

EDUCATION EDUCATION EDUCATION - ACOUSTICS ACOUSTICS ACOUSTICS

(EDUCATION AND THE WONDERFUL WORLD OF ACOUSTICS)

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1 INTRODUCTION

This lecture will consist of recollections of a lifetime of teaching and learning about acoustics, aimed at illustrating the very wide range of our subject.

It will cover the authors postgraduate studies in underwater acoustics; research in industry into diesel engine noise; as an acoustic consultant with AAD, as a full time teaching career of more than twenty years followed by part-time teaching, and including active membership of IOA London Branch; Industrial Noise Group and Education Committee.

2 POSTGRADUATE RESEARCH AT IMPERIAL COLLEGE, LONDON, PHYSICS DEPARTMENT, (UNDER THE SUPERVISION OF DR RWB STEPHENS)

Tributes to the work of Dr RWB Stephens have been made in the Acoustics Bulletin, to which this author would wish to add his own appreciation. The diverse interests of Dr Stephens were reflected in the wide range of research carried out by his students, as illustrated by the following list of research projects current during the period 1965 to 1970: Noise from gear teeth (Rayleigh waves in thin plates), Gear teeth using holography, Shock waves in water, Ultrasonic scattering from sea bed sediments, Sonoluminescence in liquid metals, Hearing aid design, Assisted resonance in halls, Surface waves in water using Moire fringe techniques, High frequency (Megahertz) sound attenuation in liquid metals, Acoustic emission, Sound propagation in ducts, Vibrational Relaxation of Carbon Dioxide in Mixtures with Noble Gases, The behaviour of gas bubbles in a cavitation field, Directivity of human hearing underwater, Underwater holography, Piezoelectric materials, and one or two more.

Air bubbles in water and collapsing cavities

Early research into cavitation arose from attempts to measure the ultimate tensile strength of pure water. It soon became clear that almost all samples of water contained small air bubbles which would grow when the water was subjected to reduced pressure and would subsequently collapse when the ambient pressure returned to normal. The collapse of such cavities is an extremely violent event and can generate very high temperature very high pressures, the emission of flashes of light (sonoluminescence) and severe erosion damage to nearby surfaces. Cavitation in ships propellers gives causes damage to the blades and the emission of a significant noise emission. Practical experiments had shown that the introduction of air bubbles into the cavitation region had led to a reduction of noise emission, but the exact mechanisms were unclear. The postgraduate study comprised two components; the attenuation of sound by screens of bubbles and the radiation of shock pulses from collapsing cavities.

Acoustic screening by gas bubbles in water

In 1933 the Belgian astronomer and physicist Marcel Minnaert published a paper in *Philosophic magazine* entitled 'On musical air-bubbles and the sound of running water.' He derived the formula for the natural frequency of vibration a single air bubble in an infinite expanse of water. The bubble and surrounding water behave like a vibrating mass-spring system (rather like a Helmholtz resonator) with the air in the bubble as the spring and the surrounding water providing the mass.

Minnaert's formula, which ignored the any effects of viscosity and of any other possible damping mechanisms showed that the natural frequency varied inversely a the radius of the bubble and for air and water at standard atmospheric pressure the natural frequency is about 300 Hz for a bubble of 1 cm radius and 3 kHz for a bubble of radius of 1mm. Air bubbles in water can absorb, reflect or scatter sound and have a profound effect on sound propagation under water and on the behaviour of sound sources and receivers close to them.

In 1956 J D McPherson published a paper, based on his successful PhD research, in on the screening of sound by gas bubbles. He devised a method using electrolysis of producing a screen of a regular plane lattice of bubbles of all of the same size (typically about 0.1mm radius thus having a natural frequency of about 30 kHz) in a tank of water and measured the transmission of sound through the screen. As a follow up to this experiment a device for producing four concentric cylindrical screens of bubbles was created. The author used this device to repeat the earlier experiments using this bubble screen array. Tone bursts were used rather than continuous sound to avoid complications from reflections from the walls of the tank, and some measurements were also made by transporting the apparatus to an anechoic tank at the Admiralty Research Labs in Teddington. The screens of single sized bubbles produced a highly frequency selective attenuation, at the bubble resonance frequency, rather like a Helmholtz resonator, with a maximum attenuations of about 25 dB for the densest bubble spacing (5mmx 5mm) at a resonance frequency of 25 kHz.

