Improving Attachments of Remotely-Deployed Dorsal Fin-Mounted Tags: Tissue Structure, Hydrodynamics, in Situ Performance, and Tagged-Animal Follow-up

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Award Number: N000141010686 / N0001412IP20008
http://www.alaskasealife.org
http://www.nwfsc.noaa.gov/research/divisions/cbd/marine_mammal/marinemammal.cfm

LONG-TERM GOALS

We recently developed small satellite-linked telemetry tags that are anchored with small attachment darts to the dorsal fins of small- and medium-sized cetaceans. These Low Impact Minimally-Percutaneous External-electronics Transmitter (LIMPET) tags have opened up the potential to monitor the movements of numerous species not previously accessible because they were too large or difficult to capture safely, but too small for tags that implant deeply within the body. One goal of this project is to improve upon our existing tagging methodology to achieve longer, less variable attachment durations by carefully examining the factors that affect attachment success. Our key goal is to develop a method for attaching tags to cetaceans that provides the data needed to answer critical conservation and management questions without an adverse effect on the tagged animal. Therefore, we will also conduct follow-up studies of whales that have been tagged with a remotely-deployed dorsal fin-mounted tag to accurately quantify wound healing and the effects of tagging on whale survival, reproduction, and behavior. The combination of these approaches will provide an improved understanding of some of the key factors affecting tag attachment duration as well as a more complete understanding of impacts to individuals due to tagging.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2012	**N/A**	**-**

4. TITLE AND SUBTITLE
Improving Attachments of Remotely-Deployed Dorsal Fin-Mounted Tags: Tissue Structure, Hydrodynamics, in Situ Performance, and Tagged-Animal Follow-up

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Alaska Fairbanks and the Alaska Sealife Center P.O. Box 1329 Seward, AK 99664

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**19**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

OBJECTIVES

1. **1.** Design an improved barnacle-style tag shape for remote-deployment by assessing the hydrodynamic properties of tag shapes
2. **2.** Examine the tissue structure of the dorsal fin and its material properties for better informed implanted attachment design.
3. **3.** Examine the in situ performance of our current attachment devices and then design and test improved retention systems
4. **4.** Conduct follow-up studies of tagged whales to accurately quantify wound healing and the effects of tagging on whale survival, reproduction, and behavior

APPROACH

1. Hydrodynamics of tag shape (Key individuals: Mittal, Howle, Andrews, Schorr, Hanson): We will determine the drag on the tag through numerical modeling and analysis, primarily computational flow dynamics. High fidelity numerical simulations working in concert with physical experiments will be used to establish qualitative as well as quantitative relationships between tag configuration and the associated flow structure and surface pressure distribution, which is ultimately the key to the force/moments on the tag.

2. Dorsal fin tissue structure (Key individuals: Hanson): To evaluate the factors influencing tissue degradation (and therefore attachment duration) we will assess the anatomical factors likely to influence long-term viability. The harbor porpoise is the only species whose dorsal fin geometry and material properties have been fully described (Hanson 2001). Interspecific differences in these parameters may be an important factor in the variability in attachment duration, as might body size scaling effects. Consequently, we selected various species for examination based on differences such as size/shape of the dorsal fin (e.g., melon-headed versus killer whale), taxonomic grouping (i.e., odontocetes versus mysticetes), or dynamic behavior (*e.g*., beaked whale versus melon-headed whale).

3. In situ behavior of retention system elements (Key individuals: Andrews, Schorr, Hanson, Howle, Mittal): A key factor is the drag load imposed by the tag body but acting on the attachment elements implanted into the dorsal fin. Although we have a good idea of how the LIMPET retention system operates when first implanted, we do not fully understand the mechanics in a living fin. Therefore, we will attempt to simulate the tissue necrosis process to determine how the retention elements behave when surrounding tissues begin to lose their structural integrity. These results, along with those from the analysis of dorsal fin histology and material properties will inform modified designs.

4. Tagging effects - follow-up studies of survival, reproduction,& behavior (Key individuals: Baird, Schorr, Andrews, Hanson): More thorough assessments of the potential impacts on survival and reproduction of individuals, as well as assessment of healing of the tag attachment sites and potential behavioral changes associated with tagging, are needed to address concerns regarding sub-lethal and potentially lethal impacts of remotely-deployed tags. As part of an ongoing collaborative study, over 120 satellite and VHF tags have been remotely-deployed on 9 species of odontocetes around the main Hawaiian Islands. Re-sighting rates for the two species with the largest sample size of tag deployments, short-finned pilot whales (n = 48 individuals) and insular false killer whales (n = 27 individuals), are particularly high, as populations are small, individuals are relatively easy to approach, and there are sufficient encounters each year to have a high probability of re-sighting previously tagged whales. We will assess impacts of remotely-deployed tags on tagged animals at a variety of levels: from wound healing and potential behavioral effects of tag attachment to reproduction and survival. Wound healing assessment will be undertaken by examination of high resolution photographs of tag attachment sites by veterinarians and FLIR imaging of tagged whales before and after tag loss. Assessment of reproduction and survival of tagged whales will utilize existing photographic datasets as well as additional photos taken during this project.

WORK COMPLETED

Objective 1: Work in computational fluids dynamics (CFD) modeling has focused on understanding the effect of tag design as well as tag orientation and location on the hydrodynamic forces. Most of the past work on tag hydrodynamics has focused on drag but our hypothesis is that lift forces might also play an important role in tag detachment. Thus the CFD simulations in the last year have focused on characterizing both components of force on the tag and the effect of gap size, angle-of-attack (AOA) and orientation, or angle of rotation (ROT), on these forces. Figure 1 illustrates the overall model of the forces acting on the tag and how these forces produce a pulling (detachment) force on the tag. A sequence of three-dimensional, unsteady, direct numerical simulations have been carried out for the tag. The simulations employ an immersed boundary solver that allows us to simulate flow past complex boundaries on fixed Cartesian grids. (Mittal et al. 2008). The simulations, being three-dimensional and unsteady, require super computing resources and we employ large-scale parallel computers for these simulations.

Water tunnel experiments with physical models of the tags were conducted at the United States Naval Academy in Annapolis, Maryland. The water tunnel had a test section of 0.4 m square x 1.8 m long. The tunnel employed turning vanes in the corners and a honeycomb flow straightener in the settling chamber. Free-stream turbulence was found to be ~0.5% (Schultz and Flack, 2003). Three tag models at 2:1 scale were constructed from ABS plastic using fused deposition modeling (FDM). The three tag configurations were the new AM-240C tag with a smooth surface finish (SmoothTag), the AM-240C tag with surface dimples (Dimpled Tag), and the AM-240A tag with a smooth surface finish (Old Tag). This rapid prototyping (RP) process produces slightly rough surfaces with a layer thickness of 0.254 mm. Before testing, each of the three tags was coated with several layers of Marine primer and sanded fair. This process eliminated the irregularities caused by the fused deposition modeling process. The dimpled tag was carefully finished so that the bumps remained intact but the FDM irregularities were filled and faired. Models were evaluated at flow speeds ranging from 1 m/s to 5.5 m/s, and orientations (angles of attack) ranging from -20 to +90 degrees (with the zero angle indicating tag alignment with the flow). These flow speeds corresponded to Reynolds numbers in the range of 56,000 to 310,000. Measurements of lift, drag, and side forces were made with submersible Hydronautics force transducers and the angle of the model was measured by a multi-turn potentiometer mounted on a custom built quadrant (Weber et. al., 2009) as shown in Figure 5. The sign convention used in reporting the forces is shown in Figure 6. In the results section presented below, the forces and flow speeds were corrected from model scale and experimental conditions to actual scale and seawater conditions using standard similitude techniques.

