193 **DA15**
Les enjeux liés aux levés sismiques dans
l'estuaire et le golfe du Saint-Laurent

6212-08-001

Airgun Arrays and Marine Mammals

(August, 2002)

Introduction

Around the world there is concern about the impact man-made sounds emitted in the oceans may have on the health and behavior of marine mammals. That concern extends to the seismic survey industry, which actively employs sound as a technique to image the earth's interior in support of hydrocarbon exploration.

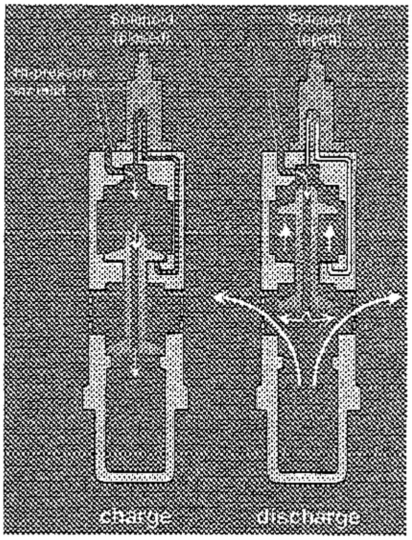
This report is intended to provide a description of the seismic source signals generated during a marine seismic survey, a brief description of the auditory processes of marine mammals, and an analysis of how the two may interact.

By closely examining the characteristics of the seismic source signals within the context of the auditory systems of marine mammals, it can be argued that there is almost no risk that seismic signals can cause physical damage to the hearing of any species of marine mammals.

In terms of negative behavioral responses caused by seismic survey "noise", there is little conclusive evidence as to cause and effect. Behavioral response remains an area requiring further research.

Single Airguns

Currently, almost all marine seismic surveys in support of hydrocarbon exploration use arrays of airguns as the source of seismic signals. An airgun array is composed of multiple airgun units. An airgun is essentially a stainless steel cylinder charged with high-pressure air. The seismic signal is generated when that air is almost instantaneously released into the surrounding water column. The effect is similar to popping a balloon—a loud sound is created when the air inside the balloon is quickly expelled into the atmosphere.



For each airgun, the amplitude (or loudness) of the seismic signal is a function of the volume and pressure of the air inside the cylinder and the cylinder's depth under the water surface. As with a balloon, the larger the cylinder volume and the higher the internal air pressure, the louder the "pop".

In simple terms, the firing of an airgun generates an oscillating bubble in the surrounding water. At the time of firing, the pressure of the air inside the cylinder far exceeds the outside pressure in the surrounding water. This difference in pressure causes a bubble to rapidly expand in the water around the airgun. It is this initial bubble expansion that generates the relatively broadband seismic pulse, i.e.,

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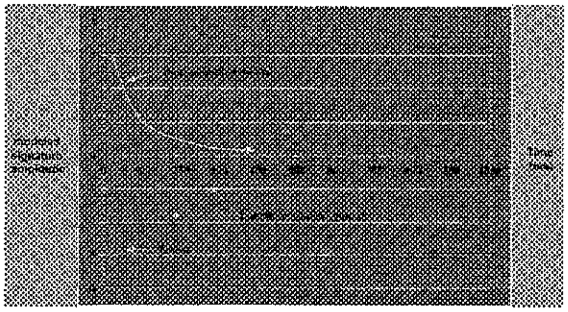
the "pop" as from a burst balloon. Because of the momentum of the bubble expansion, the bubble continues to grow until the air pressure inside the bubble becomes less than the surrounding water pressure. At that point the bubble will start to collapse. At some time during this collapse the pressure inside the bubble will again become greater than the pressure outside. The bubble will then start to expand again. This expansion/collapse cycle will continue until the bubble reaches the sea surface and vents to the atmosphere. Given that energy is lost during each cycle, the system behaves as a damped oscillator, producing smaller and smaller bubble pulses with each oscillation.

This bubble cycle is similar to what happens during a bungee jump. The first bounce is the greatest. Each subsequent bounce loses energy, so each up and down excursion is less than the one before. Finally, all the energy is lost, and the jumper comes to a stop, dangling in space.

The following plot of pressure versus time, referred to as an airgun's pressure signature, illustrates this oscillation process.



This signature shows the first, or primary, positive pressure pulse due to the initial expansion of the bubble. The following negative pulse, referred to as the "ghost", is due to the reflection of the initial pulse at the sea surface, and the subsequent damped oscillating bubble pulses are referred to as the "bubble train".

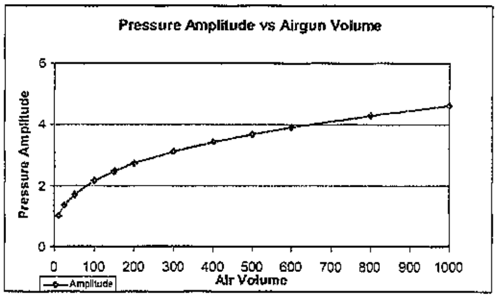
As mentioned, the "ghost" pulse is due to the reflection of the primary pulse at the sea surface. Mainly because of the large difference in density between air and seawater, the sea/air interface acts like a "mirror" to pressure waves arriving from underneath the water. These pressure waves essentially "bounce" off the interface and are redirected back down again. Also, similar to a mirror image where right-hand and left-hand are swapped, the pulse reflected at the sea surface is changed from positive to negative.