Radiation of sound by collapsing cavities

In the second part of the investigation thin walled glass spheres (5cm diameter – the size of Christmas tree balls, with walls of thickness of about 0.1mm) were evacuated and broken underwater and the shock pulse emitted from the subsequent collapse (implosion) were studied. A similar technique had previously been used at the University of Gottingen in Germany to study the sonoluminescence from the collapses. The first method of breaking the spheres involved the impact of a thin metal rod powered by a pneumatic actuator. High speed photography (10,000 frames per second) of the collapses showed that the impact created only local rupture of the glass shell, which was then 'unpeeled' by the inrushing water, thus impeding to a certain extent the violence of the collapse and interfering with its potential spherical symmetry. Several alternative methods of initiating the implosion were investigated subsequently including attaching a very small explosive fuse to the ball, generating a high intensity electrodynamically induced shock wave inside the tank, transmitting a shock pulse from a fuse/detonator into the tank via a Perspex rod acting as a waveguide. The shock wave method produced almost instantaneous shattering of the entire glass sphere and a reasonably spherically symmetric implosions.

Lord Rayleigh, in 1917 had produced a theory for the collapse of a cavity in a liquid, and a formula for the collapse time. For a sphere of radius of 5 cm in water the collapse time was 2.5 ms. Radius v time curves, taken from the frames of the high photographs for the glass spheres were in reasonable agreement with the Rayleigh theory.

The reason for the use of the glass spheres as models of collapsing cavities was to enable the content, pressure and nature of the gas inside the cavities to be controlled so that the effect of gas pressure on the collapse could be studied.

The acoustic emission from the imploding spheres was measured with a nearby hydrophone. Typically for a fully evacuated sphere (air pressure of 0.01 mm of mercury) this consisted of a short duration (about 4 microseconds) pulse of amplitude of about 6 atmospheres at a distance 10 cm from the centre of the sphere. The variation of shock amplitude with gas pressure was measured

and compared with theories for collapse. Varying the filling pressure between 0.01mm and 1mm of mercury had no effect on the peak radiated pressure, but at higher filling pressures the peak amplitude diminished, until at filling pressures of 10cm of mercury and above no distinct implosion pressure pulse was observed. The effect of varying the size of the glass spheres, and of collapse in a liquid other than water (glycerine) was also investigated.

The availability of the high speed photography and of a vertical shock tube was used to briefly investigate briefly and qualitatively the effect of a shock pulse on bubbles introduced into the tube (bubbles set into violent pulsation and fragmented) and of the so called 'dynamic cavitation' produce close to the free water surface at the top of the tube showing the creation of cavitation bubbles as a result of the reflection of the positive shock pulse as a tension pulse at the water surface.

3 NOISE SECTION, RESEARCH DEPARTMENT, CAV (LUCAS) LTD (1970 TO MID-1973).

The Noise section led by Mr M F Russell carried out research into reducing the noise of the company's products (diesel fuel injection equipment and electric alternators), and were were responsible for hearing conservation of employees in the company's factories.

Mike Russell was a pioneer of diesel noise research and committed to initiatives designed to reducing the risk of hearing loss to employees in the company's factories. These included regular audiometric testing of employees, including repeat tests to determine repeatability of audiograms; the objective testing of ear protectors at in-use noise levels using a dummy head, well in advance of standardised test procedures being available; finite difference modelling of factory spaces to predict noise levels in factories; regular training of shop floor personnel in the monitoring of noise levels; and publication of the company' own hearing conservation policy well in advance of national regulations. CAV, along with a few other large engineering companies, introduced their own hearing conservation policies, including at CAV the issuing of Guide to Noise Reduction Design Guides for company workplaces.

When not conducting routine noise and vibration testing into company products my own research was on theoretical modelling of diesel engine noise which involved the identification of vibration transmission paths whereby combustion pressure fluctuations in the engine cylinder was transmitted to the noise radiating outer surfaces of the engine. This involved setting off detonators inside the cylinder to simulate combustion and monitoring the cylinder pressure for correlation with subsequent transient vibration levels measured at various positions on the engine surface using accelerometers. All signals were recorded on a multichannel FM tape recorder and taken down to the recently opened Data Analysis Centre where the fairly recently developed FFT analysis, developed just a few years earlier, in 1965 by Cooley and Tukey, was available. The modelling also required the determination (experimental and theoretical) of natural frequencies and mode shapes of engine castings, crankshafts and camshafts.