Objective 2: Histological slides of the horizontal cross section of the central section of dorsal fins from five species of cetaceans - pilot whale, Bryde's whale, Cuvier's beaked whale, melon-headed whale and killer whale – were developed to assess geometry and collagen composition of primary structural layers. Percent composition of the three structural layers (i.e., collagen bearing); sub-papillary layer, vertical sheath and central core (Figure 11) was measured using image analysis software (Figure 12). The killer whale fin was sectioned in five locations to assess structural variability in different areas of the fin where tags have been deployed. The material properties of the major college bearing layers were also measured for these species fins using a uniaxial tester. Stress/strain curves were measured for the major layers in various orientations.

Objective 3: We have continued to integrate the results from our hydrodynamics studies, laboratory testing, and assessment of tag performance on whales in order to develop new tag designs. The tag models based on the LIMPET design that were available from Wildlife Computers in 2011 included a SPOT5 location-only model (AM-240B) and a Mk10-A dive-depth transmitting model (AM-266D). We discovered that the epoxy in both of these models could potentially crack upon impact in certain cases (<3% of cases out of > 300 deployments of the SPOT5). We worked with Wildlife Computers to come up with alternative designs that were subsequently stressed in a variety of laboratory tests before production models were delivered to the public for whale tagging. The new location-only model is the SPOT100 AM-240C, and the new depth-transmitting model is the SPLASH10 AM-292B. Additionally we worked with Wildlife Computers on a solution that would allow our LIMPET darts to be made commercially available, with thorough testing of the new prototypes. Work is continuing on simulating the tissue necrosis process and assessing the performance of the retention system under steady state and dynamic loads in artificial "tissue" as well as dorsal fin carcass tissue. Past tag deployments have been carefully analyzed to examine whether there any differences in attachment performance depending on the area of the fin or the orientation with respect to the water flow.

Objective 4: In FY12 work was directed at three tasks. 1: Support for field work off the island of Hawaii to obtain additional photos for tagged whale follow up and to increase the sample sizes for comparison of survival rates and reproduction. 2: Sorting of existing photos for species that had been satellite tagged and matching to our long-term photo-ID catalogs. 3: Social network analyses to identify stable groupings and initial assessments of survival and reproduction of tagged individuals. With NOPP support Cascadia conducted a 28-day field project in October/November 2011 and a 21-day field project in May 2012, both off the island of Hawaii (both projects were also partially supported by an ONR grant to WHOI for Dtagging). During these field projects there were 78 encounters with 7 previously tagged species and over 59,000 new photos. Additional photos were obtained from a variety of other contributors (whale or dolphin watching operators and other researchers) including encounters off Hawaii Island, Maui, and Oahu. We also obtained over 50,000 new photos of tagged species and deployed additional satellite tags through three CRC field projects supported by other funding sources. Of the 35 additional satellite tags deployed in FY12, 29 were on resident populations, thus increasing the sample size of tagged individuals that may be re-sighted for analyses of survival and reproduction.

All photographs obtained through Aug. 2012 of 4 of the 8 tagged species with photo-ID catalogs (false killer whales, pygmy killer whales, Cuvier's beaked whales, Blainville's beaked whales) have been matched to our catalogs to identify previously tagged individuals. All photos of Hawaii Island resident melon-headed whales have been scanned for re-sightings of tagged individuals. Matching of short-finned pilot whales is ongoing, prioritizing groups known to contain tagged individuals.

RESULTS

Objective 1: Our hydrodynamics work has included both computational fluid dynamics (CFD) simulations as well as water tunnel tests with physical models. Our recent CFD work has focused on the newer location-only LIMPET tag, model AM-240C. Figure 2 shows the variation of drag (Fx) and lift (Fy) forces on the tag with the size of the gap as well as angle-of-attach and orientation. The CFD results shows that drag does not vary significantly with gap size but the lift force increases rapidly as the gap is decreased. Furthermore, both drag and lift forces incease with angle-of-attack although the increase is larger for the lift force. Finally, the change in orientation of the tag in relation to incoming flow has a more complex effect on both forces with the drag force showing increase and the lift force showing no change or a decrease based on the initial angle-of-attack. Figure 3 shows the effect of gap, inclination and orientation on the pitch-up moment on the tag. Based on our simple model of the tag forces (see Fig. 1), the hydrodynamic pulling force on the tag is proportional to pitching moment. Thus Figure 3 shows that the net pulling force is highest for small gaps and large inclination angles and that in this condition, lift is the dominant contributor to the pulling force. For large gaps, the pulling force is reduced and drag is the primary contributor to the pulling force in this condition. Based on the above simulations we can hypothesize a scenario for tag detachment that is shown in Figure 4.

Water tunnel testing results include a comparison of the scaled drag force (Newtons) versus the scaled flow speed (m/s), as shown in Figure 7, indicating that there is little difference in drag between the three tag designs. However this only holds when the tag is best aligned with the flow, with its long axis parallel to the flow direction. As Figure 8 shows, the Old Tag produces substantially more drag (up to 2X) for flow angle orientations greater than ±30°. In Figure 8, the scaled flow speed is held constant at 5 m/s. The comparison of the side forces versus flow orientation produced by the three tags, shown in Figure 9, finds that the Old Tag produces substantially greater side force for flow orientations between 20° and 70°. At the extreme, the Old Tag produces approximately 3X the absolute side force. The lift force versus rotation angle for the three tags is shown in Figure 10. In contrast to the drag and side forces, the Old Tag produces lower lift over the entire range of flow orientations.

Based on our water tunnel measurements we can make the following conclusions concerning the three tag designs. (1) The Old Tag generates lower lift than the new tag in either the Smooth configuration or the Dimpled configuration across all flow orientations and flow speeds. (2) At lower flow orientation angles, the Old Tag produces lower drag and side forces than either the Smooth Tag or the Dimpled Tag across all flow speeds. (3) Above approximately 20° the Old Tag generates substantially more lift (up to 2X) and side force (up to 3X) compared to either the Smooth Tag or the Dimpled Tag. (4) Surface bumps on the dimpled tag (compared to the smooth tag), offer no clear advantage other than to flatten out the lift dependence on the flow orientation angle but this only holds at higher flow speeds. Given that we currently cannot control the rotation of the tag in flight, it appears that the new Dimpled tag has a slight advantage with the lowest overall (drag plus lift) pulling force at a variety of rotation angles.