For a given internal air pressure and depth below the surface, the peak amplitude and bubble oscillation period of an airgun's signature are proportional to the cube root of the volume of air in the airgun.

$$A \sim V^{1/3}$$

In practical terms this relationship states that the volume of an airgun would have to be increased by a factor of 8 in order to produce a two times increase in the amplitude of the seismic pulse—the cube root of 8 = 2.

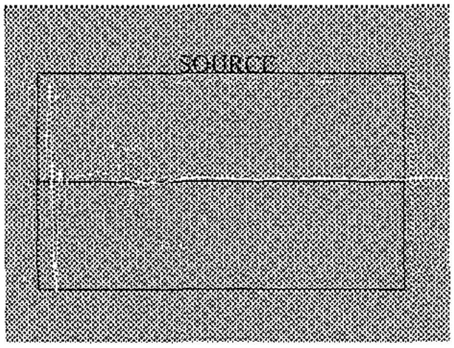
As can be seen on the following plot, an 800-in^3 airgun would be required to double the output of a 100-in^3 airgun.



Airgun Arrays

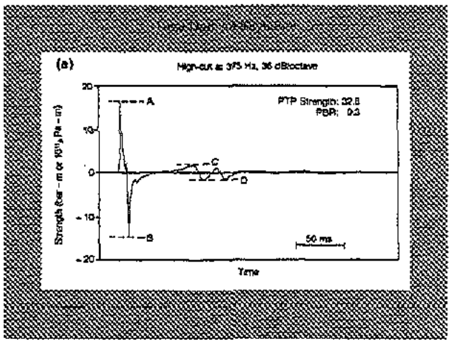
The bubble train following the initial pulse from a single airgun is not a desirable characteristic for seismic imaging objectives. Ideally, the seismic interpreter would like to deal with a single discrete seismic "echo" at each subsurface reflection surface. However, at each reflecting surface, an airgun signature will produce an "echo" from the main pulse and from each subsequent bubble pulse.

By taking advantage of the change in bubble oscillation period as a function of the cube root of an airgun's volume, the size of the pulses in the bubble train can be reduced by firing a suite of guns with different volumes in an array. The differences in the bubble pulse times from the different volume airguns cause the pulses to interfere with each other. The following signature plot shows an overlay of the signatures from the individual guns in an airgun array. The different colored pulses are out of "tune" with each other and, when added together, will act to reduce the overall bubble effect. The resulting array signature, traced in white, shows a significant reduction in the size of the remaining bubble pulses, thus approaching the ideal characteristic of a single impulse.



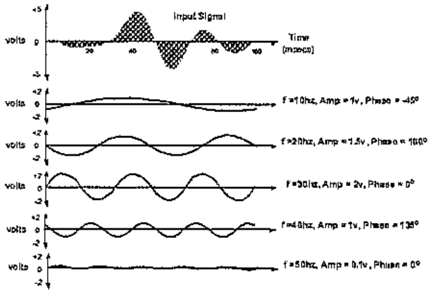
It is common in the seismic industry to quote the output of a particular airgun array in terms of time vs pressure (time domain signature) and frequency content characteristics. The time domain parameters quantify certain characteristics of the source signature.

Typically the zero-to-peak amplitude (0-P = A), peak-to-peak amplitude (PTP = A+B), and primary-to-bubble ratio (PBR = A+B/C+D) are used to characterize and compare different airgun array signatures.

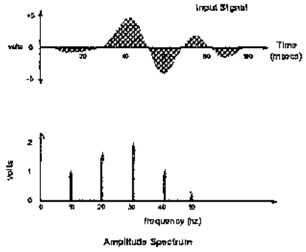


The frequency characteristics of an airgun array signature relate to how the signal "sounds". For pure tones, like those produce by individual piano keys, frequency measures how many times a second the piano wire vibrates up and down. One cycle of vibration per second is referred to as Hertz (Hz) and is the standard unit of measure for frequency. Low frequencies produce low-pitched sounds, like the moo of a cow. High frequencies produce high-pitched sounds, like the whistle of a canary.

Airgun array signatures are called broadband, because they contain a whole range of frequencies. The following figure shows how individual frequency components add together to produce a composite signal.



As shown, the signal at the top is composed of five discrete frequencies: 10, 20, 30, 40, and 50 Hz. Each frequency component has an associated strength (amplitude). When the amplitude values are plotted as a function of frequency, the signal's amplitude spectrum is produced.



The amplitude spectrum of an airgun array signature shows the strength of the composite frequencies that produce the time domain signature.

