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UNDERSTANDING THE RISK TO HARBOR SEALS FROM COLLISION WITH A TIDAL TURBINE

Andrea E. Copping[1]
Pacific Northwest
National Laboratory
Seattle, Washington, USA

Richard Jepsen
Sandia National Laboratories
Albuquerque NM, USA

Molly E. Grear
University of Washington
Seattle, Washington, USA

Alicia M. Gorton
Pacific Northwest
National Laboratory
Richland, WA, USA

Chris Chartrand
Sandia National Laboratories
Albuquerque NM, USA

[1]Corresponding author: andrea.copping@pnnl.gov

ABSTRACT

The potential risk to marine mammals colliding with turbines is one of the primary environmental concerns slowing tidal energy development in the US and Europe. Few field observations of interactions between marine animals and tidal turbines have been reported [1], necessitating supplemental risk analyses and modeling to help fill the gap. This study provides a surrogate measure of the potential consequences of collision between harbor seals and a two-bladed unducted turbine. By combining estimates of the consequences of collision with the probability of collision, the risks to harbor seals around tidal turbines can be estimated, supporting regulatory decisions, and providing feedback on turbine design to minimize potential harm. In conjunction with future assessments of interactions of marine mammals with other tidal turbine designs, a more generalizable estimate of the risk of tidal turbines to marine mammals could be developed.

INTRODUCTION

The tidal industry faces challenges to widespread deployment, including the need to assure that marine mammals will be safe from injury or death from collision with turbines. Many marine mammal populations are under stress from climate change and other human activities, and are afforded special levels of protection in many nations, where permitting (consenting) processes focus heavily on potential harm to marine mammals ([2] [3]). This study began by assessing the potential blade strike and resulting tissue damage to an endangered population of southern resident killer whales (SRKW, *Orcinus orca)* from operation of two open-center ducted tidal turbines planned for a tidal estuary in the United States [4]. The study has been extended to include the potential collision of harbor seals (*Phoca vitulina)* with an unducted turbine (i.e., fan-style turbine). The process of this research, and the initial outcomes reported here, are believed to be a useful approach to informing the marine energy industry, researchers, regulators, and stakeholders in the absence of extensive data on interactions between marine mammals and operating marine energy devices. The results of this study are presented as a means to understand the risk to these specific mammals with these specific turbines, with the goal of providing a more generalizable estimate of the risk to marine mammals around tidal turbines.

SUMMARY OF PAST WORK

The initial collision study investigated the potential blade strike and resulting tissue damage to an endangered population of SRKW from operation of two open-center ducted tidal turbines [4]. In the study, a large male SRKW was simulated in a finite element model and collision was modeled across a range of blade speeds. The numerical model included turbine blade dimensions, angle of encounter with the whale, and the approximate dimensions and biomechanical properties of the SRKW. Biomechanical properties of SRKW tissues were determined via tensile tissue testing. Model results indicated that laceration of the SRKW skin was possible but considered unlikely. Coupled with a biologically-based assessment, the most likely outcome of the encounter was damage to the underlying tissues of the SRKW, specifically hemorrhaging from tissues into the blubber layer, or the equivalent of a bruise.

APPROACH

Building on the framework and results presented in the SRKW investigation, this study provides an estimate of the potential level of injury from a turbine blade/mammal interaction for an unducted two-bladed turbine with a harbor seal. We have focused our work from two directions: estimating the approach and the forces impinging on the seal during an encounter with a tidal blade; and estimating the biomechanical properties of the seal's tissue layers and underlying skeleton to resist damage.

Interaction of Seal with Two-Bladed, Unducted Turbine

Harbor seals are found in many temperate tidal waters and are considered to be at risk for collision with turbine blades, particularly in areas where their populations are dwindling, such as northern Europe.

While harbor seals spend considerable time on land at haul out sites, they are known to frequent channel constrictions, locations that may be attractive for tidal energy development [5]. In some study sites, these marine mammals appear to hunt fish as their prey more commonly during flood tide than ebb or slack conditions [5].

A large two-bladed turbine, modeled after the Marine Current Turbine (MCT) SeaGen turbine, was used to estimate the risk to harbor seals; the consequences of collision between the turbine blade and seal were estimated with the use of a finite element model (CUBIT/PRESTO) (Figure 1). Specifications for many of the turbine blade parameters were provided by the technology developer.

Biomechanical properties of the harbor seal will be provided from testing of tissue samples from freshly dead seals and used as input to the numerical model.

