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Are Seismic Air-Gun Sources Harmful to Marine Mammals?

by Jack Caldwell[1]

GENERAL

The primary issue of noise in the oceans, and a secondary one related to seismic air-gun arrays, and their possible impacts on marine mammals, have become very visible globally: to well-developed and less-developed countries; to national governing bodies; to regulatory entities; to scientific bodies; to environmental groups; to military organizations; to media groups; to trade and lobby entities; to (some) publicly-traded and privately-held companies; and to the lay public. Several countries have very strong laws, or are enacting such laws, which (would) protect marine mammals.

Obtaining permits to shoot seismic surveys is becoming more difficult because more permitting agencies are raising questions for which answers do not yet exist about the effects on marine mammals (and fish) of the sound created by seismic surveys. The requirement to employ mitigation measures during the operation of seismic surveys is becoming more common as indicated by the fact that the oil industry currently must employ mitigation measures to protect mammals against the possible effects of loud noise when shooting seismic surveys offshore portions of the U.S., UK, Australia, Brazil, and Canada, and voluntarily employs mitigation measures numerous other places around the world. It is not actually known if the majority of the mitigation measures are successful or not. It is worth noting at this point the importance of government regulatory bodies becoming familiar with industry air-gun operations, and some of the fundamental tenets of air-gun arrays. For example, it is important to know how a seismic survey is actually shot operationally (Fig. 1). It is also fundamental to understand the common misconception that knowing the total volume of an air-gun array is a defining piece of information. It is more important to know the number of guns in the array, and something about the individual gun sizes than to know the total volume of the air-gun array itself (Fig. 2). Do seismic air-gun arrays, in routine practice, cause significant and harmful impacts to marine mammals? Biologists, acousticians, geophysicists, and government regulatory technical managers do not agree on a simple and definitive answer. What they do agree on is that there is a lack of data with which to answer that question. Most experts in the field believe that there is a very low probability of physical injury from air-gun operations. More worrisome is the possibility of air-gun noise masking communication, hampering the ability to identify and/or escape predators, or to identify and/or catch prey, and of impairing navigational abilities. Another area of uncertainty is whether the use of air-guns can cause populations to move from preferred habitats, feeding grounds, and breeding and resting areas during movements along migratory pathways. In short, does the use of air-gun arrays reduce marine mammals' ability to survive? The previous sentence is the scientific version of the fundamental question, without any political, regulatory, or governmental context. The data needed to answer this question, in a basic and fundamental way, have not been generated. (Placing this bottom-line question in a regulatory context introduces another level of complexity.) There are a few points to keep in mind as you read the rest of this document:

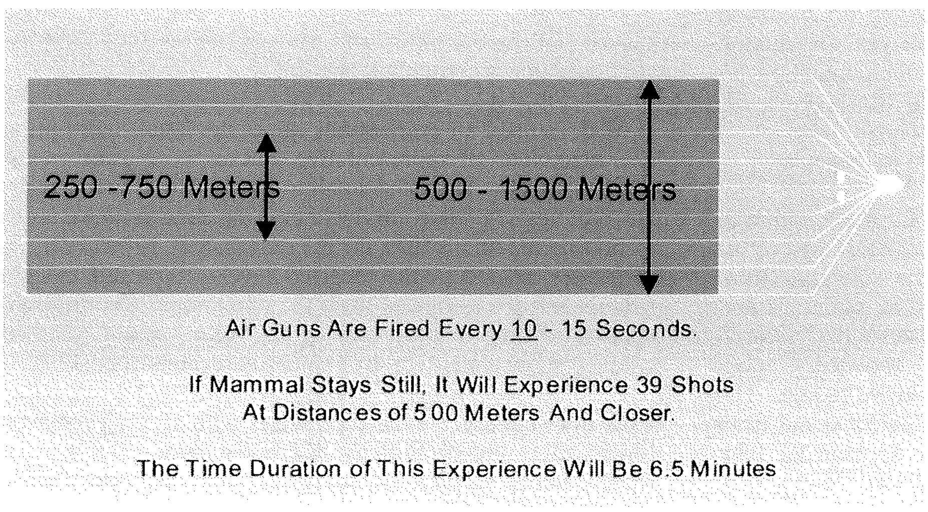

Fig. 1: Some fundamentals of 3D Seismic acquisition. If a marine mammal were directly in a seismic vessel's path, the vessel were moving from left to right as pictured above, and the mammal stayed still (i.e., did not move along with the vessel, nor away from the vessel or its path), then it would experience 39 shots at distances of 500 meters and closer, and this encounter would last about 6.5 minutes. Depending on the details of the seismic survey itself, but if it were a 3D survey, then the animal might experience a maximum of 2 or 3 more encounters like this one in a day, or in a couple of days or a week, and that would be the end of the encounters of this proximity for the entire survey.

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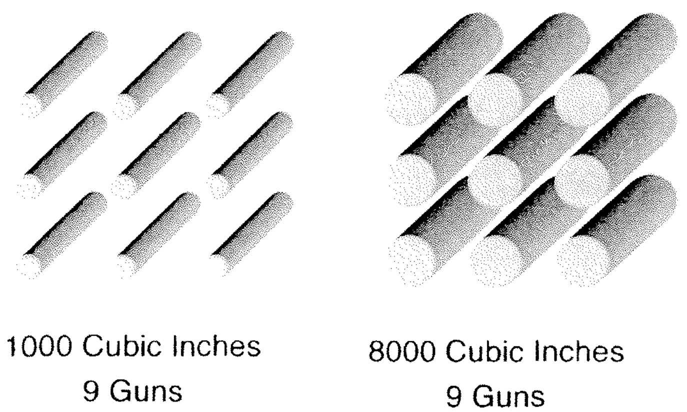


Fig. 2: Cartoon of two identical air-gun arrays except for difference in volume. Output of air-gun array varies as cube root of volume. Refer to example shown: 8000 / 1000 = 8; cube root of 8 = 2; difference in output of these two arrays is factor of two!
The number of air guns in an array is more important than the total volume of the array. Almost all arrays used by the commercial seismic industry will have a volume somewhere within the range of 1000 to 8000 cubic inches, and, as shown here, their outputs will vary by less than 6 dB as a result of that alone. It is important that the regulatory bodies around the world understand the basic aspects of air-gun operations.

1) The U.S. Navy has become increasingly involved in all aspects of this issue and now provides about US $ 15 million per year in funding (about 80 % of the world total) for research related to the effect of sound on marine mammals.

2) Public awareness about this issue has exploded.

3) 180 dB re 1 μPa (rms) has become (albeit unsupported by hard scientific data) the *de facto* danger threshold level suggested by biologists who are experts in the field; this situation will exist until better data are acquired.

4) The seismic industry knows with much more certainty what its air-gun arrays emit, and hence is better able to communicate this to other parties involved in this issue, than it did 10 to 15 years ago.

5) Data now exist that demonstrate that seismic air-gun arrays can alter the behaviour of some marine mammals, but data do not exist that demonstrate that seismic air-gun arrays cause significant and adverse behavioural changes to marine mammals in general, particularly at the stock/population level. Conversely, data do not exist that unequivocally prove air-gun arrays do not cause significant and adverse behavioural changes, so we are left with a great unknown in this area.

6) In order to generate a research proposal for presentation to the oil industry, a two-evening workshop was held in Newport Beach in December of 2000. Many of the scientists from around the world who are engaged in marine mammals and noise research attended this meeting to discuss the research approaches needed to start developing the knowledge about the effects of noise on marine mammals that we require. The five points of the research program listed below come from those discussions, and from material received from W. John Richardson (LGL, Ltd. in Toronto) and Roger Gentry (National Marine Fisheries Service, Silver Spring, MD).