Another project was the noise testing of a new in-line fuel injection pump designed to operate at higher speeds and deliver more fuel than earlier models. The noise section had designed noised reducing improvements to the pump casting in the form of additional stiffening ribs to certain areas of the pump casing. The test programme involved noise and vibration measurements, mode shape analysis and a noise test comparison of the new pump its predecessor and it the equivalent product of a competitor. The noise tests in the first instance consisted of measurement of overall dBA levels on a test bed at various speeds of 300 RPM, 500 RPM, 800 PRPM and 1100 RPM (the highest sped in earlier pumps was 1000 RPM). The usual form of display of test results was a graph of dBA v speed which was expected to show, as usual a linear increase of noise level with speed. On this occasion although there was an expected increase of noise level with speed up to 800 RPM the noise level at the highest test speed was well above the straight line trend of the graph. This indicate a new noise producing mechanism coming into play at the highest speed, confirmed just by listening and by unusually high vibration levels at certain positions on the pump casing. Noise

testing had provided a simple form of machine condition monitoring. Subsequent investigations showed that much stiffer springs were required to prevent the tappets losing contact with the cam-shaft at the highest rotation speeds, which had led to the additional impact noise from tappet bounce.

4 FROM 1973 TO 2013 – TEACHING (AND LEARNING) ABOUT ACOUSTICS AND NOISE CONTROL.

[Full time at Twickenham College (1973 to 1975), at NESCOL (1975 to 1997) and part time at NESCOL, at London South Bank University, and for the IOA (Diploma Distance Learning Tutorials) plus various others.]

A lot happened to stimulate the need for more education in acoustics and noise control in the 1970s. In 1972 The Department of Employment published its Code of Practice for reducing the exposure of employed persons to noise (this was, in effect the birth of LAeq). In 1974 both The Control of Pollution Act (part 3: Noise), and the Health and Safety at Work Act were published. Also in 1974 the Institute of Acoustics was formed from an amalgamation of the British Acoustical Society and the Acoustics Group of the Institute of Physics. The first Diploma in Acoustics courses were started in September 1973 at four Centres, and the first examinations were held in June 1978.

During this period various research and consultancy type investigations were carried out, for interest and to help improve relevance of teaching. These included:

- Industrial and building services noise, nuisance and planning cases
- Noise and vibration measurements and assessments on construction sites
- Sound insulation measurements (in an era when they were carried out using analogue sound measuring equipment, pencil and paper and log tables – it took days rather than hours!)
- Speech intelligibility and privacy investigations
- Scale modelling (1 to 10) of College classroom
- Workplace noise exposure assessments, including for divers using high pressure jet cleaning equipment underwater
- Low frequency night-time noise investigations
- Vibration measurement and assessment studies - from pile driving, from freight trains, from aircraft and from bells in a church tower, from army tanks on Salisbury plain
- A period of part-time secondment from teaching duties to work with a professional noise consultant (Ian Sharland Ltd)

5 EMPLOYMENT AS AN ACOUSTIC CONSULTANT WITH AAD LTD (NOVEMBER 1997 TO 2013)

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Some of the work carried out for AAD, such as building acoustics and planning and nuisance cases had replicated previous experience, but now carried out and reported in an improved and more professional manner. New experiences have been: computer modelling of indoor spaces (using Raynoise and Odeon), gathering and presenting expert witness evidence at Planning Inquiries, analysis and reporting of aircraft noise data gathered at community locations close to airports, and serving on a British Standards Committee (BS6472:2008, on Human Response to Vibration in Buildings).

Of particular interest was a court case which explored the conflict faced by a local authority in using automated gathering of audio recordings to obtain evidence for a nuisance investigation and the need not to infringe the privacy of the alleged nuisance maker granted under the Human Rights Act, and in complying with the requirements of the Regulatory Investigative Powers Act (RIPA). The technical evidence related the audibility and intelligibility of human speech transmitted through party walls and of to the performance of audio recording equipment.

