Building a Virtual Model of a Baleen Whale

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LONG-TERM GOALS

This long term goal of this research is to eventually CT scan an adult baleen whale. The research effort will be subdivided into three phases. The current activity only covers Phase 1, the design and testing phase. No marine mammal specimens are needed in this initial design and testing phase. Going forward with Phases 2 and 3 will be dependant upon the success of Phase 1.

OBJECTIVES

Phase 1 will accomplish the following objectives:

1. Investigate, design, test, and purchase an insulated tow bag that will, in later phases, eventually be used to contain a whale carcass and transport it to a haul-out marina where it can be hoisted into a steel cradle.

2. Design, build, and test a recirculating sea water chilling system. This unit would be palletized and be plumbed so that sea water can be recirculating into the insulated bag while the specimen is towed into the marina. This will help stave off decomposition.

3. Test towing and handling procedures with insulated bag and recirculating chilled sea water system. Measure the rate at which the sea water can be chilled while towing a bag full of sea water.

4. Design and build a steel cradle that used to hold specimen while hoisting it from the water and during transport from the marina to freezer unit.

5. Video documentation will be ongoing throughout the life of the project. If we succeed in Phase 1 of this project, we will be on track to revolutionize our understanding of the largest animals on
Earth. As a consequence, this project will have demonstrated an innovative process that may serve the public interest and as a pattern for future studies.

**APPROACH**

This project proposes to eventually CT scan an adult baleen whale! This goal may, at first, seem unattainable, but it is feasible. This daunting goal is attainable because over the past ten years, one of us (Cranford) has developed and tested a technique to scan large cetacean specimens (Cranford 1999). Once obtained the CT scan of an adult mysticete opens a broad spectrum of research offshoots that hold the potential to revolutionize our understanding of the anatomy and physiology of the largest animals on Earth. This project is the first phase of an effort that will eventually simulate mysticete hearing, a primary topic of interest to the Office of Naval Research.

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**Project Schedule and Milestones**

**Phase 1** – Christmann & Cranford (current effort)
- Investigate, design, and purchase insulated tow bag (complete by Jan. 2011)
- Design, build, and test steel cradle used to hold specimen during transport
- Chiller construction – palletized recirculating sea water system
- Test towing procedures with insulated bag and chilled sea water
- Video documentation (ongoing throughout the funding period)

**Phase 2** – Cranford & Christmann (Future Proposal 2011)
- Boat agreements and negotiations
- Locating specimen (probably airplane)
- Tow it in while chilling
- Hoist out and put in truck
- Transport to stand alone freezer
- Cut into sections if necessary
- Ship sections to Hill AFB for scanning
- Back to freezer and then ship to Smithsonian Institution for dissection and storage of skeleton

**Phase 3** – Krysl & Cranford (Future Proposal – 2012)
- Begin image processing and model preparation effort

Short of experimentally exposing live animals, which is always expensive and often impossible, the most promising technique for discovering acoustic pathways and assessing potential effects from any
particular sound, involves finite element modeling (FEM). The FEM method has been applied successfully to engineering problems over the past half century and is now in widespread use.

Our team has pioneered a suite of techniques that combine anatomic geometry obtained from CT scanners (Cranford, 1988; Cranford, 1999; Cranford et al., 1996), measurements of tissue elasticity (Soldevilla et al., 2005), and custom FEM software (Krysl et al., 2006), which produces a versatile computational environment for acoustic simulations (Krysl et al., 2008). These techniques can be used to assess acoustic exposure across a broad taxonomic spectrum.

The intellectual merit of these methods has been demonstrated by the recently published discovery of a new pathway for sound entering the head of a beaked whale (Cranford et al., 2008a) and function of the hearing apparatus in toothed whales (Cranford et al., 2010). These results challenges the long accepted paradigm of toothed whale hearing (Norris, 1968). In addition, anatomic similarities with all living toothed whales suggest that this new pathway may also be the original pathway used by the ancient whales (archaeocetes) in the Eocene. This discovery was catalyzed by the disparate views and collective efforts of experts in different disciplines, the essence of our approach.

