GEOPHYSICS, VOL. 36, NO. 6 (DECEMBER 1971), P. 1162–1173, 14 FIGS.

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SEISMIC SIGNATURES OF LARGE AIR GUNS†

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Large chamber air guns are a reliable and effective source of energy for marine seismic surveys. Air guns with chamber volumes of 300 and 1000 cubic inches demonstrate desirable low-frequency responses and high absolute energy levels. Overall performance has been compromised, however, by the bubble effect.

Previous attempts at minimizing the bubble response have resulted in loss of reliability, reduced power, or incomplete bubble suppression, or a combination thereof. In this paper, we present the results of experimental tests on air guns with 300 and 1000 cubic inch chambers and describe a divided-chamber gun which greatly attenuates the bubble effect. Significant improvements in the width and flatness of the frequency spectra are demonstrated by analysis of the actual signatures obtained in deep water and with record sections comparing the results obtained with the standard and improved guns along an identical traverse.

The bubble-attenuating air gun simultaneously provides improved resolution, high absolute-energy levels, and excellent reliability.

Air guns have proved to be very convenient and effective energy sources for marine seismic surveys. Four large air guns with chambers of 300 cubic inches each provide total energy adequate for any marine survey and have demonstrated a high reliability under all survey conditions.

Although the sudden release of the contained air produces the desired initial pulse, over-expansion and repeated oscillation of the resultant bubble produce undesired after-pulses. The basic principles of bubble oscillations are ably described by Kramer et al (1968).

In order to determine the specific performance of particular air guns, we conducted tests with a Bolt Model 1500C air gun with four different large chamber configurations. To eliminate all bottom effects, the tests were conducted in deep water (236 fathoms). A single hydrophone was suspended below the sources at a constant depth of 100 ft, and recordings were made with the air guns submerged at different depths. Data were recorded on a Texas Instruments DFS III system at constant gain with a sampling interval of one msec. Overall frequency response approximated that of a typical streamer cable system; air pressure was maintained constant at 1700 psi for all tests.

Figure 1 illustrates the signatures obtained at different depths with a special 1000 cubic inch chamber. Figure 2 shows a similar set of signatures obtained with a standard 300 cubic inch chamber.

The 1000 cubic inch chamber was then fitted with a bubble-attenuator assembly consisting of an orifice plate positioned by spacers to divide the overall chamber into two parts. This combination, designated the Uni-Pulse® 770 and hereafter called the orifice plate or divided-chamber gun, produced the results shown in Figure 3. It is significant that the amplitude of the initial pulse obtained with the combination gun is the same as that produced by the 300 cubic inch chamber, while the bubble pulse amplitudes are highly at-

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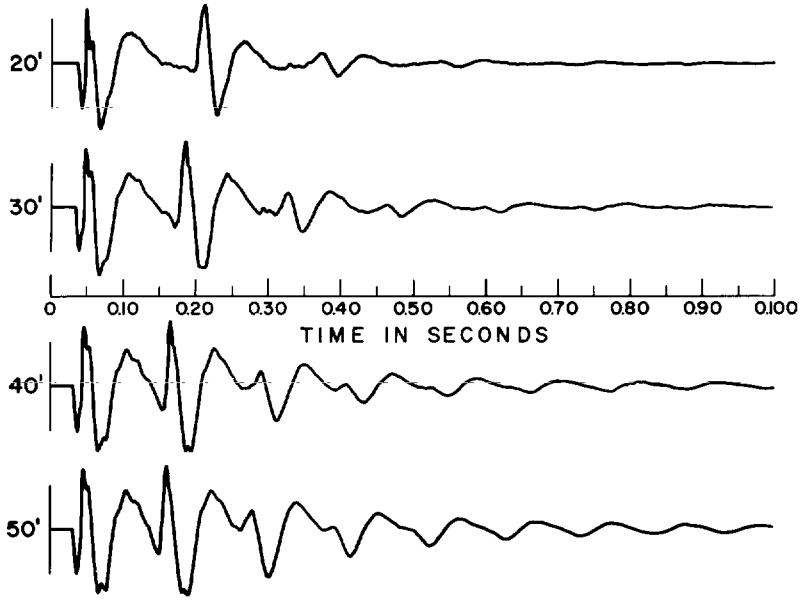


FIG. 1. Signatures of standard air gun with 1000 cubic inch chamber at different depths. Air pressure is 1700 psig.