6 THE IOA DIPLOMA

Much of my career has been enjoyably spent teaching students on the IOA Diploma course and on MSc courses at NESOT and at London South Bank University. There is much information readily available about the Diploma in Institute publications, in Bulletin reports and on the website. Therefore comments will be restricted to history and origins, progress and development, progression opportunities and projects.

History and Origins

The 1970s in the UK saw an increase in public concern about noise in the environment and in the workplace. There were very few degree and postgraduate course in acoustics and noise control in UK Universities, and there was growing demand for further education and training in this area. Many higher education colleges and Universities were attempting to meet this demand by providing a range of introductory short courses (typically three afternoons or evenings over about 6 weeks). As explained earlier the introduction of noise related legislation in the 1970s led to a further increase in demand for information and training about noise from those required to deal with new regulations. The Institute of Acoustics developed the Diploma course in the mid-1970s in response to these developments. The IOA Diploma was started in 1977 to satisfy the educational requirements for Corporate membership of the Institute.

Development - Responding to Change

Although the laws of physics and acoustics have not changed since 1978 there have been very many changes in other aspects of noise control: in the instrumentation available for the measurement of noise and vibration (in particular the introduction of digital signal processing); in methods of noise control (e.g. active noise and vibration control); in computerised noise prediction methods; in legislation, regulations, standards, and codes of practice relating to the control of noise. The Diploma course has developed to respond to all of these changes.

Since its introduction over 2000 candidates have gained the Diploma and have gone on to become corporate members of the Institute. The course is aimed at all who are, or wish to wish to be professionally employed in the fields of acoustics and noise control and has attracted delegates from a wide range of backgrounds including engineers and technicians (particularly mechanical, production and building services engineers), mathematicians, physicists and other scientists, architects, builders, acoustic and environmental consultancies and local authority environmental health practitioners, audio and sound reproduction technologists and engineers.

The Diploma is offered currently at six Higher Education Institutions in the UK and through tutored distance learning supported by extensive course materials.

The revised Diploma 2008

The Diploma was restructured in 2008 to respond to changes in the National Assessment and Rating requirements of Higher Education Funding Council, and to secure the postgraduate status of the Diploma in order to provide better opportunities for further study for future Diploma holders, and also to rationalise the delivery of the modules.

The Diploma approach and philosophy

The Diploma course aims to teach the practical application of acoustic principles to the control of noise. Most of the course members are working in this area for example in local authority environmental health departments, or with acoustic consultancy practices, and so the course is able to connect directly with their day to day activities, and in turn they are able to enrich the course by sharing these experiences during class discussions. Therefore it is the applications of theory which are emphasised rather than the detailed derivation of formulae, although such derivations are always available to those students who wish to explore them. Emphasis is also placed on the assumptions of various theories and formulae because it is these that set the limitations of their validity when applied to practical situations. The course teaches various noise level prediction methods based on simplified and idealised models of noise propagation (free field, inverse square law, diffuse sound fields for example) which are the basis of current practice and the limitations of these assumptions in practice are discussed. This emphasis on the practical applications underlies all aspects of the Diploma course: teaching, assignments, examinations and project.

Project Module

The purpose of the Project is to enable the student to demonstrate the use of the skills and knowledge gained during the course in successfully carrying out an investigation to solve and report an acoustics related problem, within a specified time scale.

Since the student will spend considerably time and effort in their project investigation the choice of topic is usually left to him / her, guided by his / her tutor.

Most projects are practically based and will involve some or all of the following stages: selection of topic area, research and literature survey, definition of aims and objectives, formulation of a methodology and time schedule for execution, gathering of data (noise and /or vibration measurements), analysis of data, formulation of proposals, implementation, testing, report writing.

Every year a wide variety of topics are investigated by Diploma students. A list of titles of successfully completed projects is printed each year in the Acoustics Bulletin (the bi-monthly IOA members magazine), and also in the current version of the Diploma Handbook for students.

Opportunities provided by the Diploma course

Many students study the Diploma whilst working in acoustic to improve their skills and knowledge as a form of career enhancement and to become corporate members of the IOA. Many job vacancies in acoustics specify the holding of a Diploma as a necessary condition of application. Other candidates not working in the field join the course to gain employment in acoustics as a career change and are successful. Others have used the Diploma as a pathway to further study for an MSc degree, and in a few cases for PhD study.