Given this description of the overall situation, and using the International Association of Geophysical Contractors (IAGC) as the coordinating body, I would suggest that research be conducted to reduce the unknowns about the effect of seismic operations on marine mammals. A description of the proposed research areas is given below. These areas are listed in order of priority, although some switching around could occur if opportunistic situations arise. Most of the suggested areas of research are needed for representative species of marine mammals from each of the main groups: baleen whales (mysticetes), large toothed whales (odontocetes, such as Sperm and Beaked Whales), smaller toothed whales (dolphins, etc.), eared seals (Sea Lions and Fur Seals), and hair seals.

RESEARCH PROGRAM TO REDUCE THE UN-KNOWNS ABOUT THE EFFECTS OF SEISMIC OPERATIONS ON MARINE MAMMALS

In-field Controlled Exposure Experiments (CEE) using tagging technology

Electronic tagging technology has developed to the point of providing data as close to cause and effect of sound on mammals in the field as would seem practically possible (although this technology will still see technical improvements even in the very-short term). These tags are attached in a variety of ways using a variety of methods, depending on the species of animal being tagged. Today, these tags stay attached for a matter of hours, with 4 to 10 hours being quite common. These high-data-rate tags (Figs. 3 & 4) record received sound levels, dive depth and 3D geometry, calling behaviour, stomach temperature, respiration rate, and heart rate. Visual tracking, which usually accompanies the tagging activity, is useless when the animal is underwater, but offers context to the animal's activities when it surfaces. Because of the relative newness of this tagging technology, the vast majority of existing data, which record animal behaviour in the vicinity of sound sources, is based on visual observations taken at the surface, plus a few studies of calling behaviour.

Using controlled sources, one has to study the behaviour of marine mammals when the source is activated within hearing distance of the animals.

Air guns will be the initial and primary source type, and the marine vibrator is certainly a possibility.

- How do pulsed air-gun sounds affect the local distribution and behaviour of representative species of marine mammals, especially large and small toothed whales, eared seals, and hair seals? (There are fewer existing data for these types of marine mammals than for baleen whales). How are these responses related to (a) received levels of pulsed air-gun sounds and (b) distances from the operations? Do different species within a particular group (e.g., small toothed whales) show consistent differences in responsiveness?

- How does exposure to air-gun pulses with varying received levels affect the physiology and underwater behaviour of representative species, including heart and respiratory rates, stomach temperature, general activities, movement and dive patterns, and calling characteristics? How does the sequence of received pulse levels, as determined by the movement