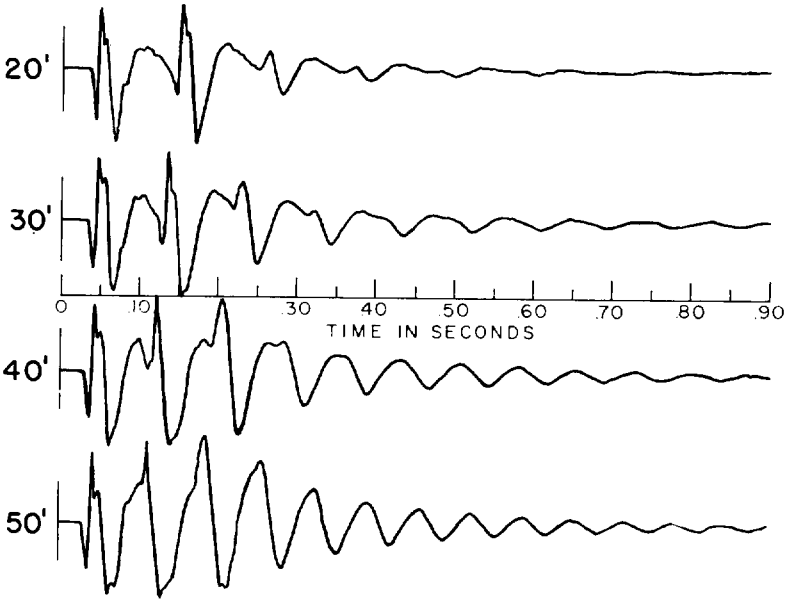


FIG. 2. Signatures of standard air gun with 300 cubic inch chamber at different depths. Air pressure is 1700 psig.

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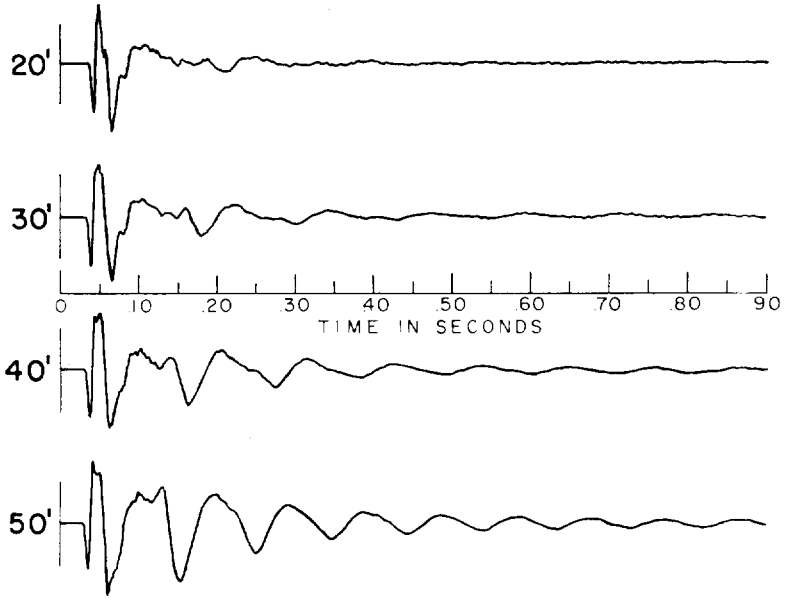


FIG. 3. Signatures of divided-chamber air gun at different depths. Air pressure is 1700 psig.

tenuated. It can also be seen that the forms of the two initial pulses are almost identical.

Figure 4 illustrates the results obtained with a standard Bolt wave-shape kit installed in the 300 cubic inch chamber. Bubble attenuation is somewhat less effective than that realized with the larger orifice-plate unit, and the amplitude of the initial pulse is reduced to about 60 percent of that given by the larger unit. It can also be seen that the 300 cubic inch, wave-shape kit combination produces a shorter pulse than does the larger unit and results in a reduced low-frequency content.

Figure 5 shows the frequency spectrum of the raw signature of the divided-chamber source at a depth of 20 ft, while Figure 6 gives the spectrum of the 300 cubic inch gun at the same depth. Severe peaking and notching is apparent in the 300 cubic inch spectrum, whereas the orifice-plate unit's spectrum is quite flat and confirms the excellent bubble attenuation observed on the actual signature. No smoothing of any type was used in computing these spectra.

Figure 7 shows the two sources discussed in this paper.

A number of conclusions can be drawn from inspection of the various signatures presented in these figures:

First: It is apparent that the shape of the initial pulse changes with the effective volume of air released. Thus, the 1000 cubic inch chamber appears to exhibit greater low-frequency response than does the 300 cubic inch chamber with the wave-shape kit, which has a direct discharge volume of about 70 cubic inches.

Second: Contrary to the generally accepted theory of surface reflection, there appears to be little significant change in the absolute amplitude or form of the initial pulse as a function of depth.

Third: The effects of gun characteristics and depth on the initial pulses cannot be clearly analyzed from the raw signatures because of the obscuring effects of the widely differing amounts and types of trailing energy.

In order to concentrate on the initial pulse, the raw signatures were smoothed with a hanning window before analysis. The half period of the cosine-squared smoothing function was made equal to the time from the initial rise to the second peak of the first bubble pulse. Since all other values are zeroed, the resultant spectral analyses should define more clearly differences in the initial pulses alone.