Diploma graduates who obtain three Merits (including a merit in the GPA module) may be considered to have met the M-level educational requirements for achieving Chartered Engineer (CEng) status through the IOA. This will require also that candidates have an accredited three year degree in a relevant subject (or equivalent qualification).

Over more than 35 years the Diploma course has successfully responded to many changes in the practice of acoustics and noise control but and still fulfils essentially the same purpose for which it was introduced to provide basic education and training in for those seeking a career in acoustics and noise control, and a route towards corporate membership of the IOA. It has also served as a route into employment in acoustics and noise control for many seeking a change of career opportunity as well as a pathway to study for MSc and in some cases PhD studies. The Institute's commitment to open access and the introduction of the Distance learning option have significantly increased access to these opportunities.

3 OTHER ACTIVITIES AND INTERESTS

History Project, involvement in writing the history of the IOA London Branch (with Tony Garton) and the history of the Education Committee and of the Diploma.

Measurement Uncertainty in Acoustics – a keen interest.

CIBSE – part of team involved with revision of CIBSE Guide B4 (Noise) and Guid A1.10 (Noise) with John Shelton.

8 CONCLUSIONS

If there is a theme to this ragbag of recollections it is the immense variety that working in acoustics offers; a theme illustrated by the work of Dr Stephens, by my own experience, and by the huge range of articles published over the years in our IOA Bulletins – and the variety offered in our meeting today – which I intend to enjoy, and hope you do too.

9 REFERENCES

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Figure 1: Bubble screen (5mm x 5mm spacing)