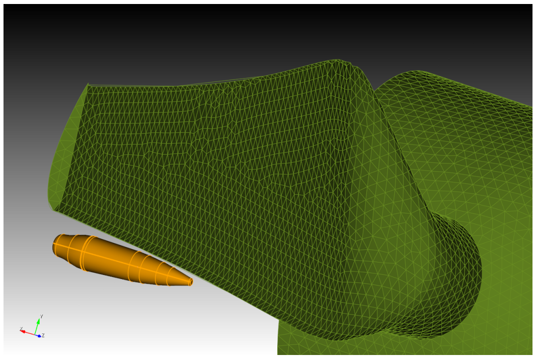


FIGURE 1. CUBIT/PRESTO MODEL OF PORTION OF TIDAL TURBINE BLADE (IN GREEN) AND HARBOR SEAL (IN YELLOW), TO SCALE.

Encounter Scenarios for Seal and Turbine Blade

For this analysis, we developed a range of scenarios that represent plausible encounter conditions, taking into account the morphology of the seal, its relative size in comparison to the tidal turbine, the seal's swimming aspects that might present different body parts to the blade, and the portion of the blade the seal might encounter. These conditions were described and ranked by the relative consequences to the seal from each encounter (Table 1). The seal might be struck near the head, midsection, or tail; on the top, bottom, or left/right sides of the body. Consequence ratings (***CR***) were developed, ranging from 1 to 5, with 5 being the most severe outcome (in rounded brackets, ( ), after the encounter description in Table 1). For example, if the turbine blade struck top of a seal's head, the most severe outcome might be expected. As there is little blubber to protect the area from damage, the encounter might result in serious injury (concussion) or death; this scenario is assigned the highest CR [5]. Alternatively, a blade strike on the seal's tail (flukes) may cause less damage, potentially impacting the mammal's swimming ability but less likely to be fatal. Fluke collisions are assigned a lower CR (***1***).

During an encounter, a seal could be struck by the tip, middle, or root of the turbine blade. Each section of the blade was also assigned a CR. The blade tip moves faster that other portions of the blade, presenting an increased risk of damage to the seal, resulting in a CR of 5. The center of the blade is considered less dangerous, likely to inflict less injury, and is assigned a CR of 3, while the blade root has less scope to affect the animal and is considered to be the least dangerous portion, with a CR of 1.

TABLE 1. ENCOUNTER MATRIX FOR SEAL AND TURBINE BLADE, BY LOCATION ON THE SEAL AND THE ASPECT FACING THE TURBINE. THE CONSEQUENCE RATING IS SHOWN IN ( ) AFTER EACH DESCRIPTION.

	Head	**Midsection**	**Tail**
Top	Blade hits top of bony part of head (no melon/fat on seal), potentially fatal (***5***)	Blade hits on fatty top of midsection, fat layer depends on age of mammal (***3***)	Bony, and flexible, damage could affect swimming ability (***1***)
Bottom	Blade hits underneath head, potential to break jawbone, affect spine (***4***)	Blade hits on fatty midsection, internal organs at risk (***3***)	Bony, and flexible, damage could affect swimming ability (***1***)
Left/ Right Side	Blade hits on left/right side of head potential to break jawbone, affect spine (***4***)	Blade hits on fatty midsection, internal organs and ribs at risk (***3***)	Bony, but more flexible, possibly unable to swim (***1***)

A range of approach angles were examined, and each angle also assigned a CR (Table 2, CR in rounded brackets, ( )). The approach angles of a seal with the turbine blade range from -60˚ to +60˚. It was assumed that the force of the tidal stream would prevent a harbor seal from approaching the blade at more than a 60º angle. The most extreme approach angles (-60˚, +60˚) were assigned the highest CR as, at this approach angle, the seal is likely to absorb the greatest momentum transfer from the blade. A perpendicular approach (0˚) was assigned the lowest CR as the seal is likely to absorb the least impact force as the force of tidal current and turbulence create backpressure, lessening the closing velocity of the seal with the blade. In the diagrams presented in Table 2, the turbine blades are either spinning clockwise or counter-clockwise, depending on the tidal cycle (i.e. turbine rotation changes direction over each tidal cycle).

RESULTS

Tissue Analysis

Preliminary tissue testing has been completed for a frozen seal sample, largely to develop and test methodologies, with additional harbor seal testing planned as soon as a fresh specimen becomes available.