Objective 2: Estimates of collagen composition were consistent with previous analyses of the harbor porpoise dorsal fin with the Ligamentous sheath always comprised of a higher percentage of collagen than the central core. Percent collagen in the Ligamentous sheath was consistently high in all species, ranging from a high of 91% in the pilot whales to a low of 77% in melon-headed whales. Inter-species variability was greater for the Central Core where the pilot whale again had the highest percentage of collagen (77%), but the Cuvier's beaked whale was lowest at 29% with the other two species in the mid-fifty percent range.

Material properties of the two primary collagen-bearing layers of the dorsal fin (Ligamentous sheath and Central Core) were measured for the species previously noted on a uniaxial tester. Stress/strain curves were developed for these layers in various orientations (Ligamentous sheath; dorsal/ventral, anterior/posterior, Central Core; dorsal/ventral, anterior/posterior, lateral). The Ligamentous sheath (dorsal/ventral orientation), showed similar post-transitional phase performance in all species except Cuvier's, which exhibited lower strength. The Anterior/Posterior and Lateral orientations of the Central Core generally had greater strength than the Central Core in the Dorsal/Ventral orientation (Figure 13). The anomalously high strength of the melon headed and Cuvier's beaked whale Central Core relative to their relatively low collagen density will require additional assessment.

Objective 3: Samples of the new location-only tag, model SPOT100 AM-240C were thoroughly tested by repeatedly firing into a hard rubber target from 2 meters away, at an extreme angle of 45 degrees, representing a worst case scenario that should produce stresses much greater than seen in field deployments on whales. Tags were also subject to extreme testing by repeatedly striking with a 16 oz. nail hammer. All tags survived these tests. To examine resistance to longer term vibrations, we mounted an AM240C tag on the stern bracket of one a Honda 150 HP outboard (Figure 14). The tag was placed a few cm below the water line at rest, and during cruising this is an area that experiences high forces, both from water flowing past and impacts at the air-water interface as the stern rises and falls, along with vibrations. The boat was operated with cruising speeds around 20 knots for about 10 hours a day for 10 consecutive days. Not only did the tag survive this test, it looked almost new and most importantly the antenna and the attachment to the darts were unchanged.

In order to assess the resistance to cracking failures upon impact, Wildlife Computers provided 6 test tags of the new AM-292B design. All test tags were impact tested at 45 degrees from a mock dorsal target at a range of 10 m and then again at 1.5 m to ensure both tag integrity and that tags would continue to function regardless of extremely severe impacts. All tags survived the impact testing. In addition to impact testing, we verified the accuracy of the pressure transducer in a calibrated pressure chamber. Six tags that had been impact tested and two new tags were pressurized on four repeated "dives" to 2,000m with stops every 500 meters to check for accuracy. Half of the tags were then removed from the chamber, and the other half were then run down to a maximum depth of 2,500 meters. The average error between the "true" depth and that reported by the tag at all stops was less than +/- 1%, with a maximum reported error of 1.8%.

Transmission durations for SPOT5 tags deployed with our 6.5cm penetrating length darts were assessed to compare hydrodynamic modeling predictions with performance on whales in the field. Transmission durations for killer whales, false killer whales, and short-finned pilot whales had large sample sizes over several years, and were not significantly different from each other (Kruskal-Wallis Multiple-Comparison, $z < 1.31$) so were compiled for this comparison. Tags known to have cracked on impact were excluded. We compared transmission duration by location on the fin (Figure 15). While there were some within species differences in location, the pooled differences were not significant across the three species (Kruskal-Wallis, $z < 1.96$). Rotation of the tag affected duration, with tags rotated leading edge up and perpendicular to swimming direction having shorter transmission durations, but the differences were not significant (Kruskal-Wallis, $z < 1.74$). Transmission durations by tag 'flushness' differed significantly - tags that had the leading edge up (into the primary direction of water flow) had significantly shorter durations than flush tags and tags with the leading edge down (Kruskal-Wallis, $z>2.75$, Figure 16), consistent with results from the hydrodynamics simulations.

Median transmission duration was 17.1 days longer for sub-adult whales (n=24) than for adults (n = 53), a result that was significant ($z = 2.06$), but differences by sex, dart version, rotation degree and number of darts properly implanted were not significant. While larger sample sizes will help elucidate factors that play a role in attachment duration, it is likely that factors we cannot control for such as individual variation, behavior, species-specific anatomical, physiological and behavioral differences, and even regional differences likely play a large role in attachment duration. Despite some significant differences in transmission duration by species, a survival curve for all species tagged with 6.5 cm long darts and sample sizes ≥ 5 plotted together creates a curve that is similar for all species (Figure 17).

Objective 4: The proportion of individuals re-sighted post-tag loss was relatively high even for infrequently encountered species: pygmy killer whales = 71%, (re-sighting periods 0.84–3.17 years); resident melon-headed whales = 67% of distinctive individuals (re-sighting periods 0.82-2.69 years); Cuvier's beaked whales = 67% (re-sighting periods 0.75-1.91 years); Insular Blainville's beaked whales = 73% (re-sighting periods 0.01 – 3.66 years). Blainville's beaked whales have known higher dispersal rates for males than females (McSweeney et al. 2007). An assessment of the proportion of females re-sighted indicated that 6 of 7 females from the insular population (85.7%) were re-sighted post-tag loss from 0.77- 3.66 years.

For Hawaiian insular false killer whales, social network analyses show three main social clusters and several smaller social clusters, with the majority of sightings of a single social cluster (Baird et al. 2012). Eighteen tags have been deployed on 16 individuals from this cluster; in 17 of 18 occasions the tagged individuals have been sighted post-tag loss/last transmission, with re-sighting periods ranging from 0.55-4.56 years (median = 2.37). For short-finned pilot whales off the island of Hawaii, prior to 2012, 52 LIMPET tags were deployed on 47 different individuals. Social groups of three of the tagged individuals have not been re-sighted since the tags stopped transmitting. Of the remaining 49 deployments, on 44 individuals, 42 individuals (representing 47 deployments) were re-sighted post tag loss/last transmission (95.9% of the deployments), with re-sighting periods ranging from 0.1 to 5.7 years (median = 2.8 years). Factors that may influence re-sighting probabilities, including social organization, and the proportion of the groups identified, are being investigated.

Assessing reproduction of previously tagged whales of all species is limited by the relatively small number of known adult females tagged, the typically long inter-birth intervals for most species, and the long intervals between re-sighting events. For some species, e.g., pygmy killer whales and melon-headed whales, no known adult females have been tagged. The only species with females known to have given birth post-tagging are Cuvier's beaked whales; two of the four known adult female Cuvier's beaked whales have been re-sighted with calves born since the females were tagged.

IMPACT/APPLICATIONS

Understanding the potential for impacts of naval activities on protected species of marine mammals and mitigating such impacts requires information on movements and habitat use. The development of better tag technologies and deployment techniques will make a significant contribution to the ability of researchers to track movements, monitor behavior, and determine distribution of species of interest.