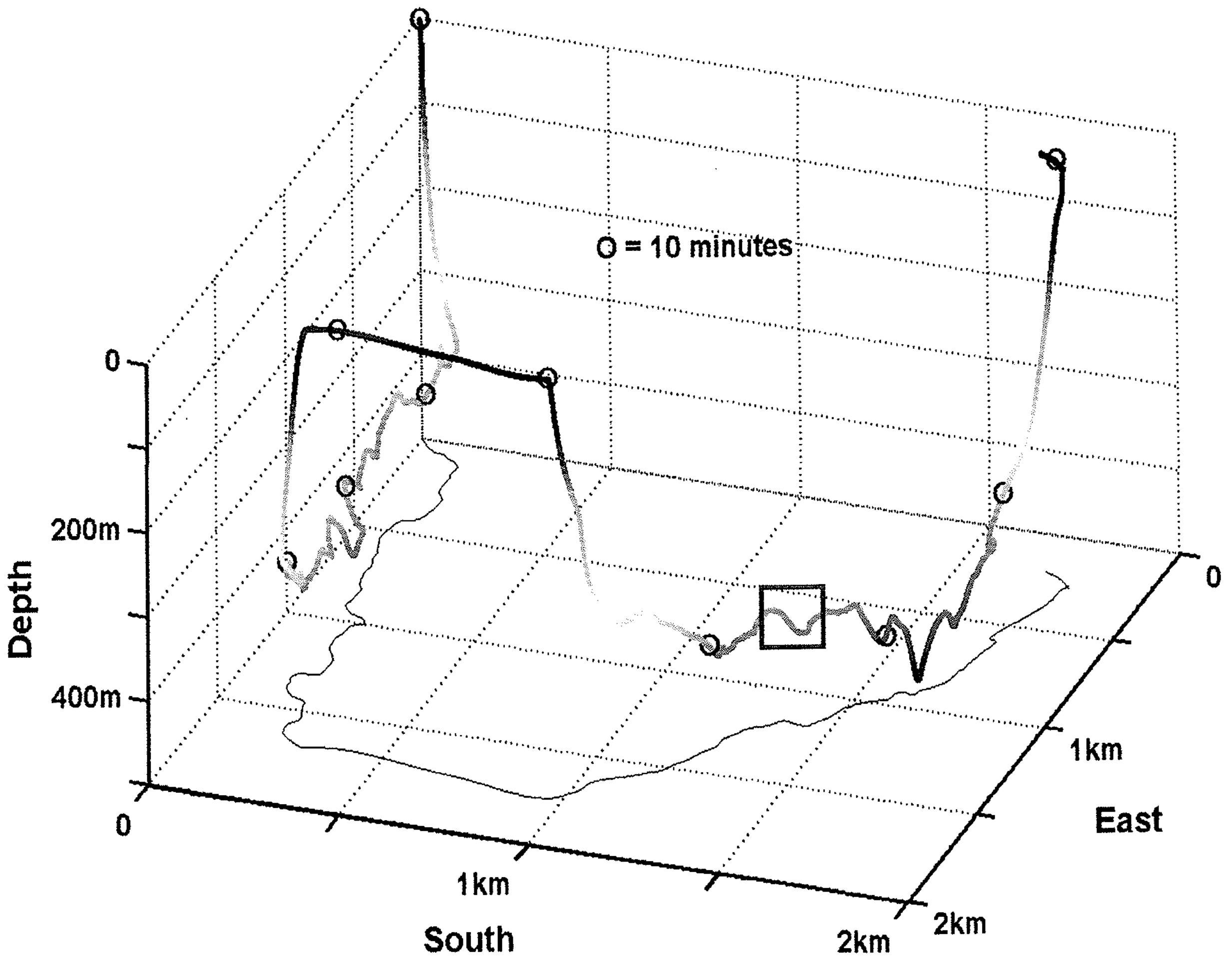
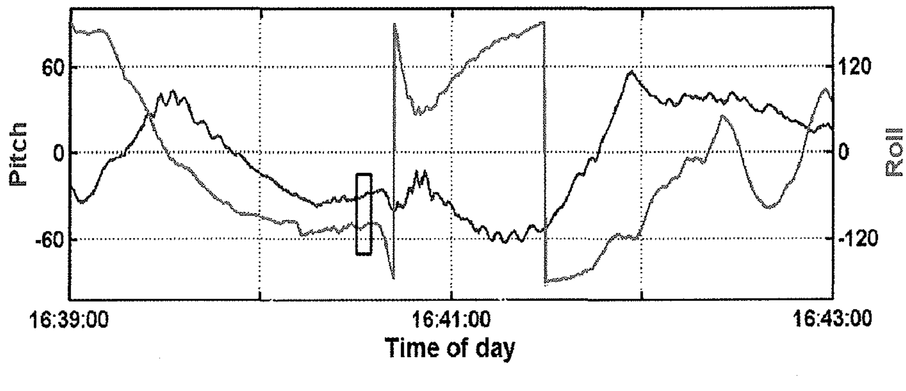


Fig. 3: 90 minutes' worth of dive geometry data from a female Sperm Whale recorded using the DTAG (Gulf of Mexico, July 2001. the record beginning in the upper left-hand corner, shows that she dived to a depth of about 400 m and stayed there for about 22 minutes, moving mostly south, before heading back to the surface, where she remained for about 11 minutes before she dived again. The second dive took almost 40 minutes, and the maximum depth reached was almost 500 m. (Graphics courtesy of Mark Johnson, Woods Hole Oceanographic Institutions)



