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Signature tests on 400-in^3 water gun and 540-in^3 air gun

by

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INTRODUCTION

The acquisition of multichannel seismic-reflection data has in general required a dependable, repeatable, high energy source with a relatively broad band frequency output. The air gun, which generates a wavelet by expelling compressed air into the water, has been one of the most common sources. The U.S. Geological Survey (USGS) has used 540-in^3 air guns alone and in pairs for multichannel seismic-reflection profiling on the Atlantic and Gulf of Mexico continental margins. The water gun, which generates a wavelet by expelling compressed water, has recently been utilized as an alternative seismic source.

The theory, operational environment, and characteristics of small- and medium-sized air guns and water guns have been compared by Hutchinson and Detrick (in press). In order to compare the relative merits of the large 540-in^3 air gun and the large 400-in^3 water gun, the USGS conducted a series of signature tests on each gun in October 1983 south of Pensacola, Florida in the Gulf of Mexico in about 3000 meters of water. This report presents the results of those signature tests.

METHOD

Four seismic sources were used: two Seismic Systems, Inc. Model P400 water guns (400-in^3) and two Bolt Associates, Inc. Model 1500C air guns with waveshaper inserts (540-in^3). Each gun was towed 17 m behind the ship and 5 m beneath the sea surface on a chain harness attached to a large Norwegian float. A gun depth of 5 m corresponds to a quarter-wavelength constructive interference frequency of 75 Hz and a half-wavelength destructive interference node of 150 Hz; this is larger than the anti-aliasing filter of 128 Hz used in this experiment. When two guns were towed, horizontal separation was maintained at about 4 m. Signatures were collected for each gun alone, for the two water guns shot simultaneously, and for the two air guns shot simultaneously.

The acquisition system consisted of an Aquatronics Ref-Tek 18 sonobuoy with a Ref-Tek 17 hydrophone (10 volts/bar) suspended 150 m beneath the sea surface. Signals from the sonobuoy were telemetered to an Aquatronics STR 70-2F sonobuoy receiver aboard the ship, then into a Texas Instruments DFS V digital recording system. Data were recorded at a 2-millisecond (ms) sampling rate and filtered at both OUT-128 Hz and 8-128 Hz. Since the 8-128 Hz signals had better signal-to-noise ratios, the OUT-128 Hz signals were not used in this analysis. When two guns were being shot simultaneously, the shot instants were synchronized by monitoring the shot-phone signals on a storage oscilloscope. The shot-phone was a single hydrophone strapped to the input hoses approximately 1 m from the gun. The air-gun signatures were aligned on the first break; the water-gun signatures were aligned on the maximum positive amplitude of the wavelet.

The shooting pattern consisted of the ship making successive passes as close as possible to the sonobuoy while shooting. Only the shots closest to the sonobuoy, i.e., those having near-vertical travel paths, have been used in this analysis. Ship speed was kept constant at 4.5 kts, the typical survey speed. Because the sonobuoy antenna was located behind the bridge, recording for each pass commenced when the buoy was about 100 m off the bow and continued until the signal-to-noise ratio deteriorated, about 0.5 km after the ship had passed the buoy. The shot interval was 10 seconds (s) at 1800-2000 psi.

The field data were processed on the USGS Vax 11/780 computer using Digicon DISCO software. This processing included demultiplexing, gain corrections, and spectral calculations. The frequency spectra were calculated using the maximum entropy method (Burg, 1975) with 300 data points (0-600 ms) and a 50-ms operator length. The power (in dB down) is normalized such that the maximum power has a value of 0.0 dB. The seismic traces were plotted at identical scales to facilitate direct comparisons.

DISCUSSION

Examples of the seismic traces and their frequency spectra are given for the single guns (Fig. 1) and the two guns fired simultaneously (Fig. 2). The very obvious 60-Hz background noise is probably the combined result of a gain-reducing resistor in the sonobuoy and the counterbalancing high-gain settings in the DFS V. The gain-reducing resistor in the sonobuoy should not have been there. This noise has been left on the traces because 1) a 60-Hz notch filter would remove the 60 Hz component of the signal and change the shape of the signal, and 2) the 60-Hz noise is constant on all signals, making a comparison of the signals still valid.