TRANSITIONS

Most parts of the LIMPET satellite tag and attachment system that we have developed and are improving in this project are commercially available from Wildlife Computers (Seattle, WA), and LIMPET tags are being acquired by and deployed by multiple organizations (e.g. Southwest Fisheries Science Center, Cascadia Research Collective, Woods Hole Oceanographic Instituion, among many others) in other projects funded by the US Navy to monitor marine mammals on Navy ranges and elsewhere.

RELATED PROJECTS

The National Marine Fisheries Service Pacific Islands Fisheries Science Center is supporting research on false killer whale movements in Hawaiian waters (Baird et al. 2010; 2012), and the Naval Postgraduate School (with funding from N45) is supporting tagging studies of a variety of species. Tag and deployment developments from this work are being incorporated into these ongoing studies. See:
www.cascadiaresearch.org/hawaii/beakedwhales.htm
www.cascadiaresearch.org/hawaii/falsekillerwhale.htm
www.cascadiaresearch.org/SCORE/SCOREMain.htm

ACKNOWLEDGMENTS

Valuable assistance was provided by the staff at Wildlife Computers, Daniel McSweeney of Wild Whale Research Foundation, Dr. Stephen Raverty of Animal Health Center, B.C. Ministry of Agriculture and Lands, and Sabre Mahaffy, Annie Gorgone and Jessica Aschettino of Cascadia Research Collective.

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Baird, R.W., Schorr, G.S., Webster, D.L., Mahaffy, S.D., McSweeney, D.J., Hanson, M.B. and Andrews, R.D. (2011). Open-ocean movements of a satellite-tagged Blainville's beaked whale (*Mesoplodon densirostris*): evidence for an offshore population in Hawai'i? Aquatic Mammals 37(4):506-511. [published, refereed].

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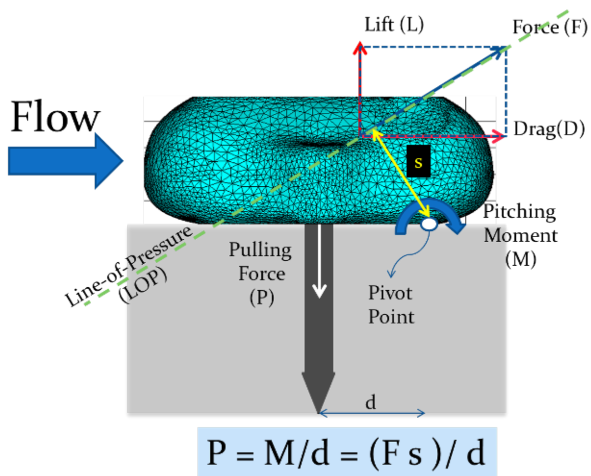

Fig. 1. Schematic illustrating the various forces and moments acting on the tag. Note that the pulling force `P` is proportional to the pitching moment `M`.

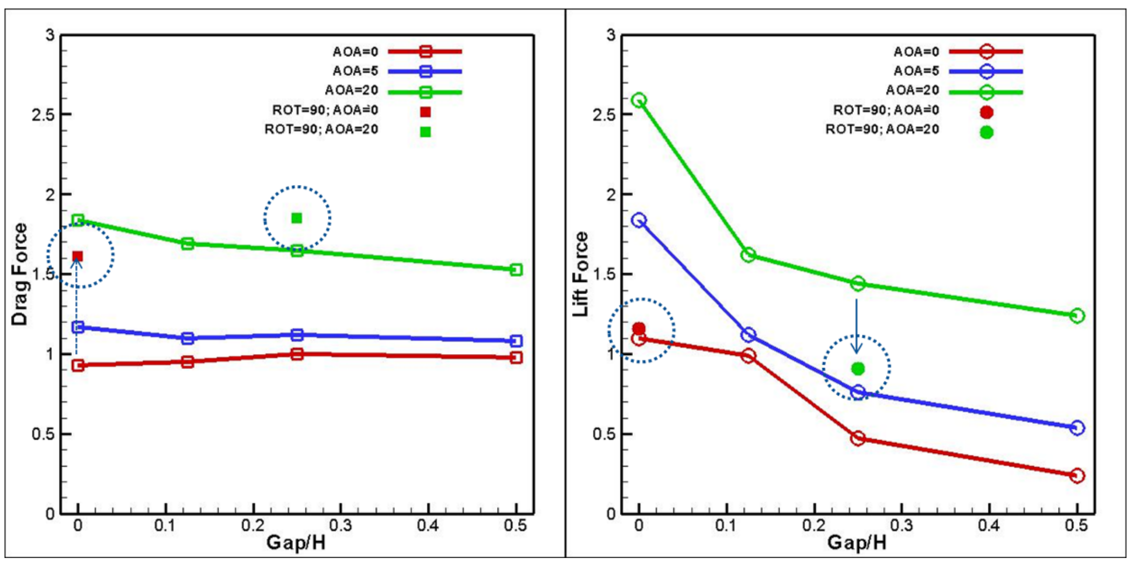

Fig. 2. The effect of varying gap, angle of attack (AOA) and orientation (rotation) on the drag and lift forces on the tag.

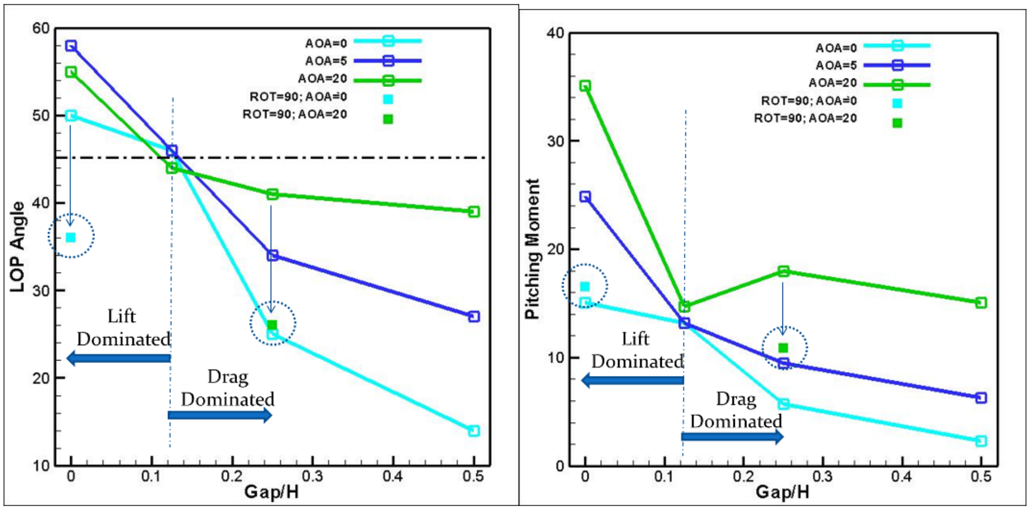

Fig. 3. Effect of gap, AOA and orientation on the direction of the net force (left panel) and pitching up moment (right panel) on the tag.

