a video or still camera, forming an image of the acoustic field in the tank. With this spatial filtering arrangement, and low acoustic pressures, the resulting optical distribution is a reasonably accurate image of the amplitude of the acoustic field.

Cylinders were suspended in the tank by fishing line, their axes aligned parallel to the optical path, and insonified normal to the cylinder axis by a transducer driven in continuous mode. By sweeping the drive frequency the different resonance modes were easily identified and recorded. Measurements were made between 150 and 250 kHz.

3.2 Results

The resonances within five brass cylindrical shells of differing eccentricity were located and photographed using the Schlieren system and compared with theoretical predictions made using a simple model [3]. Taking the internal semi-minor axis of each sample to be s, and defining a deformation parameter $\gamma = 1 - s/b$, the five samples had deformations of $\gamma = 0\%, 3.4\%, 6\%, 8\%$ and 10.4%. All samples were 100*mm* long and made from the same cylinder described in section 2. The variation of resonant frequency with deformation is shown in Figure 8 where it is seen that each resonance of the circular shell splits into two as the symmetry is broken, except for the n=0 resonance which is isolated. Many level crossings and degeneracies can be seen in the figure. The agreement between theory and experiment is generally good, but deteriorates for the most deformed shells due to the approximations used in the theory and an observed 'flattening' of the deformed shells. Theoretical predictions of the changing resonance patterns for one pair of resonances are shown in Figure 9 and experimentally obtained images are compared with theoretical predictions in Figure 10 which shows, as an example, the (3,4) resonance mode in two deformed samples corresponding to the predictions in Figure 9.

4. CONCLUSIONS

The results presented indicate that even small perturbations in the shape of cylindrical scatterers can produce significant changes in the resonance spectra and backscattering behaviour of an insonified shell. Both the Parametric Array facility and the Schlieren Visualization system have proved to be valuable tools in studying scattering by discrete objects, and investigating changes in acoustic behaviour that accompany deformation of the object.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] V F HUMPHREY and C BECKETT 'Experimental studies of acoustic scattering by cylindrical objects' in *this volume*.

[2] V F HUMPHREY, S M KNAPP and C BECKETT 'Visualization of the resonances of a fluid filled cylindrical shell using a low frequency Schlieren system', in "Physical Acoustics", O Leroy and M A Breazeale (eds), Plenum Press, New York (1991) p371-376.

[3] P A CHINNERY and V F HUMPHREY, 'Resonances of deformed cylindrical shells - experimental visualization and identification', in "Proceedings of the 2nd European Conference on Underwater Acoustics", L. Bjørnø (ed), European Commission, Luxembourg (1994) Vol 1 p159-164.