The shape of the seismic signal differs between the water gun (Fig. 1A, 1B) and the air gun (Fig. 1C, 1D). The water-gun signal shows a precursor of 50 ms, a maximum energy spike of 10 ms in which the negative portion of the wavelet is stronger than the positive portion, and a tail consisting of 4-5 wavelets of 40-50 ms, making a total wavelet length of 100-120 ms. The air-gun signal is much simpler, consisting of an initial wavelet of 50 ms and one or two bubble pulses of 40-50 ms each that follows the initial wavelet at intervals of 120-130 ms, making a total wavelet of 210-220 ms (with one bubble) or 330-350 ms (with two bubbles). The water-gun signal has a more complicated, but considerably shorter, waveform than the air-gun signal.

Variations in the amplitudes of the single water guns and air guns (Fig. 1 and Table I) are probably due to the slight differences in distance from the ship to the sonobuoy during each pass. The closer shots have undergone less signal loss due to spherical spreading of the waveform and have larger amplitudes than the more distant shots do. At comparable ranges from the sonobuoy (150 ms), the 400-in^3 water-gun amplitude (-244 millivolts - mv) is greater than the 540-in^3 air-gun amplitude (-170 mv) suggesting that the single water gun may be slightly stronger than the single air gun (although, in general, the amplitudes are about the same). The wave shaper insert in the air gun may help explain some of its reduced amplitude characterics.

The frequency spectra of the single water guns and air guns (Fig. 1) show fundamental differences between the two sources. The water gun spectra are flatter and richer in frequencies greater than 60 Hz, although not much energy occurs above 110 Hz. The air-gun spectra are more irregular and favor the frequencies less than 60 Hz. Neither gun has much energy below 10-15 Hz. A plot of the cumulative energy as a percentage of the total power vs. frequency (Fig. 3) shows that about 80 percent of the air-gun energy is contained in frequencies less than 75 Hz, whereas only 55 percent of the water-gun energy occurs in the same frequency interval.

Given the similar amplitudes of the two sources, the water-gun signal, with its shorter wavelet and higher frequency content should provide greater resolution than the air gun, although the lower frequencies of the air gun may provide greater penetration. The differences in wavelet shape and length and frequency spectra for the large guns are essentially identical in form to similar signature measurements collected on medium and small water guns and air guns (Hutchinson and Detrick, in press). Hence, the characteristics that distinguish water guns from air guns apply to a variety of gun sizes.

The amplitude of the two-gun signatures should be approximately double and the total waveform length should be approximately the same as that of the single gun. This behavior occurs with the air gun, but not with the water gun (Table I; Fig. 2). For the air gun, the two-gun amplitude (-396 mv) is slightly less than twice that for the single gun (-220 mv) at similar range, and the total signature length is essentially identical (214 ms). For the water gun, however, the amplitude for the two-gun signature (-289 mv) is only about 1.2 times that for the single gun (-244 mv) and the total signature length is 150 ms, which is 30-40 ms longer than that of the single gun. This suggests that the two water guns did not fire in phase, possibly because: a) the alignment of the two wavelets on the positive peak of the main spike was improperly done; or b) the two guns drifted closer than the non-interacting distance of 4 m (Seismic Systems, Inc., personal commun., 1983). Misalignment of the peaks could have occurred, especially since the distance between the principal positive and negative peaks is small enough (10 ms) that a small alignment error could cause major destructive interference. The more likely reason is that the guns drifted closer than 4 m, causing the outgoing water plugs to interact. Our estimated separation of the guns was about 4 m, i.e., the minimum tolerable separation. Clearly, the geometry of towing more than one water gun and the technique for aligning the traces during firing must be monitored more carefully with the water gun than with the air gun.