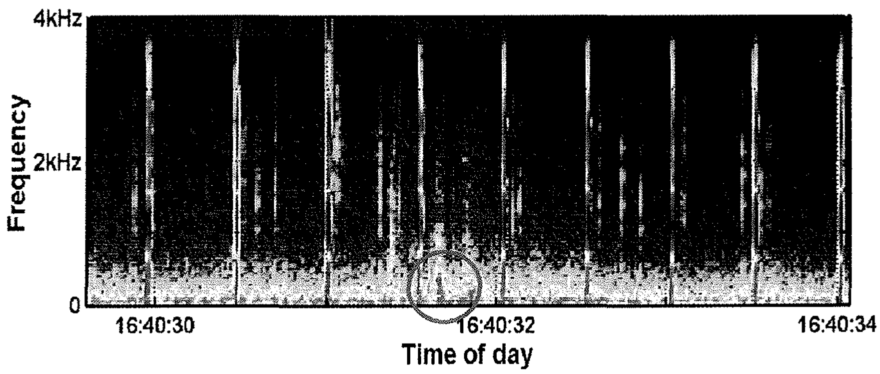


Fig. 4: Pitch, role, and audio data extracted from the portion of the DTAG record indicated by the small rectangle in Figure 3. Note the red curve in the middle of the upper graph, which is the roll curve, shows two 360 m rollovers that occur within about 50 seconds of each other. The bottom plot is fascinating. The frequency of sound or noise signal is plotted along the vertical axis and time of is plotted along the horizontal axis. Hot colours indicated high amplitudes. There appear at least four identifiable groups of noise or signals in this plot: (1) clicks from the Sperm Whale to which this particular recording tag was attached. As you can see, the clicks are emitted about every half second, are quite broadband and are relatively high amplitude; (2) weak click signals which are ghosts from the seafloor and sea surface; (3) an air-gun signal (indicated by the red circle) from a seismic survey operation located about 8 nautical miles from this particular Sperm Whale; and (4) relatively low-frequency, high-amplitude background noise.

pattern of the source, affect the responses of the animals?

- How long does the behavioural and/or physiological disruption persist in representative species from each group, if either occurs?

- What factors determine the responsiveness of representative species from each group: age/sex categories? Activity of animals? Time of year? Habitat? (Existing data indicate that reactions are quite variable. Under what conditions are the animals especially responsive?).

- Determine whether "ramp-up" ("soft start") is effective in inducing marine mammals close to an air-gun array to move away. If so, what is the optimum pulse repetition rate and rate of increase in source level? Some definition of "effectiveness" must be established. The effectiveness of ramp-up will almost certainly be species-dependent. Is "effectiveness" going to be defined as some percentage of the total number of individuals within the safety radius that exit before the maximum output level is reached. Is it going to be defined as a percentage of the time that one individual leaves the zone before the maximum is reached (eight times out of ten an individual Bottlenose Dolphin leaves the zone before the source reaches its maximum output)?

Conducting this kind of research is moderately expensive. It will cost about US $ 2 million in the summer of 2002 in the Gulf of Mexico to (hopefully) obtain 40 hours of monitoring Sperm Whales, with tags attached, while a seismic source vessel is operating in a dedicated manner providing the controlled source. (This effort will be stated as 40 tag-mammal-source hours). This effort equates to tagging 3-5 animals, so if this summer's project happens and is successful, there will be 3-5 data points for a single species in a single overall location. The industry should be thinking about reaching levels of 200 tag-mammal-source hours during 2004, which probably means funding levels of US $ 4 million by then.

