Geophys. J. R. astr. Soc. (1975) **42**, 273–280.

Research Note

Measurement of Airgun Waveforms

S. G. Smith

(Received 1975 January 23)

Summary

Airgun waveforms in the deep sea were measured from 160 in^3 and 300 in^3 guns with known firing pressure and depth, known geometry of source and receiver, and a recording system with known impulse response. The waveforms were compared with waveforms predicted from bubble oscillation theory and were found to be similar.

Downloaded from http://gji.oxfordjournals.org/ by guest on October 16, 2013

Introduction

It is important to know the shape of airgun waveforms in order to design reflection profiling systems and for synthetic seismic modelling. The use of a waveform in synthetic seismic reflection profiling modelling will be presented in a future paper. Attempts have been made to measure airgun waveforms (Giles 1968; Ziolkowski 1970; Mayne & Quay 1971; Schulze-Gatterman 1972; Giles & Johnston 1973) but these are not considered to satisfy adequately all the requirements: known impulse response of the recording system, adequate depth of water so that bottom reflections do not interfere with primary arrivals, known geometry of gun and receiver, and measurement at a sufficient depth to measure the downgoing wave into the sea bed. These effects are considered separately.

1. Impulse response of recording system

Airgun waveforms contain significant energy in the band 2–200 Hz. To record a waveform without distortion a recording system with a flat amplitude and phase response over this band would be needed. This is usually impossible, but if the frequency response or the impulse response of the system is known accurately the effect of the recording system on the waveform can be computed.

2. Adequate depth of water

If an airgun waveform has significant energy up to a time of n s after the initial pulse, then no reflected energy must be received until after n s. For a waveform duration of 1 s the sea bed must be at least 0·75 km below the recording hydrophone.

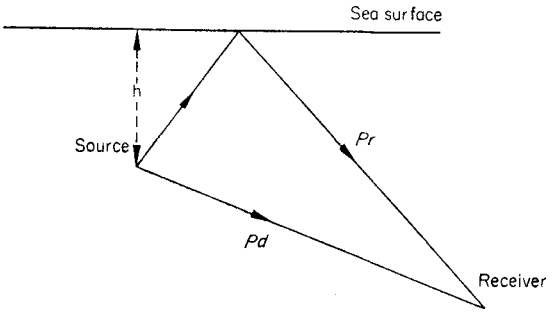


FIG. 1. The direct wave, *Pd*, and the reflected wave, *Pr*.

3. Known geometry of gun and receiver

An airgun radiates energy in all directions (Ziolkowski 1970) so a receiver records a direct wave from the gun and also a wave reflected from the sea surface (Fig. 1). The shape of the waveform recorded depends on the distance travelled by the direct wave, *Dd*, and the distance travelled by the reflected wave, *Dr*. Fig. 2 is after Ziolkowski (1971) and shows the direct waveform, *Pd*, the reflected waveform, *Pr*, and *Pt*, the received waveform, which is the sum of *Pd* and *Pr*. The relative amplitudes of *Pd* and *Pr* in *Pt* is given approximately by the ratio:

$$Pd : Pr = Dr : Dd$$

assuming symmetrical spreading and amplitude inversely proportional to distance travelled, for small amplitude oscillations. As *Dd* becomes larger the amplitudes of *Pd* and *Pr* in *Pt* tend to be equal.

4. Measurement at sufficient depth

I wished to measure airgun waveforms produced by a gun when it is being used for deep-sea profiling, in water depths of usually greater than 2 km. As the recorded

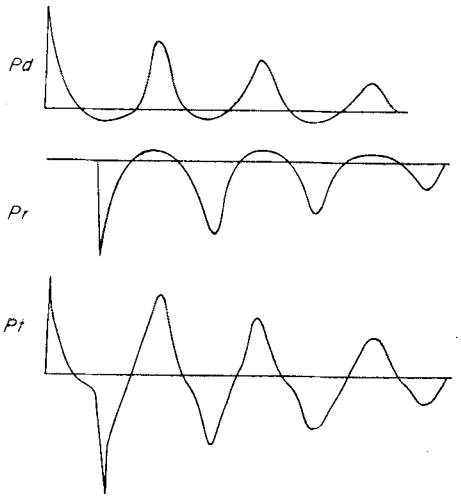


FIG. 2. The measured wave, *Pt*, formed from *Pd* and *Pr*.

