PROTECTING WHALES WHILE MAINTAINING MILITARY READINESS

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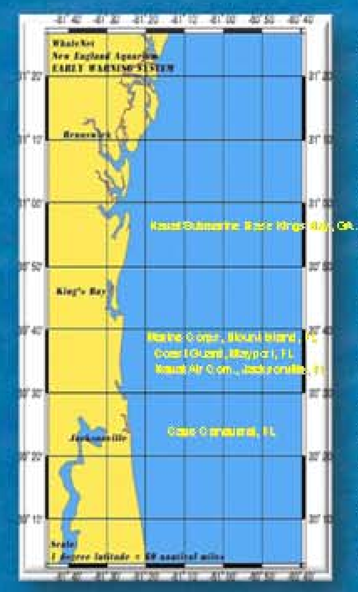
Near miss as two whales react late

ABSTRACT

Ship collisions with whales are a concern of the DoD and Navy. This project demonstrated and revealed the underlying near surface acoustical causes for ship collisions, and developed a cost effective and safe acoustical method to protect whales from ship collisions; not only near military installations, but throughout the worlds' oceans. At sea measurements have defined the geometry of acoustic shadows ahead of various ship hulls. The measurements have been used to develop a directional projector array for attachment to the bows of ships to selectively fill-in the acoustic shadows directly ahead of ships with modulated ship noise. Currently these quiet shadow zones in front of ships can attract whales seeking refuge from approaching ships. The ship alarm will defeat the near surface effects and eliminate deceptive acoustical shadows that can lure whales into the paths of ships. The technology will enable DoD vessels to operate unimpeded, safeguarding whales and maintaining military readiness. This multiyear project 06-145 is funded by the U.S. Department of Defense Legacy Resource Management Program (Navy).

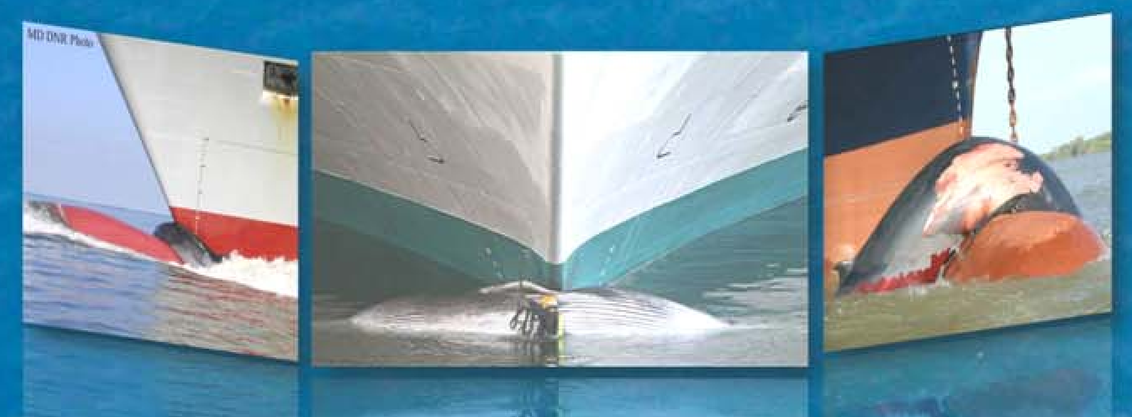


The North Atlantic right whale critical southeast habitat lies adjacent to DoD installations along the coast of Georgia and Florida. The whales endangered status, and vulnerability to ship strikes, makes it a priority concern. Their presence can effect range and training operations. Impacts are not limited to installations in the southeast, as right whales have an extensive migratory corridor which intersects both military and commercial shipping lanes from Nova Scotia down to Florida.