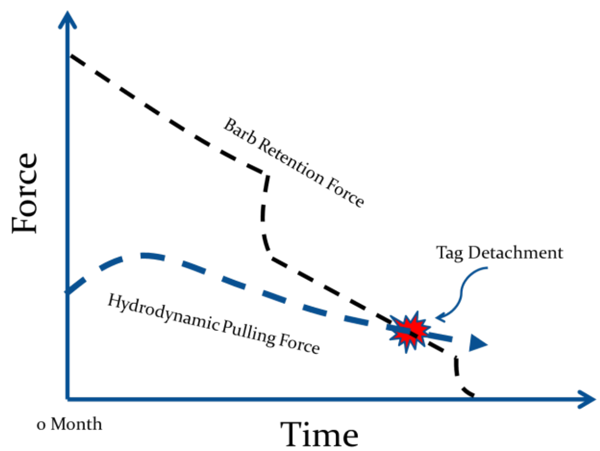

Fig. 4. Timeline of tag attachment failure based on CFD computations. Tag detaches when the pulling force equals the retention force of the darts.

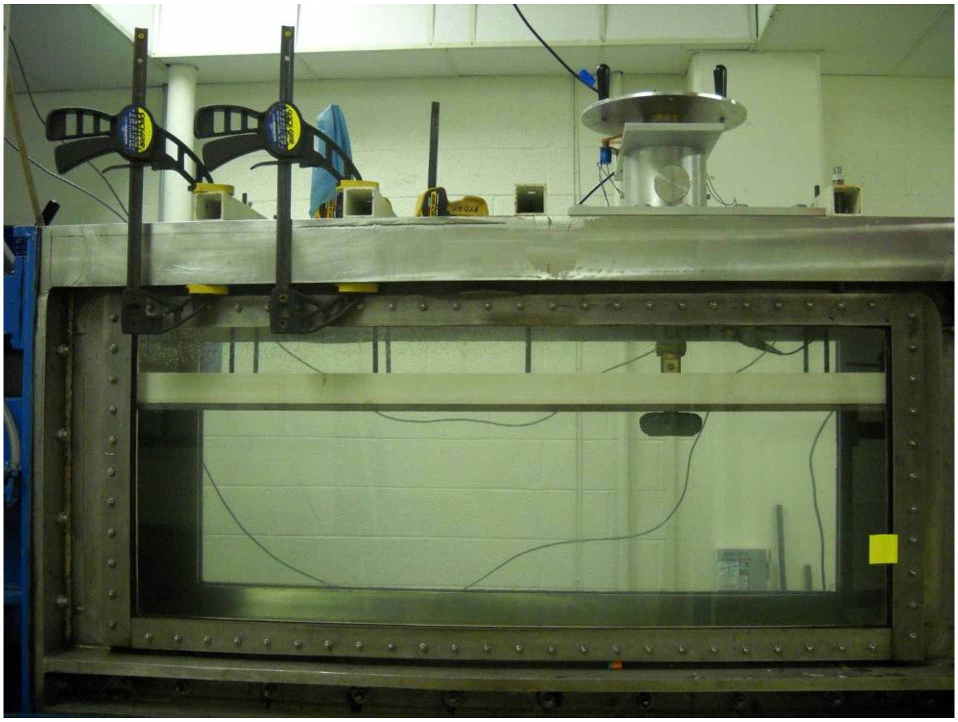

Fig. 5. AM-240C tag mounted with the force balance quadrant, installed in the United States Naval Academy water tunnel test section.

Fig. 6. Computer model of earlier tag model AM-240A (left image) and force sign convention used for reporting the results (right image). Flow is from left to right. The blue, red, and green arrows indicate, respectively, positive lift drag and side forces. The clear arrow indicates positive rotation angle.

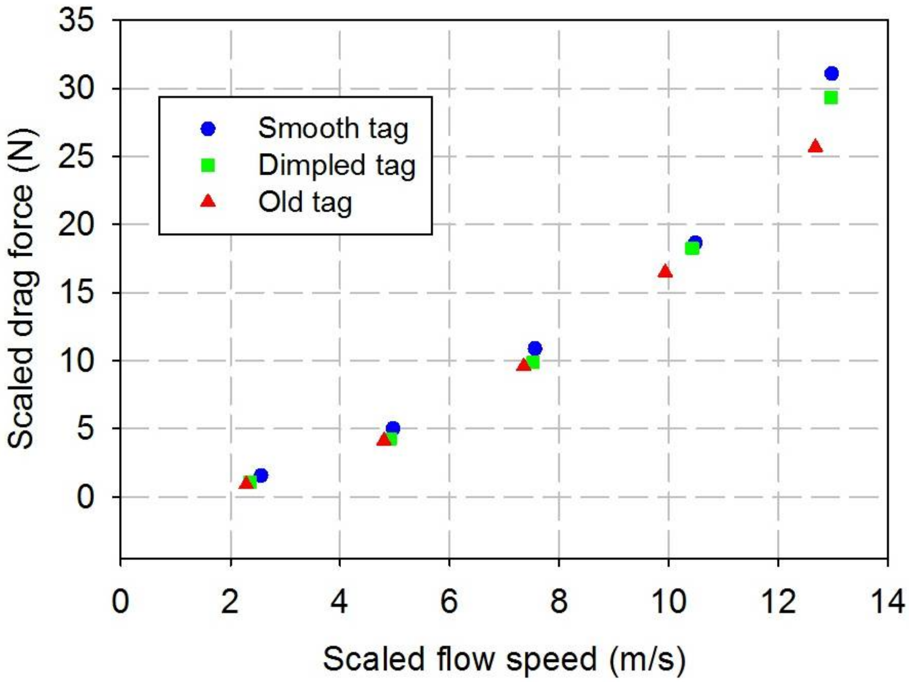

Fig. 7. Water tunnel test of the three tag models, showing scaled drag force versus scaled flow speed for the tag with its long axis parallel to the direction of flow (0° rotation). Note that there is little difference between tag types in the scaled drag force over this range of flow speeds.