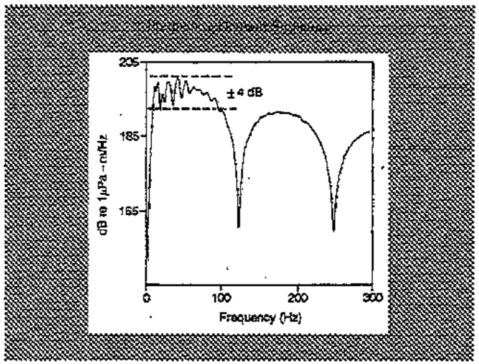
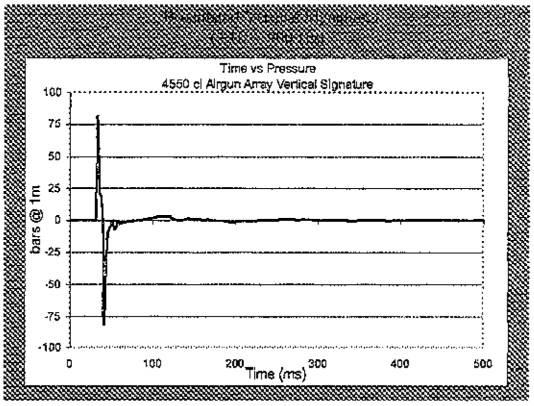
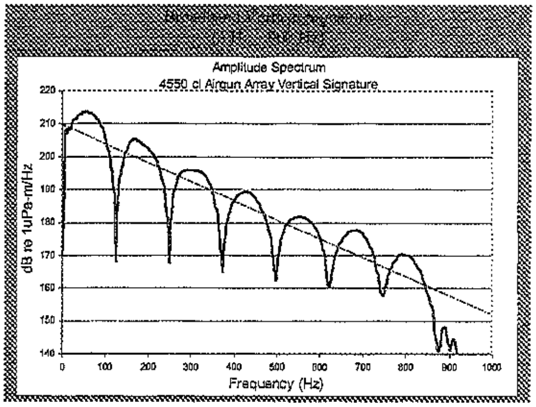


Figure courtesy of SEG

The overall bandwidth (i.e., range of frequencies) of the signature spectrum is proportional to the width of the primary pulse in the time domain—the narrower the pulse, the wider the bandwidth. The "ripples" in the spectrum at 50 Hz and below are produced by the bubble pulses, and the deep "notches" at 125 Hz and 250 Hz are due to the negative "ghost" pulse generated at the sea/air reflection surface.

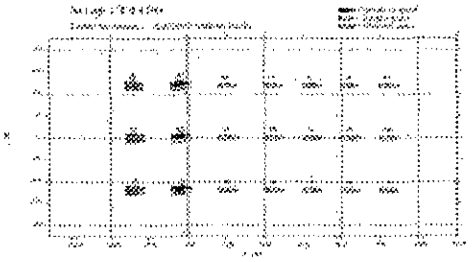


For the purpose of evaluating the environmental impact of an airgun source, the signature should be reported at the widest practical bandwidth. Therefore, the following plots show the time signature and amplitude spectrum for a typical airgun array in the 3 – 900 Hz frequency band.



Point Source Response

The following figure shows the plan view of an array and its individual volume elements. The dimensions of the array are 16.5m long (inline) by 25m wide (crossline).



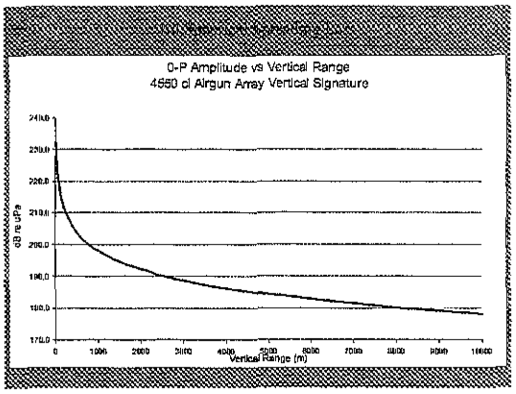
The amplitude units on the time domain signature plot are in bars (a bar is approximately equal to one (1) atmosphere of pressure at sea level) and are ***projected to a measurement position one meter distant from a theoretical point source***. That means that the pressure signal produced by all the airguns in the array is treated as if it came from a single airgun, i.e., a point source. Of course, because the individual airguns in an array are distributed in a pattern, the seismic source is not a point source. Nevertheless, the seismic industry generally reports the pressure signature amplitude in units of bars at 1m, or bar-m, although ***there is no real position in the water where pressure of that magnitude is experienced.***

The unit of pressure measurement used by the biological and acoustics community is the micro-Pascal (□Pa). One bar equals exactly 10^5 Pascals (10^5 = 100,000). Therefore 1 bar = 10^{11} μPa (10^{11} = 100,000,000,000). Since the μPa is such a small unit and the range of pressures measured from various sound sources is so large, the mathematical convenience of using a logarithmic ***decibel (dB)*** scale has been adopted to describe sound levels in air and in water. When we measure pressure, the decibel is, dB = 20 $\log_{10}$ (Measured Pressure/Reference Pressure). Since 1 bar is 10^{11} μPa, 1 bar = 20$\log_{10}$ 10^{11} = 20*11 = 220 dB re 1 μPa.

The scale for the amplitude of the frequency components of airgun signatures is typically reported in dB referenced to 1 μPa –m /Hz. Note in Figure --- there is an almost linear drop-off in spectral amplitude as a function of increasing frequency. The sound pressure at 500 Hz is less than 1/30 (-30 dB) of that at 50 Hz

Using the point source assumption, pressure measure at some distance away from the airgun array is determined by using the model of spherical spreading, that is, the pressure decreases as 1/distance from the source. For example, the pressure at 10m distance is 1/10 (-20dB) of the assumed point source strength, at 1000m its 1/1000 (-60 dB).