Figure 8 illustrates the effect of source depth on the spectra of the smoothed signatures of the

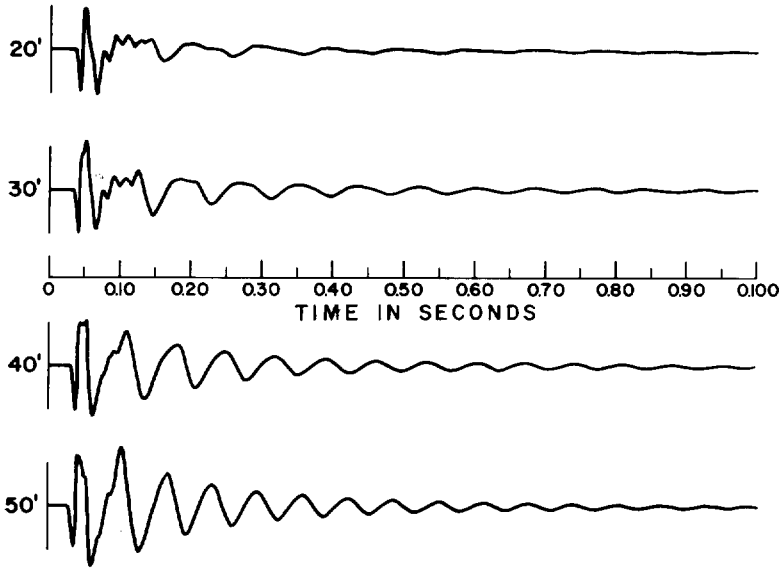


FIG. 4. Signatures of standard air gun with 300 cubic inch chamber equipped with WSK-1805-1H modification at different depths. Air pressure 1700 psig.

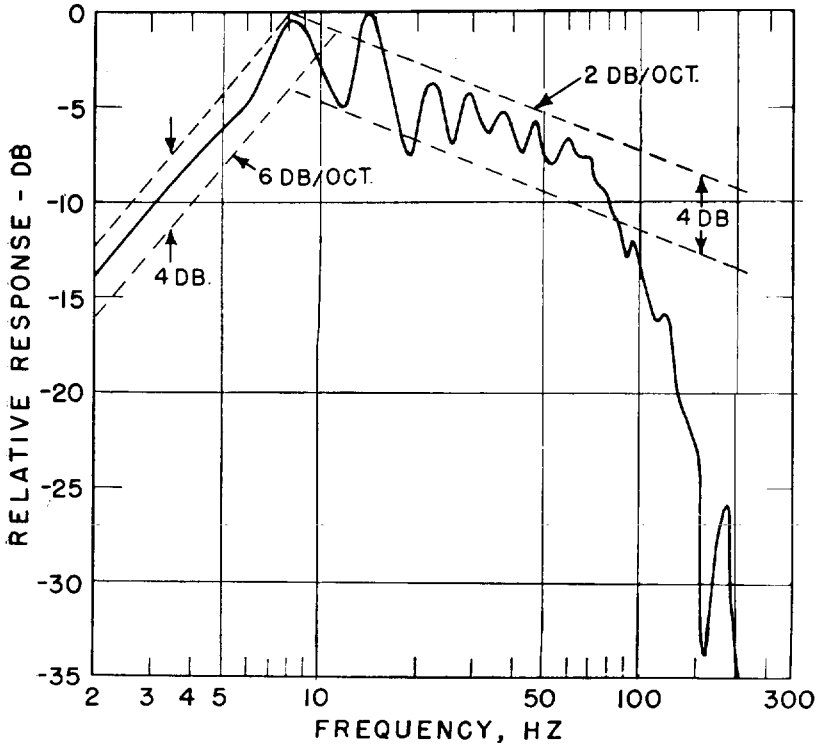


FIG. 5. Spectrum analysis of raw signature of divided-chamber air gun at a depth of 20 ft (top trace of Figure 3).

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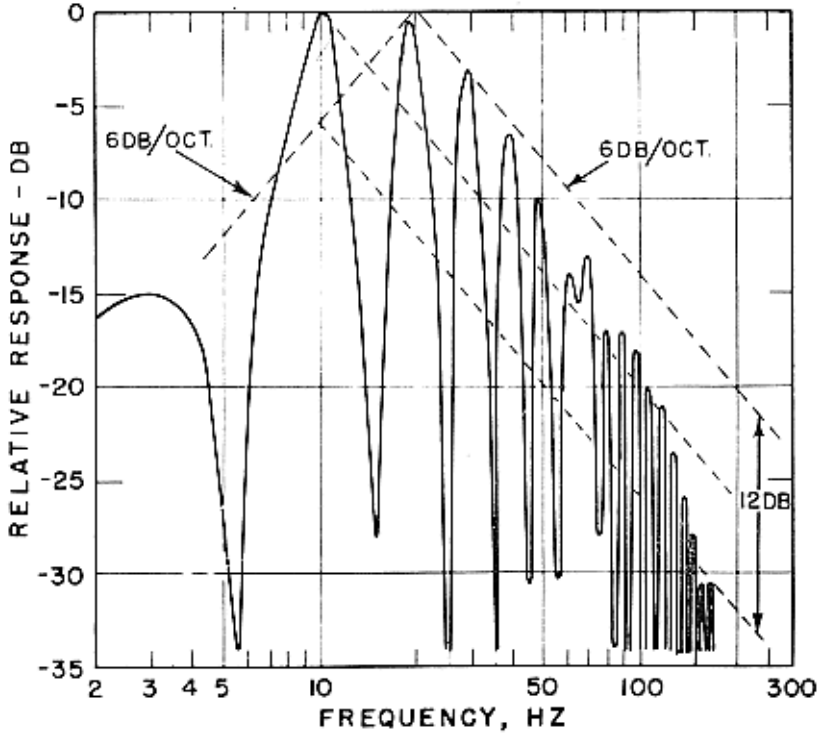


FIG. 6. Spectrum analysis of raw signature of standard air gun with 300 cubic inch chamber at a depth of 20 ft (top trace of Figure 2).