The spectra for the two-gun shots show the effect of destructive interferences of improperly aligned shots (the water gun, Fig. 2A) and the constructive interference of properly aligned shots (the air gun, Fig. 2B). Whereas the spectra for the single water guns show significant energy at 85-105 Hz, the spectrum for the two guns shows most of the energy above 75 Hz has been attenuated. The effect of firing two water guns has been to reduce the desired characteristic of the single water guns: the higher frequencies. The spectrum for the two air guns is almost identical to that of the single guns; it has the same irregularity and greatest energy between 10 and 60 Hz. The spectrum for the two water guns is much closer to that for the two air guns than to that of either of the single guns.

Our tests did not gather enough shots to measure the repeatability of the signal. However, the 220 recorded water-gun shots and the 115 recorded air-gun shots showed a qualitative similarity between the signals of each gun type (compare Fig. 1A and 1B, 1C and 1D) and a consistency in wave shape for the shots fired from any single gun. The popularity of air guns as a seismic source is evidence of their dependability and repeatability (e.g. Lugg, 1979, McQuillan and others, 1980). Experiments have shown the repeatability and dependability of smaller water guns (French and Henson, 1978; Hutchinson and Detrick, in press).

CONCLUSIONS

The signature tests on the 400-in^3 water guns and 540-in^3 air guns reported here have shown:

1) The energy output for a single 400-in^3 water gun or 540-in^3 air gun is about the same.

2) The water gun has a shorter, more complicated signature and a spectral content that is flatter and richer in higher frequencies than does the air gun. The water-gun source, therefore, should result in better resolution than would be provided by an air-gun source.

3) The air gun has a simpler but longer signature and a spectral content that contains more energy in the lower frequencies than the water gun. The net result should lead to better penetration than the water gun would provide.

4) An array of two water guns is more difficult to synchronize than an array of two air guns. The distance between the guns and the choice of which peak in energy with which to align the shots are probably critical.

5) The results of our comparison are nearly identical in content to published comparisons of smaller water guns with smaller air guns, indicating that the characteristics of each source apply to a variety of gun sizes.

The choice of any seismic sound source should be made together with variables such as hydrophone response, local geology, desired resolution, and desired penetration. Our data have demonstrated some of the advantages and disadvantages of single-gun and two-gun sources utilizing relatively large guns. A comparison of reflection data collected with each source under identical recording (and/or processing) conditions would be a valuable addition to these signature tests.

ACKNOWLEDGEMENTS

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TABLE I: SHOT CHARACTERISTICS

GUN[1]	FIRST BREAK (MS)[2]	MAXIMUM AMPLITUDE (MV)	TOTAL LENGTH (MS)[3]
Stbd 400	158	-225	118
Port 400	150	-244	107
Stbd 540	140	-220	215
Port 540	152	-170	214
2 x 400	150	-289	150
2 x 540	140	-396	214

[1]Stbd = Starboard gun, Port = port gun, 400 = 400 in^3 water gun, 540 = 540 in^3 air gun.

[2]First Break: onset of the waveform in one-way travel time. This indicates the relative distances of each source from the sonobuoy.

[3]Total Length: length of the signal from the first break to the last identifiable energy associated with the shot. This includes only the first bubble for the air guns, since the second bubble is negligible in these tests.