For the vertical signature from an airgun array (i.e., measured directly below the center of the array), the drop-off in pressure with distance is presented on the following graph:



Each decrease of 20 dB corresponds to a cascading 1/10 reduction in peak amplitude (i.e., –20 dB = 1/10, -40 dB = 1/100, -60 dB = 1/ 1,000, etc.). Also remember that this type of decay is for a point source response. Given that an airgun array is not a point source but a distributed array, that type of 1/distance extrapolation is only valid when the measurement is taken in the far-field of the array. ***Since the far-field distance is frequency- dependent, the point source model produces pressure values that over-estimate the real values in the near-field vicinity of the array. The higher the frequency, the higher the over-estimate of pressure level.***

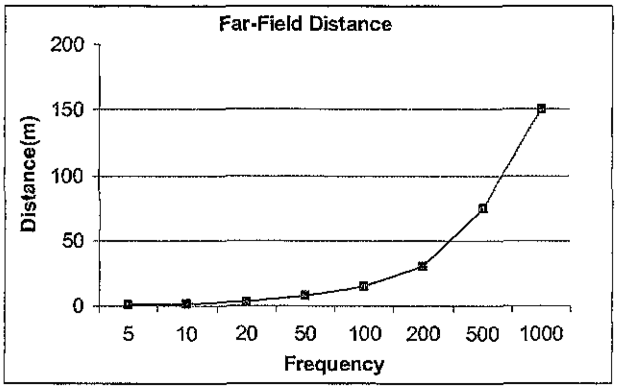
Non-Point Source Response

Up to this point the discussion has been framed in terms of a point source response. That model does not hold for the response of seismic airgun arrays. Referring to the plan view diagram for the airgun array, it can be seen that a measurement taken at any point in the immediate vicinity of the array will be influenced more by those guns close to the measurement point than by guns farther away. Again, it is very important to understand that the full array amplitude as reported in bar-m (or dB re 1 µPa –m /Hz) is never realized in the water. ***That means no animal could possibly be exposed to the pressure levels quoted at 1m from the theoretical point source.***

A point source response is a convenience that only has validity in the *far-field* of the array. The term *far-field* refers to the distance from the array where the acoustic output appears to be coming from a single point source. The following graph shows the predicted output (black line) from our example array compared to the point source assumption (red line). The distance where the two lines intersect represents the *far-field* distance, in this case around 150m.

This graph also shows that ***the maximum source level from the array is approximately 20 dB (i.e., less than 1/100) of would be quoted for a point source response.***

The *far-field* distance is a function of frequency by; $d = f * a^2/c$ where d is the far-field distance, f is frequency, a the maximum aerial dimension of the airgun array, and c the speed of sound propagation in the water. The following graph shows the relationship between d and f for the example airgun array.

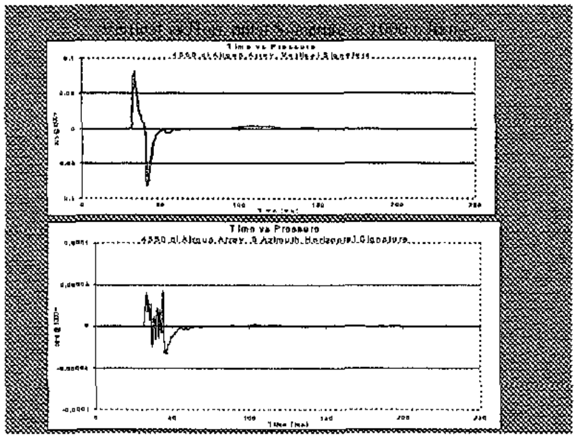


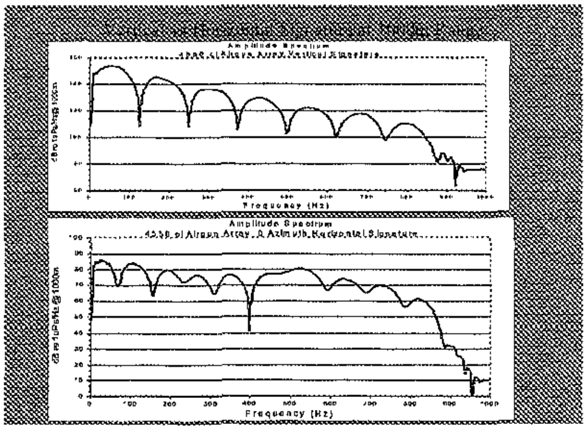
The higher the frequency the greater the distance from the array before the sound appears to be coming from a point source.

Airgun Array Directivity

Because of the pattern of airgun placement in an array, the signature changes as a function of direction (horizontal angle) and emission angle (angle from the vertical). For example, the firing times for all the airguns in the array are synchronized to ensure that the primary pulses from each gun align exactly with one another along the vertical axis of the array. This alignment produces the maximum far-field signature strength- the vertical signature.

However, if a measurement is taken at a near-horizontal emission angle directly behind the array, the response will be markedly different. Along the horizontal axis of the array, there will be a delay in the peak arrival times between various guns that is proportional to the inline spacing of the guns. For example two guns spaced 6m apart will produce a peak delay of 6m/1500m/s = 4 ms. These types of arrival delays "smear" the signature thus reducing peak pressure and high frequency output.