waveform varies with the geometry of source and receiver it is necessary to have a receiver at this depth to measure the waveform going into the sea bed. Unfortunately the waveform reflected from the sea bed would interfere with the downgoing wave for a reflector near the sea bed, so this is impossible. In practice it is necessary to use a receiver with at least 0·75 km of water below it (Section 2) and record an approximation to the deep sea waveform. When the receiver is vertically below the gun:

$$Dr = Dd + 2h$$

where h is the gun depth, and when the receiver is sufficiently deep so that $Dd \gg 2h$

$$\frac{Dr}{Dd} \simeq 1$$

so that the amplitude ratio of $Pd : Pr \simeq 1$ in Pt and the waveform is a sufficient approximation to that measured at depth. For less than 5 per cent error in $Dr/Dd = 1$ this demands a $Dr > 400$ m with $h = 10$ m.

This waveform cannot be computed by measuring Pd independently from Pr and computing Pt, by measuring the waveform near the gun, where Pd is much greater than Pr, because non-linear wave propagation can occur in the near-field of the gun.

Experimental measurement

The experimental arrangement is shown in Fig. 3. A hydrophone (a cylindrical lead titanate-zirconate pressure transducer potted in epoxy resin) and a pre-amplifier were suspended 400 m below a sonoradio buoy. The hydrophone was weighted to keep it vertically below the buoy, and vertical motions of the cable due to up and down movement of the buoy were damped out by spherical floats attached to the top of the cable. This kept the 400 m of cable approximately stationary in the water while the buoy moved up and down with the waves. The ship steamed slowly past the buoy firing a Bolt airgun, passing within 10 m of the buoy. Gun chamber sizes of

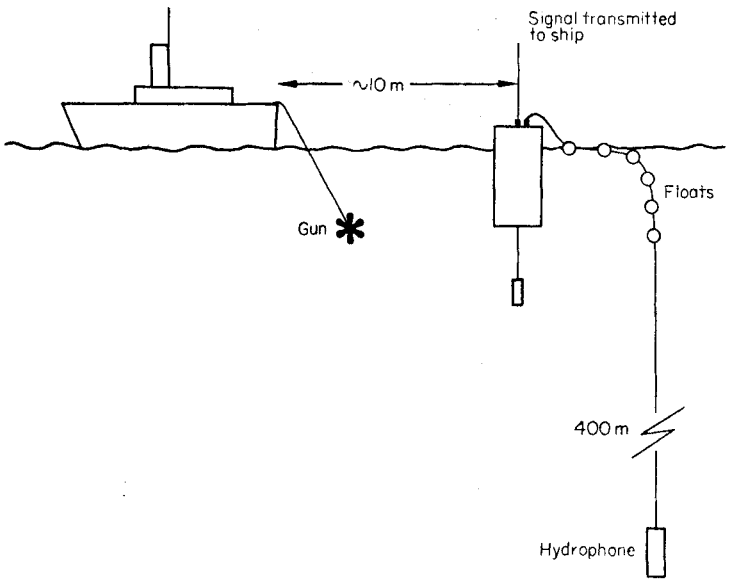


FIG. 3. The experimental arrangement used for measuring airgun waveforms.