N. A. right whale critical S.E. habitat Kings Bay Submarine Base, Georgia

BACKGROUND

Though more commonly identified and reported in busy coastal areas, collisions are not restricted to shipping lanes or shallow water environments. A common denominator is that they all occur near the surface. Here the acoustical laws of reflection and propagation significantly limit the ability of whales to hear and locate the sounds of approaching vessels. Perhaps the most serious phenomena is acoustical shadowing, as it can actually lure whales into the path of approaching ships. While the size and geometry of the shadows formed directly ahead of ships vary, propeller noise is always more intense off the port and starboard sides than it is directly ahead of approaching vessels. Observations of whales surfacing in front of ships and the high incidence of collisions with North Atlantic right whales suggests that whales near the surface are unaware of ships approaching in their direct path. The near surface acoustical conditions can confuse whales and may cause them to seek refuge by surfacing or actively swimming into the quieter zones that form directly in front of ships. Once here, hydrodynamic forces can sweep adults and especially calves into the propellers. The high incidence of collisions with calves and females exceeds normal probability and suggests that whales may be active participants in the collision phenomenon, as they seek refuge near the surface and in front of approaching ships. With increased commerce and international shipping, vessel collisions with whales have become a global concern. It is not uncommon to see a variety of whale species draped along the bulbous bow of large ships as they come into ports all over the world.



Range Rover, AUTEC range Andros, Bahamas, tongue of the ocean, 3000 ft
Carnival cruise ship 850 ft, 200 ft beam, 23 ft draft , Cape Canaveral 40 ft

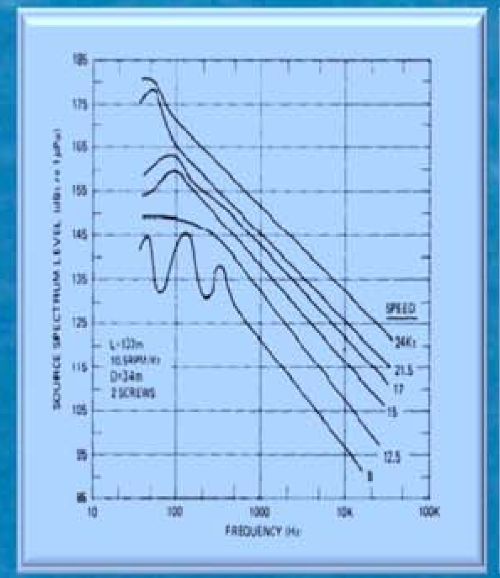
Controlled single ship approaches were conducted past vertical hydrophone arrays to measure radiated ship noise from different vessels, at various depths, distances and speeds. The measurements demonstrated a confluence of propagation factors and near surface effects that can obscure the sounds of approaching vessels and poses serious detection challenges for all marine mammals at risk.

Speed and Spherical Spreading from Propellers

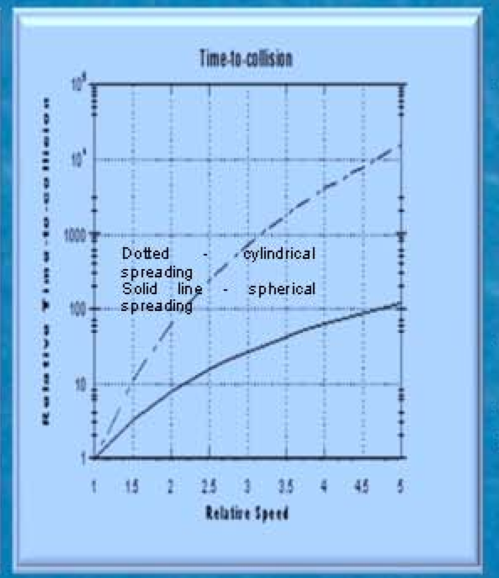
Noise intensity is a function of ship speed. Submariners can tell you from their experience with passive sonar that fast ships can be heard much farther away; and whales traveling at deeps greater than 7 m from the surface can also detect these faster ships. The resulting difference in intensity and increased range of detection are multipliers of vessel speed. Ship noise intensity is proportional to the tip velocity (U) of the propeller to the 6th power. Ship speed (V) and propeller tip speed (U) can be expressed as,

$V = U + \delta 1(U)$ where $\delta 1(U)$ is a factor that accommodates for the increased requirement on tip velocity to account for the ship's load and its' environmental parameters. The additional load on the propeller increases with speed and makes the acoustical intensity nearer to the 7th power of speed. Fast vessels can be detected farther away, however, they also can acoustically mask vessel noise and other sounds over expansive areas. In multiple ship scenarios, the lower intensity noise of nearby slower moving ships can be obscured by the sounds of distant faster ships. Since the propeller is the acoustic center for ship noise the distance from the stern to
the bow can result in significant acoustical losses ahead of the ship. Ships larger than 80 m are responsible for most of the reported collisions. Spreading losses from the propellers to the bow would be 38 dB and 40 dB for a ship 100 m long. Spreading loss is an important consideration with respect to large ships, speed and masking.