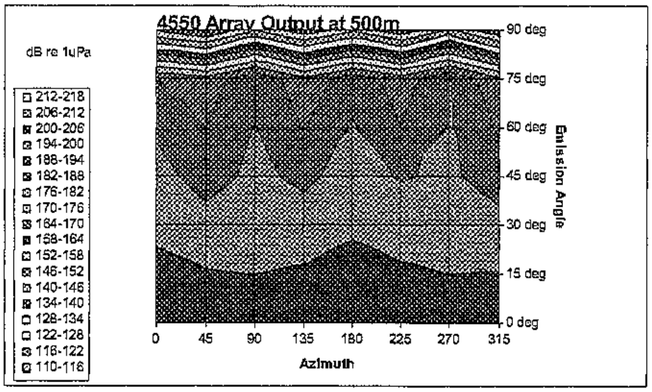


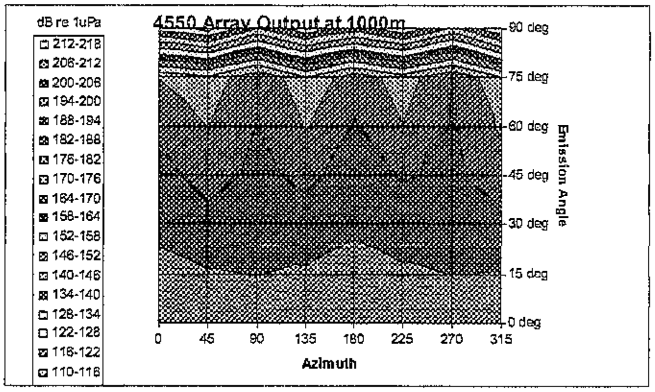


Notice the difference in the amplitude scales between the vertical and horizontal signatures. The amplitude of the horizontal signature is almost 60 dB below (or 1/1000) that of the vertical signature.

These differences in the array signature with respect to direction and angle from the vertical are referred to as the array response. It means that the "sound" (i.e. frequency content) and "loudness" (i.e. pressure strength) of the array signature will be different at different locations in the water. These differences are known as the acoustic radiation pattern and can be mapped in three dimensions.

Using signatures computed for different azimuth and emission angles, the three dimensional (3D) characteristics of the sound field generated by an airgun array can be determined for any distance from the array. The following plots map the peak amplitude (in dB re 1 µPa zero-peak) of the broadband pulse as a function of azimuth, emission angle, and distance from the source center.

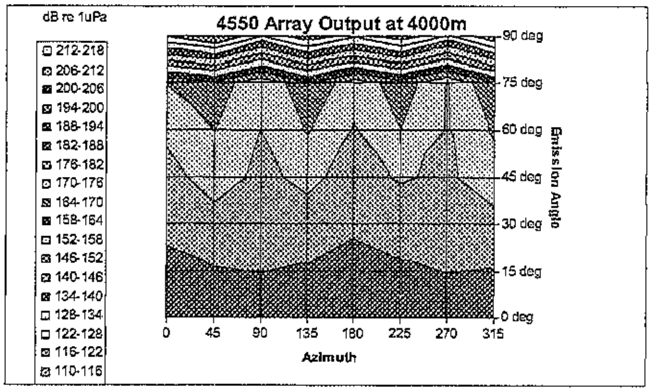




For example, the Y axis of the graph represents the emission angle where the 0 degree value represents the vertical signature and the 90 degree value represents emissions along the horizontal. The X axis represents the direction of travel for the emitted sound. The 0 degree value represents a direction directly behind the array, 90 and 270 degrees are the directions where energy travels laterally from the array, and the 180 degree direction is directly in front of the array. The peak amplitude along any direction is represented by a color defined in the legend.

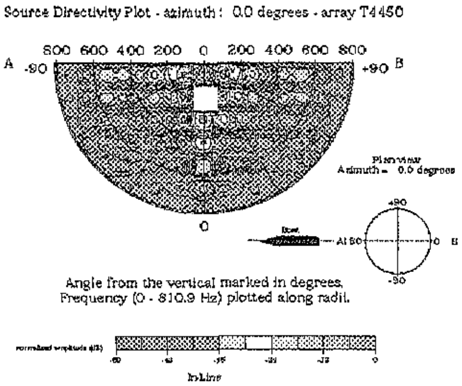
At 500 m from the center of the array the 183 dB isopleth occurs at emission angles greater than 75 degrees, or near horizontal. However, the maximum amplitude in the vertical direction is less than 206 dB, or 0.2 bars. This is equivalent to the change in pressure experienced by diving to the bottom of a 2m deep swimming pool, however, with an airgun signature the change in pressure is only experienced for a period of less than 10/1000 of a second.

At 1000m from the center of the array the 183 dB isopleth occurs at emission angles between 60 and 75 degrees. The strength in the horizontal direction is less than 140 dB. In the vertical direction the maximum level is less that 200 dB or 0.1 bar of pressure.



At a distance of 4000m, the 183 dB isopleth occurs at emission angles less than 25 degrees. Along the horizontal, the amplitudes are very small, less than 120 dB.