Preliminary frozen harbor seal tensile testing determined that seal tissue exhibits the pattern of a stiffer, protective outer skin, with an underlying less stiff fatty blubber layer (Table 3).

With the addition of planned tissue testing data from fresh seals, we can expect to decrease the variability of the results and better understand the properties of seal tissue *in vivo*.

TABLE 2. APPROACH ANGLES OF THE SEAL TO THE TURBINE. THE TURBINE BLADE IS DEPICTED IN SILVER AND THE SEAL IN BROWN. THE CONSEQUENCE RATING IS SHOWN IN [ ] AFTER EACH ANGLE.

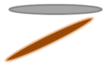
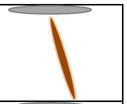
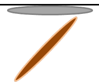
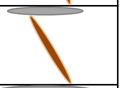
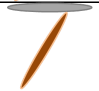
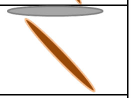
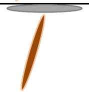
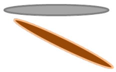
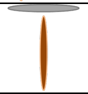
-60˚ [5]		15˚ [2]	
-45˚ [4]		30˚ [3]	
-30˚ [3]		45˚ [4]	
-15˚ [2]		60˚ [5]	
0˚ [1]			

TABLE 3. PRELIMINARY SEAL TISSUE MATERIAL PROPERTIES, IN THE 90° (ROSTRAL TO CAUDRAL) AND 0° (CIRCUMFERENTIAL) DIRECTIONS.

Material	**Direction**	**Elastic Modulus [MPa]**	**Strength [MPa]**
Blubber	0°	Not tested	0.39 ± 0.02 (n=4)
Blubber	90°	0.4 ± 0.1 (n=6)	1.01 ± 0.3 (n=6)
Skin	0°	17.0 ± 5.7 (n=3)	48.1 ±22.3 (n=12)
Skin	90°	13.5 ± 8.0 (n=4)	43.5 ± 3.2 (n=7)

Modeling the Approach of the Seal to the Turbine

Using the encounter matrix and the approach angles matrix, a composite CR was developed to provide a range of inputs to model the consequences of the seal colliding with the tidal turbine (Figure 2). The combined consequence matrix represents the consequences of a seal/blade encounter, with the deepest colors representing the highest consequences and lighter colors representing lower consequences. As indicated, a high risk of injury to the seal may result from a turbine blade-seal collision with an approach angle of -60˚ or +60˚, striking the seal on the top of the head, with the tip of the turbine blade (deepest red color). Lesser risk of damage may result from approach angles of 0˚, striking the mammal on the fluke with the center of the blade (yellow color). The consequence matrix presented in Figure 2 provides a basis to expand to a risk matrix with the addition of an estimate of the probability/likelihood of collision of the seal with the turbine blade, taking into account behavioral characteristics of seals in the vicinity of turbines.

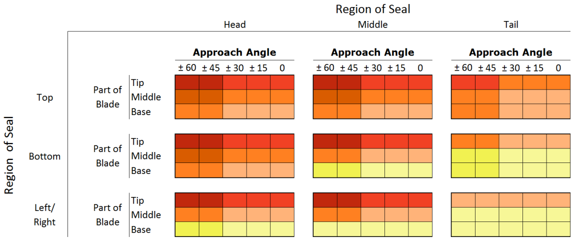
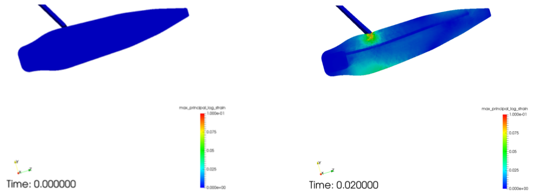


FIGURE 2. CONSEQUENCE MATRIX FOR COLLISION OF A HARBOR SEAL WITH A TWO-BLADED UNDUCTED TURBINE. THE DEEPER COLORS REPRESENT HIGHER POTENTIAL CONSEQUENCES.

Model Outputs

Preliminary modeling was completed using a generalized seal body shape, substituting tissue data from the SRKW study for the seal [4], as shown in Figure 3. The results show the approach of the seal to the turbine blade (Figure 3a) and the area of impact should the blade hit the animal (Figure 3b). Further refinement of the model is planned to include: 1) refinement of the turbine blade properties; 2) refinement of the seal body attributes to best reflect a representative seal from the overall population (e.g., representative length, girth, circumference, spinal positioning); and 3) inclusion of fresh seal tissue properties from tissue testing, as those results become available.