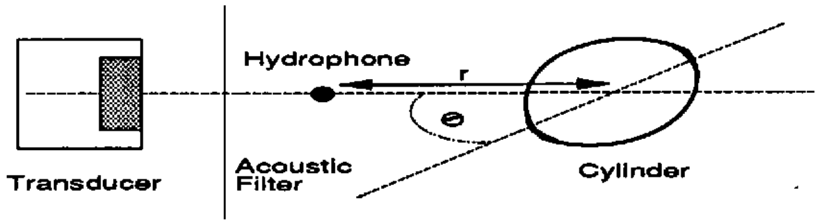

Figure 1. Scattering geometry

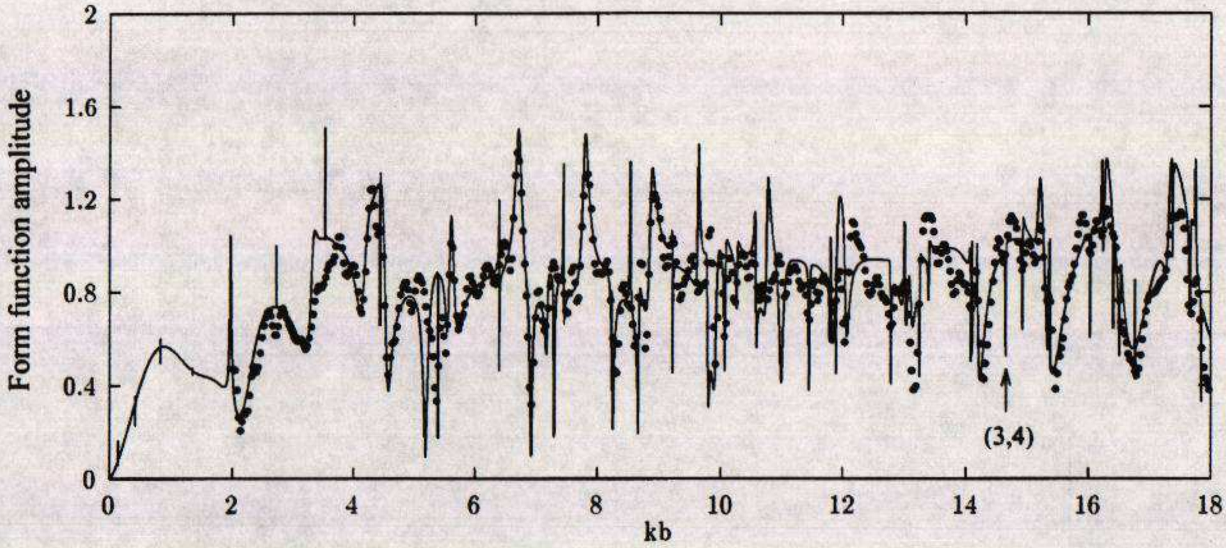

Figure 2. Backscattered form function for a water filled brass cylindrical shell having *circular* cross-section, theory (——) and experiment (•).

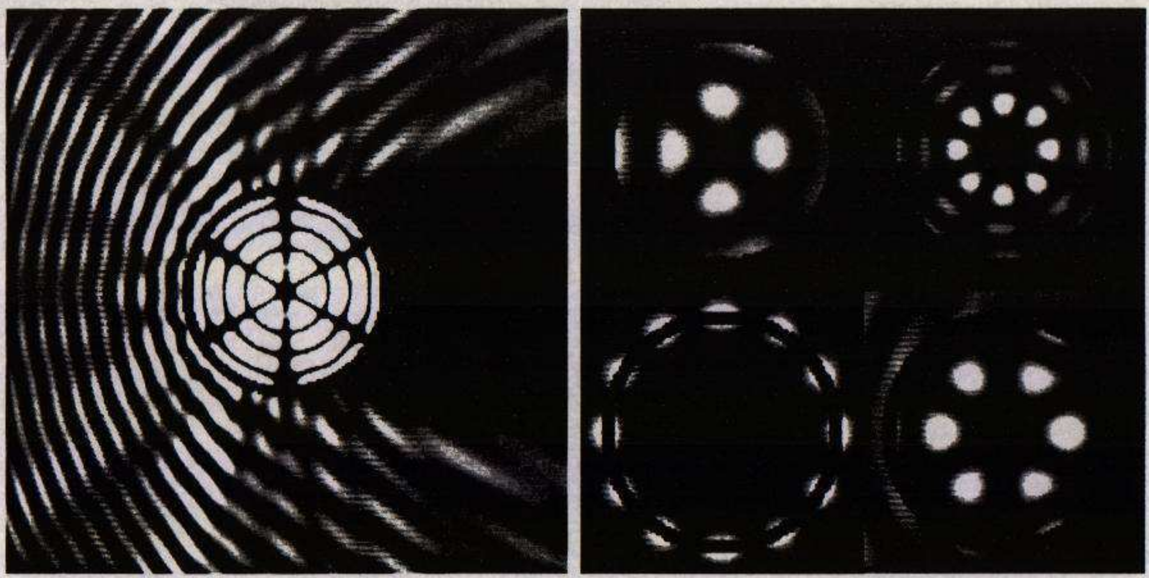

Figure 3. Resonance scattering by circular cylindrical shell; theoretical predictions of pressure amplitude. Left: (3,4) fluid column mode (*kb* = 14.66); right (clockwise from top left): (2,2) fluid column mode (*kb* = 6.92), (4,3) fluid column mode (*kb* = 12.78), n=3 shell resonance (*kb* = 7.29) and n=6 stonely wave resonance (*kb* = 1.99).