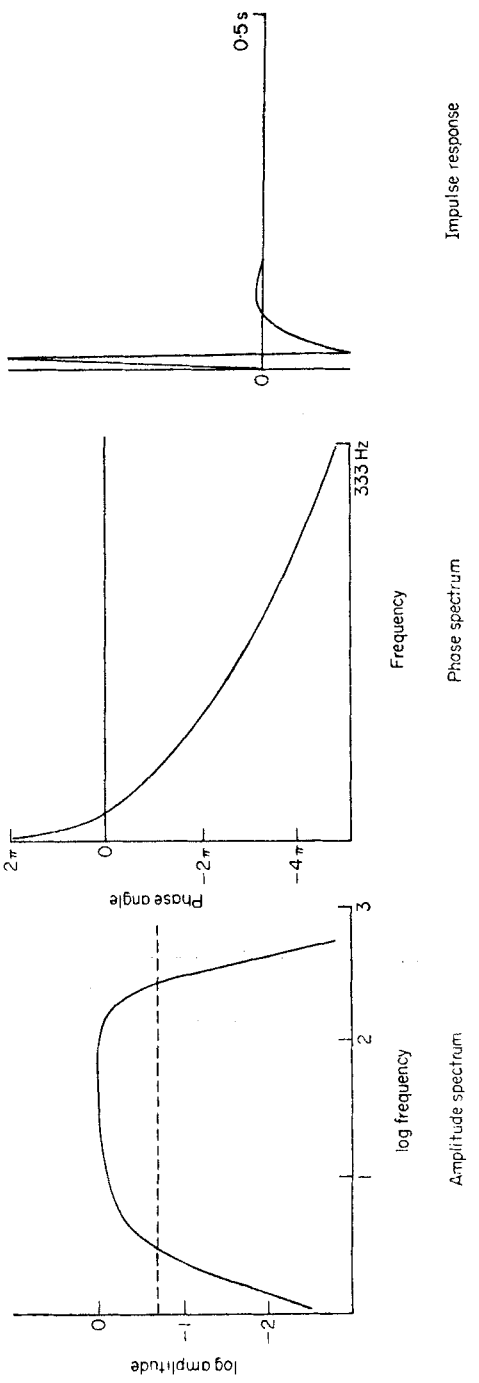


FIG. 4. Amplitude and phase spectra of the recording system and impulse response of the system. The amplitude spectrum above the dashed line is measured and the spectrum below the dashed line is calculated.