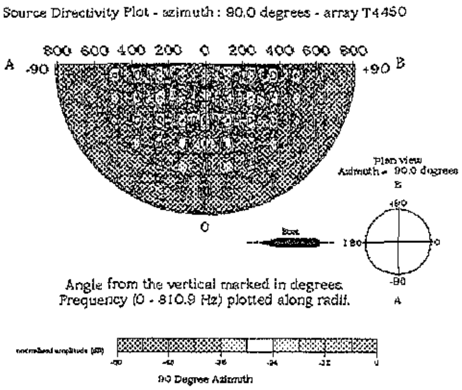
The above graphs show the three dimensional broadband pressure distribution at various distances away from the array. However, the plotted amplitude values include all the frequencies contained in the signal. It is just as important to analyze how different frequencies are emitted as a function of azimuth and emission angles. The following graph shows the acoustic radiation emitted for different frequencies from the 4450-in^3 airgun array in the vertical plan along the inline axis of the array.



The color code shows the *relative* far-field amplitude of specific frequencies as a function of emission angle. For example the outer semi-circle represents a frequency at 800 Hz. The next inner arc is at 600 Hz, the next at 400 Hz, and so forth. Emission angle is measured along the lines emanating from the 0 value in the center of the display. The line connecting 0-0 represents the vertical axis of the array, the colors along this axis represent the amplitude spectrum of the vertical signature. Emission angle is incremented in 30-degree increments up to the horizontal directions indicated by 0-B behind the array and 0-A in front of the array.

As mentioned, the line down the center of the plot is the vertical emission angle and represents the amplitude spectrum of the vertical signature. The colors along any of the other radial lines represent the amplitude spectra of signatures radiating in those directions. It can be seen that most of the broadband energy is concentrated close to the vertical (orange to yellow colors). Emissions at frequencies above 300 Hz are highly attenuated (green to blue colors) along radiation paths away from the vertical.

A similar display is produced below for acoustic emission in a plan across the width of the array.



When comparing the two radiation plots it can be seen that there is more high frequency energy emitted side-ways from the array than from front-to-back.

When the peak pressure amplitude and frequency emission plots are reviewed in conjunction the following summary statements can be constructed about the direct airgun pressure pulses propagating through the water column:

1. Most of the broadband energy emitted from the airgun array is concentrated close to the vertical emission angle.

2. In the array's near-field, pressure amplitudes will be significantly less than predicted from point source extrapolation.

3. The pressure amplitude rapidly diminishes at emission angles greater than 75 degrees.

4. Coherent high frequency energy generated by airgun arrays is generally less than 300 Hz.

In the above discussions about acoustic emissions, the primary assumption has been that the signals are propagating and will be received through a direct water path. However, if the airgun signals are reflected off the sea-floor or propagate through the earth's materials below the sea-floor before being received by an animal, other attenuation mechanisms will come into effect further reducing the overall pressure levels predicted in the above analysis.

Marine Mammal Auditory Systems

As has been described above, the signature from an airgun array is a short duration pulse that has different amplitude and frequency characteristics along different directions of emission. In order to understand what type of impact those pulses may have on different marine mammal species, there must be an understanding of the auditory capabilities of these animals.

Following is an excerpt from a report titled: ***MARINE MAMMAL AUDITORY SYSTEMS: A SUMMARY OF AUDIOMETRIC AND ANATOMICAL DATA AND ITS IMPLICATIONS FOR UNDERWATER ACOUSTIC IMPACTS.***

This report was prepared by Dr. Darlene Ketten, of Woods Hole Oceanographic Institution and Harvard University, for the US National Marine Fisheries Service. The primary purpose of the report was to study the impact of active acoustic devices used by commercial fisherman to detect catch species and/or deter non-catch specific species (in this case marine mammals) from interfering and/or being harmed by the fish take process. The information contained in this report, however, is also germane to the impact of seismic survey sources on the health and behavior of marine mammals.

*"The data show that marine mammals have a fundamentally mammalian ear that through adaptation to the marine environment has developed broader hearing ranges than those common to land mammals. Audiograms are available for 11 species of odontocetes (*tooth whales*) and pinnipeds (*seals*). For most marine mammal species, we do not have direct behavioral or physiologic audiometric data. For those species for which audiograms*

are not available, hearing ranges can be estimated with mathematical models based on ear anatomy or inferred from emitted sounds and play back experiments. The combined data show there is considerable variation among marine mammals in both absolute hearing range and sensitivity, and the composite range is from ultra to infra-sonic. Odontocetes, like bats, are excellent echolocators, capable of producing, perceiving, and analyzing ultrasonics frequencies (defined as >20 kHz). Odontocetes commonly have good functional hearing between 200 Hz and 100 kHz, although individual species may have functional ultrasonic hearing to nearly 200 kHz. The majority of odontocetes have peak sensitivities in the ultrasonic ranges although most have moderate sensitivity from 1 to 20 kHz.

No odontocete has been shown audiometrically to have acute hearing (<80 dB re 1 µPa) below 500 Hz. (emphasis added)

*Good lower frequency hearing is confined to larger species in both the cetaceans and pinnipeds. No mysticete (*baleen whales) *has been directly tested for any hearing ability, but functional models indicate that their functional hearing range commonly extends to 20 Hz, with several species expected to hear well into infrasonic frequencies. The upper functional range for most mysticetes has been predicted to extend to 20-30 kHz.*

Most pinniped species have peak sensitivities from 1-20 kHz. Some species, like the harbour seal, have best sensitivities over 10 kHz; only the elephant seal has been shown to have good to moderate hearing below 1 kHz. Some pinniped species are considered to be effectively double-eared in that they hear moderately well in two domains, air and water, but are not particularly acute in either. Others however are clearly best adapted for underwater hearing alone.