In-field uncontrolled exposure experiments (opportunistic situations)

Satellite tagging will form the basis of this kind of experiment, with as controlled information about noise sources as possible. This field research scenario would involve working in field sites where seismic operations are being conducted in a normal fashion. Both high-data-rate tags as described (Figs. 3 & 4) could be used, but lower-data-rate tags would probably play a major role. The lower-rate tag basically records the attached animal's location and transmits that information once or twice a day via satellite. These tags remain attached for weeks to months, thereby allowing their gross movements to be monitored.

If some or all individuals of a particular species move away from an area with air-gun operations, how soon does use of that area by that species return to "typical" levels? Do the same individuals re-occupy the area during the same season? The following year?

If there are repeated seismic programs in a general area over a number of years, does the use of that region by various types of marine mammals change in a manner inconsistent with the pattern of change in nearby areas with less human activity?

Survey existing passive acoustic monitoring systems and conduct field tests

Passive acoustic monitoring systems use typically small arrays of hydrophones to record the vocalization/sound generation of marine animals. There are fundamentally three technical aspects to such systems:
(1) the acquisition hardware,
(2) the location software, which determines the location from where the sound comes, and
(3) the animal identification software, which determines the type of animal by the characteristics of the sound.

Evaluate existing passive acoustic monitoring systems such as the Shell/Gordon/OceanEar system, the Cornell system, the WHOI system, various Navy systems, and any others, for which information may be available, and make recommendations based on biological aspects to the seismic industry and/or oil industry in terms of current commerciality, accuracy, user friendliness, cost-effective implementation, etc. Also evaluate what percentage of marine mammals likely to be encountered in seismic operations do not vocalize, thereby making those species undetectable using acoustic passive monitoring. This aspect becomes an issue in terms of overall cost-effectiveness of any system.

Experiments on captive animals

Determination of TTS

Can a sequence of air-gun pulses cause temporary hearing impairment (Temporary Threshold Shift, or TTS) in marine mammals? (The "rock concert" effect on humans is an example of TTS). If so, what received levels (in units of pressure) are necessary before this will occur? Are the 180 or 190 dB re 1 μPa (rms) safety criteria, as applied in some projects, necessary and effective to protect marine mammals? How does the rate of recovery to pre-exposure hearing sensitivity relate to degree of TTS as elicited by a sequence of air-gun pulses? The Newport Beach panel agreed that studying temporary threshold shift (TTS) had the highest priority among hearing research. The study has to be done using air guns as the source, and the likelihood of TTS must be examined based on air gun signal characteristics such as number of pulses (the panel recommended using the methods of Ahrron et al. 1996, with 1, 10, and 100 pulses as stimuli), signal received level, repetition rate of signals, and duration of pulses. The use of the Auditory Brainstem Response (ABR) technique, as appropriate, is recommended.

Determination of air-gun characteristics that are most impacting

Conduct studies on captive animals to discern the particular characteristics of an air-gun signal (such as received level, number of pulses, pulse duration, frequency band, rise time, and repetition rate) that might cause annoyance/avoidance in the wild. Begin to address the issue of exposure in this item.

Evaluate exposure modelling systems

These systems model the exposure levels received by animals, moving in arbitrary but specified paths, as a result of sound generation from known sources, also moving in arbitrary or orderly, but specified, ways.

There are at least two such systems in existence at this time. These systems calculate received sound levels over a 3D volume in which animal movements are also modelled, and the animal movement pattern and the sound level pattern can be merged. This allows one to see a variety of situations, including, but not limited to, the prediction of the total time of exposure to sounds over a specified level for an animal following some specified series of movements.

FINAL REMARKS

Cooperation among oil industry trade groups, some conservation groups, government regulatory agencies, academic bodies, and some oil companies is at a relatively high level in the UK, Australia, and in the U.S. The U.S. Navy is interested in coordinating with any research efforts that the oil industry might undertake. Advances in technology (acoustic tags, active and passive acoustic monitoring systems, etc.) are making field-based research a reality that requires funding, a role that the oil industry can significantly impact.