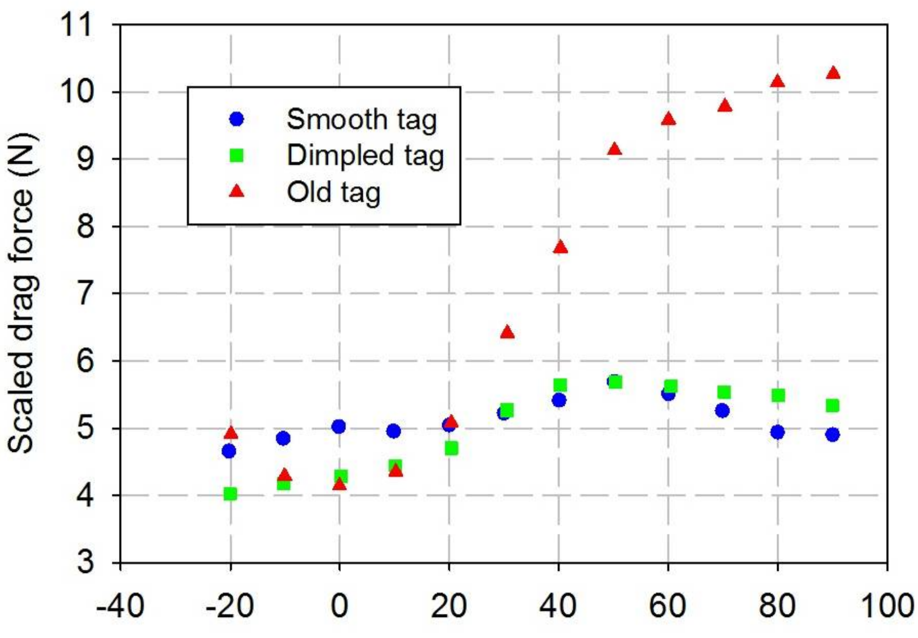

Fig. 8. Water tunnel results comparing the scaled drag force versus rotation for the three tags considered in this study at a flow speed of 5 m/s. Note that at flow orientations greater than ±30°, the old tag produces considerably greater drag.

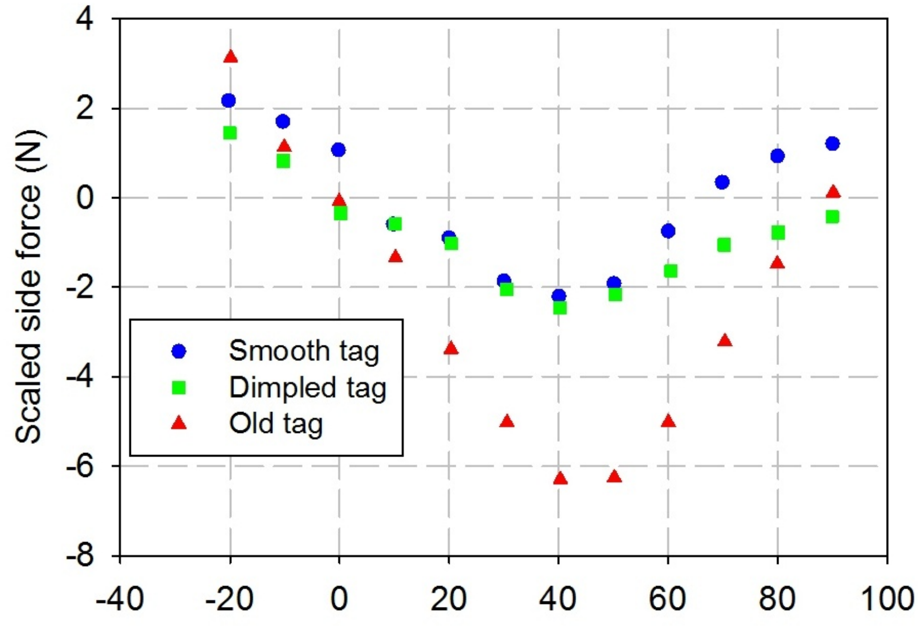

Fig. 9. Water tunnel results comparing scaled side force versus rotation angle at a fixed scaled flow speed of 5 m/s. The old tag produces substantially greater drag than either the smooth tag or dimpled tag for orientations in the range of 20° to 70°.

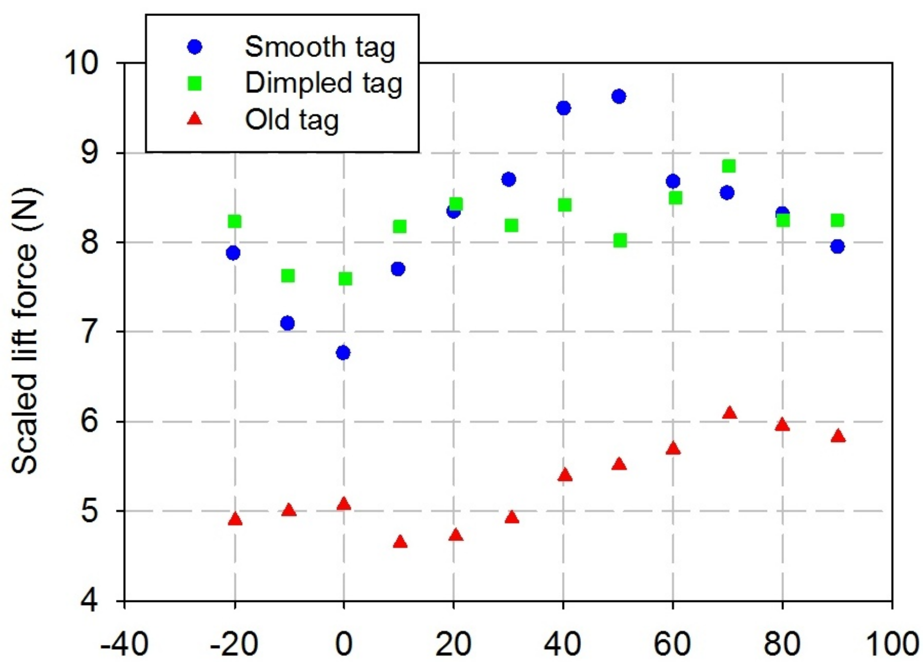

Fig. 10. Water tunnel results comparing scaled lift force versus rotation angle for the smooth, dimpled, and old tag at a constant flow speed of 5 m/s. The lift force is lower for the old tag over the entire range of flow orientations.

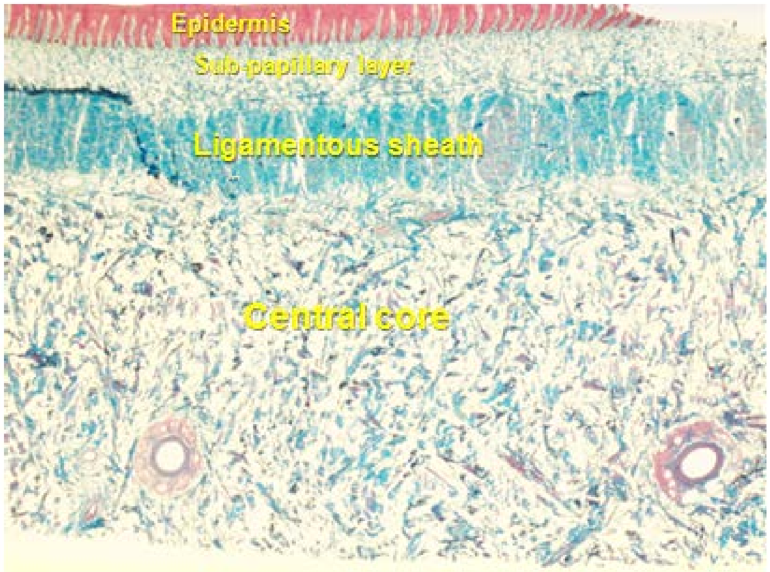

Fig. 11. A horizontal cross-section tissue sample from the dorsal fin of a Cuvier's beaked whale stained with Masson's trichome for collagen. Major structural layers are labeled.