To summarize, marine mammals as a group have functional hearing ranges of 10 Hz to 200 kHz with best thresholds near 40 dB re 1 µPa. They can be divided into infrasonic balaenids (probable functional ranges of 15 Hz to 20 kHz; good sensitivity from 20 Hz to 2 kHz; threshold minima unknown, speculated to be 80 dB re 1 µPa); sonic to high frequency species (100 Hz to 100 kHz; widely variable peak spectra; minimal threshold commonly 50 dB re 1 µPa), and ultrasonic dominant species (500 Hz to 200 kHz general sensitivity; peak spectra 16 kHz to 120 kHz; minimal threshold commonly 40 dB re 1 µPa).

The consensus of the data is that virtually all marine mammal species are potentially impacted by sound sources with a frequency of 500 HZ or higher. Relatively few species are likely to receive significant impact for lower frequency sources *(emphasis added). Those that are likely candidates for LFS impact are all mysticetes and the elephant seal. By contrast, most pinnipeds have relatively good sensitivity in the 1-15 kHz range while odontocetes have peak sensitivities above 20 kHz. These "typical" ranges are generalities based on the mode of the data available for each group. It must be remembered that received levels that induce acoustic trauma, at any one frequency, are highly species dependent and are a complex interaction of exposure time, signal onset and spectral characteristics, and received vs. threshold intensity for that species at that frequency.*

*Pilot studies show that marine mammals are susceptible to **hearing damage but are not necessarily as fragile as land mammals** (emphasis added). The available data suggest that a received level of 80 to 140 dB over species-specific threshold for a narrow band source will induce temporary to permanent loss for hearing in and near that band in pinnipeds and delphinids (Ridgway, pers.comm.; Schusterman, pers. comm.). Estimates of levels that induce temporary threshold shift in marine mammals can be made, at this time, only by extrapolation from trauma studies in land mammals."*

There are three specific pieces of information contained in the above summary that can help determine the impact marine seismic survey sources may have on marine mammals.

1. Except for the large baleen whales (mysticete) and elephant seals, the auditory frequency ranges at which most marine mammals operate are above 500 Hz, many significantly higher.

2. Received levels that can induce acoustic trauma are highly species-dependent and are a complex interaction of exposure time, signal onset and spectral characteristics, and received vs. threshold intensity of that species at that frequency.

3. Estimates of levels that induce temporary threshold shift in marine mammals can be made, at this time, only by extrapolation from trauma studies in land mammals."

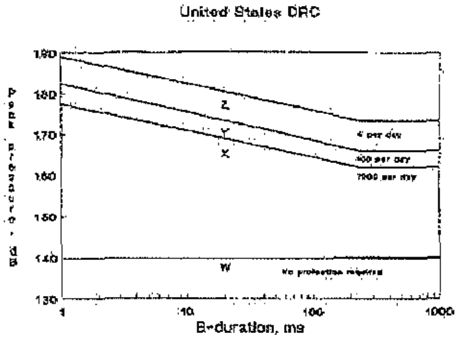
Given that the peak pressure output from airgun arrays is generally confined to frequencies below 500 Hz, there is little likelihood that airgun signals will produce acoustic trauma (i.e., temporary (TTS) or permanent (PTS) threshold shifts) in toothed whales (which include dolphins) and most seal species. That leaves a potential danger of TTS or PTS to the large baleen whales exposed to airgun signals.

As suggested by Dr. Ketten, an extrapolation from trauma studies in land mammals may provide guidance on the potential physiological danger to these particular whales.

On land, sound travels through the air in much the same way as it does in the water. However, because of the difference in the acoustic properties (density and propagation velocity) of air and water, similar sound intensities will have different pressures associated with them by a factor on the order of 61, which corresponds to a difference of 35.6 dB. In terms of the decibal scale, the reference pressure for sound in air is 20.4 µPa vs. 1 µPa for sound in water, a difference of 26 dB. Therefore, to compare pressure levels between air borne and water borne sound, an adjustment of 62 dB has to be made. In other words, the pressure level at which a marine mammal in the water experiences the same sound intensity as a land mammal in air is greater by 62 dB. (Gausland, 2000).

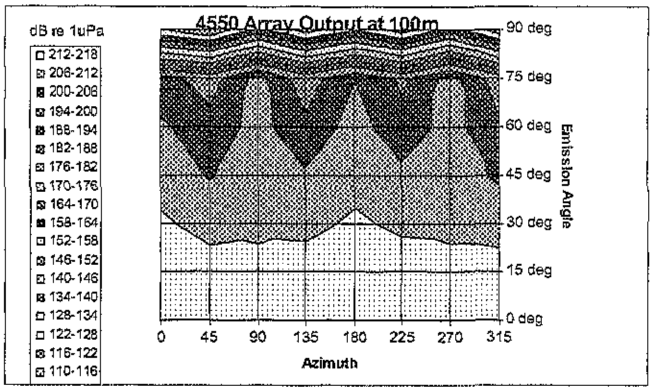
As presented in Gusland's paper, in 1968 the U.S. National Academy of Sciences, National Research Council, Committee on Hearing, Bioacoustics and Biomechanics (CHABA), published proposed damage-risk criterian for impulse noise for humans. The study and resulting recommendations were aimed at human exposure to the noise generated from the firing of military ordinance.