Recent speed reduction rules adopted along the East coast in an effort to protect North Atlantic right whales do not address the underlying acoustic challenges whales face. Ironically, reducing ship speed can actually increase the risks of collisions by reducing the ship's detectability, increasing transect time, and the subsequent opportunities for collisions. Current visual and developing passive acoustic monitoring coupled with slow speed regulations may help protect some whales by diverting ships from a whale's general vicinity, however, whales don't always vocalize and this overall strategy is still reliant upon visual surveillance. At night, when whales are very active, and during moderate sea states and periods of poor visibility, these strategies offer no protection and increase the risk of collisions. The mass momentum impacts are such that large ships traveing at 10 kts as apposed to 24 kts will still kill a whale. Slowing down a 100 meter ship to 10 kts can reduce noise intensity at the propeller -30 dB. After an additional 40 dB loss from spreading to the bow, the resulting noise projected at the bow could fall below the whale's critical ratios for hearing, thus increasing the risks of collisions, while not reducing the probability of mortality.

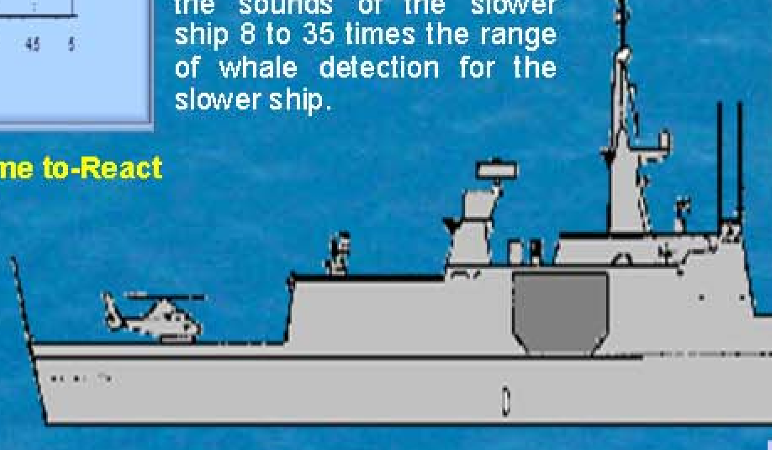


Ross curves showing ship speed vs. sound intensity



Time-To-Collision : Time to-React

The curves show the relative time a whale has to detect an approaching ship when it is submerged at least 7 meters from the surface. Using a relative speed ratio of (2). A ship traveling twice as fast, is detectable for period of time 8 to 35 times that of the slower one. The radiated noise from the faster ship can also mask the sounds of the slower ship 8 to 35 times the range of whale detection for the slower ship.



Lloyd's Mirror Effect

Lloyd's Mirror, in brief, is a consequence of the law of reflection from a plane surface. Simply stated, the angles of incidence and reflection from a plane surface are equal. When the ocean surface is smooth relative to the wavelength, the incident and reflected waves are very nearly the same amplitude, but 180° out of phase. So when the reflected wave from the surface meets the incident wave they cancel each other out. At the surface, longer wavelength (lower frequency) sounds can be lost entirely. The condition applies until the water's surface becomes rough enough to stop behaving like a mirror. For low frequencies, the mirror condition holds until the average surface roughness becomes substantial compared to the acoustical wavelength (e.g., 1/10 of a wavelength). Lloyd's Mirror Effect does not affect the higher frequencies (frequencies with wavelengths shorter than the average wave height), as there is no mirror effect from the surface reflections. However, lower frequencies with wavelengths that radiate through, or are long enough to diffract around large hulls, are significantly attenuated near the surface. Ships sufficient in size to mortally injure whales generate acoustical spectra dominated by these very low frequencies.