3a: Time, t = 0 sec. Prior to collision

3b: Time, t = 0.02 sec. Post collision. Areas in red indicate highest strain on tissue.

FIGURE 3. PRELIMINARY HARBOR SEAL MODELING RESULTS, SHOWING THE GEOMETRY OF THE SEAL AND TURBINE BEFORE COLLISION (LEFT) AND AT THE MOMENT OF ENCOUNTER (RIGHT).

DISCUSSION

Understanding the risk to marine mammals from collision with tidal turbines requires an estimate of the consequences of a collision as well as the probability of the collision taking place. Based on the superior sensory and swimming capabilities of most marine mammal species, collisions with tidal turbines are likely to be very rare, and should a collision occur, it will be very difficult to provide sufficient continuous monitoring necessary to detect the event. Weight of evidence approaches such as this one can act as a useful surrogate to determine potential risk.

Harbor Seal Collisions

The modeling analysis for a harbor seal colliding with the two-bladed turbine uses the specifications of the tidal turbine to define the forces impinging on the mammal, and derives the biomechanical properties of the seal from tissue samples. However, in an attempt to understand the probability of serious injury or death from a collision, a weighted consequence analysis has also been considered to understand the varying forces that may affect the seal under different approach and encounter conditions. Early assessments of the likely consequence of these encounters similarly indicate that the harbor seal is unlikely to be killed by a collision with a tidal blade, but could sustain serious injury. The extent of those injuries and the likelihood of the mammal recovering after the collision will be better informed with additional tissue testing for biomechanical analysis, based on a larger suite of model runs that examine each of the major consequence scenarios.

Probability of Collision

Although this analysis begins to examine the more likely approach and encounter scenarios that could result in the collision of a harbor seal with a tidal turbine, there is a need to better understand the likelihood of marine mammals coming into close proximity with a turbine blade, as well as their ability to evade a turbine blade collision should such a close encounter occur. Collaboration with other research groups working on behavioral aspects of harbor seal encounters around tidal turbines will further inform the risk outcomes.

NEXT STEPS AND RESEARCH GAPS

Our ongoing research into the consequences of a harbor seal collision with a tidal turbine blade will benefit from additional testing of fresh tissues, a course of action planned over the coming year. Tissues will be collected from adult and juvenile harbor seals to ensure that the results are representative of the population of marine mammals potentially at risk. An increased number of replicate tissue samples will be taken from each animal, in order to increase the statistical power of the tissue properties over that of the preliminary frozen tissue samples.

Further determination of the representativeness of the tissue samples will be obtained through the collection and analysis of morphometric data (length, weight, girth, etc.) from the harbor seal population living in the San Juan Islands, Washington State, including measures of skin and blubber thickness from stranded mammals.

Moving Towards a General Model for Marine Mammal Collision with Tidal Turbines

Concerns about marine mammal collisions with turbines remains one of the greatest sources of uncertainly in permitting (consenting) tidal development in the US and Europe. A generalizable method for determining risk to indigenous marine mammals in locations proposed for tidal development is needed to move the industry forward. An assessment of the probability of collisions between a marine mammal and a tidal turbine can be informed through the development of a parameterized model for mammals seen in close proximity of the turbine. This assessment will facilitate a more general understanding of the risk of these encounters. Similarly, broadening the range of species and behavioral responses is needed to inform risk analyses to span the spread of marine mammals considered to be at risk. The consequence analysis of SRKW and harbor seals covers two significant groups (a medium sized cetacean and a pinniped). Large whales, such as blue whales, humpback or sperm whales, are unlikely to be at risk of entering the relatively shallow and constricted waters where tidal energy is developed in significant numbers. However, small cetaceans, represented by porpoises and dolphins, are often found in estuarine and coastal waters where tidal energy is abundant. By adding a modeling analysis of a harbor porpoise, one of most ubiquitous small cetaceans found in these waters, significant coverage could be provided for the range of marine mammals most commonly considered at risk.

CONCLUSIONS

In the absence of direct measurements of marine mammals colliding and interacting closely with tidal turbines, modeling assessments such as the one described here can inform regulators of potential risks. As more information on the probability of encounter of marine mammals and turbines is developed, and additional representative mammals are examined, regulators will gain the confidence to allow wider deployments and expansion of tidal farms.

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