Those results were presented on the following chart.



These data show the relationship between peak pulse sound pressure on the vertical axis and pulse duration on horizontal axis with respect to recommended accepted exposure counts. This analysis indicates that exposure levels for short pulses are more tolerable than longer pulses and that lower pressure levels are more acceptable than higher pressure levels. If we accept the premise that the hearing mechanisms of marine mammals is similar to land mammals, then we can adjust the peak pressure levels on the vertical axis by 62 dB and extrapolate the exposure risks to marine mammals from airgun signals.

The following graph shows the absolute broadband peak pressure levels for the 4450-in^3 array as a function of azimuth and emission angle at a distance of 100m from the center of the source.



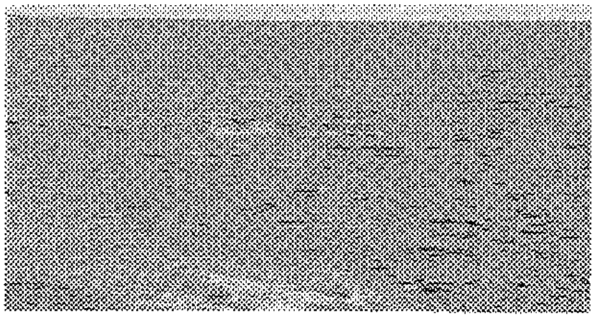
The maximum peak pressure levels of between 218 and 212 dB (re 1 µPa, 0-P) occur in a cone of about 20 - 25 degrees around the vertical axis of the array. If those levels are adjusted by 62 dB to equate to equivalent land sound intensities, the pressure levels would be around 148 – 142 dB, very close to the levels where CHABA recommends no required protection or maximum exposure counts. However, when acquiring data, a seismic survey vessel is continuously moving at speeds between 2.0 m/s and 2.5 m/s where there is very little likelihood that a large baleen whale would even be exposed to these levels for any significant length of time.

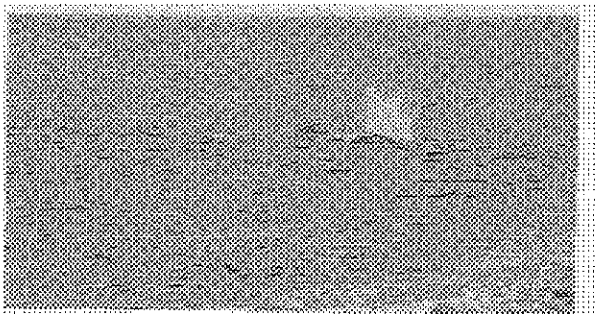
To put this in perspective, if the seismic vessel is firing its airguns every 10 seconds and approaches an animal such that it is located within the 20-degree vertical cone at a range of 100m, the animal would experience exposures at levels around 216 dB from at most one or two pulses before the emission angle and range increased, thereby quickly reducing the amplitude of subsequent pulses. For this to not be the case requires the animal to purposely stay within the 20 degree cone of maximum pressure.

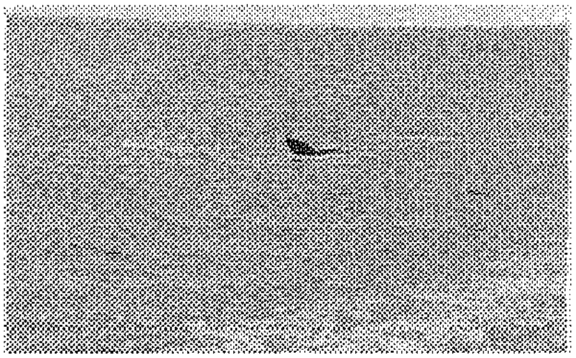
Physical Damage vs. Behavioral Responses

The above analysis addresses the risk of physical harm, it does not contend that the animals cannot hear the seismic pulses. Assuming that a wide variety of marine mammal species can hear some portion of the airgun signals the next question to be asked is "does the 'noise' from the airguns represent a behavioral disturbance?" That question does not appear to have a definitive answer. The available research is replete with studies that have conflicting results. Some researchers claim very significant avoidance responses to airgun signals by some species, others are not so certain (Richardson et al, page 393). There is much anecdotal evidence from seismic survey crews of dolphins, seals, and whales approaching an active seismic source and staying in the vicinity for some time.

The following photographs show a group of whales near an active airgun array off the coast of Gabon.







So, at this stage in time the issue of behavioral disturbance is still open to debate.

Conclusions

Analysis of the frequency content of airgun pulses and research on the auditory responses of marine mammals suggests that only large baleen whales may be susceptible to auditory risk from marine seismic sources. However, if the CHABA recommendations for human exposure to impulsive sounds are extrapolated to the marine environment the risk is almost non-existent that airgun signals will cause physical harm to any marine mammal species.

The issues of behavioral responses to airgun signals are not well understood. Results of current research are inconsistent and at times contradictory. However, given the wandering nature of both marine mammals and marine seismic exploration crews, there appears to be little chance that any particular population of mammals will be exposed to seismic signals for any length of time that could significantly effect the long term viability of the population.

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