While many large whales may have acute low-frequency hearing (an adaptation useful in deep water), near the surface it has little utility for detecting the dominant low-frequency spectra of approaching ships. Lloyd's Mirror Effect places the whales at a sensory disadvantage and thus vulnerable to ship collisions.

Blue, J.E. and E.R. Gerstein (2005) "Acoustical causes of vessels collisions with marine mammals" Chapter 16, in *Sounds in the Seas: Introduction to Acoustical Oceanography*, Herman Medwin and colleagues (eds.) Cambridge University Press, Cambridge UK.
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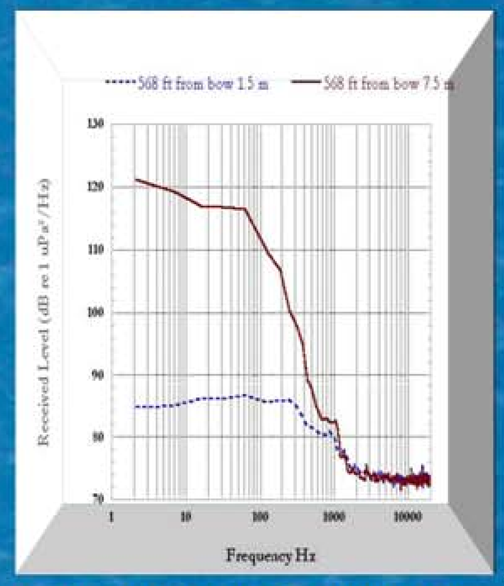
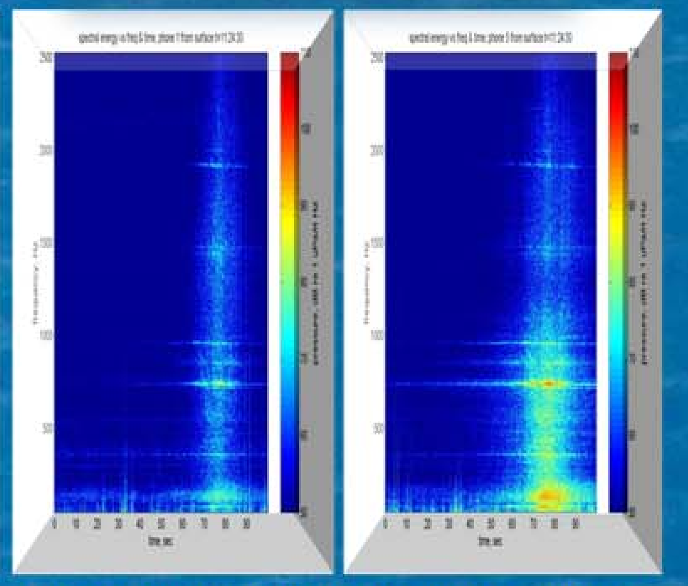


Range Rover spectra recorded at 568 ft distance at 1.5 & 7.5 m recording depths. Lloyd's Mirror Effect is evident at frequencies below 300 Hz.



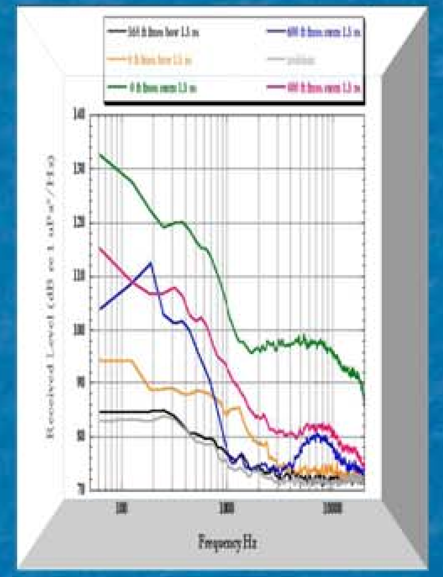
Spectrograms: Range Rover, 11 kts, recording depths 1.5 & 7.5 m. Lloyd's mirror effect is shown at frequencies below 1000 Hz .