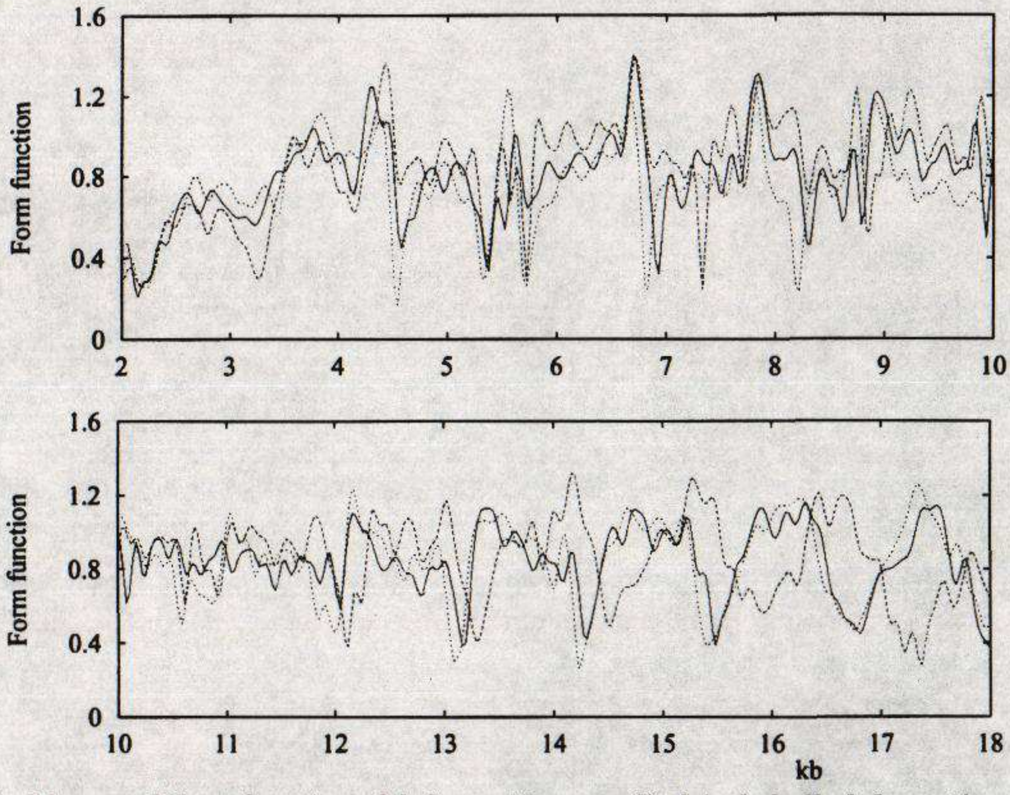

Figure 4. Measured form function of deformed brass cylindrical shell, deformation (γ) 5%. Incident beam 90° to major axis (-------), 0° (.......), circular sample (——).