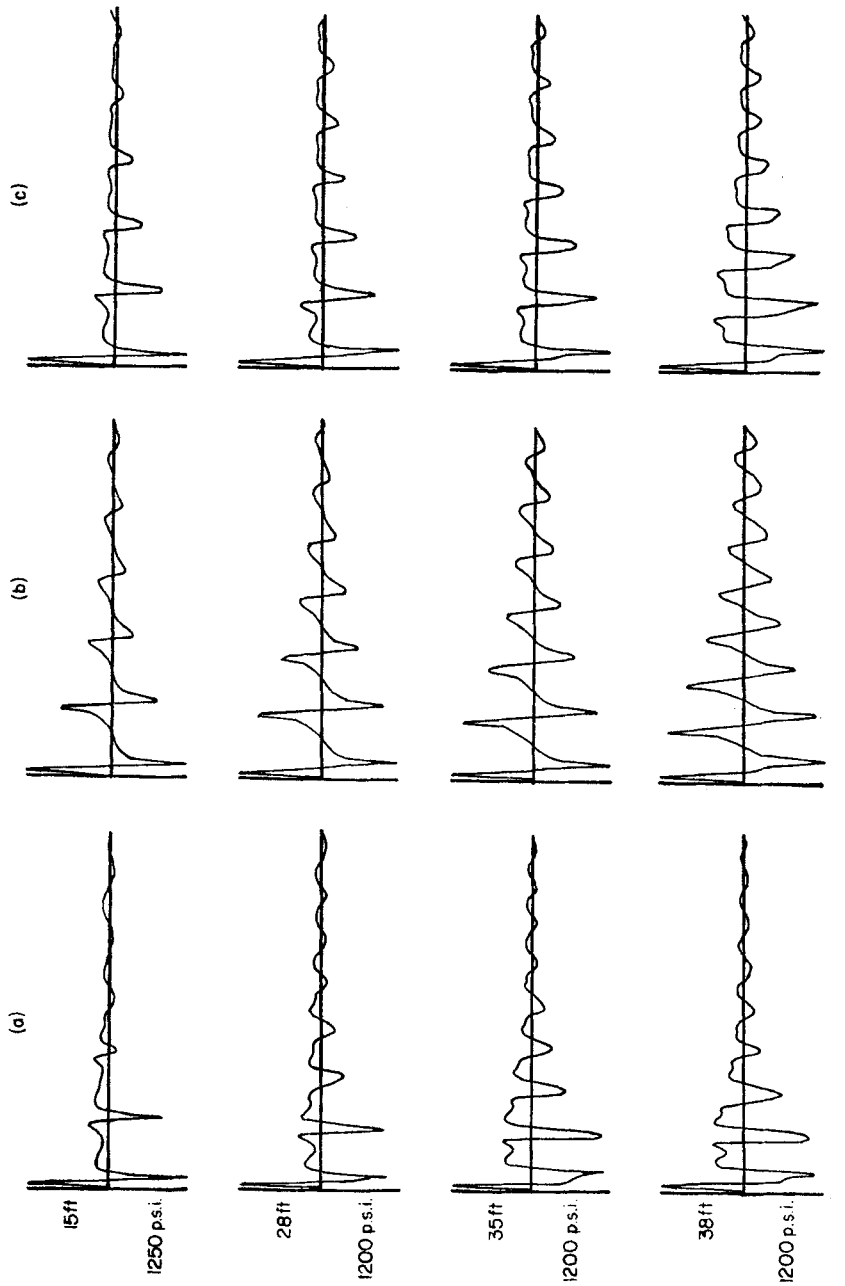


FIG. 5. 160 in³ gun. (a) Measured waveform; (b) theoretical waveform; (c) theoretical waveform convolved with impulse response of the recording system. Amplitudes are normalized and the waveform duration is 0·5 s.