The acoustical factors that contribute to collisions between marine mammals and ships are not easily observed alone. Losses from spreading, Lloyd's Mirror Effect, and acoustical shadowing are difficult to isolate. The effects are documented in time series recordings using various vessels, some with propellers above keel depth, and others with propellers below or at keel depth. The data and methods are detailed in other papers and reports (Blue and Gerstein 2005, Gerstein and Blue 2005, and Gerstein et. al., 2002). The approach of the Range Rover, a 186 meter AUTEC ship with propellers positioned at keel depth was synchronously recorded at various depths. A spectral plot and two sonograms of the ship noise are illustrated in the figures above. The spectra at 1.5 and 7.5 meter depths are represented when the ship approached at a 173 meter distance. The Range Rover's propeller position minimized acoustical shadowing and Lloyd's Mirror Effect is clearly demonstrated by 30 to 40 dB losses below 300 Hz.

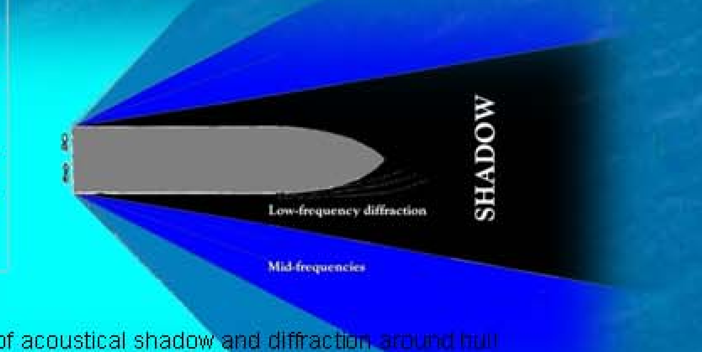
Acoustical Shadowing and Diffraction

The most confounding acoustical challenge to whales is acoustical shadowing at the bow. It's caused when the sound rays from a ship's propellers are blocked from projecting forward by the ship's hull. The majority of ships that kill whales have propeller configurations above keel depth, and the hull then shields or blocks the sounds produced by the propellers. Ship noise with wavelengths less than the ship stern dimensions are reflected back off the stern and reflect to the sides, but do not propagate forward to the bow. Only very low frequency sounds with wavelengths larger than stern dimensions can diffract around the ship's hull to the bow. However, near the surface, these lower frequencies are severely attenuated or canceled by the boundary interaction phenomenon known as the Lloyd's Mirror Effect.

The ship noise spectra from a Carnival cruise ship is represented at various distances as it passed within 21m of the vertical hydrophone arrays at a speed of 12 kits. This ship's propellers are positioned above keel depth and acoustical shadowing is demonstrated by the rapid loss at higher frequencies where the ship's hull dimensions are larger than the wavelength of propeller noise. Note that sound pressure levels do not rise significantly above ambient levels until half of the ship's length passes the arrays, and the boundary of geometric scattering is crossed.



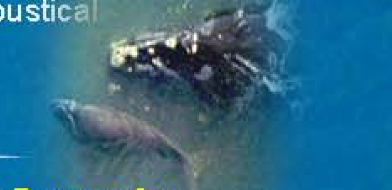
The schematic representation of the shadowing effect on the ship's sound field illustrates low frequency rays diffracting around the ship, and the successive adjacent rays diffracting from the edges of the stern with increasing frequency until, at a high enough frequency, the last ray can be considered geometrical scattering. Directly ahead of the ship, it is quiet, and whales in this path cannot detect the ship's approach. However, off to the sides the sounds of the approaching ship can be easily heard. The shadow can be a deceptive refuge from the sounds of approaching ships; luring whales to the surface into the path of the ship.



Schematic of acoustical shadow and diffraction around hull

APPLIED SOLUTION

A highly directional, dual-frequency parametric sonar has been developed to mitigate the near surface acoustical challenges and alert whales of approaching vessels. The system projector is a planar array, comprised of 45 elements, band-centered to transmit a high carrier frequency along with a lower side band signal. The non-linearity of water is used to demodulate the mixed high frequency carrier into a lower frequency waveform audible to whales. It is bow mounted, and designed to project modulated ship noise in a narrow beam directly ahead of vessels to "fill selectively "fill-in" acoustical shadows and alert whales of approaching ships.



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