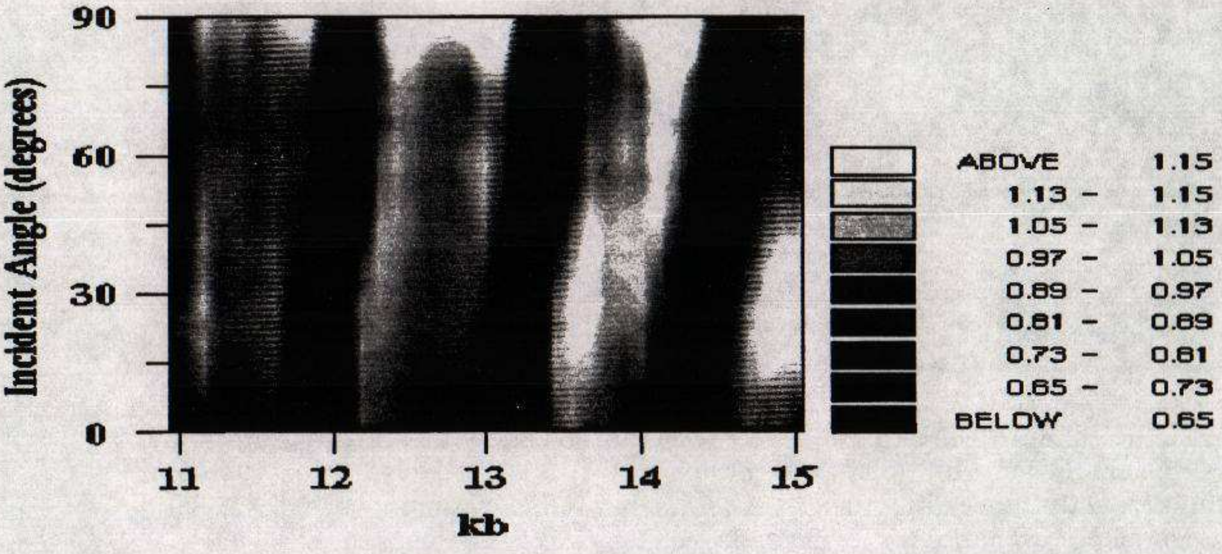

Figure 5. Variation of measured form function with incident angle and frequency.

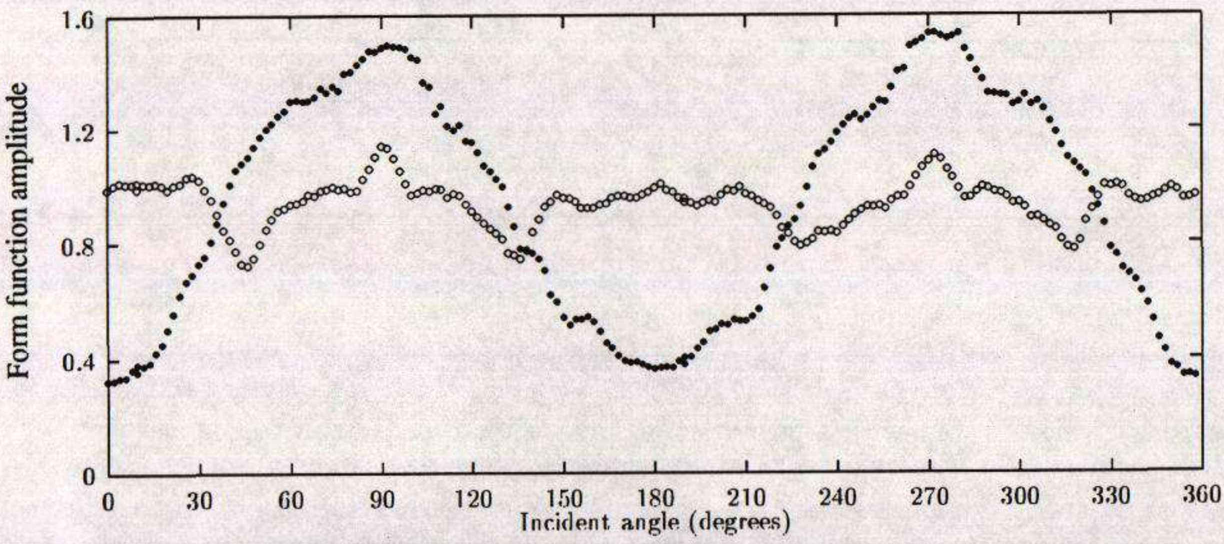

Figure 6. Variation of measured form function with incident angle at two frequencies $kb = 10.1$ (o) and 14.2 (•).