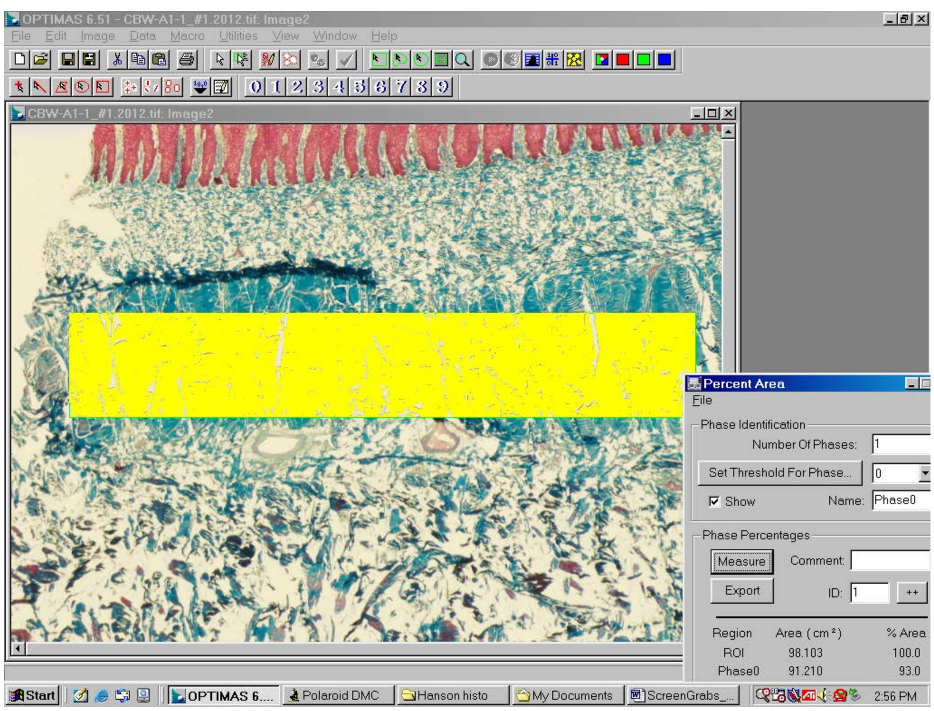

Fig. 12. Example horizontal cross-section of the dorsal fin of a Cuvier's beaked whale showing the estimation of % collagen (yellow area) for the ligamentous sheath.

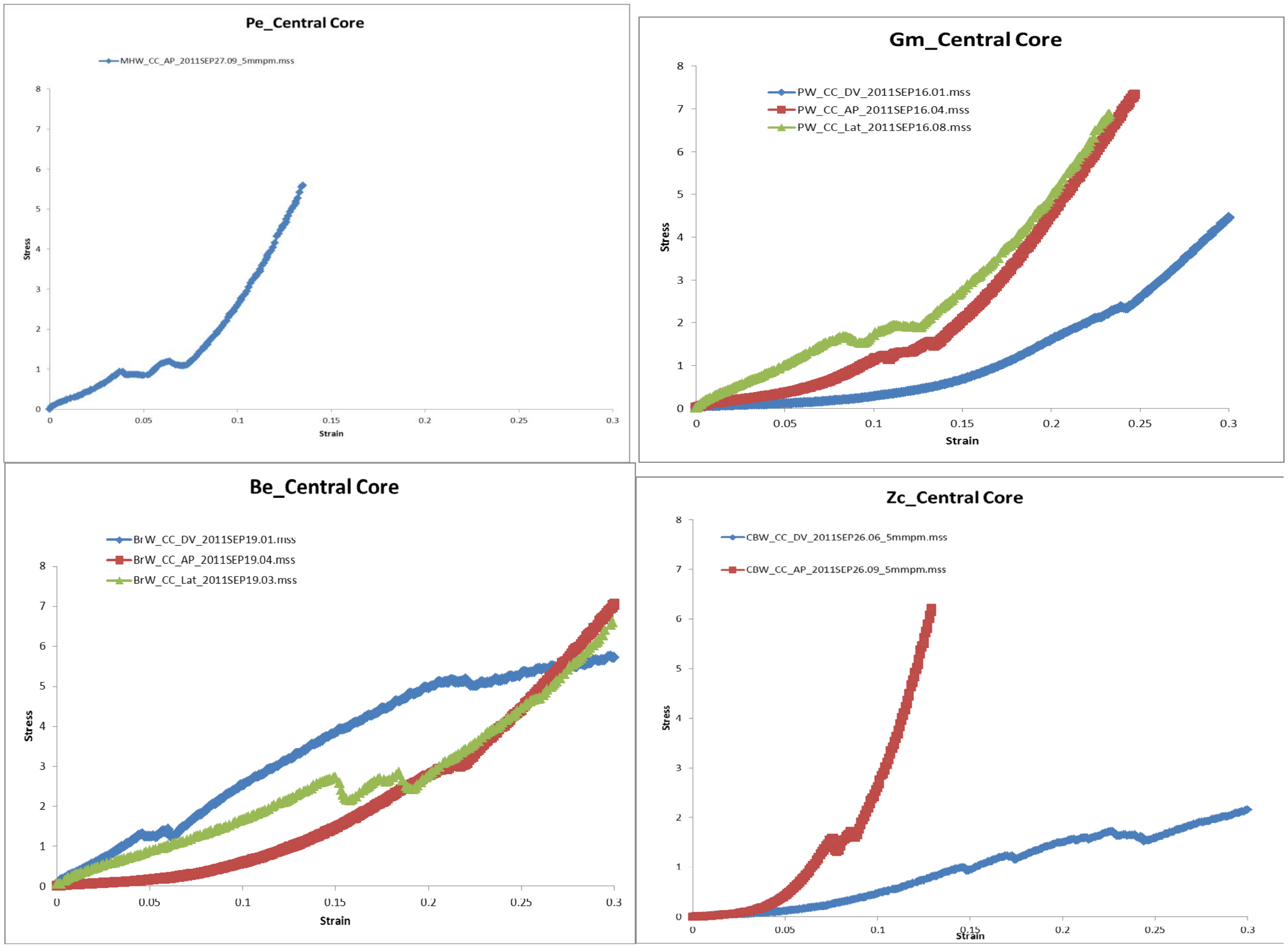

Fig. 13. Comparison of stress/strain curves for the Central Core tissue layer of the dorsal fins in three axes of orientation (dorsal/ventral (blue), anterior/posterior(red) and lateral (green)) for melon-headed (Pe), pilot (Gm), Bryde's (Be), and Cuvier's beaked (Zc) whales.

Fig. 14. Photographs of the new location-only SPOT100 AM-240C tag mounted to an outboard engine to examine resistance to strong water force and vibrations.