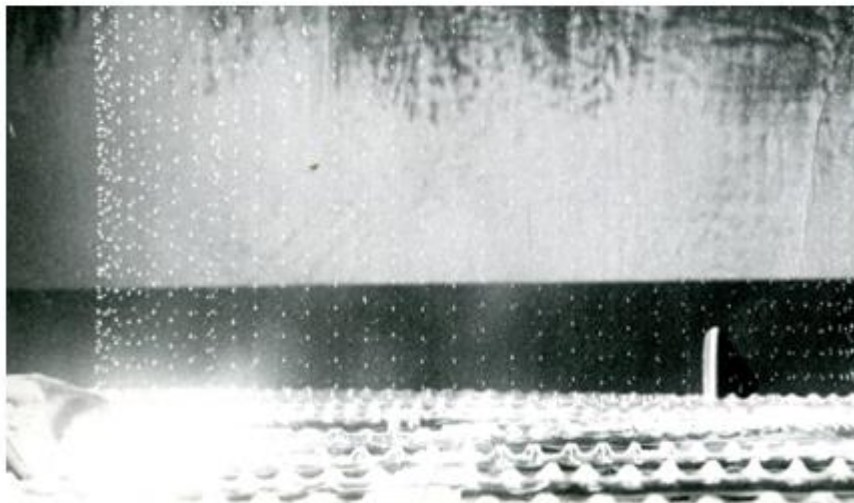


Figure 2: Attenuation by bubbles screens with bubble spacing of 0.5 mm x 0.5 mm

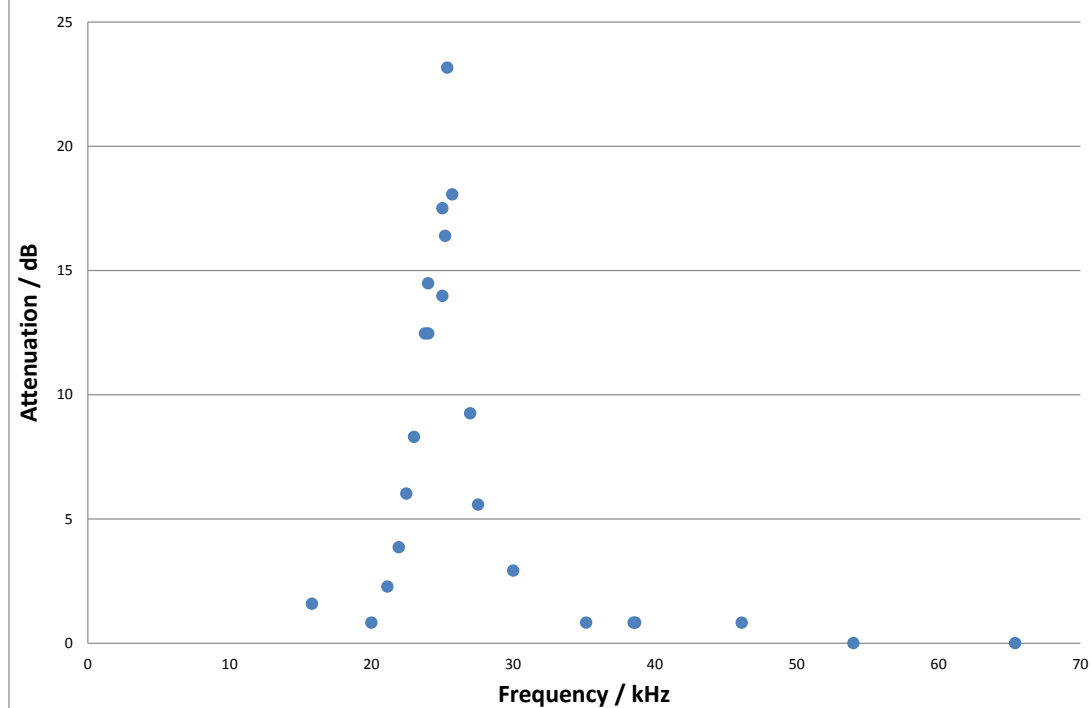


Figure 3: Evacuated glass sphere broken by plunger (500 frames per second)

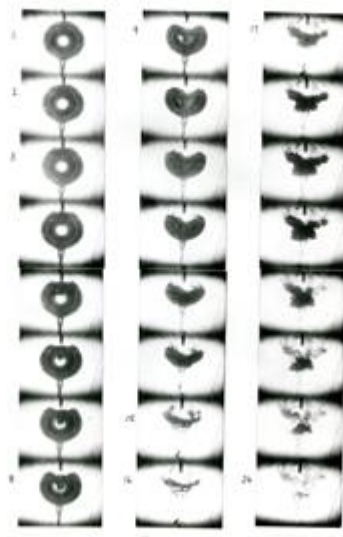


Figure 4: Evacuated glass sphere broken by shock pulse (500 frames per second)



Figure 5: Showing dynamic cavitation bubbles arising from reflection of shock pulse at interface with the cavity (broken glass sphere)

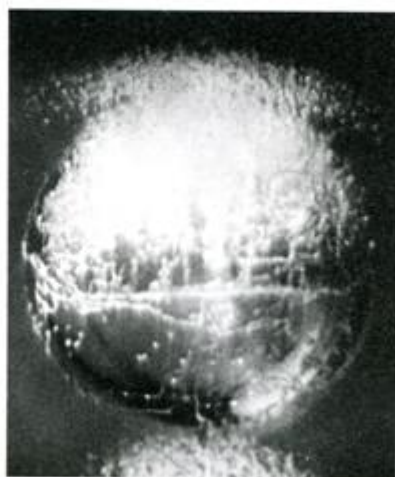


Figure 6: Radius v time curve for collapsing glass spheres and comparison with (Rayleigh) theory

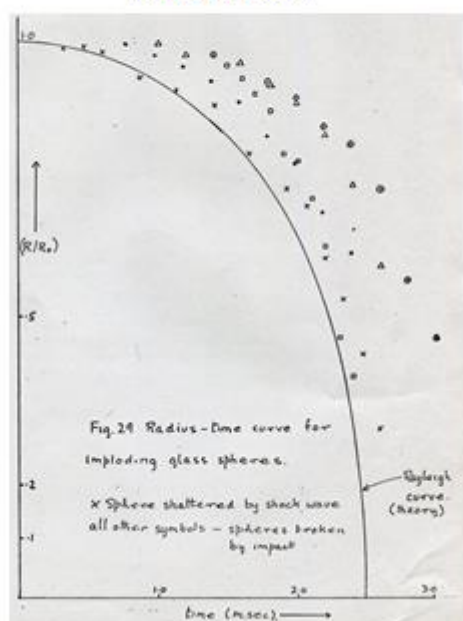


Figure 7: Showing dynamic cavitation bubbles arising from reflection of shock pulse just below the free water surface of shock tube