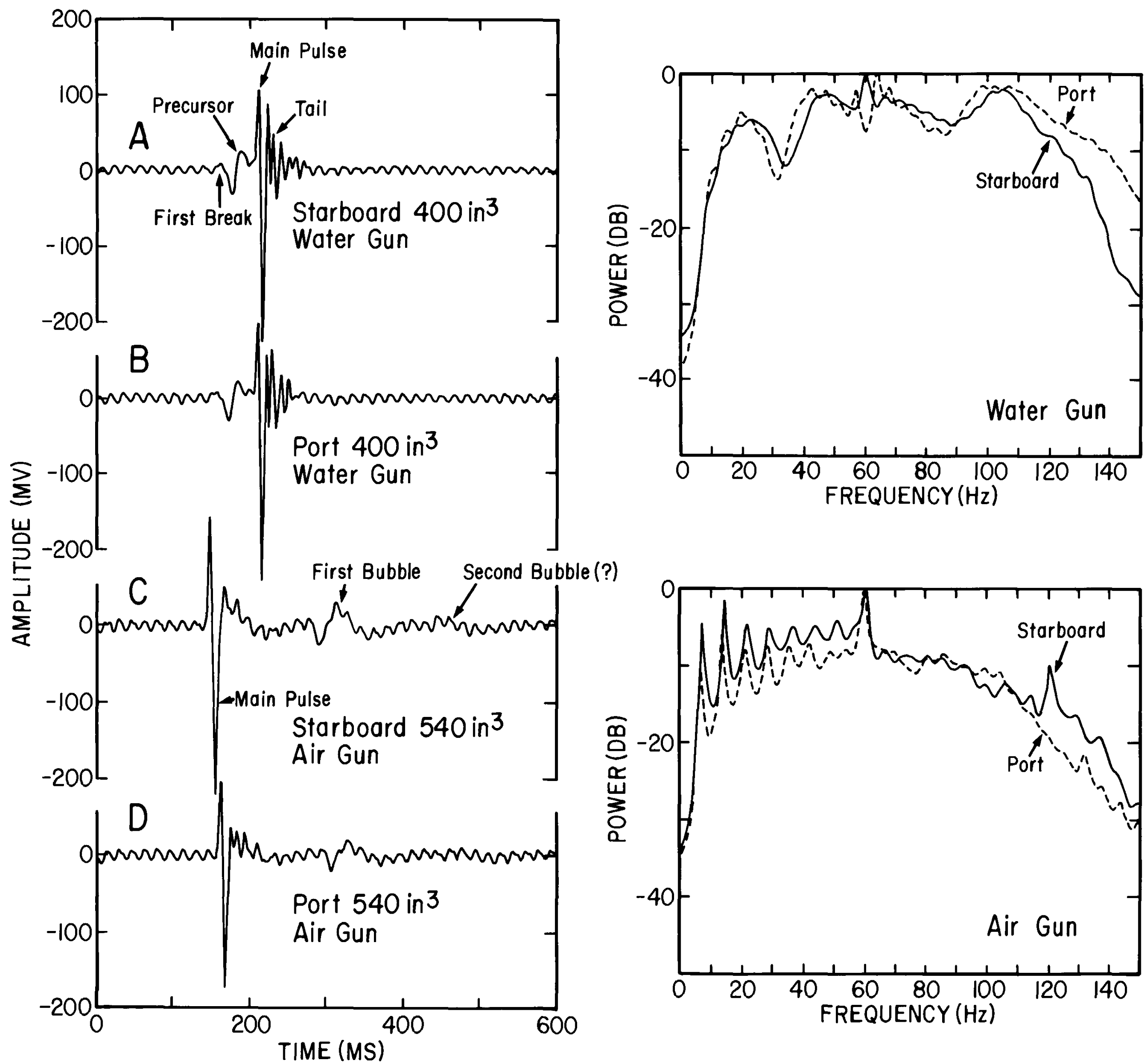

Figure 1: Signatures and frequency spectra for single-gun shots. A) Starboard 400-in^3 water gun; B) Port 400-in^3 water gun; C) Starboard 540-in^3 air gun; D) Port 540-in^3 air gun. The signatures are plotted at the same horizontal and vertical scale. The spectra are normalized such that the maximum power occurs at 0 dB down.