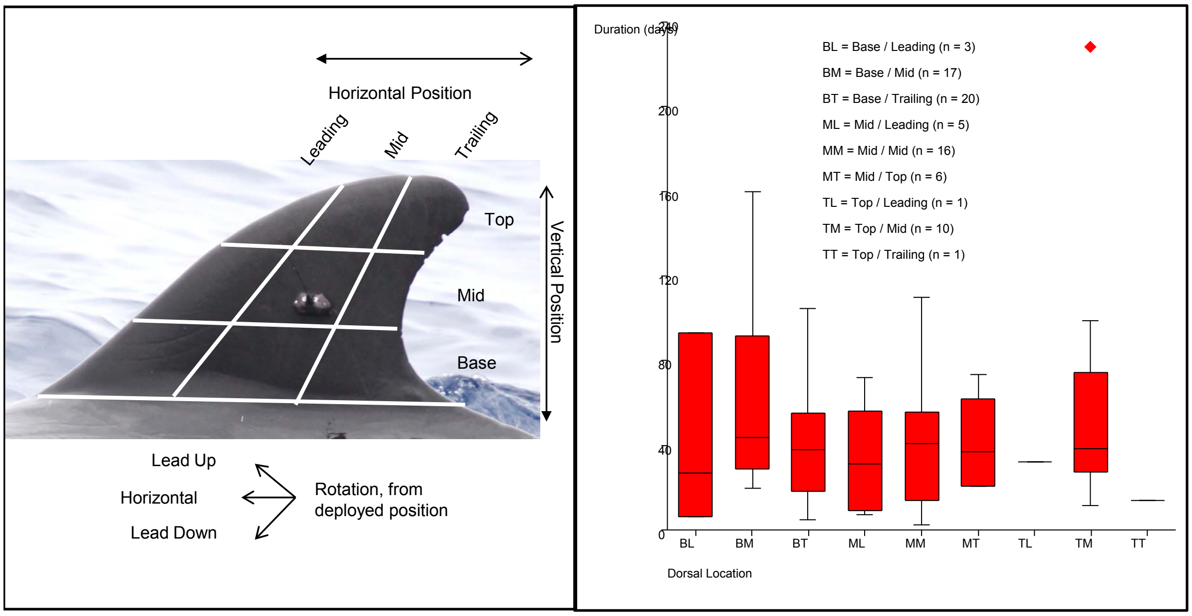

Fig. 15. Illustration of the zones for tag placement as well as determination of tag rotation (left). For tags that crossed multiple zones, the zone which captured the largest percentage of the tag was assigned. Tag location is compared in the box plot (right) for killer whale, false killer whale, and short-finned pilot whale, starting at the base of the fin on the left, going towards the top. The red diamond represents a significant outlier.

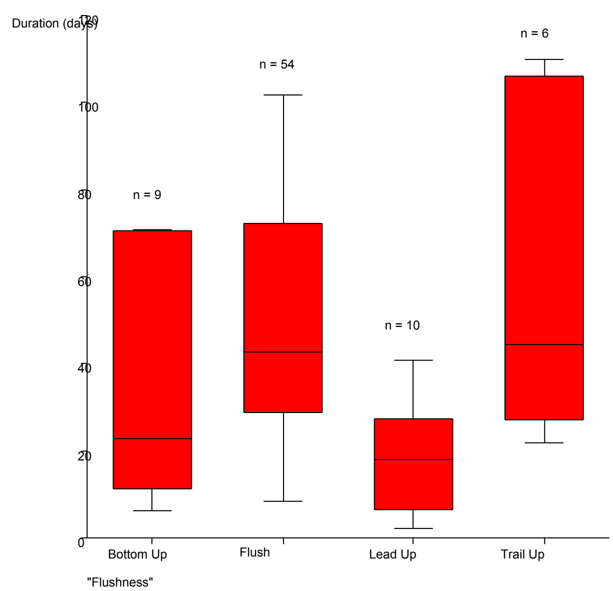

Fig. 16. Box plot comparing 'flushness' of tag for killer whale, false killer whale and short-finned pilot whales. Tags that had the leading edge lifted up, into the predominant direction of water flow, had significantly shorter transmission durations than those that were flush or had the trailing edge up (Kruskal-Wallis, z>2.75).

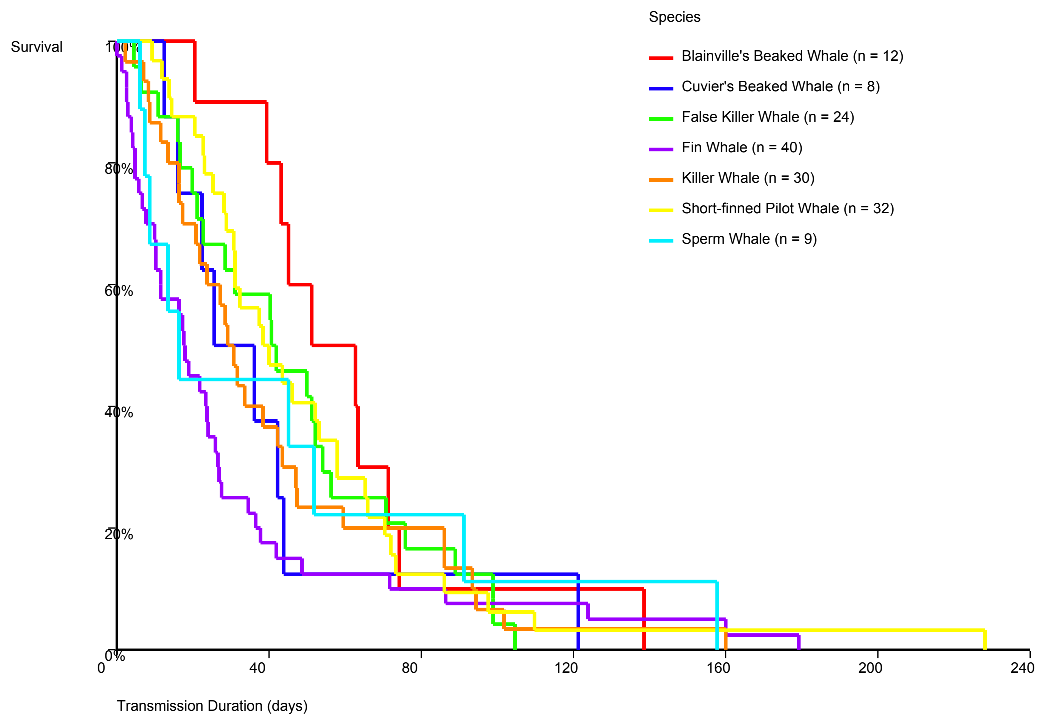

Fig. 17. Survival curve for SPOT5 tags deployed by CRC on all species where 6.5cm length darts were used and sample sizes were ≥ 5. Blainville's beaked whales (red) have the highest median transmission duration of 56.9 days while sperm whales and fin whales have the lowest with median transmission durations of 16.4 and 17.8 days respectively.