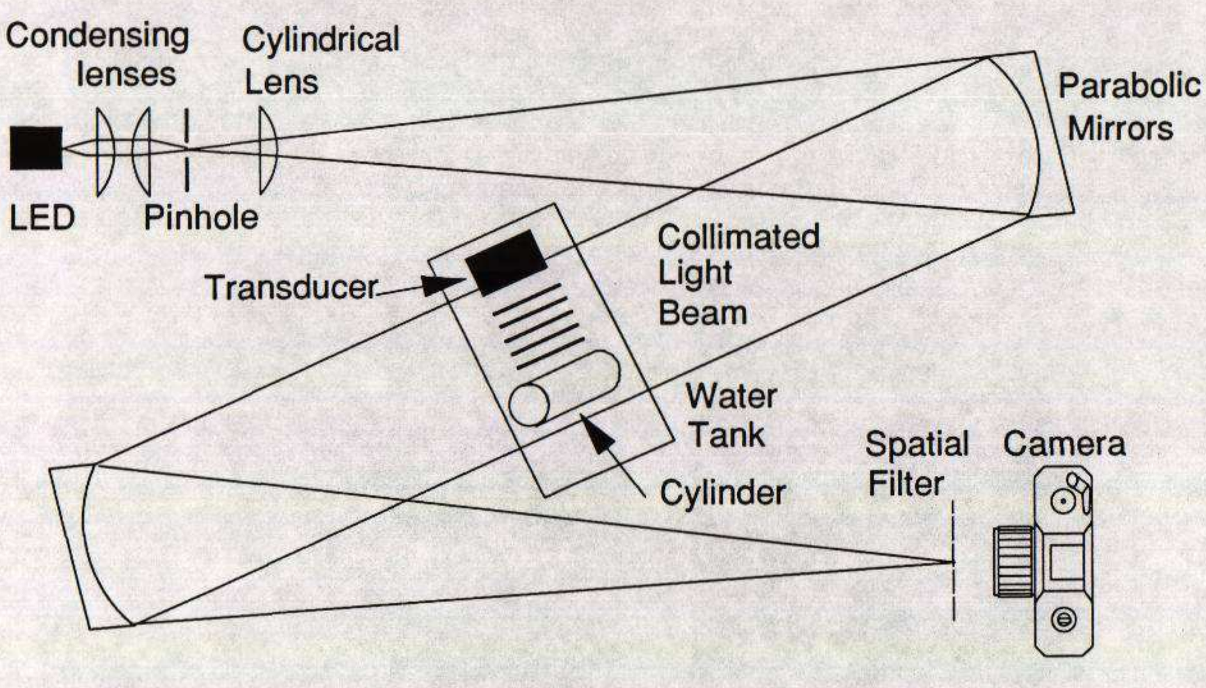

Figure 7. The Schlieren visualization system.