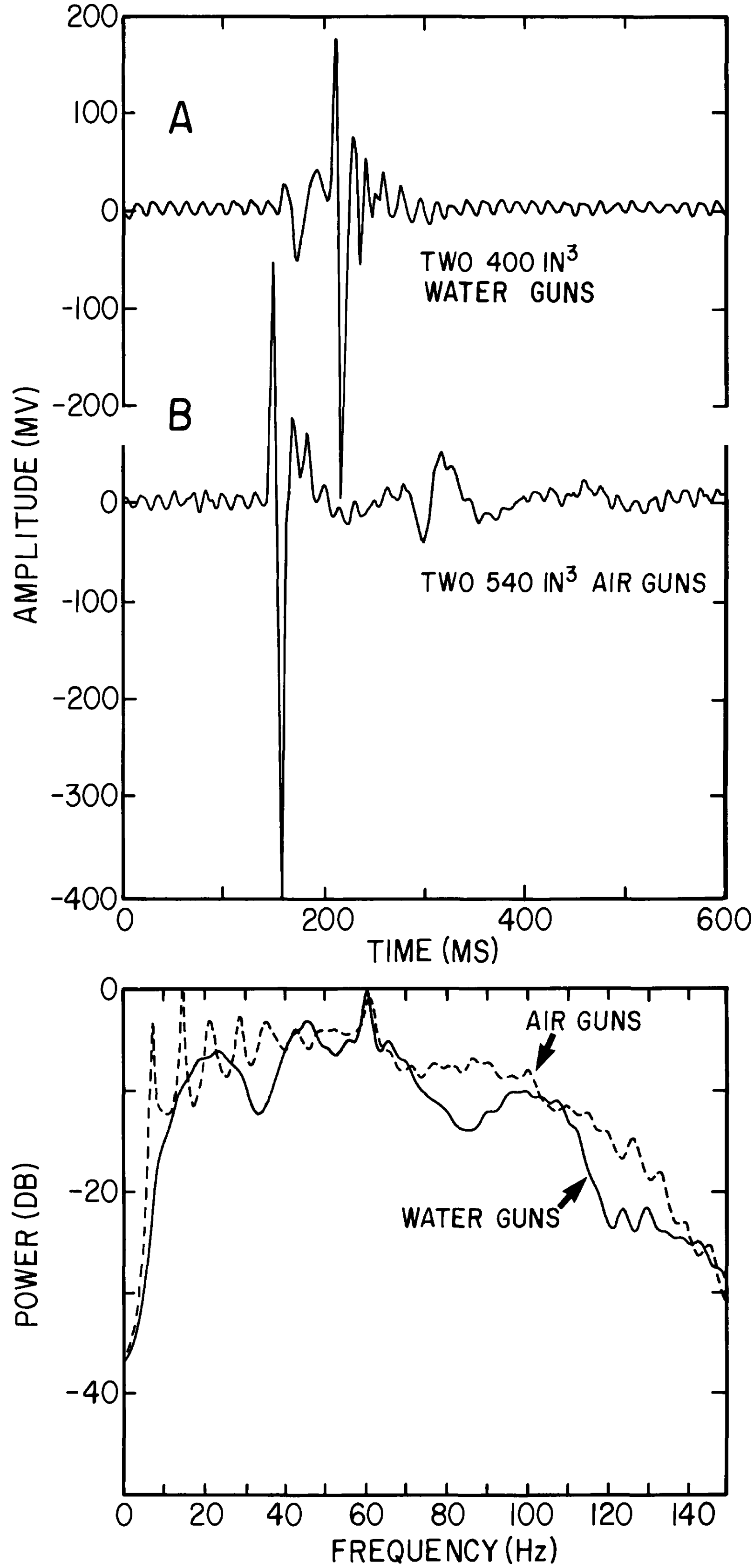

Figure 2: Signatures and frequency spectra for two-gun shots. A) two 400-in^3 water guns; B) two 540-in^3 air guns. Scales are the same as for Figure 1.