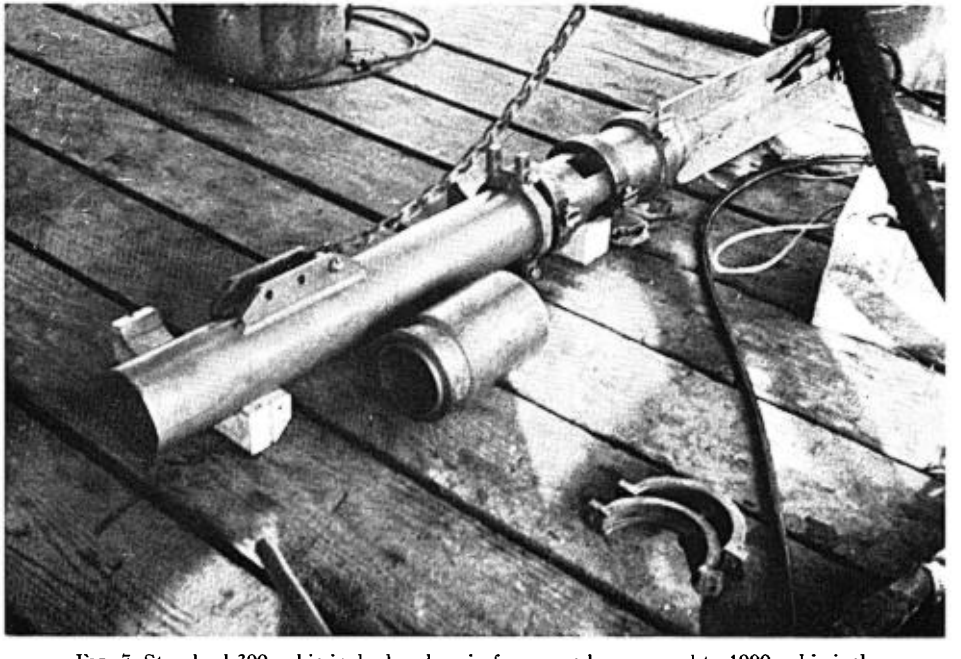


FIG. 7. Standard 300 cubic inch chamber, in foreground, compared to 1000 cubic inch, divided-chamber fitted to air gun.

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divided-chamber gun. The relative responses at the high frequencies seem to confirm generally accepted theory, since the shallow shot exhibits the better high-frequency response. The low-frequency performance, on the other hand, appears to contradict theory, since the 20-ft shot also indicates better low-frequency response then does the 40 ft shot.

This unexpected result appears to be basic, for it is characteristic of all chambers tested and was first noticed on the spectra of the raw signatures. We should remember also that the initial pulse amplitudes produced by a given chamber do not increase significantly with depth.

Figure 9 shows the comparative responses of different chambers at a constant depth of 20 ft. As expected, the largest chamber (1000 cubic inches) exhibits the best low-frequency response. The chamber with the smallest discharge volume, the 300 cubic inch unit with the wave-shape kit, produces the best high-frequency response, with some reduction in the lows. We should not forget that this change is also accompanied by a 4 db loss in initial-pulse amplitude.

Figure 10 gives a direct comparison between the spectra of the smoothed signatures of the divided-chamber gun and the regular 300 cubic inch unit. The superiority of the new unit is evident and is particularly significant when it is realized that a high degree of *real* bubble attenuation has been obtained with no loss in the initial pulse amplitude and with the overall improvement in the frequency bandwidth shown in Figure 10.

Data for the next figures were obtained during the same traverse of a survey line by alternately firing two standard 300 cubic inch guns and two divided-chamber guns. Station interval was 228 ft with a pop spacing of 114 ft. Thus, we could use alternate records to produce the two completely independent, but fully interlaced, twelve-fold record sections shown. The profile covers a distance of about 9 miles. Figure 11 was obtained from the shots with the 300 cubic inch guns, while Figure 12 is the section obtained using the alternate pops of the divided-chamber guns.

Processing parameters were identical for both sections, yet the improved definition and increased signal-to-noise ratio of the divided-chamber gun data is clearly evident. As further proof of the new guns' superiority, Figures 13 and