These computer-enabled investigative methods have already transformed our capacity to generate original knowledge and understand the bioacoustics of marine mammals (Cranford, 2000; Cranford and Amundin, 2003; Cranford et al., 2008a; Cranford et al., 2008b). The resulting simulations allow us to emulate, for example, the formation of an acoustic transmission beam or measure the amplitude differences and time delay for sound reaching each ear complex. These are just a few examples of the predictions and understanding we can glean from basic simulations.

**WORK COMPLETED**

This project is still primarily conceptual, but it is intriguing and we are moving forward.

We have planned a demonstration of the methodology that will eventually be used to bag and tow a subadult Gray Whale (*Eschrichtius robustus*) carcass. The demonstration will take place at approximately a 1/20 scale, using a small model of the bag and towing an albacore carcass, with caudal and pectoral fins trimmed to hydrodynamically simulate those of Gray Whales. The demonstration will be recorded videographically.

This demonstration should identify the viability of the methodology or where it needs refinement, with a minimum of effort and expense. This is a vital, first test of our ideas. To be sure, there are many uncharted challenges in this effort, so testing them first on a small scale is worthwhile.

The plan is to tow a carcass (whale or tuna) tail-first, and either winched slowly backwards into a trailing, open, somewhat form-fitting bag, or the bag being winched forward over the carcass. In either case, the option for either mechanical winch function is there to achieve the goal of a bagged, refrigerated carcass under slow, controlled tow, and to isolate the volume of seawater inside the bag for recirculating cooling, beginning as soon as the animal is taken under tow.

The portable chiller, a diesel-driven refrigeration system, pallet-mounted on the deck of the towing vessel, will pump recirculating enhanced brine through the bag containing the carcass. It will achieve a freezing point somewhat lowered from that of seawater, through a hose inserted into the specimen's
mouth, and recurved back toward the esophagus. The coldest water will flow forward and out into the bag, with a return suction line sending water back to the chiller from out in the bag.

The bag will insulate a finite volume of seawater that recirculates through the on-deck chiller. This should allow the hearing apparatus in the anterior part of the head to be cooled by progressively lower temperature water, for as long as the towing takes place. The lowest temperature limit is the freezing point of the enhanced brine, but only after substantial cooling and equilibrium of some or much of the specimen's anterior anatomy has been achieved. This will certainly take many hours, but this seems the best way to introduce cooling quickly, and if a tow is to take many hours at very low speed anyway, the time would be used wisely by introducing cooling early.

The bagged, cooled, and towed carcass will then be brought to the nearest haulout yard, where an appropriately-sized prefabricated steel cradle will be lowered into the water. The bagged carcass will be winched tail-first into the steel cradle. The cradle is capped at both ends, with some volume of harbor water supporting (partially floating) the specimen's entire bulk in water. The cradle, having been designed specifically for the purpose, is then raised from the water, wheeled to a waiting, chartered flatbed truck trailer, and lowered onto same, just as these facilities do every day with 20 and 30 ton sailboats and commercial vessels. The cradle is secured on the flatbed, the on-deck chiller system is transferred to the truck bed, circulating refrigeration hoses are re-connected to the specimen, and the cooling process resumes.

If all goes well, then this specimen could be the most carefully handled and preserved ever seen by investigators, with none of the crushing associated with beached or shipboard specimens, and as little decomposition as circumstances and cooling physics will allow. If we are in close contact with the Monterey charter vessels that are likeliest to witness an Orca kill on an appropriately-sized subadult here on Monterey Bay, and the tow vessel is adequately prepared and equipped as the migration approaches, then all these factors might coincide to allow this to unfold in this auspicious way.

We have settled on a manufacturer of fuel bladders for aviation gasoline and diesel handlers to produce the towing bag. The towing bag can be constructed and shipped by late November, so that a test-tow on either a redwood log or even a carcass might be conducted this winter, from the deck of the 50-foot research and survey vessel Shana Rae, based in Santa Cruz, CA (see http://www.shanarae.com).