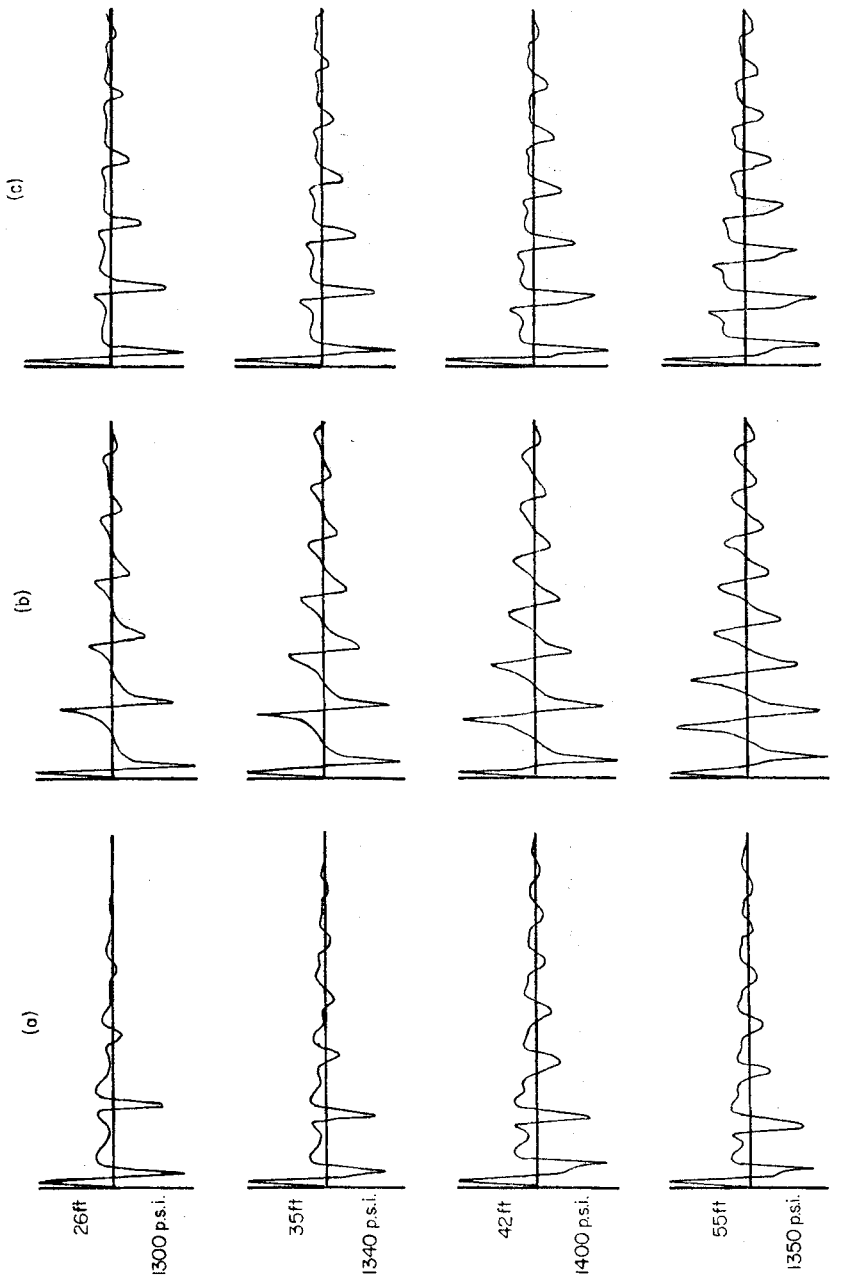


FIG. 6. 300 in³ gun. (a) Measured waveform; (b) theoretical waveform; (c) theoretical waveform convolved with the impulse response of the recording system. Amplitudes are normalized and the waveform duration is 0·5 s.

160 in^3 and 300 in^3 were used. A calibrated pressure transducer was used to continuously monitor the gun depth. Airgun signals were transmitted from the buoy to the ship, monitored on a jet-pen recorder and recorded on magnetic tape. This was repeated with the gun at different depths.

The impulse response of the whole recording system from hydrophone to tape recorder was measured: a fixed frequency voltage was input in series with the hydrophone, passed through the recording system, compared with the input signal, and amplitude and phase shift measured. It was not possible to define the low amplitude parts of the frequency response accurately by measurement, so these were calculated from electrical circuit theory (Girling & Good 1969). At higher amplitudes the calculated response was in agreement with the measured response. The amplitude and phase spectra for the recording system and the impulse response of the system (the Fourier transform of the frequency spectrum) are shown in Fig. 4. The pass band of the system is 4–160 Hz at -3 dB level.

Results

The results for the 160 in^3 and 300 in^3 guns are shown in Figs 5(a) and 6(a).

Attempts have been made to predict airgun waveforms from bubble oscillation theory by Ziolkowski (1970) and Schulze-Gattermann (1972). Schulze-Gatterman's theory applies to small amplitude oscillations, whereas Ziolkowski's allows for finite amplitude oscillations, so is more useful. Ziolkowski's theory was used to compute airgun waveforms for the same conditions of chamber volume, firing pressure, depth and geometry of gun and receiver as the measured waveforms. Damping constants of 2·5 and 1·8 s^{-1} were chosen for the 160 and 300 in^3 guns, as this provided the best match to the measured waveforms. This is in agreement with the damping constant of $31{\cdot}6/\sqrt{V}$ where V = gun chamber volume in in^3 suggested by Ziolkowski (1972, private communication). The theoretical waveforms are shown in Figs 5(b) and 6(b). These were also convolved with the impulse response of the recording system and are shown in Figs 5(c) and 6(c), for comparison with the measured waveforms.

The general form of the convolved waveforms approximates to the measured waveforms, indicating that bubble oscillation theory provides an approximate description of airgun waveforms. The main difference is that the bubble oscillation period decreases slightly faster than predicted. Ziolkowksi (1970) noted this, and suggested that this was due to the proximity of the air-water free surface.

Acknowledgment

I thank Dr Anton Ziolkowski for his airgun waveform prediction program.

Department of Geodesy and Geophysics,
University of Cambridge,
Madingley Rise, Madingley Road,
Cambridge.

References

Giles, B. F., 1968. Pneumatic acoustic energy source, *Geophys. Prospect.*, **16,** 21–53.

Giles, B. F. & Johnston, R. C., 1973. System approach to air-gun array design, *Geophys. Prospect.*, **21,** 77–101.

Girling, F. E. J. & Good, E. F., 1969. Active filters, *Wireless World*, **75,** 403–408.

Mayne, W. H. & Quay, R. G., 1971. Seismic signatures of large air guns, *Geophysics*, **36,** 1162–1173.

Schulze-Gattermann, R., 1972. Physical aspects of the 'Airpulser', *Geophys. Prospect.* **20,** 155–192.

Ziolkowski, Anton, 1970. A method for calculating the output pressure waveform from an air gun, *Geophys. J. R. astr. Soc.*, **21,** 137–161.

Ziolkowski, Anton, 1971. Design of a marine seismic reflection profiling system using air guns as a sound source, *Geophys. J. R. astr. Soc.*, **23,** 499–530.