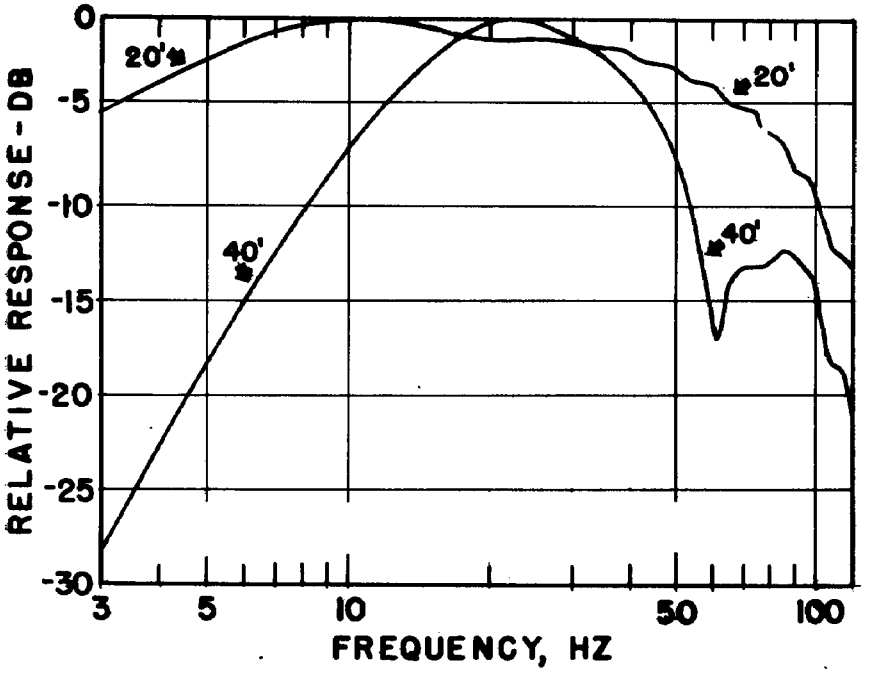


FIG. 8. Comparison of spectral analyses of hanning-smoothed divided-chamber air gun signatures at depths of 20 and 40 ft.

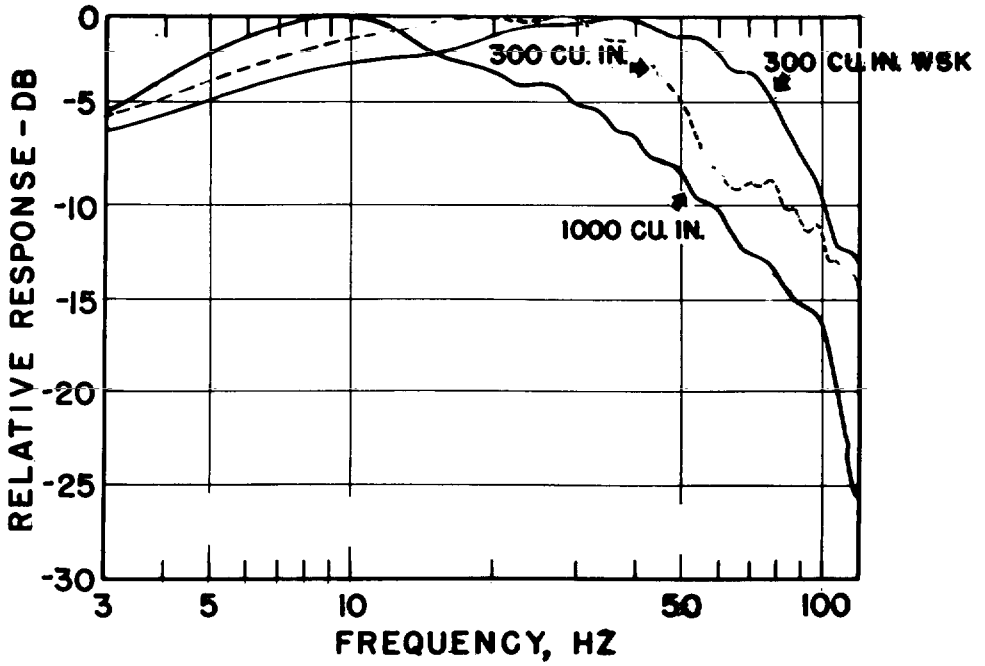


FIG. 9. Comparison of spectral analyses of hanning-smoothed signatures of different air guns at a common depth of 20 ft.

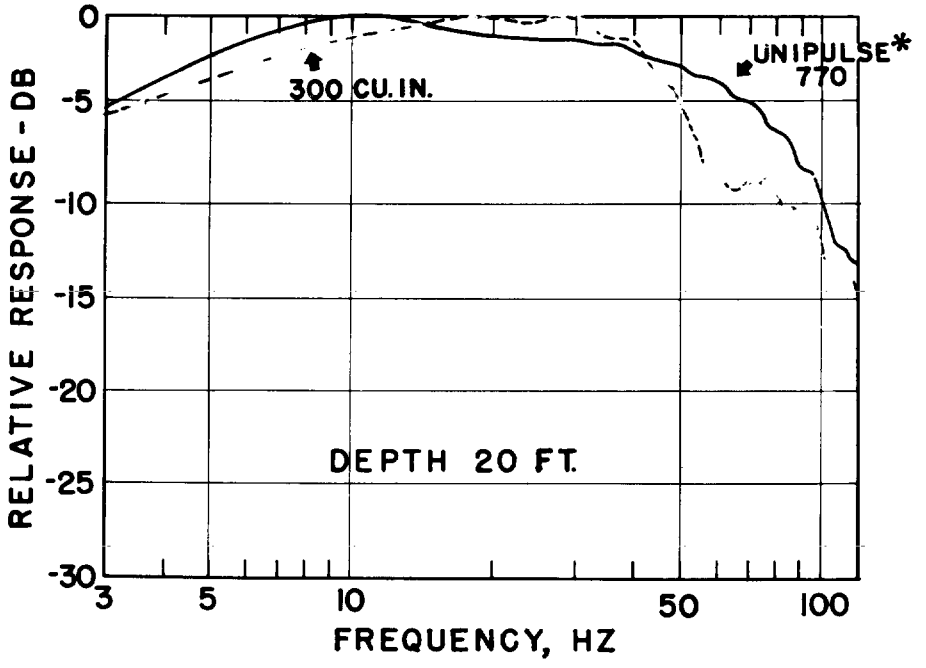


FIG. 10. Comparison of spectral analyses of hanning-smoothed signatures of standard 300 cubic inch and divided chamber air guns.