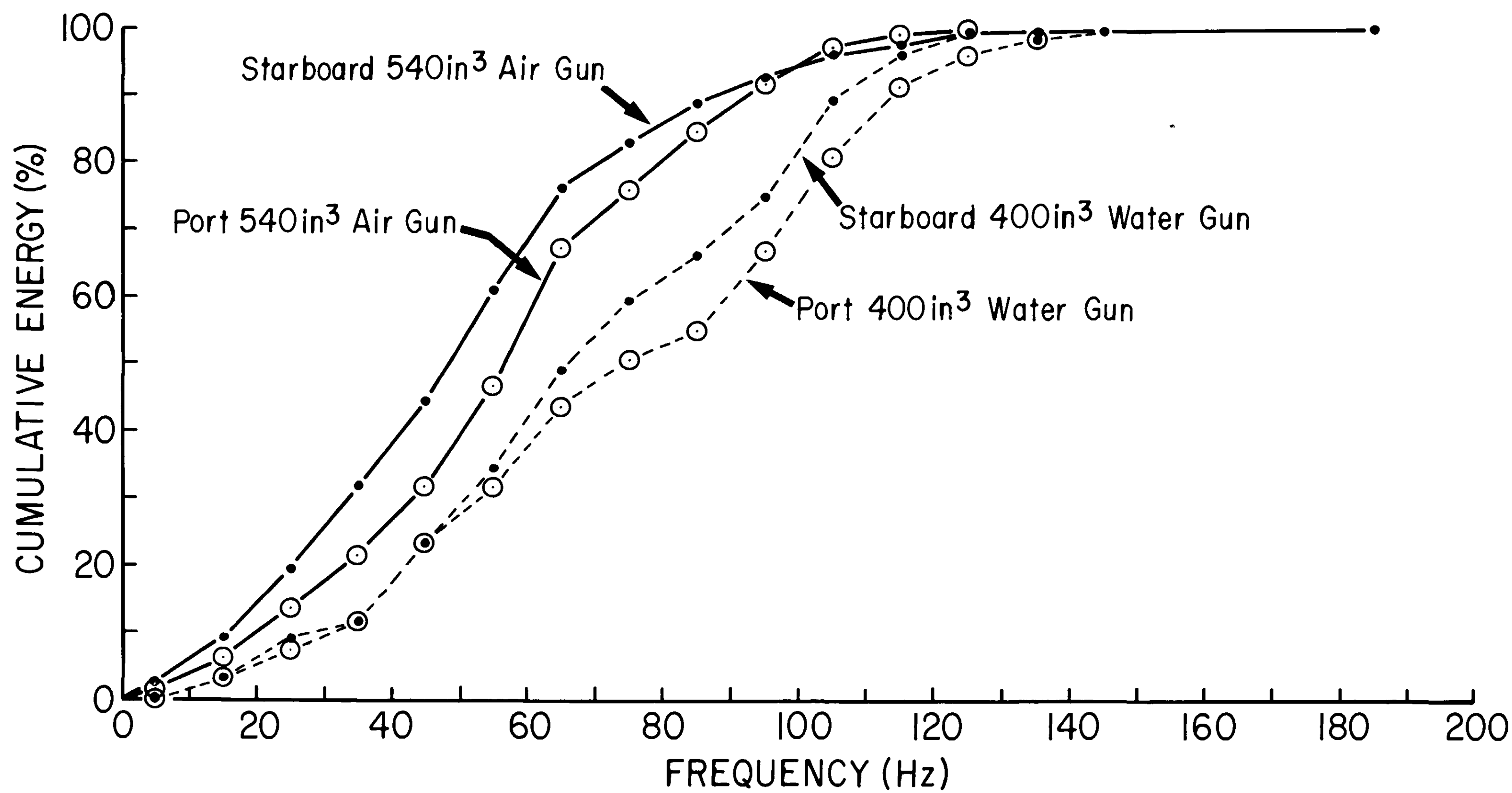

Figure 3: Relative total power for single gun shots plotted as cumulative energy vs. frequency. The points are plotted such that each 10 Hz increment is plotted in the midpoint of that interval (e.g., 20-30 Hz is plotted at 25 Hz). The offset between the air gun and water gun values indicates that the water guns have more energy at higher frequencies than the air guns.