We have entered into design discussions with a metal fabricator in Moss Landing, CA to build the steel cradle, and have outlined design plans for the cradle. This fabricator is also an ex-commercial fisherman with decades of experience in refrigeration, and there no reason to hunt further for direction on the sources for the palletized chiller system. The fishing industry is rife with experienced people that don't have enough to do in the current economy, so our resources are welcome in this regard. The portable chiller and steel cradle represent more substantial resource outlays, so without additional funding they remain just plans at this point. We are ready to proceed on both items as soon a resources are available.

**IMPACT/APPLICATIONS**

Navy sonar training operations have been hampered by concerns and lawsuits over the effects that high intensity sound exposure might have on marine organisms, specifically mammals.
There is worldwide interest in the potential effects of anthropogenic sound on mysticete (baleen) whales. Most of the research on the effects of sound has been conducted on a few small marine mammal species that can be housed in research labs and aquaria but little is known about large marine mammals, like mysticetes. Long wavelength, low-frequency sounds are likely to have their most significant interaction with the bodies of these large animals, requiring a model of mysticete anatomy to study the interaction between these animals and low-frequency sound. Improvements in industrial-grade x-ray computed tomography (CT) scanners have made it feasible to scan an adult mysticete.

One viable method to assess exposure employs a computer modeling (FEM) environment to interrogate animal systems, increasing our understanding of how those systems work, simulating the response of those systems to insult from high-intensity sounds, and assessing possible mitigation strategies prior to implementation. Producing this modeling environment is economical when compared to live animal work and provides a broad scope for investigation that cannot be matched or risked with live animals. Finally, the modeling environment allows investigators the flexibility to pivot quickly and nimbly to address inquiries of new claims or potential problems as they arise.

There is another realm of understanding that can be tapped by using FEM methods, but it might not be immediately obvious. The FEM tools allow us to conduct virtual experiments, a powerful but subtle capability. Consider the value of teasing apart the contributions of anatomic components in the formation of a sonar beam or the selective amplification function along the sound reception pathways. Our FEM tools could also be used to “test” selected changes to sonar signal characteristics or evaluate various mitigation strategies. The ability to conduct virtual experiments may prove to be the most powerful facet of the development of these FEM tools.

The success of this project will mark a sudden and conspicuous transformation in our understanding of the anatomy of mysticetes. To date, our knowledge of the anatomy of baleen whales has been largely based upon reports of centuries old dissections, using hand tools and draft animals with block and tackle, and from the whaling industry. It is a pity that the last published reference on systemic anatomy in baleen whales was by von Schulte in 1916, for a fetal fin whale. Clearly, the methodology developed for this project will greatly advance our understanding of mysticete acoustic functional morphology.

There are two major advancements that accrue from capturing in situ anatomy in an adult mysticete as a means for understanding acoustic function: the geometry of anatomy and an advantageous perspective. That is, the sizes, shapes and material composition of organs and tissue interfaces will determine their interaction with acoustic stimuli. In addition, it is very difficult to comprehend the anatomic structure of a mysticete by relying solely upon traditional methods (dissection) because the structures are much larger than the observer and any attempts to separate the slumping parts will all but destroy the indispensable anatomic geometry. These factors are currently unknown for any adult mysticete.

Modeling has several advantages. Models are flexible with respect to species and the variety of acoustic stimuli that can be tested. Once developed, models are also inexpensive to reuse in light of new information or apply to new questions. The models we propose to build are constructed at the organismal level. This allows us to investigate interactions on the whole organism or to zoom in on structures or suites of structures to address questions of sound propagation and transmission across interfaces, distribution of acoustic pressure and shear stresses, dissipated energy and heating effects,
excessive strains or displacements due to resonance, potential for cavitation, and any other mechanical impact.

The long-term, overarching research effort proposed here is robust can inform regulatory decisions about the effects of these sounds on large marine mammals and fish. Modeling has several advantages. Models are flexible with respect to species and the variety of acoustic stimuli that can be tested. Once developed, models are inexpensive to reuse in light of new information or apply to new questions.

**RELATED PROJECTS**

This project is unique. There are no related projects.

**REFERENCES**