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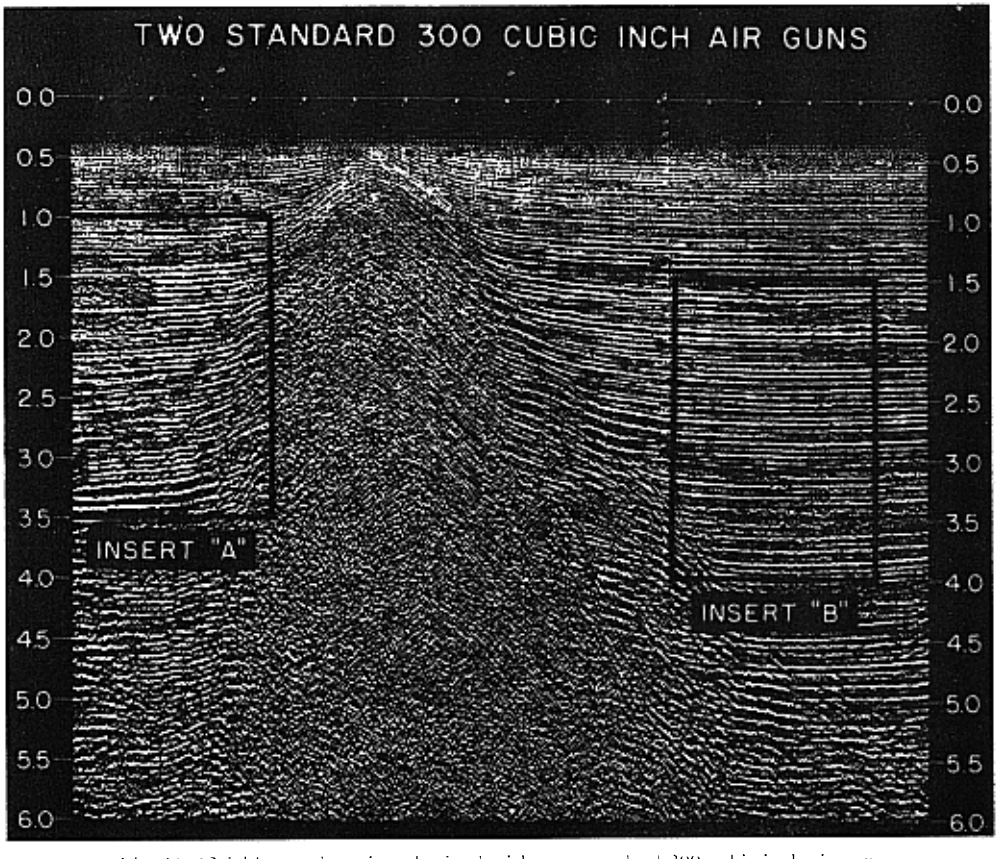


Fig. 11. 12-fold record section obtained with two standard 300 cubic inch air guns.

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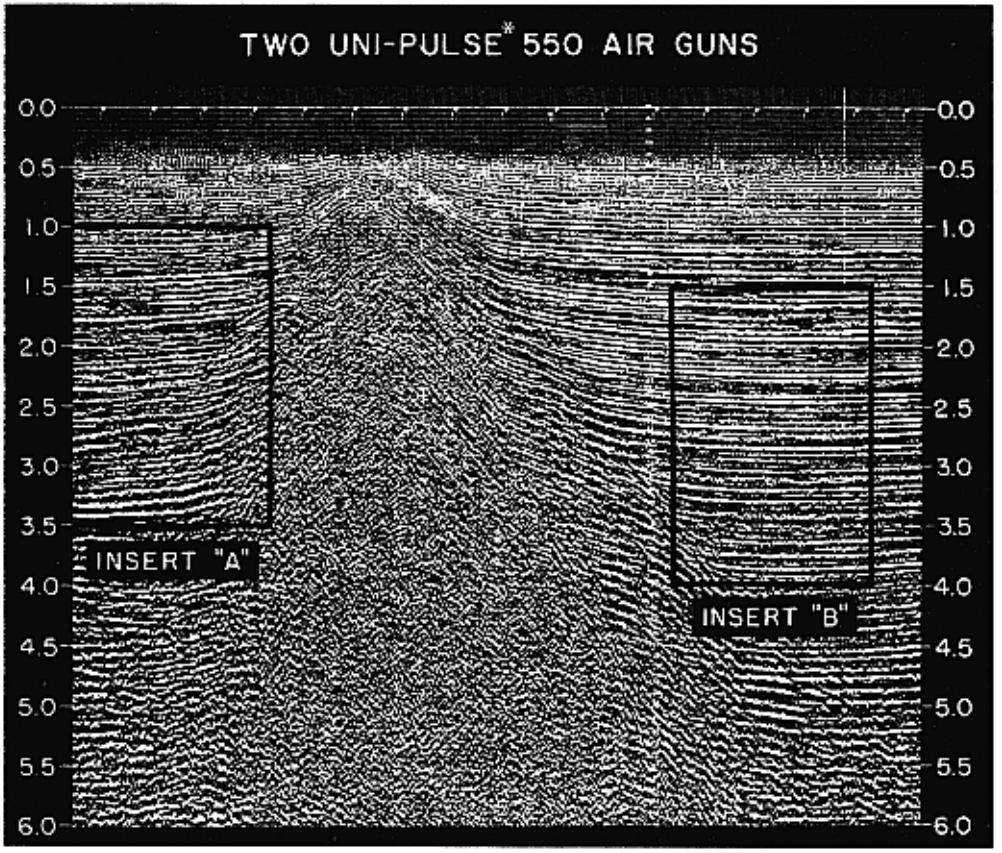