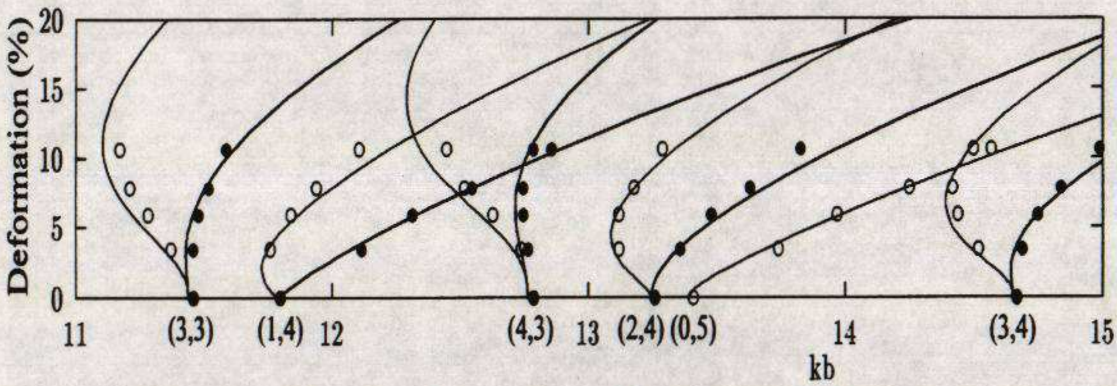

Figure 8. Variation of kb with deformation (γ) for selected fluid column resonance modes (n,m). Theory (lines) and experimental observation (points).

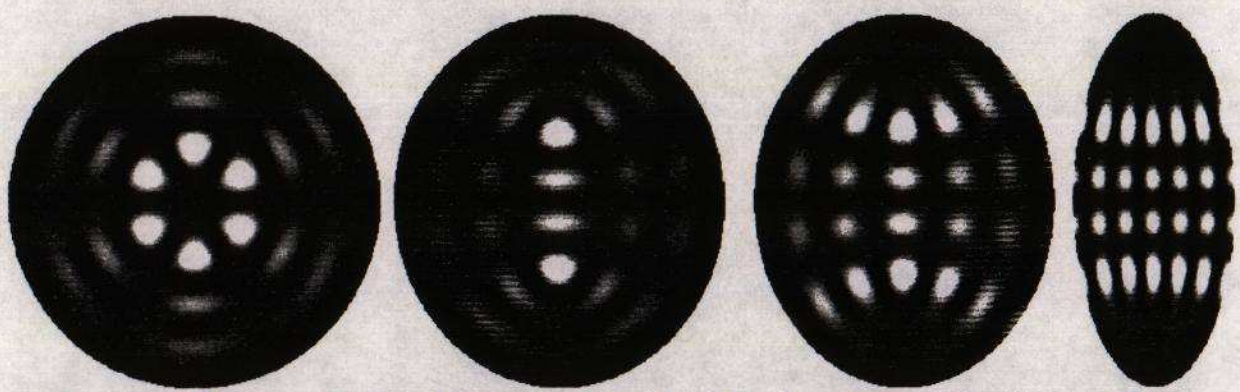

Figure 9. Theoretical calculations showing the changing pressure distribution of one branch of the (3,4) resonance as the eccentricity increases.

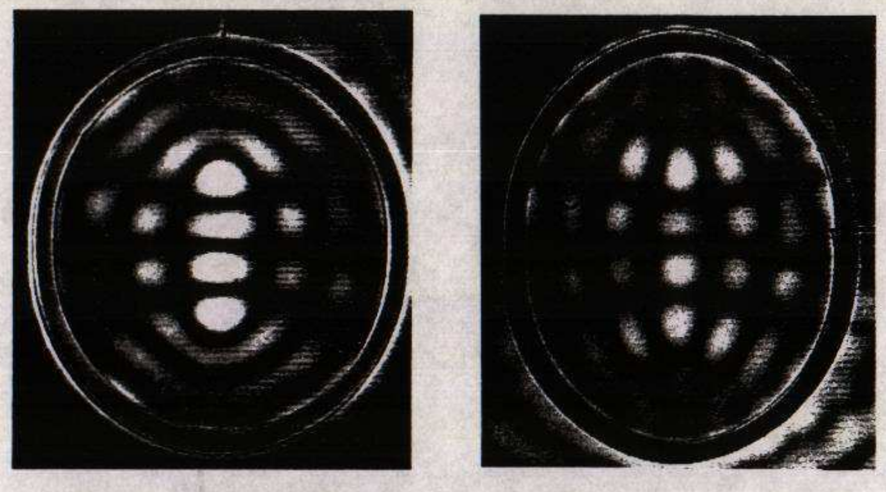

Figure 10. Experimentally observed (3,4) fluid column resonance in two deformed shells (γ = 6% and 10%) obtained with Schlieren.