FIG. 12. Comparative 12-fold record section obtained with two divided-chamber air guns. This section was obtained during the same traverse as Figure 11 by alternate firing of these guns with the two 300 cubic inch units. Processing parameters identified with Figure 11.

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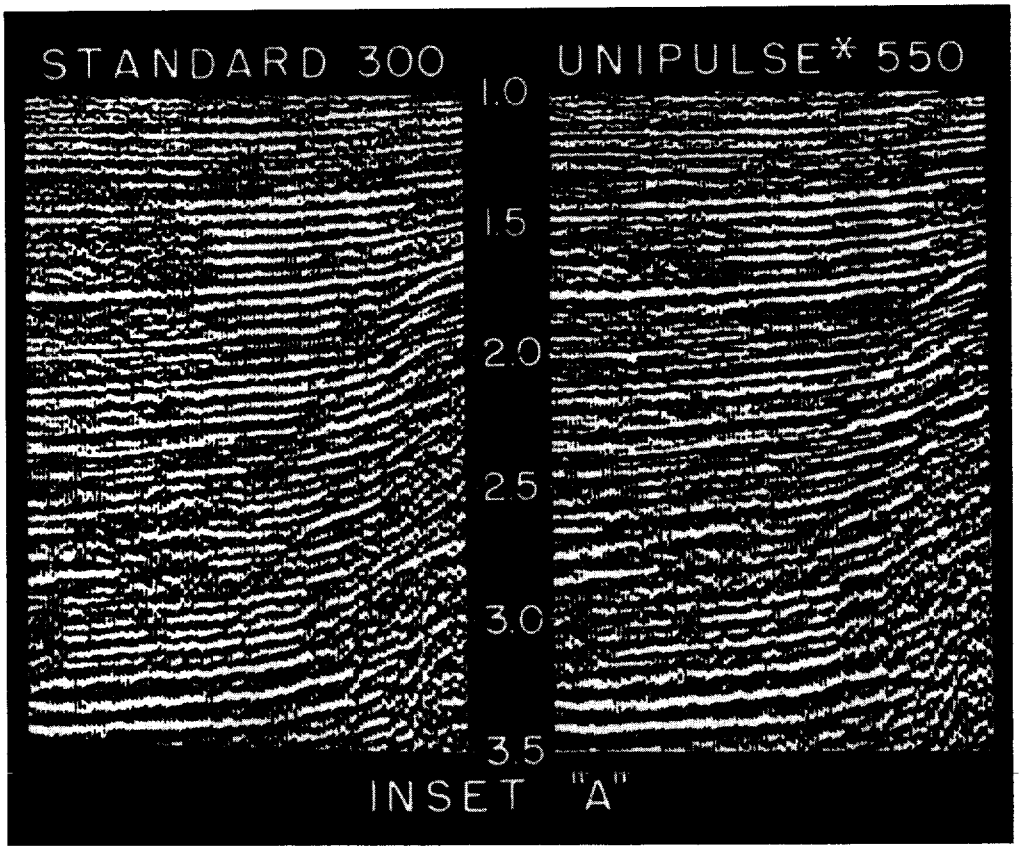


FIG. 13. Enlarged detail of portions A of Figures 11 and 12.

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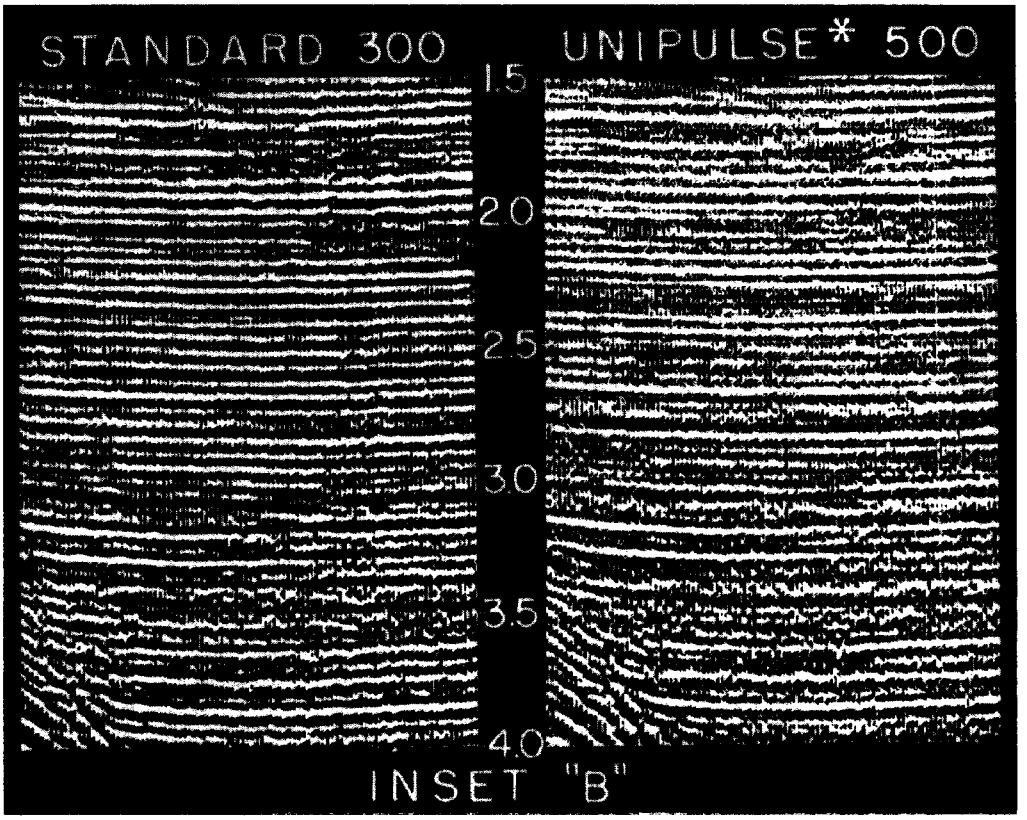


FIG. 14. Enlarged detail of portions B of Figures 11 and 12.

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14 show enlarged comparisons of outlined portions *A* and *B* of the sections in Figures 11 and 12.

In addition to producing data of better quality, it is also apparent that the divided-chamber guns provide adequate depth penetration with respect to the standard 300 cubic inch guns. Even better penetration would be obtained by following the normal practice of using four large guns on all production surveys. Our motor vessels are equipped with sufficient air capacity to support sustained firing of four divided-chamber guns at normal survey speeds.

The model of the orifice-plate gun described in this paper is designed to provide maximum bubble attenuation and highest energy at pop spacings of 164 ft or greater. A smaller unit, used for the sections of Figure 12, provides similar advantages for pop spacings as short as 114 ft.

CONCLUSIONS

Actual field tests on several large air gun chambers indicate that very effective attenuation of bubble oscillations can be obtained by dividing a large chamber into two parts connected by an orifice of suitable size. Spectral analyses of the raw signatures confirm that the frequency responses can be made significantly flatter and wider in this manner. If sufficient volume is retained on the direct discharge side of the orifice, the improvement is accomplished with no loss in the absolute amplitude of the initial pulse.

The generally accepted theory of surface reflection from the air-water interface seems to be confirmed by the variations in high-frequency response as a function of depth. The low-frequency response, however, does not appear to confirm theory, since the low-frequency content of the initial pulse increases at shallower depths. This unexpected behavior persists over the range of investigation; further tests are necessary to determine the limits and causes of this anomalous performance.

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REFERENCES

Chelminski, S. V., 1966, U. S. Patent No. 3,249,177, Acoustic wave impulse repeater: issued May 3, 1966, applied November 13, 1961, assigned to Bolt Associates, Inc.

——— 1967, U. S. Patent No. 3,310,128, Seismic exploration methods and systems: issued March 21, 1967, applied January 24, 1964, assigned to Bolt Associates, Inc.

Giles, Ben F., 1968, Pneumatic acoustic energy source: Geophys. Prosp., v. 16, p. 21–53.

Knudsen, W. C., 1958, Elimination of secondary pressure pulses in offshore exploration (A model study): Geophysics, v. 23, p. 440–458.

——— 1961, Elimination of secondary pressure pulses in offshore exploration: Geophysics, v. 26, p. 425–436.

Kramer, F. S., Peterson, R. A., and Walter, W. C., 1968, Seismic energy sources 1968 handbook: Presented at the 38th Annual International SEG Meeting, Denver, Colorado, October 1, 1968, and privately published by United Geophysical Corporation.

Luskin, B., 1968, The Par air gun: Presented at symposium on marine non-dynamite energy sources: Geophysical Society of Houston, April, 1968.

Mayne, W. H., and Quay, R. G., 1970, Seismic signatures of air guns: Presented at Second Annual Offshore Technology Conference, Houston, Texas, April, 1970.

Mott-Smith, L. M., Masraff, A. G., Otte, V. A., 1968, The air gun as a marine seismic source. Paper presented at the 38th Annual International SEG Meeting, Denver, Colorado, October 2, 1968.